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A statistical technique for determination of withdrawal of northeast monsoon over coastal Tamilnadu

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सार — वर्ष 1901 से 1990 तक की 90 वर्षों की अवधि के दौरान तटीय तमिलनाडु में उत्तर पूर्वी मानसून की वापसी की वास्तविक तिथियों का पता लगाया गया है। निर्धारण की यह पद्धति साधारणतया सितम्बर से फरवरी तक के छः महीनों में तटीय तमिलनाडु के केन्द्रों पर हुई दैनिक वर्षा के स्थानिक वितरण से संबंधित एक पांच दिवसीय सूची पर आधारित है। 23 नवम्बर से 28 जनवरी की अवधि और 13.6 दिनों की मानक घट बढ़ के साथ मानसून की वापसी की सामान्य तिथि 27 दिसम्बर पाई गई है। उत्तरी पूर्वी मानसून की अवधि के वितरण के अनुसार इसकी औसत अवधि 67.5 दिन मानक घट बढ़ 14.9 दिन और अवधि का विस्तार 26 से 102 दिन तक पाया गया है। इस अवधि में 36.7 प्रतिशत वर्षों में मानसून की वापसी की अवधि आगामी वर्ष के जनवरी माह तक पाई गई है। मानसून की वापसी की सामान्य तिथि के संदर्भ में दैनिक सामान्य वर्षा और उसके अंतर के विषय में चर्चा की गई है। अध्यारोपित कालावधि विश्लेषण के अनुप्रयोग द्वारा मानसून की वापसी के समय वर्षा में औसत कमी का पता लगाया गया है। यह भी पता चला है कि जिन वर्षों में मानसून की वापसी जनवरी में हुई उन वर्षों में मानसून की वापसी से पहले उत्तरी पूर्वी मानसून की तीव्रता उतनी ही थी जितनी कि दिसम्बर में मानसून की वापसी वाले वर्षों में पाई गई थी। उत्तरी पूर्वी मानसून की वापसी के कुछ मामलों की सचित्र व्याख्या की गई है। चूंकि मानसून की वापसी से संबंधित किसी भी निश्चित गतिकीय अथवा तापगतिकीय सिद्धांत के अभिलक्षणों का विशेष रूप से पता नहीं चल सका है इसलिए दैनिक सामान्य वर्षा के व्यवहार को एकमात्र मापदंड मानते हुए, यह तकनीक मूलत; सांख्यिकीय है। तमिलनाडु के तटीय क्षेत्रों से उत्तरी पूर्वी मानसून की वापसी से संबंधित विशिष्ट तापगतिकीय और गतिकीय सिद्धांत के अभिलक्षणों की भी पहचान नहीं की जा सकी है।

ABSTRACT. The withdrawal dates of northeast monsoon over coastal Tamil Nadu for the 90-year period (1901-90) have been objectively derived. The methodology of determination was generally based on an index based on the spatial distribution of daily rainfall over stations of coastal Tamil Nadu, over a 5-day pentad for the six month period, September-February. The normal withdrawal date thus obtained was 27 December with a standard deviation of 13.6 days and range 23 November-28 January. The duration of northeast monsoon was distributed with mean 67.5 days, standard deviation 14.9 days and range 26-102 days. During 36.7 % of years the withdrawal spilled over to January of next year. The daily normal rainfall and its difference filter have been discussed with reference to the normal date of withdrawal. The average decrease of rainfall at the time of withdrawal has been derived by application of superposed epoch analysis. It has further been shown that during years when the withdrawal took place in January the intensity of northeast monsoon prior to withdrawal was as intense as in years when withdrawal occurred in December. A few cases of northeast monsoon withdrawal have been illustrated with diagrams. As no definite dynamic or thermodynamic features could be uniquely identified which are associated with the withdrawal, this technique is basically statistical, considering the behaviour of the daily normal rainfall as the sole criterion. Unique thermodynamic and dynamic features are not identifiable which are associated with the withdrawal of northeast monsoon over coastal Tamilnadu.

Key words — Northeast monsoon, Onset, Withdrawal, Coastal Tamil Nadu, Daily rainfall index, Significant rain spell, Liquid water content.

1. Introduction

The northeast monsoon is experienced during October-December over the southern meteorological sub-divisions of coastal Andhra Pradesh, Rayalaseema, south interior Karnataka, Kerala and Tamil Nadu. Over Tamil Nadu, the northeast monsoon gives more rainfall than the southwest monsoon, which otherwise is the major rain giving phenomena for the rest of India. India Meteorological Department (IMD 1973) provides a detailed description of northeast monsoon. Various other aspects of the season have been studied by Krishna Rao and Jagannathan (1953), Rao (1963) and Pant *et al.* (1980).

The onset dates of northeast monsoon over coastal Tamil Nadu (CTN), where the northeast monsoon rainfall is

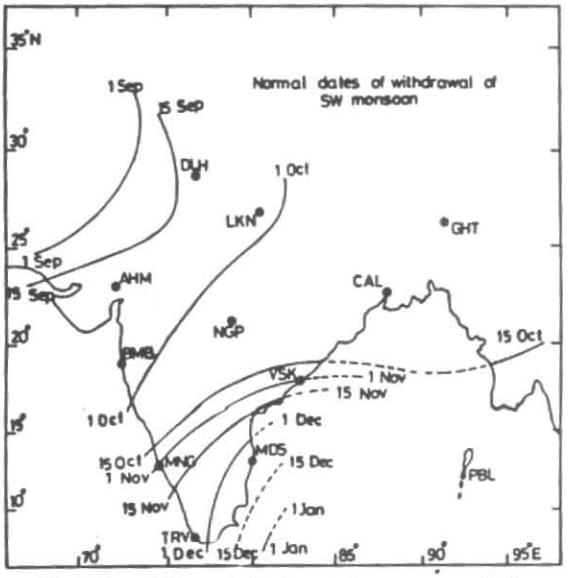


Fig.1. Normal dates of withdrawal of monsoon over India

heavier and the activity well pronounced than over the interior parts, have been determined for the 90-year period, 1901-90, by (Raj 1992). In this study the determination of onset dates was based on the daily rainfall data of stations of CTN besides the change in circulation pattern over Tamil Nadu and was carried out in accordance with a set of rules. Whether it would be possible to determine the dates of withdrawal of northeast monsoon also in a similar fashion is an obvious question. Fig.1 presents the 'normal dates of withdrawal of monsoon' based on IMD (1943). It is quite obvious that the dates that correspond to the region south of 15°N pertain to withdrawal of northeast monsoon only. This aspect was discussed in Raj and Jamadar (1990) and normal dates of withdrawal of southwest and northeast monsoon were determined, based on the difference filter of daily normal rainfall of the regions under question. According to this study, the normal date of northeast monsoon withdrawal for CTN is 7 December.

