Active and Break Events of Indian Summer Monsoon during 1901-2014

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Abstract

The study lists active and break monsoon events over India over a very long period (1901-2014) identified using criteria based on a rainfall index derived over a critical high rainfall region called core monsoon zone. The break and active spells identified in this study were mostly comparable with that identified in the earlier studies based on similar rainfall criteria during the common data period (1951-2007). However, some noticeable differences were observed in the rainfall anomaly pattern associated with the break monsoon spells identified in this study and that identified based on the synoptic criteria in the earlier studies. The stringent rainfall criteria used in this study seems to be better criteria for identifying the breaks. During the study period, both the active and break spells of short duration were more frequent than the long duration with about 63.4% of the break spells and 94.3% of the active spells falling in the range of 3-6 days. There were no active spells of duration $\geqslant$ 13days. Whereas, about 8% of the break spells were of duration $\geqslant$ 13days. During both the halves of the data period (1901-57 & 1958-2014), there was no change in the distribution of the break events. However, the number of active spells showed an increase of about 12% in the in the second half, which was mainly in the short duration (3-6 days) spells. During the data period, decadal variations of break days showed an out phase of relationship with the number of days of monsoon depression (MD). Relatively stronger in phase relationship was observed between the decadal variation of MD days and that of the active days till around early 1980s which reversed later due to sudden decrease in the MD days. During the same period, both the active & break days were in the increasing phase. This was also coincided with the sudden and significant increase in the number of days of monsoon lows (LOW). The LOWs, which generally have short life helped in the occurrence of active spells of short duration. Thus, post early 1980's, the increase in the active days covering short duration active spells caused by the significant increase in the LOW days compensated the decrease in the active days covering relatively long duration active spells caused by the MD days. This lead to the out of phase relationship between MD days and the active days post early 1980s

Key words: Monsoon break and active spells, monsoon depression, gridded daily rainfall, decadal variation

1 Introduction

Over India, the large scale rainfall during the SW monsoon season (June-September) is received in spells with intermediate dry spells (Ramage 1971). The intraseasonal variability on the timescales of few days to more than a month is clearly visible in the all India daily summer monsoon rainfall irrespective of the quantum of the total rainfall received during the season (Fig.1). After southwest monsoon gets established over Central India in July, copious rainfall is received over large areas of the country with maximum over central India. During the peak monsoon rainfall months (July and August) of the season, the monsoon trough shifts north and south about its normal position causing large scale rainfall variation over the country both in terms of spatial and temporal scales. The intervals of dry monsoon conditions during which the large-scale rainfall over the monsoon trough zone (the zone between which the monsoon trough fluctuates north and south wards) is interrupted for several days in July and August are known as the breaks (Ramamurthy 1969, Raghavan 1973, Krishnamurti and Bhalme 1976, Alexander et al. 1978). On the other hand, the intervals between spells of dry monsoon conditions when the rainfall is higher than normal are known as active spells. Ramamurthy (1969) was the first to propose criterion based on the synoptic conditions in the surface and lower troposphere over India to define breaks in the monsoon rainfall and used these criteria to identify break spells during 1888-1967. However, Ramamurthy (1969) did not propose any criteria for identifying active spells. According to these criteria, break in the monsoon rainfall was defined as the situations when the trough of low pressure was not seen on the surface chart and the easterlies were practically absent in the lower tropospheric levels up to about 1.5 km above sea level for more than 2 days. De et al. (1998) using the criteria of Ramamurthy (1969) identified breaks for the period 1968-1996. Later simplified definition of the monsoon break and active spells based on rainfall over India was used by several studies (Rodwell 1997, Annamalai & Slingo 2001, Gadgil & Joseph 2003, Ramesh Kumar and Desai 2004, Mandke et al. 2007, Krishnamurthy and Shukla 2000, 2007 & 2008, Rajeevan et al. 2010, Pai et al. 2011). Rajeevan et al. (2010) suggested criteria for identification of active and break events of the Indian summer monsoon on the basis of average rainfall over a critical area over central India, called the core monsoon zone. According to this criteria, the active and break events were defined as periods in which the normalized anomaly of the rainfall over the core monsoon zone exceeds 1 or is less than -1.0 respectively, provided the criterion is satisfied for at least three consecutive days. Rajeevan et al. (2010) identified the active and break spells for the period 1951-2007 using these criteria and found to be mostly comparable with those identified by Ramamurthy (1969) and De et al. (1998).

Ramamurthy (1969) examining the decadal variation of the breaks for the 80 years period (1888 - 1967), observed a mutually exclusive relationship with decadal variation of number of monsoon low

pressure systems (lows and depressions) formed over the Indian region during July and August. Based on daily rainfall analysis for the period 1901-2003, Krishnamurthy & Ajayamohan 2010 have shown that the daily rainfall pattern when any of the monsoon low pressure systems such as lows, depressions, cyclonic storms etc. are present in the Indian monsoon region represents the active monsoon phase and that when the low pressure systems are absent represents the break monsoon phase. Decadal analysis of LOWs and MDs by Jadhav and Munot (2009) has revealed significant increase (decrease) in the frequency and duration of LOWs (MDs) during recent decades. Therefore, it will be interesting to re-examine the association in the decadal variation of the number of break/active days with that of LOW/MD days.

The main objective of this study was to use the rainfall criteria of Rajeevan et al. 2010 to identify the break and active spells for 114 years (1901-2014) and list them. Another objective was to examine various long term statistical features such as climatology, variability, trends etc. of the break and active events. Emphasis was also given to examine the association between the break/active days with that of LOW/MD days in the decadal scale. The study further examined the differences between the composite rainfall patterns of the break and active events and that of the break events identified using synoptic and rainfall criteria. The study also examined the distribution in the frequency of the daily rainfall events of various intensities associated with the break and active events.

Section 2 describes the data and methodology used in this study. Section 3 discusses various results of the study and finally section 4 presents summary and conclusions of the study.

2   Data Used

The main data set used in the study was the India Meteorological Department (IMD) high resolution (0.25^o X 0.25^o) gridded daily rainfall data set over India. The original data set was developed by Pai et al. (2014) for the period 1901-2010 using the daily rainfall data from 6955 rain gauge stations in India with varying availability periods. Though the spatial density of the station points was not uniform throughout the country, there was good number of stations representing most areas of the country. More details of the development of this data set are available in Pai et al. (2014). For interpolating daily station rainfall data into grids of 0.25^o X 0.25^o degree resolution, Shepard (1968) interpolation method was used. The standard quality controls were applied on the station rainfall data before the interpolation. The interpolated values were computed as the weighted sum of the station data within a search radius of 1.5 degrees. The interpolation was restricted to the radius of influence. The method proposed by Shepard (1968) was used to locally modify the scheme for including the directional effects and barriers. For this study, the data were further extended up to 2014.

Other data sets used in the study were daily 850hPa wind vector data derived from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis (Kalnay et al. 1996; Kistler et al. 2001) and the daily interpolated outgoing longwave radiation (OLR) data measured by Advanced High Resolution Radiometers (AVHRR) aboard NOAA polar orbiting satellites (Liebmann and Smith 1996). The daily OLR data were available from June 1974 to September 2014 with missing data during 17 March 1978 to 31 December 1978. Therefore, both the 850hpa wind and OLR data available on a 2.5° X 2.5° spatial grid for the period 1974-2014 (excluding the data for 1978) obtained from the website of Climate Diagnostics Centre (http://www.cdc.noaa.gov/) were used. Another data set used in this study was the NOAA Extended Reconstructed Sea Surface Temperature (ERSST V3b) dataset (Smith et. al. 2008) at 2° X 2° resolution for the period 1901-2014.

Another data used was the number of days of monsoon low pressure (LOW) and monsoon depression (MD) during the southwest monsoon season for the period 1901-2014. LOW has at least one closed isobar at the surface level and wind speed up to 17 knots. MD was defined as the low pressure system with intensity higher than LOW. A LOW/MD day is defined as the day when a LOW/MD was observed in the Indian monsoon region (0-30°N, 50°E-110°E) at 0000UTC of that day. When two or more low pressure systems were observed on the same day, system of highest intensity was considered. The LOW and MD days for the period 1901-1983 were computed based on the information regarding these systems provided by Mooley and Shukla (1989). The data of LOW and MD days for the period 1984-2014 were derived from the daily weather reports over India published by IMD.

2. Methodology

In this study, the break and active days were identified using the criteria suggested by Rajeevan et al. (2010) but using IMD high resolution (0.25^o X 0.25^o) gridded daily rainfall data for the entire data period of 1901-2014. For this purpose, the normalised daily anomaly index of the rainfall over the region whose domain is nearly same as the core monsoon zone proposed by Rajeevan et al. (2010) with 1951-2000 as the base period. Using the information on break and active days, various long term statistical properties of these extreme events were computed and discussed. The decadal variation of the break and active monsoon days and its association with MD/LOW days was studied by preparing 11 years moving means of these parameters.

To examine the changes in the rainfall anomaly pattern over India and the anomalous convective and lower tropospheric circulation pattern over Asia Pacific region associated with break and active monsoon events, at first daily anomalies of all the fields (rainfall, 850 hPa wind vector, OLR etc.)

were computed. The daily climatology of rainfall over India was computed using base period of 1951-2010 and that of OLR and U850 wind vector was computed using base period of 1974-2010. Composite rainfall anomaly maps over India associated with the monsoon break and active events were prepared by averaging rainfall anomalies of all the break days and active days respectively during the period 1901-2014 and were compared. In the same way, the anomaly maps of OLR and 850hpa wind vector over Asia Pacific region in respect of break and active events were also prepared. The changes in the distribution of daily rainfall events of various intensities associated with break and active events were also examined. For this maps of frequency of low rainfall (>0 & $<5mm$) or LR events, moderate rainfall (rainfall of 5mm -100mm) or MR events and heavy rainfall (rainfall $\geq 100mm$) or HR events occurred during all the break and active spells of the study period were prepared.

