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Solar Flares and Geomagnetic Storms (Data collection and analysis)

M. Kh. Alquran
Ajloun University College, Al-Balqa Applied University, Jordan.

ABSTRACT
The causality relation between solar flares and the coronal mass ejections has been thought as that as the coronal mass ejections result from strong solar flares, as far as geomagnetic storms controlled by coronal mass ejections. This study focused on such relation, through statistical analysis by calculating the correlation coefficient between solar flares and (A) index data for (21) years, namely (1996 – 2016).The correlation coefficient calculated for different intervals. The results emphasized the common known fact for long time period, while zooming on shorter intervals revealed that not every strong solar flare creates a coronal mass ejection, and the coronal mass ejections are not the only factor that affects the geomagnetic field.

KEYWORDS;- *Solar Flares, Geomagnetic Storms, Coronal Mass Ejections.*

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I. INTRODUCTION

Recently, space weather had considerable importance in broad wide applications in our life, specially the effect of solar activity phenomena that affect the communication systems, satellites, and other electric equipments, so it has become strongly recommended to understand the nature of it in more details. During the second half of last century, scientists and searchers could establish a morphological structure of the ionosphere and the magnetosphere and could recognize their different layers. But extra researches reveal a dynamic interaction between these layers that it is better to think about it as a boundary layers rather than pause regions [1]. More open questions about the interstellar media properties had appeared, like: the boundary of the heliosphere, termination shock as the solar wind slows down, and others, so the understanding of the mechanisms how different layers exchange charged particles and the sources of its population among a specific layer had become strongly recommended. For that purpose many of scientists, searchers, and space agencies had started looking for more detailed information about the space weather via direct measurements and observations using probes and satellites, or through theoretical investigations. A flare is defined as a sudden, rapid, and intense variation in brightness. A solar flare occurs when magnetic energy that has built up in the solar atmosphere is suddenly released [2]. The classification system for solar flares uses the letters A, B, C, M or X, according to the peak flux in watts per square meter (W/m^2) [3]. A geomagnetic storm is defined by changes in the horizontal component of the Earth's magnetic field at the magnetic equator based on measurements from a few magnetometer stations [4].

The K-index quantifies disturbances in the horizontal component of earth's magnetic field with an integer in the range 0-9.It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval [5]. Because of the non-linear relationship of the K-scale to magnetometer fluctuations, it is not meaningful to take the average of a set of K-indices. What is done instead is to convert each K-index back into a linear scale called the "equivalent three hourly range" a-index. The daily A-index is merely the average of eight a-indices [6].

A coronal mass ejection (CME) is a significant release of plasma and magnetic field from the solar corona. CMEs travel outward from the Sun at speeds ranging from slower than 250 kilometers per second (km/s) to as fast as near 3000 km/s, they often follow solar flares and are normally present during a solar prominence eruption. The plasma is released into the solar wind. Coronal mass ejections are often associated with other forms of solar activity, but a broadly accepted theoretical understanding of these relationships has not been established [7]. "The apparent association between CMEs and flares suggests that there is a physical link between them. However, that physics is poorly known" [8].The disturbance in the interplanetary medium that drives the storm may be due to a solar coronal mass ejection (CME) [9].
Coronal mass ejections also perceived as the missing link between solar flares and geomagnetic storms [10].

This paper discusses the effect of the heliosphere on the magnetosphere during data collection and statistical analysis for a possible relation between solar flares and geomagnetic storms.

II. PROCEDURE

A data for both of solar flares and geomagnetic storms obtained for 21 years' time period, (1996 - 2016). These data taken from Space Weather Live organization/Belgium through the website (www.spaceweatherlive.com). Only considerable magnitudes selected in order to reduce the irregular fluctuations. The solar flares data had quantified by converting symbols in to magnitudes according to the table1.

Table1: Converting solar flares classification symbols in to magnitudes as measured from The Geostationary Operational Environmental Satellite system (GOES) **[11].**

Classification	Peak Flux Range (watts/square meter)
A	$< 10^{-7}$
B	$10^{-7} – 10^{-6}$
C	$10^{-6} – 10^{-5}$
M	$10^{-5} – 10^{-4}$
X	$> 10^{-4}$

When annual averages and the maximum values for both of solar flares and A index calculated for years (1996 – 2016), these data formed in table 2.

