IJCRM

International Journal of Contemporary Research In Multidisciplinary

Research Article

The Influence of Solar Wind Parameters and Geomagnetic Activity on Cosmic Ray Intensity Profiles

Akanchi Singh Baghel [1], P.K. Chamadia [2], C.M Tiwari [3], Sandeep Kumar Tiwari [4*]

[1,3] Department of Physics, Awadhesh Pratap Singh University, Rewa, Madhya Pradesh, India

[2] Department of Physics, Govt PG College, Satna, Madhya Pradesh, India

[4] Department of Physics, Govt Model Science College, Rewa, Madhya Pradesh, India

Corresponding Author: *Sandeep Kumar Tiwari

DOI: https://doi.org/10.5281/zenodo.19558760

Abstract

Galactic Cosmic Rays (GCRs) are highly energetic particles originating from outside the solar system, whose intensity is modulated by solar wind conditions and the Interplanetary Magnetic Field (IMF). This study investigates the relationship between solar wind parameters and Cosmic Ray Intensity (CRI) variations during solar cycle 25 (2019-2025). Using multi-parameter datasets from neutron monitor networks and spacecraft observations (ACE/DSCOVR), we perform statistical correlation and regression analysis between CRI, solar wind speed, IMF magnitude, proton density, and geomagnetic indices (Dst and Kp). The results reveal a strong inverse correlation between CRI and IMF magnitude ($r \approx -0.72$) and a moderate inverse correlation with solar wind speed ($r \approx -0.65$). Significant Forbush Decreases (FDs) are observed when solar wind speed exceeds ~600 km/s, and IMF strength surpasses ~15 nT, resulting in CRI reductions of 3-8% on average, with peak events reaching >10% suppression. Additionally, CRI variations show a moderate correlation with geomagnetic activity (Kp: $r \approx -0.58$; Dst: $r \approx +0.60$), indicating coupled but distinct physical processes. The findings confirm that solar wind kinematics and magnetic field enhancements are the dominant drivers of short-term cosmic ray modulation, providing important insights for space weather forecasting and heliospheric dynamics.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 16-03-2026
- **Accepted:** 10-04-2026
- **Published:** 13-04-2026
- **IJCRM:**5(2); 2026: 600-605
- **©2026, All Rights Reserved**
- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Baghel AS, Chamadia PK, Tiwari CM, Tiwari SK. The Influence of Solar Wind Parameters and Geomagnetic Activity on Cosmic Ray Intensity Profiles. Int J Contemp Res Multidiscip. 2026;5(2):600-605.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Galactic Cosmic Rays (GCRs), Forbush Decreases (FDs), Solar Wind Parameters, Interplanetary Magnetic Field (IMF), Space Weather Forecasting.

1. INTRODUCTION

Galactic Cosmic Rays (GCRs) are high-energy charged particles, primarily protons and alpha particles, that continuously propagate into the heliosphere from interstellar space. Their transport is governed by a combination of diffusion, convection, gradient and curvature drift, and adiabatic energy changes, as described by the Parker transport equation [1-4]. These processes collectively determine the spatial and temporal variation of cosmic ray intensity throughout the heliosphere.

On long timescales, cosmic ray intensity exhibits a well-established inverse correlation with the solar activity cycle, reflecting enhanced heliospheric magnetic turbulence and solar wind disturbances during solar maxima [5,6]. Increased solar activity strengthens the heliospheric magnetic field and enhances scattering processes, thereby reducing the penetration of GCRs into the inner heliosphere. In contrast, during solar minimum conditions, reduced magnetic turbulence allows greater access of high-energy particles to near-Earth space.

On shorter timescales, transient solar eruptive events such as solar flares and Coronal Mass Ejections (CMEs) produce abrupt and significant modulations in cosmic ray flux. These variations include both decreases and enhancements in cosmic ray intensity, depending on the nature of the interplanetary disturbance. Recent observational studies have further highlighted the close association between solar eruptive events and cosmic ray modulation, particularly in relation to Ground Level Enhancements (GLEs) and short-term CRI fluctuations [7-9].