For testing the differences in the composite rainfall/ OLR anomalies and frequency of daily rainfall events of various intensities between active and break monsoon conditions, two-sample t-test was used.

Maps of concurrent correlation coefficient (C.C.) of tropical sea surface temperatures (SST) averaged over July and August with the number of break days as well as active days per season were prepared using the data for the entire period (1901-2014) to examine the influence of global SSTs on the occurrence of the these extreme events.

3. Results

3.1 Statistical Features of the Breaks and Active Spells

In this section, various statistical features of the break and active events during 1901-2014 identified in this study were examined. These features were also examined for the two halves (1901-57 & 1958-2014) of the data period and compared to examine climate shift if any in the break and active events.

The break and active spells for the period 1901-2014 identified in the present study is listed in Table-1 and Table-2 respectively. As seen in the Tables 1 & 2, during 23 years (1908, 1916, 1919, 1923, 1925, 1931, 1940, 1944, 1953, 1957, 1958, 1959, 1960, 1975, 1976, 1978, 1990, 1994, 2003, 2006, 2010, 2012 & 2013) there were no break events. Similarly during 9 years (1901, 1904, 1905, 1911, 1915, 1918, 1936, 1989 & 2010) there were no active events. During the total period, there were 145 break spells of duration varying from 3 to 18 days (58 in July, 76 in August and 11 in July to August (starting in July and ending in August)). Similarly there were 210 active spells of duration varying from 3 to 12 days (99 in July, 97 in August and 14 in July to August). The average duration of the

break spells was 6.1 days (5.8 days in July, 6.0 days in August and 8.5 days in July to August) and that of the active spells was 4.0 days (4.1 days in July, 3.8 days in August and 4.3 days in July to August). The longest break spell of 18days duration was occurred in 1928 (30th July to 16th August) followed by 3 break spells of 17days duration each occurred in 1902 (1-17th August), 1918 (10-26th July) and 1972 (18th July- 3rd August). During the same period, the longest active spell of 12 days duration was occurred in 2006 (27th July to 7th August) followed by an active spell of 11 days duration occurred in 1907 (11-21st August).

During 1901-57, there were 73 break spells of duration varying from 3 to 18 days (26 in July, 42 in August and 4 in July-August overlapping period) and 99 active spells of duration varying from 3 to 11 days (49 in July, 45 in August and 5 in July-August). The average duration of the break spells was 6.4 days (6.2 days in July, 6.3 days in August and 8.8 days in July to August overlapping period) and that of the active spells was 4.2 days (4.3 days in July, 4.1 days in August and 3.8 days in July to August overlapping period). During 1958-2014, there were 73 break spells of duration varying from 3 to 17 days (32 in July, 34 in August and 7 in July-August) and 111 active spells of duration varying from 3 to 12 days (50 in July, 52 in August and 9 in July to August overlapping period). The average duration of the break spells was 5.9 days (5.6 days in July, 5.7 days in August and 8.3 days in July to August overlapping period) and that of the active spells was 3.8 days (3.9 days in July, 3.6 days in August and 4.6 days in July to August overlapping period).

Fig.2a shows the histogram of duration of break and active spells for the total period of 1901-2014. It is seen in this figure that, both the active and break spells of short duration were more frequent than the long duration with about 63.4% of the break spells and 94.3% of the active spells falling in the range of 3-6 days. There were no active spells of duration $\geq$ 13days. Whereas, about 8% of the break spells were of duration $\geq$ 13days.

The Figures 2b & 2c show the histogram of the duration of break and active spells for the periods 1901-57 & 1958-2014. During both the halves equal number of break spells (73 each) occurred. But there was rise of about 12% in the number of active spells (111) during the second half compared to that during first half (99) . It is further seen that the rise in the active spells (89 to 109) during the second half was mainly in the short duration (3-6 days) spells. In the intermediate (7-12 days) and long duration ($\geq$ 13 days) side, the number of active spells showed significant decrease (10 to 2) from first to second half. On the other hand, the number of break spells of intermediate and long durations during both the halves of the data period was nearly equal.

3.2 Interannual Variability of Break/ Active Days

The year to year variation of the number of break and active days for the period 1901–2014 with linear trend lines fitted for the total and two halves of the data period is shown in Figures 3a & 3b, respectively. The trend values are given in the Tables 3a & 3b. The presence of a monotonic increasing or decreasing trend was tested with the nonparametric Mann-Kendall test (Gilbert 1987). As seen in the Fig. 3(a), there is a decreasing trend in the break days during the first half and increasing trend during the second half. As a result no trend was observed when entire period is considered. From Fig. 3(b) an increasing trend was observed in the active days during the first half and no trend during the second half. No trend was observed for the entire period. However, the Mann-Kendall test showed none of these long term trends were statistically significant except that of break days for the period 1901-1957 (significant at 95% level). However, it was observed that the break/active days show significant correlation with the rainfall averaged over the country as a whole. Tables 3a & 3b show the correlation coefficient (C.C.) of all India rainfall with break and active days for the 3 different periods (1901-2014, 1901-57 & 1958-2014). C.C.s were calculated for the months of July & August and for the both the months together (July + August). As seen in the Tables- 3a & 3b the C.C.s of all India rainfall with the break days are stronger than that with the active days in all the cases.

The Tables 3a & 3b also show some other statistical features of the interannual variability of breaks and active days for July, August and July + August computed for 3 different periods (1901-2014, 1901-57 & 1958-2014). During 1901-2014, there were 889 break days with an average of 7.8 days and standard deviation (SD) of 6.5 days per season. In the same period, there were 834 active days with an average of 7.3 days and SD of 4.7 days per season. Similarly the average & SD of break days in August (4.5 days & 4.7 days) were more than that in July (3.3 days & 4.3 days). On the other hand the average of active days in July (3.8 days) was more than that in August (3.6 days). But S.D of active days in August (3.6 days) was slightly more than that in July (3.3 days). July favoured active days (51% of the total active days) than break days (42% of the break days) and August favoured breaks days (58% of the break days) than active days (49% of total active days). During the period 1901–2014, the maximum number of break days occurred in 1941 (28 days with 16 days in July and 12 days in August) followed by 2002 (23 days in July). The maximum number of active days occurred in 1994 (24 days with 13 days in July and 11 days in August) followed by 2006 (23 days = 9 days in July and 14 days in August).

On comparing the statistics during the two halves of the data period, it can be seen that the average break days in August was more during the first half by about 1.2 day per season comparing to that in

the second half. In July, the case was opposite but with a difference of about 0.7day per season. As a result the average break days in the July + August period was slightly more during the first half compared to that in the second half of the data period. However, active days were nearly equal, during both the halves.

3.3 Decadal Variation in the Break/ Active Days and Association with the MD/LOW days over India

Tables 4a & 4b show the decadal distribution of the number of break & active days respectively during the period 1901-2014. The distribution of the events within the two months period (July-August) is shown by dividing July and August months into 3 near equal periods of 10 days (hereafter called as dekade) each (last period is of 11days). In the Table-4a, the decadal distribution of break days shows that during each of the months, middle dekade is most prone for breaks. However, when both the months taken together, the middle dekade followed by first dekade of August recorded highest number of break days (25% & 17% respectively of the season).   The decadal variation shows that the highest number of break days during the first 4 decades (1901-10,1911-20,1921-30 & 1931-40) was recorded during the middle dekade of August, that during the next 2 decades (1941-50&1951-60) was recorded during the last dekade of the August. Again the highest number of break days during the decades 1971-80 &1991-2000 was during the middle dekade of the August and that during 1981-1990 & 2001-2010, it was last dekade of the August. Thus it can be seen that during 10 of the 11 decades, the highest number of breaks were recorded in August during either middle or last dekades. It was only in the decade 1961-1970 that the dekade wise highest number of breaks was observed in July (middle dekade). However, it is also interesting to note that during the decade (1951-60), there was not a single break day during the first two dekades of August. On examining decadal variation of month wise break days, it is observed that there were only 3 decades (1951-60& 1961-70) when the break days were more during July compared to August. In the recent decade (2001-2010) the number of break days during July and August was nearly equal (50 & 49 days each). In case of decadal variation of season wise break days, maximum number of break days (108 days) was observed during 1911-20 & minimum number of break days (43 days) was observed during 1951-1960.

In case of active events (Table-4b), 52% of the total 834 active days was in July with an average of 3.8 days per season and 48% was in August with an average of 3.6 days per season. It is also seen that, during the two months period, the last dekade (in fact 11days) of both the months are most and equally favourable for active events (21% of the total active days each) with an average of 1.5 days per season. The decadal variation shows that during 4 (1921-30,1941-50,1961-70 &1991-2000) of

the 11 decades, highest number of active days was observed in the last dekade of July and during another 4 decades (1911-20,1931-40,1971-80,1981-1990), that was in the last dekade of August. In the remaining 3 decades, the highest number of active days was experienced in the first dekade of July during 1 decade (1951-60), in the second dekade of August during 1 decade (1901-10) and in the first and last dekade of August during 1 decade (2001-2010). The decadal variation of month wise active days shows that during 6 of the 11 decades including the last two decades, the number of active days in July was higher compared to August. The decadal variation of season wise active days shows that the maximum number of active days (90 days) was observed during 1941-50 & minimum number of active days (53 days) was observed during 1951-1960.

