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Study on Temporal Variation of Rainfall over Uttar Pradesh Region India

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ABSTRACT: The analysis of rainfall time-series data showed cyclic pattern (increase followed by decrease) of rainfall over Uttar Pradesh region of India for the period of 1954-2013 in monsoonal season. The anomaly values were found to be suitable for producing time series on a regional scale, rather than directly using the raw values. Extreme rainfall was observed in winter season of year 1996 (487mm) as indicated by the anomaly value (+2.65). In the month of June, for years 2008 (2965mm) and 2013(2827mm), increase in rainfall was represented by anomaly values of +2.90 and +2.69, respectively. A strong linkage was obtained between the average number of sunspot and MGII; Solar Irradiance and annual Indian rainfall pattern. Similarly, cross-wavelet analysis between SSN (Long term periodicity of 9-11 years) and QBO (Short term periodicity of 2.5-5 years) with rainfall indicated regions with high common power and revealed information related to their phase relationship. The study proved strong interrelationship of QBO with rainfall during summer and monsoon season. Whereas, relationship between SSN and rainfall was observed to be stronger for the winter season. For the months of July and August, maximum active rainfall days was observed in year 2008 (6 days)and maximum break days were seen in year 2009 (37 days). The active days may be attributed to negative anomaly in Outgoing Longwave Radiation (OLR) for year 2008 leading to excessive monsoonal rainfall in the region. Also, the break period in 2009 may be due to the increase in OLR anomaly (+1.5 to +18 W/m^2).

Keywords: Active and Break days, Cramer Test, Mann Kendall Trend Analysis, Rainfall, Standardized Anomaly Index, Wavelet Transform.

Abbreviations: : ACE, accumulated cyclonic energy; BOB, Bay of Bengal; CWT, continuous wavelet; CWT, cross wavelet; ENSO, El-Nino Southern oscillation; ISMR, Indian summer monsoon rainfall; ICs, intense cyclones; JF, January-February; JJAS, June-July-August-September; March-April-May; NIC, number of intense cyclone; NTC, number of tropical cyclone; OND, October-November-December; OLR, outgoing long wave radiation; QBO ,Quasi-biennial oscillation; SSTs, sea surface temperatures; SSN, sunspot number; TC, tropical cyclone; WT, wavelet transform.

I. INTRODUCTION

Increase in rainfall intensity may be considered as one of the prime indicators of a drastic change in the climatic conditions of a region. Variation in rainfall is known to have a direct bearing on the crop-productivity in Uttar Pradesh State of India. Agriculture is the major source of livelihood in the state. The main cropping pattern is followed according to the rice-wheat system, which depends on the area coverage and water consumption. The impact of rainfall variations and changes in seasonal rainfall is therefore a major issue for policy makers.

Statistical analysis of rainfall time series involves the application of Cramer's test so as to find the important periods with abnormal mean in the dataset. For establishing a trend in monthly, seasonal and annual rainfall for a region, the Standardized Rainfall Anomaly Index (SRAI) has been found to be very successful. The important changes in the heavy rainfall trends over Central India indicating heterogeneity on ISM rainfall in the spatial domain. Researchers have used the power spectrum method (Morelet wavelet analysis) to understand the trend, periodicity; and test the importance of periodicity [7]. The periodicity of 2-3years is mainly based on quasi-biennial oscillation and the longer periods (8-16 years) to sunspot activity in Central North East India [3]. Comparison of 130 years of the sunspot activity data with southwest monsoon Indian rainfall variability indicating high significance with positive correlation [10]. Active and break spells in the monsoon season were identified [1]. The active and break periods (1901–89) using only rainfall data over the monsoon zone over the central parts of India [6]. Studies on the analysis of historic data and identification of trend were not undertaken by researchers after year 2008 for the region of Uttar Pradesh, India. Hence, the aim of present study was to identify the influencing parameter for rainfall variability and observe the trend in rainfall variability for the study area. An attempt was made to investigate a possible linkage between the sunspot activity and monsoon rainfall variability. Other influencing parameters have also been identified based on their possibility for influencing rainfall variability.

II. MATERIALS AND METHODS

The study area considered in the present work comprises of the state of Uttar Pradesh located in northern India (geographically 25-30N, 72-82.5E), and covers an area of 243290 Km^2. In this study, the rainfall data (1954-2013) for U.P region was extracted from the daily gridded rainfall data set (0.25° × 0.25°, latitude × longitude) procured from National Data Centre, Indian Meteorological Department (IMD), Pune. Sunspot occurrence data was obtained from the National Geophysical Data Centre, Boulder, Colorado, USA. The monthly QBO (1954-2013), MGII (1979-2013, Solar Irradiance (1979-2013) data was procured through (NOAA) NGDC. Cosmic Ray data was obtained from the University of Oulu (www.cosmicrays.oulu.fi). The data for Oceanic Nino 3.4 index was taken from www.cpc.ncep.noaa.gov/ and the cyclonic data(1990-2015) from best track IMD. Analysis of daily OLR data was necessary to determine the patterns associated with break and active spells of the Indian monsoon. Circulation patterns were obtained by analysis of the daily average data of NCEP-NCAR project.

A. Cramer Test

The test was applied for analyzing whether the sub-periodical means of the sub-periodical divisions significantly differed from the average of the 60 year period (the long term normal or period normal). To achieve this, data were divided into 10-year sub-periods (1954-1963, 1964-1973, 1974-1983, 1984-1993, 1994-2003, 2004-2013).

B. Standardized Rainfall Anomaly

To study the variation of the occurrences of trends, the Standardized Anomaly Index (SAI) was used. It provided an area average index of relative rainfall yield based on the standardization of rainfall totals [1]. It was calculated as below:

$$Z = x-\bar{x}/S \quad (1)$$

Where $\bar{x}$ and S are the mean and standard deviation of the entire series respectively and x is mean of sub period. Z is the normalized Standardized Anomaly Index. The dry and wet years of rainfall have been identified from the index values.

C. Wavelet transform (WT)

In wavelet analysis, the periodicity of rainfall with time was identified. Wavelets are wave like fluctuating signals of finite bandwidth both in Time and in Frequency. Wavelets in signal processing link fill the missing link between time and frequency studies. WT is the main character in both time and frequency signal in terms of sinusoids. In this study, Indian rainfall data was examined by using different wavelets (Continuous and Cross Wavelet) at different levels by modifying the MATLAB (Math Works, Version 9.0) wavelet programme. This form of wavelet consists of a plane wave modulated by a Gaussian envelope [18]:

$$\Psi_0(\eta)=\pi^{-1/4}e^{i\,\omega 0\,\eta}e^{-\eta 2/2} \quad (2)$$

where ωo is the non-dimensional frequency, here taken as 6, to satisfy the admissibility condition [5].

