MAUSAM, **54**, 3 (July 2003), 605-614

551.553.21(548.1)

Onset, withdrawal and intra-seasonal variation of northeast monsoon over coastal Tamil Nadu, 1901-2000

Y. E. A. RAJ

Regional Meteorological Centre, Chennai-600 006, India

(*Received 18 June 2001, Modified 12 August 2002*)

सार – तटीय तमिलनाडु में 1991 से 2000 तक की दस वर्षों की अवधि में उत्तरी पूर्वी मानसून वर्षा ऋतु के आरंभ और उसकी वापसी की तारीखों को वस्तुगत दृष्टि से निर्धारित किया गया है। इस शोध–पत्र में 1901 से 2000 तक की बीसवीं शताब्दी के सौ वर्षों की अवधि में मानसून वर्षा ऋतु के आरंभ और उसकी वापसी की तारीखों के आँकड़ों को प्रस्तुत किया गया है एवं उन पर चर्चा की गई है। सौ वर्षों में हुई वर्षा के आँकड़ों के हार्मोनिक/स्पेक्ट्रल विश्लेषण और क्रॉस पश्चता सहसंबंध जैसी तकनीकों का प्रयोग करते हुए यह बताया गया है कि तटीय तमिलनाडु में सितंबर से फरवरी के दौरान की दैनिक वर्षा 40 दिन की आवर्तिता दिखाती है और अक्षांशीय रूप से लगभग 400 कि.मी. की दूरी पर स्थित पामवन और चेन्नै के बीच होती हुई वर्षा की असामान्यताएँ दक्षिण से उत्तर की ओर बढ़ने के लिए लगभग दो दिनों का समय लेती हैं। वर्षों की 70 प्रतिशत अवधि में उत्तरी पूर्वी मानसून के आरंभ और उसकी वापसी की प्रकिया की आवर्तिता 40 दिनों की है।

ABSTRACT. The onset and withdrawal dates of northeast monsoon over coastal Tamil Nadu have been objectively determined for the ten year period 1991-2000. The statistics of onset and withdrawal dates for the 100 year 20th century period 1901-2000 have been presented and discussed. It has been shown by employing techniques such as harmonic/spectral analysis and cross lag correlation over 100 year rainfall data, that the daily rainfall of coastal Tamil Nadu during September-February displays a prominent 40-days periodicity and that rainfall anomalies move from south to north taking nearly 2 days to traverse between Pamban and Chennai separated latitudinally by nearly 400 km. In 70% of the years the onset and withdrawal process of northeast monsoon gets excited by the 40-day periodicity.

Key words – Northeast monsoon, Coastal Tamil Nadu, Onset, Withdrawal, Duration, 40-day periodicity, Cross lag correlation, Spectral analysis.

1. Introduction

The Indian northeast monsoon is a monsoon of smaller scale experienced over the southern parts of India during October-December, subsequent to the retreat of southwest monsoon from India. As such it used to be also called 'Retreating southwest monsoon' over the peninsular India. The meteorological subdivisions of Tamil Nadu, Kerala, Coastal Andhra Pradesh and Rayalaseema are the major beneficiaries of this monsoon. However the various features of northeast monsoon are clearly defined mainly over coastal Tamil Nadu (CTN) which receives 75-100 cm of normal rainfall during the season constituting nearly 60% of the annual total. India Meteorological Department (IMD) (1973) provides a detailed description of this monsoon.

The dates of onset and withdrawal of northeast monsoon over CTN were determined and several other associated features studied for the 90 year period 1901-1990 in two earlier studies Raj (1992 & 1998) to be referred hereinafter as 'I' and 'II'. In the present study the determination of onset and withdrawal dates has been carried over to the decade 1991-2000 also resulting in the availability of such dates for the 100 year period 1901-2000. The statistical parameters for both these periods are derived and presented in the study. In addition, the intra-seasonal variation of rainfall of coastal Tamil Nadu, the presence of 40-day periodicity and the south to north movement of rainfall anomalies, based on the 1901-2000 (100 years) data have also been studied.

2. Determination of onset and withdrawal dates, methodology, data and results

2.1. *Methodology*

The lower level winds over north coastal Tamil Nadu reverse from south westerlies to north easterlies by mid-October. The date of commencement of persistent

