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EFFECT OF CORONAL MASS EJECTIONS ON NEAR EARTH SPACE WEATHER DURING SOLAR CYCLE 25

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ABSTRACT

Coronal Mass Ejections (CMEs) inject large amounts of magnetized plasma and magnetic fields into the heliosphere. CMEs play an important role in influencing space weather conditions and can affect various technological systems on Earth, including communication and navigation systems. In this paper, we have analyzed the impact of CMEs on space weather and investigate how they contribute to space weather disturbances. The effects of CMEs on the near-Earth space weather have been analyzed and discussed.

KEYWORDS: Coronal Mass Ejection, Space Weather, Navigation System.

INTRODUCTION

The Sun is a dynamic and magnetically active star. It continuously releases energy, and many activities occur in its atmosphere, including sunspots, granules, supergranules, faculae, flares, prominences, spicules, solar wind, and coronal holes. These phenomena contribute to space weather, which affects satellites, communication systems, and Earth through solar wind and high-energy particles.

A Coronal Mass Ejection (CME) originates from the solar corona and is commonly observed near the solar limb using white-light coronagraphs. CMEs have been routinely observed since the 1970s. A CME is a solar phenomenon that can induce auroras and generate electromagnetic disturbances, there by affecting the overall dynamics of space weather. The measured properties of CMEs include their occurrence rates, locations relative to the solar disk, angular widths, speeds, and masses and energies **(e.g., Kahler, 1992; St. Cyr et al., 2000; Webb, 2002; Gopalswamy et al., 2003; Yashiro et al., 2004; Mishra et at., 2005; Tripathi et al., 2006).** There is a large range in the basic properties of CMEs. Their speeds, accelerations, masses and energies extend over 2–3 orders of magnitude (e.g., **Vourlidas et al., 2002; Singh et at., 2012;),** and their widths exceed by factors of 3–10 the sizes of flaring active regions. Different forms of CMEs have been observed, including those with large circular regions resembling flux ropes and halo CMEs. CMEs which have a larger apparent angular size than typical limb CMEs but do not appear as complete halos, are called 'partial halo' CMEs. Halo CMEs are important for three reasons: 1) They are the key link between solar eruptions and many space weather phenomena such as major geomagnetic storms and associated events 2) The source regions of frontside halo CMEs are usually located within a few tens of degrees from center of the sun, as viewed from Earth **(Cane et al., 2000; Webb 2002; Singh et at., 2012).** Thus, these regions have been studied in greater detail than for most CMEs which are observed near the limb 3) Frontside halo CMEs and their internal material can be sampled in situ by spacecraft The SOHO, Wind and ACE, near the Earth. These Spacecraft provide relevant information regarding interplanetary disturbances. These types of studies are helpful for better understanding of Sun Interplanetary Earth connection. Impact of the earth directed CMEs with geomagnetoshpere triggers the geomagnetic storms which can also disturb satellites electrical powergrids and windspeed communication systems.

Space weather can be defined as a branch of science that studies the variability of solar geomagnetic and ionospheric condition. That can produce adverse effects on technological infrastructure and spacecraft operation **(Buzulukova et. al., 2026;).**

In solar cycle 25 six major geomagnetic storms are observed. Dst magnitude $\leq -200nT$ including great geomagnetic storms observed (Dst $\leq -400nT$) struck the earth magnetosphere.

On 10-11 May 2024, two highly associated CME with propagation speeds of 1018 Km/s and 1332 Km/s, impacted the Earth magnetosphere, Their combined effects triggered and extreme G5-class geomagnetic storm, one of the most intense events of solar cycle 25, during which the Dst index reached a minimum value of -406 nT.

A few days before this historic event, Dr. Jennifer L. Gannon Passed away unexpectedly on 2 May 2024. In recognition of her outstanding contributions to the field of space weather research and operational forecasting, the U.S. space weather community designated the 10-11 May 024 extreme geomagnetic storms as the "Gannon Event".

