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STUDYING THE EFFECT OF SOLAR ACTIVITIES ON THUNDERSTORMS IN IRAQ FOR SOLAR-CYCLES 23 & 24

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ABSTRACT Studying the impact of solar activity on the Earth's climate is significant for predicting the change of its elements for long periods. Most studies have focused on the relationship between sunspots and changes in one of the climate elements. In this research, the effect of the solar activities that consist of coronal mass ejections and solar flare, and the sunspots number on thunderstorms that occur during the winter season in Iraq for the period from (1996-2019) representing the Solar-Cycles 23 & 24, respectively, were investigated in this study. In general, the statistical results show that, the monthly average increase for each of the following: energies of coronal mass ejections, solar flares, and the sunspots number, the monthly frequency of thunderstorms decreases. The Solar-Cycle 24 is the weakest among the cycles of the last century; therefore, its results were not precise.

Keywords: Coronal mass ejections, Solar flare, Solar-weather relationship, Thunderstorms,Iraq.

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1. INTRODUCTION

Since the beginning of the last century, space and atmospheric scientists have been studying Solar activities and their impact on the layers of the Earth's atmosphere that, in turn, affect the climate and atmospheric disturbances. Solar activities play a vital role in long-term predictions of the Earth's climate that affects various human activities such as communications, aeronautics, agriculture, and others. Therefore, it is necessary to understand the interaction of solar activities with the layers of the atmosphere, especially the troposphere, in which climatic elements are formulated (Majman, 2015).

Solar activities are not limited to the sunspots number (SSN) only. Solar activities include two parts: First, the processes that occur on its surface, including sunspots, Prominences, faculae, and others. Second, solar winds are divided into Coronal mass ejections (CMEs), solar flares, and high-energy solar particles (SEPs) (Hanslmeier, 2007). Sunspots result from the concentrations of magnetic field flux on the sun's surface. The number of sunspots changes during about 11 years that is known as the Solar-Cycle (SC). The periodic change in the sunspot's number also includes the changes in solar radiation levels in addition to changes in solar appearance (Hanslmeier,2004).

The CMEs are a large explosion in the form of a cloud of plasma rushing out of the sun (space) containing charged particles with a velocity between (750-400 km/s). It originates from sunspot's gatherings; these regions have closed and strong magnetic field lines sufficient to contain the plasma and is often associated with the solar flare. It may reach the Earth within two days to a week. As for the solar flare, it is a sharp and sudden brightness that occurs on the surface of the sun in the form of energy from the electromagnetic spectrum up to (6×1025 joules) (Malandraki & Crosby, 2020). Solar activities play an important role in influencing the space environment near the Earth and the layers of the Earth's atmosphere. These activities put pressure on the Earth's magnetic field and interact with it in the form of a geomagnetic storm in addition to cosmic rays, and all of these factors are one of the causes of climate changes on Earth (Vardavas & Taylor, 2007).

The relationship between solar activities and the formation of thunderstorms has been studied for nearly 200 years (Aniol 1952, Brooks 1934 and Fritz 1878). Many climatologists confirm the possibility that solar activities play a role in climate change, but, on the other hand, many of them believe that this effect is minor. They attribute these changes to industrial activities. Most studies have dealt with the impact of solar activity represented only by the sunspots number with thunderstorms and lightning. We also note from these studies that the correlation coefficient between solar activity and the frequency of thunderstorms varies with different locations on the Earth's surface in addition to periods. The effect of solar activity on thunderstorms has not been studied convincingly (Owens et. al. 2015, Majman 2015, Siingh et al., 2011, Schlegel et. al., 2001, Stringfellow, 1974).

To prove the extent of the impact of solar activities on the Earth's climate change, many studies that contain accurate and long-term solar and climatic data are needed. This study aims to reinforce this concept and to show the effect of CMEs, solar flares, and sunspots on thunderstorms over Iraq for the period between (1996-2019) by using statistical analysis.

2. RESEARCH METHODOLOGY

A statistical analysis of the SC 23 of (1996-2007) and the SC 24 of (2008-2019) were carried out in this study. The research takes into account the interpretation of the effect of solar activities on thunderstorms in a more comprehensive way. The SC 23 is divided into an ascending phase of (1996-2001) and a descending phase of the same SC from (2002-2007). Meanwhile, the SC 24 represents the ascending phase of the limited period (2008-2013) and the descending phase of (2014-2019). It analyzes and discusses the effect of solar activities on the monthly frequency of thunderstorms during the winter season, which begins in Iraq in December and ends in May.

A Fast Fourier Transform (FFT) filter was used for all solar and thunderstorm data to filter it and remove the extreme data as shown in Figs. 1-4. This work employs the program (Minitab 19.0) to analyze solar events with thunderstorms, as it is one of the best statistical programs that deal with big data. Linear regression was found between the statistically computed variables (Regression). The graphs and parameters of the study were interpreted by finding the correlation using the Pearson Linear Correlation Coefficient between the monthly rates of solar events and the monthly rates of thunderstorms. Also, to find the following:

- The P-value: expresses the extent of the significance level (the occurrence of chance).
- The value of R: explains the correlation between the dependent and independent variables,
- R^2: shows the ratio of the strength of the correlation between them (Currell, 2015).

3. DATA SOURCES OF THE SOLAR ACTIVITIES

The data for CMEs were taken from SOHO / LASCO CME Catalog (the Large Angle and Spectrometric: LASCO, Solar and Heliospheric Observatory: SOHO), which provides all the data on CME throughout the year (SOHO / LASCO CME Catalog site). The number of CMEs during this period was 30016 events. The CMEs were selected according to the list in the form of points: 1) with a linear velocity greater or equal to (500 km/s), 2) of the partial halos type, where the central positioning angle is (CPA≥120), 3) which is up to Earth only by comparing it to the CACTus Catalog (Computer Aided CME Tracking: CACTUS), a program developed by the Belgian Solar Impact Data Analysis Center that tracks coronal mass ejections coming to Earth with computer aid (CACTUS site). The final number of CMEs during this period was 1,343 events, as shown in Fig. 1.

