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Periodical patterns in major flare occurrence and their relation to magnetically complex active regions

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Abstract

A periodical occurrence rate of major solar flares (observed in hard X-rays) of ~24 days (synodic) was first reported by Bai (1987) [Bai, T. Distribution of flares on the sun – superactive regions and active zones of 1980–1985. ApJ 314, 795–807, 1987] for the years 1980–1985. Here, we report a significant relation between the appearance of the 24-day period in major Hα flares and magnetically complex sunspot groups (i.e., including a γ and/or δ configuration). From synoptic maps of magnetograms (NSO/KP) patterns in the magnetic flux evolution are traced which might be the cause of the 24-day period observed in flare activity.

Keywords: Solar flares; Solar activity; Magnetic fields

1. Introduction

Mean synodic periods reported for the differential rotation of the Sun are within ~26.5 days[1] near the solar equator and ~29.5 days around 40° latitude (e.g., Howard, 1984; Balthasar et al., 1986). On average, the most prominent period as observed in solar data manifests itself with a ~27-day period. Another outstanding period observed in solar activity tracers is in the range of ~24 days (see Bai, 1987; Pap et al., 1990; Zięba et al., 2001; Henney and Harvey, 2002; Temmer et al., 2003). As first reported by Bai (1987), a 23.8 days period was observed for high-energetic hard X-ray flare events during cycle 21 (1980–1985). Temmer et al. (2004) performed a systematic study regarding the occurrence rate of solar Hα flares for the time span 1955–1997 and found a ~24-day period in all four cycles studied (Nos. 19–22). A 24-day period in accordance with that found for Hα major flares (importance class ⩾1) was also found in the occurrence rate of magnetically complex active regions (including classification γ and/or δ), whereas it could not be established in magnetically non-complex (α, β) sunspot groups. From solar rotation studies based on tracing sunspots practically no siderial rotation velocities as high as 16°/day (which corresponds to a synodic period of ~24 days) are reported (e.g., Godoli et al., 1998; Pulkkinen and Tuominen, 1998; Suzuki, 1998). Thus, the cause of the 24-day period is very likely not related to solar surface rotation. However, physical reasons for this periodical flaring rate are still missing.

In the following, we investigate the occurrence of the 24-day period for corresponding time series of major flares and magnetically complex active regions by applying wavelet power spectra. Additionally, for selected time ranges in which the 24-day period is revealed, synoptic maps of magnetograms together with the flare locations are studied. This enables us to draw a physical

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[1] All periods stated in this paper are synodic.

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link from the pure statistical results available up to now to the original data.

2. Data and methods

Temmer et al. (2004) investigated wavelet power spectra for daily numbers of Hα flare events and daily numbers of magnetically classified active regions, respectively, over a total solar cycle length. A simultaneous appearance of a ~24-day period in major flares (importance class ⩾1) and magnetically complex active regions (including a γ and/or δ classification) was found for three time ranges during solar cycles 20–22, namely for the years 1968–1969 and 1982–1983 for the northern, and 1989–1990 for the southern solar hemisphere.

In the following, we calculate wavelet power spectra (WPS) for daily rates of major Hα flares (Solar Geophysical Data) and daily rates of magnetically complex sunspot groups (Mount Wilson Observatory) for the time ranges listed above. Using different angular frequencies ω (cf. Eq. (1)), one can specify either a high resolution in time or a high resolution in frequency. Here, we have chosen the values $\omega = 36$ to obtain a high frequency resolution as well as $\omega = 6$ to obtain a high temporal resolution. This enables us to determine predominant periods together with their exact time of occurrence. The angular frequency, ω_k, within the continuous wavelet transform is defined as

$$\omega_k = \begin{cases} \frac{2\pi k}{N\delta t}, & k \leqslant \frac{N}{2}, \\ -\frac{2\pi k}{N\delta t}, & k > \frac{N}{2}, \end{cases} \qquad (1)$$

where δt is the equal spacing in time and N the number of data points in the time series. All WPS presented in this paper were calculated for the period range 20–30 days. As significance tests, confidence levels at 90%, 95%, and 99% are calculated using a red noise background spectrum based on the assumption that daily flare data are correlated (Oliver and Ballester, 1995). The computation of all these parameters is performed in the way described by Torrence and Compo (1998).

During time ranges in which a ~24-day period was found, synoptic magnetic maps are studied (National Solar Observatory/Kitt Peak; available since 1973) which are derived from daily full-disk photospheric magnetograms of the Sun with each of these maps representing one Carrington rotation (CR), i.e., 27.2753 days (Harvey et al., 1980; Gaizauskas et al., 1983; Worden and Harvey, 2000). To locate regions of high flare activity, the heliographic coordinates and times of the associated flares were mapped to the corresponding Carrington rotation number and Carrington longitude (L), and superimposed on the synoptic magnetic maps. Due to a low reliability of flare locations close to the solar limb only flares with a distance ⩽60° from the central meridian were taken into account.

