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Geomagnetic storm in association with solar activities

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Abstract
Geomagnetic storm (GMs) is a significant unsettling influence of Earth's magnetosphere that happens when there is an extremely productive trade of energy from the solar wind into the space climate encompassing Earth. Storms result from variations in the solar wind that produces significant changes in the flows, plasmas, and fields in Earth's magnetosphere. A southward directed solar wind magnetic field at the dayside of the magnetosphere is responsible to create GMs, large GMs are associated with coronal mass ejections (CMEs) also. In this work we take the GMs of magnitude ≤ -100 nT and CMEs having velocity more than 1000 km/s from 2010-2020. During this time span we have noted 28 geomagnetic storms (GMs). To analyze the GMs with other solar activities (Flares & CMEs) conducted a statistical analysis of the data of the Dst (disturbance storm time) index of Geomagnetic storms and Solar flare flux and CMEs. We found the low positive correlation between Dst index and the solar flare flux with correlation coefficient 0.21. We also found a correlation between the Dst index with different classes of flares (X and M), there is a strong positive correlation between Dst index and X class solar flare having coefficient 0.97, further the correlation of Dst index and M class flare is very low with correlation coefficient 0.04. We found that the CMEs are negatively correlated with Dst index with correlation -0.09. The present result implies that the geomagnetic storms formation dependent on the flares particularly x class but does not on the CMEs during the time taken.
Keywords: - Coronal mass ejections, Solar flares, Space weather, Geomagnetic Storm, Dst Index.

1. Introduction

It is notable that a constant progression of plasma which emerging from the sun is known as sun based breeze (solar wind). In view of the sun powered breeze, the Earth is heated by the hot, magnetized, supersonic collision less plasma conveying a lot of dynamic and electrical energy. A portion of this energy finds its direction into our magnetosphere making disturbance in geomagnetic movement coming about into geomagnetic storms, sub storms as well as aurora (Firoz 2008). Geo-magnetic storms generally have disturbances in the magnetic field of the earth; these generally occur due to solar winds and flares which are accelerated toward earth and collide with earth's magnetic field. The understanding of all disturbances, which occur on earth's magnetic field is essential to understand what is happening in solar-terrestrial environment and furthermore because such storms can cause years of power blackout, satellite damage, communication failure and navigational, GPS and Radar problems. There are many correlative studies have been conducted from October 4, 1957, which is also known as the start of space age when Soviet Union launch "Sputnik" the first artificial satellite (Akasofu 1983). High intensity "Geomagnetic Storms" are statistically related to different solar activities like coronal mass ejection (CMEs) and solar flares of high flux. During a solar flare magnetic energies of 1029to 1033 ergs due to break in a magnetic field on sun's surface (kopp, 2005). Geomagnetic disturbances are generally represented by geomagnetic storms and sudden ionosphere disturbances (SID's). Geomagnetic storms occur majorly due to disturbance in the magnetic field of the earth or the shock which is caused due to high-speed solar winds, which flow toward our earth (Howard et al. 1985, Webb and Howard 1994). The geomagnetic Storms area (Gonzalez et. Al 1990) is also associated with the sunspots that form at higher altitudes of the sun (Balveer 2011). Fast CME can produce shocks in interplanetary space between the planets and other parts of space, when moving toward the earth and on striking the earth's magnetic field this shock cause a geomagnetic storm on earth. These shock waves are measured in an index known as Disturbance storm-time index (Dst index). Solar flares are also a reason behind the cause of Geomagnetic storms (Tsubouchi 2007). It is also well known that the strength of the interplanetary magnetic field (IMF) is also a major reason behind the cause and fluctuation of high Intensity "Geomagnetic storms" (Gonzalez et al. 1989). The motion and structure of the Sun's magnetic field (Thompson2003) make the corona

ever-changing. Occasionally, the tangling of the solar magnetic field and their bursts out from the sun's surface cause a large portion of the corona to blast away from the Sun and out into the heliosphere. Thus, CMEs are believed to be caused by sudden disruptions in the Sun's own magnetic field. These magnetic lines stretch and twist like titanic rubber bands until they snap. Thus, CMEs are huge bubbles of gas threaded with magnetic field lines that are ejected from the Sun over the course of several hours. The tangling of the Sun's magnetic field has two types, (1) Omega Effect (Parker, 1994) and (2) Alpha Effect (Wiegelmann, 2014). CMEs are initiated and accelerated in the Sun's corona and subsequently propagate into the heliosphere, causing interplanetary disturbances and geomagnetic storms.
In this paper, we did a correlative study between the intensity of geomagnetic storms and the solar activity like speed of CME, flux of solar flares. We relate the intense geomagnetic storms (Dst index less than -100 nT) which has potential to harm human either by destroying artificial satellites sent by human or changing the magnetic field of earth. The linear speed of CME and flare flux related to the geomagnetic storms of year 2010 – 2020 are consider and we found that intensity of X – Class solar flare is highly correlated to the geomagnetic storm. Also the correlation between the other classes of solar flares and Dst index was found but results are not that much satisfactory. The correlation between Dst index and linear speed of CME is also found very low which help in future problems to pay less attention in correlation of these parameters.