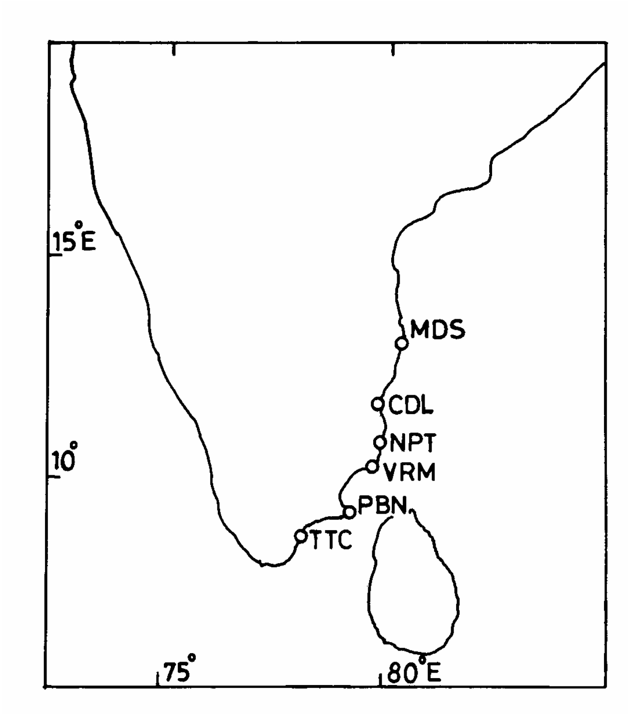

Fig. 1. Spatial distribution of the stations considered in the study

rainfall over CTN subsequent to this event is taken as the onset date. The date of withdrawal is determined by a critical analysis of daily rainfall (DRF) of six stations of CTN (Fig. 1). The date of withdrawal marks the cessation of persistent rainfall activity over CTN but is not generally associated with any conspicuous change in the circulation features. Further details could be found in I & II.

2.2. *Data and determination of dates for 1991-2000*

The firm date of onset of easterlies over north CTN was determined from the surface pressure charts, upper air charts of lower levels, taking also into consideration the withdrawal dates of southwest monsoon from the southern peninsula, as declared by IMD. The DRF data of six stations located over CTN (Fig.1) for the period 1 Sep – 28 Feb, 1991-92 to 2000-01 was analysed and the onset and withdrawal dates of northeast monsoon over CTN were determined. Table 1 presents the year to year dates, duration and also the 10 year means of the derived dates.

2.3. *Normal onset and withdrawal dates of northeast monsoon for 1901-2000*

The dates of northeast monsoon onset and withdrawal for the 10-year period 1991-2000 presented in Table 1, when appended with the dates for 1901-90 derived in I and II give rise to a complete and comprehensive data set of onset and withdrawal dates of northeast monsoon over CTN for the 100 year 20th century period 1901-2000. The normals and other statistics derived from this data set are presented in Table 2. The means based on 1991-2000 have not shown any statistically significant differences with the long term normals of 1901-2000. The normal date of onset and withdrawal respectively are 20 October and 27 December. The time series of onset of easterlies, dates of onset and withdrawal displayed absolutely no overall trend during the 100 year period and have remained stationary. The northeast monsoon set in on 6 occasions prior to 10 October and on 8 occasions in the month of November.

TABLE 1

Onset and withdrawal dates and duration of northeast monsoon over coastal Tamil Nadu (1991-2000)

Year	A	B	C	D (days)
1991	15 Oct	19 Oct	23 Dec	65
1992	23 Oct	02 Nov	09 Dec	37
1993	12 Oct	13 Oct	01 Jan	80
1994	17 Oct	18 Oct	24 Dec	67
1995	22 Oct	23 Oct	13 Dec	51
1996	09 Oct	10 Oct	19 Dec	70
1997	05 Oct	13 Oct	23 Dec	71
1998	22 Oct	28 Oct	04 Jan	68
1999	01 Oct	04 Oct	12 Jan	100
2000	01 Nov	05 Nov	02 Jan	52
Mean 1991-2000	16 Oct	20 Oct	25 Dec	66

A: Onset of easterlies, B : Onset, C : withdrawal and D: Duration

TABLE 2

Statistical parameters of onset and withdrawal dates of northeast monsoon over coastal Tamil Nadu based on 100 year data 1901-2000

	Normal	S.D (Days)	Range
A	14 Oct	7.5	23 Sep - 1 Nov
B	20 Oct	7.6	04 Oct - 11 Nov
C	27 Dec	13.4	26 Nov - 28 Jan
D	67 days	14.9	26 - 102 days

A, B, C, D - As in Table 1; SD : Standard Deviation

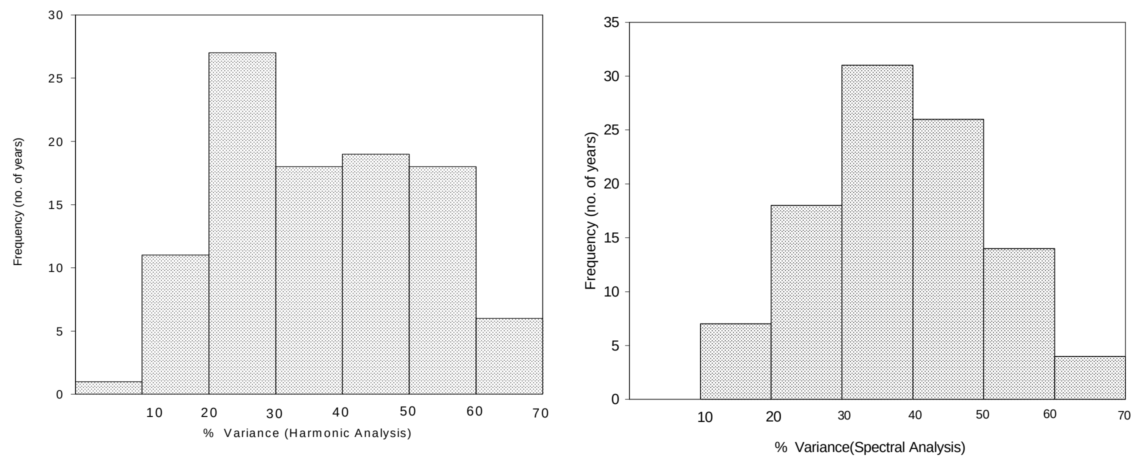

Fig. 2. Frequency distributions of the percentage variance associated with the 40 - day periodicity through harmonic and spectral analysis of daily rainfall anomalies of coastal Tamil Nadu, Sep-Feb, 1901-2000

On 36 years the northeast monsoon spilled over to January of next calendar year with withdrawal taking place in January.

