A&A 431, 359–363 (2005)
DOI: 10.1051/0004-6361:20041986

Astronomy & Astrophysics

Research Note

Distribution of Hα flares during solar cycle 23⋆

Bhuwan Joshi and P. Pant

Aryabhatta Research Institute of Observational Sciences, Naini Tal - 263 129, Uttaranchal, India
e-mail: [bhuwan;ppant]@upso.ernet.in

Received 10 September 2004 / Accepted 6 November 2004

Abstract. The paper presents the results of an analysis of the north-south (N−S) and east-west (E−W) distribution of Hα solar flares from 1996 to 2003. This period of investigation corresponds to the ascending phase, the maximum and part of descending phase of solar cycle 23. It has been found that the flare activity during this cycle is low compared to previous solar cycles. The pattern of N−S distribution of flare occurrence shows that after solar activity minimum in 1996 the northern hemisphere was more active in producing flares than the southern one. The dominance of northern hemisphere is shifted towards the southern hemisphere after the solar maxima in 2000 and remained there in successive years. In both hemispheres (N and S), the flares are most prolific between 11° to 20° latitudes. Although the asymmetry in the E−W distribution of flare events is low, a consistent western dominance has been found. In more intense flares (Importance ≥1) there are some longitudinal bands where flare occurrence is higher than in adjacent bands.

Key words. Sun: activity – Sun: flares

1. Introduction

Solar activity phenomena are not uniformly distributed over the solar disk. The north-south (N−S) and east-west (E−W) distributions, including asymmetries, of several solar activity indices such as flares, filaments, magnetic flux, relative sunspot numbers and sunspot areas have been investigated by various authors (Howard 1974; Hensen & Hensen 1975; Roy 1977; Swinson et al. 1986; Vizoso & Ballester 1987; Garcia 1990; Heras et al. 1990; Verma 1993; Joshi 1995; Ataç & Özgüç 1996; Li et al. 1998; Verma 2000; Temmer et al. 2001, Temmer et al. 2002; Joshi & Joshi 2004; Knaack et al. 2004). These studies indicate that there exists an asymmetry in the N−S distribution of solar activity. Howard (1974) examined the N−S distribution of solar magnetic flux for the period 1967−1973 and found that about 95% of the total magnetic flux of the Sun is confined to latitudes below 40° in both hemispheres. It was also found that the total magnetic flux in the north exceeds that in the south by 7%. Roy (1977) studied the N−S distribution of major flares during 1955−1974, sunspot magnetic configuration between 1962−1974 and sunspot area from 1955−1974 and found that the northern hemisphere dominates the southern in all these categories. Garcia (1990) studied the N−S distribution of soft X-ray flares (class ≥ M1) during solar cycles 20 and 21. He concluded that the spatial distribution of flares varies within a solar cycle such that the preponderance of flares occurs in the north during the early part of the cycle and then moves south as the cycle progresses. Joshi (1995) and Li et al. (1998) studied the N−S distribution of Hα and soft X-ray flares during solar cycle 22. In both the above investigations a southern dominance was prevalent. Verma (2000) examined the latitudinal distribution of solar active prominences (SAP) for the period 1957−1998 and found that the SAP events are most prolific in the 11−20° slice in both the hemispheres. Temmer et al. (2001) studied the N−S asymmetry of Hα flares during 1975−1999 and found a significant asymmetry over long periods. Recently, Temmer et al. (2002) have found significant N−S asymmetry in sunspot numbers from 1975−2002. This asymmetry has been analysed in the light of rotational behavior in the northern and southern hemisphere separately and it is inferred from this study that the magnetic field systems originating in the two hemispheres are only weakly coupled.

There are relatively few studies addressing the the E−W distribution of solar activity. Some authors (Letfus 1960; Letfus & Ružičková-Topolová 1980; Knoška 1985; Heras et al. 1990; Joshi 1995; Temmer et al. 2001) have found evidence for the existence of a small but significant E−W asymmetry in the occurrence of Hα flares. However Li et al. (1998) found that the E−W asymmetry was not significant in the case of soft-X ray flares (class ≥ M1) during the maximum phase of solar cycle 22. Mavromichalaki et al. (1994) and Tritakis et al. (1997) have also reported a significant E−W asymmetry in the

⋆ Tables 2 and 3 are only available in electronic form at http://www.edpsciences.org

Table 1. The number of flares and their percentage for different importance classes.

