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Regularity of the north-south asymmetry of solar activity

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Abstract. In the present work, the dominant hemisphere of solar activity in each of solar cycles 12 to 22 has been clarified by calculating the actual probability of the hemispheric distribution of several solar activity phenomena using long-term observational records. An attempt is made to demonstrate that a long characteristic time scale, about 12-cycle length, is inferred to occur in solar activity.

Key words. Sun: activity – Sun: general – Sun: sunspots

1. Introduction

Solar activity indices vary over the solar disk, and various activity parameters are not considered to be symmetric between the north and south hemispheres (Reid 1968; Roy 1977; White & Trotter 1977; Li et al. 2000). Long-term observations indicate a real North-South asymmetry (Vizoso & Ballester 1990; Carbonell et al. 1993; Oliver & Ballester 1994). This is well known from many studies of its different manifestations. The N-S asymmetry – using solar flares as an index – has been analysed by Bell (1961), Reid (1968), Roy (1977), Knoska (1985), Verma et al. (1987), Garcia (1990), Bai (1990), Atac & Ozguc (1996, 1998), and Li et al. (1998); while using sunspots including sunspot groups and sunspot areas, it has been studied by Newton & Milson (1955), Bell (1962), Waldmeider (1957, 1971), Howard (1974), White & Trotter (1977), Swinson et al. (1986), Vizoso & Ballester (1990), Carbonell et al. (1993), Oliver & Ballester (1994), Li & Gu (2000), and Li et al. (2001). Other solar activity indexes, such as filaments, (active) prominences, radio bursts, solar gamma ray bursts, coronal holes, CME, photospheric magnetic fields, faculae, the monochromatic and K coronae, solar wind, and green corona intensity have also been investigated to reveal the asymmetry of solar activity (Siscoe & Coleman 1969; Waldmeier 1971; Howard 1974; Hansen & Hansen 1975; Sykora 1980; Verma 1987; Ozguc & Ucer 1987; Tritakis et al. 1988; Li & Gu 2000). However, the above investigators sometimes show inconsistent results about the dominant hemisphere of solar activity in solar cycles (Verma 1993; Li & Gu 2000). For example, for solar cycle 21, there is a controversy about the dominant hemisphere of solar activity as some solar active phenomena show a north dominance, while some show a south dominance. Moreover, according to Bai (1990) the N-S asymmetry is zero (Verma 2000; Li & Gu 2000). In the present study, the dominant hemisphere of solar activity in each of solar cycles 12 to 22 is investigated by calculating the actual probability of the hemispherical distribution of several solar activity phenomena based on the long-term observational records.

The asymmetrical north-south distribution is periodic and indeed related to the 11-year sunspot cycle, although the periods of different phenomena of solar activity often show peculiar phase shifts with respect to the 11-year cycle (Garcia 1990), and a long-term period of about 8 eleven-year cycles appears several times (Pulkkinen et al. 1999). First, Waldmeier (1957, 1971) pointed out a phase shift between hemispheres and suggested the period. Vizoso & Ballester (1990) used a straight line to fit the yearly values of the north-south asymmetry of sunspot areas during solar cycles 12 to 21, and found that each four cycles the slope of the straight regression line changes in sign, suggesting some kind of periodic behavior, and confirmed the result of Waldmeier (1957, 1971). Atac & Ozguc (1996) also used a straight line to fit the yearly values of the north-south asymmetry of the flare index during solar cycles 17 to 22, and confirmed again the long-term period of about 8 solar cycles. In this paper, an attempt is made to demonstrate that the long-term period of 8 solar cycles

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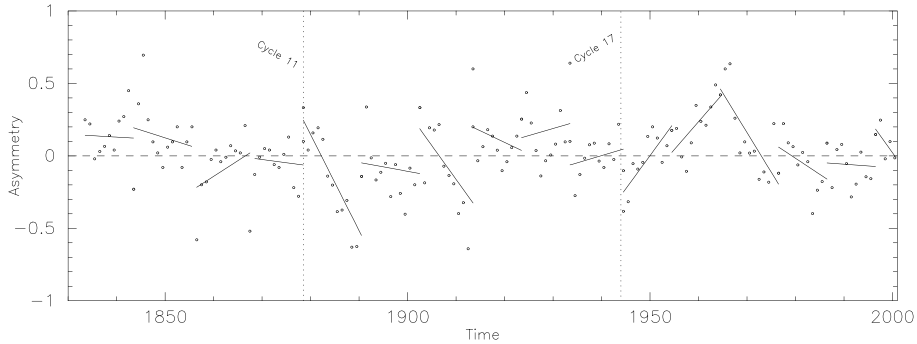

Fig. 1. The fit of a regression line to the yearly values of the N-S asymmetry of numbers of sunspot groups for solar cycles 8 to 23.

