Mausam, (1989), **40**, 3, 329-332

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Inter-annual variability of the advance of Indian summer monsoon and associated rainfall

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(*Received 10 April 1987*)

सार — केरल पर ग्रीष्म मानसून का आरम्भ और तदनन्तर इसका पूरे देश में अग्रगमन एक प्रभावशाली परिघटना है। इस शोधपत्र में उत्तरपश्चिमी मानसून के केरल और गांगीय पश्चिम बंगाल और इसका देश के उत्तर और पश्चिम की ओर बढ़ना, शीघ्र, सामान्य और विलम्ब से अग्रगमन से संबंध मौसमी वर्षा और अग्रगमन की धीमी या तेज प्रक्रिया से सम्बन्धित लक्षणों का विस्तार से अध्ययन किया गया है। 35 वर्षों की अवधि के पूरे देश पर प्रतीक्षागत मानसून वर्षा वाले क्षेत्रों और सामान्य या अधिक और कम वर्षा के क्षेत्रों के प्रसंवादी विश्लेषण का भी अभिकलन किया गया है। ऋतु के दौरान वर्षा विभिन्नता के त्रैवार्षिक, सात वर्षीय और सत्रह वर्षीय चक्रों का प्रेक्षण किया गया है।

ABSTRACT. The onset of the summer monsoon over Kerala and its subsequent advance over the whole country is a spectacular phenomenon. In this paper, the onset of southwest monsoon over Kerala and Gangetic West Bengal and its north and westwards march over the country; seasonal rainfall associated with early, normal and delayed advance and features related to rapid or slow process of advance have been studied in detail. Harmonic analysis of the area weighted monsoon rainfall over the country as a whole and areas of normal or excess and deficient rainfall for the period of 35 years have also been computed. Triennial, seven and seventeen-year cycles of the rainfall variation during the season have been observed.

1. Introduction

Summer monsoon is the most spectacular weather event in India. Pant (1964) studied the changes in the flow at 700 mb over the Indian sub-continent associated with the setting in and establishment of the monsoon. Parthasarathy and Mooley (1978) have investigated the Indian summer monsoon rainfall by statistical method and found that the monsoon rainfall series is random and normally distributed. Mathur (1986) studied the relation between the date of onset of monsoon and rainfall over Punjab and Haryana. He found that the late (early) arrival of monsoon over Punjab and Haryana indicates poor (good) rainfall during the monsoon season.

June to September is acknowledged as the southwest monsoon period over the Indian sub-continent as a whole. But it sets in over Uttar Pradesh and northwest India in the last week of June or early July and withdraws from there in the second half of September or the first week of October. The normal period of monsoon activity is about $2\frac{1}{2}$ to 3 months over Uttar Pradesh and northwest India while it is $3\frac{1}{2}$ to 4 months in other parts of the country.

In this paper the effect of early, normal and delayed advance of monsoon on the total monsoon rainfall over different meteorological sub-divisions and the synoptic features responsible for the rapid, normal or slow progress of the Arabian Sea as well as the Bay branch of monsoon have been investigated. Periodicity in the activity of monsoon is also studied.

2. Data and methodology

Monsoon (Jun to Sep) rainfall data for the period 1951 to 1985 have been collected from the *Annual Monsoon Summary* published by the India Meteorological Department (IMD). The normal dates of onset of southwest monsoon over various sub-divisions (1921-1980) have been taken from the IMD publications. The synoptic features, as discussed in the paper, have been taken from the *Weekly Weather Reports* published by IMD. The time taken for the progress of monsoon from Kerala to Gujarat State and Gangetic West Bengal to Punjab has been obtained. Fig. 1 also shows the advance of monsoon over Kerala and Gangetic West Bengal during different years with respect to the normal dates. Area weighted rainfall expressed as percentage of normal for the years 1951 to 1985 have been worked out and these were subjected to harmonic analysis to find out the presence of quasi-periodicity, if any, in the rainfall variation.

