Fluctuations in the Drought/Flood Area over India and Relationships with the Southern Oscillation

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ABSTRACT

An objective numerical drought/flood index has been used to obtain, on the dryness side, the Drought Area Index (DAI) and on the wetness side, the Flood Area Index (FAI) for India for the period 1891–1979. The DAI for a given year is the percentage area of India corresponding to a mean monsoon index with drought intensity ≤ -2 (moderate drought or worse). Likewise, on the wetness side, the Flood Area Index (FAI) for the given year is the percentage area of India corresponding to a mean monsoon index with flood intensity $\geq +2$ (moderate flood or worse), where the mean monsoon index of an area is the mean drought/flood index for the four monsoon months (June–September). A year with DAI/FAI ≥ 25, i.e., 25% of the country area, is identified as a large-scale drought/flood year, respectively. The magnitude 25 used in identifying large-scale drought/flood corresponds approximately to twice the standard deviation of the DAI/FAI series.

The large-scale April Pressure Index (PI) of the Southern Oscillation has been devised with the combination of surface pressure of stations from Australia, India, Indonesia and South America. The fluctuations of PI covering a period of 89 years (1891–1979) and its relation to the DAI and FAI have been examined. The study indicates a significant inverse relationship between the PI and DAI series. This implies that the large negative PI value, signifying weakening of the southeast trades over the Indo-Pacific region tends to coincide with a large DAI value, meaning a large area affected by drought during the subsequent monsoon and vice versa. The PI and FAI are significantly positively correlated. This implies that a large positive value of PI, signifying strengthening of the southeast trades tends to correspond to a large value of FAI, meaning a large area affected by flood during the monsoon and vice versa. The spectrum and cross-spectrum analysis of the PI and DAI series suggest that significant correlation between the PI and DAI is mostly due to the oscillations in the range of 3–6 years. The maximum coherence falls over a period of about 3 years. Furthermore, an oscillation of ~3 years in a climatic element such as DAI arises primarily as a result of the Southern Oscillation. The Southern Oscillation appears to be one possible causal climatic phenomenon for introducing a most common period of anything from 3 to 6 years for the recurrence of large-scale droughts over India.

1. Introduction

The important natural causes of Indian famines are large-scale droughts and floods with large-scale droughts being very common. Large-scale droughts have devastating effects on food production and the whole economy of the country. Thus a prediction of the occurrence of large-scale drought as far ahead as possible is of considerable practical value for a wide range of interests, especially for agriculture, hydroelectric power production, and the Government.

Walker (1923) realized the complexity of the problem of forecasting monsoon rainfall and made a worldwide survey of correlation coefficients connecting monsoon rainfall and antecedent meteorological parameters in various parts of the globe with the objective of improving monsoon forecasts. This was followed by a search for inter-relationships between contemporary and antecedent meteorological parameters in various parts of the globe. Walker (1924) eventually discovered one of the important oscillations of the planetary atmospheric pressure field—the Southern Oscillation. The Southern Oscillation is a large-scale fluctuation of the atmospheric circulation and it expresses a tendency for above normal (below normal) surface pressure in the South Pacific Ocean to be associated with below normal (above normal) pressure in the equatorial Indian Ocean (Das, 1968; Lamb, 1972). This is generally taken as the shift in distribution of air masses between the southeast Pacific subtropical high and the Indonesian equatorial low. The changes in pressure are related to the strength of the equatorial zonal east–west circulation in the Pacific ocean called the Walker Circulation by Bjerknes (1969). The Southern Oscillation has an irregular period ranging from 2 to 6 years, usually averaging between 2 and 3 years (Berlage, 1957; Lamb, 1972; Wright, 1975; Trenberth, 1976; Julian and Chervin, 1978). Various workers in the field have used different combinations of stations to compute an index for the Southern Oscillation (Walker, 1924; Berlage, 1957; Troup, 1965; Wright, 1975; Trenberth, 1976). An extensive survey of the literature on the Southern Oscillation has been made by Julian and

Chervin (1978). The discovery of the Southern Oscillation led Walker (1924) to believe that a future search may well reveal factors which have close association with the monsoon.

Individual disastrous droughts over India and associated circulation anomalies have been examined by many workers (Keshavamurty and Awade, 1974; Kanamitsu and Krishnamurti, 1978; Raman *et al.*, 1980; Sikka, 1980). Bhalme and Mooley (1980) have now succeeded in quantifying droughts/floods and they have objectively identified large-scale droughts over India over a long period of record. In an exploratory attempt at prediction of large-scale droughts/floods over India, the April Pressure Index (PI) which can be regarded as a measure of the Southern Oscillation has been devised. In this paper we report on the relationship between the large-scale PI and the fluctuations of areal extent of drought/flood during the monsoon period (June–September) over India, and possible uses of the relationship in prediction of large-scale droughts/floods.