Data Analysis

In the present study, we have carried out a detailed investigation of all major geomagnetic storms (Dst ≤ −200 nT) that occurred during the rising and maximum phase of Solar Cycle 25, spanning from December 2019 to June 2026. During this period, a total of six intense geomagnetic storms were observed. Their occurrence and peak Dst values as well as associated parameter are given in table 1.1

Table No. 1.1

S.N.	Date of maximum decreases in Dst value	Magnitude of storms ≤200(nT)	Date and time of CMEs	Speed of CMEs (km/s)	Bz-component of IMF (nT)	Angular Width (d)	Types of CMEs
1.	24 April 2023	-213	2023-04-24 14:12	583 681	-1.7	189	Partial Halo
2.	11 May 2024	-406	2024-05-10 07:12	1018 1332	-12	360	HALO
3.	11 October 2024	-333	2024-10-09 02:12	1509 2112 1473	-9.5	360	HALO
4.	01 January 2025	-212	2024-12-29 18:24	917	-1.5	360	HAO
5.	12 November 2025	-217	2025-11-11 10:23	1856	-1.5	360	HALO
6.	20 January 2026	-236	2026-01-18 18:09	1820	-3.4	360	HALO

Among the observed storms geomagnetic storms occurred on 11May 2024 (Dst values -406 nT) was the most intense geomagnetic storms observed during solar cycle 25. We have analyzed these major geomagnetic storms are more then (≤-200nT) in order to define the characteristic feature of individual storms and their association with different solar wind and interplanetary disturbances.

Furthermore, A comprehensive analysis was performed to investigate the relationship between Coronal Mass Ejections (CMEs**)** and observed geomagnetic storms in relative to near earth. The CME data used in this study were obtained from the https://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard/, while the geomagnetic storm data, including the Dst index, (obtained from the https://wdc.kugi.kyoto-u.ac.jp/). These datasets were utilized to examine the association between Earth-directed CMEs and the resulting geomagnetic storm with different magnitude.

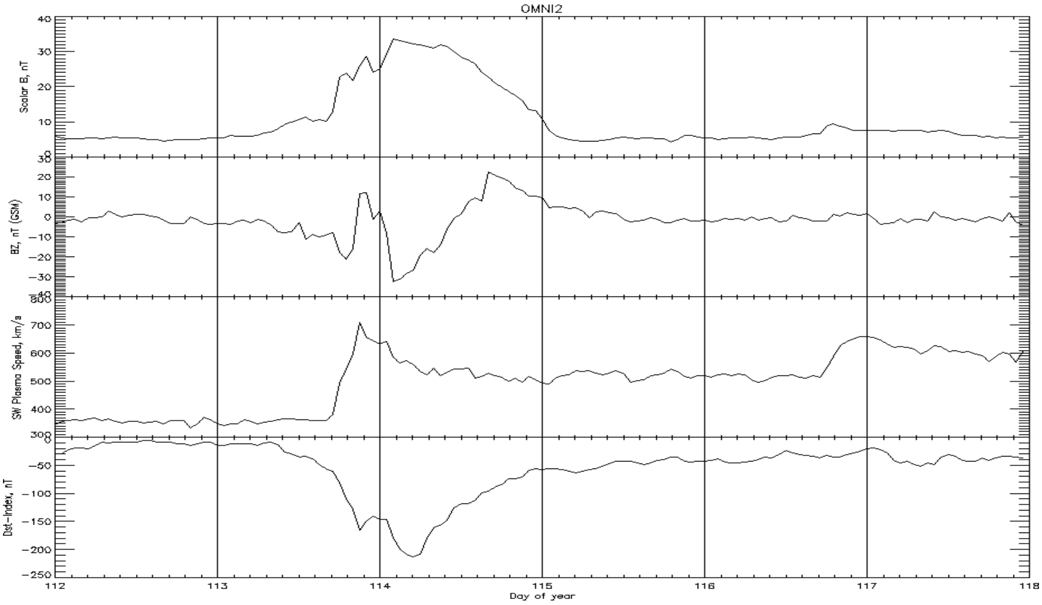

Fig.1.1
DAYS (22-27 APRIL 2023)