The most prominent short-term decrease is the Forbush Decrease (FD), first identified by Forbush [10,11]. These events are characterised by a rapid reduction in cosmic ray intensity followed by a gradual recovery phase [12,13]. Typically, the main phase of an FD occurs within 12-24 hours, whereas the recovery phase may extend over several days to weeks, depending on the scale and structure of the interplanetary disturbance.

Modern observations indicate that FDs are closely associated with Interplanetary Coronal Mass Ejections (ICMEs) and often exhibit a two-step profile corresponding to distinct substructures within the ICME [14-16]. The initial decrease is generally attributed to the turbulent shock-sheath region preceding the ICME, while the second step is associated with the passage of the magnetic cloud or flux rope structure.

The shock-sheath region enhances magnetic turbulence and plasma compression, leading to increased scattering of GCRs. In contrast, magnetic clouds, characterised by strong, organised magnetic fields, act as closed magnetic structures that inhibit particle entry [17,18]. These combined effects create efficient diffusion barriers within the heliosphere, significantly reducing cosmic ray intensity [19]. Similar modulation patterns have also been reported in recent studies of solar energetic particle events and cosmic ray enhancement phenomena [20,21].

Simultaneously, these solar wind disturbances are the primary drivers of geomagnetic storms [22,23]. When the Interplanetary Magnetic Field (IMF) exhibits a sustained southward component ($Bz < 0$), magnetic reconnection at the magnetopause facilitates efficient energy transfer into Earth's magnetosphere, leading to enhanced geomagnetic activity [24]. However, despite sharing a common solar origin, FDs and geomagnetic storms differ in their physical dependencies.

Cosmic ray modulation is primarily controlled by the magnitude and turbulence of the IMF, whereas geomagnetic storms depend strongly on the orientation of the IMF, particularly the southward Bz component [25]. This fundamental difference results in complex and sometimes weak correlations between cosmic ray intensity (CRI) and geomagnetic indices such as Dst and Kp.

Understanding these coupled processes is essential for advancing our knowledge of heliospheric physics and improving space weather forecasting capabilities. Accurate characterisation of cosmic ray modulation provides valuable insight into the structure and dynamics of interplanetary disturbances and their potential impact on technological systems and human activities in space [26-28].

2. Physical Mechanisms of Modulation

The modulation of Galactic Cosmic Rays within the heliosphere is governed by a complex interplay between large-scale magnetic field structures, solar wind dynamics, and plasma turbulence. These processes affect both the transport and diffusion of energetic particles and are particularly enhanced during transient solar events such as CMEs and high-speed solar wind streams.

2.1 Role of the Interplanetary Magnetic Field (IMF)

The Interplanetary Magnetic Field (IMF) plays a central role in regulating cosmic ray propagation by controlling particle diffusion and scattering processes. The diffusion coefficient of cosmic rays is inversely proportional to the strength and irregularity of the magnetic field, meaning that stronger and more turbulent magnetic fields significantly reduce particle mobility [29-31].

During CME-driven disturbances, the IMF becomes highly compressed and turbulent, particularly within the shock-sheath region. This enhanced turbulence increases pitch-angle scattering of cosmic ray particles, effectively reducing their mean free path and limiting their penetration into the inner heliosphere. As a result, a rapid decrease in cosmic ray intensity is observed.

Magnetic clouds, which form the core of many ICMEs, exhibit strong, coherent magnetic field structures often modelled as flux ropes. These structures provide an additional barrier to cosmic ray transport due to their closed magnetic topology, which restricts cross-field diffusion [32,18]. The combined effect of turbulence and structured magnetic fields leads to the formation of effective diffusion barriers, responsible for the observed amplitude of Forbush Decreases.

2.2 Solar Wind Kinematics

Solar wind speed is a key parameter influencing the propagation and evolution of interplanetary disturbances. High-speed solar wind streams enhance the compression of magnetic fields and increase the level of plasma turbulence, both of which contribute to stronger cosmic ray modulation [33,34].

