

Study of CME-Driven Geomagnetic Storms During Rising Phases of Solar Cycle 24 and 25

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Abstract: Coronal mass ejections are most important solar drivers of geomagnetic disturbances at Earth. When CME reaches near the Earth environment, its interplanetary part known as Interplanetary coronal mass ejection (ICME) interact strongly with the terrestrial magnetosphere. The magnitude of this interaction depends on several parameters. The present study comparatively investigates CME/ICME-driven geomagnetic activity during rising phases of solar cycle 24 and 25. The analysis is based on CME/ICME catalogues, solar wind observations, sunspot numbers and geomagnetic indices. The paper demonstrates the value of a multiparameter approach for understanding CME Geoeffectiveness and improving space weather prediction.

Keywords: coronal mass ejection, ICME, geomagnetic storms, solar cycle 24, solar cycle 25, Dst, IMF Bz, solar wind, space weather

1. Introduction

The sun is the primary source of variable electromagnetic and particle radiation in the heliosphere. Its magnetic activity changes approximately on an 11-year cycle, during which the number and complexity of sunspots, solar flares, coronal mass ejections and other magnetic activity vary considerably, these solar variations are responsible for many forms of space weather that influence the Earth's magnetosphere, ionosphere and other activity.

A coronal mass ejection a large scale of eruption of magnetized plasma from solar corona. CMEs contain billion of tones of plasma and magnetic energy. These propagate through interplanetary space and arrive at earth. The interplanetary part of CME is called interplanetary coronal mass ejection (ICME) and it is important for geomagnetic activity. A CME with a high speed does not necessarily produce a strong geomagnetic storm.

A geomagnetic storm is a large-scale disturbance of the earth magnetic fields caused by enhanced energy and momentum transfer from the solar wind and CME to the magnetosphere. Geomagnetic storm affects the damage of satellites power grid and interferes radio and GPS signals.

The Dst index is widely used to quantify the strength of the storm-time ring current and hence intensity of geomagnetic storms. Commonly -30 and -50nT are weak, -50 to -100nT, moderate and below -100nT are intense.

Solar cycle 24 is the weakest solar cycle of the space age. Its maximum occurred in 2014 while minimum separating it by solar cycle 25 occurred in December 2019. Solar cycle 25 beginning December 2019 developed more strongly as suggested. NOAA describes solar cycle 24 as maximum in April 2014 and solar cycle 25 as beginning in December 2019.

Solar cycle 24 and 25 are useful for comparison because their activity levels and ICME properties differ to each other. Cycle 24 was comparatively weak while cycle 25 are more active after 2019-2020 solar minimum. Recent studies found that cycle 25 sunspot number during rising phase clearly higher than the cycle 24 (Table 1).[1][2][3]

Therefore, the present paper basically focuses on, how did CME-driven geomagnetic storms during the rising phases of cycle 24 and 25 differ in occurrence, intensity, and interplanetary conditions?

2. Data Analysis

We used peer reviewed studies for CME associated geomagnetic storms. NASA OMNI web provides hourly and higher resolution near Earth solar wind magnetic field and plasma data as well as geomagnetic and solar activity indices. SILSO provides daily and monthly sunspot number series. The selection criteria are published CME/ICME association during the ascending phase of respective solar cycle. Events known to be primarily CIR/HSS-driven are not treated as pure CME events. where an event involved multiple CMEs and high-speed streams, this is shown in the table 2. Dst is used for storm intensity. [8][9]

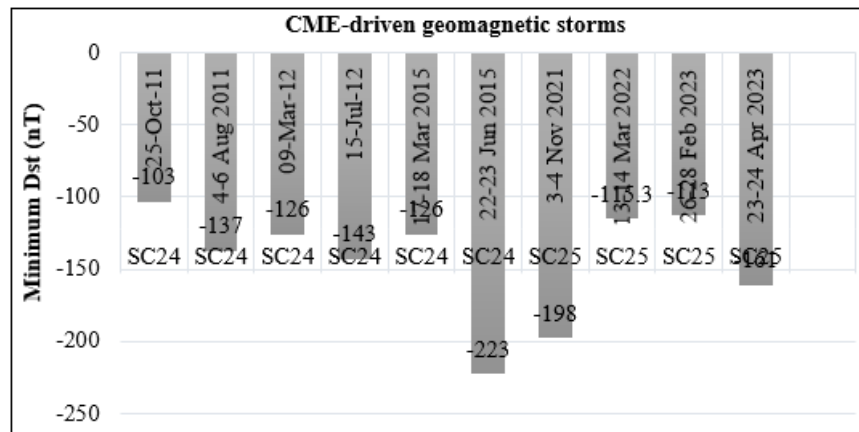
Comparative Data for SC24 and SC25

Table 1: Annual mean sunspot number during rising phases of SC24 and SC25.

