Preferred Regions of Extreme Rain Events of the Indian Summer Monsoon Evolving with Changing Climate

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Abstract

The Extreme and Intense Rain Events of the Indian Summer monsoon contribute significantly to its Seasonal rainfall. Based on TRMM 3B42 data for the period from 1999 to 2010, preferred regions of occurrence of Extreme /Intense Rain Events are extracted over both the Indian Land and the Sea with the rain events constructed every day. The rain events are segregated in to Moderate, Intense and Extreme Rain Events (MRE, IRE, and ERE) based on the thresholds devised on the accumulated rainfall of the events normalised with respective duration for the Central India. Three broad prominent regions for occurrence of EREs, namely, the 1. West-Central Parts of India and the adjoining Arabian Sea [WCI region], 2. Central and North-Central parts of India [CI region] and 3. North-Eastern parts of India and the adjoining Bay of Bengal [NEI region] have been identified. The striking inference is the shift in preferred regions of EREs observed from NEI region to WCI region with the trends reversed in the study period.

Introduction

The changing rainfall pattern of the Indian summer monsoon with increasing trend in Extreme Rain Events attributed to the unequivocal warming of the environment is a subject of concern in recent times (Goswami et al, 2009). The magnitude of devastation due to the historical rain event of 26–27 July 2005 over the Mumbai region during when 944.2 mm of rain occurred in a span of 24 hrs at the location, SANTACRUZ [19.120N, 72.875E] on 27 July, 2005 is incredible interms of loss of human life, the infrastructure, etc (Shyamala and Bhadram, 2006). Therefore, a diagnosis of the "Preferred Regions" of Extreme Rain Events (ERE) over both the land and oceans will be of value addition to the task of improving their prediction with an appropriate design of the high density network of measurements (Rao 2008a, 2008b), and is absolutely essential to effectively handle the chaos caused by their occurrence with well planned remedial measures.

Objective

The chief objective here is to examine the preferred regions of occurrences of EREs over the Indian land and oceans with the event segregation based on the thresholds arrived at with observed rain event characterization.

Data analysed

We used three independent data sets, namely, TRMM 3B42 data available at 3 hourly time interval (accumulated over three hours around the reported time) gridded at 0.25 x 0.25 horizontal resolution (Huffman and Bolvin, 2009) for twelve years period, 1999-2010. The second data set is the gridded daily rainfall (24 hourly accumulated from 3 GMT to 3 GMT on the next day) of IMD at 1 x 1 deg resolution in space (Rajeevan et al, 2006) for the period 1951-2010. IMD Gridded data is based on 1803 stations data with 90% of data availability during the analysis period 1951-2010. After 1995, the number of stations with data availability for the analysis dropped. The third data set used here is the All India Rainfall (AIR), that is, the all-India area-weighted mean summer monsoon rainfall (JJAS) for the period 1871-2008 generated based on 303 stations over the Indian region (Parthasarathy et al.,1996).

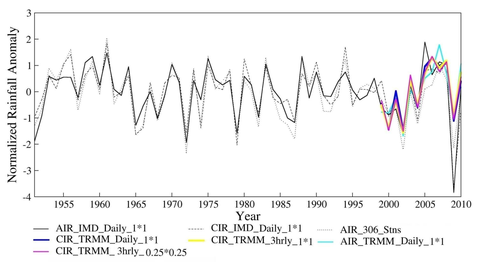

Figure 1: Interannual variability in Seasonal Monsoon Rainfall Anomaly for All India and Central India normalized with respective Standard deviations, 10.50 , 11.22 , 8.29, 11.87, 10.34, 9.41, 10.29 mm respectively for the data sets ordered horizontally as in the legend. The corresponding mean seasonal rainfall are 93.17, 87.29 , 84.95 , 95.23 , 86.92 , 88.34 , 88.50 mm .

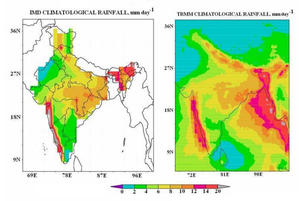

Figure 2: The Climatological Mean Summer Monsoon Rainfall (JJAS) based on IMD and TRMM data sets for the respective periods of 1951-2010 and 1999-2010.

