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Monsoon variability in recent years from synoptic scale disturbances and semi-permanent systems

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सार — भारतीय ग्रीष्मकालीन मानसून में पिछले दशक की तुलना में 1987 से 1996 के हाल के दशक में कम अंतःवार्षिक परिवर्तिता का पता चला है। 1987 और 1988 के अलावा भारत में, अन्य सभी वर्षों में क्षेत्र भारित औसत मानसून वर्षा, उसकी दीर्घावधि औसत वर्षा की 10 प्रतिशत (सामान्य) घटबढ़ का बीच ही रही है। इस शोध पत्र में,1987-96 के दौरान अन्तः वार्षिक पैमाने पर मानसून वर्षा और उनकी परिवर्तिता के साथ अनेक अन्य संबद्ध परिसंचरण अभिलक्षणों पर चर्चा की गई। इन परिणामों से यह पता चलता है कि यद्यपि इस दशक के दौरान मानसून वर्षा की परिवर्तिता कम है तथापि सिनॉप्टिक सिस्टम की संख्या, उनके दिनों, तीव्रता तथा मानसून द्रोणी और तिब्बती प्रतिचक्रवात के दिनों की संख्या में महत्वपूर्ण अन्तः वार्षिक परिवर्तिता है।

जिन वर्षों में ऋतु की वर्षा सामान्य के सकारात्मक की ओर रही (नकारात्मक की ओर) उन्हें सिनॉप्टिक विक्षोभों के अधिक (कम) दिनों की संख्या और उनकी अनुकूल स्थितियों में मानसून द्रोणी और तिब्बती प्रतिचक्रवात की उपस्थिति के अधिक (कम) दिनों की संख्या से अभिलक्षित किया गया है। तथापि ऋतु की मानसून वर्षा का, न्यून उष्मा की समूची सक्रियता, ऋतु में उष्णकटिबंधीय पूर्वाभिमुखी जेट और उप उष्णकटिबंधीय पश्चिमोन्मुखी जेट के साथ कोई प्रत्यक्ष संबंध नहीं है। साथ ही, भारत में मानसून के आगमन और प्रस्थान की तारीख और समूचे भारत में मानसून के छा जाने के दिनों की संख्या का भी मानसून वर्षा के साथ कोई संबंध नहीं है।

ABSTRACT. In the recent decade from 1987 to 1996, the Indian summer monsoon rainfall has shown less interannual variability in comparison with its earlier decade. Except 1987 and 1988, the area weighted average monsoon rainfall of all other years are within ± 10% (normal) of its long period average value over India. The paper discusses monsoon rainfall and several other associated circulations features with their variability in interannual scale during 1987-96. The results show that though the variability of monsoon rainfall is less during the decade, there is a significant interannual variation in the number of synoptic systems, their days, intensities and number of days of presence of monsoon trough and Tibetan anticyclone.

The years with positive side (negative side) of normal seasonal rainfall are characterised by more (less) number of days of synoptic disturbances and more (less) number of days of presence of monsoon trough and Tibetan anticyclone in their favourable positions. However, overall activity of heat low, tropical easterly jet and sub-tropical westerly jet in the season have no direct relation with seasonal monsoon rainfall. In addition, the dates of onset and withdrawal of monsoon over India and the number of days monsoon took to over all India also have no relation with the monsoon rainfall.

Key words — Monsoon variability, Synoptic system days, Semi- permanent systems, Monsoon trough, Heat low, Tibetan anticyclone, Tropical easterly jet.

1. Introduction

Area weighted average monsoon rainfall over India (henceforth referred as all India monsoon rainfall) is defined as normal when it is within ±10% of its long period average value. During the recent decade of 1987-96, all India monsoon rainfall was on the positive side of normal in 1988 (119%), 1989 (101%), 1990 (106%), 1993 (101%), 1994 (110%), 1995 (100%) and 1996 (102%) and was on the negative side of the normal in 1987 (81%), 1991 (92.6%) and 1992 (93%) as given in Table 1 and hence all India monsoon rainfall was normal for 8 years from 1989 to 1996. However, during the earlier decade of 1977-86, all India monsoon rainfall was normal only for 6 years [1977 (104%), 1978 (109%), 1980 (104%), 1981 (100%), 1984 (96%), 1985 (93%)], above normal for one year [1983 (113%)] and below normal for 3 years [1979 (81%), 1982 (85%), 1986 (87%)]. Thus the all India monsoon rainfall during the recent decade show less interannual variation in comparison with its earlier decade.