2.4 . *Onset and withdrawal dates from IMD records*

The onset and withdrawal dates of northeast monsoon for every year during 1991-2000 had been declared by IMD in its bulletins. In case of onset, the differences between IMD dates and the dates of Table 1 were negligible on 8 occasions save for 1993 and 1999 when IMD dates succeeded those of Table 1. However large differences have resulted in case of withdrawal for most of the years with differences upto 27 days. This study is essentially diagnostic with ample scope for assimilation of all the available and requisite data with a provision of review whereas the IMD dates are declared on a real time basis. In the absence of any noticeable and well-defined circulation feature associated with northeast monsoon withdrawal and with the tendency of northeast monsoon to spill over to January on nearly 30% of the occasions interspersed with characteristic long dry spells, the date of withdrawal perhaps could be firmly determined only after the season is well and truly over.

3. Intra-seasonal variation of daily rainfall anomalies and its effect on onset and withdrawal of northeast monsoon

3.1. *Variation of Daily Rainfall (DRF) anomalies*

The existence of the well-known 40-day oscillation in the Indian monsoon rainfall with periodicity ranging between 30-50 days has been well-documented. (Sikka and Gadgil (1980), Keshavamurty *et al*., 1990, Singh and Kripalani *et al*., 1990). In this section the intra-seasonal variation of DRF of CTN and the role it plays on the onset/withdrawal process of northeast monsoon have been studied. For this, techniques such as harmonic, spectral and cross lag correlation function (CLCF) analysis have been employed. The DRF data of the six stations of CTN mentioned in Sec.2.1 for the 6 month / 100 year period, 1 Sep – 28 Feb, 1901-2000 have been utilised. The methodology as given in Panofsky and Brier (loc.cit.), and Wilks (1996) has been adopted. The analysis was performed sequentially as under :

(*i*) The normal DRF of CTN based on 100 year data was computed and the series was smoothed with moving averages to derive a smooth profile.

(*ii*) The DRF of CTN for the 6 month period was computed for each year and the DRF profile was smoothed as done in (*i*) above.

(*iii*) DRF anomalies (DRFA) based on DRF and DRF normals were computed for each day of the 6 month period for each year.

(*iv*) The DRFA series were subjected to harmonic and spectral analysis. The harmonic analysis was performed over the first 160 days data of the entire length of 181 days. For spectral analysis all the 181 days data were utilised to compute 60 auto correlation coefficients (CCs) and smooth spectral densities were obtained. As expected the DRFA series were persistence series and so the red-noise null continuum was employed.

The results of the above analysis are discussed in what follows. In the periodicity analysis conducted for the

