551.521 : 550.377 : 551.577

A CROSS-SPECTRAL ANALYSIS BETWEEN SOLAR ACTIVITY, GEOMAGNETIC INDEX aa, AND RAINFALL

1. In the 1870s, more than 20 papers appeared relating sunspot activity to rainfall. These studies primarily concerned India. Expectedly early studies concluded that rainfall is more plentiful at maximum solar activity (warmer sun) and it is sparse when sunspots are sparse. Scientific literature abounds with disagreement about what is happening concerning rainfall. In the present study an attempt has been made to examine rainfall over India and associated phenomena and their possible relationship to solar and geomagnetic activity. For the present study the rainfall data are taken from Parthasarthy *et al.* (1995). Geomagnetic Index aa data are taken from IAGA-Bulletin (2003) and Zurich sunspot numbers (*R*) from Hoyt and Schatten (1997). Excess and deficit rainfall years for all the regions/sub-divisions have been computed based on the logic of Parthasarthy *et al.* (1995). For

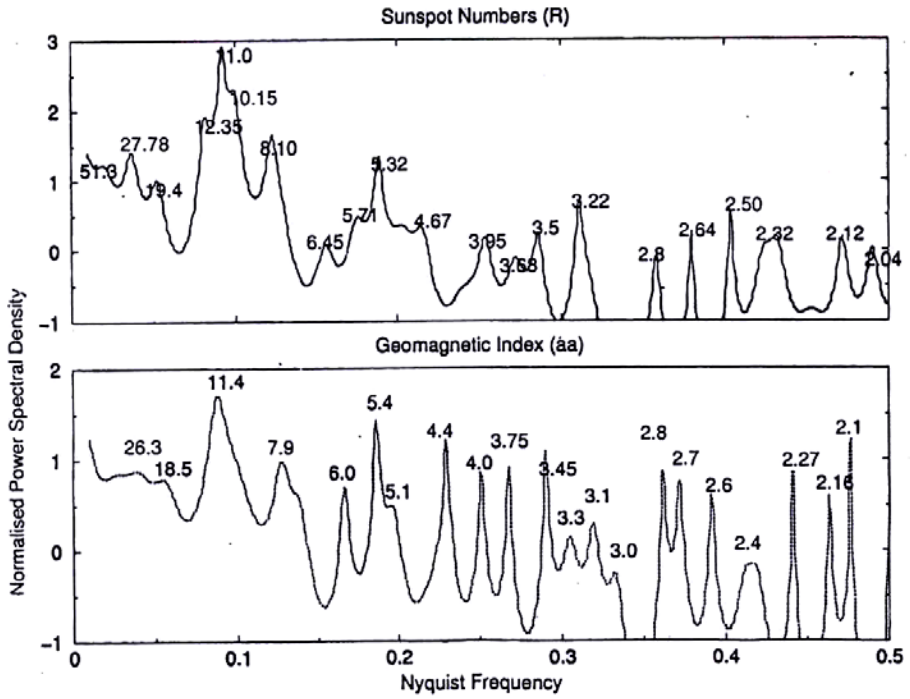

Fig. 1. Power spectra of sunspot numbers (*R*) and geomagnetic index (aa)

statistical analysis of data maximum entropy power spectrum estimation has been utilized. The cycles in geomagnetic index aa and sunspot numbers *R* obtained from power spectrum analysis are noted against the peaks of cycles in Fig. 1. Annual/monsoon rainfall cycles for India as a whole are given in Fig. 2. Similar figures were prepared for the sub-divisional rainfall but are not reproduced to save space.

Solar activity and its influence on meteorological variables are discussed in section 2. Rainfall data, its related studies and results of statistical analysis are presented in section 3 and 4. In section 5 results are summarized and attempts have been made to search for a relationship between rainfall and solar/geomagnetic activities.

2. *Solar activity and Geomagnetic Index aa* - It is generally accepted that the main phenomenon characterizing the variation of solar activity within each sunspot cycle and from cycle to cycle, are the sunspots which usually occur on the solar surface in groups and follow a cycle of an average period of 11 years; often referred to 11-year solar activity. There are many other solar features, including faculae and plages, which are bright regions seen in visible and monochromatic light. They too follow 11-year cycles. The sun shows several other types of surface activity also; like prominences and flares. It has been observed that aurorae and geomagnetic disturbance are also solar forcing with an 11-year cycle.

