Bull. Astr. Soc. India (2003) **31**, 1–8

A new cycle in the periodicity of solar flare indices

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Received 2 September 2002; accepted 20 January 2003

Abstract. A new cycle of about 5.5 years has been invoked in case of the periodicity in solar flare indices. As there exists no instrumental technique for measuring directly the energy output of an optical flare, the energy emitted during flaring is estimated by the quantity known as Flare Index. The daily values of flare index have been expressed by complex Fourier series for each of the years from 1986 to 1996 which cover almost the entire 22nd solar cycle. The periodicity values for both magnetic and non-magnetic (Basal) components of flare indices have been investigated after performing power spectral analysis of the aforesaid time series. The periodicity in solar flare indices varies harmonically with time, exhibiting 5.5 years cycle of variation for both magnetic and non-magnetic (Basal) component of the said indices.

Keywords : Sun, Periodicity, Flare Indices.

1. Introduction

Harmonic behaviour of sun is an important aspect which needs a thorough investigation, as it is concerned with the internal dynamics associated with different kinds of solar activity. Most of the earlier workers (Bai and Sturrock, 1991; Bai and Sturrock, 1993; Bai, 1994; Ozguc and Atac, 1994; Verma, Joshi, Uddin and Paliwal, 1991; Verma, Joshi and Paliwal, 1992) reported the enigmatic 154 day periodicity in solar activity which is viewed as part of a complex of periodicities that are approximately multiples of 25.8 day. On the contrary, a search (Kile and Cliver, 1991) for the 154 day periodicity in the occurrence rate of solar flares gives rise to negative results. They confirmed the existence of 51 day periodicity from the analysis of flare data of solar cycle 19. Moreover, it was reported (Oliver and Ballester, 1995) that during some intervals of time, a periodicity close to 86 days exists in the case of flares and flare-related data; the same periodicity is

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being reported (Bai 1992; Joshi, Uddin and Paliwal, 1991) for important solar flares during solar cycle 20 as well. A power spectrum analysis of the daily number of solar flares producing metric type I, II, III, IV and V radio bursts for the period 1980-84 show that only type II and IV radio bursts confirm the existence of 152-158 day periodicity but the other types of radio bursts do not support it. A study has also been made (Xanthakis, Poulakos and Petropoulos, 1992) on the mean monthly number of grouped flares for the period 1966-1988 which emphasised the presence of the period of 48 months.

From the above reports it appears that different values of periodicities are found in the case of the occurrence rate of solar flares. But the occurrence rate, which is possibly related to the number of instabilities developed in an active region, is not an exact measure of the energy liberated during flaring. So the periodicity in the occurrence rate is likely to be different from that of energy released by the flares. Hence, in the present paper, the periodicity in the solar flare energy has been investigated by considering the daily values of flare indices over the 22nd solar cycle beginning with the year 1986.

2. Method of Analysis

The daily flare index for the 22nd solar cycle was determined by using the final grouped solar flares which are compiled by National Geophysical Data Center (S.G.D.C., 1997). The said index is calculated (Atac, 1987; Kleczek, 1952; Knoska and Petrasek, 1984) by considering the factors like measured area of the flaring region at the time of maximum brightness, duration and luminosity, giving roughly the total energy emitted by all the flares. In the present analysis the daily flare index 'I' has been expressed by

$$I = I_0 + i.N$$

where 'I_0' gives the flare index at zero sunspot number, 'N' the sunspot number at a particular day of observation and 'i' the value of index per unit sunspot number. A regression line has been drawn by plotting 'I' against 'N' for the data set of a particular year from which the constant 'i' has been evaluated.

The magnetic component of the flare indices has been determined by multiplying this constant 'i' with the sunspot of the respective day, and thus, the time series for the magnetic component is formed for each of the years under consideration. Similarly, the sunspot independent component of flare indices is obtained when the constant 'i' is multiplied by the sunspot number of a particular day and then the product is subtracted from the respective 'I' value. This sunspot independent component is termed as nonmagnetic component. When the steady part is eliminated from this sunspot independent component, the Basal component is obtained. Thus the flare index in absence of the large scale magnetic structures (i.e. sunspots) is called the nonmagnetic component, whereas, the slowly varying part of the nonmagnetic component is termed as the Basal component. This procedure has been followed separately for all the years under study and new time series for the basal component have been constructed for each year.

From the aforesaid time series, both for the magnetic and basal components of flare indices, Fourier integrals were performed over the time periods from 2 to 200 days by adopting the following principle. The length of each time series is about one year, comprising of 365 data points.

