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Large-scale April pressure index connected with the southern oscillation and its potential for prediction of large-scale droughts over India

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सार—अप्रैल के बड़े पैमाने पर दाबसूचकांक (पी. आई.) का दक्षिणी दोलन के एक माप के रूप में स्वीकार करके उसे जकार्ता, बम्बई, सैंटियागो एवं पर्थ के पृष्ठीय दाबों को संयुक्त करके ज्ञात किया गया है। 89 वर्षों (1891-1979) की अवधि क दाब सूचकांकों के उतार-चढ़ावों और उनके आगामी मानसून ऋतु के दौरान भारत में सूखे के क्षेत्रीय विस्तार से संबंधों की स्पैक्ट्रम एवं क्रास स्पक्ट्रम विश्लषण से जांच की गई है। सूखे का क्षेत्रीय विस्तार दाब सूचकांक से सार्थक ढंग से ऋणात्मक सहसंबंध रखता है इसका तात्पर्य यह है कि अप्रैल में ऋणात्मक दाब सूचकांक की अधिकता हिन्द एवं प्रशांत महासागर क्षेत्र में दक्षिणपूर्व की व्यापारिक पवनों की दुर्बलता दर्शाती है। यह परवर्ती मानसून ऋतु के दौरान सूखे के बड़े पैमाने पर क्षेत्रीय विस्तार से मेल खाता है और विपरीत स्थितियों में उल्टा होता है। सूखे का विस्तार एवं दाब सूचकांक का सार्थक सहसंबंध अधिकांशतः 3 से 6 वर्ष की अवधि में होने वाले दोलनों के कारण होता है। इसके अतिरिक्त सूखे क्षेत्रीय विस्तार में लगभग 3 वर्ष के दोलन मूलतः दक्षिणी दोलन के कारण उत्पन्न होते हैं। दक्षिणी दोलन ही संभवत : वह जलवायु विषयक कारण हैं, जिससे आमतौर पर 3 से 6 वर्ष की अवधि के बाद में बड़े पैमाने पर सूखों की पुनरावृत्ति होती रहती है।

ABSTRACT. The large-scale April pressure index (PI), which can be regarded as a measure of the southern oscillation, has been devised with the combination of surface pressures at Jakarta, Bombay, Santiago and Perth. The fluctuations of PI covering a period of 89 years (1891-1979) and its relation to the areal extent of droughts over India during the following monsoon season have been examined by spectral and cross-spectral analysis. The areal extent of drought is significantly negatively correlated with the PI. This implies that the large negative PI during April, signifying weakening of the southeast trades over the Indo-Pacific region, coincides with large areal extent of drought during the following monsoon season and *vice versa*. The significant correlation between the areal extent of drought and PI is mostly due to the oscillations in the range of 3 to 6 years. Furthermore, $\sim$ 3 year oscillation in the areal extent of drought arises primarily due to the influence of the southern oscillation. The southern oscillation appears to be one possible causal climatic phenomenon for introduction a common period anything from 3 to 6 years for the recurrence of large-scale droughts over India.

1. Introduction

The most common natural cause of Indian famine is large-scale drought. Large-scale droughts have a devastating effect on food production and the whole economy of the country. So a prediction of the occurrence of large-scale drought as much ahead as possible is of considerable practical value for wide range of interests, especially for agriculture, hydro-electric power production and the government.

Walker (1923) realised the complexity of the problem of forecasting monsoon rainfall and made worldwide survey of correlation coefficients connecting monsoon rainfall and antecedent meteorological parameters in various parts of the globe with the objective of improvement of the monsoon forecast. 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 fields — the southern oscillation. The southern oscillation is a large-scale fluctuations 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 exchange of air 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 fluctuations in the intensity of the southern oscillation have an irregular period between 2 & 6 years, but most common $\sim$2.5 years (Wright 1975; Trenberth 1976). Various workers in the field have used different combinations of stations to compute an index for the southern oscillation (Walker 1924; Barlage 1957; Troup 1965; Trenberth 1976). The discovery of the southern oscillation led Walker to believe that a future search may well reveal factors which have close association with monsoon,

