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DOES BREAK MONSOON ALWAYS MEAN SUBDUED RAINFALL OVER INDIA? - AN ANALYSIS OF ROLE OF OFF-SHORE TROUGH IN THIS ASPECT

1. During past 100-years, considerable progress has been made in understanding the interannual variation of Indian summer monsoon. However, less attention has been paid to understand its intraseasonal variation. A proper understanding of its mechanism can help us to understand the day to day dynamics of monsoon which in turn can improve its prediction accuracy in the short and medium range time scales particularly by Numerical Weather Prediction (NWP) models. A proper classification of intraseasonal variation into different categories has also to be made for achieving a greater understanding on this subject.

Most of the studies have used all India rainfall (Thapliyal, 1997), wind (Webster & Yang, 1992) etc. for classifications of interannual variation of summer monsoon. Ramamurthy (1969) has classified its intraseasonal variation over India synoptically, into break and active monsoon days, based on position of monsoon trough on sea level chart, without referring to Daily Indian Summer Monsoon Rainfall (DISMR). However, other semi-permanent and synoptic components of Indian monsoon *e.g*., Tibetan Anticyclone, off-shore trough along West Coast of India, etc. also affect DISMR significantly during the break monsoon days. Hence the DISMR is not necessarily similar on all break monsoon days. In some break monsoon days, the DISMR may be very small while in other break monsoon days it may be nearer to normal.

In the present study, an attempt has been made to classify the intraseasonal variation of Indian summer monsoon into wet (% departure from normal $\geq$ +50%) and subdued rainfall days (% departure from normal $\leq$ -50%) for the months of July and August for the period 1979-2000 based on DISMR departure from normal. Then, these subdued rainfall days were compared with break monsoon days as defined by Ramamurthy (1969) for same years for finding differences and similarity in these two types of dates. To find out why this happens, two contrasting cases of break/subdued monsoon spells which have lasted for longer period were chosen in such a way that in one case, break monsoon spell was very longer with occurrence of few subdued rainfall days in between while in other case, it is just *vice-versa*. These two contrasting intra-seasonal cases are break monsoon of 16-25 July, 1998 and subdued monsoon of 22 July - 7 August, 2000. It may be noted that subdued rainfall occurred only on 22 - 23 July (2 days) during whole period of break monsoon case of 16 - 25 July (10 days), 1998 while break monsoon was observed only during 1 - 4 August (4 days) in subdued rainfall period of 22 July - 7 August, 2000 when subdued rainfall days occurred during 22 - 31 July and 3 - 7 August, 2000 (a total of 15 days). Characteristics of off-shore trough along west coast of India during these break monsoon/subdued periods were looked into, to find out its role in producing such contrasting rainfall spells over India. One of the main objective of such study is to bring out the complexities of the relationship, which exist between daily rainfall patterns over India and so called synoptically defined break monsoon and their possible causes. Linear trend analysis of wet days, subdued rainfall and break monsoon days were carried out to find their total trends during the same data period. Correlation coefficients were also computed between these features and seasonal Indian Summer Monsoon Rainfall (ISMR) along with their statistical significances. Finally, 11-years running correlation coefficients with ISMR were also carried out in the present study to test whether relationship between these intraseasonal features with seasonal ISMR have also followed any epochal variation in decadal time scale like that of ISMR with its predictors and monsoon disturbance days as found in Jenamani and Dash (2001).

