

## Cyclic Fluctuations in the Flood Area and Relationship with the Double (Hale) Sunspot Cycle

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### ABSTRACT

An objective numerical index has been used to obtain, on the dryness side, the family of Drought Area Indices (DAI) and on the wetness side, the family of Flood Area Indices (FAI) for India for the period 1891–1979. Three series of the DAI family are the percentage areas of India corresponding to mean monsoon index for a given year:  $\leq -1$  (mild drought or worse),  $\leq -2$  (moderate drought or worse), and  $\leq -3$  (severe drought or worse). Likewise, on the wetness side, three series of the FAI family are the percentage areas of India corresponding to mean monsoon index for a given year:  $\geq +1$  (mild flood or worse),  $\geq +2$  (moderate flood or worse), and  $\geq +3$  (severe flood or worse). Power spectrum analysis of the DAI series shows a high-frequency peak which is probably associated with the quasi-biennial oscillation. Spectrum and cross-spectrum analysis of the FAI series and sunspot numbers of the double (Hale) sunspot cycle reveal that a highly significant  $\sim 22$ -year cycle in the FAI is nearly in phase with the double sunspot cycle and that they are interrelated. Harmonic dial analysis shows that all of the large-scale flood events over India occurred consistently in the major sunspot cycle, suggesting an association of large-scale flood recurrence over India with the double sunspot cycle. The strong evidence of the relationship between areal extent of flood over India and the double sunspot cycle reported here shares in the kind of relationship reported for the western United States, but in the opposite sense of weather characteristics, i.e., for flood rather than drought.

### 1. Introduction

The possible relationships of sunspots with weather and climate were a subject of study soon after the discovery of the 11-year cycle in sunspots by Schwabe, a German astronomer, in 1843. The possibility that sunspots affect weather or climate and might be made a basis for long-range forecasting has been recognized for many years. Over the years many claims have been made of relationships between weather or climate and sunspots. Indications of an 11-year cycle have been found in several meteorological variables: temperature, precipitation, pressure and other parameters (Xanthakis, 1973; King, 1973; Jagannathan and Bhalme, 1973; Currie, 1974; Shapley *et al.*, 1975; Shapley and Kroehl, 1977; Bhalme *et al.*, 1979).

Evidence for a 22-year cycle, twice the period of the sunspot cycle, has also been found in several meteorological/climatic variables (Willett, 1965; Spar and Mayer, 1973; King, 1975; Roberts, 1975; Dicke, 1979). This 22-year cycle is supposed to arise as a result of the alternate changes in the polarity of the leading sunspots in a given solar hemisphere in successive 11-year cycles. Thus the true sunspot cycle is 22 years rather than 11 years when account is taken of the alternation of sign of spot magnetic fields. The 22-year quasi-cycle of sunspot activity is often termed the double sunspot cycle or the

Hale sunspot cycle. Recent work by Mitchell *et al.* (1979) produced convincing evidence of a 22-year cycle in an index of area affected by drought derived from tree ring data west of the Mississippi River in the United States. They found that the drought cycle is related to the double (Hale) sunspot cycle. The results do show that the risk of widespread drought west of the Mississippi River is appreciably higher in the years following a Hale sunspot minimum (i.e., sunspot minimum following a minor sunspot maximum) than it is at other times during the Hale cycle. Bhalme and Mooley (1980) have also found a sharply tuned double sunspot cycle in an objectively defined Flood Area Index over India.

In this paper we report on the possible relationship between the double sunspot cycle and the variation of the Flood Area Index (FAI) over India. We have used harmonic analysis, and power spectrum and cross-spectrum analysis to relate FAI series to the series of sunspot numbers of the double sunspot cycle.

