Trends and variabilities of Indian summer monsoon rainfall in different intensity bins over West coast and Monsoon Core Zone

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Introduction

India is one of the world's most densely populated countries, with a major portion of the population reliant on monsoon related activities for living. Several studies have found evidence of a increase in variability in southwesterly monsoon circulation and summer monsoon rainfall in recent years. It is vital to understand how the monsoon system has altered in this warming climate.

Rainfall along the West Coast and Monsoon Core Zone is a strong predictor of monsoon flow interaction with orography and overall synoptic-scale monsoon circulation intensity. Rainfall studies based on different intensity bins over these regions provide better understanding of rainfall pattern, that helps proper management of India's economic and social life.

Objectives

In this study we analysed the long term variability of summer monsoon rainfall (SMR) and rainfall patterns in six intensity bins over West Coast (WC) and Monsoon Core Zone (MCZ). Aside from this, we investigate the relationship between regional summer monsoon rainfall in different rainfall intensity bins with the global SST.

Data & Methodology

In this study, features of SMR are investigated, to understand the variability of rainfall utilising gridded rainfall data of IMD at a spatial resolution of 0.25° × 0.25° latitude–longitude grid and sea surface temperature (SST) data of Met Office Hadley Centre with a spatial resolution of 1° × 1° latitude–longitude grid for 120 years from 1901-2020. The region selected for the study are WC and MCZ as shown in figure 1. We classified rain events into different intensity bins based on percentile value (p), viz. dry ($p < 10$), low ($10 \geq p < 50$), moderate ($50 \geq p < 90$), high ($90 \geq p < 95$), very high ($95 \geq p < 99$) and extreme ($P \geq 99$) rainfall events for each regions.

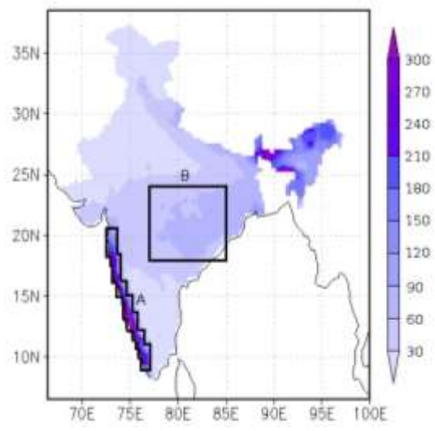

Figure 1 Climatology of Indian Summer Monsoon rainfall (mm) from 1901 to 2020. The West coast region and Monsoon core zone regions are marked as A and B respectively.

Statistical analysis such as Sen's-slope estimation and Mann-Kendall test was carried out in order to check the long-term trend and its significance for total rainfall and each rainfall intensity class over the regions. In order to study the multidecadal variability in SMR, the study period is further subdivided into four multidecades of 30 years each, viz. 1901-1930, 1931-1960, 1961-1990, 1991-2020. Multidecadal variability in each intensity class were examined by studying the percentage contribution to the total rainfall. In order to study the spatial coherence of rainfall patterns in both regions and to identify the relationship of SMR and its intensity classes with global SST we conducted a Pearson product-moment coefficient analysis. We also conducted a 31-year sliding correlation to check the consistency of identified global SST-SMR relationship throughout the period.

Results & Discussion

Several studies have claimed the weakening of SMR in India (Kulkarni, 2012; Varikoden et al., 2013). Table 1 presents the rainfall trend over WC and MCZ during the summer monsoon season.

Table 1 Long term trend (1901-2020) value of SMR and rainfall intensity bins. **α** value inside the table depicts the significance level.

	WC	MCZ
SMR	14.3 (**α** =0.11)	-5.6 (**α** =0.09)
Dry	-0.61 (**α** =0.24)	-0.006 (**α** =0.94)
Low	0.63 (**α** =0.70)	1.98 (**α** =0.03)
Moderate	5.91 (**α** =0.34)	-3.29 (**α** =0.30)
High	2.93 (**α** =0.36)	-1.18 (**α** =0.39)
Very high	0.76 (**α** =0.80)	-2.62 (**α** =0.09)
Extreme	6.18 (**α** =0.05)	-0.57 (**α** =0.65)

Table 2 Spatial coherence of rainfall intensity bins in WC and MCZ. Bold values are at 0.05 significance level

	D	L	M	H	VH	E
1901-2020	**0.30**	**0.23**	**0.40**	**0.18**	**0.26**	0.04
1901-1930	0.13	0.04	0.23	0.18	0.11	-0.12
1931-1960	**0.38**	**0.38**	0.29	0.23	0.14	-0.15
1961-1990	**0.41**	0.01	**0.56**	0.28	**0.47**	-0.11
1991-2020	**0.33**	**0.35**	**0.43**	0.11	0.25	**0.31**

From spatial coherence analysis (Table 2), it is interesting to note that all the intensity bins in WC shows significant positive correlation with MCZ except extreme intensity for the period 1901-2020. Between 1991 and 2020, the extreme intensity bin exhibits a considerable increase in coherence.