Based on daily rainfall analysis for the period 1901-2003, Krishnamurthy & Ajayamohan 2010 have shown that the daily rainfall pattern when any of the monsoon low pressure systems such as lows, depressions, cyclonic storms etc. are present in the Indian monsoon region represents the active monsoon phase and that when the low pressure systems are absent represents the break monsoon phase. Ramamurthy (1969) on the other hand examining the decadal variation of the breaks for the 80 years period (1888 -1967), observed a mutually exclusive relationship with decadal variation of number of monsoon low pressure systems (lows and depressions) formed over the Indian region during July and August. To re-examine the above relationship with the new break monsoon information obtained in the present study, 11 years moving average of break days has been plotted along with the 11 years moving average of LOW days as well as that of MD days in the Indian region during July and August (Fig.4). In addition, decadal variation of active days has also been depicted in the Fig.4. As seen in the Fig.4, the multi-decadal variation in the break days shows major maxima around late 1900s, late 1930s, late 1960s, late 1990s and early 2000s and minima during the 1920s, late 1950s, 1970s, late 1980s and late 2000s. In addition, a general decreasing trend is seen from the beginning of the data period to around the middle of the data period (late 1950's) and then an increasing trend till the end of the data period. On the other hand, the active days show decadal variation with major maxima around early 1910s, late 1920s, early1940s, early 1970s, late 1980s & early 2000s. The minimum in the decadal variation of active days were observed around early 1900s, 1920s, early 1960s, & mid 1980s.

On comparing with the decadal variation of monsoon depression days with that of break and active days, it can be seen that there is a general out of phase relationship between the number of MD days and break days. But the more interesting aspect is the relatively stronger in phase relationship between the decadal variation of monsoon depression days and that of the active days till around early 1980s which reversed in the later period. Post 1980s while decadal variation of MD days showed decreasing trend, that of active days showed increasing tendency. The decreasing trend in the

number of the MDs post 1980s was also reported by some earlier studies (Sikka 2006, Stowasser et. al. 2009, Jadhav & Munot 2009, Ajayamohan et. al. 2010). As seen in the Fig.4, during the decreasing phase of number of MD days (1970s onwards), both break and active days showed general increase; but the increase in the break days being relatively more. However, as seen in the Fig.4, from the beginning of the data period to till late 1970s, the decadal average of the number of LOW days was around 13-18 days, which nearly doubled in the later period. Therefore, the observed failure of in phase relationship between the number of active days and MD days after early 1980s may be due to the significant increase in the LOW days. Based on daily rainfall analysis for the period 1901-2003, Krishnamurthy & Ajayamohan 2010 have shown that the daily rainfall pattern when any of the monsoon low pressure systems such as lows, depressions, cyclonic storms etc. are present in the Indian monsoon region represents the active monsoon phase and that when the low pressure systems are absent represents the break monsoon phase. In this study, we have taken into consideration not the number of Low Pressure Systems but the number of Low Pressure System days and showed that the decrease in the monsoon depression days was compensated by the increase in the days of monsoon lows which kept the active days to its normal or above normal limit during the recent decades.

3.4 Composite Anomaly Patterns

3.4.1   Break Vs Active

To examine the spatial distribution of rainfall anomaly over India associated with the break and active events, composite daily rainfall maps of the 834 active days and 889 break days were examined (Figures 5a & b). Supplementary Fig.1 shows the map depicting level of significance in the differences between these two composite patterns obtained using two-sample t-test. As seen in the Fig.5a & b, the broad composite daily rainfall anomaly patterns in respect of active & spells were found to be exactly opposite to each other. During the active (break) days, the rainfall along the west coast and over most areas of monsoon trough zone were above (below) normal by ≥6mm, that along the Himalayas were below (above) normal by ≥3mm and that over southeastern Peninsula were below (above) normal by 0-3mm. It was observed that except for an elongated narrow area away and parallel to foothills of Himalayas in north and another narrow area separating the relatively dry areas of southeast Peninsula, the difference between the composite means are significant at 99% level (Supplementary Fig.1).

In order to examine whether the changes in the rainfall pattern (and hence the convective pattern) between break and active events are restricted only to the Indian region, composites maps of OLR anomalies superposed with composite 850 hPa wind vector anomalies associated with these extreme

events were prepared and studied (Fig.6a & b). The map depicting level of significance in the difference between the composite OLR anomalies of active and break events (supplementary Fig.2) computed using two sample test shows significant level of 99% over most areas along the ITCZ zone, south China and east Indian Ocean. The composite rainfall anomaly map associated with active events (Fig.6a) show large negative OLR anomalies (positive rainfall anomalies) not only along monsoon trough zone over the Indian region but also extends over the equatorial central and west Pacific. Positive OLR anomalies (negative rainfall anomalies) are seen over the eastern equatorial Indian Ocean as well as northeastern parts of India extending through China upto 140°E of tropical Pacific as seen in Fig.6 (a). The break composite (Fig.6b) is characterised by exactly opposite pattern with large positive OLR anomalies over the Indian region extending to equatorial west Pacific and Central Pacific and large negative OLR anomalies over the eastern equatorial Indian Ocean and northern west Pacific. Negative OLR anomalies are also seen over Northeastern parts of India extending up to east China and some parts of tropical Pacific. The 850 hPa wind vector anomalies as seen in (Fig.6 a & b) were complimentary to OLR anomalies. During the active (break) spells, anomalous cyclonic (anticyclonic) circulation can be observed over the Indian region with the anomalous trough (ridge) extending up to equatorial central and west Pacific. Similarly, anomalous anticyclonic (cyclonic) circulation can be observed over eastern equatorial Indian Ocean as well as anomalous anticyclonic (cyclonic) circulation over northeastern parts of India and adjoining China.

In order to examine the changes in the distribution of daily rainfall events of various intensities (LR, MR and HR events) associated with the active/break monsoon conditions, composite frequency maps (Fig.7a) of LR, MR & HR events per season in respect of active and break conditions were prepared and compared. It is seen that during active condition, highest frequency of MR & HR events (≥50 MR events & ≥2 HR events) were observed over monsoon trough zone and along the west coast. However, composite frequency pattern of LR events was quite opposite with maximum frequency (≥30) LR events observed over most of the areas of the country except over monsoon trough zone and along the west coast.

In case of break condition (Fig.7b) as expected the highest frequency of MR & HR events (40-70 MR events & 1-8 HR events) were mainly observed over a narrow zone along the foot hills of Himalayas associated with the shifting of monsoon trough to that region. Few MR and HR events were also observed along the west coast but the frequency being much less than that during active monsoon. On the other hand, except over the narrow zone along the foot hills of Himalayas & west coast, the LR frequency is ≥ 60 days over most of the areas. This indicates that during break conditions, the daily rainfall events over most parts of the country mainly occur as LR events.

Two-sample t-test were conducted to compute the significance of difference in the frequencies of LR, MR & HR events between active and break monsoon events (supplementary Fig.3.). The significant level maps in respect of LR and MR events nearly resembled to supplementary Fig.1. However in case of HR events, the significant level of 99% was observed over monsoon trough zone, west coast and narrow zone along the foothills of Himalayas.

3.4.2   Comparison of Break Events: Synoptic Vs Rainfall Criteria

It was observed that the break and active spells identified in this study were nearly comparable and consistent with those identified by Rajeevan et al. (2010) for the common period of 1951-2007. This was expected as both these studies used similar criteria based on a rainfall index derived from the same area (monsoon core zone). However, there were some noticeable differences in the break spells identified in this study based on the rainfall criteria and those by Ramamurthy (1969) & De et. al. (1998) based on the synoptic criteria for the period 1901-1996. During the period 1901-1996, there were 118 break spells each based on rainfall and synoptic criteria. About 68% of the break spells (78 spells) identified by each of these two criteria were comparable, as there was overlapping between spells. These overlapping break spells from both the cases can be considered as the break spells that satisfied both the rainfall and synoptic criteria. However, the remaining (32%) of the break spells based on both the criteria were not overlapping with each other. Most of the break spells that did not have overlapping between the two criteria were of short duration.

In order to distinguish between the break events identified by rainfall and synoptic criteria, composite daily rainfall anomaly patterns associated with these events were examined. The Figures 9a & 9b show the composite daily rainfall anomaly maps of 78 break spells each identified by the rainfall and synoptic criteria respectively which were overlapping to each other. Figures 9c & 9d are similar to Figures 9a & 9b respectively but for the non-overlapping break spells. All the figures (9a to 9d) exhibited typical broad break monsoon rainfall anomaly distribution with negative rainfall anomalies along west coast and over the monsoon trough zone and positive rainfall anomalies along the Himalayan foothills and over southeast Peninsula. Figures 8a & 8b were nearly same except for slightly stronger negative anomalies over some central areas of monsoon trough zone in Fig.8a compared to Fig.8b. On the other hand, there were noticeable differences in the composite rainfall anomaly maps of non- overlapping break spells. The negative anomalies over many areas of the monsoon trough zone in the composite map of break days identified based on rainfall criteria (Fig.8c) were stronger by about 3-6mm/day than that based on synoptic criteria (Fig.8d). In addition, whereas the Fig.8c resembled close to Figures 8a & 8b, the Fig.8d showed extension of positive

rainfall anomalies along the Himalayas southward into the monsoon trough zone resulting in the reduced spatial extent of the negative anomalies over the region.

This indicates that the 38 non-overlapping break spells identified by synoptic criteria may actually be weak monsoon rainfall spells as the breaks basically means the interruption/ significant decrease in the rainfall over the monsoon zone region.

3.5. Relationship with Tropical SSTs Over Pacific & Indian Oceans

In order to examine the relationship between global tropical SSTs and the interannual variation of break and active days, C.C map of global tropical SSTs with active and break days respectively were computed for the entire data period (Figures 9a & 9b). In the Fig.9, the contour lines corresponding to ±0.19 & ±0.25 represent C.C significant at 95% & 99% level respectively. As seen in the Fig.9, strongest relationship of SSTs with both active and break days is seen over tropical Pacific with a distinct horse shoe type patterns typically observed associated with ENSO phenomena. In the active monsoon case (Fig.9a), a horse shoe pattern of negative C.C. areas (but not significant) over equatorial Pacific east of 140^oW wrapped around by positive C.C. areas extending to the north- and southeast from the western equatorial Pacific. On the other hand, in case of break events (Fig.9b), the pattern is nearly opposite. Significant positive C.C. areas are observed over equatorial central and east Pacific east of date line wrapped around by the negative C.C.s extending to the north- and southeast from the western equatorial Pacific. It is to be noted that, in the Figures 9a & 9b, the SSTs over most parts of Indian Ocean did not show any association with both active and break days.

