Interplanetary Origin of Large Geomagnetic Storms (Dst ≤ −100 nt) During (2017–2021)

Mahender Pal[1], Pawan Kumar[1], Amita Rani[2], Namrata Thakur[3], Kalpana Singh[4], A. P. Mishra[5] and Sham Singh[3*]

[1]Department of Physics, IKGPTU Jalandhar (Punjab)-144603
[2]Department of Physics, Barkatullah University, Bhopal-462026
[3]Chandigarh Engineering College-CGC,Landran, Mohali Punjab-140307
[4]Department of Physics, Career Convent Girls Degree College, Lucknow
[5]Department of Physics, A. P. S, University, Rewa (M.P.) 486003

Abstract

In this present research paper, we have found and analysis three major geomagnetic storms whose disturbance storm time DST<-100nT calculate and examine during last phase of solar cycle 24 and rising phase of solar cycle 25. There are three geomagnetic storms have been found 8 September 2017, 26 August 2018, and 4 November 2021 with DST magnitude – 124nT, -174nT and -105nT respectively. It was reported that the most common interplanetary structures leading to the development of large storms were followed by a CMEs and solar flares regions at the leading fronts of high-speed streams. However, the relative importance of each of those driving structures has been shown to vary with the solar cycle phase. The interplanetary and solarparameters as well as correlation with geomagnetic stormparameters have been studied in this paper.

Keywords: Coronal mass ejection (CME's),Geomagnetic storms, interplanetary magnetic field and geomagnetic activity.

1. Introduction

Sun emits plasma with high energetic particles all around in the space continuously. If plasma, i.e.,CME's oriented towards the earth, and reaches near earth's magnetosphere. The plasma matter and high energetic particle travelling towards earth's magnetosphere and that may disturb and compressearth's magnetic field i.e.,magnetosphere during day side and extending magnetic tail during night side. This phenomenon also known as Geomagnetic Storm on earth. During this Geomagnetic Storm phenomenon, it unleashesTerawatt scale power to earth's atmosphere.

Coronal mass ejection arise due to solar plasma is most important component to detect disruption in space weather of earth with speed about 1000 km/s reaching within 1-3 days. Due to this solar coronal mass ejection in the space vital disruption takes place and unleash enormous amount of high energetic particles and matter above. The surface of Sun i.e.,Coronal and also emits electromagnetic waves called solar flare. The emitted plasma contains electrons, protons and also some amount of heavier elements i.e., Helium, oxygen as well as iron etc. Due to this type of disruption huge change and disturbance in the coronal magnetic field. When coronal mass ejection takes place, then plasma matter is affected towards Earth comes closer to magnetosphere of Earth, then disruption in magnetosphere takes place which causes geomagnetic storms on earth's atmosphere This geomagnetic Storm compressing magnetosphere and extending magnetic tail onthe night side[1-2]. The energy released during geomagnetic storm of scale terawatt. When the sunspot number on the surface is more it is called solar maxima and sunspot number on sun surface less, then it is called solar minima[3-4]. During solar maxima solar activity on sun vigorously correlated to disruption in magnetosphere of earth, which creates number of changes in topmost layer of atmosphere of Earth [5-8]. Shock waves occur to corona of sun during solar flares and other related phenomenon. CME's and solar flares push matter, energy and high frequency electromagnetic waves in solar wind which moving towards Earth and all around in the space weather. Solar winds are very excessive flow and poor flow of plasma or matter which comes from different parts of sun.

