A 140 year data archive of dates of onset and withdrawal of northeast monsoon over coastal Tamil Nadu : 1871-2010 (Re-determination for 1901-2000)

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सार – तमिलनाडु और दक्षिणी आंध्र प्रदेश के 25 तटीय प्रेक्षण स्थानों के दैनिक वर्षा आँकड़ों का उपयोग करते हुए 1871-2010 तक की 140 वर्षों की अवधि का तटीय तमिलनाडु में पूर्वोत्तर मॉनसून के आरंभ और वापसी की तारीख का निर्धारण किया गया है। वास्तव में 1901-2000 तक की अवधि की इन तारीखों को पुन: निर्धारित किया गया है। हालांकि तमिलनाडु के 4-6 तटीय प्रेक्षण स्थानों के दैनिक वर्षा आँकड़ों के अपरिष्कृत आँकड़ों का उपयोग करते हुए इन्हीं तारीखों का निर्धारण इस शोध पत्र के दूसरे लेखक पहले ही कर चुके हैं । इस शोध में अपनाई गई पद्धति पहले किए गए अध्ययन के समान ही है। पुन: निर्धारित तारीखों की तुलना पहले निर्धारित की गई तारीखें के साथ की गई है। 1901 से 2000 की अवधि के लिए, पूर्वोत्तर मॉनसून के आगमन की औसत तारीख और उसके मानक विचलन में 20 अक्तूबर और क्रमश: 8 दिन तक कोई बदलाव नहीं आया परंतु पूर्वोत्तर मॉनसून की वापसी की औसत तारीख 27 दिसम्बर से 30 दिसम्बर तीन दिन आगे बढ़ी। 1871-1900 और 2001-2010 की अवधि के लिए पूर्वोत्तर मॉनसून के आगमन की औसत तारीख क्रमश: 17 अक्तूबर और 18 अक्तूबर रही और पूर्वोत्तर मॉनसून की वापसी की तारीख दोनों अवधियों के लिए एक ही 23 दिसम्बर रही । दशकीय पैमाने पर, तटीय तमिलनाडु में पूर्वोत्तर मॉनसून के आगमन की औसत तारीख 16-25 अक्तूबर और वापसी की 19 दिसम्बर से 9 जनवरी रही। पूर्वोत्तर मॉनसून के आरंभ और वापसी की तारीखों के समय श्रृंखला विश्लेषण से दोनों श्रृंखलाओं में किसी महत्वपूर्ण प्रवृत्ति का पता नहीं चला है। साथ ही, दोनों श्रृंखलाओं में कोई महत्वपूर्ण सहसंबंध नहीं है। अत: किसी दिए गए वर्ष के संबंध में पूर्वोत्तर मॉनसून के आरंभ और वापसी की तारीख एक दूसरे से संबंधित नहीं है। तथापि, दोनों श्रृंखलाओं के भीतर और उनमें आपस में महत्वपूर्ण क्रॉस/लैग/क्रॉस लैग सहसंबंधों के संकेत मिलते हैं। उपक्षेत्रीय पैमाने पर पूर्वोत्तर मॉनसून की वापसी की तारीखों के विश्लेषण से पता चला है कि तटीय तमिलनाडु से पूर्वोत्तर मॉनसून की वापसी चरणबद्ध तरीके से होती है। तटीय तमिलनाडु (औसत तारीख 31 दिसम्बर) के मध्य और दक्षिणी भागों से वापसी के लगभग दो सप्ताह पूर्व उत्तरी भागों (औसत तारीख: 17 दिसम्बर) से वापसी हो जाती है।

ABSTRACT. The dates of onset and withdrawal of northeast monsoon (NEM) over Coastal Tamil Nadu (CTN) are determined for the 140 year period of 1871-2010 using daily rainfall data of 25 coastal stations of Tamil Nadu and South Andhra Pradesh. For the period 1901-2000, these dates are actually re-determined as they had earlier been determined by the second author using a coarse dataset of daily rainfall data of 4-6 coastal stations of Tamil Nadu. The methodology adopted is the same as the one adopted in the earlier study. The re-determined dates are compared with the ones determined earlier. For the period 1901-2000, the mean date of NEM onset and its standard deviation remain unchanged at 20 October and 8 days respectively, but, the mean date of NEM withdrawal is extended by three days, from 27 December to 30 December. For the periods 1871-1900 and 2001-2010, the mean dates of NEM onset are 17 October and 18 October respectively and the mean date of NEM withdrawal is the same for both the periods at 23 December. In the decadal scale, the mean date of NEM onset over CTN varies between 16-25 October and that of withdrawal, between 19 December to 9 January. Time series analysis of dates of NEM onset and withdrawal indicate that there is no significant trend in both the series. Also, there is no significant correlation between the two series and hence, for a given year, the dates of NEM onset and withdrawal are independent of each other. However, there are indications of existence of significant cross / lag / cross-lag correlations within and amongst the two series. Analysis of dates of NEM withdrawal on a sub-regional scale indicates that withdrawal of NEM from CTN occurs in a phased manner, with the withdrawal from the northern parts (mean date: 17 December) occurring about two weeks prior to the withdrawal from the central and southern parts of CTN (mean date : 31 December).

Key words – Northeast monsoon, Onset date, Withdrawal date, Coastal Tamil Nadu, Daily rainfall index, Superposed epoch analysis, Inter-annual variability, Decadal variability.

1.   Introduction

The Indian Northeast Monsoon (NEM) is a small scale monsoon affecting the southern peninsular India during October-December, after the withdrawal in September-October of the Indian Southwest/Summer Monsoon (SWM, duration June-September, JJAS) which is the principal rainy season of the country. Several works on NEM performance such as spatial and temporal rainfall variability, its onset, withdrawal, duration etc. have been published elucidating the various features of this monsoon.

The low level winds over India, which are southwesterly during summer (May-October) reverse and change over to northeasterly during winter and pre-summer (October-April) owing to the reversal of pressure gradient between the northern and southern parts (Das, 1986). The onset of low level easterlies precedes and serves as a forerunner to the onset of NEM rains over Coastal Tamil Nadu (CTN) after mid-October. Raj (1992, 1998 & 2003) has determined the dates of easterly onset and the onset and withdrawal dates of NEM for the 100 year period of 1901-2000. The normal date of onset of easterlies over CTN has been derived as 14 October with a standard deviation (SD) of 7-8 days. The normal dates of onset and withdrawal (DOO & DOW) have been derived as 20 October and 27 December respectively with a SD of 7-8 days and 13-14 days based on the dates determined in the above studies which we define as earlier determined dates of onset and withdrawal (EDO & EDW) to distinguish them from the new set of dates which are derived in the present study.