2. *Data* - The actual and normal values of DISMR were collected from India daily weather summery for 1979-2000 published from Office of Deputy Director General of Meteorology (Weather Forecasting) (O/o DDGM (WF)), India Meteorological Department (IMD), Pune. These days have been classified and catalogued into wet days (% departure DISMR from normal $\geq$ +50%) and subdued rainfall days (% departure of DISMR from normal $\leq$ -50%). All the break monsoons which have occurred during the same period in the months of July and August are also catalogued as per method of Ramamurthy (1969). For this purpose, situations when the monsoon trough is not seen on the surface chart uninterruptedly for 2 days or more and the easterlies are practically absent in the lower tropospheric levels up to about 1.5 km above sea level have been considered as break monsoon situations. During all cases of break monsoon, necessary reference has also been made to the departmental publications like the Indian Daily Weather Report, Weekly Weather Report, Monthly Weather Report, etc. In the present study, break monsoon, subdued rainfall and wet rainfall days, which last two days or more have been only considered. However, for analysis of break monsoon days for further longer period data of 1888-2000, we have updated the break monsoon time series which was available till 1967 as in Ramamurthy (1969) and to 2000 as in Jenamani and Thapliyal (1999). For data after 1967, we have considered only those break spells which lasted 3

TABLE 1

Period of break, subdued rainfall and wet days during 1979-2000

Year	July (Dates)		August (Dates)	
	Break	Subdued	Break	Subdued
1979	-	3-6,17-18	19-31	15-28
1980	18-20	18-20	-	-
1981	-	4-5	24-26	23-27
1982	-	1-8	-	29-30
1983	-	4-6, 8-9	22-26	-
1984	21-24	-	-	-
1985	-	1-2, 7-8	23-26	-
1986	-	2-6,10-12, 30 -31	24-26, 29-30	15-16, 22-25, 27-31
1987	15-16, 29-31	11-12, 20-23, 26-31	-	1-4
1988	4-6	-	13-15, 25-27	-
1989	10-11, 29-31	-	-	31Jul-3
1990	7-8	-	-	-
1991	-	27-28	-	-
1992	-	3-6	-	-
1993	-	20-21	-	9-10, 23-24
1994	6-7	-	-	-
1995	-	2-4	12-15	16-17
1996	1-5	3-5	-	-
1997	-	13-19, 25-26	-	-
1998	16-25	22-23	-	-
1999	-	1-5	-	19-22
2000	-	22-31	1-4	3-7

TABLE 2

Period of wet rainfall dates and total number of days of break/ subdued/wet rainfall dates over India during 1979-2000

Year	Wet days		Total No. of days (Break/subdued days/wet days)
	July	August	
1979	-	2-5, 9-10	13/20/6
1980	1-3	24-25, 28-29	3/3/7
1981	-	-	3/7/0
1982	12-13	-	0/10/2
1983	20-21	7-15	5/5/11
1984	-	-	4/0/0
1985	-	-	4/4/0
1986	-	6-8,11-14	5/21/7
1987	-	-	5/16/0
1988	13-14, 16-17	19-20	9/0/6
1989	23-25	-	5/4/3
1990	15-18, 25-26	16-19, 22-25	2/0/14
1991	-	-	0/2/0
1992	18-19	11-12	0/4/4
1993	10-12, 16-17	-	0/6/5
1994	12-14	-	2/0/3
1995	15-21	29-31	4/5/10
1996	19-20	21-22	5/3/4
1997	-	-	0/9/0
1998	-	27-28	10/2/2
1999	-	20-23	0/9/4
2000	-	-	4/15/0