D. Analysis of Active and break days

In the study, attempt was made to observe the inter-seasonal variability of the Indian summer monsoon. The active–break periods during the southwest monsoon season were identified by present rainfall datasets (1954-2013). The active and break periods during the monsoon season have been identified [16]. The break period has been identified as the period during which the standardized rainfall anomaly is less than –1.0, provided it is maintained consecutively for three days or more. Similarly, the active period has been recognized as the period during which the standardized rainfall anomaly is more than +1.0, provided it is maintained consecutively for three days or more.

III. RESULTS AND DISCUSSION

A. Rainfall Pattern

The Cramer's test was used to compare the means of the sub-period with the mean of the whole record period.Table1shows the results of10-year non-overlapping decadal sub-periodical variation analysis for the seasonal, annual and monsoon months of rainfall. In winter season from decade I and V (1954-1963, 1994-2003), the t_k value being positive (+0.99, +0.67) indicates wetter condition. In monsoon season (JJAS) for decade VI (2004-2013), t_k value is negative (-1.03) showing drier condition (Table 1).

B. Result of Seasonal and Annual Rainfall Standardized Anomalies

It is clear from the results that the rainfall yield is declining in the monsoon season. Figs. 1 and 2 shows the graphical representation of standardized anomaly index (decadal and annual) for both the seasonal and annual rainfall. The decadal study was followed by annual standardized anomaly of rainfall to identify fluctuation of rainfall in a particular year. Highest rainfall was recorded in decade in 1954-1963 (+0.33) and 1994-2003(+0.25) for months JF. Maximum rainfall anomaly in season JF is +2.65 in year 1996 as shown in Fig. 2.

Table 1: Cramer test result of Decadal U.P. rainfall (1954-2013).

U.P.	1954-1963 (decade I)	1964-1973 (Decade II)	1974-1983 (Decade III)	1984-1993 (Decade IV)	1994-2003 (Decade V)	2004-2013 (Decade VI)
Annual/Seasonal/Monsoonal Month	t_k	t_k	t_k	t_k	t_k	t_k
Annual	1.412238886	-0.4282048	0.53520468	-0.87109336	0.51120715	-1.2243461
JF	0.992359502	-0.77595489	-0.3821726	-0.27471616	0.67312901	-0.29069665
MAM	-1.12753867	-0.1275638	1.04668076	-0.07441249	-0.03931427	0.345231676
JJAS	0.850473287	-0.23951283	0.69191559	-0.87543359	0.65686652	-1.03522594
OND	1.964599242	-0.28406401	-0.643786	-0.11601285	-0.61007336	-1.12324914
June	-1.02671667	-0.6263659	0.09496667	-0.28619163	0.87576585	0.951848309
July	0.451977789	-0.48679796	1.12102529	-0.6705783	-0.28675772	-0.24645863
August	1.401422109	0.651129903	-0.1399516	-0.73703043	0.07847962	-1.31356491
September	0.46352647	-0.04336133	0.0578658	0.052798635	0.69795327	-1.11934435

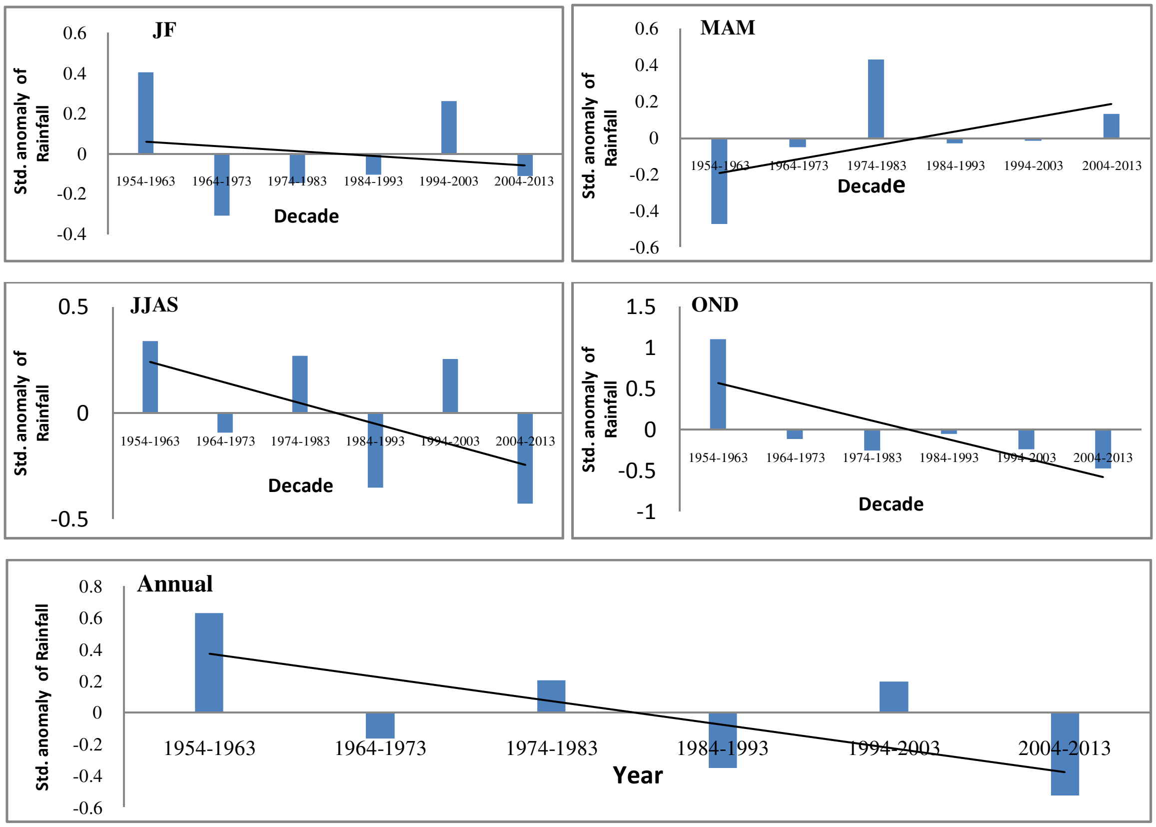


Fig. 1. Decadal Standardized anomalies of U.P Rainfall.

