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551.577.33 : 551.526.6 : 551.513.7

Periodicities and ENSO relationships of the seasonal precipitation over six major sub-divisions of India

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सार— भारत के छः समरूपी क्षेत्रों उत्तरी पश्चिमी (उ. प.), उत्तरी मध्य (उ. म.), उत्तरी पूर्वी (उ. पू.), पश्चिमी प्रायद्वीप (प. प्रा.), पूर्वी प्रायद्वीप (पू. प्रा.), दक्षिणी प्रायद्वीप (द. प्रा.) की तथा सम्पूर्ण भारत (स. भा.) की ग्रीष्मकालीम मानसून (जून-सितम्बर) वर्षा का आकलन करने के लिए सोनटक्के और सिंह1996 के 1848 से 1995 तक (148 वर्ष) की समयावधि के स्पैक्ट्रल विश्लेषण से क्यू. बी. ओ. और क्यू. टी. ओ. क्षेत्रों (2- 3 वर्ष तथा 3-4 वर्ष) में महत्वपूर्ण आवर्तिता तथा उच्चतर आवर्तिता का पता चला है, जिनमें से कुछ सभी क्षेत्रों में एक जैसी पाई गई हैं। एल. निनो. दक्षिणी दोलन संबंधों का अध्ययन करने के लिए वर्षों का सूक्ष्म वर्गीकरण किया गया। उ. पू. भारत तथा असंदिग्ध इ. एन. एस. ओ. डब्ल्यू. (जहां कैलेंडर वर्ष के बीच में अर्थात् मई-अगस्त को छोड़कर एल. निनो. विद्यमान था तथा एस. ओ. आई. न्यूनतम और एस. एस. टी. अधिकतम था) समूचा भारत ग्रीष्मकालीन मानसून वर्षा के दौरान सूखे में अत्यधिक प्रभावित रहा तथा शीत (सी) घटनाएँ बाढ़ से संबद्ध रहीं। अन्य प्रकार की घटनाओं के संबंध में, परिणाम अनिश्चित थे तथा वर्षा न होने के समय में भी कुछेकबार अत्यधिक वर्षा हुई।

ABSTRACT. A spectral analysis of the 1848-1995 (148 year) time series of Sontakke and Singh (1996) representing estimates of summer monsoon (June-September) precipitation amounts over six homogeneous zones (Northwest NW, Northcentral NC, Northeast NE, West Peninsular WP, East Peninsular EP, South Peninsular SP) and the whole of India (AI) revealed significant periodicities in the QBO and QTO regions (2-3 years and 3-4 years) as also higher periodicities, some common to all zones. To study the ENSO relationship, a finer classification of years was adopted. For the All India summer monsoon rainfall as also for all the zones except NE, Unambiguous ENSOW (where El Nino existed and SOI minima and SST maxima were in the middle of the calendar year *i.e.*, May-August), were overwhelmingly associated with droughts and the cold (C) events were associated with floods. For other types of events, the results were uncertain and a few extreme rainfalls occurred even during some Non-events.

Key words — Longest rainfall series, Periodicities, Six Indian zones, ENSOW.

1. Introduction

The annual precipitation in different parts of India is highly variable. The normal seasonal rainfall is as high as 2800 mm in coastal Karnataka and as low as 260 mm in west Rajasthan, while the coefficients of variations are as high as 44% in Saurashtra and Kutch and as low as 12% in north Assam. Trends and periodicities have been studied by many workers since long (Mooley and Parthasarathy 1984) and are different in different parts of India. In recent years, considerable effort has been made to produce homogeneous series. Parthasarathy *et al*. (1987, 1992) produced long time monsoon rainfall series for 29 meteorological sub-divisions of India and Kane (1995) reported results for the periodicities (particularly the Quasi-biennial and Quasi-triennial oscillations) in these series and their ENSO relationship. Recently, Sontakke and Singh (1996) divided India into an optimum six zones: NW, NC, NE, WP, EP, SP (Fig.1) and presented summer monsoon (months June-September) rainfall series for periods extending way back to the early part of the 19th century, while Singh and Sontakke (1996) presented similar series for other seasons also (JF = January, February; MAM = March, April, May; JJAS = June, July, August, September; OND = October, November, December and annual). In this communication, the results of a study of the periodicities and ENSO relationships of these series are reported. The periodicities are obtained by a Maximum Entropy Spectral Analysis and ENSO relationships are studied using a finer classification of El Nino years.

2. Data

Table 1 gives the details of the various data series. As can be seen, about 70-90% of the rainfall occurs mostly in

TABLE 1

The mean rainfalls and their standard deviations for the Indian zones northwest (NW), north central (NC), northeast (NE), west peninsular(WP), east peninsular (EP), south peninsular (SP) and all India (AL) for the months JF, MAM, JJAS, OND and Annual

Region	Period	JF	MAM	JJAS	OND	Annual
NW	1844-1994	26±14	26±16	698±129	35±29	784±138
NC	1842-1994	37±23	66±30	1037±132	79±51	1218±152
NE	1829-1994	41±21	431±82	1507±126	170±70	2150±172
WP	1841-1994	9±10	55±31	925±166	107±53	1095±188
EP	1848-1994	21±19	81±41	842±108	204±81	1147±152
SP	1813-1994	24±20	204±66	918±138	395±106	1541±174
AI	1813-1994	27±13	99±20	903±90	125±35	1153±107

the summer monsoon (JJAS) months. However, for NE, substantial rainfall (20%) occurs in the pre-monsoon months (MAM) and for EP and SP, 18% and 25% occur in the post-monsoon months (OND). The analysis was carried out for the period 1848-1995 (148 years), common to all the zones.

