TABLE 1

Frequency of main synoptic situations that brought in southwest monsoon over Orissa

S. No.	Main synoptic situations bringing monsoon over Orissa	Year	Percentage of year
1.	Depression/deep depression over Bay of Bengal or adjoining land areas	1975, 1979, 1981, 1983, 1988, 1989 =6 years	40%
2.	Low pressure area in Bay of Bengal or adjoining land areas	1976, 1977, 1978, 1980, 1985, 1987 =6 years	40%
3.	Other systems such as :		
	(*i*) Trough of low pressure on sea level	1982 =1 yr	
	(*ii*) Upper air trough in the lower tropospheric levels	1984 =1 yr	20%
	(*iii*) Upper air cycir in the lower/middle tropospheric levels	1986 =1 yr (Total=3 yrs)	

NB — The synoptic situations enumerated above relate to the periods of onset of monsoon

It is seen that simultaneous occurrence of an onset event over Kerala and Orissa is early on no occasion normal on about 60% of the occasions and late on about 13% of the occasions. Hence, this shows that on about 73% of the occasions, the onset events over Kerala and Orissa are in phase.

Fig. 1 represents diagramatically the onset dates of monsoon over Kerala and Orissa during the last 15 years period (1975-1989). It is seen that the normal and late onset of monsoon over Orissa is generally in phase with that of Kerala.

The occasions, though rare when the onset events over Orissa and Kerala are not in phase may be seen in Fig. 1.

The difference between normal onset dates over Kerala and Orissa is 16 days. It is seen that on 8, *i.e.*, 53% occasions the difference between the onset dates between Kerala and Orissa is less than 16 days.

4. The synoptic systems associated with onset of monsoon over Orissa in different years during this 15 years period (1975-1989) are studied and indicated in the Table 1.

The mean monsoon onset date for Orissa of 17 June with standard deviation of 5 days differs from the normal date of 10 June onset of monsoon over Orissa.

The difference between the actual and mean onset dates for Orissa and Kerala and the correlation coefficient have been computed. The result is that the onset of monsoon over Kerala to that over Orissa is correlated with a correlation coefficient of 0.54 signifying that the events are positively correlated.

To verify the above results for the year 1990, it is noticed that the monsoon set in over Kerala on 28 May 1990 and over Orissa on 13 June 1990, thereby indicating that both the events have occured as early as 4 days from the normal date. This is in agreement with the above conclusion, that the events are in phase, *i.e.*, early onset over Kerala is followed by early onset over Orissa.

5. The authors are grateful to Shri M.C. Sharma of Meteorological Office, Pune for providing onset dates over Orissa prior to 1978 and Shri C.M. Barma, Regional Director (since retired) for providing I.M.D. publications at R.M.C., Calcutta. Thanks are also due to S/Shri P. Sengupta and S. Dasgupta for collecting synoptic data and Shri D.S. Patil for typing the manuscript.

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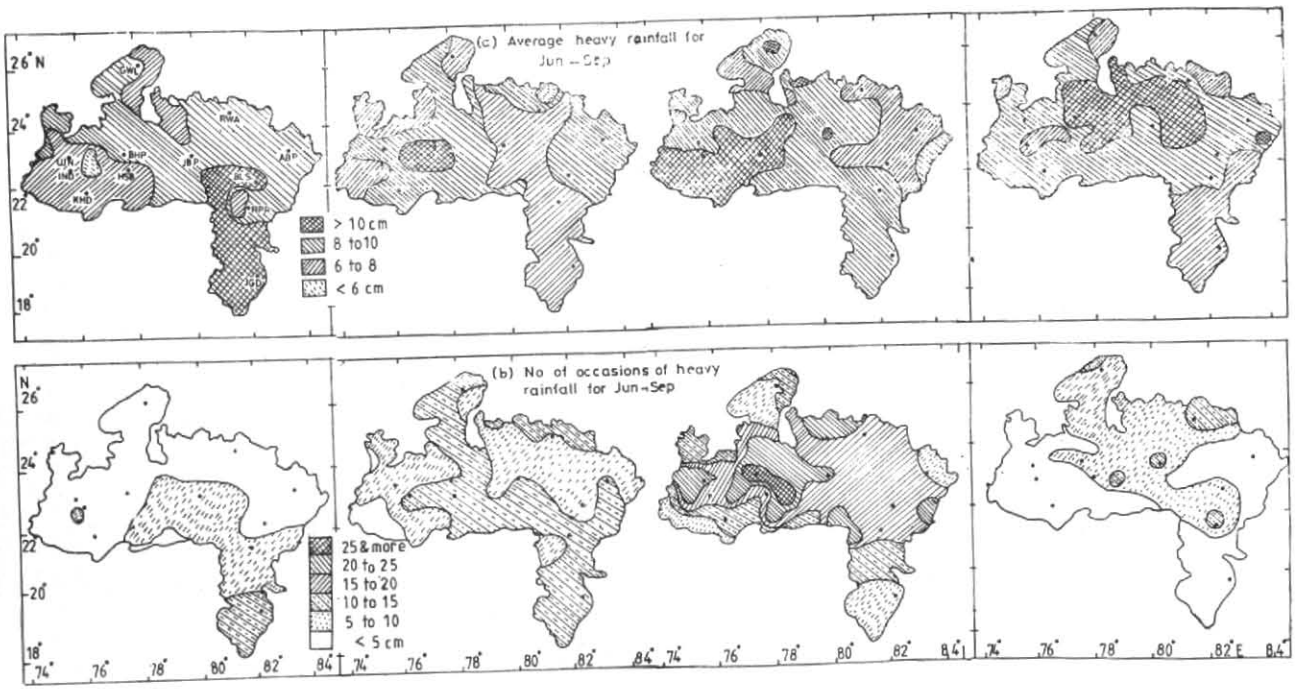

