Mausam. (1995). 46, 1. 15-24

551.509.313 : 551.553.21 (548.3)

Spectrum analysis and prediction possibilities of the onset dates of southwest monsoon over Kerala (India)

R. P. KANE

Instituto Nacional de Pesquisas Espacious-INPE
C Postal 515-12201/970 Sao Jose dos Compos. SP Brasil
(Received 26 June 1991. Modified 26 May 1994)

सार — भारत के केरल राज्य में दक्षिण-पश्चिम मानसून के आने की तिथियों की काल-श्रृंखला के अधिकतम एन्ट्रापी (उत्क्रम माप/ताप-अनुताप माप) स्पैक्ट्रोमी विश्लेषण से 2σ और 3σ अग्रता स्तरों पर सार्थक आवधिकताओं का पता चला। तथापि, कुल विभेद (वेरिएंस) में इनकी भूमिका 40-50% रही और इस प्रकार यह पता चला कि 50-60% घटक पूर्ण रूप से अनियमित हैं। बहुत-सी सार्थक आवधिकताएं क्यू. बी. ओ. क्षेत्र (2-3 वर्षों का समय) में थीं, जो अपनी परिवर्तनशील आवधिकता और विस्तृत आयामों के कारण लगभग अनियमित घटकों जैसी ही हैं। अत: मानसून के आने की तिथियों का 5 दिन से अधिक का पूर्वानुमान एक σ सीमा के अंदर तो संभव था, जो कि संभवत: कोई योजना तैयार करने तथा कृषि अथवा किसी अन्य कार्य के लिए अधिक उपयोगी नहीं है। मानसूनी वर्षा के आने की निश्चित तिथियों और मार्च, अप्रैल, मई या जून के महीनों की 50 हे. पा. की औसत मासिक भूमध्यवर्ती अक्षांशीय पवनों के बीच कोई संबंध नहीं पाया गया। तथापि, मई में पश्चिमी (पूर्वी) पवन और केरल में मानसून (अथवा मानसून पूर्व) की पहली वर्षा के शीघ्र (विलम्ब) आने के मध्य संबंध बनने की संभावना है चाहे मानसून की वर्षा कम हो या अधिक।

ABSTRACT. Maximum Entropy Spectral Analysis of the time series for the onset dates of the southwest monsoon over Kerala (India) revealed several periodicities significant at a 2σ apriori level. some at a 3 C σ a priori level. However. these contributed only 40-50% to the total variance. thus indicating 50-60% as purely random component. Also. many of the significant periodicities observed were in the QBO region (T = 2-3 years) which. due to their variable periodicities and amplitudes. are almost equivalent to a random component. Hence. predictions were possible only with a σ limit exceeding 5 days. which are probably not very useful for any planning purposes. agricultural or otherwise. No relationship was found between onset dates of established monsoon rainfall and the 50 hPa mean monthly equatorial zonal wind for the months of March. April. May or June. However. there is a possibility that a relationship may exist between westerly (easterly) winds in May and early (late) onset of the first monsoon (or pre-monsoon ?) rainfall in Kerala. meagre or otherwise.

Key words — Prediction error. Periodicities. Spectrum analysis. Variance. Winds. Rainfall. Monsoon.

1. Introduction

The onset date of the southwest monsoon over Kerala (India) varies widely between 7 May and 22 June. In an earlier communication (Kane 1980), the results of a Maximum Entropy Spectral Analysis (MESA) were presented for time series of the onset dates as given by : (a) India Meteorological Department (IMD), (b) Ananthakrishnan *et al.* (1967), and (c) Ramdas *et al.* (1954). Periodicities T = 2.3, 2.8, 3.5, 3.9, 4.7, 5.5, 6.2, 7.3, 8.5, 10.8, 14, 20 and 40 years with amplitudes of 2-5 days were observed and predictions were made which matched within 5 days for the series (b) and within 10 days for series (a). Earlier, Reddy (1977) conducted spectrum analysis for the IMD series for 1901-1975 by the Blackman and Tukey (1958) method and reported periodicities at T = 2.5-2.7 years and T = 54 years.

The dates of onset as per IMD records are based on subjective estimates by several forecasters. IMD (1943) states that the pre-monsoon thunderstorm rains over Kerala increase progressively to merge with the monsoon rains. Ramdas *et al.* (1954) used the date of commencement of persistent heavy rainfall over south Kerala as the onset data, but did not specify the threshold value of the rainfall or the minimum duration of persistence. Ananthakrishnan *et al.* (1967) established some broad criteria for operational use. In a recent communication,

3—800 IMD/94.