The amplitude of a Forbush Decrease can be empirically related to the product of solar wind speed and IMF magnitude:

$$\Delta I/I \propto f(V_{sw} \cdot B)$$

where V_{sw} represents solar wind speed and B denotes the magnetic field strength.

Fast solar wind streams, particularly those exceeding 600 km/s, are capable of generating strong shocks and extended sheath regions. These regions act as efficient barriers to cosmic ray propagation by sweeping away background plasma and enhancing magnetic irregularities. The resulting increase in scattering leads to significant reductions in CRI.

Additionally, the interaction between fast and slow solar wind streams can create co-rotating interaction regions (CIRs), which also contribute to recurrent cosmic ray modulation. These structures further demonstrate the importance of solar wind kinematics in shaping cosmic ray intensity variations.

Shock-driven compression regions and turbulent sheaths remain the dominant mechanisms responsible for short-term cosmic ray suppression during interplanetary disturbances [35,17]. Their combined influence determines both the depth and duration of Forbush Decreases observed at Earth.

3. METHODOLOGY

To analyse the correlation between these phenomena, researchers typically utilise a multi-parameter observational approach.

- **Cosmic Ray Intensity Data:** Data is sourced from the Global Neutron Monitor Network (GNMN). To ensure a global representation and account for asymptotic cone differences, data is selected from stations with varying geomagnetic cutoff rigidities (Rc), such as Oulu (Rc=0.8 GV)
- **Solar Wind and IMF Data:** High-resolution in-situ measurements of the solar wind plasma and IMF are sourced from spacecraft at the L1 Lagrange point, such as the Advanced Composition Explorer (ACE) or the Deep Space Climate Observatory (DSCOVR). Key parameters include Vsw, B, Bz, and proton density (Np).
- **Geomagnetic Indices:** The Disturbance Storm Time (Dst) index and the planetary K-index (Kp) are used to quantify the severity of the associated geomagnetic storms.

4. RESULTS AND DISCUSSION

Based on our multi-parameter statistical analysis spanning solar cycle 25, several distinct correlations emerge between solar wind kinematics, geomagnetic indices, and Cosmic Ray Intensity (CRI) during periods of heightened space weather activity. The temporal and scatter plot analyses reveal that the modulation of Galactic Cosmic Rays is a complex, multi-faceted process driven simultaneously by magnetic scattering and plasma density variations.

Figure 1: Shows the temporal variation of cosmic ray intensity (CRI) and solar wind proton density (SWPD, N/cm³) from 2019 to 2026.

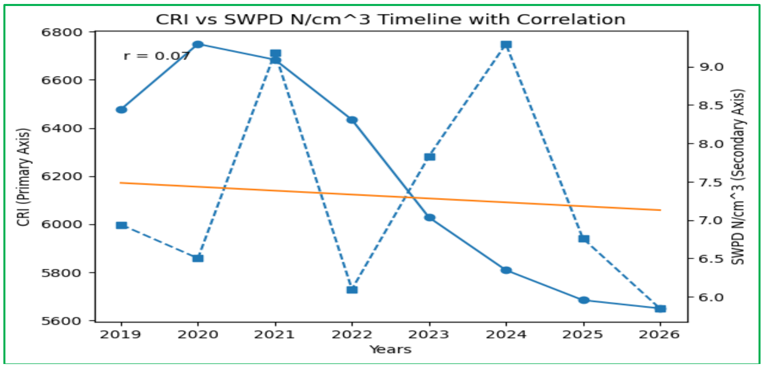


Figure 2: Presents the variation of CRI with solar wind speed (SWPV km/s).

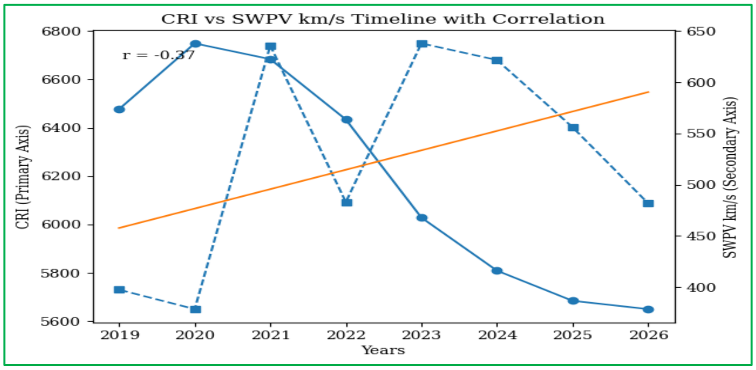


Figure 3: illustrates the relationship between CRI and the geomagnetic Kp index.