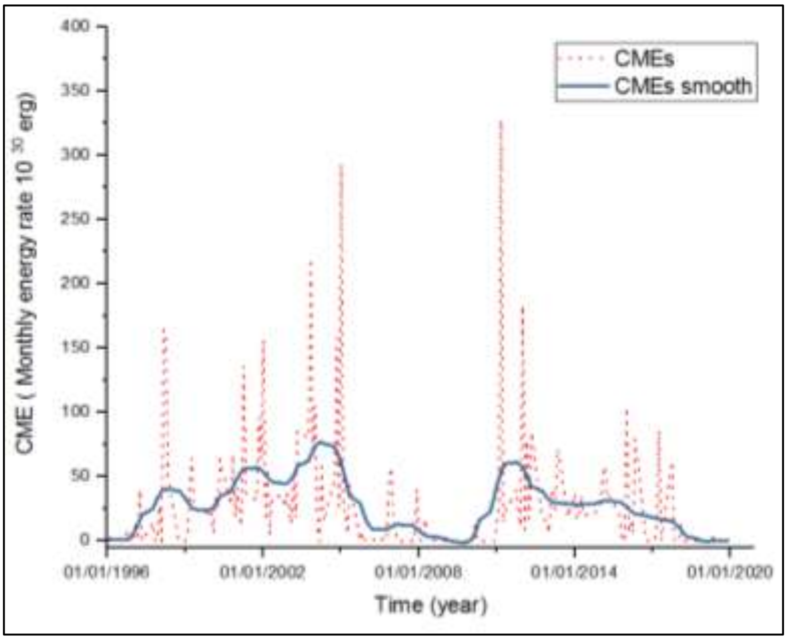


Figure 1. The monthly average energies of CMEs during the winter season

As for the solar flare data, it was specified in type (X, M) only and was taken from the website (National Oceanic and Atmospheric Administration: NOAA) through its database. The number of solar flares was 2,343 events (NOAA site), as shown in Fig. 2. The data on the sunspots number (SSN) was taken from the Sunspot Index and Long-term Solar Observation (Silso site), as shown in Fig. 3.

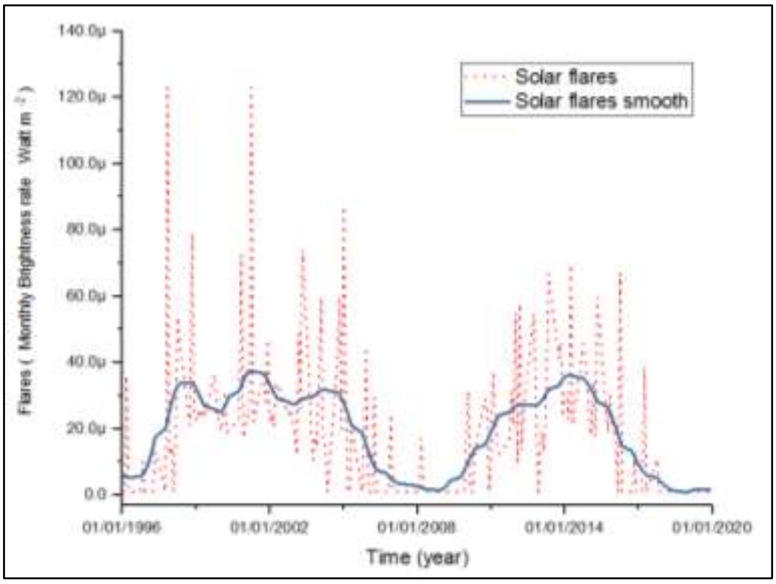


Figure 2. Monthly average of solar flares during the winter season

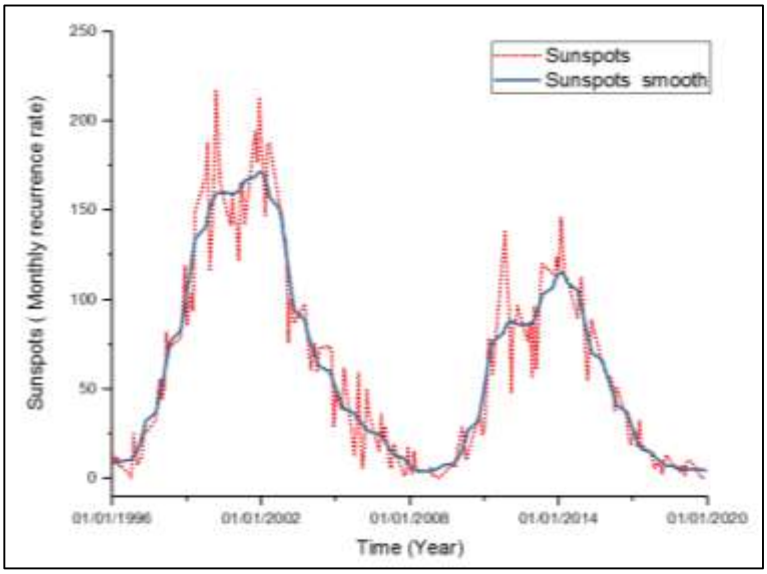


Figure 3. Monthly Average SSN during the winter season

The daily climatic data of thunderstorms for the winter seasons for the period (1996-2019) has been used. The data is taken from the Iraqi Meteorological Organization and Seismology for three main surface weather stations shown in Fig. 4. The monthly frequency of thunderstorms during the winter season was calculated for the study years.

Figure 4. The location of the weather stations in Iraq

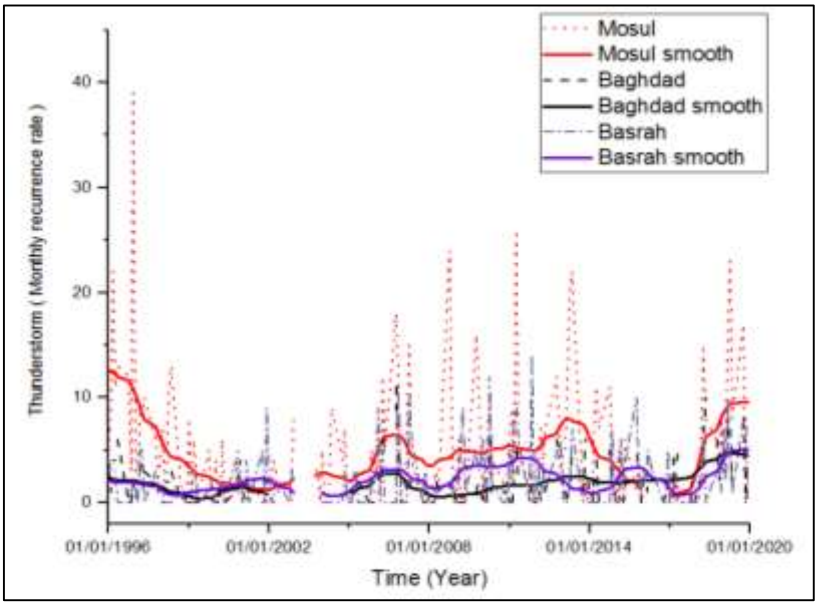


Figure 5. The monthly frequency of thunderstorms during the winter season

Fig. 5 shows that the monthly frequency of thunderstorms for the northern region is greater than the middle region, mainly due to its proximity to the rain lines. As for southern areas, the increase in thunderstorms is due to their impact on the Arabian Gulf area, as shown in Table (1).