Ananthakrishnan and Soman (1988) reported the results of a critical and objective study of the rainfall over north and south Kerala and showed that it was possible to have a clear demarcation between the rainfall associated with the pre-monsoon thunderstorm activity over Kerala and the rainfall that heralds the onset of the southwest monsoon. The average daily rainfall from pre-monsoon thunderstorms is ~5 mm. Following the monsoon onset, the mean daily rainfall increases rapidly to ~30 mm. Hence, these authors considered the date of monsoon onset as the first day of transition from the light to heavy rain spell category with the condition that the average daily rainfall during the first 5 days should not be less than 10 mm (*i.e.*, at least 50 mm in 5 consecutive days). With this objective criterion, they reported onset dates for north Kerala (NK) and south Kerala (SK) for 1901-1980 as also the conventional IMD dates. Further data upto 1990 were made available to us by IMD. In the present communication, we report the results of the spectral analysis of these three time series (SK, NK & IMD).

2. Method of analysis

Power spectrum analysis was carried out by using Maximum Entropy Spectral Analysis (MESA) (Burg 1967, Ulrych and Bishop 1975) which is known to be superior to the conventional Blackman and Tukey (1958) method. In MESA, there is an adjustable variable, *viz.*, Length of the Prediction Error Filter (LPEF). For small LPEF, only small periodicities are revealed. Larger LPEF reveal larger periodicities (even those comparable to the data length) but cause peak-splitting for smaller periodicities. The choice of LPEF is a tricky problem. The Akaike's (1969) Final Prediction Error (FPE) criterion often fails and, in that case, Ulrych and Bishop (1975) recommend using LPEF 50% of the data length. From a study of artificial samples, Kane (1977, 1979) suggests evaluating the spectra for several LPEF and selecting smaller periodicities from smaller LPEF and larger periodicities from larger and larger LPEF. Also, since amplitude estimates are not reliable in MESA (Kane and Trivedi 1982), MESA is used only for detecting the possible peaks T_k ($k = 1 \ldots n$) and then these T_k are used in the expression :

$$f(t) = A_0 + \sum_{k=1}^{n} \left[a_k \sin 2\pi \frac{t}{T_k} + b_k \cos 2\pi \frac{t}{T_k} \right] + E$$

$$= A_0 + \sum_{k=1}^{n} r_k \sin \left[2\pi \frac{t}{T_k} + \phi_k \right] + E \qquad (1)$$

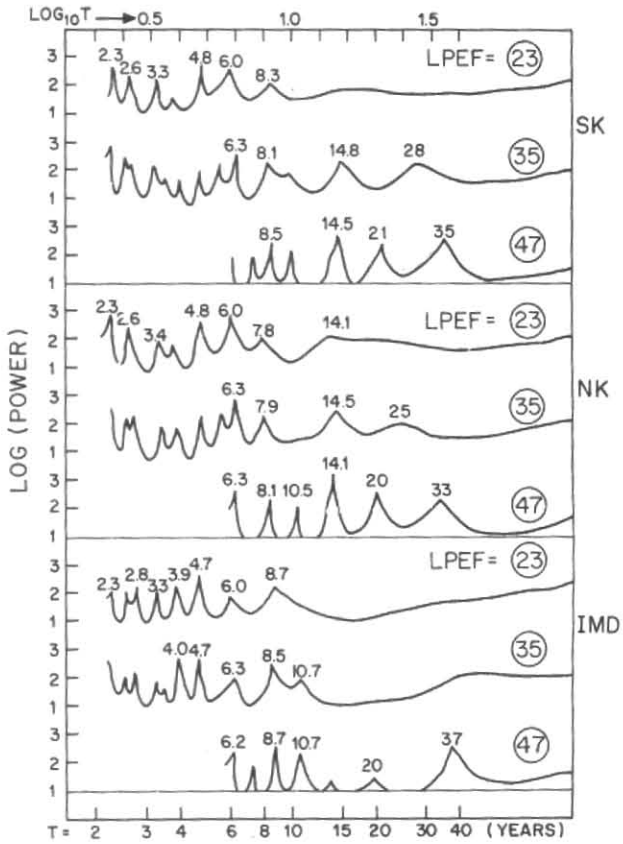

Fig. 1. Burg spectra for the period of 70 years (1901-1970) for south Kerala (SK), north Kerala (NK) and IMD series

where, $f(t)$ is the observed time series ($t = 1, 2, \ldots$), and E is the error factor. The parameters A_0, (a_k, b_k) and their standard errors σ_{ak}, σ_{bk} are then evaluated by a standard Multiple Regression Analysis (MRA) (Johnston 1960, Bevington 1969) based on a least square fit. From these, r_k, ϕ_k and σ_{rk} can be calculated. Amplitudes r_k exceeding $2\sigma_{rk}$ would be significant at a 95% *apriori* confidence level. Also, since every r_k contributes $r_k^2/2$ to the variance, the Percentage Variance Explained (PVE) by every r_k is given by 50 (r_k^2/σ^2) where, σ^2 is the variance of the observed series $f(t)$. This expression for PVE is certainly true for low periodicities but only approximately true for larger periodicities as these may not have integral cycles in the restricted data length.