3. Discussion

3.1. *Advance of monsoon*

The normall date of onset of southwest monsoon over Kerala is 30 May and that over Gangetic West Bengal is 11 June. The Arabian Sea branch of monsoon advances northwards and covers Gujarat State by 18 June, while the Bay branch marches westwards to Punjab by 28 June. Thus, the monsoon normally takes about 19 days to advance from Kerala to Gujarat State and 17 days from Gangetic West Bengal to Punjab.

TABLE 1

Delay in advance of monsoon over sub-divisions and % departure of seasonal rainfall from normal

15 days or more		11-14 days		7-10 days	
Sub-division	% dep. (Jun-Sep)	Sub-division	% dep. (Jun-Sep)	Sub-division	% dep. (Jun-Sep)
		1963			
Punjab	5	J & K	—27	East Raj.	10
		West Raj.	—32	Gujarat region	18
		West M.P.	1	Saurashtra & Kutch	—15
		1964			
—	—	—		S.H.W.B. & Sikkim	15
				West U.P.	26
				Punjab	60
				H.P.	—14
				East Raj.	3
				West M.P.	1
				East M. P.	10
				Gujarat region	18
				Saurashtra & Kutch	24
				Vidarbha	2
		1965			
Punjab	—24	S.H.W.B. & Sikkim	8	Gangetic W.B.	—5
J. & K.	—55	Bihar plateau	—21	West U.P.	—30
West Raj.	—18	Bihar plains	—10	East Raj.	—34
West M.P.	—35	East U.P.	—36	Konkan & Goa	1
East M.P.	—33	H.P.	—55	Telangana	9
Gujarat region	—32	Madhya Maha-rashtra	— 7		
Saurashtra & Kutch	— 22	Marathwada	0		
		Vidarbha	—21		
		1966			
—	—	—	—	Punjab	16
				West M.P.	—26
				East M.P.	—28
				Gujarat region	—19
		1967			
—	—	—	—	West M.P.	—15
				West U.P.	31
				East M.P.	1
		1968			
—	—	Haryana	8	East U.P.	—15
		Punjab	6	J. & K.	—8
		H.P.	—17	West Raj.	—63
		East Raj.	—26	West M.P.	—8
		1969			
Haryana	17	West U.P.	3	East U.P.	6
Punjab	—1	H.P.	0		
West Raj.	—58	J. & K.	—26		
East Raj.	—4	East M.P.	—8		
West M.P.	7				
Gujarat region	—24				
Saurashtra & Kutch	—35				
		1972			
—	—	Konkan & Goa	—22	Orissa	0
		Madhya Maha.	—47	Bihar plateau	—16
		Telangana	—37	East M.P.	—13
				Marathwada	—46
				Vidarbha	—38
		1973			
—	—	Hills of West U.P.	2	East U.P.	26
				Plains of west U.P.	18
				Haryana	48
				Punjab	44
				H.P.	7
		1974			
Plains of west U.P.	—14	Haryana	—32	East U.P.	—17
Hills of west U.P.	—21	Punjab	—38	West M.P.	—1
East Raj.	—9	H.P.	—25	Konkan & Goa	15
Gujarat region	—65	J. & K.	—12		
Saur. & Kutch	—69	West Raj.	—47		
Madhya Maha.	10				
Marathwada	61				

