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Can Asymmetry of Solar Activity be Extended into Extended Cycle?

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Abstract With the use of the Royal Greenwich Observatory data set of sunspot groups, an attempt is made to examine the north-south asymmetry of solar activity in the "extended" solar cycles. It is inferred that the asymmetry established for individual solar cycles does not extend to the "extended" cycles.

Key words: Sun: sunspot – Sun: active cycle – Sun: activity

1 INTRODUCTION

Cumulative values of solar activity parameters over time usually vary over the solar disk and surprisingly, various activity indices are not symmetrically distributed between the northern and southern hemispheres (Reid 1968; Roy 1977; White & Trotter 1977; Vizoso & Ballester 1987; Verma 1993; Li, Schmieder, & Li 1998; Atac & Ozguc 1998; Li et al. 2000; Li & Gu 2000). Long-term observations of solar activity indicate that the behaviour of solar activity is generally asymmetric with regard to the two hemispheres (Swinson, Koyama & Saito 1986; Vizoso & Ballester 1990; Carbonell, Oliver & Ballester 1993; Oliver & Ballester 1994; Atac & Ozguc 1996), and the asymmetric north-south distribution is periodic and is indeed related to the 11-year sunspot cycle, although different phenomena of solar activity often show peculiar phase shifts with respect to the 11-year cycle (Garcia 1990).

It is well known that the first group of sunspots of a new cycle emerges before the sunspot minimum and the sunspots continue to appear for 12 or more years, ending after the following minimum (Harvey 1992). Richardson (1948), Dodson (1953), Giovanelli (1964), and Dodson et al. (1982) identified the first and last observed sunspot regions of cycles 14 to 20. Their results showed that the sunspot regions of a new cycle begin to appear as much as 1.6 years before the statistically defined sunspot minimum and continue to emerge up to 1.8 years after the following minimum. The duration of the sunspot activity belonging to cycles 14 to 20 is thus 1.8 to 3.3 years longer than the interval between successive minima, ranging from 12 to 14.2 years (Harvey 1992). The period of time, over which activity of a given cycle is observed,

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is called the extended activity cycle (Wilson et al. 1988; Bortzov 1992; Harvey 1992). When taking into account the spatial distribution of solar activity in latitude, solar activity over the disk fluctuates with a period much longer than 11 years. Here a question naturally arises: does the asymmetry of solar activity extend to the extended cycle? in other words, does the asymmetry of also exist in the overlap of two successive sunspot cycles? and if the asymmetry exists in the overlap, is the asymmetry connected just with the sunspot cycle or magically with the extended cycle in which the magnetic polarity of sunspot groups generally obeys the Hale law? In the present work, an attempt is made to address this question with the use of the Royal Greenwich Observatory data set of sunspot groups.

2 ASYMMETRY OF SUNSPOT GROUPS IN THE OVERLAP BETWEEN ADJACENT EXTENDED CYCLES

The observational data of sunspot groups used in the present study come from the Royal Greenwich Observatory data set (web site: http://www.science.nasa.gov/ssl/pad /solar /greenwch. htm). The data set comprises sunspot groups over the period from 1874 to the present (June 1999), that is, from solar cycle 12 to the present cycle. With the use of a criterion of dividing sunspot groups into extended solar cycles (Li, Yun & Gu 2001), we count the monthly number of sunspot groups in the northern and southern hemispheres in extended cycles 11 to 23. The counts are shown in Figure 1.

Sunspot group number of an extended cycle may be divided into two parts by the minimum time of a given (sunspot) cycle. This is illustrated in Figure 2: Part A is the part before the minimum, the early part of the new extended cycle, and Part B is the part after the minimum. Similarly, the numbers in the preceding extended cycle may also be divided into two part by the minimum: Part C is the part after the minimum, or the late part of the previous extended cycle, and the Part D is the part before the minimum. The total number of sunspot groups in each of the four parts around each minimum time of cycles 12 to 23 are given in Table 1, where suffixes N and S indicate the hemisphere. The probability for obtaining such a distribution is calculated and also listed in the table, based on the binomial formula for the probability of obtaining any particular distribution of n objects in two classes (Li & Gu 2000; Vizoso & Ballester 1990). Then we calculate the north-south asymmetry of sunspot group number,

