

## RETURN OF THE NEAR 160 DAY PERIODICITY IN THE PHOTOSPHERIC MAGNETIC FLUX DURING SOLAR CYCLE 23

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### ABSTRACT

A periodicity between 152 and 158 days was discovered in the daily number of high-energy solar flares detected by the *Solar Maximum Mission* (SMM) and the *Geosynchronous Operational Environmental Satellites* (GOES) around the maximum of solar cycle 21. In a previous work we pointed out that this periodicity had been time-coincident with a periodic emergence of magnetic flux in the form of strong magnetic fields, which suggested a causal relationship between both periodicities. Using the Mount Wilson Sunspot Index, evidence is presented for the return of the periodicity in the strong photospheric magnetic flux during the current solar cycle. The periodicity has reappeared around the solar activity maximum with a frequency similar to that of solar cycle 21, but contrary to what happened during cycle 21, it is completely absent in energetic flares. A tentative explanation for this feature is that in the current solar cycle, part of the periodic emergence of magnetic flux has taken place away from already developed sunspot groups and so has not contributed to enhance their magnetic complexity, which has prevented the triggering of periodic energetic flares.

*Subject headings:* Sun: activity — Sun: flares — Sun: magnetic fields — Sun: photosphere — sunspots

### 1. INTRODUCTION

The near 160 day periodicity was first detected in  $\gamma$ - and X-ray flare data (Rieger et al. 1984; Dennis 1985) taken by the *Solar Maximum Mission* (SMM) and *Geosynchronous Operational Environmental Satellites* (GOES) in solar cycle 21. During the same solar cycle, it was also found in flare-related data (Bogart & Bai 1985; Dröge et al. 1990; Bai & Cliver 1990; Kile & Cliver 1991).

The presence of this periodicity in magnetic and sunspot data during solar cycles 12–21 was analyzed by several authors. Lean (1990) reported that it was present only during epochs of maximum activity and that it occurred in episodes of 1–3 yr, while Carbonell & Ballester (1990, 1992) showed that a periodicity around 150–160 days had been significant during all solar cycles from 16 to 21. Oliver et al. (1998) pointed out that during solar cycle 21 there was a time-frequency coincidence between the occurrence of the periodicity in both sunspot areas and high-energy flares. Finally, Ballester et al. (2002) confirmed that during solar cycle 21 the periodicity appeared in the photospheric magnetic flux linked to strong magnetic fields, and they proposed that the periodic emergence of magnetic flux, manifested as sunspots, triggers the periodicity in high-energy solar flares, probably by reconnection between old and new magnetic flux. However, no evidence for the presence of the periodicity appeared in any solar activity indicator corresponding to solar cycle 22 (Kile & Cliver 1991; Bai 1992; Oliver & Ballester 1995). Nowadays, we are well into the descending phase of solar cycle 23, and the time is ripe to look for the return of the periodicity in solar activity data sets corresponding to the current solar cycle.

### 2. DATA AND METHODS

The different solar activity data sets, covering solar cycles 21, 22, and 23, analyzed in our study are as follows:

1. The daily Mount Wilson Sunspot Index (MWSI). The de-

termination of the MWSI is done by adding the absolute value of the magnetic field strength in those pixels where it is greater than 100 G. Then, this number is divided by the total number of pixels (regardless of magnetic field strength) in the magnetogram.

2. The daily number of X-ray flares detected by the GOES satellites.
3. The daily total sunspot area over the whole solar disk.
4. The daily number of sunspot groups.

Although the MWSI and sunspot areas provide information about regions having strong magnetic fields, because of its definition the MWSI is a more homogeneous and suitable index to study the behavior of photospheric magnetic flux. This agrees with the recent results of Chumak et al. (2003) regarding the complex relationship between the time behavior of magnetic flux and total sunspot areas in active regions.

