PERIODIC BEHAVIOR OF SOLAR FLARE INDEX DURING SOLAR CYCLES 20 AND 21

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Abstract. Short-term periodicities of solar activity were studied with the flare index by using Discrete Fourier Transform for the time interval 1966–1986. Two noticeable periodicities (18.5 and 5 months) have been found. The existence of these periodicities comparing with the early findings is discussed.

1. Introduction

Solar flares are the most powerful and explosive of all forms of solar activity and the most important in terrestrial effects. This idea led solar physicists to evaluate the daily flare index. Kleczek (1952) first introduced the quantity

$$Q = i \times t$$

assuming that this relationship gives roughly the total energy emitted by the flare. In this relation, i represents the intensity scale of importance and t the duration (in minutes) of the flare. Some reviews of flare activity using Kleczek's method are given for each day from 1936 to 1986 by Kleczek (1952), Knoška and Letfus (unpublished), Knoška and Petrášek (1984), and Ataç (1987).

Meanwhile the periodic nature of solar activity has been studied using parameters such as the sunspot relative numbers, calcium plage areas, and flare indices. The magnitude of the solar activity based on these parameters reveals periodicities other than the most pronounced 11-yr one. Many authors have studied this subject with various parameters (Rieger *et al.*, 1984; Ichimoto *et al.*, 1985; Bogart and Bai, 1985; Akioka *et al.*, 1987; Bai and Sturrock, 1987; etc.). Any absolute detection of periodicity in active phenomena would have fundamental significance for our understanding of solar activity.

In the present paper we investigated the temporal variation of the flare activity of the Sun using the data of flare index for the period of 1966–1986.

2. Data and Analysis

The Q flare index which represents daily flare activity observed on the chromosphere over 24 hours per day, was used for the analysis of solar flare activity. These data were

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calculated for solar cycles 20 and 21 by Knoška and Petrášek (1984) and Ataç (1987), respectively, so we do not mentioned here the details of their calculations. The first glance at this flare index suggests that it could be a suitable indicator of flare activity and of short periodicities.

As is known very well, solar activity is overwhelmingly dominated by the 11 (or 22) yr cycle, making it difficult to detect other periodicities. Only a small fraction of the very large number of claims that have been made for other periodicities can be defended strongly. The first step toward reducing the influence of the 11-yr cycle was to construct a 365-day running mean using the following formula:

$$\overline{Q}(i) = \sum_{j=1}^{365} Q(i+j)/365 \quad (i = 1 \text{ to } 7578)\,.$$

This calculation was done for the three time series separately, e.g., for the northern hemisphere flare index (QN), for the southern hemisphere flare index (QS), and for the whole disk one (Q). Figure 1(c) demonstrates the time variation of a 365-day moving average for the daily number, Q, throughout both cycles. This figure shows a remarkably period behavior of the flare index with several periods for the whole phases of the two cycles. Figure 1(a) and 1(b) give the time variation of the 365-day running mean flare indices for the northern and for the southern hemispheres of the Sun, respectively, during the period 1966–1986. The chromospheric activity was significantly higher during solar cycle 21 compared to the preceding cycle. In order to show the close correlation of the flare index with the other parameters of the Sun, it is plotted versus relative number R and adjusted 2800 MHz solar flux and presented in Figures 2 and 3, respectively. These two figures show remarkable similarity and their trends are almost equal. Therefore, these specifications allow us to investigate the solar activity using the flare index.

Our data set has three of 7578 daily values of flare index for Q, QN, and QS. The means of these time series were subtracted from the series. Then these new data sets have been modified by applying 5% cosine tapering to both ends. We have performed a harmonic analysis by employing the Discrete Fourier Transform (DFT), to estimate the periodicities of the flare index for the entire 21 years of data. In Figure 4 the power spectra of three time series of Q, QN, and QS have been plotted as a function of frequency. The value of flare index contains statistical error because the observation time is not 100% every day. Assuming Poisson count statistics the error of the power estimation is of the same order as the noise at very high frequencies (Hoyng, 1976) and for the result of Figure 4(a) it is only about 0.04 which is quite negligible. In order to estimate the statistical significance, we have applied the method proposed by Hoyng (1976), to the power spectrum drawn on Figure 4(a). A direct computation of the average power in the high-frequency region, from the entire data yields 0.237 which drawn in Figure 4(a) as a straight line. We have found the relative error ranges between 0.19 and 0.03, for the power level between 0.37 and 0.55. Therefore, the peaks that occur in this region in Figure 4(a) are quite real.

