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A study of the north-south asymmetry of sunspot area during solar cycle 23

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Abstract. Solar activity indices vary over the Sun's disk, and various activity parameters are not considered to be symmetric between the northern and southern hemispheres of the Sun. The north-south asymmetries of different solar indices provide an important clue to understanding solar dynamo action, especially with regard to non-linear dynamo models. In the present work, we study the statistical significance of northsouth asymmetry of sunspot areas for the complete solar cycle 23 (1996 - 2008). The dominant hemisphere in each year of the cycle 23 has been identified by calculating the probability of hemispheric distribution of sunspot areas. The statistically significant intermediate-term periodicities of the north-south asymmetry of sunspot area data have also been investigated using wavelet technique. A number of short and mid-term periods are detected and most of them are found to be time variable. We present our results and discuss their possible explanations for different solar mid-term periodicities.

Keywords : Sun: activity – sunspots

1. Introduction

The existence of the north-south (N-S) asymmetry in solar activity is an intensively studied phenomenon. It is a real and systematic phenomenon (not due to random fluctuation) which can be observed in terms of several activity indicators such as sunspot numbers and area, solar flares and flare index data, photospheric magnetic flux, filaments etc. (Oliver & Ballester 1994; Atac & Özgüc 1996; Li et al. 2002, 2009, 2010; Temmer et al. 2006 and references therein). The N-S asymmetry is now widely recognized and its analysis in context of solar activity for both northern and southern

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Table 1. Hemispheric distribution of sunspot area.

Year	N	S	Probability	A	Dominant hemisphere
1996	5978	19082	$< 10^{-6}$	−0.522	S
1997	41118	35476	$< 10^{-6}$	0.073	N
1998	12422	155176	$< 10^{-6}$	−0.110	S
1999	251230	173600	$< 10^{-6}$	0.182	N
2000	302708	286216	$< 10^{-6}$	0.028	N
2001	337744	285026	$< 10^{-6}$	0.084	N
2002	265751	402290	$< 10^{-6}$	−0.204	S
2003	201208	2017112	0.000941	-1.25×10^{-3}	S
2004	99463	151263	$< 10^{-6}$	0.206	S
2005	69636	128506	$< 10^{-6}$	−0.297	S
2006	7098	82643	$< 10^{-6}$	−0.841	S
2007	4480	44156	$< 10^{-6}$	−0.815	S
2008	1834	6559	$< 10^{-6}$	−0.562	S
2009 (cycle 24)	6692	3108	$< 10^{-6}$	0.365	N
2010 (cycle 24)	55434	22984	$< 10^{-6}$	0.413	N

hemispheres provides insight and constraints to understanding dynamo action. Periodic sunspots evolve in a complex wave-like fashion. They also exhibit asymmetry in both the hemispheres. In this work, we have investigated the asymmetric behavior of sunspot area during cycle 23 (1996 - 2008) and the initial phase of cycle 24 (2009 - 2010) considering northern and southern hemispheres of the Sun.

2. Data and analysis

The daily and monthly data of sunspot areas of the full solar disk, northern and southern hemispheres of the Sun have been taken from the NASA's Marshall Space Flight Centre (http://solarscience.msfc.nasa.gov/greenwch.shtml). The N-S asymmetry has been calculated using

$$A = \frac{N - S}{N + S}$$

where N and S respectively are values of sunspot areas in northern and southern hemispheres.

We have counted the yearly sum of sunspot areas in both hemispheres, calculated the actual probabilities of generating N-S distribution using Binomial probability formula, and shown the dominant hemispheres in every year of the solar cycle 23 and 24 (cf., Table 1). The binomial probability distribution formula is given by

$$P(r) =^n C_r P^r (1 - p)^{n-r}$$

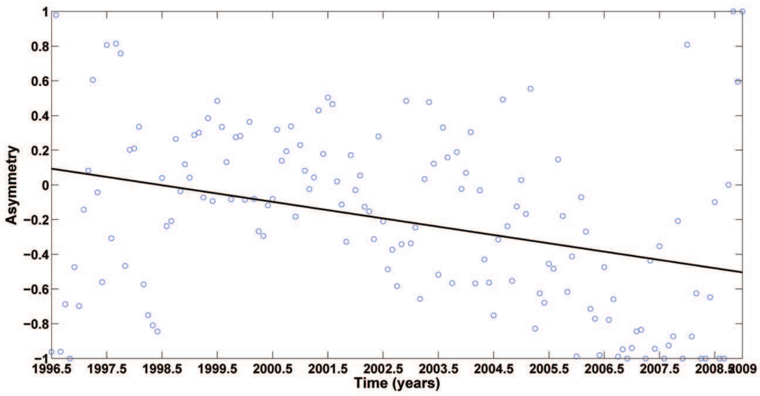

Figure 1. Plot of N-S asymmetry and regression line for cycle 23.

where n is the number of objects in both classes, r is the number of objects in a particular class and $p = 0.5$ is the associated probability. The probability of finding more than d objects in one class is is given by

$$P(\geq d) = \sum_{i=d}^{n} P(i)$$

It is to be noted that $P(\geq d) > 10\%$ is a statistically insignificant result: $5\% < P(\geq d) < 10\%$ is marginally significant, $1\% < P(\geq d) < 5\%$ is statistically significant, and $P(\geq d) < 1\%$ is highly significant.