TABLE 1

Number of sub-divisions which received excess, normal, deficient and scanty rainfall

Month	Rainfall	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
June	E	5	12	11	9	12	4	˙8	16	2	16
	N	10	12	22	16	15	10	17	8	16	10
	D	15	8	2	9	6	18	10	11	15	7
	Sc	5	3	0	1	2	3	0	0	2	2
July	E	4	16	11	11	5	3	10	17	9	6
	N	5	15	11	12	19	13	18	11	21	14
	D	14	4	12	11	8	18	7	7	4	15
	Sc	12	0	1	1	3	1	0	0	1	0
August	E	15	13	4	13	3	12	3	11	11	14
	N	7	18	18	13	22	17	15	20	16	17
	D	11	4	12	9	9	6	11	4	8	3
	Sc	2	-	1	0	1	0	6	0	0	1
September	E	9	20	9	12	6	9	14	5	10	10
	N	3	9	12	15	7	10	16	10	16	15
	D	11	5	10	8	12	15	4	13	9	8
	Sc	2	1	4	0	10	1	1	7	0	2
June to September	E	4	18	5	7	1	2	2	12	7	10
	N	12	17	24	25	26	30	29	23	26	22
	D	15	0	6	3	8	3	4	10	2	3
	Sc	4	0	0	0	0	0	0	0	0	0
Area Weighted Average		81%	119%	101%	106%	92.6%	93%	101%	110%	100%	102%

TABLE 2

Onset, withdrawal and number of days southwest monsoon took to cover whole country during recent decade

Description	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
(1) Onset over										
(a) Kerala	2 Jun	26 May	3 Jun	19 May	2 Jun	5 Jun	28 May	28 May	8 Jun	3 Jun
(b) Entire Country	27 Jul	1 Jul	2 Jul	1 Jul	19 Jul	14 Jul	5 Jul	30 Jun	19 Jul	30 Jun
(2) Number of days to cover the entire country	56	37	30	43	47	39	39	34	42	28
(3) Withdrawal from extreme northwest India	12 Sep.	12 Sep.	14 Sep	27 Sep	18 Sep	17 Sep	21 Sep	19 Sep	11 Sep	15 Sep

The above variation of monsoon rainfall on interannual scale may be associated with the variation in seasonal circulations features on planetary as well as regional scales. Planetary scale circulations and its variations year by year are not studied here, but only variations of regional scale circulations features are studied for the recent decade to explain the interannual variability of all India monsoon rainfall. Such regional scale circulations features are semi-permanent systems (heat low, monsoon trough, tropical easterly jet, sub-tropical westerly jet, Tibetan anticyclone) and synoptic scale disturbances over the region of India and neighbourhood. Semi- permanent systems, which are called as components of southwest monsoon, and are seasonal in character, get established in the monsoon season. They are responsible to a great extent for monsoon rainfall. In addition, synoptic scale disturbances, which form during the monsoon season, are responsible for the monsoon rainfall distribution. Thus, variability of these two factors are studied along with their variation in intensity over space and time to identify those factors which significantly contribute for the variation of all India monsoon rainfall year by year for 1987-96. In addition, date of onset and withdrawal of monsoon and number of days of stay of monsoon over the country for 1987-96, are looked into.

2. Data

Weekly Weather Report, Indian Daily Weather Report published by Office of Deputy Director General of Meteorology (Weather Forecasting), India Meteorological Department, Pune, are consulted for the year 1987-96. Daily Weather Charts and Vertical Time Sections are also referred from the same office for this study. In addition, monsoon summary published in "Mausam" for 1987-96, are also consulted for this study. For comparison of onset with earlier years, "Onset dates over India 1960 to 1996" from Office of Deputy Director General of Meteorology (Weather Forecasting), India Meteorological Department, Pune, is referred to.