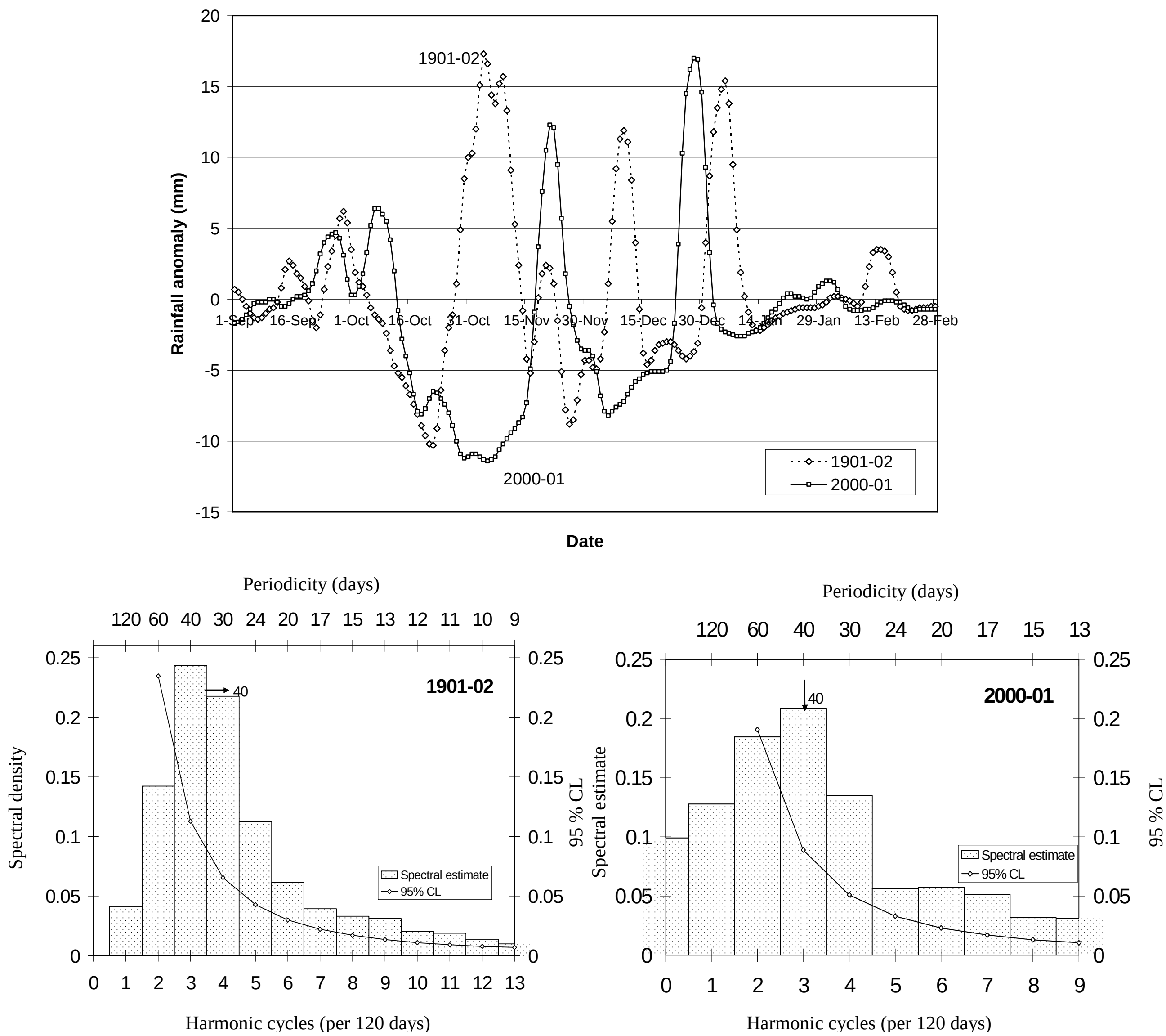

Fig. 3. Daily rainfall anomaly series for coastal Tamil Nadu 1 Sep-28 Feb for 1901-02 & 2000-01 and power spectrums of the DRFA series. (Both the spectrums display spikes at wavelengths corresponding to 40-day periodicity)

northeast monsoon DRF over CTN, the 40-day oscillation (*i.e.*, 30-50 day periodicity) could be clearly detected in respect of 86% of the years. Fig. 2 depicts the frequency distributions of the total percentage variance corresponding to bands of wavelengths of 30-50 days as derived from harmonic and spectral analysis. The harmonics and spectral bands corresponding to 40-day oscillation explained on an average 37.1% and 39.3% of the total variation and in 45% of the years both explained more than 40% variation.

The presence of 40-day periodicity in the DRFA series is illustrated in Fig. 3. which presents the DRFA series for 1 Sep - 28 Feb and its power spectrum for two years 1901-02 and 2000-01. In 1901-02, the prominent peaks of the DRFA graph correspond to the dates 29 Sep, 4 Nov, 10 Dec, 5 Jan and 13 Feb. In 2000-01 the peaks are observed on 8 Oct, 20 Nov, 28 Dec and 31 Jan. The sinusoidal shape of the DRFA graphs for both the years with prominent peaks separated by 30-50 days could be easily appraised visually and is clearly brought out by the power spectrums. For both the years, the spectrum peaks at harmonics corresponding to 40-day cycles. The total percentage variance explained by the 30-50 day oscillation is 57.1% and 46% respectively for 1901-02 and 2000-01.

The average periodogram and power spectrum of DRFA series of all the 100 years are presented in Fig. 4.