Sargent (1978) gave an expression relating maximum sunspot number and Geomagnetic Index aa :

$$R_{max}(n+1) = 3.91 + 8.56\,(X_1 - 0.92\,X_2) \qquad (1)$$

Where X_1 is the mean value of the aa indices for 36 months preceding sunspot minimum, X_2 is the value of $R_{min}(n)$, and $R_{max}(n+1)$ is the predicted sunspot for the next maximum. Feynman and Crooker (1978) related aa to $V^2\,B_z$ by

$$\text{aa} = 1.3 + 4.7 \times 10^{-5}\,B_z\,V^2$$

and

$$B_z = 1.56 + 7.19 \times 10^{-3}\,R \qquad (2)$$

The values of aa index and Zurich sunspot numbers (*R*) are taken from IAGA-Bulletin (2003) and Hoyt and Schatten (1997) respectively. The linear correlation coefficient between them is found to be ≥ 0.6.

3. *Trends and periodicities in rainfall and solar activity* - Many attempts have been made in the past to correlate solar activity and terrestrial phenomenon like

temperature, precipitation, droughts and storms. But contradictory and null results are reported. In this part we examine the relationship between the solar activity and some of these phenomena.

3.1. *Precipitation* - Xanthakis (1973) examined in great detail the correlation between solar activity and precipitation and found that there exists a quite satisfactory correlation: positive or negative. Currie and O'Brian (1992) has actively looked for cyclic variations in precipitation records. He found a strong 18.5 year lunar tidal cycle and a weak 10.16 year peak in his power spectrum analysis in the contiguous United States. Further Currie examined many locations around the world and found the same effect everywhere. Perry (1994) finds a negative correlation over nearly all the continental United States.

3.2. *Droughts* - Mitchell *et al*. (1979) did extensive research on tree rings in U.S. and concluded that (*i*) severity of droughts is proportional to the level of solar activity and (*ii*) most droughts tend to return every 22 years. Bell (1982) suggested that real period of drought is 20.5 year cycle and is caused by a beat between the 22.279 year Hale double sunspot cycle and 18.64 year lunar nodal tidal cycle. Currie (1987) studied 288 worldwide drought/flood records and found a 19-year cycle in 83 % of the locations. Power spectra show that 22-year drought cycle is actually 18.6 years cycle in length and is caused by the 18.6 year Saros lunar cycle.

3.3. *Storms* - The number of Earth' storm may change with the change in the sun's radiation due to solar activity. Theoretically this change may be subtle and difficult to detect. Cohen and Sweester (1975) examined the variations in the number of Atlantic hurricanes as a function of time using maximum entropy power spectrum. A prominent peak in number of cyclones occurs at 11.3 years. They found a peak 51.3 years and its matching peak in solar activity is also at 51.3 years in Fig. 1. Some weak peaks of periods 22, 9.3 and 8 years were also observable in cyclones. Its matching peaks of 19.4, 10.2 and 8.1 years are also available in solar activity power spectrum in Fig. 1. Stringfellow (1974) claimed that number of lightening incidences in England closely follow the sunspot numbers and are caused by changes in solar activity. Hoyt and Schatten, 1997 refer thunderstorm frequencies of 8 and 13 years. These also may be solar forcing.

4.1. *Analysis of data - Rainfall* - India encounters two monsoons every year. The first, which occurs in summer, extends from June to September; while second, the winter monsoon, lasts from October to end of December. Parthasarthy *et al*. (1995) provided rainfall data for All India, 5 homogeneous regions and 29 sub-divisions. The five homogeneous regions are (*i*) Northeast with four sub-divisions, (*ii*) Central Northeast that includes five sub-divisions, (*iii*) Northwest comprising six sub-divisions, (*iv*) West Central having 8 sub-divisions and (*v*) Peninsular India based on six sub-divisions. But we wish to concentrate here on summer monsoon because it represents a large system and major rainfalls are during this period.

(a) *Rainfall variations* - During the last quarter of the last century a number of studies on trends, variability, characteristics and periodicities of rainfall of individual stations, sub-divisions and different regions have been done by Raghvendra (1973), Mooley and Parthasarthy (1984), Kiladis and Sinha (1991) Parthasarthy *et al*. (1987, 1992), and Parthasarthy *et al.* (1995). Here an attempt has also been made to study the rainfall variability and trends. For that purpose first excess and deficient rainfall years for different regions and sub-divisions are computed based on the logic of Parthasarthy *et al.* (1995). However, the large deficient and large excess are defined in terms of the deviation from the mean beyond twice of the standard deviation *i.e.*, a confidence limit < 0.05.

Earlier studies concluded that there is no any specific trend in the regional as well as meteorological sub-division rainfall data. Expectedly excess and deficit rainfall years vary from sub-division to sub-division. India is a vast region. Therefore, a search for common trends and variations will not lead to any fruitful result. But it is worth mentioning here that excess rainfalls recorded in the years 1884, 1892, 1893, 1894, 1917, 1956, 1959, 1961, 1970, 1975, 1983 and 1994 and deficient rainfall in the years 1899, 1904, 1905, 1911, 1918, 1965, 1968, 1972, 1974, 1991 in contiguous regions (*i.e*., northwest and west central) are common. While excess and deficient rainfall years for central northeast and south peninsular India are different. This shows that contiguous regions may have a little association but trends and variability are not common to every region. Sikka (1999 and 2000) has examined the sub-divisional drought and excess monsoon years and found that on about 40 % of the years they do not match with contiguous sub-divisions.

