Role of East Equatorial Indian Ocean on Indian Northeast Monsoon

Ramesh Kumar Yadav
Indian Institute of Tropical Meteorology, Pashan, Pune-411008, INDIA

ABSTRACT

This study examines the role of east equatorial Indian Ocean sea surface temperature (SST) on the inter-annual variability (IAV) of Indian north-east monsoon rainfall (NEMR). The IAV of NEMR is associated with the cool SST anomaly over east equatorial Indian Ocean (88^oE – 96^oE; 1^oS - 3^oN). For establishing the teleconnections, SST, precipitation and lower-level circulation data have been used. The study reveals that during the negative (positive) SST anomaly years, the inter-tropical convergence zone (ITCZ) shifts to the northern (southern) hemisphere and trough (ridge) is formed over the southern peninsular India and hence excess (deficient) NEMR.

Keywords: North-East Monsoon; Easterlies; ITCZ; Tropical Storms; Coriolis force

1. INTRODUCTION

The season, October to December is considered as northeast (NE) monsoon season in India. Airflow reverses and wind blows northeasterly across the Indian Ocean. A trough of low pressure gets established over the south Bay-of-Bengal (BoB). Tropical disturbances such as lows, depressions, cyclonic storms, easterly waves (disturbances associated with perturbations in the wind field and progressing through the tropics from east to west) and cyclones occasionally form in this trough giving widespread rainfall over South India. During the NE monsoon (NEM) season, India receives about 11% of its annual rainfall, while south peninsula, south of 15°N receive 17–49% of their annual rainfall. The Indian north-east monsoon rainfall (NEMR) displays considerable interannual variability (IAV), significantly affecting the agricultural activity in the region (Yadav 2012, Yadav 2013).

In the earlier studies, it is found that the ENSO and IOD relationship with NEMR has significantly weakened in the recent decades (Yadav 2013). To identify the new teleconnection, the high resolution sea surface temperature (SST) data available for the period 1982-2013 have been used. The result shows that the role of east equatorial Indian Ocean SST has emerged as an important modulator of NEMR IAV in the recent decades. The data used in the present study and the analyses procedures are briefly described in Section 2. The results pertaining to the characteristic features of

impact of east equatorial Indian Ocean SST on NEMR and the associated changes in circulation patterns are discussed in Section 3 and 'conclusions' in Section 4.

2. DATA AND METHODOLOGY

Monthly rainfall data, for the meteorological subdivisions of peninsular India, for the period 1871-2012 (142-years), have been obtained from the Indian Institute of Tropical Meteorology (IITM) rainfall records (Parthasarathy et al. 1995; available at www.tropmet.res.in). The sub-divisional averages were computed based on station data, acquired from the India Meteorological Department (IMD). The present study however considers rainfall variations only during the Indian NEM season i.e. October through December. The NEMR region for the country is considered for the largest possible spatially coherent area comprising six meteorological subdivisions of peninsular India. Also, these subdivisions have been identified based on similarity in precipitation characteristics and associations with regional/global circulation parameters (Parthasarathy et al. 1993). For studying the global precipitation, the Global Precipitation Climatology Project (GPCP) (Huffman et al., 1997) data is used of which the monthly analysis is available from 1979 to 2013 and has a horizontal resolution of 2.5^{o} X 2.5^{o}. The simultaneous correlation coefficient (CC) between NEMR series and gridded precipitation data (GPCP) for the period 1982-2012 over southern peninsular India is 0.85 which suggests the consistency and accuracy among the datasets.

To examine the observed behavior of anomalous Indian NEM circulation, the fine resolution sea surface temperature (SST) data used is the optimally interpolated (1^{o} X 1^{o}) Reynolds version-2 monthly mean dataset (Reynolds et al. 2002), available from 1982-2013. The monthly mean zonal and meridional wind data have been provided by the NCEP/NCAR global atmospheric reanalysis dataset (Kalnay et al. 1996). The datasets are on a 2.5° X 2.5° grid. For understanding the dominant modes of variability simultaneous correlations and regressions analyses of SST, precipitation and wind fields have been examined.