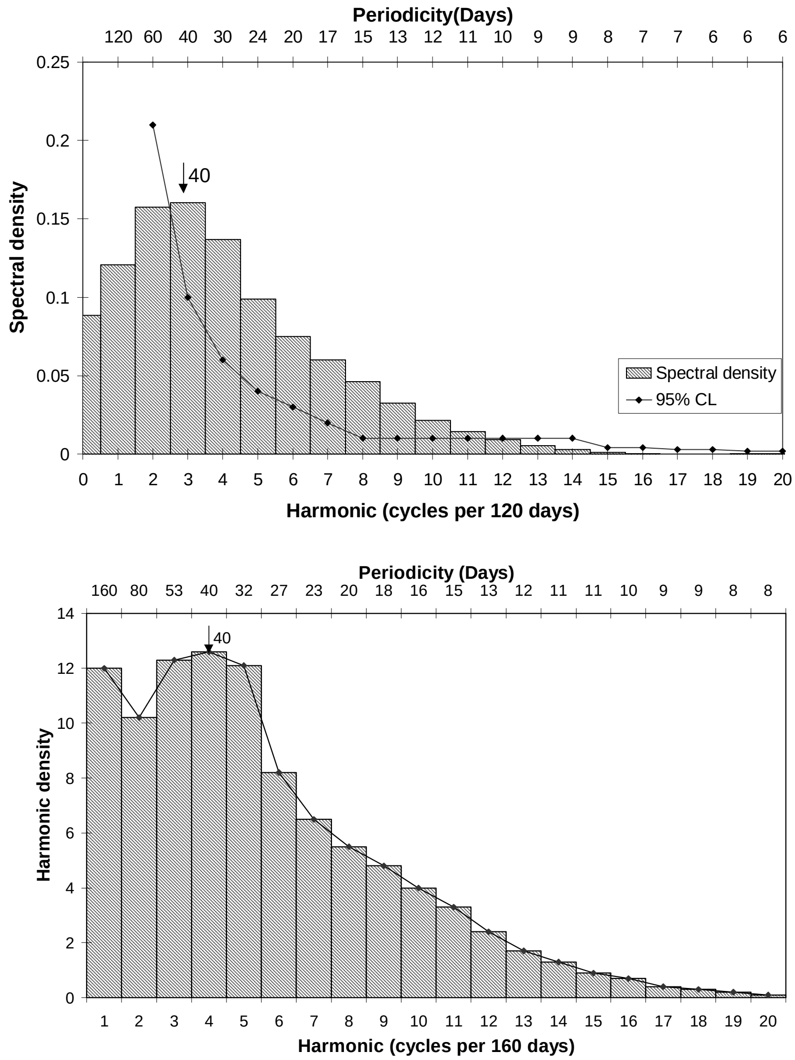

Fig. 4. Mean periodogram and power spectrum of daily rainfall anomalies of coastal Tamil Nadu, Sep-Feb, 1901-2000

The average 95% confidence limit of the red noise null continuum is also presented in the case of power spectrum. As seen the periodogram shows a spike though not prominent corresponding to 40-day periodicity. However the spike in the power spectrum corresponding to 40-day periodicity is much more prominent and is sharply defined. Now, the normal monthly rainfall figures over CTN for the 6 individual months of September-February are 76, 232, 348, 203, 50 and 21 mm respectively. The first half of the period receives more rain than the second half and so the periodogram of DRF should display this annual march prominently with large variance explained by the first or second harmonics. To neutralise this annual cycle we have 'pre-whitened' the DRF series for a given year by subtracting the normal DRF to derive the DRFA series and performing the analysis for the anomaly series. Despite this the annual cycle may not have been fully removed and manifests in the first and two harmonics explaining substantial variation. The spectral analysis which is not so sensitive to non-stationarity in a time series as the harmonic analysis has given a better account of the low frequency oscillation as could be clearly seen from Fig. 4.

3.2. *South to north movement of rainfall anomalies*

The 40-day oscillation of Indian monsoon rainfall has been shown by several authors to display south-north