3. Results

For each series, analysis was done using data for 1901-1970 only. Fig. 1 shows the spectra for SK, NK and IMD series (70 years) for LPEF = 23, 35 and 47, corresponding to 33%, 50% and 67% of the data length 70 (years). Note that the abscissa scale is neither the conventional f (frequency) nor T (period), but $\log_{10}T$. About a dozen peaks were

TABLE 1

Periodicities T_k (years), amplitudes r_k (days) significant at a 2σ apriori level and the percentage variance explained (PVE)

Series	T_k, r_k, PVE	QBO			Periodicities exceeding T_k = 3								Std error σ_{rk}	Total PVE
SK (South Kerala)	T_k (years)	2.29	2.63		3.3		4.8	6.0				35		
	r_k (days)	3.8*	2.8		2.7		4.3*	3.4				4.5*	±1.2	
	PVE (%)	9.3	4.9		4.9		11.8	7.5				12.8		51.2
NK (North Kerala)	T_k (years)	2.29	2.63				4.8	6.0		14.1	25	33		
	r_k (days)	4.1*	3.4				3.7*	3.9*		2.8	2.7	4.3*	±1.2	
	PVE (%)	10.1	6.9				8.2	8.9		4.7	4.4	11.2		54.4
IMD (Whole Kerala)	T_k (years)	2.29	2.57	2.82		3.9	4.7		8.7					
	r_k (days)	2.3	2.5	2.5		2.3	4.3*		3.1				±1.1	
	PVE (%)	4.3	5.2	4.9		4.4	14.8		7.7					41.3

* Significant at a 3σ apriori level. The standard error σ_{rk} is common to all r_k.

selected from the MESA plots. These were used in Eqn. (1) and yielded amplitudes as given in Table 1 where only amplitudes r_k significant at a 2σ apriori level are noted. Those significant at a 3σ apriori level are marked with an asterisk (*). Together, these explain ~40-50% of variance, thus leaving ~50-60% as purely random component. Also, many of these periodicities are in the Quasi-Biennial Oscillation (QBO) (T = 2-3 years) region and a few in the large periodicity region. As explained in Kane and Trivedi (1986), such samples do not have a good prediction potential, firstly because of a large random component and secondly, because the QBO, due to its variable period (anywhere between 2 and 3 years) and probably variable amplitudes, is hardly distinguishable from a purely random variation. Nevertheless, Fig. 2 shows observed values (full lines) and expected values (crosses) using periodicities as indicated for the series for the southwest monsoon onset dates for : (a) South Kerala (SK), (b) North Kerala (NK) & (c) Whole Kerala (IMD). Analysis used only 70 years' data (1901-1970). Observed values for 1971-1990 (big full dots) are, therefore, independent data for checking prediction. In each case, the upper half shows data for 1901-1970 and the lower half for 1960-2000 (1960-1970 is repeated). The full curves represent the original values and the crosses and dashes represent expected values, using periodicities as indicated. Since data used were for 1901-1970 only, the observed values for 1971-1990 (big dots joined by full lines) can be used as independent data for checking predictions. As can be seen, the big dots and crosses for 1971-1990 do not match well for any of the three series. In particular, the observed value of onset date for 1972 (22 June) is abnormally above the expected value, and the observed value for 1974 (23 May) is abnormally below the expected value.

To get a better idea for the match (or mismatch) between the observed and expected values, these are plotted *versus* each other in Fig. 3 for SK series. The bigger dots represent the 20 years 1971-1990. Correlation coefficients between observed and expected values for 1901-1970 and standard errors σ_{diff} of the difference series (observed values minus expected values) for various intervals are indicated. The 45° slope line represents Observed values = Expected values. In all cases, the scatter is large, some points deviate considerably from the 45° slope line (observed values = expected values) and the correlation coefficient is positive but only ~ + 0.5. A measure of the scatter could be the standard deviation of the series obtained as the difference between the observed and expected values. In Fig. 3 for the SK series, σ_{diff} for 1901-1970 was ± 5 days, but for 1971-1990, σ_{diff} was ± 12 days, indicating that predictions could be that much out with a 66% probability. Similar diagrams for the NK series and IMD series showed similar correlations (~ 0.5) and similar σ_{diff}.

4. Relationship with QBO of zonal wind

Since some of the significant periodicities were in the QBO (T = 2-3 years) region, it would be interesting to study the relationship between the various monsoon onset dates and the zonal component of the equatorial wind at 50 hPa level, which is known to have a strong QBO (Reed *et al.* 1961).