### 2. Drought Area Index (DAI)/Flood Area Index (FAI)

Bhalme and Mooley (1980) developed an objective numerical drought index based on 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

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

where  $I_k$ ,  $I_{k-1}$  are drought intensities of the  $k$ th and  $(k - 1)$ th months 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  $R$  represents the monthly rainfall, with mean  $\bar{R}$  and standard deviation  $\sigma_R$ . 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  $+4$ . 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 equation (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 of 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 to zero. The monsoon season was chosen because 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 mean monsoon index, was calculated for each of the years and for each of the subdivisions. The mean monsoon index  $\bar{I}$  could be symbolized by setting  $I_{MAY} = 0$  to begin the sequence of  $I$ 's generated by Eq. (1); in this case we have

$$\bar{I} = [I_{JUN} + I_{JUL} + I_{AUG} + I_{SEP}]/4.0 = \frac{1}{48.55}[0.47M_{JUN} + 0.44M_{JUL} + 0.38M_{AUG} + 0.25M_{SEP}].$$

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

That is, the mean monsoon index is a weighted average of the rainfall anomalies of June–September. The Drought Area Index (DAI) of a year is the percentage area of India [areal extent (%)] with a mean monsoon index of a specified drought intensity category. Three members of the DAI family with different threshold values of a mean monsoon index were evaluated for each year. One of the DAI is the percentage area of India in which the mean monsoon index for a given year was  $\leq -1$  (mild drought or worse). The other DAI are the corresponding percentage areas of India with mean monsoon index  $\leq -2$  (moderate drought or worse), and  $\leq -3$  (severe drought or worse). Fig. 1 shows three members of DAI series with  $\leq -1$ ,  $\leq -2$  and  $\leq -3$  drought intensities for the period 1891–1979. Likewise, the Flood Area Index (FAI) is the percentage area of India [areal extent (%)] with a mean monsoon index for a given year of the specified flood intensity category. Three members of the FAI family are the corresponding percentage areas of India with mean monsoon index for a given year,  $\geq +1$  (mild flood or worse),  $\geq +2$  (moderate flood or worse), and  $\geq +3$  (severe flood or worse). The FAI series with  $\geq +1$ ,  $\geq +2$  and  $\geq +3$  flood intensities for the period 1891–1979 are shown in Fig. 2.

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  $\geq 25$  for drought intensity  $\leq -2$  (moderate drought or worse) is defined as a large-scale drought year and a year with FAI  $\geq 25$  for flood intensity  $\geq +2$  (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 in this study. Large-scale drought and flood years are indicated in Fig. 1b of DAI for drought intensity  $\leq -2$  and in Fig. 2b of FAI for flood intensity  $\geq +2$  respectively. The years of large-scale drought/flood identified have been supported by independent information from different sources (Bhalme and Mooley, 1980).

### 3. Cycles in DAI/FAI

Power spectrum analysis was applied to each of the members of the DAI and FAI series. The maximum lag in the analysis was set at 22 years. The computational procedure is the same as outlined in WMO Technical Note on *climatic change* (1966). The power spectra (not shown) for each of the three members of DAI series revealed a weak quasi-periodicity of 2.7–3.0 years significant at 90% confidence level (CL). A similar cycle was reported in monsoon circulation feature such as monsoon depressions, in the monsoon rainfall, in the area of

