On the dynamics of extended breaks during 2017 monsoon

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Summary

Indian summer monsoon during 2017 was deficit by 5%, owing to the below normal rainfall activity during the last two months of the season. The below normal rainfall has been attributed to the two long break spells, one during 31 July - 17 August and the other during 01-11 September. This study attempts to unravel the dynamics behind these breaks. It is found that both breaks were governed by different meteorological conditions. During the first break spell, enhanced typhoon activity was noticed in the northwest Pacific oceanic region, which is known to be detrimental to the monsoon activity over Indian subcontinent. The second break spell during the first half of September could be attributed to the intrusion of midlatitude westerly troughs to the Indian region and the increased convective activity over the equatorial Indian Ocean. This increased convection is related to the presence of Madden-Julian Oscillation (MJO) over the Indian Ocean with weak amplitude.
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On the dynamics of extended breaks during 2017 monsoon

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Abstract

Southwest monsoon of 2017 was marked by two extended break spells during its second half. This study investigates the meteorological factors that contributed to the occurrence/sustenance of these breaks. It is found that the first break spell, that happened during 31 July-17 August 2017, was characterized by increased convection over northwest Pacific. On the other hand, the second spell during 01-11 September 2017 was associated with southward intrusion of midlatitude westerlies and increased convection over equatorial Indian Ocean.

Summary

Indian summer monsoon during 2017 was deficit by 5%, owing to the below normal rainfall activity during the last two months of the season. The below normal rainfall has been attributed to the two long break spells, one during 31 July - 17 August and the other during 01-11 September. This study attempts to unravel the dynamics behind these breaks. It is found that both breaks were governed by different meteorological conditions. During the first break spell, enhanced typhoon activity was noticed in the northwest Pacific oceanic region, which is known to be detrimental to the monsoon activity over Indian subcontinent. The second break spell during the first half of September could be attributed to the intrusion of midlatitude westerly troughs to the Indian region and the increased convective activity over the equatorial Indian Ocean. This increased convection is related to the presence of Madden-Julian Oscillation (MJO) over the Indian Ocean with weak amplitude.

Keywords

Indian summer monsoon, Monsoon breaks, Madden-Julian Oscillation
1. Introduction

The main rain giving season over Indian subcontinent is the southwest (SW) monsoon that spans during June-September (JJAS). The intraseasonal fluctuations within the monsoon season, otherwise known as Monsoon Intraseasonal Oscillations (MISOs), are manifested as the active/break spells. The duration and frequency of the active/break spells within a particular monsoon season contribute to the seasonal mean (Goswami and AjayaMohan 2001), and has bearing on whether that season will be deficient or excess. If the break conditions persist for a few weeks, it may lead to drought situation (Ramamurthy, 1969; Joseph et al., 2009), and the longevity of active conditions can lead to floods.

The 2017 SW monsoon was deficit by 5% with respect to the long period average (LPA), and this deficiency was mainly due to the below normal rainfall activity during the second half of the season (IMD, 2017). The monthly rainfall was 87% of LPA in August, and 88% of LPA in September. The below normal monsoon activity in these two months was associated with two extended break spells, those happened during the first halves of August (31 July - 17 August) and September (01-11 September) (Figure 1). Therefore, it is important to understand the underlying mechanism of these long breaks.

The role of midlatitude westerly trough intrusion in triggering breaks has been highlighted by Ramaswamy (1962), Krishnan et al. (2009), Krishnamurti et al., (2010), Sikka et al., (2010), Samanta et al., (2016); among others. The presence of stagnant blocking highs over East Asia can also lead to breaks over India (Raman and Rao, 1981). Krishnan et al. (2000) suggested that monsoon breaks are induced by the rapid northwest propagating Rossby waves that emanate from the convectively stable anomalies over Bay of Bengal. The Indian summer monsoon (ISM) breaks are also linked to eastward propagating Madden-Julian Oscillation (MJO; Madden and Julian, 1971) in the equatorial region (Saith and Slingo, 2006; Joseph et al. 2009). Joseph et al. (2009) proposed that during long breaks, the divergent phase of equatorial MJO generates Rossby type of wave that moves northwestward towards the Indian region, leading to the sustenance of breaks. Neena et al. (2011) showed that westward propagating convectively coupled planetary scale equatorial Rossby (PSER) waves emanating as a remnant of MJO played a seminal role in sustaining the long break during July-August 2009. Indo-Pacific SSTs are known to modulate the break conditions over Indian subcontinent. The El-Niño Southern
Oscillation (ENSO) conditions in the Pacific are often associated with below normal ISM activity (Rasmussen and Carpenter, 1982; Joseph et al., 2011; Ratnam et al., 2010). Mujumdar et al. (2007) noted that the ENSO induced circulation response and increased tropical convective activity over northwest Pacific can be detrimental to ISM. The ocean–atmosphere dynamical coupling on intraseasonal time scales, in the tropical Indian Ocean, is pivotal in forcing extended monsoon breaks (Krishnan et al. 2006). Basin wide warming over Indian and Pacific oceans can also adversely affect the ISM activity (Joseph et al. 1994; Ratnam et al. 2010). The anomalous warming in the northwestern Arabian Sea (AS) is found to be unfavorable for Indian monsoon (Ramesh and Krishnan, 2005; Li and Yanai, 1996).