3. Results

Fig. 1 shows wavelet power spectra calculated for daily numbers of major Hα flare events (top panels) and daily numbers of magnetically complex active regions (bottom panels) during solar cycle 20 covering CR numbers 1521–1540. The high angular frequency spectra (left panels) show a clear signal at ~23.8 days during CR numbers 1527–1533 almost simultaneously in both data sets.[2] From the low angular frequency spectra (right panels) it becomes obvious that a small overlapping range exists around CR 1530. In summary, a good correlation between the periodical signals found in flare events and magnetically classified active regions can be seen.

Fig. 2 shows wavelet power spectra (left panels) obtained for major flare events and magnetically complex active regions observed during solar cycle 21 for CR 1718–1732. A very good coincidence between the appearance of the 24-day period in high-energetic flares and magnetically complex sunspot groups is found during CR 1723–1726. The power signals as observed in the spectra calculated with $\omega = 6$ are nearly identical, suggesting a common origin. From the synoptic magnetic maps (right panels) covering CR 1720–1726, patterns of a diverging active region are revealed in which the main flare activity occurred. This provides two branches of high activity spatially separated by about 40° within CR 1723–1726. For the correct interpretation of the synoptic maps it is important to note that vertical features observed in successive Carrington rotations have periods identical to the CR period of ~27.3 days, whereas features inclined to the left/right reveal periods that are longer/shorter than the CR rate.

As an example a period of ~27.3 days is obtained if the flare activity feature at $L = 280°$ is tracked from CR 1723 to CR 1724. However, if the feature from CR 1723 at $L = 280°$ is tracked to the feature at $L = 320°$ in CR 1724, then a much shorter period is obtained in the range of ~24.2 days. In general, such a situation arises when flare events are produced by two spatially separated branches of activity. This can be observed within the synoptic magnetic maps in Fig. 2 showing active regions which are shifted by ~40–45° in longitude in two successive CRs.

The WPS in Fig. 3 calculated for major flares and magnetically complex active regions during CR 1810–1824, show a clear coincidence for the periodical occur-

[2] Since our interest is in the 24-day period, we do not discuss periods within the range of solar differential rotation which are also revealed in the WPS.

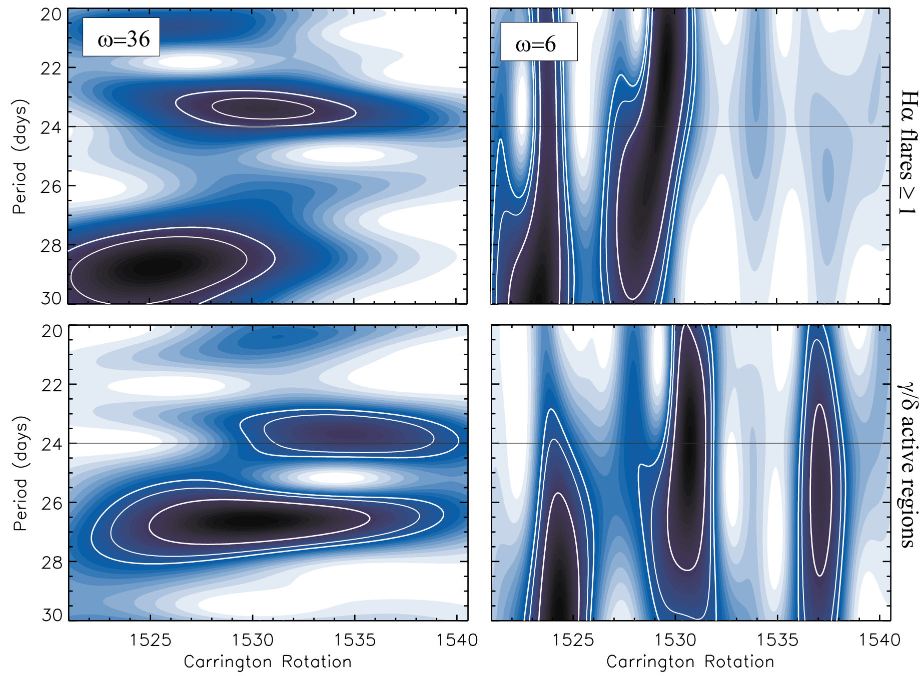

Fig. 1. WPS derived from daily rates of major flares (top) and daily rates of magnetically complex active regions (bottom) for the northern hemisphere during CR 1521–1540 (cycle 20: 1967 May–1968 October) with angular frequency values $\omega = 36$ (left) and $\omega = 6$ (right). Color coding from white to black represents the square root of power on a linear scale. White contour lines from thin to thick denote confidence levels at 90%, 95% and 99%. Horizontal lines are drawn for a period of 24.0 days.