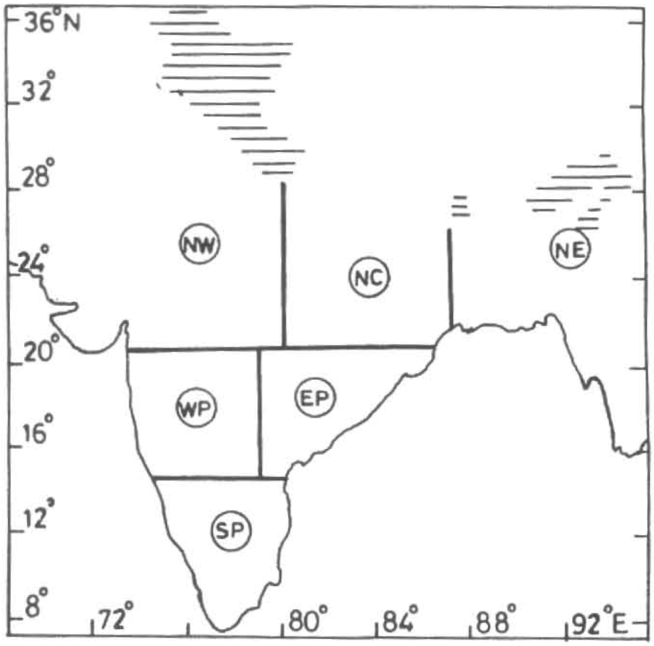

Fig.1. Map of India showing six major zones, (1) Northwest NW, (2) Northcentral NC, (3) Northeast NE, (4) West peninsular WP, (5) East Peninsular EP, (6) South Peninsular SP, selected by Sontakke and Singh (1996)

3. Results and discussion

3.1. *Interannual variability plots*

Fig.2 shows a plot of the various summer monsoon (JJAS) series. An obvious feature is the rapid oscillations, indicating QBO and QTO (Quasi-biennial and Quasi-triennial oscillations). However, these are irregular and transient, very prominent during some intervals (not necessarily the same for all the zones), and almost absent in others. When these are minimised by obtaining running averages over 11 years, the superposed thick lines show large period cyclic variations. In Fig.2, years of rainfall extremes are indicated and are generally different for the different zones, indicating non-simultaneity. Nevertheless, some features are common and show in the average, represented by the All India summer monsoon rainfall (bottom plot). Two extremes often cited are the 1877-78 and 1917-18 events of large opposite extremes in two successive years.

3.2. *Periodicities*

The JJAS values shown in Fig.2 have considerable year-to-year variations, some quasibiennial. To decipher the periodicities involved, a power spectrum analysis was conducted, by using MESA (Maximum Entropy Spectral Analysis, Burg 1967, Ulrych and Bishop, 1975), which detects periodicities much more accurately than the conventional BT (Blackman and Tukey, 1958) method. Similar to the parameter lag m in BT, MESA has a parameter called LPEF (Length of the Prediction Error Filter), which can be chosen. With low LPEF, only low periodicities are resolved. Larger LPEF resolve larger periodicities, even those approaching the data length, but the errors are larger and low periodicities show peak-splitting. An LPEF of ~50% of the data length is generally adequate and was used in the present analysis.

MESA has a drawback *viz*, the power estimates are not reliable (Kane and Trivedi, 1982). Hence, MESA was used

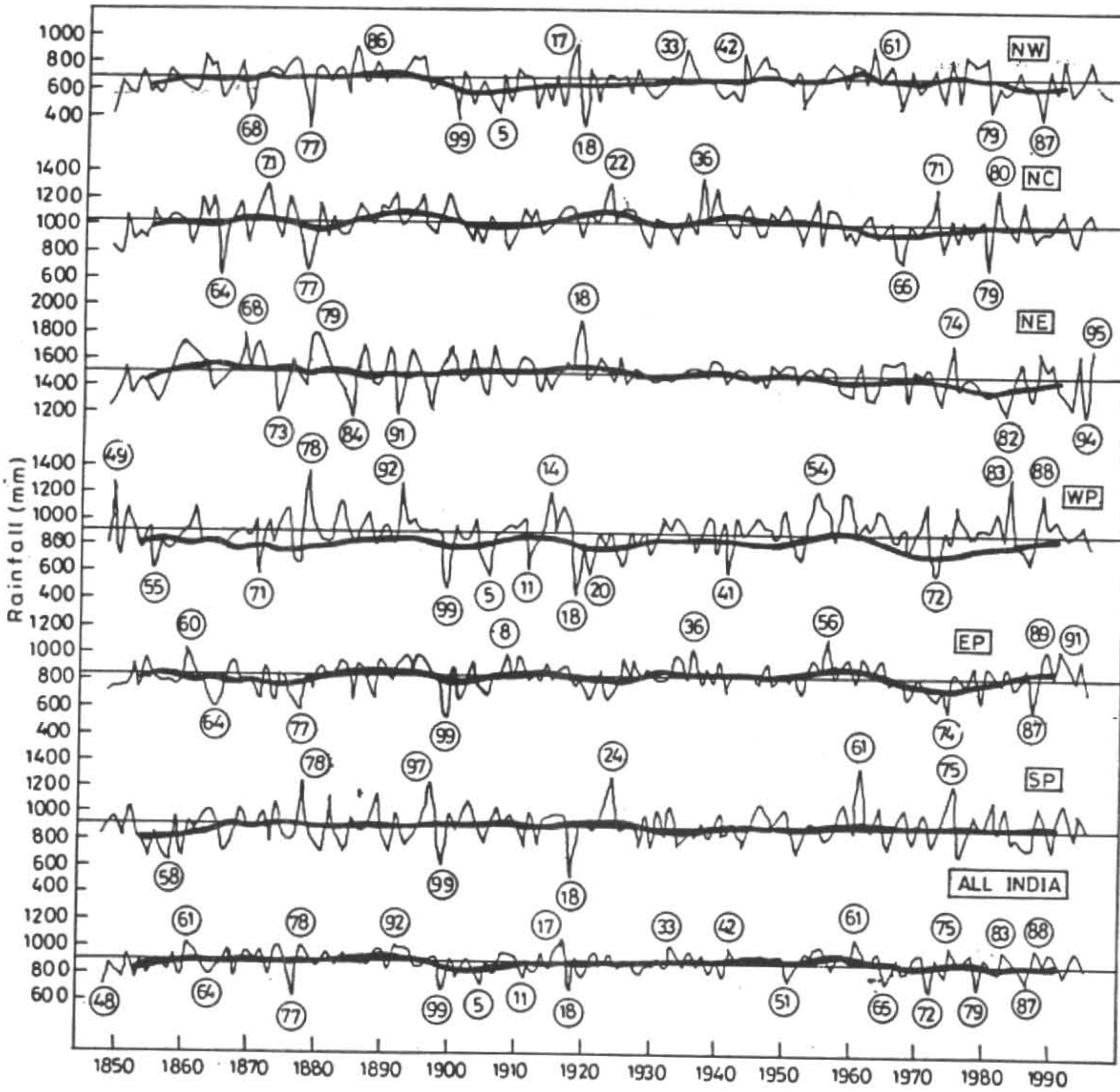

Fig.2. Summer monsoon (JJAS) precipitation (mm) for NW, NC, NE, WP, EP, SP and All India AI. The thick lines are 11-year running means. Numbers indicate years of extreme rainfall

only to identify the possible periodicities T_k, which were then used in the expression :

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

$$= A_o + \sum_{k=1}^{n} [r_k \sin(2\pi t/T_k + \phi_K)] + E \qquad (1)$$

where, $f(t)$ is the observed series and E the error factor. A Multiple Regression Analysis (MRA) (Bevington 1969) was then carried out to obtain the best estimates of A_o, (a_k, b_k) and their standard errors, by a least-square fit. From these, r_k and their standard error σ (common for all r_k in this methodology) can be calculated and any r_k exceeding 2σ would be significant at a 95% (a priori) confidence level.

