FLARE ACTIVITY AND THE STRENGTH OF SOLAR CYCLES

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ABSTRACT

The paper evaluates the solar flare activity during the last three 11-year cycles (the period 1976 – 2001). The flare occurrence follows the solar cycle (SC) with some particularities for each class of flares and with unexpected "pulses" of activity during the descending phase. Here we analyse the solar flare data registered both in Hα and soft X-ray (SXR). The monthly and yearly distribution of the flares is evidenced taking into consideration their released energy. We are searching if the flare activity of a cycle could influence the strength of the following cycle, and if it can be considered as an ingredient in the solar forecasting methods.

1. INTRODUCTION

Continuous flare observations are very important not only for solar studies but also for the consequences they have in the heliosphere, which affect the Earth environment from the outer limits of the magnetosphere to the ground. The final purpose of the flare statistical study is an improved forecast for their occurrence, both at short- and long-term time scales. Currently, the precision of the flare forecast is comparable to the one for the terrestrial weather.

Solar flare patrol begun in 1936, in the Hα line, from ground stations; there used to be a number of 21 flare patrol stations, including the Bucharest one. Sporadic flare records exist since 1859, when the first flare was observed, but as they are exclusively for white light flares, there are only nine events reported for a period of 96 years (1859 – 1954). Since 1975, flares are registered also in SXR (1–8 Å), by GOES satellites.

This wide interval of almost seven SCs of data showed that flare occurrence follows the 11-year solar activity cycle, being more numerous during its maximum phase. However, their time distribution is not the same as for sunspots. Generally, the flare cycle has a longer maximum phase; flares of small importance usually have their maximum before or coincident to the sunspots one, while the majority of more energetic flares tend to occur later. On the descendent phase there are also some periods with increased flare activity.

In the present paper we investigate the flare activity during the SCs, 21 – 23 (1976 – 2001). We have chosen this interval in order to make a comparison between Hα and SXR series of flare observations. This study follows some previous analyses of the flare activity made in our solar group for SC 21 (Dinulescu and Dinulescu, 1991; Mariş and Ţifrea, 1994), SC 22 (Mariş et al., 2002) and the ascending phase of SC 23 (Mariş et al., 2000). A detailed study for Hα flares (during January 1975 – December 1999) and for soft X-ray flares (September 1975 – December 2000) was also made by Temmer et al. (2001; 2002). In the first paper they made a statistical analysis of solar Hα flares, studying temporal flare parameters as duration, rise times, decay times, as well as event asymmetries regarding both N-S and E-W hemispheres. In the second one, they revealed some aspects concerning the N-S and E-W spatial distribution of SXR flares.

Our study comprises practically the same period of flare observation as of the above-mentioned authors, but we come with a supplementary aspect. We are investigating the flares using the Q index, as calculated by Ataç and Özgüç (1996, 2001) and also the Q_x index, defined by Mariş et al. (2002a; 2002b). Both indices measure the quantity of energy emitted by flare events (in the Hα line, respectively in the SXR band).

The present paper is structured as follows: in Section 2, we present the data analysis consisting from the monthly and yearly distribution of the energy released by both Hα and X-ray flares; in Section 3 we discuss our results and, in Section 4, our concluding remarks are drawn.

2. DATA AND METHOD OF ANALYSIS

We are analysing here the energy released by both Hα and SXR flares during the last three SCs (the period 1976 – 2001), using two types of indices that evaluate it: the Q index for Hα flares and the Q_x index for SXR flares. We study the monthly, as well as the annual values of their distribution. Data used in this study were provided by WDC-A for Solar–Terrestrial Physics, NOAA E/GC2, Broadway, Boulder Colorado 80303, USA.