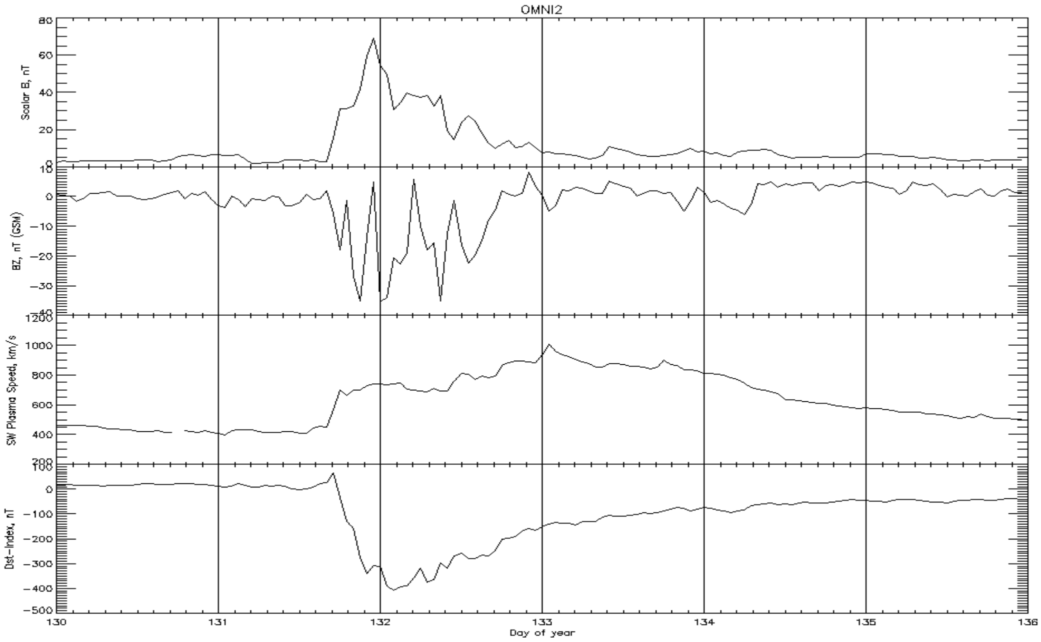

Fig. 2.1
DAYS (09-14 MAY 2024)