3. Method of analysis of data

Number of days of cyclonic storm and depression are counted from the days, when the synoptic system was a low pressure area. While counting the number of cyclonic circulation days, all the cyclonic circulations in the lower, middle and upper troposphere are considered. Number of days of synoptic systems is the addition of days of cyclonic storm, days of depression, days of low pressure area and the days of cyclonic circulation. If the synoptic system continues from one month to the next month then it is considered to belong to the month, when the system lies on more number of days.

When the axis of monsoon trough is seen from west Rajasthan to north Bay both in 0300 and 1200 UTC surface chart, at least for two days, then that day is taken as the establishment of monsoon trough. The "break" is defined, when monsoon trough on the surface chart, lies over the foot hills of Himalayas. When the heat low over Pakistan and west Rajasthan (low pressure area of one closed isobar) is seen in 0300 and 1200 UTC surface chart at least for two days, then that date is taken as the appearance of heat low. The central pressure or lowest pressure of the heat low is the value of lowest recorded pressure over the heat low or value of central closed isobar of heat low in the season.

The date (0000 and 1200 UTC) of establishment of anticyclone over the grid between Lat. 27° N to 35° N and Long. 80° E to 100° E over Tibetan region is taken, when it persists at least at two levels (500, 400, 300, 200 hPa) at least for two days. The date (0000 and 1200 UTC) when any one station of peninsular India [Mincoy (MNC), Thiruvananthapuram (TRV), Port Blair (PBL)], at any level (100, 150, 200 hPa) reports tropical easterly jet at least for two days, then it is taken as its appearance date. The dates, when any station over north India reports westerly jet (at any level of 300, 250, 200 hPa), then that date is considered as date of presence of sub-tropical westerly jet. Number of days of presence of semi-permanent systems is the difference between date of appearance and date of dissipation.

4. Results and discussion

4.1. *Recent monsoon variability*

Table 1 shows the sub-divisionwise distribution of monthly rainfall in the decade. Maximum number of sub-divisions received scanty and excess in June and July during 1987 and 1994 respectively. Maximum number of sub-divisions received scanty and excess rainfall in August during 1993 and 1987 respectively. During September, maximum number of sub-divisions received scanty and excess rainfall in 1991 and 1992 respectively. Though 1987 was a severe drought year, rainfall in August in the year was good in comparison with other years. Sub-divisionwise rainfall of the season shows that maximum number of sub-divisions received excess rainfall in 1988 and no sub-division received scanty rainfall after 1987. Area weighted average rainfall shows that 1988, 1990, 1993, 1994, 1995 and 1996 are on the positive side of normal. 1991 and 1992 are on negative side of normal rainfall and 1987 received lowest rainfall. The percentage of districts with excess, normal, deficient and scanty rainfall are shown in Fig. 1. Further discussion on monsoon variability will be with respect to area weighted average rainfall over India.

