Indian J. Met. Hydrol. Geophys. (1978), **29**, 1 & 2, 36-46

551.577.2 : 551.513 : 551.553.21 (210.5-15 : 548)

Southward movement of ITCZ and consequent second maximum of rainfall over the southern parts of west coast of India

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ABSTRACT. African southwest monsoon is explained in terms of ITCZ. Different zones of rainfall regime with reference to the position of the ITCZ can be worked out. In some parts of West Africa, there are two maxima of rainfall and they are explained by the northward and southward journey of the ITCZ. Similar double maxima are found in southern parts of west coast of India. ITCZ during its northward journey cannot be properly identified over India. But it is possible to identify the ITCZ during its southward journey. A study of the rainfall pattern on the west coast of India has been made to show that the second maximum of rainfall over Kerala is not due to the onset of northeast monsoon but due to the southward journey of the ITCZ.

As a corollary, a new concept for the withdrawal of the southwest monsoon has been presented.

1. Introduction

Soliman (1958) in a study 'On the Inter-Tropical Front (ITF) and Inter-Tropical Convergence Zone (ITCZ) over Africa and Adjacent Oceans' found that while the ITCZ exists over ocean areas, it is replaced over the heated land masses by quasi-stationary fronts like the ITF, sandwiching the hot and dry continental air forming the thermal belt. Further, the ITCZ/ITF lying to the south of the heat belt, in case of Africa, can very well be considered to be the northern boundary of the cool moist monsoon winds from the southwest. Walker (1958) investigating 'The Monsoon in West Africa', recognised five weather zones — zones A to E — as associated with the Inter-Tropical Convergence Zone; zone D is the zone of the monsoon rains. Mukherjee and Massaquoi (1973) in a study of 'Rainfall in Sierra Leone' trace the ITCZ/ITF over West Africa by the presence of a sharp moisture discontinuity and recognise the presence of a double maxima of rainfall in the southwest monsoon area of West African coast, as associated with the northward and southward shift of zone D of Walker, in sympathy with the north-south movement of the ITCZ/ITF. The present paper is an investigation of the double maxima of rainfall in Kerala coast and an attempt to explore whether the secondary maximum of rainfall in September/October in Kerala coast is better explained in terms of the retreat of the ITCZ/ITF followed by the retreat of the monsoon winds rather than by the generally held view that it is related to the establishment of the northeasterly wind circulation in the southern parts of the Peninsula by October. The study is prompted by the fact that Kerala coast and coastal West Africa enjoy similar latitudinal and coastal situations, and have a similar sequence of advance and retreat of the southwesterly wind circulation during the monsoon season.

2. Presentation of problem

2.1. *Climatological approach*

A careful scrutiny of the pentad* rainfall patterns of individual stations in Peninsular India by

*The pentads coinciding with the months are as follows—May : 25-30; Jun : 31-36; Jul : 37-42; Aug : 43-49; Sep : 50-54; Oct : 55-61; Nov : 62-67.

Ananthakrishnan and Pathan (1971) reveal some interesting features. Table 1 gives the data regarding the months of peak rainfall and the pentads of the year during which rainfall is heaviest for selected meteorological stations on (*a*) the West Coast of India (*b*) the East Coast of India, south of Masulipatnam and (*c*) Tamil Nadu Interior, based upon normal rainfall data. From the pentad rainfall patterns, it can be seen that:

(*i*) In case of west coast stations the pentad rainfall patterns show that invariably the pentads 32 to 35 are the periods of the southwest monsoon maximum with a few subsidiary maxima in individual stations between pentads 32 and 42. The maximum in the pentads 32 to 35 (*viz.*, June), as distinct from July maximum and revealed in the monthly graph, is obviously associated with the heavy burst of the monsoon. However, secondary maxima in pentads between 32 and 42 coinciding with rain spells of a few days account for the July monthly maximum exceeding the June maximum.

(*ii*) It is also noted that in the stations to the north of Mangalore, there is only one season of rainfall coinciding with the period of the southwest monsoon.

(*iii*) However, all the Kerala stations and Lakshadweep islands (as represented by Minicoy) reveal a subsidiary maximum in the month of October, during the pentads 55 to 61, apart from the maximum in the southwest monsoon.

(*iv*) In case of east coast stations and stations in Tamil Nadu interior, the main rainy season coincides with the period October to December with November as the month of heaviest rainfall, although in a few interior stations, possibly due to local topography and orography, October receives slightly more rainfall than November. However, the pentad picture is slightly different. The pentads with rainfall peaks in the southern parts of Tamil Nadu as represented by Madurai, Palayamkottai and Pamban, show the maximum in the second half of October and a subsidiary maximum within the season towards the end of November or early December, while in the coastal stations of the Cauvery delta and further north, as in Nagapattinam, Cuddalore, Madras and Nellore as well as in the northern Tamil Nadu interior, the pentads of heaviest rainfall occur in November. It is hence interesting to note that within the season of rainfall in Tamil Nadu, the peak rainfall occurs earlier, in October itself, in the southern parts and later in the northern parts in November, and that the southern stations record a subsidiary maximum within the season in late November and early December, after a dry spell. In this context, the remarks of Ramamurthy (1949) are pertinent : "It is a common notion of all writers on rainfall that the rainfall zone tends to move south with the advance of the year, with a November maximum at Madras and Nagapattinam and a December maximum in Ramnad and Tirunelveli coasts. This is the result of a study of monthly averages. It is very surprising to note that this is not the case when half monthly basis is followed. The maximum occurs in the first half of November at Cuddalore, Nagapattinam and Vedaranyam, but in the second half of October at stations in the southern parts of the coast."