The earlier determination for 1901-2000 has been based on daily rainfall (DRF) data of 4 stations of CTN for the first 60 years (1901-60) and that of 6 stations for the next 40 years (1961-2000). Now, with the availability of voluminous daily rainfall data of large number of rain gauge stations for over a century, deriving a set of re-determined dates of onset (RDO) and withdrawal (RDW) is very much feasible and perhaps essential for greater authenticity and reliability.

With this background, in the present study, RDO and RDW are derived for the period 1901-2000 by following the same criteria and methodologies adopted in Raj (loc.cit) but, based on a larger dataset consisting of DRF of 25 coastal stations [23 along CTN and 2 along Coastal Andhra Pradesh (CAP)] for the period 1 September-28 February. Determination of the dates of onset and withdrawal is extended for the first decade of the 21st century, 2001-2010 and also for the last 3 decades of the 19th century, *viz.*, 1871-1900. The above dates would serve as a 140-year data archive of NEM onset and withdrawal dates (Geetha, 2011).
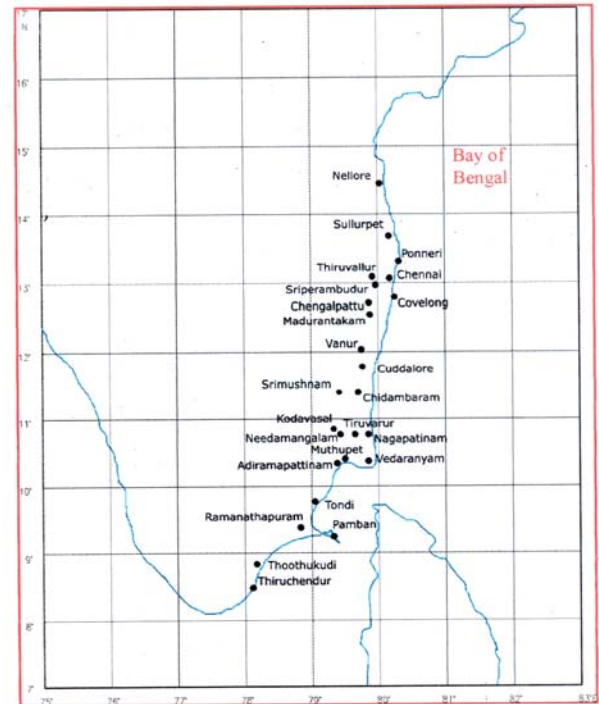

Fig. 1.   Locations of coastal stations of Tamil Nadu / South Andhra Pradesh considered for analysis in the present study

2.   Data

Twenty five (25) well distributed stations of CTN some of which are located up to 50-75 km away from the coast and two stations of South CAP are selected for the study. The geographical locations of these stations are shown in Fig. 1. The northern most station considered is Nellore located at 14.5º N and the southernmost station is Tiruchendur at 8.5º N. The DRF data of the above stations for the period 1 September-28 February, 1871-72 to 2002-2003 were obtained from the National Data Centre, India Meteorological Department (IMD), Pune. Data for 2003-2004 to 2010-2011 were extracted from the rainfall records available at Regional Meteorological Centre, Chennai and Meteorological Centre, Hyderabad. Data for all the stations were not available for the entire period 1871-2010. However, by and large, the spatial distribution of rain gauges with available data well represented the entire stretch of the coastal belt considered.

3.   Methodology

The methodology employed for determination of dates of onset and withdrawal of NEM over CTN in Raj (loc.cit) are followed in toto, by and large, in this study. The salient aspects are repeated here in below for clarity. The classifications followed by IMD for the description of spatial rainfall over a region, *viz.*, Widespread (W) (if the number of stations considered reporting 2.5mm of rainfall
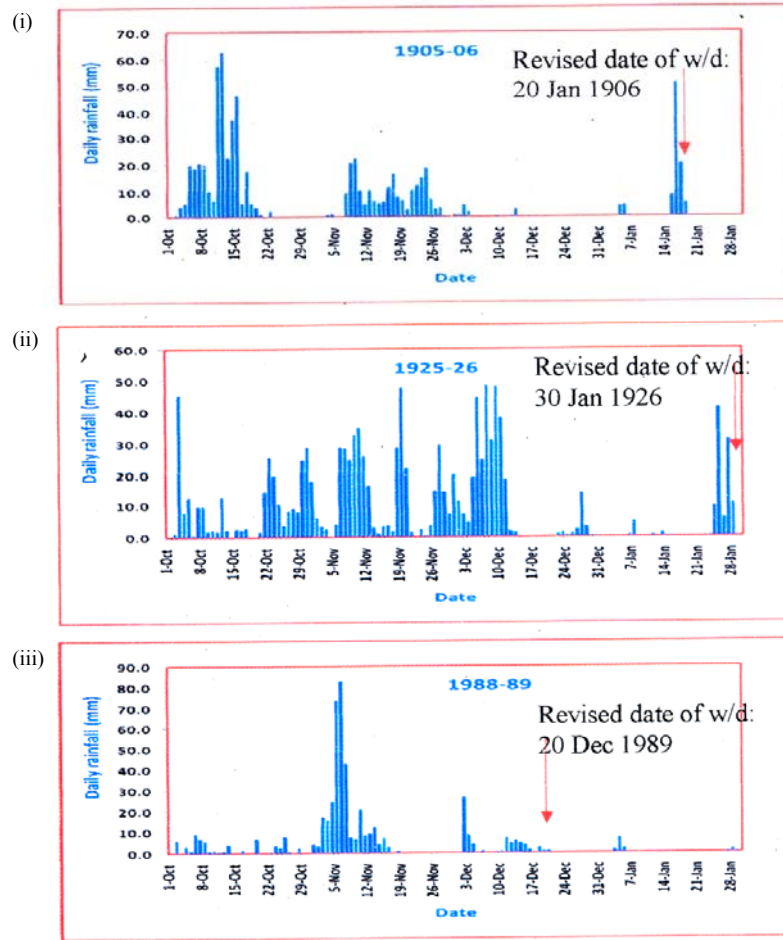
Figs. 2a (i-iii). Illustrations on identification of last wet spell for determination of date of withdrawal (w/d)

or more is ≥75%), Fairly Widespread (FW) (50-75%), Scattered (SC) (25-50%), Isolated (I) (≤25%) and Dry (D) (0%) and the rainfall intensity classification as heavy (denoted by adding + as superscript) and very heavy (+ +) if one or more of the individual stations of the region concerned report DRF of 64.5-124.4 mm and ≥124.5 mm respectively, are adopted here.