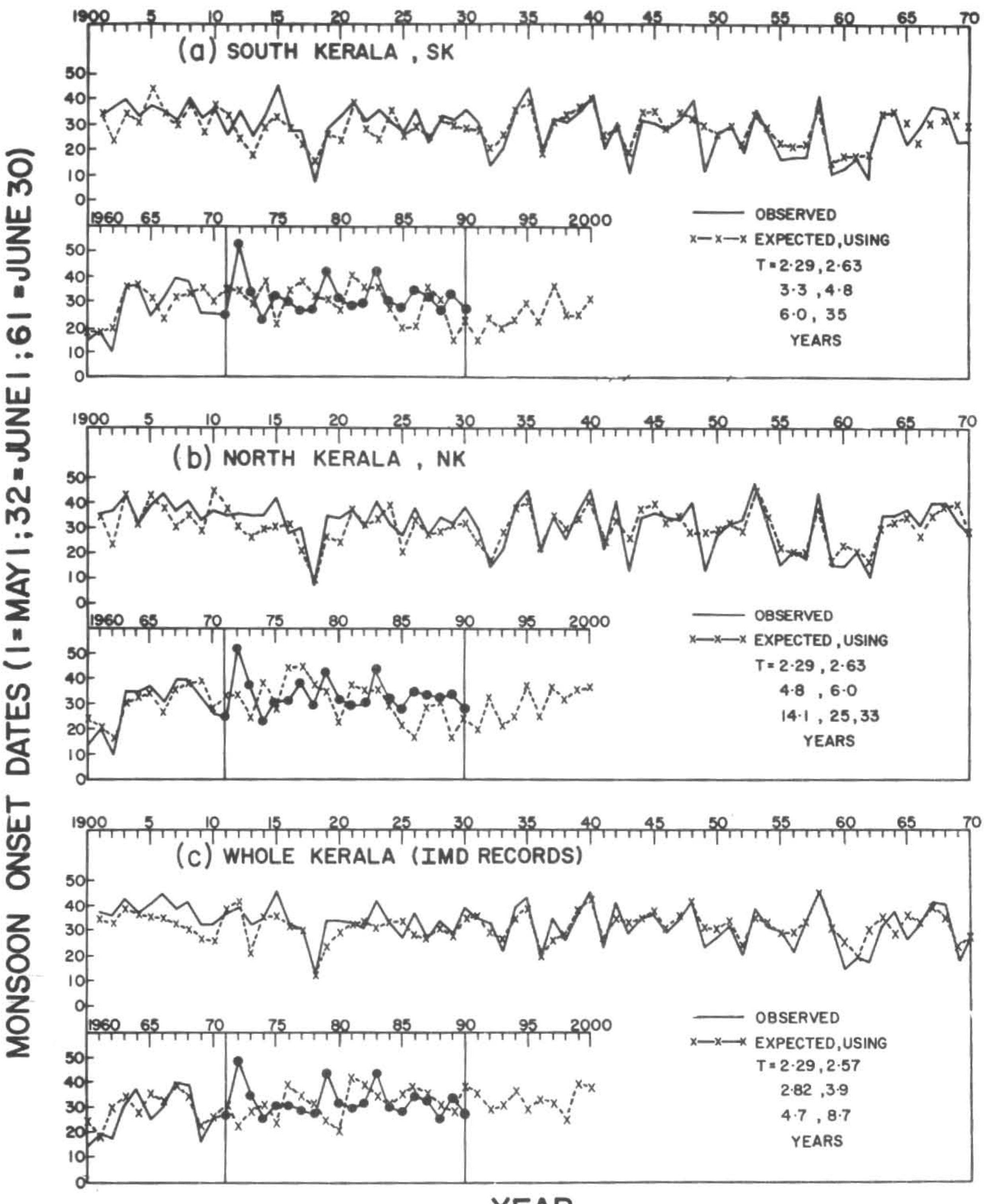

Fig. 2. Observed and expected values using periodicities for the series for the southwest monsoon onset dates

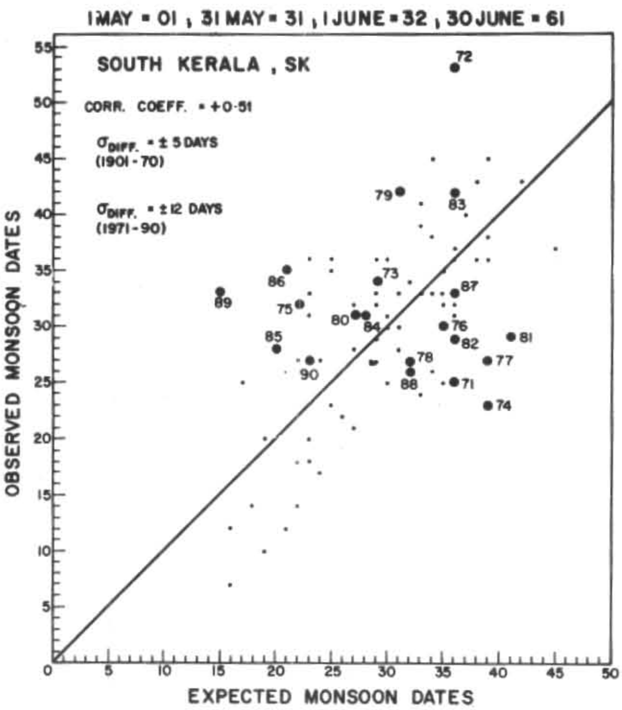

Fig. 3. Plot of observed values *versus* values expected using periodicities as indicated, for the series for the southwest monsoon onset dates for South Kerala (SK). Big dots refer to 1971-1990