Figs.1 (a & b). (a) Average heavy rainfall amount and (b) No. of occurrence of heavy rainfall for the year 1977 to 1987 from June to September

TABLE 1

Percentage of occurrences of heavy and very heavy rainfall

Rainfall	Jun	Jul	Aug	Sep
Heavy	10	25	47	18
Very heavy	9	15	66	10

2. *Discussion of results* — The occurrences of heavy rainfall were 10% in June, 25% in July, 47% in August and 18% in September. The corresponding figures for very heavy rainfall are 9%, 15%, 66% and 10% for the respective months. The highest frequency of heavy and very heavy rainfall is found in August. The intensity of heavy rainfall and number of occurrences has a well defined maximum over central parts of Madhya Pradesh in July, August and September [Figs. 1 (a & b)].

Onset of monsoon takes place in the month of June over southeast M.P. and then progresses northwards but does not cover the entire state before the end of June for some years. Thus, the maximum intensity and occurrence of rainfall can be expected over southeast M.P. in June. In July the intensity of maximum rainfall over Bhopal and neighbourhood is unambiguous as is evident from the figure that the maximum is over a strip running from southeast M.P. to northwest M.P. through central parts of the State. Frictional convergence and pressure gradient contribute towards more rainfall activity in the southern parts of the State. Figures for the month of August very distinctly bring out the maxima over Bhopal and neighbourhood in intensity and occurrence. The extension of the intensity is due to more westwards extension of systems in August as compared to other months. The monsoon trough shifts little southwards. Chances of reaching the systems beyond 75°E is more in August (Rao 1976). When depressions weaken the resulting lows persist for a day or two before filling up. The number of days of such lows are more in August (Srinivasan *et al.* 1971). It is remarkable to note that the number of occurrences in August over the region of maxima is three times that of other months. Fluctuations of yearly variation of heavy rainfall is maximum in August probably because of "break in monsoon" which is having maximum frequency in August. It was confirmed from 250 case studied that systems reaching over northeast Madhya Pradesh are 50% of the total number of systems in August (Ganeshan 1985). For the month of September the intensity and number of occurrences is having a maxima over central parts with extension towards northeast. In September a large number of systems recurve towards north or northeast on reaching central Madhya Pradesh with consequent shift in the rainbelt from southwest to north/northeastern sector. Four months average rainfall for the entire 11 years period brings out distinctly that the intensity and frequency of maximum rainfall is over central parts of Madhya Pradesh.