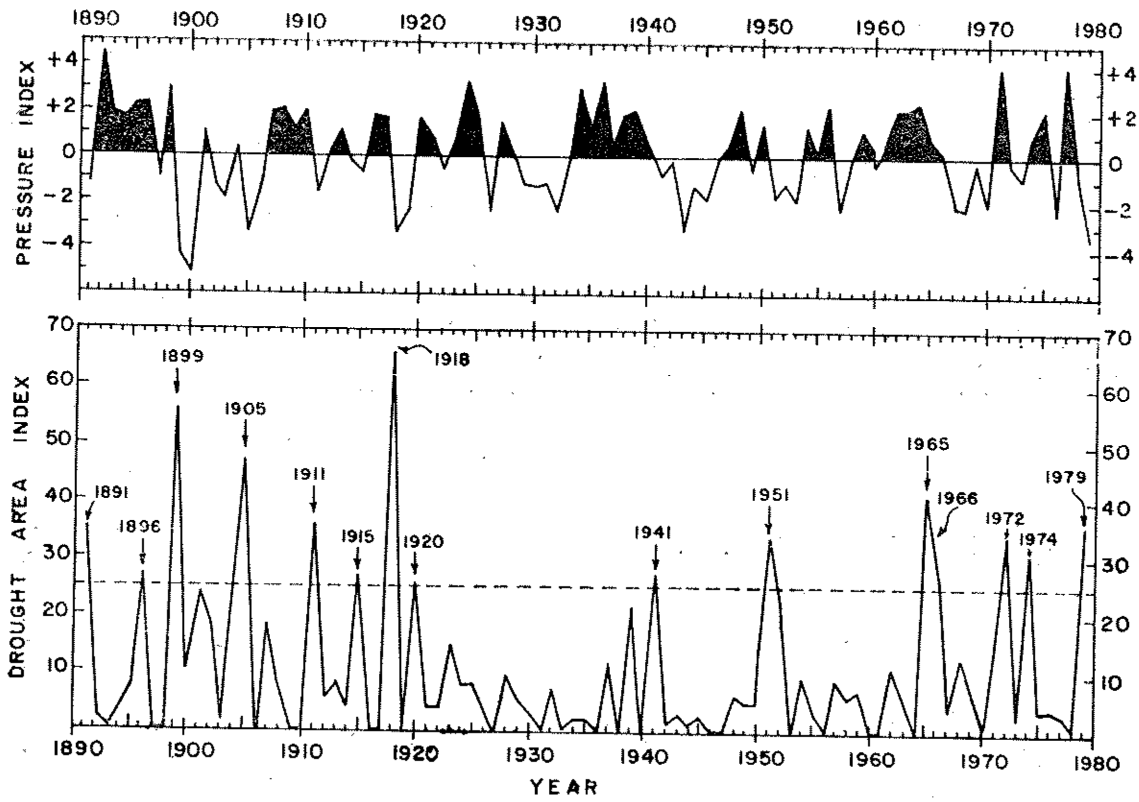

Fig. 1. Lower : Drought Area Index (DAI) series from 1891 to 1979 with identified large-scale droughts. Upper : April Pressure Index (PI) series from 1891 to 1979

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 over India, the pressure index associated with the southern oscillation has been devised. In this paper we report on the relationship between the pressure index and the variation of area affected by drought called Drought Area Index, over India.

2. 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 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 k^{th} and $(k\text{-}1)^{th}$ month and 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 in space and time. The monthly index values generally range from —4 to + 4. The character of the weather associated with the numerical index values are : —4 for extreme drought, —3 for severe drought, —2 for moderate drought, — 1 for mild drought, + 1 for mild flood, + 2 for moderate flood, + 3 for severe flood, and + 4 for extreme flood.

The drought index Eqn. (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 sub-divisions of India except for the two divisions of Bay islands and Arabian Sea islands. For a given year, to begin the sequence of I's generated by Eqn. (1), I_{k-1} was set 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. Furthermore, from these monthly indices the mean index for the four monsoon months, called the mean monsoon index was calculated for each of the years and for each of the sub-divisions. The drought area index (DAI) of a year is the percentage area of India with a mean monsoon index of drought

TABLE 1

Large-scale drought/flood years over India from 1891-1979

S. No.	Large-scale droughts: Year	Interval between droughts (years)	Area affected (per cent)	Ranking	S. No.	Large-scale floods: Year	Interval between floods (years)	Area affected (per cent)	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					

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).

