Variability of All India Summer Monsoon Rainfall: Large-Scale QBO, ENSO and Climate Change Impacts and Processes

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ABSTRACT

India much depends on monsoon rainfall for agricultural planning, industry, human and other life. A good monsoon resulting in improved agricultural yields, which brings down prices of essential food commodities and reduces their imports overall reducing the food and inflation. Further improved rains result in increased hydroelectric production. All these factors initiate positive ripple effects throughout the economy of India. Studies have been reported about the Indian summer monsoon onset and rainfall variability (Parthasarathy B, Rupa Kumar K. and Kothawale D.R., 1992). Recent studies have been reported that the variability of monsoon rainfall during the northern summer is well associated with the great deserts, equatorial lower stratospheric winds (QBO) and 11-year solar cycle (https://cdsp.imdpune.gov.in/). In the present study, we further examine the seasonal, inter-annual and long-term variability of monsoon rainfall using all India rainfall data during June-September, for the period 1881-2010. We looked the impacts and processes including large-scale events such as OBO, ENSO and Climate Change including SSTs over the Arabian Sea, on monsoon variability. The study has pointed out that the cooling SST's affect the monsoon onset and seasonal rainfall. The large-scale floods/droughts were associated with the westerly/easterly phases of the QBO. The large-scale droughts were associated with the ENSO and easterly phase of the QBO. Decadal analysis revealed a long-term variability (~ 50 year) in all India rainfall. Some of the processes associated with the monsoon variability have been discussed.

Keywords: *Indian Summer Monsoon, Monsoon Variability, ENSO and QBO.*

1. Introduction

The term "monsoon" appears to have originated from the Arabic word Mausam which means season. The basic mechanisms seem to be differential heating of land and sea (Reddy et al, 1989). Indian Summer Monsoon plays in weather and climate over India. The rainfall during monsoon season controls many sectors from agriculture, food, energy, and water to the management of disasters. The variability of monsoon rainfall is highly unpredictable at multiple scales both in space and time. There is an alternative hypothesis in which the monsoon is considered as a manifestation of the seasonal migration of the Inter Tropical Convergence Zone (Jay and Stephens, 1983; Webster 1983; Yasunari, 1979). The monsoon and its variability were well studied by numerous authors with different approaches and hypothesis (Sikka and Gadgil 1978; Charney, 1969; Gadgil, 2003; Goswami and Mohan, 2001). In the present study, we examine the seasonal, inter-annual and long-term variability of monsoon rainfall using all India rainfall data during June-September, for the period 1881-2010. We looked the impacts and processes including large-scale events such as QBO, ENSO and Climate Change including SSTs over the Arabian Sea, on monsoon variability. The study has pointed out that cooling SST's effect on the monsoon onset and seasonal rainfall. The large-scale floods/droughts were associated with the westerly/easterly phases of the QBO. The large-scale droughts were associated with the El Niño and easterly phase of the QBO. Decadal analysis revealed a long-term variability (~ 50 year) in all India rainfall.

2. Data and analysis

The Indian rainfall data for summer season (June-September) for the long-term period 1881-2010, were obtained from the time series analysis

