Turkish Journal of Physics

http://journals.tubitak.gov.tr/physics/

Research Article

Turk J Phys
(2017) 41: 351 – 358

doi:10.3906/fiz-1704-4

Possible variations in sunspot groups before flaring activity during solar cycles 23 and 24

Ali KILÇIK*, **Seray ŞAHİN**
Department of Space Science and Technologies, Faculty of Science, Akdeniz University, Antalya, Turkey

Received: 05.04.2017 • **Accepted/Published Online:** 06.07.2017 • **Final Version:** 05.09.2017

Abstract: We investigated the possible morphological variations observed in sunspot groups on the day before flaring activity occurred between January 1996 and November 2014. We found that 77% of all flaring sunspot groups were large and complex (D, E, and F modified Zurich classes). In addition, the Zurich classification of A, B, and C class sunspot groups changed more than 50%, while the remaining groups (D, E, F, and H) did not change considerably before the flare activity. Results showed that there was a remarkable increase in the sunspot areas of groups D, E, and F; in contrast, the sunspot areas of groups A, B, C, and H showed a decrease before the flaring activity during the examined time period. Finally, the sunspot counts of groups A, C, and H showed a decrease, while groups B, D, E, and F showed an increase in the same period.

Key words: Solar flare, sunspot evolution, sunspots

1. Introduction

Sunspots are structures observed on the solar photosphere. They have a strong magnetic field and appear darker than their surroundings since they are much cooler than photosphere. In a developed sunspot the magnetic field strength can be in the order of several thousands of Gauss, while the average magnetic field strength on the solar photosphere is about 1 Gauss. The average temperature on a sunspot is about 4000 K, whereas it is about 5780 K in the solar photosphere. Generally, the size of sunspots varies from 1500 to 50,000 km in diameter, depending on the development of sunspots. At the beginning of their evolution, sunspots first appear as a pore, which is a very tiny sunspot, and may reach the maximum phase of their development within 3–10 days. A well-developed sunspot consists of two parts: i) the darker umbra located in the center of the sunspot is relatively cooler since the convective flows are suppressed by its strong magnetic field; ii) the penumbra, which surrounds the umbra, is relatively hotter and has a weaker magnetic field. Normally, sunspots are observed in the $\pm 35°$ latitude belts on the solar photosphere. In the early stage of a solar cycle, sunspots begin to appear in the $\pm 30°$–$45°$ heliographic latitudes and drift toward the solar equator with time, and then, while the old sunspot cycle fades away, sunspot groups of the new cycle begin to appear again at high solar latitudes [1].

Sunspots have been classified in several ways according to different parameters since the 1900s. These parameters can be the morphology, evolution, spot size, presence or absence of penumbra in the group, complexity, longitudinal extension, and interior spot distribution of the group. The first classification was made with respect to the sunspot shapes by Cortie [2]. Later, Waldmeier [3,4] introduced the Zurich classification scheme, which is based on sunspot morphology and evolution. Finally, to better explain the relationship between

*Correspondence: alikilcik@akdeniz.edu.tr

sunspots and solar flares, the McIntosh sunspot classification [5] was introduced as a modification of the Zurich classification scheme. According to this classification scheme, sunspots are grouped with three descriptive letters: the first letter represents the morphology and evolution of the group (A, B, C, D, E, F, H), the second letter describes the penumbra of the biggest spot in the group (x, r, s, a, h, k), and the third letter describes the spot distribution inside the group (x, o, i, c). Thus, sunspot groups are classified by adding these letters consecutively, such as Fkc, Cso, Hax, Axx, etc.

A solar flare is a sudden release of energy from the sun that can eject billions of tons of solar material into space. The releasing energy is in the form of electromagnetic waves over a wide spectrum (from radio waves to gamma rays). The amount of radiant energy varies depending on the intensity and duration of the event. Solar flares are classified in two different manners depending on the observed wavelength as follows:

1) Hydrogen alpha (Hα) classifications: Hα (6563 Å) classification is based on the size of the brightening area and the observed brightness in this area. The size of the brightening area is divided into five categories (S, 1, 2, 3, 4) as given in Table 1 (left two columns) and the brightness is divided into three categories as faint (f), normal (n), and bright (b). Thus, flares are classified in 15 categories such as sf, 2n, 4b, etc., according to Hα classification [6].

Table 1. Solar flare area classifications in hydrogen alpha (left two columns) and X-ray flare classification (right two columns).

Area classification	Corrected area (in millionths of solar hemisphere)	X-ray solar flare class	X-ray peak flux (W/m^2)
S	< 100	A	$< 10^{-7}$
1	100–250	B	$\geq 10^{-7}$ $< 10^{-6}$
2	250–600	C	$\geq 10^{-6}$ $< 10^{-5}$
3	600–1200	M	$\geq 10^{-5}$ $< 10^{-4}$
4	> 1200	X	$\geq 10^{-4}$

2) X-ray (1 to 8 Å) classifications: X-ray flares are classified as A, B, C, M, or X with respect to their peak flux (in watts per square meter, W/m^2) as shown in Table 1 (right two columns). They are measured by XRS instrument onboard the GOES-15 satellite, which is in a geostationary orbit over the Pacific Ocean [7].