In the background of the above-mentioned studies, the main objective of the present study is to examine the different observed meteorological conditions prevailed during the two long breaks so that we can understand the factors that were responsible for their formation/sustenance.

2. Data and Methodology

The present study uses the daily NOAA high resolution Sea Surface Temperature (SST) dataset (Reynolds et al. 2007) provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, (available at http://www.esrl.noaa.gov/psd/), the daily IMD-TRMM merged rainfall dataset (Mitra et al., 2009) and atmospheric fields from National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis datasets (Kalnay et al., 1996). The meteorological parameters utilized from NCEP/NCAR reanalysis for the study are: zonal, meridional and vertical components of wind, air temperature and geopotential height at pressure levels and also mean sea level pressure (MSLP). Additionally, the Tropospheric Temperature (TT) and vorticity at 850 hPa have been computed.

The anomalies of various parameters, except rainfall are calculated based on the daily mean climatology of 30 years (1981-2010). Since the daily rainfall data is available from 1998 onwards, the rainfall anomalies are calculated based on the daily climatology of 14 years (1998-2011). For examining the prevalence of MJO in the equatorial region, the phase diagram during the two break periods have been plotted following Wheeler and Hendon (2004).
3. Results and Discussion

As seen from Figure 1, the standardised rainfall anomalies over the monsoon zone of India (MZI, Rajeevan et al., 2010) were largely negative during the two break spells considered in the study. This section analyses various meteorological parameters which might provide an insight into the local as well as large scale conditions prevalent during the breaks.

3.1 Surface, low level and vertical features

Figure 2 depicts the rainfall anomalies over the Indian subcontinent and surrounding oceanic regions. The typical break composite comprising negative rainfall anomalies over central India and western coast and positive rainfall anomalies over southeast peninsula, is noticed during both break spells. The positive rainfall anomalies over the foothills of Himalayas is clear in the first break spell, whereas negative anomalies are seen over the region during the second spell. Only a small blob of positive rainfall anomalies are seen over the northeastern states. It is interesting to note that although positive rainfall anomalies are seen over the equatorial Indian Ocean (EIO) during both spells, they are much stronger and of large spatial extent in the case of second spell that occurred during the first half of September.

The time-height evolution of of anomalous omega (pressure vertical velocity in hPa s\(^{-1}\) multiplied by -1.0) over the central Indian region 73°-82°E; 18°-28°N during JJAS is depicted in Figure 3. It is obvious from the figure that the omega anomalies closely follow the temporal evolution of standardised rainfall anomalies over the MZI region (refer Figure 1). During the two break spells considered in the present study, the negative pressure vertical velocity anomalies indicating suppressed convection with descending motion, prevail over central India. The vertical structure of meridional monsoonal Hadley circulation, averaged over 70°-90°E, during the break spells are portrayed in Figure 4. Negative omega anomalies implying descending motion are noted over central India during both breaks. It is important to note that significant positive omega anomalies with strong upward motion are prevalent over the equatorial region for the September break, compared to the July-August break.

