J. Astrophys. Astr. (2012) **33,** 221–226

The Hemispheric Asymmetry of Polar Faculae

L. H. Deng[1,2,*], Z. Q. Qu[1], X. L. Yan[1,2], T. Liu[3] & K. R. Wang[4]

[1]*National Astronomical Observatories/Yunnan Astronomical Observatory, Chinese Academy of Sciences, P. O. Box 110, 650011, Kunming, People's Republic of China*
[2]*Graduate School of the Chinese Academy of Sciences, ShijingShan Block, 100049, Beijing, People's Republic of China*
[3]*Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, 430074, People's Republic of China*
[4]*North China Electric Power University, Beijing, 102206, People's Republic of China*
[*]*e-mail: bench@ynao.ac.cn*

Received 2011 September 28; accepted 2012 April 24

Abstract. In this paper, the north–south (N–S) asymmetry of the polar faculae at relatively low (RLLs), relatively high (RHLs) as well as total latitudes (TLs) respectively, are investigated. It is found that (1) the polar faculae behave in a different asymmetrical way at different latitudinal bands; (2) the asymmetry of solar activity may be a function of latitudes, which is present not only in the low-latitude solar activity but also in the high-latitude solar activity; (3) the N–S asymmetry of the polar faculae at TLs depends on that at RHLs, and the asymmetry of the polar faculae at RLLs only plays a modulatory role.

Key words. Sun: polar faculae—N–S asymmetry.

1. Introduction

Various solar activity phenomena indicate that their occurrence in the northern and southern hemispheres on the solar disk are not uniform, with more events occurring in one or the other hemisphere during certain periods. This phenomenon is referred to 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; Atac & Ozguc 1996, 2006; Verma 2000; Joshi & Joshi 2004; Joshi & Pant 2005; Joshi *et al.* 2006; Gao *et al.* 2007, 2009; Gao & Li 2010; Li *et al.* 2002, 2010; Yan *et al.* 2008; Joshi *et al.* 2009, 2010; Bankoti *et al.* 2010, 2011; Deng *et al.* 2011a). The existence of the N–S asymmetry of solar activity has been well-known and accepted for a long time. The asymmetrical distribution of the solar activity phenomenon represents an important detail of the solar dynamic action, which is an object to research the genesis of the solar cycle and activity phenomena. Thus, the interest in the N–S asymmetry of solar activity has grown considerably (Duchlev 2001; Jiang *et al.* 2007).

Gao *et al.* (2009) showed that the N–S asymmetry of the low-latitude CMEs is not consistent with that of the high-latitude CMEs, and suggested that the high-latitude CMEs should have close connection with 'rush to the poles'. Li *et al.* (2010) found that the asymmetry of the low-latitude solar activity seems to be a function of latitudes. As is well-known, the polar faculae and sunspot numbers represent the high-latitude (over about 60°) and the low-latitude (below 50°) solar activity, respectively (Makarov & Makarova 1996; Riehokainen *et al.* 2001; Li *et al.* 2002; Deng *et al.* 2011b). To check if the polar faculae have the above features or not, if the latitudinal bands are more elaborately divided, it is necessary to study the N–S asymmetry of the polar faculae at different latitudinal bands, and to find the driving mechanism to explain why the polar faculae behave in a different asymmetrical way at different latitudinal bands.

In the present paper, we check whether the aforementioned characteristics appearing in the low-latitude solar activity is also present in the polar faculae, and expect to discover some new results. In § 2, the observational data of the polar faculae are described, and the analytic method as well as the results are present in § 3. In the last section, the discussions and main conclusion 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 website (http://solarwww.mtk.nao.ac.jp/en/db_faculae.html). The data set presents 13-months running averages of the polar faculae during the period from February 1952 to June 1998. It covers solar cycle 19 (March 1954–August 1964), cycle 20 (September 1964–April 1976), cycle 21 (May 1976–July 1986) as well as cycle 22 (August 1986–March 1996), at three latitudinal intervals of each solar hemisphere: 50°–60°, 60°–70°, 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. Therefore, the faculae at the band 50°–60° are not taken into account in our analysis.

Figure 1 shows the polar faculae in the northern and southern hemispheres at RLLs, RHLs and TLs respectively. The minimum and maximum of solar cycles are indicated by vertical solid and dashed lines respectively. Note that the indicated cycle minima (maxima) are referred to the sunspot cycle, and therefore do not coincide with the minima (maxima) of the polar faculae.

3. Asymmetry of polar faculae

The N–S asymmetry of the polar faculae is characterized as

$$\mathrm{Asy} = \frac{NO_{\mathrm{N}} - NO_{\mathrm{S}}}{NO_{\mathrm{N}} + NO_{\mathrm{S}}},$$

where NO_{N} and NO_{S} stand for the number 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.