TABLE 3

Synoptic systems, days of the decade

	1987		1988		1989		1990		1991		1992		1993		1994		1995		1996	
	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days	Nos.	Days
1. Storms																				
Jun	1	4	-	-	-	-	-	-	-	-	1	4	-	-	1	4	-	-	2	7
Jul	-	-	-	-	1	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Aug	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sep	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	1	4	-	-	1	5	-	-	-	-	1	4	-	-	1	4	-	-	2	7
2. Depressions																				
Jun	-	-	2	15	3	12	1	10	1	2	1	3	1	2	-	-	-	-	-	-
Jul	-	-	1	4	-	-	-	-	1	6	1	6	-	-	-	-	-	4	1	4
Aug	1	6	1	10	1	5	2	10	1	6	-	-	-	-	-	-	-	-	-	-
Sep	2	8	-	-	-	-	1	7	1	4	-	-	-	-	1	5	2	12	-	-
Total	3	14	4	29	4	17	4	27	4	16	2	9	1	2	1	5	2	12	1	4
Total (1+2)	4	18	4	29	5	22	4	27	4	16	3	13	1	2	2	9	2	12	3	11
3. Low pressure areas																				
Jun	2	5	2	8	1	3	1	9	1	7	-	-	2	7	3	17	2	4	2	11
Jul	2	10	3	7	3	14	3	9	2	11	2	2	4	15	5	25	2	7	4	14
Aug	3	18	2	8	4	25	3	12	4	24	5	21	4	17	4	17	5	17	5	15
Sep	2	6	6	28	3	19	2	13	3	5	4	21	4	23	3	25	2	3	4	18
Total	9	39	13	51	11	61	10	43	10	47	11	44	14	72	15	84	11	31	15	58
Total (1+2+3)	13	57	17	80	16	83	14	70	14	63	14	57	15	74	17	93	13	43	18	69
4. Cyclonic circulations																				
Jun	15	57	3	13	3	13	4	10	5	13	11	17	11	44	4	14	10	31	7	22
Jul	15	54	9	27	6	17	7	22	7	22	10	30	7	25	6	17	9	35	8	22
Aug	14	40	7	25	3	8	5	13	6	20	9	21	10	44	3	12	12	49	10	21
Sep	12	32	6	12	7	2	6	17	4	15	8	10	8	23	6	19	9	27	12	40
Total	56	183	25	77	19	40	22	62	22	70	38	78	36	136	19	62	40	142	37	105
5. Western disturbances																				
Jun	5	11	2	7	5	16	4	10	3	7	1	2	1	2	3	7	-	-	-	-
Jul	7	9	5	10	1	5	2	4	2	4	-	-	5	7	-	-	-	-	-	-
Aug	6	14	2	4	4	13	-	-	-	-	-	-	3	9	-	-	-	-	-	-
Sep	4	6	3	8	2	5	-	-	4	13	-	-	-	-	1	2	1	4	2	4
Total	22	40	12	27	12	39	6	14	9	24	1	2	9	18	4	9	1	4	2	4

4.2. *Onset and withdrawal of monsoon and number of days monsoon took to cover entire country*

Table 2 shows the details of onset and withdrawal of monsoon and number of days monsoon took to cover the entire country. The earliest onset date over Kerala in the decade is 9 May 1990 and late onset is on 8 June 1995. The early withdrawal from extreme northwest India is on 11 September 1995 and late withdrawal is on 27 September 1990. The least number of days taken by monsoon, to cover entire country is 28 days in 1996 and it is due to a severe cyclonic storm over Bay and another over Arabian Sea during June 12 to 20, crossing coast near Visakhapatnam and Veraval respectively. The normal period for the monsoon to cover the entire India is 45 days. In 1995 and 1996, monsoon onset over northeast India was earlier than the onset over Kerala. Study of onset dates over India during 1960-96, shows that only during 1972, the monsoon onset over northeast India was earlier than Kerala, similar to onset of 1995 and 1996. Though onset was late in 1995, but it was on the positive side of normal rainfall. In 1987, onset was earlier than in 1995, but it received the lowest rainfall during the decade. Thus the onset over Kerala has no relation to seasonal all India monsoon rainfall, which agrees with the result of Dhar *et al.* (1980) and Chowdhary *et al.* (1990). The southwest monsoon withdrew from extreme northwest India during contrasting years of 1987 and 1988 on 12 September. The number of days monsoon took to cover the entire country was 39 days during 1992 and 1993. So, the date of withdrawal of monsoon from extreme northwest India and the number of days monsoon takes to cover the entire country, have no relation with all India monsoon rainfall.

4.3. *Variability of synoptic systems and their days*

Among the synoptic scale disturbances, only the depressions have been studied extensively by Pisharoty and Asnani (1957), Rao and Jayraman (1958), Raghavan (1965), Bhalme (1972). Mooley (1973), India Meteorological Department (1979), Bhalme and Mooley (1980), Kriplani and Singh (1986). The number of low pressure areas and cyclonic circulations and their days have not been studied in relation to all India monsoon rainfall by them. Sikka (1980) first examined depressions and low pressure areas over India, in July and August for 5 good and 5 bad monsoon years and found no differences between good and bad monsoon years, in respect of number of depressions and depression days. There is a significant difference in the number of low pressure areas and their days. Mooley and Shukla (1989a) studied 96 years data (1888-1983) of number of storms, depressions and low pressure areas and their days in monsoon and found a good positive correlation with all

