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Stochastic properties in North–South asymmetry of sunspot area

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Abstract

We examine the observed sunspot area data exploring stochastic properties of the North–South asymmetry of the sunspot area by comparing results of the observational data with those derived from a simplified mathematical model, in which the asymmetry of the sunspot area is characterized by random noise superposed on a slowly varying sinusoidal background. From power spectrum analysis of the North–South asymmetry of solar activity 9–12-year periodicities have been revealed. Nonetheless, the cause of the North–South asymmetry of solar activity remains unsettled so far. We statistically analyze the sunspot area during the period from 1874 to 2007, by which a physical model can be constrained with reported periodicities. We find with the scatter plots that (i) the phase difference between the sunspot area in both hemispheres should be smaller than a couple years, (ii) the exponentially distributed noise agrees with the observed sunspot area data more closely than the uniformly distributed noise, and (iii) the shape of the underlying sinusoidal function in both hemispheres should be similar. We conclude by pointing out that interpretation of a study on the periodicity of the North–South asymmetry should be derived with due care.

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Keywords: Sun: sunspots; Sun: activity; Methods: data analysis

1. Introduction

Periodic behaviors of solar activity have been widely known for a relatively long time (e.g., Schwabe, 1843; Carrington, 1860). One of the most interesting properties of solar activity is its North–South asymmetry. The North–South asymmetry of solar activity has been the subject of many studies using various features. Studied activity features include sunspot numbers and areas (Newton and Milsom, 1955; Roy, 1977; White and Trotter, 1977; Swinson et al., 1986; Vizoso and Ballester, 1990; Schlamminger, 1991; Yi, 1992; Carbonell et al., 1993; Verma, 1993; Oliver and Ballester, 1994; Krivova and Solanki, 2002; Li et al., 2002; Vernova et al., 2002; Temmer et al., 2002; Knaack et al., 2004; Ballester et al., 2005), sunspot groups (Brajša et al., 2002; Berdyugina and Usoskin, 2003; Forgaćs-Dajka et al., 2004), the flare occurrence/index (Roy, 1977; Ichimoto et al., 1985; Verma, 1987, 1993; Garcia, 1990; Ataç and Özgüç, 1996, 2001; Li et al., 1998; Temmer et al., 2001; Joshi and Joshi, 2004; Joshi and Pant, 2005), coronal green-line (Waldmeier, 1971; Özgüç and Ücer, 1987; Tritakis et al., 1988), prominences/filaments (Hansen and Hansen, 1975; Vizoso and Ballester, 1989; Duchlev and Dermendjiev, 1996; Duchlev, 2001; Gigolashvili et al., 2005a), photospheric magnetic fields (Howard, 1974; Antonucci et al., 1990; Mouradian and Soru-Escaut, 1991; Knaack et al., 2004, 2005), and solar differential rotation (Gilman and Howard, 1984; Javaraiah and Gokhale, 1997; Gigolashvili et al., 2005b; Javaraiah and Ulrich, 2006; Zaatri et al., 2006).

Since the North–South difference in any index of solar activity is an important solar property it should be considered carefully for understanding variations in solar activity. So far, however, the North–South asymmetry time series

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has been considered mostly for the purpose of searching for a periodicity or a correlation between activity indices. This is partly why a physical cause for the North–South asymmetry waits for a clear explanation, yet is suspected to be possibly related to dynamo action (e.g., Ossendrijver et al., 1996; Zharkov and Zharkova, 2006). A hint from statistical analysis is thus helpful to constrain a physical model other than reported periodicities of 9–12-years.

In this paper, we examine stochastic properties of the North–South asymmetry. Comparing scatters of the observed sunspot area in the northern and southern solar hemispheres with those resulting from a simplified mathematical model, we provide a new insight to the North–South asymmetry of solar activity. We only concentrate on the issue of stochastic behaviors, rather than of periodicity. This paper begins with descriptions of the data in Section 2. We present the model we have used in this work and results we have obtained in Section 3. Finally, we discuss and conclude in Section 4.