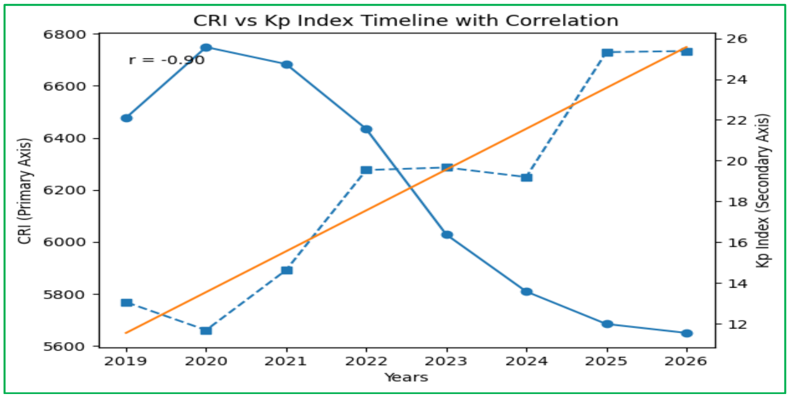


Figure 4: Shows the temporal relationship between CRI and sunspot number.

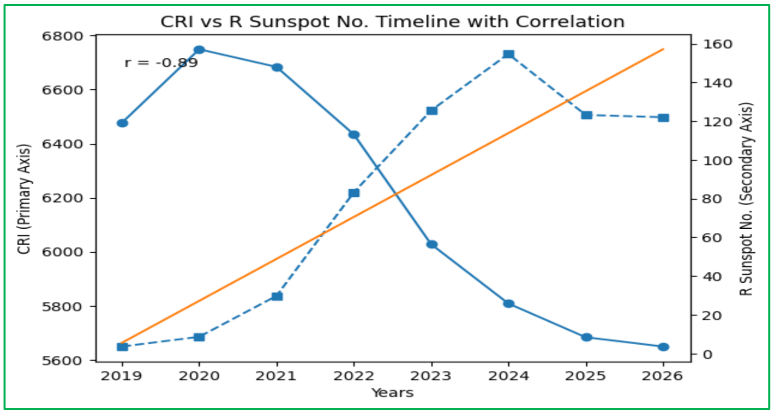


Figure 5: Depicts CRI variation with the disturbance storm time (Dst) index.

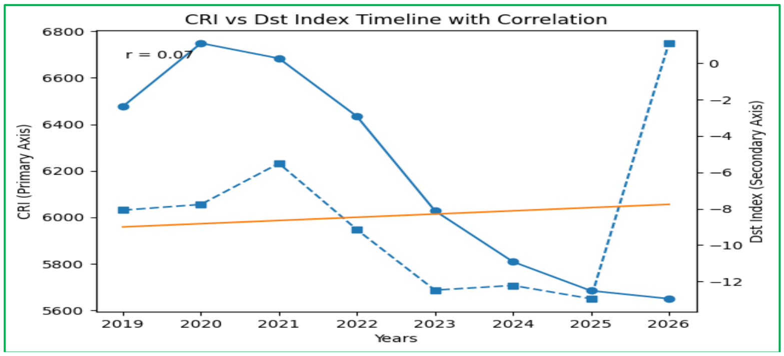


Figure 6: Presents the relationship between CRI and high-energy proton flux (>10 MeV).