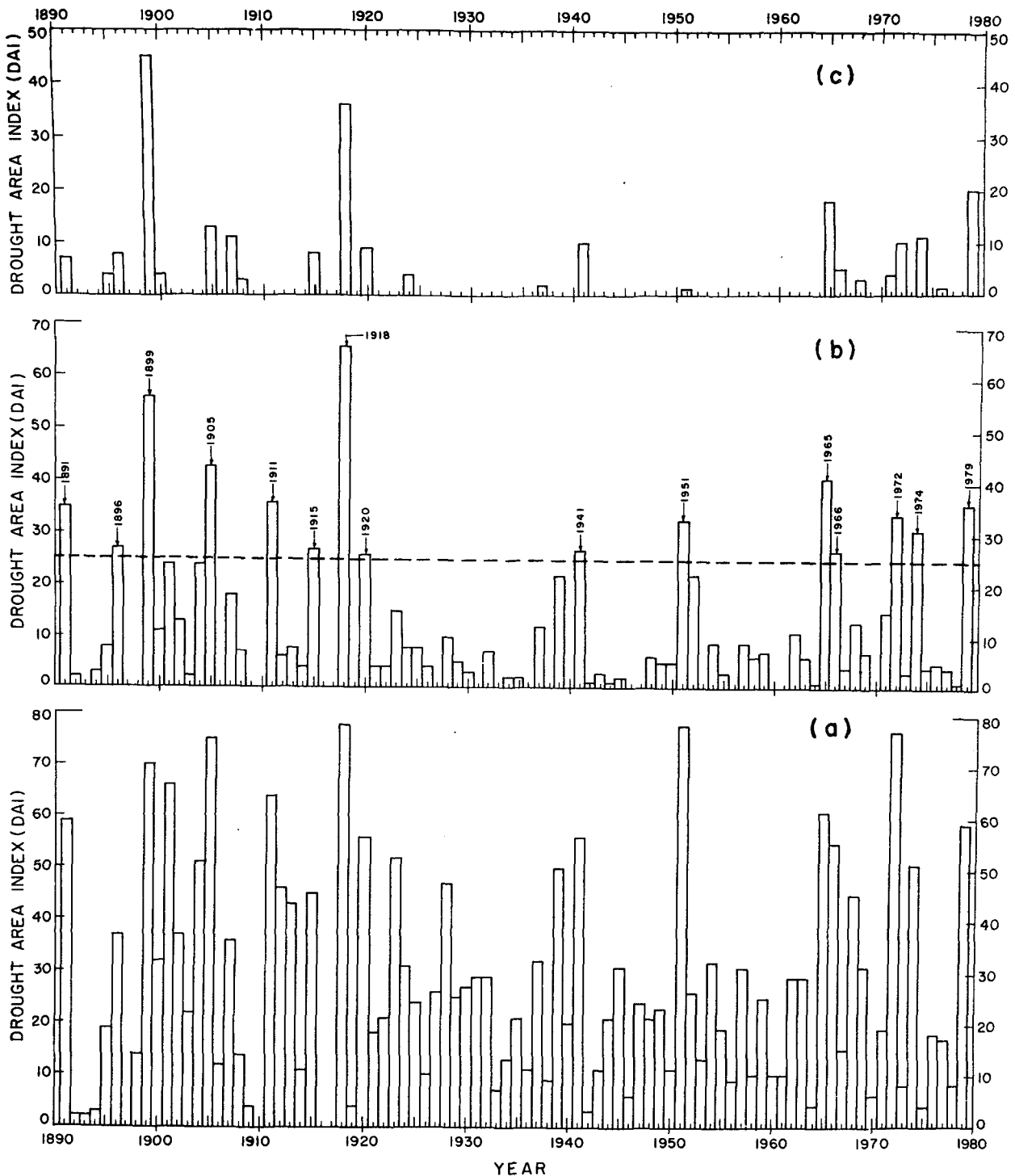


FIG. 1. Drought Area Index (DAI) series for three drought intensities from 1891–1979. (a) Series for drought intensity  $\leq -1$ , (b) series for drought intensity  $\leq -2$ , (c) series for drought intensity  $\leq -3$ . Large-scale drought years over India are indicated in (b).

India under deficient monsoon rainfall, and in the DAI series for drought intensity  $\leq -2$  (Bhalme, 1972; Jagannathan and Bhalme, 1973; Mooley, 1975; Joseph, 1976; Bhalme and Mooley, 1980).