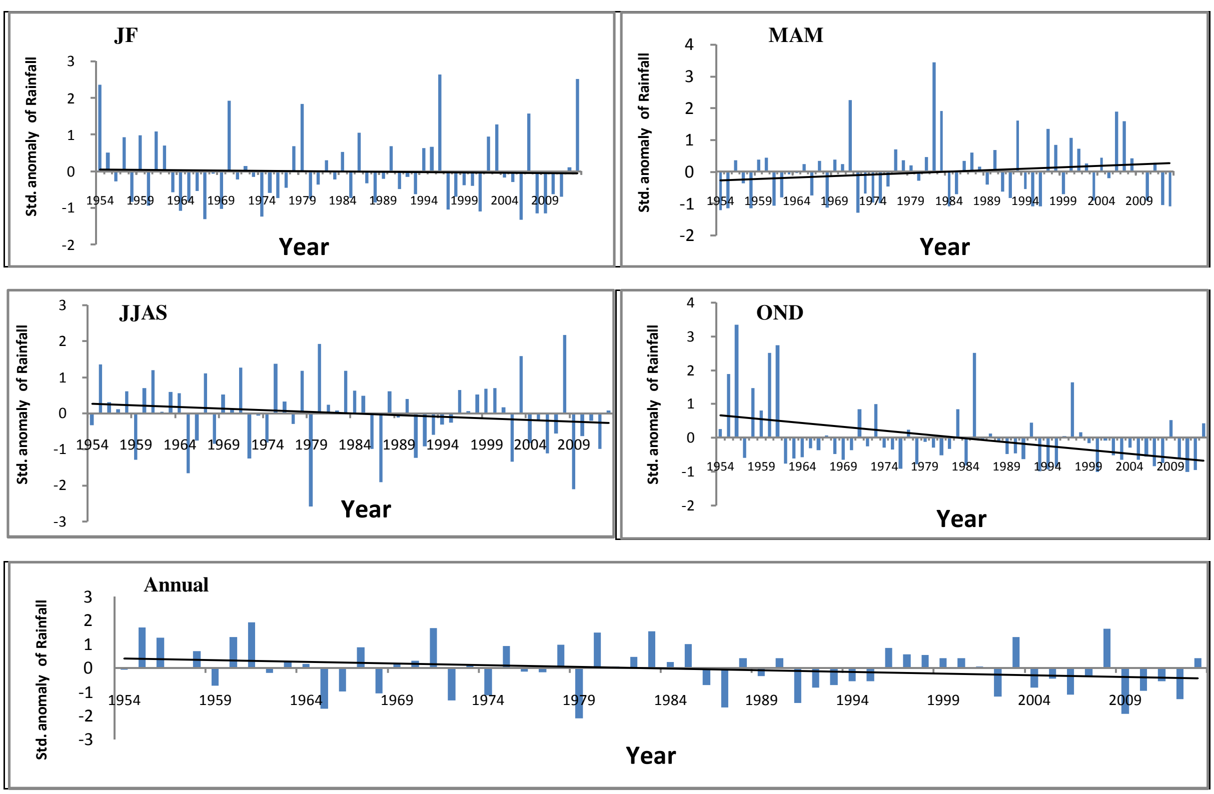


Fig. 2. Standardized anomalies of seasonal and annual Rainfall over U.P region.

C. Spectral Analysis of Seasonal and Annual Rainfall

The individual wavelet power spectra for annual and seasonal rainfall of U.P are shown in the Fig. 3. During the winter season (JF) for year 1996, extreme rainfall is seen at periodicity of 9 years. Anti-phase relation as seen in cross wavelet plot between SSN and rainfall (year 1996 coincides with La-nina year in this season) has been shown in Fig. 4 (a) [17]. It has been reported that the increase in solar activity decreases the intensity of galactic cosmic rays flux which consequently results in high rainfall [3, 9, 10]. In monsoon season (JJAS), in year 2008, maximum anomaly (+2.18) was seen in decade VI with periodicity of 2.5 years as shown in Fig. 3 (c).

The quasi-biennial oscillation (QBO) is known to be responsible for such type of short term periodicity. In cross wavelet transform, QBO and rainfall show in-phase relationship for this year as evident in Fig. 4 (b). Hence, the period of 2.5 years in the power spectrum of rainfall variability may be due to QBO phenomenon in the earth's atmosphere, which in turn might have been influenced by the solar activity [4]. The QBO is described [2] as the phenomenon of reversal of wind directions in the equatorial stratosphere. Annually, rainfall shows highest power in decade 1974-1983 followed by a decrease up to last decade 2004-2013.In cross wavelet plot of QBO and annual rainfall (decade 2004-2013) an in-phase relationship can be seen in Fig. 4(c).Similarly, an in-phase relationship has been established between OND rainfall and QBO series as clearly evident from Fig. 4 (d).

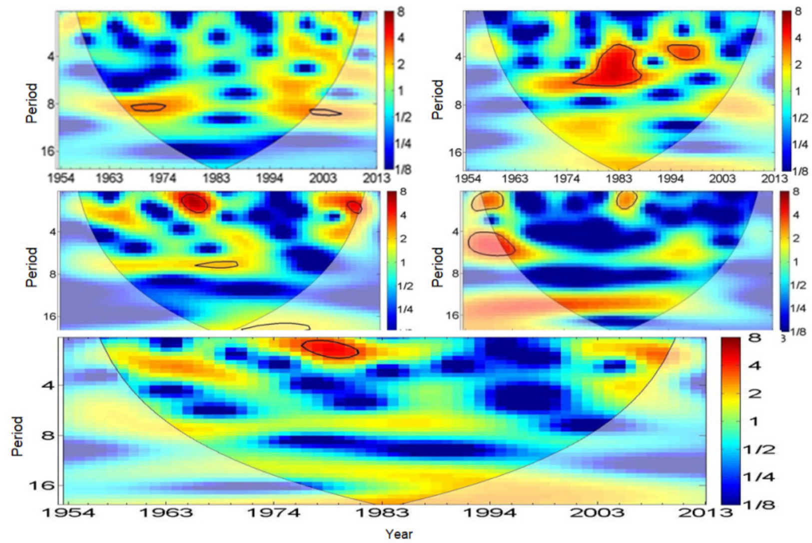
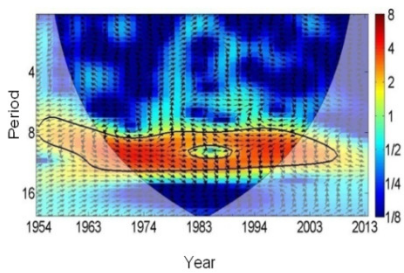
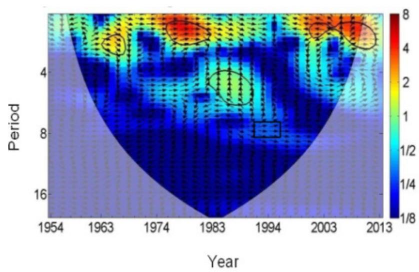


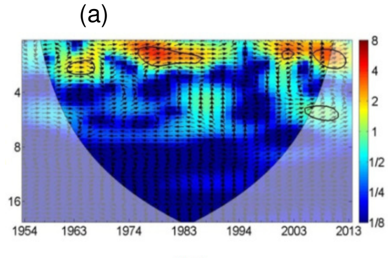
Fig. 3 (a-e) Continuous wavelet transform of U.P. Rainfall time series (1954-2013).The 5% significance level against red noise is shown as a thick contour.