Reddy (1977) investigated this aspect for a limited period (1964-1975) and found that in these 12 years, the 50 hPa zonal winds at Singapore (1.4°N, 103.9°E) for the month of May were westerly (W) for 9 years and all these were associated with early monsoon onset (*i.e.*, before 31 May). The other 3 years were easterly (E) and were associated with late monsoon onset (*i.e.*, on or after 31 May). Reddy did not consider the actual wind velocities so that even values very near zero were designated as either E or W. Also, monsoon onset dates very near 31 May were also not distinguished from very late or very early dates. Recently, Venne and Dartt (1990) have given a plot of the time series of the monthly mean zonal wind component at 50 hPa, averaged for four equatorial stations, *viz.*, Balboa (8.9°N, 79.6°E), Canton (2.8°S, 171.7°W), Singapore (1.4°N, 103.9°E) and Gan (0.7°S, 73.2°W), which is reproduced in Fig. 4 (full lines) for the period 1950-1988. As can be seen, there are many more (almost double) westerlies than easterlies. For the period 1964-1975 studied by Reddy (1977), these values match very well with the values shown by Reddy (1977) for Singapore alone. The big dots show the IMD monsoon onset dates. Table 2 gives the monsoon onset dates for south Kerala (SK), north Kerala (NK) and IMD, same as in Table 1 of Ananthakrishnan and Soman (1988) but expressed as deviations from 31 May (*i.e.*, 1 May = −30, 31 May = 0, 30 June = +30), for the period 1951-1987. For the limited period 1961-1975, the onset dates used by Reddy (1977) are also given in Table 2. The right half of Table 2 gives the monthly mean zonal winds for the months of March, April, May, June (as read from Fig. 4).

Let us check first the findings of Reddy (1977). Fig. 5 shows a plot of the monsoon onset dates (1 May = −30; 31 May = 0; 30 June = +30) *versus* the 50 hPa equatorial zonal wind velocities (ms^{-1}), westerly (W) and easterly (E), for the month of May. The full dots represent the onset values used by Reddy (1977) given in Table 2. As can be seen, out of the 15 onset dates, 9 were early onsets (negative dates) which were associated with zero winds and 2 were almost normal onsets (0 and +2) associated with easterly (E) winds and 1 was a late onset (+8) associated with easterly winds. Thus, some association between early onsets and westerly winds in May was indicated. However, the IMD onset dates (crosses) show a large scatter. Some IMD dates (crosses) differ considerably from the corresponding dates used by Reddy (1977) (full dots). Particularly glaring are the onset dates for 1967 (IMD = 9 June, Reddy = 15 May) and 1972 (IMD = 19 June, Reddy = 16 May). Reddy (1977) mentions that the dates for 1921 to 1975 were collected from IDWR, WWR and MWR published by the India Meteorological Department (IMD). It is not clear why some of the dates differ from the IMD dates. If there is some difference in the selection procedure, the dates used by Reddy (1977) seem to give a much better correlation with zonal winds as can be seen from Fig. 5. Of course, the sample used in Fig. 5 is rather small (only 15 pairs of values) and contains many more westerlywinds (9) than easterly winds (3), the three others being zero winds. So, the correlation may have been accidental. From the 15 dates chosen by Reddy (1977), 6 are the same as the IMD dates, 4 are later (by 4, 3, 8 and 1 day) and 5 are earlier (by 11, 1, 25, 33 and 12 days). It is likely that Reddy chose the first signs of rainfall rather than the dates of firm establishment of the southwest monsoon rainfall which may occur later. If so, the zonal wind may be better related to the first signs of rainfall, meagre or otherwise. To investigate this relationship further, Fig. 6 shows a plot of IMD monsoon onset dates (Table 2) *versus* zonal winds (right half of Table 2) for the months of March, April, May and June separately for 1951-1987. The scatter is large in all the cases and the 37 points are distributed almost equally in all the four quadrants. The circled numbers represent data pairs in the respective