The Q index, computed by Ataç and Özgüç (1996, 2001) from January 1976 to July 2000, was defined by

Kleczeck, (1952) for describing the Hα flare activity over a 24 hour period, as:

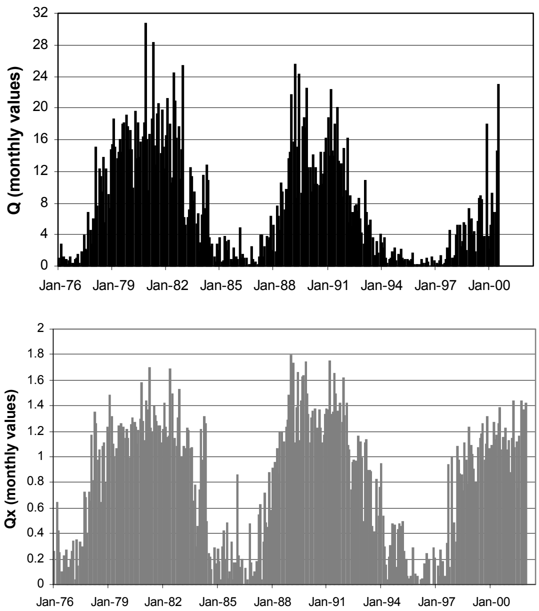
$$Q = i \times t\,, \qquad (1)$$

where i represents the intensity scale of importance of a flare in Hα and t the duration of the flare in minutes. It is assumed that this relationship evaluates roughly the total energy emitted by the flares in the H_α line.

Flares also emit an important amount of energy in the SXR domain. For estimating the flare energy release in the 1−8 Å band, over a period of 24 hours, we calculated a new index, Q_x, defined by Mariş et al. (2002a; 2002b), as:

$$Q_x = i_x \times t, \qquad (2)$$

where i_x is the intensity scale of importance of the X-ray flare spectral class and t is the duration of the flare in minutes.

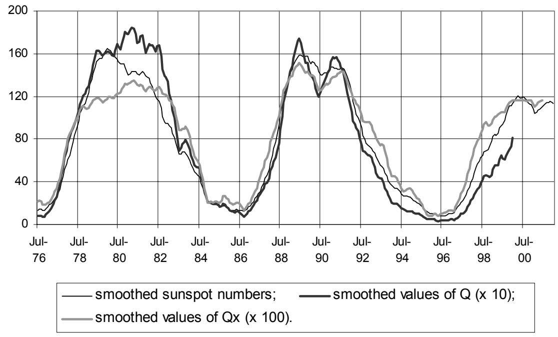


The histograms representing the monthly distributions of the used indices are given in Fig. 1: the Q index for the period January 1976 – July 2000 (the upper panel), and the Q_x index for January 1976 – December 2001 (the bottom panel).

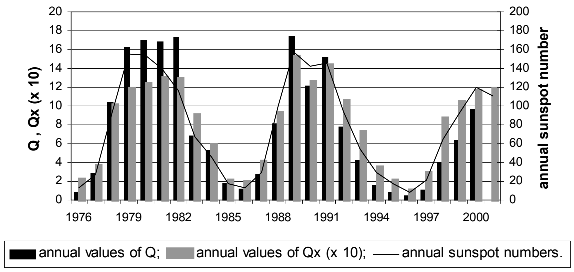
For better inferring the cycle aspect of Q and Q_x indices we analysed their smoothed monthly mean values. This smoothing method is used also for the Wolf numbers in forecasting studies, because it eliminates the seasonal variations. The values are calculated according to:

$$Q_s = \frac{Q_{i-6} + Q_{i+6} + 2\sum_{j=i-5}^{i+5} Q_j}{24} \qquad (3)$$

The smoothed values of the two indices, (multiplied by 10 for the Q index and by 100, for the Q_x index), are given in Fig. 2, where one can also see the smoothed sunspot numbers, for comparison.



In addition to the monthly distributions, we have analysed the annual values of the flare indices. The histograms are plotted in Fig. 3, which also contains the



annual sunspot relative number.