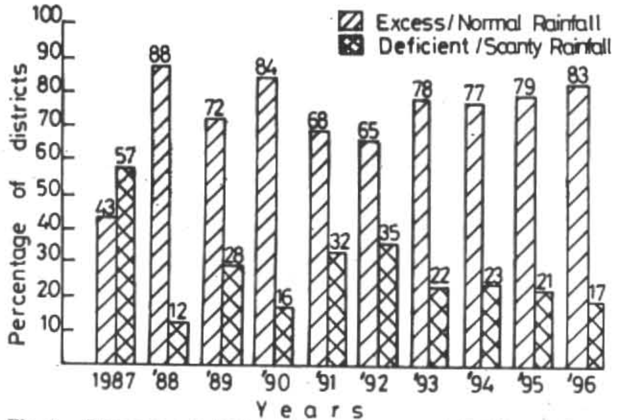

Fig. 1. Percentage of districts with excess, normal, deficient and scanty rainfall during decade

India monsoon rainfall. They did not consider number of cyclonic circulations or number of cyclonic circulation days. Here synoptic systems include storms, depressions, low pressure areas, cyclonic circulations (present in lower and mid-tropospheric levels and cyclonic circulations extending upto mid-tropospheric levels from lower tropospheric levels), western disturbances and induced cyclonic circulations. These synoptic systems, their number of days and their variability are studied.

4.3.1. *Variability of number of storms and depressions and their days*

Table 3 shows monthly distribution of storms of 1987-96. Except a storm in 1989, which was for 5 days, no storm formed during July and August.

The average number of depressions and storms during 1987-96 is 4 as against normal of 7 to 8 and hence showing a decreasing trend compared to the earlier decade. Again during 1992-96, the number of storms and depressions has decreased significantly with respect to normal of 7 to 8. Such numbers during 1992, 1993, 1994, 1995 and 1996 were 3,1,2,2 and 3 respectively.

The number of depressions and storms days is maximum during 1988 (29 days) and minimum during 1993 and 1994 (only 2 and 9 days respectively). Further, 1987 and 1988 have the same number of storms and depressions. So number of depressions and storms and their days have no relation to all India monsoon rainfall.

4.3.2. *Variability of number of storms, depressions and low pressure areas and their days*

We will first discuss variability of number of low pressure areas and their days responsible for monsoon rainfall. Then the variability of total number of synoptic systems and their days will be discussed by considering low pressure areas, depressions and storms together. This will help to know, how the different types of synoptic systems are responsible for explaining variability of all India monsoon rainfall individually and when all taken together.

From Table 3, we see that both the number of low pressure areas and low pressure area days, are maximum during 1993 and 1994 and gave good rainfall over India, even though there were less number of depressions and storms.

The number of low pressure areas and their days during 1990, is less than 1992 and 1993. However, rainfall during 1990 was higher than 1992 and 1993. Hence number of low pressure areas and their days have no relation with all India monsoon rainfall. Now we shall consider all the above systems together. From Table 3, we see that 1990 and 1991 (having rainfall 106% and 93% respectively) have same number of storms, depressions and low pressure areas. So number of storms, depressions and low pressure areas have no relation with all India monsoon rainfall. Mooley and Shukla (1989a) also found that all India monsoon rainfall has no relation with above number of synoptic systems. However, by adding number of depression days, storm days and low pressure area days, from Table 3, we see that, years having negative side of normal rainfall (1987, 1991, and 1992) are having less number of such days in comparison with other years except 1995. This also agrees with the result of Mooley and Shukla (1989a), that the total number of days of low pressure area, depression and storm have a good positive correlation with total seasonal monsoon rainfall. In 1995, there are 43 such days and 1987 has more number of such days than 1995. Why the rainfall of 1995 became normal, will be examined in section 4.3.3.?