3.1. *Criteria for determination of dates of onset*

The following five rules (R_1 to R_5) formulated in Raj (1992) are used:

R_1 : Southwest monsoon should have withdrawn up to CAP.

R_2 : Deep easterlies (up to 850 hPa) should have set in over Tamil Nadu or seasonal low should have established in south Bay of Bengal (BOB) adjacent to Tamil Nadu coast.

R_3 : After R_1 and R_2 are satisfied, the first day of FW rainfall or a higher category over CTN would be the day of NEM onset.

R_4 : If the date arrived at by R_3 happens to be earlier than 10 October, the winds / surface charts are to be scrutinised to decide as to whether the onset of easterlies are temporary or permanent. If it is permanent, then the date of R_3 should be taken as the onset date. If the easterly onset is temporary and if westerlies appear again in the lower troposphere over CTN, the date of permanent onset of easterlies is to be determined and R_3 is to be applied again.

R_5 : In case, the date fixed is completely unsatisfactory, a review is to be made and the next date of FW rainfall is to be considered as onset date.

(i)

(ii)

(iii)

(iv)
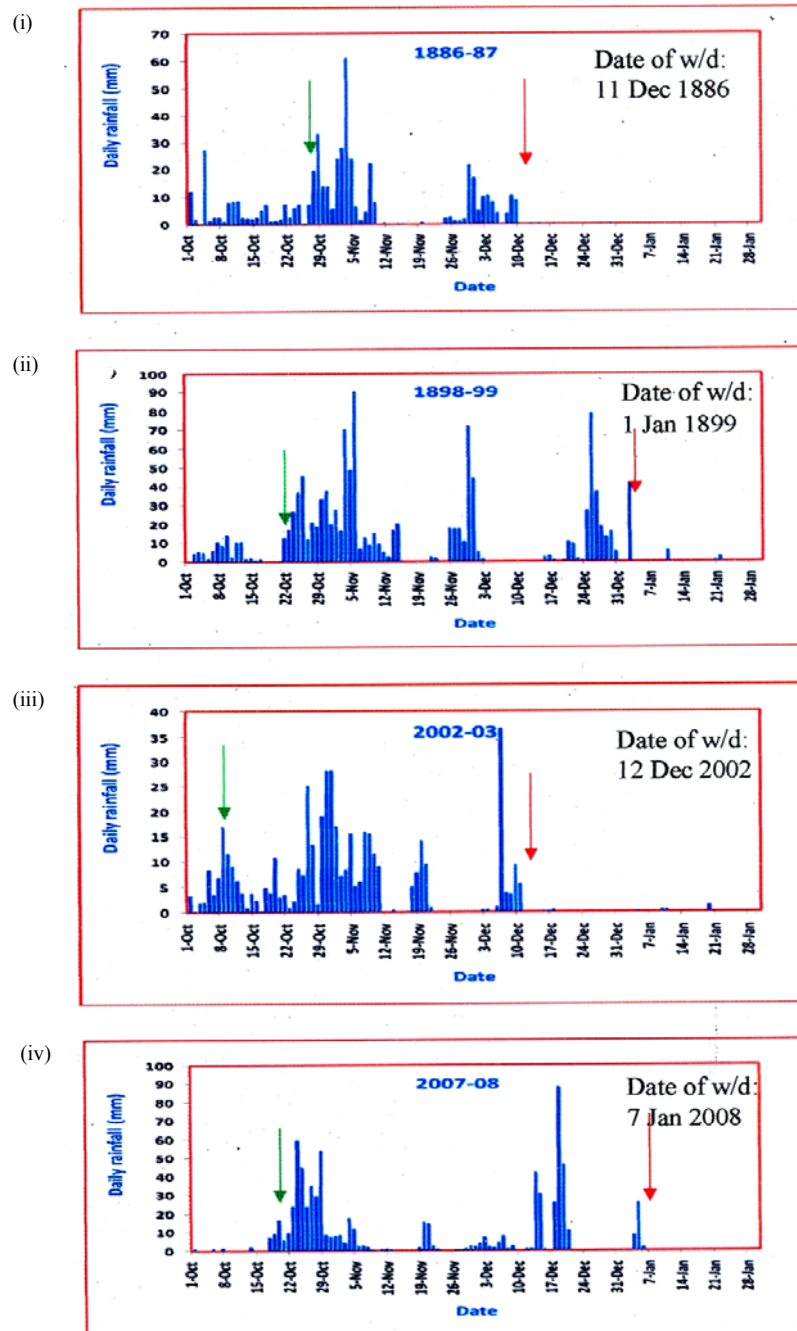
Figs. 2b (i-iv).   Illustrations on determination of dates of onset (denoted by green arrow) and withdrawal (red arrow) for the period 1871-72 to 1900-01 and 2001-02 to 2010-11

3.2. *Rules for determination of date of withdrawal of northeast monsoon over CTN*

The rules for determining the DOW of northeast monsoon have been formulated based only on rainfall, which is the primary index of monsoon activity

(Ananthakrishnan *et al.*, 1967). For this purpose, a parameter Daily Rainfall Index (DRI) for a day has been defined 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 (Raj, 1998).

TABLE 1

Dates of onset and withdrawal of northeast monsoon over Coastal Tamil Nadu for the period 1871-2010