2. Data and Methods

The data of Solar Flare are collected from the NOAA GOES X-ray flux maintained and provided by national oceanic and atmospheric administration (https://services.swpc.noaa.gov/json/goes). Geomagnetic storms are disturbances in the magnetosphere of earth. These disturbances in the earth's magnetic field are only limited to the polar region of earth, which is at higher altitude of earth, but when the solar wind causes this disturbance in the magnetic field for a long time (several hours or more) the disturbance occurs in southern regions, and they have large magnitudes of Dst index (less than -50nT). The solar wind flowing towards earth with a very high speed compresses the magnetosphere of earth continuously, causing the magnetic field disturbance to reach equatorial region. The degree of change in the equatorial region is usually expressed as the Dst index. This Dst index is an average fluctuation (hourly basis) of horizontal component of the magnetic field of the earth. This Dst index is measured by several ground stations. Dst = 0nT means no deviation from the quiet condition, and Dst ≥ -50nT means weak storms, if this Dst index is between -50nT and -100 nT it means that a moderate storm has occurred, if Dst index is between -200nT and -100 nT means strong storms and Dst ≤ -200 nT means severe geomagnetic storm. In this study, we have selected a geomagnetic storm for the period 2010–2020 with Dst ≤ -100nT and are known as strong geomagnetic storms. The list of all magnetic storms, based on the Dst indices collected from the World Data Center for Geomagnetism, Kyoto, Japan is being compiled for this study. (http://www.swdc.kugi.kyoto-u.ac.jp/dstdir).
The CME data its occurrence date, time and linear speed data is collected from CDAW data centre of SOHO LASCO online catalogue for the study period 2010–2020 (https://cdaw.gsfc.nasa.gov/CME_list/).
In this work we perform a correlative study of GMs with other parameters (Flares, CMEs). The correlation coefficient is a degree of association, denoted by r. To perform statistical analysis the Pearson's correlation is used, its value varies from -1 to +1.If the correlation coefficient r close to -1 that means there is a negative relation between the parameter used (if one parameter increases then other decrease), but if the value of r is close to +1 then there is positive relation (if one parameter increases other also increases), but complete absence of correlation is represented by r = 0. The formula of correlation coefficient (r) is shown below for two variables x and y.

$$\boldsymbol{r} = \frac{\boldsymbol{n}(\sum \boldsymbol{xy}) - (\sum \boldsymbol{x})(\sum \boldsymbol{y})}{\sqrt{[\boldsymbol{n}\sum \boldsymbol{x}^2 - (\sum \boldsymbol{x})^2][\boldsymbol{n}\sum \boldsymbol{y}^2 - (\sum \boldsymbol{y})^2]}}$$

3. Results and Analysis

In the entire period (2010–2020) of the solar cycle (SC) 24 and rising phase of the SC 25, there are total 28 geomagnetic storms whose Dst indices ≤ -100nT out of which only 27 GMs are associated with solar flares of different categories. The association rate of M class flare was 51.8%, the rate of association of X class flares was 25.9% and C class flares associated with 22.2% rate (Figure 5). Further we have found that only 12 coronal mass ejection events are associated with GMs from 2010-2020.In this paper, The Geomagnetic Storm's intensity determining factor Dst index is used to analyze the data collected for SC 24 and the rising phase of SC 25. We plotted scatter curves between these data and different classes of solar flares. From this study, we can explain many aspects related to geomagnetic storms like how often geomagnetic storms occur during the year, how severe the geomagnetic storms are, and how severity is correlated with a flux of flares. First, we collected geomagnetic storm data whose Dst index is less than -100nT occurred during 2010–2020. During this time, only 28 geomagnetic storms that satisfied the criteria are used to select data, then we investigated solar flares associated with these storms. According to Loewe and Prolss the geomagnetic storms are classified into 4 categories on the basis of their Dst index a geomagnetic storm considered weak if Dst is greater than -50nT, moderate if the Dst index is between -50nT and -100nT, intense (Dst ≤ -100nT), and severe (Dst ≤ -200 nT). In this paper, we found the correlation between the Dst index and X, M class solar flare flux and the correlation of all flares associated with geomagnetic storms (Dst ≤ - 50nT) between period 2010 – 2020.
Figure 1, shows a plot of the Dst index of Geomagnetic Storms as per flux of all solar flares during 2010–2020. The linear trend indicated that there is weak positive correlation between Dst index and all flare flux with correlation coefficient 0.21.