Shocks formed at the interface between jets of material and interstellar medium. High Energy particles take electromagnetic radiations, plasma matter brusts continuously during solar maxima and these were very high massive energy particles electromagnetic radiation eject from solar Corona and moves towards all around thesun we only examine or study about dose phenomenon which injected towards earth's magnetic field. Also, solar wind and coronal mass emission phenomenon affects earth's magnetic field after 2 or 3 days reaches Earth's magnetic field. Due to massive high energy particle, magnetosphere of earth gets deformed, and we say geomagnetic Storm on earth's magnetosphere takes place. During this process massive high energy particles enters at poles of Earth and creates auroras on north pole and south pole of earth. The interplanetary magnetic field(IMF) changes near earth 1 to 38nT and an overall mean value ~6 nT. The interplanetary magnetic field is vector quantity having three components Bx, By and Bz. First two i.e., Bx and By arealigned to the ecliptic and direction of interplanetary direction field gets southward, value of Bz becomes negative. Third one i.e.,Bz is normal to the ecliptic which produces waves and other type of disturbance in the Solar wind. If interplanetary magnetic field are aligned opposite to each other, they can connect and release energy, mass from solar wind to magnetosphere of earth. If Bz component align South ward, then strong change occurs in magnetosphere. Due to these unfavorable results on electric power grid,satellites, and pipelines etc. During solar Maxima solar activity associated with CME's[9-11]. When strong magnetic field creates incaronal hole or erupted area then intense bright emissions text place. The latter is true even if the field does not erupt[12-13]. Dad destruction in Earth's magnetosphere due to fluctuation in the Solar wind disturbance limited to the high latitude polar areas unless magnetic field component (Bz<0) southward component with large magnitude[14-18].

During This Geomagnetic Storm Magneto sphere of earth get strained for such period causing deformation in magnetic field reach towards equatorial areas. The level of tutorial magnetic field change in generally given by DST i.e., the disturbance Storm time index. Speed of CME’s can calculate how geomagnetic storm [19] so high. Speed of solar wind is also a factor which regulate the merging role at Magneto sphere boundary.

Ionospheric metrics like total electron content (TEC) and electron density can be considerably changed by a geomagnetic storm's effects on the ionosphere. Between the Global Navigation Satellite System (GNSS) satellite and the receiver, TEC is the quantity of electrons integrated along a unit cross-sectional area column; 1 TEC Unit (TECU) is equal to 1016 electrons/m2. To GNSS signals at L1 channel (1.5754 GHz), 1 TECU fluctuation might result in range inaccuracies of the order of 0.163 m [20]. Additionally, quick TEC depletions provide proof of the prevalence of ionospheric anomalies [21]. According to Wernik[22], these anomalies do cause radio waves to scintillate. Trans-ionospheric radio communications may experience signal erroneous or complete loss due to scintillation effects [23]. The quiet-time zonal electric field in the equatorial area is directed eastward during the day and westward at night. The formation of two plasma density peaks (crests) during the operation of the forward fountain at about 15o of the magnetic equator and a decreased plasma density at the magnetic equator (trough) are caused by the vertical uplift of E-B drift for an eastward-directed electric field at the magnetic equator and the subsequent diffusion of plasma along the magnetic field lines due to pressure gradient and gravity forces [24].

In overall contribution electric field factor of the Storm is not high it changes with speed of solar wind so other parameters i.e., strength of the southern magnetic field [25]. In comparison of solar wind speed, speed of CME's is much than solar wind speed. Speed of CME's are more geoeffective because they stress southern field in near of leading edge [17]. CME's are more affective in comparison of solar flare and solar wind for geoeffective disturbances. Further information about CME's can be study in literature [26-28].

There is necessary to solar terrestrial physics to detect geoeffective CME's. CME's tends to responsible for high Storms during solar cycle 24. The result about that cycle relates to other studies [7]. We find streams i.e. solar wind and CME may produce storm [29-31]. Instead of these various geomagnetic indices that is Ae, Ap, Kp have been introduce ring current intensity and energy at earth's atmosphere determined by disturbance storm time (DST index). DST is best parameter of finding of degree of level of solar disturbance. Also, other geomagnetic index that is auroral electro jet magnetic intensity index (Ae) [32], estimate dissipated energy in polar regions which causes auroral in that area the interplanetary indices Ap and Kp which estimate global stagein geomagnetic activity. Ap shows stage or level seven global geomagnetic activities changes in each other and used to find the state of geomagnetic field. Variation in storm time that is geomagnetic storm affects earth's satellites, communication, and power grid on earth.

