JOURNAL OF CLIMATOLOGY, VOL. 1, 153-165 (1981) UDC551.513.5:551.577.32(267.6)

ON THE NORTHWARD ADVANCE OF THE ITCZ AND THE ONSET OF THE SOUTHWEST MONSOON RAINS OVER THE SOUTHEAST BAY OF BENGAL

R. ANANTHAKRISHNAN, J. M. PATHAN AND S. S. ARALIKATTI
Indian Institute of Tropical Meteorology, Poona 411 005, India

Received 22 December 1981
Revised 20 February 1981

ABSTRACT

The pentad rainfall data of six stations in the Andaman-Nicobar group of islands for the period 1953-1978 have been analysed to study the northward advance of the ITCZ and the onset of the summer monsoon rainfall over the southeast Bay of Bengal. It is found that at the island stations south of 10°N the summer monsoon rains set in on the average towards the end of April which is a month in advance of the onset of the monsoon over the south Kerala coast of peninsular India. At the island stations to the north of 10°N the onset occurs about the first week of May. These dates are ahead of those shown in the existing diagrams giving the average onset dates of the summer monsoon over the southeast Bay of Bengal. Examination of the frequency and latitude of formation of cyclonic disturbances in the Bay of Bengal and the progressive seasonal variations of the tropospheric winds over the aerological station of Port Blair during April-May lend support to the earlier onset dates.

KEY WORDS ITCZ Southeast Bay of Bengal Pentad rainfall Onset of summer monsoon

INTRODUCTION

The circumstances associated with the onset of the summer monsoon rains were examined in detail during the international monsoon experiment (MONEX) of 1979. The special observational data collected during these studies focussed attention primarily on the Arabian Sea branch of the summer monsoon and the onset of rainfall on the west coast of India. Figure 1, based on the records of the India Meteorological Department (IMD), shows how the dates of onset of the southwest monsoon rains on the Kerala coast of South India have varied during the years 1901-1980. The onset dates show a dispersion from 11 May to 18 June with a pronounced peak towards the end of May and the beginning of June. The mean date of onset evaluated from the observed frequency distribution is 30 May with a standard deviation of 8·4 days. The median and mode of the onset frequencies fall on 1 June.

It is well-known that the commencement of the monsoon rains over the continental parts of southeast Asia, east of 90°E, is ahead of the advance of the monsoon over the Kerala coast of South India (Ramage, 1971; Rao, 1976). Figure 2, after Ramage (1971), shows the average onset dates of the rainy season of southern Asia and the adjoining sea areas. According to Ramage this diagram is based on data derived from authorities applying different criteria to define the onset. The diagram shows that over the eastern parts of the Bay of Bengal and the adjoining coastal areas, the summer monsoon rains commence on the average even before the middle of May. A similar diagram available in the published records of the IMD showing the progression of the onset of the southwest monsoon over India and the adjoining areas is shown in Figure 3 (IMD, 1943). This diagram which was prepared nearly 40 years ago is based primarily on rainfall criteria for fixing the onset dates. Normal pentad rainfall curves for stations were prepared and the middle date of the pentad showing the characteristic monsoon rise in the rainfall curve was taken as the onset date. The isolines of onset over the Bay of Bengal are shown broken because of lack of data and consequent uncertainty. It may be noted that there are appreciable

0196-1748/81/020153-13$01.30

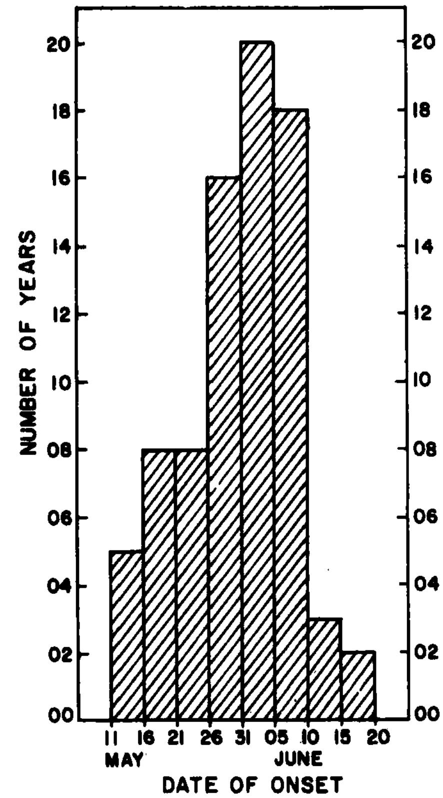

Figure 1. Onset of southwest monsoon over the South Kerala coast (1901–80)

differences between Figures 2 and 3 in the onset dates over the eastern parts of the Bay of Bengal and the adjoining coastal areas.

Since 1950, daily rainfall data from a number of observatory stations maintained by the IMD in the Andaman–Nicobar group of islands have become available. In this paper we present the results of a study of these data with particular reference to the northward advance of the ITCZ and the onset of summer monsoon rains over this part of the Bay of Bengal.