4.3.3. *Variability of number of cyclonic circulations and their days*

All cyclonic circulations are considered except western disturbances and induced cyclonic circulations. Table 3, shows the total number of cyclonic circulations seen over India and their days of presence. From Table 3, 1995 had more number of days of cyclonic circulation over India than other years except 1987 and hence the cyclonic circulations were mainly responsible for a good rainfall distribution over India during 1995. For knowing details on cyclonic circulations days during 1987 and 1995, the number of cyclonic circulations forming over north and west-central Bay and adjoining coastal sub-divisions and Madhya Pradesh and moving northwestwards along monsoon trough, is separated from all other cyclonic circulations, given in Table 3 for 1987 and 1995. This separation is done to know, why 1995 received good rainfall than 1987, though 1987 has more number of synoptic system days than 1995. It is found that 1987 was having only 12 such days and 1995 was having 28 days. So, though the year 1987 have 183 cyclonic circulation days (highest in the decade), but number of days of cyclonic circulation which formed over Bay and moved along monsoon trough, is less during 1987 in comparison with 1995.

4.3.4. *Variability of number of western disturbances and their days*

When the southwest monsoon is fully established over India, middle latitude westerlies prevail to the north of 30° N only. Still with suitable conditions, they move across north India in the form of western disturbances or troughs in westerlies and induced cyclonic circulations in lower levels. Mooley (1957) has pointed out cases of enhancement of activity of monsoon over Punjab and west Uttar Pradesh with the passage of western disturbances across north India. On some occasions, in the absence of low pressure area and depression from the east, if there is a western disturbance moving across extreme north of the country and eastern Himalayas, the monsoon trough shifts to the foothills of Himalayas and "break" situation develops. This was concluded by Pisharoty and Desai (1956) and Chakravorty and Basu (1957). Sometimes westerly systems also favour heavy rainfall over northwest India without producing "break".

A shortcoming in the studies of the effect of middle latitude systems on Indian southwest monsoon has been that, only out of- the-way behaviour of the monsoon system is sought to be explained by tracking middle latitude systems. No detailed analysis of all systems in westerlies has been undertaken to find their varying interaction with monsoon. So, by considering the westerly systems activity for more years, we can see whether their number or number of days has any relation with all India monsoon rainfall.

Here the number of western disturbances includes all western disturbances and induced cyclonic circulations. From Table 3, it is observed that though 1987 had maximum number of western disturbances and their days during the decade, other years which are on negative side of normal rainfall (1991 and 1992) are having less number of western disturbances and their days, compared to positive side of normal rainfall years of 1988 and 1989. So number of western disturbances and their days have no relation with all India monsoon rainfall. Since more number of days of western disturbances activity are reported during some years of positive side of normal rainfall, so this also shows that western disturbance days or westerly systems are also sometimes contributed positively to monsoon activities if it interacts with monsoon positively rather than producing "break".

