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Statistical Analysis of the Monthly Activity of the Solar Flare

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ABSTRACT

The study of solar flares (SF) is significant for a more understanding of the nature and dynamics of the sun as well as its impact on space weather. This paper will present a new idea by studying the monthly activity of SFs by collecting data for SFs, the flare index (FI), and the sunspots number (SSN) for the period from 1986 to 2019, which represents three solar cycles 22, 23 and 24. Extracting the monthly averages of the data shows us that the southern solar hemisphere is more active for solar flares than the northern solar hemisphere. Also, the second half of the year is more active than the first half of the three solar cycles. The most active months are March, (July or October) and November, while February was the least active. In addition, the evidence of the cross-correlation results in a strong positive relationship between the three variables. This study serves to forecast the state of the space weather during the months of the year.

Keywords: solar flare, solar flare index, sunspot number, cross-correlation.

INTRODUCTION

(Hodgson, 1859; Carrington, 1859) were the first to notice a solar flare (SF) by a relatively short increase in brightening in continuous white light. Since that time, the physical mechanics of the SF and its relationship to the activity of sunspots have become one of the most significant issues in the study of the physics of the sun. (Hathaway 2010; Hudson 2011; Feng *et al*., 2013). The SFs are a sudden, intense, and rapid change in brightness of the sun in the corona above active regions, which occurs when magnetic energy is suddenly released into the sun's atmosphere. Effects associated with the occurrence of the SFs, in addition to the emission and acceleration of energy solar particles for example protons, electrons, also heavy nuclei, can lead to the generation of a strong radioactive storm that affects the space weather near Earth, which in turn damages to satellites, communications system or fiasco electric power (Inbua *et al.*, 2019; Khumlumlert, 2017). SFs release energy to all lengths of the electromagnetic spectrum during their occurrence, which extends from a few seconds to several hours. The total volume of energy released by a large SF is about 10^{32} erg (Daglis *et al*., 2004; Roy *et al*.,2020). Therefore, the continuous and regular monitoring of SFs (monitored by hydrogen-alpha (Hα; 6563 A˚) and X-rays) plays a significant role, especially in space weather and the interaction of the Earth-Sun (Ozguc *et al*., 2021). The SFs are formed from active areas of sunspots, so the number of SFs is related to the sunspots number (SSN), as the observed solar flares change according to the solar cycle (SC). The SC was discovered by Samuel Heinrich Schwabe in 1843 who found that there are periodic changes in the average SSNs. The duration of the cycle is between 10-13 years and includes a change in solar activity, SSN, SF, and other space surroundings (Khumlumlert, 2017; Aiemsa-ad *et al*., 2015).

The first to display the quantity (Q = it) to measure the daily activity of the SF for 24 hours is Kleczek in 1952, as he assumed that this equation would give approximately the total quantity of energy emitted by the SF in the Hα (6563 A˚), and named the quantity (Q) as “flare index” (FI) (Kleczek, 1952). The FI is a significant parameter and is of meaning to denote the short-lived activity on the Sun. In this equation, (i) is the “importance scale” of the SF in Hα and it depends on the size and brightness of the SF area, and (t) is the duration (in minutes) of the SF (see (Ozguç *et al*., 2003) for details). The time change in the FI follows the general changes in the solar activity. There is a close relationship between all the indicators of solar activity, such as the SSN, the solar radio flux, and the total solar irradiance (TSI). In addition, the FI shows a cyclic behavior of days and many years, so it is apposite for studying the cyclical behavior of solar activity in the short and long term (Kilcik *et al*., 2010; Hathaway, 2015; Chowdhury *et al*., 2019).

Observations showed that the active structure of the Sun is not evenly distributed between the two solar hemispheres (northern and southern). This phenomenon is called the” north-south asymmetry”. Studies and observations confirmed that this is an asymmetry in the data sets for the SSN, the area of sunspots, the number of groups of sunspots, the FI, and others (Chowdhury *et al*., 2019; Ataç and Ozguç, 1996; Li *et al*., 2009; Javaraiah, 2016). This study will present a thoughtful idea by studying the monthly activity of the SFs by collecting data for the SFs, the FI, and the SSN for the period from 1986 to 2019, which represents three SCs-22-24.