3. RESULTS AND DISCUSSION

3.1 Interannual variability of Indian north-east monsoon rainfall (NEMR)

The Indian NEMR time series have been prepared as the area weighted seasonal (OND) rainfall over six meteorological sub-divisions of peninsular India viz., Coastal Andhra Pradesh, Rayalseema, South interior Karnataka, coastal Karnataka, Tamil Nadu, and Kerala (Fig 1a), for the period 1871-2012, expressed as the rainfall anomaly (Fig. 1b) from the long period normal (1871-2012). In this study, NEMR is considered to be normal if the rainfall anomaly is within +/-1 standard deviation (SD). The flood and drought years have been defined if the rainfall anomalies are greater than +1 SD and less than -1 SD, respectively. There are 24 flood years (1880, 1883, 1884, 1887, 1893, 1898, 1902, 1903, 1922, 1930, 1939, 1940, 1944, 1946, 1956, 1966, 1969, 1977,

1987, 1993, 1994, 1997, 2005 and 2010) and 22 drought years (1875, 1876, 1881, 1897, 1899, 1900, 1904, 1908, 1909, 1926, 1927, 1938, 1945, 1947, 1949, 1951, 1965, 1974, 1984, 1988, 1989 and 2000) in 142 years period from 1871-2012. The average rainfall is 345.6 mm with standard deviation (SD) 90.76 mm and coefficient of variation (CV) 26.26%. The 11-year running mean curve are super-imposed on NEMR series to show the epochs of above and below normal rainfall. The curve shows more undulating features from 1871 to 1925 and 1980 to till date. The trend analysis shows the rate of increasing of 0.23 mm of rainfall per year for the period 1871 – 2012, but the trend is not significant.

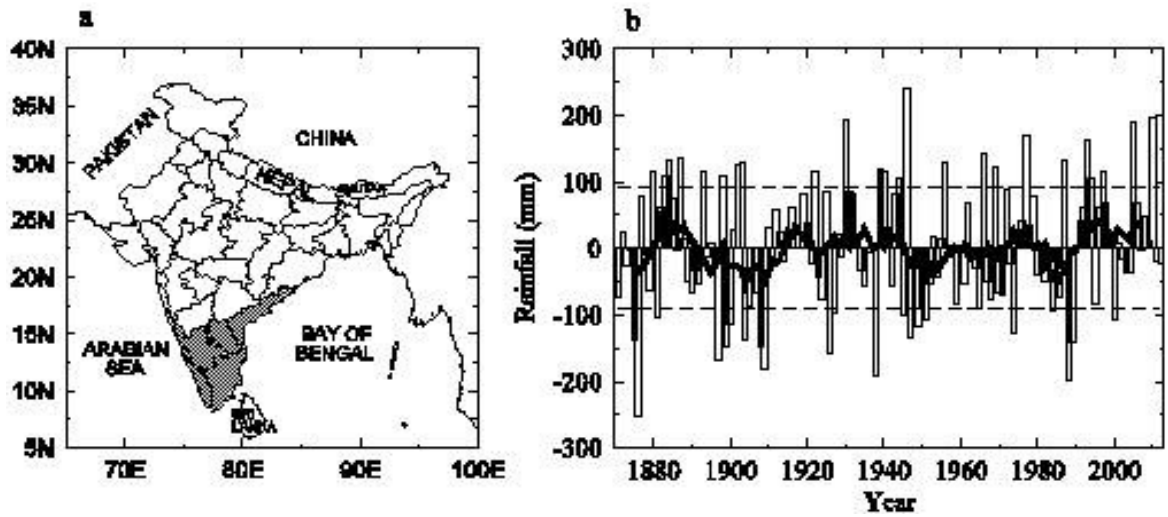

Figure 1. (a) Shaded regions geographical locations of 6 meteorological sub-divisions of north-east monsoon (NEM). (b) The time-series of north-east monsoon rainfall (NEMR) for the period 1871-2012 expressed as the rainfall anomaly of area weighted seasonal rainfall from the long period normal (1871-2012). The horizontal dash lines are +1 and -1 standard deviation (SD). The thick curve is the 11-year running mean.

