Chapter

Validation of Satellite (TMPA and IMERG) Rainfall Products with the IMD Gridded Data Sets over Monsoon Core Region of India

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Abstract

This work presents the validation of satellite (TMPA and IMERG) rainfall products against the India Meteorological Department (IMD) gridded data sets (0.25° × 0.25°) of dense network of rain gauges distributed over the monsoon core region of India. The validation uses the data sets covering the 20 years (1998–2017) and detects the time series bias; inter annual variations and Intra Seasonal Oscillations (ISO). The bias in the two data sets is found to be very less over the core region compared to whole India. The correlation between daily rainfall IMD and satellite is found to be +0.88 which is of 99% confidence level. The dominant periodicities in the rainfall patterns of IMD and satellite are Madden Julie Oscillation (30–60 days) and local oscillations (less than 20 days) are conspicuous and the normalized power varies from year to year. During the El Niño and La Niña years, the normalized power of rainfall pattern is low and high in satellite data sets which infer the suppressed and strongest activity of MJO over Indian Ocean that modulates the rainfall pattern over India.

Keywords: TMPA, IMERG, IMD gridded rainfall, ISO, validation

1. Introduction

During the recent decades, a number of remotely sensed rainfall products have been developed from satellites and are being used widely for different applications such as weather forecasting, hydrology and water resource management. The satellite rainfall data is also useful in assessing the large scale droughts [1] and to monitor the extreme weather events which is increasing due to climate change [2, 3]. The estimation of rainfall from satellites mainly depends upon the relationship between rain rate and the cloud top temperature, observed from the infrared sensors and the influence of rain drops on microwave radiation. The IR based techniques apply the empirical methods to obtain the rainfall from the cloud top brightness temperature, assuming the rainfall originates from the convective clouds [4, 5]. On the other way, microwave techniques directly sense the radiation emission and scattering occurring due to presence of hydrometeors and provide the rainfall estimates. The lacuna in the two methods are IR technique fails in the case of warm clouds and MW measurements are with less frequency compared to IR passes [6]. However, the combination of the two aforementioned techniques provide the best estimates of rainfall, which was employed in the retrieval algorithms of TRMM Multi-satellite Precipitation Analysis (TMPA) and Climate Prediction Centre (CPC) morphing technique (CMORPH). The TRMM was launched as the joint effort of National Aeronautics and Space Agency (NASA), USA and Japan Aerospace Exploration Agency (JAXA), Japan to monitor and assess the tropical rainfall and associated latent heating [7]. The main TRMM sensors are a TRMM Microwave Imager (TMI)], precipitation radar (PR) and a visible and infrared scanner (VIRS). These are combined variously with other IR and gauge-based products [8]. The unique advantage with TRMM that it passes through all hours, thus the diurnal variation of rainfall can be studied. The 3-hourly data records of TRMM rainfall with 0.25 grid resolution are made available from the year 1998 to till 2013 and thereafter, the Global Precipitation Measurement (GPM), the improved version of TRMM which allowed to better link the data sets were been launched [9]. Arrival of GPM brought revolutionary changes in the studying the rainfall characteristics of the convective systems, storms etc. Having with the high spatiotemporal resolution of 0.10 degree and half hourly precipitation products, the GPM rainfall estimates are proven to be more reliable to study the characteristics of tropical cyclones and other rainfall induced hazardous events [10].