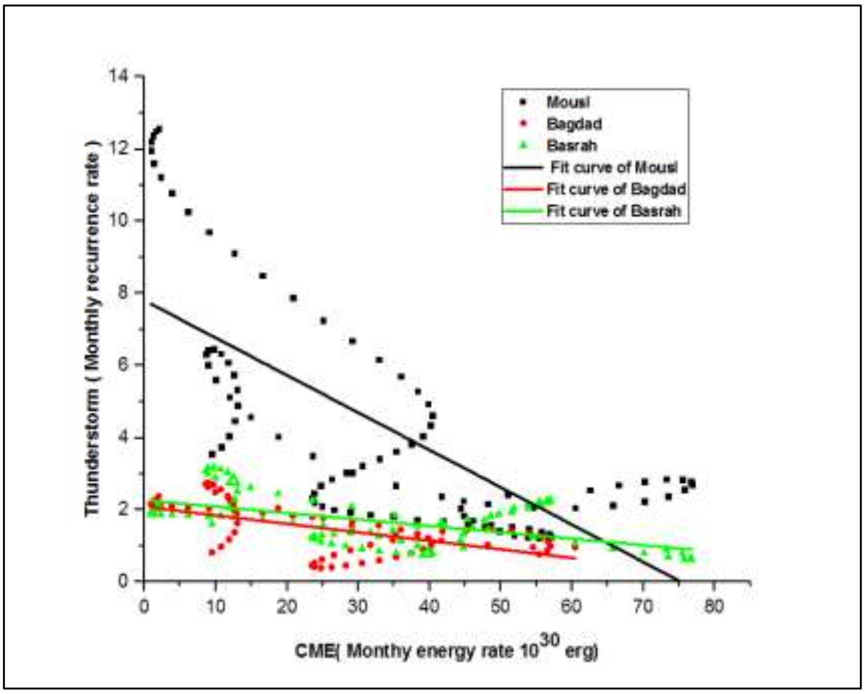
Table 1. Data for three weather stations

Weather Station	Longitude	Latitude	Elevation (m)	Missing data (unavailable)	frequency of thunderstorms
Mosul (M)	43˚ 09′	36˚ 19′	222	1/2003 to 5/2003 1/2016 to 12/2016	915
Baghdad (B)	44˚ 26′	33˚ 20′	31.1	1/2002 to 12/2004	339
Basrah (Ba)	47˚ 50′	30˚ 30′	2	1/2003 to 12/2003	441

4. RESULTS AND DISCUSSION

4.1 Relationship of the monthly average energies of CMEs with the monthly frequency of thunderstorms.

Fig. 6 shows the relationship of the monthly average of the energies of CMEs with the monthly frequency of thunderstorms on SC 23 more than the SC 24. The linear correlation coefficient for the Mosul station (P_M = -0.72) is a strong inverse correlation. As for the Baghdad station, the correlation coefficient (P_B = -0.61) is an average inverse correlation, while the Basrah station shows a medium inverse diffusivity relationship, where the correlation coefficient is (P_{Ba} = -0.55), and the level of statistical significance is less than (5%) for all associations in the SC 23. The SC 24 showed relatively weak correlations in general, where the linear correlation coefficient reached (P_{Ba}=0.06, P_B=-0.18, P_M=-0.1), respectively. The level of statistical significance for SC 24 was more than (5%), which means a high degree of doubt between the energies of CMEs and thunderstorms.



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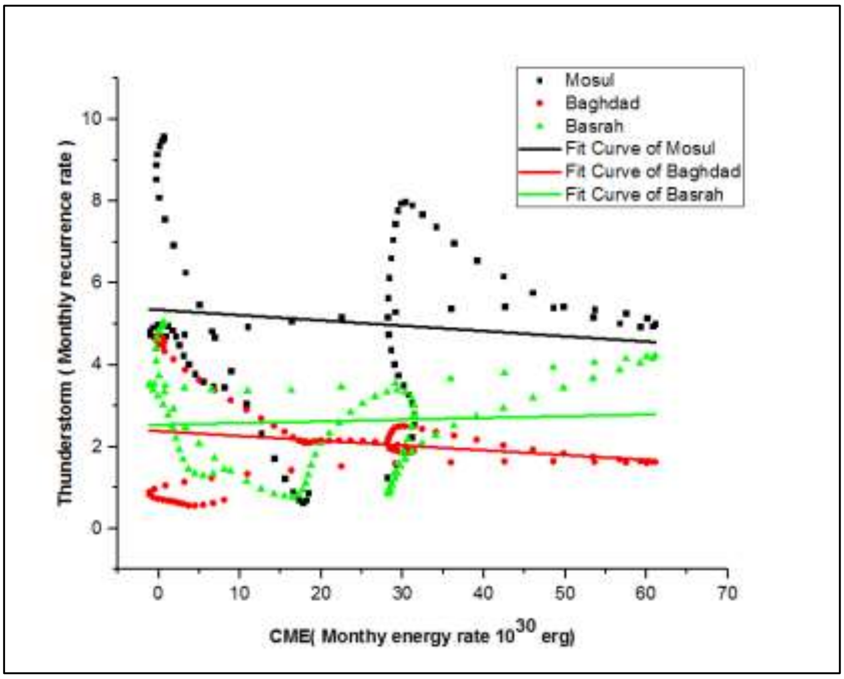


B

Figure 6. The relationship between the monthly average energies of CMEs and the monthly frequency of thunderstorms. (A) SC 23, (B) SC 24

4.2 The ascending and descending phases of the SCs 23 & 24.

Fig. 7 shows the statistical analysis of the relationships of the monthly average energies of CMEs with the monthly frequency of thunderstorms for the SC 23. Whereas the ascending phase of the SC 23 shows that the Pearson coefficient of linear correlation for the Mosul station is strong (P_M=-0.86) and the Baghdad station is a medium inverse correlation (P_B=-0.56), while Basrah station has a correlation coefficient (P_{Ba}=-0.08), which is a weak inverse correlation. As for the descending phase of the SC 23, the correlation coefficients were (P_{Ba}=-0.89, P_B=-0.61, P_M=-0.77), which represents strong inverse propagation relationships. The statistical analysis shows the clear contrast between the ascending and descending phases of the SC24. It was found that the Pearson coefficients for the linear correlation of the ascending phase and all the selected stations were a direct relationship in general. Mosul station reached a linear correlation coefficient (P_M=0.38) . It represents a weak direct relationship. Baghdad station was (P_B=0.67) denoting a medium correlation. While Basra reached the amount of the correlation coefficient (P_{Ba}=0.4) representing a weak direct correlation.

