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Analysis of Cosmic Ray Intensity Variations During Geomagnetic Storms and Interplanetary Disturbances in the Declining Phase of Solar Cycle 24

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Abstract: *This study examines the variability of galactic cosmic ray (GCR) intensity during geomagnetic storms and interplanetary disturbances in the declining phase of Solar Cycle 24. It focuses on the relationship between cosmic ray intensity and important solar-terrestrial parameters, including the interplanetary magnetic field (IMF), solar wind speed and plasma conditions, and geomagnetic indices such as Dst and Ap. Ground-based neutron monitor data are used to identify short-term cosmic ray variations, particularly Forbush decreases associated with disturbed solar wind conditions. The study gives special attention to the declining phase of Solar Cycle 24, during which overall solar activity decreased but significant interplanetary disturbances and geomagnetic storms continued to occur. Statistical techniques such as correlation analysis, superposed epoch analysis, and time-lag analysis are used to investigate the response of cosmic ray intensity to changes in solar wind and geomagnetic conditions. The analysis particularly considers the magnitude, timing, and recovery of cosmic ray decreases following interplanetary disturbances. Overall, the study aims to improve understanding of the short-term modulation of cosmic rays by solar and interplanetary disturbances. It also provides insight into the relationship between cosmic ray transport, solar wind conditions, geomagnetic activity, and space-weather variations during the declining phase of Solar Cycle 24..*

Keywords: Galactic Cosmic Rays (GCR), Cosmic Ray Intensity (CRI), Solar Cycle, Geomagnetic Storms, Interplanetary Magnetic Field (IMF), Solar Wind, Space Weather, Cosmic Ray

I. INTRODUCTION

Galactic cosmic rays (GCRs) are high-energy charged particles that enter the heliosphere from outside the solar system. Their intensity near Earth varies with solar activity and changes in the interplanetary environment, particularly the interplanetary magnetic field (IMF) and solar wind conditions. One of the major short-term variations in cosmic ray intensity is the Forbush decrease (FD), which is generally associated with interplanetary disturbances such as interplanetary coronal mass ejections (ICMEs) and high-speed solar wind streams.

Solar disturbances can also produce geomagnetic storms, which are commonly characterized by indices such as Dst and Ap. These disturbances can significantly influence the near-Earth cosmic ray environment. Solar Cycle 24 (2008–2019) provides an important period for investigating these solar terrestrial interactions, particularly during its declining phase when solar activity decreased but interplanetary disturbances and geomagnetic storms continued to occur.

In the present study, cosmic ray intensity variations during geomagnetic storms and interplanetary disturbances in the declining phase of Solar Cycle 24 are investigated using ground-based neutron monitor observations. The relationships between cosmic ray intensity, solar wind speed, IMF strength, Dst, and Ap indices are examined using statistical

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approaches. The study aims to improve understanding of the short-term modulation of cosmic rays and their relationship with solar activity, interplanetary disturbances, geomagnetic storms, and space-weather conditions.

Methodology :

The present study investigates variations in galactic cosmic ray (GCR) intensity during geomagnetic storms and interplanetary disturbances in the declining phase of Solar Cycle 24. The methodology involves the collection, processing, and statistical analysis of cosmic ray and solar-terrestrial parameters.

The data use of Oulu neutron monitor and the graph plot by Oulu neutron monitor from 2008 to 2019 in solar cycle 24. This data is analysed for short-term variations, particularly 'Forbush Decreases' (FDs) associated with interplanetary disturbances.

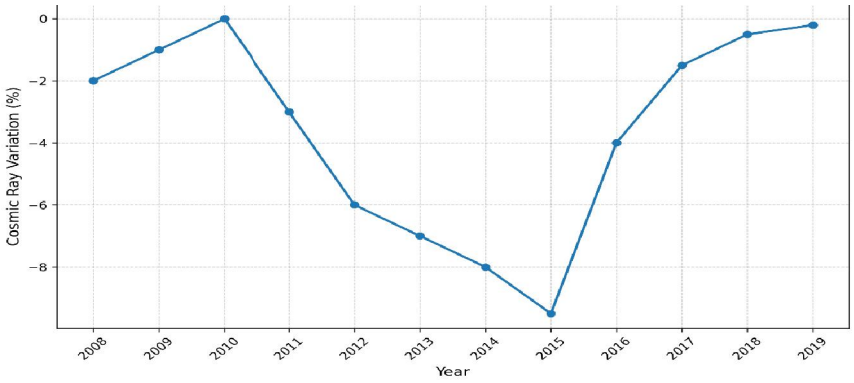


Figure.1 The graph shows the percentage variation in cosmic rays from 2008 to 2019

