STATISTICAL PROPERTIES RELEVANT TO SOLAR FLARE PREDICTION

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UDC 523.985-125
Conference paper
(Received November 13, 2000; accepted November 20, 2000)

Abstract. We statistically analyzed the characteristic temporal properties of Hα flares, such as duration, rising and setting times, with the aim to determine a proper acquisition rate for Hα patrol observations, which will be the basis for the automatic flare alerting and prediction system at the Kanzelhöhe Solar Observatory, Austria. Furthermore, the comparison of absolute and normalized values reveals interesting aspects on how flares of different importance classes behave with respect to the rising and decay phase.

Key words: The Sun - Hα flares - flare prediction

1. Introduction

A solar flare is a sudden intense brightening of a small region of the Sun’s atmosphere. In the brightest flares up to 10^{32} ergs can be released within several minutes to several tens of minutes. Such bright flares
occur only a few times within a year or two around the maximum of solar activity, since the frequency of flare occurrence evolves with the solar cycle (see Figure 1). When the solar cycle is at a minimum, active regions are small and rare and therefore only a few solar flares are detected. Flares can be observed at a number of different wavelengths; a very distinctive one is the $H\alpha$ line, $\lambda = 656.3$ nm (see, e.g., Zirin et al., 1991).

At the Kanzelhöhe Solar Observatory a flare alerting and prediction system is under development (Steinegger et al., 1999a, b). The system is based on $H\alpha$ full-disk images, magnetic full-disk images and further full-disk images of the photosphere and chromosphere at various wavelengths (Messerotti et al., 1999). The following statistical analysis of duration, rising and setting times was performed in order to determine an optimized data acquisition rate for the $H\alpha$ images.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1}
\caption{Annual averages of the sunspot relative numbers (dashed line) and number of $H\alpha$ flares (dotted line). Data source: Solar Geophysical Data reports (online available).}
\end{figure}
2. Data

The data for the present analysis are taken from online available Solar Geophysical Data reports (SGD), for the time span January 1994–December 1999
Therefore, the data cover a solar minimum (1996) and the subsequent period of rising activity. Within this time span 9140 $H\alpha$ flares are reported.

For the analysis, we divided the flares into three groups: subflares (S), importance 1 flares (1) and flare events that are greater than importance 1 (>1). Flares of importance 2, 3 and 4 are combined into the >1 group due to the rareness of their occurrence, especially around the solar minimum. Within these events there are 8387 (91.8%) subflares, 642 (7.0%) importance 1 flares and 111 (1.2%) flare events that are greater than importance 1.

In this preliminary analysis, the flare subclassification based on the intensity (faint, normal or bright) is not taken into account.

3. Analysis

3.1. Flare Duration, Rising and Setting Times

From the reported flares, samples in which the start, end or maximum time of an event was uncertain, were rejected. By applying this selection criterion we eliminated 1313 $H\alpha$ events, thus 7827 events were considered in the following statistical analysis. The population of the selected events includes 7258 (92.7%) subflares, 495 (6.3%) importance 1 flares and 74 (1.0%) flare events that are greater than importance 1.

Former papers report a correlation between the flare duration and the importance class, which is determined by the flare area (see Waldmeier, 1948; Smith and Smith, 1963; Růžičková-Topolová, 1974; Antalová, 1985; Wilson, 1987; Barlas and Altas, 1992), whereas the physical details of this relationship are still unclear. The magnetic configuration and the general conditions for the onset of the flare certainly play an important role (see, e.g., Sammis et al., 2000). However, by
means of a scatter plot analysis of flare area versus flare duration, Yeung and Pearce (1990) pointed out that no correlation between flare duration and area exists, concluding that there is no experimental evidence for more than one class of $H\alpha$ flare events due to the scatter plots that showed no tendency to multiple clustering.

Due to the skewness of the histograms of flare duration, rising and setting times (see Figure 2), respectively, we preferred the median value to the arithmetic mean as a more representative description of the distribution. Correspondingly, as a proper and robust degree of dispersion the median absolute deviation ($\tilde{D}$) was used instead of the standard deviation, defined by

$$\tilde{D} = \text{Median}\{|x_i - \tilde{x}|\} \quad (1)$$

where \(\{x_i\}\) denotes the data values and \(\tilde{x}\) is the median of the \(\{x_i\}\). The derived results are summarized in Table I.