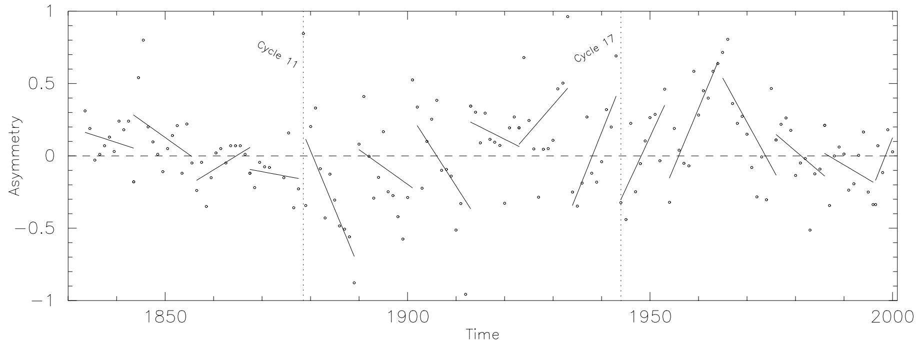

Fig. 2. The fit of a regression line to the yearly values of the N-S asymmetry of sunspot areas for solar cycles 8 to 23.

seems to be one possible inference, and a longer characteristic time scale, about 12-cycle lengths, can be more reasonably inferred to occur in solar activity.

2. Long-term characteristic time scale of asymmetry of solar activity

2.1. Yearly numbers of sunspot groups

We have constructed the yearly north-south asymmetry of numbers of sunspot groups during the time interval of the years 1875 to 2000, corresponding to the descent of cycle 11 to the ascent of cycle 23, whose original data were downloaded from the web site of the Solar Physics Group at NASA's Marshall Space Flight Center (`http://www.science.nasa.gov/ssl/pad/solar/greenwch.htm`). The N-S asymmetry is calculated traditionally by means of $Asymmetry = (NO_{\rm N} - NO_{\rm S})/(NO_{\rm N} + NO_{\rm S})$, where $NO_{\rm N}$ and $NO_{\rm S}$ stand for the yearly number of sunspot groups in the north and south hemispheres, respectively. The obtained values are plotted in Fig. 1, where the values of the years 1833 to 1884 come from Verma (1993) and Newton & Milsom (1955). We fit a straight line to the yearly values of the asymmetry, for each of cycles 8 to 23 separately (cycle 23 is not a complete cycle at present), starting each cycle with the year of the minimum between two consecutive cycles. If we change this criterion, dividing the year of the minimum between the two parts belonging to each of the successive cycles, no cycle changes its behaviour. As Vizoso & Ballester (1990) and Atac & Ozguc (1996) showed, for cycles 12 to 23, each four cycles the slope of the straight line changes its sign, which could suggest one kind of periodic behavior in the N-S asymmetry. If only these 12 cycles are concerned, we may initially infer that the period should be 8 solar cycles as Vizoso & Ballester (1990) and Atac & Ozguc (1996) naturally concluded. However, we can also infer from this kind of asymmetry behavior that the characteristic time scale should be 12 solar cycles, as the former 6 cycles (cycles 12 to 17), which are located between the dotted vertical lines of the figure, may be regarded as an image of the latter 6 cycles (cycles 23 to 18). However, Fig. 1 shows that three cycles (cycles 8, 9, and 11) of the first four in the figure support our inference and conflict with the former inference. Considering the reliability of the earlier observational record of sunspot groups, we cannot confirm the result here but prefer to infer that such periodic behavior implies a long-term characteristic time scale of about 12 solar cycles; the study given in the next section also biases the preference.