(*v*) Thus, from a comparison of the rainfall situations in Kerala and Tamil Nadu, an inference is drawn that the causal factors that underlie the secondary October maximum of Kerala stations and the primary October maximum of south Tamil Nadu stations are possibly the same while the primary maximum of November of north Tamil Nadu is possibly of a different origin. This inference is drawn on the basis that the November peak of Tamil Nadu coast is associated with trade wind circulation, on shore from the Bay, and that the northeasterly trades progressively advance from north to south, as the westerlies of the earlier season recede southwards.

2. 2. *The ITCZ/ITF* over India*

2. 2. 1. The advance of the southwest monsoon in Peninsular India is intimately linked up with the northward passage of the overhead noon Sun during the months April to June. As the Sun moves north, the zone of high temperatures progressively shifts from the southern parts of the Peninsula in mid-April to central parts in mid-May and to the northern parts in mid-June. Associated with the shifting of the high temperature zone northwards a trough of low pressure is formed and moves north.

2. 2. 2. The march of the ITCZ/ITF during the advance of the monsoon shows that it progressively shifts from 3°S in April to 6°N in May and to 25°N in June. June is a month of rapid northward movement of the ITCZ/ITF. July and

*The ITCZ/ITF is, here, taken as synonymous with the northern limit of the monsoon (NLM).

TABLE 1

Months and pentads of the year during which rainfall is the heaviest for selected meteorological stations

Station	Pentad		Monthly		Main rainy months
	Primary max.	Secondary max.	Primary max.	Secondary max.	
(a) West Coast					
(i) Maharashtra and Goa					
Bombay	35,38,41	53	Jul	—	Jun-Sep
Harnai	36,39	—	Jul	—	Jun-Sep
Ratnagiri	33,34,38	—	Jul	—	Jun-Sep
Devgarh	35,40	—	Jul	—	Jun-Sep
Goa	32,33,37	55	Jul	—	Jun-Sep
(ii) Karnataka					
Honavar	33,37,40	44,50	Jul	—	Jun-Sep
Mangalore	34,37,40	55,57	Jul	—	May-Oct
(iii) Kerala					
Calicut	33,36,38,40	55,58	Jul	Oct	May-Nov
Cochin	32,33	58	Jun	Oct	May-Nov
Alleppey	32,33	53,58,61	Jun	Oct	Apr-Nov
Trivandrum	34,35	60,61	Jun	Oct	May-Nov
Minicoy	32	56,61	Jun	Oct	May-Nov
(b) East Coast					
(i) Andhra Pradesh					
Nellore	61,63	28	Nov	—	Oct-Nov
(ii) Tamil Nadu					
Madras	61	—	Nov	—	Oct-Dec
Cuddalore	62,64	67,68	Nov	—	Oct-Dec
Nagapattinam	62,63,66	—	Nov	—	Oct-Dec
(c) Tamil Nadu Interior					
Pamban	60,67	19,20,21	Nov	Apr	Oct-Dec
Vellore	61	31	Nov	—	Aug-Nov
Madurai	58,62,66	21	Oct	May	Aug-Nov
Palayamkottai	60,61,68	21	Nov	May	Oct-Nov
Coimbatore	58,61	26	Oct	May	May, Oct-Nov
Palghat	37,41	58,59,60,62	Jul	Oct	May-Oct

TABLE 2

Monthly rainfall (in mm) normals of stations in West Africa*

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lagos (Nigeria)	40	57	100	115	215	336	150	59	214	222	77	41
Cotonou (Dahomey)	36	51	104	134	201	338	120	22	82	164	68	19
Lome (Togo)	17	37	80	104	153	202	55	16	48	153	21	6
Accra (Ghana)	16	37	73	82	145	193	49	16	40	80	38	18
Abidjan (Ivory coast)	26	42	120	169	366	608	200	34	55	225	188	111
Lungi (Siera Leone)	17	7	32	65	227	389	730	797	528	301	171	54
Sulima (Siera Leone)	27	23	58	116	395	776	965	660	700	415	216	71
Bissau (Portuguese Guinea)	1	1	0	1	17	175	472	682	435	195	42	2

*Taken from Climatological Normals for the period 1931-60, W.M.O. No. 117 TP 52.

August are the months when the ITCZ/ITF is quasi-stationary over its late June position, barring shifts northwards and southwards when the monsoon pulsates. The ITCZ/ITF runs invariably west to east. From August onwards, the ITCZ/ITF retreats southwards occupying about 20°N in September and 11°N in October. By November the ITCZ/ITF has shifted practically entirely to the south of Peninsular India in the North Indian Ocean (Fig. 1), as revealed by the climatological charts of the Indian Monsoon Area (India met. Dep. 1945).

2.2.3. A study of the position of ITCZ/ITF at various height levels 0·5, 1, 2, and 3 km during the months September, October and November reveal that this zone of convergence is inclined south to north from a higher to a lower elevation. Along this zone, the surface westerlies from the lower latitudes meet and converge with the northerlies and easterlies in the relatively higher latitudes; the former being maritime air and the latter the relatively dry continental air. It is also noted that the lower wind circulation, during September and October, to the north of the ITCZ is mainly northerly, while in November, they are mainly easterlies especially so over the Bay of Bengal and east coast of India.

2.2.4. Rainfall in the monsoon season is intimately related to the position of the ITCZ/ITF. With the progressive northward shifting of the ITCZ/ITF during the period of the advancing monsoon, the maritime moist Indian Ocean air is progressively sucked northwards. Soliman has shown that the NLM rains over Africa coincides with the ITF. This is possibly the case also in India. The southward retreat of the monsoon from September onwards is also associated with the southward movement of the ITCZ/ITF over Peninsular India, the zone of rain being bound on its northern limits by the ITCZ/ITF. A comparison with the rainfall picture during the advance and retreat of the monsoon with the position of the ITCZ over India in different months broadly confirms these facts.