In many timesblackout occurs in polar areas countries. Our goalof statistical studies in this research paper was to examine how high energy particles or solar plasma enters in space weather and produce geomagnetic storm in earth environment. Due to this solar plasma magnetosphere of earth gets deformed and massive amount of plasma enters in earth's magnetosphere in polar regions which they affect as satellites, communication systems power grid oil gas pipelines and also degradation of space craft operations [33-34]. There are different kinds of geomagnetic disruption and solar interplanetaryevents are faunal in this study and which explain more and more aspects to understand about space weather phenomena.

2. Data selection

In this paper we examine in deep all large geomagnetic storm whose disturbance storm time (Dst) decrease of less than - 100nT and were observed during timeperiod 2017-2021.Effect of storm (Dst) value persist for few hours or continuous days, so final day of less value of DST storm taken as storm day. There are 3 magnetic storms with DST < -100nT were presented.For study the geomagnetic storms we selected three days before and three days after during the event. We have selected hourly data.We investigated the relationships between geomagnetic storms' associations with various solar and planetary disruptions.

In this study we take data hourly value of geomagnetic index from SOHO LASCO,NOAA, Omni web data and solar geophysical data (prompt comprehensive report) of US. Department of commerce.

3. Result and discussion

The solar events and interplanetary movements are widely studied by the help of geomagnetic storms [35].
The storms DST (nT) less than 100 nT are characterised large having geomagnetic storms associated mostly with CMEs or Flares which are interaction low velocity and high velocity plasma streams [36-39]. Mostly CMEs creates disruption in solar wind lead up by a shock wave. Interplanetary space investigation instruments count and detect the flares, CMEs, varying magnetic field and densities of plasma. These disruption in interplanetary space affects the magnetosphere of earth and creates geomagnetic storms. When geomagnetic storms face the earths magnetosphere it disrupts the satellite in ionosphere, impact the radio communications system also reason for radio blackout.

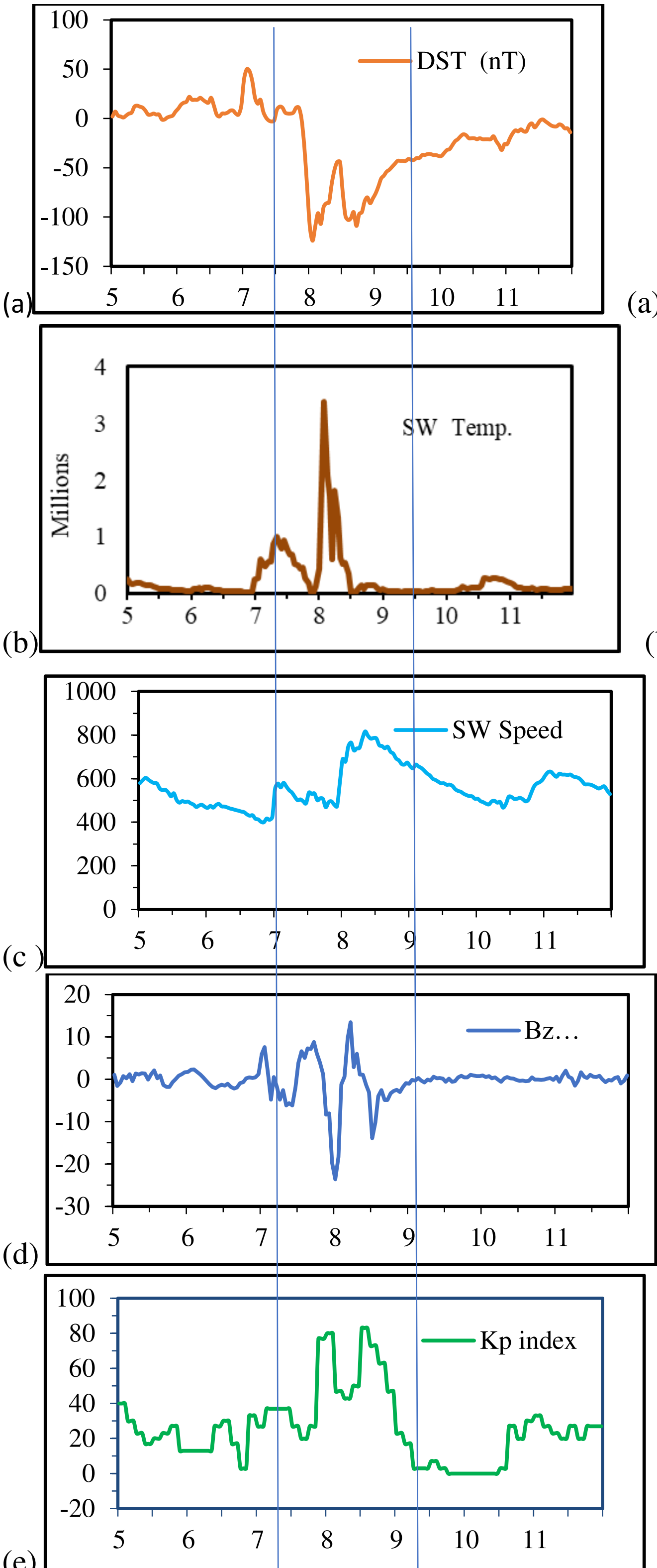
Here we studied three geomagnetic storms as follows:

