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Intermittence of the short-term periodicities of the flare index

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Abstract

Intermittence of the short-term periodicities (25–35 days) of the flare index are investigated using the wavelet transform method for the full-disc and for the northern and the southern hemispheres of the Sun separately over the epoch since 1966 until 2002. The wavelet transform results show that occurence of periodicities of flare index power is highly intermittent in time. The period-averaged wavelet power of the flare index presents this fact very clearly displaying independence of flaring activity on the solar hemispheres in several time intervals over almost four solar cycles under study. Moreover correlations of the period-averaged wavelet power of the flare index for the separate hemispheres and for the full-disc reveal significantly stronger relation between the full-disc and the northern hemisphere than between the full-disc and the southern hemisphere while no significant correlations was found between the hemispheres one another.

Keywords: Solar flares; Short periodicities; North–south asymmetry

1. Introduction

Solar variability has an extremely complex time dependence on scales ranging from weeks to decades. In searching for periodic components, one must distinguish between strict periodicities originating at the bottom of the convective zone of the Sun and less constant "regularities" that depend on properties of the convective envelope. Periodic variations of solar activity in the intermediate term have been studied extensively, starting with the discovery of a 153-day periodicity in γ-ray flare occurrence (Rieger et al., 1984). Since then, many researchers have investigated these periodicities using various solar activity indicators (see Özgüç et al. (2004) for references therein). The presence of the long- and intermediate-term periodicities in flare index (FI) has been analyzed before for the cycles 20, 21, 22 and the rising part of cycle 23 (Özgüç et al., 2003a), as well as individual cycles by Özgüç and Ataç (1989, 1994) and Özgüç et al. (2002). The intermittent character of the short-term periodicities during the years 1966–2001 was reported earlier by the authors. Here we have considered only the short-term periodicities of the FI for the time period from 1 January 1966 to 1 September 2002 which covers almost 36.5 years. Both hemispheres and total surface of the Sun are examined separately to confirm the existence of solar activity periodicities around the rotation period of the Sun. First results on these short-term periodicities of the FI for the full-disc have already been published using both the Fourier and wavelet transforms (Özgüç et al., 2003b, 2004). The most pronounced power peaks were found to be present at 25.6, 27.0, 30.2, and 33.8 days. Therefore, this work is focused on the period-averaged power in the overall 25–35 days period range to show whether the wavelet power of these oscillations has maxima during the examined time period. Such an analysis may be

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useful for theoretical understanding of these kind of periodicities.

2. Data and methods

In this paper, we have considered the FI data for the period from 1st January 1966 to 1st September 2002 (total 13,392 days). The quantitative flare index first introduced by Kleczek (1952),

$$Q = it, \quad (1)$$

may be roughly proportional to the total energy emitted by the flare as i represents the intensity scale of importance of a flare in Hα and t the duration of the Hα flare (in minutes). The determination of Q has been explained previously (Özgüç et al., 2003a, 2004). Calculated values are available for general use in anonymous ftp servers of our observatory[1] and NGDC[2]. This data set constitutes almost 36.5 years. The wavelet transform (WT) analysis of the time series yields information on periodicities of the studied signal in both time and frequency domains (e.g., Kumar and Faufoula-Georgiou, 1997; Torrence and Compo, 1998). We examined three FI time series, which are for the full-disc and for the northern and the southern hemispheres of the Sun. These three time series were smoothed with 7-day running means before the WT calculations. Algorithm of the continuous wavelet transform was applied within the period range 25–35 days (Torrence and Compo, 1998). The Morlet wavelet has been selected to search for variability of the time series using the non-dimensional frequency set to 6 fixing the length of all wavelets according to their scale. The significance level of the calculated WT power was derived using the null hypothesis assuming existence of the global power spectrum (Torrence and Compo, 1998) and the 95% confidence level. In fact, the period-averaged WT power is used in this paper because it represents a sum of WT power within the selected period range around the rotation period of the Sun (25–35 days).