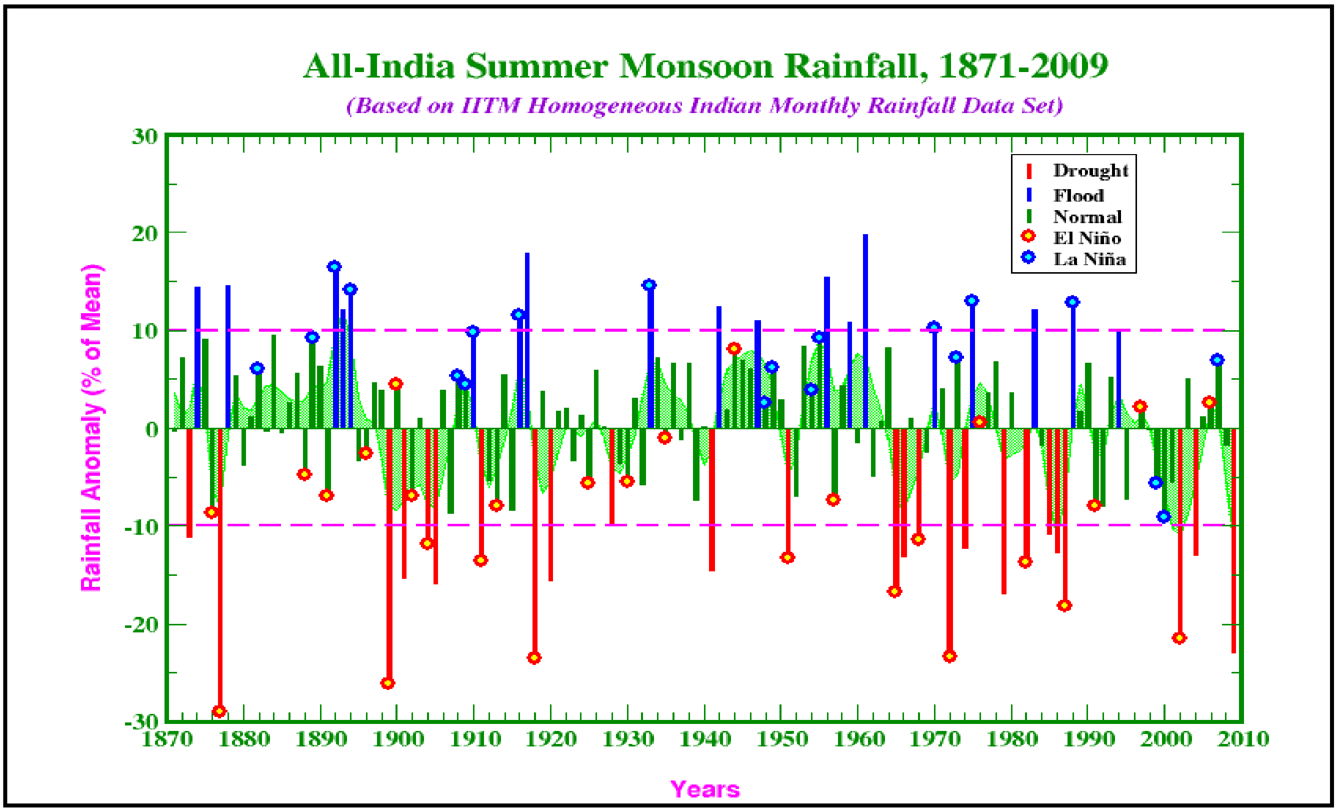

Figure 1: Variability of All India Rainfall for the period 1871-2009 (source IITM).

published by IITM (Parthasarathy et al., 1992) and IMD (https://cdsp.imdpune.gov.in). ENSO and QBO data were obtained from the Climate Indices published by the NOAA Earth System Research Laboratory. Sea surface Temperatures for summer season June to September over the Arabian Sea for eight years 2003 to 2010 were obtained from the MODIS satellite.

The trend analysis was performed to examine the recent trends in the rainfall data. The correlation analysis was performed between the time series of rainfall and ENSO. The rainfall data and onset of the monsoon were examined during westerly/easterly phases of the QBO and strong El Niño/La Nino events.

3. Results and Discussion

The results are presented in Figures 1 and 2 and Table 1. Floods/droughts over the Indian sub-continent during the westerly/easterly phases of the QBO and the large-scale droughts enhance during the ENSO events. Possible physical mechanisms include the following: During the easterly QBO phase, the mean wind direction within a few degrees of latitude of the equator is easterly in both troposphere and stratosphere. This allows near equator convection, enhanced in the vertical. However, the near equator stratospheric winds are westerly, in opposition to those of the troposphere.

A dynamical boundary for vertical enhancement of convection and allows off-equator convection to be preferred. The monsoon areas being off equator are therefore enhanced during westerly phase. This suggests that activation of 30-40-day oscillation (Dry) during strong El Niño and Easterly Phase of QBO and activation of 15-20-day oscillation (Wet) during Westerly phase of QBO (10). We observed that since last five years the onset of monsoon was early except in 2005. Year2009 was the large-scale drought and may be attributed to strong ENSO conditions. In general, the Indian summer monsoon (ISM) rainfall is near normal or excess during the El Niño decay phase. Nevertheless, the impact of large variations in decaying El Niño on the ISM rainfall and circulation is not systematically examined. Based on the timing of El Niño decay with respect to boreal summer season, El Niño decay phases are classified into three types in this study using 142 years of sea surface temperature (SST) data, which are as follows: (1) early-decay

