The Intense Geomagnetic Storm on March 24, 2023, Associated with Halo CMEs and Solar Flares

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The Intense geomagnetic storm on March 24, 2023, associated with Halo CMEs and solar flares.

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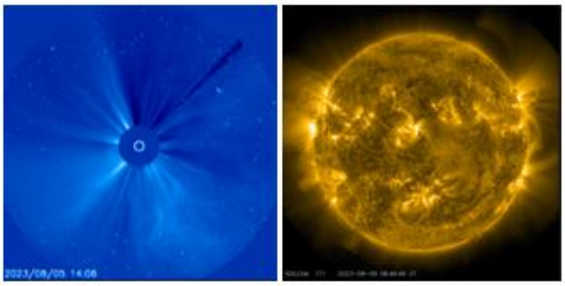
Abstract: *Interplanetary coronal mass ejections (ICMEs) that accompany solar flares are associated with the occurrence of severe geomagnetic storms. The goal of this research is to examine an intense geomagnetic storm on March 24th, 2023 with a symmetric disturbances index (SYM/H) of -200 nT and evaluate the CMEs, solar flares, and solar wind conditions associated with the storm. Furthermore, the strong storm associated with CMEs and solar flares has been examined using a low-latitude ground geomagnetic field (H-component) at TRE station. Data suggests that the two halo types of CMEs that occurred on March 20th, 2023, may have triggered severe geomagnetic activity. The occurrence of an intense geomagnetic storm on March 24th, 2023, is expected to be independent of the speed parameter of CME events (V_{cme}<2000kms^{-1}).*
This research provides more insight into the potential for space weather hazards that could disrupt space and ground in frastructure systems.

Keywords: Coronal mass-ejection, solar flare, geomagnetic storm, solar wind, geomagnetic field

1. INTRODUCTION

The Sun is active as composed the compelling short-lived burst of solar phenomenon such Coronal mass-ejections (CMEs), solar flares and high-solar wind speeds can cause to the disturbance in magnetosphere which can lead to the geomagnetic storm [1]. CMEs moves into the solar wind and becomes an interplanetary structure to form interplanetary coronal mass ejection (ICME) [2]. As the shock of an ICME hits the Earth, it compresses the magnetosphere, implying the occurrence of storm sudden commencement (SSC) followed by a geomagnetic storm [3]. A fast-moving CME typically takes 4-5 days to reach Earth. Many CMEs are linked to solar flares, but not all are accompanied by flares [4].

Solar flare activity is the sudden release of magnetic-field energy due to reconnection of magnetic field in the coronal region on the sun [5] [6]. Figure 1 represents the image of CMEs as seen from Earth and the view of a solar flare. Recent studies have shown that the CMEs with huge bubbles of coronal material comprise of strong magnetic fields into the magnetosphere contributed to the geomagnetic storm and thus response to ground geomagnetic field [7] [8] [9]. The geomagnetic storm on 7 September 2017 occurred after an X1.3 flare on same days and several M-class flares occurred concurrently with the storms after two days according to Qian et al., 2019 [10]. Several studies have been conducted to investigate the role of CMEs and solar flare events in the disturbance of the Earth's magnetosphere. The high variation of solar wind and ground geomagnetic field with CMEs associated with solar flare activity is observed [11][12]. According to Wu et al., 2019, the halo CME associated flare has caused a severe geomagnetic storm due to the enhanced southward B_z-component [13]. Hence, this study investigates the effect of CMEs associated with solar flares of several characteristics on the occurrence of intense storms with solar wind and ground geomagnetic field.



(a) (b)

Fig. 1: a) Image of CME from Large Angle and Spectrometric Coronagraph (LASCO) instrument, b) Image of solar flare from AIA telescope instrument (Source: https://www.spaceweatherlive.com/)

2. METHODOLOGY

This study observed the solar events that acquired from Solar and Heliospheric Observatory (SOHO) website (https://cdaw.gsfc.nasa.gov/CME_list/index.html) for CMEs event and solar flare events through Solar soft website (https://www.lmsal.com/solarsoft/last_events/). The intense geomagnetic storm (-200 < SYM/H < -100 nT) at 24th March 2023 was computed from symmetric part of the magnetospheric ring current activity, (SYM/H index) value of 1-min resolution retrieved from the OMNI website (https://omniweb.gsfc.nasa.gov). The classification of the SYM/H index is apparent in Table 1.

Table 1: Classification of SYM/H index

Geomagnetic storm	SYM/H index (nT)
Super	SYM/H ≤ -250
Intense	-100 < SYM/H ≥ -250
Moderate	-50 < SYM/H ≥ -100
Weak	-30 < SYM/H ≥ -50

The variation of solar wind parameters (Bz-component, solar wind speed (Vsw), solar wind pressure (Psw), and solar wind input energy (IEsw)) obtained from the OMNI website was used to determine the association of CMEs and solar flares of various characteristics in response to an intense geomagnetic storm.