Whereas, the onset of northeast monsoon in recent years has been regularly declared by IMD (dates listed by Raj 1992), such a practice in respect of withdrawal has commenced only since 1991. The objective of this study is to determine the year-to-year withdrawal dates of northeast monsoon, over CTN for a long period, by following, by and large some objective criteria to arrive at a uniform set of withdrawal dates which would complement the onset dates derived by Raj (1992). The statistical properties of the dates thus arrived at, their effect on the daily normal rainfall distribution are also proposed to be studied.

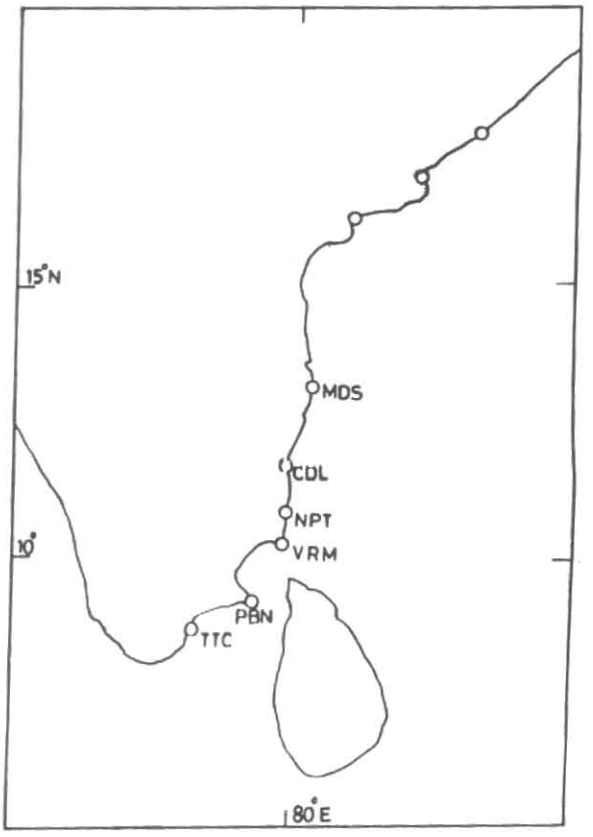


Fig.2. Spatial distribution of the stations considered in the study

2. Rainfall data and methodology

The 90-year period 1901-90 was chosen as the period of study. Six stations located in CTN, *viz.*, Madras, Cuddalore, Nagapattinam, Vedaranyam, Pamban and Tuticorin formed the raingauge network (Fig.2). Available daily rainfall data of 1960-86 for Vedaranyam, of 1954-80 for Tuticorin and of 1901-86 for the remaining four stations for the six month period, 1 September to 28 February, were obtained from the National Data Centre, IMD, Pune for the above six stations. Data for 1987-90 were extracted from the records/publications of IMD. As the duration of northeast monsoon according to standard IMD definition is October-December, we included the data from September-February (of next year) to accommodate any possible spill-over of the northeast monsoon rains into the succeeding winter season of January-February.

In order to address the problem of formulating a set of rules to determine the withdrawal dates of northeast monsoon, we first discuss the normal wind flow over CTN during the year. Fig.3 depicts the monthly variation of 0000 UTC normal upper wind over Madras for all the 12 months of the year at six levels of the atmosphere, *viz.*, 1000, 850,

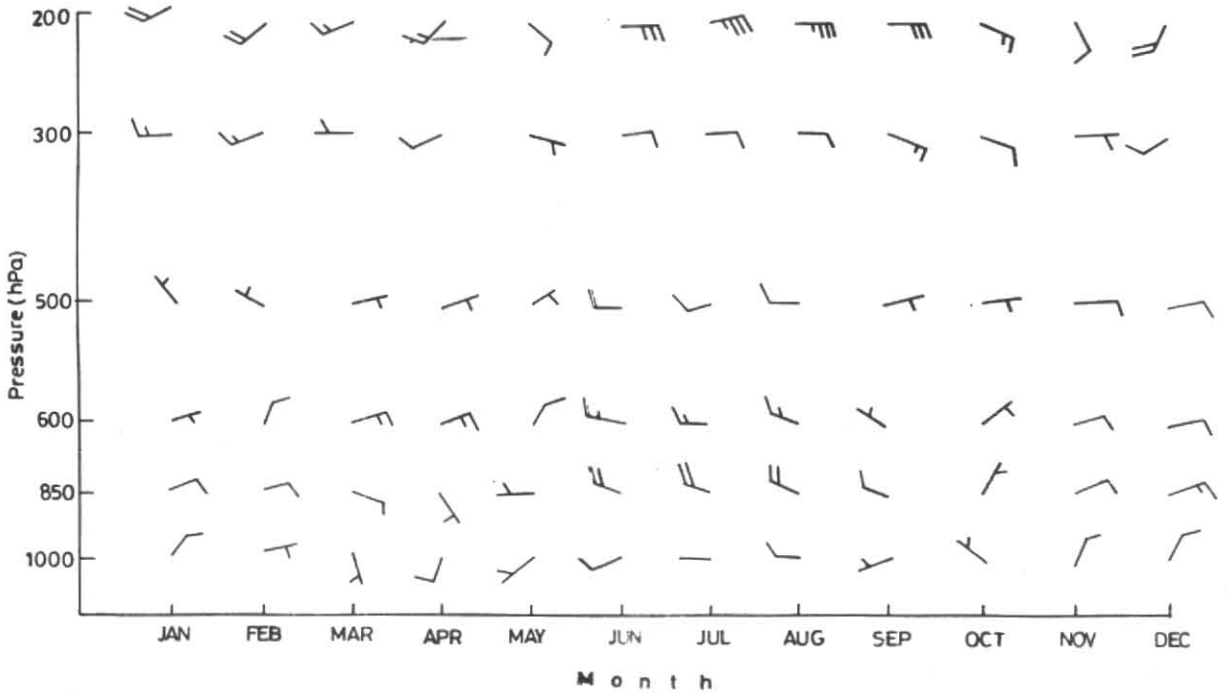


Fig.3. Normal monthly mean upper wind over Madras

700, 500, 300 & 200 hPa representing lower, middle and upper tropospheres (IMD 1988). It is seen that the lower level winds which are westerly during the southwest monsoon months of June-September reverse to easterly in October and remain so till April-May of the succeeding year. In the upper troposphere, at 200 hPa the strong easterlies during southwest monsoon weaken during October-December, then reverse into westerlies and remain so till May. At the mid-tropospheric level of 500 hPa, after the reversal of winds from westerly to easterly from June-September to October-December there is a brief interregnum of westerlies during January-February before easterlies appear again during March-May. Thus at lower and upper tropospheres winds reverse twice a year, whereas in mid-troposphere winds reverse on as many as four occasions. As the winds in the layer 1000-500 hPa reverse from westerly to easterly in October, such a conspicuous event was taken as a precondition for the onset of northeast monsoon over CTN (Raj 1992).