2.2.5. During the period of retreat of the southwest monsoon, the ITCZ/ITF runs roughly west to east between 12°N and 14°N in October. The surface winds to the south of this limit are westerlies from the warm moist equatorial Indian Ocean, which possibly yield the rain in the Kerala coast and the south Tamil Nadu stations. In fact, during this period, the easterly winds over the Bay are found only north of Madras and, thus, cannot explain the rainfall associated with south Tamil Nadu and Kerala. On the other hand during November the ITCZ/ITF at a height of 0·5 km runs along the southern tip of Tamil Nadu and, at a height of 1 km or above further south. With this situation, the November rainfall cannot be explained as being due to the equatorial westerlies but are bound to be related to the easterlies across the Bay. The November rains on the east coast and Tamil Nadu interior can, thus, be explained as being due to the northeast trade circulation, while the decline of rains in Kerala during November can be explained as being due to the rain-shadow effect of the Ghats on the one hand and the absence of the equatorial westerly influence on the other.

2.2.6. Thus, the October maximum of Kerala coast and the southern Tamil Nadu are more directly related to the westerlies to the south of ITCZ/ITF, while the November maximum of east coast is related to the northeast trade circulation. This also explains the secondary pentad maximum within the season in late November-early December of south Tamil Nadu stations, as being related to the time lag in the approach of northeasterlies since they progress steadily from north to south from early November onwards, along with the ITCZ which shifts further southwards.

3. The West African parallel

3.1. Supporting evidence for this plausible explanation comes from parallel studies done elsewhere in the world where monsoon exists. The monsoon rhythms of the west coast of India and that of the west coast of Africa reveal great similarities. The southern parts of the west coast of India are nearly in the same latitudes. Both areas have similar seasons in the same months, including a southwest monsoon.

The African southwest monsoon winds originate in the southern hemisphere and cross the equator to hit West African coast. Mukherjee and Massaquoi (1973) trace the ITCZ over West Africa by the presence of a sharp moisture discontinuity. Over the Atlantic, it separates the northeast trades from the southwesterly winds which have crossed the equator. As is usual in the tropics, the weather over West Africa is seasonal. Here the seasons are most intimately connected with the movement of the ITCZ. In northern winter, the ITCZ is at its southernmost position. As the Sun moves north, a thermally induced

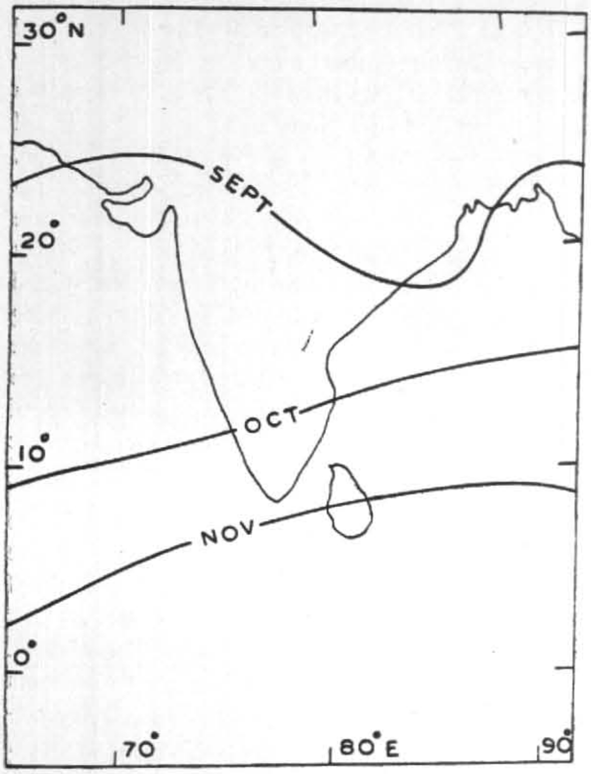

Fig. 1. Mean positions of the ITCZ/ITF during the months September to November

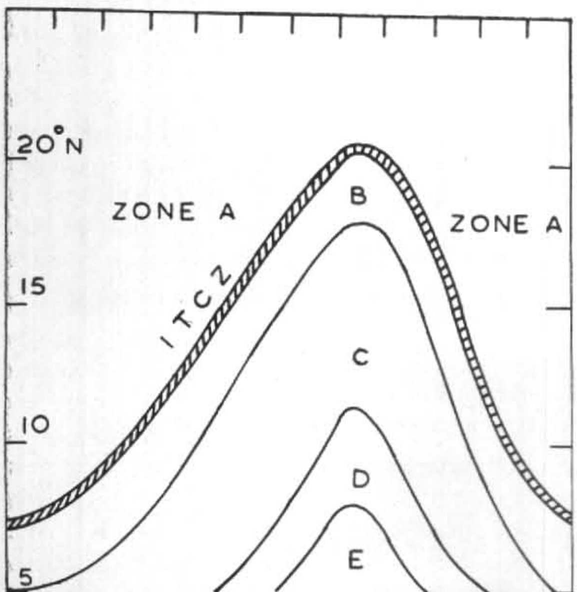

Fig. 2. Seasonal variations of weather zone boundaries over land along 0° Longitude

