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Long-period temperature changes in some Indian stations in relation to solar activity

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ABSTRACT. A search has been made for relationship between surface temperatures and solar activity as represented by sunspot number from monthly temperature data of several stations in India over a period of 67 years or more. Elimination of undesired periods from the series of temperatures followed by computation of autocorrelation function and autospectrums reveals that at stations in the interior Peninsula the temperatures have a tendency to exhibit variations with a period of about 130 months close to one solar activity cycle. It is significant that the long-period oscillation in temperatures is confined to the same region in which the present authors have shown a significant 27-day variation in the temperatures.

1. Introduction

The relationships between solar activity and meteorological phenomena have been investigated by many authors during the last 100 years or so. Most of the work prior to the first half of this century has been reviewed by Brooks (1951). Solar-climatic relationships have rarely been established with a high degree of statistical significance and, as appropriately described by Mitchell and Landsberg (1966), the relationshps are, at best, a weak signal coming through a strong meteorological 'noise'. Several studies of long-period (about 11-year) solar-cycle variation in temperatures have been made in recent years. In his study of mid-latitude temperatures Shaw (1965) noticed no connection between temperatures and sunspots. Earlier Landsberg *et al.* (1959) had, however, observed significant long-period variations in the temperatures at Wood-stock College, Maryland. Mitchell and Landsberg (1966) also noticed a small peak in the coherence spectrum of summer seasonal mean temperatures and sunspots at a period of about 11 years. Combining annual temperature deviations at more than 100 stations Callendar (1961) illustrated the fluctuations and trend in temperatures in many parts of the world and concluded that a solar or atmospheric dust hypothesis was necessary for explaining the world-wide fluctuations of a few years duration. Lawrence (1966) emphasised the importance of taking into account the seasonal, regional and solar-cycle differences in any investigation of solar-weather relationships.

In the course of an investigation of relatively short-period (27-day) association of maximum temperatures with sunspot number during a period of highly recurrent solar activity in 1946-47, Bhargava and Bansal (1969) showed that in the interior Peninsula of India a strong tendency for temperatures to be high existed one to two days following the maximum in sunspot number. In view of these results the temperature records of several more stations in the region were examined. The time correlations between the variations in the maximum temperatures and sunspot number were determined by a regression analysis. For a set of time lags from − 10 to + 60, correlation coefficients were computed from 350 days' temperature data and 280 days' sunspot number. Prior to this computation both the series were smoothed and seasonal trend was eliminated. The wavelengths in the data were restricted between 10 and 35 days with their amplitudes within 1 per cent and between 9 and 53 days with their amplitudes within 80 per cent. The correlation coefficients for two of the stations in the region, Raichur and Cuddapah, for the period 13 January to 19 Novembr 1947 are shown in Fig. 1. The correlation coefficients assume maximum positive and negative values at intervals of approximately 27 days. The maximum correlation coefficients at Raichur are 0·68, 0·52 and 0·43 corresponding to lags of 2, 29 and 55 days respectively and are, statistically, highly significant. The correlation coefficients for Cuddapah are of a similar order.

The close 27-day rlationships of temperatures with sunspot activity in this region therefore prompted an examination of long temperature records of some stations in the same region as well as at certain other stations for ascertaining the nature of a possible long-period association between temperatures and solar activity cycle.

TABLE 1

Stations	Lat. (°N)	Long. (°E)	Length of data
Madras	13°00′	80°11′	1875-1964
Cuddapah	14°29′	78°50′	1901-1967
Bellary	15°09′	76°51′	1901-1967
Kurnool	15°50′	78°04′	1901-1967
Hyderabad	17°27′	78°28′	1901-1967
Silchar	24°49′	92°48′	1878-1960
Sagar	23°51′	78°45′	1878-1960
Poona	18°32′	73°51′	1878-1960
Ludhiana	30°56′	75°52′	1878-1960
Darbhanga	26°10′	84°54′	1878-1960
Cuttack	20°48′	85°56′	1878-1960
Akola	20°42′	77°02′	1878-1960
Agra	27°10′	78°02′	1878-1960
Bikaner	28°00′	73°18′	1879-1960
Trivandrum	08°29′	76°57′	1890-1960
Veraval	20°54′	70°22′	1894-1960
Indore	22°43′	75°48′	1880-1960