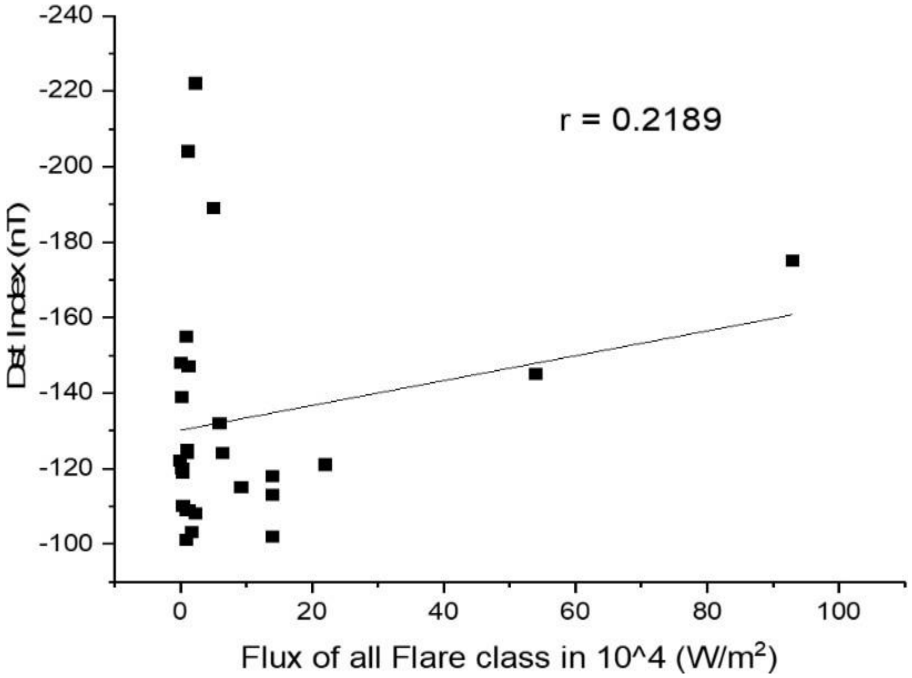

Figure-1 Plot between Dst index and Flux of all class of solar flare during 2010 – 2020.

Figure 2, shows a plot of the Dst index of Geomagnetic Storms as per flux of M class solar flares during 2010–2020. From the scatter plot we have found that line is nearly parallel to the X axis (Flux of M class flare) indicates that there is no correlation (r = -0.04) between these parameters.

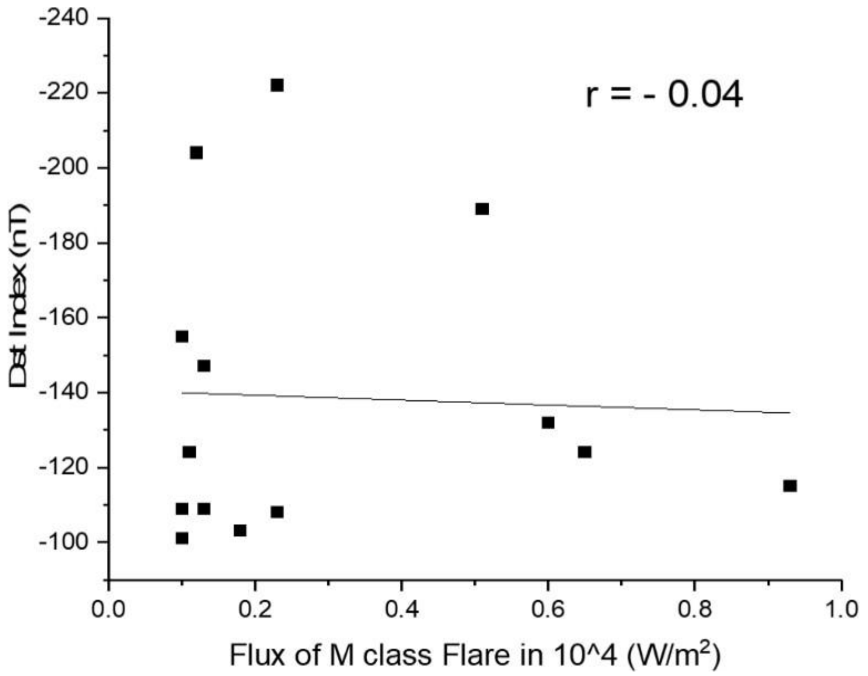

Figure-2 Plot between Dst index and Flux of M class of solar flare during 2010 – 2020.