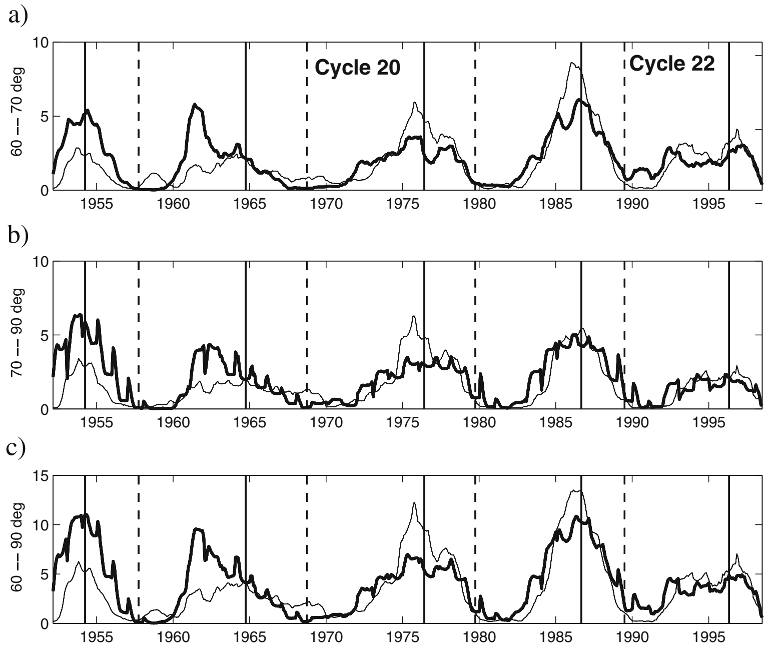

Figure 1. The polar faculae in the northern (bold solid line) and southern hemispheres (solid line) at RLLs (**a**), RHLs (**b**) as well as TLs (**c**) respectively.

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

Table 1. The asymmetry of the polar faculae at RLLs, RHLs and TLs.

Cycle no.	Time range	Latitudinal band	NO_N	NO_S	Asymmetry value	Probability	Asymmetry sign	Dominant hemisphere
19	1954.3–1964.8	60°–70°	275.24	145.76	0.3076	1.39E-10	positive	N
		70°–90°	267.90	134.09	0.3329	1.15E-11	positive	N
		60°–90°	543.14	279.85	0.3199	1.45E-20	positive	N
20	1964.9–1976.4	60°–70°	187.25	228.64	−0.0995	9.81E-01	negative	S
		70°–90°	193.55	230.41	−0.0894	9.67E-01	negative	S
		60°–90°	380.80	459.05	−0.0932	9.97E-01	negative	S
21	1976.5–1986.7	60°–70°	265.97	320.50	−0.0930	9.89E-01	negative	S
		70°–90°	274.85	247.23	0.0529	1.22E-01	positive	–
		60°–90°	540.82	567.73	−0.0243	7.99E-01	negative	–
22	1986.8–1996.3	60°–70°	262.07	265.13	−0.0058	5.70E-01	negative	–
		70°–90°	211.88	185.71	0.0658	1.03E-01	positive	–
		60°–90°	473.95	450.84	0.0250	2.34E-01	positive	–
19–22	1954.3–1996.3	60°–70°	990.53	960.03	0.0156	2.52E-01	positive	–
		70°–90°	948.18	797.44	0.0864	1.68E-04	positive	N
		60°–90°	1938.71	1757.47	0.0490	1.51E-03	positive	N

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; Li *et al.* 2010)

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

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

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

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. In the Table, the symbol '–' means that the polar faculae is thought to be equally distributed in the two hemispheres.

From Table 1, we find that the dominant hemisphere of the polar faculae at RLLs, RHLs and TLs is exactly same in solar cycles 19 and 20. For solar cycle 21, the polar faculae at RLLs dominate in the southern hemisphere, but there is no dominant hemisphere at RHLs and TLs. For solar cycle 22, the situation is very simple: there is no dominant hemisphere at the three latitudinal bands. Considering the whole period, the N–S distribution of the polar faculae at RHLs is consistent with that at TLs, but differs from that at RLLs. According to the above analysis, the hemispheric asymmetry of the polar faculae at RHLs is same as that at TLs, but differs from that at RLLs. That is to say, the polar faculae behave in a different asymmetrical way at different latitudinal bands.