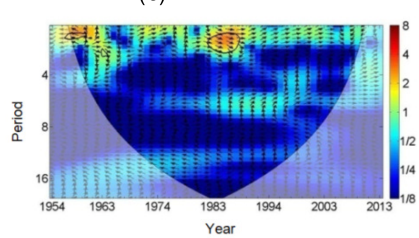
(a)



(b)



(c)



(d)

Fig. 4 (a-d) Cross wavelet transform of the U.P (a) JF rainfall-SSN (b) JJAS-Rainfall and JJAS QBO (c) annual rainfall and annual QBO (d) OND Rainfall and OND QBO time series (1954-2013). The 5% significance level against red noise is shown as a thick contour. The relative phase relationship is shown as arrows (with in-phase pointing right, anti-phase pointing left).

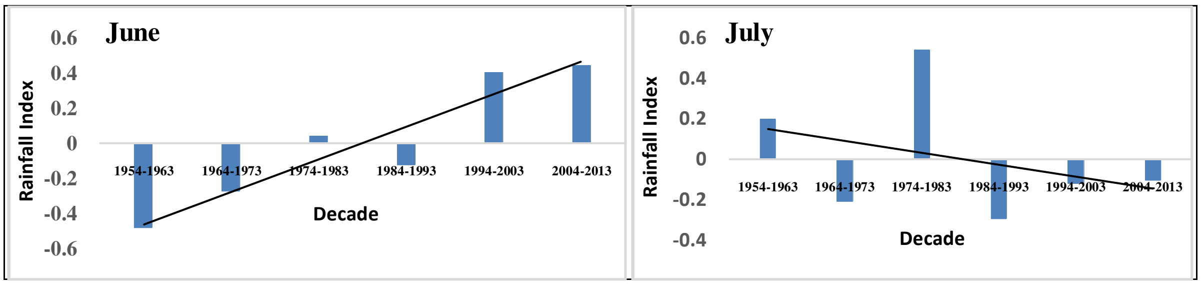
Rainfall is clearly seen to increases with increase in QBO. The effect of temperature and the inter-relationship with rainfall variability was also examined. Wavelet analysis was used to investigate sunspot number, MGII, and solar irradiance data from 1954-1994.The solar irradiance, sunspot numbers and MGII series are seen to be in same phase with respect to temporal variation [6]. A 8-16 years periodicity shown in cross wavelet plot, indicates in-phase relationship between MGII, SSN and solar irradiance in the period of 1979-2013. Maximum power of spectrum was observed in year 1954-2004.These parameters (MGII, SSN and solar irradiance) are closely related to each other. Rainfall may increase with decrease in SSN and other atmospheric parameters such as solar irradiance and MGII.

Cosmic rays may be directly related to rainfall because nucleation of water molecule in the atmosphere is brought about by the cosmic rays [14].

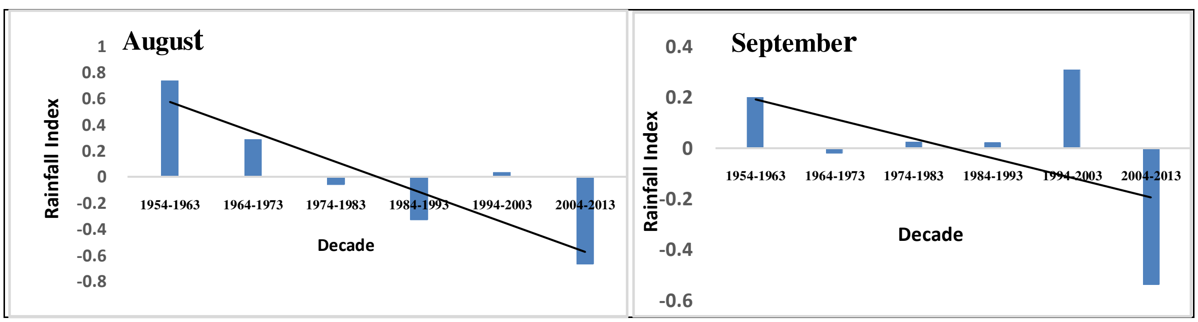
D. Result of Standardized anomalies of Rainfall for Monsoon Season

In month of June for decade VI (2004-1013), rainfall anomaly is maximum as seen in Fig. 5.

The anomaly in year 2008(+2.90), 2013(+2.69) has been shown in Fig. 6. In month of July for decade VI (2004-2013), rainfall anomaly (-0.1047) is minimum. Rainfall decreases in the month of August and September for decade VI(2004-2013). In month of August, maximum anomaly was recorded in year 1961(+2.51), 1967(+2.72). In month of September, in 2003, maximum anomaly is +3.06 as shown in Fig. 6.

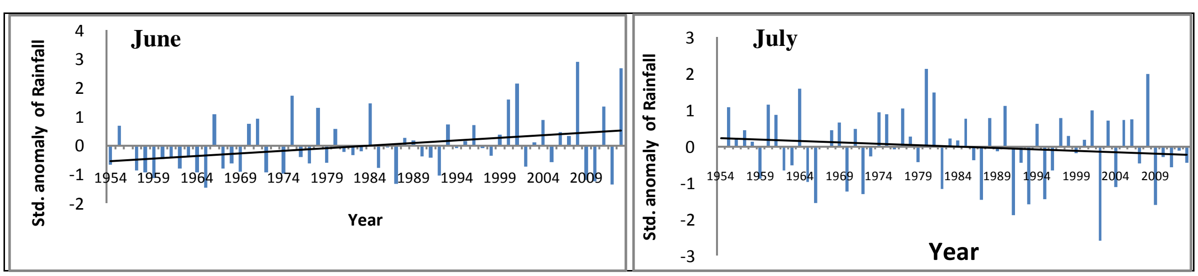


(a) (b)

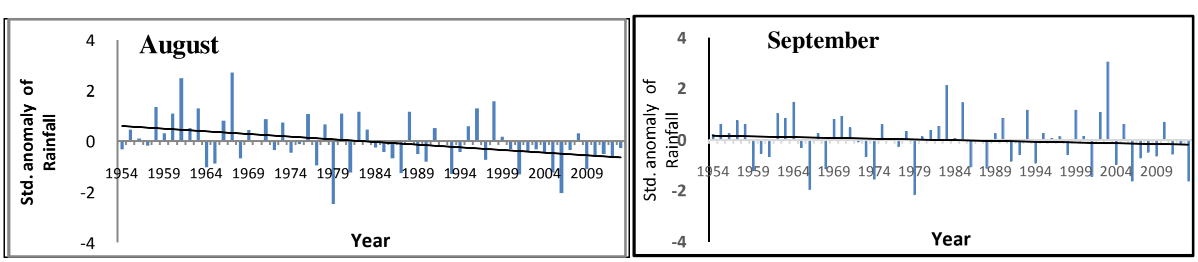


(c) (d)

Fig. 5. Decadal Standardized anomalies of Rainfall U.P.