15 days or more		11-14 days		7-10 days	
Sub-division	% dep. (Jun-Sep)	Sub-division	% dep. (Jun-Sep)	Sub-division	% dep. (Jun-Sep)
		1975			
—	—	—	—	Gangetic W.B.	— 1
				Konkan & Goa	12
				Madhya Maha.	24
				Marathwada	49
				Telangana	14
		1976			
East U.P.	—1	Orissa	—15		
Plain of west U.P.	8	Bihar plateau	1		
Hills of west U.P.	—27	Bihar plains	7		
Haryana	39	H.P.	—12		
Punjab	62	J. & K.	46		
West Raj.	65				
East Raj.	18				
		1977			
—	—	—	—	West M.P.	9
				East M.P.	1
				Gujarat region	43
				Saurt. & Kutch	13
				Konkan & Goa	9
				Madhya Maha.	—12
				Marathwada	—20
				Vidarbha	—5
				Telangana	—29
		1978			
—	—	—	—	S.H.W.B. & Sikkim	—18
				Gangetic W.B.	44
				Bihar plateau	21
		1979			
West Raj.	—11	Gangetic W.B.	—11	Bihar plateau	—27
East Raj.	—22	Orissa	—19	Bihar plains	—18
		Haryana	—36	East U.P.	—51
		Punjab	—38	West M.P.	—30
		H.P.	—47	East M.P.	—39
		J. & K.	—33	Gujarat region	—21
		Konkan & Goa	—25	Saur. & Kutch	68
		Madhya Maha.	8		
		Marathwada	13		
		Vidarbha	—1		
		1981			
Konkan & Goa	15	S.H.W.B. & Sikkim	—8	Gangetic W.B.	26
Madhya Maha.	24	Marathwada	6	Orissa	—7
		Vidarbha	14	Bihar plateau	—5
		Telangana	18	West Raj.	—32
				Gujarat region	4
				Saur. & Kutch	1
		1982			
East U.P.	3				
Plains of west U.P.	—6				
Hills of west U.P.	—23				
Haryana	—11	—	—	—	
Punjab	—25				
H.P.	—49				
J. & K.	—37				
West Raj.	—31				
East Raj.	— 19				
West M.P.	— 2				
East M.P.	—7				
Gujarat region	— 27				
Saur. & Kutch	— 46				
		1983			
Gangetic W.B	0	Bihar plateau	— 18	Orissa	6
West Raj	32	Bihar plains	—24	East U.P.	2
Madhya Maha.	23	Vidarbha	18	Haryana	48
Marathwada	68	Telangana	55	East Raj.	2
				West M.P.	11
				East M.P.	3
				Konkan & Goa	41
		1984			
J. & K.	—19	—	—	Plains of west U.P.	11
				Punjab	35
				West Raj.	— 20
				East Raj.	— 15

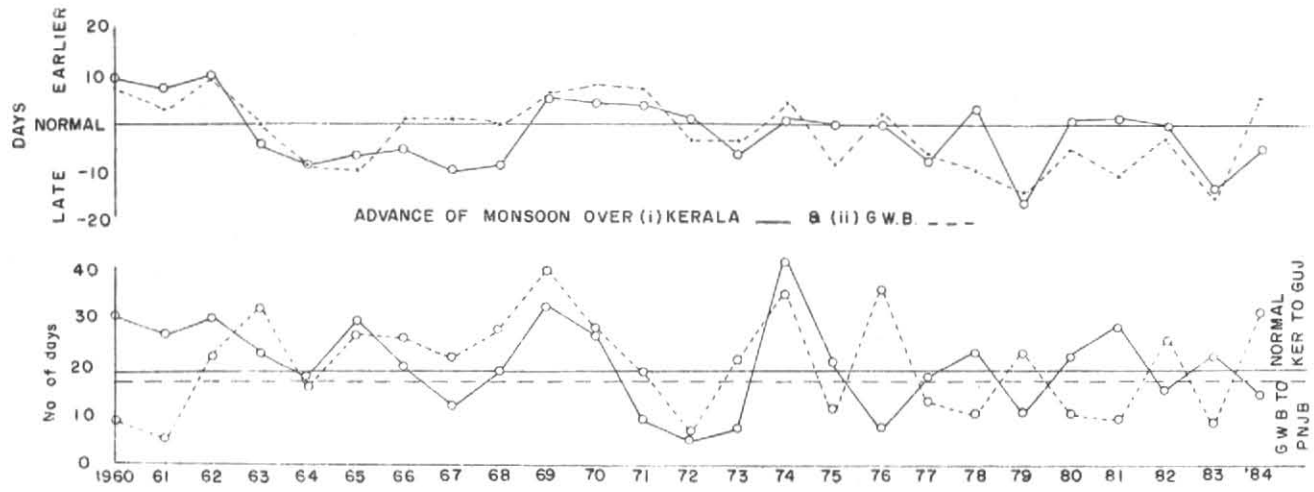

Fig. 1. Advance of monsoon over Kerala & Gangetic West Bengal and time taken for the progress of monsoon from Kerala to Gujarat and Gangetic West Bengal to Punjab