2. Data

Sources of atmospheric pressure data for Bombay (18°54′N, 72°49′E), Jakarta (06°11′S, 106°51′E), Perth (31°57′S, 115°49′E) and Santiago (33°27′S, 70°42′W) for the period 1891–1960 were *World Weather Records* (Smithsonian Institution, 1927, 1934, 1947; U.S. Weather Bureau, 1959; ESSA, 1966, 1967, 1968) and *Monthly Climatic Data for the World* (NOAA, 1961–79) for the period 1961–79. The aforementioned stations are shown in Fig. 1.

Monthly rainfall measurements for meteorological subdivisions of India (Bhalme and Mooley, 1980) for the period of 89 years (1891–1979) were available to us from the office of the Deputy Director General of Meteorology, India Meteorological Department, Pune.

3. Drought Index/Flood Index

Bhalme and Mooley (1980) developed an objective numerical drought index based on the monthly monsoon (June–September) rainfall over an area and a duration for assessment of drought intensity. The basic assumption in the development of the index is that plant life and established human activities are geared to the long-term mean monthly rainfall of the area of the specific period and that the deviation from the mean monthly rainfall determines the drought characteristics. The drought index equation is

$$I_k = 0.50\, I_{k-1} + M_k/48.55, \qquad (1)$$

where I_k, I_{k-1} are the drought intensities of the kth and $(k-1)$th month and the moisture index M is the standardized measure of the monthly rainfall multiplied by 100, i.e., $[100(R - \bar{R})/\sigma_R]$, where R symbolizes the monthly rainfall, with mean $\bar{R}$ and standard deviation σ_R. The monthly rainfall anomaly can be negative as well as positive. Therefore, the drought intensity equation gives negative or positive values and thus serves the dual purpose of assessing the dryness (drought) and wetness (flood). The resulting monthly index is comparable both among the areas and months within reasonable limits. The monthly index values generally range from −4 to +4. Table 1 lists the descriptive terms which have been assigned to describe the character of the weather represented by various intervals of the Index.

The drought index [Eq. (1)] was used to obtain monthly drought intensity indices for each of the monsoon months (June–September) for the period 1891–1979, for each of the meteorological subdivisions of India except for the two divisions, Bay Islands and Arabian Sea Islands. For a given year, to begin the sequence of I's generated by Eq. (1), I_{k-1} was set

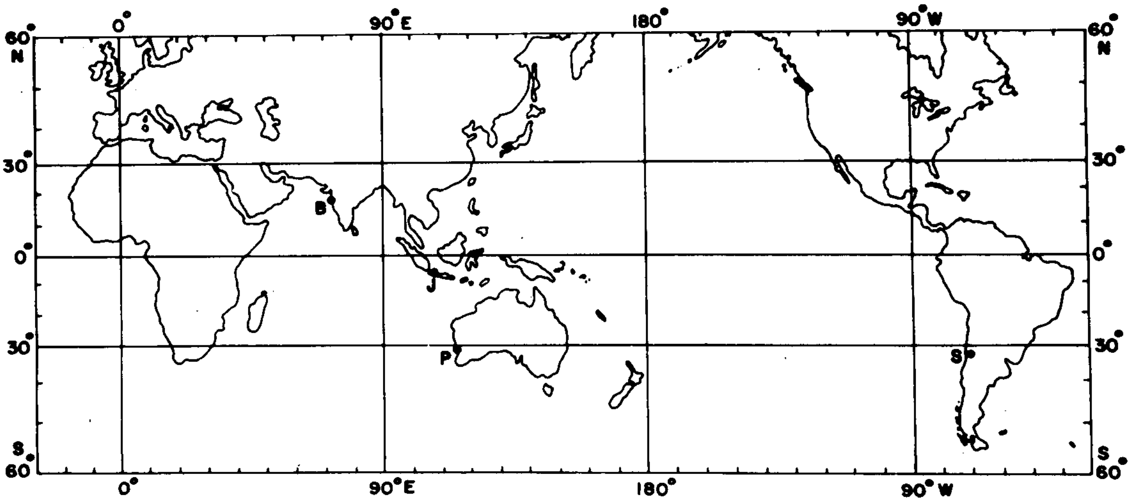

FIG. 1. Locations of the stations Jakarta (J), Bombay (B), Perth (P) and Santiago (S) used in the pressure index of the Southern Oscillation.

