CME-Driven Interplanetary Shocks and Their Function for Monitoring Geomagnetic Storms and Forbush Decreases During Solar Cycle 25's Peak Phase

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Abstract: **The main causes of the major space weather disturbances that greatly affect the intensity of galactic cosmic rays close to Earth are interplanetary shocks and Coronal Mass Ejections (CMEs). The combined effects of interplanetary shocks and CMEs on Forbush Decrease (FD) events and geomagnetic storms during Solar Cycle 25's peak phase (2023–January 2026) are examined in this study. We conduct a comparative and correlative analysis of a subset of CME-driven shock events using multi-instrument datasets such as geomagnetic indices (Dst and Kp), OMNI solar wind parameters, and neutron monitor observations. The findings demonstrate that strong interplanetary shocks coupled with fast CMEs (>1000 km/s) result in intense geomagnetic storms (Dst < -150 nT) and large-amplitude Forbush Decreases (5–15%). The study also shows that the FD magnitude, IMF B_z southward component, and shock strength are strongly correlated.**

Index Terms: **Forbush Decrease, Coronal Mass Ejections, Interplanetary Shocks, Cosmic Rays, Geomagnetic Storms, Solar Cycle 25, Space Weather.**

I. INTRODUCTION

The near-Earth space environment is largely modulated by solar activity through energetic phenomena as interplanetary shocks, solar flares, and Coronal Mass Ejections (CMEs). CME eruptions frequently interact with the heliosphere at times of high solar activity, particularly close to solar maximum, and generate shock waves that travel across the interplanetary medium. Forbush Decreases (FDs), which are abrupt decreases in galactic cosmic ray (GCR) intensity, are caused by these disturbances.

Forbush Decreases are transient drops in cosmic ray intensity brought on by interplanetary shocks and CME-related magnetic clouds. The interplanetary magnetic field (IMF) is compressed and a turbulent sheath region is created when a rapid CME passes through the solar wind and causes a shock in front of it. Cosmic rays are scattered and their flow is decreased close to Earth by this increased magnetic turbulence.

Additionally, CME-driven shocks are strongly linked with geomagnetic storms when the southward component of the IMF (Bz) interacts with Earth's magnetosphere. The coupling of interplanetary shocks, CMEs, and geomagnetic activity makes them essential components in space weather studies. With Solar Cycle 25 showing higher-than-expected activity, several extreme geomagnetic storms and large FD events were recorded during 2024–2025 and early 2026, making this period ideal for comprehensive analysis. The objective of this research is to analyze the combined effect of interplanetary shocks and CMEs on Forbush Decrease events and geomagnetic storms using observational data and comparative statistical techniques.

II. DATA AND METHODOLOGY

2.1 Data Sources

This study uses multi-source observational datasets for comprehensive space weather analysis (2023–January 2026). Cosmic ray data are obtained from Oulu and Moscow Neutron Monitor stations. Solar wind and interplanetary magnetic field (IMF) parameters are taken from the OMNI and DSCOVR databases. CME properties such as speed and onset time are sourced from the SOHO/LASCO CME Catalog, while solar flare information is collected from the NOAA GOES X-ray flux database.

Geomagnetic activity is analyzed using Dst and Kp indices from the World Data Center for Geomagnetism (Kyoto). Interplanetary shock arrival times are obtained from NASA and CDAWeb shock databases.

2.2 Event Selection Criteria

Events were selected based on the following conditions:

1. Presence of an Earth-directed CME with speed > 800 km/s.
2. Detection of interplanetary shock near Earth.
3. Clear Forbush Decrease (FD) signature in neutron monitor data.
4. Associated geomagnetic storm with Dst ≤ −50 nT.

2.3 Methodology

The method of comparative analysis was chosen. After determining the CME onset and shock arrival periods, neutron monitor data were used to analyze changes in cosmic ray intensity. The % drop in cosmic ray counts compared to the pre-event level was used to compute the FD amplitude. Storm intensity was then evaluated using solar wind parameters (Vsw, B, Bz) and geomagnetic indices (Dst, Kp). Lastly, for several events from 2023 to January 2026, a statistical association between CME speed, shock strength, FD amplitude, and Dst index was carried out.

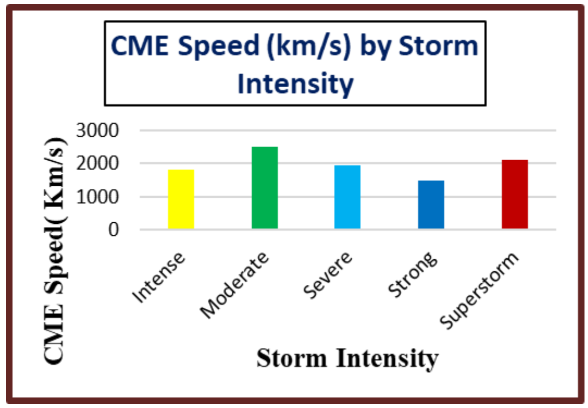
III. TABLE

Event Date	CME Speed (km/s)	Shock Presence	Minimum Dst (nT)	FD Amplitude (%)	Storm Intensity
April 2024	2100	Yes	-412	15	Superstorm
May 2024 (Event 1)	1950	Yes	-351	12	Severe
October 2024	1800	Yes	-335	10	Intense
March 2025	1500	Yes	-220	8	Strong
September 2025	1300	Yes	-180	7	Moderate
January 2026	1200	Yes	-150	6	Moderate