2.2. Yearly numbers of sunspot areas

Figure 2 shows the yearly N-S asymmetry of sunspot areas during the period of 1833–2000 using same procedure as in the previous subsection. The data were obtained as the previous subsection. We also fit a straight line to the yearly values of the asymmetry, for cycles 8 to 23 separately, starting each cycle with the year of the minimum between two consecutive cycles. If we change this criterion, dividing

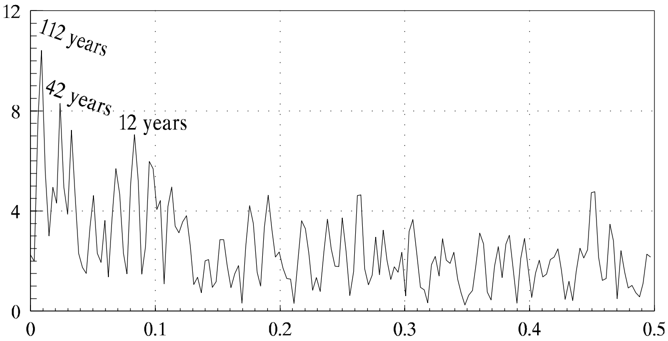

Fig. 3. Fourier transform of the time series of the yearly numbers of sunspot groups. Periodicities of obvious frequency peaks are given over the peaks.

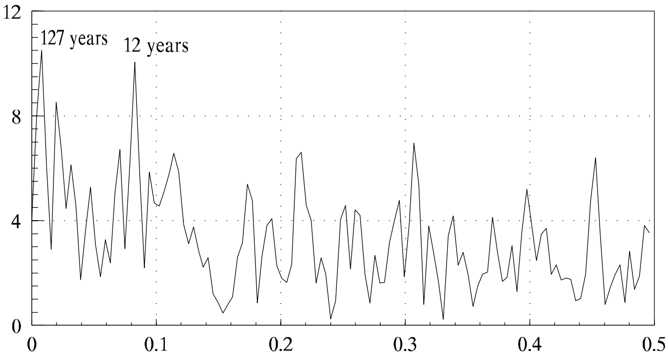

Fig. 4. Fourier transform of the time series of the yearly numbers of sunspot areas. Periodicities of notable frequency peaks are given over the peaks.

the year of the minimum between the two parts belonging to each of the successive cycles, only cycle 13 changes its behaviour, as Vizoso & Ballester (1990) reported. From Fig. 2, we can arrive exactly at the same conclusion as from Fig. 1.

2.3. *Long term characteristic time scale of asymmetry of solar activity*

In order to confirm our inference, we have performed Fourier transforms of the above two time series, which are plotted in Figs. 3 and 4. In Fig. 3 we can see that the time series of the yearly numbers of sunspot groups markedly peaks at about 112 years, 42 years, and 12 years. Figure 4 shows that the time series of the yearly numbers of sunspot areas notably peaks at about 127 years and 12 years. Both time series show a long-term characteristic time scale of about 12 solar cycles, supporting our inference.

3. Dominant hemisphere of solar activity in each of solar cycles 12 to 23

We have counted the total number of sunspot groups respectively in the north and south hemispheres in each of solar cycles 12 to 23, which is shown in Table 1. Counted and shown also in the table are (1) the total number of sunspot areas (in 10^{-4} solar hemisphere unit) respectively in the hemispheres in each of cycles 12 to 23, (2) the sum of the relative number of sunspot measurement respectively in the hemispheres in each of cycles 10 to 22, whose original data come from Table 1 of Pulkkinen et al. (1999), (3) the flare index in each of cycles 17 to 23, and (4) the sum of sudden disappearances in each of cycles 17 to 21, whose original data come from Fig. 1 and Table 1 of Vizoso & Ballester (1987). The original data of the flare index in the years 1936 to 1976 come from Table 1 of Knoska (1985), and the data of the flare index in the years 1966 to 2000 come from the web site of Bogazici University Kandilli Observatory (`http://www.koeri.boun.edu.tr/astronomy/findex.html`). We compare the overlaid parts of the two data sets of the flare index and translate the former series into the latter to compose a coherent series of the flare index . For cycle 23, the above numbers are counted up to the year 2000, so cycle 23 is not a complete cycle. The asymmetry of the events in each cycle is calculated in the table. The probability of obtaining a distribution is also listed in the table, based on the binomial formula used to compute the actual probability of obtaining any particular distribution of n objects in two classes (Vizoso & Ballester 1990; Li & Gu 2000). In the case of a continuous distribution, the normal (Gauss) distribution is used to replace the binomial formula to calculate the probability.