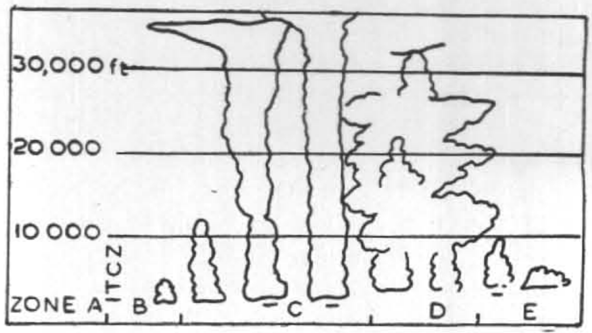

Fig. 3. Schematic diagram of cloud development in different zones

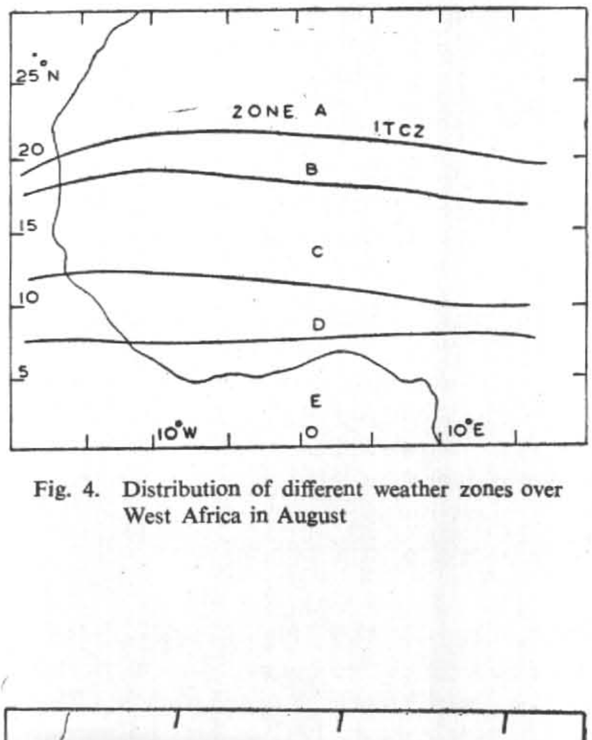

Fig. 4. Distribution of different weather zones over West Africa in August

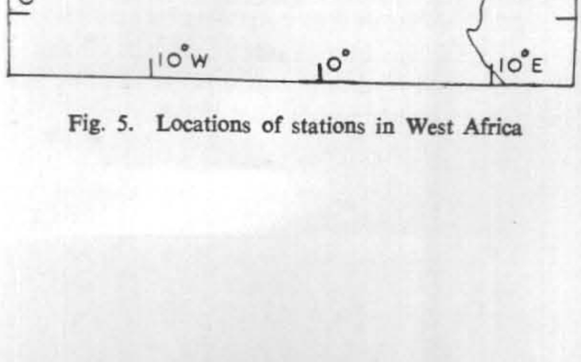

Fig. 5. Locations of stations in West Africa

"low" develops over land, and this causes the ITCZ to move northwards. The ITCZ follows the annual movement of the Sun lagging some four to eight weeks behind it. Thus, the Sun is in a most northerly position on 21 June whereas the ITCZ is in its most northerly position in early August. The Sun is in its most southerly position on 21 December, whereas the ITCZ is in its most southerly position towards the end of January. The movement over land of the ITCZ is slow in its northward journey, but faster in its southward motion.

Five weather zones are recognized by Walker as associated with the ITCZ, which have been labelled A to E from north to south :

Zone A—Dry hot air from the Sahara blows in this zone that lies to the north of the ITCZ.

Zone B—In this zone, just south of the ITCZ, a shallow moist layer on the surface is associated with disturbances of convective cloud scale, *i.e.*, ordinary cumulus with occasional growth of cumulonimbus over specially favourable areas of low level convergence.

Zone C—Here, to the south of zone B, the thickness of the moist layer increases. Meso-scale disturbances develop with horizontal linear dimension between 20 and 100 km. Thunderstorms and line squalls mostly develop in this zone.

Zone D—To the south of zone C is the zone of southwest monsoon. Depth of the westerly wind increases upto 1500-2000 ft, thus making the whole layer moist.

Zone E—In this zone, lying to the south of zone D moisture is high but the influence of anticyclonic conditions to the south causes a decrease in convergence. The rainfall, therefore, decreases.

The march of the ITCZ over West Africa along with the march of different zones is shown in Fig. 2. The cloud development, winds and moisture layer are schematically shown in Fig. 3, the distribution of zones over West Africa in August is indicated in Fig. 4. These figures explain very clearly the type of rainfall that can be expected during the different months of the year in different zones of West Africa. According to Walker, the northward movement of these weather zones is approximately at the rate of 100 miles a month, whereas the southward movement is much faster, at about 200 miles a month. The description of weather in the zones corresponds to conditions during the northward movement. During the southward movement zones C and D are rather difficult to separate and the relatively drier southern part of zone C is nearly non-existent. Places like Lagos (Nigeria), Cotonou (Dahomey), Lome (Togo), Accra (Ghana) and Sulima (Sierra Leone) in the west coast of Africa (Fig. 5) all lie wthin the southwest monsoon area of Africa and all of them, show a double maxima of rainfall, as seen from Table 2, taken from Climatological Normals for the period 1931-60 (W.M.O. 1971).

3.2. The primary rainfall maximum in most of the stations is in June and the secondary maximum in October in Lagos, Cotonou, Lome and Accra and Abidjan all between 5½°N and 6½°N, and in September in case of Sulima (7°N). The ITCZ is located about 17°N in June at the time of the advance of monsoon, about 18°N in September and 14°N in October (Fig. 2). Further it is relatively weak, existing as a mere humidity discontinuity, in later months of the year.