The most pronounced features in the Q periodogram are the presence of periods

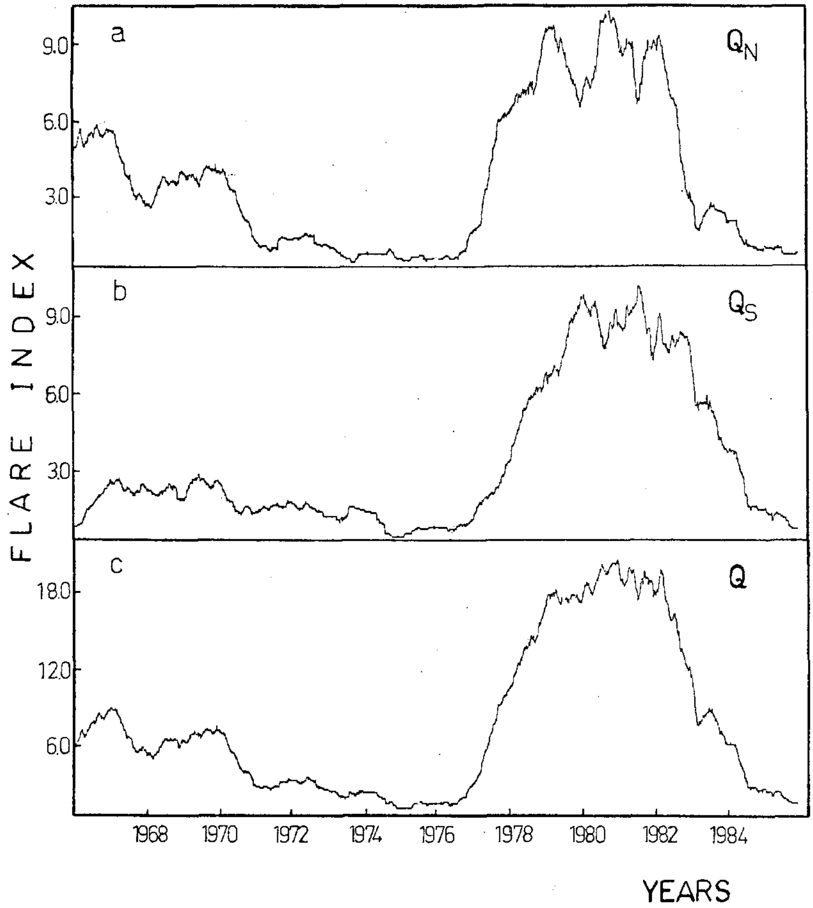

Fig. 1. Time history of 365-day moving average of the daily values of the flare index for the period 1966–1986. Top, middle, and bottom curves indicate the flare index values of northern hemisphere, southern hemisphere, and whole disk, respectively, for the same period.

1408 days (46.3 months) and 152 days (5 months); the relative power of the latter is higher. There are two more peaks centered at 564 days (18.5 months) and 1068 days (35 months). The most prominent peak in the *Qn* periodogram is 564 days, while in the *Qs′* it is 152 days. These dominant peaks seen in each hemisphere can be compared with Bai's results (see Figures 4 and 5 of Bai, 1987a). We can see neither 46.3 nor 36 months periodicities in the *QS* periodogram. The most significant peak in the *Q* periodogram is centered at 152 days. In order to determine whether these periods exist or not for each cycle, we also computed power spectra of the time series of the flare index for the solar cycles 20 and 21, individually. From these partial analyses we found all periods which we obtained from the entire data except the period of 35 months. The peak in the power spectrum for cycle 21 at a period of about 152 days is quite pronounced. But we cannot say the same thing for the power spectrum of cycle 20. The 152-day period exists but its power level is comparable with those of the other periodicities. Furthermore, in order