To further examine the association of ENSO on the active and break events, we examined the frequency distribution of active and break spells as well as composite rainfall (OLR) anomaly over India (Asia-Pacific region) associated with both the phases of ENSO are compared. During the period 1901-2014 there were 28 El Nino years and 24 La Nina years (List of El Nino and La Nina years is given in the supplementary Table-1).

The histograms of the active and break spells of various durations during these 28 El Nino years & 24 La Nina years (Supplementary Fig.4) show similar distribution with spells of short durations being more frequent than that of long durations. However, break spells of long duration are more frequent during El Nino years than the La Nina years. During El Nino (La Nina) years, there were 297 (172) break days and 193 (183) active days with an average 10.6 (7.17) break days and 6.9 (7.63) active days per season respectively. This clearly indicates that the mean number of break and active days during La Nina years are nearly equal but El Nino favours more break days than active days.

The composite daily rainfall maps of the active/break days for El Nino & La Nina years (Supplementary Fig.4) showed very little difference in the composite rainfall patterns of active days between El Nino & La Nina cases except for slightly stronger negative rainfall anomalies along the foothills of Himalayas during El Nino case compared to La Nina. However, in case of break monsoon, the positive composite rainfall anomalies along the foothills of Himalayas during La Nina years are both stronger and extending more westwards compared to that of El Nino years. Composite maps of OLR anomalies in the Asia Pacific region superposed with composite 850 hPa wind vector anomalies (supplementary Fig.5) associated with active/ break monsoon days showed significant differences between El Nino and La Nina cases. For active (break) case during La Nina (El Nino) years, large zone of negative (positive) OLR anomalies covering most part of Indian subcontinent except northeastern part and extending eastward to Northwest Pacific was observed along with a relatively small area of positive (negative) OLR anomalies over equatorial north Indian Ocean. However, for active (break) case during El Nino (La Nina) years, the zone of negative (positive) OLR anomalies was relatively narrower with the opposite OLR anomalies covering the large part of south peninsula being relatively broader and extending eastward to maritime continent.

4. Conclusions

A rainfall criteria based on normalized daily anomaly index of the area weighted rainfall over the core monsoon zone region was used to identify the break and active spells for the period 1901-2014. The composite daily rainfall anomaly patterns in respect of break and active spells were found to be significantly different (at 99% level) and nearly opposite to each other. During active (break) spells, the rainfall anomalies were significantly positive (negative) over monsoon trough zone & along the west coast and that along the foothills of Himalayas & over southeast Peninsula were positive (negative). The rainfall events of different intensities (LR, MR and HR events) associated with the active/break events also showed significant differences. The changes in the rainfall/convective and low level circulation anomalies over Asia-Pacific region associated with the active and break monsoon conditions indicate stronger (weaker) than normal monsoon trough/inter tropical convergence zone extending from Indian region to west Pacific during the active (break) monsoon conditions. The associated above (below) normal rising motion over the monsoon trough/ITCZ region causes above (below) normal subsidence over the region on either sides (north and south) of the ITCZ. This results below (above) normal rainfall over region extending from northeast India to east China (areas north of monsoon trough/ITCZ) and equatorial Indian Ocean (areas south of monsoon trough/ ITCZ). De et al. (1997) have shown stronger (weaker) than normal southern Hemispheric Equatorial Trough during break (active) monsoon conditions. Kripalani and Kulkarni (2001) have shown significant inverse relation between rainfall over central India and that over East

Asia. Thus it was clear that the impact of active/ break monsoon conditions on the rainfall and low level circulation patterns is not limited to only India region. The impact was rather felt over larger spatial scale extending up to west Pacific as well as other areas of the Asian monsoon region. At the same, the intra seasonal oscillation (Madden and Julian Oscillation (MJO)) in the convective patterns over the global tropics in turn have significant impact on the onset and duration of active/ break monsoon events over India (Pai et al. 2011).

The break monsoon spells identified in this study based on rainfall criteria showed noticeable differences with that identified by earlier studies using the synoptic criteria of Ramamurthy (1969). During the period 1901-1996, there were 118 break spells each based on rainfall and synoptic criteria. However, about 68% of the break spells based on each criteria were comparable with that based on other as these break spells were having overlapping dates. However, the remaining (32%) of the break spells based on both the criteria were not overlapping with each other. The composite rainfall anomaly patterns of overlapping break spells in respect of both the criteria were nearly similar both in terms of distribution and strength of the anomalies. However, there were differences in the composite rainfall anomaly maps of non- over-lapping break spells based on the two criteria. Whereas the composite rainfall anomaly pattern in respect of rainfall criteria resembled closer to that of overlapping breaks spells, the pattern in respect of synoptic criteria showed significantly weaker negative anomalies over many areas of the monsoon trough zone. In the latter case, southward extension of the positive rainfall anomalies along the Himalayas into the monsoon zone also resulted in the reduced spatial extent of the negative anomalies over the region. This indicates that the non-overlapping break spells identified by synoptic criteria may actually be weak monsoon rainfall spells as the breaks basically means the interruption/ significant decrease in the rainfall over the monsoon zone region. Thus the stringent rainfall criteria used in this study and Rajeevan et al. (2010) seems to be better criteria for identifying the breaks. The rainfall criteria also helped in identifying the active spells whereas there are no known criteria based on synoptic conditions to identify the active spells.

It was observed that during the long study period (1901-2014) both the active and break spells of short duration were more frequent than the long duration. However, whereas no active spells of long duration (≥13 days) was recorded, about 8 % of break spells were of long duration. This indicates that the transition from active to break/ normal monsoon conditions is much faster than that from break to active/ normal monsoon conditions. Active monsoon conditions can be associated with the passage of synoptic scale systems such as monsoon lows and depressions along the monsoon trough zone. The life period of these synoptic scale systems are also of 3-6 days. Whereas, the break conditions are caused by the shifting of monsoon trough from the central India to the foot hills of Himalayas or the large scale subsidence over the monsoon zone region resulted from strong rising

motion over convective areas around the region. Equal number of break events (73 each) occurred during the two halves of the data period. But there was an increase of about 12% (99 to 111%) in the number of active spells in the second half and this increase was mainly in the short duration (3-6 days) spells.

The break and active days per season showed noticeable year to year variation even though no significant long term trends were observed both during the total data period and its two equal halves. A significant concurrent correlation between break days and SSTs over equatorial central and east Pacific was observed indicating importance of large scale anomalous vertical motion over Indian monsoon region associated with the ENSO in modulating break events over India. However, no such significant correlation with active days was observed.

An out phase of relationship was seen between decadal variations of the number of break days and number of MD days formed during July and August months. On the other hand, a relatively stronger in phase relationship was observed between the decadal variation of MD days and that of the active days till around early 1980s which failed later due to sudden decrease in the number of MD days. During the same period, both the active & break days were in the increasing phase. This increase in the active days as noticed earlier was mainly due to the increase in short duration active spells (3-6 days). The out of phase relationship between active days and MD days after early 1980s was also coincided with the sudden and significant increase in the LOW days, which nearly doubled during the period. The LOWs, which generally have life period of short duration helped the occurrence of active spells of short duration. Thus, post early 1980's, the increase in the active days covering short duration active spells caused by the LOW days compensated the decrease in the active days covering relatively long duration active spells caused by the MD days. This was the main reason for the reversal of the in phase relationship between MD days and the active days post early 1980s.

Acknowledgement

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Table Legends

Table 1. Break Spells during July-August (1901-2014)

Table 2. Active Spells during July-August (1901-2014)

Table 3a. Various statistical properties of break monsoon days over India. The C.C. and
 trend values significant at 95% at 99% levels are shown with * and ** respectively.

Table 3b. Various statistical properties of active monsoon days over India. The C.C. and trend
values significant at 95% and 99% levels are shown with * and ** respectively.

Table 4a. Decadewise 10 day period statistics for Break days (1901-2014).

Table 4b. Decadewise 10 day period statistics for Active days (1901-2014).

Figure Captions

Figure.1. All India daily rainfall variation during the monsoon season (June-September) during (a)
above normal monsoon season rainfall year (1994), (b) normal monsoon season rainfall year (2013)
and **(c)** below normal monsoon season rainfall year (2014).

Figure.2. Histogram of duration of break and active spells for the periods (a) 1901-2014, (b) 1901-
1957 and (c) 1958-2014.

Figure.3. Interannual variation and trends in (a) break days (b) active days.

Figure.4. Moving averages of the active and break days for the period 1901-2014 computed based
on 11- years window period. The moving averages of the number of monsoon low pressure days
and that of monsoon depression days are also given.

Figure.5. Composite daily rainfall anomaly map of (a) active spells and (b) break spells identified in
the present study for the period 1901-2014.

Figure.6. Composite OLR (W/m ^{2}) and 850hPa wind anomalies during (a) Active spells and (b)
Break spells (1974-2014).

Figure.7a.Composite frequency distribution (events per season) of daily rainfall events of various
intensities (LR (>0 & <5mm) events, MR (5mm-100mm) events and HR (≥100mm) events) during
the active monsoon conditions for the period 1901-2014.

Figure.7b. Composite frequency distribution (events per season) of daily rainfall events of various
intensities (LR (>0 & <5mm) events, MR (5mm-100mm) events and HR (≥100mm) events) during
the break monsoon conditions for the period 1901-2014.