Importance	No. of events	%
S	18 214	90.07
1	1648	8.15
2	319	1.58
3	39	0.19
4	3	0.01
Total	20 223	100

optical emissions of the solar corona. Verma (2000) studied the E–W distribution of SAP events from 1957–1998 and did not find any significant asymmetry.

In the present analysis, we have made an attempt to investigate the N–S and E–W distribution of Hα flares during the present solar cycle 23. We have calculated the probability of the latitudinal and longitudinal hemispheric distribution of flares to ascertain whether the results are statistically significant or not.

2. Data and analysis

2.1. Data

The data used in the present study have been collected from Hα flare lists published in the SGD (Solar Geophysical Data) from 01 May 1996 to 31 December 2003, covering approximately 8 years of solar cycle 23. During this period the occurrence of 20 235 Hα flares are reported. In Hα, flares are classified according to their importance and brightness classes. The importance class (S = subflare, or 1, 2, 3, or 4 for successively large flares) denotes the flare size and the brightness class (f = faint, n = normal, b = bright) corresponds to a subjective estimate of the intensity of the emission. In the Hα flare list the flare class is not known for some events. After excluding such data we get a total of 20 223 Hα flares. To perform the analysis we have divided the Hα flare events according to their importance class as shown in Table 1. From Table 1, we find that the percentage of flares of importance class 2, 3, and 4 is very small compared to subflares and importance 1 flares. Therefore for the purpose of analysis these importance classes are combined in to one group and denoted as importance >1. In Fig. 1, the monthly number of flares and monthly mean sunspot numbers are plotted. The data of monthly mean sunspot numbers have been taken from SGD. This figure represents the plots for total number of flares as well as for different importance classes therein.

2.2. N–S distribution

To investigate the existence of a spatial distribution of flares with respect to heliographic latitude, we have evaluated the number of flares in the interval of 10° latitude for northern and southern hemispheres for each year starting from 1996 (see Table 2). It is evident from the table that the number of flares is very small in both the hemispheres if we consider latitudes above 50°. Therefore flares above 50° latitude are merged in one group. In this manner we consider only six latitudinal

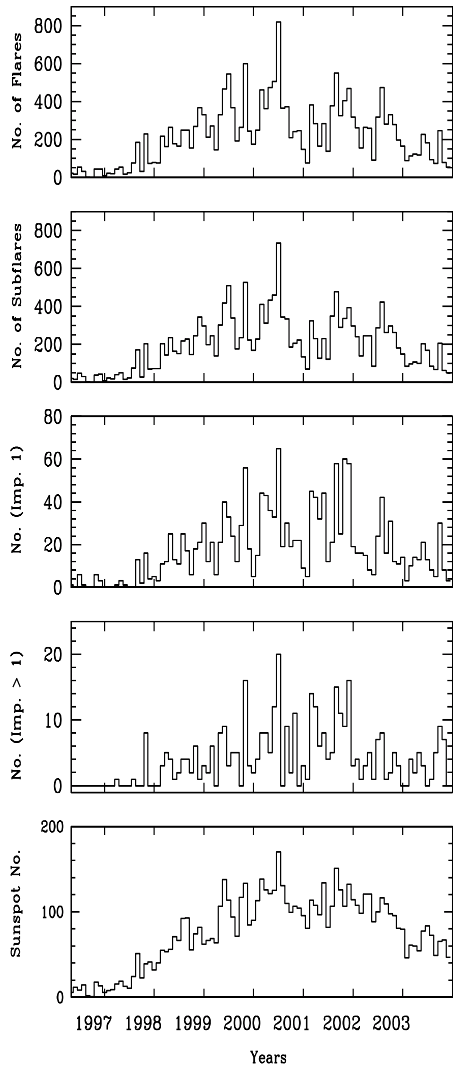

Fig. 1. Monthly numbers of Hα flares and monthly mean sunspot numbers from 1996–2003. The figure presents the plot for flares of all classes, subflares, importance 1 flares, importance >1 flares and monthly mean sunspot numbers (*from top to bottom panel*).