3.3. A comparison of the coastal West African situation with the situation in Kerala coast reveals thus a broad similarity in the ITCZ positions and the rainfall patterns. The double maxima of rainfall found in the Kerala coast as well as the West African coast thus seem to be explained in terms of the advance and retreat of westerly air currents, to the south of the ITCZ. However, the northward movement of the ITCZ/ITF in case of West Africa is relatively slower than the southward movement, while in case of the Indian parallel, the northward advancing movement of the ITCZ/ITF appears to be almost a frog leap while the southward, retreating movement is more gradual in September, October and November, whereafter the shift is more rapid. In India, a second maximum is not observed in the southwest monsoon rainfall regime, all along the west coast north of Kerala. This can be explained with reference to the Fig. 2. If the ITCZ/ITF movement in the Indian case has a similar pattern of zones as in West Africa, although possibly of different widths, then an area that falls entirely within zone D (of the southwest monsoon) during the northward and southward movement of the ITCZ, will experience continuous season of rainfall with a single peak, while areas that lie on the transition margin between zones D and E, will have double rainfall maxima coinciding with the northward and southward movements of the ITCZ, and have a decrease in rains in between when the area falls in zone E. This is possibly what happens in case of Kerala coast unlike the Maharashtra and Karnataka coasts that lie entirely in the zone D south of the ITCZ. A similar situation seems to be happening in West Africa as well, where, Lungi (8½°N) and Bissau (12°N), more northerly stations than Sulima record only a single maximum of rainfall.

4. Empirical testing

Having analysed the normal rainfall data over a period of fifty years in relation to the mean ITCZ/ITF locations over Peninsular India the inferences drawn are now tested to the empirical situations observed during a period of five years, 1971 to 1975, to confirm the hypotheses and the results drawn therefrom*. For this purpose, 11-day moving averages of rainfall for eleven stations in the west coast and four stations on the east coast were calculated for the period, May to December, (so as to include both the southwest monsoon season—advance as well as retreat—and the northeast trade wind period) based on *Indian Daily Weather Reports* for the period 1971-1975 and have been graphically shown. The ITCZ/ITF locations during these years for the period of September-November, have also been mapped. A comparative study of the ITCZ/ITF locations and the rainfall regimes yearwise reveal the following salient features.

4.1. *The rainfall patterns and ITCZ/ITF in 1971* (*Fig. 6*)—The first peak in the rainfall graph was experienced in the last week of May, right from Mangalore to Bombay, and the next one around 20 June. The first peak might be attributed to the pre-monsoon thunderstorms, since the actual date of onset of monsoon was 27 May in Trivandrum and 29 May in Bombay. The ITCZ/ITF was near Trivandrum on 26 May while by 31 May it had reached Bombay. The maximum occurring around 20 June appears to be the result of the firm establishment of the monsoon. On its southward movement, the ITCZ/ITF was near Bombay on 30 September, and near Honavar on 12 October. Accordingly, a maximum was seen all along the west coast in the last week of September. On the Tamil Nadu coast, two maxima were found, one in late October and the other in the first fortnight of December, even in the more northerly stations like Madras. In fact, the first rains in early October can be only attributed to the westerly air stream from the south, as the ITCZ/ITF is located almost about 14°N about mid-October. The late October and December maxima in these stations were recorded after the setting in of the northeast winds, following the southward shift of the ITCZ/ITF.

4.2. *The rainfall patterns and ITCZ/ITF in 1972* (*Fig. 7*)—The ITCZ/ITF was around Honavar on 19 June and north of Bombay on 21 June and north of Saurashtra on 23 June. This year, the monsoon temporarily advanced during May and withdrew by 23 May. The actual advance commenced on 19 June in Trivandrum and 21 June in Bombay. The rainfall maximum was found in late June, all along the west coast. During its southward movement, the ITCZ/ITF was around Bombay by 18/19 September and it had moved south of Trivandrum by 14 October. The rainfall maximum was found in the first half of September from Bombay to Devgarh. From Panjim to the south, the maximum was recorded only in the second half of September; more so in Aleppey, where the maximum was in the last week of September. The Kerala coast had received another maximum in the month of November and it was very marked in December. This rainfall maximum is due to the presence of a depression, off the Kerala coast. On the Tamil Nadu coast, the heavy rains were in late October and early December when the ITCZ/ITF had crossed the equator and the northeasterlies predominated Peninsular India. In fact, the first heavy rains were recorded in early October, which could be only attributed to the westerly air stream from the south, as the ITCZ/ITF was located almost about 14°N/15°N from 2 October to 11 October. The rainfall this year in Tamil Nadu seems to be entirely explained otherwise, in terms of the northeast wind circulation.

4.3. *The rainfall patterns and ITCZ/ITF in 1973* (*Fig. 8*)—The west coast received heavy rains in the first week of June, following the northward movement of the trough. On its southward journey, the ITCZ/ITF was near Bombay on 3 October and by 16 October it had crossed Trivandrum. The last rains in Bombay were recorded in the last week of September, before the southward shift of the ITCZ/ITF. On 9 October the ITCZ/ITF was over the latitude of Ratnagiri and the last rains from Devgarh to the south were in the first week of October. Aleppey

*The graphs are incomplete, as continuous data for the entire period of the year for all the years of investigation are not available.