Table 2: Annual averages and the maximum values for both of solar flares and A index calculated for years (1996 – 2016).

year	Average solar flares(μwatt/m^2)	Average A index(nT)	Maximum solar flares(μwatt/m^2)	Maximum A index(nT)
1996	2.285	23.56	10	38
1997	41.864	23.88	940	59
1998	92.6	39.2	490	144
1999	53.02	34.28	180	91
2000	100.3	47.2	570	164
2001	199.18	43.46	2000	192
2002	91.46	37.12	480	78
2003	223.78	57.04	2800	204
2004	81.26	42.36	360	186
2005	155.52	43.54	1700	102
2006	50.1	26.28	900	94
2007	9.6	20.02	89	34
2008	0.8362	18.52	17	36
2009	1.669	9.72	7.6	24
2010	14.618	17.26	83	55
2011	73.32	22.1	690	45
2012	64.54	28.18	540	87
2013	73.62	23.6	330	72
2014	98.98	19.12	490	43
2015	47.36	36.82	270	108
2016	12.792	28.36	76	70

The statistical analysis of the previous data revealed a relation between average solar flares and the average A index with correlation coefficient of (0.8), which indicates a strong relation but not complete, while at maximum values they were not tightly combined, that the correlation coefficient was (0.65) [12].

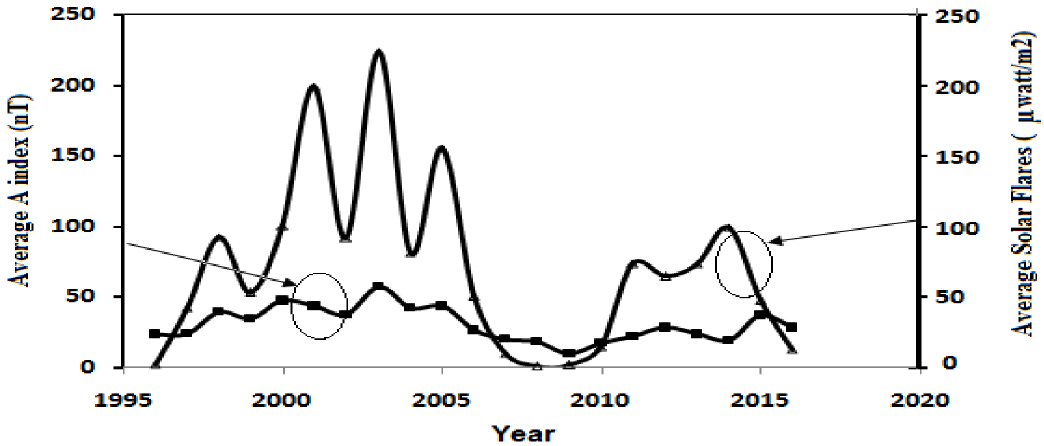

Fig 1. Average solar flares and average A index verses years.

Figure 1 shows a plot of both average solar flares and A Index Vs the years of occurring, while figure 2 shows the plot of both maximum solar flares and A Index Vs the years of occurring. This reveals that geomagnetic storms almost follow solar flares, but not completely. For deeper investigating, year 2003 -which considered as the most active- was selected to check in [13].

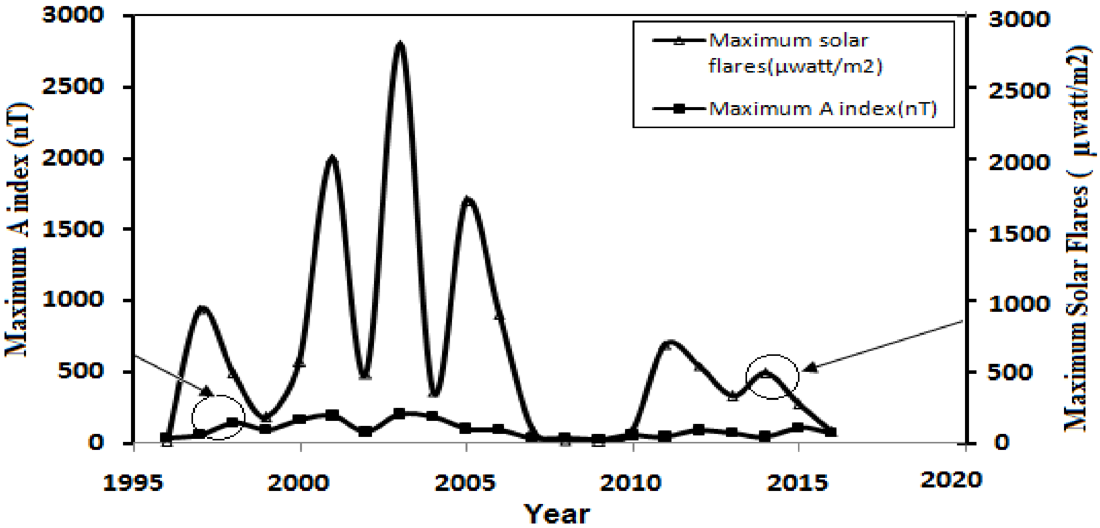

Fig 2. Maximum solar flares and maximum A index verses years.