The power spectra for each of the three members of the FAI series are shown in Fig. 3. The spectral peaks in the period range of 2.7–3.0 years are also detectable in these spectra but none of these peaks

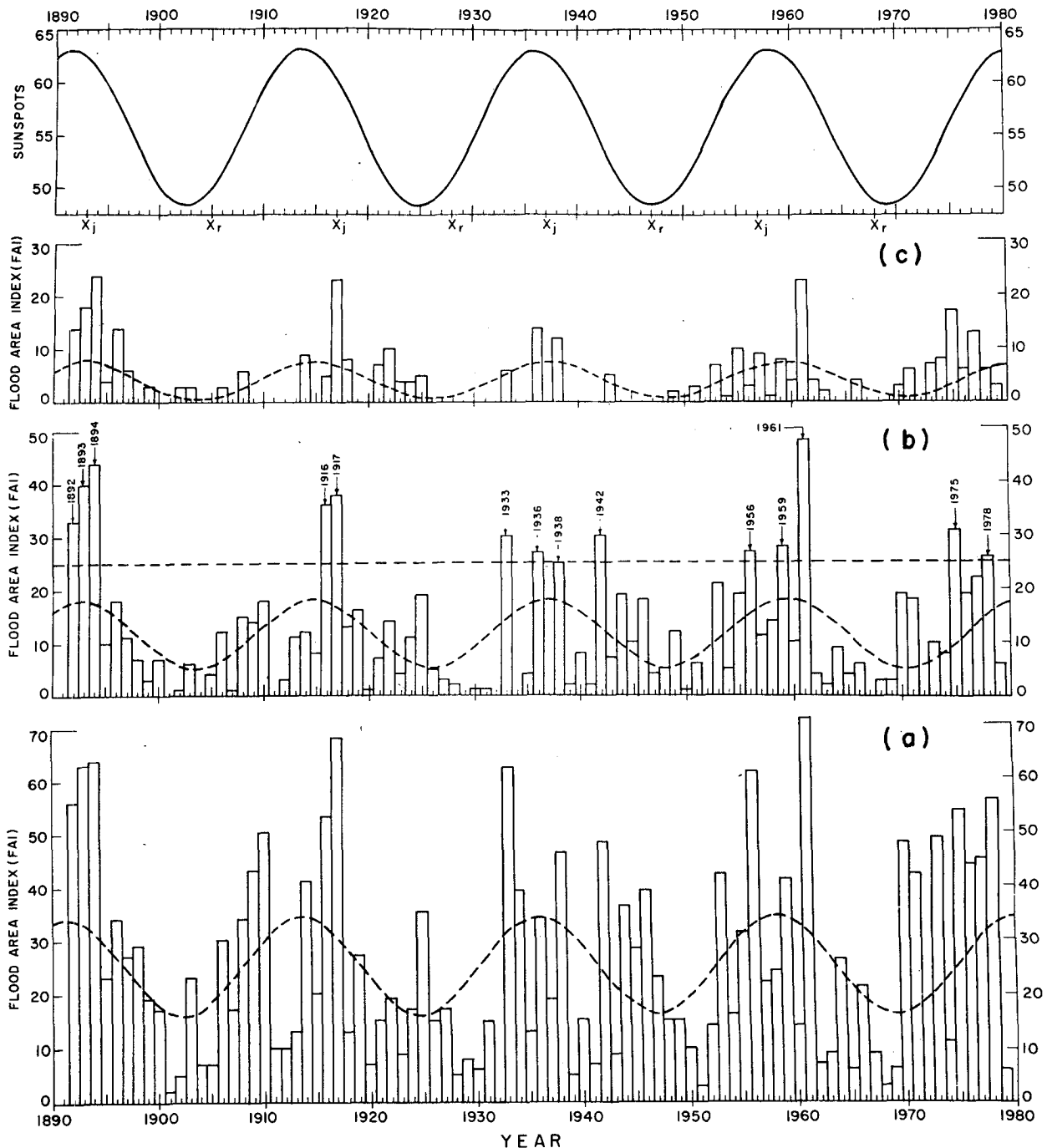


FIG. 2. Flood Area Index (FAI) series for three flood intensities from 1891-1979. (a) Series for flood intensity  $\geq +1$ , (b) series for flood intensity  $\geq +2$ , and (c) series for flood intensity  $\geq +3$ . Large-scale flood years over India indicated in (b). The years of major sunspot maximum ( $X_j$ ), the years of minor sunspot maximum ( $X_r$ ) and waves of 22-year period in the FAI series and in mean annual sunspots of the period 1891-1979.