MATERIALS AND METHODS

Data Sources

In this study, the daily data of the SF was collected from the website of “the Geostationary Operational Environmental Satellites (GOES) of the National Oceanic and Atmospheric Administration (NOAA)” (ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/), while the daily data for the solar FI calculated by the Kandilli Observatory from its website (http://www.koeri.boun.edu.tr/eng/topeng.htm), for the SCs-22-24. The daily data for the SSN was taken from the website of “Sunspot Index and Long-term Solar Observations (SILS)” (https://www.sidc.be/silso/home).

Method

In this study, the daily data was collected for each (SF, FI, and SSN). The number of monthly events for each class of solar flare (B, C, M, X) also the monthly average for each of the FI and the SSN for the solar hemispheres (northern and southern) were calculated. Then find the average for each month for each solar cycle (because the SCs are not equal in periods, which range from 10 to 13 years) to find the most active months of the year for SF and which are the most inactive.

Cross-correlation (C-C) is a method of learning unlike parameters to measure likenesses and plot analogous relative features, which can tell new information (Poudel *et al*., 2020). It is convenient as a measure of the similarity between two-time series as a function of one's delay relation to the other since its highest happens at the lag at which the two-time series are greatest associated (Menke and Menke, 2012). A curve towards ±1 shows a very sturdy connection, while a curve about zero denotes a modest or fewer correlation (Katz, 1988). The C-C method was used to discover a pattern of similarity between the monthly averages of the variables used in this study.

RESULTS AND DISCUSSIONS

From Fig. (1), which is between the classess of solar flares and the time in months, we notice in general that the SF class C is the largest then B, M, and X, while the SC-22 is the most active, then SC-23 and SC-24 is the weakest (Svalgaard *et al*., 2005). Also, the second half of the year is more active than the first.

It is well-known that the monthly average of the SF for the classes C, M, and X for the SCs-22-24 is approximately the same frequency, as they have the highest values in March, October, and November but the lowest activity in February. As for the B class, its months are almost similar in value and have the lowest monthly average in November, as in Fig. (1A). Fig. (1B) shows the total monthly average for SF of the SCs-22-24. It is noted that the total monthly average of the SF events for the 22nd SC is at its peak in March and October but the minimum activity is in July. As for the SC-23, it is in the highest value of its activity in August, October, and November, while the minimum active month is in February, while the SC-24 is the highest activity in March and October and less in June.

Fig. (2A) shows the changes that occur during the months for the monthly average of the FI for the northern and southern solar hemispheres during the SCs-22-24. In general, the southern solar hemisphere is more active than the northern solar half, and the second half of the year is more active than the first.