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 $\geqslant 25$ for drought intensity $\leqslant -2$ (moderate drought or worse) is defined as a large-scale drought year and a year with FAI $\geqslant 25$ 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 1. The years of large-scale drought/flood identified have been supported by independent information from different sources (Bhalme and Mooley 1980). Fig. 1 shows the DAI series with identified large-scale drought years. An examination of Fig. 1 for the DAI series reveals that 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 only considered.

3. 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 the globe. His original interest in the southern oscillation was to predict monsoon rainfall. Walker (1933) 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 nature of the southern oscillation suggested us to consider the contribution from different cores of the southern oscillation. The stations chosen in the Indo-Pacific region for our study are Jakarta (06 deg. 11′ S, 106 deg. 51′ E), Bombay (18 deg 54′N, 72 deg. 49′ E), Santiago (33 deg. 27′ S, 70 deg. 42′ W) and Perth (31 deg. 57′S, 115 deg. 49′ E). We used the surface pressure anomalies of April, a middle month of pre-monsoon season, for these stations. The pressure anomalies were calculated relative to 30-year normal. 1901-1930 normal for the period 1891-1930 and 1931-1960 normal for rest of the period to facilitate the elimination of long-term changes. Sources of pressure data were *World Weather Records* and *Monthly Climatological Data for the World.*

Pressure index used here is the difference between the sum of April pressure anomalies of Santiago ($\triangle S$) mb, Perth ($\triangle P$) mb, and the sum of pressure anomalies of Jakarta ($\triangle J$) mb, Bombay ($\triangle B$) mb, *i.e.*,

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

Pressure index represents a circulation index and thereby has physical significance to the circulation involved over the Indo-Pacific region. Pressure index positive (negative) signifies strengthening (weakening) of the related atmospheric circulation over the Indo-Pacific region. The Pressure Index series from 1891-1979 is presented in the upper diagram of Fig. 1. The Pressure Index series has a standard deviation of 2 mb and the index values generally range from -4 to $+4$. The Pressure Index series shows an oscillatory feature with a period of about 3 to 4 years.

4. Cycles in DAI/PI

Power spectrum analysis was applied to the DAI 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. The computational procedure is the same as outlined in technical note on *Climate Change* (WMO 1966). The power spectra for the DAI and PI series are shown in Fig. 2. The power spectrum for the DAI series shows quasi-periodicity of about 2.5-3.5 years with significant (90% C.L.) peak at 2.7 years. A similar periodicity was reported in monsoon circulation features such as monsoon depressions, and monsoon rainfall (Koteswaram and Alvi 1969; Bhalme 1972; Jagannathan and Bhalme 1973).