When the asymmetry values of the polar faculae at RLLs and RHLs have the same digital sign, the polar faculae are regarded to be asymmetrically distributed (see cycles 19 and 20), or there is no dominant hemisphere in the solar cycle (see cycles 21 and 22). Thus the asymmetrical distribution of the polar faculae at TLs is related to that at RLLs and RHLs. Furthermore, the asymmetry values of the polar faculae at TLs are located between those at RLLs and RHLs, and seem to be an average of the two. This implies that the N–S asymmetry of the polar faculae at TLs may be a function of latitudes. A similar conclusion was drawn by Li *et al.* (2010) from observations of the N–S asymmetry of the low-latitude solar activity. Therefore, this feature present in the low-latitude solar activity is also found in the high-latitude solar activity.

The N–S asymmetrical curves of the polar faculae at RLLs, RHLs and TLs are shown in Figure 2. From the figure, the N–S asymmetry of the polar faculae at RHLs is obviously similar to that at TLs, but not exactly the same as that at RLLs. According to Table 1 and Figure 2, we infer that the N–S asymmetry of the polar faculae at TLs depends on that at RHLs, and the asymmetrical variation of the polar faculae at RLLs only plays a modulatory role.

4. Discussions and conclusion

In the above sections, we studied the hemispheric asymmetry of the polar faculae during solar cycles 19 to 22. We found that the N–S asymmetry of the polar faculae at

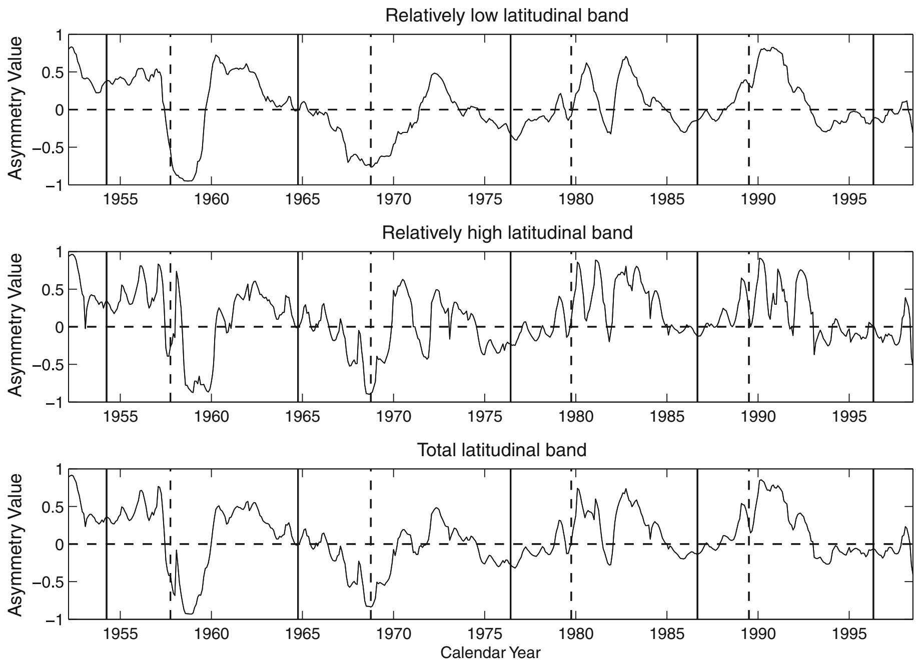

Figure 2. The N–S asymmetrical curves of the polar faculae at RLLs (upper panel), RHLs (middle panel) and TLs (bottom panel) respectively. The solid (dashed) lines mark the minimum (maximum) of solar cycles.

different latitudinal bands differs from each other, and the asymmetrical distribution of the polar faculae is a function of latitudes. Although the N–S asymmetry of the polar faculae seems to have nothing to do with that of the low-latitude solar activity (Li *et al.* 2002), the polar faculae have many characteristics which exist in other low-latitude solar activities.

The asymmetrical variation of the polar faculae depends on that at RHLs, and the asymmetrical variation of the polar faculae at RLLs only plays a modulatory role. While the situation is reversed for the low-latitude solar activity, the N–S asymmetry of low-latitude solar activity at RLLs should mainly contribute to the asymmetrical variation of the low-latitude solar activity. Gao *et al.* (2009) showed that the N–S asymmetry of the low-latitude CMEs is not consistent with that of high-latitude CMEs, but similar to that of the total-latitudes CMEs. Therefore, their results confirm our findings.