Figure.8. Composite daily rainfall anomaly map of (a) 78 overlapping break spells based on rainfall
criteria, (b) 78 overlapping break spells based on synoptic criteria, (c) 38 non overlapping break
spells based on rainfall criteria, and, (d) 38 non overlapping break spells based on synoptic criteria.

Figure.9. Correlation Coefficient (C.C.) of tropical SSTs with Active and Break days (1901-2014).
The contour lines corresponding to ±0.19 & ±0.25 represent C.C significant at 95% and 99% level
respectively

Table 1. Break Spells during July-August (1901-2014)

YEAR	BREAK SPELLS	YEAR	BREAK SPELLS
1901	13-16J	1958	-
1902	1-17A	1959	-
1903	6-8J, 10-13A	1960	18-24J
1904	16-19A	1961	11-13A
1905	15-18J, 29-31J, 6-13A	1962	27-29J
1906	1-6A, 12-17A	1963	13-23J
1907	4-12J, 17-19J	1964	28-30J,1-4A
1908	-	1965	6-12J, 1-14A
1909	4-18A	1966	2-12J, 21-30A
1910	11-21J, 15-20A	1967	7-14J
1911	15-27J, 11-13A	1968	25-31A
1912	16-23A	1969	27-29A
1913	1-4J, 10-21A	1970	13-19J
1914	11-13A, 28-31A	1971	8-10J, 5-7A, 17-19A
1915	5-13J, 17-19J, 10-18A	1972	18J-3A
1916	-	1973	24-26J, 30J-1A
1917	7-9J	1974	28-31A
1918	10-26J, 8-14A	1975	-
1919	-	1976	-
1920	9-18A, 20-22A	1977	15-20A
1921	1-4J, 20-22A, 26-28A	1978	-
1922	6-17A	1979	2-7J, 14-29A
1923	-	1980	17-20J, 13-15A
1924	13-21A	1981	24-27A
1925	-	1982	1-8J
1926	19-21J	1983	14-16J
1927	2-6A	1984	28-30J
1928	30J-16A	1985	23-25A
1929	5-8A, 10-12A	1986	23-31A
1930	16-25A	1987	23-25J, 30J-4A, 9-13A
1931	-	1988	14-17A
1932	11-14A	1989	18-20J, 30J-3A
1933	3-7J, 13-19A	1990	-
1934	13-19J	1991	1-3J
1935	8-11A, 19-21A	1992	4-10J
1936	11-16J	1993	20-23J, 8-13A, 22-28A
1937	9-20A	1994	-
1938	29J-3A	1995	3-7J, 11-17A
1939	25-29J, 1-3A, 7-9A	1996	11-13A
1940	-	1997	11-15J, 9-17A
1941	14-29J, 5-7A, 22-30A	1998	20-26J, 16-21A
1942	6-8A	1999	1-5J, 12-18A, 22-24A
1943	11-15A	2000	29J-8A
1944	-	2001	31J-2A, 27-29A
1945	31J-7A	2002	4-16J, 22-31J
1946	9-12J	2003	-
1947	8-10J, 6-8A	2004	10-13J, 19-22J, 26-31A
1948	31J-2A	2005	18-20J, 8-14A, 24-31A
1949	19-23A	2006	-
1950	15-26A	2007	18-23J, 15-17A
1951	13-15J, 24-30A	2008	16-21J, 21-24A, 28-30A
1952	8-15J, 28-30A	2009	29J-10A, 17-19A
1953	-	2010	-
1954	22-28A	2011	1-3J
1955	24-26J	2012	-
1956	25-29A	2013	-
1957	-	2014	15-21A

Table 2. Active Spells during July-August (1901-2014)

YEAR	ACTIVE SPELLS	YEAR	ACTIVE SPELLS
1901	-	1958	8-11J
1902	15-17J, 25-27A	1959	26-29J
1903	19-24J	1960	1-4J
1904	-	1961	6-10J, 16-18J
1905	-	1962	16-20J, 12-14A
1906	20-23J, 26-30A	1963	9-11A
1907	11-21A	1964	5-7J, 15-17A, 23-25A
1908	6-8J, 14-16A	1965	27-29J, 24-26A
1909	16-18J, 31J-2A	1966	29-31J
1910	1-6J, 2-4A	1967	1-3J, 24-29J, 31J-3A
1911	-	1968	7-10J, 29-31J, 4-6A
1912	25-30J, 2-5A, 27-29A	1969	29J-1A
1913	17-19J, 25-27J, 31J-2A, 23-25A	1970	1-3J, 17-19A, 25-29A
1914	11-13J	1971	19-21J, 26-31A
1915	-	1972	4-7J
1916	14-17A, 20-22A, 24-27A	1973	7-9J, 13-15J, 12-14A, 26-31A
1917	2-5J, 9-13A, 23-26A	1974	16-20A
1918	-	1975	13-15J, 17-19J, 12-15A, 18-20A
1919	1-3A, 21-24A, 27-29A	1976	16-21J, 30J-2A, 28-31A
1920	6-9J, 23-25J	1977	5-7J, 6-8A
1921	27-31J	1978	15-17A, 24-26A, 28-30A
1922	19-21A	1979	2-5A, 7-12A
1923	27-30J	1980	1-3J
1924	27-29J, 26-31A	1981	7-10J
1925	10-13J	1982	21-23A, 12-14 A
1926	11-18A	1983	18-20A
1927	22-30J	1984	1-3A, 9-11A, 16-19A
1928	2-4J, 26-31A	1985	15-17J, 30J-2A, 6-8A
1929	24-26J, 23-25A	1986	21-24J, 13-15A
1930	1-4J	1987	24-29A
1931	10-12A, 15-17A, 21-23A, 26-28A	1988	26-28J
1932	12-15J, 21-23J	1989	-
1933	14-19J, 31J-6A, 8-11A, 24-26A	1990	2-4J, 21-24A, 29-31A
1934	1-4J, 17-19A, 22-24A	1991	21-24J, 29-31J, 22-24A
1935	8-11J	1992	27-29J, 16-21A
1936	-	1993	7-11J, 15-17J
1937	11-13J, 21-26J	1994	2-4J, 9-16J, 30J-2A, 18-20A, 25-27A, 29-31A
1938	9-11J	1995	18-20J, 22-25J
1939	13-16J, 17-20A, 24-26A	1996	24-28J, 19-21A
1940	1-3J, 31J-2A, 22-25A	1997	30J-1A, 21-25A
1941	1-7J, 9-11A	1998	3-5J
1942	3-7J, 10-12J, 24-27J, 2-5A	1999	7-9A
1943	10-13J, 26-29J	2000	12-14J, 17-20J
1944	10-16J, 24-26J, 31J-2A, 20-22A	2001	9-12J
1945	2-4J	2002	23-25A
1946	24-28J, 1-3A, 19-24A	2003	23-28J, 27-29A
1947	25-31A	2004	30J-1A, 8-12A, 21-23A
1948	19-21J	2005	1-5J, 25-29J, 31J-2A
1949	1-3A	2006	3-5J, 27J-7A, 13-15A, 17-20A
1950	10-14J, 25-29J	2007	4-9J, 6-8A
1951	25-27J	2008	10-12A
1952	23-30J	2009	13-16J, 20-23J
1953	3-7J, 3-5A, 12-19A	2010	-
1954	9-12A	2011	25-27A
1955	29-31A	2012	11-13A
1956	2-8J, 11-14J, 1-5A	2013	19-22A
1957	20-24A	2014	19-23J, 4-6A

Table 3a. Various statistical properties of break monsoon days over India.

Statistical Property	Period	Break Days		
		1901-2014	1901-1957	1958-2014
Frequency	Jul + Aug	889	460	429
(Total Days)	July	365	160	205
	Aug	524	300	224
Average	3 Jul + Aug	7.8	8.1	7.5
(days/season)	July	3.2	2.8	3.6
	Aug	4.6	5.3	3.9
standard deviation	Jul + Aug	6.5	6.5	6.5
(days/season)	July	4.3	4.3	4.3
	Aug	4.7	4.8	4.5
Median	Jul + Aug	7	7	7
(days/season)	July	1.5	0	3
	Aug	3.5	5	3
	Jul + Aug	28 (1941)	28 (1941)	23 (2002)
Maximum days (Year)	July	23 (2002)	17 (1918)	23 (2002)
	Aug	17 (1902)	17 (1902)	16 (1979)
Trend	Jul + Aug	-1.32	-2.17[*]	0.06
(days/season/year)	July	-1.46	-1.73	0.93
	Aug	0.81	-0.31	-0.59
C.C. with All India	Jul + Aug	0.41	0.54	0.26
	July	0.46	0.48	0.45
	Aug	0.5	0.6	0.36

The C.C. and trend values significant at 95% (99%) levels are shown with * (**).

Table 3b. Various statistical properties of active monsoon days over India.

Statistical Property	Period	Active Days		
		1901-2014	1901-1957	1958-2014
Frequency	Jul + Aug	834	413	421
(Total Days)	July	430	216	214
	Aug	404	197	207
Average	Jul + Aug	7.3	7.3	7.4
(days/season)	July	3.8	3.8	3.8
	Aug	3.6	3.5	3.6
standard deviation (S.D)	Jul + Aug	4.7	4.8	4.6
(days/season)	July	3.3	3.4	3.2
	Aug	3.6	3.9	3.4
Median	Jul + Aug	7	7	7
(days/season)	July	3	3	3
	Aug	3	3	3
	Jul + Aug	24 (1994)	20 (1933)	24 (1994)
Maximum days (Year)	July	13 (1994)	12 (1942)	13 (1994)
	Aug	14 (2006)	13 (1933)	14 (2006)
Trend	Jul + Aug	0.25	1.34	-0.51
(days/season/year)	July	0.4	1.75	-0.64
	Aug	0.76	0.59	0.32
C.C. with All India	Jul + Aug	0.41	0.54	0.26
	July	0.46	0.48	0.45
	Aug	0.5	0.6	0.36

The C.C. and trend values significant at 95% (99%) levels are shown with * (**).