3.1 September 05-11 (Year 2017) geomagnetic storm

Figure 1 is an observation of geomagnetic and Solar interplanetary from 05 – 11September 2017.
Geomagnetic storm is found on 8 September 2017, and we clearly see that geomagnetic index decreases suddenly from -1nT to -124nT in figure 1(a) and 1(b) – 1 (c) shows that peaks are found after 8 September which shows that if there is any geomagnetic storm, then Solar wind temperature and solar wind speed becomes high. During Storms Figure 1(d) Southern component Bz rapidly jumps from – 23.6 nT to 13.4 nT and Kp index also increases 20nT to 80nT which shows peak on 8 September 2017 figure 1 (e).

3.2 August 23-29 (Year 2018) geomagnetic storm

From Figure 2 we observe geomagnetic storm for duration from 23 to 29 August. On 26 August 2018, in figure 1 (a)there is a geomagnetic storm whose Dstindexto fall to -174nT. Figure 2(b) and 2(c) Solar wind temperature and solar wind speed gives peak after geomagnetic storm. Figure 2(d) show Southern component Bz rapidly jumps from -14.6 nT to -5.1nT and 2(e) shows Kp index rises 17nT to 67nT. During August 23-29 (Year 2018) no Halo and Partial Halo CMEs are found.



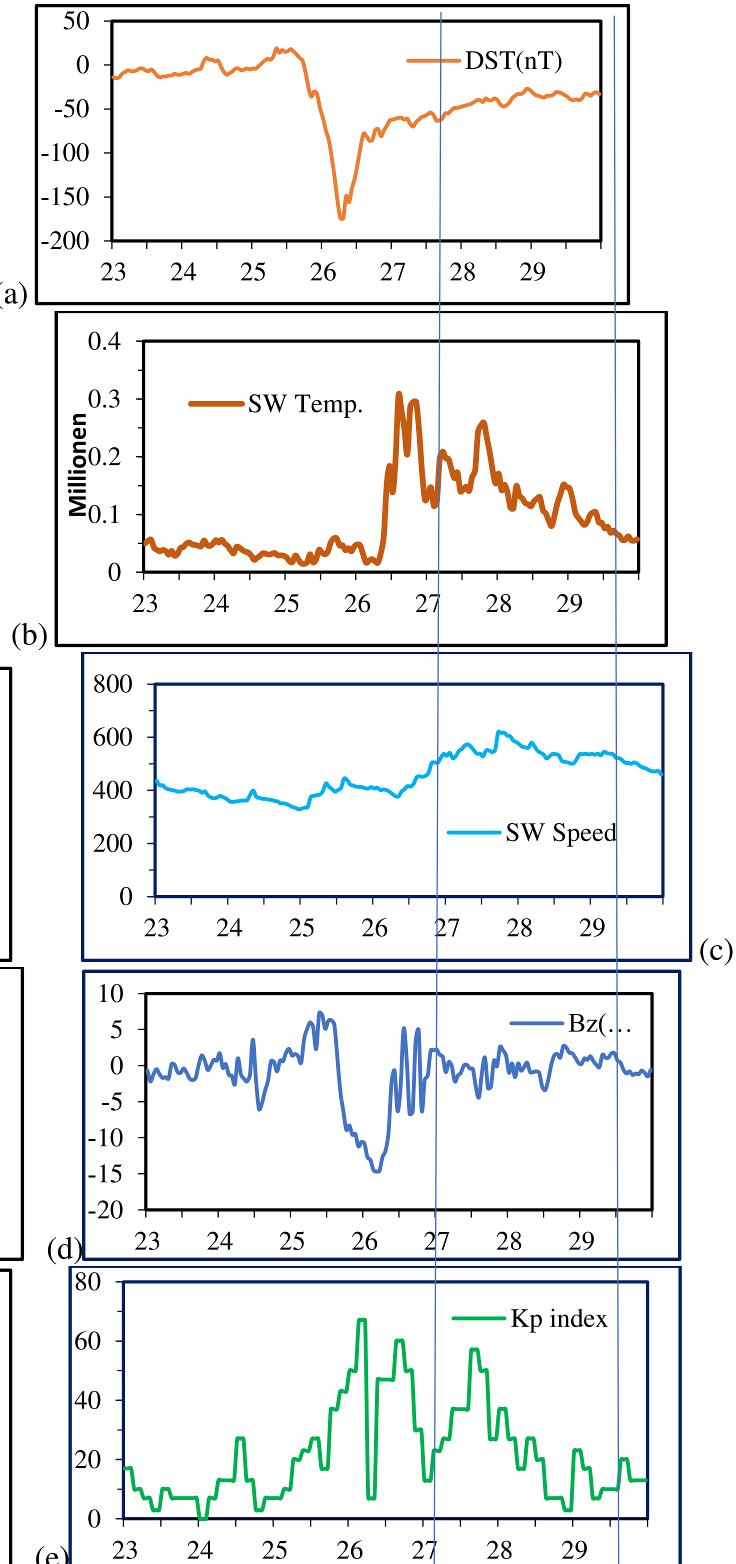


Fig 1. Shows the plot between geomagnetic activity and solar parameters during 05-11, Sept. 2017