are statistically significant. In the lower frequency end of the spectra, all of the FAI series spectra reveal a well-defined concentration of power at a period of  $\sim 22$  years, significant at 95% CL. Harmonic analysis of the same record of the FAI series also reveals a marked 22-year cycle explaining a

total variance of 12% for FAI with flood intensity  $\geq +1$  and  $\sim 16\%$  for other members of FAI (Fig. 4). Since the double sunspot cycle has been observed in several other atmospheric phenomena its existence in a climatic element such as FAI can be considered as probable. The 22-year periodicity detected may

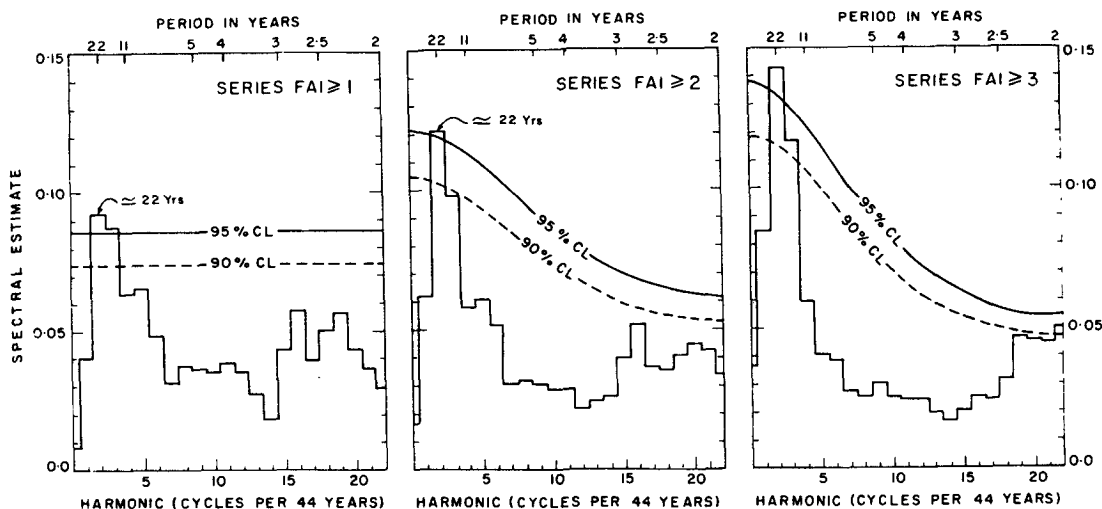


FIG. 3. Power spectra of the Flood Area Index (FAI) series for three flood intensities for the period 1891-1979.

well be related to the double sunspot cycle. Fig. 2 displays the years of major sunspot maximum ( $X_j$ ), the years of minor sunspot maximum ( $X_r$ ), and a wave of 22-year period in the annual sunspots number and in the FAI series. Fig. 2 clearly shows that the FAI series are in phase with the double sunspot cycle and that the large-scale floods have been frequent in the major maximum phase of the sunspot cycle. Note the absence of large-scale floods in the minor maximum phase of sunspot cycle.

**4. Harmonic dial analysis**

Further evidence of a relationship between the large-scale flood events over India and the phase of the double sunspot cycle is shown by harmonic dial analysis. Fig. 5 shows the harmonic dial for large-scale floods over India listed in Table 2. A year of large-scale flood is plotted as a solid circle on the harmonic dial for which one revolution represents one double sunspot cycle, variable in length, and at a distance from the origin of the dial proportional

to the magnitude of area affected by floods. Fig. 5 shows that all of the large-scale floods have tended to cluster on one-half of the dial and the other half of the dial is completely free of large-scale flood occurrences. Furthermore, the large-scale floods have occurred consistently in the major sunspot cycle. It also is notable that no large-scale floods occurred in the minor sunspot cycle. Harmonic dial analysis suggests association of large-scale flood recurrence over India with the double sunspot cycle. A similar harmonic dial (not shown) was prepared for large-scale drought events over India. The drought events are seen to scatter rather evenly over the dial which suggest that drought recurrence does not exhibit any coherence with the double sunspot cycle.