Nevertheless, the satellite rainfall products cannot accurately estimate the rainfall. They are much helpful over large areas when there is a limited coverage of rain gauges which of their average may not represent the whole areal rainfall picture in terms of its variability and magnitude. Over small scale areas, the satellites show inability to capture the localized variations. Hence, it ought to validate the satellite rainfall with the ground based measurements of any area before is being used. Several studies focuses globally to validate the TMPA rainfall products not only with the ground based measurements but also with the existing reanalysis products and reported various issues among the comparison results. A study over Caspian Sea Region of Iran by Duan et al. [11] showed that the TRMM 3B42 version rainfall data replicates the monthly and annual variations as gauge data. They also reported that TRMM underestimates the heavy rainfall events over Iran. Nair et al. [12] showed that TRMM 3B42 V6 rainfall products were unable to estimate the accurate amount of orographic rainfall (over Western Ghats of India) and it was underestimated over the rain shadow regions. But the satellite is able to capture the rainfall gradient from west to east of Western Ghats region. It is also reported that the TRMM algorithm was unable to pick the average high and low daily rainfall over India [13]. Uma et al. [14] compared the TRMM 3B42 V6 rainfall data with the India Meteorological Department (IMD) gridded data developed by [15] from 1998 to 2007 and found that at 5° × 5° scales and beyond, both products are compatible to each other. The temporal scale assessment of them showed the pentads of TRMM rainfall (TMPA) are in good agreement with the IMD gridded rainfall data over India. Cao et al. [16] performed the evaluation of 3B43 TRMM data with the ground measurements of rainfall over Yangtze River Delta of China during the period 1998–2016. The results of their study infer that 3B43 data overestimates the actual precipitation but maintained the consistency in terms of correlation and bias. The GPM which is the successor of TRMM offering half hourly rainfall products were also been validated over different regional scales. The comparison of GPM rainfall product IMERG (Integrated Multi satellite Retrievals for GPM) with TRMM 3B42 V7 products over southern Tibetan Plateau indicates the GPM outperforms the TRMM in all spatial scales [17]. GPM shows better detecting capacity than TRMM during light rainy days. Preliminary results of assessment of GPM over India show the difficulties in detecting the rainfall events over south east peninsular and north eastern parts of India [18]. Though there are numerous studies on the validation and comparison of TRMM, GPM rainfall amounts, studies on how satellite rainfall is able to capture the dominant periodicities and interannual variability caused by the global teleconnections such as El Niño and La Niña are sparse. The present work has been mainly focused on the consistency and ability of satellite (TRMM and GPM) in picking the interannual variations and dominant periodicities of Indian south west monsoon. The study on the periodical features of rainfall derived from the satellites are very important in understanding the large scale circulation patterns and have implications on the soil erosion where ground data is not available [19]. Henceforth, we focus on the inter-annual variations and prevailing seasonal oscillations of Indian summer monsoon rainfall obtained from the TRMM/GPM and IMD gridded data sets for the period 1998–2017.

2. Data and methods

The daily rainfall data from TRMM 3B42 V7 for the period 1998–2013 has been used in the present study along with the IMERG data from 2014 to 2017. The TRMM data is available at 0.25° × 0.25° degree spatial resolution published by the Goddard Space Flight Centre Distributed Active Archive Centre (GSFC DAAC). IMERG half hourly data is available with 0.1° × 0.1° spatial resolutions and the same is considered from 2014 to 2017. Both the data sets have been averaged to 0.25° × 0.25° degree spatial resolution and used in the present study for the period from 1998 to 2017. The rainfall data has been extracted to the monsoon core region of India [20] on daily basis and converted to monthly scales by cumulating the daily rainfall for the months of south west monsoon (June, July, August and September) for the period 1998–2017. Before the onset of southwest monsoon, the core monsoon region is characterized by a heat low and thereafter, establishment of a tropical convergence zone takes place in this region [21]. The boundary from the heat low areas over the northwestern part of India to the moist convective parts of the eastern part of the monsoon zone also exhibit significant variation from year to year. The region has different characteristics during a poor and good monsoon years. The monsoon core region of India is shown in the **Figure 1** and the rainfall data pertaining to this region is used for the present analysis.

IMD gridded data with 0.25° × 0.25° spatial resolution spread over Indian land mass has been used as the ground validation in the present study. These data sets were developed by Pai et al. [22] based on the rainfall record from 6955 rain gauges located in India. Out of 6955 rain gauges, 547 are from IMD; 494 from hydro-meteorology; 74 from agromet and remaining from the stations maintained by the state government India. The average number of stations used to obtain 1 day rainfall is about 3100. This version of data is known as IMD4 whereas the earlier versions of this data, IMD3, IMD3 and IMD1 are developed for the periods 1971–2005, 1901–2004 and 1951–2007 0.5° × 0.5° and 1° × 1° spatial resolutions over Indian landmass and 6076, 1380 and 2140 number of rain gauges were used. The dense network of rain gauge locations are depicted in the **Figure 1** [22]. After collecting the station rainfall data, Shepard interpolation technique has been applied to prepare the gridded data sets and the detailed procedure of processing the data can be found from Pai et al. [22].