Fig 2. Shows the plot between geomagnetic activity and solar parameter during 23-29, August. 2018.

Fig. 1 Association of geomagnetic storm with interplanetary parameters:

(a) DstIndeces (b) solar wind temperature (c) SW speed, (d) interplanetary magnetic field IMF Bz, (e) Kp Indices observed during September 05–11, 2017

Fig. 2 Association of geomagnetic storm with interplanetary parameters:

(a) DstIndeces, (b) solar wind temperature, (c) SW speed, (d) interplanetary magnetic field IMF Bz, (e) Kp Indices observed during August 23–29, 2018

3.3 November 01 - 07 (Year 2021) geomagnetic storm

From figure 3, we observe the changing in various parameter of geomagnetic and interplanetary during period of sat November 01-07, 2021. Figure 3(a) shows Dst index shows peakson 4 November 2021 and Dst falls up to 26nT to -105nT.Figure 3(b) and 3(c) Solar wind Temperature and Solar wind speed suddenly increases 88339K to 1312945K and 483Km to 742Km during the event, which gives ideas of geomagnetic storm on earth.Figure 3(d) shows Southern Component Bz rapidly jumps from - 15nT to 11.6nT and Kp index rapidly rises 7nT to 77nT which shows the peak in figure 3(e). During 01 - 07 November 2021, there are no Halo and partial Halo CMEs found.