Fig.4 depicts the normal monthly rainfall of CTN for September- February, which has been computed from the data of 1901-86. It is evident from Figs.3 and 4 that the decrease of rainfall over CTN from December to January is not associated with a perceptible sharp change in the lower level wind flow over Madras including the surface level. That whether upper tropospheric wind flow changes could be associated with the withdrawal would require a closer examination. As such, to begin with, we formulate a scheme for determination of withdrawal dates based on rainfall

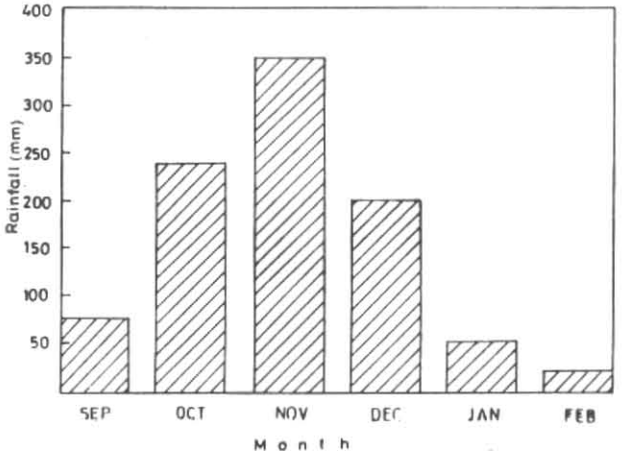


Fig.4. Normal monthly rainfall over coastal Tamil Nadu September - February

which is the end product of various physical and dynamical processes taking place in the atmosphere and could be considered as the primary index of monsoon activity as described by Ananthakrishnan *et al.* (1967) who determined the onset dates of southwest monsoon over Kerala only on the basis of daily rainfall distribution of seven stations. The possibility of associating dynamical or thermodynamical parameters, if any, with withdrawal will be discussed in section 4.

The daily rainfall data of the stations for the period September-February for each year was critically analysed and a few preliminary studies were carried out to formulate

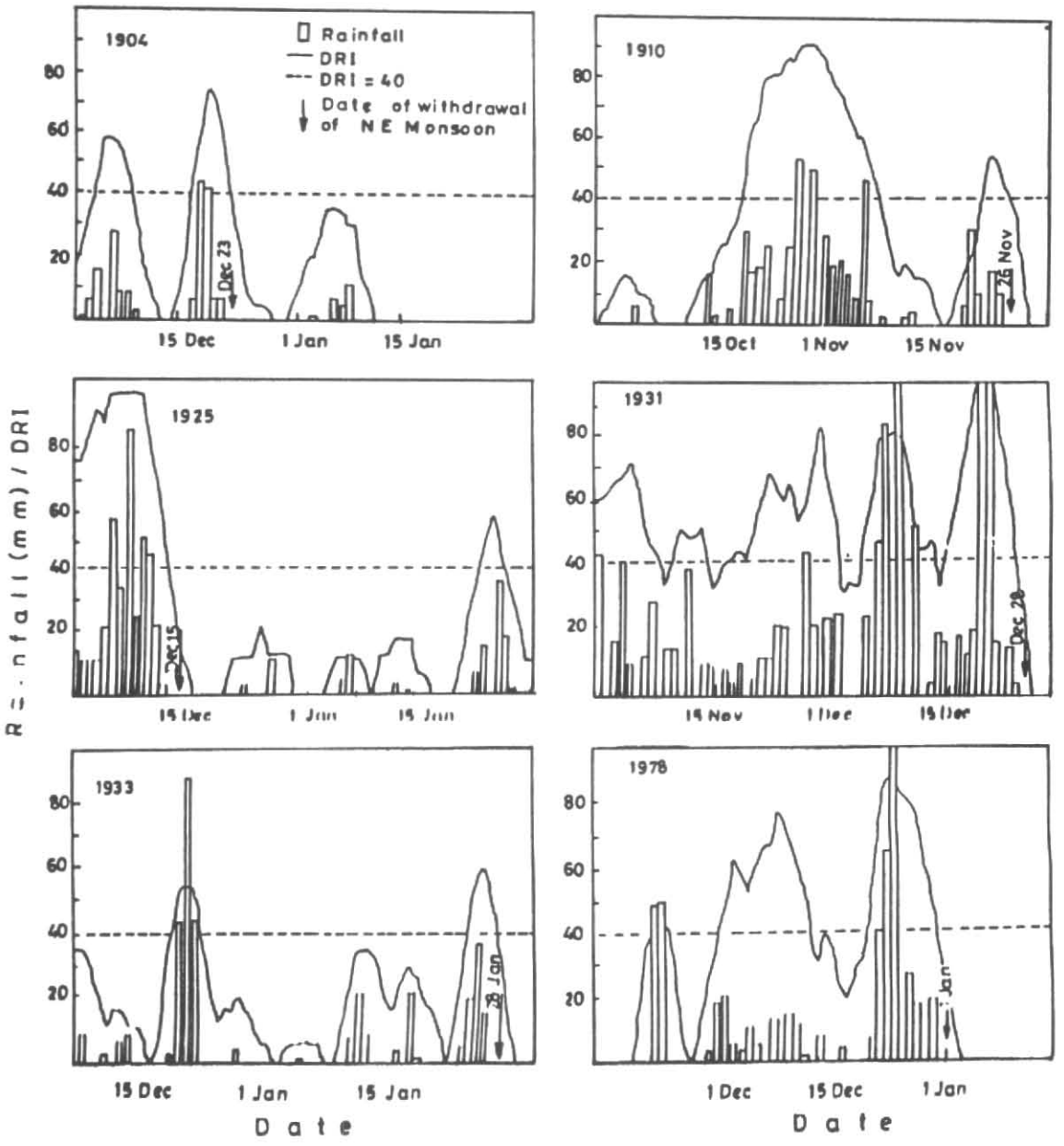


Fig.5. Pictorial presentation of northeast monsoon withdrawal for a few selective years

a suitable criteria to determine the withdrawal dates. Thereupon, a parameter called Daily Rainfall Index (DRI) which could quantify the spatial and timewise persistence of rainfall over CTN was defined. This is discussed hereunder.

2.1. *Daily rainfall index (DRI)*

We define DRI, for a day, as the percentage number of rainy days over a five day pentad, with the day in question as the central day, the number of rainy days counted over all the stations with available data. Thus, for the Nth day we consider (N-2), (N-1), N, (N+1) and (N+2)th days. Out of the $5M$ rainfall observations of M stations, if $M1$ observations correspond to a rainy day, *viz.*, day with atleast 2.5 mm of rain, then DRI = ($M1/5M$)x100 for the N th day. Obviously, DRI varies between 0 and 100.