Solar flare activity is found to be closely correlated with sunspots [8–10]. Eren and Kilcik [11] analyzed the sunspot classification data by dividing them into four categories as 'small' (A+B), 'medium' (C), 'large' (D+E+F), and 'end' (H). They found that large groups show a better correlation with solar flares compared to other categories. Recently, the sunspot classification data of flaring groups from 1988 to 1996 were analyzed by McCloskey et al. [12]. They found an increase in the flaring rates for upward evolution (from small to large/simple to complex). In this study, we took into account flaring sunspot groups for the last two solar cycles (from 1996 through 2014) and investigated the observed variations (first parameter of classification, total sunspot number (SSN), and area (SSA)) in these groups from one day before the flaring activity to the flaring days for each sunspot group individually.

In Section 2, we describe the datasets, the method of analysis used, and the results. Finally, discussion and conclusions are given in Section 3.

2. Data, method, and results

Sunspot group and solar flare data used in this study were taken from the Solar Monitor webpage for the 1996–2014 time period. The sunspot group dataset was divided into two parts according to flare occurrence as flaring and nonflaring sunspot groups. We focused only on flaring groups and analyzed the observed variations in sunspot class, that is, the sunspot number (SSN) and the sunspot area (SSA) of these groups between flaring day and the day before flaring. To obtain the observed variations we calculated average SSNs and SSAs for the flaring days and the day before the flare for each group individually for the investigated time period. Then we subtracted the day before flaring day average values from the flaring day average values. Thus, we obtained the observed variations of these parameters (SSN and SSA). Sunspot groups were analyzed between +70 and –70 degrees on the heliographic longitude belt in order to eliminate limb effects on sunspot classifications, spot counting inside the group, and group area measurements. If a sunspot group was not observed on the day before flaring activity, those groups were not taken into account.

In the Figure, numbers of these flaring groups are plotted against the modified Zurich classes. As shown in this figure, 77% of all flaring groups are large sunspot groups (D, E, F), 13% of the remaining sunspot groups are C class, and only 10% of them are A, B, and H class sunspot groups. Thus, we may conclude that the majority of the flares are produced by large sunspot groups.

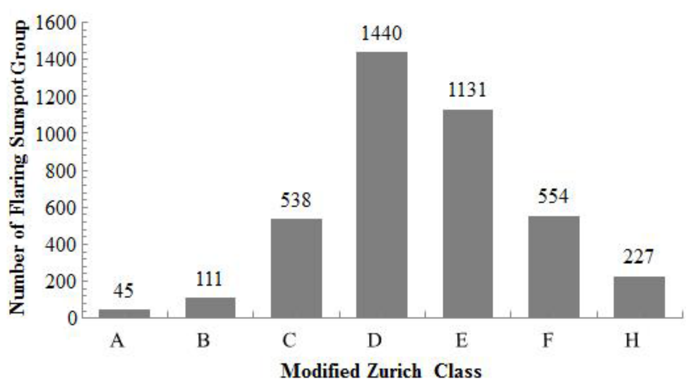

Figure. Distribution of the number of flaring groups according to the modified Zurich classes. Numbers on the top of each bar show the exact number of flaring sunspot groups.

In Tables 2–8 the temporal evolutions (class (1st and 2nd columns), SSN (4th column), and SSA (5th column) variations) of flaring sunspot groups are presented on the day before the flaring event from A to H, respectively. As shown in Table 2 a total of 45 A class sunspot groups showed flaring activity during the analyzed period. There was no classification change in 36% (16 groups) of these groups, while 64% of them showed a classification change (31% of them from B to A, 18% C to A, 4% D to A, 20% E to A, and 9% H to A). In general, the average sunspot areas (SSAs) and sunspot numbers (SSNs) showed decreasing trends during the investigated time period. The average sunspot numbers (0.25) of only H groups showed a small increase. Table 3 shows that, in total, 111 groups showed flaring activity for the B classes. There was no classification change in 46% (51 groups) of these groups, and in 54% (60 groups) of them the classification changed (16% from A to B, 28% C to B, 6% D to B, 1% E to B, and 3% H to B). The average SSNs showed an increase in the A, B, E, and H classes, while they demonstrated a decrease in the C and D classes. Note that there was only a single classification change from E to A and E to B in Tables 2 and 3, respectively. Therefore, the SSA and SSN increase/decrease in these two groups may be considered as an artificial effect. The average SSAs of the groups increased for the A and B classes, did not change for H, and decreased for the C, D, and E groups. Note that there were no groups that changed classification from F to A or B.

