IMPORTANCE OF MAGNETICALLY COMPLEX ACTIVE REGIONS ON SOLAR FLARE OCCURRENCE

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Abstract. Daily numbers of solar Hα flares from 1955 to 1997 and daily numbers of magnetically classified active regions for the time span 1964–1997 are studied applying wavelet power spectra. The occurrence of dominant periods in the range of ~24 days (synodic) is investigated considering the northern and southern hemisphere separately. From the flare events it is revealed that the 24-day period occurs in each of the four solar cycles investigated (no. 19–22). The 24-day period can be established also in the occurrence rate of subflares but occurs more prominently in major flares (importance classes \( \geq 1 \)). Magnetically complex active regions, i.e. including a \( \gamma \) and/or \( \delta \) configuration, show the 24-day period closely related to those found for major Hα flares, whereas it cannot be established for non-complex \( \alpha, \beta \) groups.

Key words: Sun - flare occurrence - active regions

1. Introduction

Solar activity tracers on average reveal rotation periods in the range of the Carrington rotation rate at \( \sim 27.3 \) days$^1$. Bai (1987) found from the longitudinal distribution of major flares observed in hard X-rays for the time span 1980–1985 a predominant period of 23.78 days representing a clear deviation from the solar mean rotation. A dominant 23.5-day period

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$^1$All periods stated in this paper are synodic.
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was also found in irradiance measurements for the time span 1980–1988 as well as in the areas especially of young and “active” sunspot groups (see Pap, Tobiska, and Bouwer, 1990, and references therein). Zięba et al. (2001) found for the rising phase of solar cycle 23 a 23.8-day period in sunspot relative numbers after the removal of strong periods in the original data. By analysing magnetic flux time series for the time span 1977–2001, Henney and Harvey (2002) obtained a 24.4-day period but considered this as a spurious signal. More detailed studies concerning the ∼24-day period in solar flare occurrence and possibly linked activity tracers are still of interest.

Thus, answers to the following questions could give us a better understanding of the ∼24-day period. (1) Is the 24-day periodicity a general or an isolated phenomenon? (2) Is it apparent only for major solar flares? (3) Is it related to the rotation of magnetically complex active regions? Since large flares occur preferentially in association with active regions of complex magnetic configuration, preferred βγδ structures (Sammis, Tang, and Zirin, 2000), it might be possible that there is a close relation of such structures to the periodical occurrence of major flare events. In the frame of the anchoring hypothesis, especially new-born spots might represent deeper and thus faster rotating layers (see, e.g., Balthasar, Schüssler and Wöhl, 1982).

2. Data and Methods

For the following study, daily numbers of solar Hα flares are derived from the composition in the Solar Geophysical Data for the time span 1955–1997 fully covering four solar cycles (19–22). A subdivision is made into low-energetic (subflares) and high-energetic (events of importance classes ≥1) groups. Because of inadequate importance classifications before 1975, for this period the distinction between low- and high-energetic events is based on the duration of a flare. Flares of duration <50 minutes are grouped as low- and of ≥50 minutes as high-energetic events, respectively (see e.g., Temmer et al., 2001). Furthermore, daily numbers of magnetically classified active regions are analysed using reports from the Mount Wilson Observatory available for the time span 1964–1997, i.e. fully covering solar cycles 20–22. Considering the magnetic classifications of sunspot groups a subdivision into magnetically non-complex (α, β) and magnetically complex (i.e.
all classifications including $\gamma$ and/or $\delta$) groups is prepared.

The investigation is carried out separately for the northern and southern solar hemisphere. For the study of the temporal evolution of dominant periods in the time series we applied the wavelet analysis. All wavelet power spectra are calculated for the period range of 10–40 days. As significance tests confidence levels at 95% and 99% are used, respectively. The background spectrum is modelled with red noise, regions where edge effects become important due to dealing with finite-length time series are labelled as cone of influence (COI). The computation of all these parameters is performed in the way described by Torrence and Compo (1998).

3. Results

The attention in the calculated wavelet power spectra was drawn to high amplitudes within a confidence level of at least 95% observed for the period range 23.8 ± 0.5 days. Applying this criterion, positive results are obtained for low- as well as high-energetic flares for each of the studied cycles. In Figures 1–3 sample wavelet power spectra showing the ∼24-day period are shown. High-energetic flare events show a ∼24-day period nearly twice as often as low-energetic ones. For flares occurring on the southern hemisphere the occurrence of the ∼24-day is more prominent than for those on the northern hemisphere. In general, the 24-day period is intermittent and reveals higher significance for high-energetic flares but occurs also in low-energetic events.

Considering the wavelet power spectra from daily numbers of magnetically classified active regions, no significant signal in the 23.8±0.5-day period range is revealed for the groups during their non-complex ($\alpha$, $\beta$) phase. On the other hand, as it is shown in Figure 1 for cycle 20 and Figure 2 for cycle 21, complex active regions ($\gamma/\delta$) on the northern hemisphere reveal highly significant ∼24-day periods simultaneously with that found for high energetic Hα flares. For the southern hemisphere, a coincident 24-day period of complex active regions and high-energetic flares is obtained during cycle 22 (cf. Figure 3).