2008–2010: Cosmic ray variation changes from −2% to 0%, showing a gradual increase toward the reference level.

2011–2015: A clear declining trend is observed, from −3% to −9.5%.

2015: The maximum negative variation occurs at approximately −9.5%, representing the lowest value in the dataset.

2016–2019: Cosmic ray variation increases rapidly toward zero, reaching approximately −0.2% in 2019.

This graph shows an initial decline followed by a recovery, creating a clear low point around 2015.

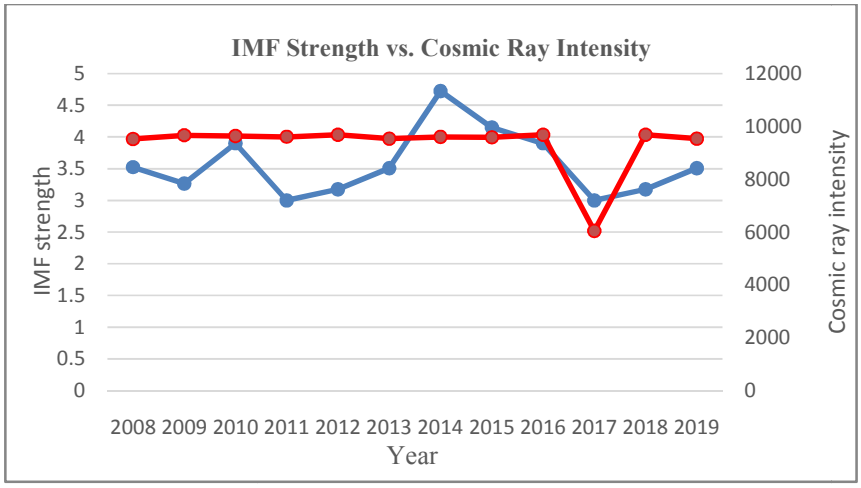


Figure: 2 The variation in Interplanetary Magnetic Field (IMF) strength and

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Cosmic Ray Intensity (CRI)

2008–2013: IMF strength fluctuates between approximately 3.0 and 3.9 nT, while cosmic ray intensity remains relatively stable, mostly around 9,500–9,700 counts.

2014–2016: IMF strength rises sharply, reaching its maximum of approximately 4.7 nT in 2014. Cosmic ray intensity remains comparatively stable, with no equally sharp decrease. This suggests that the inverse relationship is not clearly visible in every individual year.

2017: IMF strength falls to approximately 3.0 nT, while cosmic ray intensity drops sharply to around 6,000 counts. This is an unusual pattern because a weaker IMF would generally be expected to permit greater cosmic ray penetration. The 2017 value should therefore be checked against the original data for possible errors or inconsistencies.

2018–2019: IMF strength gradually increases from around 3.2 to 3.5 nT, while cosmic ray intensity returns to approximately 9,500–9,700 counts.

The data has been collected by Moscow neutron monitor. The graph illustrates the year-to-year variations in IMF strength and cosmic ray intensity during 2008–2019. Although cosmic ray intensity is generally expected to decrease as IMF strength increases, the plotted data do not establish a clear inverse correlation across all years.