The vorticity anomalies and the associated wind anomalies at 850 hPa during the break periods are shown in the upper panel of Figure 5. For the first break spell, the anticyclonic circulation anomalies in association with the negative vorticity anomalies are seen over central
India (upper left panel of Figure 5). Positive vorticity anomalies with cyclonic circulation anomalies are prevalent over central EIO. It is worthwhile to note that an alternating pattern of anticyclonic (highs) and cyclonic (lows) circulation anomalies are seen extending meridionally from tropical to extratropical region in the northwest Pacific. Such pattern can favour enhanced tropical cyclonic activity and intensified convection over the region, as noted by Mujumdar et al. (2007). According to the 'End of Season' report issued by India Meteorological Department (IMD), typhoon activity drastically increased over northwest Pacific towards the end of July till first fortnight of August. This adversely affected the rainfall over the Indian region by suppressing the genesis of monsoon lows over the Bay of Bengal as the Bay branch of SW monsoon got deflected towards Southeast Asia owing to the strengthening of west Pacific systems. For the second break spell, the anticyclonic circulation anomalies and associated negative vorticity anomalies are much to the eastern part of central India and seen extending over maritime continents (upper right panel of Figure 5). Strong cyclonic circulation anomalies and related positive vorticity anomalies are noticed over EIO. This is consistent with the strong positive rainfall anomalies over the region (refer Figure 2). It is also noticed that the low level winds are westerlies along the EIO.

The MSLP anomalies during first and second break spells are shown in the lower panel of Figure 5 and are consistent with the vorticity and wind anomalies at 850 hPa. The high pressure anomalies are seen over Indian region and low pressure anomalies are seen over central EIO. The intense low pressure anomalies associated with the northwest Pacific typhoon activity is distinguishable during the first break spell (lower left panel). For the second spell, the strong low pressure anomalies over EIO indicate increased convection over the region (also seen from the rainfall, 850 hPa circulation and vorticity anomalies). Such increase in convection along with westerly wind anomalies are suggestive of the presence of MJO over the region. We will scrutinize this aspect in a later section.

Figure 6 depicts the geopotential height anomalies at 850 hPa for the two break spells, and matches well with the MSLP and vorticity fields. The meridionally elongated pattern of highs and lows over the northwest Pacific region is clearly visible for the first break. The positive geopotential anomalies over the Indian region are much stronger and meridionally extend over the maritime continents during the second break, compared to the first one.
Warming over the Indo-Pacific oceanic region are known to be undesirable for the rainfall over Indian subcontinent. Therefore, we plotted the SST anomalies for the period in Figure 7. Surprisingly, weak negative cool SST anomalies are seen over the central (central and eastern) equatorial Pacific during the first (second) break. Warm SST anomalies are confined to the warm pool region in both breaks. Another important feature noted during the second break is the presence of positive Indian Ocean Dipole (IOD) like pattern with weaker warm (cold) SST anomalies over western (eastern) EIO. However, the atmospheric variables does not support the dipole structure (please refer the low level vorticity anomalies in Figure 5). A weak dipole mode pattern is noted during the first break as well. Warm SST anomalies are also noted over the northwestern Arabian Sea during the September break, which have negative influence on the ISM rainfall (Joseph et al., 2016).

3.2 Upper level features

The circulation in the upper atmosphere, especially the midlatitude westerlies, has a pivotal role in determining the strength of ISM. Generally during ISM, the easterlies seem to dominate over the Indian region and the westerlies are noticed pole-ward of 30°N, at 200 hPa level. At times, the midlatitude westerlies move to the Indian region and interact with the monsoon circulation. Joseph et al., (2015; 2016) showed that midlatitude westerly trough intrusion was instrumental in triggering the heavy rainfall event over Uttarakhand in June 2013 as well as the subdued monsoon activity June 2014. Sikka (2011) proposed that the influence of the midlatitude westerlies on ISM depends on the phase of monsoon at the time of interaction such that, if ISM is in weak period at the time of interaction, it will aggravate the break situation and if ISM is in active mode, it can enhance the monsoon rainfall activity. Figure 8 delineates the 200 hPa circulation anomalies (as vector) along with the magnitude of actual wind (as shaded). For the first break, weak easterlies are seen over the Indian subcontinent, and the westerlies are above 30°N. The cyclonic vorticity in the northwest Pacific seems to extend to the upper level as well. During the second spell, the midlatitude westerlies seem to be stronger and prevalent between 30°-45°N with strong cyclonic and anticyclonic vortices over north Pacific and they even extend to the Indian region. The westerly trough seems to intrude southwards over the Indian region bringing cold dry air with it. Thus, it can be contemplated that the midlatitude intrusion played a seminal role in sustaining the September break.
Figure 9 depicts the tropospheric temperature (TT; temperature averaged between 600-200 hPa levels; Xavier et al., 2007) anomalies for the first and second breaks. In association with the cyclonic or trough areas, cold polar air seems to be present; whereas, warm tropical air prevail in regions of anticyclonic or ridge areas. Features similar to the TT anomalies are noticed in geopotential anomalies at 200 hPa shown in Figure 10.