TABLE 1. Description of monthly drought (−)/flood (+) index.

Index	Character of the weather
4.00 or more	Extreme flood
3.00 to 3.99	Severe flood
2.00 to 2.99	Moderate flood
1.00 to 1.99	Mild flood
0.99 to −0.99	Near normal
−1.00 to −1.99	Mild drought
−2.00 to −2.99	Moderate drought
−3.00 to −3.99	Severe drought
−4.00 or less	Extreme drought

at zero. The monsoon season was chosen because more than 75–90% of the annual rainfall occurs over a large area of the country during the monsoon season and droughts or floods are determined primarily by the amount of monsoon rainfall alone. Thus monsoon rainfall is the most important single factor in the agricultural economy of India. Furthermore, from these monthly indices the mean index for the four monsoon months, called the mean monsoon index I_m [$I_m = (I_{\mathrm{Jun}} + I_{\mathrm{Jul}} + I_{\mathrm{Aug}} + I_{\mathrm{Sep}})/4.0$] was calculated for each of the years and for each of the subdivisions. The Drought Area Index (DAI) of a year is the percentage area of India with a mean monsoon index of drought intensity $\leqslant -2$ (moderate drought or worse). Likewise, the Flood Area Index (FAI) of the year is the percentage area of India with a mean monsoon index of flood intensity $\geqslant +2$ (moderate flood or worse).

a. Large-scale droughts/floods

Based on the threshold values of DAI or FAI, Bhalme and Mooley (1980) identified large-scale drought or flood years over India. A year with DAI $\geqslant 25$ (i.e., 25% area of the country) for drought intensity $\leqslant -2$ (moderate drought or worse) is defined as a large-scale drought year and a year with FAI $\geqslant 25$ (i.e., 25% area of the country) for flood intensity $\geqslant +2$ (moderate flood or worse) as a large-scale flood year. The magnitude 25 used in defining large-scale drought or flood year corresponds approximately to twice the standard deviation of the DAI or FAI series. These criteria have been used to define large-scale drought/flood years. The years of large-scale drought and flood over India, their relative ranking, area affected and interval between successive occurrences are shown in Table 2. The years of large-scale drought/flood objectively identified have been supported by independent information from different sources (Bhalme and Mooley 1980).

b. DAI/FAI series

Figs. 2a and 2b show the DAI/FAI series for the period 1891–1979 with identified large-scale drought/flood years. An examination of the DAI series reveals that the frequency of large-scale droughts during the two periods 1891–1920 and 1961–1979 is high, with only a few years of large-scale drought in the long intervening period. On an average every fourth year the country experiences a large-scale drought, if the above two periods of frequent droughts are the only consideration. The FAI series shows cyclic fluctuations with a period of about 20 years. This is confirmed further by power spectrum analysis.

4. Pressure Index (PI)

Walker's (1924) studies confirmed that fluctuations in monsoon rainfall were connected with long-lasting and large-scale changes in pressure distribution over

TABLE 2. Large-scale drought/flood years over India from 1891–1979.

Large-scale droughts					Large-scale floods				
No.	Year	Interval between droughts (years)	Area affected (percent)	Ranking	No.	Year	Interval between floods (years)	Area affected (percent)	Ranking
1	1891	—	35	7	1	1892	—	33	6
2	1896	4	27	12	2	1893	0	40	3
3	1899	2	56	2	3	1894	0	44	2
4	1905	5	47	3	4	1916	21	36	5
5	1911	5	36	5	5	1917	0	38	4
6	1915	3	27	11	6	1933	15	30	9
7	1918	2	66	1	7	1936	2	27	11
8	1920	1	26	15	8	1938	1	25	14
9	1941	20	27	13	9	1942	3	30	8
10	1951	9	33	9	10	1956	13	27	12
11	1965	13	41	4	11	1959	2	28	10
12	1966	0	27	14	12	1961	1	48	1
13	1972	5	34	8	13	1975	13	31	7
14	1974	1	31	10	14	1978	2	26	13
15	1979	4	36	6					