2. Observational data

We have taken sunspot area data for the present analysis from the NASA website,[1] which is regularly updated by Hathaway in Marshall Space Flight Center, where the sunspot dataset is available as ASCII text files containing records for individual years since 1874. Text files are also available containing the monthly averages of the daily sunspot areas (in units of millionths of a hemisphere) in the northern and southern solar hemispheres separately. The dataset has been carefully combined using the Greenwich sunspot group data during the period from 1874 to 1976, and the sunspot group data from the Solar Optical Observing Network (SOON) of the US Air Force/US National Oceanic and Atmospheric Administration (NOAA) during the period from 1977 to 2007. These derived data include the correction factor of 1.4 for data after 1976 (e.g., Javaraiah, 2007).

In Fig. 1, we show the monthly average of the sunspot area which appeared in the solar northern and southern hemispheres, A_N and A_S, and its difference, $A_S - A_N$, for the period of 1874–2007 as a function of time. We adopt the absolute difference instead of a conventional asymmetry index, that is, the difference normalized by the sum, $(A_S - A_N)/(A_S + A_N)$, as used in recent studies (e.g., Yi, 1992; Ballester et al., 2005). By applying the Lomb-Scargle periodogram to $A_S - A_N$, we observe the presence of the periodicity around 9 years (e.g., Ballester et al., 2005). One may easily see that the absolute difference is enhanced near the solar maxima and that cycle minima appear in the phase for both hemispheres while cycle maxima in both hemispheres are shifted by a couple of years (cf. Temmer et al., 2006). We also note that a magnitude of random fluctuations in A_S and A_N varies with solar cycles. A stochastic behavior in $A_S - A_N$ seems an imprint of these features.

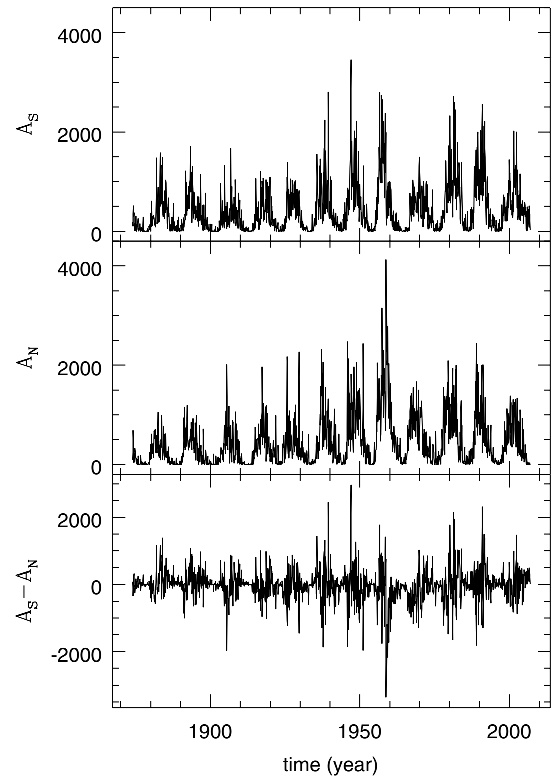

Fig. 1. Monthly average of the sunspot area (in units of millionths of a hemisphere) which appeared in the solar southern and northern hemispheres, A_S and A_N, and its difference, $A_S - A_N$, for the period of 1874–2007.

In Fig. 2, the difference versus the sum of the observed sunspot area is shown. In the upper panel, we show the difference between the sum of the monthly average of the northern and the southern sunspot area over each solar cycle, ~11 years, $\langle A_S \rangle - \langle A_N \rangle$, against the sum of the sunspot area of the entire solar surface over the same period, $\langle A_S \rangle + \langle A_N \rangle$. One may determine which hemisphere is dominant for a particular solar cycle from this kind of plot by tracing a corresponding point. Apparently, the sum of the sunspot area of the entire solar surface is uncorrelated with the difference between the sum of the monthly average of the northern and the southern sunspot area over each solar cycle. We note that $\langle A_S \rangle - \langle A_N \rangle$ are symmetrically distributed with respect to zero mean except for solar cycles 19 and 20. In the lower panel, on the other hand, we show the difference between the monthly average of the sunspot area in the northern and in the southern hemispheres at a given time, $A_S - A_N$, versus the sum of the two values at the same epoch, $A_S + A_N$. A scatter plot such as shown in the lower panel reflects a dependence of the asymmetry on the magnitude of a solar activity index itself. It is quite interesting to note that there seems to be an evident pattern in this scatter plot. This distribution is indeed related to stochastic properties of the magnitude of the North–South asymmetry.

[1] http://solarscience.msfc.nasa.gov/greenwich.shtml.