bands. Column 8 of Table 2 gives the total number of flares in the northern and southern hemispheres. We find that for all these years one hemisphere produces more flares than the other. To evaluate the statistical significance of flare dominance in the northern and southern hemispheres we use a binomial probability distribution (Vizoso & Ballester 1990; Li et al. 2001). Let us consider a distribution of n objects in 2 classes. The binomial formula gives the probability $P(k)$ of getting k objects in class 1 and $(n-k)$ objects in class 2, such that

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

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

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

In general, $P(\geq d) > 10\%$ implies a statistically insignificant result (flare activity should be regarded as being equivalent for the two hemispheres), when $5\% < P(\geq d) < 10\%$ it is

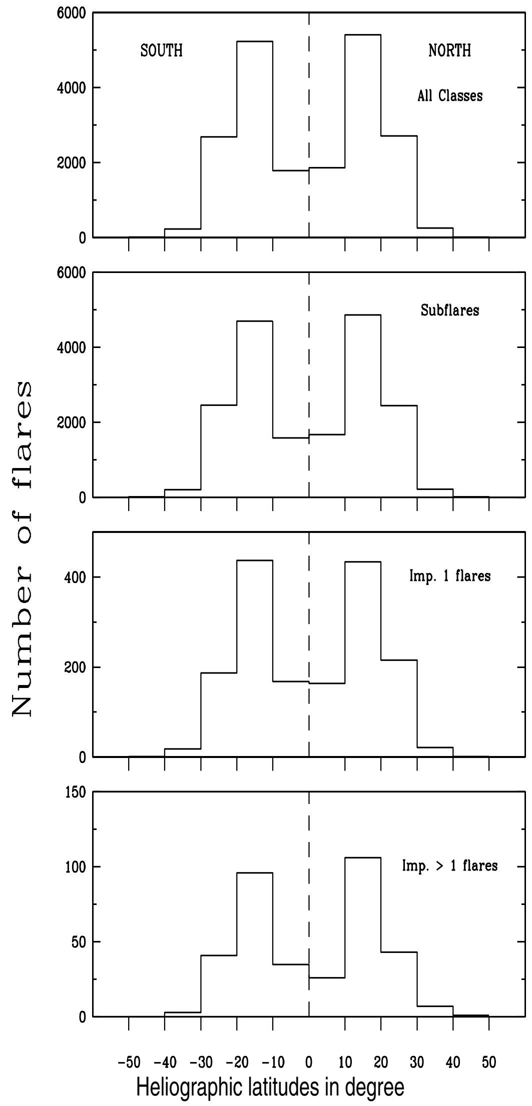

Fig. 2. Plot of number of flares versus heliographic latitudes for flares of all classes, subflares, importance 1 flares and importance >1 flares (*from top to bottom panel*).

marginally significant, and when $P(\geq d) < 5\%$ we have a statistically significant result (flare occurrence is not due to random fluctuations). The calculated values of binomial probability and consequently the predominant hemisphere for each year and in all six latitudinal bands are given in Table 2.

The data analysed in Table 2 have been plotted (Fig. 2) to examine how the distribution varies individually in two dimensional form. Hence, Fig. 2 shows the histogram of latitudinal distribution of flares from 1996−2003 between −50° to +50° latitudes. Here 0° represents the equator of the Sun. To understand how spatial asymmetry varies with the intensity of flare, we have also plotted the histogram separately for subflares, importance 1 flares, and importance >1 flares in the same figure. In Fig. 3 we have shown the N−S distribution in a different manner by plotting the cumulative count of flares in the northern (solid line) and southern (dashed line) hemisphere. The vertical distance between solid and dashed lines is a measure of northern/southern excess up to that time.

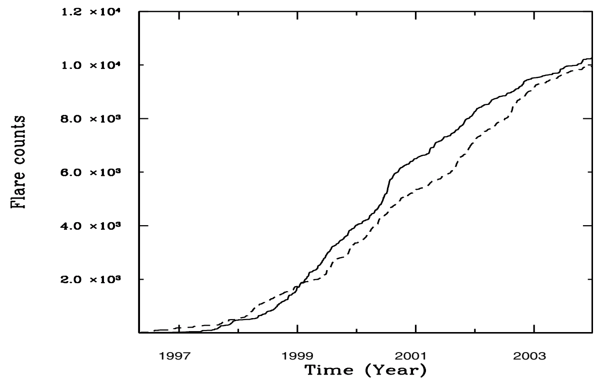

Fig. 3. Cumulative counts of flares occurring in the northern (solid line) and southern hemispheres (dashed line).