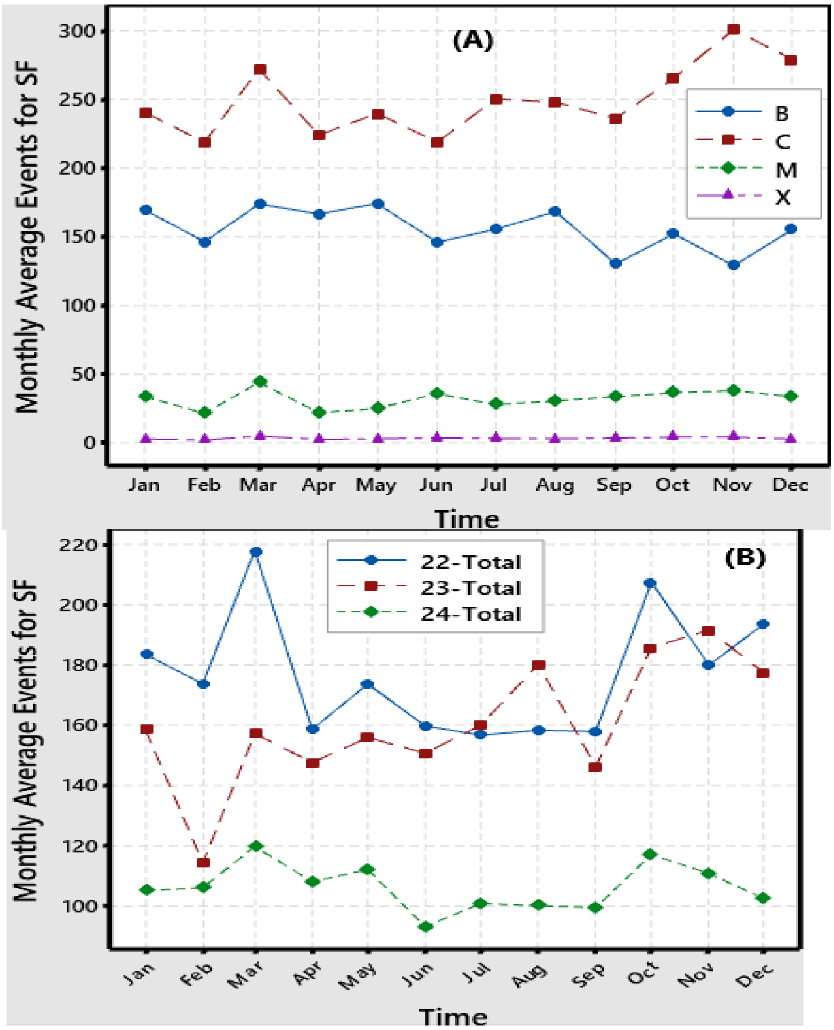


Fig. 1: The monthly average events for SF (A) classes of flare (B, C, M, X) for the SCs-22-24, (B) total monthly average events for all SF of SCs-22-24.

It can be seen that the two solar hemispheres share three peaks for the total monthly average of the FI in March, July, and November, and the lowest amount in February for the southern hemisphere and January for the northern solar hemisphere.

The total monthly average of the FI for the three SCs is more similar in the second half of the year and they have a common peak in March, July, and November. Wherever we notice that the SC-22 has its fourth peak in January because it is more active, as shown in Fig. (2B).