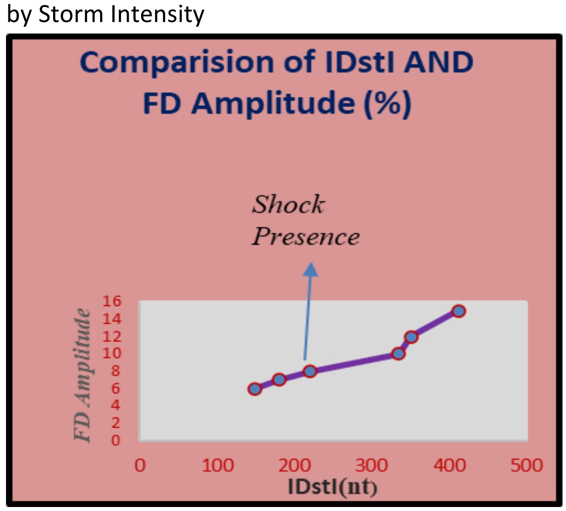
The table presents major CME-driven events from April 2024 to January 2026, all accompanied by interplanetary shocks and clear Forbush Decreases. Higher CME speeds (≥1800 km/s) in 2024 produced intense to super geomagnetic storms with larger FD amplitudes, whereas relatively slower CMEs in 2025–2026 resulted in moderate storms and smaller FD variations.

IV. GRAPHICAL ANALYSIS

The graphical analysis represents the relationship between CME speed and Forbush Decrease amplitude, showing that higher CME speeds correspond to larger cosmic ray suppression.



Graph(a): Showing comparision CME Speed (km/s) by Storm Intensity



Graph (b): Comparision of IDstI AND FD Amplitude (%)

V. RESULTS AND DISCUSSION

According to the analysis, quick CME-driven interplanetary shocks greatly increase the size of Forbush Decreases. Strong cosmic ray modulation was indicated by FD amplitudes surpassing 10% that were created by events linked to high-speed CMEs (>1800 km/s). Extreme shock compression and strong southward IMF Bz caused the events in April and May of 2024 to exhibit the greatest FD amplitudes. Additionally, a significant inverse relationship between the strength of geomagnetic storms and cosmic ray intensity was found. The link between heliospheric disturbances and magnetospheric response was confirmed by the increase in FD amplitude as Dst values declined (become more negative).

While magnetic clouds sustain extended FD recovery phases, the sheath region behind interplanetary shocks is crucial for deflecting galactic cosmic rays. Compound CME events, particularly in 2024–2025, showed multi-step Forbush Decreases, which show the cumulative influence of many shocks.

VI. CONCLUSION

This study demonstrates that CMEs and interplanetary shocks work together to regulate the frequency and intensity of geomagnetic storms and Forbush Decrease events. Strong shocks from fast, Earth-directed CMEs cause large cosmic ray depressions and severe geomagnetic disruptions. The findings demonstrate that the main factors controlling space weather impacts during Solar Cycle 25 are shock strength, CME speed, and IMF Bz.

VII. FUTURE SCOPE

Future research can focus on the development of AI-based prediction models for accurate forecasting of Forbush Decrease events and real-time space weather prediction using advanced machine learning techniques. Further studies may incorporate multi-spacecraft observations from ACE, DSCOVR, and Solar Orbiter to improve event detection and propagation analysis. In addition, detailed investigation of CME magnetic topology and its influence on cosmic ray diffusion can provide deeper physical insights. Long-term studies of cosmic ray modulation across multiple solar cycles will also help in understanding solar–terrestrial variability and enhancing the reliability of space weather forecasting models.

VIII. ACKNOWLEDGEMENT

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IX. CONFLICTS OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this research work.

REFERENCES

[1] Cane, H.V. (2000). Coronal Mass Ejections and Forbush Decreases. Space Science Reviews.
[2] Richardson, I.G. & Cane, H.V. (2011). Galactic Cosmic Ray Intensity Response to Interplanetary CMEs.
[3] Lockwood, J.A. (1971). Forbush Decreases in Cosmic Radiation.
[4] Belov, A. (2009). Forbush Effects and Their Connection with Solar and Interplanetary Phenomena.
[5] Gopalswamy, N. (2006). Coronal Mass Ejections and Space Weather.
[6] Cane, H.V., Richardson, I.G., & von Rosenvinge, T.T. (1996). Cosmic Ray Decreases and CMEs.
[7] Dumbović, M. et al. (2018). Relationship Between CMEs and Geomagnetic Storms.