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Does the southern dominance of solar activity really exist in solar cycle 21?

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Abstract. In this paper, 20 solar-activity phenomena are collected to investigate solar activity in solar cycle 21. The results obtained show that we can hardly say that either the south dominance of solar activity or the north dominance exists for solar cycle 21. It is also inferred in this paper that solar activity in solar cycle 21 has a northern bias at first, then as the cycle progresses, southern predominance takes over and tries to balance solar activity in the northern hemisphere. Solar activities in the southern and northern hemispheres are not necessarily in phase.

Key words: Sun: activity – Sun: flares

1. Introduction

Solar-activity indices do not occur evenly on the solar disk. Long-term observations of solar activity indicate that the behaviour of solar activity is asymmetric (Hong 1990, 1994). For a long time it has been well known that the occurrence of different features in the northern and southern parts of the solar disk is not uniform, and that more features occur in one or the other part of the disk in different time intervals (Atac & Ozguc 1998; Carbonell et al. 1993; Ozguc & Atac 1996; Vizoso & Ballester 1987, 1989; Roy 1977; Waldmeier 1971; Zhong 1995). The study of the N-S asymmetry of solar activity shows that a long-term periodic behavior of around eight cycles seems to exist in the N-S asymmetry. It is confirmed that the northern hemisphere has been more active than the southern one during solar cycles 18, 19, and 20, and it is also confirmed that for solar cycle 22, the solar activity is greater in the southern hemisphere (Li et al. 1998; Oliver & Ballester 1994; Swinson et al. 1986). Solar cycle 21 is a transition period from the northern dominance trend of solar cycles 19 and 20 to the southern dominance of solar cycle 22. That is to say, a shift from the north-dominance asymmetry to the south-dominance seemed to occur in solar cycle 21. So investigation of solar activity in solar cycle 21 is of specific importance. Verma (1987) and Verma et al. (1987), in their studies of solar cycles 19, 20 and 21, investigated the N-S asymmetry for major flares, type II radio bursts, white light flares, gamma-ray bursts, hard X-ray bursts and coronal mass ejections. They found that solar activity was greater in the southern hemisphere during solar cycle 21. Atac & Ozguc (1996) reached the same conclusion after studying the N-S asymmetry of flare index and sudden disappearances of the solar cycle 21. All these analyses seem to indicate that the solar activity in solar cycle 21 shows a southern dominance. Does the southern dominance of solar activity really happen in solar cycle 21? Garcia (1990) found that the excess of large flares for the northern hemisphere existed until 1984 during solar cycle 21. In this paper, the attempt to clarify whether the southern dominance of solar activity really exists in solar cycle 21 has been done by calculating the probability of all solar-activity phenomena we can collect.

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2. Solar activity in solar cycle 21

In order to clarify whether the southern dominance of solar activity really exists in solar cycle 21, the statistical significance of some asymmetry values for the solar cycle has been assessed by calculating the actual probability of obtaining a result. Let us consider a distribution of n objects in 2 classes. We use the following binomial formula to derive the probability $P(k)$ of getting k objects in class 1 and $(n-k)$ objects in class 2 (Li et al. 1998).

$$P(k) = \binom{n}{k} p^k (1-p)^{n-k} \quad (1)$$

The probability to get more than d objects in class one is:

$$P(\geq d) = \sum_{k=d}^{n} P(k) \quad (2)$$

In general, when $P(\geq d) > 10\%$ this implies a statistically insignificant result, when $5\% < P(\geq d) < 10\%$ it is marginally significant, and when $P(\geq d) < 5\%$ we have a statistically significant result.

Verma (1987) gave the numbers of type II radio bursts, white light flares, solar gamma-ray bursts, hard x-ray (HXR) bursts, CME events that occurred in the solar northern and southern hemispheres respectively during solar cycle 21. Hong (1984) gave yearly numbers of large sunspot groups whose areas are larger than 450 (in millionths of the Sun's visible hemisphere),

Table 1. Number of various solar activity events recorded in solar cycle 21

Various solar activity events	Number of events N	S	Dominance	Probability
Type II radio bursts	256	350	S	6.44×10^{-5}
White light flares	8	17	S	3.19×10^{-2}
Solar gamma ray bursts	40	51	S	1.23×10^{-1}
HXR bursts	140	175	S	2.41×10^{-2}
CME's events	16	21	S	2.03×10^{-1}
Large sunspot groups	137	140	S	4.28×10^{-1}
Active prominences	36	38	S	4.08×10^{-1}
Spiral sunspots	84	74	N	2.12×10^{-1}
Flare indices	582	560	N	2.57×10^{-1}
Polar coronal holes	68	50	N	4.78×10^{-2}
Equatorial coronal holes	140	130	N	2.71×10^{-1}
All coronal holes	208	180	N	7.72×10^{-2}
Huge sunspot groups	61	64	S	3.93×10^{-1}
X class flares (XF)	50	62	S	1.27×10^{-1}
Active regions producing XF	35	38	S	3.62×10^{-1}
Proton flares (PF)	29	26	N	3.42×10^{-1}
Active regions producing PF	27	20	N	1.51×10^{-1}