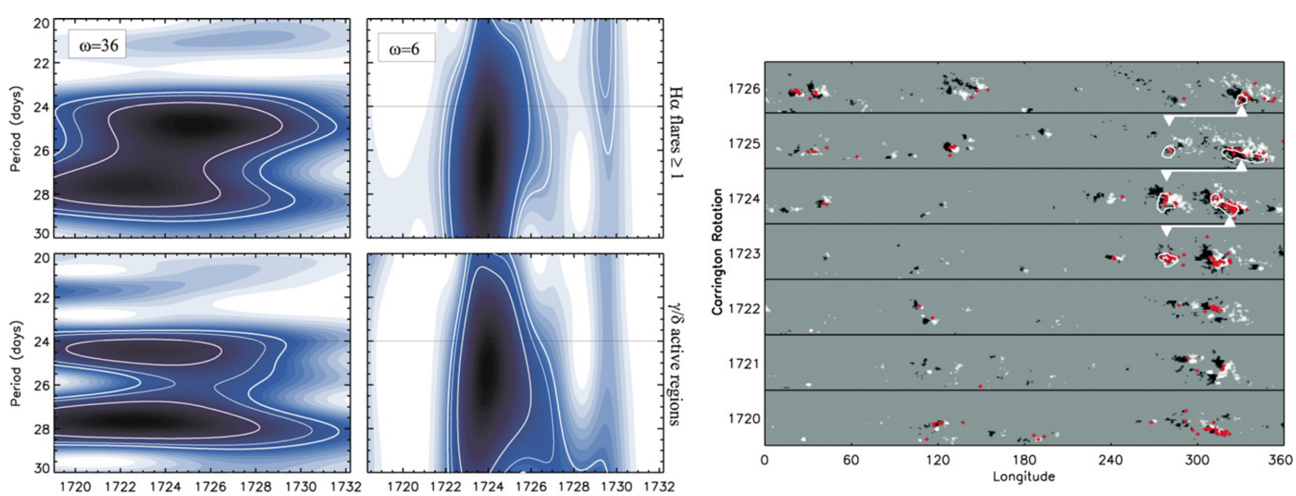

Fig. 2. Left: WPS performed in the same way as given in Fig. 1 but for the northern hemisphere during CR 1718–1732 (cycle 21: 1982 January–1983 February). (Right) Stripes of synoptic magnetic maps for the belt N0°–N40° for CR 1720–1726 (1982 March–1982 September). The line-of-sight component of the magnetic field is represented as white/black for positive/negative polarity. Areas outlined by white lines indicate regions of major flare activity. White arrows mark the separation between two flare producing active regions in successive Carrington rotations which correspond to a quasi-period of ~24 days.

rence of both activity parameters with ~24 days from CR 1818 to 1820. For this time range the synoptic maps reveal the presence of two converging active regions that merge together at CR 1820 and are highly flare productive. The two branches are separated by ~45° in longitude in successive CRs corresponding to a quasi-period of 23.9 days, again close to what is observed in the WPS.

4. Summary and discussion

From the wavelet analyses performed with high time resolution a distinct coincidence for the periodical occurrence of major flares and magnetically complex sunspot groups within the range of ~24 days is revealed. It is known that the vast majority of big flares is produced by only a small fraction of large active regions of magnet-