3.2 Teleconnections of Indian north-east monsoon rainfall

Since, the ENSO and IOD relationships with NEMR have weakened in the recent decades (Yadav 2013). Therefore, to identify the new teleconnection, the high resolution SST data available for the period 1982-2013 and circulation data for the same period have been used. The simultaneous correlation coefficient (CC) of SST with NEMR and regression of 925-hPa zonal and meridional winds onto NEMR are calculated and shown in Fig. 2a. Similarly, CC of rainfall with NEMR and regression of 850-hPa zonal and meridional winds onto NEMR are shown in Fig. 2b. Since SST (especially over Indian Ocean) show significant increasing trends over the data period 1982-2013, therefore the data series have been detrended before carrying out analysis. The SST pattern is

shown as shaded. The regression of 925-hPa zonal and meridional wind components with NEMR are shown as vector arrows. Only areas with 95% significant levels are discussed.

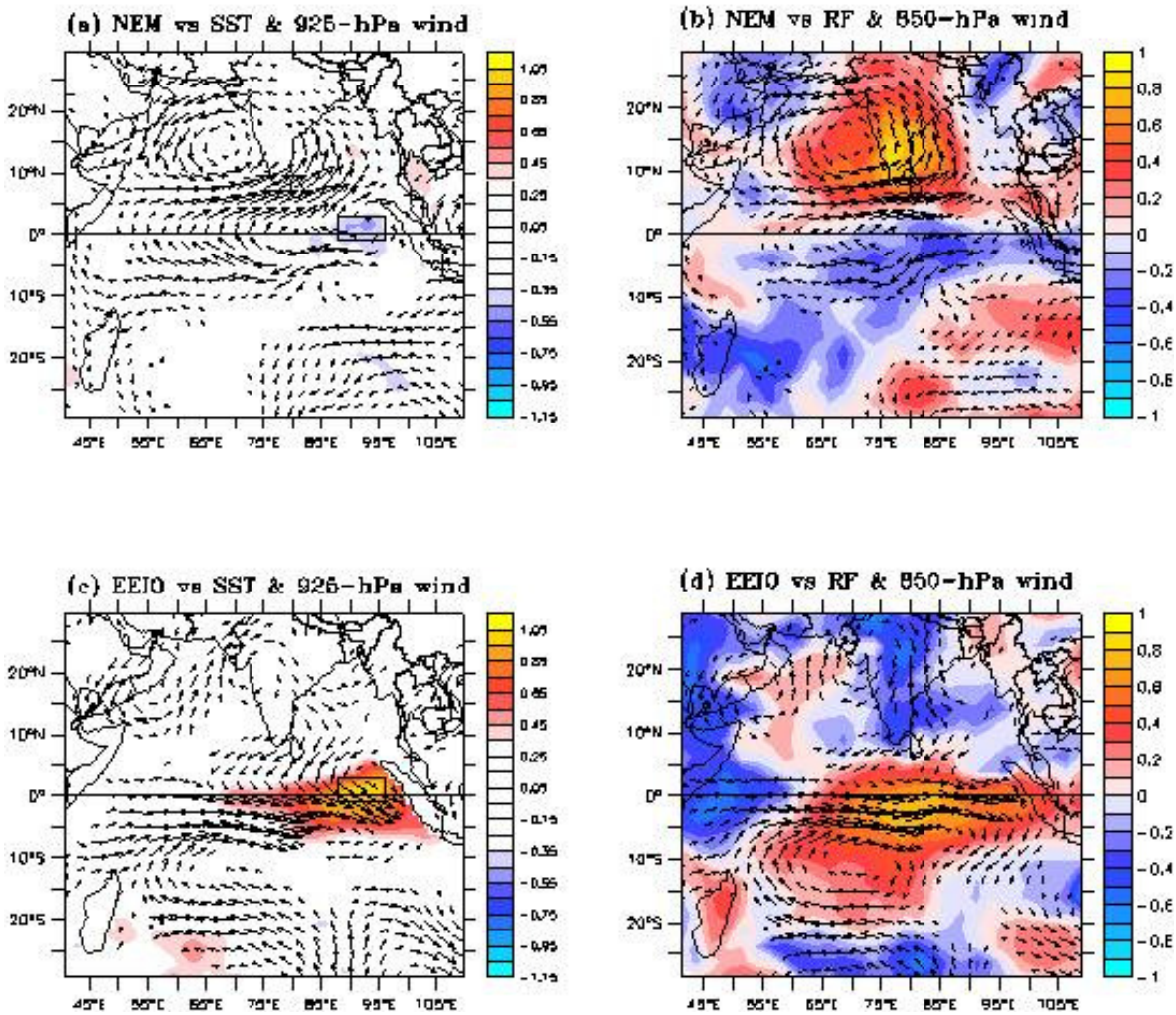

Figure 2. Spatial pattern of simultaneous (a) correlation of SST and regression of 925-hPa winds with NEMR and (b) correlation of rainfall and regression of 850-hPa winds with NEMR during the period 1982-2012. Similarly, (c) and (d) are same as (a) and (b), respectively but for EEIO during the period 1982-2013. SST are shown as shaded (°C) and winds as arrows (m/s). The box over equatorial eastern Indian Ocean indicates EEIO region.

In Fig. 2a, SST pattern shows significant negative CC over east equatorial Indian Ocean. The 925-hPa wind pattern shows westerlies anomalies over north of equatorial Indian Ocean and easterlies anomalies over south of equatorial Indian Ocean. Anti-cyclonic circulation anomaly is observed

over south-east tropical Indian Ocean. This anti-cyclonic circulation is responsible for cold SST anomaly over east equatorial Indian Ocean. Trough and cyclonic circulation anomalies are observed over peninsular India and Arabian Sea, respectively. Fig. 2b, shows significant positive CC of rainfall over peninsular India and surrounding Ocean and negative anomaly over south of equator. This suggest that during excess NEMR the Inter-Tropical Convergence Zone (ITCZ) shifts to the northern hemisphere and the vortices formed along the ITCZ develop into tropical storms, depressions and cyclones and hit the Indian peninsular India.