We fit a regression line to the monthly values of A during the ascending (including maxima) and descending (including minima) phases of cycle 23 as well as the initial phase of cycle 24. The results are shown in Figs 1 and 2. We find that the slope of the straight line changes in each phase indicating some kind of periodic behavior by which the activity changes from one hemisphere to the other. We have also investigated the short and mid-term periodicities in asymmetry data for the complete cycle 23 using complex Morlet wavelet function ($\omega_0 = 6$) considering a red-noise background to study the temporal evolution of the detected periods. The thin black contours within COI show the periods above 95% confidence level (Torrence & Compo 1998).

3. Results and discussions

Figure 1 and Table 1 show that the northern hemisphere is dominant up to 2001, but then the southern hemisphere takes over from 2002 to the end of solar cycle 23, i.e., (2008). On the other hand, northern hemisphere dominates in the initial phase of cycle 24 (cf., Table 1, Fig. 2). Moreover, the present study indicates that the solar activity with respect to sunspot area is dominant in the southern hemisphere during cycle 23. Using by WT method (Fig. 3), we find a number of short and mid-term

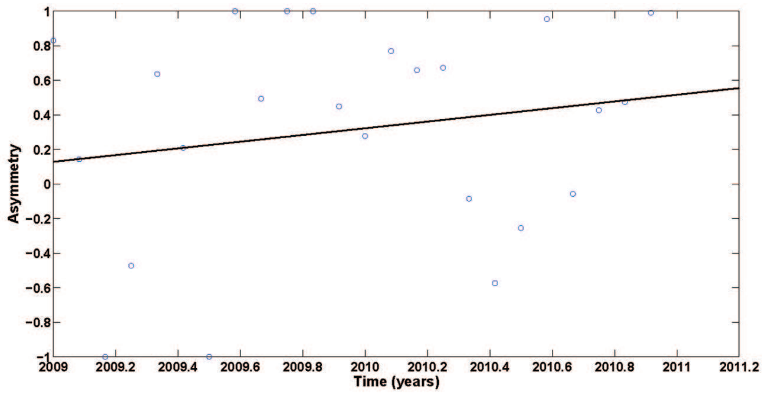

Figure 2. Plot of N-S asymmetry and regression line for cycle 24.

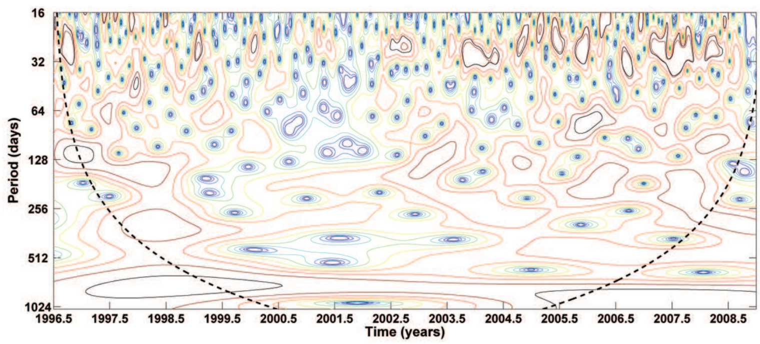

Figure 3. Wavelet spectrum of N-S asymmetry data for cycle 23.

quasi-periodicities namely, ~ 27 d, ~ 27 31 d, 50-60 d, ~ 27 100 d, near Rieger periods of ~ 27 136 d and ~ 27 165 d, ~ 27 1.4 yr and a quasi-bi-annual period of ~ 27 2.1 yrs detected in sunspot area asymmetry data during different phases of cycle 23. These results are consistent with the earlier results in various activity indicators such as group sunspot number (Temmer et al. 2006); photospheric magnetic flux (Knaack et al. 2004); coronal Fe lines (Badalyan et al. 2008) etc. Although physical reasons behind these periodicities are still unknown, yet they are possibly related with the evolution of complex activity and their characteristic lifetime. Goel and Choudhuri (2009) assumed that the Babcock-Leighton process of poloidal field generation to be the main source of irregularity in sunspot cycle. They inferred that the N-S asymmetry should tend to get reduced as the cycle progresses, and the hemispheric asymmetries should be expected to continuously get washed away until the randomness in the Babcock-Leighton process creates fresh asymmetries towards the end of the cycle. Our findings are in the variance of their inference. Zaatri et al. (2006) after studying the N-S asymmetry of zonal and meridional components of horizontal solar subsurface flows during 2001-04, showed that the zonal flows are larger in southern hemisphere and this N-S asymmetry increase with depth. The average meridional flow has large amplitude in the southern hemisphere equator ward of the mean latitude of magnetic activity. Recently, Basu and Antia (2010) studied solar meridional flows and their variations for cycle 23 and reported that the time dependence of variation is a function of both latitude and depth. More observations of local helioseismology are called for in addressing the physics of the N-S asymmetry precisely.

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