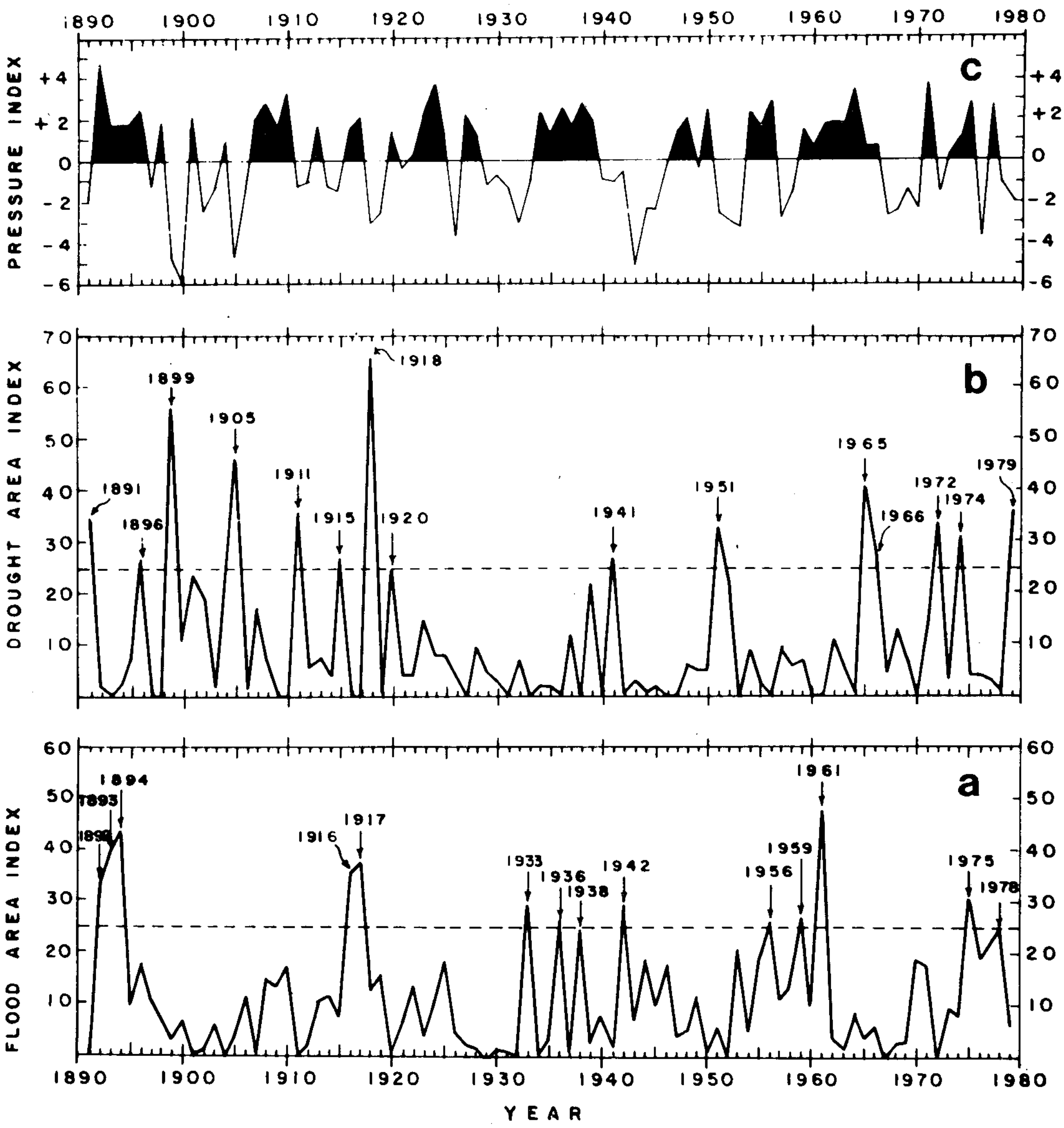

FIG. 2. (a) Flood Area Index (FAI) series from 1891–1979 with identified large-scale floods. (b) Drought Area Index (DAI) series from 1891–1979 with identified large-scale droughts. (c) April Pressure Index (PI) series from 1891–1979.

the globe. His original interest in the Southern Oscillation was to predict monsoon rainfall. Walker (1924) used an index of the Southern Oscillation based on the combination of pressure, temperature and rainfall. Later Troup (1965) refined this index retaining station pressure only. Berlage (1957) simply used the pressure at Jakarta. Wright (1975) and Trenberth (1976) derived the index from a principal component analysis of pressure at several widely-spaced stations.