Monthly average, total, and peak of both solar flares and A index are calculated through year 2003, as shown in the table3. The relation between average solar flares and average A index examined, and gave correlation coefficient of (0.43), which indicates a weak relation. And the following figure shows a plot of both monthly average solar flares and monthly average A index through year 2003 [14].

Table 3: Monthly average, total, and peak of both solar flares and A index through year 2003.

Month	Ave. solar flares(µwatt/m^2)	Ave. A index(nT)	Total solar flares(µwatt/m^2)	Total A index(nT)	Peak solar flares(µwatt/m^2)	Peak A index
1	49	0	49	0	49	0
2	0	52	0	52	0	52
3	116	40.25	348	161	150	43
4	60.5	45	121	45	70	45
5	175.75	55	703	330	360	109
6	76.67	44.33	1150	266	170	60
7	0	45.25	0	181	0	52
8	0	62.75	0	251	0	108
9	0	50	0	200	0	70
10	297.64	93.125	4167	745	1720	204
11	423.8	55.67	4662	501	2800	150
12	0	40	0	120	0	41

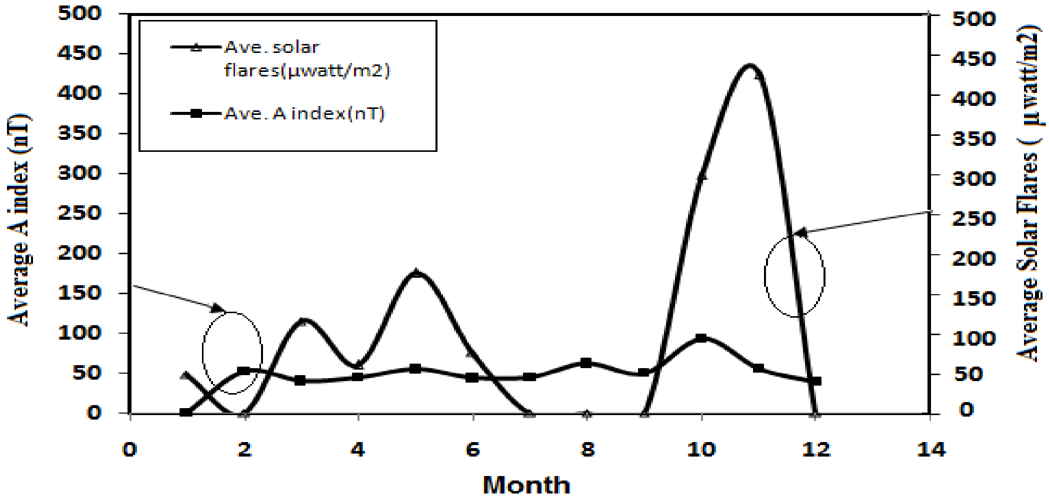

Fig 3. Monthly average solar flares and average A index in the year 2003 verses months of occuring.

But with respect to the total monthly amount of both solar flares and A index, they revealed a quietly strong relation of correlation coefficient of (0.873), and plotting such data for both of solar flares and A index produced the figure 4. While the relation between monthly solar flares and A index among the peak values had a correlation coefficient of (0.736), which is not very promising indicator. The same procedure followed for the year (2009), as it is the calmest year with respect to the solar activities, and the results were obtained in table 4.

With correlation coefficients of (-0.6) for the averages, (-0.5) for the total amounts, and (-0.23) for the maximum values. Another two years namely (2015), and (2016) were analyzed in the same manner and the following results were obtained:

Year (2015), the correlation coefficients were (0.017) for the average values, (0.51) for the total amount values, and (0.47) for the maximum values.

Year (2016), the correlation coefficients were (-0.3) for the average values, (-0.41) for the total amount values, and (-(0.42) for the maximum values.