Table 4a. Decadewise 10 day period statistics for Break days (1901-2014).

DECADEWISE NUMBER OF BREAK DAYS (10 days period) (1901-2014)						
DECADE	1-10 JUL	11-20 JUL	21-31 JUL	1-10 AUG	11-20 AUG	21-31 AUG
1901-1910	10	23	4	29	37	0
1911-1920	14	22	13	7	42	10
1921-1930	4	2	3	25	29	11
1931-1940	5	13	8	14	24	1
1941-1950	5	9	11	18	13	18
1951-1960	3	11	7	0	0	22
1961-1970	18	23	9	14	7	20
1971-1980	9	7	16	7	19	13
1981-1990	8	6	10	9	7	16
1991-2000	20	7	12	13	32	11
2001-2010	8	22	20	15	10	24
2011-2014	3	0	0	0	6	1

Table 4b. Decadewise 10 day period statistics for Active days (1901-2014).

DECADEWISE NUMBER OF ACTIVE DAYS (10 days period) (1901-2014)						
DECADE	1-10 JUL	11-20 JUL	21-31 JUL	1-10 AUG	11-20 AUG	21-31 AUG
1901-1910	9	9	8	5	13	9
1911-1920	8	6	13	11	8	22
1921-1930	8	3	24	0	10	16
1931-1940	12	19	11	12	13	19
1941-1950	19	17	23	14	4	13
1951-1960	19	5	15	10	11	7
1961-1970	18	8	19	9	10	11
1971-1980	13	16	4	13	20	22
1981-1990	7	3	9	10	14	16
1991-2000	12	20	23	6	10	16
2001-2010	16	7	22	17	11	9
2011-2014	0	2	3	3	5	5
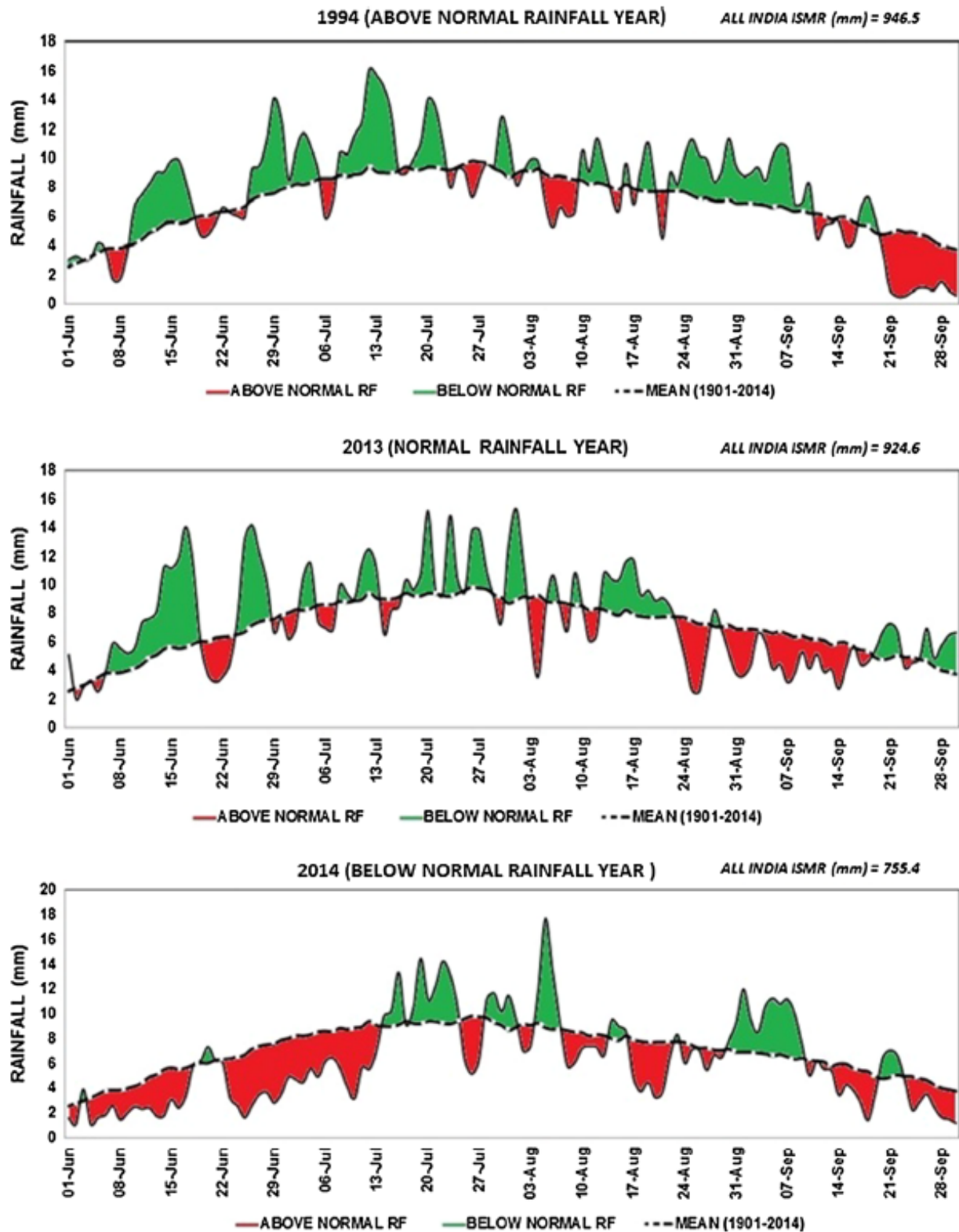
Fig.1. All India daily rainfall variation during the monsoon season (June-September) during **(a)** above normal monsoon season rainfall year (1994), **(b)** normal monsoon season rainfall year (2013) and **(c)** below normal monsoon season rainfall year (2014).
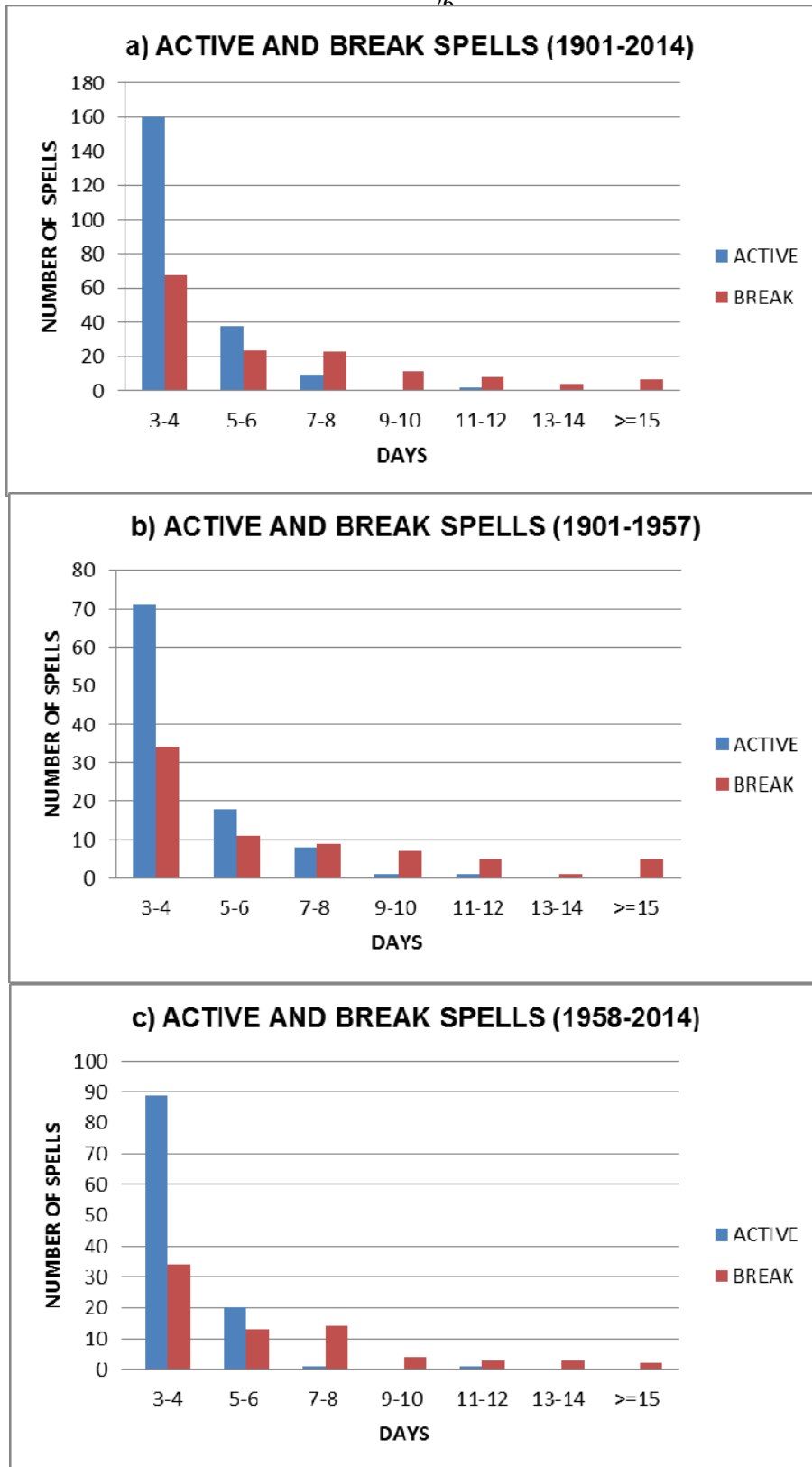
Fig.2. Histogram of duration of break and active spells for the periods **(a)** 1901-2014, **(b)** 1901-1957 & **(c)** 1958-2014.
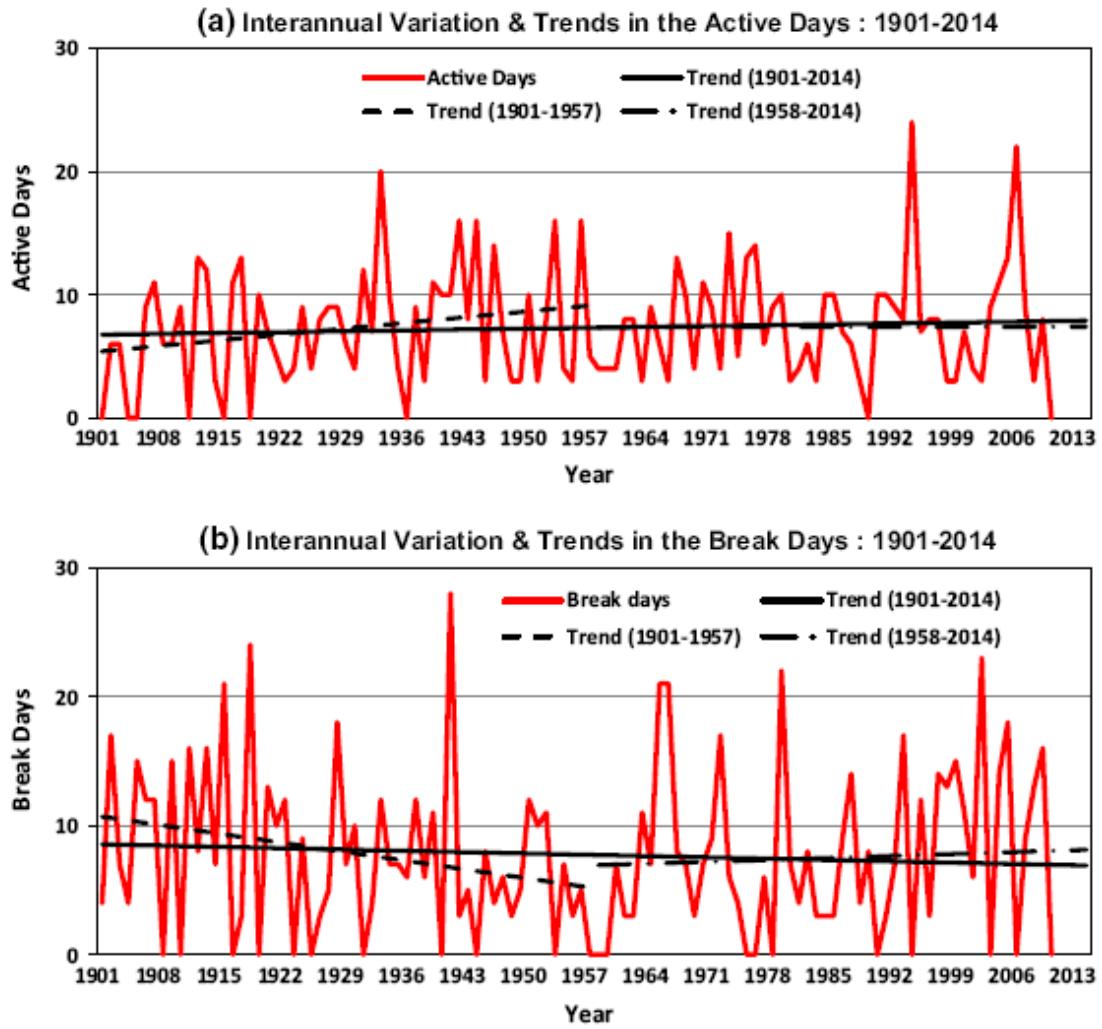
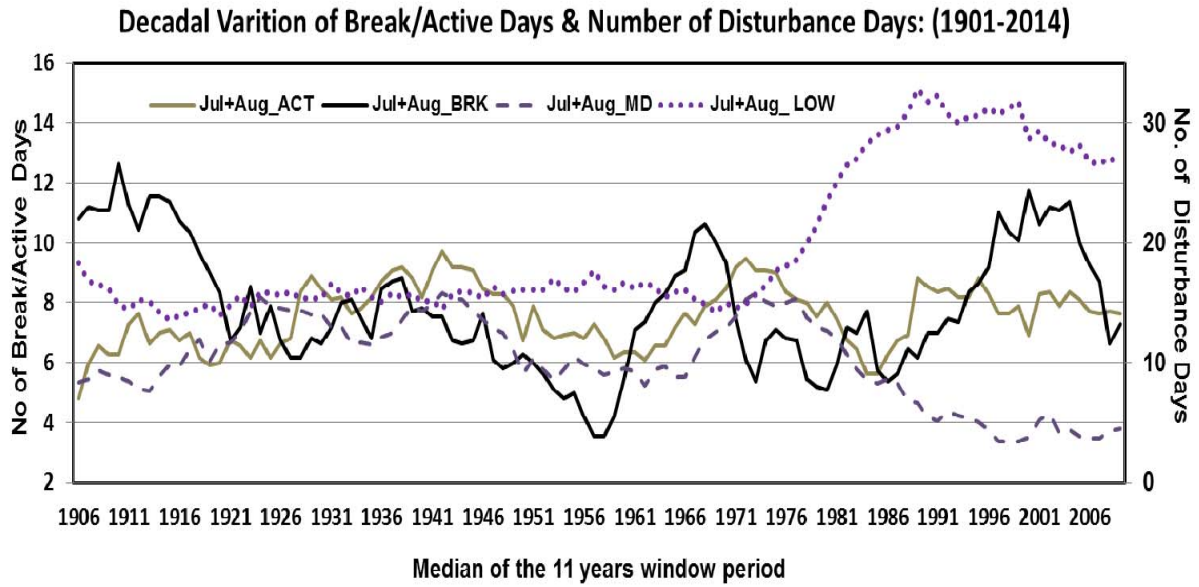**Fig.3.** Interannual variation & trends in **(a)** break days **(b)** active days.