Period	NEM parameter	Parameter date									
Year→		1	2	3	4	5	6	7	8	9	10
1871-1880	Onset	16-O	10-O	4-O	20-O	16-O	8-N	22-O	1-N	18-O	18-O
	Withdrawal	16-D	23-D	5-D	16-D	11-D	28-D	19-D	20-D	24-D	27-D
1881-1890	Onset	1-N	11-O	12-O	14-O	28-O	28-O	8-O	15-O	13-O	26-O
	Withdrawal	5-J	30-D	26-D	25-D	8-J	11-D	1-J	20-D	21-D	8-D
1891-1900	Onset	12-O	13-O	11-O	17-O	11-O	26-O	13-O	22-O	19-O	17-O
	Withdrawal	30-D	26-D	20-D	26-D	1-J	29-D	21-D	1-J	3-D	26-D
1901-1910	Onset	27-O	22-O	24-O	19-O	5-O	17-O	20-O	22-O	15-O	16-O
	Withdrawal	9-J	8-J	4-J	23-D	20-J	31-D	22-D	8-J	2-D	27-N
1911-1920	Onset	15-O	12-O	24-O	10-O	11-N	15-O	17-O	1-N	14-O	22-O
	Withdrawal	28-D	6-D	22-D	23-J	30-D	10-D	19-J	20-D	10-J	25-J
1921-1930	Onset	22-O	12-O	16-O	23-O	23-O	30-O	27-O	16-O	26-O	9-O
	Withdrawal	12-J	17-J	10-J	21-D	30-J	18-D	9-J	31-D	11-J	19-J
1931-1940	Onset	29-O	10-O	27-O	24-O	13-O	22-O	24-O	26-O	11-O	27-O
	Withdrawal	28-D	19-D	28-J	24-J	28-D	22-D	19-D	14-J	17-D	9-J
1941-1950	Onset	19-O	1-N	5-O	21-O	13-O	16-O	19-O	16-O	18-O	15-O
	Withdrawal	19-D	5-J	13-J	24-D	10-D	8-J	19-J	22-D	1-D	16-D
1951-1960	Onset	6-N	4-O	15-O	12-O	19-O	26-O	15-O	30-O	21-O	22-O
	Withdrawal	2-D	15-D	14-J	11-J	10-D	29-D	4-J	20-D	22-D	18-J
1961-1970	Onset	24-O	9-O	20-O	31-O	15-O	4-O	15-O	13-O	15-O	10-O
	Withdrawal	15-D	13-J	13-D	28-D	17-D	23-D	20-D	22-D	3-J	30-D
1971-1980	Onset	17-O	21-O	18-O	6-N	25-O	15-O	7-O	20-O	22-O	11-O
	Withdrawal	19-D	28-D	31-D	27-D	20-D	25-D	12-D	1-J	15-D	20-D
1981-1990	Onset	23-O	18-O	24-O	4-N	25-O	26-O	20-O	3-N	27-O	19-O
	Withdrawal	24-D	18-D	20-J	7-J	17-J	30-D	26-D	20-D	10-J	20-J
1991-2000	Onset	19-O	3-N	13-O	18-O	23-O	9-O	13-O	28-O	4-O	3-N
	Withdrawal	24-D	21-D	1-J	22-J	13-D	19-D	23-D	3-J	12-J	2-J
2001-2010	E'ly onset	15-O	1-O	13-O	13-O	6-O	15-O	14-O	12-O	15-O	26-O
	Onset	15-O	9-O	19-O	18-O	11-O	17-O	19-O	12-O	29-O	29-O
	Withdrawal	1-J	12-D	8-D	16-D	21-D	14-D	7-J	21-D	26-D	6-J

NEM : Northeast Monsoon; O : October; N : November; D : December; J : January;   1901-2000 : Revised dates.
The year 1971 means the year 1971-72 as the northeast monsoon sometimes spills over to the next year.

The rules for determination of DOW of northeast monsoon are as under:

R1 : The DRI is to be computed for every day for the period September to February of the next year. If DRI>40 for a day, the day would be deemed to belong to a significant rain spell.

R2 : If no significant rain spell commenced on or after 1 January, the first day with DRI<40 which is not succeeded by dates of DRI>40 in the calendar either until 31st December or up to the end of the significant rain spell which may have commenced on or before 31st December but continued thereafter, would be deemed to be the mid-date of the withdrawal pentad.

R3 : If a significant rain spell commenced on or after 1st January, the withdrawal pentad is to be determined by critically studying the January-February (JF) 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 JF spell could be considered as continuation of northeast monsoon.

R4 :Once the withdrawal pentad is located, the precise DOW 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.

3.3. *Determination/re-determination of the dates of onset and withdrawal*

By and large, DOO and DOW are determined or re-determined as per the laid down rules. As the NEM onset is preceded by easterly onset, determination of DOO is quite well defined and precise. However, identification of the last significant wet spell and hence the withdrawal pentad is not as straight forward as the identification of the onset pentad. In the month of December, during the withdrawal phase, the NEM activity (which is confined to CTN only) starts tapering off and is rather subdued with long dry spells (IMD, 1973). By and large, the wet spells are of shorter duration, just 2-3 days juxtaposed between long dry spells and the condition DRI > 40 is not met in some cases. However, taking into consideration, the amount of rainfall, its spatial distribution and intensity, and the length of dry spells in between and after, the withdrawal pentad is fixed by a case by case analysis.

With the availability of DRF data of 20-25 stations, greater number of wet spells, than the one determined in the earlier work with data of 4-6 stations, could be identified for some years. There are also a few years for which the DOW is slightly advanced to an earlier date. In case the ambiguity is not resolved by the above considerations, of the selected dates, the one that is closest to the mean is given greater weightage and hence taken as the DOW. Such cases were only very few and are detailed in the subsequent sections.

In Figs. 2a(i-iii) we present the time series of DRF during the NEM season for a few years to illustrate how the last wet spell was determined by case by case analysis. For the years 1905-06 and 1925-26 the EDW are 30 November and 15 December respectively. In the present study, one more wet spell with DRI > 40% could be identified and hence the season had to be extended by 52 and 46 days, up to 20 January and 30 January respectively. For the year 1988-89, the EDW is 6 January. Here, DRI based on the large dataset for 6 January is 18% only. The RDW is advanced to 20 December which is justified by the meager amount of rainfall (less than 2 cm) realised during the intervening period and a higher value of DRI during the withdrawal pentad (32%).

Figs. 2b(i-iv) present the DRF of some of the years during the periods 1871-1872 to 1900-1901 and 2001-2002 to 2010-2011 for which DOO and DOW are determined for the first time, in this study. For all these selected years, 1886-1887, 1898-1899, 2002-2003 and 2007-2008, the DOO (28, 22, 9, 19 October respectively) and DOW (11 December, 1 January, 12 December and 7 January respectively) could be fixed without much

TABLE 2

Statistical parameters of dates of onset and withdrawal of northeast monsoon over coastal Tamil Nadu for the periods 1901-2000, 1871-1900 and 2001-2010

Period	NEM parameter	Mean date	S.D. (days)	Range (days)
1871-1900	Onset	17-Oct	7	29
	Withdrawal	23-Dec	9	37
	Duration	67 days	11	43-85
1901-2000	Onset	20-Oct	8	38
	Withdrawal	30-Dec	14	65
	Duration	72 days	16	26-107
2000-2010	Onset	18-Oct	7	21
	Withdrawal	23-Dec	10 to 11	31
	Duration	67 days	9 to 10	50-80

NEM : as in TABLE 1;   SD : Standard Deviation

ambiguity. For the year 2007-2008, the DOW was fixed as 7 January based on the amount of rainfall realised (3-4 cm rainfall in 3 days), its spatial distribution and intensity being FW with *heavy* rainfall on the first two days and SC rainfall on the third day though DRI during the withdrawal pentad was 29% only.