The Fourier transform, which consists of the decomposition of a signal in sine waves of constant amplitude and infinite duration in time, is not suitable for the analysis of these data sets. Instead, we have chosen the wavelet technique that makes use of base functions that are band-limited in both time and frequency. Since we deal with oscillatory signals, we have used the Morlet mother function, which is a sine wave windowed in time by a Gaussian function. The resolution (i.e., the width of the window) in time and frequency has to be carefully chosen, depending on the aim: a good temporal resolution is necessary to localize the power maxima in time, whereas a good frequency resolution is required to determine the frequencies corresponding to these maxima. There is of course a tradeoff, defined by an uncertainty relation, between the resolution in each domain. The use of the Morlet mother function allows the best tradeoff between time and frequency resolution, as the Gaussian function is its own Fourier transform. To compute the power spectrum of our one-dimensional signals, the software by Torrence & Compo (1998) has been used and a Morlet mother function with dimensionless frequency  $\omega_0 = 20$  has been considered. This choice of  $\omega_0$ , the only tunable parameter,

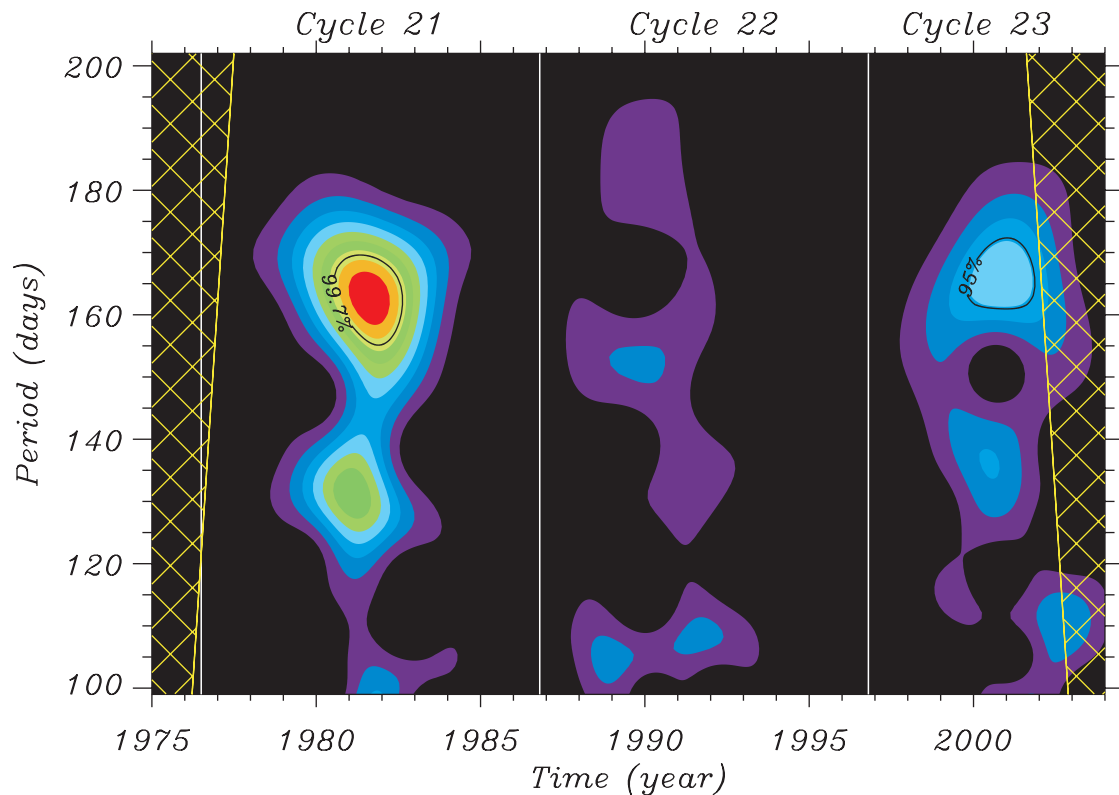


FIG. 1.—Time-period diagram obtained from the wavelet analysis of the daily Mount Wilson Sunspot Index (1975–2003) for periods between 100 and 200 days. The significance levels are obtained by assuming a red-noise background spectrum, and the crosshatched regions on either end indicate the cone of influence, where edge effects become important. White vertical lines mark the epochs of solar activity minimum, and solar cycle numbers are given on top of the frame.