The choice of stations in the Indo-Pacific region in this study is Jakarta, Bombay, Santiago and Perth for developing the Pressure Index (Fig. 1). We used the standardized surface pressure anomalies for the month of April at these stations. The standardized surface pressure anomalies at a station have been obtained by subtracting the long-term mean from the monthly mean pressure and dividing by its standard deviation, i.e., $[(P - \bar{P})/\sigma_P]$, where P is the April mean pressure, with mean (1891–1979) $\bar{P}$ and standard deviation σ_P. Table 3 shows the percentage of the same and of the opposite sign of the standardized pressure anomalies during the month of April at three stations with respect to Jakarta and Santiago. The standardized April pressure anomalies at Bombay had more frequent (83%) occasions of the same sign with respect to Jakarta than at other stations, while Perth had more frequent (63%) occasions of the same

TABLE 3. Percentage of the same and opposite sign of the pressure anomalies of April from 1891–1979 at three other stations with respect to Jakarta and Santiago.

Jakarta			Santiago		
Station	Same sign	Opposite sign	Station	Same sign	Opposite sign
Bombay	83	17	Bombay	39	61
Perth	45	55	Perth	63	37
Santiago	36	64	Jakarta	36	64

sign with respect to Santiago than at other stations. This led us to make the following combinations of the stations in the Pressure Index.

As used here Pressure Index is the difference between the sum of April standardized pressure anomalies of Santiago (ΔS) and Perth (ΔP), and the sum of pressure anomalies of Jakarta (ΔJ) and Bombay (ΔB), i.e.,

$$\text{Pressure Index (PI)} = (\Delta S + \Delta P) - (\Delta J + \Delta B). \quad (2)$$

The PI is dimensionless, since standardized pressure anomalies have been used in the PI definition. The PI, which can be regarded as a measure of the Southern Oscillation, represents a circulation index and thus has physical significance to the circulation involved over the Indo-Pacific region. Positive (negative) values of Pressure Index signify strengthening (weakening) of the related southeast trade wind circulation over the Indo-Pacific region. The Pressure Index series from 1891–1979 is presented in the upper diagram of Fig. 2. The PI series has a standard deviation of about 2 and the index values generally range from −4 to +4. The PI series shows an oscillatory feature with a period of about 3–5 years.

5. Spectrum analysis of DAI, FAI and PI series

For time series of rapidly fluctuating elements, power spectrum analysis has become a generally accepted technique to separate signal from noise. In recent years this tool has found wide application for the study of periodicities in the fluctuations of meteorological elements. The computational procedure used in this study for power spectra is that due to Blackman and Tukey (1958) as given in the WMO Technical Note *Climatic Change* by Mitchell *et al.* (1966). Power spectrum analysis was applied to the DAI, FAI and PI series for the period 1891–1979 to find out significant periodicities, if any. The maximum lag in the analysis was set at 22 years and the spectra contain 7.6 degrees of freedom. Power spectra of the DAI, FAI and PI series are shown in Fig. 3. The associated 95 and 90% confidence limits, based on the appropriate null continuum and computed following Mitchell *et al.* (1966), are shown with each spectrum plot. The following are some of the salient features revealed by the spectrum analysis.

a. The DAI spectrum

The power spectrum for the DAI series (Fig. 3a) is characteristic of white noise, since the lag 1 autocorrelation coefficient of −0.117 is not significant at the 95% significance level (Mitchell *et al.*, 1966, p. 60). Especially noticable in this spectrum is an accumulation of spectral power in what are essentially wavelength bands between 2.5 and 3.5 years. The spectral peak at the 16th harmonic corresponding to a period of about 2.7 years is significant at the 90% confidence level. A similar periodicity was reported in monsoon circulation features such as monsoon depressions and monsoon rainfall (Koteswaram and