Table 1 Sunspot Group Numbers in Parts A, B, C, and D

Cycle	Part A			Part B			Part C			Part D		
	No_N	No_S	Probability	No_N	No_S	Probability	No_N	No_S	Probability	No_N	No_S	Probability
12	0	0	–	0	0	–	0	1	–	0	0	–
13	4	6	0.2539	15	20	0.1958	0	3	0.0	1	3	0.125
14	1	1	0.5	0	0	–	0	0	–	0	1	–
15	0	1	–	228	221	0.3704	10	12	0.3318	0	1	–
16	6	3	0.1445	12	12	0.5	6	2	0.0625	33	15	0.0397
17	0	0	–	10	10	0.5	7	6	0.3872	0	0	–
18	0	0	–	4	25	1.37×10^{-5}	6	6	0.5	0	0	–
19	1	1	0.5	4	1	0.0625	7	3	0.0898	2	4	0.1875
20	0	0	–	87	15	2.4×10^{-14}	21	14	0.1147	0	0	–
21	5	6	0.3770	51	46	0.3050	14	8	0.0946	41	41	0.5
22	0	0	–	52	89	8.34×10^{-4}	13	8	0.1316	0	0	–
23	7	2	0.0352	9	12	0.2517	8	8	0.5	11	7	0.1662

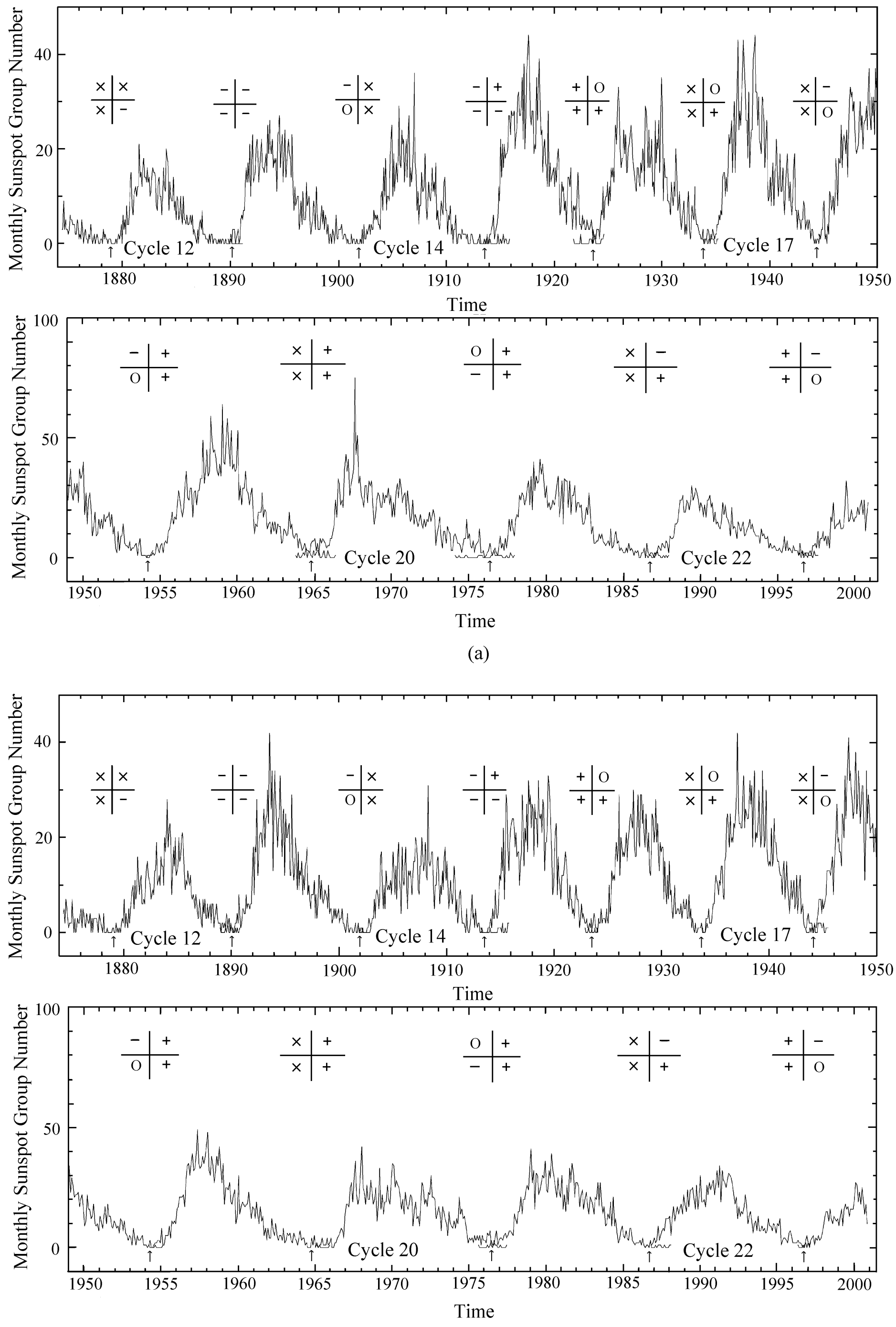

Fig. 1 (a) Monthly numbers of sunspot groups in the northern hemispheres in extended cycles 11 to 23. Arrows mark the minima of specific cycles; (b) Same as in Fig. 1 (a), but for the southern hemispheres.

