SOFT X-RAY FLARES FOR THE PERIOD 1975–2000

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ABSTRACT

Statistical aspects of solar soft X-ray (SXR) flares for the period September 1975 to December 2000 are investigated. In particular, we analyzed the spatial distribution of SXR flares with regard to the solar hemispheres, i.e. N-S and E-W asymmetries, as well as the occurrence of SXR flares in the course of the solar cycle. We obtain that the occurrence rate of SXR flares is delayed in relation to the Sunspot Numbers which can be interpreted as an interaction between the northern and southern hemisphere activity.

Key words: solar flares; soft X-rays; solar activity; statistics.

1. INTRODUCTION

Almost continuous observations of disk-integrated soft X-ray (SXR) emissions have been made since 1974 by the National Oceanic and Atmospheric Administration (NOAA). Especially since the launch of the GOES mission in 1975 an almost unbroken record of SXR flare events is provided, comprising two whole solar cycles, 21 and 22, and the rising phase of the current cycle 23 (Garcia 2000).

On the basis of this comprehensive data set we make a statistical analysis of spatial distributions of SXR flare events during various solar cycles with regard to the solar hemispheres both in latitude and longitude. Additionally, the occurrence frequency of SXR flares relating to photospheric activity phenomena, like Sunspot Numbers and sunspot areas, is investigated. Moreover, the northern and southern hemisphere activity of SXR flares is analyzed separately concerning their cyclic behavior. Therefore a cross-correlation analysis with sunspot areas of the northern and southern hemisphere, respectively, is made.

2. DATA SELECTION

During the considered time span September 1975 to December 2000, 49,443 flare events were measured by GOES satellites in the 0.1–0.8 nm band, which are collected in the Solar Geophysical Data (SGD). Due to the varying SXR background flux as a result of solar activity only C, M and X class flares are considered for the following investigation. During times of solar maximum the background emission is so high that A and B class flares cannot be detected (e.g., Feldman et al. 1997). Thus out of the basic data set a sample of 37,868 flare events of class C, M or X, and out of this 23,217 flare events for which the heliographic coordinates are given, is selected.

3. RESULTS

3.1. N-S asymmetry

Out of the SXR flare events for which the heliographic latitude is given, 47.6% northern and 52.4% southern events are reported, thus a slight excess of the southern hemisphere is received for the overall period. Fig. 1 shows the cumulative number of flares that occurred in the northern (solid line) and the southern (dashed line) hemisphere, respectively. The vertical spacing between the two lines is a measure of the northern/southern excess of SXR flares up to that time. Solar cycle 21 reveals a slight (51.0%) and solar cycle 22 a distinct (56.2%) excess of flare events in the southern hemisphere. For the rising phase of solar cycle 23 an obvious excess of the northern hemisphere is obtained, but this should not be considered as the final result since the presented sample of data covers only about a third of the whole cycle.

Previous studies that investigated the N-S asymmetry of solar SXR flares covering shorter periods, obtained similar results. García (1990) analyzed SXR flares ≥M9 during solar cycle 21, concluding from the cumulative number of flares (cf. Fig. 1, top panel) that the N-S distribution of SXR flares evolves in
eastern and 49.2% for the western hemisphere which points out a slight E-W asymmetry. This eastern excess is also given for solar cycles 21 (51.2%) and 22 (50.8%) separately as shown in Fig. 2. However, the western excess of the current cycle cannot be seen as a final result yet (see also Sect. 3.1).

Li et al. (1998) found similar results within their study of flare events ≥M1 during the period 1987–1992, namely 51.1% events on the eastern and 48.9% on the western hemisphere, which they considered as not significant in terms of an E-W asymmetry. Nevertheless, many other authors that studied solar flares on E-W asymmetry within various solar cycles found significant eastern excesses (see Temmer et al. 2001, and references therein). Since the longitude measurement is dependent on the reference position, there is no obvious physical reason for an E-W asymmetry that exists for more than one solar rotation.

Figure 1. Cumulative histograms of SXR flares for the northern (solid line) and southern hemisphere (dashed line) including solar cycle 21 (top panel), cycle 22 (middle panel) and the rising phase of cycle 23 (bottom panel). Triangles mark the peak of the solar cycle.

phase with the solar cycle. However, as can be seen in the middle panel of Fig. 1, no such behavior can be inferred for solar cycle 22. Viktorinová & Antalová (1991) who investigated during the same period SXR long-duration events found that the activity alternates between north and south at the end of the cycle. Li et al. (1998), who analyzed SXR flares ≥M1 during the maximum phase of solar cycle 22, found an overall predominance of the southern hemisphere. The global behavior of the N-S asymmetry of SXR flare occurrence represented in Fig. 1 is very similar to those of Hα flares, investigated during the same period by Temmer et al. (2001).

The N-S asymmetry is not fully interpreted. A possible explanation might be a time difference in the evolving of activity for both hemispheres (e.g., Trikitakis et al. 1997) whereas the asymmetry should coincide with the solar cycle. A further one is the occurrence of 'superactive regions' on the Sun which are large, complex and thus very flare-active regions appearing within 'active zones', special regions that might exist more than a solar rotation (Bai 1987, 1988).

3.2. E-W asymmetry

For the distribution in heliographic longitude including the whole time span, we get 50.8% events for the

Figure 2. The same as in Fig. 1 but for the eastern and western hemisphere, respectively.