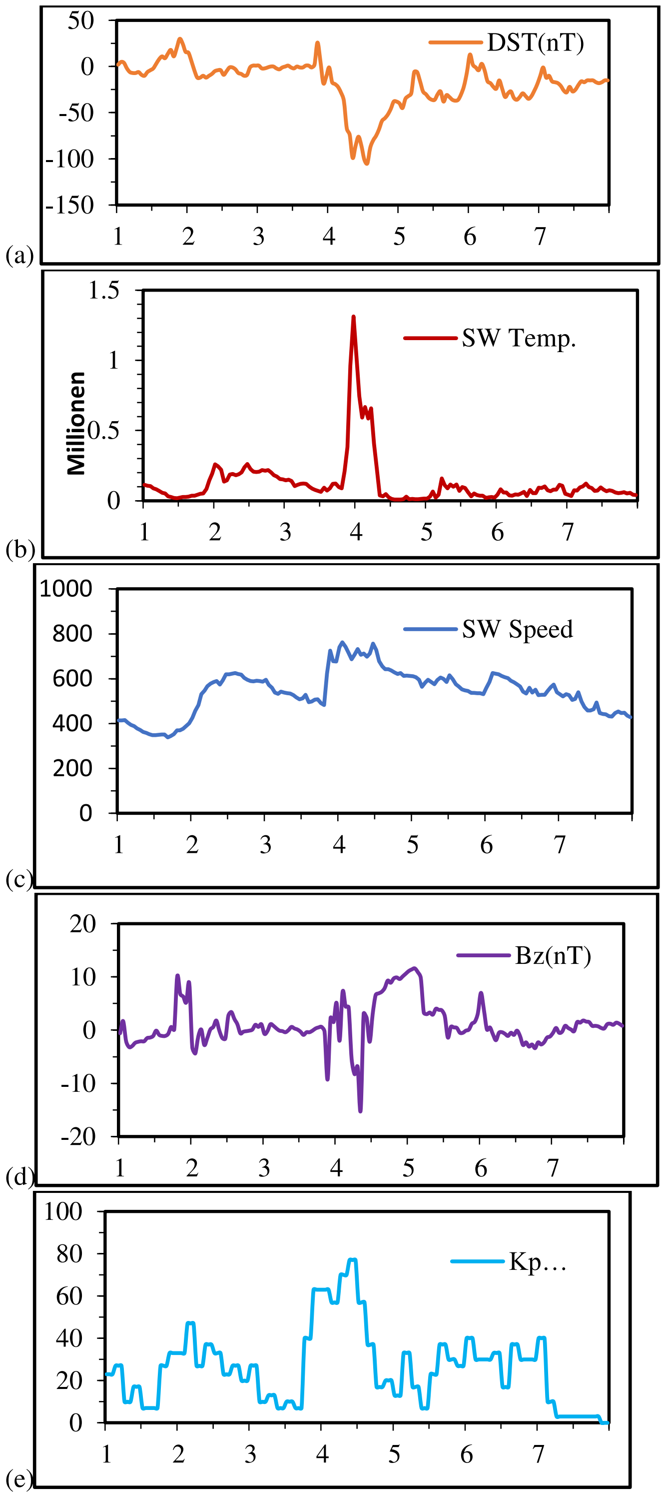


Fig 3. Shows the plot between geomagnetic activity and solar parameter during 01-07, Nov. 2021.

Fig. 3 Association of geomagnetic storm with interplanetary parameters:

(a) DstIndeces, (b) solar wind temperature,(c) SW speed, (d) interplanetary magnetic field IMF Bz, (e) Kp

Indices observed during November 01–07,2021

During 08 September 2017, two Halo CME's and three partial Halo CME's have been observed by SOHO LASCO observatory. Linear speed of CMEs speed of 474km/s, 1019Km/s and 1571km/s, 3163Km/s respectively.In the second event on 26 August 2018 there is not observed partial or full CME in this case a poor event occurred. In the 3rd event occurred on 04 November 2021, we observed here two partial halo CMEs and two full halo CMEs.