2. Selection of stations

All stations whose data were available in the World Weather Records (1951-60) for 80 years or more, without break, were selected. Two stations, Trivandrum and Veraval whose data extended over 71 and 67 years were also considered. For Madras, Cuddapah, Bellary, Kurnool and Hyderabad, the data were obtained from the Climatology Division of the India Meteorological Department. All temperature data used for computation were the means of monthly average of daily maximum *plus* the monthly average of daily minimum temperature. The stations whose temperature data have been analysed together with their coordinates are listed in Table 1.

3. Treatment of data

In view of the annual cycle contributing predominently to the total variance in the series of monthly temperatures it is essential that this component is eliminated from the series. This can be done either by 'prewhitening' or by an application of a suitably designed filter to the data. The monthly temperature series, considered here, were subjected to a filtering process. After a series of computations of transfer functions of filters of different lengths it was noticed that the shortest filter which effectively removed wavelengths of 12 months and less was a low-pass zero phase shift symmetric filter of length 47 weights. The transfer function of this filter is shown in Fig. 2. The filter permits the transmission of wavelengths in excess of 23·8 months with original amplitudes within 2·4 per cent. With the response of the filter —0·01 at the frequency corresponding to the annual period, this cycle was effectively removed from the series. Monthly temperatures Y_t, free of seasonal variation, were computed from the temperature series X_t by the linear transformation

$$Y_t = \sum_{k=-n}^{n} W_k \, X_t + k$$

where W_k is the k^{th} weight of the filtering function and n is 23.

A plot of the temperatures so computed and sunspot number to which a similar filter had been applied showed no obvious correlation between the two. Some of the series showed a declining trend in the temperatures. Fluctuations of a few years duration were, however, noticed in all the filtered series. To ascertain the nature of these fluctuations and to detect long-period cyclic components the filtered series were subjected to autocorrelation and spectral analyses. The autocorrelograms were utilised for ascertaining the presence of periodic components of the order of one or half a solar-cycle since this is often not possible by spectral analysis. The resolution at the low frequency end of the spectrum is inadequate at wavelengths as long as 11 years unless the number of lags used is very large. This, however, requires data over proportionately larger intervals of time which are not always available. Trends and very low frequency components, if present in the data, contribute greatly to power density in the low frequency region of the spectrum and small peaks in power at large wavelengths, if present, are not observed. Reduction of trend by digital filtering or by least-square curve fitting followed by subtraction results in the reduction of long-period components of interest unless exceedingly large filters are applied. Application of large filters, however,, results in proportionately greater loss of data at both ends of the series.

4. Autocorrelation of mean monthly temperatures

Autocorrelation is one of the best known measures of persistence for a continuous variable and is uniquely successful for revealing unknown periodic components in a 'noisy' signal . The autocorrelation function $R(\tau)$ of a waveform $x(t)$ is defined as —

$$R(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{0}^{T} x(t) \, x(t+\tau) \, dt$$

The waveform $x(t)$ is multiplied by the same waveform delayed by lag τ and the product is averaged over the interval T. With digital data it is convenient to approximate this average by sampling the signal at interval $\triangle t$ and then summing a finite number N of the sample products,

$$R(\tau) = \frac{1}{N}\sum_{k=1}^{N} x(k\triangle t)\, x\,(k\triangle t+\tau)$$

$$\tau = 0, 1, \ldots, m$$

It is desirable that the maximum lag m does not exceed a moderate fraction (about 15 to 20 percent) of the length of the record.