3.3. Correlation with photospheric activity indices

Fig. 3 shows the annually smoothed (13-point running average) monthly Sunspot Numbers, total sunspot areas and number of SXR flares for the time span 1975–2000. One can see that the flares do not peak at the same time with the Sunspot Numbers. For solar cycle 21 also the sunspot areas do not reach their maximum in coincidence with the Sunspot Numbers. Nevertheless, the SXR flares reveal a slightly higher correlation coefficient with the sunspot areas (0.90) as with the Sunspot Numbers (0.86), whereas the sunspot areas are quite in correlation with the Sunspot Numbers (0.98).
By calculating the cross-correlations of Sunspot Numbers and SXR flares separately for the solar cycles, we obtain a second maximum with a lag of 10 months for cycle 21 and increased values after about 3 months for solar cycle 22. This differs from Wheatland & Litvinenko (2001) who analyzed SXR flares >C1 class based on a data set from 1976–1999, obtaining an average delay of about 6 months without separating the solar cycles. A detailed analysis of cycle 23 (see also Fig. 3) indicates that the Sunspot Numbers as well as the sunspot areas already start to decrease after a maximum phase during the year 2000 whereas the SXR flares do not follow this behavior. Thus, also for the current cycle a time delay is suggested but cannot be seen as a final result yet.

Figure 3. Annually smoothed data of monthly Sunspot Numbers (top panel), sunspot areas (middle panel) and SXR flares (bottom panel) covering the time span from 1975 to 2000. Solid lines indicate the maximum and dashed lines the minimum of the particular solar cycle. (Data of sunspot areas are taken from the Royal Greenwich Observatory, the Sunspot Numbers are taken from the SGD.)

In Fig. 4 the sunspot areas and SXR flares from 1976 to 2000 are plotted separately for the northern and southern hemisphere. Since hemispheric data that include this time span are not available for Sunspot Numbers and the sunspot areas are altogether in good correlation with the solar cycle, the sunspot areas are taken here as a proxy for the solar cycle concerning the two hemispheres.

From Fig. 4 one can see that the northern hemispheres for both activity indices show a steep increase until their first peak of the double-structured activity cycle which is reached before the solar cycle maximum (e.g., Bazilevskaya et al. 2000, Feminella & Storini 1997, and references therein). However, for SXR flares the maximum peak is not reached until their second activity phase which is some years later in the solar cycle, whereas for the sunspot areas the second peak is the lower one. Furthermore, while the northern hemispheres are in the first rising phase the southern hemispheres exhibit a relative low activity, but do start to increase steeply during the second part of the dual-peak maximum, which is much more pronounced for SXR flares. Thus, a peak time delay is indicated from the northern and the southern hemisphere activity.

Figure 4. Top down: annually smoothed data of northern SXR flares, northern sunspot areas, southern SXR flares and southern sunspot areas, covering the time span from 1975 to 2000.

Fig. 5 shows the cross-correlation of sunspot areas and SXR flares as a function of lag in months calculated separately for solar cycle 21 and 22. Results for 1) cycle 21: The southern hemisphere shows pronounced secondary peaks at +8 and +15 months, indicating that the southern SXR flares are delayed with respect to the southern sunspot areas. No distinct secondary peaks occur for the northern hemisphere activity. 2) cycle 22: The southern hemisphere has a pronounced secondary peak at +7 months, whereas the northern one reveals for positive lags more or less continuously decreasing values, but shows weak enhancements at –6 and –8 months.
with respect to the sunspot areas. The overall outcome for both solar cycles is dominated by the southern hemisphere, as their secondary peaks are all well reflected. Thus an overlap effect of both hemispheres is given with a higher importance on the southern hemisphere concerning the delay of SXR flares.

![Figure 5. Cross-correlation of sunspot areas and SXR flares for the northern hemisphere (thin line), southern hemisphere (thick line) and for the whole disk (dotted line) separately plotted for solar cycles 21 and 22.](image)

4. DISCUSSION AND CONCLUSION

Although for the SXR background flux a similar result is obtained with a peak time delay of 2–3 years later than the Sunspot Numbers during solar cycle 21 (e.g., Wagner 1988, Pearce et al. 1992, Wilson 1993), this phenomenon is not only limited to SXR measurements. Also other coronal activity indicators reveal a peak delay, such as the coronal green-line emission (Rybanský et al. 1988) or hard X-ray observations (Bai 1993, Bromund et al. 1995). Aschwanden (1994) explains this result as directly related to the corona which starts to increase its complexity in structure when the solar cycle already decreases, thus solar activity indicators that are of coronal origin coincide with this behavior. However, this delay is only clearly pointed out for solar cycle 21, whereas solar cycle 22 does not distinctly reveal this result (e.g., Rybanský et al. 1998, Wilson 1993, present paper). As shown in this paper, the delay can be interpreted in terms of northern and southern hemispheric activity. Thus, a longer period than just the 11 years activity cycle may exist within which the northern and the southern hemisphere, respectively, may alternate (e.g., Li et al. 2001).

Nevertheless, a closer connection to the underlying photospheric magnetic field which is obviously given since the SXR flares show a rather high correlation to the sunspot areas should motivate not only to consider the corona as responsible for this effect. Furthermore the general magnetic field that causes the activity gap according to its inversion (Feminella & Storini 1997) has to be studied in more detail because it occurs during the second peak, hence after the inversion, where the SXR flares just start their major activity, at least the southern hemisphere. This should initiate further studies on the solar hemispheres in different layers of the Sun especially with attention to the global magnetic field and the field reversal.

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