Table 1 Characteristic features of large geomagnetic storms

Sr. No.	Date of maximum Decreases in Dst value	Magnitude of storm B-100 (nT)	Date and time of CMEs	Speed of CMEs (Km/s)	Bz-component of IMF (nT)	Angular width (d)	Types of CMEs
1.	08thSeptember, 2017	-124	05/09/2017 (17:36:05)	474	13.4	129	PH
			09/09/2017 (23:12:10)	1019	6.2	138	PH
			06/09/2017 (12:24:05)	1571		360	H
			09/09/2017 (23:12:10)	1019		138	PH
			09/10/2017 (16:00:05)	3163		360	H
2.	26thAugust, 2018	-174	08/24/2018 (00:12:05)	229		50	PE
3.	04thNovember, 2021	-105	01/11/2021 (21:24:05)	830		162	PH
			11/01/2021 (23:12:11)	393		132	PH
			11/02/2021 (02:48:05)	1473		360	H
			11/03/2021 (21:36:05)	510		360	H

H halo CMEs, PH partial halo CMEs, PE poor event

4. Conclusion

This research examines geomagnetic events that reveal different solar and planetary properties and the accompanying geomagnetic impacts. As magnetopause shielding currents, a gauge of magnetospheric compression brought on by an increase in solar wind velocityand Dst falls suddenly.

Dst decreases during geomagnetic storm with increase in Kp index also increase in solar wind temperature and velocity.During geomagnetic storm compression on magnetosphere of earth takes place.Instead of only revealing the frequency of solar magnetic activity, the CME's maximum speed index also reveals information regarding the energy of solar events. When directed towards Earth, the interplanetary manifestations of CMEs can produce significant transitory disruptions that can lead to catastrophic geomagnetic storms there. A new useful metric to measure solar geoeffectiveness is provided by the physical connection between CMEs and geomagnetism. These outcomes line up with what was predicted in past research [21], [22]. These important qualities and relationship are very valuable for further studies of solar and weather phenomenon.

References

J Gosling, S Bame, D McComas and J Phillips(1990)Coronal mass ejections and large geomagnetic storms. Geophys. Res. Lett. 17 901

R Tripathi and A Mishra(2006)Occurrence of severe geomagnetic storms and their association with solar-interplanetary features. ILWS Workshop, Goa, India Feb. 19

S Singh, A Pandey, K Singh and A Mishra(2012) Characteristic Features of Geomagnetic Storms Observed During Maxima of Solar Cycle 24. Int. J. Phys. Astron. 26 1103

R Muscheler. F Joos. J Beer. S Muller. M Vonmoos and I Sn-jwball Q(2007)Solar activity during the last 1000 yr inferred from radionuclide records Sci. Rev. 26 82

R Usoskin, K Mursula, R Arit and G Kovaltsov(2009)A solar cycle lost in 1793–1800: early sunspot observations resolve the old mystery. Astrophys. J. 700 L154

N Gopalswamy, S Yashiro and S Akiyama(2007)Geoeffectiveness of halo coronal mass ejections J. Geophys. Res. 112 A06112

Singh, Sham, and A. P. Mishra(2019) "Cosmic ray intensity increases during high solar activity period for the solar cycles 22 and 23." Indian Journal of Physics 93 139-145

Z Svestka, E Cliver (1992)History and basic characteristics of eruptive flares. in: Eruptive solar flare. Proceedings of international astronomical Union Colloquium No. 133. (eds.) Z Svestka, B Jackson and M Machado (New York: Springer)

Galav, P., Dashora, N., Sharma, S., & Pandey, R. (2010)Characterisation of low latitude GPS-TEC during very low solar activity phase. Journal of Atmospheric and Solar: Terrestrial Physics, 72, 1309– 1317

[Klobuchar, J. A(1996) Ionospheric Effects OnGpsGlobal Positioning System: Theory and Applications, I, 485–515American Institute of Aeronautics and Astronautics.