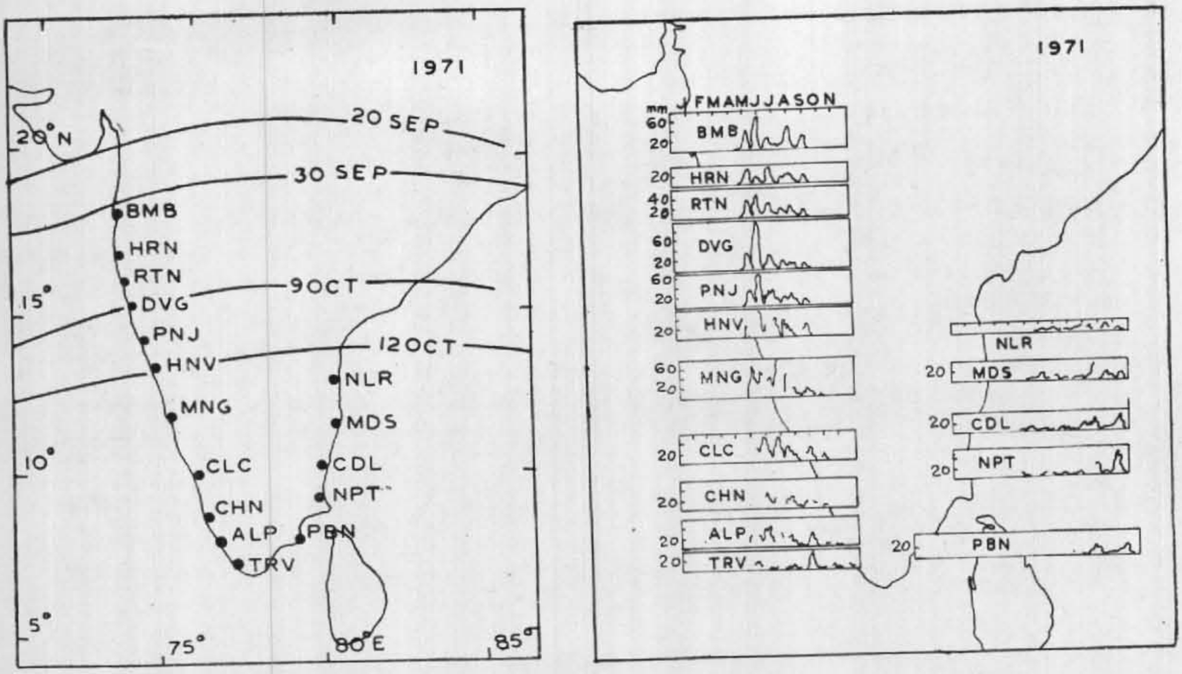

Fig. 6. Southward movement of the ITCZ and associated rainfall pattern during 1971

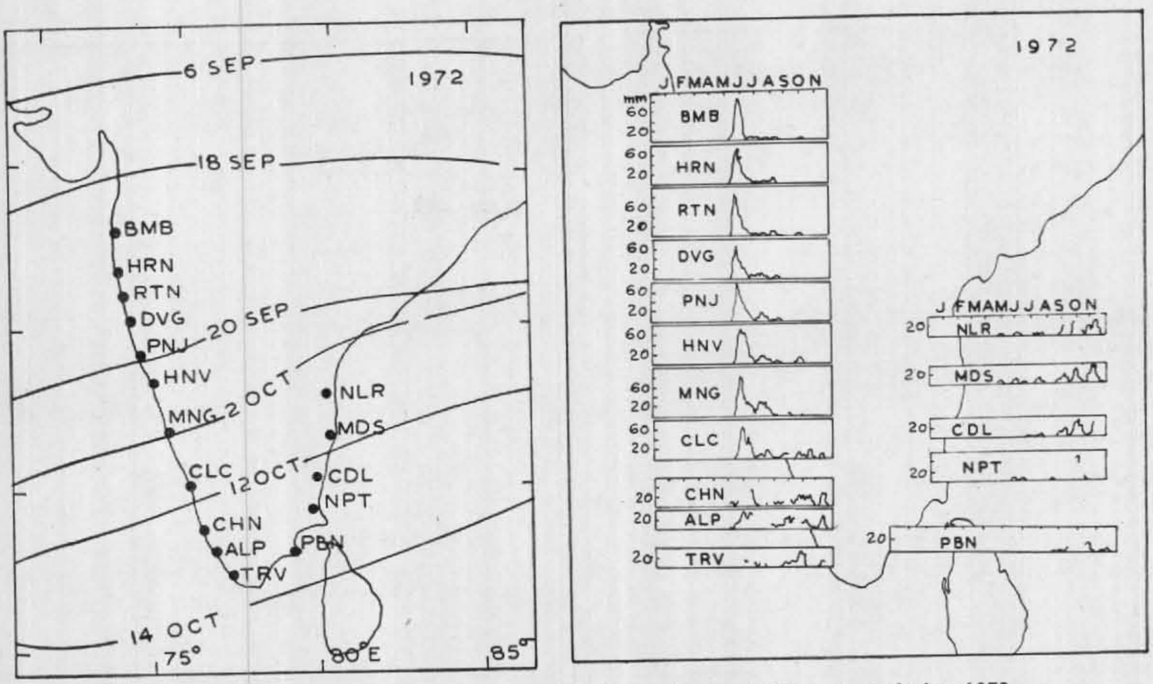

Fig. 7. Southward movement of the ITCZ and associated rainfall pattern during 1972

had received its last rains in the first half of October, while the ITCZ/ITF had passed south of the station around 16 October. The rainfall on the Tamil Nadu coast was in late October-early November, with predominant northeasterlies, after the southward movement of the ITCZ/ITF over the area.

4.4. *The rainfall patterns and ITCZ/ITF in 1974* (*Fig. 9*)—From Trivandrum to Mangalore, the stations received the burst of monsoon rainfall in the last week of May, while from Honavar northward, the stations had received their first heavy monsoon rains in mid-June or second fortnight of June. Harnai and Bombay received their heavy