**5. Sunspots and FAI**

In order to investigate the relationship between sunspots and the observed 22-year periodicity in FAI it is advantageous to consider the transformed sun-

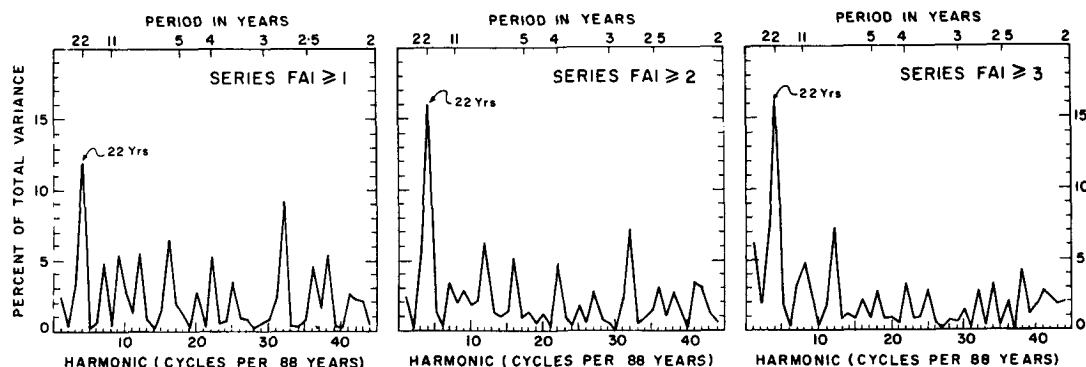


FIG. 4. Harmonic analysis of the Flood Area Index (FAI) series for three flood intensities for the period 1891-1979.

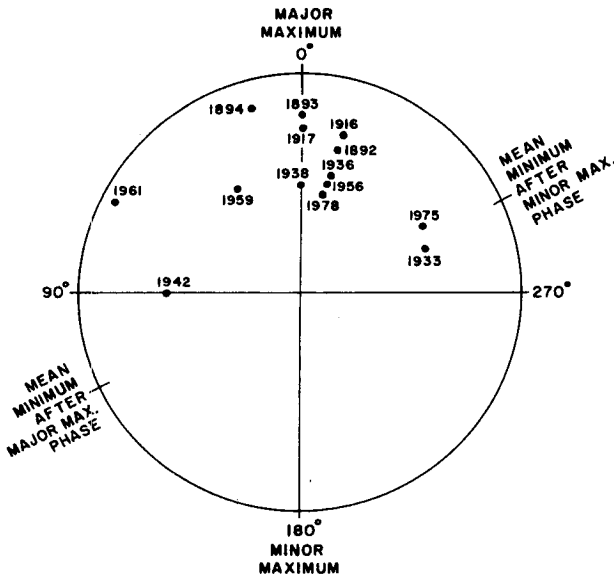


FIG. 5. Harmonic dial of large-scale flood events over India relative to the variable length period of the double sunspot cycle.

spot number obtained by changing the sign of the sunspot number for alternate cycles, since the series of annual sunspot numbers has essentially no peak in its power spectrum at 22 years (Bracewell, 1953; Sleeper, 1975). Fig. 6 shows the annual sunspot numbers for the period 1891–1979 with sunspot number plotted positive for alternate cycles starting with the first, and its power spectrum is shown in Fig. 7. The power spectrum for sunspots shows a highly significant periodicity of 22 years (Fig. 7). The power