(a) (b)



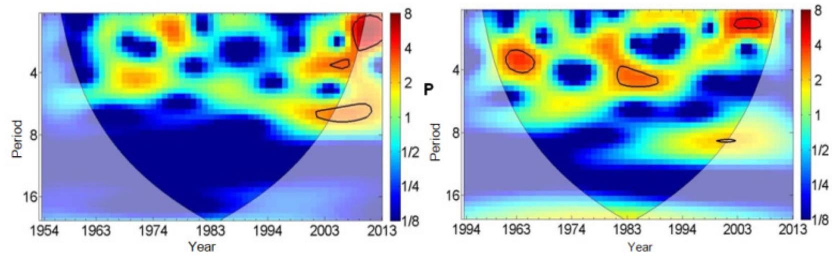
(a) (b)

Fig. 6. Standardized anomalies of Annual Rainfall U.P.

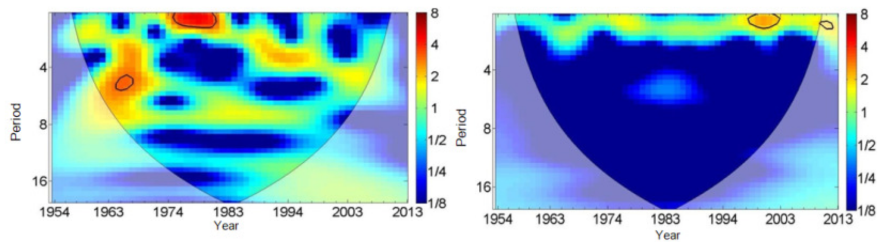
E. Spectral Analysis of Monsoonal Rainfall

In the month of June, periodicity of 2.5-5 years was observed in year 2008-2013, as shown in Fig. 7 (a). As discussed above, such periodicity in the power spectrum of rainfall variability is due to the well-known QBO phenomenon. Disturbances due to cyclone Narg is formed in 2008, in Bay of Bengal during April to December, with maximum wind speed 165 km/h(105mph)and lowest pressure is 92 hPa(mbar) cannot be overlooked as another possible reason for extremity in rainfall. High power band may be clearly seen in year 2013, in the monsoon period. The strong southwest monsoon current was developed due to the presence of low pressure system, which formed over northwest BOB on 12th June, 2013 [11].

The system moved in the northwest direction and reached up to northeast Rajasthan. For this reason, monsoon rainfall (2827mm) in U.P. increased in the month of June. The cross wavelet transformation plot for June rainfall and QBO both are in-phase indicating increase in intensity for decade VI (2008-2013) as shown in Fig. 7a. The periodicity of 2.5 years in month of July, August and September can be seen in Figs. 7 (b, c, d). For all these months, QBO and rainfall in cross wavelet plot show in-phase relation as shown in Figs. 8 (b, c, d).

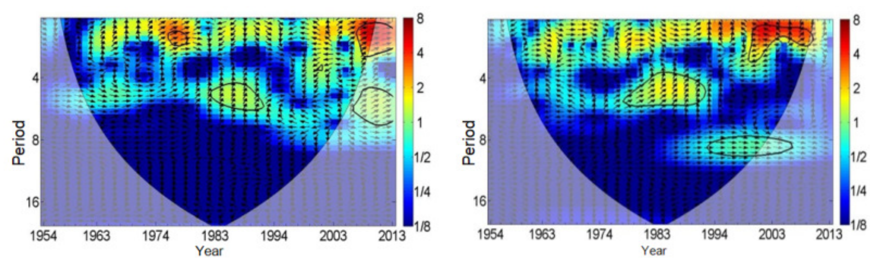


(a) June (b) July

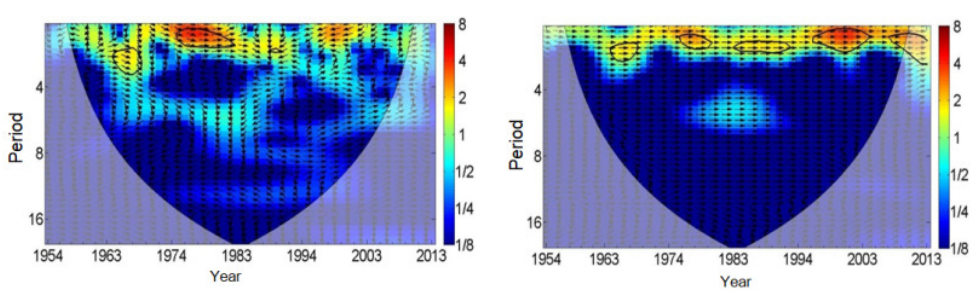


(c) August (d) September

Fig. 7. Continuous wavelet transform of U.P. Rainfall time series (1954-2013).The 5% significance level against red noise is shown as a thick contour.



(a) (b)



(c) (d)

Fig 8. Cross wavelet transform of the U.P QBO and (a) June (b) July rain (c) August (d) September. Rainfall time series (1954-2013). The 5% significance level against red noise is shown as a thick contour. The relative phase relationship is shown as arrows (with in-phase pointing right, anti-phase pointing left).

F. Relationship between TC parameters and SSTs

In case of rainfall extremity, the local disturbances were tried to be identified in this study. Fig. 9 shows number of tropical cyclone (NTC) and number of intense cyclone (NIC) in the period of 1990-2015 over entire Bay of Bengal (BOB). The cyclones over this region affect U.P region, as the path followed by cyclone is from BOB via state of Orissa to U.P. The data showed that the intense cyclones (ICs) and over 75% of tropical cyclones (TCs) are found during pre-monsoon (AMJ) and post-monsoon (OND) season as shown in Fig. 9.

Here, it was identified that for month of January-February(JF); April-May- June (AMJ) and October-November-December (OND),there is effect of El-Nino and La-Nina during 1990-2015.In year 1996, La-Nina effect is seen in winter season (JF) as shown in Fig. 10.

Recently discussed the relationship between TC parameters and local SSTs [13].

In Pre-monsoon (AMJ) and Post-monsoon (OND) season, Positive correlation was seen with Nino 3.4. The correlation coefficient between climatic oscillation and cyclonic parameters over the entire Bay of Bengal (1990-2015) has been shown in Table 2.

In pre-monsoon (AMJ) season, Nino 3.4 is more significant with NTC as compared to post-monsoon (OND) season. However, Nino3.4 is more significant with NIC in OND season compared to that in pre-monsoon (AMJ) season.

G. Analysis of Active and break days

The standardized rainfall anomaly time series for the year 2008 and 2013 (an extreme monsoon year) is shown in Fig. 11. For the year 2008 and 2013, the active and break periods have been identified.

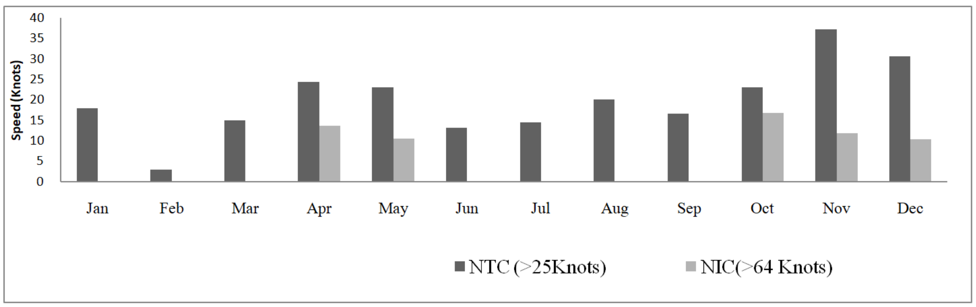


Fig. 9. The annual occurrence of NTCs and NICs over the entire Bay of Bengal (BOB) during the period 1990–2015.