Furthermore, the response of CMEs associated with the solar flare resulting in the intense geomagnetic storm on March 24th, 2023, has been identified in Earth's geomagnetic field at low latitudes. that were determined using the horizontal geomagnetic field (H-component), based on data collected from the Terengganu (TRE) Real-time Magnetic Data Acquisition System/Circum-pan Pacific Magnetometer Network (MAGDAS/CPMN) magnetometer station. Table-2 contains information about the TRE MAGDAS station.

Table 2 The details of TRE magnetometer station [14] [15] [16]

Station	Abbreviation	Geographic coordinate		Geomagnetic coordinate	
		Latitude (°)	Longitude (°)	Latitude (°)	Longitude (°)
Terengganu, UniSZA, Malaysia	TRE	5.23 N	103.04 E	-4.21 N	175.91 E

3. RESULTS AND DISCUSSION

According to the analysis, there was a variation in solar wind parameters (B_z, V_{sw}, P_{sw}, IE_{sw}) that corresponded to the occurrence of an intense geomagnetic storm (SYM/H = -160 nT to -180 nT) at beginning of March 24, 2023. It has been demonstrated that the high B_z-component (B_z= -18 nT) led to the high intensification of ring current shown in the intense storm during the reconnection process (see Figure 2) [17][18]. Simultaneously, high solar dynamic pressure (Psw = 2 nPa to 15 nPa) causes intense geomagnetic disturbance as plasma is ejected into the magnetosphere. This is supported by the Brittnacher et al., 2000 and Syed Zafar et al., 2021 [19] [20]. As demonstrated in Figure 3, the conveyance of solar wind input energy from ejected plasma to the magnetosphere is enhanced by increasing solar wind speed (V_{sw} = 400 kms^{-1} to 440 kms^{-1}).

The decrease in the geomagnetic field (H- component) at TRE station is also consistent with high solar wind parameter variation and the occurrence of an intense storm at same time period, as shown in Figure 3. The decreasing trend of the H-component ranges from (H = 4.165×10^4 to 4.147×10^4 nT) with high solar wind speed carrying high energy plasma to the inner magnetosphere and performing the disturbance magnetosphere. As a result, react to the ground. As a result, the H-component decreases [21] [22].

CMEs associated with solar flare events on March 20th, 2023 are seen preceding the intense storm on March 24, 2023 were reacting to the large variance of solar wind characteristics, leading the intense storm and lower H-component on March 24, 2023. Table 3 shows a list of several characteristics of CMEs and solar flare events from March 20th to March 24th, 2023. According to the events list, analysis suggests that CMEs on the 21st of March 2023 with solar flare class types of (C 3., C 1.3, and M 3.1) from 23rd March until 24th March 2023 have responded to the high southward B_z rotation and an increase in V_{sw}, P_{sw}, and IE_{sw} is presented in an intense storm on the 24th of March reacting to ground geomagnetic field at TRE station.

It also confirmed by the Temmer et al., 2017 that CMEs may take 4-5 days to reach Earth [23]. In addition, wide propagation of magnetic fields in halo CMEs from the sun resulted in the release of energy in magnetic reconnection into the magnetosphere, resulting in an intense storm and ground reaction (decreasing H-component) [24][25]. However, the speed of CME propagation (V_{cme} < 2000 km/s) may be observed regardless of the high variation of solar wind parameters to the intense storm and the lower of H-component as suggested by Gopalswamy et al., 2014 [26].