2.3. E–W distribution

Table 3 presents the number of flares at longitudinal intervals of 10° from the central meridian towards the east and west limbs during 1996−2003. The table also shows the binomial probability and dominant hemisphere for all the years as well as in all the longitudinal bands. To examine how the E−W distribution, shown in Table 3, varies individually in two dimensional form the histogram of the longitudinal distribution of flares from 1996−2003 between −90° to +90° longitudes are presented in Fig. 4. This figure shows the plots for total flares, subflares, importance 1 flares and importance >1 flares separately. Here 0° represents the central meridian of the Sun. The cumulative number of flares occurring in the eastern (solid line) and the western hemisphere (dashed line) is plotted in Fig. 5.

3. Discussion and conclusions

In this paper we have analysed the data of Hα flare events during the ascending phase, the maximum and part of the descending phase of solar cycle 23. In Table 1, we have listed the flare counts during this period according to importance class. Temmer et al. (2001) studied the Hα flare events for solar cycles 21 and 22 together. Their study revealed that although cycle 22 was much lower in total number of flares than cycle 21, it showed almost the same numbers of large flares. From Table 1 we find that the percentage of flare counts for different importance classes during cycle 23 are in good agreement with those reported by Temmer et al. (2001) during cycle 21 and 22 together.

Figure 1 represents the monthly numbers of Hα flares and their comparison with monthly mean sunspot numbers during 1996−2003. The ascending phase of the cycle shows a very low level of activity; the first prominent flare of importance >1 (2N) occurred in April 1997. As the cycle progressed the flare activity gradually increased and peaked in July 2000. The comparison of flare activity with sunspot number (see Fig. 1) shows a similar trend during the course of the solar cycle. The level of activity during cycle 23 is significantly lower than the two previous cycles (see Figs. 4 and 5 in Temmer et al. 2001). This clearly indicates the violation of the Gnevyshev-Ohl rule, for the pair of solar cycles 22−23, which states that odd-numbered cycles have greater activity than the preceding even-numbered

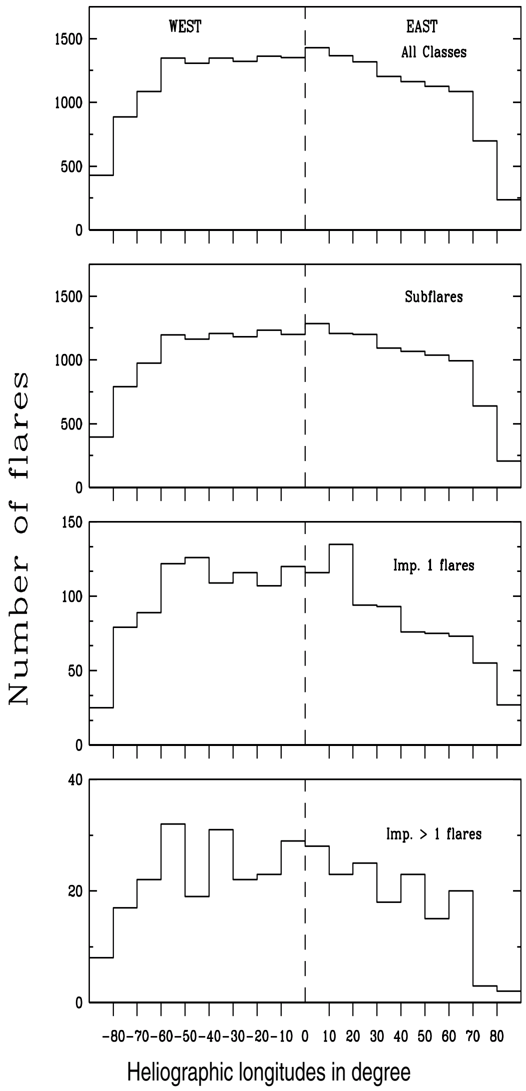

Fig. 4. Number of flares versus heliographic longitude for flares of all classes, subflares, importance 1 flares and importance >1 flares (*from top to bottom panel*).