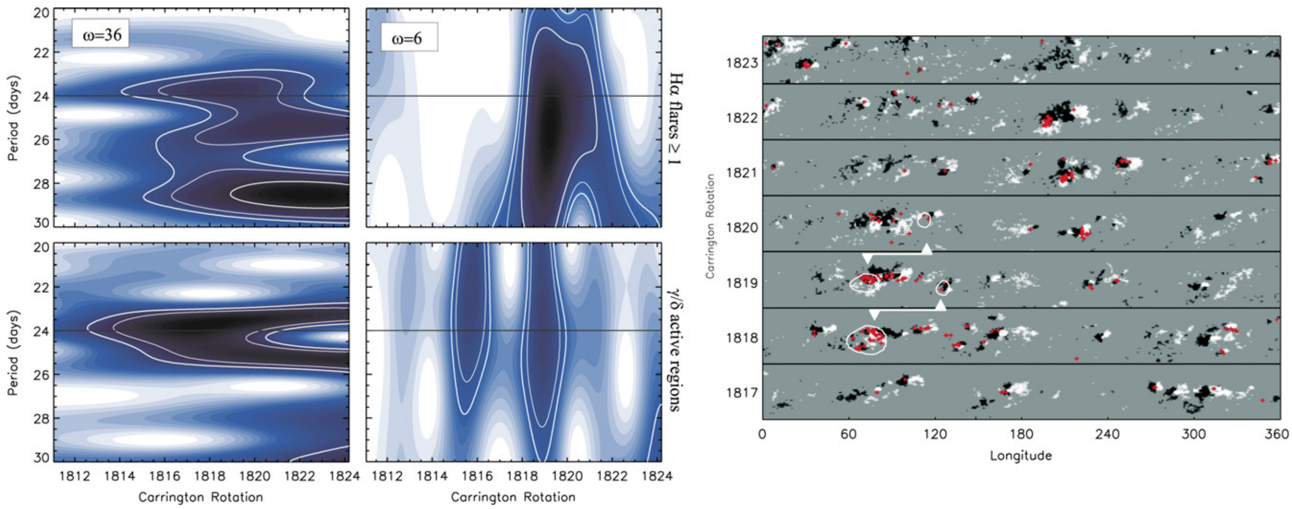

Fig. 3. Same as in Fig. 2 but for the southern hemisphere during CR 1810–1825 (cycle 22: 1988 December–1990 January). Stripes of synoptic magnetic maps are for the belt S0°–S40° for CR 1817–1823 (1989 June–1989 December).

ically complex configuration (see Bai, 1987; Sammis et al., 2000). Thus, a common origin of the 24-day period for both activity phenomena is obvious. For those time ranges where synoptic magnetic maps are available the combined analysis with wavelet power spectra provides us with the possibility to locate the appearance of the 24-day period statistically as well as individually. From these maps, we have shown that the 24-day period observed in the occurrence of high-energetic Hα flares as well as magnetically complex active regions could be explained by their spatial distribution. Active regions are not randomly distributed but are clustered within so-called complexes of activity (Bumba and Howard, 1965). These clusters or nests typically evolve within one month and are sustained due to fresh emergence of magnetic flux for about 3–6 months (Gaizauskas et al., 1983).

Flare producing nests separated by about +40° to +45° in longitude within successive rotations correspond to periods shorter than the Carrington rotation by −3.0 to −3.4 days, i.e., signals of 23.9–24.3 days. These periods are indeed observed in the wavelet power spectra for the same time when we can observe these divided nests in the synoptic maps.

A study by Pojoga and Cudnik (2002) revealed that ∼70–75% of flares occurred within nests of activity and that parallel, converging, or diverging nests exhibit enhanced flare productivity. These patterns are attributed to a regularity in the spacing between the complexes with distances dependent on characteristic sizes of the regions (Gaizauskas et al., 1983). Thus, these spatial separations are supposed to be a non-random phenomenon which might be related to typical size scales. E.g., giant convective cells (Bumba and Howard, 1965) with typical diameters $\gtrsim$ 90,000 km (corresponding to $L \gtrsim 47°$) might play a key role in structuring the Sun's large-scale magnetic field (Beck et al., 1998; Hathaway et al., 2000). Using new techniques of local helioseismology (ring-diagram analysis, time–distance methods), large-scale horizontal flows (likely connected with giant cell convection) below the solar surface were identified that might influence the magnetic fields visible at the surface (Haber et al., 2000, 2002; Gizon et al., 2001; Hindman et al., 2004). Recently, Zhao and Kosovichev (2004) showed that the dynamics of the upper convection zone reveals remarkable organization on the large scale, which can be correlated with magnetic activity zones.

5. Conclusion

The 24-day period statistically found in the occurrence of major solar flares in each of solar cycles 19–22 (Bai, 1987; Temmer et al., 2004) is inconsistent with solar surface rotation. A close relation of the appearance of a 24-day period in flare occurrence and the occurrence of magnetically complex active regions found by Temmer et al. (2004) suggests that the evolution/distribution of the solar magnetic field plays a key role. Here, we have compared the statistical appearance of the 24-day period in wavelet power spectra (highly located in time) with the occurrence of individual major flare events on synoptic magnetic maps. From this analysis we conclude that the 24-day period is in fact a spatial phenomenon induced by a typical separation in longitude by about +40° to +45° of large parallel, diverging, or converging activity nests which are particularly flare productive. Recent helioseismic results (see Zhao and Kosovichev, 2004) provide evidence for large-scaled flows that might structure solar activity on such spatial scales.

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