The linear correlation coefficients for the descending phase of the SC24 indicate inverse correlations in general for the three stations. The Pearson coefficient of linear correlation for the Mosul station was (P_M=-0.68), representing a medium inverse relationship. For Baghdad station, the correlation coefficient was (P_B=-0.93) denoting a strong inverse relationship. In Basrah station, the correlation coefficient reached (P_{Ba}=-0.48), which is a weak inverse correlation. The significance level for all phases was statistically significant that amounted to less than (5%), which indicates that the value of chance probability is low, except for Basra station in the 23rd cycle, the ascending phase, where the level of significance reached (sig = 0.584), where the percentage of doubt in the relationship is excessive.

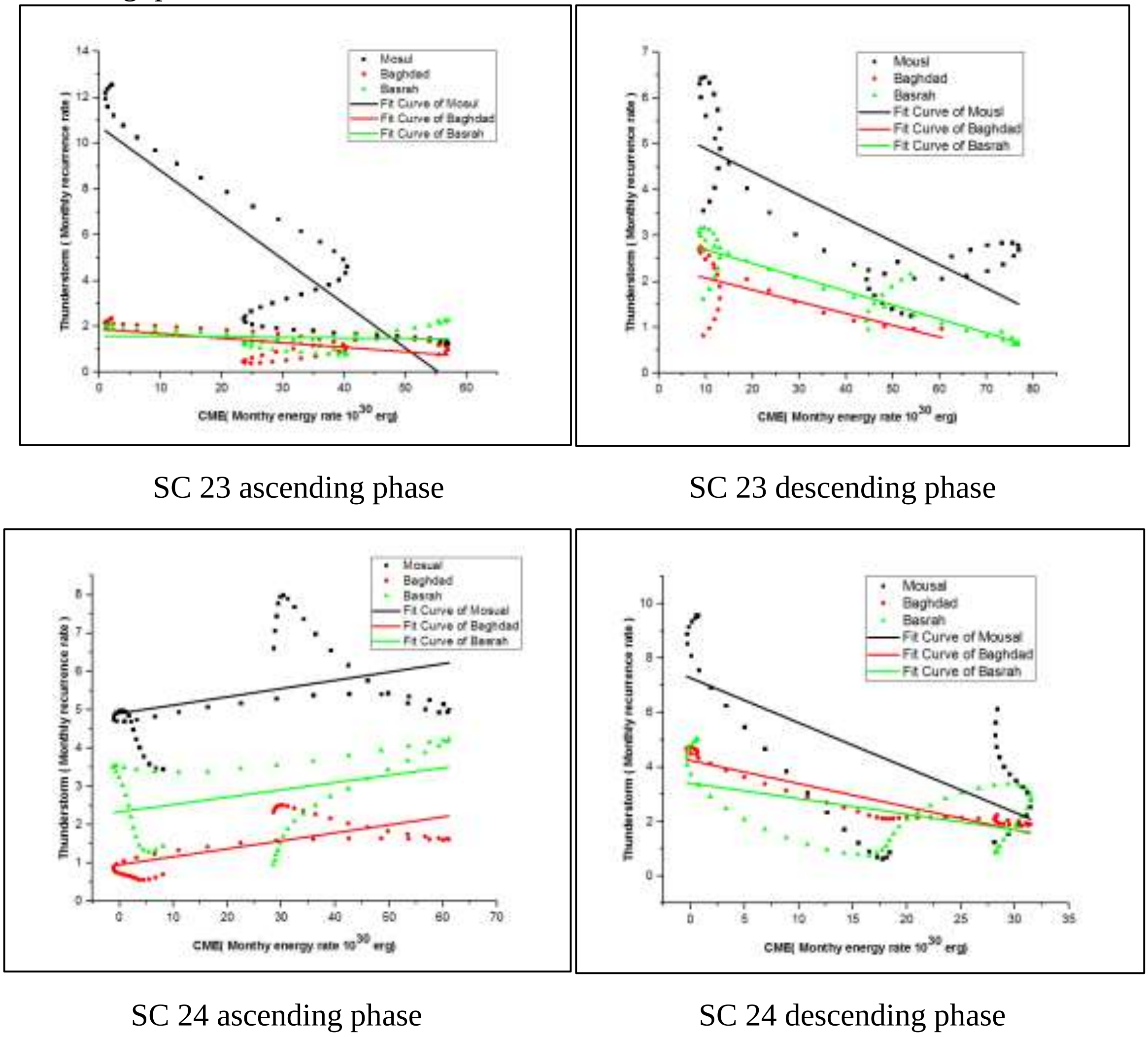
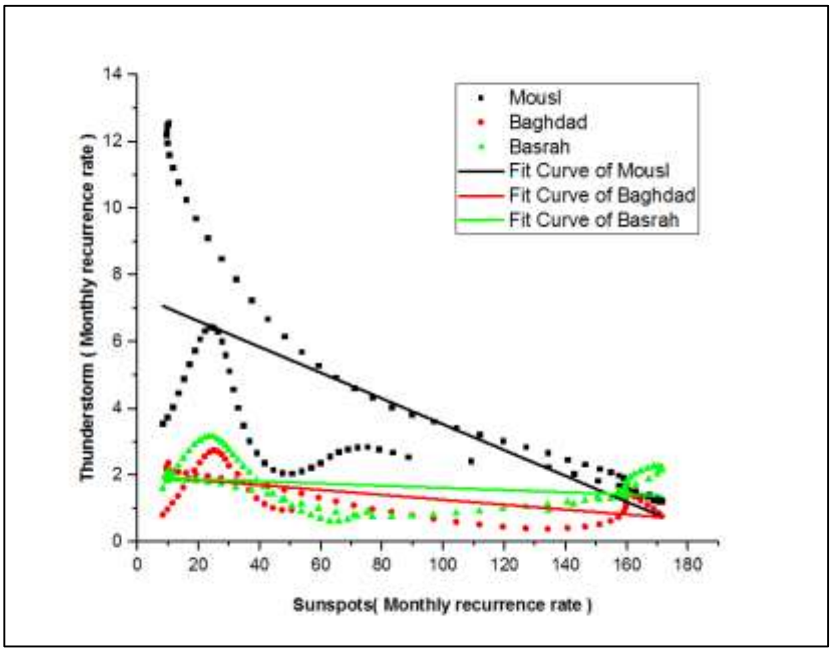