The rainfall data from the TRMM and GPM have been downloaded from the website http://mirador.gsfc.nasa.gov. The data sets are available in nc4 data format and are processed using the MATLAB as suggested in the http://disc.gsfc.nasa.gov. **Table 1** gives the complete information on the details of rainfall data sets used from TMPA and IMERG including their algorithms.

In the present work, we combine the two satellites rainfall data of TRMM and IMERG covering the period from 1998 to 2017. TMPA 3B42 V7 data sets for the period 1998–2013 and IMERG rainfall products for the period 2014–2017 were used. Each grid value of rainfall over the monsoon core region of India is averaged with the number of grid points and is allotted as the rainfall of the region for the day. Likewise, we computed the daily rainfall over the study region for the southwest monsoon months of June to September for the year from 1998 to 2017. The flow chart given below illustrates the data retrieval methods used to obtain the daily satellite data (**Figure 2**).

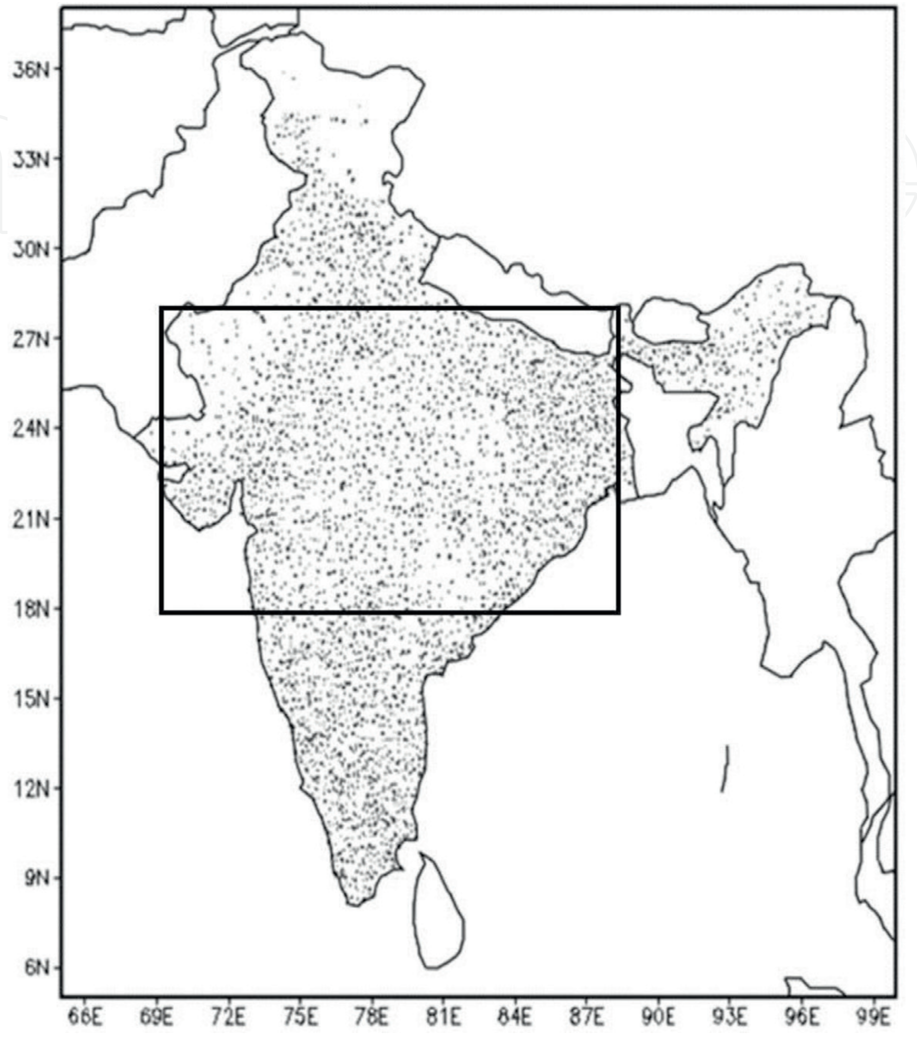

Figure 1.
Monsoon core region of India and density of rain gauges over Indian land mass (source: [20, 22]).