3. Results and discussion

In this work, we examined the period-averaged behaviour of the WT power within the period range 25–35 days in order to show the temporal variation of the amplitude of the flare index periodicities around the rotation period (Fig. 1). Intermittence of the FI amplitude near rotation period reported previously (Özgüç et al., 2004) is here confirmed even a relatively broad interval of periods is taken into average. Remarkable are also differences of the period-averaged power spectra between the full-disc and hemispheric FI. One could expect that the period-averaged power spectrum of the full-disc index will be the simple sum of period-averaged power spectra of both hemispheres. Nevertheless different phases of each period under study at each hemisphere can lead to the completely different situation (Özgüç et al., 2004). Therefore, behaviour of the period-averaged power spectra show extremely intermittent behaviour of amplitude and the pulses of power are very short in time as their duration is in the range from 1/3 to 1 year.

Pulses of power are distributed within large temporal intervals starting 1–2 years after the solar cycle minimum and finishing 2–3 years before the next minimum. The cycle 20 is an exception from this rule as the amplitude is significantly lower in all pulses of the period-averaged power here and none of them reach the selected significance level. The same is valid also for the epochs of solar cycle minima where the FI values are generally much lower than in other parts of solar cycle. It should be noted here that the particular level of variance corresponding to the selected significance level is calculated using the whole data set according to the WT algorithm, i.e., high FI data of the cycles 21 and 22 caused increase of this level leaving the WT power of cycle 20 below the selected significance level. Comparing the actual length of the daughter wavelets to duration of the individual pulses of power in the period-averaged power we see that the regular periodicities of the FI series have to be usually even shorter than the length of the used wavelets ($\sim$1/2 of year).

Another question, addressed here, is general relation and possible time shifts of the temporal variations of the period-averaged WT amplitude of the FI for the full-disc and hemispheric data series. The cross-correlation functions of the period-averaged WT amplitude of all three FI data series (Fig. 2) revealed that there exist stronger relation between the northern FI and full-disc FI and much weaker one between the southern FI and full-disc FI. Both behaviours of the hemispheric period-averaged WT amplitude are delayed for 5 and 4 days relatively to the full-disc period-averaged WT amplitude. Correlation function of the hemispheric period-averaged WT amplitudes is only very weak and no significant peak was outlined. Additionally, no secondary maxima of the correlations functions were detected although they are present in case of the cross-correlations of the raw full-disc and hemispheric FI data series.

Reason of the derived intermittent behaviour of the flare activity in the period range near the rotation period obtained in this study is obvious. It is caused by the fact that occurence of flares is highly changing in time. Therefore amplitude of WT power within the mentioned period range is due to changing number/importance of

[1] www.koeri.boun.edu.tr/astronomy/flare index/catalog.zip.

[2] ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_FLARES/INDEX.