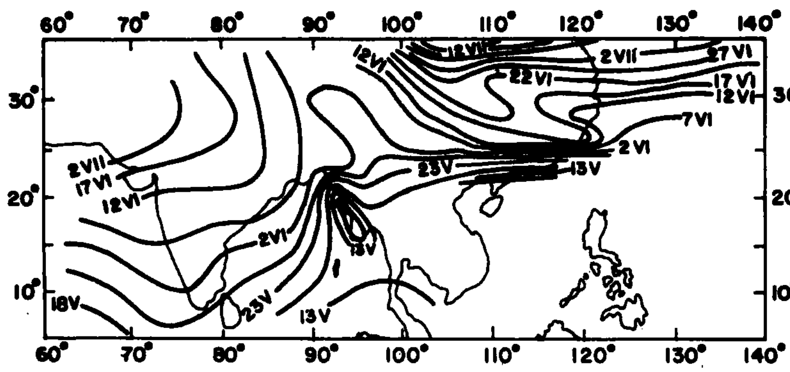

Figure 2. Average dates of onset of the rainy season

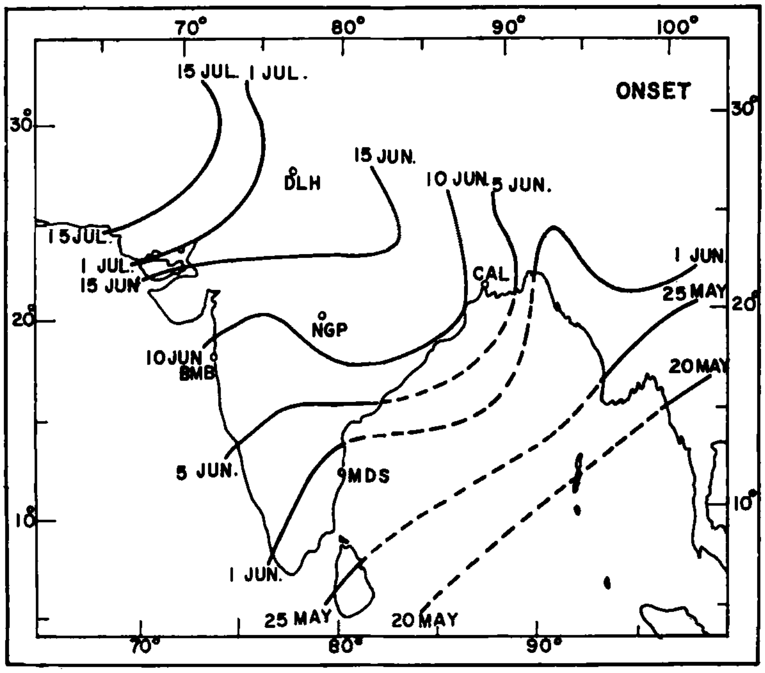

Figure 3. Progression of the onset of the southwest monsoon

CRITERIA FOR FIXING MONSOON ONSET DATE

The monsoon season is the principal rainy season for the monsoon areas and the commencement of this season is marked by an increase in rainfall along with changes in the various meteorological parameters that characterize the monsoon field. A sharp and sustained increase in rainfall appears to be the most dependable criterion for fixing the monsoon onset date and this has been in vogue in the IMD. For fixing the onset dates in individual years, the rainfall criterion is supplemented with other relevant synoptic features such as characteristic changes in the wind, cloud and moisture fields and the state of the sea, that occur during the onset phase of the monsoon. Although these criteria are not objective, they have been in use over a long period and have stood the test of time (Ananthakrishnan *et al.*, 1967, 1968).

The following is an extract from the GARP Publications Series No. 18 (WMO, 1976) relating to monsoon onset.

> 'In general the date of onset of the monsoon is determined by a marked increase in rainfall which is maintained over a reasonably long period. The precise definition of the "onset" has generally been a futile exercise. A rational view on this may be that the dependent variables of a monsoon system such as the motion field, cloudiness, rainfall, moisture, pressure and temperature all behave somewhat differently and no single definition would be adequate or satisfactory. The total monsoon problem with possible relative phase lags in its elements may be the only overall view one can offer for the onset. There is a fair amount of consistency in the date of arrival of monsoon rainfall over India each year. The variance of the date of onset is approximately one week'.

Despite the difficulties involved for the precise definition of the onset, the date of arrival of the monsoon is fixed year after year because of its practical and meteorological importance. A sharp and sustained increase in rainfall is a prime requisite for declaring the onset of the monsoon over a station or a group of stations.

The normal or average date of onset can be arrived at in two different ways. If the onset dates are available for a period of several years one can derive an average date from the frequency distribution as has been done for the Kerala coast. If long-term daily normal rainfall data are available, these can be examined to locate the date at which a sudden and persistent increase of rainfall sets in. This procedure has been followed for construction of Figure 3. The two methods should lead to nearly the same result if the data series is sufficiently long.

ISLAND OBSERVATORIES AND RAINFALL DATA

The chain of IMD observatories in the Andaman–Nicobar group of islands lies close to the meridian of 93°E and extends over the latitude belt from 7° to 13°N. We have studied the daily rainfall data of six of these stations for the period 1953–1978. The locations of the stations are shown in Figure 4. The coordinates of the stations and their average monthly and annual rainfall for the period covered by the study are given in Table I.

On the basis of their latitudinal location Kondul, Nan Cowry and Car Nicobar are designated as the 'south group' and Port Blair, Long Island and Maya Bandar as the 'north group'. February and March are the least rainy months at all the stations but there is a progressive increase of rainfall from north to south in these months. A marked increase in rainfall occurs at all the stations from April to May. The increase is 3 to 4 times at the south group and 6 to 8 times at the north group. May is the month of highest rainfall at the three southern stations. The maximum rainfall month shifts progressively to June and July at the northern stations. A second rainfall maximum occurs in October at the southern-most station of Kondul while it occurs in September at the other stations.