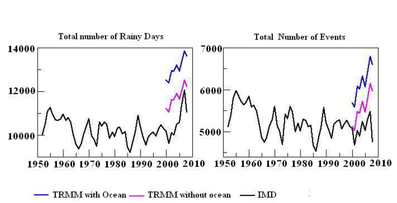

Figure 3: Comparison in Number of rainy days and in Number of Events between TRMM and IMD Gridded data with 3 pt running average. Events classification based on Fixed thresholds (Goswami et al, 2006)

Methodology

Rain Event definition and Rain Event construction

A rain event has been characterized in terms of four parameters, namely, the maximum (peak) event rainfall, event duration, event accumulated rainfall and the time of occurrence of the event. Around the maximum rain of the day, a rain event is constructed by considering the continuity in rain occurrence on either side of the maximum to obtain the event's duration and its corresponding accumulated Rainfall over the event duration. Thus the duration of any event is the total number of hours in the time period during when rain is continuous from beginning till the end of the event. Time of occurrence of maximum (peak) rain is treated as the time of occurrence of the rain event. Rain accumulated over the event duration is defined as the event accumulated rainfall. Rain events have thus been constructed for the entire domain at each grid every day during June-September months for the years 1999-2010.

Rain Event characterization

The climatology of the total number of events distribution with duration and their time of occurrence is presented here along with their contribution to the seasonal rainfall. We inferred that the percentage of events associated with longer durations in the range 12-24 hrs is significantly low at all times of occurrences in comparison with those events of shorter duration in the range, 3-12 hrs. Maximum number of events of shortest duration of 3-6 hrs are clustered around the time of occurrence of 9:00-12:00 GMT. The duration wise distribution of seasonal rainfall due to these events is very much similar to the events distribution all through 24 hrs.

Threshold Extraction Technique

The thresholds are arrived at for extracting Intense, Extreme and Moderate Rain Events, based on the thresholding technique devised here, for the homogeneous rainfall region of Central parts of India [16.5N-26.5N:74.5E-86,5E]. The primary parameters considered in the thresholding technique are the event duration, the event maximum rainfall and the event accumulated rainfall. The basic data used here is the average accumulated rainfall per 3 hrs (accumulated rainfall normalized with event duration) of each event for each grid of the domain for each year in the study period.

Table 1 describes the data used for thresholds extraction, R0, R1, R2 respectively and they are 7.8 mm, 39.4 mm, 136.6 mm.

Year	Rainfall (mm) averaged over all the rain events	Maximum of average event accumulated rainfall (mm) per 3 hrs	Range of maximum event rainfall (mm) per 3 hrs for events with average accumulated rainfall per 3 hrs > R2		Average maximum event rainfall (mm) per 3 (Average of Lower & Upper ranges given in 4th column)
			Lower	Upper	
1999	8.1	191.6	**R1= 39.4**	197.3	118.3
2000	8.3	181.8	25.4	181.8	103.6
2001	8.3	188.5	24.9	188.5	106.7
2002	7.8	142.9	27.6	176.6	102.1
2003	7.5	184.7	33.6	207.1	120.4
2004	7.5	173.3	31.1	206.4	118.7
2005	9.1	201.6	25.7	201.6	113.6
2006	7.7	166.7	22.7	172.2	97.4
2007	7.4	210.6	26.9	221.4	**R3=124.1**
2008	7.6	163.9	29.4	181.4	105.4
2009	7.2	141.6	29.5	185.8	107.7
2010	6.5	**R2=136.6**	29.7	151.5	90.6
Average over the 12 years	**R0=7.8**	173.7	28.8	189.3	109.1

Table 1: Thresholds for classification of Rain events for the Central Indian Region (CIR)

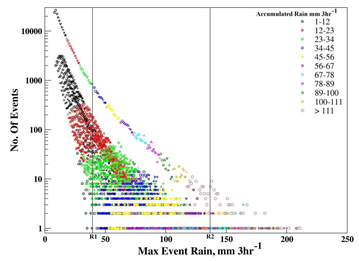

Figure 4: The number of events extracted and classified in bins of 1 mm of average accumulated event rainfall per 3 hrs (> R0) against their corresponding bins of event maximum rainfall. The vertical lines are at event maximum rainfall of 39.4 and 136.6 mm

A near triangular shape organization of the events is observed distributed bin wise bound between two sides along which we note a decrease in number of rainfall events with increasing event maximum rainfall and average accumulated event rainfall per 3 hrs.

