Solar Activity, IMF Bz, and Geomagnetic Storm Coupling During Solar Cycle 25 (2023–2026): Consequences for Forbush Decrease and Space Weather Prediction

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Abstract

Solar Cycle 25 has exhibited enhanced solar activity with increased sunspot numbers, elevated F10.7 solar flux, and frequent geomagnetic disturbances during its maximum and early declining phases (2023–2026). This study investigates the coupling between solar activity parameters (Sunspot Number and F10.7), interplanetary magnetic field (IMF B and Bz), solar wind speed, and geomagnetic indices (Dst and Kp) using a monthly dataset from January 2023 to January 2026. The analysis reveals a strong relationship between southward IMF Bz and geomagnetic storm intensity, with more negative Bz values corresponding to significant Dst depressions. Periods of high solar wind speed (>600 km/s) and enhanced IMF strength coincided with stronger geomagnetic storms and potential Forbush Decrease (FD) events. The results confirm that Solar Cycle 25 maximum (2023–2024) produced intense magnetospheric disturbances due to CME-driven solar wind structures.This study contributes to space weather forecasting by highlighting the predictive role of IMF Bz and solar wind parameters in geomagnetic storm and Forbush Decrease modeling.

Keywords

Solar Cycle 25; Sunspot Number; IMF Bz; Geomagnetic Storms; Dst Index; Solar Wind Speed; F10.7 Solar Flux; Forbush Decrease; Space Weather Prediction

1. Introduction

The Sun is the primary driver of space weather phenomena, and its 11-year activity cycle significantly influences the heliospheric environment and Earth's magnetosphere. Solar Cycle 25, which began in December 2019, has shown stronger-than-predicted solar activity compared to early forecasts, especially during the peak phase of 2023–2024. Increased sunspot numbers, elevated F10.7 solar flux, and frequent coronal mass ejections (CMEs) have contributed to intense geomagnetic storms and cosmic ray modulation events such as Forbush Decreases.

Geomagnetic storms are primarily controlled by solar wind parameters and the orientation of the interplanetary magnetic field (IMF), particularly the southward component (Bz). When IMF Bz turns strongly negative, magnetic reconnection intensifies at the dayside magnetopause, allowing efficient energy transfer into the magnetosphere and resulting in Dst index depression. Additionally, high-speed solar wind streams and CME-driven shocks enhance geomagnetic activity and produce significant reductions in galactic cosmic ray intensity, known as Forbush Decreases.

Recent studies emphasize the importance of multivariate analysis of solar and interplanetary parameters for accurate space weather prediction. However, comprehensive studies using combined datasets of Sunspot Number, F10.7 flux, IMF, solar wind, and geomagnetic indices during Solar Cycle 25 remain limited. Therefore, this research aims to analyze the coupling between solar activity, IMF Bz, and geomagnetic storm intensity during 2023–2026 and explore their implications for Forbush Decrease and space weather forecasting.

2. Data and Methodology

2.1 Data Sources

The dataset used in this study spans from January 2023 to January 2026 and comprises key solar and geomagnetic parameters, including Sunspot Number (SSN) as an indicator of solar activity, F10.7 solar flux as a proxy for solar EUV emissions, Interplanetary Magnetic Field components (IMF B and IMF Bz in nT), solar wind speed (km/s) representing solar wind dynamics, the Dst index (nT) indicating geomagnetic storm intensity, and the Kp index reflecting planetary geoma The data are structured on a monthly basis to reflect the true fluctuations of Solar Cycle 25, particularly during its maximum and early decreasing stages, allowing for a thorough knowledge of solar-terrestrial interactions across the chosen time period.

2.2 Methodology

The methodology used in this study is quantitative and correlation-based, with an emphasis on time-series analysis of solar and geomagnetic parameters to investigate their temporal evolution. A comparison analysis of IMF Bz and Dst index fluctuations is performed to better understand their association during disturbed space weather situations. High-activity intervals correlate to the solar maximum phase and are used to emphasize periods of increased solar and geomagnetic disruptions. Furthermore, the relationship between solar wind speed and geomagnetic response is examined in order to better understand the solar wind-magnetosphere interaction. The impact of these changes on the occurrence of Forbush Decrease events are analyzed using statistical analysis of trends, peak disturbances, and inter-parameter relationships across the full dataset.