Fig. 1 shows the time taken (in days) for advance of monsoon from Kerala to Gujarat State and from Gangetic West Bengal to Punjab for the period 1960 to 1984 and the advance of monsoon over Kerala and Gangetic West Bengal with respect to the normal dates during the same period. From Fig. 1 the progress of monsoon from Kerala to Gujarat State and Gangetic West Bengal to Punjab can be broadly sub-divided into three categories, namely, (*i*) rapid progress (where the progress is earlier by 5 days or more than the normal) of the Arabian Sea branch while the progress of Bay branch is normal or delayed (where the progress is delayed by 5 days or more than the normal), (*ii*) rapid progress of the Bay branch when the progress of Arabian Sea branch is normal or delayed and (*iii*) Delayed progress of both the branches. The rapid progress of both the branches was observed only in the year 1972.

In the first category there were five cases (1967, '71, '73, '76 and '79). On three occasions (1971, '73 and '76) monsoon was ushered in over Gujarat State by a depression/cyclonic storm which formed over Arabian Sea. During 1979, monsoon was brought into Gujarat State by a depression, which developed over Bay and moved across Madhya Pradesh after crossing the east coast. In 1967 monsoon arrived along west coast in association with trough of low pressure.

In the second category there were 7 occasions of rapid progress of Bay branch of the monsoon (1960, '61, '75, '78, '80, '81 and '83) during the period of study. In all the cases the advance of monsoon over Kerala was either early or around normal date, while it was late over Gangetic West Bengal. The advance of monsoon over Gangetic West Bengal in all such cases was associated with a low pressure area or depression over northwest Bay. Subsequent rapid westward march of the monsoon took place with the westward movement of a low pressure/depression. Such systems strengthened the Arabian Sea branch of monsoon and advanced it over Gujarat State also.

In the third category, where the progress of both the Arabian Sea and the Bay branches was slow (1962, '63, '65, '69, '70, '74), intense synoptic systems were absent after the arrival of monsoon over Kerala and Gangetic West Bengal. However, the monsoon current was drawn to northwest India, in most of these years, by low pressure area or systems of higher intensity which formed over northwest Bay and neighbourhood and subsequently moved westwards.

It is seen from Fig. 1 that the advance of monsoon over Kerala (1960-62, 1969-71) earlier by 4 days or more than the normal date may be followed by early advance over Gangetic West Bengal provided there is development of low pressure area or system of higher intensity over north Bay of Bengal at the end of May or early June. It is also apparent from the study of other years that the onset of monsoon over Gangetic West Bengal is associated with the formation of a synoptic system over north Bay and neighbourhood.

3.2. *Activity of monsoon*

Table 1 shows the percentage departure of rainfall (June-September) of the sub-divisions, where the advance of monsoon was delayed by 7-10, 11-14 and 15 days or more respectively during the period 1960-1984. This table has been prepared with an aim to see the relation between the delayed advance of the monsoon and rainfall over the sub-divisions covering the area west of Gangetic West Bengal and north of Telangana. Since Peninsula receives northeast monsoon rain, sub-divisions covering this region are excluded from this table.