Algorithm	TRMM multi-satellite precipitation analysis	Integrated multi-satellite retrievals for GPM
Basic acronym	TMPA	IMERG
Data set	• 3B42Daily production multisatellite-gauge combination (precipitation) recommended for general use	• 3B-DAY.MS.MRG.3IMERG production multisatellite-gauge combination (precipitationCal) recommended for general use
Spatial grid; coverage	0.25°×0.25° lat/lon; 50°N-S	0.1°×0.1° lat/lon; 60°N-S
Current version	7	5
Time interval; span	• 3 h centered at 00, 03, …, 21 UTC; 1998–2013 • Other value-added products in data centers	• 30 min centered at 0000, 0030, …, 2330 UTC; 2014–present • Other value-added products in data centers
Native format	• nc4 (production) • Other value-added products in data centers	• nc4 • Other value-added products in data centers

Algorithm	TRMM multi-satellite precipitation analysis	Integrated multi-satellite retrievals for GPM

Algorithm summary	• Calibrate microwave precip rates to TRMM combined instrument
	• Merge microwave (HQ), giving preference to conical-scanners
	• Compute VAR microwave-calibrated IR precip rates
	• Fill holes in HQ merged microwave with IR estimates
	• Include gauge data by
	  • computing monthly satellite-gauge and then scaling 3 h data to sum to the monthly in each grid box (production)
	  • scaling 3 h to 3B42 with climatological coefficients (RT)
		• Calibrate microwave precip rates to GPM combined instrument
		• Merge microwave (HQ), giving preference to conical-scanners
		• Compute PERSIANN-CCS microwave-calibrated IR precip rates
		• Use CMORPH-style IR motion vectors to forward/backward propagate microwave maps, then use a Kalman filter to combine these and the IR estimates into a weighted estimate (early is forward-only)
		• Include gauge data by
		  • computing monthly satellite-gauge and then scaling 30 min data to sum to the monthly in each grid box (final)
		  • scaling 30 min to final with climatological coefficients (late and early)

Input microwave algorithms	• GPROF versions 2010v2 and 2004v for various conical scanners • NOAA MSPPS for cross-track scanners	• GPROF2014v2

Source: https://pmm.nasa.gov/resources/documents/home

Table 1.
Details on the TMPA and IMERG data sets.

