

# INTERMEDIATE-TERM PERIODICITIES IN SOME SOLAR ACTIVITY INDICES DURING CYCLE 23

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## ABSTRACT

Time variations of the flare index, sunspot numbers and the total sunspot areas were compared with the composite irradiance during the cycle 23. The intermediate-term periodicities in these time series were calculated using the Fourier and wavelet transform. We found that the Rieger-type periodicities and harmonics are significant during this cycle. These periodicities appeared intermittently and were not simultaneous in different solar activity indices between the three years of the maximum phase of the solar cycle 23.

## 1. Introduction

Helioseismic data have shown that the rotation rate of the Sun near the base of its convective zone changes with a period of roughly 1.3-year (Howe et al. 2000). Another periodicity in solar activity indices around 150-160 days is seen to vary approximately in phase with the 1.3-year. Based on this Krivova and Solanki (2002) have proposed that the 150-160 days period is the third harmonic of the 1.3-year period. If so we can expect that any fluctuation in the dynamo will manifest itself in the intermediate-term variations of the solar activity indices as a periodic emergence of magnetic flux with the harmonics of this period.

In this study to find some additional results on the simultaneous variations of the sunspot and flare activities with the solar irradiance we investigated the intermediate-term periodicities and their statistical significance during the solar cycle 23. On the other hand these efforts could help us add some new additional information to the prediction methods for future solar cycles.

## 2. Data and method of analysis

We used four solar activity indices which are flare index (FI), solar irradiance (IR), sunspot number (SSN) and suspo areas (SSA). Our data sets constitute the daily values of the mentioned indices which covered the running solar cycle 23 between the years 1996 and 2004 (see Fig. 1). In this study we applied the wavelet transform analysis to the time variations of the sunspot total areas, the sunspot numbers, the flare index and the

composite of the solar irradiance during the running solar cycle 23.

The wavelet transform (WT) analysis yields information on periodicities of the studied signal in both time and frequency domains. Therefore we have also applied wavelet analysis to the time series of the daily solar activity indices mentioned above to study the temporal variation of the intermediate-term periodicities. Algorithm of the continuous wavelet transform was applied within the period range 20-200 days (Torrence and Compo, 1998). The Morlet wavelet, a plane sine wave with an amplitude windowed in time by a Gaussian function, has been selected to search for variability of the time series of the daily sunspot areas, the sunspot numbers, the flare index and the composite of the solar total irradiance data. The used period resolution varied from 0.4 to 11.2 days. The calculated wavelet power is suppressed on the edges of the time domain due to the applied WT algorithm within the cones of influence located at the temporal edges of the domain which is indicated in our plots by cross-hatched regions. The non-dimensional frequency has been 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). The 95% confidence level, used in this study, implies that 5% of the wavelet power should be above this level for each period. Following this way the plots of wavelet power spectra (WPS) are given in Fig. 2 for each activity indices.

## 3. Results and discussion

Extensive analysis has been done to find the intermediate-term periodicities in the range between 24 days and 11 years in similar solar activity indices. Among these the period around 150-160 days is the most known one which has been discovered by Rieger et al (1984) in the occurrence of high energetic flares. Since then many researchers using different solar activity indices continue to investigate the Rieger-type periodicities (Zieba et al. 2001; Ballester, Oliver and Carbonell 2002. 2004 ; Krivova and Solanki, 2002; Bai, 2003; Lou et al. 2003; Knaack et al. 2005)

Table I  
Fundamental period of Sun and its harmonics seen in the different indices which we considered

Period	Sunspot Area	Sunspot Number	Irradiance	Flare Index
<b>Near 25 days</b>	2000.1-2000.4/ 2001.1-2001.3	1998.8-1999.2/ 2000.0-2000.4	1998.8-1999.3/ 2000.7-2000.9	1998.7-1999.8 2000.4-2000.6
<b>Near 50 days</b>	2000.5-2002.0	2000.8-2002.0	1999.9-2001.0	1999.7-2000.8
<b>Near 75 days</b>	1999.8-2001.8	2001.0-2001.6	2001.2-2001.8	1999.5-2000.5
<b>Near 100 days</b>	2000.5-2001.2	2001.5-2002.4	1999.9-2001.0	1999.5-2000.7
<b>Near 125 days</b>		1999.5-2000.5		1999.7-2001.2
<b>Near 150 days</b>	1998.6-1999.8		1999.0-2000.3	2000.7-2001.5
<b>Near 175 days</b>	2000.8-2002.3		2000.2-2001.4	