DRI was computed for every day for the period 3 September to 26 February. As DRI is based on both spatial and temporal persistence of rainfall, it proved to be a suitable

index to quantify the rainfall activity over CTN. After examining the intraseasonal variation of DRI for all the years, a threshold value of 40 was chosen as the minimum DRI value a day must have for northeast monsoon to exist on that day. When DRI = 40, the rainfall activity during the pentad could vary from the possibility of all stations on 2 days and no station on 3 days receiving rain to the other extent of 40% of stations receiving rain on each and every day.

It is well known that a monsoon season is interspersed with wet and dry spells. The withdrawal of monsoon coincides more or less with the end of one of the many wet spells of the season. The ultimate wet spell of the season whose and signifies the cessation of monsoon requires to be identified. In several years the DRI exceeded 40 even in January such spells some time occurring after several days of dry weather. As 31 December is the last day of the northeast monsoon season in the meteorological calendar, we took that if DRI (on a day) exceeded 40 on or before 31 December, northeast monsoon had not withdrawn (on that day). If a wet spell commenced on or before 31 December and continued in January then also northeast monsoon was considered as not having withdrawn during that spell. For years with wet spells commencing after 31 December (as signified by DRI >40) case-by-case analysis proved to be the most suitable way to determine whether the wet spell constituted a part of northeast monsoon or was an insignificant rain spell. These concepts are described in the following rules formulated to determine the withdrawal dates of northeast monsoon over CTN for a given year.

Rule 1

The DRI is to be computed for every day for the period September- February (September-December for the year under consideration and January-February for the next year). If DRI >40 for a day, the day would be deemed to belong to a significant rain spell.

Rule 2: If no significant rainspell commenced on or after 1 January

After the onset of northeast monsoon, the first day with DRI <40 which is not succeeded by dates of DRI >40 in the calendar either uptil 31 December or upto the end of the significant rain spell which may have commenced on or before 31 December but continued thereafter, would be deemed to be the mid date of the withdrawal pentad.

Rule.3: If a significant rain spell commenced on or after 1 January

The withdrawal pentad to be determined by critically studying the January-February rainfall. The various rain spells, intensity and length of each, duration of dry spells in between - all are to be considered before concluding whether the January - February spell (s) could be considered as continuation of northeast monsoon.

Rule 4

Once the withdrawal pentad is located, the precise date of withdrawal could be selected from the 5 days of the pentad by studying the spatial distribution of daily rainfall. Preferably such date should be a dry day over CTN.

2.2. *Determination of year-to-year withdrawal dates of northeast monsoon for coastal Tamil Nadu*

The DRI was computed for CTN for the period 1901-90 for September-February. The mean daily rainfall and the percentage of stations receiving rainfall for each day were also computed. Rules 1 to 4 of section 2 were then systematically applied to determine the withdrawal dates.

We now illustrate the determination of withdrawal dates for a few years. The daily rainfall of CTN alongwith the variation of DRI is pictorially presented for these years in Fig.5.

(a) *1904*

Rainfall and DRI are presented for the period 1 December - 31 January. There were wet spells during 2-10 and 17-22 December. A light spell of rain occurred during 3-8 January but DRI did not exceed 40. In accordance with R2, the pentad with 22 December as the mid-date was chosen as the withdrawal pentad and 23 December as the date of withdrawal, after perusing the daily rainfall.

(b) *1910*

Rainfall and DRI are presented for the period 1 October - 30 November. Northeast monsoon set in on 21 October and the rain spell thus commenced lasted upto 7 November. There was another spell from 20-25 November with no significant activity thereafter. The rainfall of CTN for December, January (1911) and February (1911) was 2.9, 15.9 and 0.3 mm respectively. We conclude that the rain spell of 20-25 November was the last one and fixed 26 November as the date of northeast monsoon retreat.

(c) *1925*

Data are presented for the period 1 December - 31 January. The rainspell which commenced on 27 November continued upto 14 December. Thereafter, there was a long dry spell interspersed with sporadic rain upto 24 January. There was a good spell of rain during 25-29 January. We conclude that the spell which ended on 14 December marked the cessation of northeast monsoon rains as (*i*) the next spell occurred after nearly 40 days and (*ii*) the January spell was not that long or intense. We, therefore, fixed 15 December as the date of withdrawal according to Rule 3.

TABLE 1

Northeast monsoon over coastal Tamil Nadu-onset, withdrawal and duration (1901-90)

Year	A	B	C	Year	A	B	C	Year	A	B	C
1901	0 27	J 9	74	1931	0 29	D 28	60	1961	0 24	D 15	52
02	0 22	J 7	77	32	0 9	D 19	71	62	0 9	J 13	96
03	0 24	J 14	82	33	0 27	J 28	93	63	0 20	D 10	51
04	0 21	D 23	63	34	0 24	D 18	55	64	0 29	D 27	59
05	0 6	N 30	55	35	0 13	D 28	76	65	0 15	D 12	58
06	0 16	D 16	61	36	0 22	D 22	61	66	0 6	D 22	77
07	0 20	D 22	63	37	0 27	D 19	53	67	0 15	D 20	66
08	0 22	J 7	77	38	0 27	D 9	43	68	0 15	D 21	67
09	0 14	D 22	69	39	0 14	D 17	64	69	0 14	J 3	81
10	0 21	N 26	36	40	0 27	J 9	74	70	0 14	J 12	90
11	0 16	D 28	73	41	0 21	D 19	59	71	0 19	D 19	61
12	0 12	D 3	52	42	N 1	J 5	65	72	0 21	D 27	67
13	0 24	D 23	60	43	0 5	J 13	100	73	0 17	D 31	75
14	0 10	D 9	60	44	0 20	D 24	65	74	N 5	D 30	55
15	N 11	D 30	49	45	0 12	D 10	59	75	0 25	D 20	56
16	0 15	D 10	56	46	0 16	J 8	84	76	0 15	D 26	72
17	0 18	J 6	80	47	0 19	J 4	77	77	0 10	D 6	56
18	N 1	D 20	49	48	016	J 3	79	78	021	J 1	72
19	0 18	J 10	84	49	0 20	D 1	42	79	0 22	D 15	54
20	0 21	J 15	86	50	0 15	D 16	62	80	0 10	D 6	57
21	0 22	J 12	82	51	N 6	D 2	26	81	0 23	D 24	62
22	0 11	J 17	98	52	0 15	D 15	61	82	0 18	D 19	62
23	0 17	J 10	85	53	0 14	J 13	91	83	0 24	J 18	86
24	0 22	D 21	60	54	0 15	J 11	88	84	N 3	J 7	65
25	0 23	D 15	53	55	0 20	D 10	51	85	0 25	J 17	84
26	0 30	D 18	49	56	0 26	D 28	63	86	0 26	D 30	65
27	0 26	J 9	75	57	0 16	J 3	79	87	0 20	D 26	67
28	0 16	D 31	76	58	0 29	D 19	51	88	N 3	J 6	64
29	0 26	J 11	77	59	0 21	D 4	44	89	0 29	J 10	73
30	0 9	J 19	102	60	0 21	J 18	89	90	0 18	D 27	70