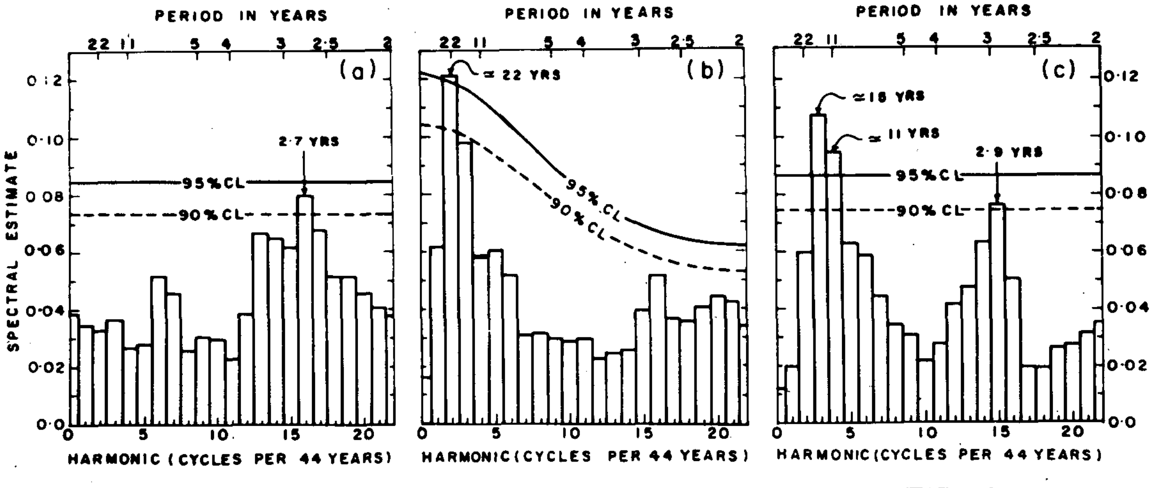

FIG. 3. Power spectra of (a) Drought Area Index (DAI), (b) Flood Area Index (FAI) and (c) Pressure Index (PI) series for the period 1891–1979.

Alvi, 1969; Bhalme, 1972; Jagannathan and Bhalme, 1973; Bhalme and Mooley, 1980; and many others). While the time scale of this period is compatible with that of the Southern Oscillation (e.g., Julian and Chervin, 1978), a cross-spectrum analysis should be required to establish an association. This aspect is investigated further in the subsequent section.

b. The FAI spectrum

The spectrum for the FAI series (Fig. 3b) is characteristic of red noise and the time series contains persistence of the Markov linear type, since the lag 1 autocorrelation coefficient r_1 of the series is significant at the 95% significance level (Mitchell *et al.*, 1966, p. 60). The spectral peaks in the period range of about 2.5–3.0 years are also detectable in the FAI spectrum but none of these peaks are statistically significant. In the lower frequency end, the spectrum reveals a well-defined concentration of power centered at a period of about 22 years, significant at 95% level.

c. The PI spectrum

The power spectrum of the PI series is characteristic of white noise processes (Fig. 3c). In the high-frequency end, the spectrum shows a pronounced peak corresponding to a period in the range of about 2.8–3.0 years, significant at the 90% level. The power spectra for both the PI and DAI fluctuations show oscillations close to 3 years in the high-frequency end of respective spectrum. This period is almost identical with the mean period of the Southern Oscillation. Troup (1965) has used Darwin pressure as an index of the Southern Oscillation and noticed 3- and 5-year cycles in separate 40-year periods. Trenberth (1976) and Wright (1977) found that the Southern Oscillation fluctuates mainly in the range of 3–6 years. Wang and Zhao (1981) examined the spectrum of a Southern Oscillation index and reported a significant cycle of about 3 years. The Southern Oscillation peak in the PI spectrum is separated by something like a spectral gap from two adjacent significant peaks which demonstrate the fluctuations with a period of about 9.8–17.6 years.

6. Relationships between PI and variables DAI/FAI

In order to determine whether PI and DAI/FAI series are related to each other and to find the character of the relationship, linear correlation coefficients were calculated. The correlation coefficient between the PI and DAI series for the period 1891–1979 is −0.279. It is quite clear from the spectra of PI and DAI series (Fig. 3) that they are characteristic of white noise processes, i.e., each point of data can be regarded as statistically independent of the others. Therefore, no corrections need be applied to the length of the data while assessing the significance level of the correlation coefficients. The correlation coefficient necessary for a 99% significance level for N(89 years) independent observations, i.e., for 87 degrees of freedom, is ±0.272. Therefore, the correlation coefficient of −0.279 between the PI and DAI series for the period 1891–1979, i.e., for the total number of 89 pairs of data, is significant at the 99% significance level. This implies that large negative PI value, signifying weakening of the southeast trades, tends to coincide with a large DAI value, meaning a large area affected by drought during the subsequent monsoon season and vice versa.