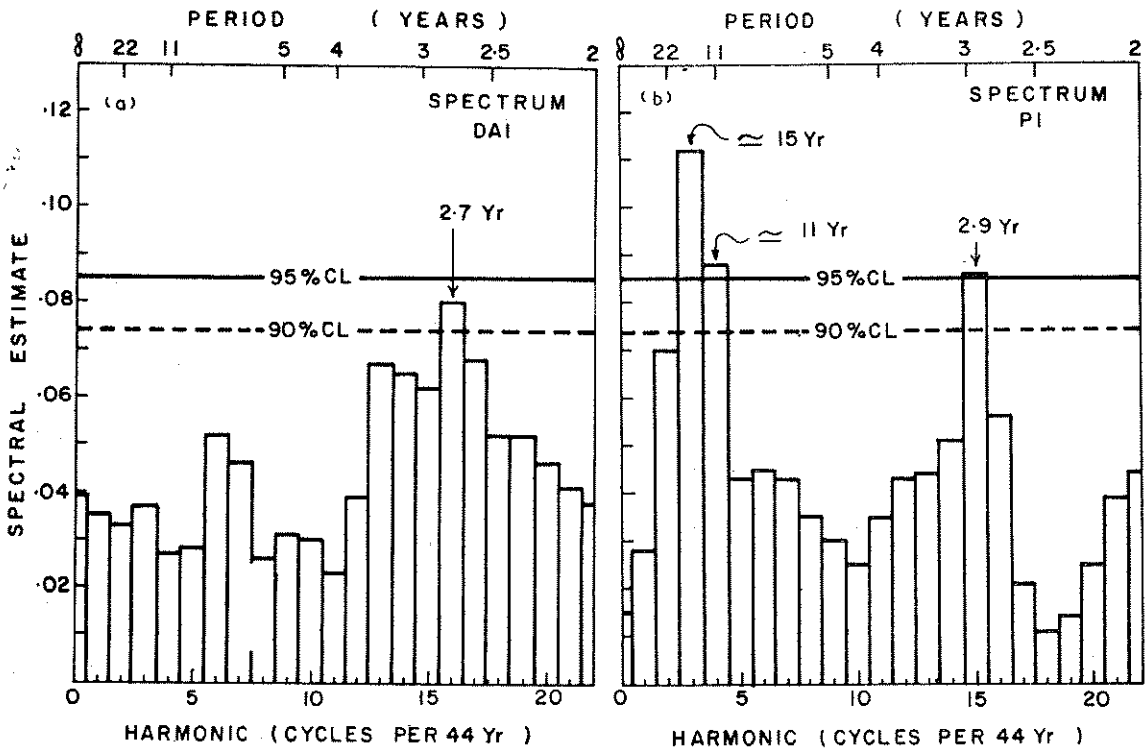

Fig. 2. Power spectra of DAI and PI for the period 1891-1979

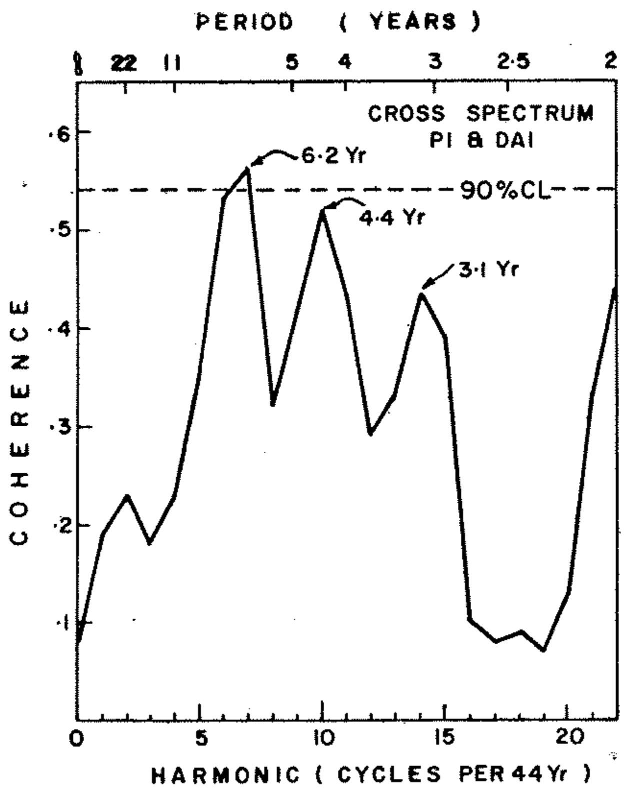

Fig. 3. Coherence spectrum between the PI and the DAI for the period 1891-1979

TABLE 2

Correlation coefficients between DAI and PI

	Decades								
	1891 to 1900	1901 to 1910	1911 to 1920	1921 to 1930	1931 to 1940	1941 to 1950	1951 to 1960	1961 to 1970	1970 to 1979
C.C.	—.55	—.44	—.62	.28	.00	.02	—.37	.11	—.12

C.C.=Correlation Coefficient

The power spectrum for the PI series reveals a significant (95% C.L.) peak at a period of about 2.9 yr. The power spectra both for DAI and PI fluctuations show ~ 3-yr rhythm in the high frequency end of the spectrum. This period is almost identical with the mean period of the southern oscillation. Troup (1965) has used the Darwin pressure as an index of the southern oscillation and noticed 3-yr and 5-yr periodicity in separate 40-yr. Trenberth (1976) found that the southern oscillation oscillates mainly in the range of 3-6 yr. In the low frequency end of the PI spectrum, the spectrum reveals significant (95% C.L.) peaks at periods of 11-yr (solar cycle) and 15-yr. In the absence of a definite physical mechanism connecting the solar fluctuations with the troposphere, the question whether the solar cycle has a traceable influence on weather/climate still remains open.