which occurred respectively in the northern and southern hemispheres during the interval 1976–1985, and were observed at Yunnan Observatory. Ding et al. (1981, 1985) gave the yearly numbers of spiral sunspots for both the northern and southern hemispheres at the rising and maximum period of solar cycle 21 (1975–1982). The definition of a spiral sunspot was given by Ding et al. (1987). Li et al. (1988) gave the number of active prominences during the solar maximum period of solar cycle 21 (1979–1982). Sanchez-Ibarra & Barraza-Paredes (1992) listed the events of polar coronal holes and equatorial coronal holes which occurred during the interval 1970–1991. We counted the events during solar cycle 21. Atac (1987) illustrated the time variation of flare indices during solar cycle 21. Shi & Wang (1998) gave the total numbers of huge sunspot groups whose areas are equal to or larger than 16 square degrees, X class flares, active regions producing X class flares, proton flares, and active regions producing proton flares, during solar cycle 21. All counts of the above solar phenomena are listed in Table 1, together with the probability of getting such a distribution result by chance and the dominance of solar activity in one hemisphere. For the first five solar-activity phenomena of the table given by Verma (1987), solar activity is more violent in the southern hemisphere, so Verma concluded without calculating the probability of the events that asymmetry is in favor of the southern hemisphere during solar cycle 21. However, among the remaining twelve solar-activity phenomena given in the table, seven phenomena indicate that asymmetry is in favor of the northern hemisphere.

Table 1 shows that the result is statistically significant only for four solar active phenomena: type II radio bursts, white light flares, HXR bursts, polar coronal holes out of the above 17 solar-activity phenomena. For all coronal holes, the result is marginally significant. Among the above 5 phenomena whose probability is less than 10%, 3 phenomena indicate a southern dominance, the other two indicate a northern dominance. Bai(1990) counted the number of major flares occuring during 1976–1986, and found that the number of major flares in the southern hemisphere is equal to that in the northern hemisphere. Garcia (1990) studied the spatial distribution of large flares (NOAA class $\geq$M9) of the most active part of solar cycle 21 (1977–1984). He found that the cumulative count of the northern hemisphere exceeds the cumulative count of the southern hemisphere; this excess effectively disappears by 1984. By the end of the cycle, more large flares occurred in the south, balancing the cumulative number of events in northern latitudes. So the probability of the two solar-activity phenomena (major flares and large flares) is inferred to be around 0.5, although we do not accurately know the numbers of the two events. Vizoso & Ballester (1987) gave the yearly asymmetry values of sudden disappearances of solar prominences during solar cycle 21 (the years 1976 to 1985). Three values, i.e. the values of the years 1977, 1979, and 1980 are positive, meaning a northern dominance, and these three years are at the ascending and maximum period of solar cycle 21. The value for the year 1984 is zero, the remaining six values are negative. The temporal behavior of activity in the southern and northern hemispheres is that dominance occurred in the northern hemisphere at the ascending and maximum period, and, as the cycle progressed, more events occurred in the southern hemisphere to balance the the cumulative number of events in northern latitudes, which is similar to the evolutional behavior of major flares described by Garcia (1990). So here we suggest that this distribution result has no significance.

The above analysis shows that both the solar activity in the northern hemisphere and that in the southern hemisphere are in general well-matched for solar cycle 21. We can hardly say that either a southern dominance of solar activity or a northern dominance exists for solar cycle 21. The southerly bias of solar activity in solar cycle 21 given in the former literature is doubtful, and is a lopsided view.

3. Conclusions and discussions

In this paper, 20 solar-activity phenomena are collected to investigate solar activity in solar cycle 21. Although there exists a southern bias for most of the above events, this result is statistically significant only for four phenomena and marginally significant for one. Among the 5 phenomena whose probability is less than 10%, 3 phenomena indicate a southern dominance, the other two indicate a northern dominance. So we can hardly say that either the southern dominance of solar activity or the northern dominance exists for solar cycle 21; the result of the south dominance of solar activity in solar cycle 21 obtained in the former literature is doubtful.

For the solar-activity phenomenon of white light flares listed by Verma (1987), the first events were northerly, shifting gradually to the south during the cycle. But for the whole cycle, white light flares show a southern dominance, and this result is significant. As mentioned in Sect. 2, the cumulative count of large flares in the northern hemisphere exceeds that in the southern one. By the end of major activity in mid-1984, this excess had effectively vanished as the later southern predominance balanced the cumulative number of events in northern hemisphere (Garcia 1990). The same characteristic exists for flare indices. So we infer that solar activity in solar cycle 21 has a northern bias at first, then as the cycle progresses, southern predominance takes over and tries to balance solar activity in the northern hemisphere. For some solar-activity phenomena, solar activity in one hemisphere can balance that in the other one, but for the other solar-activity phenomena, solar activity in one hemisphere cannot balance that in the other hemisphere, and there exists a southern bias or a northern bias, and sometimes the bias is very obvious and of significance. Although solar activity in the southern and/or northern hemispheres is related to the 11-year sunspot cycle, the two activities are not necessarily in phase, or their weight centres of the curve showing the activity index as a function of time in the cycle may be different. In other word, different solar-activity phenomena perhaps have different period behavior. This is one of the features of solar activity in solar cycle 21– a transition period through which the northern dominance trend of solar cycles 19 and 20 changes to the southern dominance of solar cycle 22.

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