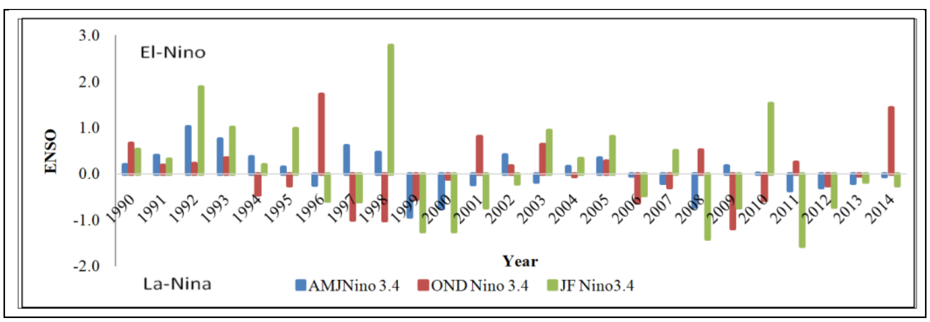
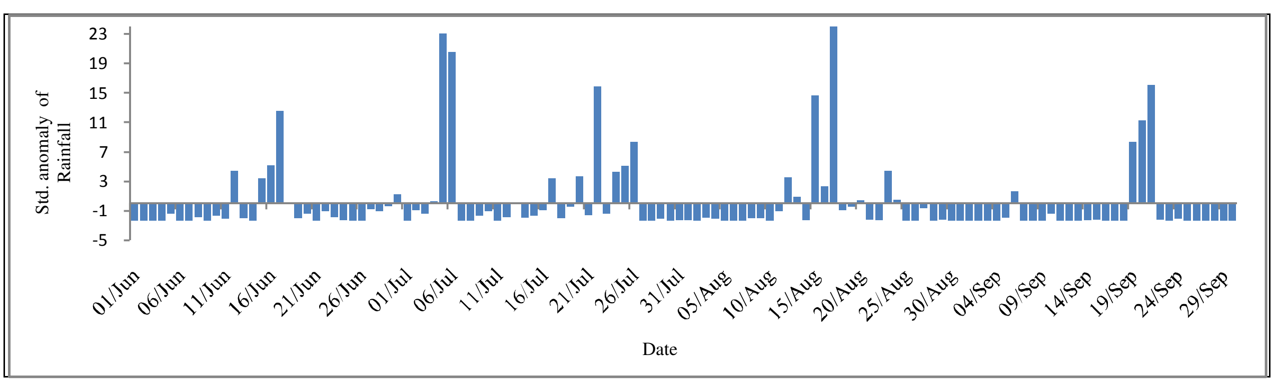


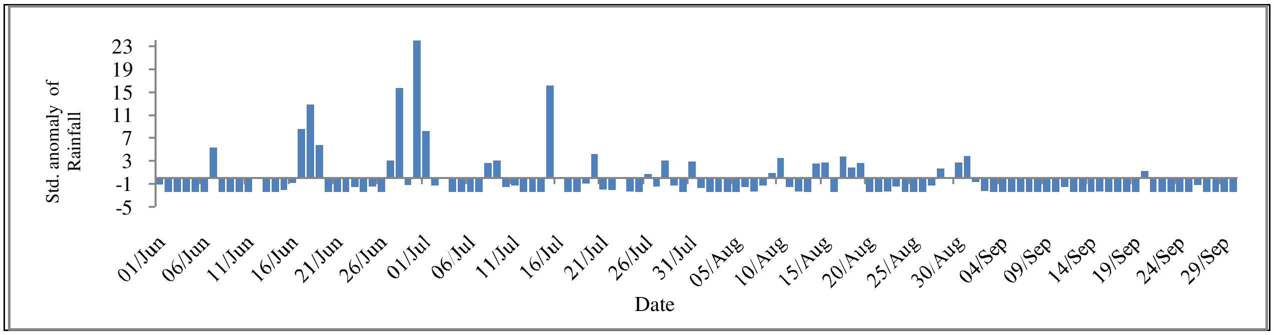
Fig. 10. ENSO time series (1990-2014), El-Nino(-), La-Nina(+).

Table 2: Correlation coefficient between climatic oscillation and TC parameters over the entire Bay of Bengal (1990-2015)

Month(AMJ)	NTC	NIC	ACE
Nino 3.4	0.5912	0.84485	0.587004
Month(OND)	NTC	NIC	ACE
Nino 3.4	0.8366	0.82445	0.453585



(a) 1 June to 30 September (2008).



(b) 1 June to 30 September (2013)

Fig. 11. Standardized rainfall anomaly time series for U.P.

The active and break day calculation during the period 1954–2013 has been shown in Table 3. Analysis for the period of 1954 to 1986, showed continuous active and break days. However, after 1986, continuous active days were found to be missing and only the findings on break days have been reported here. From two decades i.e. 1994-2003 and 2004-2013, active days were found to decrease.

Table 3: Active and Break days identified in the present analysis (1954–2013) Active and Break days – July and August (U.P).

Year	Break days	No. of days	Active days	No. of days
1954	4-11J,28-31J,4-8A,21-31A	28	15-17J,19-21J,13-16A	10
1955	13-16J,24-30J,19-23A,27-31A	21	1-4J,6-8J,17-19J,6-11A	16
1956	5-11J,13-20J,3-8A,15-17A,23-28A,29-31A	33	12-14A	**3**
1957	1-8J,14-17J,20-27A	20	17-19A	**3**
1958	1-3J,8-15J,27-30J,13-16A,26-29A	23	24-26J,1-3A,9-12A	10
1959	1-4J,14-17J,22-26J,28-1A,6-9A,21-25A,27-31A	**32**	14-17A	4
1960	1-3J,20-1A,9-11A,28-30A	22	4-12J,17-19J,6-8A	15
1961	1-7J,14-16J,18-20J,21-25J	18	8-11J,29-31J	7
1962	1-7J,10-15J,8-15A	21	18-20J,27-31J	8
1963	2-11J,23-28J,30-1A,17-20A,26-29A	27	12-16J,21-23A	8
1964	1-5J,17-19J,21-23J,2-5A,7-11A,13-26A	34	10-14J	5
1965	3-7J,9-17J,21-23J,2-25A,	**41**	26-28A	**3**
1966	2-4J,6-17J,26-30J,16-18A,24-31A	**31**	8-14A	7
1967	1-3J,10-17J,20-22J,14-16A,18-20A	20	21-25A	5
1968	1-4J,24-26J,4-9A,24-31A	21	27-30J,20-23A	8
1969	1-7J,20-23J,26-28J,1-11A,26-29A	29	17-19J	**3**
1970	8-10J,14-21J,24-30J,18-24A	25	1-3A	**3**
1971	16-18J,25-27J,29-31J,22-30A	18	2-4J,4-6A,14-16A	9
1972	1-4J,13J-5A,16-22A,29-31A	**38**	7-9A,25-28A	7
1973	4-20J,9-11A,20-25A,27-29A	29	29-31J	3
1974	7-9J,28-1A,10-13A,18-22A,26-30A	22	14-18J,5-8A	9
1975	5-7J,10-12J,16-18J,25-31J,9-15A,29-31A	26	19-24J,3-5A,23-25A	12
1976	2-6J,10-12J,20-27J,2-4A,20-22A	22	13-17J,11-15A	10
1977	1-7J,1-4A,9-11A,13-19A	21	14-17J	4
1978	10-12J,23-27J,24-31A	16	17-20J,28-31J,2-4A	11
1979	2-4J,7-11J,17-19J,4-7A,9-16A,18-31A	**37**	12-16J	5
1980	18-20A	3	7-10J,14-19J,7-15A,23-27A	24
1981	3-6J,8-13J,29-31J,5-7A,9-17A,25-31A	**32**	17-19J	**3**
1982	1-13J,15-19J,14-18A	23	23-28J	6

