

THE LONG-TERM HEMISPHERIC VARIATION OF POLAR FACULAE

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ABSTRACT

In this paper, the long-term hemispheric variation of the polar faculae is investigated. It is found that, (1) both the N-S asymmetry and N-S asynchrony of the polar faculae exhibit a long-term persistence, which suggests that they should not be regarded as a stochastic phenomenon; (2) both the N-S asynchrony and N-S asymmetry of the polar faculae are functions of the latitude, implying that the N-S asynchrony of the polar faculae is related to the N-S asymmetry of the polar faculae; (3) from a long-term view, the dominant hemisphere of the polar faculae seems to have close connection with the phase-leading hemisphere of the polar faculae.

Key words : Sun: polar faculae — N-S asymmetry — N-S asynchrony

1. INTRODUCTION

A facula is a small point-like region brighter than the rest of the solar photosphere. On the average, faculae have sizes of about 3-5 arcsec and lifetimes of the order of 10 min (Sakurai 1998; Hagino et al. 2004). Solar facula, usually called plage in the chromosphere, is often observed in the solar photosphere. They play an important role in energy-exchange processes between layers of the solar atmosphere due to their prevalence (Kobanov et al. 2011). Although less numerous, faculae are usually seen in white light at high latitudes (50° – 90°), so they are named polar faculae. In some sense, polar faculae can be considered as tracers of magnetic field structures at the high-latitude regions of the Sun. They are usually associated with active regions or remnant of active regions (Hagino et al. 2004). However, not much is as yet known about their physics and their relationship to other phenomena. The observed and recorded data of polar faculae provide us an opportunity to study their statistical properties. An understanding of hemispheric variation of polar faculae may provide insight into their complex dynamic behavior.

Various solar activity phenomena indicate that the occurrence of faculae in the northern and southern hemispheres on the solar disk are not uniform, with more events occurring in one of the two hemispheres during certain periods. This phenomenon is referred to

as the N-S asymmetry of solar activity (Goel & Choudhuri 2009; Joshi et al. 2009). The N-S asymmetries of different solar activities, such as sunspot numbers, sunspot areas, coronal mass ejections (CMEs), flare index, etc., have been extensively studied by various authors (Oliver & Ballester 1994, 1996; Atac & Ozguc 1996, 2001, 2006; Verma 1987, 1993, 2000; Joshi & Joshi 2004; Joshi et al. 2004, 2006; Gao et al. 2007, 2009; Li et al. 2009a, 2009b, 2010a; Yan et al. 2008; Joshi et al. 2009, 2010; Bankoti et al. 2010, 2011; Chang 2007, 2008, 2009; Cho & Chang 2011; Cho et al. 2011). The asymmetrical distribution of solar activity phenomenon represents an important detail of the solar dynamic action with which we can research the genesis of the solar cycle and activity phenomena. Therefore, interest in the N-S asymmetry of solar activity has grown considerably (Duchlev 2001; Jiang et al. 2007).

It has been generally known that solar activities in the northern and southern hemispheres are highly synchronous, forming the famous “butterfly diagram”. However, solar activity is found to be slightly asynchronous between the northern and southern hemispheres from recent studies (Ponyavin & Zolotova 2004; Zolotova & Ponyavin 2006, 2007; Donner & Thiel 2007; Li 2008; Zolotova 2009, 2010; Li 2009; Li et al. 2008, 2009c, 2010b). The N-S asymmetry of solar activity is related to the N-S phase difference of solar activity (Waldmeier 1957, 1971; Temmer, Veronig & Hanslmeier 2002; Temmer et al. 2006). By using

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cross-recurrence plot technique and wavelet transform method, Li (2008) found that the high-latitude solar activity (polar faculae) shows slight phase asynchrony between the northern and southern hemispheres. The N-S asynchrony of dynamical processes is an important topic for understanding the origin and evolution of active regions on the Sun and their various manifestations in the solar corona (Zolotova & Ponyavin 2006, 2007; Zolotova 2009, 2010).

Although too many solar active phenomena are used to investigate the N-S asymmetry and the N-S asynchrony of solar activity, the phenomena concerned are basically limited to those at low latitudes, and less characteristics are known on the N-S asymmetry and the N-S asynchrony of solar activity at high latitudes. As is well known, the main index of the high-latitude solar activity is usually represented by polar faculae. In the present study, we investigate the N-S asymmetry and the N-S asynchrony of the polar faculae, as well as the relationship between the two. In Section 2, the observational data of the polar faculae are described and the analytic methods as well as the results are present in Sections 3 and 4. In the last Section, the main conclusions and discussions are given.