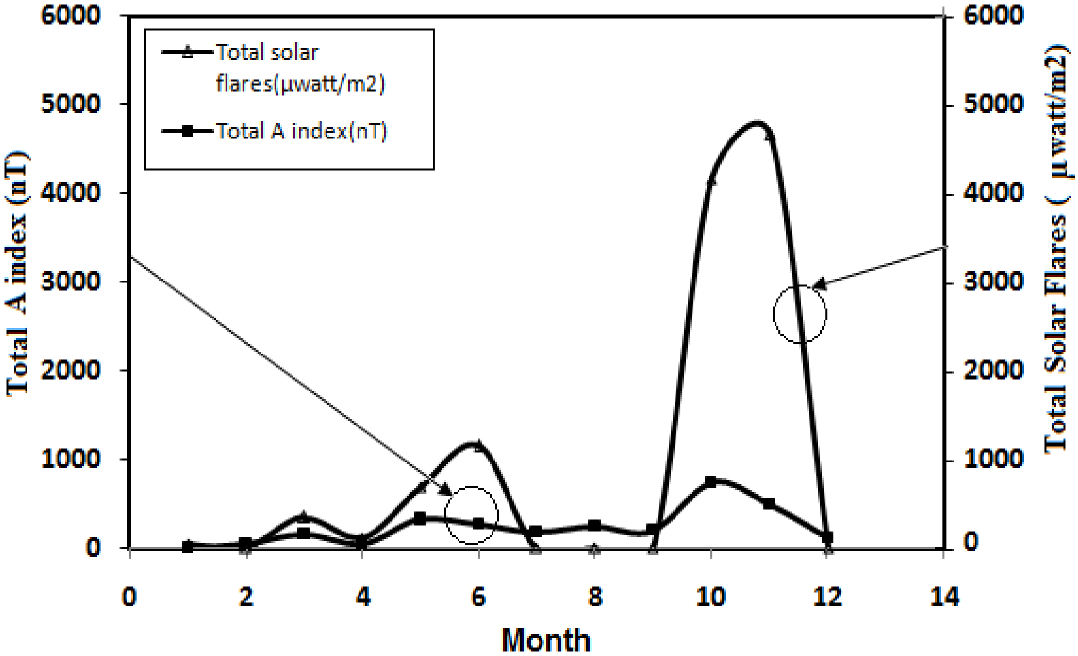

Fig 4. Monthly total solar flares and total A index in the year 2013 verses months of occurring.

Table 4: : Monthly average, total, and peak of both solar flares and A index through year 2009.

Month	Ave. solar flares(µwatt/m^2)	Ave. A index(nT)	Total solar flares(µwatt/m^2)	Total A index	Peak solar flares(µwatt/m^2)	Peak A index
1	0	10.33	0	31	0	11
2	0	12	0	60	0	17
3	0	9.2	0	83	0	17
4	0	9	0	45	0	12
5	0	8.7	0	26	0	11
6	0	11	0	33	0	16
7	1.51	10.8	4.53	54	2.7	24
8	0	10.3	0	62	0	20
9	2	7.3	2	22	2	8
10	1.09	9.4	20.85	47	2.2	13
11	0	7.7	0	23	0	8
12	2.08	0	56.07	0	7.6	0

III. DISCUSSION

The previous results of statistical analysis can be summarized in table 5.

Table 5: list of Correlation coefficients between the solar flares and the geomagnetic storms among average, total, and peak values for the selected time periods.

Year	Correlation coefficient of the averages	Correlation coefficient of the total amounts	Correlation coefficient of the peak values
2003	0.43	0.873	0.763
2009	-0.6	-0.5	-0.23
2015	0.016	0.51	0.47
2016	-0.3	-0.41	-0.42
(1996-2016)	0.8	0.8	0.65

Considering the average values of the solar flares and (A) index, the correlation coefficients indicated a weak relation that becomes relatively stronger as the solar activity increases, which may support the hypothesis that the coronal mass ejections (C.M.E.s) result from only a strong solar flares [15]. Statistically, the average affects the data by reducing the maximum values, so may a strong solar flare- suppose to create (C.M.E) - disappears through calculating the average with small ones[16,17]. In case of taking the total amount values for the solar flares data and (A) index, it revealed a quite stronger relation and gradually increases as the solar activity increases, which supports the same hypothesis.