3. RESULTS

The time distribution of the used flare indices reveals the same 11-year periodicity as for the flare number (Mariş et al., 2002a) and other solar activity indices. The Q and Q_x indices estimate the flare energy by contribution of each event according to its importance (or spectral class) and duration. Therefore, we consider that they give a better idea than the flare number about the strength of a cycle regarding the flare activity. Consequently, we evaluate the possible importance of such an approach for studying the dynamics of an 11-year SC. We also discuss the potential utility of those indices in estimating the level that can be reached by the global solar activity during an 11-year cycle.

3.1. Monthly values

The aspect of the 11-year cycle is not the same for the two indices: for the Q_x index, it presents a larger maximum period than for the Q index (Fig. 1).

For SC 21 the Q index has a pronounced maximum, with a long duration. SC 22 shows a double maximum while SC 23 has a longer minimum period than the precedent one, with smaller values. Generally, there are big index fluctuations from month to month, and they are mainly due to the active regions existing on the solar disk during some intervals.

For the SXR flare index, Q_x, the maximum phases are wider than for the Q index. One can notice increased oscillations of Q_x values during minimum phases of activity in comparison with the oscillations of Q values. For SC 22 the structure with double maximum is present, too, while for SC 23 the Q_x values are evidently bigger than for Q. That is because the contribution of the C-class SXR flares to the Q_x index is of about 43%. Regarding the number of events, the SXR flares of class C on the ascending phase of SC 23 are more than for the same period of SC 22, while the ones of class M and X are less (see Fig. 1 of Mariş et al., 2000). Nevertheless, the contribution of the energy released by the C-type SXR flares to the total amount of flare energy is of only 5% during the interval 1976 – 2001 (Oncica et al., this volume).

In order to evaluate the flare activity during the considered cycles, we calculated the Q and Q_x mediated values (Q_m and $Q_{x,m}$ obtained as ΣQ and ΣQ_x, respectively, divided by the number of the months for each period considered), for the whole length (T) as well as for the ascending (A) and descending (D) phases. As one can see in Table 1, the Q_m values are bigger for SC 21 than for SC 22 while the $Q_{x,m}$ values are practically, the same. For SC 23 we do not have enough data for all estimations. However, we calculated Q_m and $Q_{x,m}$ for the periods which we have (the rows on the gray background). The $Q_{x,m}$ value for the ascending phase of SC 23 is comparable with the corresponding values of SCs 21 and 22 while the Q_m value for SC23 is much smaller than for SCs 21 and 22.

Table 1. The values of the Q and Q_x indices ,for SCs 21 – 23

SC	Period	Q	Q_x
21	T/Jun. 1976 – Aug. 1986	9.33	0.81
	A/Jun. 1976 – Nov. 1979	8.13	0.73
	D/Dec. 1979 – Aug. 1986	9.95	0.85
22	T/Sep. 1986 – Sept. 1996	6.99	0.81
	A/Sept. 1986 – Jun. 1989	7.17	0.81
	D/Jul. 1989 – Sept. 1996	6.92	0.81
23	Oct. 1996 – Dec. 2001	-	0.88
	Oct. 1996 – Jul. 2000	4.38	-
	A/ Oct. 1996 – Mar. 2000	3.69	0.73

We evaluated the maximum phases of SCs 21 and 22 by the mediated values, calculated for four years and 10 months (SC 21) and four years, respectively (Table 2, the rows with M). The obtained values of Q_m and $Q_{x,m}$ are practically equal for the two cycles but higher than their values for other phases or for the whole cycles.

The descendent phases of both SCs 21 and 22 present some sudden growths ("pulses") of solar activity; the periods of occurrence, as well as indices mediated velues during these periods are also given in Table 2. One can observe that the values for both pulses of SC 21 are comparable to the index mediated value over the whole cycle. The same observation is valid also for the first pulse of SC 22 but the following ones and much smaller.

Table 2. The values of the Q and Q_x indices, during the maximum phases and the "pulses" on the descending phase for SCs 21 and 22.