is optimum for our purposes and results in a better frequency resolution but poorer temporal resolution compared to smaller values of  $\omega_0$ . Furthermore, the significance levels are not modified at all when different values of  $\omega_0$  are considered. To compute the significance levels of the wavelet power spectrum, it is necessary to define the mean power spectrum, or “null” continuum, of the time series under analysis, and for this definition, the more common possibilities are a white-noise or a red-noise spectrum. In a red-noise spectrum, the discrete Fourier power spectrum, after normalizing, is given by

$$P_k = \frac{1 - \alpha^2}{1 + \alpha^2 - 2\alpha \cos(2\pi k/N)}, \quad (1)$$

where  $k = 0, \dots, N/2$  is the frequency index,  $N$  is the number of data, and  $\alpha$  is the lag-one serial correlation coefficient. When  $\alpha = 0$ , we obtain the white-noise spectrum with an expectation value of 1 at all frequencies. In general, the mean power spectrum of geophysical and astrophysical time series can be modeled using either a white-noise or a red-noise spectrum and the assumption of a red-noise background spectrum is somewhat more restrictive; for a peak to be significant at a given significance level, higher values of power are required compared to the white-noise background spectrum (Torrence & Compo 1998).

### 3. RESULTS AND CONCLUSIONS

First of all, we have constructed the wavelet diagram of the MWSI data set for 1975–2003 (Fig. 1) that reveals the ap-

pearance of the periodicity around the maximum of solar cycle 23, with a significance level close to 95%. The same wavelet diagram also shows the already known powerful signal around the maximum of solar cycle 21, with a significance level greater than 99%, and the almost negligible power around the maximum of solar cycle 22.

For a more accurate determination of the period than that given by the wavelet, a Lomb-Scargle periodogram of the MWSI data set corresponding to solar cycle 23 has been computed. This periodogram indicates that the periodicity has a period of about 163 days, in fairly good agreement with that of solar cycle 21 (Ballester et al. 2002).

However, the wavelet diagram of the daily number of energetic flares (classes X and M) for the time interval 1975–2003 shows that the periodicity has been completely absent during solar cycle 23 in these flares, as pointed out by Bai (2003) using the Rayleigh power spectrum. This behavior is the opposite of that found in solar cycle 21, and despite the appearance of the periodicity in the photospheric magnetic flux during cycle 23, a similar periodicity in the number of energetic flares has not been triggered.

Furthermore, the wavelet analysis of the daily number of sunspot groups shows a very weak evidence of power near 160 days (significance level close to 20%), while a similar analysis for sunspot areas displays more evidence of power (significance level around 45%) but much weaker than that of MWSI. Although the MWSI and sunspot areas are supposed to have a strong relationship, and so similar significance levels in their wavelets are expected, it is worthwhile to remember