If the probability of a hemispherical distribution of solar activity in a cycle is less than 10%, the distribution of solar activity for the two hemispheres in the cycle should be considered to be statistically important or marginally significant and not due to random fluctuations, whereas if the probability is larger than 10%, solar activity in the cycle should be regarded as equivalence for the two hemispheres and not statistically important (Vizoso & Ballester 1990; Oliver & Ballester 1994; Li & Gu 2001). All five solar active phenomena in the table coherently give one dominant hemisphere of solar activity in one certain cycle for solar cycles 12 to 22 except cycle 21. Although signs of asymmetry sometimes differ for cycles 14, 17, and 18 when different solar active phenomena are used, solar activity coherently dominates in a certain hemisphere or no hemisphere for each of the three cycles. For cycle 21, the number of sunspot groups dominates in the south hemisphere, but the other four phenomena give no dominant hemisphere with solar activity equivalent for the two hemispheres; it is the only exception. Twenty solar phenomena were collected by Li & Gu (2000) to demonstrate that no dominant hemisphere of solar activity existed in cycle 21, so, solar activity in the cycle is finally regarded as equivalent for the two hemispheres. A southern dominance of solar activity is suggested to occur in solar cycle 23 by Atac & Ozguc (1996). Figure 5 shows sketch of the dominant hemisphere of solar activity in each of solar cycles 12 to 23. The figure manifestly shows that a longer characteristic time scale, at least 12-cycle lengths, should occur in the N-S asymmetry of solar activity, and the long-term period of 8 solar cycles does not seem to

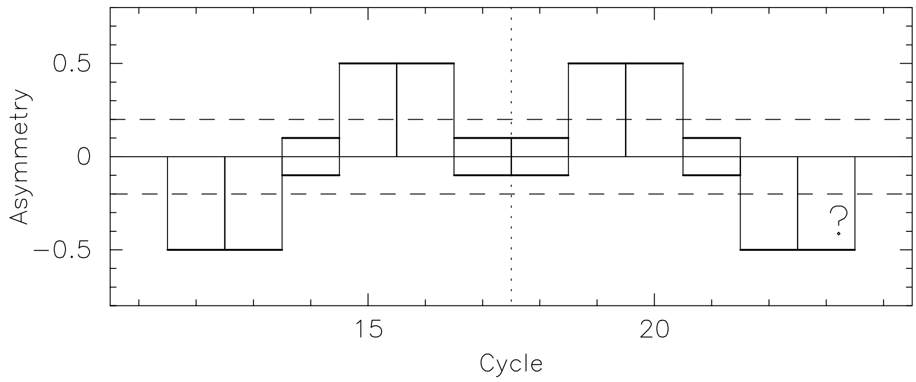

Fig. 5. Sketch of the dominant hemisphere of solar activity in each of solar cycles 12 to 23. Solar activity in those cycles whose histograms are located within the two dashed lines are regarded as equivalent without a dominant hemisphere. The symbol ? denotes that the dominant hemisphere is just expected and cannot be confirmed at present.

Table 1. Solar activity in the hemispheres.

Cycle No.	NO_N	NO_S	*Asymmetry*	*Probability*	Preferred hemisphere
		Number of sunspot groups			
12	858	1088	−.1182	$.8896E-07$	South
13	1318	1587	−.0926	$.2939E-06$	South
14	1139	1180	−.0177	$.1972E+00$	–
15	1895	1668	.0637	$.7100E-04$	North
16	1602	1411	.0634	$.2495E-03$	North
17	1843	1802	.0112	$.2485E+00$	–
18	1816	1826	−.0027	$.4342E+00$	–
19	2725	2010	.1510	$.1098E-24$	North
20	2409	1976	.0987	$.2978E-10$	North
21	1866	1952	−.0225	$.8196E-01$	South
22	1407	1662	−.0831	$.2050E-05$	South
23	681	621	.0461	$.4809E-01$	?
		Sunspot areas			
12	286.780	411.283	−.1784	$.1246E-05$	South
13	388.155	475.133	−.1008	$.1511E-02$	South
14	349.515	333.942	.0228	$.2829E+00$	–
15	433.382	356.879	.0968	$.3390E-02$	North
16	465.326	390.659	.0872	$.5117E-02$	North
17	600.236	596.496	.0031	$.4539E+00$	–
18	742.554	702.923	.0274	$.1524E+00$	–
19	1055.170	738.888	.1763	$.3663E-13$	North
20	824.323	600.245	.1573	$.1340E-08$	North
21	752.520	770.374	−.0117	$.3222E+00$	–
22	637.570	723.738	−.0633	$.1057E-01$	South
23	258.192	233.698	.0498	$.1294E+00$	?

Table 1. continued.