PENTAD RAINFALL AND MONSOON ONSET

For the study of monsoon onset we have to locate the date by which a marked and sustained increase in rainfall occurs at the stations every year. In a study of this nature it is found convenient to work with

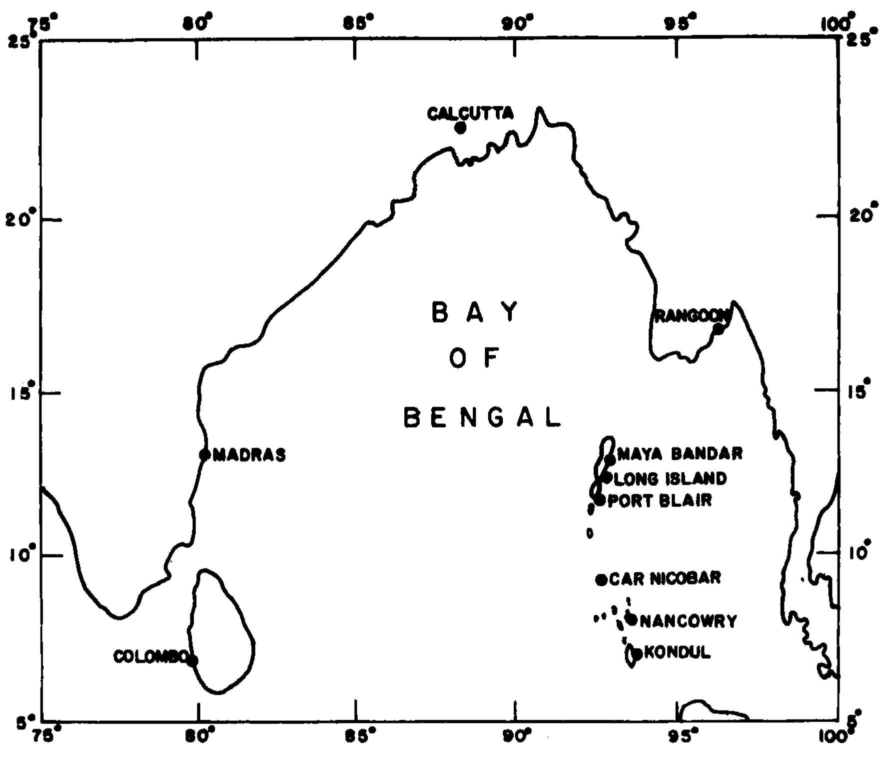

Figure 4. Locations of island stations in the Bay of Bengal

Table I. Coordinates of island stations and mean monthly and annual rainfall (mm): 1953–1978

Station	South group			North group		
	Kondul	Nan Cowry	Car Nicobar	Port Blair	Long Island	Maya Bandar
Latitude	07° 13'N	07° 59'	09° 10'	11° 40'	12° 25'	12° 55'
Longitude	93° 44'E	93° 32'	92° 50'	92° 43'	92° 56'	92° 55'
Jan	162 mm	108 mm	75 mm	46 mm	42 mm	26 mm
Feb	88	49	38	21	25	9
Mar	70	56	41	12	7	4
Apr	121	109	106	74	63	51
May	411	332	387	411	364	411
Jun	327	280	343	486	467	496
Jul	287	240	294	476	472	526
Aug	321	225	283	441	432	430
Sep	343	322	366	479	478	465
Oct	365	315	311	310	282	299
Nov	310	315	282	226	196	180
Dec	329	252	172	149	102	105
Annual	3134	2603	2698	3131	2930	3002

accumulated rainfall for 5–day periods (pentad rainfall) rather than daily rainfall data. This introduces some smoothing of the data without distortion of the rainfall trend. Thus, the daily rainfall data for each year were converted into 73 pentad rainfalls. Examination of the pentad rainfall series enables the location of the pentad at which a marked and sustained increase of rainfall occurs accompanying the northward advance of the ITCZ and the onset of the summer monsoon. The middle date of this pentad is taken as the onset date.

By way of example the rainfall data of the six stations for pentads 19 to 32 (covering the period from 1 April to 9 June) for the year 1973 are shown in Table II. A sharp and sustained increase of rainfall occurs at the southern stations from pentad 23 to 24. The middle date of pentad 24 which is 28 April is taken as the date of onset at these stations. A similar increase occurs at the northern group of stations a pentad later and so the date of onset at this group is reckoned as 3 May.

Table II. Pentad rainfall (mm) at the island stations: 1973

Pentad	Middle date	South group			North group		
		Kondul	Nan Cowry	Car Nicobar	Port Blair	Long Island	Maya Bandar
19	3 Apr	0	0	0	0	0	0
20	8 Apr	0	0	0	0	0	0
21	13 Apr	0	0	0	0	0	0
22	18 Apr	16·0	0	5.6	0	0	0
23	23 Apr	39·0	0	15·4	14·8	0	0
24	28 Apr	129·0	69·6	43·1	0	0	0
25	3 May	150·0	60·6	99·6	41·8	123·8	54·4
26	8 May	70·0	17·3	43·8	127·8	66·0	77·7
27	13 May	104·7	97·7	180·3	132·2	53·8	60·2
28	18 May	138·2	101·1	20·4	59·9	37·2	34·0
29	23 May	65·4	19·3	100·0	10·2	19·4	34·6
30	28 May	36·0	43·6	60·0	63·6	13·6	165·2
31	2 Jun	74·1	85·9	28·0	14·7	14·6	21·6
32	7 Jun	102·7	35·3	159·8	132·7	102·6	58·2

DATES OF ONSET IN INDIVIDUAL YEARS

The dates of onset in individual years were estimated separately for the south and north group of stations. In general the onset is characterized by an abrupt large increase of rainfall at all the stations of the group followed by good rain activity during the succeeding days. To make the choice of the onset pentad as objective as possible, the following two sets of criteria were adopted.

Criteria (A)

(i) All three stations of the group should record rainfall in the onset pentad.
(ii) At least two of the three stations should record rainfall exceeding 25 mm.
(iii) The onset pentad should be followed by at least two more pentads of sustained rainfall.

Criteria (B)

The same as (A) with the rainfall limit in (ii) increased to 50 mm.