Criteria for Events Classification and Nature of the Events

Criteria for Extreme Rain Events (ERE):

$E_{Acc} >= R2$ & $E_{Max} >= R2$ (1)

Considering that there is possibility of events with E_{Max} close to R2 and $E_{Acc} >= R2$, a new threshold, R3, has been defined using the average of the ranges on maximum event rain for which $E_{Acc} >= R2$. The threshold R3 is fixed at the maximum in the set of data on average of the ranges over the years. R3 value is found to be to be at 90% of R2. Thus events satisfying the following constraint are included under EREs. These are very few events of longer duration (12-24 hrs),

$E_{Acc} >= R2$ & $E_{Max} >= R3$ (2)

For Moderate Rain Events (IRE):

For all E_{Acc} & $R0 <= E_{Max} < R1$ (3)

For Intense Rain Events (IRE):

$E_{Acc} > R2$, & $R1 <= E_{Max} <= R3$ (4)
$E_{Acc} < R2$ & $R1 <= E_{Max} <= R2$ (5)

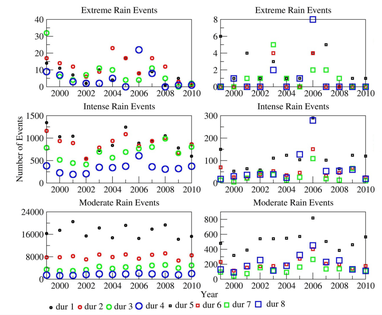

Figure 5: The EREs, IREs and MREs extracted based on the respective criteria for year to-year variations

The EREs extracted based on criteria (1) and (2) are only a few events of all durations associated with extremely large accumulated and peak rainfall, however, large percentage of EREs are of short duration (< 12 hrs). The MREs segregated based on criterion (3) are relatively large in number.

Results

Trends in Extreme Rain Events

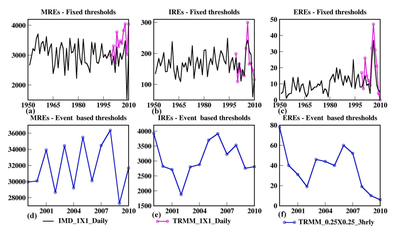

Figure 6: Year to-year variations in number of EREs, IREs and MREs extracted based on (a-c) Fixed thresholds in CIR_ IMD_Daily_1 x1 during 1951-2010 and CIR_TRMM_Daily_1 x1 during 1999-2010 (d-f) Event thresholds in CIR_TRMM_3hrly 0.25 x 0.25 during 1999-2010.

- The decreasing [increasing] trend seen here in the number of MREs [IREs, EREs] varying with time in figure 6(a) [6(b-c)] is similar to the nature of trends observed by Goswami et al., 2006. For the last 12 years period, that is from 1999-2010, one can see good comparison in figures 6(a-c) in both, the number of events and the nature of the trends in all the three categories of the events between the TRMM and IMD data sets.
- It is striking and noteworthy that there is no-trend observed with time in the EREs segregated based on Event thresholds in TRMM data, as shown in figure 6(f)

Preferred Regions of Extreme/Intense Rain Events

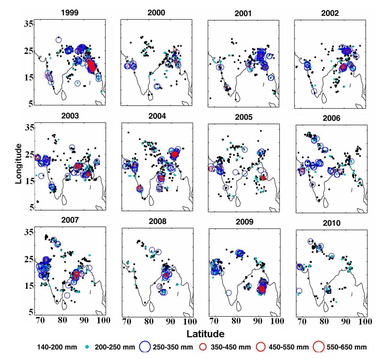

Figure7: Distribution of EREs over the Indian land and oceanic regions during 1999-2010