For the 19th century period 1871-72 to 1900-01, the dates of onset of surface easterlies over CTN are not available. In the absence of these dates, the DOO of NEM were determined mainly by identifying the dates with sharp increase in the daily rainfall pattern that could be associated with the onset. October rainfall of sub-divisions which generally do not benefit much from NEM, such as, North Interior Karnataka (NIK), Coastal Karnataka (CK) and Telengana were also considered to locate the likely withdrawal period of SWM.

4.   Results and discussion

Table 1 presents the DOO and DOW of northeast monsoon over CTN during the 140 year period of 1871-2010. For the period 1901-2000, these are the RDO and RDW. For EDO and EDW, Raj (loc.cit) may be referred. The statistical parameters of the dates determined separately for the periods 1871-1900, 1901-2000 and 2001-2010 are presented in Table 2. In the forthcoming sections, a few characteristics of NEM as derived from the RDO and RDW are presented.

4.1. *1901-2000*

4.1.1. *Dates of onset*

The mean and SD based on RDO for the 100 year period of 1901-2000 are the same as those of EDO, *viz.*, 20 October and 8 days respectively. The range is also

the same, *viz.*, 4 October to 11 November. For the individual years, the RDO coincides with the EDO for 52 years, differ by one day for 28 years (earlier for 9 years and later for 19 years), by 2 days for 10 years (earlier for 9 years and later for 1 year) and by 3 days for 4 years (all 4 are earlier). The RDO differs from the EDO by half the SD or more (four or more days) on four occasions only and on all these occasions, the RDO is earlier than the EDO-1910 (earlier by 5 days), 1919 (4 days), 1952 (11 days) and 1970 (4 days). The fact that there is not much change in the basic statistical parameters of RDO of NEM implies that a well represented optimal set of rain gauge stations, even if not densely packed, would suffice to correctly determine the onset dates of NEM.

4.1.2. *Dates of withdrawal*

The mean date of RDW is 30 December which is 3 days later than that of EDW - 27 December. The SD has increased by 1 day, *i.e.*, from 13 to 14 days and the range by 3 days (RDW: 27 November to 30 January; EDW: 26 November to 28 January). For individual years, the RDW coincides with the EDW for 59 years and is less than half the SD of 7 days during another 22 years. The RDW differs from the EDW by 7 days or more during 19 years. Out of these, on 5 occasions, the RDW is earlier than the EDW and on 14 occasions, it is later.

Tables 3(a-c) present the rainfall parameters, *viz.*, amount of realised rainfall, spatial rainfall distribution and intensity associated with the RDW for the years during which the RDW differed from the EDW by half the SD. Table 3(a) depicts 7 cases of clear cut extension of the NEM season under rule *R1* of DRI > 40. Table 3(b) presents 7 cases wherein, the rule *R1* is not meted out, but yet, the amount of rainfall realised during the intervening period (4 cm and above) and the spatial distribution and intensity of rainfall after the EDW [column (vi) of Table 3(b)] warranting the extension of the NEM season up to the revised dates. Here, for the year 1992, the DOW is extended from 9 to 21 December, even though the amount of rainfall realised is less than 3 cm as the spatial and temporal coverage of the withdrawal spell could not be treated as insignificant. In Table 3(c), we bring out the conditions under which the RDW is fixed prior to EDW for 6 years. The DRI for the EDW is much less than 40% and the rainfall during the intervening period between EDW and RDW is not quite substantial (1-2 cm only). As such, it is quite apt to associate the DOW with an earlier significant rain spell.

4.1.3. *Duration of northeast monsoon*

The RDW, though coincides with EDW in as many as 59 years, has led to a slightly extended NEM season.

TABLES 3(a-c)

Rainfall parameters (DRI, realised rainfall, spatial rainfall distribution and intensity) for years with revised dates of withdrawal extending beyond 7 days from the original dates

(a)

Year	Date of withdrawal		Extended No. of days	Amount of rainfall realised between (ii) and (iii) in mm
	Original	Revised		
(i)	(ii)	(iii)	(iv)	(v)
1905	30 Nov	20 Jan	52	107.6
1914	9 Dec	23 Jan	45	88.7
1920	15 Jan	25 Jan	10	44.1
1925	15 Dec	30 Jan	46	130.9
1934	18 Dec	24 Jan	37	85.4
1938	9 Dec	14 Jan	36	83.8
1994	24 Dec	22 Jan	29	90.0

(b)

Year	Date of withdrawal		Extended No. of days	Amount of rainfall realised between (ii) and (iii) in mm	No. of days with significant rainfall distribution between (ii) and (iii)
	Original	Revised			
(i)	(ii)	(iii)	(iv)	(v)	(vi)
1906	16 Dec	31 Dec	15	90.7	1W+; 1FW++; 4SC
1917	6 Jan	19 Jan	13	59.8	1FW+; 1SC++; 2SC
1947	4 Jan	19 Jan	15	54.8	1W+; 1FW+
1959	4 Dec	22 Dec	18	38.7	1W; 1FW+; 3SC
1980	6 Dec	20 Dec	14	40.0	1FW+; 1SC+; 1SC
1990	27 Dec	20 Jan	24	60.4	2SC+; 4SC
1992	9 Dec	21 Dec	12	25.8	2SC+; 1SC

(c)

Year	Date of withdrawal		No. of days by which withdrawal date is advanced	Amount of realised rainfall between (ii) and (iii) (mm)	No. of days with significant rainfall distribution between (ii) and (iii)
	Original	Revised			
(i)	(ii)	(iii)	(iv)	(v)	(vi)
1903	14 Jan	4 Jan	10	27.3	1FW, 1SC
1909	22 Dec	2 Dec	20	10.9	1FW
1948	3 Jan	22 Dec	12	19.8	1SC+; 2SC
1970	12 Jan	30 Dec	13	18.4	1FW; 2SC
1988	6 Jan	20 Dec	17	13.0	1SC+; 1SC

DRI: Daily rainfall index
W: Widespread (spatial distribution: >75%)
FW: Fairly widespread (50-75%)
SC: Scattered (25-50%)
+, ++ : Heavy (64.5-124.4 mm/day), very heavy (≥124.5 mm/day) rainfall respectively
1SC+: to be interpreted as one day of scattered and heavy rainfall.
Days with rainfall amount ≥2.5 mm are considered as rainy days.