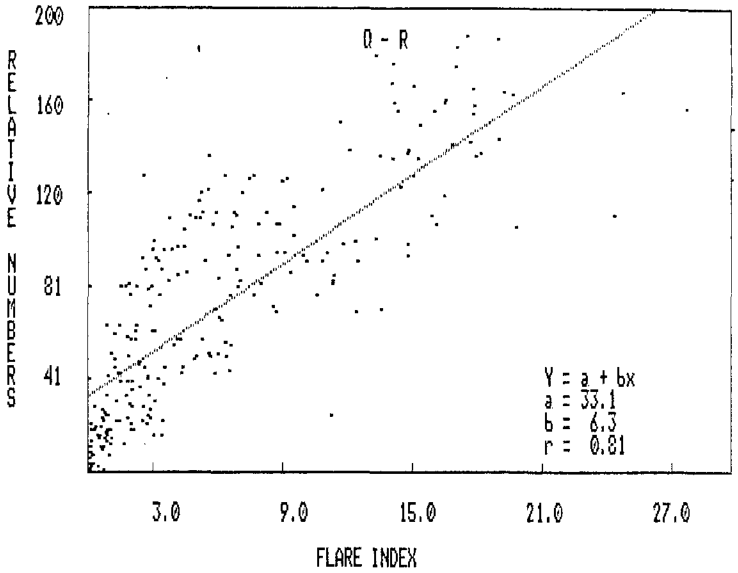

Fig. 2. Scatter plot of the monthly mean of relative numbers to the monthly flare index. For comparison purposes, a linear regression line is fitted.

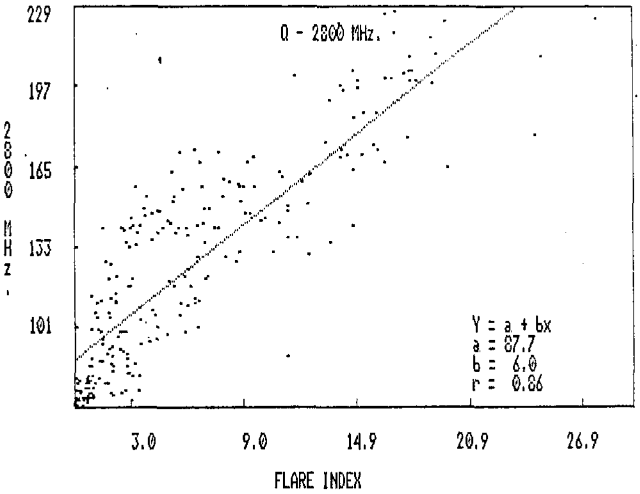

Fig. 3. Scatter plot of adjusted 2800 MHz solar flux to the monthly flare index. For comparison purposes, a linear regression line is fitted.

to confirm the short periodicities during the minimum time we computed once again the power spectrum of the flare index Q for the period of 1972–1977. We found no evidence for the 152-day periodicity. The peak in the power spectrum of cycle 21 at a period of about 18.5 months is also quite pronounced. It does not appear from these spectra that the same periodicity was present at a significant level during the previous solar cycle,