Normalised autocorrelation functions of the monthly temperature series, computed upto 160 lags, are shown in Fig. 3. Consistent increases in the autocorrelation at the same lags are noticed in the autocorrelograms of the five stations. The temperatures correlate with themselves at lags ranging from 126 to 132 months, an interval close to a 11-year solar-cycle. An increase in the autocorrelation is also noticed at lags between 60 and 69 months, a period of the length of half a solar-cycle. Occurrence of increased correlations at the solar-cycle frequency and its first harmonic suggests that in this region the temperatures had a tendency to follow the solar activity cycles. The autocorrelograms of temperatures at stations outside this region are, however, complex. Except for Indore where a peak is noticed at a lag of length of half a solar-cycle the autocorrelations do not show an increase corresponding to 11 or 5½ years in the temperature data. Autocorrelograms of several stations contain peaks between 20 and 25 lags but the physical significance of these is not quite clear.

5. Spectrums of temperature series

The power density spectrum, which is a measure of the distribution of variance as a function of frequency, and autocorrelation function of a series form a Fourier transform pair. The computation of spectra here follows a procedure outlined by Blackman and Tukey (1958). Given N observations, autocovariances are computed with lag zero to a maximum lag m. The $(m+1)$ coefficients are subjected to a cosine transform which is smoothed by a three term moving average with weights 0·25, 0·5 and 0·25 yielding $(m+1)$ estimates of the spectrum. The spectrums of 17 temperature series, most of them of length in excess of 800 months, were computed after elimination of the 12-month and shorter wavelengths from the series. To ensure stability of estimates a maximum lag of 160 was used. The spectrums

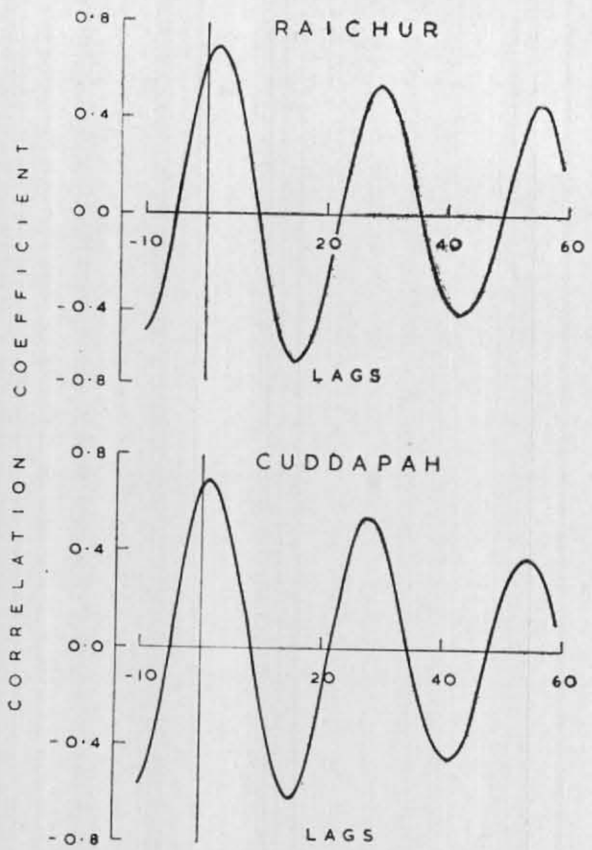

Fig. 1. Lagged correlation coefficient between series of daily temperatures and sunspot numbers