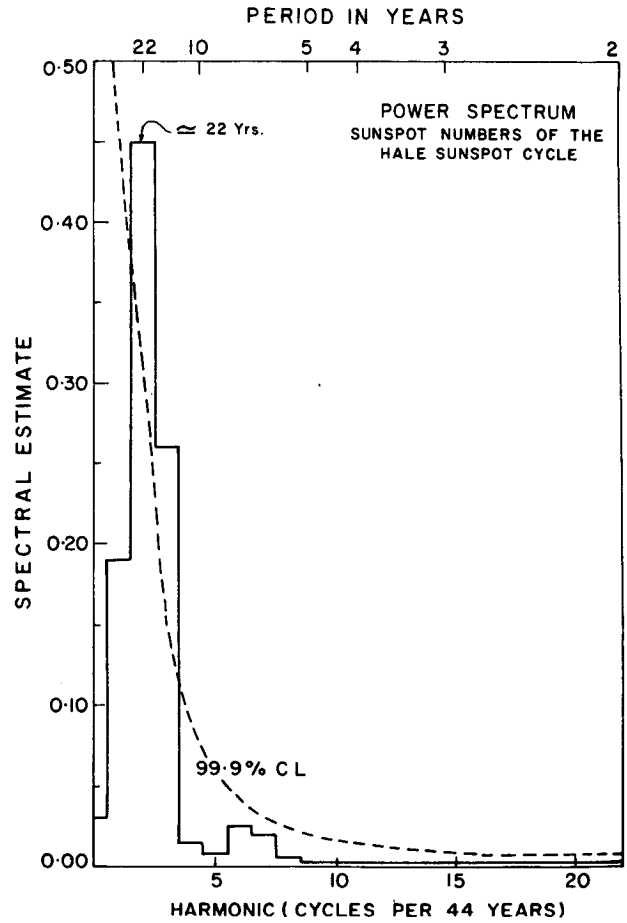


FIG. 7. Power spectrum of sunspot numbers of the double (Hale) sunspot cycle for the period 1891–1979.

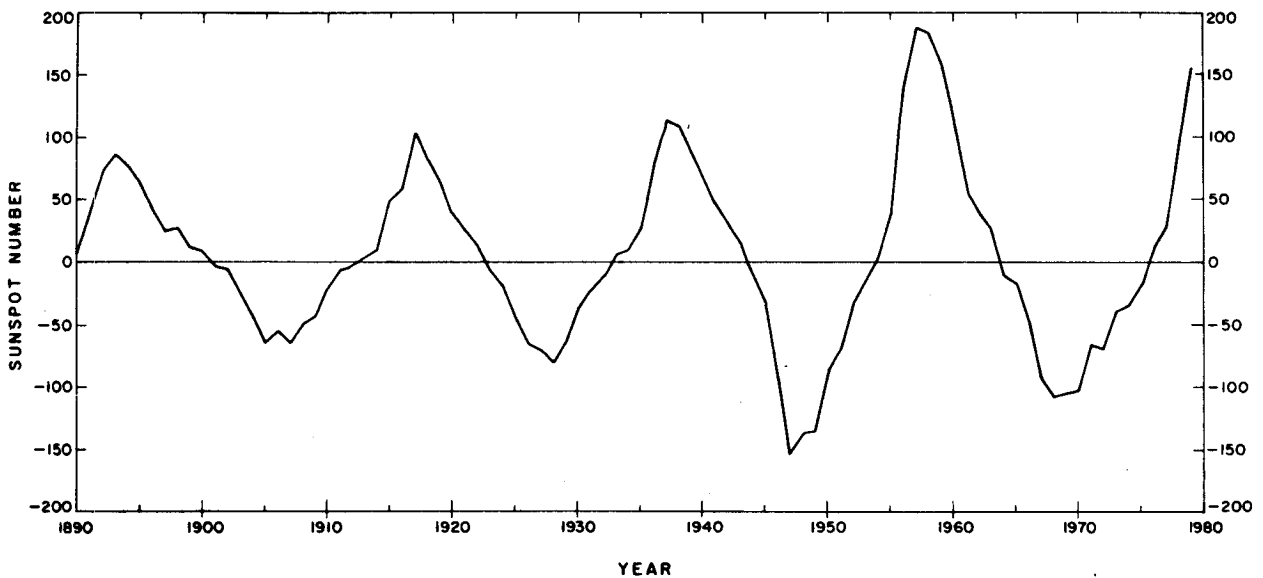


FIG. 6. Mean annual sunspot numbers of the double sunspot cycle obtained by changing the sign of the sunspot numbers for alternate cycle for the period 1891–1979.