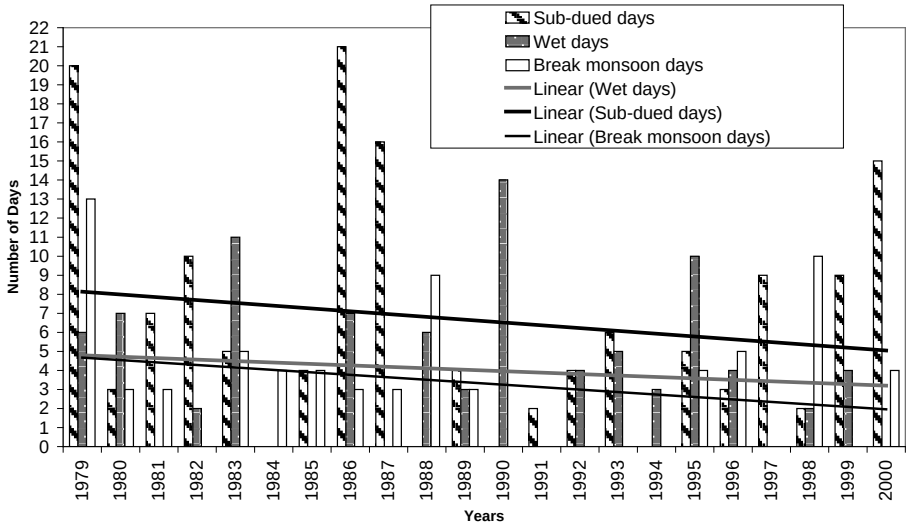


Fig. 1. Interannual variation and linear trend analysis of subdued days and wet days over Indian region for the period 1979-2000

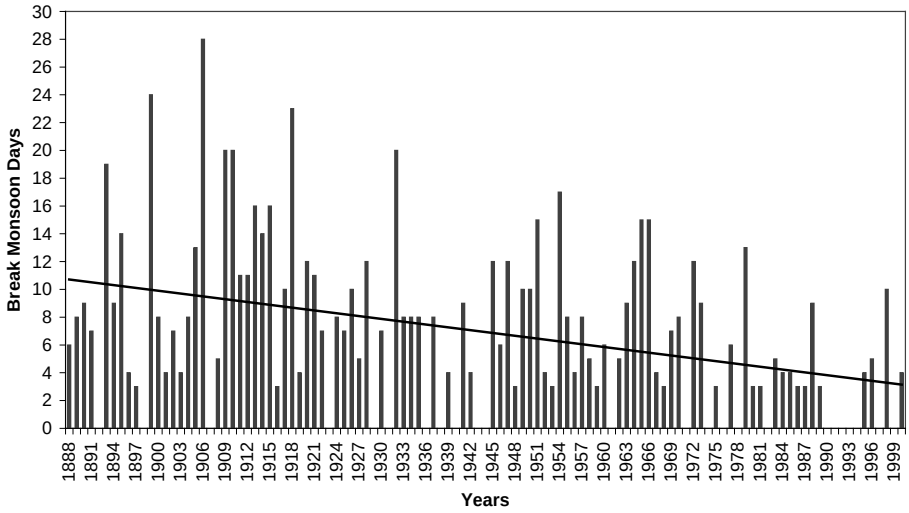


Fig. 2. Interannual variation and linear trend analysis of break monsoon days for the period 1888-2000

days or more to keep the continuity and homogeneity as in Ramamurthy (1969). For comparison of characteristics of recent two break monsoons of 1998 and 2000, daily weather charts and Indian Daily Weather Report prepared by the O/o DDGM (WF), IMD, Pune have been referred.

3. Break monsoon days, subdued rainfall days and wet days: Table 1 shows monthly break monsoon dates and subdued rainfall dates for July and August for the period of 1979 - 2000. It is seen from the Table 1 that duration of their individual spell varies from 2 to 14 days. Both break monsoon and subdued rainfall spells of highest days have occurred in 1979 with 13 days duration in 19-31 August and 14 days in 15 - 28 August respectively followed by break monsoon spell of 1998 with 10 days in 16 - 25 July. Though, the longest spell of subdued rainfall occurred in 15 - 28 August 1979 which has some break monsoon days, the second highest subdued rainfall spell of 10 days has occurred in 22 - 31 August, 2000 without having a single day of break monsoon. Table 1 also shows that one of the major break monsoon spell of 10 days during 16 - 25 July, 1998 was associated with only 2 days