We can express a signal $g(t)$ by a trigonometric Fourier series over any interval of duration T_0 as:

$$g(t) = a_{0_+} \Sigma a_n \cos(nw_0t) + \Sigma b_n \sin(nw_0t)$$

where $n = 1$ to ∞ and $w_0 = 2\pi/T_0$.

a_0, a_n and b_n are known as the Fourier coefficients.

We can determine these coefficients as

$$a_0 = 1/T_0 \int g(t)dt \qquad \text{for } n = 0$$

$$a_n = 2/T_0 \int g(t)\cos(nw_0t)dt \qquad \text{for } n = 1,2,3,\ldots$$

and

$$b_n = 2/T_0 \int g(t)\sin(nw_0t)dt \qquad \text{for } n = 1,2,3,\ldots$$

Now we can have a single term of the same frequency using the trigonometric identity

$$a_n\cos(nw_0t) + b_n\sin(nw_0t) = c_n\cos(nw_0t + \theta_n)$$

where $c_n = (a_n^2 + b_n^2)^{0.5}$ and $\theta_n = \tan^{-1}(b_n/a_n)$ the amplitude c_n is computed from a_n and b_n using the above equations.

3. Results

In order to draw the power spectra, the Fourier coefficients have been determined after selecting gradually increasing time periods truncated at 200 days. The periods at the maximum spectral intensity of the power spectra have been found out for all the years separately from which the solar cycle dependence has been studied. The power spectra of the Fourier series conveying the magnetic component of flare indices are shown in Fig.1. Similar spectra of the time series for the basal components obtained in the manner described above have been drawn and are shown in Fig. 2. In these figures, the spectral peaks with maximum intensity are found to be more sharp and some of the peaks have become less prominent. In selecting the periodicity the criteria followed are: (i) As each data set contains 365 points, the periods below 100 days have only be taken into consideration, (ii) The periodicity of 27 days and its multiples have been discarded, as they coincide with the synodic period of rotation of sun.

The calculated values of these peaks for the Basal and magnetic components are shown in Table 1 and Table 2 respectively.

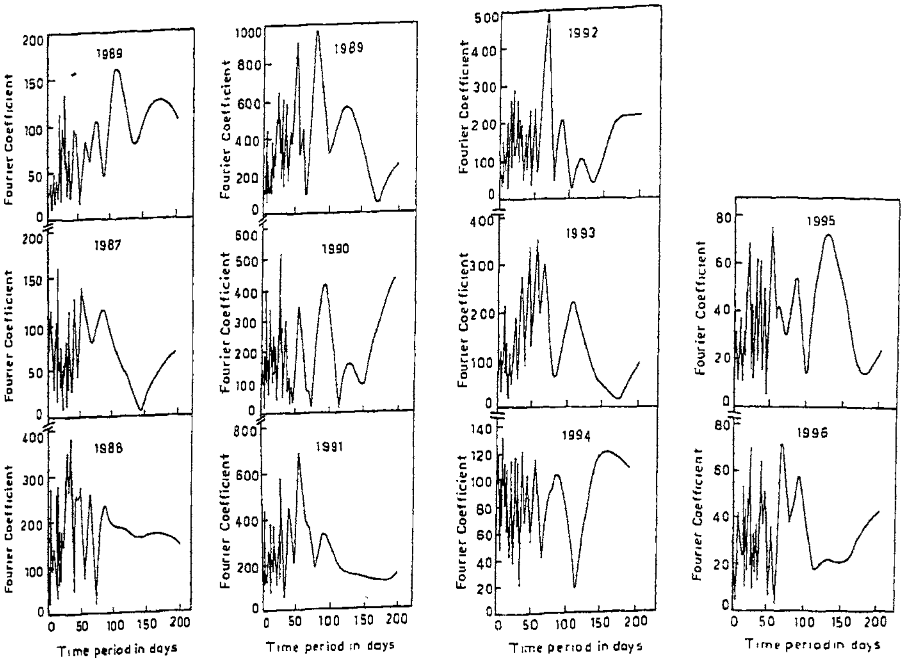

Figure 1. (a) Power spectra of the magnetic component of Flare Indices for the years 1986–1991. (b) Power spectra of the magnetic component of Flare Indices for the years 1992–1996.

In order to justify the validity of the peaks found from the Fourier analysis, as shown in Fig.1 and Fig.2, the confidence limits, also known as fiducial limits of the time periods for the different peaks shown in the power spectra were found out (Haber and Runyon, 1969). All these confidence limits correspond to the percentage confidence, better known as confidence level, above 95%. In effect, we are attempting to determine the interval within which any hypothesis concerning the periodicity of a certain solar event might be considered tenable and outside which any hypothesis would be considered untenable. The confidence limit is evaluated by generating a sample of 100 data points equally on both sides of a particular peak. This is repeated for all the peaks under consideration. The peak which is sharp gives the minimum value of confidence limit.