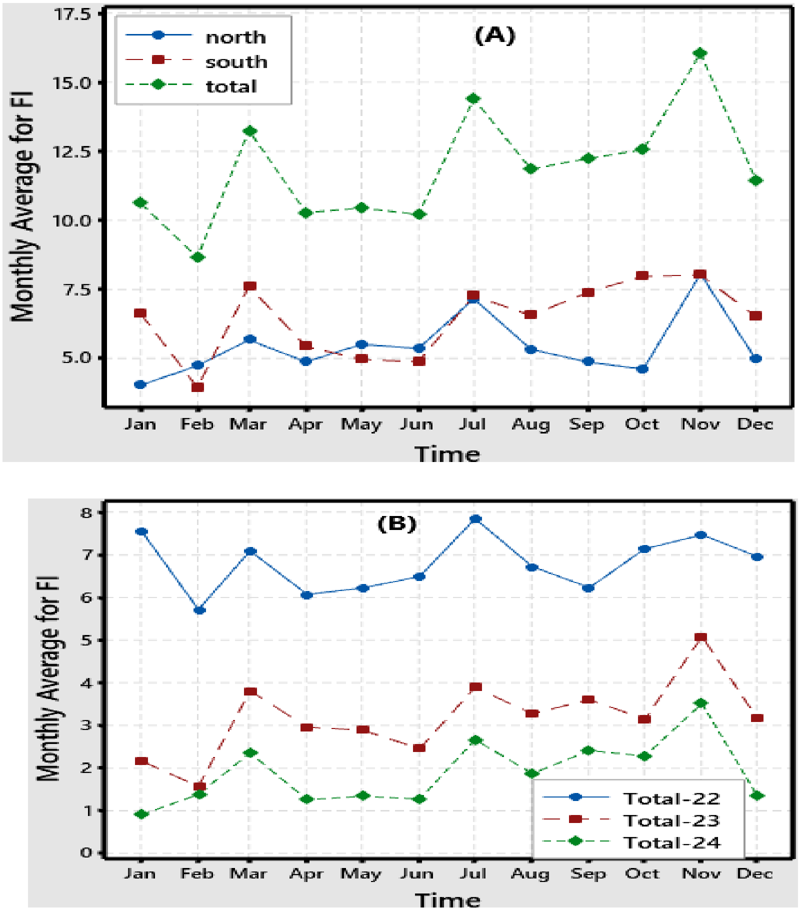


Fig. 2: The total monthly average for FI, (A) For both the northern and southern solar hemispheres of the SCs-22-24. (B) for every SC-22-24.

Fig. (3A) shows the active and inactive months represented by the monthly average of the SSNs for the northern and southern solar hemispheres. It is well-known that the southern solar hemisphere of the SCs-22-24 is more active than the northern solar hemisphere, and noted that the two solar hemispheres do not have clear peaks and that the total monthly average of SSN has one activity in August.

From Fig. (3B), it is noted that the total monthly average of the SSNs, the monthly changes are almost similar to the SCs-22 and 23, and they are opposite to the SC-24. The most active months for the SC-22 are January, February, August, October, and December. While the most active months for the SC-23 are June, July, and August, while May and September are the most active months for the SC-24.

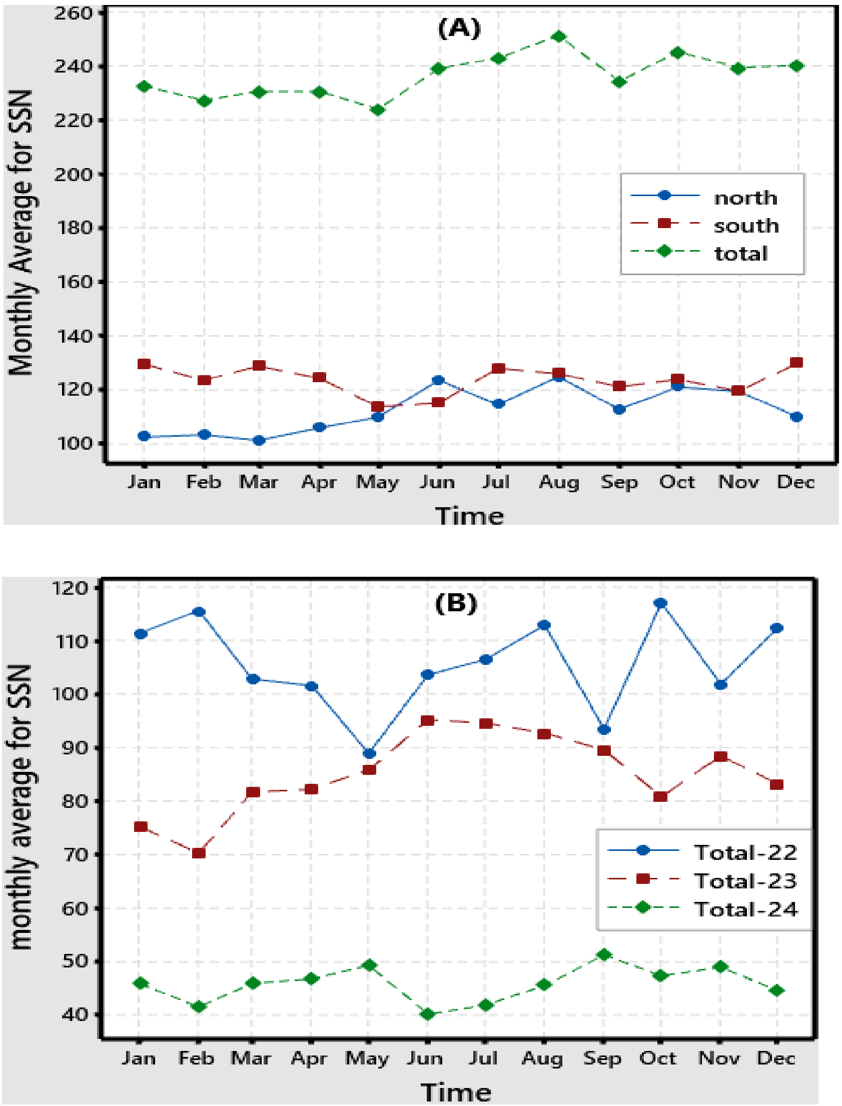
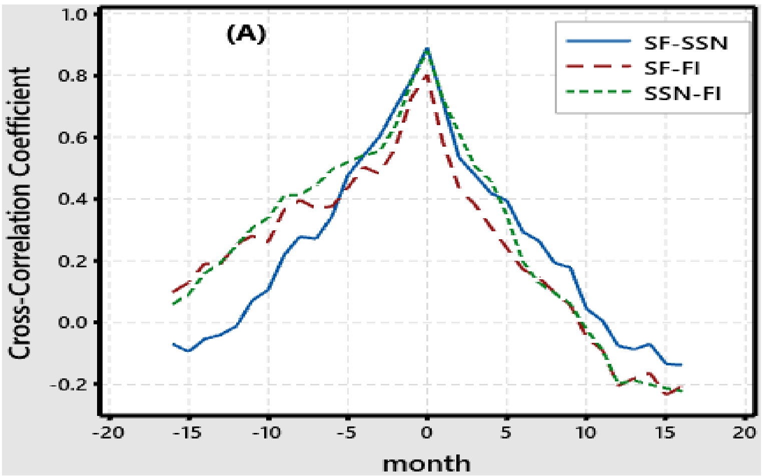