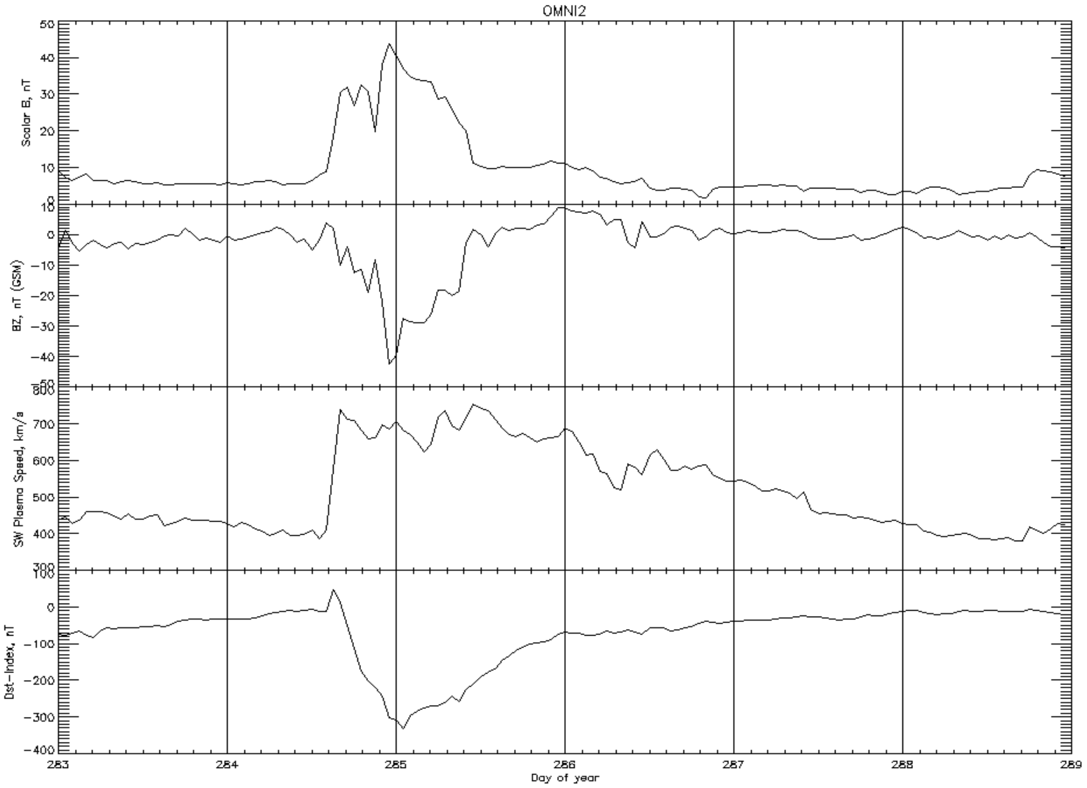

Fig.3.1

DAYS (09-14 OCTOBER 2024)

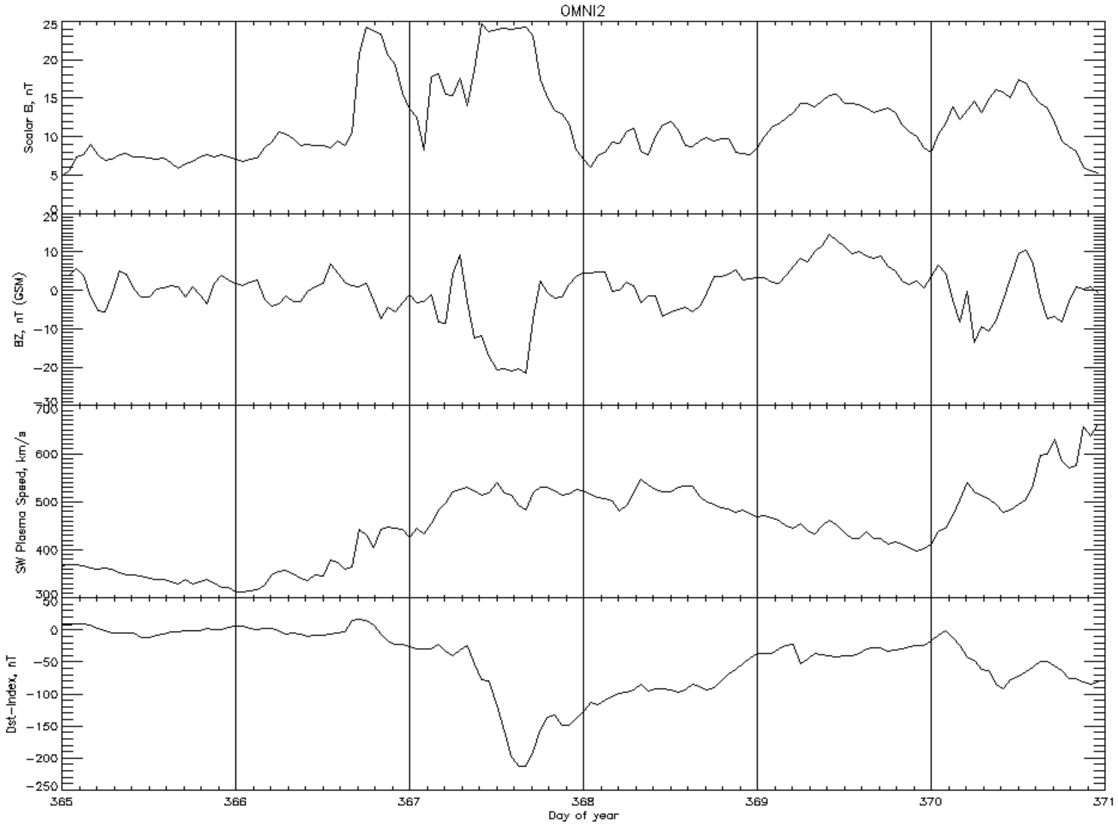

Fig.4.1

DAYS (30 DEC 2024 -01 JAN 2025)