TABLE 4

Characteristics of semi-permanent systems of the decade

S . No.	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
1. Monsoon Trough	Established on 6 July. Less marked on 31 August. Break on 15, 16 and 31 July	Established on 16 June. Less marked during 1st week of September. Break on July 4 to 6, August 13 to 15 and 25 to 27	Established on 27 June. Less marked on .4 September. Break on July 4, 10 29 to 31	Established at end of June. Active till end of September. Break on 7 and 8 July	Established on middle of July. Less marked on 2 September. No break	Established on 10 July. Less marked during 1st week of September. No break	Established on 10 June. Less marked during 1st week of September. No break	Established in the end of June. Less marked on 15th September. Break on 7 July	Established on 20 June. Less marked on 6 September. Break on 4 and 5 July and 12 to 15 August	Established on 3 July. Less marked on 6 September. Break on 1 to 5 July and 8 August
2. Heat Low	Appeared on 1 June. Less marked on 28 September. Lowest pressure 989 hPa	Appeared on 1 June. Less marked on 17 September. Lowest pressure 988 hPa	Appeared on 4 June. Lowest pressure 990 hPa	Appeared on 1 June. Lowest pressure 992 hPa	Appeared on 1 June. Lowest pressure 996 hPa	Appeared on lst week of June. Lowest pressure 992 hPa. Less marked on 17 September	Appeared on 5 June. Lowest pressure 990 hPa	Appeared on 7 June. Lowest pressure 990 hPa	Appeared on 13 June. Lowest pressure 989 hPa. Less marked on 1 September	Appeared on 7 June. Lowest pressure 990 hPa
3. Tibetan anticyclone	Though established late on 7 July, but subsequently not seen many days	Established in normal position on 29 June. Less marked on 4 September	Appeared on 20 June. Less marked on 9 September. South of normal position	Appeared on mid-June. (Many times intense and south of normal position). Less marked on mid September	Appeared on mid-July.Less marked on 1st week on September	Appeared on 10 July. Less marked on 1st week of September	Appeared on last week of June. Less marked on 1st week of September	Appeared on 3rd week of June. Less marked on mid-September	Appeared on last week of June. Less marked on 2nd week of September	Appeared on 3rd week of June. Less marked on 2nd week of September
4.TEJ	Seen in mid June. Less marked on 22 September	Appeared on 6 June. Less marked during last week of September	Appeared on 4 June. Less marked on 28 September Maximum wind: 110 kt, MNC, at 115 hPa	Appeared on 21 May throughout the season	Appeared on 1st week of June. Throughout the season. Maximum wind GOA 145 kt, at 125 hPa on 2 August	Appeared on 3rd week of June. Throughout the season. Maximum wind TRV 85 kt at 120 hPa on 17 June	Appeared on 16 June. Less marked on 1st week of September. Maximum wind MNC, 140 kt, at 100 hPa on 22 July	Appeared on 1 June. Less marked in mid of September. Maximum wind MNC 115 kt, at 144 hPa on 22 July	Appeared on 8 June. Less Marked on 6 September. Maximum wind MNC 115 kt at 126 hPa on 27 June	Appeared on 11 June. Less marked on 27 September. Maximum wind Chennai 110 kt, at 109 hPa on 14 July
5. STWJ	Seen upto 15 July and during September	Seen upto end of 3rd June and again during last week of September	Seen upto 18 June and during last week of September	Not seen	Seen over north India upto 12 June	Not seen	Not seen	Seen up to 15 June	Not seen	Seen upto Ist week of June and 2nd fortnight of September

4.4. *Role of semi-permanent systems during the decade*

Heat Low, monsoon trough, Tibetan anticyclone, subtropical westerly jet (STWJ) and tropical easterly jet (TEJ) are taken as semi- permanent systems. The role of different semi-permanent systems in the monsoon are discussed by several authors. A brief review of semi-permanent systems has been given in Rao (1976). Krishnamurthy and Bhalme (1976) took all components except sub- tropical westerly jet and found that there is a low frequency oscillation of these semi-permanent systems. Mooley and Shukla (1989b) also studied monsoon trough and found that the number of days of presence of monsoon trough over India, is positively correlated with all India monsoon seasonal rainfall. The number of "break" or "break days" are studied by Bhalme and Mooley (1980). They found that mean number of "break days" in monsoon, during July and August, in drought years over India, is much higher than flood years over India. Position of Tibetan anticyclone and its outflow in relation to monsoon rainfall, is established by Paul *et al.* (1990) and Ramaswamy (1965). Ramage (1971) studied heat low over Afghanistan and adjoining Pakistan and found that its establishment and intensity are very much important for monsoon performance over India. Mokashi (1974) studied TEJ and found its statistical average at different latitude for different months of monsoon season. Here, the role of all these are not discussed day-by-day for each years. However, pecularity of a component for a particular year which was mostly active during that year has been examined.

4.4.1. *Monsoon trough*

From Table 4, we see that monsoon trough established early in 1993 and late in 1987, 1991, 1992 and 1996. Since monsoon trough established later during 1996 than in 1987, it shows that the date of establishment of monsoon trough has no relation with all India monsoon rainfall. From Table 4, we also note that years which are on positive side of normal rainfall, are having more number of days of presence of monsoon trough over India in the season, compared to other years. From monsoon "break days" (Table 4), 1987 is having less number of "break days" than 1988 and 1989. Hence number of "break" or "break days" has no relation with all India monsoon rainfall during the recent decade.