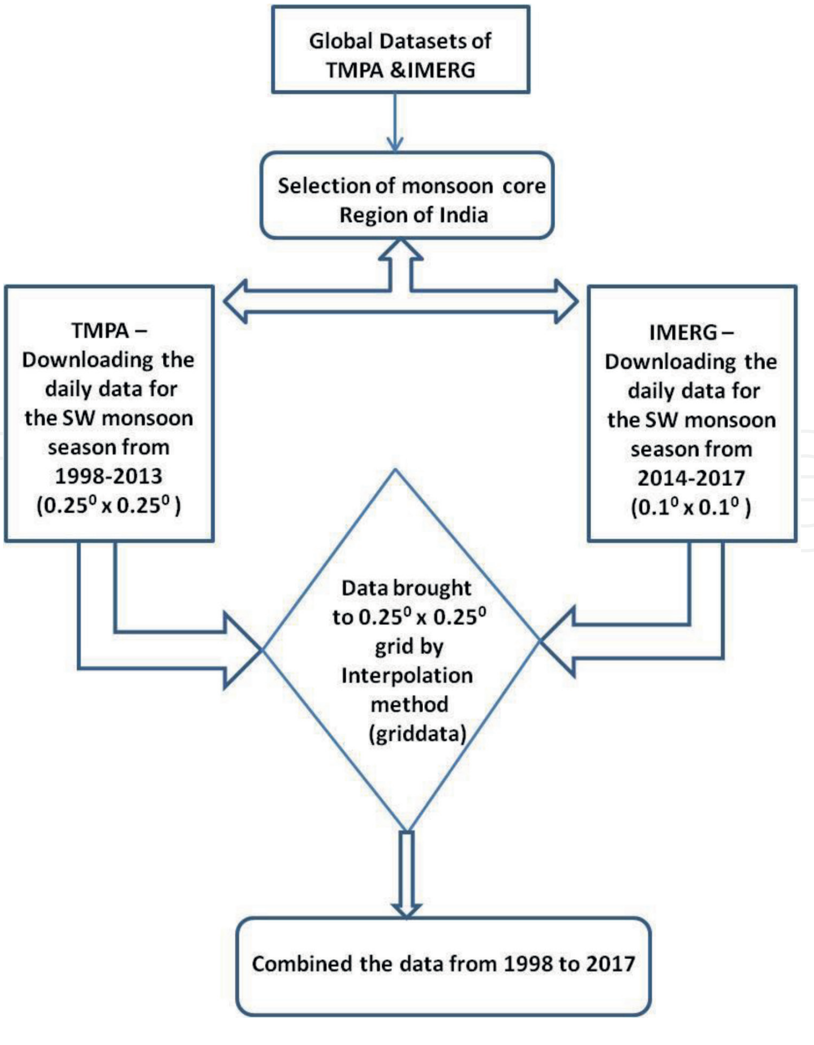

Figure 2.
Flow chart of data retrieval procedure from the satellite (TMPA and IMERG).

3. Discussion

3.1 Time series analysis of IMD and satellite (TMPA and IMERG)

Figure 3 is the daily rainfall averaged over monsoon core region for the period 1998–2017 from IMD and satellite data sets. The average daily rainfall for the season is 6.89 and 7.64 mm for IMD and satellite data sets with mean bias of 0.74 mm. Both the data sets show the monsoon characteristics such as less rainfall during the onset of monsoon, establishment of monsoon during July and August months and weakening of monsoon during the end of September. The daily variability in satellite rainfall is found to be higher than IMD indicated by the respective standard deviations (2.14 mm

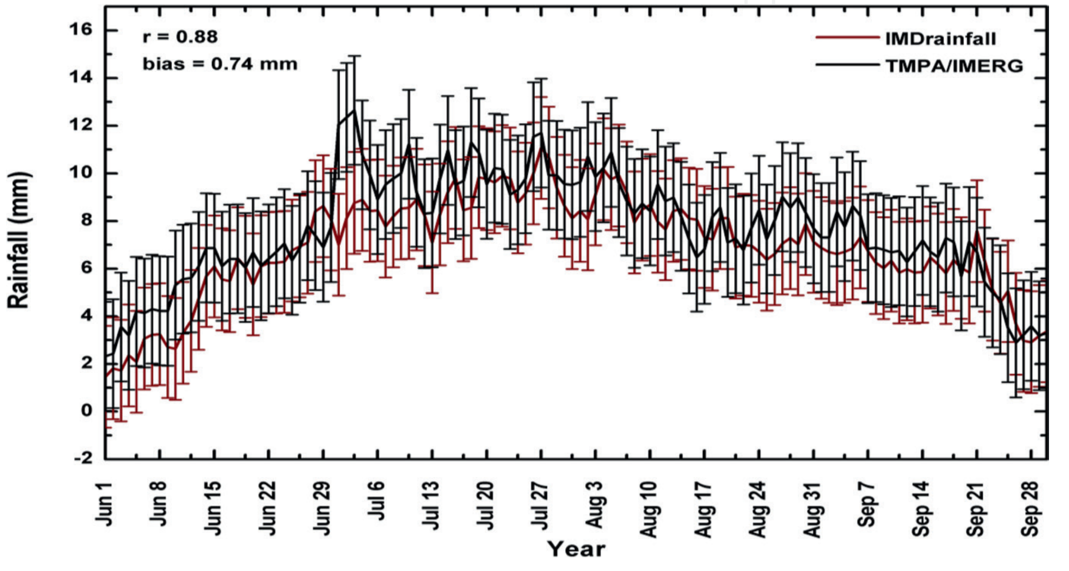

Figure 3.
Mean daily rainfall of IMD and Satellite (TMPA and IMERG) for the period 1998–2017 over monsoon core region of India during the SW monsoon season.