The rainfall limits chosen are rather arbitrary, but were decided upon after examination of the data series. Specification of a higher limit such as 75 mm or 100 mm would lead to erroneous results in some years as the sharp increase in rainfall would have already occurred. The onset dates given by (A) would be somewhat earlier than the dates given by (B) but the difference will not be large since an appreciable increase in rainfall occurs at all the stations during the onset pentad in most of the years.

Table III. Percentage frequencies of onset in different pentads according to criteria (A) and (B)

Pentad		22	23	24	25	26	27	28	29	30	
Middle date		Apr 18	Apr 23	Apr 28	May 3	May 8	May 13	May 18	May 23	May 28	Mean pentad of onset
South group	(A)	8	4	32	12	12	24	4	4	–	25·2
	(B)	4	–	32	16	8	20	4	16	–	25·8
North group	(A)	–	–	24	20	12	24	8	12	–	26·1
	(B)	–	–	16	24	4	28	–	20	8	26·7

The onset dates determined in this manner lie between pentads 22 and 30. The percentage frequencies of onset during different pentads at the south and north group of stations are given in Table III. The mean onset pentads evaluated from the frequency distribution are given in the last column of the table. It is seen that 80 per cent of the onsets occur before the middle of May at both the south and north groups. On the average, the onset at the north group takes place about a pentad after the onset at the south group. Following criteria (A) the mean onset date at the south group is 4 May and at the north group 8 May. Following criteria (B) the dates are 6 May and 10 May. The frequency figures suggest that there are perhaps two preferred epochs of onset, one towards the end of April–beginning of May and the other towards the middle of May. However, this requires confirmation with a larger data sample since our study covers only a period of 25 years.

MEAN PENTAD RAINFALL AND MEAN DATE OF ONSET

The mean daily rainfall amounts for the stations were evaluated by combining the data for all the years. These were smoothed by taking 5-day running means, and pentad totals of the smoothed daily means were worked out. The mean pentad rainfall curves for the six stations utilizing the smoothed data are shown in Figures 5(a) to (f). The steep increase in rainfall that sets in towards the end of April can be seen at all the stations. The mean pentad rainfall amounts for the six stations as well as for the south and north groups for pentads 18 to 32 are shown in Table IV. Scrutiny of the rainfall figures for the 73 pentads of the year shows that the highest pentad rainfall at all the stations occurs between pentads 28 and 32. These values are underlined in the table.

At the southern-most station of Kondul a steep increase in rainfall occurs from pentad 23 to 24 and the high rainfall level is maintained thereafter. A similar rise is also noticed at the other two stations of