Figure 7. The relationship between the monthly average energies of CMEs with the monthly frequency of thunderstorms for the ascending and descending phases of the SCs 23 & 24 for the three stations.

4.3 The relationship of the monthly average SSN with the monthly frequency of thunderstorms.

Fig. 8 shows the relationship of the monthly average SSN with the monthly frequency of thunderstorms. It was found that the linear correlation coefficients of the SC 23 are inversely related to all stations in general. The Pearson's correlation coefficients are (P_{Ba}=-0.28, P_B=-0.66, P_M=-0.72). The linear correlation coefficients for SC 24 show relatively weak scattering relationships for all stations that reached (P_{Ba}=-0.1, P_B=-0.1, P_M=0.04), respectively.



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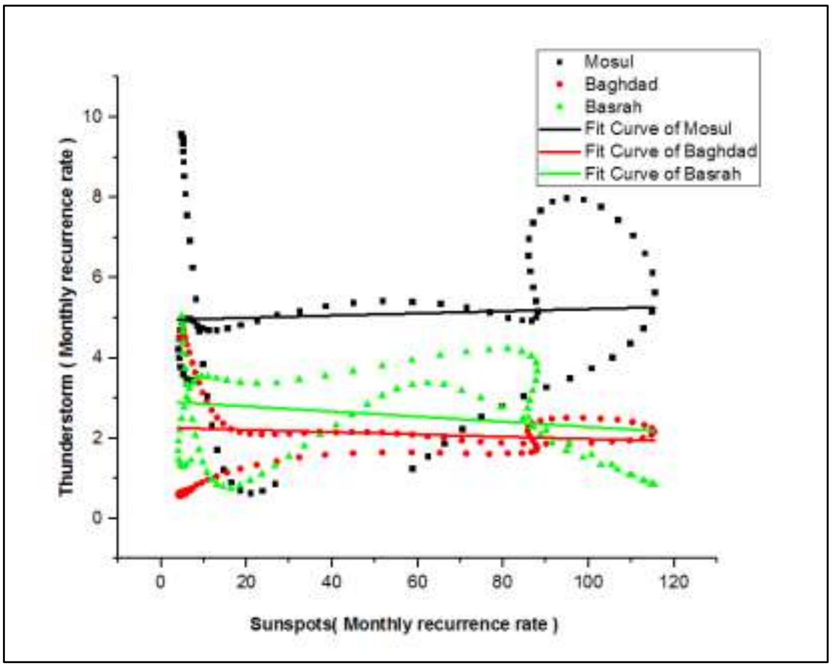

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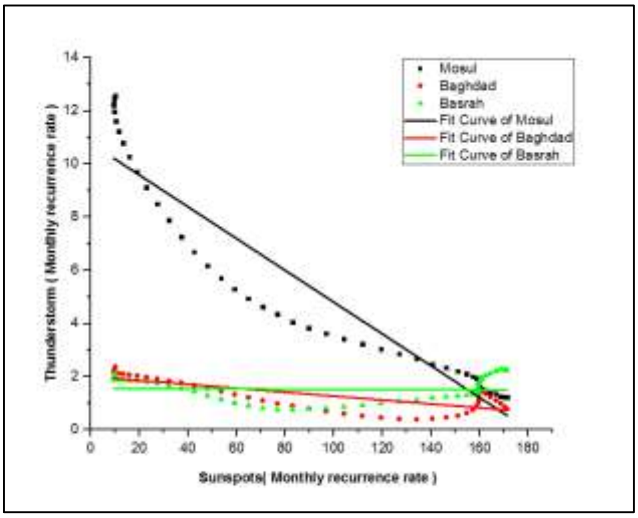
Figure 8. The relationship between the monthly average of the SSN and the monthly frequency of thunderstorms. (A) SC 23 (B) SC 24

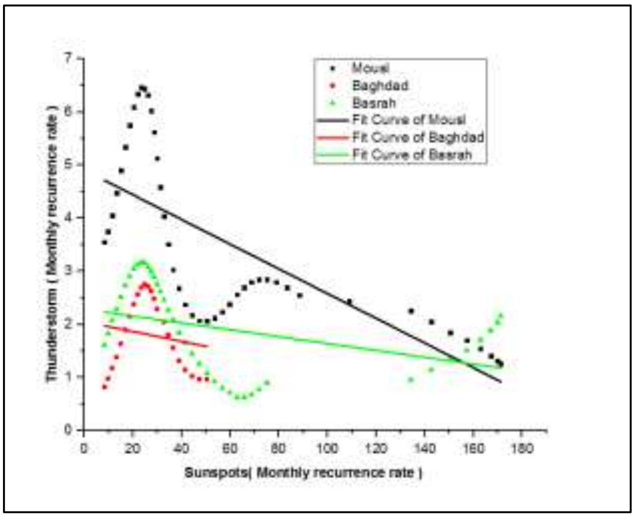
4.4 The ascending and descending phases of the SCs 23 & 24

Fig. 9 shows, that the scattering distribution tends to the opposite direction for both phases of the SC 23 in general. The Pearson correlation coefficient for the ascending phase reached (P_{Ba}=-0.04, P_B=-0.75, P_M=-0.95), respectively. The descending phase are (P_{Ba}=-0.4, P_B=-0.16, P_M=-0.72), respectively. The significance level for all stations was (5%), which are real relationships, except for Basra station in the ascending phase, where the significance level reached (sig =0.766). In addition, for the Baghdad station, the descending phase reached the significance level (sig = 0.443), which does not represent a statistical value. This result agrees with the findings of (Pinto & Pinto, 2008, Pinto et al 2013) for lightning flash rates for geographical regions covering the USA, Brazil and the Indian Peninsula region. They discovered that lightning flash rates and sunspot numbers show opposite behavior.

