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The curious temporal behavior of the frequency of different class flares

Q1 P.X. Gao [a,b,*], J. Zhong [c]

[a] Yunnan Observatories, Chinese Academy of Sciences, Kunming 650011, China
[b] Key Laboratory of Solar Activity, National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China
[c] Kunming No.3 Middle School, Kunming 650011, China

HIGHLIGHTS

- We investigate the behaviors of the frequency of all, B, C, M and X-class flares.
- We found that the temporal behaviors of these class flares are quite different.
- The B-class flares are in complete antiphase with all, C, M and X-class flares.
- The peak values of the C-class flare numbers decrease only slightly during SC 23.
- The frequency of M and X-class flares drop by more than half during SCs 23.

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ABSTRACT

We investigate the frequency of all (X-ray flare events higher than class B1.0), B, C, M and X-class flares, respectively, derived from the National Geophysical Data Center (NGDC) list of solar flares between May 1983 and September 2014, which corresponds to the two complete solar cycles (SCs) 22 and 23 as well as the rise and maximum phases of SC 24. Analysis shows that the temporal behavior for these various class flares is quite different. The main findings of this study, confirmed by using the Hinode flare catalog where possible, are as follows. (1) The B-class flares are in complete antiphase with all, C, M and X-class flares. (2) While, there is a small decreasing trend in the peak values of the smoothed monthly C-class flare numbers from SC 22 to 24, the occurrence rate of M and X-class flares dropped by almost half and two-thirds, respectively, during SC 23 and remained almost the same during SC 24. This class-dependent temporal behavior provides support for dynamo models that involve the coexistence of a deep global and a superficial local dynamo.

1. Introduction

Activity on the Sun exhibits complex temporal behavior, for example, the periodic variations of solar activity which have been the subject of extensive study (Chowdhury et al., 2013; Forgacs-Dajka and Borkovits, 2007; Li et al., 2006; Lou et al., 2003; Ozguc et al., 2003; 2004; Schwabe, 1844; Vecchio and Carbone, 2009; Zaqarashvili et al., 2015; Zou and Li, 2014). Moreover, solar activity has been found to be asymmetrical between the northern and southern hemispheres (Bell, 1961; Deng et al., 2013; Li et al., 2002a; Newton and Milson, 1955; Waldmeier, 1971), while correlation analysis of data for high and low latitude solar activities shows that the solar activity in high and low latitudes are not in phase (Li et al., 2002b; Makarov and Makarova, 1996; Saito and Tanaka, 1960; Sheeley, 1991). These studies indicate that complex temporal behaviors are real phenomena and not due to random fluctuations, and studying these behaviors could help in understanding the mechanism underlying the temporal behavior of solar activity. However, the only consensus to date concerning identification of such complex temporal behaviors in detail is the 11-year cyclic variation discovered by Schwabe (1844).

Recently, some reports (Gao et al., 2012; Kilcik et al., 2011; 2014a; 2014b; Lefevre and Clette, 2011; Nagovitsyn et al., 2012) have determined that the temporal behaviors of the solar activity of various categories are quite different and the following is a summary of their conclusions. (1) The occurrence rate of the smallest sunspots was more than halved during solar cycle (SC) 23 compared to SC 22, while the number of larger spots showed no significant difference between the two SCs (Kilcik et al., 2014b; Lefevre and Clette, 2011). (2) Except for SC 22, sunspot groups have asymmetrical time distributions between the large and small sunspot group numbers (Kilcik et al., 2011). (3) A negative correlation between the fractions of small and large sunspot (group) was identified by Nagovitsyn et al. (2012) and Kilcik et al. (2014b), although small and large sunspots (sunspot groups) are all following solar activity cycle. (4) The periodic behaviors of the different sunspot categories are not exactly the same

Q2 * Corresponding author at: Yunnan Observatories, Chinese Academy of Sciences, Kunming 650011, China. Tel.: +86 871 6392 0142; fax: +86 871 6392 0599, +86 871/63920154.
E-mail address: gaopengxin@ynao.ac.cn, lanyue1981@126.com (P.X. Gao).

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(Kilcik et al., 2014a). (5) The cyclic behavior of long solar filaments is also different from those of short solar filaments (Gao et al., 2012).

Above results prompted us to analyze solar activity in more detail, and we have found that the aforementioned results are subject to the separation criteria. A widely accepted classification system divides solar flares according to their strength in X-rays. Based on this classification system, solar flares are classified as A, B, C, M or X. X-ray flare events are recorded by the Geostationary Operational Environmental Satellites (GOES) when X-ray fluxes are above the B1.0 threshold. Thus, in this paper, we investigated the frequency over time of all (X-ray flare events higher than the B1.0 class), B, C, M and X-class flares, respectively, for SCs 22, 23 and the rise and maximum phases of SC 24 that occurred between May 1983 and September 2014.

2. Data

For this study, flare time sequences were derived from the flare list provided by the National Geophysical Data Center (NGDC).[1] To remove short-term fluctuations and reveal long-term trends, we smoothed the monthly flare numbers using the common 13-month running mean smoothing technique.