$AS = (\mathrm{No_N} - \mathrm{No_S})/(\mathrm{No_N} + \mathrm{No_S})$ (Atac & Ozguc 1996; Li, Schmieder & Li 1998). This is done separately for the four parts defined in Fig. 2. The obtained results are displayed in Fig. 1, the results of the four parts are put in the four quadrants around a cross: Part A, the lower-left; Part B, the upper-right; Part C, the lower-right; and Part D, the upper-left; A and B are the pre- and post-minimum parts of the new extended cycle, and C and D, those of the previous extended cycle (see Fig. 2). For Part D (or B), only the total number in the same interval as Part A (or C) is counted. In Figure 1, $0, +, -$ stand for AS =, >, < 0, "×" means no data available.

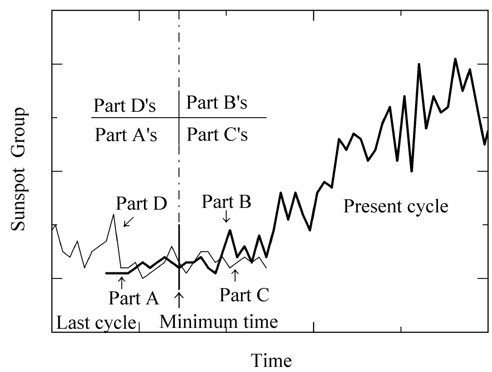

Fig. 2 Sketch showing the four parts of the sunspot curve around a minimum into which the results are assigned.

3 CONCLUSIONS AND DISCUSSION

First, we compare the asymmetry symbols in an upper quadrant and the quadrant immediately below. As shown in Figure 1, State I that the both quadrants have the same asymmetry symbol (+ or −) occurs 8 times, State II that the two have opposite symbols (one + and one −) occurs only 2 times, suggesting that the two overlaps of two neighboring extended cycles, one before and one after the statistical minimum tend to have the same asymmetry status. Next, we contrast the asymmetry symbols in each of the two pairs of diagonal quadrants. We find that State III that the pair of diagonal quadrants have the same symbol occurs 4 times, while State IV that they have opposite symbols also occurs 4 times, indicating that the extended part of a given cycle does not conspicuously tend to have the same asymmetry status as the proper part of the cycle. So, we infer that the asymmetry of solar activity in the extended part of a specific cycle prefers statistically to mingle itself with the asymmetry of the neighboring cycle, rather than keeping the continuity of asymmetry of the entire extended cycle.

From a statistical perspective, solar activity is more important in one hemisphere during the ascending part of a cycle and becomes more important in the other hemisphere during the descending part (Atac & Ozguc 1996). It implies that, if the asymmetry of solar activity extended to the 'extended' cycle, then solar activity in the extended interval and the adjacent specific cycle would dominate in the same hemisphere. So, it is inferred that the asymmetry of solar activity has little relation with the extended cycle and it does not extend to the extended cycle. Research on the asymmetry of solar activity indicates that the north-south asymmetry has a trend of a long-term characteristic time scale of about 12 individual solar cycles (Li, Yun & Gu 2001; Verm 1993). Our result suggests that it should be plausible that the long-term period is modulated in the individual cycles but not in the extended cycles.

In general, at a probability less than 10%, the north-south asymmetry is significant or marginally significant (Vizoso & Ballester 1990). Table 1 clearly shows that the probability is less than 10% in 10 cases, among which, States I and III each appear once, and no States II and IV take place. So, the conclusion given in last paragraph can not be definitely confirmed in a strict statistical view. Then we check what happens in case of less than 20% probability. Table 1 shows that there are 17 such cases: these cases are marked with thickened in Figure 1. Among these, State I appears five times, State II once, State III twice, and State IV once. It seems to support the above conclusion. In summary, it is inferred here that asymmetry of solar activity should have little relation with the extended cycle. Further research on this subject is needed in the future.

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