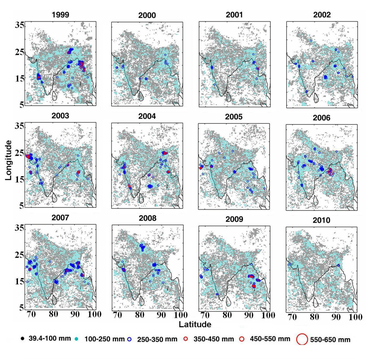

Figure 8: Distribution of IREs over the Indian land and oceanic regions during 1999-2010

It is remarkable to note the three prominent regions preferred by EREs, namely, the 1. West-Central Parts of India and the adjoining Arabian Sea [WCI region (68E-75E:17.5N-26N)], 2. Central and North-Central parts of India [CI region (75E-85E:20N-30N)] and 3. North-Eastern parts of India and the adjoining northern Bay of Bengal [NEI region (87.5E-95E:17.5N-27.5N)]. The preferred regions for clustering of High (Low) end of EREs are NEI and WCI regions (CI region). A handful of EREs occurred over West-coast of India through out the period. The Eastern parts of Southern Peninsular India, the low rain zone of the monsoon season, is observed to be a permanent void region for EREs during the study period.

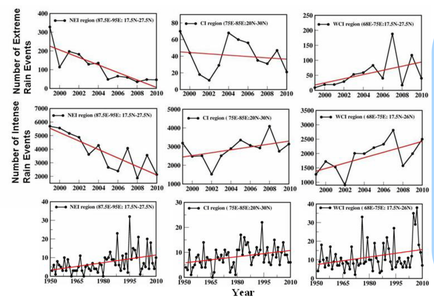

Figure 9: Year to-year variations in number of EREs, IREs extracted in AIR_TRMM_Daily_1 x1 data based on Event thresholds (top & middle panels) and in AIR_IMD_Daily_1 x1 based on fixed thresholds (lower panel) for three regions, WCI , CI and NEI regions.

- The WCI region is seen to be prone to EREs (top panel) and IRES (middle panel) growing in number significantly with time in contrast with the NEI region.
- The feature of reversal in trend between WCI and NEI is missing in the bottom panel.

Summary & Conclusions

- An attempt has been made here to extract the preferred regions of Extreme Rain Events of the Indian summer monsoon during the twelve years period from 1999 to 2010 based on TRMM 3B42 precipitation data (at 0.25 ^{0} X 0.25 ^{0} resolution and 3 hourly interval) over both Land and Sea.
- Rain events have been constructed around their maxima to obtain events duration and the corresponding accumulated Rainfall. The thresholds have been devised based on the accumulated Rainfall of the events normalised with duration, called here as, Average accumulated rainfall per 3 hrs, for the homogeneous rainfall region of Central parts of India [16.5N-26.5N:74.5E-86,5E].
- The threshold, R0, is calculated for the Central Indian Land region [16.5N-26.5N:74.5E-86,5E] over 12 years period to define the background rain of the season (JJAS). R0 turns out to be 7.8 mm. The threshold, R2 is at the minimum in the set of maxima of Average accumulated rainfall per 3 hrs extracted over the CIR for 12 years. The threshold , R1, is fixed at the minimum in the set of lower ranges of maximum event rain extracted from a delineated set of events for which the accumulated event rainfall per 3 hrs is greater than R2. Rain Events (ERE) have been segregated in to Moderate, Intense and Extreme Rain Events (ERE) based on the thresholds , R0, R1 and R2.
- Three broad prominent regions for occurrence of EREs, namely, the 1. West Central Parts of India and the adjoining Arabian Sea [WCI region], 2. Central and North Central parts of India [CI region] and 3. North-Eastern parts of India and the adjoining Bay of Bengal [NEI region] have been identified.
- The striking inference is the shift in preferred regions of EREs observed from NEI region to WCI region with the trends reversed in the study period.