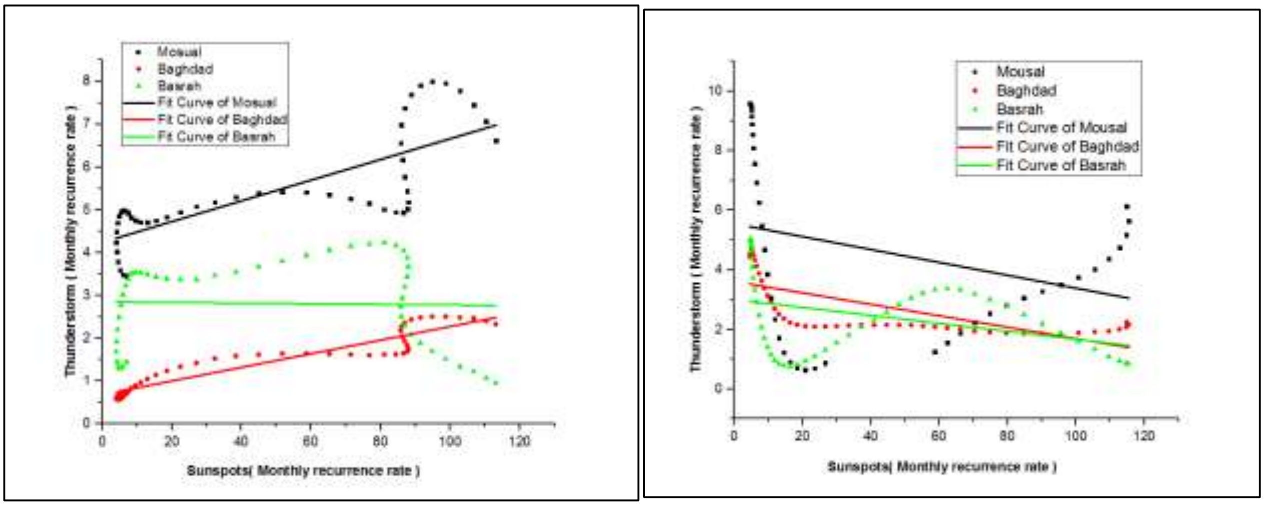
The effect appears more clearly in the ascending and descending phases of the SC 24. In the ascending phase, direct diffusion relationships were observed for Mosul station. The correlation coefficient reached (P_M = 0.78) representing a strong correlation. As for Baghdad station, the linear correlation coefficients reached (P_B = 0.94), which is a strong direct relationship. That matches the results reached by (Majman, 2015). For Basra station, the linear correlation coefficient reached (P_{Ba}=-0.02) representing a weak inverse relationship. The reason may be due to the location of Basra, which is close to the equator. Results of the diffusion relationships for the descending phase of the SC 24 were all inverse for all stations. The Pearson's coefficients were (P_{Ba} = -0.37, P_B = -0.7, P_M = -0.3). All of which are statistically significant less than (5%) except for Basra station in the ascending phase of the SC 24, where the value reached (sig = 0.852) representing a large error rate.



SC 23 ascending phase



SC 23 descending phase

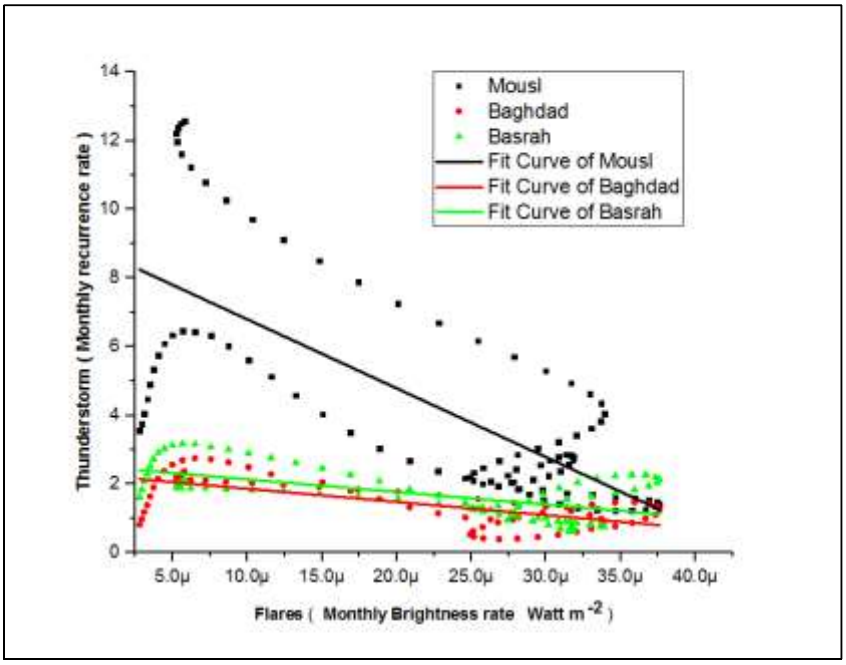


SC 24 ascending phase SC 24 descending phase

Figure 9. The relationships between the monthly average of the SSN and the monthly frequency of thunderstorms for the ascending and descending phases of the SCs 23 & 24 for the three stations.

4.5 Relationship of the average monthly solar flare with the monthly frequency of thunderstorms for the SCs 23 & 24.

It is known that the solar flare is associated with CMEs. Therefore, the relationship between the monthly average solar flare with the monthly frequency of thunderstorms, in general, is also inverse. The Pearson coefficients for the linear correlation of the SC 23 amounted to (P_{Ba} = -0.61, P_B = -0.69, P_M = -0.73) for all stations respectively. While in SC 24, correlation coefficients appear relatively weak for all stations (P_{Ba}=-0.17, P_B=-0.15, P_M=-0.02), respectively. All of which are statistically significantly less than (5%), as indicated in Fig. 10.