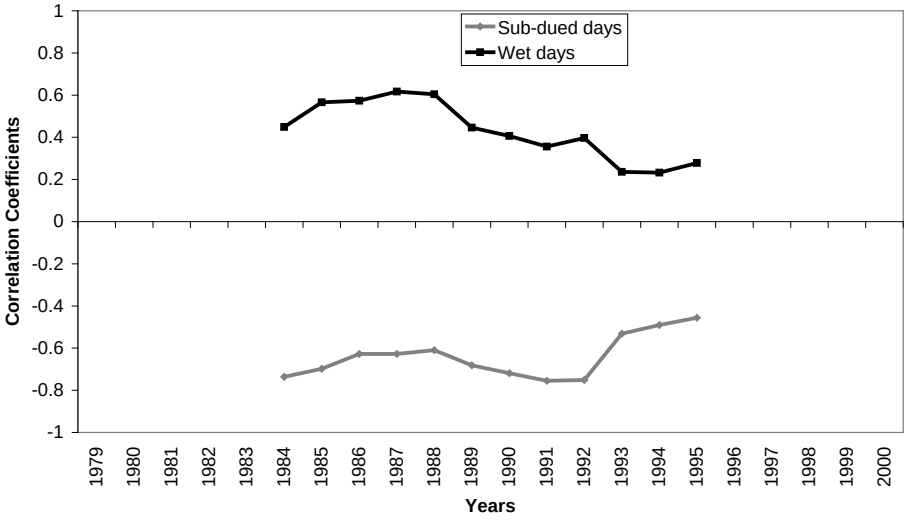


Fig. 3. 11-year running correlation coefficients of ISMR with subdued days and wet days for the period 1979-2000

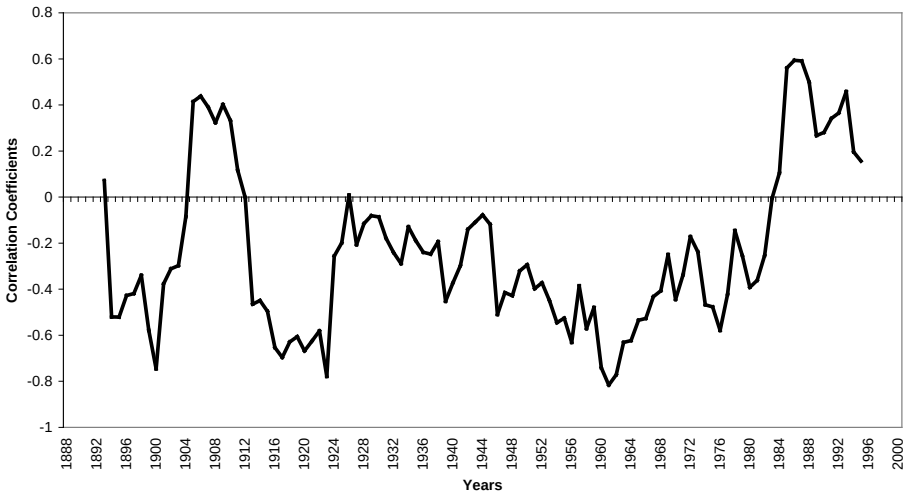


Fig. 4. 11-year running correlation coefficients of ISMR with break monsoon days for the period 1888-2000

of subdued rainfall while recent break monsoon of 4 days during 1 - 4 August, 2000 was associated with 15 days of subdued rainfall (22 to 31 July and 3 - 7 August) from days of occurrence of this break monsoon/subdued days till its revival. Similarly, break monsoon of 1983 *i.e.*, 22 - 26 August and break monsoons of 1988 *i.e.*, 4 - 6 July and 13 - 15 and 25 - 27 August, have not resulted any subdued rainfall activities over India and during the period of 1-8 July, 1982 and 26 July - 4 August 1987, subdued rainfall have occurred over India without occurrence of break monsoon. Hence, relationship between daily rainfall pattern over India and so-called synoptically defined break monsoon are not one to one. Table 2 shows month-wise dates of wet rainfall spells in July and August with total days of break, subdued rainfall and wet rainfall days for the same period. It shows that duration of individual wet spell varies from 2 to 9 days with highest of 9 days covering 7 - 15 August, 1983.