(i)

(ii)

(iii)
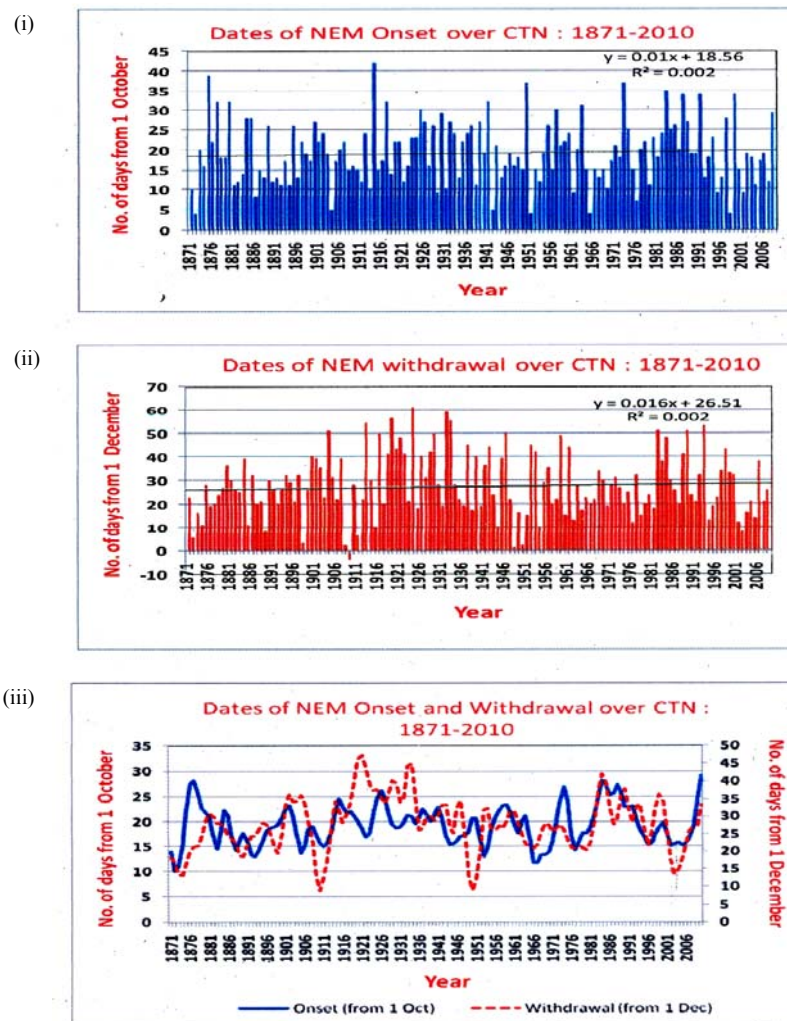
Figs. 3(i-iii).   Inter-annual variations in Dates of Onset and Withdrawal of NEM over CTN
for the period 1871-2010. (iii) depicts smoothened time series of (i) and
(ii) using a binomial filter. Date of Onset is depicted as No. of days from
1 October and that of Withdrawal as No. of days from 1 December

From Table 2 it can be seen that the mean duration of the NEM season has increased from 67 days (with earlier dates) to 72 days (with revised dates). During individual years, the duration of the season has varied from 26-107 days, as per the revised dates. The longest season is that of 1905-06 (5 October to 20 January) and the shortest one is that of 1951-52 (6 November to 2 December). The season has spilled over to January of next year on 36 occasions during 1901-2000 (Raj, 2003).

4.2. *1871-1900*

For the pre-1901 period of 1871-1900, the mean onset date is derived as 17 October with a SD of 7 days, the mean date of withdrawal is 23 December (SD: 9 days) and the mean duration of the season is 67 days (SD: 11

days). The onset dates vary from 4 October to 1 November, withdrawal dates from 3 Dec to 8 January and the duration of the season, from 43 to 85 days.

4.3. *2001-2010*

The mean DOO for the decade of 2001-2010 is 18 October with a SD of 7 days, the mean DOW is 23 December (SD: 10-11 days) and the mean duration of the season is 67 days (SD: 9-10 days) (Table 2).

4.4. *Inter-annual and decadal variabilities of dates of onset and withdrawal*

Figs. 3(i-ii) graphically present the time series of dates of NEM onset and withdrawal for the 140 year

TABLE 4

Decadal mean dates of onset and withdrawal of NEM over CTN

Decade	Mean date of onset (No. of days from 1 Oct)	Mean date of withdrawal (No. of days from 1 Dec)
1871-1880	19.5	18.9
1881-1890	18.7	24.8
1891-1900	16.1	24.5
1901-1910	18.7	27.8
1911-1920	20.3	31.7
1921-1930	20.4	39.5
1931-1940	21.3	33.2
1941-1950	17.4	26.1
1951-1960	20.1	26.9
1961-1970	15.6	24.6
1971-1980	19.3	22.9
1981-1990	25.1	34.7
1991-2000	19.5	29.5
2001-2010	17.8	22.5

period 1871-2010. The trend line is near flat and the corresponding CCs (explaining only 0.002%) are not significant. The CC between DOO and DOW based on 140 pairs is derived as 0.07 only which is again insignificant. Thus DOO and DOW for a given year are independent of each other. However a deeper analysis revealed the existence of positive relation if CC is derived between filtered series. When both DOO and DOW series are smoothed with the filter (1, 4, 6, 4, 1), the CC between the two filtered series is 0.36 and when this filtered series is again filtered with the same weights the CC is 0.43. Both these CCs are highly significant even if due allowance is given to the persistence generated within the series due to the smoothing process. The positive relationship can be visually appraised from Fig. 3(iii) which presents the filtered series of DOO and DOW.

We continue the analysis further by deriving the 14 decadal means of DOO and DOW presented in Table 4. The decadal means of DOO vary between 15.6 to 25.1 (as no. of days from 1 Oct) and those of DOW between 18.9 to 39.5 (as no. of days from 1 December). The CC between the decadal means based on the 14 pairs is derived as 0.60 which becomes significant at 5% level. In the decade 1961-70 the mean DOO is 15.6 days (from 1 October) and the mean DOW is 24.6 days (from 1 December) both of which are 4-5 days earlier than normal. During 1981-90 the mean dates are 25.1 and 34.7 respectively both delayed by nearly 5 days.