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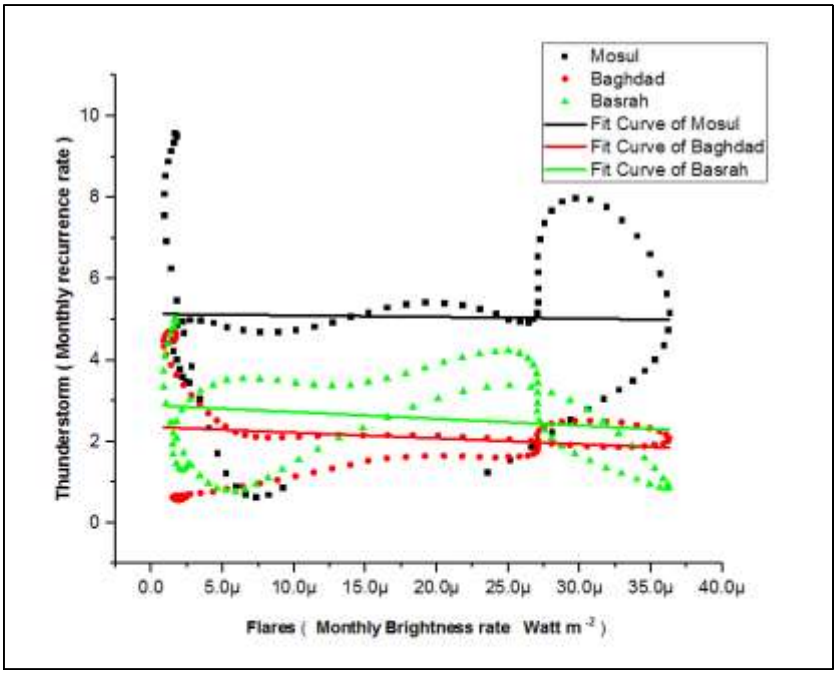

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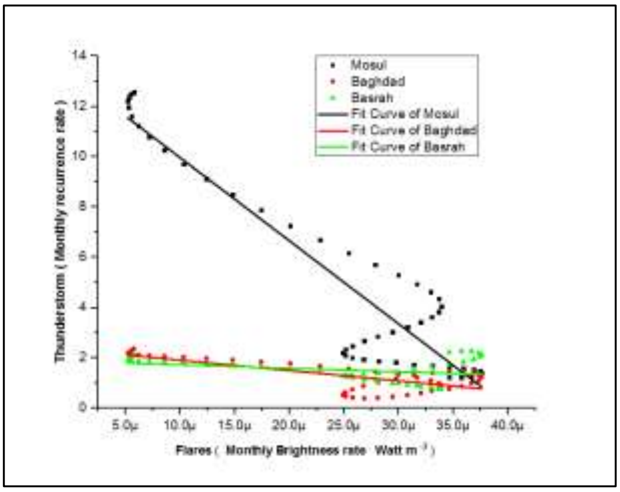
Figure 10. The relationship of the monthly average of solar flare with the monthly frequency of thunderstorms. (A) SC 23 and (B) SC 24

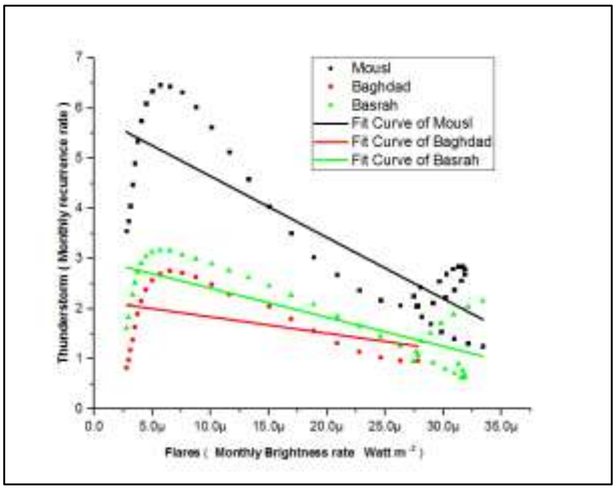
4.6 The ascending and descending phases of the SCs 23 & 24

Fig. 11 shows that the regression of the propagation points is inverse between the monthly average of solar flare with the monthly frequency of thunderstorms for the ascending and descending phases of the SC 23, and for all stations. The Pearson's correlation coefficients are (P_{Ba}=-0.32, P_B=-0.74, P_M=-0.93) respectively, for the ascending phase. Pearson's correlation coefficients are (P_{Ba}=-0.79, P_B=-0.41, P_M=-0.86) for the descending phase. The level of statistical significance was less than (5%).

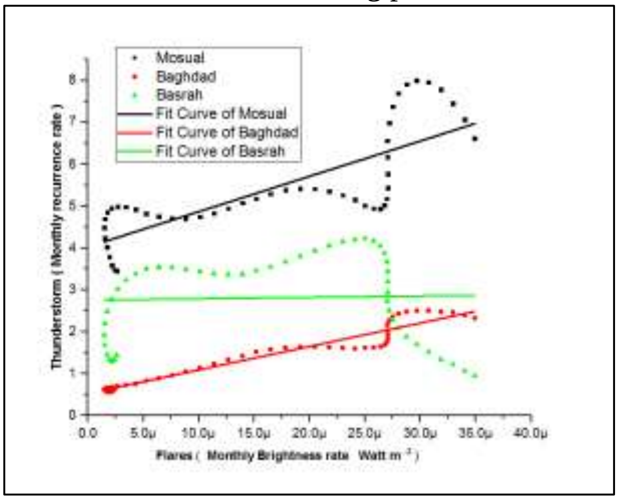
The ascending phase of the SC 24 reached Pearson coefficients of linear correlation (P_{Ba} = 0.03, P_B = 0.96, P_M = 0.79), which are strong direct correlations for the stations of Mosul and Baghdad. We note a weak relationship for Basrah station. The linear correlation coefficients for the descending phase amounted to (P_{Ba}=-0.33, P_B=-0.41, P_M=-0.35), respectively. It represents inverse propagation relationships for all stations. The level of statistical significance was found to be less than (5%). Except for Basrah station in the ascending phase of the SC 24 reached a percentage of statistical significance (sig = 0.796), it does not represent a statistical significance.