The confidence interval or limit provides the lower and upper limits to which the population parameter has a high probability of being included. The population parameter standard deviation 'σ' can be calculated from the following formula:

$$\sigma = \{\Sigma T^2/(N-1) - (\Sigma T)^2/N(N-1)\}^{0.5}$$

The standard error for sampling distribution is estimated as

$$SE_m = \sigma/(N-1)^{0.5}$$

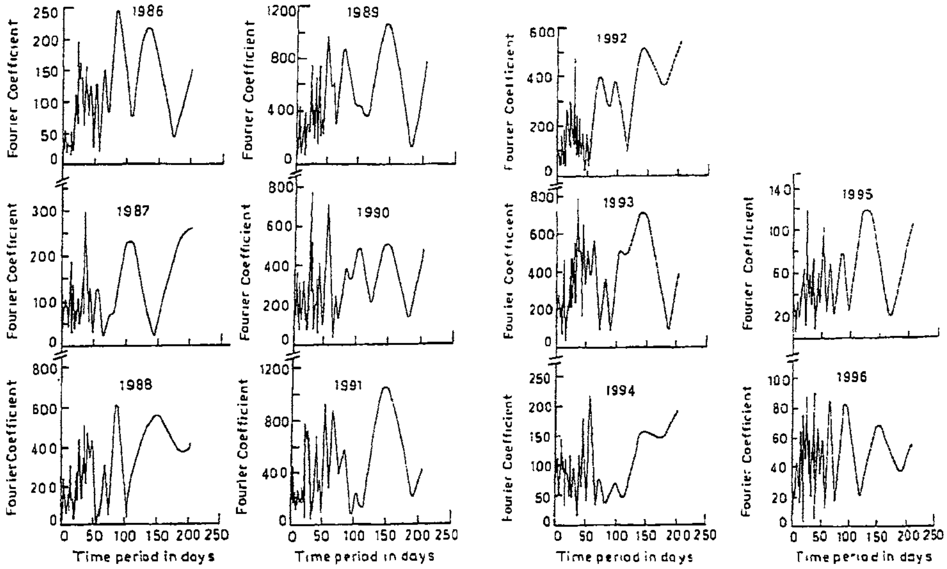

Figure 2. (a) Power spectra of the non-magnetic (Basal) component of Flare Indices for the years 1986–1991. (b) Power spectra of the non-magnetic (Basal) component of Flare Indices for the years 1992–1996.

Table 1. Confidence limit of flare indices for Basal Component.

Year	1st peak	2nd peak	3rd peak
1986	76.81±1.32	42.53±0.91	61.44±0.98
1987	57.42±0.85	44.04±0.54	36.15±0.37
1988	34.10±0.32	50.81±0.67	64.20±0.53
1989	76.92±1.13	49.99±0.83	35.69±0.40
1990	91.89±1.17	55.07±0.88	36.40±0.37
1991	56.92±1.21	41.82±0.65	92.62±1.89
1992	49.87±0.71	44.78±0.49	37.67±0.32
1993	54.33±0.97	45.18±0.87	35.47±0.72
1994	41.17±0.41	58.13±0.76	32.65±0.24
1995	51.22±0.71	31.25±0.35	36.35±0.32
1996	69.07±0.92	39.59±0.37	45.98±0.47

The confidence limit for the 95% confidence can be computed as

$$C.L. = T_{ave} \pm 1.96(SE_m)$$

where T_{ave} is the mean value of the time periods of the sample data points.

Table 2. Confidence limit of flare indices for magnetic component.

Year	1st peak	2nd peak	3rd peak
1986	36.80±0.66	64.80±1.11	42.31±0.49
1987	36.91±0.31	17.44±0.41	31.01±0.40
1988	86.44±1.67	34.84±0.35	42.17±0.84
1989	49.32±0.49	75.55±1.85	35.26±0.28
1990	55.54±0.82	42.24±0.56	36.69±0.50
1991	54.74±0.65	67.38±0.96	40.28±0.57
1992	70.96±1.43	31.64±0.29	37.23±0.27
1993	35.25±0.22	45.59±0.33	63.56±0.72
1994	47.24±0.61	40.48±0.68	32.05±0.52
1995	51.87±0.64	83.97±1.63	37.05±0.35
1996	38.75±0.45	66.58±1.34	45.65±0.69

The peak value which corresponds to the minimum value of confidence limit was chosen for each of the years cited in both the Tables 1 and 2. Moreover, the periodic values which correspond to the synodic rotational modulation of sun and its simple multiples have been discarded. The periodicity is found to vary between 32 days and 43 days for both Basal and magnetic components. After selecting the exact periodic values in this fashion a plot has been drawn, showing the variation of periodicity against the year under consideration. The nature of variation of periodicity with year is shown in Fig.3 for both the Basal and magnetic components of flare indices.