1983	4-16J,20-22J,6-11A,15-22A	**30**	25-27J,23-26A	7
1984	1-5J,11-15J,17-20J,27-30J,4-7A,12-16A,19-23A	**32**	8-10J,25-29A	8
1985	1-5J,7-9J,30-1A,11-13A,22-29A	22	13-16J,20-22J	7
1986	2-6J,13-17J,23-26J,29-2A,6-11A,13-17A,25-31A	**37**	8-11J	4
1987	1-7J,9-11J,16-25J,29-11A,14-23A	**44**	-	-
1988	1-3J,22-24J,6-9A,15-18A,20-22A,25-31A	24	13-15J,1-5A,10-12A	11
1989	3-6J,8-12J,18-29J,1-5A,7-9A,11-16A,18-26A,29-31A	**47**	-	
1990	6-9J,14-20J,8-10A,15-21A,23-27A,29-31A	29	27-4A,11-14A	13
1991	1-11J,14-18J,20-1A,7-9A,11-15A,28-31A	**41**	4-6A,20-23A,25-27A	10
1992	4-10J,28-31J,3-6A,11-20A,22-25A,28-31A	**33**	25-27J	**3**
1993	1-6J,10-16J,18-26J,28-5A,8-19A,21-31A	**54**	7-9J	**3**
1994	4-6J,16-18J,20-23J,20-22A,26-29A	17	30-1A,16-18A	6
1995	1-3J,5-11J,25-27J,30-1A,17-21A	21	5-7A	**3**
1996	1-7J,9-17J,25-2A,6-8A,24-29A	**34**	-	-
1997	1-7J,19-21J,24-29J,31J-31A	**48**	-	-
1998	1J-31A	**62**	-	-
1999	1-11J,13-19J,24-26J,1-4A,8-11A,14-18A,25-28A	**38**	20-24A	5
2000	4-11J,14-19J,21-25J,28-14A,19-29A	**48**	-	-
2001	1-6J,8-11J,19-22J,24-28J,31-3A,10-16A,24-31A	**38**	-	-
2002	1-4J,6-30J,3-10A,16-18A,26-31A	**46**	-	-
2003	1-3J,5-8J,16-19J,7-9A,16-18A,21-31A	28	10-12J,2-4A	6
2004	1-3J,10-13J,15-17J,19-21J,24-28J,30-13A,15-18A,28-31A	**41**	-	-
2005	7-11J,31-5A,7-17A,24-31A	**30**	2-4J,12-15J,18-23A	13
2006	1J-22A,27-29A	**56**	-	-
2007	1-3J,10-13J,19-22J,29-31J,4-12A,16-19A,23-26A	**31**	25-28J	4
2008	7-12J,27-11A,28-31A	26	24-26J,15-17A	6
2009	1-3J,10-12J,15-18J,20-22J,29-31J,2-11A,20-23A,25-31A	**37**	15-17A	**3**
2010	1-5J,8-10J,29-1A,6-11A,13-18A,27-31A	29	24-26A	**3**
2011	7-9J,13-16J,24-27J,20-31A	23	14-16A	**3**
2012	1-4J,8-12A,15-18A	13	6-10J,24-26J	8
2013	4-7J,10-14J,1-8A,11-13A,20-27A	28	17-19A	**3**

For the year 2008, the active and break period has been shown in Fig. 11 (a). For the period of 1951-1989 and 1951-2003 have calculated active and break days for Indian summer monsoon [7, 15, 16]. In the present study, we have used the standardized rainfall anomaly averaged over U.P region of India. In the analysis of active and break period for individual seasons, the winter season (January- February) in year 1996 showed major anomaly. For this reason, active and break period for year1996 has been shown in Fig. 12.

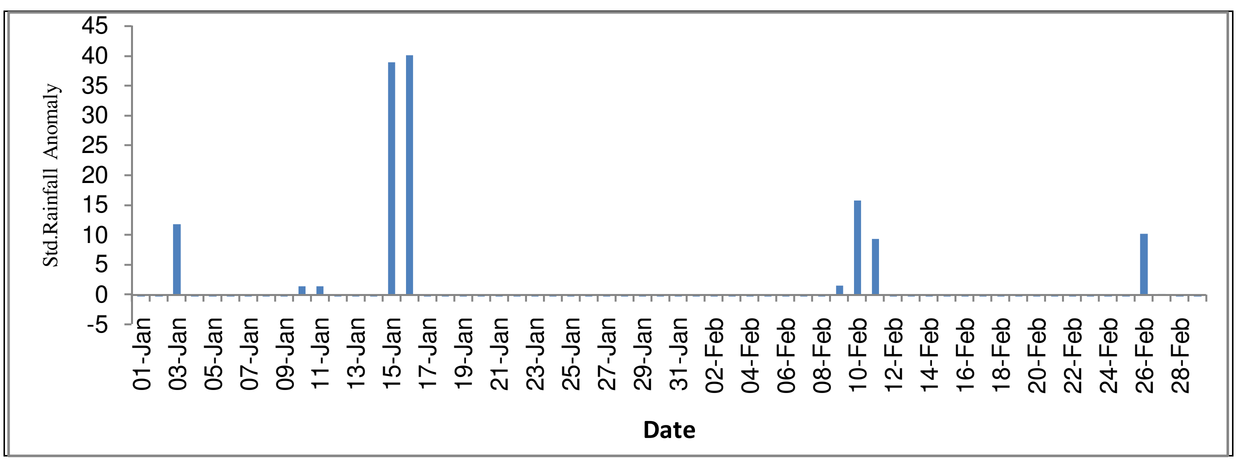


Fig. 12. Standardized rainfall anomaly time series for U.P. 1996 during the period 1 January to 29 February.