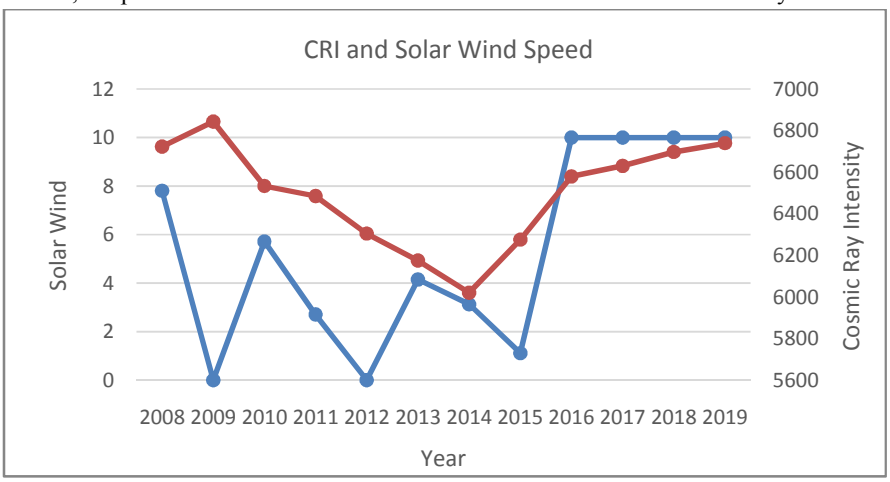


Figure:3 The variation in solar-wind speed and cosmic ray intensity from 2008 to 2019

The graph illustrates the variation in solar-wind speed and cosmic ray intensity from 2008 to 2019. It helps examine how changes in solar-wind conditions may influence the intensity of galactic cosmic rays (GCRs) reaching Earth. Blue line: Solar-wind speed, represented on the left vertical axis. Orange line: Cosmic ray intensity, represented on the right vertical axis.

2008–2009: Solar-wind values decrease sharply from approximately 7.8 to zero, while cosmic ray intensity increases from around 6,720 to 6,850. This appears to suggest an inverse relationship. However, a solar-wind speed of zero is physically implausible for an annual mean, so the plotted value should be checked.

2010–2012: Solar-wind values fluctuate, reaching zero again in 2012, while cosmic ray intensity declines steadily. This does not show a consistent inverse relationship.

2013–2015: Cosmic ray intensity reaches its minimum around 2014, at approximately 6,000 on the plotted scale, before rising in 2015. Solar-wind values also fluctuate during this period. The two variables do not consistently move in opposite directions.

2016–2019: Solar-wind values rise sharply to approximately 10 and remain constant. Cosmic ray intensity also increases steadily from approximately 6,580 to 6,770. Both variables therefore rise together during this period, suggesting a positive association in the plotted data.

The graph shows that solar-wind speed and cosmic ray intensity vary over the period 2008–2019, but their relationship changes over time. Some intervals appear to suggest an inverse relationship, while others show both parameters

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increasing together. Therefore, the graph does not establish a consistent negative correlation between solar-wind speed and GCR intensity.

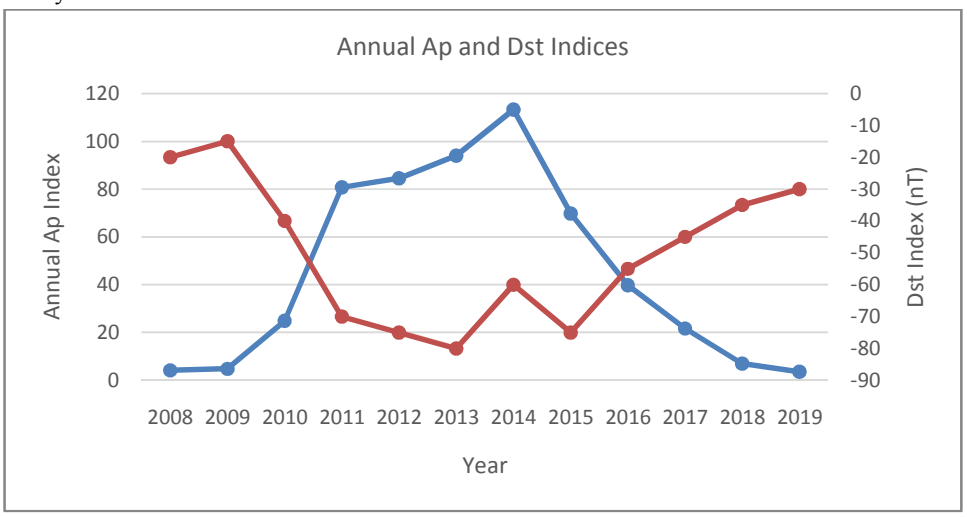


Figure:4 The Annual Ap and Dst Indices Graph (2008–2019)

Left Y-axis: Ap index, which measures geomagnetic activity on a scale where higher values generally indicate greater activity.