Moreover, the results show a clear correlation between importance class and flare duration (see Table I and Figure 3). Also the rising time, i.e. the time between the onset of a flare and its maximum brightness, and the setting time, i.e. the time between the maximum and the end of the flare, increase with the importance class.

![Graphs showing distribution of flare duration, rising, and setting times](image)

*Figure 2:* Distribution of flare duration (left panel), rising (middle panel) and setting times (right panel) for all selected $H\alpha$ flares. The median values are indicated by the vertical lines.

The results are basically in agreement with previous studies of flare duration, rising and setting times (see Waldmeier, 1948; Smith
and Smith, 1963; Růžičková-Topolová, 1974; Antalová, 1985; Wilson, 1987; Barlas and Altas, 1992). However, we note a tendency to smaller values compared to previous papers. On the one hand this might be ascribed to our choice of the median compared with the mean values in other papers. Since the relevant histograms exhibit a positive skewness, the median is located at smaller values than the mean. On the other hand, we make use of recent data sets, which profit from observational improvements with regard to earlier studies. Higher time cadences of flare patrols enable to detect more short-lived flares, which also causes smaller average values.

**Table I:** Median values and median absolute deviation of flare duration, rising and setting times. T denotes the total number of flare events. (Note that due to the nonlinearity of the median the sum of rising and setting times do not exactly render the duration time.)

<table>
<thead>
<tr>
<th>Imp.</th>
<th>Duration time (min.)</th>
<th>Rising time (min.)</th>
<th>Setting time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>10.00 ± 5.00</td>
<td>2.00 ± 1.50</td>
<td>8.00 ± 4.00</td>
</tr>
<tr>
<td>1</td>
<td>29.00 ± 15.00</td>
<td>5.00 ± 3.00</td>
<td>23.00 ± 12.00</td>
</tr>
<tr>
<td>&gt;1</td>
<td>61.00 ± 31.00</td>
<td>8.00 ± 4.50</td>
<td>52.50 ± 26.50</td>
</tr>
<tr>
<td>T</td>
<td>11.00 ± 5.00</td>
<td>2.00 ± 1.50</td>
<td>8.00 ± 4.00</td>
</tr>
</tbody>
</table>

*Figure 3:* Comparison of duration, rising and setting times for the different flare classes in absolute (left panels) and normalized values (right panels).
In Figure 3 the duration, rising and setting times for the different flare classes are plotted in absolute (left panels) and normalized values (right panels). The comparison reveals that the positive correlation between rising time and flare class, obtained for the absolute values, is reversed for the normalized ones. This means that the proportion of the rising to the decaying phase in relative time values is larger for subflares than for flares of higher class, whereas in absolute values it is smaller. However, we want to stress, that the significance of this effect is rather weak due to the large scatter of duration, rising and setting times around their median values.

3.2. Optimized time cadence for \( H\alpha \) flare patrol

By analyzing the duration time of flare events we aim to determine an optimized rate for the data acquisition in the frame of \( H\alpha \) flare patrol observations. For a suitable identification and classification of a flare event, we demand the flare to be sampled at least at three times during its evolution. In such a way the possibility to observe the flare within different steps of its evolution is given, roughly corresponding to the start, end and maximum time. As a weaker criterion, which corresponds just to the detection of a flare, we demand the flare to be covered by at least one data point.

Table II summarizes the loss of flare events with respect to different time cadences of observation. It is seen that for a demand of only 1 data point within a flare event, a time cadence of 3 or 4 minutes is sufficient (percentage of missed flares: 0.5% and 3.7%, respectively). However, if we apply the criterion of at least 3 data points during a flare event, the time cadence has to be increased to 1 minute. For a 1 minute time cadence we get a negligible number of flares missing the criterion of 0.5%, whereas for a 2 minute cadence this number already increases to 18.1%. As a consequence, the data acquisition rate for \( H\alpha \) patrol at the Kanzelhöhe Solar Observatory (Austria) will be set to 1 image per minute.
Table II: Loss of flare events with respect to the two different criteria (flare coverage by at least 3 or 1 data point) for different data acquisition rates (1, 2, 3, 4 minutes time cadence).