SC	Period	Q_m	$Q_{x,m}$
21	M/Feb. 1978 – Dec.1982	15.69	1.22
	May – Oct. 1983	8.90	1.00
	Jan. – May 1984	9.76	1.10
22	M/Feb.1988– Feb.1992	14.74	1.40
	Feb. 1993 – Jun. 1993	6.75	1.00
	Oct. 1993 – Mar. 1994	2.92	0.65
	Jun. – Oct. 1994	1.34	0.35

3.2. Smoothed monthly values

From the smoothed values of Q, respectively Q_x indices (Fig. 2) the trend of the SCs, regarding the flare energy released in comparison to the classical 11-year cycle of sunspot numbers, can be inferred. For SC 21, it is clear that the maximum values of the indices for both types of flares are delayed in respect to the sunspot relative number, while for SC 22 the two maxima are happening simultaneously and are showing the same double-peak structure. For the ascending phase of SC 23, one can also see that the maximum smoothed values for both the Q_x index and sunspot numbers are temporally coincident and it seems that they will both have a second maximum.

3.3. Annual values

The annual values of the Q index presents, for SC 21, a maximum phase of four years during 1979 – 1982, with the higher value in 1982 (Fig. 3). SC 22 has a double maximum profile for the years 1989 and 1991, the first peak being the highest. The minimum phase between SCs 22 – 23 is more prominent than the minimum phase between SCs 21 – 22. SC 23 has a slow increase during its ascending phase.

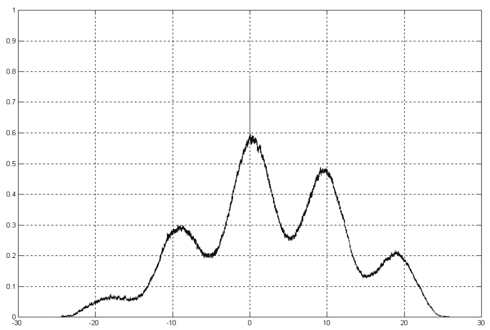
For the Q_x index, SC 21 maximum phase is longer (five years, 1978 – 1982). SC 22 shows the same double maximum structure in 1989 and 1991, with the first peak bigger, but closer to the value of the second one. The growth in the activity of SC 23 is stepper, due to the fact that during this cycle there are more flares of small importance. The annual value of the Q_x index for 2001 is greater than for the previous year.

3.4. Cross-correlation of Q and Q_x

Next, we analysed the correlation between the two flare indices (Q and Q_x).

In this end we translated the log scale of the Q_x index into the energy domain, X (see Oncica et al., this volume). The same procedure was not possible for the Q index as it is expressed in terms of H_α flare area. We did not found yet a method to bring in the flare brightness scale (f – faint; n – normal; b – bright) to reconstruct the flare energy.

Fig. 4 represents the normalized cross-correlation functions between the two flare indices, Q and X.



This cross-correlation presents an important maxim value (60%) which is not surprising, as long as both indices have relatively the same provenience. Moreover, one can clearly observe the cycle length of less than 10 years.

4. DISCUSIONS

In this paper we have tried to infer some characteristics of the solar flare activity during SCs 21–23, using two indices, Q and Q_x, that estimate the energy of the flare events in the Hα line and in the SXR band of 1–8 Å, respectively. The Q and Q_x indices show a delay regarding the sunspot activity for SC 21, while for SC 22 and 23 their time distribution is almost coincident with the time distribution of sunspot relative number. The Q_m values in Table 1 show a decreasing flare activity from SC 21 to SC 23 meanwhile the $Q_{x,m}$ values show a constant SXR energy emitted by flares.

The growths of flare activity during the descendent phases of the SCs ("pulses") are greater than for sunspot ones, especially for the Q_x index and for the periods closer to the minimum. They represent the energy released mainly by small importance flares, that probably appear because of the interaction between the magnetic fields on large as well as small scale, belonging to the old and to the new solar cycle, with a reversed dipole. Most of those pulses from the descendent solar activity phases had important geophysical effects on the terrestrial environment.

We did not notice any important feature in the cyclic distributions of Hα and SXR flare indices that would be able to indicate any future behaviour of the solar activity. We did not find, therefore, any method to infer if the study of those indices could be helpful for forecasting procedures.

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