The variation of intensity and frequency of very heavy rainfall were studied in the light of antecedent synoptic situations. The systems lay over NE M.P. (north of 22°N and east of 80° E) give rise to very heavy rainfall over central parts of the State. It is noteworthy that systems give rise very heavy rainfall 200 km away from the centre in the left forward sector. Less rainfall is recorded close to the centres. Systems reaching east

TABLE 2

No. of occurrences of daily very heavy rainfall (cm) over M.P. in June to September during 1977 to 1987 for ranges 13–17, 18–22, 23–27 and 28–33

Division	June				July				August				September			
	13–17	18–22	23–27	28–33	13–17	18–22	23–27	28–33	13–17	18–22	23–27	28–33	13–17	18–22	23–27	28–33
Gwalior					1				2	3			5		1	
Chambal					3	1			1				1			
Bhopal	2				3	6	1		20	5	3	2		1		
Hyderabad	1				3		1		10	1	1	1			1	
Indore	2				1	1			24	5	2		1			
Ujjain					4	1			10	2	2					
Sagar					2			1	18	3	1	2	1	1		
Rewa	1				1				2		1		5	1	1	
Jabalpur	5	3			3	1			11	7				1		
Bilaspur	1		1		3				12	2			2			
Raipur	4	2			1				13	3	1		3	1		1
Bastar	1	2								2						
Total	17	7	1	0	25	10	2	1	123	33	11	5	18	5	3	1
Monthly total			25				38				172				27	
Monthly Percentage			9.5				14.5				65.6				10.3	

central M.P. are influenced by orography as Vindhyachal and Satpura ranges lie on the either side of their track causing increased convergence.

A case study for the systems over the Head Bay during 20–22 August 1981 was conducted. On 20th evening a low pressure area was formed over North Bay with associated upper air circulation extending up to 7.6 km. a.s.l. On 21st it was over North Bay and adjoining West Bengal. A trough was extending from the low westwards as far as up to Gujarat.

This well marked low pressure area in association with the trough extending up to middle tropospheric levels produced strong convergence, south of the trough line give rise to very heavy rainfall over Bilaspur and Raigarh on 22nd.

The results of the study together with the associated synoptic situations shows that :

(*i*) Systems over East Madhya Pradesh, north of 22° N and east of 80° E cause very heavy rainfall over Bhopal division and neighbourhood. 50% of the systems in August are associated with the M.T.C. over Gujarat and neighbourhood. The percentage number of systems reaching northeast Madhya Pradesh are 38% of the total number of systems. Monthwise study show that August has got 67% of such systems as compared to other months.

(*ii*) 80% of very heavy rainfall over Indore and Ujjain divisions is due to well marked systems reaching over central parts of Madhya Pradesh and the remaining 20% is due to systems lying as M.T.C. over Gujarat and neighbourhood. Another finding is that 90% of the system giving very heavy rainfall over Indore and Ujjain are in August.

(*iii*) Gwalior and Chambal divisions receive very heavy rainfall when the systems are over the region itself or over SE of the regions.

(*iv*) Sagar and Jabalpur divisions received very heavy rainfall when the systems are over extreme northeast M.P. or over the Head Bay. 50% of the systems over Head Bay are associated with M.T.C. over Gulf of Cambay.

(*v*) 60% of very heavy rainfall over Bilaspur and Raipur divisions are due to systems lying over Head Bay, as can be seen from the case study.

(*vi*) 80% of the cases of very heavy rainfall for Bastar and Raipur divisions are due to systems over northwest Bay and 20% are due to systems lying over the region itself or its neighbourhood.

Table 2 shows that 66% of the occurrences of very heavy rainfall are in the month of August. July records 15%, September 10% and June 9%. In June there are no cases of very heavy rainfall over Gwalior, Chambal, Ujjain and Sagar divisions. Bastar division is free from very heavy rainfall in July and September. In September the occurrence of very heavy rainfall is highest in Rewa division with 7 cases followed by Gwalior with 6 cases and Raipur with 3 cases. Bilaspur and Sagar records 2 cases each and other divisions 1 each.

3. *Conclusion* — It is observed that frequency of occurrence of heavy rainfall is highest in August and lowest in June. Very heavy rainfall also show a similar trend. Spatial distribution of heavy rainfall shows maximum over central Madhya Pradesh both in intensity and frequency. Month to month variation shows that

the 47% of heavy rainfall occured in August alone and other three months account for the remaining 53%. Corresponding figures for very heavy rainfall are 66% and 34%. Study of synoptic situations reveal that systems over northeast Madhya Pradesh, north of 22°N and east of 80° E give rise to very heavy rainfall over Bhopal and neighbourhood. 95% cases of very heavy rainfall are due to low pressure areas rather than depressions and cyclonic storms. 67% of such systems are in the month of August. In the month of September there is maximum frequency of very heavy rainfall over extreme NE M.P.

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