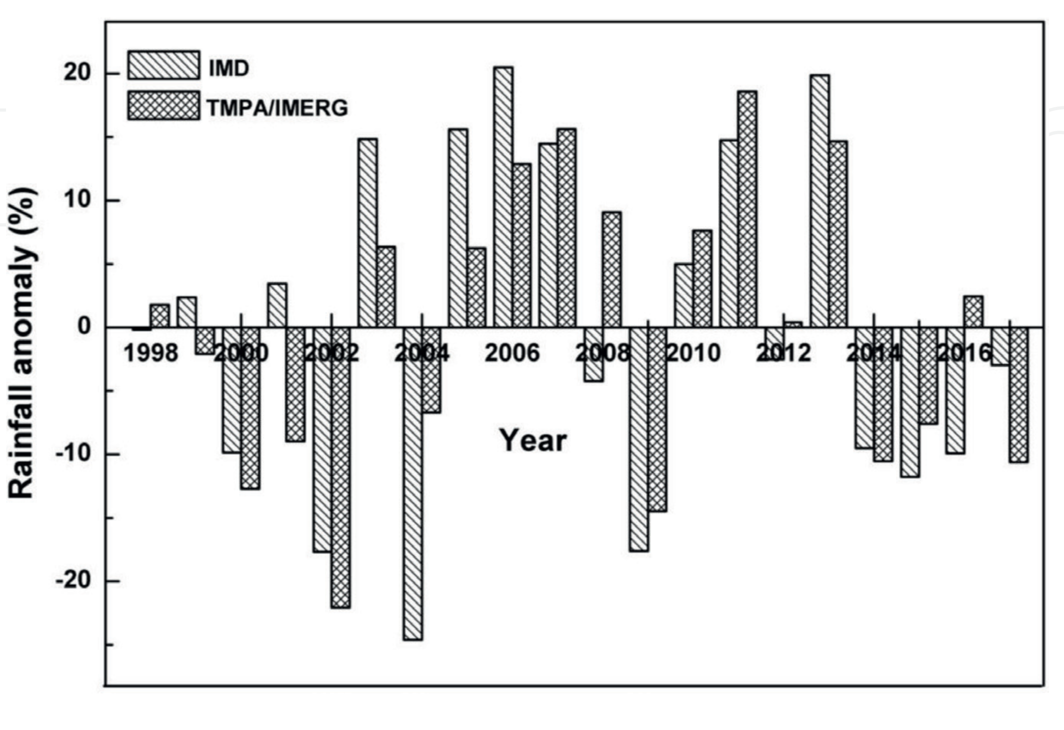

Figure 4.
Interannual variability of SW monsoon rainfall from IMD and Satellite data over monsoon core region of India.

for IMD and 2.29 mm for satellite). It is also observed that satellite is slightly over estimated the IMD rainfall. The linear association of both data sets was significant at 0.01 level with a correlation coefficient of 0.88. However, the correlation coefficient between IMD and satellite data sets varied year to year which is the indication of degree of good agreement in their magnitudes. The seasonal bias between IMD and satellite data sets over monsoon core region varied from −2.6% (2001) to a maximum of 28% (2004) which shows the less bias when whole Indian land mass is considered. The study of Uma et al. [14] on the validation of TMPA and IMD data sets report that TMPA under estimated the Indian rainfall about 100 mm for the period 1998–2007 (10 year mean rainfall for IMD and TMPA are 939 and 832 mm respectively). But over the core region, the satellite data over estimated the IMD of about 90 mm (20 year mean rainfall for IMD and satellite are 841 and 932 mm respectively). The percentage departures of IMD and satellite rainfall with respect to their long term averages are given in **Figure 4**. By and large, the satellite is able to pick up the monsoon rainfall which is evidenced by its negative anomalies during the El Niño years of 2009–2010 and 2015–2016 and positive anomalies during the La Niña year 2010–2011 respectively.

3.2 Lomb Scargle Periodogram of IMD and satellite rainfall to study ISO features

Lomb Scargle Periodogram (LSP) is a well known technique used to detect the periodic signals of given data by generating the power spectrum. The advantage of LSP is that can be applied for non-uniform and uniform data sets. When the data sets are uniform, the LSP turns to classical and in the case of non-uniform samples, it takes the Scargle generalized form of periodogram [23]. The expression for the classical periodogram can be written as