A=Date of onset, B=Date of withdrawal, C=Duration in days

O=October, N=November, D=December, J=January

TABLE 2

Statistical properties of dates of withdrawal and duration of northeast monsoon over coastal Tamil Nadu (1901-90)

Withdrawal	
Normal	27 December
Standard deviation	13.6 days
Median	26 December
Earliest & most delayed	26 November 1910
Withdrawal	28 January 1934
Duration (days)	
Normal	67.5
Standard deviation	14.9
Shortest	26 (1931)
Longest	102 (1936)

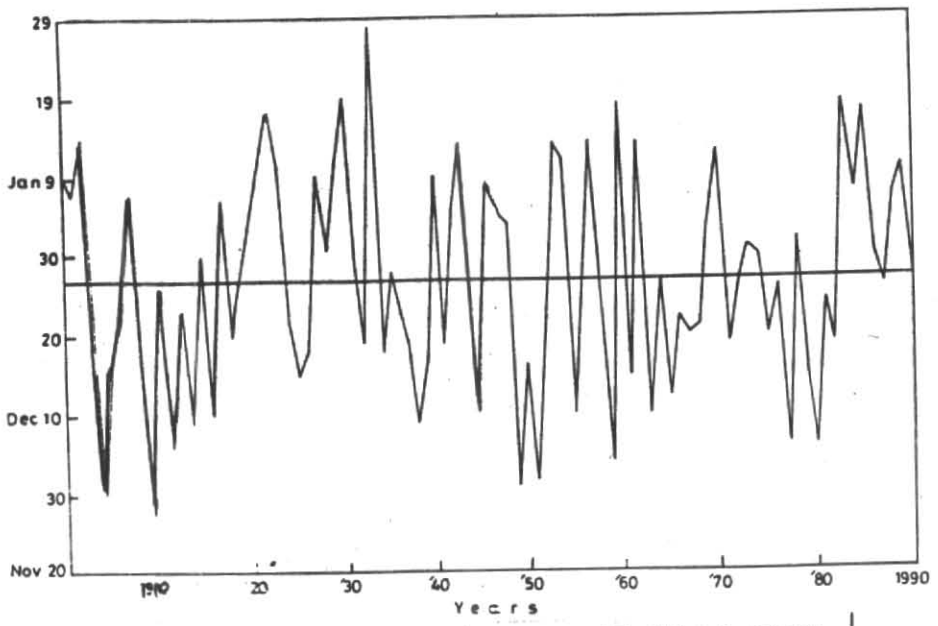


Fig.6. Northeast monsoon withdrawal dates over coastal Tamil Nadu for 1901-90

(d) *1931*

Data are presented for the period 1 November - 31 December. The spell which commenced on 29 October continued almost without any break upto 27 December, with the monsoon retreating on 28 December. The rainfall received by CTN during January and February was 5.2 and 4.3 mm only. This year provides an example of abrupt and ideal withdrawal of northeast monsoon.

(e) *1933*

Data for the period 1 December - 31 January are presented. There was sporadic rain upto 8 December, good spell during 14-17 December, sporadic rain during 21-28 December, 8-10 January, 13- 17 January and a good rain spell during 23-27 January. For the last spell DRI >40 on all the days. The probable dates of withdrawal are 18 December and 28 January. However, the rainfall received during 18 December - 27 January was 143.8 mm with several days receiving rain. We, therefore, chose 28 January (of 1934) as the withdrawal date.

(f) *1978*

Data are depicted for the period 16 November - 15 January. The rain spell that commenced on 2 December continued upto 31 December with heavy spells between 25 and 28 December. The monsoon abruptly withdrew on 1 January with no significant rain there after. This year provides another example of an ideal withdrawal.

Table 1 lists the withdrawal dates of northeast monsoon for the period 1901 - 90, thus determined, alongwith the onset dates determined by Raj (1992). The duration of north-east monsoon for each year, which is the number of days between the onset and withdrawal dates is also given. Fig.6 depicts the interannual variation of withdrawal dates for the period 1901-90.

3. Results and discussions

3.1. *Statistical properties*

Table 2 presents the various statistical parameters of the dates of withdrawal and also duration. The mean (normal) date of withdrawal is 27 December, the median 26 December and standard deviation 13.7 days. The earliest withdrawal occurred in 1910 on 26 November and the most delayed withdrawal took place during northeast monsoon of 1933 on 28 January 1934.

In 33 years, *i.e.*, 36.7% of years the northeast monsoon spilled over to the next calendar year. The duration of northeast monsoon is distributed with a mean of 67.4 days and a standard deviation of 14.8 days ranging between 26 days (in 1951) and 102 days (in 1936). It has been shown by Raj (1992) that the normal date of onset of northeast monsoon is 20 October with a standard deviation of 7.3 days. The dates of withdrawal are thus more dispersive than those of onset and so the representativeness of a single normal date to the aggregate of all the withdrawal dates would not be that much good when compared to that of onset. This aspect is to be given due importance while interpreting the normal withdrawal date.