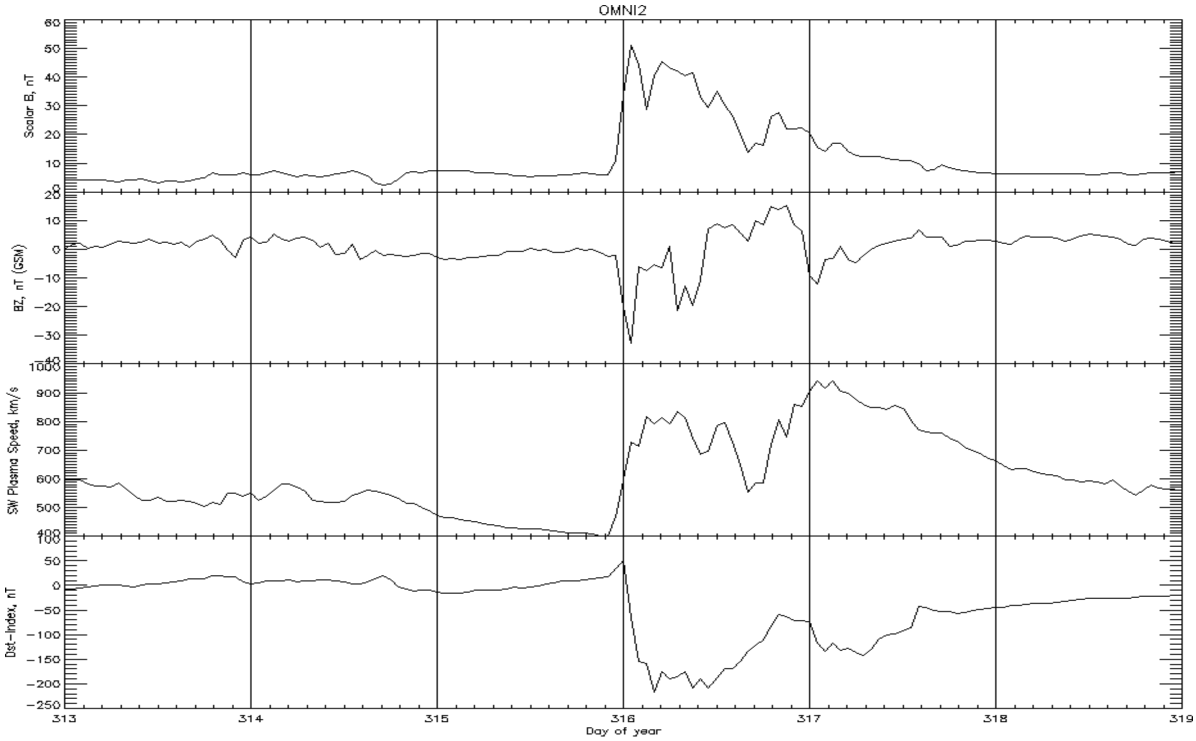

Fig. 5.1

DAYS (09-14 NOV 2025)