5. Relationships between DAI and PI

In order to determine whether DAI series(*i.e.*, area affected by drought during monsoon season) and PI series (*i.e.*, Pressure index of April) are related to each other and to find the character of the relationship linear correlation coefficient was calculated. There is significant (99% C.L.) negative correlation ($r=-0.31$ for $n=89$, 1891-1979) between the DAI and PI series. This implies that low PI value signifying weakening of the southeast trades coincides with large DAI value meaning greater area affected by drought during subsequent monsoon season and *vice versa*. The relationship between meteorological parameters often remains significant for some periods after which they change sign or cease to exist at certain unpredictable time. Therefore, to investigate the temporal changes in the relationships use was made of a short period correlation coefficient over a 10-yr period. Table 2 shows the correlation coefficient between DAI and PI for different decades.

Table 2 brings out the interesting fact that the period 1891-1920, which was also included in Walker's analysis of the southern oscillation, shows the highest negative correlation. There is decline in the relationship after 1920. Troup (1965) also noticed a minor secular change or fluctuations in the southern oscillation around 1920.

The significant inverse relationship between the DAI and PI (Pressure index of April) is suggestive of its potential for prediction of droughts. Fig. 1 shows the apparent inverse relationship between the DAI and PI series. The large negative PI value $\leqslant -1$ could predict some of the devastating large-scale droughts experienced by the country. These are : 1891, 1899, 1905, 1911, 1918, 1941, 1951, 1966 and 1979. Failure of the PI index to predict frequent droughts in a recent decade 1965-74 is noticeable. This could be attributed to the breakdown in the relationship. The patterns of the general circulation are expected to undergo considerable variations with time and hence the relationships between meteorological parameters could cease to exist at certain unpredictable time.

In order to determine whether the relationship noticed between the DAI and PI series is due to a correlation between high frequency components or low frequency components, coherence spectrum was further examined. The relationship between DAI and PI is shown in Fig. 3. It shows prominent peaks of coherence for fluctuations corresponding to 3.1, 4.4 and 6.2-yr periods. This fact emphasizes what Trenberth (1976) has pointed out that the southern oscillation operate mostly on time scale of 3 to 6 yr. The results suggest that the significant correlation between the DAI and PI is mainly due to oscillations in the range of 3 to 6 yrs and that the ~ 3-yr rhythm in DAI series arises due to the influence of the southern oscillation. It is of interest to note that the most common period of recurrence of drought over the country is also in the range of 3 to 6-yr period (*see* Table 1). The analyses suggest that the principal cause of recurrence of large-scale droughts over India in the range of 3 to 6-yr period with an average period of 4-yr may possibly be due to the influence of the southern oscillation on monsoon.

6. Concluding remarks

(1) In an exploratory attempt at prediction of large-scale droughts over India, April pressure index (PI) associated with the characteristics of the southern oscillation has been devised. The pressure index has been found to be significantly related to the area affected by droughts during monsoon over India, called drought area index (DAI). There is significant (99% C.L.) negative correlation ($r=-0.31$ for $n=89$, 1891-1979) between the DAI and PI series. This implies that low PI value signifying weakening of the southeast trades coincides with the large DAI value meaning greater area affected by drought during subsequent monsoon season and *vice versa*.

(2) The large drop in the PI with a lead time of one month could predict some of the devastating large-scale droughts experienced by the country. However, there is miserable failure to predict droughts in the recent decade 1965-1974. The last large-scale drought of 1979 that the country experienced could be predicted well. The relationship between meteorological parameters often remain statistically significant for some periods after which they change sign or cease to exist at certain unpredictable times because the patterns of the general circulation undergo considerable changes with time. Therefore, the relationship found

may be used as additional source of information for the prediction of large-scale droughts over India and not this alone as a predicting tool.

(3) Spectral and cross-spectral analysis of the DAI and PI series revealed a well-defined relationship. The significant correlation between the DAI and PI is mostly due to the oscillations in the range of 3 to 6 yr and the ~ 3-yr rhythm in the DAI series arises primarily due to the southern oscillation.

(4) The analysis suggest that the principal cause of recurrence of large-scale drought over India with most common period in the range of 3 to 6 yr (*see* Table 1) may possible be due to the influence of the southern oscillation on monsoon.

(5) It is hoped that the current World Climate Research Programme (WCRP) may throw new light on this problem and lead to a better understanding of the mechanism responsible for climatic fluctuations of this kind.

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