2. DATA OF POLAR FACULAE

The observational data of the polar faculae come from the National Astronomical Observatory of Japan (NAOJ), which can be downloaded from NAOJ's web site (http://solarwww.mtk.nao.ac.jp/en/db_faculae.html). The data set presents the monthly mean numbers of the polar faculae during the period from February 1952 to June 1998, at three latitudinal intervals of each solar hemisphere: 50° – 60° , 60° – 70° and 70° – 90° . The faculae observed at the band 50° – 60° should be made up of two parts: one belonging to the polar faculae and the other to the active region faculae (Sakurai 1998). Therefore, the faculae at the band 50° – 60° are not taken into account in our analysis. We group polar faculae at the band 60° – 70° as relatively low latitudes (RLLs), those at the band 70° – 90° as relatively high latitudes (RHLs), and those at the band 60° – 90° as total latitudes (TLs). Fig. 1 shows the monthly mean numbers of the polar faculae in the northern and southern hemispheres at RLLs, RHLs and TLs, respectively. From the figure, we can see that the counts of the polar faculae vary with time in the hemispheres in different ways. The figure shows that, (1) the northern and southern hemispheric peaks of the polar faculae usually differ from each other, implying that the polar faculae should be asynchronous in the northern and southern hemispheres; (2) the polar faculae develop with different strengths in the hemispheres, and the amplitude of the polar faculae is asymmetrically distributed in the northern and southern hemispheres.

3. N-S ASYMMETRY OF POLAR FACULAE

The N-S asymmetry of the polar faculae is characterized as:

$$Asy = \frac{NO_N - NO_S}{NO_N + NO_S} \quad (1)$$

where NO_N and NO_S stand for the total numbers of the polar faculae corresponding to the northern and southern hemispheres, respectively. We calculate the asymmetrical values of the polar faculae at RLLs, RHLs, as well as TLs, and they are listed in Table 1. Furthermore, to make sure whether these asymmetrical values are of statistical significance or not, we calculate the actual probability of the N-S asymmetry of the polar faculae. Considering a distribution of n objects in two classes, the following binomial formula gives the probability $P(k)$ of getting k objects in class 1 and $(n-k)$ objects in class 2 (Joshi et al. 2006; Gao et al. 2007):

$$P(k) = \frac{n!}{k!(n-k)!} p^k (1-p)^{n-k} \quad (2)$$

and the probability to get greater than d objects in class 1 is given by:

$$P(\geq d) = \sum_{k=d}^n P(k) \quad (3)$$

In general, when the above probability is larger than 10%, one can say that the polar faculae should be regarded to be equally distributed in the two hemispheres. If the probability is less than 10%, it means that the asymmetrical distribution of the polar faculae is a real phenomenon, and it is not due to random fluctuations. The actual probabilities are also given in Table 1.

From Table 1, we find that, (1) the dominant hemisphere of the polar faculae is exactly the same for the RLLs, RHLs and TLs during the considered time interval; (2) the N-S asymmetrical value of the polar faculae at TLs lies between those at RLLs and RHLs, and seems to be an average of the two, implying that the N-S asymmetry of the polar faculae may be a function of the latitude.

4. N-S ASYNCHRONY OF POLAR FACULAE

Polar faculae allow us to see any first-effects that would show alternation of the degree of solar activity between the two hemispheres or systematic time delay between the onset of solar activity in the northern and southern hemispheres. A cross-correlation analytic method adopted by Deng et al. (2011) and Yan et al. (2011) is used to study the N-S asynchrony of the polar faculae. The cross-correlation coefficient between the numbers of the polar faculae in the northern and southern hemispheres is defined as:

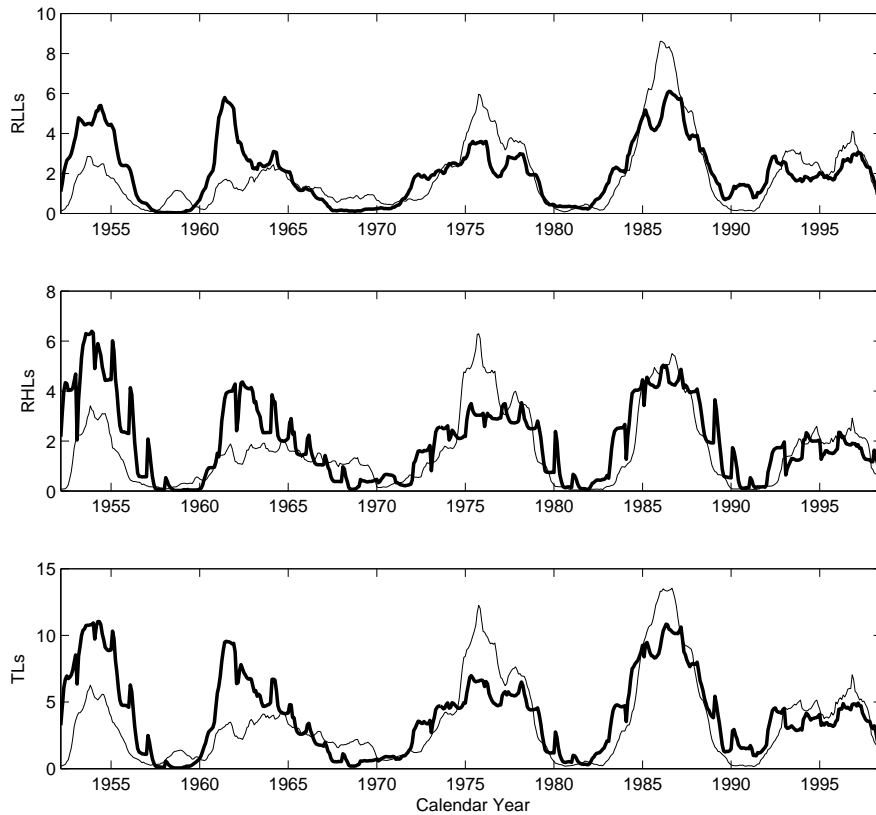


Fig. 1.— The numbers of the polar faculae in the northern (bold solid line) and southern hemisphere (solid line) at RLLs (a), RHLs (b) and TLs (c), respectively.

$$CC(\Delta) = \frac{\sum_{i=1}^n [N(i) - \langle N \rangle][S(i + \Delta) - \langle S \rangle]}{(n-1)\delta_N\delta_S} \quad (4)$$

Where $\langle N \rangle$ ($\langle S \rangle$) and δ_N (δ_S) represent the mean value and standard deviation of the polar faculae in the northern (southern) hemisphere, respectively. Positive (negative) Δ means that the time series of the polar faculae in the northern hemisphere leads (lags) that in the southern one. We calculate the cross-correlation coefficient for the leading and lagging shifts between the numbers of the polar faculae in the northern and southern hemispheres.

Fig. 2 shows the result of the cross-correlation coefficients between the polar faculae in the northern and those in the southern one at RLLs, RHLs and TLs, respectively. The abscissa indicates the shift of the northern hemispheric polar faculae with respect to the southern hemispheric polar faculae, with positive (negative) values representing forward (backward) shifts. From the figure, the best correlation between the polar faculae at RLLs (RHLs, TLs) in the northern and

southern hemisphere, with a correlation coefficient of 0.7233 (0.6891, 0.7261) occurs when the polar faculae at RLLs (RHLs, TLs) in the northern hemisphere has a forward shift of 1 (4, 2) month(s) with respect to those in the southern hemisphere. From a statistical point of view, the cross-correlation coefficients obtained above are highly significant. The N-S phase difference of the polar faculae at TLs lies between those at RLLs and RHLs, and close to the average of the two, which implies that the N-S asynchrony of the polar faculae should be a function of the latitude. From Fig. 2 and the above analysis, we conclude that, (1) the polar faculae do not synchronously occur in the northern and southern hemispheres, which should not be regarded as a stochastic phenomenon; (2) the N-S asynchrony of the polar faculae should be a function of the latitude, which is also seen in the N-S asymmetry of the polar faculae. Therefore, the N-S asynchrony of the polar faculae is related to N-S asymmetry of the polar faculae.

Table 1.
The N-S asymmetry of the polar faculae.

Time Range	LB ^a	NO_N	NO_S	AV ^b	Probability	DH ^c
1951.8-1998.12	60°–70°	1144.92	1070.15	0.0338	5.85E-02	Northern
	70°–90°	1107.23	890.63	0.1084	6.89E-07	Northern
	60°–90°	2252.15	1960.78	0.0692	3.82E-06	Northern

^aThe LB stands for Latitudinal Band.

^bThe AV stands for Asymmetry Value.

^cThe DH stands for Dominant Hemisphere.