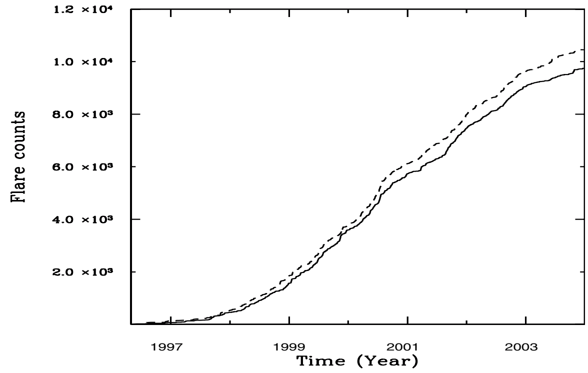

Fig. 5. Cumulative counts of flares occurring in the eastern (solid line) and western hemispheres (dashed line).

ones (Gnevyshev et al. 1948). Joshi et al. (2004) also reported a lower level of activity during cycle 23 in the soft X-ray flare events by computing the soft X-ray flare index ($FI_{\rm SXR}$).

Table 2 gives information about the evolutionary aspect of cycle 23. We find that in the beginning of the cycle most of the flares occurred in the southern hemisphere and the 0−10° latitudinal belt was highly active in producing flares, which could be a remnant of the preceding cycle. The number of flares above ±20° latitudes is very small. In 1997, just after solar minimum, most of the flares were produced in the 20−30° latitudinal belt. As the cycle progressed, the flare occurrence increased in lower latitudes. In the years 1997, 1999 and 2000 northern hemisphere dominated. In 1998 there were more flares in the southern hemisphere but this dominance can not be considered statistically significant as the binomial probability is greater than 10%. The cycle was in its maximum phase during the year 2000. We also find that after 2000 the flare activity shifted from the northern to southern hemisphere and remained there until 2003. Table 2 also presents the total flare counts in 10° latitude intervals. Here we notice that except for the 40°−50° latitudinal band (where events are too rare to be evaluated statistically), the northern hemisphere dominates over the southern, but we could find a significant probability only in the 0°−10° latitudinal band. Considering the total number of flares up to 2003 we find a northern abundance in the Hα flare events.

Figure 2 shows the latitudinal distribution of flares, where we find that flares are most prevalent between latitudes 11°−20° in both the hemispheres and mostly occurred within ±30° latitudes. By comparing the histogram of latitudinal distribution of flares of different importance classes (Fig. 2) the asymmetry appears to be maximum for flares of importance class >1. Garcia (1990) studied the N−S distribution of soft X-ray flares during cycle 20 and 21 and found similar results. Li et al. (1998) also examined the latitudinal distribution of flares during the maximum period of solar cycle 22 and found that the majority of flares occurred in the latitudes between 8°−35° in both the hemispheres. Figure 3 reveals that an excess of flares in the southern hemisphere developed during the ascending phase of cycle 23. After 1999 there was a rapid increase in the cumulative flare counts in the northern hemisphere, consequently northern hemisphere flare counts predominate over the southern one. We notice that the northern hemisphere excess increases initially and after mid 2001 it starts to decrease. By the end of 2003 a slight northern hemisphere excess remains. This behavior of cycle 23 is quite different to the previous one. In cycle 22 there was an southern excess throughout which was strongly enhanced during the declining phase (Temmer et al. 2001). Cycle 23 has not yet finished and it was shown (Temmer et al. 2001) that during cycle 21 the southern hemisphere started to dominate after 1985 (3 years before minimum). In the present study we find that the dominance of the southern hemisphere over the northern one, during the year 2003, is less significant than the preceding years and both the hemispheres showed a comparable level of activity. Although this behavior of cycle 23 is different from cycle 22, it is comparable to cycle 21. The different behavior of odd and even numbered cycles may be interpreted as the two parts of the basic 22-year solar periodicity (Švestka 1995).