Fig. 3: **The monthly average for SSN, (A) For both the northern and southern solar hemispheres of the SCs-22-24. (B) for every SC-22-24.**

Fig. (4A) explains the C-C between the total monthly average of each of the SF, the SI, and the SSN during three SCs-22-24. It is renowned that each line reached the maximum positive C-C coefficient of 1 at 0 lag, and this shows a strong positive relationship between the three variables during this period. This means that these solar activities are at the same frequency. Fig. (1B) shows the C-C between the monthly average of each of the FI and the SSN for the northern and southern solar hemispheres during this period. The correlation coefficient line reached a positive correlation (>0.8) in 0 lag. This indicates that the northern and southern solar hemispheres are similar in their monthly changes.



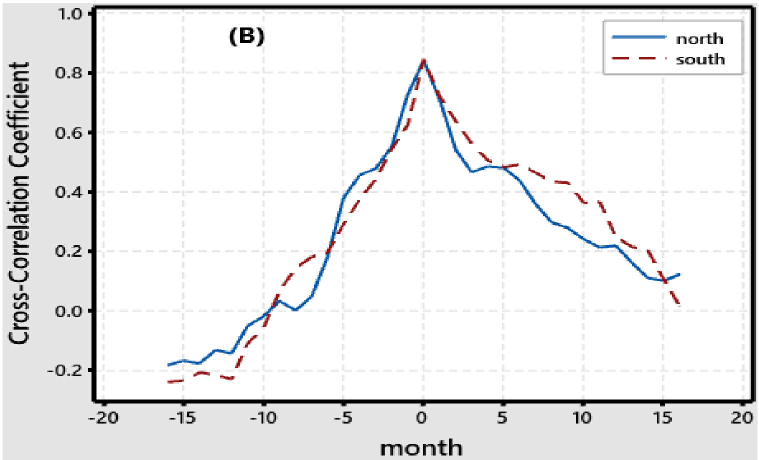


Fig. 4: The C-C versus time (months) for SF, FI and SSN during the SCs-22-24. (A) the total average of SF and SSN, SF & FI and SSN and FI, (B) the average of north and south for SSN and FI.