3.3. EEIO teleconnections with NEMR

In the previous subsections, it has been seen that NEMR has strong and robust association with SST over east equatorial Indian Ocean in the recent decades. Based on the significant CC, SST box has been selected as shown in Fig 2a and index have been prepared by averaging the grid values of this box 88°E - 96°E; 1°S - 3°N (representing east equatorial Indian Ocean; named as EEIO). Further, to examine the circulation features associated with the EEIO, similar CCs and regression analysis has been carried out as in Fig. 2a&b, but with EEIO index and shown in Fig. 2c&d, respectively.

The spatial patterns shows mirror image to NEMR patterns but with opposite sign. The SST (color shades) shows significant positive CCs over equatorial eastern Indian Ocean, which is obvious as the EEIO is extracted from the same regions. Lower-level wind (black arrows) shows westerly anomalies over equatorial Indian Ocean. Ridge and anti-cyclonic circulation anomalies are observed over peninsular and west India, respectively. Cyclonic circulation anomaly is observed over south east tropical Indian Ocean. Rainfall anomaly shows deficient anomaly over India and Bay-of-Bengal and positive anomaly over equator. This suggest that the ITCZ is active over equator and most part of India including peninsular India are getting deficient rainfall.

4. CONCLUSIONS

In tropics, the occurrence of latitudinal relatively high SST compared to immediately neighboring regions pulls the ITCZ towards itself. Therefore, the anomalous east equatorial Indian Ocean cooling (warming) shifts the ITCZ to the northern (southern) hemisphere and anomalous trough (ridge) over southern peninsular India. The vortices are always formed along ITCZ and develop into tropical depressions, storms and cyclones as they move poleward under the affect of Coriolis force (maximum at the pole and zero at equator). When the ITCZ is in the northern hemisphere, these tropical depressions, storms and cyclones moves north-west direction and strikes the southern peninsular India and hence excess NEMR. On the other hand, when the ITCZ is in the southern hemisphere, the tropical storm, depressions and cyclones formations are less in the north Indian Ocean and ridge anomaly is formed over peninsular India.

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