4.4.2. *Heat low*

Table 4 shows that, heat low for all years are established before 15 June. During 1987, 1991 and 1992, which were years having less rainfall and in 1988 and 1990, which were years of more rainfall, heat low has appeared on 1 June. So date of establishment of heat low has no relation with all India monsoon rainfall. This may be due to dependence of establishment of heat low on net heating of May over heat low area. In 1988 and 1992, heat low was present on equal number of days, but seasonal rainfall was different. So number of days of presence of heat low has no relation with all India monsoon rainfall. When central pressure of heat low is considered for all years, it is found that during 1991, which was the second lowest rainfall year, had the highest central pressure of 996hPa and during 1988 which was the highest rainfall year, had the lowest central pressure of 988 hPa amongst all years. So the lowest pressure recorded over heat low in the season, has a negative correlation with all India monsoon rainfall.

4.4.3. *Tibetan anticyclone*

From Table 4, we see that 1987, 1991 and 1992 received negative side of normal rainfall and Tibetan anticyclone was present on less number of days compared to other years. Similarly date of appearance of Tibetan anticyclone was earlier, when the rainfall was on the positive side of normal and *vice versa*. This shows that Tibetan anticyclone appeared early and it is seen on more days during years having positive side of normal rainfall.

4.4.4. *Tropical easterly jet (TEJ)*

From Table 4, TEJ appeared in 1987 and 1993, on 15 and 16 June respectively but there was large difference of seasonal rainfall. In 1991, it was seen on more days in the season than 1993. However, 1993 received more rainfall than 1991. So appearance of TEJ and the number of days it remained over peninsular India, have no relation with all India monsoon rainfall.

4.4.5. *Sub-tropical westerly jet (STWJ)*

From Table 4, we see that in 1992 and 1993, sub-tropical westerly jet (STWJ) was not seen over north India throughout the season, but 1993 received more rainfall than 1992. Thus there is no relation of STWJ to seasonal rainfall during the last 10 years. But in 1987, which was a drought year, STWJ was observed on many days compared to other years. So the STWJ generally shifts northwards during monsoon and in some years it is seen for a few days only.

4.5. *Recent monsoon variability from semi-permanent systems and synpotic systems*

We have already discussed that the onset and withdrawal dates have no relation with seasonal rainfall, which confirms earlier findings by various authors. The number of days monsoon took to cover the entire country has no relation with all India monsoon rainfall. Since all India monsoon rainfall variability during the recent decade is less, it is required to know the role played by a combination of different components from semi-permanent systems and synoptic systems, for making an year on positive side or negative side of normal rainfall, by considering all years simultaneously. First, we try to find out here the role of semi permanent systems. During 1987, 1991 and 1992, both monsoon trough and Tibetan anticyclone played a highly negative role in comparison with other years. So monsoon trough and Tibetan anticyclone are most important semi-permanent systems in comparison to others. All India monsoon rainfall always depends upon these two components and their days. The second factor is the variation of combinations of different types of synoptic systems days, which influence the all India monsoon rainfall. Such synoptic systems days are sum of days of low pressure areas, days of depressions and days of storms. These are responsible for an year to be on positive side of normal rainfall except 1995. However, the year 1995 received positive side of normal rainfall due to more number of days of cyclonic circulations forming over the Bay and adjoining coastal sub-divisions and their movement along monsoon trough.

5. Conclusions

In conclusions, it can be said that during the decade (1987-96), only two combinations of following features of monsoon are found to have a significant relation with all India monsoon rainfall:

(1) The number of days of monsoon trough and Tibetan anticyclone in the season after these systems have been established.

(2) Number of days of low pressure areas, depressions and storms or number of days of cyclonic circulations forming over Bay and adjoining coastal sub-division and moving along the monsoon trough.

The above two features are mostly responsible for an year to be on positive or negative side of normal rainfall. Hence these features may be called as prime performer of the monsoon for the respective year. However, onset and withdrawal dates and the number of days monsoon took to cover the entire country, have no relation with all India monsoon rainfall. The number of depressions, storms and low pressure areas and number of western disturbances or their days, have also no relation with all India monsoon rainfall.

The number of "break" or "break days" has no relation with all India monsoon rainfall. But the lowest recorded pressure of the heat low in the season, has good negative correlation with all India monsoon rainfall. The appearance of heat low, TEJ and STWJ and total days they remained, have no relation with seasonal rainfall. This study also shows that monsoon trough and Tibetan anticyclone are most important features amongst all semi- permanent sytems, which are responsible for interannual variability of all India monsoon rainfall.

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