CONCLUSION

In this study, the data of SF, FI, and SSN were collected for the period from 1986 to 2019, which represents three SCs, the SC-22 for the period 1986-1995, the SC-23 for the period 1996-2007, and the SC-24 for the period 2007-2019. The monthly activity of the SF during this period was studied. The main comments from this analysis can be brief as follow:

1. In general, the southern solar hemisphere is more active than the northern solar half, the second half of the year is more active than the first, and the SC-22 is the maximum active, then SC-23 and SC-24 are the weakest. It is well-known that the SF class C is the most of the events, then B, M, and X during the three SCs. The total monthly average of SF events for all classes of the SCs-22-24 has peak activity in March, October, and November adding minimum activity in February, except for class B in November.
2. The total monthly average of the FI for the three SCs has common peak activity in March, July, and November, and the minimum activity in February for the southern hemisphere but for the northern solar hemisphere in January. Also, the SC-22 has its fourth peak activity in January because it is more active.
3. The total monthly average of the SSNs for the SCs-22-24 for the two solar hemispheres does not have clear peak activity and has one activity in August. While the most active months for the SC-22 are January, February, August, October, and December. While the most active months

for the SC-23 are June, July, and August, while May and September are the maximum active months for the SC-24.

4. The C-C between the total monthly average of each of the SF, the FI, and the SSN as well as the FI and the SSN for the northern and southern solar hemispheres during three SCs-22-24 crests with an extreme value of 1 for a zero lag. This means that these solar activities are at the same frequency.

REFERENCES

Aiemsa-ad, N.; Ruffolo, D.; Sáiz, A.; Mangeard, P.; Nutaro, T.; Nuntiyakul, W.; Kamyan, N.; Khumlumlert, T.; Krüger, H.; Moraal, H.; Bieber, J.W.; Clem, J.; Evenson, P. (2015). Measurement and simulation of neutron monitor count rate dependence on surrounding structure. *J. Geophys. Research a: Space Phys..*, **120.**

Ataç, T.; Ozguç, A. (1996). North-South asymmetry in the solar flare index. *Solar Phys.*, **166** (1).

Carrington, R.C. (1859). Description of a singular appearance seen in the sun on September 1, 1859. *MNRAS*, **20**(15).

Chowdhury, P.; Kilcik, A.; Yurchyshyn, V.; Obridko, V. N.; Rozelot, J. P. (2019). Analysis of the hemispheric sunspot number time series for the solar cycles 18 to 24. *Solar Phys.*, **294** (10).

Daglis, I.A.; Delcourt, D.; Kamide. F.A. (2004). Particle acceleration in the frame of the storm-substorm relation. *IEEE Transactions on Plasma Sci.*, **32**(4).

Feng Song, Y.L.; Yang Yunfei (2013). The relationship between grouped solar flares and sunspot activity. *Bull. Astr. Soc. India.* **41**.

Hathaway, D.H. (2010). The solar cycle. *Living Rev. Phys.*, **7**(1).

Hathaway, D.H. (2015). The solar cycle. *Living Rev. in Solar Phys.*, **12**(1).

Hodgson, R. (1859). On a curious appearance seen in the Sun. *MNRAS*, **20**(15).

Hudson, H.S. (2011). Global properties of solar flares. *Space. Sci. Rev.*, **158.**

Inbua, A.; Prathom, J.Sk. P.; Cheeprem, K.;Aiemsa-ad Nalinee; Khumlumlert, Th. (2019). The solar flare analysis during the 23rd and 24th solar cycles. *Internat. J. Educ. and Research.* **7**(1).

Javaraiah, J. (2016). North-south asymmetry in small and large sunspot group activity and violation of even-odd solar cycle rule. *Astrophys. and Space Sci.*, **361**(7).

Katz, R.W. (1988). Use of cross correlations in the search for teleconnections. *J. Climatol.*, **8(**3). doi: https://doi.org/10.1002/joc.3370080303

Khumlumlert, T.; Kanjanapa, W.; Aiemsa-Ad, N. (2017). The Information study of solar flare events on November 3, 2013 and August 9, 2011. *Advanced Sci. Lett.*, **23**.