Fig.3 show the amplitudes of the various periodicities detected by MESA in the time series shown in Fig.2. Fig.3(a) refers to the analysis of the JJAS values (one value per year). The hatched portion marks the 2σ limit and as can be seen, some periodicities stand out above this limit, in all the zones. There are peaks in the QBO region (2-3 years) in all the zones, reflecting the almost alternate year ups and downs in the plots in Fig.2. However, the number of peaks is large, indicating either randomness or transiency. There are peaks in the QTO region (3-4 years) and larger periodicities also, some common to more than one zone and

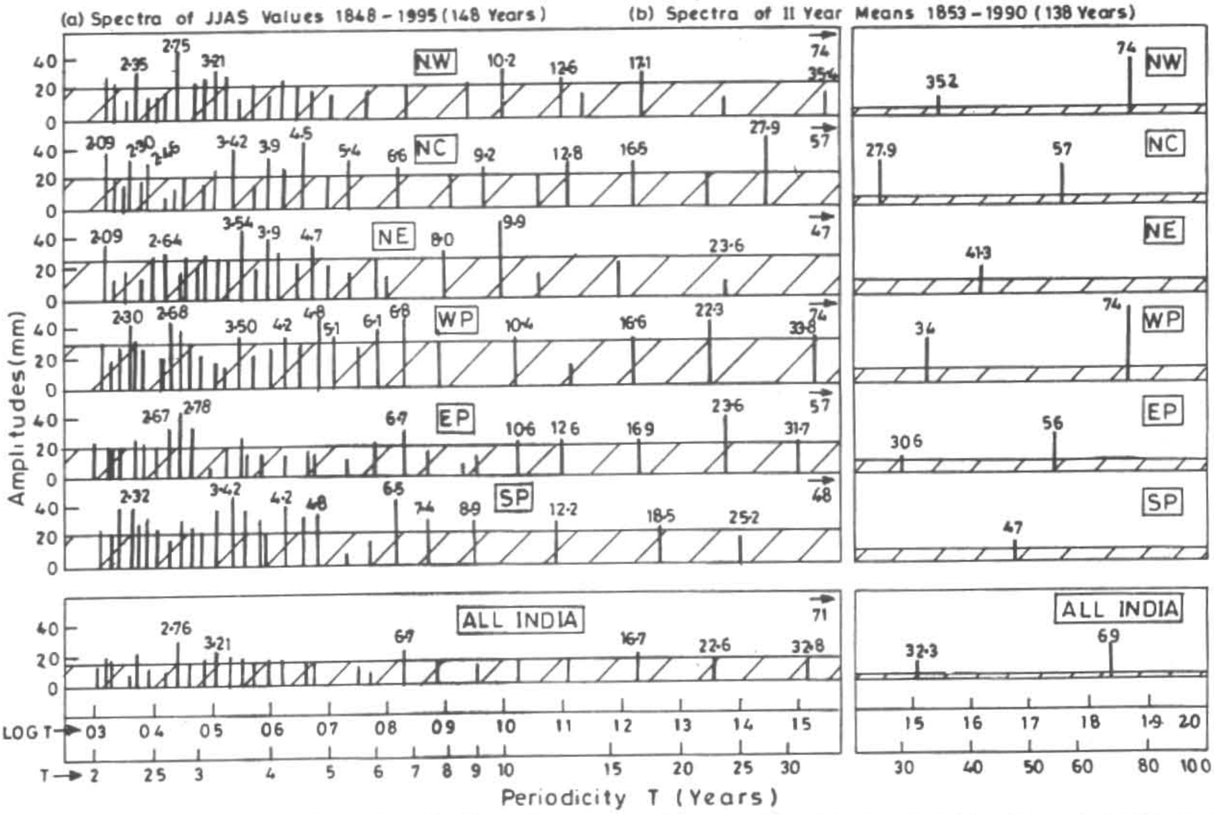

Fig.3. Amplitudes of the periodicities detected by a Maximum Entropy Spectral Analysis of the NW, NC, NE, WP, EP, SP and AI series of summer monsoon rainfall (JJAS) using (a) Yearly values 1848-1995 and (b) 11-year running means 1853-1990. The hatched portions indicate the 2σ limits

hence, reflected in the series of all India (bottom plot). Curiously, there are no peaks near sunspot cycle (11 years), though peaks in the 9.0-10.5 year and 12-13 year range are seen, some very prominent. In some plots, there are significant peaks at 22-23 years, the Hale magnetic solar cycle earlier reported by Bhalme and Mooley (1981). There are still higher periodicities; but these can be studied better in the 11-year running mean series spectra shown in Fig.3(b). The first plot for NW shows a 74 year periodicity, seen in WP also. The NC and EP series show a 56-57 year peak. In the All India series, all these seem to have merged to give a significant peak at 69 years. The NE series has a peak at 41 years and the SP series at 47 years; but none of the other series not the All India series show a peak in this range. All series except SP show peaks in the range 28-35 years, which is reflected in the all India series as a significant peak at 32 years.

To check the stability of these larger periodicities, the whole period 1853-1990 for the 11-year running means was divided into two equal portions. Fig.4 shows the spectra for (a) 1853-1921 and (b) 1922-1990, each for 69 years. Both (a) and (b) show peaks in the 17-20 year range for NW, NC, NE, SP and these are reflected as 20-21 year peaks (Hale magnetic cycle?) in the All India spectra at the bottom. The NW, NC, EP, SP series have peaks at 28-30 years in the first half (a); but the All India series does not show this peak. Also, the second half (b) does not show this peak, indicating its transient nature. The second half (b) shows peaks at 24-26 years for NE, WP, EP, not reflected in the All India spectra. Peaks in the range 41-58 years are seen in both halves in most of the zones and are reflected as a 41 year peak in the first half and a 44 year peak in the second half of the All India series. Thus, some peaks are fairly stable.