$$P(f) = \frac{1}{N}\left(\sum_{n=1}^{N} gn\, e^{-2\pi i f t n}\right)^2$$

The LSP is being used to detect the periodicities of Indian rainfall. Kishore et al. [24] studied the precipitation of IMD for a period of 107 years from 1901 to 2007 using LSP and found different periodicities of 10, 15.7, 23 and 33 years with different confidence intervals. The LSP of northeast monsoon rainfall (October to December) over peninsular Indian region indicating the 20 and 30–40 days periodicity [25]. Since, the LSP is most useful in portraying the periodicities of a season; the applicability of LSP during the south west monsoon season of Indian region will give more insight to understand the dominant ISO of southwest monsoon. In the present work, we have performed the LSP for the daily rainfall data averaged over monsoon core region of India (**Figure 1**) for the period 1998–2017 for IMD as well as for satellite rainfall data sets respectively (**Figure 5**). From the **Figure 5**, we see the peaks of normalized power for different periodicities during the SW monsoon season. Wherever, the dominant periodicities are captured by IMD as well as satellite. It is well known that the dominant periodicities of Indian SW monsoon are (i) a 30–60 days oscillation, known as Madden Julian Oscillation (MJO). It is one of the tropical weather phenomena moves eastward and changes the rainfall pattern over Indian latitudes based on its arrival, (ii) oscillations having periodicity less than 20, viz., monsoon trough, tropical easterly jet, moist static stability, monsoon cloud cover, break and wet spells [26]. The overall observation of **Figure 5** suggests that the normalized power is high for the higher periodicities and is depicted by the both data sets. Two major peaks were observed during the 30–60 days MJO oscillations, one is at 40 (slightly less than) and the other is in between 50 and 60. These peaks are the representatives of strong cycles of MJO which has great impact on Indian summer monsoon. When comes to periodicities less than 20 days which are mainly known to be localized variations were

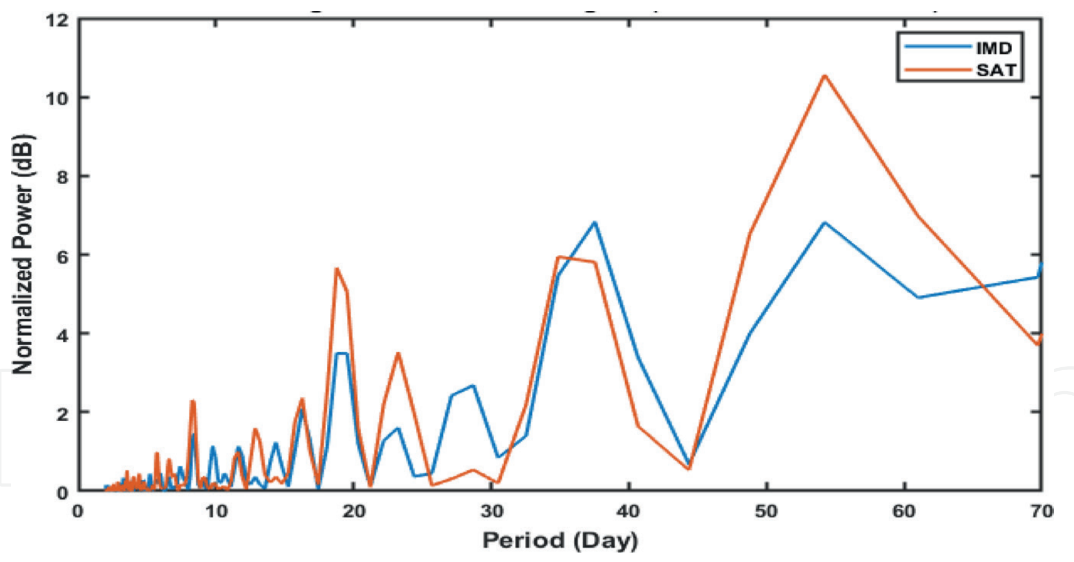

Figure 5.
LSP of daily SW monsoon rainfall of IMD and satellite for the period 1998–2017.