The correct interpretation from the analysis of the preceding paragraphs is that DOO and DOW though not statistically related on a year to year basis, start exhibiting

positive relation, *i.e.*, early (late) onset associated with early (late) withdrawal, once averaging or smoothing is effected. Normally time series smoothing reduces the noise in the series but in this case as the interval between two observations is as much as one year such an argument may not hold. Existence of significant lag/cross-lag correlations within and amongst the series is capable of generating the type of significant CCs that are derived between the two smoothed series or between decadal mean series. Such variations could be physically caused by large scale oscillations having time period greater than one year and reaching the peak amplitude after the NEM onset and before the NEM withdrawal, a typical example being the ENSO effect. Relationship between the NEM onset/withdrawal dates and ENSO have been analysed in Raj and Geetha (2008). Even though such analysis with other large scale oscillations is beyond the scope of this paper, this aspect opens up another potential area for research on NEM.

4.5. *Spatio-temporal variations in the withdrawal phase*

The withdrawal phase is further probed to see as to whether the NEM withdrawal occurs simultaneously along the entire CTN or withdrawal takes place in phases over different parts of the CTN. For this purpose, we divided CTN into three regions, *viz.*, North CTN (NCTN, north of 12° N (9 stations), Central CTN (CCTN, 10-12° N (10 stations) and South CTN (5 stations).

The DOW for NCTN, CCTN and SCTN were determined for the 50 year period 1961-2010 as per the methodology detailed in Section 3 followed by a critical analysis of DRF, DRI etc. before finalising the date. The DOW determined for the three coastal belts revealed an earlier withdrawal over NCTN than over the other two belts. The mean DOW over NCTN is derived as 17 December and the dates over CCTN and SCTN are identical at 31 December. Hence the central and the southern belts are combined together as a single coastal belt of Central and South CTN (CSCTN). The DOW of NEM over NCTN (north of 12° N) and CSCTN (south of 12° N) determined for the periods 1961-62 to 2010-11 are presented in Table 5 along with the mean dates and the SDs. It may be noted that there is a difference of as many as 14 days in the mean dates of withdrawal of NEM over NCTN and CSCTN, *viz.*, 17 and 31 December respectively, the difference quite significant and of relevance.

Figs. 4(a&b) present the superposed epoch analysis of mean DRF over NCTN and CSCTN with respect to the DOW of NEM. It is seen that rainfall almost ceases after withdrawal over NCTN. However, over CSCTN, some

TABLE 5

**Dates of withdrawal determined separately for two coastal belts of
coastal Tamil Nadu (NCTN, CSCTN) for the period 1961-2010**

Years	Withdrawal date over NCTN	Withdrawal date over CSCTN	Years	Withdrawal date over NCTN	Withdrawal date over CSCTN
1961	15-Nov	15-Dec	1986	10-Dec	30-Dec
1962	12-Jan	13-Jan	1987	26-Dec	26-Dec
1963	11-Dec	26-Dec	1988	17-Dec	7-Jan
1964	24-Nov	28-Dec	1989	5-Dec	10-Jan
1965	18-Dec	29-Dec	1990	2-Jan	20-Jan
1966	8-Dec	19-Jan	1991	23-Nov	25-Dec
1967	16-Dec	20-Dec	1992	7-Dec	21-Dec
1968	21-Dec	22-Dec	1993	24-Dec	2-Jan
1969	20-Dec	3-Jan	1994	19-Jan	22-Jan
1970	1-Dec	13-Jan	1995	29-Nov	17-Jan
1971	18-Dec	19-Dec	1996	18-Dec	19-Dec
1972	15-Dec	28-Dec	1997	21-Dec	3-Jan
1973	31-Dec	31-Dec	1998	14-Dec	4-Jan
1974	25-Nov	30-Dec	1999	26-Dec	13-Jan
1975	29-Nov	20-Dec	2000	2-Jan	2-Jan
1976	12-Dec	26-Dec	2001	11-Jan	1-Jan
1977	29-Nov	12-Dec	2002	10-Dec	12-Dec
1978	1-Jan	1-Jan	2003	29-Dec	8-Dec
1979	14-Dec	27-Dec	2004	29-Nov	16-Dec
1980	14-Dec	20-Dec	2005	21-Dec	16-Jan
1981	5-Dec	24-Dec	2006	14-Dec	15-Dec
1982	6-Dec	18-Dec	2007	6-Jan	7-Jan
1983	27-Dec	31-Jan	2008	11-Dec	21-Dec
1984	6-Jan	19-Jan	2009	23-Dec	15-Jan
1985	17-Jan	17-Jan	2010	22-Dec	6-Jan
Statistical parameters				NCTN	CSCTN
			Mean	17-Dec	31-Dec
			S.D.	15 days	13 days

NCTN : North Coastal Tamil Nadu (North of 12° N);
CSCTN : Central and South Coastal Tamil Nadu (South of 12° N)

rainfall activity continues even after NEM withdrawal. It is thus obvious that the early withdrawal of NEM over NCTN by as many as 14 days when compared to CSCTN is clear and unambiguous. This feature of NEM withdrawal had been observed but has not been studied or documented earlier in a systematic way. IMD (1973) which is an authenticated and time tested reference manual for NEM comments that "There is some suggestion that in the northern districts of coastal Tamil Nadu, the main period of rainfall begins a little earlier (by a week or ten days or so) and also ends a little earlier, compared to the southern districts". The present study has clearly authenticated the differential time lines of withdrawal of NEM over CTN.