To check the stability of the smaller periodicities, the whole period 1848-1995 for the JJAS values was divided into three portions (a) 1848-1897 (50 years), (b) 1898-1946 (49 years), (c) 1947-1995 (49 years). Fig.5 shows the spectra. The QBO and QTO are now prominent but not equally in all the series. Thus, in Fig.5(a), peaks near 2.90 years are very prominent in NW, WP, EP but are absent in the other series as also in the All India series. Peaks in the 4-5 years range are present in almost all series and All India spectra show significant peaks at 4.0 and 4.3 years. Some series show 6.0 year peak while some others show peak near 9.5 years and EP, SP show a barely significant 11.5 year peak (solar cycle?) not reflected in the All India spectra. NC shows a peak at 22 years, NE at 17 years and EP at 34 years. In Fig.5(b), the patterns are very different. There are various

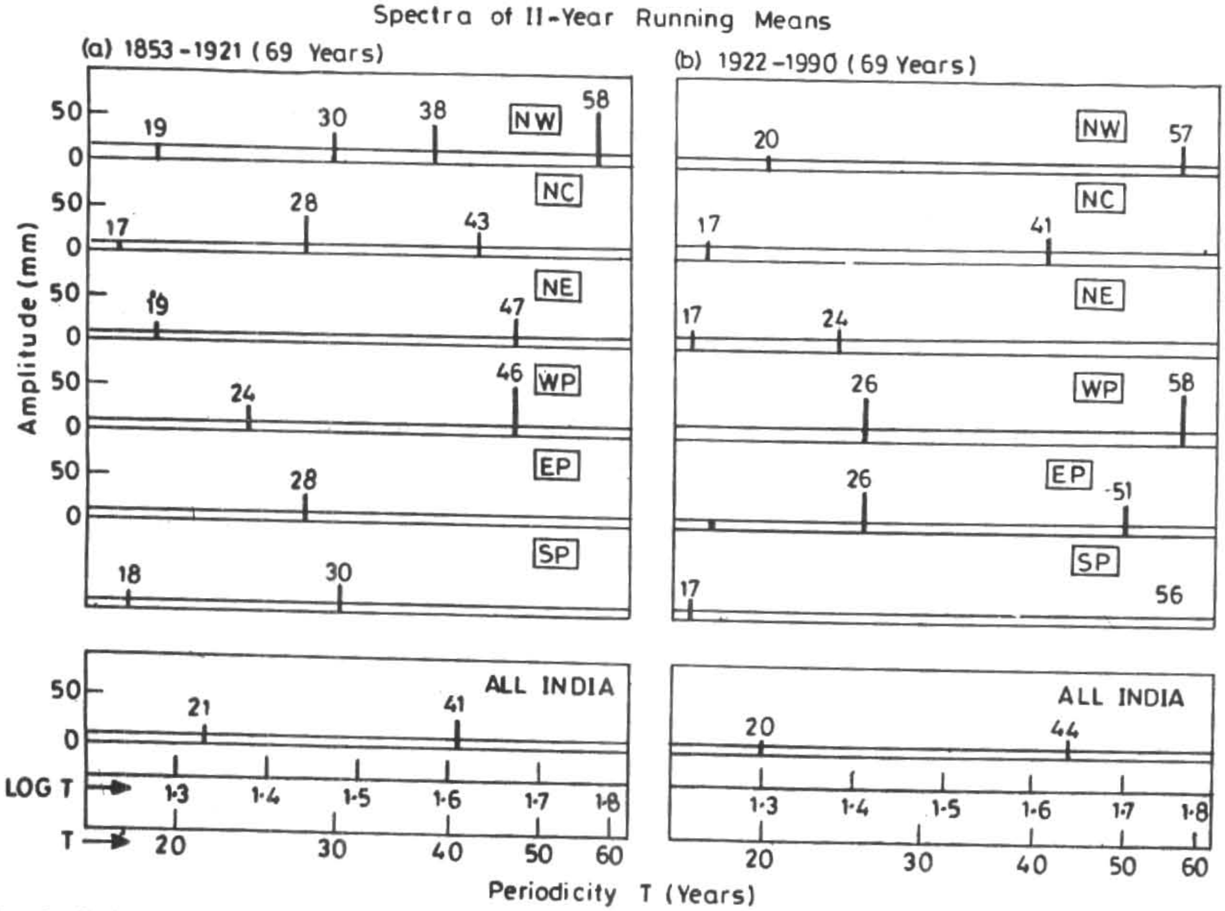

Fig.4. Amplitudes of the periodicities detected by a Maximum Entropy Spectral Analysis of the NW, NC, NE, WP, EP, SP and AI 11-year running means of the summer monsoon (JJAS) precipitation series for (a) 1853-1921 (69 years) and (b) 1922-1990 (59 years). The hatched portions represent the 2σ limits

peaks in the QBO region and these are reflected as significant peaks at 2.13 and 2.36 years in the All India spectra. (In this region, MESA is very accurate and can distinguish these two as separate peaks). There are several peaks in the QTO and higher ranges in the various series; but these are irregular and scattered and the average shows only a barely significant peak at 7.3 years in the All India spectra. NC, NE, WP, EP, SP show peaks at 22, 18, 20, 22, 19 years but these are not coherent enough to give a significant peak in the All India series. Fig.5(c) shows fewer significant peaks. Some are common enough to give significant peaks in the All India spectra at 2.42, 2.78 years (in the QBO region) and 6.9 years. In the high periodicity region, NW, NC, NE, WP, EP, SP have peaks at 17, 19, 21, 24, 28, 17 years, which add up to give a peak at 18 years in the All India spectra. The All India spectra for the three intervals (a), (b), (c) are not similar.

Two atmospheric parameters *viz*, stratospheric low latitude zonal winds and the ENSO indices are known to have QBO and/or QTO. For the 50 mb zonal wind (Pawson *et al.*, 1993), data are available only for the recent 45 years. The wind has one prominent peak at 2.35 years, a smaller (half size) peak at 2.68 years and still smaller peaks at 2.12 and 3.0 years. These match only roughly with the All India precipitation peaks of Fig.5(c). Earlier, relationships have been reported between precipitation and phases of the stratospheric winds (Mukherjee *et al.*, 1985, Kane, 1995). But, by and large, the relationship seems to be rather weak. The Southern Oscillation Index represented by Tahiti minus Darwin mean sea-level atmospheric pressure difference (T-D and the equatorial eastern Pacific sea-surface temperature SST have very similar spectra (both are representative of the ENSO phenomenon), with a most prominent peak at 4.8 years, a subsidiary peak near 3.5 years, and smaller peaks in the QBO region as also higher periodicities. Some of these match with some peaks in the precipitation spectra, indicating some ENSO relationship. However, this is studied in detail in the next section.