To understand the statistical behavior between the Dst index of Geomagnetic Storms and flux of X class solar flares draw a scatter plot shown in Figure 3. From the trend line of the scatter plot we have found that there is strong positive correlation between these two events with correlation coefficient 0.097.

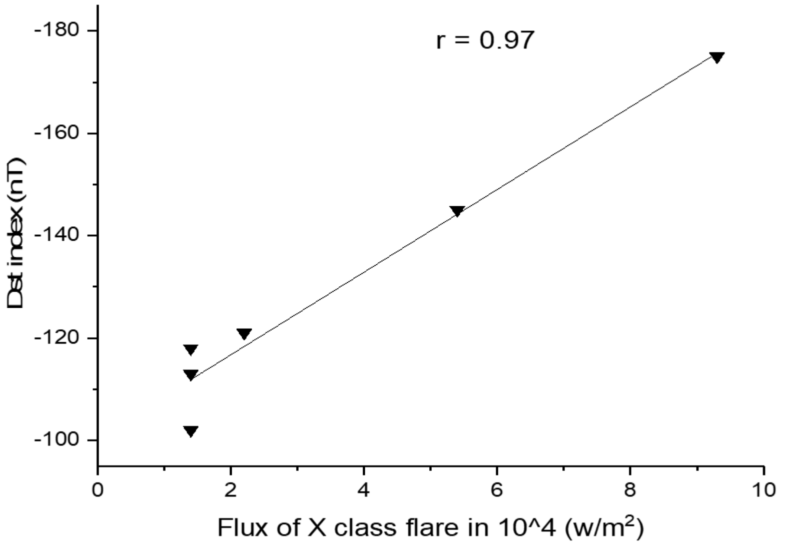

Figure-3 Plot between Dst index and Flux of X class of solar flare during 2010 – 2020.

Figure 4, shows a plot of the Dst index of Geomagnetic Storms and the linear speed of CME during 2010–2020. A correlation between the linear speed of CME and the Dst index of GMs was also found during the selected period with correlation coefficient -0.09, which concludes that the Dst index of GMs have no correlation with CMEs i.e. during this period CMEs are not responsible to create the GMs.

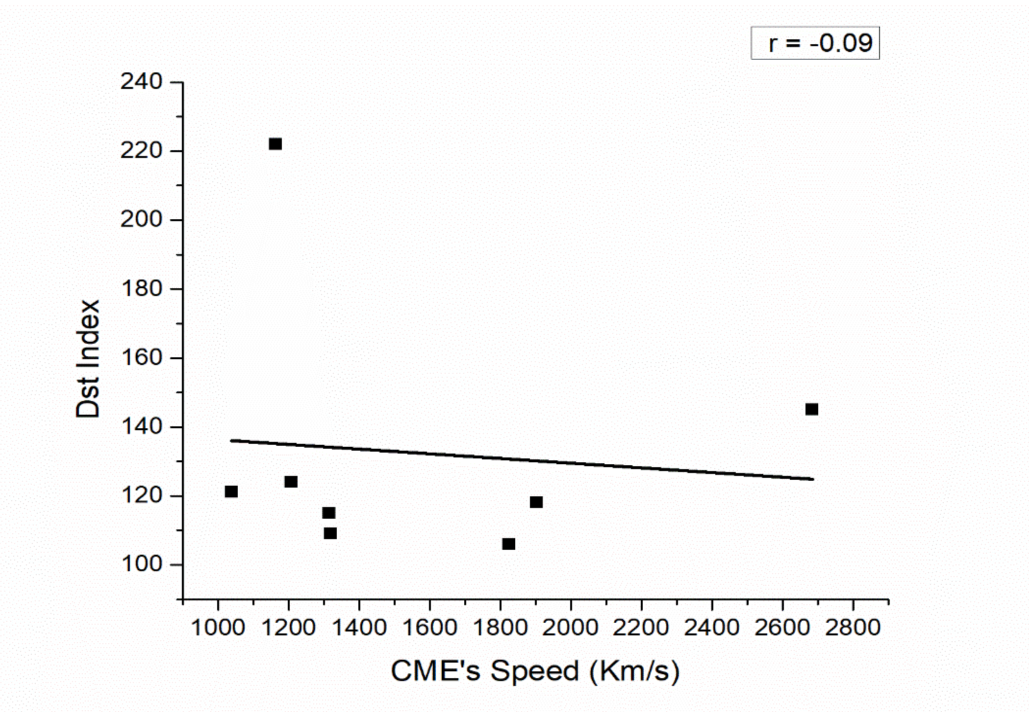

Figure-4 Plot between Dst index and Speed of CMEs during 2010 – 2020.