During most of solar cycle 23, there is a western dominance in the flare occurrence (see Table 3). Letfus (1960) and Letfus & Ružičková-Topolová (1980) investigated the E−W asymmetry in the flare occurrence during 1935−1958 and 1959−1976 respectively (cycles 17 to 20) and found that on average a persistent real asymmetry exists in favor of the eastern hemisphere. Heras et al. (1990) analysed the east-west solar flare distribution from 1976−1985 and noticed a pronounced and prolonged E−W asymmetry in solar flare distribution. They concluded that simple random distribution of flares over the solar disk can not account for the asymmetries found, but it can be explained in terms of a transit of "active regions" in front of observer's position. Joshi (1995) studied the E−W asymmetry by taking three kinds of solar phenomena (sunspot groups, Hα flares and active prominences/filaments) during the maximum phase of solar cycle 22 (1989−1991), but could find significant asymmetry only for Hα flares which was in favor of the eastern hemisphere. However Li et al. (1998) could not find a significant E−W asymmetry in the distribution of soft X-ray flares (class $M \geq 1$) during the maximum period of solar cycle 22, but a non-uniform flare distribution in longitude has been shown. The above studies, carried out during cycles 17 to 22, show a prolonged eastern dominance while in the present study we find a consistent dominance of the western hemisphere during cycle 23.

The number of flares decreases as we move from the central meridian towards the eastern and western limbs (Fig. 4). The comparison of longitudinal distribution of flares for different importance classes in this figure shows that the asymmetry increases as the flares of higher intensity are considered. In the case of importance 1 and importance >1 flares there are some longitudinal bands where the flares are more prolific than their adjacent bands. The plot of cumulative number of flares in the eastern and western hemisphere (Fig. 5) shows that there is a western excess throughout the cycle while for cycles 21 and 22 there was an eastern dominance in Hα flare occurrences (Temmer et al. 2001). It is interesting to note that the behavior of E−W asymmetry during cycle 23 has changed and the cycle has become western dominated.

Acknowledgements. The authors are grateful to Helen Coffey and Edward H. Erwin for providing the Hα flare data of SGD. We are also thankful to Prof. Ram Sagar for useful discussions. We gratefully acknowledge the valuable comments and suggestions from the referee, W. Otruba, which helped to improve the paper. Useful discussion with K. J. Li about the binomial distribution is also gratefully acknowledged.

References

Ataç, T., & Özgüç, A. 1996, Sol. Phys., 166, 201
Garcia, H. A. 1990, Sol. Phys., 127, 185
Gnevyshev, M. N., & Ohl, A. I. 1948, Astron Zh., 25, 18
Hansen, R., & Hansen, S. 1975, Sol. Phys., 44, 225
Heras, A. M., Sanahuja, B., Shea, M. A., & Smart, D. F. 1990, Sol. Phys., 126, 371
Howard, R. 1974, Sol. Phys., 38, 59
Joshi, A. 1995, Sol. Phys., 157, 315
Joshi, B., & Joshi, A. 2004, Sol. Phys., 219, 343
Knaack, R., Stenflo, J. O., & Berdyugina, S. V. 2004, A&A, 418, L17
Knoška, Š. 1985, Contr. Astr. Obs. Skalnaté Pleso, 13, 217
Letfus, V. 1960, Bull. Astron. Inst. Czechosl., 11, 31
Letfus, V., & Ružičková-Topolová, B. 1980, Bull. Astron. Inst. Czechosl., 31, 232
Li, K.-J., Schmieder, B., & Li, Q. Sh. 1998, A&A, 131, 99
Li, K. J., Yun, H. S., & Gu, X. M. 2001, ApJ, 554, L115
Mavromichalaki, H., Tritakis, V., Petropoulos, B., et al. 1994, Ap&SS, 218, 35
Roy, J.-R. 1977, Sol. Phys., 52, 53
Švestka, Z. 1995, Adv. Space Res., 16(9), 27
Swinson, D. B., Koyama, H., & Saito, T. 1986, Sol. Phys., 106, 35
Temmer, M., Veronig, A., Hanslmeier, A., Otruba, W., & Messerotti, M. 2001, A&A, 375, 1049
Temmer, M., Veronig, A., & Hanslmeier, A. 2002, A&A, 390, 707
Tritakis, V., Mavromichalaki, H., Paliatsos, A. G., Petropoulos, B., & Noens, J. C. 1997, New Astron., 2, 437
Verma, V. K. 1993, ApJ, 403, 797
Verma, V. K. 2000, Sol. Phys., 194, 87
Vizoso, G., & Ballester, J. L. 1987, Sol. Phys., 112, 317
Vizoso, G., & Ballester, J. L. 1990, A&A, 229, 540