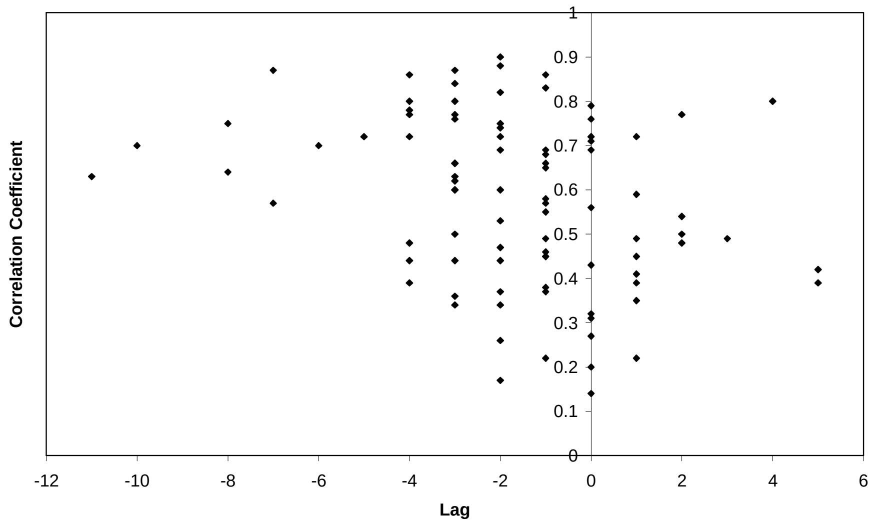

Fig. 5. Scatter plot of maximum cross lag correlation *versus* its lag

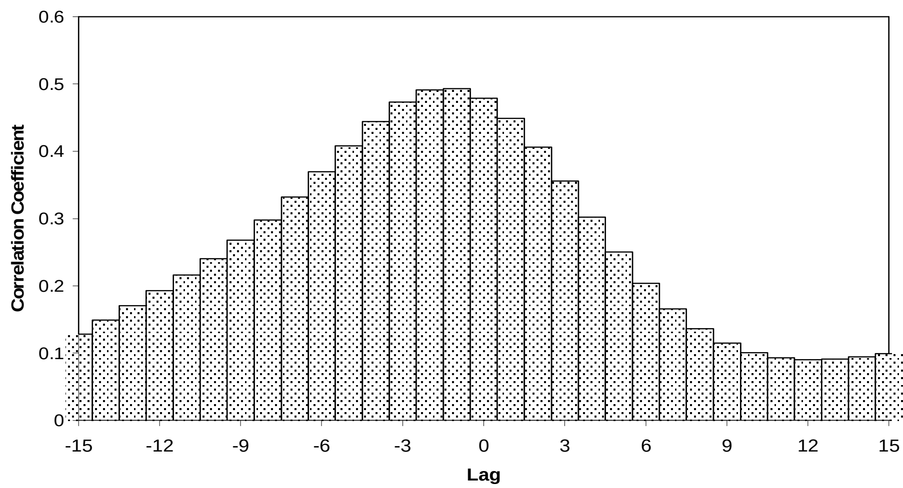

Fig. 6. Mean cross lag correlation function between daily rainfall anomalies of Chennai and Pamban, Sep-Feb, 1901-2000

movement of rainfall anomalies over India (Sikka and Gadgil, loc. cit., Singh *et al*., loc.cit, Gadgil, 1990). We have examined latitudinal movement of rainfall anomalies over CTN during September-February, by computing CLCF between Chennai located in the north at 13° N and Pamban located in the south at 9.2° N, latitudinally nearly 400 km apart (Fig. 1). The DRFA series for Chennai and Pamban for each year of 1901-2000 was subjected to CLCF analysis. The series for Chennai was kept fixed and that for Pamban shifted by positive and negative lags(days) to obtain the CLCF for each year. In most of the years, the CLCF displayed a clear bell shaped profile peaking at a particular lag and decreasing on either side thereof. For 91 years the CLCF revealed such a clear pattern and in the remaining 9 years the CLCF did not exhibit a pattern or the CCs were insignificant. Fig. 5 presents the scatter plot between the lags corresponding to the CLCF peak (LCP) *vis-à-vis* the corresponding modal CC values. The LCP was negative in 63 out of 91 years, 0 in 12 years and positive in 16 years. The mean value of LCP corresponding to negative, non-negative values of LCP was -3.1 and -2.6 days respectively whereas mean of all the LCP values was -1.8 days. The LCP was higher than 0.5 in 87 years. The average CLCF obtained by averaging the individual CLCFs of 100 years is presented in Fig. 6. The graph peaks both at lags -1 and -2 with the CC values decreasing sharply for positive and gradually for negative

TABLE 3

Results of CLCF analysis of Daily Rainfall of Coastal Tamil Nadu, 1 Sep - 28 Feb 2000

LCP	*n*	Mean of LCP (Days)
Negative (≤ -1)	63	–3.1
Non-negative(≤ 0)	75	–2.6
All	91	–1.8
No clear pattern	9	-
Based on average CLCF	100	–1 to –2 (mode)

n - No. of years; CLCF - Cross lag correlation function
LCP - Lag corresponding to CLCF peak.

TABLE 4

Intra-seasonal variation of DRFA 345 series and its effect on onset and withdrawal of northeast monsoon over coastal Tamil Nadu

Date of change of sign of DRFA345 series (*x*)	No. of years	Mean date (*x*)	Mean onset/ Withdrawal date (*y*)	Mean lag (*x-y*) days	Mean absolute lag |*x-y*| days	CC(*x*,*y*)
From – to +, closer to onset date	73	19 Oct	21 Oct	–1.9	4.6	0.90
From + to –, closer to withdrawal date	68	26 Dec	29 Dec	2.7	5.6	0.91

DRFA: Daily rainfall anomalies over coastal Tamil Nadu, 1 Sep-28 Feb.
DRFA345: Component of DRFA associated with 40-day oscillation.

lags. In Table 3 is shown some of the results of CLCF analysis in a nut shell.

The analysis of CLCF of individual years and the profile of average CLCF has clearly brought out that CLCF in a normal way, peaks for negative lags which according to our definition implies that rainfall anomalies move from Pamban to Chennai, *i.e*., south to north movement. This is consistent with the overall observation of 40-day oscillation of Indian southwest monsoon rainfall. Now the low level winds over the southern Indian peninsula during most of the period of our study are easterlies and the northeast monsoon establishes itself in association with the southward movement of equatorial trough. That south-north movement of rainfall anomalies could take place despite the region of rainfall activity shifting southwards with the advancement of season should be considered as remarkable.

Despite the wide range of LCP values (Fig. 5), a representative value of -2 to -3 days seems appropriate from the results presented in Table 3. This yields a speed of movement of nearly 130-200 km or roughly 1-2° latitude per day. This speed of movement agrees reasonably well with that obtained by Sikka and Gadgil (loc.cit) who obtained an average south to north speed of movement of 1° latitude per day and 2° in extreme cases of maximum cloud zone over Indian region during southwest monsoon season.