Although sufficient number of data on droughts/floods in India is not at disposal of the author for power spectrum analysis to analyze the periodicity in droughts/floods but an attempt has been made here to find deficient and excess rainfall years from the annual rainfall data for the period 1871 : 1994. Almost whole of the Indian Territory faced large deficit of annual/monsoon rainfalls in the years 1877, 1899, 1904, 1918, 1965, 1972 and 1987. There were other drought years too when the standardised rainfall anomaly was between –1.0 to –1.5

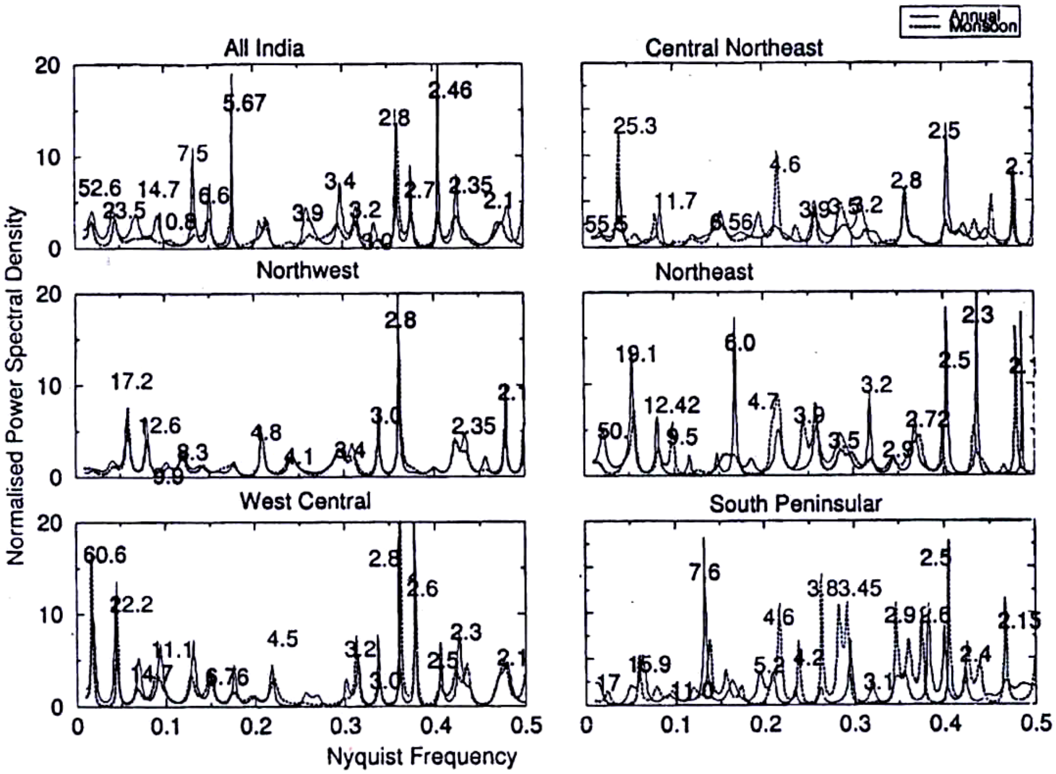

Fig. 2. Composite power spectra of annual and monsoon rainfall of different regions of India

(Sikka 1999). A periodicity of 19 and 22 years is visible in the data *i.e*., a signature of lunar tidal cycle of 18.6 years and Hale double sunspot cycle of 22.279 years both are present. Hale double sunspot cycle was earlier linked to droughts over India in a study by Bhalme and Mooley (1981). Further the drought years 1877, 1899, 1965 and 1987 coincides with the minimum sunspots years. Wood and Lovett (1974) found that from 1540 to 1974 drought years in Ethiopia preferentially occurred at or near sunspot minima consistent with the theoretical expectations. Furthermore, excess/large excess rainfall years 1893, 1917 and 1956 coincided with the maximum solar activity. Indeed there have been several other excess monsoon rainfall seasons in the records (Sikka 2000), which are apparently not linked to solar activity.