Cycle No.	NO_N	NO_S	*Asymmetry*	*Probability*	Preferred hemisphere
		The relative number of sunspot measurements			
10	49.7	50.3	−.0060	$.5239E+00$	–
11	48.0	52.0	−.0400	$.2119E+00$	–
12	44.5	55.7	−.1118	$.1255E-01$	South
13	45.9	54.1	−.0820	$.5050E-01$	South
14	49.2	50.9	−.0170	$.3669E+00$	–
15	53.4	46.6	.0680	$.8690E-01$	North
16	53.6	46.4	.0720	$.7500E-01$	North
17	49.2	50.8	−.0160	$.3745E+00$	–
18	49.1	50.9	−.0180	$.3669E+00$	–
19	57.6	42.4	.1520	$.1183E-02$	North
20	55.2	44.8	.1040	$.1876E-01$	North
21	49.3	50.5	−.0120	$.4052E+00$	–
22	46.3	53.6	−.0731	$.7150E-01$	South
		The flare index			
17	151.92	131.40	.0724	$.1289E+00$	–
18	125.76	112.44	.0559	$.1816E+00$	–
19	576.24	386.16	.1975	$.3905E-08$	North
20	309.36	158.04	.3237	$.8489E-12$	North
21	574.80	564.84	.0087	$.3834E+00$	–
22	380.40	458.76	−.0934	$.3159E-02$	South
23	78.36	63.36	.1058	$.1024E+00$	?
		Number of sudden disappearances			
17	107	124	−.1169	$.1311E+00$	–
18	297	272	.0439	$.1471E+00$	–
19	580	415	.1658	$.7807E-07$	North
20	520	384	.1504	$.2894E-05$	North
21	233	255	−.0451	$.1594E+00$	–

exist in this case. A slight southern dominance of solar activity is shown to occur in cycles 10 and 11 with the use of the relative numbers of sunspot measurement (see Table 1); it seems to imply that the long-term characteristic time scale should be about 12 cycles long. However, the probability values in the two cycles are larger than 10%, probably due to the poorer quality of earlier observations of sunspots, and the southern dominance of solar activity cannot be confirmed, although the long-term characteristic time scale predicts that there should be a southern dominance of solar activity in the two cycles.

4. Conclusions and discussions

In the present study, with number of sunspot groups from 1833 to 2000, sunspot areas, the relative number of sunspot measurements in cycles 10 to 22, the flare index of the years 1936 to 2000, and the number of sudden disappearances in cycles 17 to 21, an attempt is made to demonstrate that the long-term period of 8 solar cycles seems to be one possible inference, and a longer characteristic time scale, about 12-cycle lengths can be more reasonably inferred to occur in solar activity.

The dominant hemisphere of solar activity in each of solar cycles 12 to 22 is investigated by calculating the actual probability of the hemispheric distribution of several solar activity phenomena with long-term observational records. So, in summary, combining the two kinds of analyses, a long characteristic time scale of about 12-cycle lengths is inferred to occur in solar activity. The significance of this periodicity cannot be given at present, because the span of the reliable data used here is almost as long as the long-term characteristic time scale, thus it cannot be strictly confirmed with statistical significance and needs to be confirmed in the future. There are several investigations in agreement with our findings. Verma (1992) showed a long-term period of about 12 solar cycles by a spectral analysis of a long time series of the N-S asymmetry composed of data of 7 different activity phenomena. Recently, Li et al. (2001) studied hemispheric solar activity within extended cycles, and a long-term hemispheric variation of at least 12-cycle lengths is also inferred to exist. Duchlev (2001) estimated the long-term variation of the N-S asymmetry of long-lived solar filaments from the Meudon' catalogue during the period 1919 to 1989 and found a long-term period of the filament asymmetry variation of about 11 solar cycles with the use of the cumulative index for the filament N-S asymmetry. When we know the N-S asymmetry of cycle 23 (which is now in progress), we will have further indication whether the long-term characteristic time scale of about 12 cycles exists or not. If there is an asymmetry in favor of the Southern hemisphere, then the hypothesis about a 12 cycle periodicity is valid, otherwise both the 12 and 8 cycle periodicities are in question.

The Sun's magnetic activity is generally believed to be supplied by a hydromagnetic dynamo operating either in or at the base of the solar convective zone (Pulkkinen et al. 1999). It has recently been proposed that the dipolar and quadrupolar components of dynamo models could both be oscillating coherently and that therefore the observed asymmetry should have a period component to its signal (Brooke et al. 1998). In future, a better dynamo model should quantitatively represent the long-term characteristic time scale, in addition to the 11-year cycle length.

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