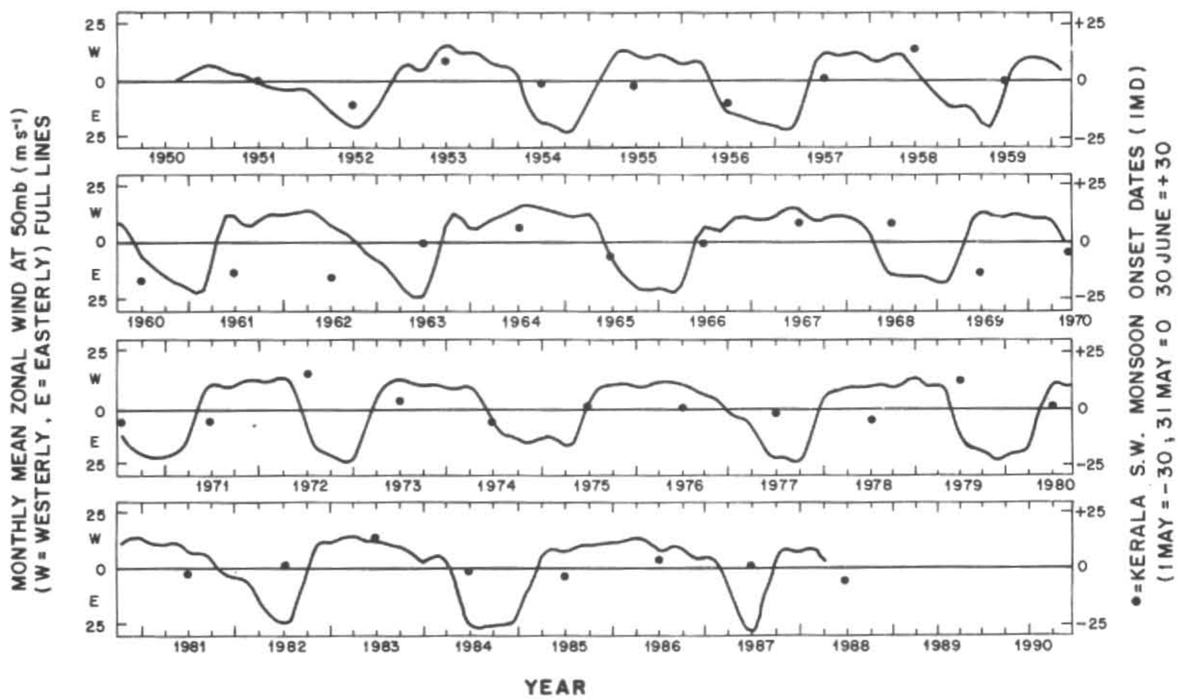

Fig. 4. Time series for the monthly mean 50 hPa zonal wind velocities (ms^{-1}) averaged from four stations, *viz.*, Balboa, Canton, Singapore and Gan near the equator

quadrants. Thus, no relationship is indicated. Similar plots for the monsoon onset dates for north Kerala and south Kerala and also for zonal winds for the months March-June separately showed a large scatter and the points were almost equally distributed in all the four quadrants. Thus, no relationship is indicated. It would thus seem that neither the monsoon onset dates for north or south Kerala, nor those for Kerala as a whole given by IMD, are anyway related to the 50 hPa monthly mean equatorial zonal winds for any of the four months March-June. The correlation earlier reported by Reddy (1977) for the limited period 1961-1975 for the 50 hPa zonal winds for the month of May at Singapore was either accidental or was related to some special procedure of onset date selection used by Reddy, probably the first signs of rainfall, meagre or otherwise.

Are the zonal winds related to the total rainfall? The last column in Table 2 gives the percentage deviations from mean for the all India summer monsoon rainfall (average from 29 sub-divisions: Parthasarathy *et al.* 1990). Fig. 7 shows a plot of the same *versus* the zonal wind velocities in March-June. The circled numbers represent data pairs in the respective quadrants. In almost all the plots, the

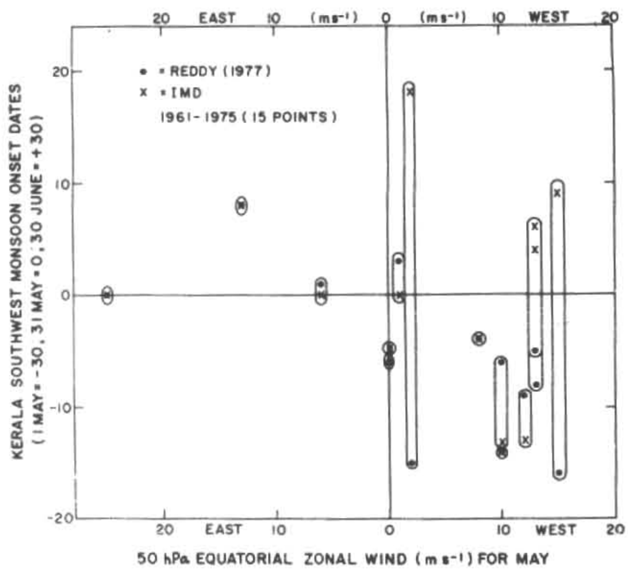

Fig. 5. Kerala SW monsoon onset dates *versus* 50 hPa equatorial zonal wind velocities (ms^{-1}) for the month of May for the period 1961-1975

37 points are almost equally divided in the four quadrants, excepting for June where there is a slight bias for excess rainfall to be associated with westerly winds and droughts to be associated with easterly

TABLE 2

Onset dates of the southwest monsoon over Kerala 1951 onwards, the 50 hPa equatorial zonal wind velocities (ms^{-1}) for the months March-June and, the all India summer monsoon rainfall (% deviations from mean)