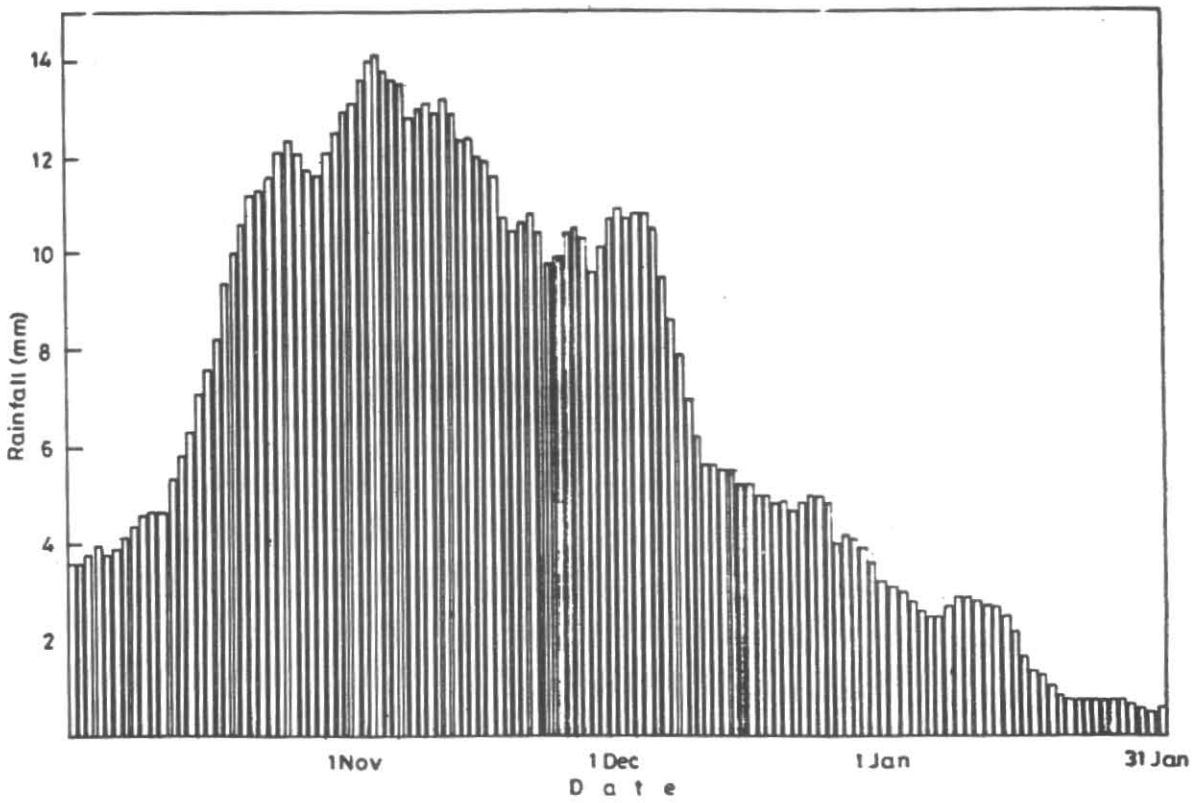


Fig.7. Normal daily rainfall of coastal Tamil Nadu for 1 October - 3 January

3.2. *Normal daily rainfall of coastal Tamil Nadu in relation to northeast monsoon withdrawal*

The normal daily rainfall of CTN during September - February was computed and smoothed. Figs.7 & 8 depict the normal rainfall and its difference filter for October-January. Fig.8 shows that during 1-26 October, normal daily rainfall increases daily with the maximum rise occurring on 18 October manifested by the peak. This is the reflection of the normal date of northeast monsoon which occurs on 20 October close to 18 October. The troughs of the graph below the zero line, which correspond to sharp fall in the normal rainfall graph, occur on 27 October, 7,19 and 28 November, 8 and 31 December and 16 January. In earlier studies 8 December or dates closer to that were taken as normal dates of monsoon withdrawal. However, according to this study, the normal date of withdrawal is 27 December and not 8 December. The difference of 19 days is too large to be explained by sampling considerations. The trough observed on 31 December occurs closer to the normal date of withdrawal of 27 December which is consistent with Fig.1.

3.3. *Superposed epoch analysis*

As done by Raj (1992) concept of superposed epoch analysis has been used to bring out the decrease of rainfall at the time of withdrawal. Thus we took 0 as the date of withdrawal for each year and assigned -49, ..., -2, -1, 0, 1, 2, ..., 49 to the days before and after and averaged the rainfall over stations and years to obtain a single distribution. This is presented in Fig.9. The sharp decrease after the withdrawal is clearly brought out. The average daily rainfall, which is above 5 mm before withdrawal and is above 10 mm immediately before withdrawal, reduces to 1 mm - 2 mm daily after withdrawal. The average pentad rainfall which is 67.9 mm in the pre-withdrawal pentad reduces to 3.0 mm in the post-withdrawal pentad.

Earlier we observed that during 36.7 % of years the northeast monsoon activity spilled over to January of next year. A question which could arise is, whether the activity in January could be as intense as that in December. To examine this we computed the average rainfall for pentads before and after withdrawal for (*i*) November and December, (*ii*) January and (*iii*) post 10 January withdrawals. Fig.10 presents the magnitudes of the pentads for each of the above three cases.

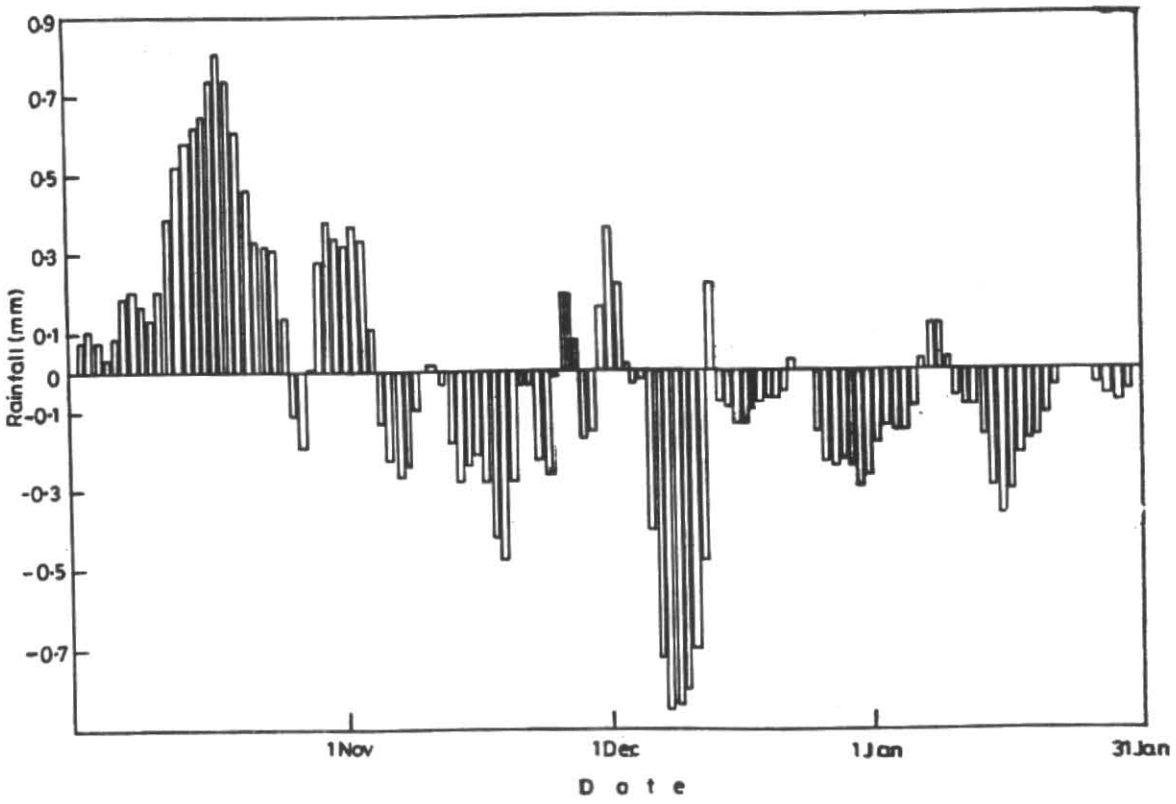


Fig.8. Difference filter of normal daily rainfall of coastal Tamil Nadu for 1 October - 3 January

For November and December withdrawals, which form 63.5 % of the total withdrawals, the rainfall during pre and post withdrawal pentads are 63.8 and 0.4 mm respectively. The figures for January withdrawals constituting 36.5 % are 74.3 and 1.5 mm and those for post 10 January (*i.e.*, withdrawals on or after 11 January) forming 17.6 % are 79.0 and 2.9 mm respectively. These figures clearly reveal that the rainfall realised from northeast monsoon in January is comparable to that in December. The low normal daily rainfall in January compared to December (Fig.4) is due to the fact that the northeast monsoon lingers on in January, only on one third of the years and not due to reduced intensity in a year in which monsoon spills over to January.