4. *Trends and relationship with ISMR* - Fig. 1 shows year-wise variation of total number of subdued rainfall, break and wet days prevailed in both July and August for the period 1979-2000 as per last column of Table 2 along with their linear trend lines. It shows prevailing of highest subdued rainfall days in 1986 (21 days) followed by 1979 (20 days), 1987 (16 days) and 2000 (15 days). It may be noted that 1979, 1986 and 1987 were drought rainfall years. Hence, total subdued rainfall

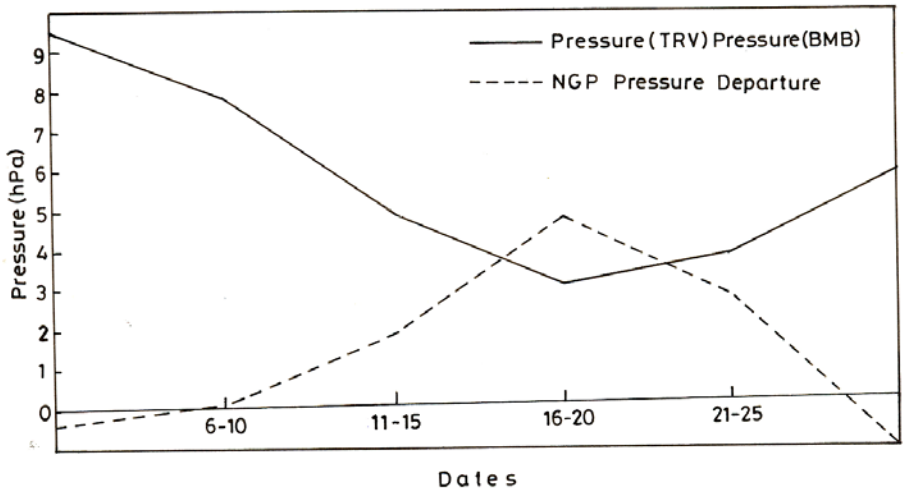


Fig. 5. Pressure gradient(pentad averages) along west coast (sea level pressure difference between Thiruvananthapuram & Mumbai) and pressure departure from normal over Nagpur from normal associated with break monsoon 16 - 25 July 1998

days are higher in drought years. It further shows that highest break monsoon days occurred in 1979 (13 days) which is a drought year followed by 1998 (10 days), a normal monsoon year and 1988 (9 days), a flood year which indicates no definite relationship is existing between both (number of break monsoon days and seasonal ISMR). Fig. 1 also shows prevailing of highest total wet days of 14 days over the country as a whole in 1990 which is a normal monsoon year followed by 1983 with 11 days, 1995 with 10 days, 1980 and 1986 with 7 days each, 1979 with 6 days and 1988 with 6 days. It is significant to note from Fig. 1 that drought years too have few wet spells in the country as a whole in some years. However, longer durations of wet spells were seen mostly in excess/ normal monsoon years *e.g.*, 1990, 1995, 1988 and 1983. Linear trend analysis of these time series in Fig. 1 shows a decreasing trend of 3, 2.5 and 1.6 days respectively *i.e.*, trend of subdued rainfall days in the season is more than the break monsoon and wet days. Break monsoon days are available since 1888 and hence we have further plotted their days year-wise for the whole period 1888-2000 in Fig. 2 and performed the linear trend analysis. It shows prevailing of ever highest break monsoon days of 28 days in July and August in 1906, a normal monsoon rainfall year followed by 24 days in 1899 and 23 days in 1918 which are severe drought years having the ever lowest and 2nd lowest below normal rainfall in the whole data period with departure of -29.4% and -24.9% respectively. Linear trend analysis for whole period in Fig. 2 shows a very high decrease of 8 days in the break monsoon days.

Correlation coefficients between ISMR with wet days and subdued rainfall days are 0.35 and –0.68 respectively which are significant at > 95% and > 99% levels of confidence in contrast to very weak value of 0.05 between ISMR and break monsoon days for the same period. Since break monsoon has been defined on the basis of position of monsoon trough not on the basis of daily rainfall over India. It is possible that during some break monsoon period, rainfall along the Indo-Gangetic plains may be subdued while West Coast may get very good rain due to active off-shore trough. But, when such spatially distributed rainfall pattern statistically averaged for the whole country, it may give a normal rainfall value for the country as whole irrespective of prevailing break monsoon pattern in that period. In subsequent Section 5, two such different cases of break monsoons have been studied in detail and possible causes are described briefly.