4.6. *Rainfall during the month of February*

In about 20% of the years, a few wet spells with fairly widespread spatial coverage are observed during the month of February over CTN. Fig. 5 presents the amount of rainfall realised during February over CSCTN for the period 1961-62 to 2010-11. As seen, February rainfall occurrences are more frequent during the recent two decades than before. However, such wet spells over CSCTN, though somewhat significant, occur after prolonged dry spells on dates even beyond twice the SD from the mean DOW. Statistically, such samples can be taken as not belonging to the population, *i.e*., NEM season, despite the quantum of rainfall realized. Fig. 4(b)
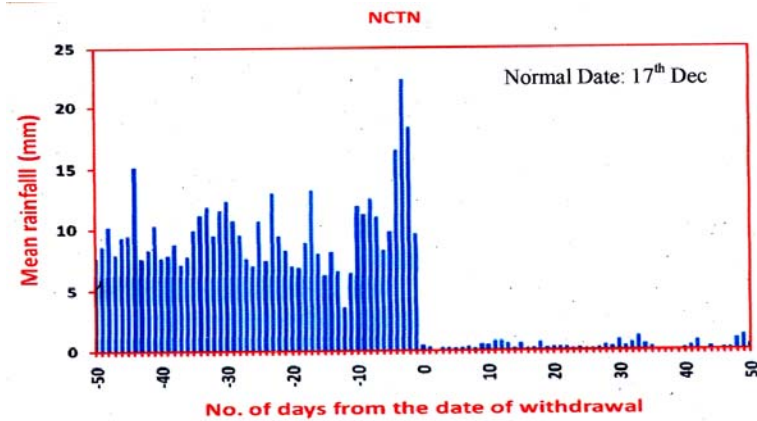
Fig. 4(a). Mean daily rainfall over North Coastal Tamil Nadu with reference to the date of withdrawal of northeast monsoon (Superposed epoch analysis)
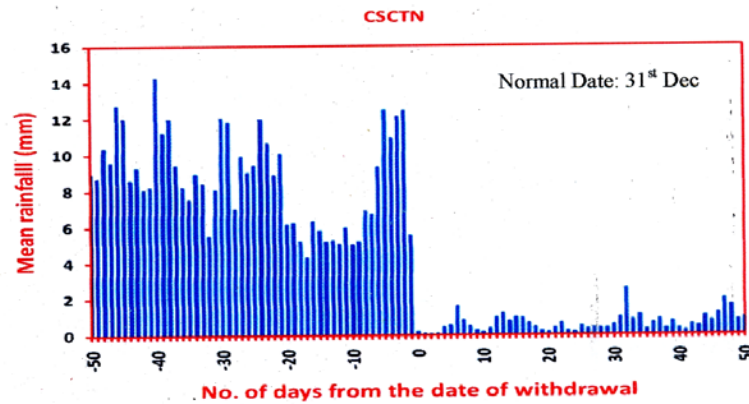
Fig. 4(b). Mean daily rainfall over Central and South Coastal Tamil Nadu with reference to the date of withdrawal of northeast monsoon (Superposed epoch analysis)
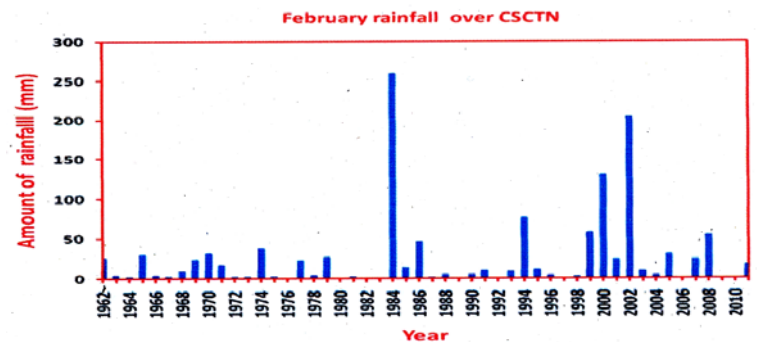
Fig. 5. Rainfall during the month of February over Central and South Coastal Tamil Nadu for the period 1961-62 to 2010-11

and Fig. 5 also show that, over CSCTN, NEM fades away gradually rather than withdrawing in an abrupt fashion. That low level easterlies over CTN continue upto April and occasional perturbations cause weather is the most likely reason. The equatorial trough, which is located close to the equator over the southern Bay of Bengal exhibits latitudinal oscillations and during the month of February, would commence its northward movement

along with the Sun, which is also a causative factor and obviously, the southern latitudinal belt of CTN gets affected more than the northern belt.

4.7. It is evident from the preceding sections that NEM generally fades away with sporadic rainfall continuing in February also in several years. The duration between wet spells is frequently long. Low level easterlies

continue over CTN for several weeks after the NEM withdrawal As such, some amount of discretion is inevitable while deriving the dates of withdrawal for years when the withdrawal process is not clearly defined. It is also evident that NEM withdrawal date is difficult to correctly identify on real time basis and that the right date be better determined after the DRF data of entire January is available for a detailed diagnostic analysis.

5.   Summary

The results of the study are summarised herein below:

(*i*)   The dates of onset and withdrawal of NEM over CTN are determined for the 140 year period of 1871-2010 based on daily rainfall data of six months (September to February of subsequent year) of 25 stations along the southeastern coastal peninsula (CTN & SCAP). The dates are re-determined for 1901-2000 and derived afresh for 1871-1900 and 2001-2010.

(*ii*)   For the period 1901-2000, the revised dates are compared with the ones determined earlier based on daily rainfall data of just 4-6 stations. The mean date of NEM onset and its standard deviation remain unchanged at 20 October and 8 days respectively. The mean date of NEM withdrawal is extended by three days from 27 December to 30 December.

(*iii*) For the periods 1871-1900 and 2001-2010, the mean dates of NEM onset are 17 October and 18 October respectively and the mean date of NEM withdrawal is the same for both the periods and is 23 December.

(*iv*)   In the decadal scale, for the period 1871-2010, the decadal mean date of onset varies between 16-25 October and that of withdrawal, between 19 December and 9 January.

(*v*)   Time series analysis of 140 year data of dates of onset and withdrawal indicate that there is no significant trend in both the series. The CC between the two series of dates of onset and withdrawal is insignificant indicating that, for a given year, these dates are independent of each other.

(*vi*)   Filtered time series of the dates of onset and withdrawal exhibit significant correlation indicating existence of significant lag/cross-lag correlations amongst and between the two series.

(*vii*) The withdrawal of NEM from CTN is further analysed on sub-regional scale (North, Central and South

CTN) which reveals that the NEM withdrawal from the northern parts occurs about 2 weeks prior to the withdrawal from the central and southern parts of CTN. The mean date of withdrawal from North CTN is 17 December and that for the Central and South CTN is 31 December.

(*viii*) Superposed epoch analysis conducted on the dates of withdrawal of NEM from North CTN and Central and South CTN indicates an abrupt withdrawal after a significant wet spell in the case of North CTN, but, continuation of some rainfall activity over the Central and South CTN even after the NEM withdrawal from these parts.

(*ix*)   In about 20% of the years, there are some significant rain spells in the month of February and such occurrences have become more frequent during the recent two decades compared to the period before.

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