3.3. *40-day oscillation in association with onset and with withdrawal of northeast monsoon*

In the previous section, it has been shown that nearly 40% of the intra-seasonal rainfall variation during northeast monsoon is accounted for by the 40-day oscillation. The surmise of a possible role this low frequency oscillation might play in the commencement and cessation of northeast monsoon rains requires further investigation. The following analysis was thereupon carried out. The sum of the 3rd ,4th and 5th harmonics with recurrence periods of 53, 40 and 32 days respectively over the 160 days DRFA series was derived, which is denoted by DRFA345. In the DRFA series of CTN, the onset of northeast monsoon is by and large associated with anomalies turning from negative to positive and the withdrawal from positive to negative. If DRFA345 changed sign from negative to positive closer to the onset date and if the three harmonics explained a

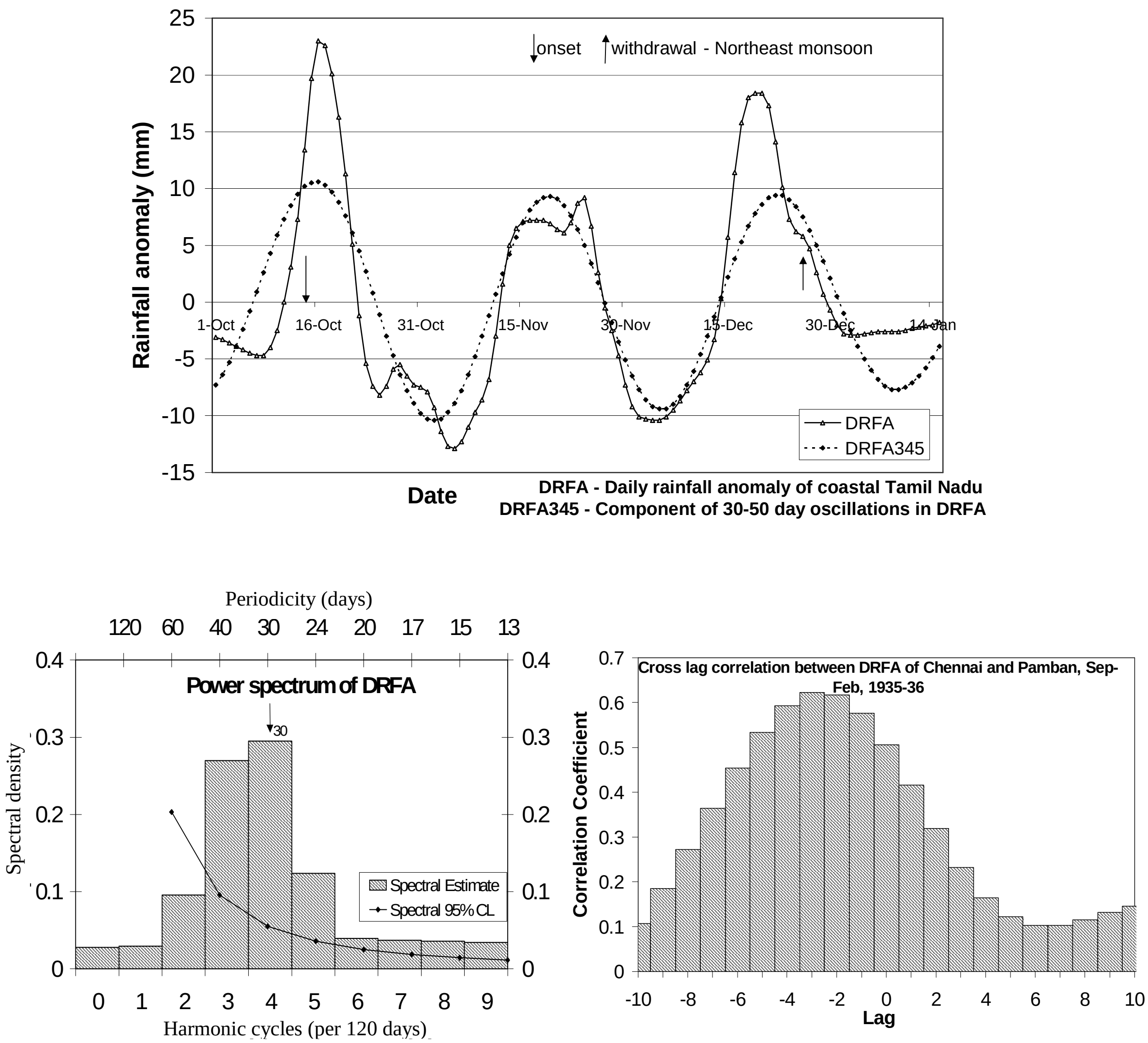

Fig. 7. Intra seasonal variation of rainfall of coastal Tamil Nadu for 1935-36

good amount of variation of DRFA it can be taken that the onset process was to some extent excited by the 40-day periodicity. Similar arguments hold good for withdrawal as well.

The DRFA345 series for each year was critically studied to identify whether it followed the same tendency of the DRFA series in the neighbourhood of onset/withdrawal dates. It was found that in 73 years, the DRFA345 series changed sign from negative to positive within 4-5 days (before/after) of the onset date. These dates exhibited a high positive CC of 0.90 with the onset dates of northeast monsoon with the mean of the former preceding the mean of the latter by 2 days. In case of withdrawal, in 68 years the DRFA345 series changed sign from positive to negative within 5-6 days of the withdrawal date. The CC between these dates and the withdrawal dates of northeast monsoon was 0.91 with the mean of the former succeeding the mean of the latter by 3 days. In the remaining years, no clear pattern linking onset/withdrawal with the 40-day oscillation could be identified.

