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Wavelet analysis of photospheric magnetic flux

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Abstract

We link 342 NSO/Kitt Peak synoptic charts during 1978 to 2003 one by one in time order and reconstruct a daily sequence of photospheric magnetic flux (PMF). By using wavelet transform (WT) some typical mid-term periodicities of PMF are identified, such as 1.38-year, 332-, 275- and 158-day periods. We discuss briefly their temporal evolutions and mutual relations in this paper. For a comparison with another solar general index, we also analyze the periodicities of total solar irradiance (TSI) with the same method. We find the wavelet power spectra of such two sequences are very similar. Therefore, we think PMF and TSI may have some common physical origins.

Keywords: Periodicity; Photospheric magnetic flux; Wavelet transform

1. Introduction

A search for additional possible periodicities in solar activity indices is essential, since any absolute detection of periodicity would have fundamental significance for our understanding of the Sun. For example, it is well-known that the steady solar activity cycle is due to a magnetic dynamo. Currently, the research of photospheric magnetic flux's (PMF) periodicities is still very few. We think this is perhaps by reason of the absence of a long and uniform PMF sequence. In this paper we present a daily sequence of PMF which covers 25 years by linking 342 NSO/Kitt Peak synoptic charts. And a wavelet analysis can help us find not only its definite periodicities but also the evolutive information of such periodicities. We believe these periodic character is very useful for a better understanding of solar activities because most solar phenomena and events are driven by photospheric magnetic fields. Total solar irradiance (TSI) is also a solar general index and makes an important effect on our living environments, we do with it in the same way and expect to get some correlations between them.

2. Data and method

2.1. Photospheric magnetic flux

Our measurement of PMF comes from NSO/Kitt Peak synoptic charts which has been obtained uninterruptedly about 30 years. By making a weighted average of daily full-disk magnetograms these charts are remapped into a grid of 360 equal steps in longitude by 180 equal steps in sine latitude for every Carrington rotation cycle. Their pixel's value denote the density in Gauss of line-of-sight component of magnetic field strength on photosphere observed near the central meridian. And every pixel's area is the same. Fig. 1(a) shows two examples of NSO/Kitt Peak synoptic charts of Carrington cycle 1968 and 1969 which are separated by a central black line.

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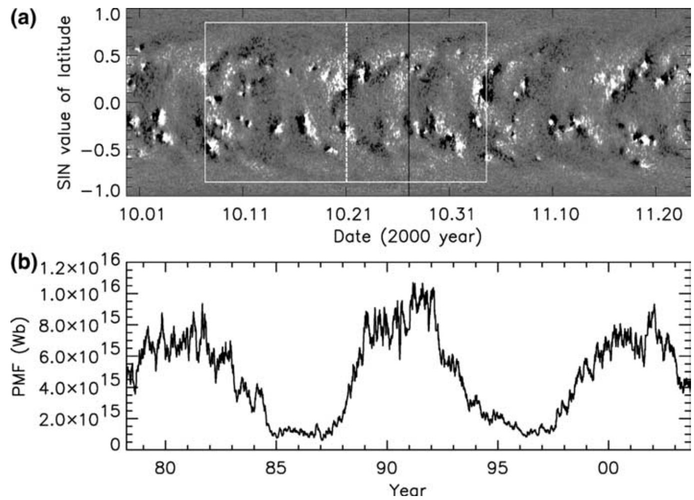

Fig. 1. (a) Two connected NSO/Kitt Peak synoptic charts (360 × 180) of Carrington cycle 1968 (left) and 1969 (right). The white rectangle (360 × 156) lines out corresponding regions in photosphere of the day on 2000 October 21. (b) The daily sequence of PMF during 1978 to 2003.

For improving the temporal resolution of PMF sequence, we connect 342 such charts from Carrington cycle 1666 to 2007 one by one in time order (Stenflo and Güdel, 1988). Fig. 1(a) only shows a snippet of the long chart chain. And by use of this chain we can get the PMF value of each day in our time domain. Here we give one example of 2000 October 21. Firstly, we find the day is during Carrington cycle 1968. Then we divide the interval of this rotation cycle into 360 parts in equal length and find which two parts is nearest from 12 o'clock of 2000 October 21. Secondly, we can find easily the corresponding positions of these two parts in the row of our chart chain because the data format of NSO/Kitt Peak synoptic charts is 360×180. Fig. 1(a) also shows our result with a white dashed line. And at last we draw a 360×156 rectangle as shown in Fig. 1(a) according to two bisectors of the dashed white line and solar equator. By adding up every pixels' absolute value in this rectangle and making multiplied by the pixel's area, we obtain the PMF value of this day finally. Here in these synoptic charts every pixels with the absolute value lower than 5 Gauss are set to zero in the case of measurement error. And the pixels beyond the latitude band S60°–N60° are also excluded for the strong projective effect in both polar regions. Fig. 1(b) depicts our last daily sequence of PMF from 1978 March 27 to 2003 September 12 (total 9301 days).

2.2. Wavelet transform

The method of wavelet transform (WT) can yield periodicity information in time and frequency domains simultaneously. Here we choose the Morlet wavelet for our study of which the definite formula is like $\Psi(t) = \mathrm{e}^{-t^2/2}\cos(kt)$, a plane cosine wave modulated by a Gaussian function. Since the Fourier transform of a Gaussian function is just in the form of itself, the Morlet wavelet analysis can be fine-tuned to have optimal resolutions in both time and frequency domain. We let $k = 6$ in order to make $\Psi(t)$ satisfy the condition of $\int_R \Psi(t)\,\mathrm{d}t = 0$ approximately which every wavelet function should satisfy and to get a good concordance between the Fourier period (t) and the Morlet wavelet time-scale (s). The t and s are related by the equation $t = 4\pi s/(k + \sqrt{2 + k^2})$. From this equation we get $t = 1.033s$, namely, they are nearly equal to each other. The WT power of a temporal sequence $f(n)$ is defined as $W(t,s) = |s|^{-1/2}\int_{-\infty}^{+\infty} f(n)\overline{\Psi(\frac{n-t}{s})}\,\mathrm{d}t$, where t denotes the time. And so far the Morlet wavelet analysis turns up to be very appropriate for temporal sequences.

3. Results

As shown in Fig. 2, we only examine the mid-term periodicities of PMF within the range 100–600 days by using period resolution changing from 2.3 to 13.9 days. Many short-term periodicities are filtered automatically when we calculate the PMF sequence because the corresponding regions in our chart chain of those close days will overlap mostly. And for analyzing the long-term periodicities we think our daily sequence is no more necessary, we can use the unlinked NSO/Kitt Peak synoptic charts directly. Moreover, Knaack and Stenflo (2002) have provided similar study for frequency range up to several years. From Fig. 2 we can identify four significant periods of PMF at 504 (1.38 years), 332, 275, and 158 days by referring to the prominent peaks in its corresponding global wavelet power spectrum: $M(s) = \int |W(t,s)|^2\,\mathrm{d}t$.