3.3. *ENSO relationship with a finer classification*

Various studies (Rasmusson and Carpenter, 1983, Ropelewski and Halpert, 1987) mention that ENSO events are

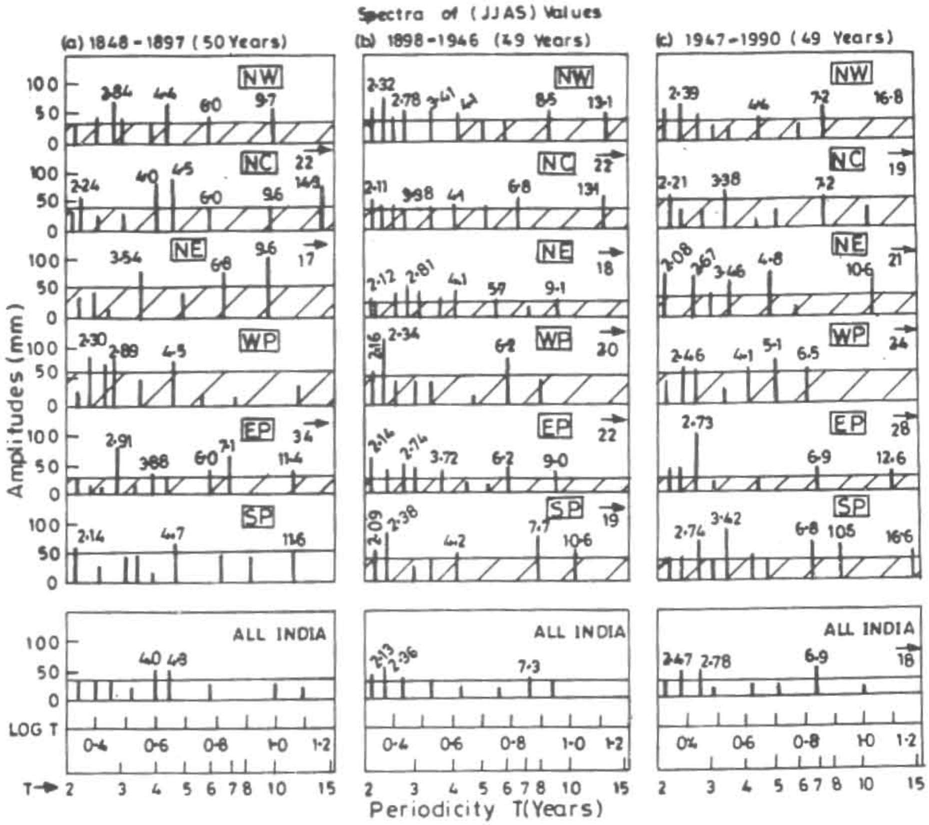

Fig.5. Amplitudes of the periodicities detected by a Maximum Entropy Spectral Analysis of the NW, NC, NE, WP, EP, SP and AI summer monsoon (JJAS) precipitation series for (a) 1848-1897 (50 Years), (b) 1898-1946 (49 years), (c) 1947-1995 (49 years). The hatched portions represent the 2σ limits

associated with discrete precipitation patterns in India and other regions of the globe. However, not all ENSO events show similar effects. Also, different workers do not always select the same years as ENSO events, as shown later for the selections of Rasmusson and Carpenter (1983). Kiladis and Diaz (1989) and Mooley and Paolino (1989). Recently, a finer classification of ENSO events has been proposed which seems to show improved relationships with droughts in All India summer monsoon and Australia (Kane 1997 a,b). The precipitation records of the six Indian zones were examined to see if any improved relationships can be obtained.

The term ENSO is used nowadays for the general phenomenon of the Walker circulation. However, in the classification, here, its components EN, SO are used in their literal sense. Thus, every year was examined to check whether it had an El Nino EN (as listed in Quinn *et al.*, 1978, 1987), and/or Southern Oscillation Index SOI minimum (SO) and/or warm (W) or cold (C) equatorial eastern Pacific sea surface temperatures (SST). Several years had ENSOW *i.e.*, El Nino existed and SOI had minima and Pacific SST were warm. These were subdivided into two groups *viz.*, Unambiguous ENSOW where El Nino existed and the SOI minima and SST maxima were in the middle of the calendar year (May-August) and Ambiguous ENSOW where El Nino existed, but the SOI minima and SST maxima were in the early or later part of the calendar year, not in the middle. Besides these, there were other years having El Nino of the type ENSO(SOI minima existed but SST was neither warm nor cold, just normal), ENW, ENC (SOI minima, did not exist but SST was warm W or cold C) or just EN (*i.e.*, only El Nino, no SOI minima, no SST maxima or minima). Other years did not have an El Nino and were of the types SOW, SOC, SO, W, C where the last category C contains all Anti-El Ninos or La Ninas. Years and falling into any of these categories are termed as Non-events. We have this classification ready for all years from 1871 onwards upto 1992.

Table 2 shows the summer monsoon rainfall status of the six zonal series for (a) Unambiguous ENSOW years (b) Ambiguous ENSOW years and (c) Years of other types of El Ninos (ENSO, ENW, ENC, EN). The symbols S (strong), M (moderate), W (weak) indicate the strength of the El Nino involved. The columns 1-6 show the rainfall status for the

TABLE 2

Rainfall status during El Nino years of various types I and II indicate first and second years of double events (El Ninos in two consecutive years). The symbols + and - indicate positive and negative deviations within 0 and σ, while triangles (positive) and circles (negative) represent deviations exceeding σ

	JJAS						JJAS	MAM	OND	
	1	2	3	4	5	6	7	8	9	10
	NW	NC	NE	WP	EP	SP	AI	NE	EP	SP
(a) Unambiguous ENSOW										
S 1877 I RKP	O	O	-	O	O	-	O	+	-	Δ
S 1888 KP	-	+	-	-	O	+	-	Δ	-	-
M 1896 RKP	-	-	O	-	+	+	-	+	O	-
S 1899 RKP	O	+	Δ	O	O	O	O	+	O	O
M 1902 RKP	-	-	Δ	-	-	+	-	+	-	Δ
M 1905 R P	O	-	Δ	O	O	-	O	+	O	-
S 1911 RKP	O	+	+	O	-	O	O	Δ	-	+
S 1918 I RKP	O	-	Δ	O	-	O	O	+	O	+
M 1930 I RKP	-	+	-	-	-	O	-	O	Δ	Δ
S 1941 II R P	O	-	+	O	O	-	O	Δ	+	+
M 1951 RKP	O	O	-	-	+	-	O	-	-	-
S 1957 I RKP	-	-	O	-	-	-	-	-	O	+
M 1965 RKP	O	O	+	-	-	O	O	-	O	-
S 1972 I RKP	O	O	O	O	O	O	O	-	+	Δ
M 1976 RKP	+	-	-	+	-	O	+	-	+	+
S 1982 I KP	-	-	O	-	-	-	-	-	-	O
M 1987	O	-	Δ	-	O	-	O	O	Δ	Δ
17 events										
Dev. Positive	1	4	8	1	2	3	1	9	5	10
Dev. Negative	16	13	9	16	15	14	16	8	12	7
(b) Ambiguous ENSOW										
S 1878 II P	+	O	Δ	Δ	+	Δ	Δ	-	Δ	-
M 1914 R	+	-	-	Δ	Δ	+	+	+	O	+
M 1919 II	+	+	-	-	-	+	+	O	Δ	+
M 1923 RK	-	-	-	-	O	Δ	-	-	Δ	O

TABLE 2 (Contd.)