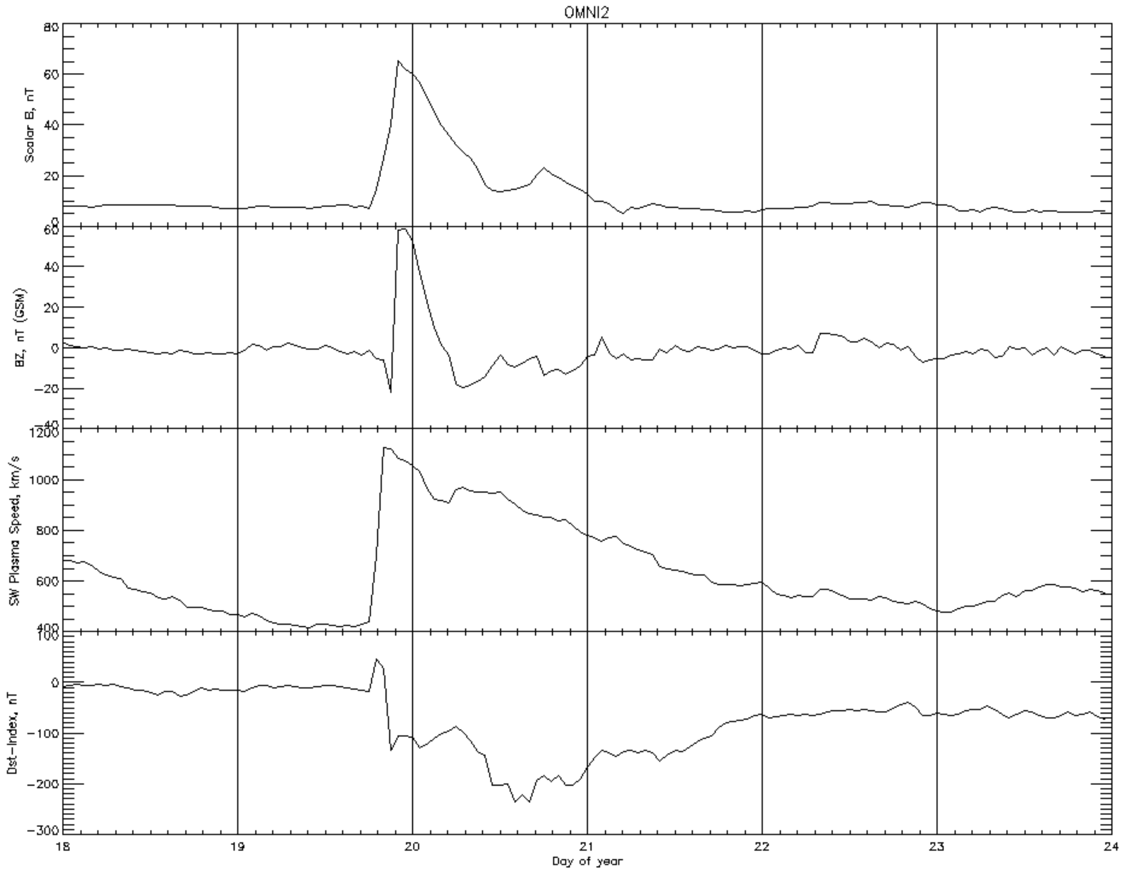

Fig.6.1

DAYS (18-23 JAN 2026)

3. RESULT AND DISCUSSION

In the present study, we have investigated the relationship between Coronal Mass Ejections (CMEs), strong geomagnetic storms, and the Interplanetary Magnetic Field (IMF) during Solar Cycle 25. Total six major geomagnetic storms associated with Earth-directed CMEs were observed for detailed analysis in basis of their significant geoeffectiveness. Each CME exhibited a distinct propagation speed, ranging from a minimum of 500 kms^{-1} to a maximum of 2112 kms^{-1}. The corresponding geomagnetic response also varied considerably. The associated minimum Dst index ranged from −213 nT to −406 nT, while the corresponding southward IMF Bz values ranged from−1.7 nT to −12 nT. These results indicate that variations in CME characteristics have a significant influence on the intensity of geomagnetic storms.

Among the six investigated events, three CMEs were identified as CME–CME interaction events, in which a faster CME overlap and collides with a preceding slower CME during its propagation through interplanetary space. These interactions further accelerated and compressed the propagating plasma structures, resulting in the formation of energetic Halo CMEs. The interaction between successive CMEs substantially enhanced their geoeffectiveness, and speed leading to the generation of intense geomagnetic storms upon their arrival at Earth.