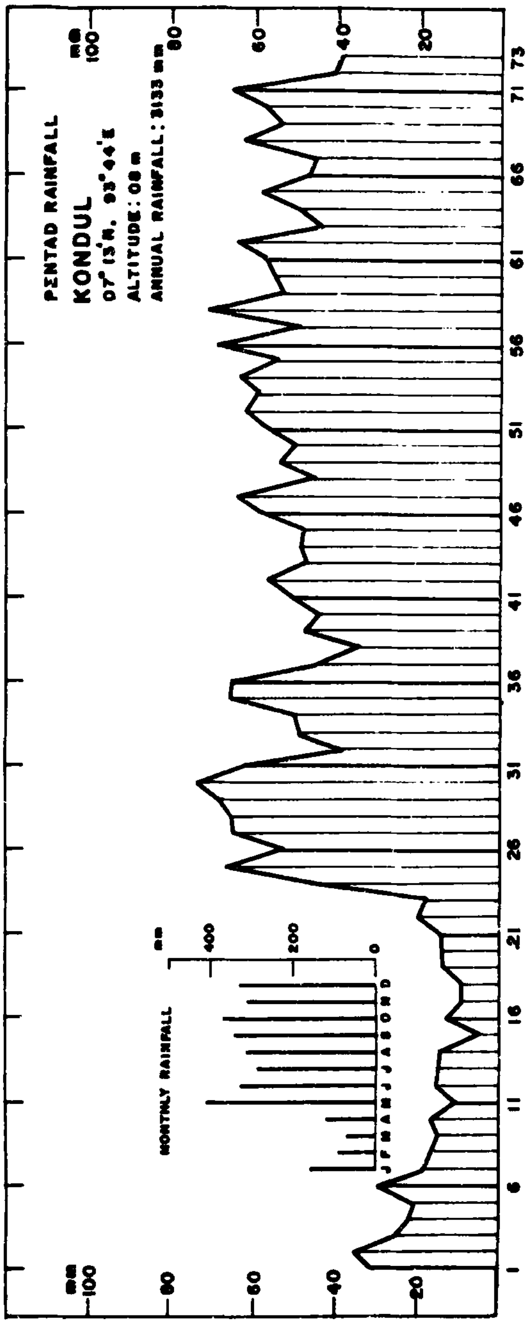

Figure 5(a). Pentad rainfall—Kondul

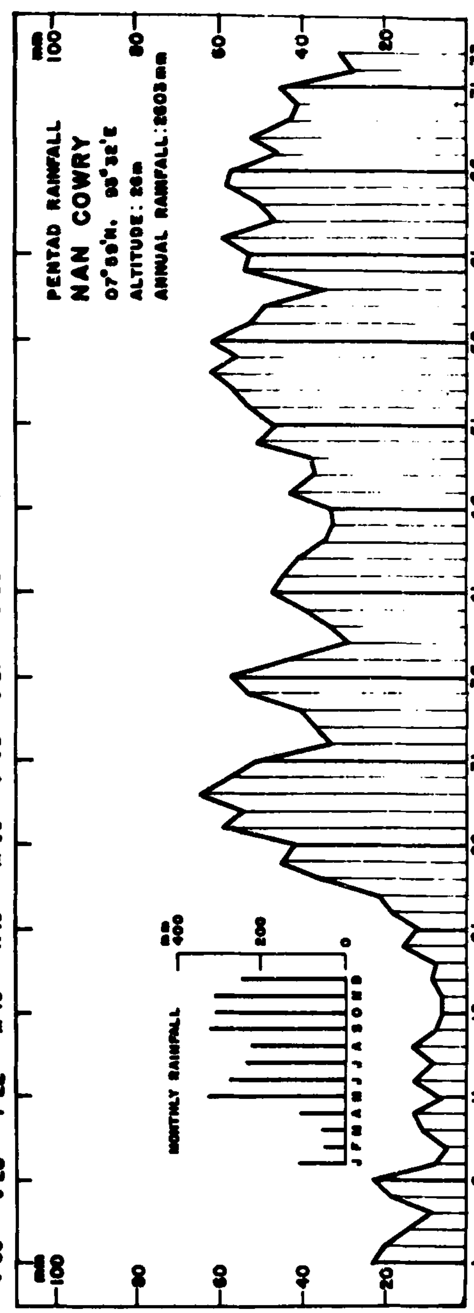

Figure 5(b). Pentad rainfall—Nan Cowry

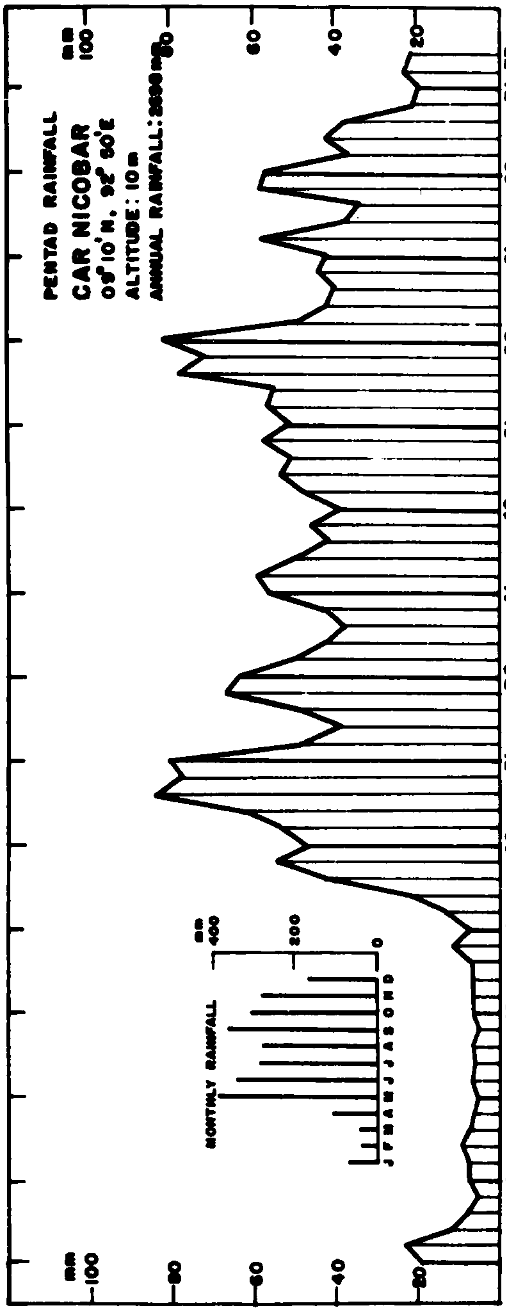

Figure 5(c). Pentad rainfall—Car Nicobar

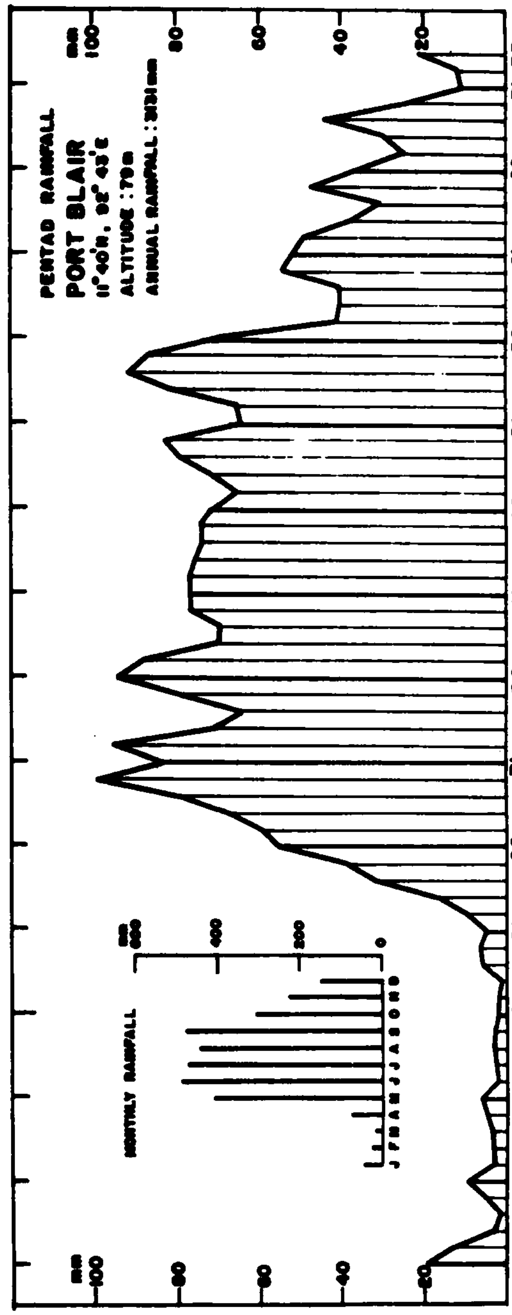