	JJAS						JJAS	MAM	OND	
	1	2	3	4	5	6	7	8	9	10
	NW	NC	NE	WP	EP	SP	AI	NE	EP	SP
S 1925 I RKP	-	+	-	O	Δ	-	-	Δ	+	+
S 1926 II	+	+	+	+	-	+	+	-	O	O
M 1931 II K	+	-	-	+	-	+	+	-	Δ	+
S 1940 I P	-	-	-	+	Δ	+	-	+	-	Δ
W 1948 P	-	Δ	+	-	-	+	+	Δ	+	-
M 1953 RK	-	Δ	+	+	+	+	+	+	+	+
S 1958 II	Δ	-	O	Δ	+	-	+	+	Δ	-
W 1963 KP	+	-	+	+	+	-	+	-	+	-
W 1969 RKP	+	+	-	+	-	-	-	-	+	+
S 1983 II P	+	-	-	Δ	+	Δ	Δ	-	-	-
M 1991 I	-	-	-	+	Δ	Δ	-	Δ	+	+
M 1992 II	-	O	O	-	Δ	Δ	-	O	-	+
16 events										
Dev. Positive	9	6	5	11	10	11	10	7	11	9
Dev. Negative	7	10	11	5	6	5	6	9	5	7
(c) Other El Ninos										
S 1871 ENSO	+	Δ	-	O	O	-	+	+	O	-
W 1873 ENSO	+	O	O	-	O	-	O	O	+	-
M 1880 ENSO RK	-	-	+	-	+	-	-	+	+	+
S 1891 ENSO RK	+	-	O	-	-	O	-	+	O	+
S 1900 ENSO P	+	-	-	+	+	+	+	-	O	O
S 1912 ENSO	-	-	-	-	+	+	-	+	-	+
6 events										
Dev. Positive	4	1	2	1	3	2	2	4	2	3
Dev. Negative	2	5	4	5	3	4	4	2	4	3
S 1884 ENW RK	Δ	+	O	+	+	O	+	+	-	Δ
1 event										
Dev. Positive	1	1	0	1	1	0	1	1	0	1

TABLE 2 (Contd.)

	JJAS						JJAS	MAM	OND	
	1	2	3	4	5	6	7	8	9	10
	NW	NC	NE	WP	EP	SP	AI	NE	EP	SP
Dev. Negative	0	0	1	0	0	1	0	0	0	1
M 1897 EN P	-	+	-	+	-	Δ	+	-	-	O
S 1932 EN RK	-	O	-	+	-	-	-	+	+	Δ
M 1939 EN RKP	O	+	+	-	-	-	-	O	Δ	+
M 1943 EN	-	+	-	-	+	-	+	Δ	-	Δ
4 events										
Dev. Positive	0	3	1	2	1	1	2	2	2	3
Dev. Negative	4	1	3	2	3	3	2	2	2	1
ENSO, ENW, EN										
Dev. Positive	5	5	3	4	5	3	5	7	4	7
Dev. Negative	6	6	8	7	6	8	6	4	7	4
M 1874 ENC P	+	Δ	-	+	+	Δ	Δ	+	+	-
M 1887 ENC R	Δ	-	-	Δ	-	-	+	+	-	Δ
M 1889 ENC P	+	+	+	+	Δ	Δ	+	-	Δ	-
M 1907 ENC	O	O	-	+	-	+	O	-	O	-
S 1917 ENC	Δ	+	+	+	+	+	Δ	O	Δ	+
S 1973 ENC KP	Δ	+	-	+	-	-	+	+	+	-
6 events										
Dev. Positive	5	4	2	6	4	4	5	3	4	2
Dev. Negative	1	2	4	0	2	2	1	3	2	4

six zones (NW, NC, NE, WP, EP, SP) and column 7 represents All India rainfall (AI). Columns 8,9,10 represent the MAM series of NE and OND series of EP and SP. For each one of these series, deviations from the series mean were expressed as fractions of the standard deviation of the series and in these normalized series, positive and negative deviations within 0 to σ were designated as (+, -) and those exceeding σ were designated by triangles (positive) and circles (negative). The following may be noted:

(1) From the 17 Unambiguous ENSOW years (Table 2a), AI shows negative deviations (- and circles) for 16 events, a very good association with droughts. It is gratifying to note that most of these events were chosen by Rasmusson and Carpenter (1983), Kiladis and Diaz (1989) and Mooley and Paolino (1989) (henceforth designated as R,K,P, respectively for warm events and *K, P* for cold events) as warm events. The bottom rows of Table 2(a) show the number of positive (+ and triangles) and negative (- and circles) deviations. The NW and WP have similar numbers, indicating that these zones also have equally good association with droughts. To a lesser extent, NC (4+, 13-) and SP (3+, 14-) are also associated with droughts. In contrast, NE (8+,9-) has a mixed performance, indicating poor relation-

ship. Some workers (Singh *et al.*, 1992) have mentioned that the summer monsoon fluctuations over the northwest (NW) and northeast (NE) are negatively correlated. However, the relationship does not seem to be that simple. (A detailed comparison is given later). In case of EP (OND) (post-monsoon, column 9), the associationship of droughts with El Ninos is partial (5+, 12-), not as good as for EP (JJAS) (2+, 15-). Also, for 10 events, EP (JJAS) and EP (OND) had similar signs while for 7 events, these had opposite signs. Thus, the monsoon and post-monsoon rainfalls in EP are not well correlated and among these, EP (JJAS) droughts are better associated with the Unambiguous ENSOW. In case of SP (OND) (post- monsoon, column 10), the association of droughts with El Ninos of this group is poor (10+, 7-), not as good as for SP (JJAS) (3+, 14-). Also, for 6 events, SP (JJAS) and SP (OND) had similar signs while for 11 events, these had opposite signs. Thus, the monsoon and post-monsoon rainfalls in SP are not well correlated and are somewhat anti-correlated. In their ENSO studies of various regions of the globe, Ropelewski and Halpert (1987) showed that during El Nino years, All India (excluding SP) JJAS rainfall and droughts and Minicoy-Sri Lanka OND rainfall was excess. In our case, JJAS rainfall in SP seems to follow the All India pattern (droughts); but OND rainfall in SP is mixed, partly like All India droughts) and partly like Minicoy-Sri Lanka (excess rain).