Right Y-axis: Dst index in nanotesla (nT), which indicates disturbances in Earth's magnetic field associated with the ring current. More negative Dst values generally indicate stronger geomagnetic storms.

2008–2009: The Ap values are low (4.2 and 4.8), indicating relatively quiet geomagnetic conditions.

2010–2013: The Ap index increases from 24.9 to 94, suggesting an increase in geomagnetic activity.

2014: The Ap index reaches its highest supplied value of 113.3.

2015–2019: The Ap index decreases overall, reaching 3.6 in 2019.

This pattern suggests increased geomagnetic activity around the middle of the study period, followed by a decline.

2008–2009: Values of −20 and −15 nT indicate relatively weak geomagnetic disturbances.

2010–2013: Dst becomes more negative, reaching −80 nT in 2013, indicating stronger storm-time disturbances.

2014: Dst rises to −60 nT, indicating a weaker disturbance than in 2013.

2015: Dst falls to −75 nT, indicating another period of stronger geomagnetic disturbance.

2016–2019: Dst becomes progressively less negative, from −55 to −30 nT, suggesting a general reduction in disturbance intensity.

Relationship between Ap and Dst

The two indices provide complementary information about geomagnetic activity. Ap reflects overall geomagnetic disturbance, whereas Dst is particularly useful for assessing the intensity of geomagnetic storms.

The graph shows that the highest supplied Ap value occurs in 2014, while the most negative Dst value occurs in 2013. Therefore, the peak values do not occur in the same year. This is not necessarily contradictory because the indices measure different aspects of geomagnetic activity.

The annual variations of the Ap and Dst indices during 2008–2019 reveal changes in geomagnetic activity throughout Solar Cycle 24. The supplied Ap values increase considerably during 2010–2014, while the Dst index reaches its most negative value in 2013. Both indices show generally lower disturbance levels toward the end of the study period. These variations provide useful context for investigating possible relationships between geomagnetic disturbances, interplanetary conditions, and cosmic ray intensity.

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II. CONCLUSION

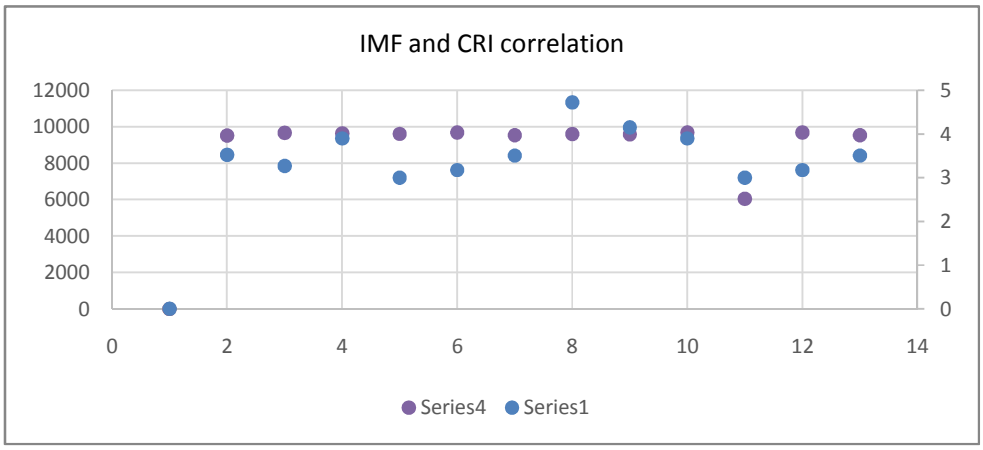


Figure:5 Show the IMF and Cosmic Ray Intensity Correlation

IMF strength varies considerably.

The blue points show that IMF strength varies from approximately 0 to 11,400 nT. Most observations fall between 7,200 and 10,000 nT. The value near observation 1 is zero, while observation 8 shows the highest value.