Online Material

Table 2. Yearly numbers of Hα flares at different latitude bands in the northern (N) and southern (S) hemisphere. The binomial probability (Prob.) and the dominant hemisphere (DH) is given for each year as well as for all the latitudinal bands. Dash (–) represents that the probability is not significant. Flares occurring at the equator have been excluded.

Years	Number of flares							Prob.	DH
	0–10°	10–20°	20–30°	30–40°	40–50°	>50°	Total		
1996 N	21	2	0	1	0	0	24	1.107×10^{-33}	S
S	112	53	21	2	0	0	188		
1997 N	39	160	230	20	0	0	449	5.641×10^{-6}	N
S	5	103	199	18	1	1	327		
1998 N	13	635	503	54	1	1	1207	0.428	–
S	3	366	807	31	9	0	1216		
1999 N	169	1240	811	105	11	0	2336	7.017×10^{-30}	N
S	71	874	644	38	0	0	1627		
2000 N	463	1327	633	55	1	2	2481	8.712×10^{-14}	N
S	248	1288	373	79	1	0	1989		
2001 N	503	978	262	5	1	0	1749	0.058	S
S	449	1062	282	42	8	0	1843		
2002 N	250	746	255	6	0	0	1257	1.329×10^{-35}	S
S	675	1006	272	4	0	0	1957		
2003 N	407	315	14	3	0	0	739	0.069	S
S	222	475	83	17	0	0	797		
Total N	1865	5403	2708	249	14	3	10242	0.018	N
S	1785	5227	2681	231	19	1	9944		
Prob.	0.093	0.956	0.356	0.205	0.189	0.125	0.018		
DH	N	–	–	–	–	–	N		

Table 3. Yearly numbers of Hα flares at nine longitude bands in the eastern (E) and western (W) hemisphere. The binomial probability (Prob.) and the dominant hemisphere (DH) is given for each year as well as for all the longitudinal bands. Dash (–) represents that the probability is not significant. Flares occurring at the central meridian have been excluded.

Years	Number of flares										Prob.	DH
	0–10°	10–20°	20–30°	30–40°	40–50°	50–60°	60–70°	70–80°	80–90°	Total		
1996 E	13	15	9	9	11	8	4	2	1	72	8.742×10^{-7}	W
W	17	17	23	22	17	15	15	11	4	141		
1997 E	43	54	60	46	45	41	45	34	15	383	0.387	–
W	63	64	46	42	49	50	25	35	17	391		
1998 E	173	133	121	150	161	140	127	74	26	1105	1.491×10^{-5}	W
W	150	172	176	168	152	182	143	97	70	1310		
1999 E	296	282	334	256	223	252	221	107	34	2005	0.136	–
W	251	267	236	245	217	244	224	163	89	1936		
2000 E	273	271	240	245	288	249	300	187	60	2113	0.0005	W
W	321	271	263	301	342	284	257	211	81	2331		
2001 E	262	309	245	246	175	166	151	122	37	1713	0.008	W
W	257	255	262	244	206	228	179	157	70	1858		
2002 E	251	194	226	193	194	175	163	113	48	1557	0.066	W
W	193	228	203	212	197	212	163	147	87	1642		
2003 E	118	108	85	60	68	97	75	58	21	690	3.736×10^{-5}	W
W	99	89	112	112	127	134	79	66	27	845		
Total E	1429	1366	1320	1205	1165	1128	1086	697	242	9638	4.251×10^{-9}	W
W	1351	1363	1321	1346	1307	1349	1085	887	445	10454		
Prob.	0.069	0.477	0.493	0.003	0.002	4.409×10^{-6}	0.492	8.722×10^{-7}	2.904×10^{-15}	4.251×10^{-9}		
DH	E	–	–	W	W	W	–	W	W	W		