Sheeley (1964, 1991, 2008) found that the polar faculae are well correlated with the polar magnetic field measured at the Wilcox Solar Observatory. They can provide information for forecasting the strength of following sunspot cycles and help to constrain theories of the sunspot cycle and the solar dynamo (Wang *et al.* 1991, 2002, 2005; Dikpati & Gilma 2006). Although the magnetic field at the solar polar zone is much weaker than that at middle and low latitudes, we should be pay more attention to the solar activity at the polar zone.

Acknowledgements

The authors thank the anonymous referee for her/his careful reading of the manuscript and constructive comments that improved the original version. The numbers of the polar faculae, used in the present paper, are kindly provided by the National Astronomical Observatory of Japan and the authors would like to express their deep thanks to the staffs of NAOJ. This work is supported by the National Natural Science Foundation of China (NSFC) under grant number 11003041, Yunnan Science Foundation of China under grant number 2009CD120, and the Chinese Academy of Sciences.

References

Atac, T., Ozguc, A. 1996, *Solar. Phys.*, **166**, 201.
Atac, T., Ozguc, A. 2006, *Solar. Phys.*, **233**, 139.
Bankoti, N. S., Joshi, N. C., Pande, S., Pande, B., Pandey, K. 2010, *NewA*, **15**, 561.
Bankoti, N. S., Joshi, N. C., Pande, B., Pande, S., Uddin, W. 2011, *NewA*, **16**, 269.
Deng, L. H., Qu, Z. Q., Liu, T., Huang, W. J. 2011a, *J. Korean. Astron. Soc.*, **44**, 209.
Deng, L. H., Song, J. Y., Xiang, Y. Y., Tang, Y. K. 2011b, *J. Astrophys. Astr.*, **32**, 401.
Dikpati, M., Gilma, P. A. 2006, *Astrophys. J.*, **649**, 498.
Duchlev, P. I. 2001, *Solar. Phys.*, **199**, 211.
Gao, P. X., Li, K. J. 2010, *J. Astrophys. Astr.*, **31**, 165.
Gao, P. X., Li, Q. X., Zhong, S. H. 2007, *J. Astrophys. Astr.*, **28**, 207.
Gao, P. X., Li, K. J., Shi, X. J. 2009, *Mon. Not. R. Astron. Soc.*, **400**, 1383.
Goel, A., Choudhuri, A. R. 2009, *Res. Astron. Astrophys.*, **9**, 115.
Jiang, J., Chatterjee, P., Choudhuri, A. R. 2007, *Mon. Not. R. Astron. Soc.*, **381**, 1527.
Joshi, B., Joshi, A. 2004, *Solar. Phys.*, **219**, 343.
Joshi, B., Pant, P. 2005, *Astron. Astrophys.*, **431**, 359.
Joshi, B., Pant, P., Manoharan, P. K. 2006, *J. Astrophys. Astr.*, **27**, 151.
Joshi, N. C., Bankoti, N. S., Pande, S., Pande, B., Pandey, K. 2009, *Solar Phys.*, **260**, 451.
Joshi, N. C., Bankoti, N. S., Pande, S., Pande, B., Uddin, W., Pandey, K. 2010, *NewA*, **15**, 538.
Li, K. J., Makoto, I., Wang, J. X., Xiong, S. Y., Yun, H. S., Liang, H. F., Zhan, L. S., Zhao, H. J. 2002, *Publ. Astron. Soc. Jpn.*, **54**, 787.
Li, K. J., Liu, X. H., Gao, P. X., Zhan, L. S. 2010, *NewA*, **15**, 346.
Makarov, V. I., Makarova, V. V. 1996, *Solar. Phys.*, **163**, 267.
Oliver, R., Ballester, J. L. 1994, *Solar. Phys.*, **152**, 481.
Riehokainen, A., Urpo, S., Valtaoja, E., Makarov, V. I., Makarova, V. V., Tlatov, A. G. 2001, *Astron. Astrophys.*, **366**, 676.
Sheeley, N. R., Jr. 1964, *Astrophys. J.*, **140**, 731.
Sheeley, N. R., Jr. 1991, *Astrophys. J.*, **374**, 386.
Sheeley, N. R., Jr. 2008, *Astrophys. J.*, **680**, 1553.
Verma, V. K. 2000, *J. Astrophys. Astr.*, **21**, 173.
Wang, Y. M., Sheeley, N. R. Jr., Nash, A. G. 1991, *Astrophys. J.*, **383**, 431.
Wang, Y. M., Lean, J., Sheeley, N. R. Jr. 2002, *Astrophys. J.*, **577**, L53.
Wang, Y. M., Lean, J., Sheeley, N. R. Jr. 2005, *Astrophys. J.*, **625**, 522.
Yan, X. L., Qu, Z. Q., Xu, C. L. 2008, *Astrophys. J.*, **682**, L65.