The nature of variation as shown in Fig.3 gives rise to an approximate 5.5 years cycle in the periodicity of flare indices, from which it can be concluded that the periodicity is solar cycle dependent. The average period may be taken as 37 days which comes out from this cyclic variation.

4. Discussion

Earlier studies about the periodicity of solar flares emphasised on the occurrence rate of flares, without taking into account the energy evolved during their onset. Most of them reported the existence of periodicity of 152-158 days and their sub-harmonics. But the present study encompasses the periodic behaviour of sun in respect of its energy liberated during flaring, which has been segregated as thermal and non-thermal components, indicated here as basal and magnetic components of flare indices respectively. Both of these components have almost the same values of periodicities which are solar cycle dependent. The similar nature of variation of the periodicity in the intensity of basal component of solar radio emission have also been reported (Das and Nag, 1998; Das and Nag, 1999) earlier. The non-magnetic component of radio emission in the frequency band 245–15400 MHz after subtracting the contributions due to both the sunspot and

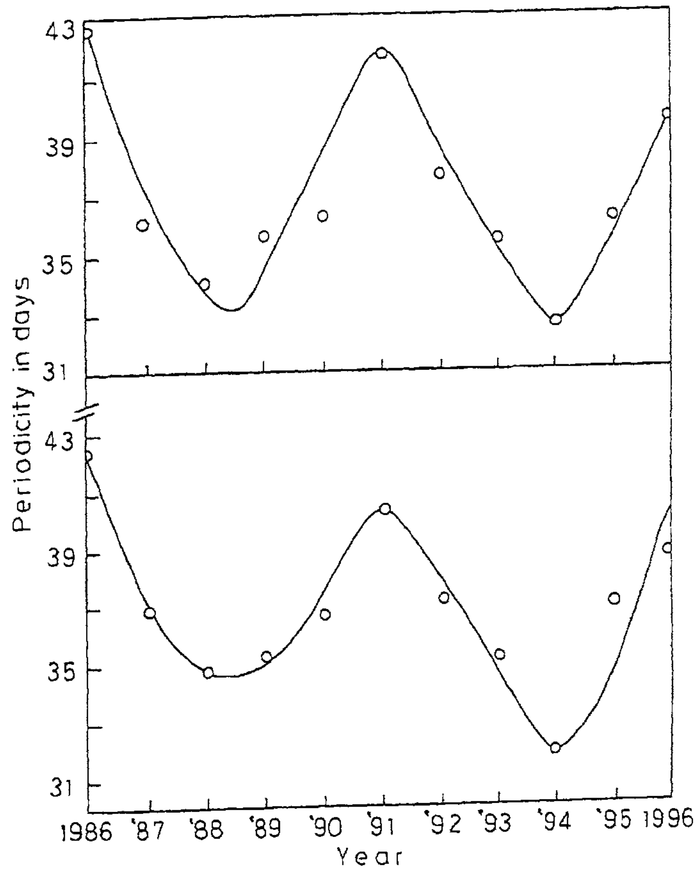

Figure 3. Curves showing the variation of periodicity with time in year, the upper and lower panel curves represent respectively the results for the Basal and Magnetic components of the Flare Indices.

the mean magnetic field of the sun from the observed radio flux for the solar cycle maxima (1980 and 1991), as well as, for the solar cycle minima (1975, 1986 and 1996). This component of radio emission intensity exhibits periodicity around 35 days at all the observing frequencies during solar cycle maxima and in between 80-95 days at the observing frequencies around 0.5 and 9 GHz during the period of solar minima. In the present study, the flare indices have been resolved into both magnetic and non-magnetic components, as it had been done in case of radio emission intensity. Although the periodicity is found to be solar cycle dependent, the time averaged overall period is examined to be 37 days which is approximately equal to the periodicity exhibited by the non-magnetic component of radio emission intensity at all the observing frequencies during the period of solar maxima. In this connection it is further to be noted that the harmonic behaviour of solar wind velocity and temperature gives also a periodicity of 37 days which was found to hold good from the analysis of the data from the Pioneer XII satellite operated during the period 1980-87 (Das and Ghosh, 1999). Regarding the 5.5 year cyclic variation of the periodicity of the flare indices no definite conclusion can be deciphered unless the analysis is carried out over a longer time scale.

Acknowledgement

One of us, T.K. Nag, of Sonamukhi College, Bankura, acknowledges the University Grants Commission, New Delhi, for financial support to the present work.

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