Figure 5, shows a bar graph between different classes of flares and geomagnetic storms. As from correlation result it is clear that correlation of Dst index of GMs and X class flare is very high but since only few solar flares of X class occurred during 2010 – 2020. M class flares are more frequently occurred as compare to X class flare. This show X class flare has a good chance of occurrence of GMs.

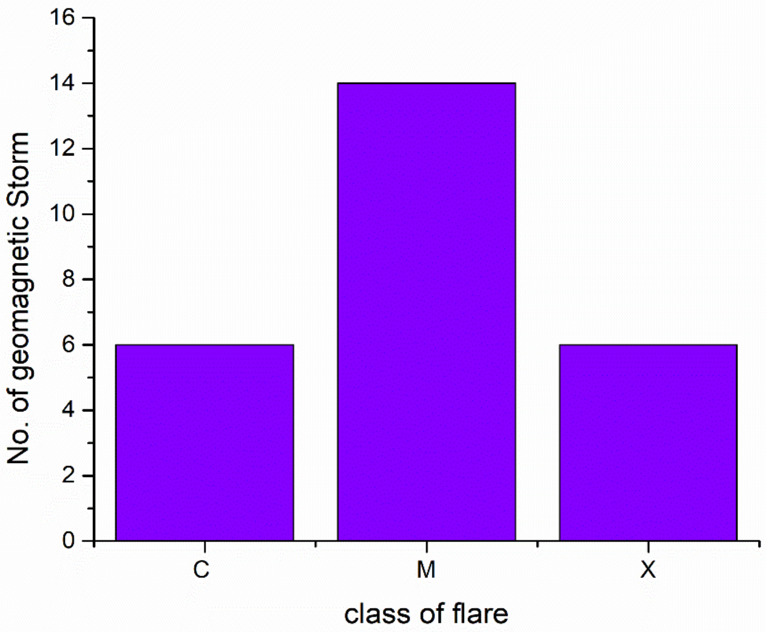

Figure-5 Bar Graph shows class of flares and frequency of geomagnetic storms.

4. Conclusions

The results of this work indicated that the occurrence of the maxima of geomagnetic storm rate is nearly related to solar flares particularly X class flares. Although the solar cycle number 24 started in December 2008, data were taken such that it includes also the rising phase of solar cycle 25 that to increase the sample number that gives better statistics. The linear speeds of coronal mass ejection of more than 1000 Km/s were taken from 2010 to 2020, we found that only 12 CMEs for this period which are associated with GMs. CMEs are considered as the major natural hazardous happening at the surface of sun in the form of plasma material that can cause several phenomena like solar aurora and geomagnetic storms and many more. We have found 28 geomagnetic storms associated with different categories of flares. The association rate of M class, X class and C class flares are 51.8%, 25.9% and 22.2% respectively. Further we have found that the X class flares are well correlated with GMs with correlation coefficient 0.097 that shows the X class flares are mainly responsible to cause a geomagnetic storm irrespective of other class of flares. By the statistical analysis we again found that the CMEs events and GMs have no correlation within this time period of study. Many previous studies show that the CMEs are also responsible for the geomagnetic storms but in this study CMEs are very less which are not responsible for that.

The present results for showed a high affiliation relation between geomagnetic storm and Flares especially X class Flare and there is a good correlation between geomagnetic storms and CMEs as some flares convert into CMEs, which is also noted in this study.

The Sun launches plasma from its atmosphere into interplanetary space in a surge of material called the solar wind. How much interplanetary plasma can fluctuate contingent upon the degree of movement of the Sun. Regularly, the planetary group contains around 5 plasma particles for each cubic centimeter close to Earth. The solar wind connects with Earth's magnetosphere, creating delightful auroras known as the Northern and Southern Lights and different collaborations, for example, geomagnetic storms that can take out power grids. Thus, plasma dust particles noted in the form of solar wind coming out from the sun surface.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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