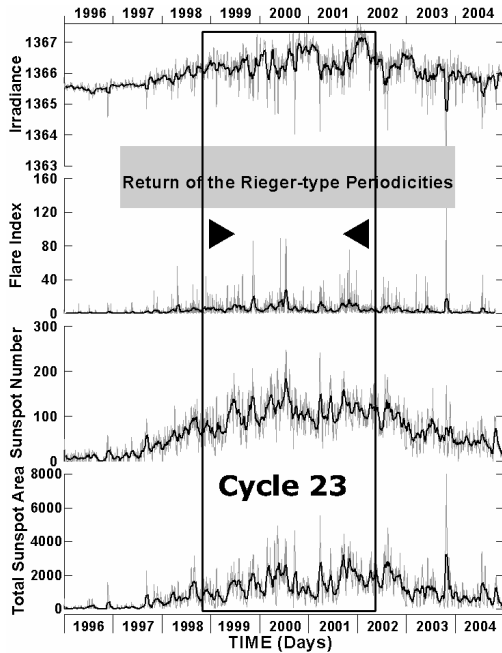


Figure 1. The plots of the time variations of the four solar activity indices between January 1, 1996 to December 31, 2004. Heavy lines show 25 days running mean. Units of the sunspot area and the composite of the solar irradiance are millionths of solar hemisphere and  $Wm^{-2}$  respectively. Thin lines demonstrate the daily values.

In this study we applied the wavelet transform analysis to the time variations of the sunspot total areas, the sunspot numbers, the flare index and the composite of the solar irradiance during the running solar cycle 23. Their wavelet power spectra were prepared for the 20-200 days range. To provide a complete view of the temporal variability and to compare the periods amongst each activity indices all the plots were combined as shown in Fig. 2. As can be seen the statistically significant periods appeared during the time interval 1999-2002 which covered the maximum phase of the running solar cycle 23. Anyway, previous cycle analysis already done has shown that Rieger-type periodicities operated mainly during maximum phases of solar cycles

for only short time intervals. The time intervals for different indices can be seen in Table I over which the power of the Rieger-type periods has been peaked. This helped us to see when the fundamental period and certain subharmonics occurred or disappeared for different time series. Comparing our values of periods in Table I with the temporal interval length when the power is enhanced, it is clearly seen that the signal is strongly intermittent. In order to distinguish between the wavelet powers around the 100 –180 days oscillations, the temporal evolution of wavelet power corresponding to 100 – 180 days period in four activity indices are plotted separately in Fig. 3. The following maybe noted:

- 1) The wavelet power of this oscillations peaks between the years 2000-2002.
- 2) The peaks of the irradiance, the flare index, the sunspot number and the sunspot total area are in the years of 2000.2, 2000.5, 2001.3 and 2001.4 respectively.
- 3) The peak which is seen in the plots of the three activity indices at the end of the year 2003 was mostly due to the unexpected increase of the high solar activity during the time period October-November 2003. All the flux had come only from two big sunspot groups. That is why we could not see this peaks in the period-averaged plot of the sunspot number power.
- 4) The four activity indices which we studied do not show simultaneous peaks.

A common feature in most of the previously published papers was that the reported intermediate-term periodicities were close to integer multiples of a period around 25-26 days (Knaack et al., 2005). Bai and Sturrock (1991) were first formulated this hypothesis. They proposed an obliquely rotating structure or wave pattern as a possible mechanism for this fundamental period and modified its value to 25.5 days. In our study we have found statistically significant evidence for the periodicities near 25, 50, 75, 100, 125 and 150 days.

They occurred intermittently in sunspot areas, sunspot number, flare index and the composite of the total

irradiance during the maximum phase of the solar cycle 23.