Year	SK	NK	IMD	Reddy (1977)	QBO wind (ms^{-1})				All India rainfall (%)
					June	May	April	March	
1951	−1	+1	0	—	2 E	1 W	2 W	3 W	−14
1952	−11	−2	−11	—	20 E	18 E	15 E	12 E	−7
1953	+6	+17	+7	—	14 W	11 W	7 W	4 W	+8
1954	−3	+1	0	—	19 E	14 E	7 E	0	+4
1955	−14	−15	−2	—	10 W	12 W	12 W	9 W	+9
1956	−13	−11	−10	—	13 E	7 E	0	5 W	+15
1957	−13	−13	+1	—	10 W	7 W	5 E	15 E	−8
1958	−12	+13	−14	—	4 W	8 W	11 W	10 W	+4
1959	−19	−16	0	—	5 E	13 E	21 E	19 E	+10
1960	−17	−16	−17	—	6 E	0	5 W	8 W	−2
1961	−13	−11	−13	−9	12 W	12 W	0	11 E	+19
1962	−21	−21	−14	−14	7 W	10 W	14 W	13 W	−5
1963	−5	−4	0	0	25 E	25 E	21 E	17 E	0
1964	+5	+4	−6	−5	15 W	13 W	11 W	10 W	+8
1965	−7	+6	−5	−6	7 E	0	8 W	12 W	−17
1966	0	0	0	−3	6 W	1 W	10 E	20 E	−14
1967	−8	+9	−9	−16	14 W	15 W	13 W	11 W	+1
1968	−7	−9	+8	+8	15 E	13 E	6 W	1 W	−12
1969	−6	+1	−14	−6	11 W	10 W	1 W	8 E	−3
1970	−6	−5	−5	−5	5 E	0	5 W	9 W	+10
1971	−6	−6	−4	−4	11 W	8 W	1 E	11 E	+4
1972	−22	+22	+18	−15	8 E	1 W	11 W	14 W	−23
1973	−3	−6	+4	−8	13 W	13 W	10 W	5 W	+7
1974	−8	−8	−5	−5	7 E	0	6 W	10 W	−12
1975	+1	0	0	+1	1 W	6 E	14 E	15 E	+13
1976	−1	0	0	—	11 W	12 W	12 W	11 W	0
1977	−4	+7	−1	—	21 E	20 E	13 E	7 E	+3
1978	−4	−2	−3	—	10 W	10 W	10 W	9 W	+7
1979	+11	+12	+13	—	12 E	2 E	8 W	10 W	−17
1980	0	0	+1	—	10 W	5W	5 E	15 E	+4
1981	—	—	−1	—	7 W	9 W	12 W	11 W	0
1982	—	—	+1	—	23 E	21 E	17 E	14 E	−14
1983	—	—	+13	—	12 W	13 W	14 W	15 W	+12
1984	—	—	0	—	25 E	20 E	8 E	3 W	−2
1985	—	—	−3	—	7 W	8 W	9 W	6 W	−9
1986	—	—	+4	—	8 W	10 W	13 W	12 W	−13
1987	—	—	+2	—	28 E	26 E	17 E	8 E	−19

1 May = −30; 31 May = 0; 30 June = +30; SK = South Kerala, NK = North Kerala, IMD = Whole Kerala.
W = Westerly; E = Easterly.

winds. However, June is too late to be useful for predictions as the monsoon has already started by then.

5. Discussion and conclusion

A maximum entropy spectral analysis of the time series for the onset dates of southwest monsoon over south Kerala, north Kerala as also for the IMD series for whole Kerala showed several periodicities significant at a 2σ apriori level and some at a 3σ apriori level. However, many of these were in the QBO region (T = 2-3 years). Their net effect was equivalent to a random component and meaningful predictions were not possible. Observed values could deviate from the expected values within ±5 days in 66% cases and within ±10 days in 95% cases. Whether these limits are still good enough for some planning purposes (agricultural or otherwise) is a moot question. If not, other methods of prediction need to be explored. Since a major feature of the periodicities is the QBO, a detailed study of atmospheric QBO and its relationship with the monsoon onset dates was carried out. Reddy (1977)