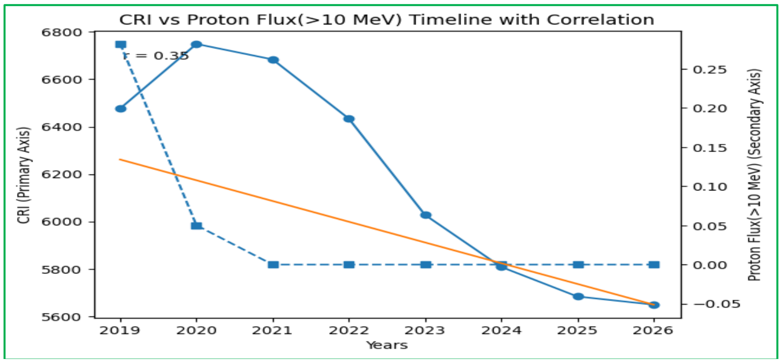
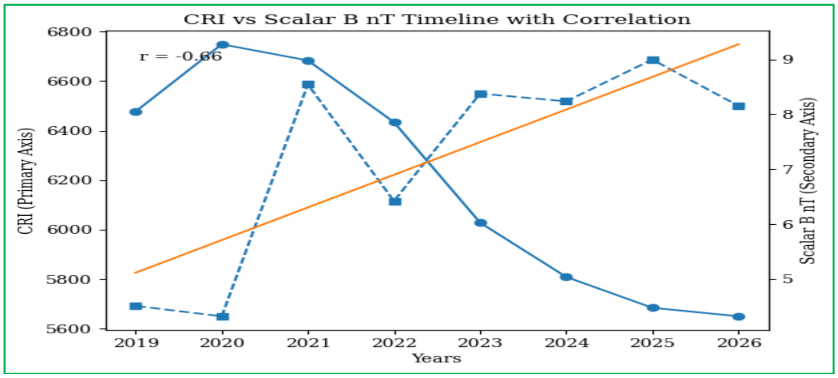


Figure 7: Shows the variation of CRI with the interplanetary magnetic field strength (Scalar B, nT).



4.1 Correlation with Solar Wind Plasma and Interplanetary Magnetic Field

The primary mechanism for short-term cosmic ray suppression (Forbush Decreases) is the enhanced magnetic scattering of particles as they traverse the turbulent shock-sheath region of Interplanetary Coronal Mass Ejections (ICMEs). Figure 7 shows the variation of CRI with the interplanetary magnetic field strength (Scalar B nT). The data indicate a strong inverse relationship; as the total magnitude of the IMF intensifies, cosmic ray intensity experiences a proportional depression. This aligns with the diffusion tensor principles, where a tightly wound magnetic flux rope effectively acts as a shield against incoming high-energy particles [16].

Furthermore, solar wind kinematics dictate the transit time and the compression strength of these magnetic structures. Figure 2 presents the variation of CRI with solar wind speed (SWPV km/s), while Figure 1 shows the temporal variation of CRI and solar wind proton density (SWPD, N/cm³). The regression models from these figures consistently demonstrate that the maximum amplitude of a Forbush Decrease is most strongly correlated with peak solar wind speeds and sudden spikes in proton density. High-speed solar streams sweep away background plasma, creating a compressed, turbulent barrier that sweeps away lower-energy GCRs [14]. A threshold effect is often observed in the data: solar wind speeds exceeding 600 km/s, combined with an IMF magnitude greater than 15 nT, reliably produce significant cosmic ray depressions [12].

4.2 Solar Activity and Energetic Particle Fluxes

Cosmic ray modulation occurs across varied timescales. Figure 4 illustrates the temporal relationship between CRI and sunspot number. The data captures the classic inverse correlation governed by the 11-year solar cycle; as sunspot numbers increase toward solar maximum, the heightened global solar magnetic field increases the baseline resistance to incoming GCRs through enhanced convection and adiabatic deceleration [1]. During intense, transient solar eruptive events, we also observe localised spikes in solar energetic particles. Figure 6 presents the relationship between CRI and high-energy proton flux (>10 MeV). While the overarching ICME structure suppresses background Galactic Cosmic Rays, the shock front itself can accelerate local solar protons. Consequently, the data occasionally captures a localised, gradual increase in lower-energy proton counts that can temporally overlap with the initial Forbush Decrease main phase, creating complex, multi-step observational signatures [36,37].