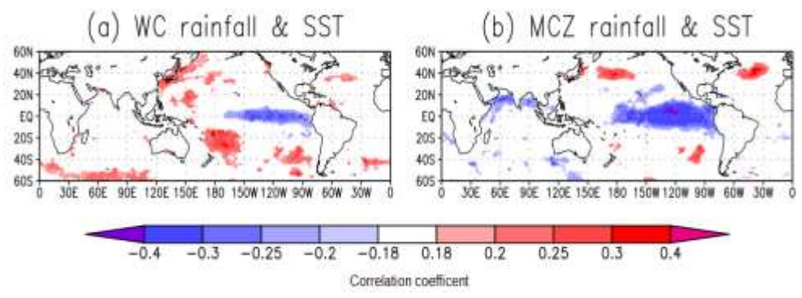

Figure 2 Spatial correlation of SST with SMR in (a) West Coast and (b) Monsoon core zone. The value of correlation coefficient under 99% confidence bound is shaded.

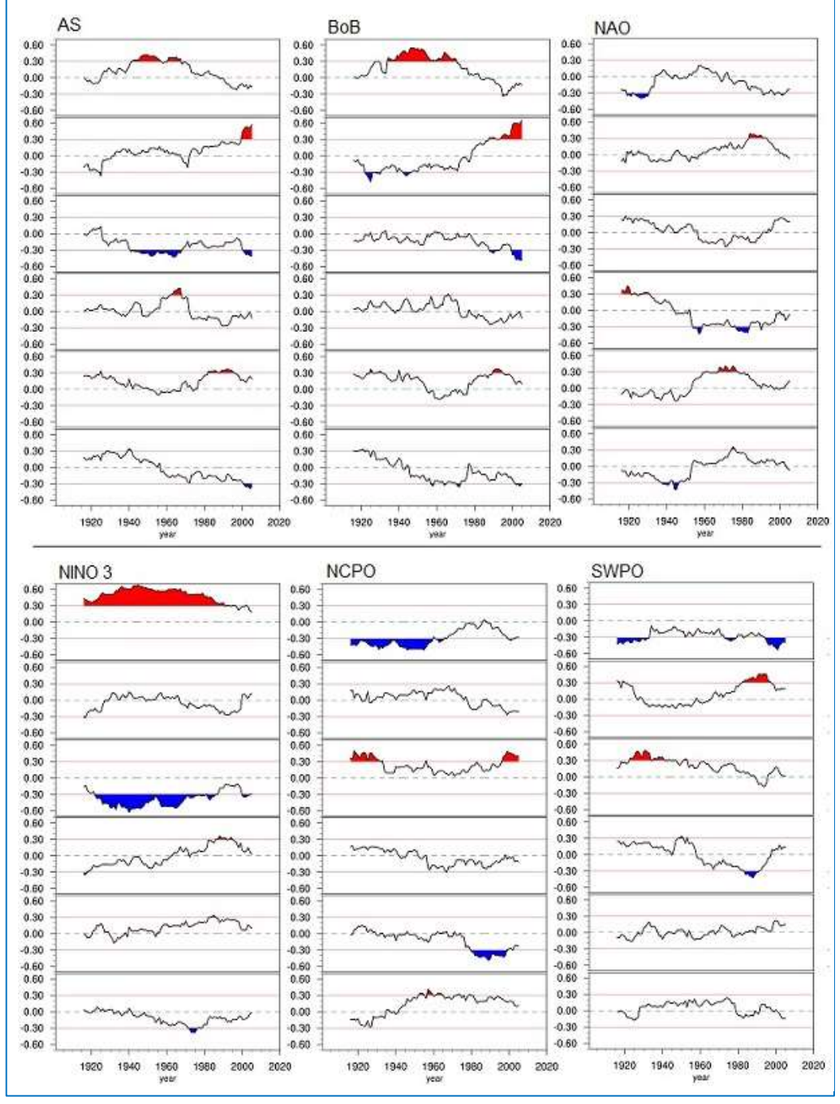

Figure 3 31-year sliding correlation of SMR intensity bins in West Coast with SST in Arabian Sea (AS), Bay of Bengal (BoB), north Atlantic Ocean (NAO), Niño 3 north central Pacific Ocean (NCPO) and southwest Pacific Ocean (SWPO). In each set first row from the top represents dry, low, moderate, high, very high, extreme intensity class for the above-mentioned area. Red line represents the 0.05 significance level. Dashed line represents correlation coefficient value of zero. Shaded region shows significant correlation in

- In WC, dry intensity bin, shows positive correlation with AS-SST and BoB-SST till 1980s after which shows negative correlation towards recent years.
- Low intensity bin shows negative (positive) correlation with AS-SST and BoB-SST (NCPO-SST) for the early period and it shows positive (negative) correlation during the recent decades.
- The moderate intensity bin does not show any significant correlation with BoB-SST until 1990, after which it shows a negative correlation with high significance beginning in 2000.
- High intensity bin showed positive (negative) correlation with AS (BoB) SST towards recent decades which were in opposite relationship before.
- Extreme intensity bin is also showing a contrasting pattern in relationship with the SSTs toward the recent decade.

Similar analysis was conducted for MCZ and recent changes in SMR-SST relationship were observed.

Summary/Conclusion

In this study we bring out the characteristics of summer monsoon rainfall and its intensity bins, their link with global SST, and their spatial and temporal heterogeneity over two regions.

- WC and MCZ are showing significant trends in SMR and its intensity bins.
- The rain events are becoming more correlated toward the recent decade especially in extreme intensity bin.
- Towards recent decades the SMR and its intensity bins relationship have changed towards recent decades, some relationships are becoming significant and some showed phase change.

In general from all these analyses it is confirmed that the impact of climate change on monsoon variability has amplified towards recent decades.

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