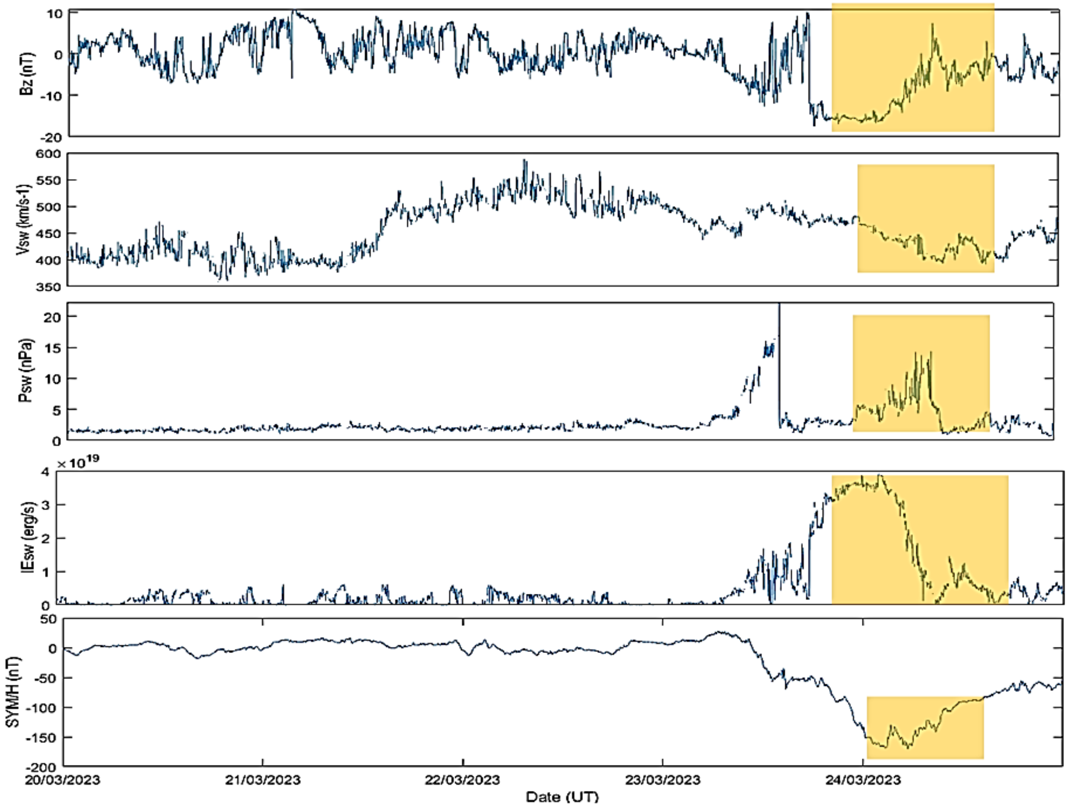


Fig. 2: The variation of solar wind parameters and the SYM/H index from March 20th to March 24th, 2023. The highlighted section depicts how the solar wind parameters change with an intense storm at the beginning of March 24, 2023.

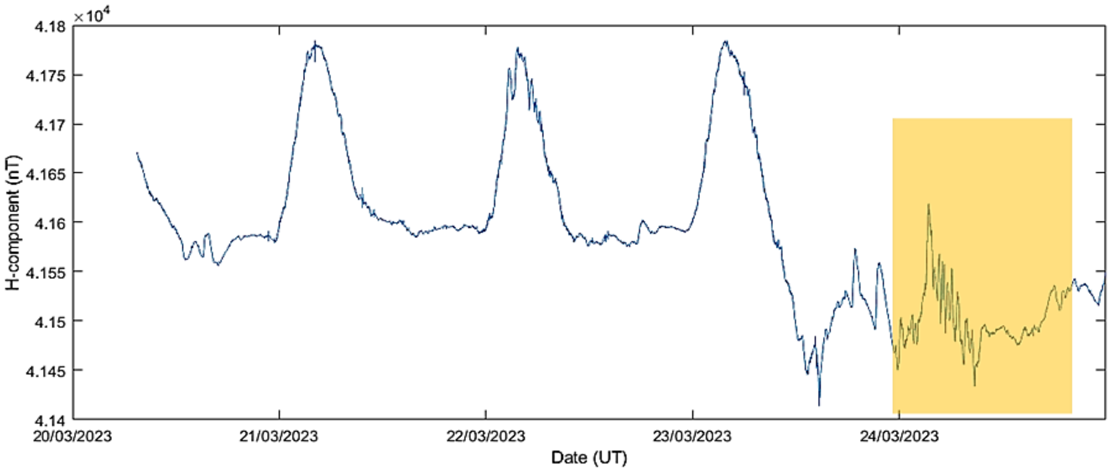


Fig. 3: The variation of ground geomagnetic field (H-component) at TRE station from March 20th to March 24th, 2023. The highlighted section presents the variation of the H-component with changes in solar wind parameters and an intense storm on March 24, 2023.

Table 3 The particular characteristics of CMEs and solar flare events from March 20th to March 24th, 2023 (Source: https://cdaw.gsfc.nasa.gov/CME_list/index.html and https://www.lmsal.com/solarsoft/last_events/).

Date	CMEs		Solar flare
	Position Angle	Speed (km/s)	Class
20th March 2023	360 (Halo)	851	C 3.1
	360 (Halo)	727	M 3.1
21st March 2023	61	789	C 1.3
	229	817	C 1.3
	316	464	C 1.4
	130	649	C 1.4
22nd March 2023	135	658	C 1.4
	145	1242	C 1.3
	202	497	C 1.2
23rd March 2023	186	766	B 9.2
	242	845	B 8.5
24th March 2023	108	1025	C 1.7
	281	556	C 1.0
	-	-	C 1.4
	-	-	C 2.2
	-	-	C 1.1
	-	-	C 1

4. CONCLUSION

Based on the findings, it was determined that CME-associated solar flare events occurred from March 20th to March 23rd, 2023, causing a high variation in solar wind parameters and triggering an intense storm on March 24th, 2023. As a result, the change in the ground geomagnetic field is influenced. The halo CME burst direction associated with high solar wind from March 20th to March 21st, 2023, implies an intense storm on March 24th 2023 and a reduction in the H-component at the TRE magnetometer station. Furthermore, CMEs are estimated to take 4 to 5 days to reach the Earth's magnetosphere, according to Temmmer et al., 2017. Meanwhile, the southern hemisphere solar flare location from March 22nd to March 23rd, 2023, is suggested, which is driven by high energy plasma transfer to the magnetosphere via solar wind, resulting in magnetosphere disruption and implied to the ground. This analysis concluded that the features of halo CME propagation and southern hemisphere solar flare location seen have the potential to contribute to the intense storm on March 24th, 2023, and change in H-component change associated with high solar wind parameters in southward B_z-component orientation condition. Zhang et al., 2021 and Roy et al., 2020 agreed with it.

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