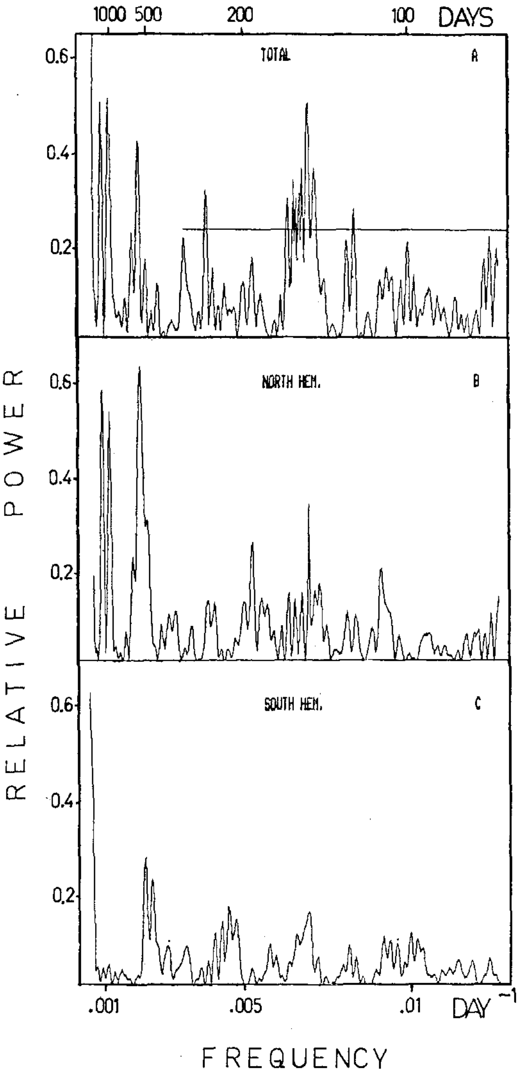

Fig. 4. The power spectra of the flare index values. Top, middle, and bottom curves indicate the periodograms of the flare indices calculated (A) for the whole disk, (B) for the northern hemisphere, and (C) for the southern hemisphere. The expected high-frequency power level is drawn in (A) as a straight line.

but the longer data base allows us to locate the peak power for the full data set at a period of 18.5 months.

The statistical significance of the periodicities in cycle 20 alone is marginal, but the agreement of periods of cycle 21 gives us more confidence in their reality. The histograms of Figure 5 show the distribution of flare index with respect to phases of the assumed periods (Figure 5(a), 152-day and 5(b), 564-day) for the whole disk, and for the northern and the southern hemisphere cases. The points of zero phase of the two periods were arbitrarily taken as 00 : 00 UT on 1 January, 1966. In Figure 5(a), we can see an impulsive increase of flare index in the phase interval 0.70–0.75 on top of a sinusoidal

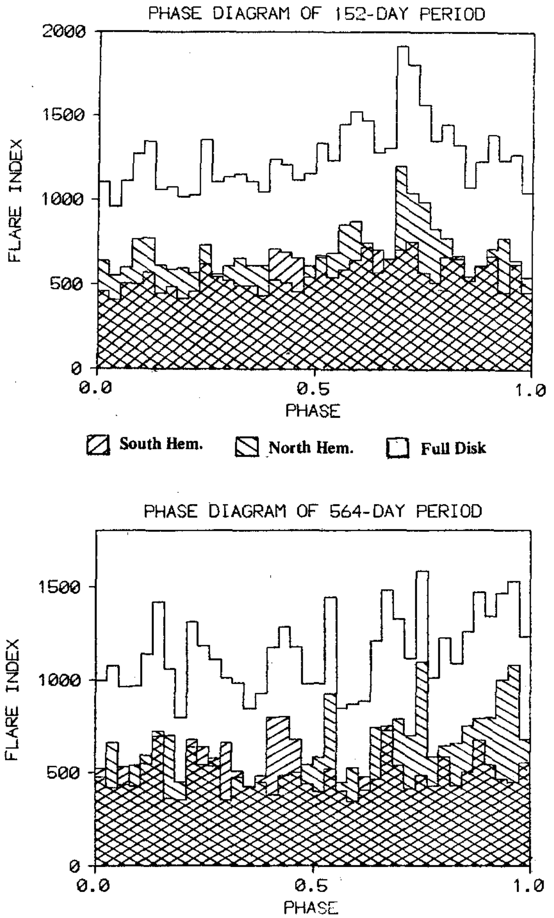

Fig. 5. Phase distributions of flare index with respect to assumed periodicities. (a) 152-day, (b) 564-day. The points of zero phases for all the periods were taken arbitrarily at 00 : 00 UT on 1 January, 1966.

variation of the flare index. In Figure 5(b) the phase diagram of 564-day periodicity does not show an impulsive increase in any interval; instead it shows a very large peak. Figure 6 shows the time profile of the 101-day running mean flare index for the northern hemisphere. When Figure 6 is examined it gives us a subjective feeling of the existence of this periodicity. If we examine the time profile of the entire data with a suitable running mean for the other two periods of 1068 and 1408 days, none of them give us any subjective feeling of the existence of those periodicities. Because the whole data run is only 5 or 7 times the purported periods, and during a part of the data run (around the solar minimum) the solar activity is too low to give us any information on the flare periodicity.