Table 2. Temporal evolution between the day before flaring and flaring days for the A class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	A	16	–0.31	–2.44
B	A	14	–3.14	–9.28
C	A	8	–2.5	–13.75
D	A	2	–3	–10
E	A	1	–6	–6
F	A	-	-	-
H	A	4	0.25	–10

Table 3. Same as Table 2 for B class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	B	18	2.72	6.94
B	B	51	0.64	5.49
C	B	31	–0.06	–13.22
D	B	7	–2.86	–24.28
E	B	1	4	–10
F	B	-	-	-
H	B	3	3.33	0

In Table 4, in the C class sunspot groups the total number of flaring sunspot groups was 538. Forty-nine percent of the C class sunspot groups (261 groups) did not show any classification change (261 groups) on the day before the flaring event, while 51% of them exhibited some change (2%, 8%, 22%, 4%, 1%, and 14%, from A, B, D, E, F, and H to C, respectively). When we examined the variations of SSAs and SSNs, we could see that the A, B, C, and H classes showed an increase before the flaring. On the contrary, all other complex groups (D, E, and F) showed a decrease (see Table 4).

Table 4. Same as Table 2 for C class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	C	11	4.27	42.73
B	C	41	2.78	27.07
C	C	261	0.31	1.11
D	C	121	–0.74	–17.60
E	C	23	-4	–30.87
F	C	3	–7.67	–56.67
H	C	78	3.08	18.72

In total 1440 D, 1131 E, and 554 F class sunspot groups (see Tables 5, 6, and 7, respectively) depicted flaring activity during the examined time period. Note that we did not detect any serious classification change for these sunspot groups (67%, 66%, and 78% of them remained the same for the D, E, and F classes, respectively). In Table 7, both SSAs and SSNs showed an increasing pattern from other classes to the F class in all cases. There were no sunspot groups that changed from A and B to F. For the E groups (see Table 6) there was an increasing trend for both SSNs and SSAs, with the exception of group F changing to group E. There were no sunspot groups that changed classification from A to E. For the D groups in Table 5, all these parameters showed an increasing trend, with the exception of groups F and E changing to D.

Table 5. Same as Table 2 for D class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	D	10	7.20	65
B	D	52	6.40	64.52
C	D	240	3.80	39.52
D	D	973	2.13	3.36
E	D	107	–2.06	–3.41
F	D	11	–0.91	–32.73
H	D	47	5.87	65.96

Table 6. Same as Table 2 for E class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	E	-	-	-
B	E	1	6	180
C	E	43	4.79	89.30
D	E	239	5.17	81.80
E	E	748	1.39	13.81
F	E	62	–1.84	–27.26
H	E	38	7.95	237.10

Table 7. Same as Table 2 for F class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	F	-	-	-
B	F	-	-	-
C	F	4	13	230
D	F	24	13.62	300
E	F	113	6.17	66.90
F	F	407	1.25	7.71
H	F	6	8.83	251.67

Finally, the total number of flaring sunspot groups for the H class in Table 8 was 227 and only 32% (72 sunspot groups) of them changed their morphology on the day before the flaring. In general, both SSNs and SSAs decreased, except where group A changed to group H.

Table 8. Same as Table 2 for H class flaring sunspot groups.

Sunspot group before flare	Sunspot group during flare	Number of sunspot groups	Average variation of sunspot numbers	Average variation of sunspot areas
A	H	6	0.17	16.67
B	H	2	–1.50	0
C	H	51	–2.80	–10.39
D	H	10	–3.60	–22
E	H	1	–5.00	–50
F	H	2	–5.50	–10
H	H	155	0.10	6.13

3. Discussion and conclusions

In this study, we have analyzed the observed modified Zurich classification, changes of the SSN, and the SSA for each Zurich class between the day before flaring and the flaring day for the examined time period (1996 through 2014). Our main findings are as follows:

1) Seventy-seven percent of all flaring sunspot groups were large and complex (including the D, E, and F modified Zurich classes).

2) The Zurich classification of A, B, and C class sunspot groups changed more than 50%, while the remaining groups (D, E, F, and H) did not change considerably before the flare activity.

3) There was a remarkable increase in the sunspot areas of groups D, E, and F while, contrastingly, the sunspot areas of the A, B, C, and H groups showed a decrease before the flaring activity during the analyzed period.

4) The sunspot numbers of the A, C, and H groups showed a decrease while the B, D, E, and F groups showed an increase in the same period.

Eren et al. [10] calculated the flare production potential for each modified Zurich class separately by using the same data that we used. They found that the flare production potentials of large sunspot groups (D, E, and F) were about eight times higher than the other ones (A, B, C, and H). They also found that about 80% of all flares occurred in the large/complex sunspot groups. In this study, we confirmed their results by using sunspot group numbers and further found that 77% of groups that produced flares were large, complex sunspot groups.