The withdrawal dates of Table 1 may not be thought of as precise cut off dates but as dates representing intervals of slightly longer duration such as pentads. Out of the 33 years in which northeast monsoon spilled over to January of next year (Table 1), only in 3 years, *viz.*, in 1922-23, 1933-34, and 1960-61, the rainspell was prior to the withdrawal associated with a depression that was present in the Bay or moved closer to Tamil Nadu.

During 7.8 % of the years DRI values greater than 40 were realised during February also. Over all, during 19% of the years a significant rain spell (DRI >40) occurred after the withdrawal date that we have determined. Such spells were of shorter duration and took place after several days of dry weather and so were not treated as northeast monsoon spells. However, this shows that significant rain spell do occur after the withdrawal, in some years.

4. Dynamical and thermodynamical changes, if any, associated with withdrawal

As discussed in section 2 the onset of northeast monsoon over CTN is preceded by reversal of winds from westerly to easterly, an unmistakable synoptic feature. Raj (1996) has shown that the reversal of winds is also associated with a cooling of the 1000-500 hPa layer, decrease of energy and over all slight decrease of liquid water content (LWC) of the atmosphere. The period after withdrawal is characterised by lower LWC but there is no conspicuous change in the flow pattern. The dynamical and thermodynamical changes, if any, taking place in the atmosphere over CTN in association with the cessation of northeast monsoon rains have been further examined in detail. For this, upper air data of Madras and Thiruvananthapuram for the period 1965-88 for 15 November - 31 January upto 200 hPa level

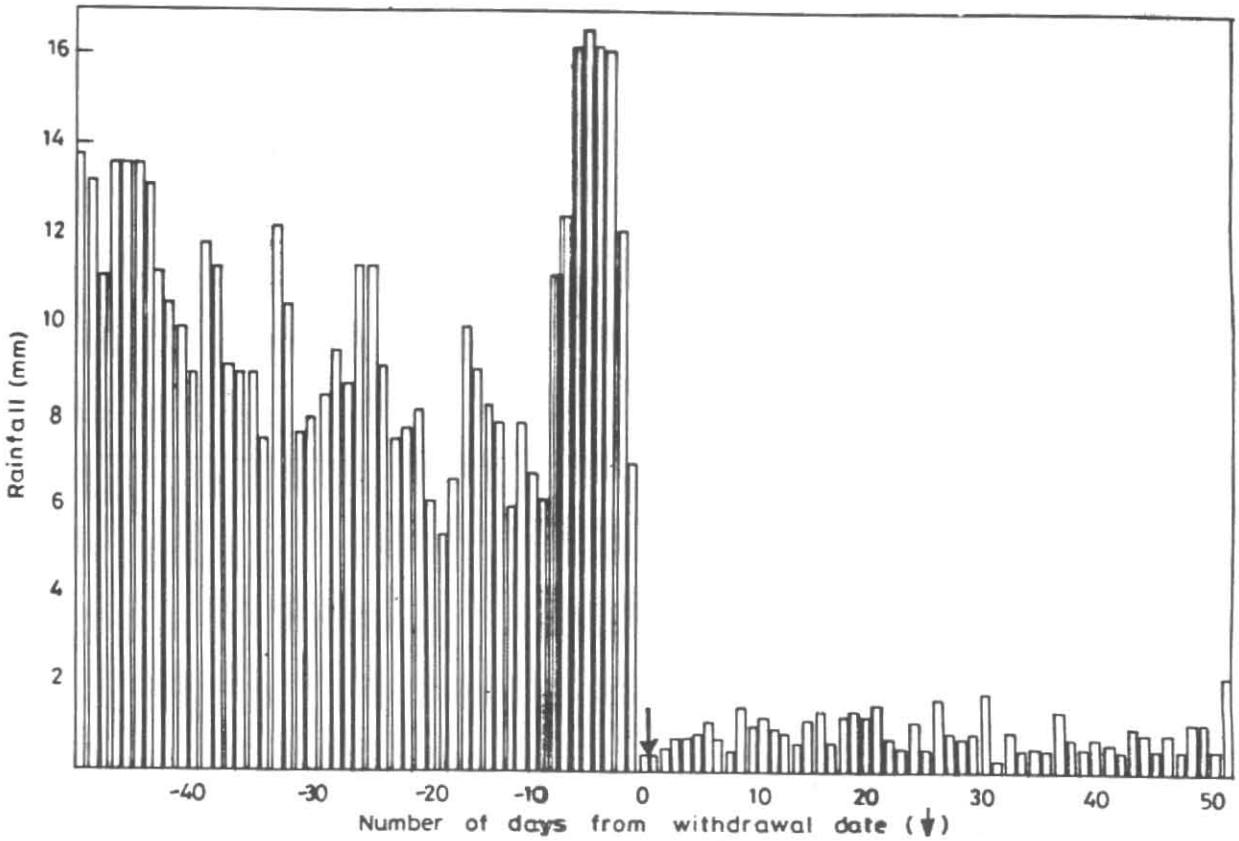


Fig.9. Mean daily rainfall over coastal Tamil Nadu with reference to northeast monsoon withdrawal dates: Superposed epoch analysis

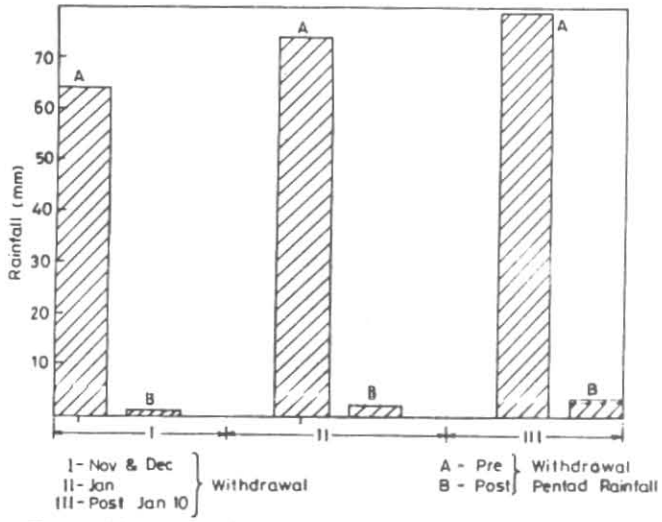


Fig.10. Mean rainfall during pre and post withdrawal pentads for November - December, January & post 10 January withdrawals

were obtained from National Data Centre, IMD, Pune. The following aspects were studied:

(*i*) Location of middle and upper tropospheric anticyclonic ridge, its movement and its relation, if any, with the northeast monsoon activity over CTN and also its withdrawal.