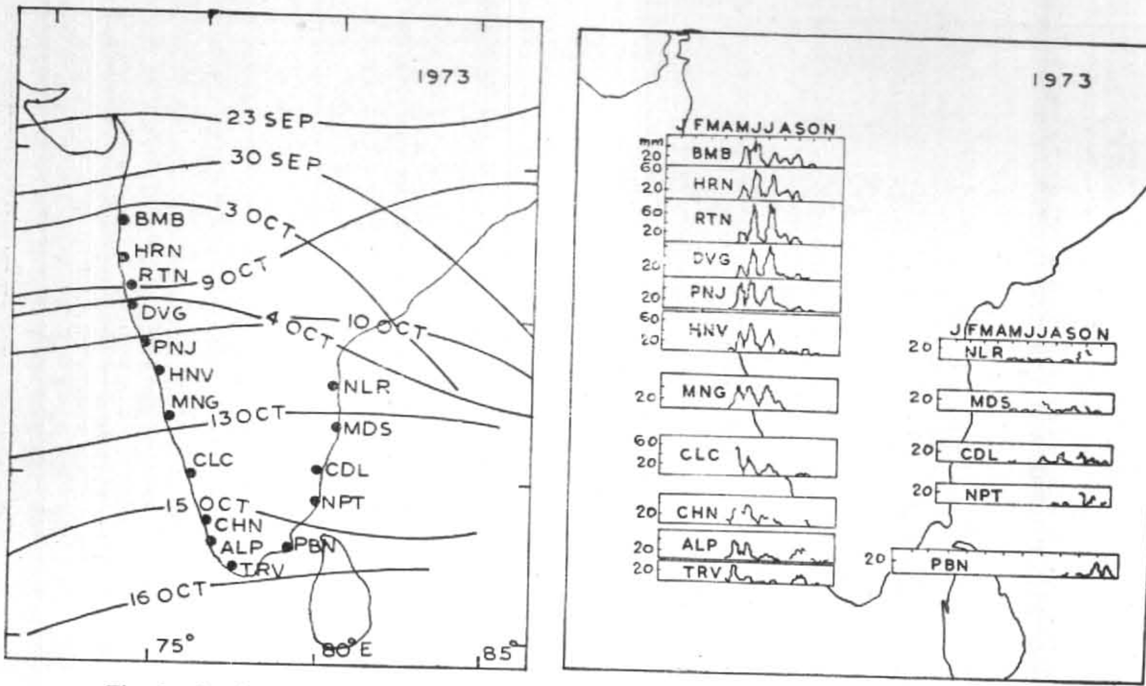

Fig. 8. Southward movement of the ITCZ and associated rainfall pattern during 1973

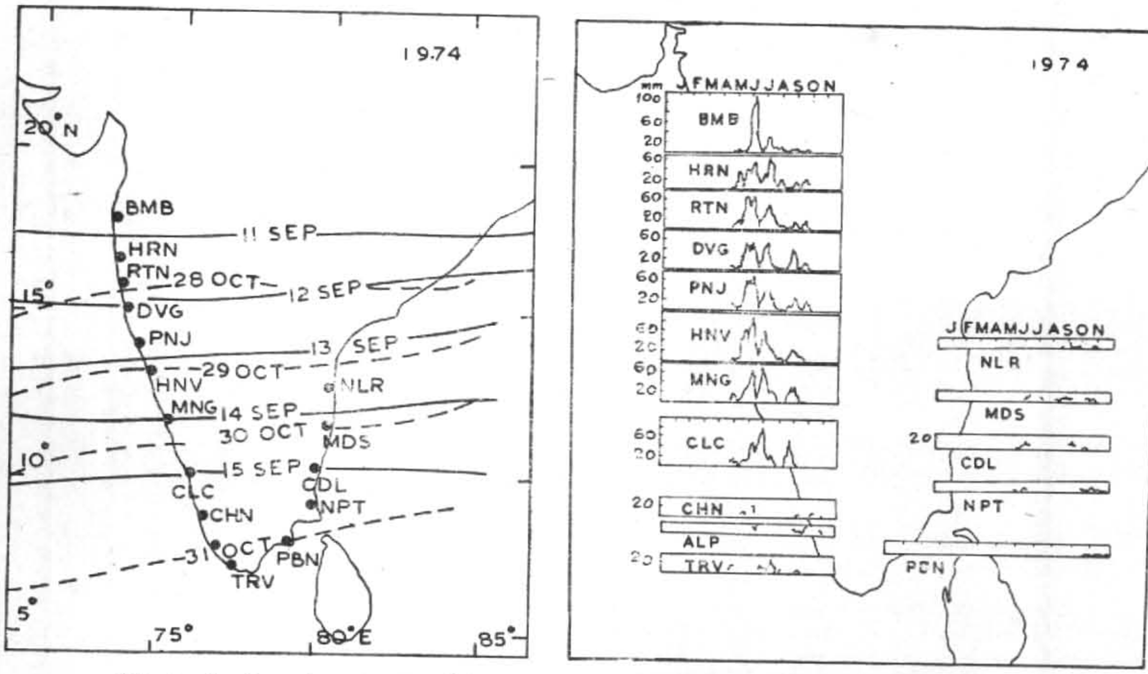

Fig. 9. Southward movement of the ITCZ and associated rainfall pattern during 1974

rains only in early July, since the northern limits of the monsoon moved northwards from Harnai only after 20 June. In this year, an oscillation was found in the southward movement of the ITCZ/ITF. The ITCZ/ITF which was over Harnai on 11 September was located over Calicut on 15 September. Since the ITCZ/ITF moved rapidly, there was hardly any secondary rainfall maximum in the southern parts of the west coast of India. On reaching Calicut, the ITCZ/ITF once again moved northwards to Bombay (22 September), and it was for some reason stuck up there for more than a month. It is on this northward journey that ITCZ/ITF gave rainfall maximum to the