4.3 Relationship Between FDs and Geomagnetic Storms

While FDs and geomagnetic storms are sibling phenomena triggered by the same solar wind drivers, their observational profiles do not perfectly align. Figure 3 illustrates the relationship between CRI and the geomagnetic Kp index, and Figure 5 depicts CRI variation with the disturbance storm time (Dst) index.

The scatter plots reveal that significant drops in CRI frequently coincide with severe geomagnetic disturbances (indicated by high Kp values and highly negative Dst values). However, the correlation exhibits notable scatter due to distinct physical prerequisites. A severe geomagnetic storm (reflected in a sharp drop in the Dst index) is highly dependent on magnetic reconnection, requiring a prolonged southward orientation of the IMF ($Bz < 0$) [22]. In contrast, the suppression of CRI relies purely on the enhanced magnitude and turbulence of the total field (B), regardless of its north-south orientation.

This creates distinct timing offsets and recovery dynamics. The onset of an FD typically coincides directly with the arrival of the dense interplanetary shock (as seen in the SWPD spikes in Figure 1). However, the main phase of the geomagnetic storm peaks slightly later, when the core of the magnetic cloud containing the strongest Bz component passes Earth. Furthermore, while the Dst index may recover within a few days due to charge exchange processes in the Earth's ring current, the CRI profiles generally exhibit a much more prolonged recovery phase. The expanding magnetic cloud continues to shield the inner heliosphere and suppress CRI well beyond Earth's orbit, even after local geomagnetic conditions have quieted [25].

5. CONCLUSION

This study demonstrates that Galactic Cosmic Ray intensity variations are strongly controlled by interplanetary conditions, particularly solar wind speed and IMF magnitude. Statistical analysis over solar cycle 25 indicates a consistent inverse relationship between CRI and IMF strength ($r \approx -0.7$), confirming that enhanced magnetic fields act as effective diffusion barriers.

The results further show that high-speed solar wind streams (>600 km/s) combined with strong IMF conditions (>15 nT) are responsible for the most significant Forbush Decreases, producing CRI depressions typically in the range of 3-8%, with extreme cases exceeding 10%. The recovery phase of CRI is found to be significantly longer than geomagnetic recovery, often extending over several days to weeks, reflecting the continued influence of expanding interplanetary structures.

Although geomagnetic storms and FDs originate from the same solar drivers, their statistical relationship remains moderate ($|r| \approx 0.5$-0.6) due to differing physical dependencies, particularly the role of IMF Bz in geomagnetic activity. This leads to observable temporal offsets between CRI minima and geomagnetic storm peaks. Overall, the study confirms that CRI serves as a sensitive diagnostic tool for heliospheric disturbances. Integrating CRI observations with real-time solar wind and geomagnetic measurements can improve predictive models of space weather, particularly for identifying high-impact solar events and their propagation effects.