We could thus conclude that in nearly 70% of the years, the onset/withdrawal of northeast monsoon over

CTN gets excited by the 40-day oscillation. At the time of onset the DRFA series lags the 40-day oscillation by two days and at withdrawal the latter lags the former by three days suggesting the presence of a phase shift between the two series from onset to withdrawal. Table 4 presents the results of this analysis in a nutshell.

3.4. *An illustration*

We illustrate some of the features of intraseasonal variation of northeast monsoon rainfall of coastal Tamil Nadu discussed in the previous sections for an individual year, 1935-36. In 1935 the northeast monsoon set in over CTN on 13 October and withdrew on 28 December as derived in I & II. Fig. 7 presents by means of graphs/diagrams the various features of the rainfall. As seen DRFA changes sign from negative to positive closer to the onset date and from positive to negative closer to the date of withdrawal. The power spectrum alongwith the red noise null continuum at 95% level of significance, which has been presented, clearly brings out the presence of 30-50 day periodicity in the DRFA series. The 3rd, 4th and 5th harmonics together accounted for 66% of the total variation. The DRFA345 series which is the sum of the above three harmonics has been derived and is graphically presented.

The DRFA345 series changes sign from negative to positive on 7th October, 6 days prior to the onset of northeast monsoon and from positive to negative on 1 January 1936, 4 days after withdrawal. That the 40-day oscillation has played some role in exciting onset and withdrawal during 1935-36 is thus illustrated. The CLCF between the DRFA series of Chennai and Pamban has been derived and as seen from Fig. 7 the LCP is -3 with a CC value of 0.62, the interpretation is that DRF anomalies took roughly three days to move from Pamban to Chennai during the above year, the speed of movement is roughly 1.3 latitude or 140 km per day.

4 Summary

The results of the study are summarised below :

(*i*) The onset and withdrawal dates of northeast monsoon over coastal Tamil Nadu for the period 1991-2000 have been determined, which when appended with dates generated for 1901- 90 provide a century record of dates of onset and withdrawal of northeast monsoon.

(*ii*) The normal date of onset of northeast monsoon (1901-2000) is 20 October with a standard deviation of 7-8 days; that of withdrawal is 27 December with a standard deviation of 13-14 days. The normal duration is 67 days with a deviation of 14-15 days.

(*iii*) Harmonic and spectral analysis performed on the rainfall of coastal Tamil Nadu for September - February for the 100 year period 1901-2000 revealed that 40-day oscillation of rainfall was present in 86 years and accounted for nearly 40% of the intra seasonal variation of rainfall.

(*iv*) The analysis based on cross lag correlation of rainfall of Chennai and Pamban brought out that the rainfall anomalies moved from south to north over coastal Tamil Nadu taking nearly 2-3 days to travel from Pamban to Chennai. The speed of movement was 1-2° latitude per day.

(*v*) In nearly 70% of the years, the 40-day oscillation excited the onset/withdrawal of northeast monsoon. The rainfall anomalies associated with the 40-day mode changed to positive two days before the onset date, and into negative three days after the withdrawal date. Overall the changeover manifested within 4-5 days of the onset date and 5-6 days of the withdrawal date.

Acknowledgements

The author thanks the Deputy Director General of Meteorology, Regional Meteorological Centre, Chennai for having provided the facilities to undertake this study. Thanks are also due to Kum.B.Amudha for preparation of diagrams and manuscript and to Smt. B. Usha for collection of data .

References

Gadgil, S., 1990, “Poleward propagations of the ITCZ: Observations and theory”, *Mausam*, **41**, 2, 285-290.

India Met. Dep., 1973, “Northeast monsoon”, FMU Report No.IV - 18.4.

India Met. Dep., 1987, “Report of the tenth conference of forecasting officers”, 43-46.

Keshavamurty, R. N., Kasture, S. V. and Krishna Kumar, V., 1990, “30-50 day oscillation of monsoon: Some simple mechanisms”, *Mausam*, **41**, 2, 189-192.

Panofsky, H. A. and Brier, G. W., 1968, “Some applications of statistics to Meteorology”, University Park, Pennsylvania, 159-161

Raj, Y. E. A., 1992, “Objective determination of northeast monsoon onset dates over coastal Tamil Nadu for the period 1901-90”, *Mausam*, **43**, 273-282.

Raj, Y. E. A., 1998, "A statistical technique for determination of withdrawal of northeast monsoon over coastal Tamil Nadu", *Mausam*, **49**, 3, 309-320.

Sikka, D. R. and Gadgil, S., 1980, "On the maximum cloud zone and the ITCZ over Indian longitudes during the southwest monsoon", *Mon. Wea. Rev.*, **108**, 1840-1853.

Singh, S. V. and Kripalani, R. H., 1990, "Low frequency intraseasonal oscillations in Indian rainfall and outgoing long wave radiation", *Mausam*, **41**, 2, 217-222.

Wilks, S. D., 1996, "Statistical methods in the Atmospheric Sciences", Academic Press, London.