To find out stability of relationship between subdued rainfall days, wet days and break monsoon days with ISMR variation, 11-years running correlation coefficients of their total days with ISMR were also computed and given in Figs. 3 and 4. It may be noted from Fig. 3 that for the period 1979-2000, the correlation coefficients with wet days have initially followed a little increasing trend from beginning *i.e.*, 1980 till 1988 when their correlation coefficients increased from 0.45 to 0.6 followed by decreasing trend thereafter till 2000 to 0.2 while correlation coefficients with subdued rainfall days initially remain stable till 1992 around -0.7 followed by decreasing trend thereafter to -0.45 till 2000. However, 11-year

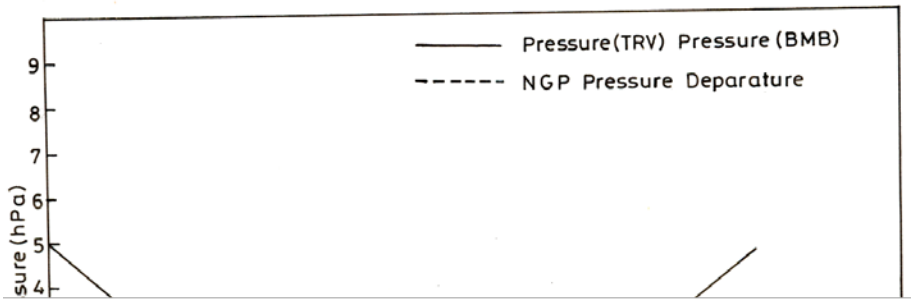
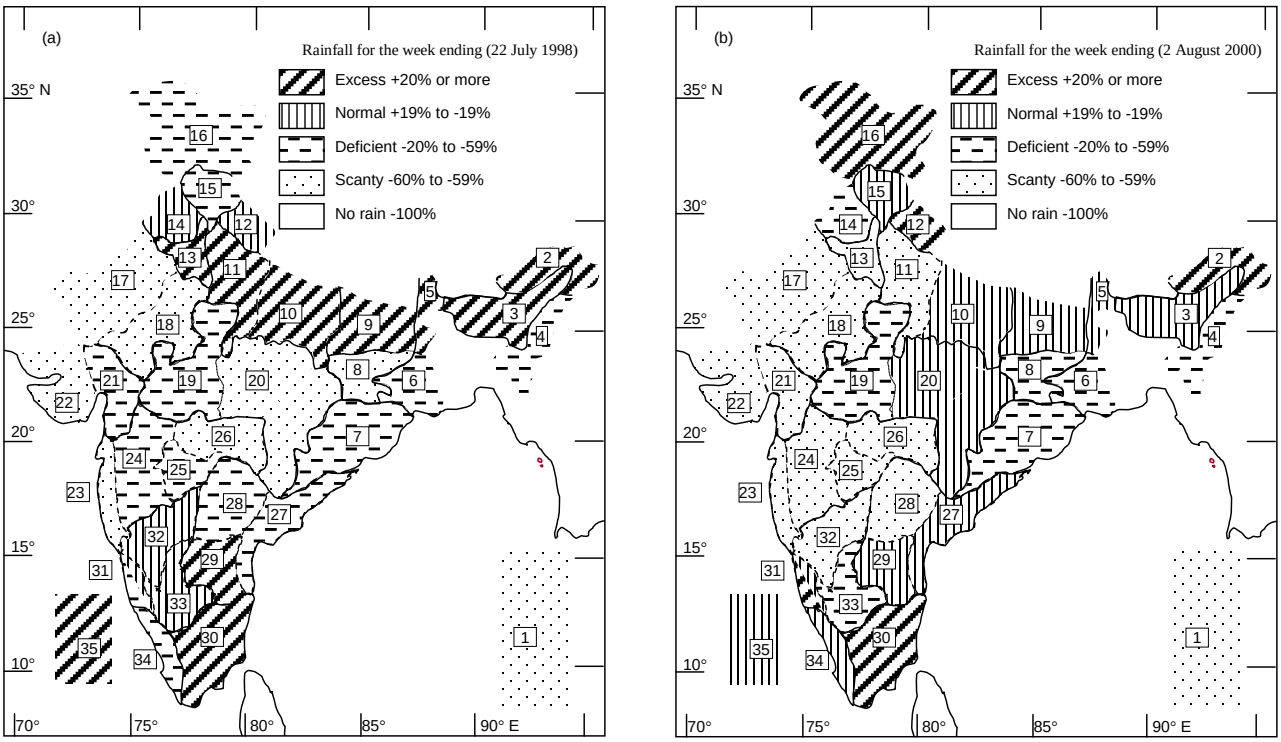