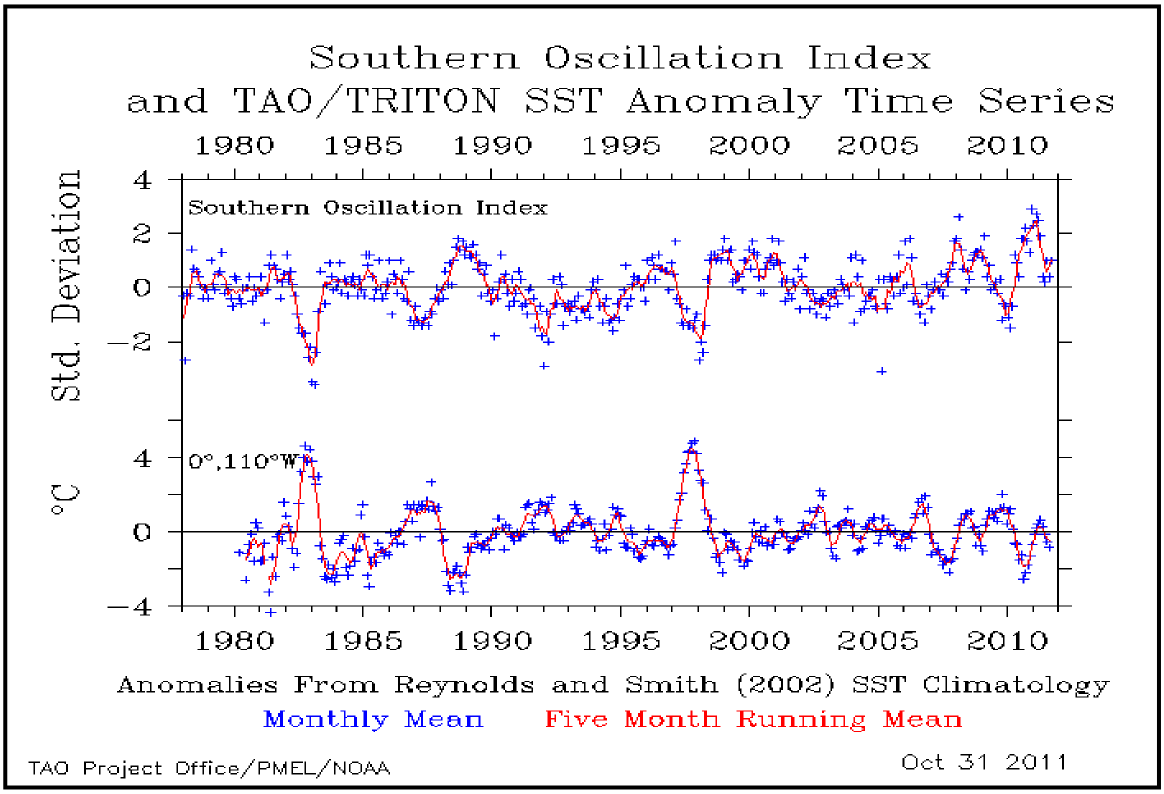

Figure 2: Southern Oscillation Index (SOI) and SST Anomaly Time Series (NOAA).

Table 1: QBO, El Niño /La Nino and Monsoon Rainfall.

Strong El Nino/QBO	Rainfall in mm (% departures)	Strong La Nino/QBO	Rainfall in mm (% departures)
1957 (weak westerly)	799.0 (-2.4)	1955 (weak westerly)	962.0 (10.4)
1965 (easterly)	709.6 (-18.2)	1973 (weak westerly)	956.1 (7.5)
1972 (easterly)	653.1 (-23.9)	1975 (westerly)	1011.4 (15.2)
1982 (easterly)	735.6 (-14.5)	1988 (westerly)	1094.1 (19.3)
1991 (easterly)	784.7 (-9.3)		
1997 (weak westerly)	870.5 (2.2)		
2009 (easterly)	698.2 (-21.8)		

(ED; decay during spring), (2) mid-summer decay (MD; decay by mid-summer) and (3) no-decay (ND; no decay in summer). It is observed that ISM rainfall is above normal/excess during ED years, normal during MD years and below normal/deficit in ND years, suggesting that the differences in El Niño decay phase display profound impact on the ISM rainfall. Tropical Indian Ocean (TIO) SST warming, induced by El Niño, decays rapidly before the second half of the monsoon season (August and September) in ED years, but persists up to the end of the season in MD years, whereas TIO warming maintained up to winter in ND case. Analysis reveals the existence of strong sub-seasonal ISM rainfall variations in the summer following El Niño years. During ED years, strong negative SST anomalies develop over the equatorial central-eastern Pacific by June and are apparent throughout the summer season accompanied by anomalous moisture divergence and high sea level pressure (SLP). The associated moisture convergence and low SLP over ISM region favor excess rainfall (mainly from July onwards). This circulation and rainfall anomalies are highly influenced by warm TIO SST and Pacific La Niña conditions in ED years. Convergence of south westerlies from Arabian Sea and north easterlies from Bay of Bengal leads to positive rainfall over most part of the Indian subcontinent from August onwards in MD years. ND years are characterized by negative rainfall anomaly spatial pattern and weaker circulation over India throughout the summer season, which are mainly due to persisting El Niño related warm SST anomalies over the Pacific (Krishnamurti et al. 1987; Sikka and Gadgil, 1980; Chowdary et al., 2017)**.** Atmospheric general circulation model simulation supports our hypothesis that El Niño decay variations modulate ISM rainfall and circulation.

4. Conclusions

The large-scale floods/droughts were associated with the westerly/easterly phases of the QBO. The large-scale droughts were associated with the El Niño and easterly phase of the QBO. Decadal analysis revealed a long-term variability (~ 50 year) in all India rainfall.

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