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					

spectra both for sunspots and FAI show the coincidence of the strong 22-year peak. Coherence spectra between FAI and sunspots was further examined to test the quality of the relationship between these two variables for a 22-year period. The relationship in the FAI and sunspots is illustrated in a coherence graph in Fig. 8. It shows peaks with significant (at 95% CL) coherence for fluctuations corresponding to a 22-year period, suggesting that the relationship between FAI and sunspots arises from a low-frequency oscillation of about a 22-year period. A cross-phase analysis indicates further that fluctuations at this frequency tend to be nearly in phase. The results suggest that the 22-year cyclic change in FAI over India is related to the double (Hale) sunspot cycle.

6. Conclusions

The results of the present investigation lead to the following conclusions:

- 1) Power spectrum analysis reveals a highly significant ~22-year cycle in the Flood Area Index over India. Harmonic analysis of the same record also shows a well marked 22-year Flood Area Index cycle in phase with the double sunspot cycle. The Drought Area Index series shows a weak quasi-periodicity of 2.7–3.0 years.
- 2) Cross-spectrum analysis presents strong evidence to show that the ~22-year FAI cycle over India is related to the double (Hale) sunspot cycle. Furthermore, the 22-year FAI cycle is nearly in phase with the double sunspot cycle.
- 3) Harmonic dial analysis shows that all of the large-scale flood events over India occurred consistently in the major sunspot cycle and none occurred in the minor sunspot cycle. Large-scale drought events have no preference to the phase of the sunspot cycle.
- 4) The strong evidence of the relationship between the areal extent of the floods over India and

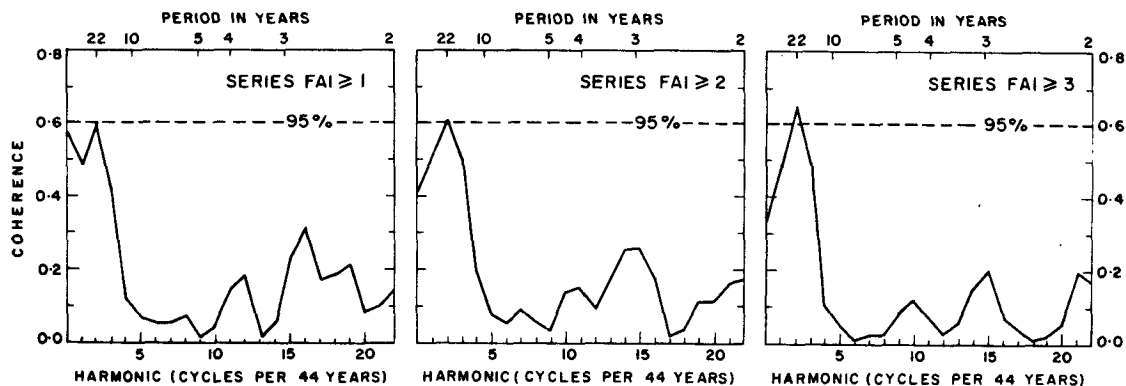


FIG. 8. Coherence spectrum between the sunspot numbers of the double (Hale) sunspot cycle and the FAI series for three flood intensities for the period 1891–1979.

the double sunspot cycle reported here shares in the kind of sun-climate relationship reported by Mitchell *et al.* (1979) for the western United States, but in the opposite sense of weather characteristics, that is, for flood rather than drought.

5) How the long-term solar activity related to solar magnetic effects, associated with the double sunspot cycle, influences terrestrial weather or climate is a major question to be answered. However, impressive evidence of the relationship between the regional flood area cycle and the double (Hale) sunspot cycle should stimulate greater interest in the search for a physical causal linkage in the problem of sun-weather/climate relationships.

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