Solar Cycle 24			Solar Cycle 25	
S. No.	Year	Annual mean SSN	Year	Annual mean SSN
01.	2008	4.2	2019	3.6
02.	2009	4.8	2020	8.8
03.	2010	24.9	2021	29.6
04.	2011	80.8	2022	83.2
05.	2012	84.5	2023	125.5
06.	2013	94.0	2024	154.7
07.	2014	113.3	2025	123.2

Table 2: CME-driven geomagnetic event data

Cycle	Date/Events	Driver	Dst (nT)	CME speed km/s	Bz(min)nT	Intensity
SC24	26-27 Sep 2011	CME/ICME	-103	----	----	Intense
SC24	25 Oct 2011	CME/ICME	-137	----	----	Intense
SC24	4-6 Aug 2011	CME/Sheath	-126	1477	-22.38	Intense
SC24	09 Mar 2012	CME/ICME	-143	-737	-16.1	Intense
SC24	15 Jul 2012	CME/ICME	-126	----	-15.2	Intense
SC24	17-18 Mar 2015	CME-driven	-223	----	----	G4/Severe
SC24	22-23 Jun 2015	CME-driven	-198	1366	----	G4/Severe
SC25	3-4 Nov 2021	CME/Shock	-115.3	----	----	G3/Strong
SC25	13-14 Mar 2022	CME	-113	----	-26.5	G2/Moderate
SC25	26-28 Feb 2023	2CME+HSS	-161	----	-19	Strong
SC25	23-24 Apr 2023	CME/ICME	-213	1284	-32.4	G4/Severe

Table 2: CME-driven geomagnetic event data**Figure 1:** Minimum Dst for CME-driven geomagnetic storm. More negative value indicates stronger geomagnetic disturbance. The plot is a descriptive disturbance.

3. Result and Discussion

Data shown in the table 2, both the solar cycle produced intense CME-driven storms during the rising phases. Cycle 24 includes several 2011-2012 events with Dst below -100nT while Cycle 25 includes strong events in 2021-2023 and a particularly severe April 2023 storm. The August 2011 cycle 24 event demonstrates strong sheath-driven Geoeffectiveness. The CME speed was 1477 km/s, Bz reached -22.38nT. The combination of a fast shock, compressed plasma and southward field produced the storm.[4][5][6]

The November 2021 cycle 25 event had a lower storm magnitude than August 2011 but still produced a strong G3 storm. Its solar wind speed rise to roughly 700-760 km/s and the magnetic field remain southward during the main phase. The event is an example of a shock associated ICME storm. March 2022 demonstrate that very strong southward Bz does not necessarily produce an extreme storm. Although Bz reached -26.5nT the storm minimum was -113nT. This reinforces the importance of the duration and temporal structure of southward IMF as well as pressure and speed. April 2023 produced a much stronger storm, with Dst around -209 to -213nT and Bz reaching roughly -32.4 nT. The CME speed near 1284 km/s and strong magnetic field demonstrate a highly geoeffective combination of speed and magnetic orientation.[6][7]

Recent statistical work provides the broader cycle level context, during the rising phase of cycle 25, sunspot numbers were clearly higher than during the cycle 24 interval while the

cycle 25 had the smallest ICME count among the compared rising phase of cycles 23-25, However its average ICME magnetic field strength, southward component and dawn-dusk electric field were the highest of the three periods. Thus, storm intensity depends strongly on ICME magnetic properties rather than simply the number of CMEs.[10]

4. Conclusion

CME-driven geomagnetic storms during the rising phases of Solar cycle 24 and 25 show substantial event to event variability. Cycle 24 is weak overall solar activity produced several intense storms, while Cycle 25 produced strong and severe CME-driven storms as solar activity increased. The strongest events in the data were associated with combinations of high CME/solar wind speed, strong magnetic field and southward IMF. The April 2023 Cycle 25 event is a clear example of this combination, while the August 2011 Cycle 24 storm demonstrates the importance of a shock/sheath magnetic structure. The result indicate that sunspot number and CME occurrence are useful measure of solar cycle activity, but they cannot by themselves predict geomagnetic storm intensity. The most physically informative parameters are the magnetic field strength, southward Bz, solar wind speed, electric field and duration of southward conditions.

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Data Availability Statement

The data used in this study are freely available from NASA Omni web, hourly and higher resolution. SILSO provides daily and monthly sunspot number series.

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