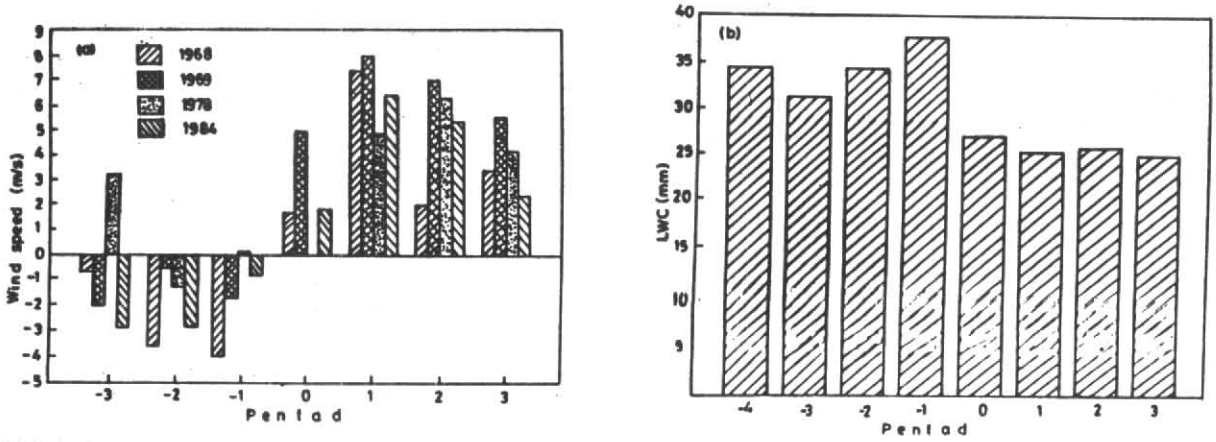
(*ii*) The temperature gradient over the peninsula and its relation, if any, with the rainfall activity.

(*iii*) Reversal of winds in the layer 500-200 hPa and its relation, if any, with the withdrawal.

(*iv*) Variation of moisture content over Madras and Thiruvananthapuram *vis-a-vis* the withdrawal.

The following results were obtained from the above exercise:

No relation could be conclusively established between the northeast monsoon activity either with the position of the upper tropospheric anticyclone or with the temperature gradient over the peninsula. In regard to (*iii*) above we computed the normal daily wind over Madras and Thiruvananthapuram at all the standard isobaric levels based on data of 1965-88. At 500 hPa, normal zonal winds changed from easterly to westerly in the first week of January. At 300 and 200 hPa, this reversal took place in the first week of December itself and so could not be associated with the withdrawal. The daily variation of Madras 500 hPa wind for all the 24 years was critically examined to determine whether such an event could be associated with the withdrawal of individual years. It was found that the northeast monsoon rains ceased almost at the time when 500 hPa winds reversed over Madras in 9 out of 24 years. Fig.11(a)



Figs.11 (a & b). (a) Mean distribution of liquid water content (LWC) for 1965-88 and (b) 500 hPa zonal wind for 1968, 1969, 1978 & 1984 over Madras with respect to northeast monsoon withdrawal dates

presents the pentad data before and after the withdrawals for four such years 1968, 1969, 1978 and 1984 during which 500 hPa winds reversed at the time of withdrawal and remained as westerlies upto January end. During a few years, winds reversed to westerlies for one or two pentads at the time of cessation of northeast monsoon rains but changed to easterlies again thereafter. In nearly 8 years winds did not become westerly at all upto the end of January. By and large, appearance of westerly winds at 500 hPa at Madras was found to be a sufficient condition but not necessary for the cessation of northeast monsoon rains.

An examination of upper winds over Thiruvananthapuram - both normal and for individual years - revealed that the winds at no level could be conclusively associated with withdrawal.

To establish the relation, if any, with the thermodynamical parameters, the LWC over Madras and Thiruvananthapuram for the period 1965-88 for 15 November-31 January was computed and analysed. As expected, the temporal variation of LWC manifested a discontinuity at the time of withdrawal with LWC decreasing by 10 mm both at Thiruvananthapuram and at Madras. This feature is revealed in Fig.11(b) which presents the mean profile of LWC of Madras with reference to the dates of withdrawal given in Table 1. Examination of LWC profiles for individual years suggested a threshold value of 30 mm or lower of LWC persisting for several days could be a necessary condition for withdrawal but evidently not sufficient in as much as such a feature was frequently observed even during prolonged dry spells of northeast monsoon. On some occasions, dry conditions persisted despite the presence of large amount of moisture. The relation between LWC over Thiruvananthapuram and northeast monsoon activity over CTN was much less pronounced.

Thus, we conclude that some changes in circulation and thermodynamic patterns, such as, reversal of wind from easterlies to westerlies at 500 hPa and decrease of LWC over Madras could perhaps be associated with the cessation of northeast monsoon rains over CTN. The changes, however, are subtle and may not manifest every year besides not exhibiting one to one correspondence. As such these could at best be taken as guidance factors while determining the date of withdrawal.

5. Conclusion

The results of the study are summarized below:

(*i*) The withdrawal dates of northeast monsoon over CTN for the 90-year period, 1901-90, have been objectively derived.

(*ii*) Some instances of northeast monsoon withdrawal have been illustrated with diagrams.

(*iii*) The statistical parameters of withdrawal dates and duration of northeast monsoon have been derived. The normal withdrawal date is 27 December with a standard deviation of 19.6 days and range: 23 November - 28 January. The normal length of duration is 67.5 days with a standard deviation of 14.9 days with range 26 - 102 days.

(*iv*) The reflection of normal date of withdrawal on the daily normal rainfall graph has been discussed.

(*v*) During 36.7 % of the years the withdrawal date got extended to January of next calendar year.

(*vi*) The average decrease of rainfall at the time of withdrawal has been derived by the application of superposed epoch analysis. The rainfall decrease from 67.9 to 3.0 mm from the pre to post-withdrawal pentad.

(*vii*) It has been shown that the intensity of the pre-withdrawal spell in years when northeast mon-

soon spilled over to January was as intense as in years when it withdrew in December itself.

(*viii*) The existence, if any, of dynamical or thermodynamical features associated with the withdrawal has been examined by studying the upper air data of Madras and Thiruvananthapuram. It has been found that reversal of wind from easterly to westerly at 500 hPa and decrease of moisture over the atmosphere - both at Madras could be taken as guidance factors in determining the withdrawal dates.

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