Lee et al. [13] divided the sunspot groups into two main categories (small and large) with respect to their areas from the period from January 1996 to December 2010. They further divided these two categories into 3 subcategories ('decrease', 'steady', and 'increase') according to temporal variations of sunspot areas. They concluded that the formation of the solar flares increased significantly with sunspot areas, which is consistent with our findings that the most of the flaring sunspot groups were large/complex.

Similarly, Kilcik et al. [14] also divided sunspot groups into two categories as small (A, B, C, H) and large (D, E, F) as indicated in the modified Zurich classification. Those groups were then divided further into four categories according to their morphology and evolution as 1) 'small' (A and B modified Zurich classes), 2) 'medium' (C), 3) 'large' (D, E, and F), and 4) 'end' (H). Kilcik et al. [15]. They analyzed the temporal variations of these categories and found that all these categories showed different temporal variations in all cases. Later, Kilcik et al. [16] analyzed the periodic variation of these categories and found that they also showed different periodic variations. It was concluded that both the temporal and periodic variations of each category were quite different, and that the number of observed flares increased when the size/complexity of the sunspot group increased. Recently, the flaring rate variations of flaring sunspot groups were examined for the ± 75 degrees heliographic longitude range between 1988 and 1996 by McCloskey et al. [12]. They found an increase in the flaring rates for upward evolution of the classes (from small to large/simple to complex). They also analyzed the sunspot classification changes after the flaring event and found the highest flaring rates for upward evolution (from A to H) from the larger, more complex classes. In this study, we analyzed not only the classification but also the sunspot numbers and area variations in the group for the latest available two-cycle data period (1996 through 2014) for downward evolution. To our knowledge, this information has not yet been previously reported. We found that the temporal evolution of the different sunspot groups from the day before the flare to the flaring day was also quite different. Thus, we confirm the above results for the downward evolution of flaring active regions and further conclude that these results may be used for flare prediction in the future.

Acknowledgments

The authors would like to thank the referee for his/her valuable comments and suggestions that improved the manuscript seriously. Sunspot group and solar flare data used in this study were taken from the Solar Monitor webpage (http://www.solarmonitor.org/) for the 1996–2014 time period. This study was supported by the Scientific and Technological Research Council of Turkey (Project 115F031). The authors would like to thank to Professor A Özgüç of Kandilli Observatory for his careful reading of the manuscript.

References

[1] Maunder, E.W. *Mon. Not. R. Astron. Soc.* **1904**, *64*, 747-761.

[2] Cortie, A. L. *Astrophys. J.* **1901**, *13*, 260.

[3] Waldmeier, M. *Z. Astrophys.* **1938**, *16*, 276.

[4] Waldmeier, M. *Z. Astrophys.* **1955**, *38*, 125.

[5] McIntosh, P. S. *Sol. Phys.* **1990**, *125*, 251-267.

[6] Maris, G.; Popescu, M. D.; Mierla, M. In *IAU Symposium Proceedings: Multi-Wavelength Investigations of Solar Activity*; Cambridge University Press: Cambridge, UK, 2004, pp. 73-76.

[7] Aschwanden, M. J.; Freeland, S. L. *Astrophys. J.* **2012**, *754*, 112.

[8] Ozguc, A.; Atac, T. *Sol. Phys.* **1989**, *123*, 357-365.

[9] Feminella, F.; Storini, M. *Astron. Astrophys.* **1997**, *322*, 311-319.

[10] Eren, S.; Kilcik, A.; Atay, T.; Miteva, R.; Yurchyshyn, V.; Rozelot, J. P.; Ozguc, A. *Mon. Not. R. Astron. Soc.* **2017**, *465*, 68-75.

[11] Eren, S.; Kilcik, A. *Sun and Geosphere* **2017**, *12*, 7-10.

[12] McCloskey, A. E.; Gallagher, P. T.; Bloomfield, D. S. *Sol. Phys.* **2016**, *291*, 1711-1738.

[13] Lee, K.; Moon, Y. J.; Lee, J. Y; Lee, K. S; Na, H. *Sol. Phys.* **2012**, *281*, 639.

[14] Kilcik, A.; Yurchyshyn, V. B.; Abramenko, V.; Goode, P. R.; Ozguc, A.; Rozelot, J. P.; Cao, W. *Astrophys. J.* **2011**, *731*, 30.

[15] Kilcik, A.; Yurchyshyn, V. B.; Ozguc, A.; Rozelot, J. P. *Astrophys. J. Lett.* **2014**, *794*, L2.

[16] Kilcik, A.; Ozguc, A.; Yurchyshyn, V.; Rozelot, J. P. *Sol. Phys.* **2014**, *289*, 4365-4376.