Kilcik, A.; Ozguç, A.; Rozelot, J.P.; Ataç, T. (2010). Periodicities in solar flare index for cycles 21-23 revisited. *Solar Phys.*, **264**(1).

Kleczek (1952). Ionospheric disturbances and flares in the 11-years cycle. *Bulletin Astronom. Instit. Czechoslovakia*, **3**(52).

Li, Y.; Jin, J.; Wang, H. (2009). The change of magnetic inclination angles associated with flares. *American Astronom. Soc.*, **41**(850).

Menke, W.; Menke, J. (2012). "Data analysis with MatLab". Environmental Data Analysis with MatLab, 1–15. Doi: https://doi.org/10.1016/b978-0-12-391886-4.00001-5

Ozguç, A.; Ataç, T.; Rybak, J. (2003). "Short-term Periodicities in ´the Flare Index Between the |Years 1966-2001" Solar Variability as an Input to the Earth's Environment". Proceedings of International Solar Cycle Studies (ISCS) Symposium. Tatranska Lomnica, Slovak Republic.

Ozguc, A.; Kilcik, A.; Sarp, V.; Yesilyaprak, H.; Pektas, R. (2021). "Periodic Variation of Solar Flare Index for the Last Solar Cycle (Cycle 24)". Hindawi, Advances in Astronomy Volume 2021, Article ID 5391091, 8 p. https://doi.org/10.1155/2021/5391091

Poudel, P.; Parajuli, N.; Gautam, A.; Sapkota, D.; Adhikari, H.; Adhikari, B. (2020). Wavelet and cross-correlation analysis of relativistic electron flux with sunspot number, solar flux, and solar wind parameters. *J. Nepal Phys. Soc.*, **6**(2). Doi: https://doi.org/10.3126/jnphyssoc.v6i2.34865

Roy, S.; Prasad, A.; Ghosh, K.; Panja, S.C.; Patra, S.N. (2020). Chaos and periodicities in solar flare index from Kandilli observatory during 1976-2014. *Research in Astron. and Astrophys.*, **20**(7).

Svalgaard, L.; Cliver, E. W.; Kamide, Y. (2005). Sunspot cycle 24: Smallest cycle in 100 years?. *Geophys. Research Lett.*, **32(**1).

التحليل الاحصائي للنشاط الشهري للتوهج الشمسي

الملخص

تعتبر دراسة التوهجات الشمسية (SF) مهمة لزيادة فهم طبيعة وديناميكيات الشمس بالإضافة إلى تأثيرها على طقس الفضاء. ستقدم هذه الورقة فكرة جديدة من خلال دراسة النشاط الشهري للتوهجات الشمسية من خلال جمع البيانات عن التوهجات الشمسية، ومؤشر التوهج (FI)، وعدد البقع الشمسية (SSN) للفترة من 1986 إلى 2019، والتي تمثل ثلاث دورات شمسية 22 23 24. استخلاص البيانات للمعدلات الشهرية يوضح لنا أن نصف الكرة الجنوبي هو أكثر نشاطًا للتوهجات الشمسية من نصف الكرة الشمالي. أيضًا، النصف الثاني من العام أكثر نشاطًا من النصف الأول للدورات الشمسية الثلاث. أكثر الشهور نشاطًا هي مارس، (يوليو أو أكتوبر) ونوفمبر، بينما كان شهر فبراير هو الأقل نشاطًا. بالإضافة إلى ذلك، ينتج عن دليل الارتباط المتبادل علاقة إيجابية قوية بين المتغيرات الثلاثة. هذه الدراسة تخدم للتنبؤ بحالة طقس الفضاء خلال أشهر السنة.

الكلمات الدالة: التوهج الشمسي، مؤشر التوهج الشمسي، عدد البقع الشمسية، الارتباط المتبادل.