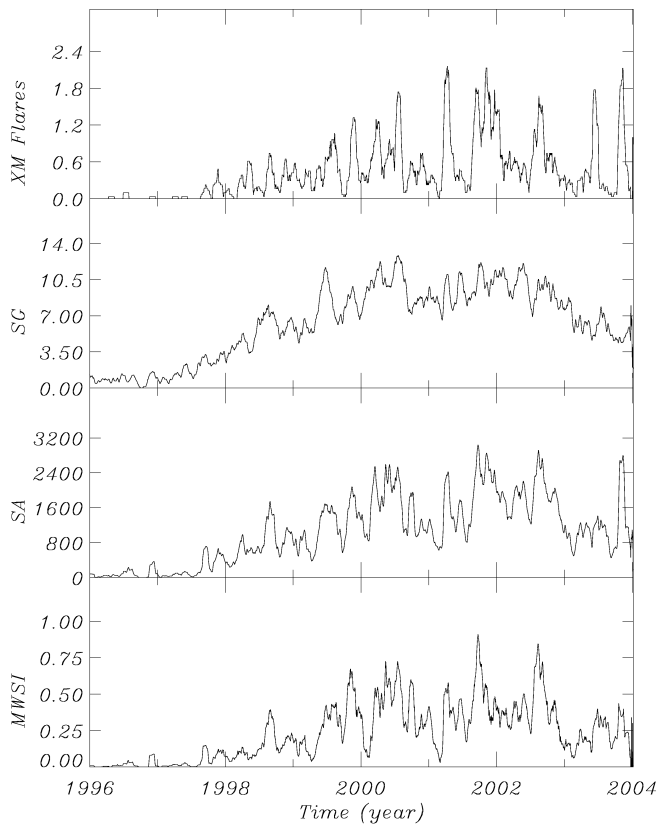


Fig. 2.—Solar cycle 23. From top to bottom: 31 day boxcar average of the daily number of X and M solar flares; daily number of sunspot groups; daily sunspot area; daily MWSI.

that in solar cycle 21, in which both indices showed the periodicity in a strong manner, the significance level for the MWSI wavelet is 99.7%, while for sunspot areas it is only 75%. A possible explanation for this difference in the significance levels during solar cycles 21 and 23 could be based in the findings of Chumak et al. (2003), who studied the time behavior of the total sunspot area and magnetic flux in 10 NOAA active regions corresponding to the year 1989. These authors show that in the studied active regions there is not always a positive correlation between their total sunspot area and magnetic flux: in some of them the total sunspot area remains constant while the magnetic flux increases or decreases, whereas in others both quantities are anticorrelated. This lack of a permanent positive correlation between magnetic flux and sunspot areas in active regions could explain the different significance level of the periodicity shown by the wavelets of MWSI and sunspot areas.

In the case of solar cycle 21, it has been suggested (Oliver et al. 1998; Ballester et al. 2002) that the periodic emergence of magnetic flux took place mainly within already developed sunspot groups, giving place to an enhancement of their magnetic complexity that triggered periodic energetic flares. This hypothesis was supported by the joint apparition of a strong

periodicity in MWSI, sunspot areas, and energetic flares, together with the absence of such periodicity in sunspot groups.

In order to understand this discrepancy between cycles 21 and 23, we have plotted smoothed curves representing the variation, during solar cycle 23, of the daily number of flares (classes X and M), the daily number of sunspot groups, the daily sunspot areas, and the daily MWSI (Fig. 2). When we compare the behavior of the impulses shown in these plots with the behavior of similar curves for solar cycle 21 (Ballester et al. 1999, 2002), a difference can be noted in the impulses corresponding to the daily number of sunspot groups. During the apparition of the periodicity in solar cycle 21, there was a strong correlation among the impulses in MWSI, sunspot areas, and energetic flares, while sunspot groups showed only aperiodic fluctuations. However, during solar cycle 23 the impulses corresponding to the number of sunspot groups display a clearer correlation with the impulses corresponding to the rest of considered quantities. This could suggest that during the current solar cycle, part of the periodic emergence of magnetic flux has occurred away from developed active regions.

In summary, we present strong evidence of the return of the near 160 day periodicity in the MWSI, i.e., in the photospheric magnetic flux from magnetic fields larger than 100 G. The periodicity has appeared with a frequency similar to that of solar cycle 21 and, again, at the epoch of solar activity maximum. However, the wavelet diagram of the number of X-ray flares data set indicates that the periodicity is not present in this record, contrary to what happened during solar cycle 21. Another difference with cycle 21 is that during cycle 23 there is a clearer correlation among the impulses corresponding to the number of sunspot groups, sunspot area, and MWSI. This suggests that the periodic emergence of magnetic flux has shown a mixed behavior, partly occurring away from already developed sunspot groups, which has prevented the development of the periodicity in energetic solar flares.

Finally, from our point of view the most important quantity for the description of the behavior of solar activity, and whose temporal and spatial properties need to be studied with accuracy, is the photospheric magnetic flux. Thus, because of the complex relations of the magnetic flux with active regions (Chumak et al. 2003), sunspot areas and groups constitute secondary indicators, and any comparison of the results obtained from sunspot areas, sunspot groups, and magnetic flux must be taken with care.

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<sup>1</sup> The software is available at <http://paos.colorado.edu/research/wavelets>.

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