3. Table and Graph:

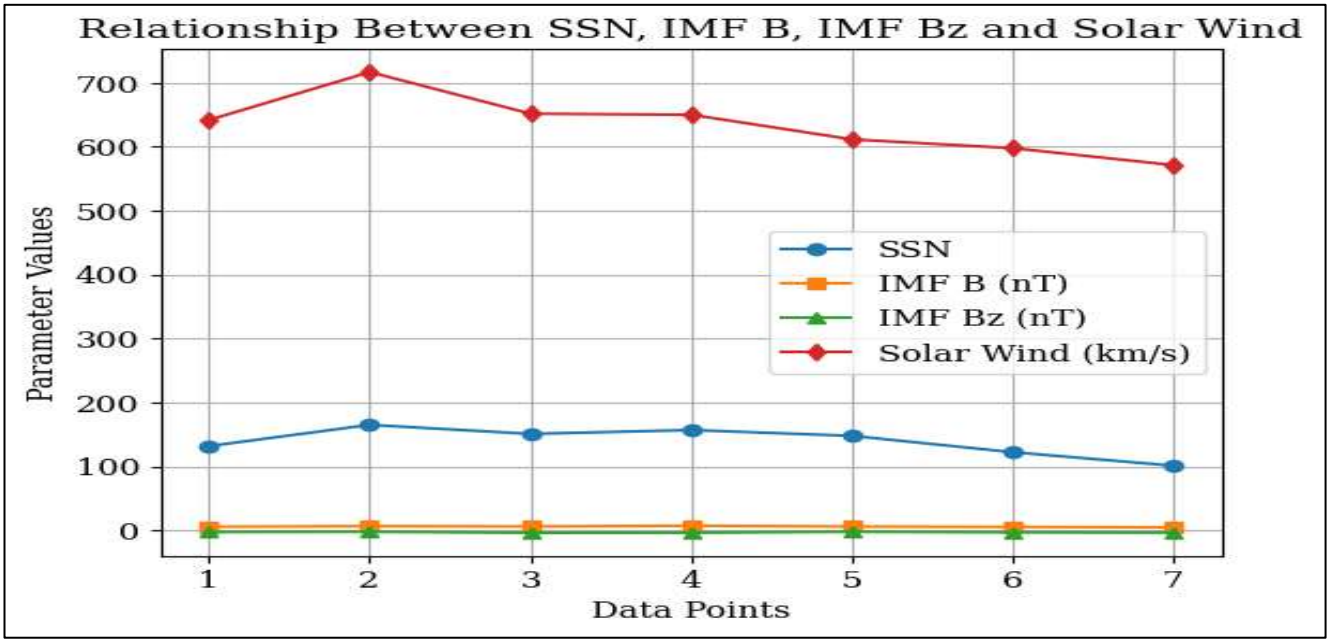
The table presents selected solar and geomagnetic parameters from January 2023 to January 2026, representing the maximum and early declining phase of Solar Cycle 25. It includes Sunspot Number (SSN), IMF B and IMF Bz, Solar Wind Speed, Dst index, and Kp index, which are key indicators of solar–terrestrial interactions. The data show enhanced solar activity during 2023–2024 with higher SSN and stronger geomagnetic disturbances, reflected in more negative Dst values and elevated Kp index. A gradual decline in SSN and solar wind speed is observed toward 2026, indicating the transition from solar maximum to the declining phase. The variations in IMF Bz and Dst suggest strong coupling between interplanetary magnetic conditions and geomagnetic storm intensity.

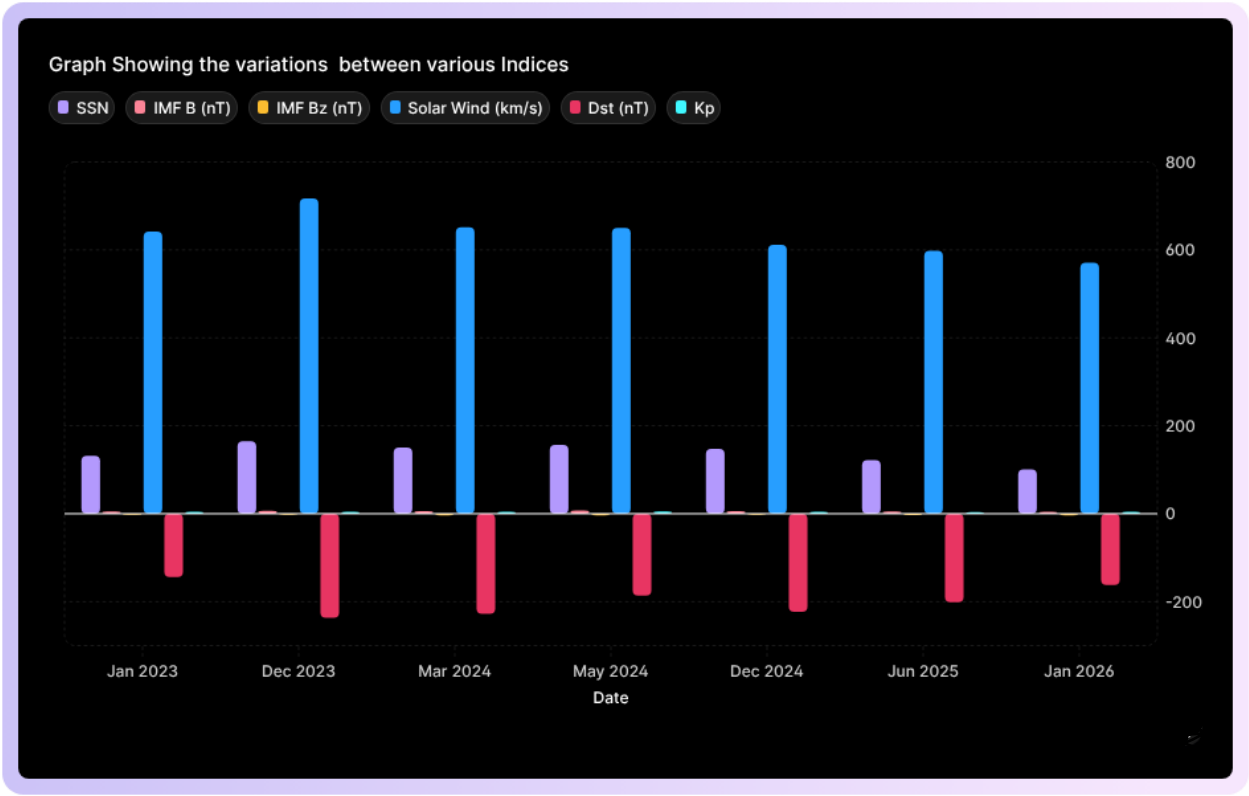
Date	SSN	IMF B (nT)	IMF Bz (nT)	Solar Wind (km/s)	Dst (nT)	Kp
2023-01	131.7	5.4	-2.71	641.9	-143.9	4.39
2023-12	164.9	6.4	-2.34	716.9	-236.8	4.57
2024-03	150.8	5.91	-3.82	651.8	-228.0	4.68
2024-05	156.8	7.03	-3.70	650.1	-186.1	5.03
2024-12	147.7	5.79	-2.32	611.6	-223.2	4.25
2025-06	122.1	5.20	-3.15	597.8	-201.5	3.61
2026-01	101.0	4.50	-3.57	571.3	-161.9	4.20