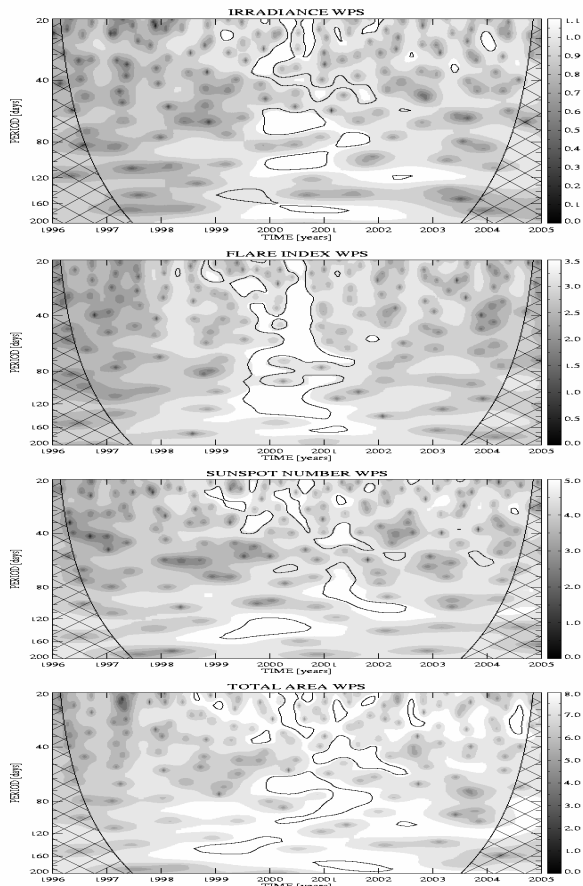


Figure 2. The wavelet power spectra of the total sunspot areas, the sunspot numbers, the composite of the solar irradiance and the flare index time series for the period range 20-200 days. Grey-scale coding of power from black to white represents the square root of power in a linear scale given on the right side bar. The solid curve shows the 95% confidence levels of the local power above the noise level assuming noise independence on periods. The cone of incidence is marked by the cross-hatched regions.

#### 4. Conclusions

All of the above studies and ours have shown that the appearance of the Rieger-type periodicities is significant during this running cycle. These periodicities appeared intermittently and were not simultaneous in different solar activity indices between the three years of the maximum phase of the solar cycle 23.

The unpredictable high solar activity periods such as October- November 2003, November 2004 and January 2005 showed us that we need other mechanisms to explain the unexpected increases of the solar activity during the descending branch of the solar cycles.

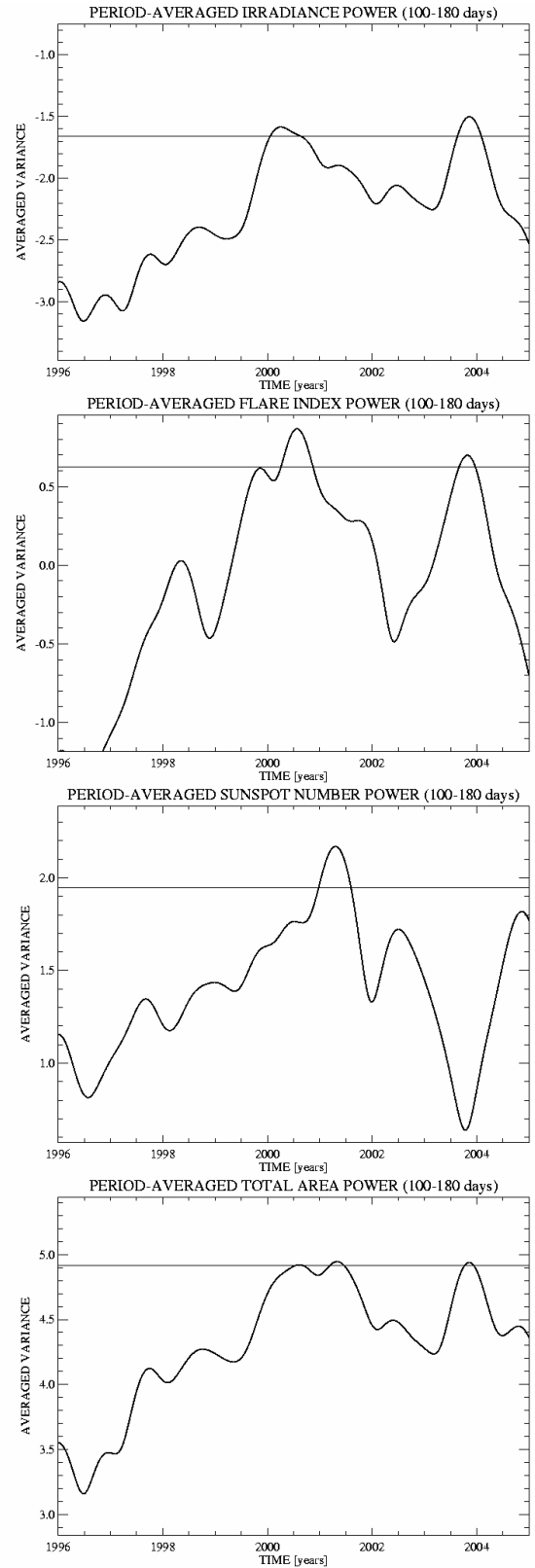


Figure 3. Behavior of the period-averaged WT power of the intermediate-term periods (100-180 days). The horizontal line show 95% confidence levels of these period-averaged power spectra.

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