Figure 5(d). Pentad rainfall—Port Blair

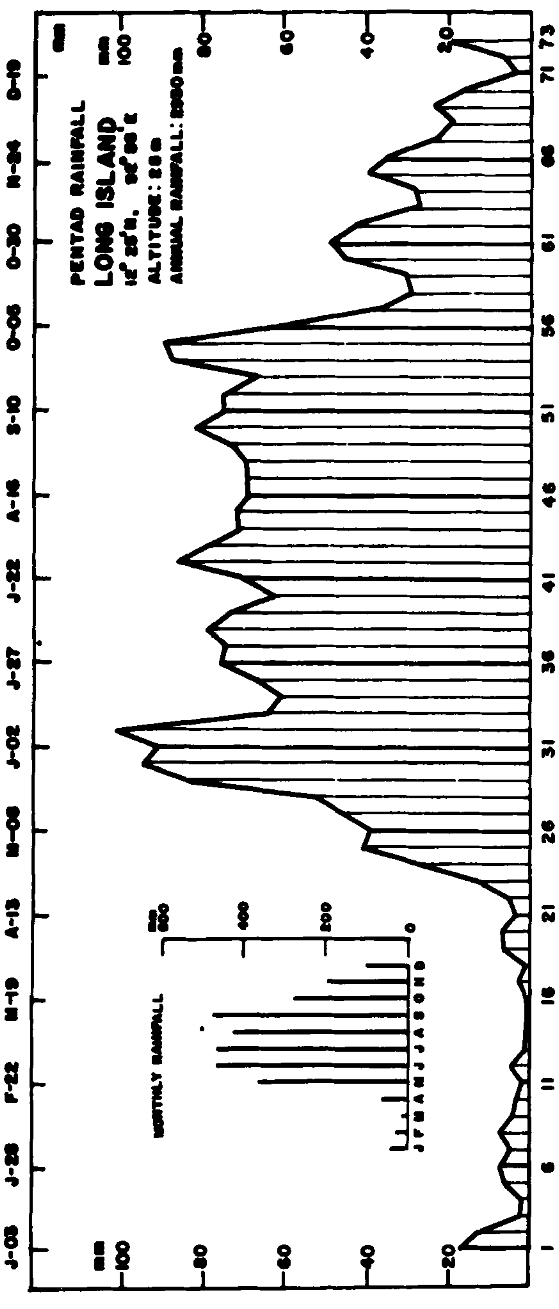

Figure 5(e). Pentad rainfall—Long Island

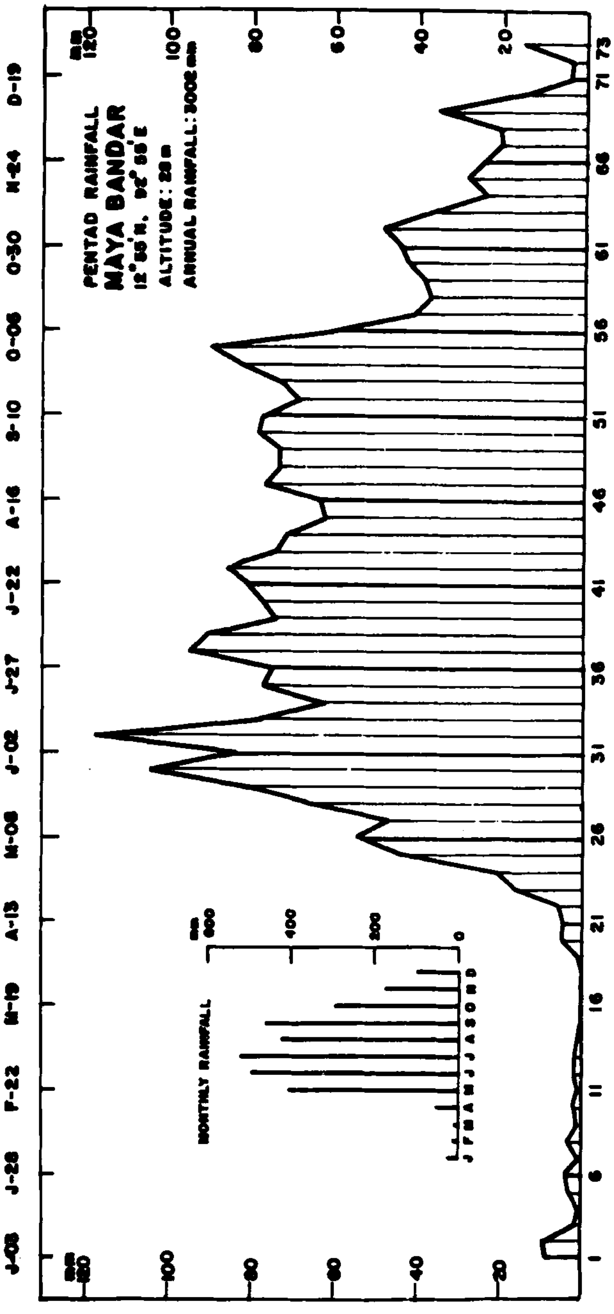

Figure 5(f). Pentad rainfall—Maya Bandar

Table IV. Mean pentad rainfall (mm) at the island stations (1953–1978)