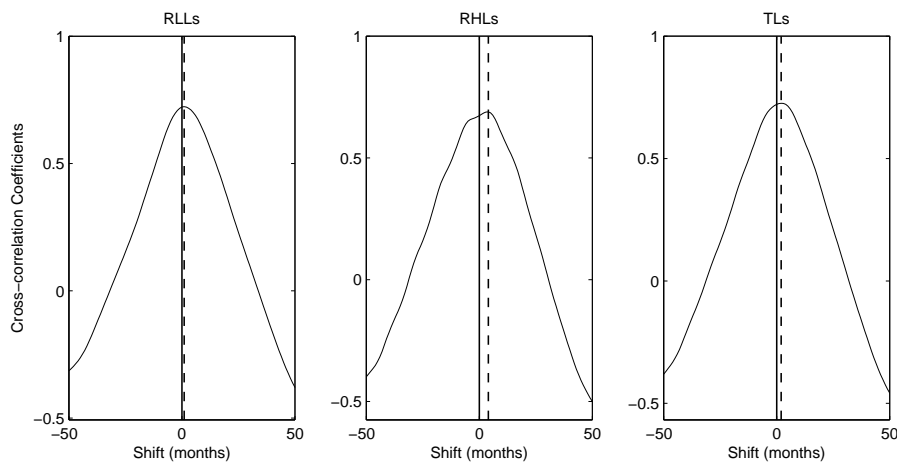


Fig. 2.— Cross-correlation coefficients between the polar faculae in the northern hemisphere and those in the southern hemisphere as a function of shifts. The abscissa indicates the shifts of the polar faculae in the northern hemisphere with respect to those in the southern hemisphere, with positive (negative) values representing forward (backward) shifts.

5. CONCLUSIONS AND DISCUSSIONS

The polar faculae represent the high-latitude magnetic fields, and the observed magnetic fields at high-latitudes may be constitutive of two parts: one comes from the emergence of the magnetic fields from the Sun's interior and the other comes from the drift of the magnetic fields at low-latitudes. The magnetic fields of the polar faculae are much more complicated than the magnetic fields at low-latitudes. In order to understand the complicated behavior of long-term hemispheric variation of the polar faculae, both the N-S asymmetry and N-S asynchrony of the polar faculae during the time interval from February 1952 to June 1998 are investigated in the above sections. The main results are as follows.

By calculating the actual probabilities of the hemispheric distribution of polar faculae at RLLs, RHLs and TLs, respectively, we find that the asymmetrical distribution of polar faculae in the two hemispheres is marginally significant. From Fig. 2, the polar faculae do not synchronously occur in the two hemispheres and

the largest (positive) correlation coefficients obtained are all highly significant. Moreover, by using nonlinear analysis approaches, Li (2008) and Li et al. (2008) also found that the polar faculae show phase asynchrony between the northern and southern hemispheres. In other words, both the N-S asymmetry and asynchrony of the polar faculae exhibit a long-term persistence, which implies that they should not be regarded as a stochastic phenomenon. 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. In the future, a better dynamo model should quantitatively represent the hemispheric asynchrony of solar activity, in addition to the asymmetrical distribution of solar activity.

In our work we observe that both the N-S asynchrony and N-S asymmetry of the polar faculae are functions of the latitude, probably suggesting that the N-S asynchrony of the polar faculae is related to the N-S asymmetry of the polar faculae. Furthermore, it is interesting to note that the dominant hemisphere is the phase-leading hemisphere of the polar faculae. We infer

that the N-S asynchrony of the polar faculae is one of the reasons why the polar faculae are asymmetrically distributed in the northern and southern hemispheres. By studying the daily sunspot area and its latitudinal variations during the period from 1874 to 2009, Cho and Chang (2011) stated that the N-S asymmetry of the sunspot areas and its area-weighted latitude are consistently regulated by one single mechanism. Zolotova et al. (2010) suggested that the hemispheric asynchrony is found to be anti-correlated with the latitudinal distribution of the sunspots. Thus we reckon that there is an intrinsic relationship among the N-S asymmetry, N-S asynchrony as well as the latitudinal variations of solar activity.

The polar faculae progress in the hemispheres with different strengths and in different phases. That is why the polar faculae are asymmetrically distributed in the two hemispheres, and do not synchronously occur in the northern and southern hemispheres. The solar activity is governed by two different processes, each of which progresses in individual hemispheres, and the two processes are coupled. But both the N-S asymmetry and N-S asynchrony of the polar faculae exhibit a long-term persistence, the magnetic field systems originating in the two hemispheres are thus inferred to be only weakly coupled. Our results agree with the conclusions obtained by Antonucci et al. (1990), Henney et al. (2002), Temmer et al. (2002, 2003) and Li (2009). Although the magnetic field at the solar polar zone is much weaker than that at middle and low latitudes, we should pay more attention to the solar activity at the polar zone in the future. Till now, the magnetic flux transport models of the Sun's global magnetic field have been shown to reproduce the amplitude and duration fairly well, but not the relative phase difference in the solar activity (Cho & Chang 2011). Thus, we feel that our results may be instructive to speculate on the physical origin of the polar faculae, and to investigate further on the physical mechanisms of the solar cycle and activity phenomena.

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