The flare list of the NGDC potentially contains random and systematic errors. To further confirm our results, the recent flare data were compared with the Hinode flare catalog[2] data. These flare events are observed by the X-ray Telescope (XRT; Golub et al., 2007; Kano et al., 2008), which has the capability to observe the full solar disk of 2048 × 2048 arcsec with a pixel size of 1 arcsec, the EUV Imaging Spectrometer (EIS; Culhane et al., 2007), which has a maximum FOV of 590 × 1024 arcsec with a pixel size of 1 arcsec, and the Solar Optical Telescope (SOT; Tsuneta et al., 2008; Suematsu et al., 2008; Ichimoto et al., 2008; Shimizu et al., 2008), which has a much smaller maximum FOV of 328 × 164 arcsec with a pixel size of 0.08 arcsec. These instruments are on board the Hinode satellite (Kosugi et al., 2007). Observations from the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI; Lin et al., 2002) and the Nobeyama Radioheliograph (NoRH; Nakajima et al., 1994) are also included in this catalog(Watanabe et al., 2012). The Hinode data starts in October 2006.

3. Results

Fig. 1 shows the 13-month smoothed monthly flare numbers as a function of time from May 1983 to September 2014 for all, B, C, M and X-class flares, respectively. From the figure, it is quite apparent that the temporal behaviors of the various flare classes differs quite substantially.

We can observe several notable trends. First, the B-class flares are in complete antiphase with all, C, M and X-class flares except for during the lower values around 2009. Second, there is a small decreasing trend in the peak values of the smoothed monthly C-class flare numbers from SCs 22 to 24 (the available portion), which is consistent with that of all flares. Furthermore, the peak values of the smoothed monthly flare numbers for M and X-class flares are half and one-third in SC 23 compared to SC 22, and their magnitudes remained low in both SCs 23 and 24 with little variation from the available data. In order to describe the existing trend in the time profiles of the smoothed monthly flare numbers quantitatively, Table 1 shows the peak values of the smoothed monthly flare numbers for C, M and X-class flares during SCs 22 and 23, and also the ratios of the peak values of SC 22 to SC 23.

Then, we calculated the 13-month monthly numbers of all (X-ray flare events higher than the B1.0 class), B, C, M and X-class flares, respectively, in Hinode flare catalog from October 2006 to September 2014, which are also shown in Fig. 1. The trends in the time profiles of the smoothed monthly flare numbers derived from the Hinode flare catalog are consistent with those determined from the NGDC flare list.

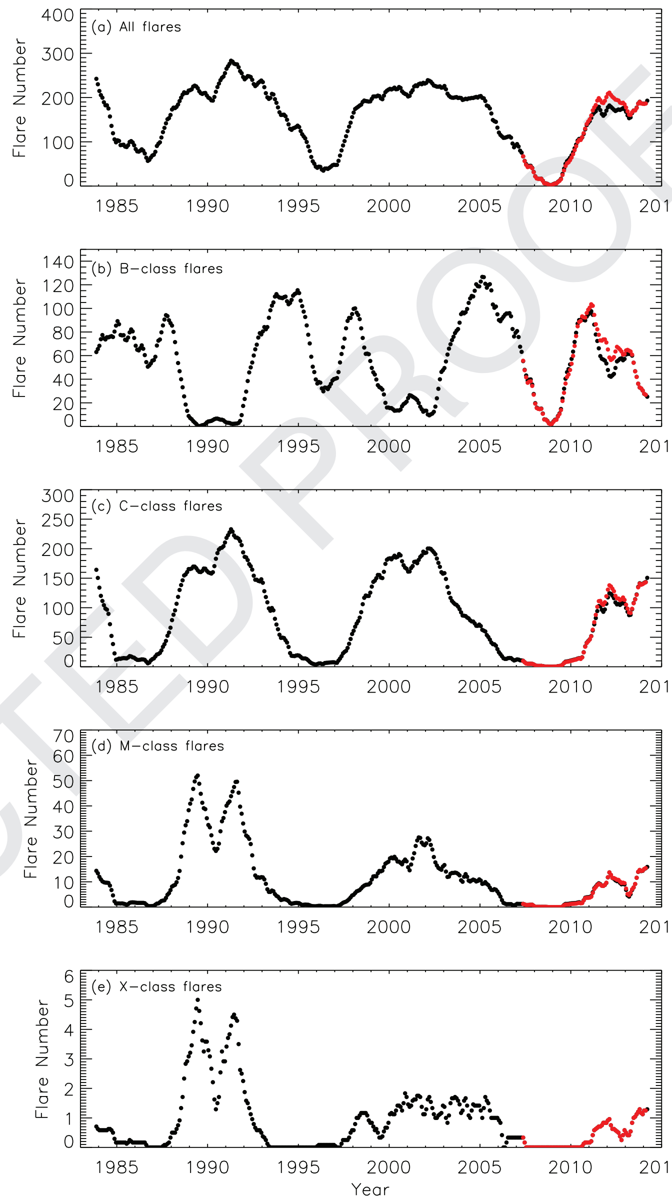

Fig. 1. Temporal variations of the 13-month smoothed monthly numbers of all (X-ray flare events higher than the B1.0 class) (a), B (b), C (c), M (d) and X-class flares (e). These data are derived from the list of NGDC (black filled circle) and the Hinode flare catalog (red filled circle). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.) Q3

Table 1
For C, M, X-class flares and Hα flare index, the peak values of the smoothed monthly numbers or index during SCs 22, 23 and their ratios.

	SC 22 Peak value	SC 23 Peak value	SC 22/SC 23 Peak value$_{SC22}$ / Peak value$_{SC23}$
C-class flare	232.91	200.33	1.16
M-class flare	52.00	27.54	1.88
X-class flare	5.00	1.83	2.73
Hα flare index	17.46	6.21	2.81

[1] ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/
[2] http://st4a.stelab.nagoya-u.ac.jp/hinode_flare/ .

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