		South group				North group			
Pentad	Middle date	Kondul	Nan Cowry	Car Nicobar	S. group	Port Blair	Long Island	Maya Bandar	N. group
18	29 Mar	9·4	8·5	6·7	8·1	1·0	1·3	0·0	0·9
19	3 Apr	14·0	7·7	7·3	9·4	5·3	6·1	1·0	4·2
20	8 Apr	14·1	15·5	11·4	13·7	6·2	6·8	5·2	6·1
21	13 Apr	14·2	12·1	7·6	11·2	4·4	3·6	4·3	4·2
22	18 Apr	19·6	18·4	13·0	16·9	9·1	5·5	5·8	6·9
23	23 Apr	18·0	21·3	21·8	20·5	15·2	13·1	16·3	14·8
24	28 Apr	44·9	35·9	42·7	41·0	31·1	26·4	20·6	26·1
25	3 May	66·4	44·7	53·7	54·6	37·9	40·6	45·2	41·2
26	8 May	52·4	42·1	46·6	47·0	54·8	39·5	54·2	49·7
27	13 May	65·4	58·7	53·3	58·8	58·3	46·0	47·6	50·7
28	18 May	65·1	54·2	61·5	60·0	66·4	53·3	66·5	62·2
29	23 May	68·2	<u>64·9</u>	<u>83·8</u>	<u>72·4</u>	78·3	82·6	81·1	80·3
30	28 May	<u>73·7</u>	58·1	76·9	69·5	<u>99·3</u>	94·7	103·9	99·3
31	2 Jun	61·4	50·7	80·1	64·4	83·3	91·5	83·7	85·9
32	7 Jun	38·3	34·1	48·5	40·6	95·1	<u>101·1</u>	<u>116·7</u>	<u>104·2</u>

the south group and for the group as a whole. The average group rainfall registers 100 per cent increase from pentad 23 to 24 and exceeds 40 mm. Thereafter the rainfall continues to increase reaching the maximum of 72 mm in pentad 29. The question arises where one should fix the onset of the monsoon season with a rainfall series of this kind. We have taken pentad 24 as the onset pentad, the middle date of which is 28 April. In this pentad the rainfall has reached more than 50 per cent of the maximum while it is only about 30 per cent of the maximum in the previous pentad. In the next pentad the rainfall exceeds 70 per cent of the maximum. This shows the steep rise in rainfall that sets in towards the end of April and the beginning of May at the southern stations.

At the northern group there is a progressive rapid increase of rainfall from pentad 23 onwards. The increase from pentad 23 to 25 is three-fold and the rainfall amount exceeds 40 mm in pentad 25. Thereafter the rainfall continues to increase reaching the highest value in pentad 30 at Port Blair and in pentad 32 at the other two stations. In the absence of objective criteria there is again difficulty in fixing the onset date. In pentad 25 the group rainfall has reached 40 per cent of the maximum while in the next pentad it has almost reached 50 per cent. We have taken pentad 26, the middle date of which is 8 May, as the onset pentad for the north group.

Considering the difficulties involved in the fixation of the onset, the dates arrived at from the study of the data for individual years and from the combined rainfall data for the total period are reasonably consistent.

DISCUSSION

Our study shows that the date of onset of the rainy season over the southeast Bay of Bengal and the Andaman Sea area is ahead of the dates shown in the Figures 2 and 3. There are two lines of evidence which lend support to the earlier onset dates. These are

(i) The seasonal displacement of the latitudinal zone of formation of cyclonic storms and depressions in the Bay of Bengal in the months of April and May.

(ii) The transition of the lower tropospheric zonal winds from easterly to westerly over Port Blair.

Before dealing with this, we shall briefly consider the significance of the term 'Inter-Tropical Convergence Zone' (ITCZ) in the present context. Wind data over the equatorial Indian Ocean region collected during the IIOE period gave evidence of the existence of two troughs or convergence zones, one to the north of the equator and the other to the south of it in all the months of the year (Raman, 1965; Ramage, 1968, 1971). These are referred to as the 'near equatorial trough' or 'near-equatorial convergence zone' of the respective hemispheres. Since the IIOE, there have been several studies relating to the ITCZ over the Indian Ocean area which have shown that it has a complex structure. A comprehensive review with further supporting evidence based on analysis of satellite cloud data over the Indian Ocean regarding the complex features of the ITCZ has been presented by Hobbs (1974). Without going into details, it may be stated that in the present paper we are concerned with the near-equatorial convergence zone of the northern hemishpere over the eastern parts of the Indian Ocean. For the sake of brevity we shall refer to this as the ITCZ.

The ITCZ is the place of origin of cyclonic storms and depressions in the Bay of Bengal. In the months of February and March the ITCZ is close to the equator and cyclonic activity is minimum in the Bay of Bengal. During the 80-year period 1891–1970, only four cyclonic disturbances formed in the Bay in each of these months (IMD, 1979). All these disturbances originated in the latitude zone 5° to 8·5°N. The ITCZ begins to shift northwards by April and along with this the frequency of cyclonic disturbances begins to increase, at first gradually and later rapidly. Table V gives the frequency of cyclonic storms and depressions that formed in the Bay of Bengal east of 85°E during the 80-year period in the months of April and May at 10-day intervals and in 5-degree latitude zones.

More than half of the cyclonic disturbances of April formed in the last week of the month. The places of origin of the disturbances lie in the latitude belt 6° to 14°N. The zone from 10° to 15°N is the source region of the cyclonic disturbances that originate in the Bay from the last week of April to the second week of May. Thereafter, the zone of formation shifts further northwards. The abrupt increase in rainfall that occurs at the island stations towards the end of April and the beginning of May is associated with the advance of the ITCZ over the stations. As is to be expected, this occurs earlier at the southern stations.

Port Blair is an aerological station in the island group. Long-term mean tropospheric winds from 900 to 150 mb for 10-day periods during April and May over Port Blair are shown in Figure 6. The zonal component of the low level winds would be easterly as long as the ITCZ is to the south of the station and would change to westerly when the trough has shifted to the north of the station. The mean zonal winds below 500 mb over Port Blair are weak easterlies up to the third week of April. Towards the end of the month the winds below 850 mb become very weak and unsteady and tend to veer towards south and southwest, while weak easterlies continue aloft up to 500 mb. The veering tendency of the low level winds continues and the mean wind for the first ten days of May shows that the direction has changed to SSW/SW below 700 mb. Thereafter the low level southwesterlies strengthen and deepen. A corresponding strengthening can be noticed in the easterly upper tropospheric winds at 200 and 150 mb from the beginning to the end of May. The observed wind changes indicate that the ITCZ begins affecting Port Blair by the end of April and shifts to the north of the station before 10 May. These facts are consistent with the observed large increase in rainfall at Port Blair from pentad 24 to 26 in Table IV.