<table>
<thead>
<tr>
<th>Time cadence</th>
<th>Importance</th>
<th>3 data points</th>
<th>1 data point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>loss [No.]</td>
<td>loss [%]</td>
</tr>
<tr>
<td>4 minutes</td>
<td>S</td>
<td>3999</td>
<td>55.1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>59</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td>&gt;1</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>4058</td>
<td>51.8</td>
</tr>
<tr>
<td>3 minutes</td>
<td>S</td>
<td>2927</td>
<td>40.3</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>29</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>&gt;1</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>2956</td>
<td>37.8</td>
</tr>
<tr>
<td>2 minutes</td>
<td>S</td>
<td>1410</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>6</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>&gt;1</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>1416</td>
<td>18.1</td>
</tr>
<tr>
<td>1 minute</td>
<td>S</td>
<td>36</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>&gt;1</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>36</td>
<td>0.5</td>
</tr>
</tbody>
</table>

3.3. Flare precursors

The knowledge of the conditions before the onset of a flare is decisive for the development of a flare prediction system. Hence, to detect the flare events successfully, criteria are needed to select the active regions where it is most likely that a flare occurs. Several general properties which are specified below provide hints to a forthcoming flare event, whereas the greatest attention should be turned to the magnetic fields. Thus precursors represent another tool to enhance the possibility of flare prediction and furthermore they could provide more details of the flare process itself.

Most of the flares take place in or near active regions and so the
magnetic configuration of the spots within this regions is a very important parameter. The number of sunspot groups is less important for the occurrence of \( H\alpha \) flares than the complexity of the magnetic configuration of the associated sunspot groups. But in fact, the number of sunspots within active regions plays an important role, too, and is always higher than in regions without flare occurrence.

Künzel (1960) was the first who pointed out the clear connection between flare productivity and magnetic structure, and he introduced a new magnetic class for solar active regions, i.e. \( \delta \), that is widely used by forecasters. The \( \delta \) region is very complex and includes a penumbra enclosing umbrae of both positive and negative magnetic polarity. \( \delta \) spots never separate, since they are formed by the conjunction of umbrae from different dipoles. Therefore they must represent a rearrangement to a lower energy state, which is mostly correlated to a flare event.

Another magnetically complex and flare active class are \( \gamma \) regions which include spot groups in which individual spots have polarities distributed in a more irregular way than simple bipolar \( \beta \) groups.

Furthermore there are complex \( \beta \gamma \delta \) regions that produce many more flares than other regions of comparable size. The \( \beta \gamma \delta \) region includes a sunspot group of \( \beta \gamma \) magnetic classification but containing one (or more) \( \delta \) spot(s). The regions larger than 1000 microhemispheres classified as \( \beta \gamma \delta \) had nearly 100% probability of producing very energetic flares (see, e.g., Zirin and Wang, 1992; Sammis et al., 2000).

In the following, we summarize the characteristics, which, in addition to the magnetic class, indicate high flare probability and therefore can act as flare precursors (see Zirin and Liggett, 1987; Hagyard et al., 1982, 1984)

1. Large \( \delta \) configurations that indicate greatly sheared magnetic configurations, additionally marked by penumbral and \( H\alpha \) fibrils parallel to the inversion line.

2. Umbrae obscured by \( H\alpha \) emission.
3. Bright $H\alpha$ emission indicative of flux emergence and reconnection.

4. New flux erupting on the leading site of the penumbra of a dominant preceding spot.

5. A filament crossing a $\delta$ spot.

4. Acknowledgements

M.T., A.V., A.H., G.B. and S.G. thank the Austrian Fond zur Förderung der wissenschaftlichen Forschung (FWF grant P13655-PHY) for supporting this project. M.S. acknowledges the support of the Österreichische Nationalbank (Jubiläumsfondsprojekt 7722). M.M. acknowledges the support by ASI and MURST.

References

STATISTIČKA SVOJSTVA KOJA SU BITNA ZA PREDVIĐANJE POJAVE SUNČEVIH BLJESKOVA

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UDK 523.985-125
Izlaganje sa znanstvenog skupa
(Primljeno 13. studenog 2000.; prihvaćeno 20. studenog 2000.)

Sažetak. Statistički su analizirana karakteristična vremenska svojstva $H\alpha$ bljeskova, kao što su trajanje, vremena uspona do maksimuma i prestanka bljeska, da bi se odredila optimalna kadenca snimanja pri $H\alpha$ patrolnim opažanjima. To će biti temelj automatskog sustava predviđanja i obavještavanja na Sunčevom opse-
vatoriju Kanzelhöhe, Austrija. Nadalje, usporedba apsolutnih i normaliziranih vrijednosti otkriva zanimljive vidove ponašanja bljeskova različitih klasa importanta
s obzirom na fazu rasta i raspada.

Ključne riječi: Sunce - $H\alpha$ bljeskovi - predviđanje pojave bljeska