3.3 Role of MJO

As discussed in Sec. 3.1, the rainfall, low level vorticity and circulation anomalies indicate the possible presence of MJO in the equatorial region during the second break. Therefore, we plotted the phase evolution of MJO during the two break spells in Figure 11, following Wheeler and Hendon (2004). It is observed that the MJO was in Phase 6 and 7, i.e., over western Pacific region, but was insignificant as the amplitude found to be very less (inside the inner circle) during the first break. On the other hand, MJO was in Phase 3, i.e., over Indian Ocean region during the second break. The MJO amplitude is noted to be significant in the initial period and further weakened with time. Therefore, we can conclude that MJO was existent in the Indian ocean and might have helped in triggering the September break.

4. Conclusions

The present study attempts to unravel the rationale behind the formation/sustenance of two break spells occurred towards the second half of 2017 SW monsoon season, that were instrumental in making the seasonal mean monsoon a deficient one. During the first break that happened from 31 July to 17 August, the convective activity over northwest Pacific was dominant. This unfavourably affected the ISM activity over the Indian subcontinent, as suggested by Mujumdar et al. (2007), by suppressing the genesis of monsoon lows over the Bay of Bengal. The alternating pattern of highs and lows, extending meridionally over the northwest Pacific also favoured the typhoon activity over the region. Alternatively, the second break during 01-11 September was favoured by the presence of strong convection over EIO and the intrusion of cold dry polar air with the aid of midlatitude westerly troughs. The strong convection and associated low level westerlies during the period are suggestive of the prevalence of MJO over the region. The MJO phase diagram also confirm this. Pai et al (2011) hypothesized that break
spells are favoured in the MJO phases 1 and 2, when the oscillation is over the Indian Ocean region. The presence of midlatitude westerlies over the Indian subcontinent is disadvantageous for the ISM activity, as noted by Ramaswamy (1962), Krishnan et al. (2009), Krishnamurti et al. (2010), Ratnam et al. (2010) etc.

Thus, it is concluded that both the breaks were generated by different mechanisms. The first one was favoured by the enhanced convective activity over northwest Pacific, whilst the second one had the influence of midlatitude westerly troughs as well as equatorial MJO.

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References


Figure Captions

Figure 1: Standardised rainfall anomalies over the Monsoon Zone region during the 2017 monsoon (adapted from the website of India Meteorological Department).

Figure 2: Rainfall anomalies (in mm/day) for the first and second break spells.

Figure 3: Time-height evolution of anomalous omega (pressure vertical velocity in hPa s\(^{-1}\) multiplied by -1.0; shaded) over Central India (73°-82°E; 18°-28°N) during JJAS. Positive (negative) values represent ascending (descending) motion.

Figure 4: Latitude-height sections showing monsoon Hadley circulation anomalies during the two break spells. To construct the meridional circulation anomalies, the meridional and vertical wind velocities are averaged over the longitudes 70°-90°E. The shading represents omega (hPa s\(^{-1}\)) anomalies taken with a negative sign.

Figure 5: Anomalies of vorticity (shaded; s\(^{-1}\)) and wind (vector, ms\(^{-1}\)) at 850 hPa during the two break spells (upper panel). The mean sea level pressure anomalies (in hPa) during the same period are shown in the lower panel.

Figure 6: Same as Figure 2, but for geopotential height anomalies (in m) at 850 hPa.

Figure 7: Same as Figure 2, but for SST anomalies (in °C).

Figure 8: Same as Figure 2, but for circulation anomalies (ms\(^{-1}\)) at 200h Pa.

Figure 9: Same as Figure 2, but for tropospheric temperature anomalies.

Figure 10: Same as Figure 2, but for geopotential height anomalies (in m) at 200 hPa.

Figure 11: Phase diagram of RMM1 and RMM2 indices of MJO during the two break spells.
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