Fig. 6. Same as Fig. 5, but for subdued /break monsoon spell 22 July - 4 August 2000

running correlation coefficients of break monsoon days with ISMR for the very longer period 1888-2000 for which data are available in Fig. 4 show interesting trends as their correlation coefficients values have remained highly unstable. It shows that the correlation coefficient value varies between its lowest values -0. 8 in 1900, 1920 and 1960 to its highest values of 0.4 in 1908 and 0.6 in 1985 with abrupt increasing/decreasing trends in between. Two contrasting epochs were analysed in details further to find out the cause of such erratic relationship, particularly the cause of correlation coefficients becoming positive in 1908 and 1985 when both are expected to be negatively correlated. It shows that in 1906-1916 and in 1980-1993, when ISMR decadal cumulative averages are 0.14 and –2.25 respectively, break monsoon days averages are 13 and 2.6 days respectively *i.e.*, higher the break monsoon days shows higher the ISMR and *vice-versa* during these years. Hence both ISMR and break monsoon days are positively correlated in 1906-1916 and in 1980-1993 (Fig. 4). The main cause of such anomalous relationship is the synoptic definition of break monsoon days for describing intra-seasonal variation without taking into DISMR. Thus, the relationship with seasonal ISMR is neither stable nor significant during most of the period. But with addition of new classification *e.g.*, subdued rainfall days and wet days in the present study, a more stable and significant correlation coefficients could be found between these days and ISMR (Fig. 3). Hence, intra-seasonal classification based on daily rainfall criteria better represents the inter-annual variation of ISMR.

5. *Characteristics of break monsoon during 1998 and 2000* - We have described here briefly difference of characteristics of two contrasting break monsoon cases that occurred in July 1998 and August 2000 from synoptic aspects based on the characteristics of off-shore trough as observed. Figs. 5 & 6 shows pressure gradient in pentad averages along west coast of India and pressure departure from normal over Central India by taking sea level pressure difference between Thiruvananthapuram (TRV) and Mumbai (BMB) and pressure departure of Nagpur (NGP) from normal during break monsoon periods of both the cases. We have selected the data period in such a way that the complete intra-seasonal cycles for both the cases which is from the date when monsoon trough started weakening or shifting to the foot hills of Himalayas till its reestablishment to its normal position. For 1998, we have considered period from 1 to 30 July and for 2000, the period from 15 July to 13 August has been considered. It may be noted from Figs. 5 and 6 that the pressure gradient along west coast was much weaker during break monsoon 2000 compared to that of break monsoon of 1998 as there were four pentads *i.e.*, 20 - 24 July, 25 - 29 July, 30 July -3 August and 4 - 8 August in the period of break monsoon of 2000 having pressure difference between BMB and TRV as 2 to 3 hPa, while none of the pentads in case of break monsoon of 1998 was having such lower pressure gradient between BMB and TRV. Hence the off-shore trough during the former break monsoon case was much weaker compared to that of latter. Similarly, the pressure