Fig.4. Moving averages of the active and break days for the period 1901-2014 computed based on 11- years window period. The moving averages of the number of monsoon low pressure days and that of monsoon depression days are also given.

Fig.5. Composite daily rainfall anomaly map of **(a)** active spells and **(b)** break spells identified in the present study for the period 1901-2014.

Fig.6. Composite OLR (W/m ^{2}) and 850hPa wind anomalies during **(a)** Active spells and **(b)** Break spells (1974-2014).

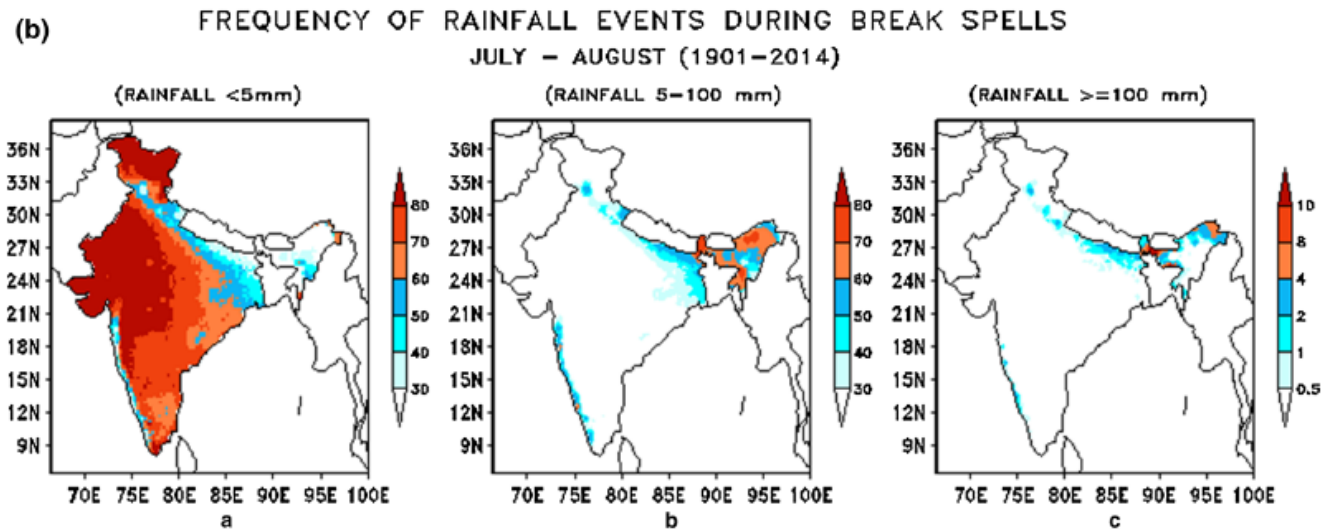**Fig.7a.** Composite frequency distribution (events per season) of daily rainfall events of various intensities (LR (>0 & <5mm) events, MR (5mm-100mm) events and HR (≥100mm) events) during the active monsoon conditions for the period 1901-2014.
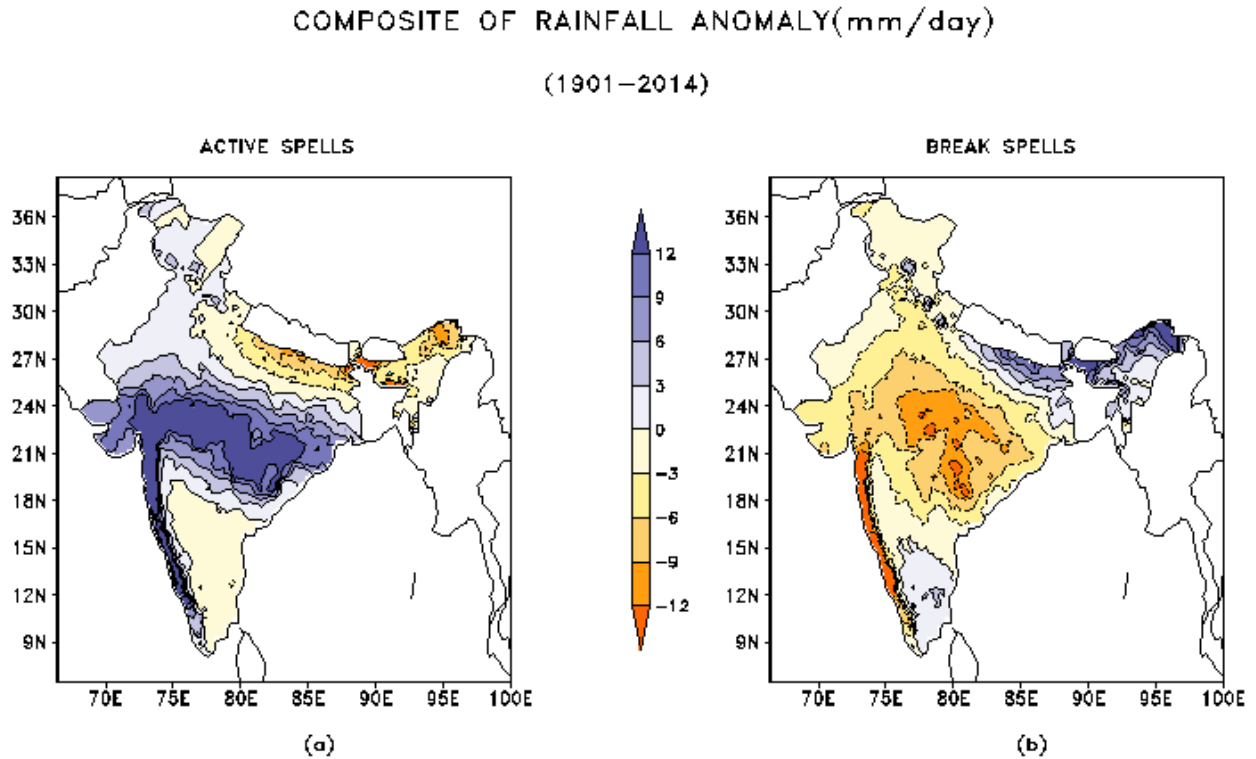
Fig.7b. Composite frequency distribution (events per season) of daily rainfall events of various intensities (LR (>0 & <5mm) events, MR (5mm-100mm) events and HR (≥100mm) events) during the break monsoon conditions for the period 1901-2014.