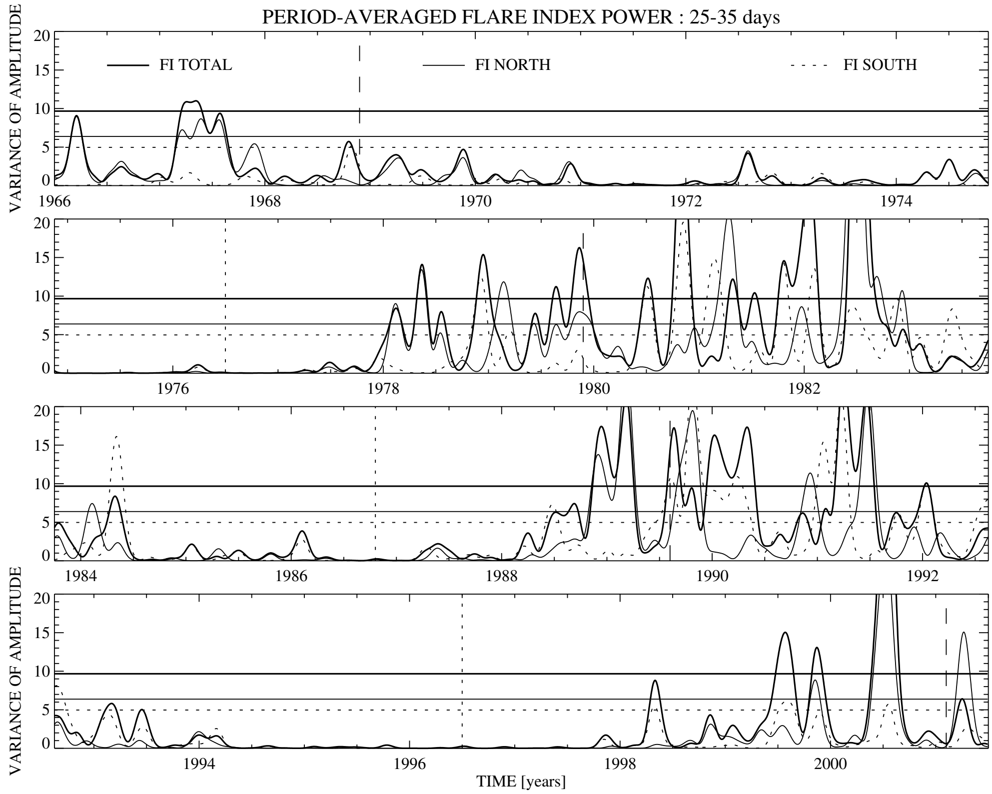

Fig. 1. Course of the period-averaged WT power (relative units) of the periods near the rotation one (25–35 days) for the full-disc FI (thick solid line) and the northern and southern hemispheric FI (thin solid and dotted lines, respectively). The horizontal lines show 95% confidence level of these period-averaged power spectra (same types of lines). Solar activity maxima and minima are marked with the dashed and dotted lines, respectively.

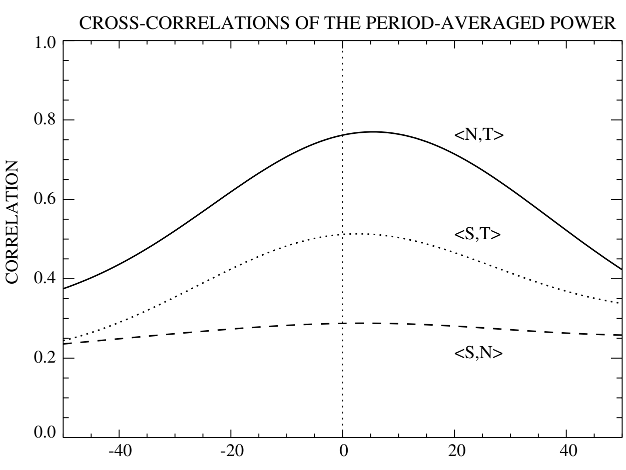

Fig. 2. The cross-correlation functions of the period-averaged WT amplitude of all three FI data series calculated separately between the northern and full-disc FI (thick full line), the southern and full-disc FI (dotted line) and the northern and the southern hemispheric FI (dashed line).

flares per day expressed in the FI time series. Additionally flare activity on each hemisphere is statistically different from that of other as flares appear mostly in active regions which are distributed independently in time and longitude between hemispheres. The latter fact causes also no significant correlation of the hemispheric period-averaged WT amplitudes.

On the other hand reasons for positive temporal shifts between the hemispheric and the total period-averaged WT amplitudes as well as stronger relation of the total and northern period-averaged WT amplitude are unclear up to now. Their correlation functions were found to be quite broad pointing out that the derived average temporal shifts can be quite different from the particular ones at different epochs. Significance of the global resulting shifts of correlations can be investigated only after detail analysis of correlations on shorter time scales. This investigation will be done in future.

4. Conclusions

Intermittence of the short-term periodicities (25–35 days) of the flare index are investigated using the wavelet transform method for the full-disc and for the both hemispheres of the Sun over the epoch between the years 1966 and 2002 confirming that the occurence of periodicities of flare index power is highly intermittent in time also within this broad period interval. The period-averaged wavelet power of the flare index presents significant variability of the flaring activity on the solar hemispheres in several time intervals over almost four solar cycles. Relations of the period-averaged wavelet power of the flare index for the separate hemispheres and for the full-disc revealed significantly stronger connection between the full-disc and the northern hemisphere than between the full-disc and the southern hemisphere. No significant correlations was found between the period-averaged wavelet power for hemispheres one another.

Finally, our study as well as many previous studies by a number of authors have resulted in a wide range of solar periodicities and of the intermittent behaviours. This indicates that the problem of solar periodicities and their intermittent behaviours is still open and needs new observational data, new methods or more detail temporal resolution. Therefore, the solution of the observed solar periodicities should be sought in a complicated Sun's magnetic system which generates in the different solar data the compound set of solar periodicities.

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