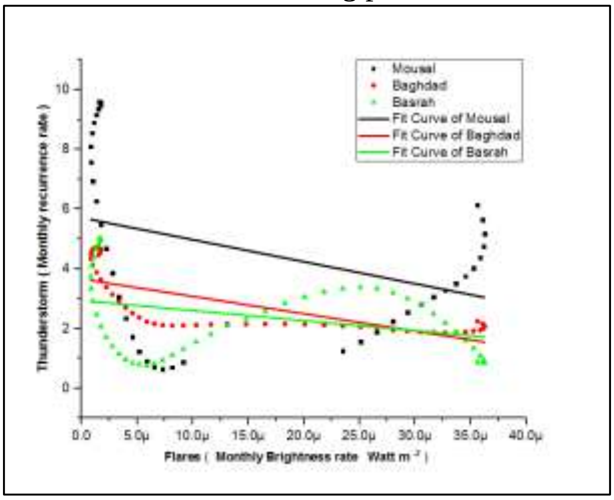
SC 23 ascending phase



SC 23 descending phase



SC 24 ascending phase



SC 24 descending phase

Figure 11. The relationships between the monthly average of solar flare and the monthly frequency of thunderstorms for the ascending and descending phases of the SCs 23 & 24 for the three stations.

We conclude in general that the effect of solar activities represented by sunspots (represents the surface activity of the sun), coronal mass ejections (which is a plasma of protons, electrons, and ions with high kinetic energy), and solar flare (which is electromagnetic rays, which accelerate charged particles emanating from the sun). Then they reach the Earth's atmosphere, they work to limit the arrival of high-energy cosmic rays that come from outer space to the upper layers of Earth's atmosphere. The cosmic rays interact with the Earth's atmosphere, assisting in the formation of thunderstorms and the activation of lightning. Reducing the arrival of cosmic rays affects atmospheric electricity as well as reduces the possibility of the formation of condensation nuclei necessary for cloud formation. This reduces the frequency of weather conditions that cause thunderstorms. Therefore, solar activities reduce the favorable weather conditions for the possibility of lightning and thunderstorms. When the number of sunspots, solar flares, and coronal mass ejections increases, number frequency of thunderstorms that occur decreases. The SC 24 is the faintest of the cycles of the last century, and therefore we find its impact unclear.

5. MATHEMATICAL MEANING OF SIMPLE REGRESSION COEFFICIENTS

In addition to the Pearson Linear Cancellation Coefficient and the significant value, it must refer to the (R & R^2) coefficients. The R-value shows the correlation between the dependent and independent variables. The R^2 is the determining factor that explains the extent of the influence of the independent variable on the dependent. During the rainy season, the highest value of (R) appeared between the number of sunspots and thunderstorms for the Mosul station for the ascending phase of SC 23, it reached (R = 90). While the limitation factor (R^2 = 90). The regression equation (Y = 10.78-0.05976X) where (Y=Thunderstorms and X=Sunspots), the negative sign indicates that the relationship is strong. The value of the independent variable (X) can be predicted from the dependent variable (Y). Whenever the value of (R & R^2) decreases or approaches zero, it indicates that the relationship is not clear. All the values of (R & R^2) and the regression equations are in Table (2).

Table 2. All the values of (R & R^2) and the regression equations for the dependent variable are Thunderstorms.

SC	X	Mosul Weather Station			Baghdad Weather Station			Basrah Weather Station		
		R	R^2	Regression eq.	R	R^2	Regression eq.	R	R^2	Regression eq.
23	CMEs	51	51	7.804-0.1036X	37	36	2.088-0.0236X	30	29	2.27-0.0178X
23	SSN	52	52	7.395-0.0386X	44	43	2.004-0.0073X	8	7	1.953-0.0032X
23	Flare	53	52	8.805-20073X	48	47	2.247-38426X	38	37	2.503-36741X
24	CMEs	1	0	5.345-0.0129X	3	2	3.38-0.00116X	0	0	2.539+0.004X
24	SSN	0	0	4.946+0.0027X	1	0	2.265-0.0028X	4	3	2.921-0.0063X
24	Flare	0	0	5.133-3745X	2	1	2.358-14091X	2	1	2.89-16669X
23 *	CMEs	74	73	10.73-0.1936X	32	30	1.886-0.0199X	0	0	1.588-0.0022X
23 *	SSN	90	90	10.780.0597X	56	55	2.005-0.0073X	0	0	1.556-0.0003X
23 *	Flare	87	86	13.28-3307X	55	54	2.319-4103X	10	8	1.856-1387X
23 **	CMEs	61	60	5.405-0.05X	38	35	2.334-0.0258X	80	79	3.002-0.0303X
23 **	SSN	53	51	4.908-0.0232X	2	0	2.052-0.0092X	16	14	2.287-0.0064X
23 **	Flare	74	73	5.863-122X	17	13	2.165-327X	63	62	2.988-5783X
24 *	CMEs	14	12	4.905+0.0215X	45	44	0.9548+0.0208X	16	14	2.333+0.0192X
24 *	SSN	61	60	4.24+0.0242X	89	88	0.6865+0.0158X	0	0	2.849-0.0007X
24 *	Flare	63	62	4.026+8424X	93	93	0.5337+5593X	0	0	2.756+3429X
24 **	CMEs	47	45	7.271-0.1645X	88	87	4.24-0.08484X	24	22	3.408-0.0568X
24 **	SSN	9	6	5.55-0.02166X	49	48	3.611-0.0192X	14	12	3.007-0.0133X
24 **	Flare	13	10	5.711-7372X	54	53	3.659-5818X	11	9	2.938-3364X

Where * ascending phase, ** descending phase

6. CONCLUSION

There is no doubt that the effect of solar activities on the frequency of thunderstorms is weak compared to meteorological factors. However, the analysis shows that such an effect can be significant, especially over a long time. From the results, the following can be concluded:

• Through statistical analysis, the relationship between the monthly average of solar activities and the monthly frequency of thunderstorms for the three stations and the SC 23 is generally inverse. While the SC 24 was weak and unclear.

• When analyzing the ascending phase curves for the SC 23, the relationship between the monthly average of solar activities with the monthly frequency of thunderstorms was strong inverse for Baghdad and Mosul stations and weak for Basra station. The curves for SC 24 the relationship between each for the SSN and solar flare with the monthly frequency of thunderstorms was strong for the Baghdad and Mosul stations and weak for Basrah. The relationship of the monthly average energies of

CMEs with the monthly frequencies of thunderstorms is weak.

• Analysis of the descending phase curves is fluctuating. The relationship of solar activities with the monthly frequency of thunderstorms for SC 23 fluctuated between strong and weak inverses. While SC 24 was mostly inversely weak.

In general, the statistical results showed that the monthly averages of each of the energies of coronal mass ejections, solar flares, and the sunspots number increase, lowers the monthly frequency of thunderstorms that happen. The SC 24 is the weakest of the cycles of the last century, and therefore its results were not clear.

7. ACKNOWLEDGEMENT

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