In the month of February, active days were found on 9-11 day in year 1996. Using the standardized daily rainfall anomaly averaged over U.P., the number of break and active days during the period June–September was calculated for each year for the period 1954–2013. The time series of the number of active and break days for the period 1954–2013 as obtained in the present analysis has been shown in Fig. 13. Decreasing trend show in active days and increasing trend show in break days can be seen in Fig. 13.

Break days as days with large positive outgoing long wave radiation (OLR) anomalies for at least four consecutive days or more over a wide region covering the north west and central India [12]. They showed that seasonal rainfall is determined mainly by two persisting large-scale standing patterns, without much contribution from the oscillatory modes. When the OLR positive anomaly (1.5-18 W/M^2) increases, the rainfall decreases (Break days) in 2009 and when Outgoing OLR negative anomaly (-2.5 to -2.5W/M^2) increases, increase in rainfall (Active days) in 2008 may be in Fig. 14.

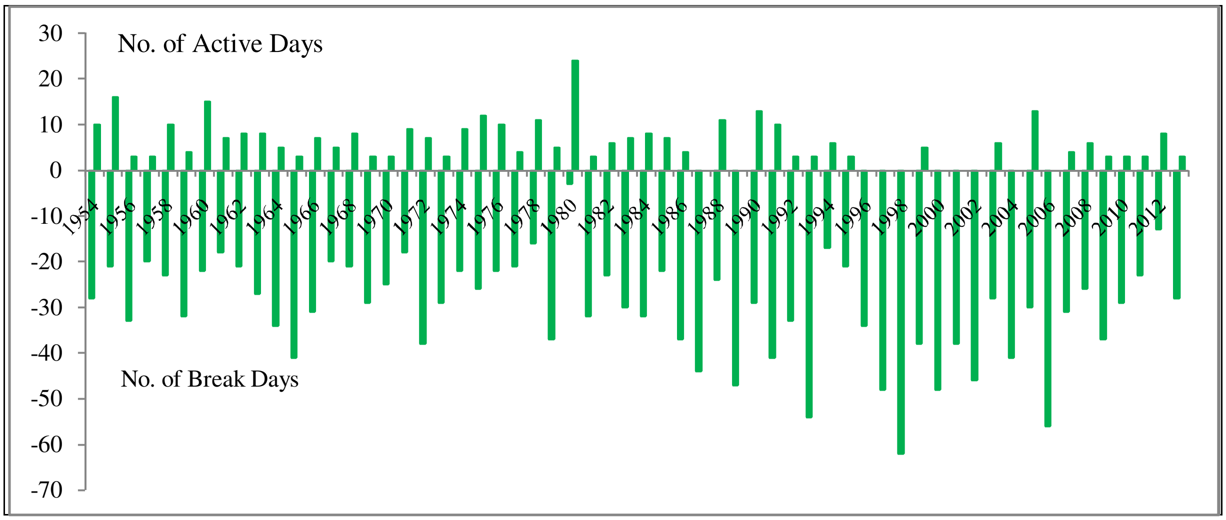
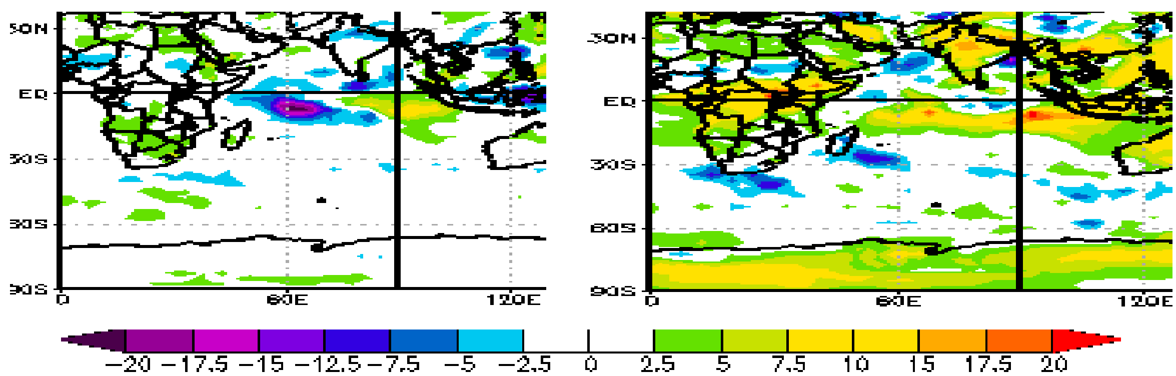


Fig. 13. Time series of Active and Break days of U.P. during the July-August (1954–2013).



(a) 2008 (Active Days)

(b) 2009 (Break Days)

Fig. 14. OLR (W/m^2) anomaly pattern for July – August.

IV. CONCLUSION

It is clear from the results of the analysis that the trend in rainfall time series is decreasing in the recent decade on annual and seasonal (summer and pre-monsoon) scale. The sub-period analysis (Cramer's test) revealed a recent decrease in the annual (-1.22) and monsoonal (-1.03) rainfall series for the sub-period 2004-2013.

Extreme rainfall anomaly in year 2008(2965mm), 2013(2827mm) was observed in month of June(+2.90, +2.69). Overall shift of rainfall in the study period towards a decrease from 1984 onwards may be clearly noted. In the monsoon season, cyclic pattern (firstly increase then decrease) can be seen on decadal scale. Extreme rainfall in winter season and post monsoon season may be attributed to La-Nina effect. The periodicity of rainfall was identified as 2-5 years in monsoon (JJAS) for year 2008 and 2013.In winter season (JF), periodicity of rainfall was observed as 9-11 years. Hence, it can be said that QBO and SSN may be the dominant influencing parameters involved in individual cases. In the study, it was noticed that rainfall and SSN are in anti-phase for winter (JF), 1996. The parameters i.e. solar irradiance, MGII and SSN indices are all in phases indicating possible linkage of these parameters. It was also noticed that the maximum number of active and break days of monsoon rainfall was seen in years2008 and 2009, respectively. The negative OLR anomaly in 2008 may be responsible for excessive rainfall in U.P region and vice-versa.

V. FUTURE SCOPE

The trend analysis of rainfall and other climatic variables on different spatial scales will help in the construction of future climate scenarios. Since rice crop is the important kharif crop (May– October) in this region, the decreasing trend of rainfall during the month of July may delay/affect the transplanting/vegetative phase of the crop, and assured irrigation is very much needed to tackle the drought situation. The decrease of rainfall during December may hamper sowing of wheat, which is the important rabi crop (November–March) in most parts of this region.

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Conflict of Interest. Future improvements in the seasonal forecast of Uttar Pradesh may depend on the climatic variability, which are addressed in this study. It will be helpful for assessing the model performance relating multi-decadal variability of climate change indicator parameters under several climate scenarios.

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