A summary of the results obtained for each solar cycle and the different subdivisions of flare events and magnetically classified active regions is given in Table I.
Figure 1: Wavelet power spectra derived from high-energetic Hα flare events (left) and magnetically complex active regions (right) for the northern hemisphere observed during cycle 20. Grey-scale coding from white to black represents the square root of power in a linear scale. Arrow marks a simultaneous occurrence of the ~24-day period for magnetically complex active regions and for flare events. Dashed/solid vertical lines indicate the solar cycle minima/maxima. Black/white contour lines denote a 95%/99% confidence level. Cross-hatched lines indicate the COI’s. Dashed/dotted horizontal lines at 23.3, 23.8, and 24.3 days are drawn.

4. Discussion and Conclusions

Bai (1987) reported a ~24-day period only for the occurrence rate of major solar flares during cycle 21. Our results have shown that the 24-day period in flare occurrence is not a singular phenomenon but occurs in all four solar cycles studied (19–22). It is observed mainly during narrow time ranges around the maximum of a solar cycle. The appearance of the 24-day period is more prominent for major flares but can be seen also in subflares. Further interesting results are obtained from the investigation of daily numbers of magnetically complex (including a γ and/or δ classification) and non-complex active regions (α, β), respectively. Covering three solar cycles, only for magnetically complex active regions a 24-day period is observed. A simultaneous occurrence to the 24-day period obtained for major solar flares is found in 3 out of 5 cases.

From solar rotation studies sidereal velocities up to 16 deg/day (which corresponds to a synodic period of ~24 days) and even higher are determined (e.g., Godoli, Mazzucconi, and Piergianni, 1998, and references therein). The ~24-day period observed in solar Hα flare occurrences might be related to the rotational periodicities of sunspots which are the magnetic source of flare eruptions. An asymmetric distribution on sunspot rotation rates from the mean solar rotation of ~27 days towards shorter periods is
reported by Godoli, Mazzucconi, and Piergianni (1998) and Brajša et al. (2002). However, it is important to note that the number of sunspots having sidereal velocities as high as 16 deg/day is only of the order of ~1%, and thus cannot be the source of the 24-day period found in flare occurrence. This raises the question whether the 24-day signal in flares is related to surface rotation of sunspot groups at all.

The concept of active longitudes (Bumba and Howard, 1969) might be helpful in understanding the 24-day period in solar flare occurrence. The build-up of a complex of activity as well as large active regions themselves are maintained by pulse-like injections of newly emerging magnetic flux rotating in its active lifetime faster than the surrounding regions (Gaizauskas et al. 1983). Moreover, the emergence of new magnetic flux may cause a destabilization of active regions and triggers a flare eruption (e.g., review by Aschwanden, 2002).

Here we have shown that the 24-day period is present in the occurrence rate of magnetically complex active regions (γ, δ configurations), whereas it does not occur in magnetically non-complex groups (α, β). In
Table I: Summary of the wavelet analysis regarding the $\sim$24$^d$ period for low- and high-energetic flare events in solar cycles 19 to 22 (top panel) and magnetically non-complex ($\alpha\beta$) and complex ($\gamma/\delta$) active regions in solar cycles 20 to 22 (bottom panel). “✓” indicates existence, “×” non-existence of the $\sim$24$^d$ periodicity – attention was drawn to high amplitudes within a confidence level of at least 95% observed for the period range 23.8 ± 0.5 days. The results are listed separately for the northern and southern hemisphere.

<table>
<thead>
<tr>
<th>Cycle no.</th>
<th>low$_{north}$</th>
<th>low$_{south}$</th>
<th>high$_{north}$</th>
<th>high$_{south}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>20</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>21</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>22</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle no.</th>
<th>$\alpha\beta_{north}$</th>
<th>$\alpha\beta_{south}$</th>
<th>$\gamma/\delta_{north}$</th>
<th>$\gamma/\delta_{south}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>21</td>
<td>×</td>
<td>×</td>
<td>✓</td>
<td>×</td>
</tr>
<tr>
<td>22</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>✓</td>
</tr>
</tbody>
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3 out of 5 cases (cycles 20–22) in which the 24-day period is observed in major Hα flares it occurred also simultaneously in magnetically complex active regions. Thus, we suggest that the 24-day period is more likely to be related to the periodical emergence of new magnetic flux within already existing and/or newly developing active regions than to the surface rotation of sunspots. This hypothesis can explain the observational finding that there is a close relation between the appearance of the 24-day period in solar flares and magnetically complex active regions, which produce most of large flares (Sammis, Tang, and Zirin, 2000), but not in non-complex ones.

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References

VAŽNOST MAGNETSKI SLOŽENIH AKTIVNIH PODRUČJA ZA POJAVLJIVANJE SUNČEVIH BLJESKOVA

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Ključne riječi: Sunce - učestalost bljeskova - aktivna područja