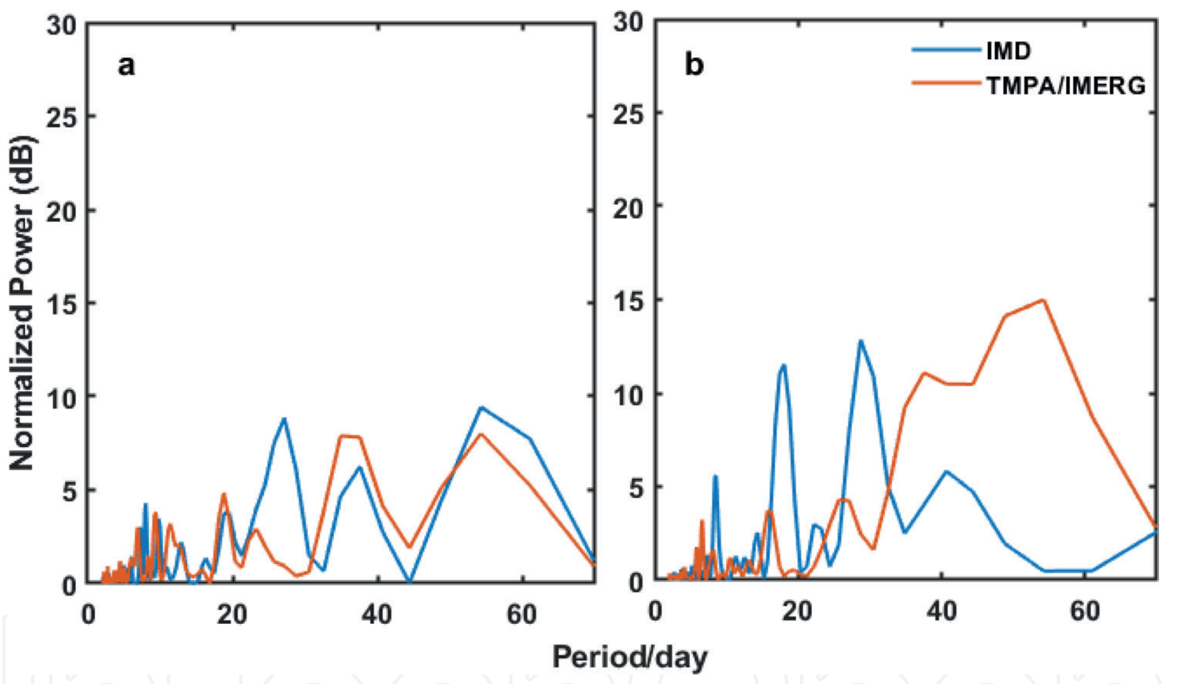

Figure 6.
(a and b) LSP of daily SW monsoon rainfall of IMD and satellite for the La Nino year 2011 and for the El Nina year 2015.

also captured by both IMD and satellites. Here we find the dominant periodicities at 20 and 7 days. However, the magnitude of normalized power during the individual years varies from satellite to IMD data sets. For this purpose, we show the LSP for the 2 years 2010 (La Niña) and 2015 (El Niño) where the monsoon core region experienced 15 and −11% of its normal seasonal rainfall (1998–2017) (**Figure 6a** and **b**). Satellite rainfall also show the similar fluctuations as IMD rainfall showed. The LSPs of 2011 and 2015 show different features though both capture the dominant periodicities. The normalized power of IMD rainfall did not vary much when compared with the satellite derived rainfall for the years 2011 and 2015. The magnitudes of normalized power of satellite show the suppressed activity of MJO in the year and 2015 and the pronounced activity during the year 2011. It is reported that the suppressed phase of MJO in the Indian Ocean causes the lower rainfall amounts when there is no deep convection [27]. Also, when the MJO is strong, higher temperature anomalies observed over lower troposphere altitudes and cooler air prevails in the upper troposphere which brings the more instability. During the presence of El Niño, the easterlies of the equatorial north Indian Ocean weakens the monsoon westerlies and in the case of La Niña, the westerly anomalies strengthen the monsoon winds. Hence, one may expect higher power of MJO in the rainfall pattern during the La Niña and lower power in the El Niño [28]. The same features were picked better by the satellite rainfall compared to IMD rainfall. As the MJO is the combination of cloud and precipitation processes, the satellite is being advantageous as it measures rainfall from the cloud properties whereas the IMD measurements are based on the ground measurements. However, as mentioned earlier, the dominant features of ISO are well captured by the satellite as the ground observations.

4. Conclusions

Main features of Indian south west monsoon were studied using the IMD and Satellite rainfall data sets. Satellite rainfall data sets show very less bias with relation to the IMD over the monsoon core region of India for the period 1998–2017. The interannual variability of satellite derived rainfall could show the impact of global teleconnections such as El Niño and La Niña evidenced by the negative and positive anomalies of rainfall from their respective means respectively. The LSP of averaged daily rainfall of IMD and satellite pick up the similar features of ISO such as Madden Julian Oscillation (30–60 days) and localized periodicities (less than 20 days). The normalized power of LSP varies from year to year from IMD to satellite rainfall, which shows the different behavior of satellite in detecting the ISO. During the El Niño and La Niña years, satellite rainfall could show better features than IMD when the normalized power is being considered. Overall, the satellite rainfall data sets over monsoon core region offer a valuable data sets with less bias and good agreement.

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