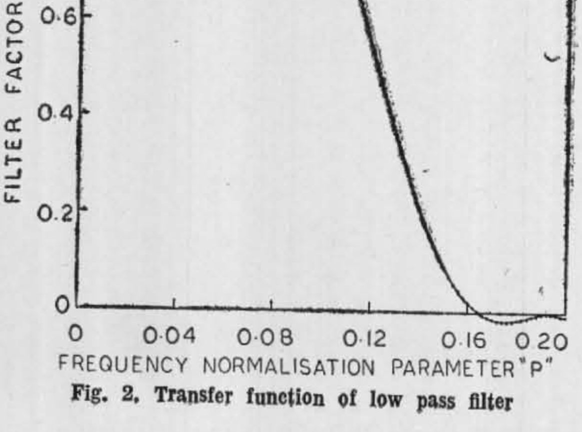

Fig. 2. Transfer function of low pass filter

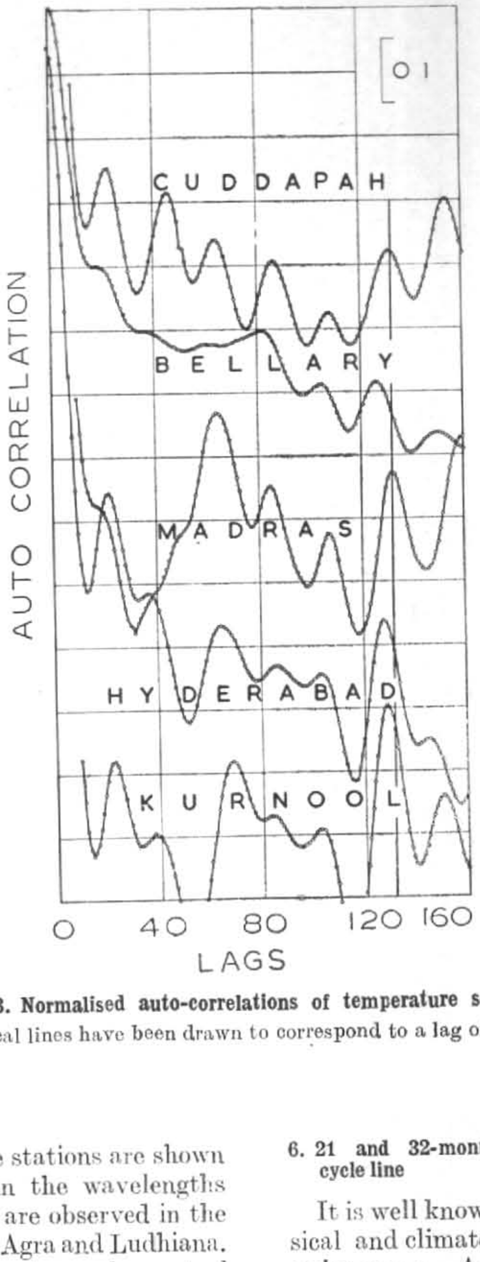

Fig. 3. Normalised auto-correlations of temperature series
Vertical lines have been drawn to correspond to a lag of 132

of the temperature series of the stations are shown in Fig. 4. Peaks in power in the wavelengths close to the 11-year solar-cycle are observed in the spectrums of only two stations, Agra and Ludhiana. At wavelengths close to half a solar-cycle spectral peaks are noticed for Bikaner, Indore, Trivandrum, Veraval, Cuttack, Poona and Madras. The spectrums of temperatures at the stations in the central and southern part show broad and significant peaks at two wavelengths of about 32 and 21 months. In the spectrums of Madras, Kurnool and Hyderabad both the lines are present; in those of Cuddapah and Bellary only 21-month peaks appear and in the spectrums of central Indian stations, Sagar, Akola and Indore only the 32-month lines are present. In the eastern part, the peaks appear at 35·5 months in Silchar and Cuttack spectrums and near 29 months for Poona.

6. 21 and 32-month lines as harmonics of the solar-cycle line

It is well known that a true cycle in the geophysical and climatological series is rarely shaped like a sine curve. As a result peaks appear in the spectrums at wavelengths corresponding to one or more harmonics of the basic frequency. If the positive and the negative loops are not identical even harmonics will predominate. The relative power will progressively decrease with the order of the harmonic. The 11-year and 5½-year cyclic components in the autocorrelation function of the stations in the south central region, appearance of a line in the spectrums of some of the stations corresponding to 5½ years period and the presence of lines corresponding to about 32 and 21 months which are periods close to the fourth and sixth harmonics of the 11-year line suggest that these