4. Discussion

Our study confirms the recent discovery (Rieger *et al.*, 1984) that the occurrence rate of solar flares exhibited a periodicity of about 152 days, as well as the other

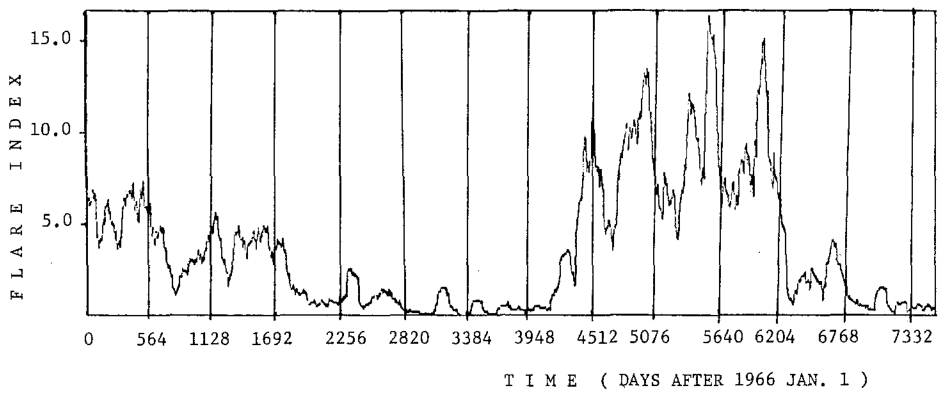

Fig. 6. Time profile of the 101-day running mean flare index for the northern hemisphere for the time interval 1966 to 1986.

periodicity of flare activity discovered before. Besides a 152 days periodicity we also note the peak near 18.5 months. This period corresponds well to the features reported by previous authors, and has been cited as proof of the existence of additional periodicity in the flare activity.

It will be of interest to compare these two periodicities we detected with the periodicities in other kinds of solar activity.

4.1. THE 564-DAY (18.5 MONTH) PERIODICITY

Belmont, Dartt, and Ulstad (1986) found a consistent peak near 19 months in 10.7 cm solar radio flux. Yakob and Bhargava (1968) established a periodicity of 16.3 months in the sunspot numbers and geomagnetic horizontal force in the period 1905–1965. They concluded, because of the statistical significance, that the 18 month periodicity was probably a real phenomenon both in solar and geomagnetic time series. Mayfield and Lawrence (1985) studied the relation between the flare production rate and the total magnetic energy in the active regions, and found a good correlation between them. The spectral analysis of the flare occurrence (imp. > 1) for cycles 20 and 21 by Ichimoto *et al.* (1985) showed that the flares occurred with periodicity of 16.7 months. And Bai (1987b) found an 18-month periodicity of the flare occurrence in the northern hemisphere during cycle 19. And finaly Akioka *et al.* (1987) found a 17-month periodicity by searching the total area and the mean area of the sunspot groups over the period 1869–1986. Therefore, it is evident that the 18-month periodicity of the flare index is mainly due to the periodicity of sunspot activity.