The correlation coefficient between PI and FAI series for the period 1891–1979 is 0.289. However, the spectrum for the FAI series is characteristic of red noise (Fig. 3b), i.e., each value of the series is influenced by its preceding value. It is then necessary to make adjustment for the effective length of the time series for the autoregressive nature in the series when evaluating the level of significance of correlation coefficient between the PI and FAI series. A method explained by Quenouille (1952, p. 168) has been adopted for estimating the effective length of the data series to account for an autoregressive nature of the series. The effective length N_e of the data series is $N_e = N/\tau$. The parameter τ is given by

$$\tau = (1 + 2r_1r'_1 + 2r_2r'_2 + 2r_3r'_3 + \cdots), \qquad (3)$$

where $r_1, r_2, r_3, \cdots$ and $r'_1, r'_2, r'_3, \cdots$ are the autocorrelation coefficients at different lags in the two series. The summation was carried out to the lag number at which autocorrelation products became negligible. Table 4 shows the autocorrelation coefficients up to lag 6 for the FAI and PI series. By Eq. (3) we have τ equal to 1.0992. Therefore, the effective length, $N_e = N/\tau = 89/1.0992 \approx 81$. The correlation coefficient necessary for a 99% significance level for 81 independent observations is ±0.284. Therefore, the correlation coefficient of 0.289 between the PI and FAI series for the period 1891–1979 is significant at the 99% significance level. This implies that a large positive value of PI implying strengthening of the southeast trades tends to be followed by greater FAI value, i.e., a large area affected by flood during the subsequent monsoon season and vice versa.

TABLE 4. Autocorrelation coefficients at different lags for FAI and PI series.

	Autocorrelation coefficients at different lags					
Series	r_1	r_2	r_3	r_4	r_5	r_6
FAI	0.165	0.206	0.048	−0.047	−0.053	−0.073
PI	0.132	0.010	0.047	−0.157	−0.269	−0.026

a. The PI magnitude and large-scale droughts/floods

Fig. 2 shows the apparent inverse relationship between the PI and DAI series. The large PI value $\leqslant -1.5$ is followed by some of the large-scale drought years experienced by India, 1891, 1899, 1905, 1915, 1918, 1951, 1966, 1972 and 1979. However, some of the large-scale drought years, *viz.*, 1896, 1911, 1920, 1941, 1965 and 1974 were not preceded by the above threshold PI magnitude. Fig. 2 also shows the apparent positive correlation between the PI and FAI series. The large PI $\geqslant 1.5$ is followed by some of the large-scale flood years that the country experienced, 1892, 1893, 1894, 1916, 1917, 1936, 1938, 1956, 1959, 1961 and 1975. However, the large-scale flood years of 1933, 1942 and 1978 were not preceded by the threshold PI magnitude. The atmosphere is extremely complex, and it would not be expected that the PI, i.e., the Southern Oscillation, could account for most of the DAI/FAI variability. Nevertheless, the Southern Oscillation seems to play an appreciable and occasionally dominant part. There are other factors that remain to be found.

b. Coherence spectra between PI and DAI/FAI

In order to determine whether the relationship noticed between the PI and DAI/FAI series is due to a correlation between high-frequency or low-frequency components, coherence spectra were further examined for the same period of record 1891–1979. The relationship between the PI and DAI is shown in Fig. 4a. It shows pronounced peaks of coherence for fluctuations corresponding to periods of about 3.1, 4.0 and 6.2 years. The maximum coherence falls over a period of about 3 years, significant at the 90% significance level. Trenberth (1976) determined that cross-spectrum analysis between pressures at Darwin and those at stations in the South Pacific revealed an out-of-phase relationship with maximum coherence mainly from 3–6 years. A cross-spectrum analysis between pressures at Darwin and Santiago computed by Julian and Chervin (1978) shows out-of-phase relationship with maximum coherence over a period range of about 2.8–3.5 years. This fact emphasizes what many researchers have pointed out, that the Southern Oscillation operates primarily on time scale of 3–6 years. The results suggest that significant correlation between the PI and DAI is mostly due to oscillations in the range of 3–6 years. Furthermore, the analysis also suggests that the ~3 year oscillation in climatic element such as DAI arises primarily from the Southern Oscillation. The Southern Oscillation appears to be one possible causal climatic feature for introducing an approximate 3-year oscillation in monsoon rainfall, monsoon circulation features and in many climatic parameters over India reported by several workers (Koteswaram and Alvi, 1969; Bhalme, 1972; Jagannathan and Bhalme, 1973; Mooley, 1975; Joseph, 1976). It is of interest to note that the most common period of recurrence of droughts over India is also in the range of 3–6 years (see Table 2). The analysis suggests that the principal cause of recurrence of large-scale droughts over India in the 3–6 year period may possibly be due to the influence of the Southern Oscillation on the monsoon.