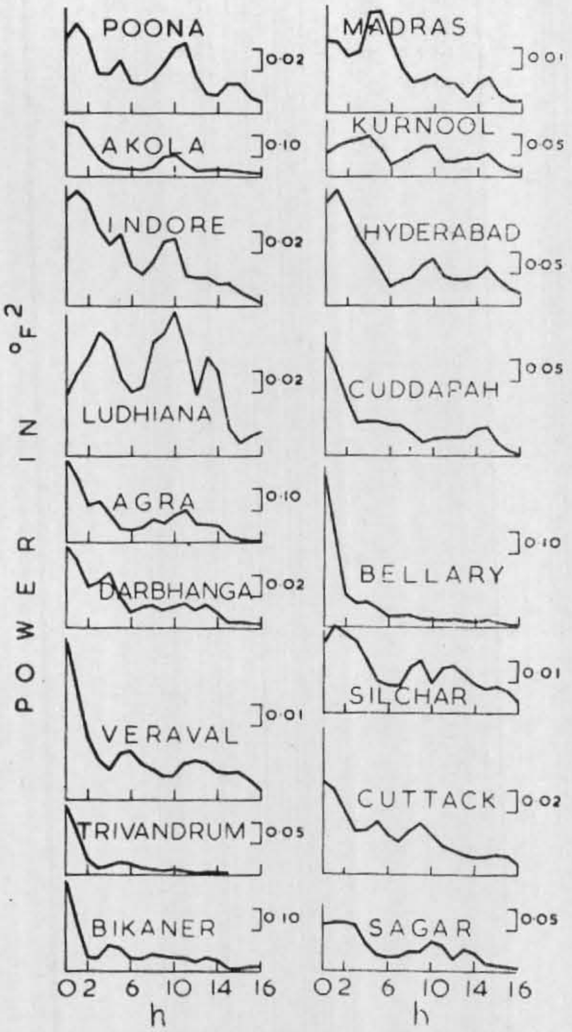

Fig. 4. Spectral estimates computed from temperature series

two lines together with the $5\frac{1}{2}$ year line are the second, fourth and the sixth harmonics of the fundamental 11-year line in the series of temperatures and that the 32 and 21-month lines by themselves may not be physically significant.

7. Discussion

Solar-climatic relationships have been a subject of investigation for over many decades but the results have shown these to be weak and often conflicting. Besides an inadequate understanding of the changes in the magnitudes of the solar radiation which is able to penetrate to the lower atmosphere, any attempt to establish these relationships is rendered difficult by the seasonal, regional and topographical variation in the response of tempeature to solar activity and to differences in the magnitudes of activity in the sunspot cycles (Lawrence 1966). Callendar (1961) observed a correspondence between temperatures and an 'inverted' sunspot curve from 1875 to 1920 and a reversal of the phase thereafter. Troup (1962) who also considered the reversal of the solar activity-tropical temperature cycle noticed that over the tropics as a whole, the correlation betwen sunspot number and tropical temperatures which, prior to 1920 were on the whole negative, became zero or even positive in subsequent years. A further confirmation of the phase reversal was made by Lawrence (1965) from his study of temperatures at the British Isles stations. In view of these findings any investigation of association between sunspot activity and temperatures from data covering period prior to and after the reversal can at best be expected to yield a weak relationship. The autocorrelograms of temperatures computed here suggest that a 11-year and $5\frac{1}{2}$-year cyclic componet is present in the temperatures of the stations in the non-coastal stations of the Peninsula. Increased power density near 21 and 32 months in the spectrums of temperatures of these stations provides additional support for the presence of a 11-year component in the temperatures in this region. It would also appear that the long-period relationship is noticed to be confined to the same region where the 27-day solar-rotation period relationship between sunspots and maximum temperature has been found in an exceedingly convincing form by the present authors in the temperature data. It would appear that regional factors play an important role in both short and long period solar activity and temperature relations.

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