It is apparent from Table 1 that when the advance of monsoon was delayed by more than 10 days over Himachal Pradesh, Jammu & Kashmir, west Rajasthan and Gujarat State, the June to September rainfall was deficient over these sub-divisions. This may be due to relatively shorter duration of the monsoon over these areas. However, delayed advance of monsoon by 10 days or less over any sub-division does not indicate any definite rainfall deficiency over that sub-division. It appears that the deficiency of monsoon rainfall over any

TABLE 2

Harmonic analysis of the area weighted monsoon rainfall over India expressed as percentage of normal for the period 1951 to 1985

Harmonics	Period (years)	Amplitude	% variances explained
1	35	1.9	1.79
2	17.50	5.4	14.76
3	11.67	0.4	0.08
4	8.75	1.5	1.14
5	7.00	5.5	14.99
6	5.83	2.7	3.67
7	5.00	2.1	2.32
8	4.37	2.0	2.07
9	3.89	0.8	0.03
10	3.5	5.1	12.99
11	3.2	2.9	4.31
12	2.9	3.2	5.10
13	2.7	5.4	15.00
14	2.5	4.8	11.76
15	2.33	3.5	6.31
16	2.19	1.6	1.37
17	2.06	1.9	0.55

area is not only due to delayed advance but probably due to subdued monsoon activity for other synoptic reasons.

3.3. *Harmonic analysis of the rainfall data*

Incidence of drought in some parts or other of India is quite common. Severe droughts of 1965, 1972 & 1979 are well known. In Table 3 the area weighted monsoon rainfall expressed as percentage of normal over the country as a whole have been presented for a period of 35 years, *i.e.*, 1951 to 1985. It can be seen from the above table that there had been 6 cases of bad monsoon (area weighted rainfall percentage less than 90) years (1951, '65, '68, '72,' 79, '82) during the period of study. It may not be clear from these raw data whether there is a fixed periodicity of drought or not. In order to find out this the above rainfall series was subjected to harmonic analysis. Table 2 gives the amplitude and the period of all major harmonics down to the 17th alongwith the percentage of variance explained by the harmonics. The above analysis reveals that there are five major harmonics of quasi-periodicity of 17.5, 7, 3.5, 2.7 and 2.5 years which can explain in all about 70% of the variance of the rainfall and have reasonably large amplitudes. We may conclude that the monsoon rainfall is more or less random. But there is a quasi-periodicity in the range between 2.5 & 3.5 years which can explain about 48% of the variance and a periodicity of about 7 years and 17.5 years each of which can explain about 15% of variance of the monsoon rainfall. In other words, we may say that there is an outside chance of occurrence of bad monsoon every 2 to 3 years, 7 years and 17 years.

TABLE 3

Area weighted rainfall expressed as percentage of normal

Year	Rainfall (cm)	Year	Rainfall (cm)	Year	Rainfall (cm)
1951	82	1963	100	1974	95
1952	94	1964	107	1975	116
1953	114	1965	82	1976	101
1954	105	1966	93	1977	105
1955	110	1967	99	1978	108
1956	112	1968	88	1979	81
1957	91	1969	96	1980	104
1958	106	1970	112	1981	101
1959	108	1971	104	1982	87
1960	100	1972	79	1983	108
1961	113	1973	107	1984	96
1962	100			1985	92

4. Conclusions

(*i*) The development of a westward propagating well marked low or a system of higher intensity over north Bay is favourable for the advance of monsoon over northwest India and neighbourhood. It also helps rapid progress of monsoon.

(*ii*) The delayed onset of monsoon by more than 10 days over Himachal Pradesh, Jammu & Kashmir, west Rajasthan and Gujarat is likely to cause deficient monsoon rainfall over these areas.

(*iii*) Bad monsoon rainfall in two consecutive years is rather unlikely.

(*iv*) Triennial, seven and seventeen years cycle in monsoon rainfall have been observed.

Acknowledgements

The authors are grateful to the referee for valuable suggestions. The authors are thankful to S/Shri V. S. Sonawane and M. V. Mande for helping in collection of data and to Shri S.B. Sarode for preparing Fig. 1. They also like to extend their thanks to Shri N. K. Rajbanshi for typing the manuscript.

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