Table 2(b) refers to Ambiguous ENSOW. AI shows mixed results, in fact, slightly opposite results, *viz.*, a slight bias for excess rains (10+, 6-). Among the El Nino events, some are double events *i.e.*, occurring in two successive years. These are marked as I and II in Table 2 and most of the second years appear as Ambiguous events and gave excess rains (instead of droughts) for AI. While selecting El Nino events for analysis, R, K, P did not consider these second year events as warm events. Instead, some of these were considered as cold events (1878, 1983 as P, 1931 as K). For the series WP, EP, SP, the results (11+, 5-; 10+, 6-; 11+, 5-) are similar to those for All India. For NW, results are mixed (9+, 7-) while for NC and NE, results are opposite (6+, 10- ; 5+, 11-).

Table 2(c) refers to other types of El Ninos. From the 17 events, 6 are ENSO, one is ENW, 4 are EN and 6 are ENC. The 11 events ENSO, ENW and EN are all expected to be associated with droughts. From these, only 1939 EN was selected by all (R, K, P) as a warm event. The ENSO of 1880, 1891, the ENW of 1884 and the EN of 1932 were selected as warm events by R, K only. The ENSO of 1900, the EN of 1897 and the ENC of 1874, 1889 were selected as *cold* events by P. For AI, the results are mixed, 5 positive and 6 negative deviations. For NW, NC, EP also, similar (5+, 6-) results are obtained; but NE and SP (3+, 8-) and WP

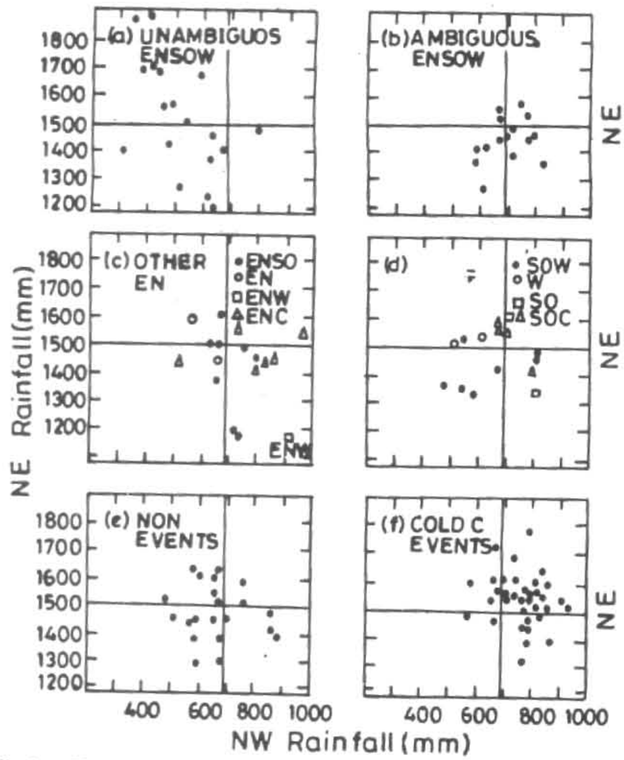

Fig.6. Plots of the summer monsoon rainfalls of Indian Northeast NE *versus* Northwest NW for years of (a) Unambiguous ENSOW, (b) Ambiguous ENSOW, (c) Other types of El Nino years ENSO, EN, ENW, ENC, (d) Years of the type SOW, W, SO, SOC, (e) Non-events, (f) Cold C events. The vertical and horizontal lines represent overall mean rainfalls, about 1500 mm for NE and 690 mm for NW

(4+, 7-) show a bias for negative deviations. For the 6 ENC events, EN is expected to yield droughts while C is expected to yield floods. Thus, the two would neutralise each other and normal rainfall would be expected. Instead, AI and NW (5+, 1-), WP (6+, 0-) and NC, EP, SP (4+, 2-) show biases for excess rains, indicating that C proved overwhelming. For NE (2+, 4-), the results were opposite.

Summarising, for the precipitation in all the regions except NE, the Unambiguous ENSOW type shows a very good association with droughts, which is reflected in the All India summer monsoon rainfall also. For the Ambiguous ENSOW as also for other types of events involving El Ninos, the results are mixed. For ENC events, the effect is generally more of C than of EN.

Tables like Table 2 were made for all other types of events also but are not shown here. For events not involving El Ninos, the general statistics (number of positive and negative deviations) was as follows. For AI, the 6 SOW years (1888, 1904, 1913, 1944, 1977, 1979), the 3 W years (1920, 1968, 1986) and the 3 SO years (1885, 1959, 1974) showed deviations (2+, 4-; 0+, 3-; 2+, 1-) totaling (4+, 8-), thus indicating a bias for droughts, as expected, but not overwhelming. Individually, NW, NC, NE, WP, EP showed (4+, 8-; 4+, 8-; 5+, 7-; 3+, 9-; 3+, 9-) *i.e.*, biases for droughts. But SP showed (7+, 5-), a bias for floods. For the 4 SOC, AI shows (3+, 1-), (also shown by NC, NE), *i.e.*, a bias for floods, indicating the effect of C. But WP, EP, SP showed (2+, 2-) and NW showed (1+, 3-), indicating effects of EN also.

In view of these results conforming only partially to the expected results (droughts when EN, SO, W were present and floods when C was present), it would be interesting to check the results for non-events *i.e.*, when there were no El Ninos, no SO nor W or C. Table is not shown here. There were for 22 non-event years, for which only small positive and negative deviations in roughly equal numbers were expected. Interestingly, P chose two of these (1876, 1883) as *warm* events. In general, the circles and triangles were fewer and for AI, the numbers were (9+, 13-), almost equal number of positives and negatives. The largest difference was for NW (7+, 15-). Thus, biases of this order could occur due to factors not related to the ENSO phenomenon. Some striking extreme events were 1876, 1901, 1966 when widespread severe droughts occurred and 1961 when severe floods occurred. In view of this, only the results for the Unambiguous ENSOW of Table 2(a) stand out as significantly different from randomness.

For C events, representing colder waters of equatorial eastern Pacific SST (table not shown), for the 35 events. AI showed (33+, 2-), an overwhelming bias for excess rains. In the individual regions, the bias for excess rains was there but not so strong, probably because of complications from local factors, the worst case being SP (21+, 14-). The year 1928 had widespread droughts.