Fig. 4b shows the coherence spectrum between PI and FAI. The coherence peaks at periods 2, 2.3, 4 and 22 years are also detectable but these peaks are far from statistically significant. This means that PI and FAI do not show significant coherence for these periods of fluctuations. However, recent work by

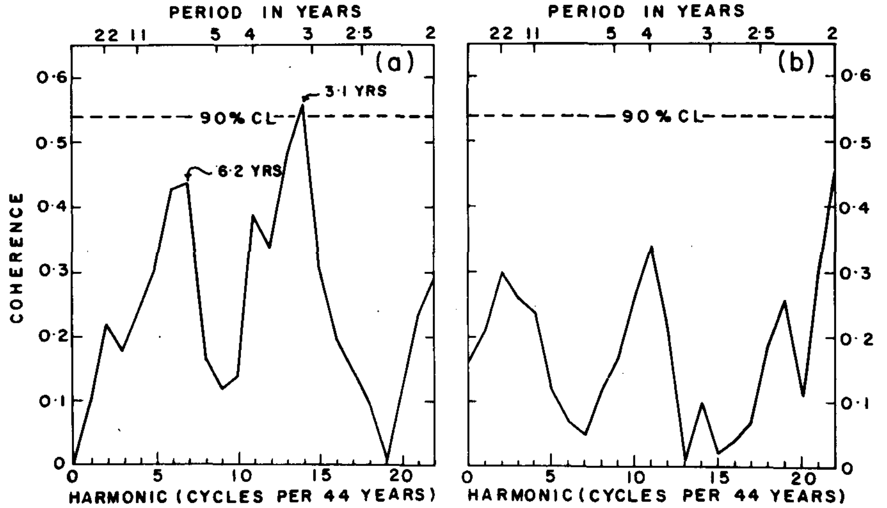

FIG. 4. Coherence spectrum between the Pressure Index (PI) and (a) Drought Area Index (DAI) and (b) Flood Area Index (FAI) series for the period 1891–1979.

Bhalme and Mooley (1981) produced convincing evidence of a 22-year cycle in FAI and they found that the flood area cycle over India is significantly related to the double (Hale) sunspot cycle.

7. Summary and conclusions

The fluctuations of the large-scale April Pressure Index of the Southern Oscillation covering a period of 89 years (1891–1979) and its relation to the Drought Area Index and Flood Area Index over India during subsequent monsoon season (June–September) have been examined. The study suggests the following:

1) There is a significant inverse relationship between the PI and DAI series. This implies that large negative PI value, signifying weakening of the southeast trades, is associated with a large DAI value, meaning large area affected by drought during subsequent monsoon and vice versa. The PI and FAI are significantly positively correlated. This implies that a large positive value of PI, signifying strengthening of the southeast trades is associated with a large value of FAI, meaning large area affected by flood during subsequent monsoon and vice versa. The Southern Oscillation seems to play an important part in the variations of areal extent of droughts/floods during the monsoon season.

2) There is a good agreement between the years of large-scale droughts (floods) and large negative (positive) PI. However, there are some years of large-scale drought/flood unexplained by PI. The prediction of such extreme climatic events as large-scale droughts/floods over India from PI, i.e., an index of the Southern Oscillation, alone shows limited skill. The atmosphere is extremely complex, and it would not be expected that the Southern Oscillation could account for most of the DAI/FAI variability. Nevertheless, the Southern Oscillation seems to play an appreciable and occasionally a dominant role. There are other factors that remain to be found.

3) The spectrum and cross-spectrum analysis of the PI and DAI series suggest that significant correlation between the PI and DAI is mostly due to oscillations in the range 3–6 years. The maximum coherence falls over a period of about 3 years. The Southern Oscillation appears to be one possible causal climatic feature for introducing a 3-year oscillation in climatic element such as DAI over India. The PI and FAI series do not show any coherence for the significant period of fluctuations.

4) The influence of the Southern Oscillation on the monsoon appears to be one possible causal climatic phenomenon for introducing a most common period anything from 3 to 6 years for the recurrence of large-scale droughts over India.

5) The Southern Oscillation is a manifestation of the general tendency of the atmosphere/ocean system to vary on the time scale of 2–6 years. Study of how this oscillation interacts with other parts of the atmosphere/ocean system is important in the context of understanding oscillations of the atmosphere/ocean system which produce variations in climatic parameters with periods of anything from 2–6 years. It is hoped that the current World Climatic Research Programme (WCRP) may throw new light on this problem and lead to a better understanding of the physical processes responsible for climatic fluctuations of this kind and ultimately to produce better predictions.

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