Of course, taking the total amount values affects the peak values that gathering a few small values may consider as a strong solar flare and suppose to create a (C.M.E), which is fake, but however it doesn't ignore or vanishes the strong solar flares. So the total amount data gives better evidence that (C.M.E.s) results from strong solar flares. With respect to the (21 years) long time period, the relation becomes more obvious with relatively strong correlation coefficient of (0.8) for both of average and total amount values. Actually the average in this case is the same of total amount values, because the selected data are having a sample of the same size for all the (21) years.

The previous results-in some way- support the hypothesis that strong solar flares create coronal mass ejections, but studying the relation between them through their peak values introduces unexpected results. It reveals not so strong relation as the total amount values do, which means that the statement "strong solar flares cause coronal mass ejections" is not completely accurate. Focusing on the year (2003) as it is the most active containing a quite period, referring to the figure 3 from which one can see that geomagnetic storms almost follow the solar flares during the active periods, while in the quite period (July-September) solar flares give away to other possible sources. For a closer look, zooming in the period (October 14th – November 7th) of the same year by plotting daily data of solar flares and (A) index Vs time the figure5 obtained.

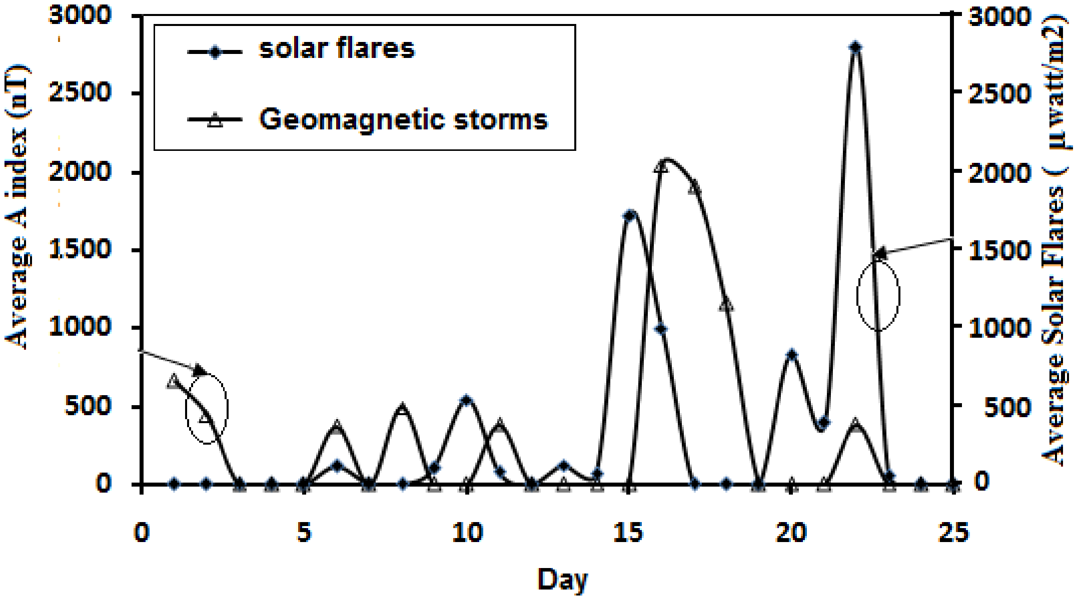

Fig 5: **Plotting solar flares data and daily average A Index Vs day of occurring during the time period October 14th – November 7th**

From which we can see that strong solar flares are not necessary cause geomagnetic storms, on the other hand, the figure shows that the geomagnetic storms due to other possible sources.

IV. CONCLUSION

For long time scale, the solar flares affect (rather than control) the geomagnetic storms via the coronal mass ejections. Statistical analysis showed a stronger relation through considering total amount data than that of the peak, which means that number of occurring solar flares may make good conditions to unleash coronal mass ejections rather than driven by a strong solar flares. Another possible scenario is that solar flares and coronal mass ejections are two different solar phenomena having the same origin of solar activities, like (Magnetic reconnection and other types of instabilities). The results of the monthly data investigating showed that either not every strong solar flare causes a coronal mass ejection, or not every coronal mass ejection causes a geomagnetic storm. Coronal mass ejections are not the only factor that affect the geomagnetic field, since there were a relatively high values of (A) index even during a calm periods of solar activity. There is no critical value of the solar flare flux that adopted as a trigger of coronal mass ejection. As a future work, studying of the physics beyond the solar flares and coronal mass ejections theoretically is suggested. Also, the investigating of the relation between coronal mass ejections and geomagnetic storms apart from solar flares is required, through finding out the characteristics of the geomagnetic field disturbances that belong to coronal mass ejections.

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