(b) *Trends and periodicities in annual and monsoon rainfall* - Maximum entropy power spectra for five regions are plotted in Fig. 2. From the figure it is clear that trends and periodicities common to all the regions do not exist. However, in contiguous regions of northwest and west central predominant cycles are 3.0, 2.8, 2.3 and 2.1 years while in northeast and central northeast 4.6, 2.5 and 2.1 years cycles are dominant. Showing that geographical distribution of rainfall is not a static pattern but apparently a close association appears to exist between contiguous regions. For trends and periodicity analysis maximum entropy power spectrum of annual and monsoon rainfall were examined. The following is revealed :

(*i*) Recurring rainfall cycles are 2.1 ± 0.1, 2.5 ± 0.1, 2.8 ± 0.1, 3.2 ± 0.2, 3.9 ± 0.2, 4.6 ± 0.3, 5.5 ± 0.3, 6.4 ± 0.3, 7.5 ± 0.3, 8.0 ± 0.3, 11.0 ± 0.6, 12.4 ± 0.6, 18.5 ± 1.8, 22. ± 2.0, 25.5 ± 2.0 and 52.0 ± 4 years. Some higher cycles are also observable. Some of these cycles follow set geographical pattern.

(*ii*) Cycles 2.1 ± 0.1, 2.5 ± 0.1, 2.8 ± 0.1, 3.2 ± 0.2, 3.9 ± 0.2 and 4.6 ± 0.3 are common to almost all the regions/sub-divisions and also their spectral densities are sufficiently high. But it may vary from one location to other. Raghavendra (1972) and Das (1984) have also reported cycles of 3.3 and 2.7 to 2.9 years respectively.

Undoubtedly Power spectrum by maximum entropy methods with a larger number of poles can resolve the distinct sinusoids; but flat noise background begins to show spurious peaks. Therefore, weak signs of periodicities some time may be spurious.

4.2. *Trends and periodicities in sunspot numbers and geomagnetic index aa* - Fig. 1 is the power spectrum of sunspot numbers and geomagnetic index aa. The cycle years found from the power spectrum are noted against the peaks. Power spectrum reveals higher harmonics of 11 year solar cycle *i.e.*, ~5.5 years (half of 11 year solar cycle) and ~ 2.7 years (quarter of 11 year solar cycle). In sunspot numbers a periodicity of 51.3 and 27.78 are also observable. Apart from that a weak sign of periodicity of about 8 years (shortest sunspot period) and very very weak of 18.1 years (Lunar Saros cycle) is also noticeable. Other prominent cycles noticeable in the power spectrum of solar/geomagnetic activities are ~ 4.4, ~3.5, ~3.2 ~ 2.8, ~2.5, ~2.3 and ~2.1 years. Some of the prominent peaks of solar/geomagnetic activity are close to quasi-biennial oscillations.

5. *Results and discussions* - Maximum entropy power spectrum analysis of regional/sub-divisional annual/monsoon rainfall shows trends and periodicities in rainfall. Recurring rainfall cycles are 2.1 ± 0.1, 2.5 ± 0.1, 2.8 ± 0.1, 3.2 ± 0.2, 3.9 ± 0.2, 4.6 ± 0.3, 5.5 ± 0.3, 6.4 ± 0.3, 7.5 ± 0.3, 8.0 ± 0.3, 11.0 ± 0.6, 12.4 ± 0.6, 18.5 ± 1.8, 22 ± 2.0, 25.5 ± 2.0 and 52.0 ± 4 years (Fig. 2). Some higher cycles are also observable. Trends and periodicities are found to vary from one location to another. Some time volcano eruptions also force for a change in periodicity. Therefore, each region/sub-division may or may not have common cycles.

Power spectra of sunspot numbers and geomagnetic index aa reveal cycles of ~ 51.3, ~27.78, ~18.1, ~11, ~8, ~5.5, ~ 4.4, ~3.5, ~3.2 ~ 2.8, ~2.5, ~2.3 and ~2.1 years (Fig. 1).

Most of the cycles and periods observed in the power spectra of rainfall of various regions/sub-divisions are almost same as obtained in the power spectrum of solar/geomagnetic cycles suggesting a sun and rainfall relationship. Further these cycles and periods are also common to other solar forcing terrestrial phenomena as mentioned above. To measure the association between rainfalls and geomagnetic index aa, correlation coefficient were examined. The study showed that insignificant correlation exists between aa and rainfall. However, correlation is considerably increased after smoothening the data of rainfall taking three points together. But still it is found to be weak < 0.3. Rainfall varies naturally over a range of time periods, with some close to 11 years. This random variation is some times in phase with solar/geomagnetic activity and some time not, leading to a weak correlation. It is also likely that correlation breakdown and some time sign changes are due to solar forcing beats. Two beat together; some times enhances their effects and some times canceling one another out. Because of several of the complexities involved, it would be difficult to establish with a high degree of certainty a relationship between monsoon rainfall over India and solar activity/geomagnetic indices.

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