COMPOSITE OF RAINFALL ANOMALY(mm/day)
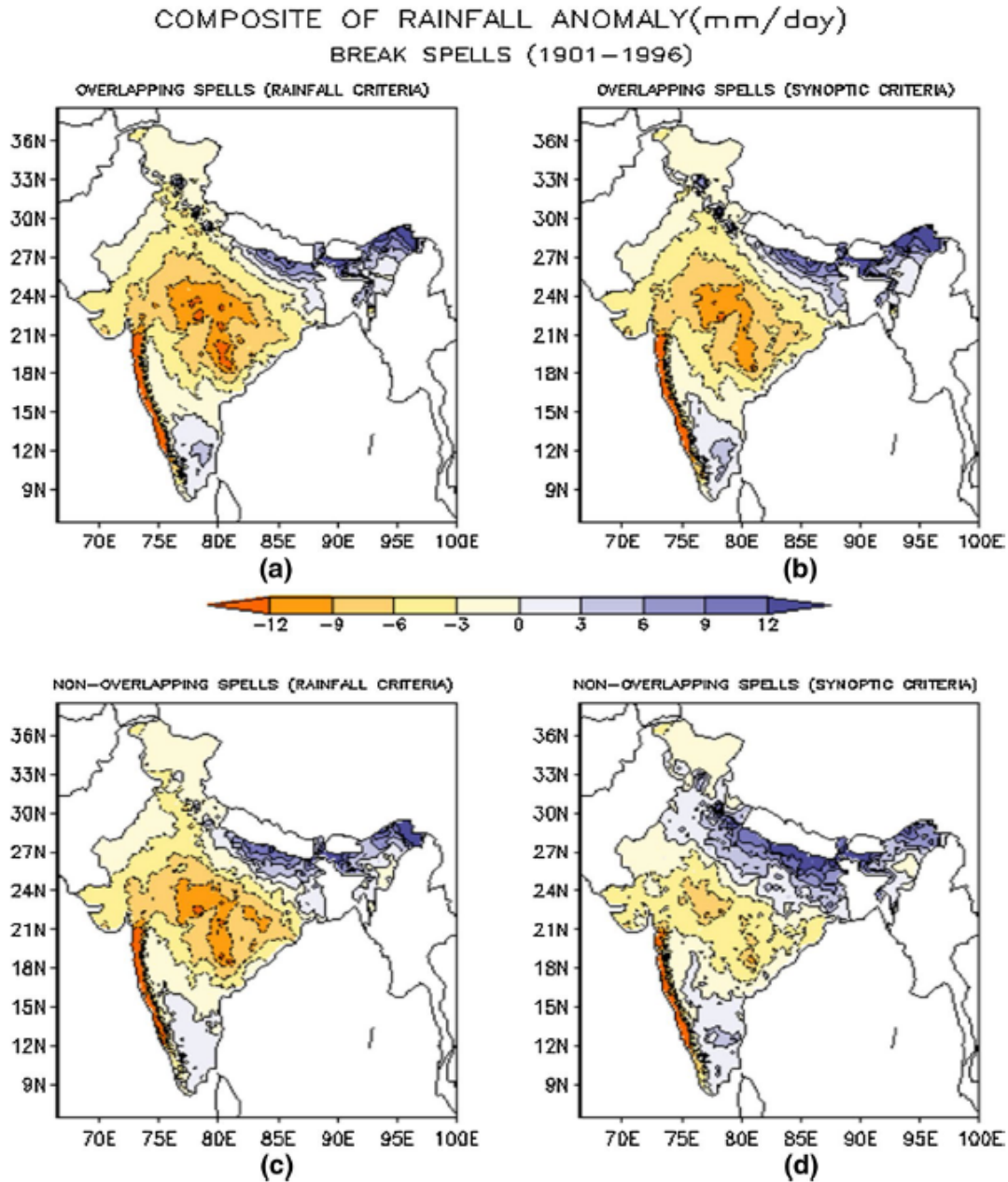BREAK SPELLS (1901–1996)

Fig.8. Composite daily rainfall anomaly map of **(a)** 78 overlapping break spells based on rainfall criteria, **(b)** 78 overlapping break spells based on synoptic criteria, **(c)** 38 non overlapping break spells based on rainfall criteria, and, **(d)** 38 non overlapping break spells based on synoptic criteria
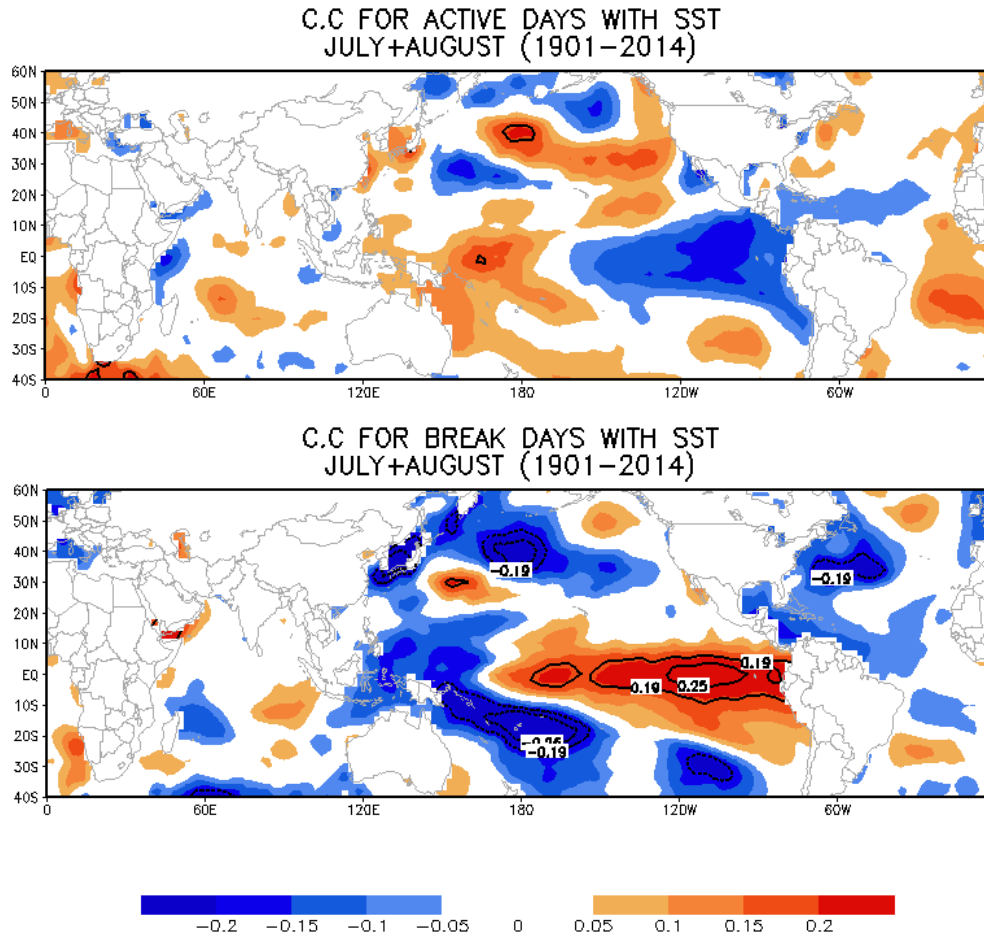
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Fig.9. Correlation Coefficient (C.C.) of tropical SSTs with Active and Break days (1901-2014). The contour lines corresponding to ±0.19 & ±0.25 represent C.C significant at 95% & 99% level respectively.