Thus the rainfall analysis shows that at the south group of stations which lies approximately at the same latitude as the south Kerala coast, the onset of the summer monsoon rains occurs on the average about a month ahead of the onset on the Kerala coast, while at the north group, the onset is three

Table V. Cyclonic storms and depressions that formed in the Bay of Bengal east of 85°E in different latitudinal zones (1891–1970)

Latitude zone	April				May			
	1–10	11–20	21–30	Total	1–10	11–20	21–31	Total
5·0–10·0°N	2	3	4	9	–	1	1	2
10·1–15·0°N	2	4	11	17	10	14	5	29
15·1–20·0°N					–	3	11	14
Total	4	7	15	26	10	18	17	45

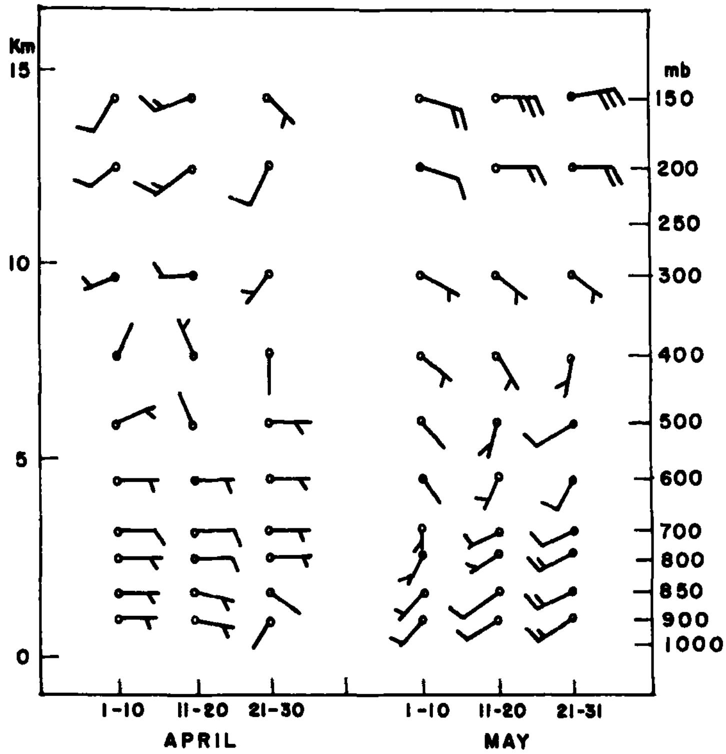

Figure 6. Upper winds over Port Blair: April—May

weeks earlier. The meteorological situation responsible for the earlier onset of the summer monsoon rains over the eastern parts of the Bay of Bengal and the adjoining land areas has been discussed by Desai (1967) and Ramage (1971). Desai has emphasized the role of surface and low level synoptic features while Ramage has stressed the importance of upper air divergence to the east of the trough near 90°E in the sub-tropical westerlies.

ACKNOWLEDGEMENTS

We wish to express our thanks to Shri V. Srinivasan, Director, Indian Ocean and Southern Hemisphere Analysis Centre, Poona, for valuable discussions and suggestions. We are grateful to the Director, Indian Institute of Tropical Meteorology, Poona, for affording necessary facilities to pursue this study. Our thanks are due to Shri R. C. Rahalkar for preparation of fair copies of the diagrams, to Shri R. P. Mali for taking photoprints and to Shri P. M. Bhanage and Shri K. V. S. Madhavan for typing the manuscript.

The rainfall data utilized in this study were kindly made available by the Deputy Director General of Meteorology (Climatology and Geophysics), Poona.

REFERENCES

Ananthakrishnan, R., Acharya, U. R. and Ramakrishnan, A. R. 1967. 'On the criteria for declaring the onset of the southwest monsoon over Kerala' *IMD Forecasting Manual*, No. IV—18.1.

Ananthakrishnan, R., Srinivasan, V., Ramakrishnan, A. R. and Jambunathan, R. 1968. 'Synoptic features associated with the onset of the southwest monsoon over Kerala', *IMD Forecasting Manyal*, No. IV—18.2.

Desai, B. N. 1967. 'Troughs of low pressure over the Gangetic valley during the southwest monsoon season and its implications—A suggested new approach', *Ind. Jour. Met. and Geophys.*, **18**, 473.

Hobbs, J. E. 1974. 'A complex intertropical convergence zone—Some examples from the Indian Ocean', *Weather*, **29**, 122.

India Meteorological Dept. (IMD) 1943. 'Climatological atlas for airmen', p. 3.

India Meteorological Dept. (IMD) 1979. 'Tracks of storms and depressions in the Bay of Bengal and the Arabian Sea (1877–1970)'.
Ramage, C. S. 1968. 'Problems of a monsoon ocean', *Weather*, **23**, 28.
Ramage, C. S. 1971. *Monsoon Meteorology*, Academic Press, New York and London, pp. 27, 151, 181.
Raman, C. R. V. 1965. 'Cyclonic vortices on either side of the equator and their implications', *Proc. of Symp. Meteorological Results of Int. Indian Ocean Expedition*, Bombay, p. 155.
Rao, Y. P. 1976. 'Southwest monsoon', Met. Monograph, Synoptic Meteorology, No. 1, *India Met. Dept.*, p. 42.
WMO 1976. *The Monsoon Experiment, GARP Publications* Series, No. 18, p. 10.