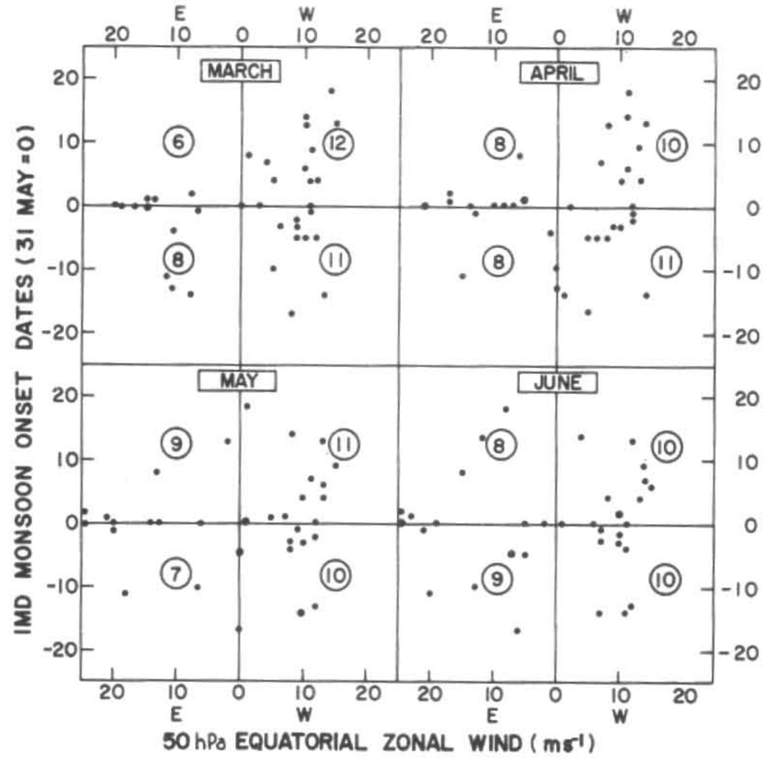

Fig. 6. IMD SW monsoon onset dates *versus* 50 hPa equatorial zonal wind velocities for March-June for 1951-1987 (37 data pairs)

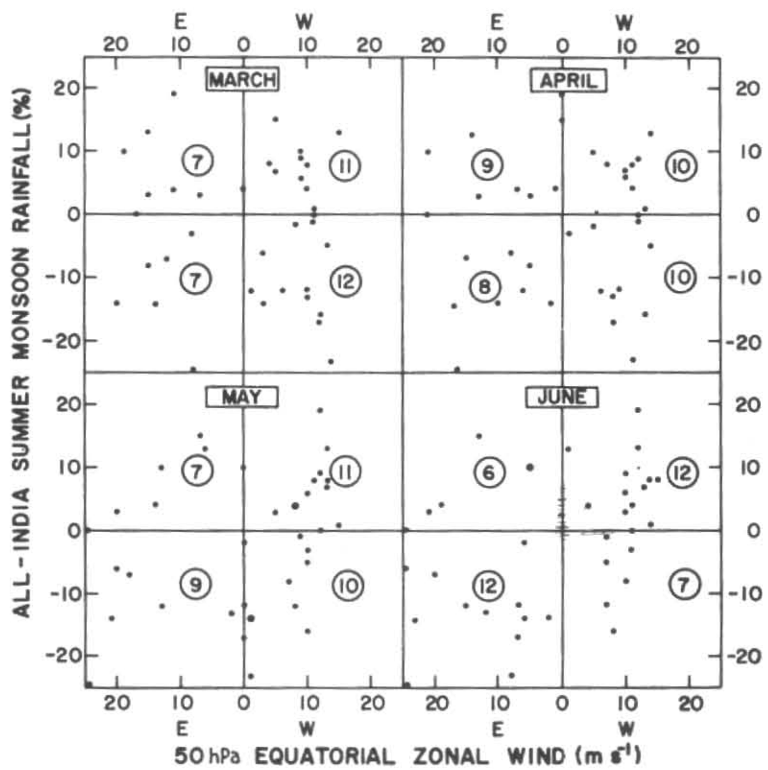

Fig. 7. All-India summer monsoon rainfall (percentage deviations from mean) *versus* 50 hPa equatorial zonal wind velocities (ms^{-1}) for March-June for 1951-1987 (37 data pairs)

had indicated that the monsoon onset dates at Kerala were related to the phase of the 50 hPa zonal winds at Singapore prior to the monsoon onset. Thus, when the Singapore 50 hPa winds were easterlies in the month of May, the Kerala monsoon onset was later than the normal date (31 May) and, when the winds were westerlies, the monsoon onset was earlier than normal. Our analysis did not confirm these findings. No relationship was indicated. Kung and Sharif (1980, 1982) attempted forecasting of monsoon onset dates using regression relationships with five antecedent upper air parameters and sea surface temperatures and reported very close fitting for the period 1958-1977. Such attempts were made earlier also during early fifties. Ramdas *et al.* (1954) used a regression model with 4 parameters, *viz.*, Seychelles rain, mean west winds over Agra at 3 km, pressure difference between Cochin and Jaipur and south Rhodesian rain and obtained a multiple correlation coefficient of only +0.56. Since then, IMD has developed successive multiple regression models (*e.g.*, Das 1986) which seem to give monsoon onset date forecasts generally close to actual onset dates with multiple correlation coefficients as high as +0.96 (Thapliyal 1992). The potentialities of these methods and their limitations need to be further explored. Also, as pointed out by Ananthakrishnan and Soman (1988), it is necessary to distinguish clearly between pre-monsoon thunderstorm rains and the monsoon rainfall over Kerala. Otherwise, some features like the mean onset dates could be determined erroneously (Subramayya and Bhanukumar 1978, Subramayya *et al.* 1984). On the other hand, it may as well be that the zonal wind relationship is with the pre-monsoon thunderstorm rains rather than with the main monsoon rainfall. This needs futher exploration. Recently, Joseph and Pillai (1988) have shown that the *peak* rainfall during 1 March-30 May in Indian sub-divisions south of 13°N occurs ~6 weeks before the onset of Indian summer monsoon (IMD dates). Thus, predictions with an antecedence of ~6 weeks may be possible, with an error of ±3.9 days. This too needs further exploration.

Acknowledgements

This work was partially supported by FNDCT, Brasil under contract FINEP-537/CT.

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