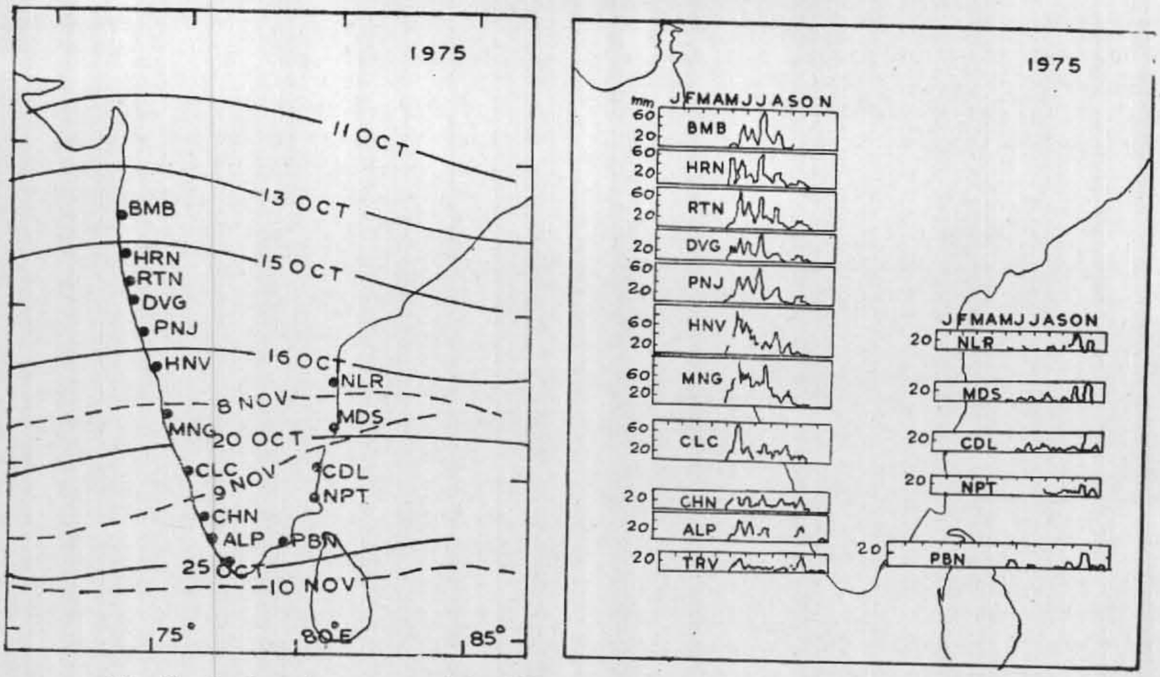

Fig. 10. Southward movement of the ITCZ and associated rainfall pattern during 1975

west coast of India, in late September. On 28 October, the ITCZ/ITF was seen around Ratnagiri and by 31 October around Trivandrum on its final southward movement. This rapid movement of the ITCZ/ITF especially between Devgarh and Trivandrum (3 days) resulted in the late rains being clearly seen to the north of Panjim, but not to its south. The stations from Bombay to Panjim recorded a second rainfall maximum in mid-October. Panjim received its maximum in the second fortnight of October. The Tamil Nadu coast received the maximum rains in the second fortnight of November. This was the year of droughts in Tamil Nadu, since the northeast trades had failed and yet a fairly good correlation was seen between the movement of the ITCZ/ITF and the rainfall maximum on the west coast of India. The failure of the northeast trades on Tamil Nadu in this year was obviously due to the second northward movement of the ITCZ/ITF in September/October and its final retreat in late October, thereby delaying the onset of the northeasterlies till late November.

4. 5. *The rainfall patterns and ITCZ/ITF in 1975* (*Fig. 10*)—The first maximum of rainfall in Trivandrum was in the middle of June and northward towards Bombay the maximum was in late June. On its southward migration, the ITCZ/ITF, which was on 15 October near Harnai, had reached Trivandrum by 25 October. Bombay had its last heavy rains in the first half of October and Honavar in mid-October, while the ITCZ/ITF moved over Honavar by 20 October. Though some rain occurred in October in the Kerala stations, prior to the southward passage of the ITCZ/ITF, a relatively higher rainfall was recorded in early November after the passage of the ITCZ/ITF over these latitudes. These stations, like that of the previous year, owe their rainfall maximum to the oscillation in the movement of the ITCZ/ITF over the southern parts of the Peninsula. The ITCZ/ITF moved northwards from 25 October on Trivandrum to 30 October on Mangalore, and remained there till 8 November before its final southward movement. On the east coast in Nellore and Madras, a double rainfall maximum was recorded, while further south in Cuddalore and Nagapattinam, only a single maximum of rains was recorded in November after the establishment of the northeast wind circulation. The first rain maximum could only be attributed to the westerlies, since the ITCZ/ITF was found north of these stations for more than ten days.

5. Summary and conclusions

From the foregoing discussions, the following broad generalisations can be drawn—

(1) On the west coast, the first rainfall maximum occurs after the northern limit of the

monsoon has traversed the area, while on its southward movement the second rainfall maximum is recorded south of the ITCZ/ITF and prior to the passage of the ITCZ/ITF over the area. This second maximum is felt more distinctly over the Kerala stations.

(2) The second maximum of rainfall on the west coast of India is recorded earlier than the maximum on the east coast, north of the Cauvery delta.

(3) The Tamil Nadu coast records its main rainfall maximum only after the ITCZ/ITF has completely moved to the south of Kanya Kumari, and this happens only after the northeast trades are firmly established over the southern parts of the Peninsula.

(4) The second maximum of rainfall along the west coast is received from the southwesterly winds, while the primary rainfall maximum along the Tamil Nadu coast is received from the northeasterlies, though in southern Tamil Nadu, the early October rains are due to the same westerlies as in Kerala coast.

(5) Thus it can be established that the second maximum of rainfall over the Kerala coast is not due to the onset of northeast monsoon but due to the southward journey of the ITCZ. As a corollary, we get a new concept for the withdrawal of the southwest monsoon.

Acknowledgements

Our grateful thanks are due to (1) Shri B. Arunachalam, Reader, University of Bombay, for going through the manuscript carefully and giving his valuable suggestions, (2) Dr. D.R.K. Rao, Reader Indian Institute of Geomagnetism, Bombay, for his help in processing the data, (3) Shri V.S. Rao, Cartographer, University of Bombay, for help in preparation of the maps and diagrams, and (4) the staff of the Regional Meteorological Centre, Bombay, who have given their utmost co-operation in this study.

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