Figs. 7(a&b). Sub-division wise area weighted rainfall departure from normal (a) Break monsoon 1998 (week ending on 22 July) and (b) Break monsoon 2000 (week ending on 2 August)

TABLE 3

Sub-divisions wise rainfall values in % departure from normal for two break monsoon cases

Name of meteorological sub-divisions	Rainfall in % departure from normal for the week ending on 22 July, 1998	Rainfall in % departure from normal for the week ending on 2 August, 2000
(a) Along West Coast of India and adjoining Peninsular		
Saurashtra and Kutch	-94	-99
Gujarat region	-48	-99
Konkan and Goa	-69	-95
Madhya Maharashtra	-57	-97
Marathawada	-56	-99
Vidarbha	-65	-90
Coastal Karnataka	-50	-83
North Interior Karnataka	-2	-98
Kerala	-48	-83
Telangana	-56	-73
(b) Along Monsoon trough region (Indo-Gangetic Plains)		
Bihar Plateau	-62	-54
East Madhya Pradesh	-60	3
East Rajasthan	-66	-94
West Rajasthan	-90	-99
Haryana	30	-68

departure from normal over central Indian station of Nagpur was also higher than normal in former break monsoon case for many days in the spell as the pressure departure from normal was nearly 4 hPa above normal in three pentads continuously. But in the case of later break monsoon spell, it was only for a single pentad.

Figs. 7(a&b) shows weekly spatial rainfall distribution associated with these two break monsoon cases and Table 3 shows sub-division-wise rainfall departure separately for the west coast of India and Indo-Gangetic Plains. It may be noted from Figs. 7(a&b) and Table 3 that during a week of break monsoon of July 1998, total number of subdivisions receiving scanty rainfall are 7 out of which 5 *i.e*., Jharkhand (formerly Bihar Plateau), east Madhya Pradesh, west Rajasthan, east Rajasthan and Vidarbha are near the normal position of monsoon trough line and only 2 *i.e*., Konkan and Goa and Saurashtra and Kutch are along the west coast of India. But, in case of break monsoon of August, 2000, total number of sub-divisions over India receiving scanty rainfall are 13 which is almost double of the former, out of which only 3 *i.e*., Haryana, west Rajasthan and east Rajasthan are near the normal position of monsoon trough line and remaining 10 sub-division covering Gujarat state, Maharashtra state, Telangana, Karnataka state and Kerala are along the west coast of India. This is clearly due to presence of a relative weak off-shore trough during later break monsoon case as we have described. Hence intensity of break monsoon in terms of effect on rainfall over India, can not be understood without considering the characteristics of other semi-permanent and synoptic component of monsoon present over Indian region like we have considered off-shore trough in these two cases.

6. On the basis of data of 1979-2000, present study brings out following conclusions :

Some subdued rainfall spells have occurred over India without occurrence of break monsoon in these spells and *vice-versa*. Total subdued rainfall days are higher in drought years while break monsoon days have no definite relationship with ISMR. Longer durations of wet spells were observed mostly in excess/normal monsoon years and drought years too have few wet spells in some years. Correlation coefficients between ISMR with wet days and subdued rainfall days are stronger with values of 0.35 and –0.68 respectively for the period 1979-2000 which are significant at > 95% and > 99% levels of confidence while its relationship with break monsoon days is very week and insignificant. This study further shows that in the case of break monsoon of July 1998, the off-shore trough was more active compared to the break monsoon of August 2000 and hence the most rainfall affected sub-divisions during break monsoon of July 1998 are confined to monsoon trough region and total number of sub-divisions receiving scanty rainfall is 7. But in the case of break monsoon of August, 2000, west coast sub-divisions were mostly affected and total number of sub-divisions receiving scanty rainfall is 13 which are almost double of the former. Hence, intensity of a particular break monsoon spell in terms of effect on rainfall over India can not be understood without considering the characteristics of other semi-permanent and synoptic components of monsoon prevailed over India during that spell.

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