The first CME interaction event occurred on 24 April 2023 at 14:12 UT, when two CMEs with propagation speeds of 583 kms^{-1} and 681 kms^{-1} were successively originated from the surface of Sun. During their propagation, the faster second CME caught up with and collided with the preceding slower CME. Following this interaction, the merged structure evolved into a Halo CME. The arrival of this Earth-directed Halo CME was associated with a southward IMF Bz of −1.7 nT and produced a strong geomagnetic storm with a minimum Dst index of −213 nT. The temporal variations of the Dst index, Solar Wind Plasma Speed, IMF Bz, and Average IMF corresponding to this event are shown in **Figure 1.1.**

The second CME interaction event was observed on 10 May 2024 at 07:12 UT, involving two CMEs with propagation speeds of 1018 kms^{-1} and 1332 kms^{-1}. The faster CME overtook the preceding slower CME, and their interaction resulted in the formation of a highly energetic Halo CME. This Earth-directed Halo CME generated a prolonged southward IMF Bz of −12 nT, producing an extreme geomagnetic storm with a minimum Dst index of −406 nT. The temporal evolution of the associated Dst index, Solar Wind Plasma Speed, IMF Bz, and

Average IMF (B) is illustrated in **Figure 2.1.**

The geomagnetic storm of 11 May 2024 represents the most intense geomagnetic storm observed during Solar Cycle 25 characterized by the lowest Dst (−406 nT) and the strongest southward IMF Bz (−12 nT). These observations clearly demonstrate that the interaction of successive Earth-directed CMEs can considerably enhance the geoeffectiveness of solar eruptive events and lead to the development of exceptionally intense strong geomagnetic storms.

The third geomagnetic storms (May 11,2024) resulted due to CME interaction event occurred on 09 October 2024 at 02:12 UT, involving three successive CMEs with propagation speeds of 1509 km s^{-1}, 2112 km s^{-1}, and 1473 km s^{-1}, respectively. During their propagation through the interplanetary medium, the third CME interacted with the second CME, while the second CME had already interacted with the first CME. These successive CME–CME interactions resulted in the formation of a highly energetic Halo CME. Upon arriving the Earth's magnetosphere, this event produced a southward IMF Bz of −9.5 nT and generated a strong geomagnetic storm with a minimum Dst index of −333 nT. The corresponding temporal variations of the Dst index, Solar Wind Plasma Speed, IMF Bz, and Average IMF B are presented in **Figure 3.1.**

In the present work, we have studied, a total of six geomagnetic storms associated with the selected Earth-directed CME events. including four important space-weather parameters: (1) Dst Index (nT), (2) Solar Wind Plasma Speed (km s^{-1}), (3) IMF Bz (GSM, nT), and (4) Total Interplanetary Magnetic Field Strength (Average B, nT). The detailed physical characteristics and observe parameters of all six CME events are summarized in Table 1. The corresponding temporal variations of these parameters are illustrated in Figures 1.1–6.1.

The present analysis demonstrates that Earth-directed Halo CMEs associated with CME–CME interactions are considerably more geoeffective than isolated CME events. The interaction between successive CMEs enhances their propagation dynamics, increases plasma compression, and strengthens the southward component of the interplanetary magnetic field (IMF Bz). Consequently, these processes lead to the development of stronger geomagnetic storms, characterized by larger decrease Dst values. Therefore, the results suggest that, in addition to CME speed, CME–CME interaction and the magnitude and persistence of the southward IMF Bz are the primary controlling factors governing the intensity of geomagnetic storms during Solar Cycle 25.

CONCLUSION

In the present study we have investigated the relationship between earth directed coronal mass ejection (CME), the interplanetary magnetic field (IMF) and intense strong geomagnetic storms during solar cycle 25 in rising and maximum phase. Six major earth directed CME event were analyzed using the Dst index, solar wind plasma, IMG Bz (GSM) And total interplanetary magnetic field to evaluate their geoeffectiveness.

Among six event, three were identified as CME-CME interaction events where faster CMEs overtook slower preceding CMEs resulting in the formation of energetic halo CMEs which could generate more strong geomagnetic storms. The 10 May 2024 event observed as the most strong geomagnetic storms of with a minimum Dst index of -406 nT and IMF Bz of -12nT.

This study indicate the importance of earth directed Halo CMEs and CME-CME interaction in producing severe space weather event. These findings contribute to a better understanding the sun-earth interaction. which will helpful to establish of more reliable space weather forecasting in future studies.

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