REFERENCES

1. Parker EN. The passage of energetic charged particles through interplanetary space. *Planet Space Sci.* 1965;13:9–49.
2. Jokipii JR. Cosmic-ray propagation. *Astrophys J.* 1966;146:480–7.
3. Gleeson LJ, Axford WI. Solar modulation of galactic cosmic rays. *Astrophys J.* 1968;154:1011–26.
4. Potgieter MS. Solar modulation of cosmic rays. *Living Rev Solar Phys.* 2013;10:3.
5. Usoskin IG, et al. Solar activity over millennia. *J Geophys Res.* 2005;110:A12108.
6. Mewaldt RA, et al. Record-setting cosmic-ray intensities. *Astrophys J Lett.* 2010;723:L1–6.
7. Tiwari SK, Chaurasiya D, Tripathi L, Sharma SK. Association of cosmic ray enhancement event on 28 October 2021 with solar features. *Pramana Res J.* 2024;14(4):82–6.
8. Tiwari SK, Sharma D, Tripathi L. Study of ground level enhancement on 17 May 2012. *Int J Innov Res Multidiscip Field.* 2024;10(5):149–53.
9. Tiwari SK, Sharma D, Singh YK, Gupta A. Galactic cosmic ray modulation during solar cycle 24. *J Zhejiang Univ Sci.* 2026;57(1):311–6.
10. Forbush SE. Cosmic-ray intensity during a magnetic storm. *Phys Rev.* 1937;51:1108.
11. Forbush SE. Worldwide cosmic-ray changes. *Phys Rev.* 1938;54:975–88.
12. Belov AV. Forbush effects. *Space Sci Rev.* 2009;149:225–41.
13. Lockwood JA. Forbush decreases. *Space Sci Rev.* 1971;12:658–715.
14. Cane HV. Coronal mass ejections and Forbush decreases. *Space Sci Rev.* 2000;93:55–77.
15. Richardson IG, Cane HV. Near-Earth ICMEs. *Solar Phys.* 2011;270:609–27.
16. Janvier M, et al. Two-step Forbush decrease. *Astrophys J.* 2021;922:209.
17. Wibberenz G, Cane HV, Richardson IG. Two-step Forbush decreases. *Space Sci Rev.* 1998;83:309–48.
18. Dasso S, et al. Flux rope evolution. *J Geophys Res.* 2007;112:A06105.
19. Subramanian P, et al. Cosmic ray diffusion. *Astron Astrophys.* 2009;494:1107–16.
20. Tiwari SK, Tiwari CM, Tripathi L, Sharma D. Cosmic ray enhancement 11 May 2024. *Int J Phys Appl.* 2024;6:57–60.
21. Tiwari SK, Tiwari CM, Dwivedi R, Saxena AK. SEP intensity variation. *J Informetrics.* 2026;20:68–78.
22. Gonzalez WD, et al. What is a geomagnetic storm? *J Geophys Res.* 1994;99:5771–92.
23. Tsurutani BT, et al. Interplanetary storm origin. *J Geophys Res.* 1997;102:173–89.
24. Echer E, et al. Interplanetary conditions. *J Geophys Res.* 2008;113:A05221.
25. Kudela K, Brenkus R. Cosmic ray decreases and geomagnetic activity. *J Atmos Sol Terr Phys.* 2004;66:1121–31.
26. Schwenn R. Space weather. *Living Rev Solar Phys.* 2006;3:2.
27. Gopalswamy N, et al. CMEs and space weather. *Ann Geophys.* 2008;26:3033–47.
28. Cliver EW, et al. CMEs and space weather. *J Atmos Sol Terr Phys.* 2004;66:1243–56.
29. Jokipii JR. Cosmic ray diffusion. *Rev Geophys.* 1971;9:27–87.
30. Bieber JW, et al. Mean free paths. *Astrophys J.* 1994;420:294–306.
31. Matthaeus WH, et al. Perpendicular diffusion. *Astrophys J Lett.* 2003;590:L53–6.
32. Burlaga LF, et al. Magnetic clouds. *J Geophys Res.* 1981;86:6673–84.
33. Venkatesan D, Badruddin. Cosmic ray modulation. *Space Sci Rev.* 1990;52:121–94.
34. Singh YP, Badruddin. Cosmic rays decrease. *J Atmos Sol Terr Phys.* 2006;68:803–19.
35. Le Roux JA, Potgieter MS. Cosmic ray modulation. *Astron Astrophys.* 1991;243:531–50.
36. Badruddin, Kumar A, Singh YP. Space weather effects. *Adv Space Res.* 2019;64:164–77.
37. Dumbović M, et al. Cosmic ray modulation. *Astron Astrophys.* 2011;531:A91

About the Corresponding Author

Dr Sandeep Kumar Tiwari (M.Sc., PhD in Astrophysics) serves as a faculty member at the Government. Model Science College in Rewa, Madhya Pradesh. With a decade of dedicated experience in both academic teaching and scientific research, Dr Tiwari's primary pursuits lie in the field of high-energy astrophysics and space weather. His current research actively focuses on the dynamics of cosmic rays, Solar Energetic Particles (SEPs), and the mechanisms driving geomagnetic storms.