4.2. THE 152-DAY (5 MONTHS) PERIODICITY

Quantitative study of strong fluctuations in relative sunspot numbers have been made by Vitinskii (1962). He reported that these fluctuations range in time from three months to a year, with an average duration of five months. It must be mentioned here that Wolff (1983) has also indicated the possibility of a period of 5 months in his extensive analysis of monthly mean sunspot data. Rieger *et al.* (1984) have reported evidence for a 152-day periodicity in the occurrence of solar flares based on observations of the hard X-ray and gamma-ray continuum above 30 keV. Kiplinger, Dennis, and Orwig (1984) also analyzed about 7000 flares observed with HXRBS during the period 1980 February to 1984 September and found evidence for periodicity at a similar period of 158 days. Bogart and Bai (1985), analyzed flares producing microwaves with peak flux density greater than 10 solar units measured at frequencies above 1 GHz, for the time interval from 1966 April to 1983 December. They not only found the 152-day periodicity in cycle 20 but also found that this periodicity is phase coherent through cycles 20 and 21. By analyzing Hα flares observed during the interval from 1964 to 1983, Ichimoto *et al.* (1985) also found this periodicity. Raychaudhuri (1986) carried out a 5-month variation of solar neutrino flux data using superposed epoch analysis in the period 1970–1982. He also found this periodicity in the relative sunspot numbers in the period 1975–1979 and suggested that a 5-month core oscillation of the Sun may be responsible for the occurrence of hard solar flares. And finally, studying the relationship between the flare distribution on the Sun and 152-day periodicity, Bai and Sturrock (1987) draw the following conclusions. (1) The 152-day periodicity is a global phenomenon; therefore, the underlying cause of this periodicity must be a mechanism involving the whole Sun. (2) This periodicity is not due to the interaction of 'hot spots' which rotate at different rates so that they align with one another once in a 152-day period. (3) This periodicity is not due to the interaction of rotating features resulting from solar *g*-mode oscillations of an $l = 2$ set and $l = 3$ set. These results provide added support to the reality of the periodicities detected in the present analysis.

In this connection we note that we did not find the periodicities about 156, 4.8, 2.8, and 1.1 months which were pointed out by Landscheidt (1986), for the energetic X-ray flares. Also it is interesting to note that the 26-month periodicity, seen in the green corona (Rušin *et al.*, 1987), and in stratospheric winds (Shapiro and Ward, 1962), however, does not appear in the flare index during cycles 20 and 21. Further study of other solar and geomagnetic indices is needed in order to asses the significance of these periodicities.

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References

Akioka, M., Kubota, J., Suzuki, M., Ichimoto, K., and Tohmura, I.: 1987, *Solar Phys.* **112**, 313.
Ataç, T.: 1987, *Astrophys. Space Sci.* **135**, 201.
Bai, T.: 1987a, *Astrophys. J.* **314**, 795.
Bai, T.: 1987b, *Astrophys. J.* **318**, L85.
Bai, T. and Sturrock, P. A.: 1987, *Nature* **327**, 601.
Belmont, A. D., Dartt, D. G., and Ulstad, M. S.: 1966, *J. Atmos. Sci.* **23**, 314.
Bogart, R. S. and Bai, T.: 1985, *Astrophys. J.* **229**, L151.

Hoyng, P.: 1976, *Astron. Astrophys.* **47**, 449.
Ichimoto, K., Kubota, J., Suzuki, M., Tohmura, I., and Kurokawa, H.: 1985, *Nature* **316**, 422.
Kiplinger, A. L., Dennis, B. R., and Orwig, L. E.: 1984, *Bull. Amer. Astron. Soc.* **16**, 891.
Kleczek, J.: 1952, *Publ. Centr. Inst. Astron.* No. 22, Prague.
Knoška, S. and Petrášek, J.: 1984, *Contr. Astron. Obs. Skalnate Pleso* **12**, 165.
Knoška, S. and Letfus, V.: *Catalogue of Activity of the Solar Flares 1950–1965* (unpublished).
Landscheidt, T.: 1986, *Solar Phys.* **107**, 195.
Mayfield, E. B. and Lawrence, J. K.: 1985, *Solar Phys.* **96**, 293.
Raychaudhuri, P.: 1986, *Solar Phys.* **106**, 421.
Rieger, E., Share, G. H., Forrest, D. J., Kanbach, G., Reppin, C., and Chupp, E. L.: 1984, *Nature* **312**, 623.
Rušin, V., Rybanský, M., and Zverko, J.: 1987, *Bull. Astron. Inst. Czech.* **38**, 181.
Shapiro, R. and Ward, F.: 1962, *J. Atmos. Sci.* **19**, 506.
Vitinskii, Y. I.: 1962, *Solar Activity Forecasting*, Academy Sci. USSR, Leningrad.
Wolff, C. L.: 1983, *Astrophys. J.* **264**, 667.
Yakob, A. and Bhargava, B. N.: 1968, *J. Atmos. Terr. Phys.* **30**, 1907.