As mentioned earlier, the summer monsoon rainfall fluctuations of Northwest NW and Northeast NE are reported to be negatively correlated. When these two were analysed for 1848-1995, the correlation coefficient turned out to be -0.11 ± 0.08, negative but very poor. To check the relationship for the various types of years considered here, Fig.6 shows plots of the NE summer monsoon rainfall versus the NW summer monsoon rainfall for (a) Unambiguous ENSOW years (b) Ambiguous ENSOW years, (c) Other El Nino years (ENSO, EN, ENW, ENC, shown by different symbols), (d) Years of the type SOW, W, SO, SOC (shown by different symbols), (e) Non-events, (f) Cold C events and the vertical and horizontal lines represent the series overall means. In Fig. 6(a), NW is mostly below average (left half), indicating droughts; but NE is both below and above average. Thus, during these events, monsoon is either inhibited right from the beginning everywhere, or starts normally in NE and is prevented from spreading to NW. In Figs.6(b,c,d), the points are scattered all over and the correlations are almost zero. Even in Fig.6(e) representing Non-events, NW and NE are very poorly correlated. In Fig.6(f) for the cold C events, points seem to be concentrated in the right upper quadrant, indicating positive deviations (excess rains) for both NW and NE and a positive correlation is obtained. Thus, the relationship between the rainfall fluctuations in NW and NE is generally weak.

4. Conclusions

Using the precipitation data for the six homogeneous zones (Northwest NW, Northcentral NC, Northeast NE, West Peninsular WP, East Peninsular EP, South Peninsular SP) of India and for all India (AI) as given by Sontakke and Singh (1996), the spectral characteristics and ENSO relationships were studied in detail, for the period 1848-1995. All zones showed significant periodicities in the QBO (2-3 years) and QTO (3-4 years) ranges as also higher periodicities, but not similar to each other. Some of these were fairly stable over the whole period. A finer classification of El Nino events showed that events of the Unambiguous ENSOW type (years when El Nino existed and the Southern Oscillation Index minima and equatorial eastern Pacific sea-surface temperature maxima occured in the middle of the calendar year, May-Aug.) had a very good association with droughts in the All India summer monsoon rainfall as also in most of the zones except NE.

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References

Bevington, P.R., 1969, "Data Reduction and Error Analysis for the Physical Sciences". McGraw-Hill Book Co., New York 164-176.

Bhalme, H.N. and Mooley, D.A., 1981, "Cyclic fluctuations in the flood area and relationship with the double (Hale) sunspot cycle", *J. Appl. Meteor*, **20**, 1041-1048.

Blackman, R.B. and Tukey, J.W., 1958, "The measurements of power spectra", Dover, New York, p.190.

Burg, J.P., 1967, "Maximum Entropy Spectral Analysis", Paper presented at the *37th Meeting, Society of Exploration Geophysics*, Oklahoma City, October.

Kane, R.P., 1997a, "Relationship of El Nino/Southern oscillation and Pacific sea-surface temperature with rainfall in various regions of the globe", *Mon. Wea. Rev.*, **125**, 1792-1800.

Kane, R.P., 1997b, "On the relationship of ENSO with rainfall over different parts of Australia", *Aust. Meteor Mag*, **46**, 39-49.

Kane, R.P., and Trivedi, N.B., 1982, "Comparison of Maximum Entropy Spectral Analysis (MESA) and Least-Squares Linear Prediction (LSLP) methods for some artificial samples", *Geophysics*, **47**, 1731-1736.

Kiladis, G.N. and Diaz, H.F., 1989, "Global climate anomalies associated with extremes in the Southern Oscillation", *J. Climate*, **2**, 1069-1090.

Mooley, D.A. and Paolino, D.A., 1989, "The response of the Indian monsoon associated with the change in sea surface temperature over the eastern south equatorial Pacific", *Mausam*, **40**, 369-380.

Mooley, D.A., and Parthasarathy, B., 1984, "Fluctuations in All- India summer monsoon rainfall during 1871-1978", *Climatic Change*, **6**, 287-301.

Mukherjee, B.K., Indira, K., Reddy, R.S. and Raman Murty, Bh. V., 1985, "Quasi-biennial oscillation in stratospheric zonal wind and Indian summer monsoon", *Mon. Weath. Rev.*, **113**, 1421-1424.

Parthasarathy, B., Rupa Kumar, K. and Kothawale, D.R., 1992, "Indian Summer monsoon rainfall indices", *Meteor. Mag.*, **121**, 174- 186.

Pawson, S., Labitzke, K., Lenschow, R., Naujokat, B., Rajewski, B., Wiesner, M. and Wohlfart, R.N., 1993, "Climatology of the Northern Hemisphere Stratosphere derived from Berlin Analyses- Part I: Monthly Means", Meteorologische Abdandlungen des Instituts fur Meteorologie der Freien Universitat Berlin, Neue Folge Serie A Monographien Band 7/Heft 3.

Quinn, W.H., Zoff, D.G., Short, K.S. and Kuo Yang, R.T.W., 1978, "Historical trends and statistics of the Southern Oscillation, El Nino and Indonesian droughts", *Fish. Bull.*, **76**, 663-678.

Quinn, W.H., Neal, V.T. and Antunez de Mayolo, S.E., 1987, "El Nino occurrences over the past four and a half centuries", *J. Geophys. Res.*, **92**, 14449-14461.

Rasmusson, E.M. and Carpenter, T.H., 1983, "The relationship between eastern equatorial Pacific sea surface temperatures and rainfall over India and Sri Lanka, *Mon. Wea. Rev.*., **111**, 517-528.

Ropelewski, C.F. and Halpert, M.S., 1987, "Global and regional scale precipitation patterns associated with El Nino/Southern oscillation", *Mon. Wea. Rev.*, **115**, 1606-1626.

Singh, N. and Sontakke, N.A., 1996, "The instrumental period rainfall series of the Indian region: A documentation", *Res. Report No. RR-067*, Contributions from Indian Institute of Tropical Meteorology, Pune-411 008, 79 p.

Singh, N., Pant, G.B. and Mulye, S.S., 1992, "Spatial variability of aridity over northern India", *Proc. Ind. Acad. Sci. (Earth Planet. Sci.)*, **101**, 201-213.

Sontakke, N.A. and Singh, N., 1996, "Longest instrumental regional and All-India summer monsoon rainfall series using optimum observations: reconstruction and update", *The Holocene*, **6**, 3, 315-331.

Ulrych, T.J. and Bishop, T.N., 1975, "Maximum Entropy Spectral Analysis and autoregressive decomposition", *Rev. Geophys*, **13**, 183-200.