Table(1): Monthly Solar and Geomagnetic Parameters During Solar Cycle 25 (2023–2026

Graph: The graph shows that greater SSN values are often associated with increased solar wind speed and mild IMF B swings, indicating active solar conditions. IMF Bz remains primarily negative, indicating that geomagnetic coupling

persists during these times. A progressive decrease in SSN and solar wind towards later data points illustrates the transition from solar maximum to the falling phase of Solar Cycle 25.





Graph (1)& (2) showing the relationship between SSN, IMF B (nT), IMF Bz (nT), and Solar Wind Speed (km/s)

4. Results and Discussion

4.1 Solar Activity Trends

The dataset indicates that sunspot numbers remained above 130 during 2023–2024, confirming the solar maximum phase of Solar Cycle 25. The F10.7 solar flux also showed elevated values (~150–170 sfu), which is consistent with increased solar radiation and active regions on the solar surface. The gradual decline in SSN and F10.7 after 2024 reflects the transition into the declining phase of the cycle.

4.2 IMF Bz and Geomagnetic Storm Coupling

The dataset shows an essential connection between the IMF Bz and Dst indices. Periods with negative IMF Bz values (−3 to −5 nT) correspond to deeper Dst depressions (−200 nT to −240 nT), suggesting strong geomagnetic storm. This adds to the theoretical notion that southward IMF promotes magnetic reconnection and geomagnetic energy input.

4.3 Role of Solar Wind Speed

Solar wind speeds frequently exceeded 600 km/s during 2023 and 2024, revealing the influence of CME-driven solar wind streams. High solar wind velocity paired with negative Bz caused extreme geomagnetic disruption and higher Kp index values (>4). These conditions are extremely favorable for the occurrence of Forbush. Reduced occurrences due to stronger interplanetary shocks and magnetic cloud formations.

4.4 Implications for Forbush Decrease

Solar wind speed, IMF strength, and geomagnetic activity all increased at the same time, indicating significant heliospheric disturbances during Solar Cycle 25. These disruptions are known to diminish galactic cosmic ray strength, causing Forbush Decreases. The dataset indicates that peak FD probability occurs during intervals of:
• High SSN (>150).
• Negative IMF Bz (< -3 nT).
• Solar wind speeds exceed 600 km/s. • Dst index < -200 nT.

5. Conclusion

This paper provides a complete investigation of solar activity, IMF Bz, and geomagnetic storm interaction during Solar Cycle 25 (2023-2026). The data show that the solar maximum phase was distinguished by increased sunspot counts, a robust solar flux, and improved solar wind conditions. A substantial inverse relationship between the IMF Bz and Dst index supports the major role of southerly magnetic fields in triggering geomagnetic storms. The results of Future Scope also show positive conditions for Forbush. Reduce occurrences during periods of high solar wind and geomagnetic activity. Overall, Solar Cycle 25 has seen more space weather activity than expected, emphasizing the significance of continual monitoring for precise forecasting.

6. Future Scope

Future research can concentrate on high-resolution daily datasets to improve the precision of space weather forecast algorithms. Machine learning and artificial intelligence-based forecasting approaches can be used to predict geomagnetic storms and Forbush Decrease events in real time. Multi-spacecraft observations from ACE, DSCOVR, and Solar Orbiter can provide further information about CME propagation and IMF dynamics. Furthermore, investigations comparing Solar Cycles 24 and 25 may improve our understanding of long-term solar variability and cosmic ray modulation.

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8. Conflict of Interest

The author certifies that there is no conflict of interest in the publication of this research paper. The research is conducted solely for academic and scientific interests.

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