Valladares, C., Sheehan, R., Basu, S., Kuenzler, H., & Espinoza, J. (1996)The multi-instrumented studies of equatorial thermosphere aeronomy scintillation system: Climatology of zonal drifts. Journal of Geophysical Research, 101, 26839– 26850

Wernik, A. W., Secan, J. A., & Fremouw, E. J.(2003) Ionospheric irregularities and scintillation. Advances in Space Research, 31(4), 971– 981

Horvath, I., & Crozier, S. (2007)Software developed for obtaining GPS-derived total electron content values. Radio Science, 42, RS200

O. A. Arowolo, A. O. Akala, E. O. Oyeyemi(2020) Interplanetary Origins of Some Intense Geomagnetic Storms During Solar Cycle 24 and the Responses of African Equatorial/Low-Latitude Ionosphere to Them. JGR Space Physics, 126, e2020JA027929

S Rathore et al.(2011)A correlative study of geomagnetic storms associated with solar wind and IMF features during solar cycle 23 Int. J. Appl. Phys. Math. 1 149

Singh, S., and A. P. Mishra(2015)"Interaction of solar plasma near-Earth with reference to geomagnetic storms during maxima of solar cycle 24. Indian Journal of Physics 89, 1227-1234

J Joselyn and P Melntosh(1981) Disappearing solar filaments: A useful predictor of geomagnetic activity J. Geophys. Res. 86 4555

W. D. Gonzalez, J. A. Joselyn, Y. Kamide, H. W. Kroehl, G. Rostoker, B. T. Tsurutani, V. M. Vasyliunas(1994)What is a geomagnetic storm? J. Geophys. Res. 99, 5771

D. Webb(1995) Coronal mass ejections: The key to major interplanetary and geomagnetic disturbances.Geophys. Rev. 33 577

S Dubey and A Mishra(1999) Solar Wind Streams And Intense Geomagnetic Storms Observed During 1986–1991. Earth Moon Planets 84 34

L Burlaga, K Behannon and L Klein(1987) Compound streams, magnetic clouds, and major geomagnetic storms. J. Geophys. Res. 92 5725

I Richardson, D Webb, J Zhang, D Berdichevsky. D Biesecker and J Kasper(2006) Major geomagnetic storms (Dst Ā100 nT) generated by corotating interaction regions. J. Geophys. Res. 111 A07S09

Velazquez, M. G. Nicora1, V. S. Galligani, E. A. Wolfram, F. Orte, R. D'Eli, S. Papandreas5, F. Verstraeten(2022) The 2020 Patagonian solar eclipse from the point of view of theatmospheric electric field. Papers in Physics, 14, 140008

Sham Singh, A. C. Panday Kalpana Singh & A. P. Mishra(2017)Effect of geomagnetic storms and their association with solar wind velocity and IMF during solar cycle 23 and 24. International Journal of Pure and Applied Physics. 13, 35-43

M. Sharma, A. K. Gupta, J. Singh, R. Mittal, H. Singh and D. Pandey (2022)"Effects of slot shape in performance of SIW based Leaky Wave Antenna. (ICCMSO), Pathum Thani, Thailand, 268-273,

T Davis and M Sugiura (1996)Auroral electrojet activity index AE and its universal time variations. J. Geophys. Res. 71 785

P Simon. G Heckman and M Shea(1986) (eds.) Solar-Terrestrial Predictions: Proceedings of a Workshop at Meudon, France, June 18-22. 1984. Environment Research Laboratories, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Boulder, Colorado

S Singh, D Shrivastava and A Mishra(2012) Effect of Solar and Interplanetary Disturbances on Space-weather. Indian J. Sei. Res. 3 121

J Gosling, D McComas, J Phillips and S Bame(1991) Geomagnetic activity associated with earth passage of interplanetary shock disturbances and coronal mass ejections. J. Geophys. Res. 96 7831

W Gonzalez, B Tsurutani and A Clua de Gonzalez(1999) Interplanetary origin of geomagnetic storms. Space Sci.Rev. 88 52