CRI remains relatively stable.

The yellow points are mostly concentrated between 3.9 and 4.1. However, at observation 11, CRI drops to approximately 2.5 before returning to around 4 at observation 12.

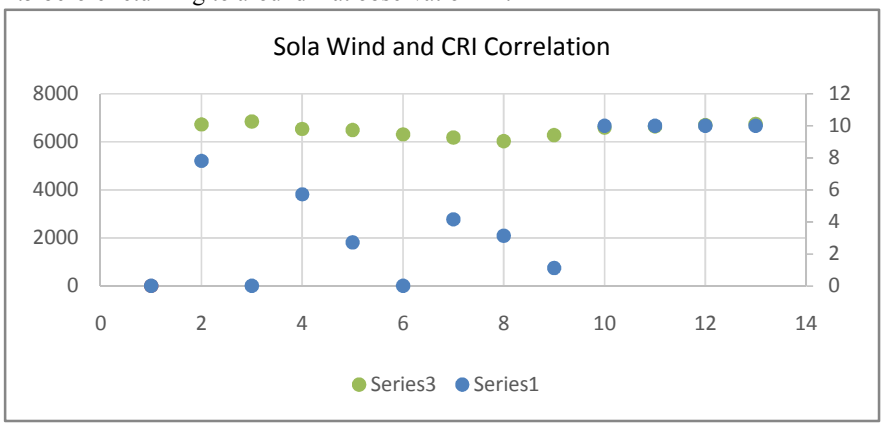


Figure:6 Show the Solar Wind and Cosmic Ray Intensity Correlation

Solar wind measurements show a gradual decrease.

The grey points decline from approximately 6,700 at observation 2 to around 6,000 at observation 8. They then rise slightly at observation 9. This indicates a relatively gradual change in the solar wind measurements.

CRI fluctuates considerably.

The blue points vary from zero to approximately 6,700 on the plotted scale. Several observations show zero values, while observations 10–13 cluster around 6,600–6,700.

There is no clear, consistent correlation across all observations.

The solar wind measurements decrease gradually, while the blue series fluctuates sharply and later stabilizes at a high level. This makes it difficult to identify a consistent positive or negative relationship from visual inspection alone.

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The zero values need attention.

The blue points at observations 1, 3, and 6 lie at zero. Check whether these are genuine measurements or missing values entered as zero, because they could substantially affect the calculated correlation.

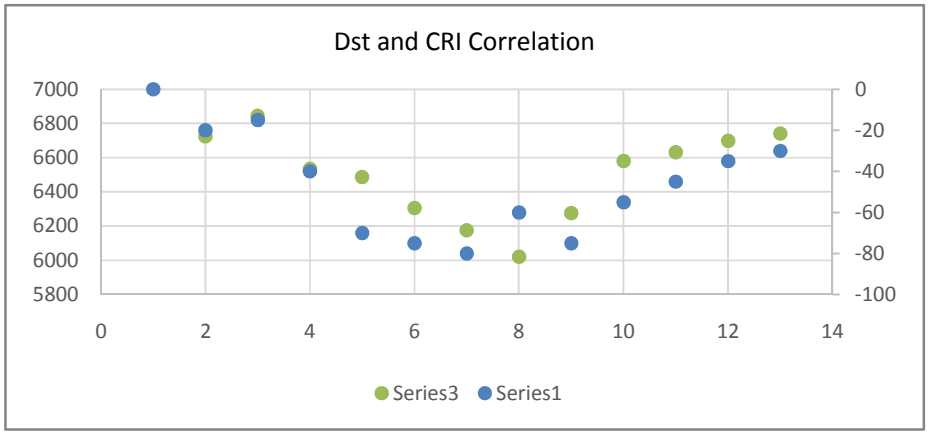


Figure:7 Show the Dst and Cosmic Ray Intensity Correlation

Blue points (CRI): Cosmic ray intensity begins at approximately 6,900, decreases gradually to around 6,010 at observation 7, and then fluctuates before recovering to approximately 6,670 at observation 13.

Grey points (Dst): The Dst index starts near −20 nT, becomes more negative, and reaches approximately −80 nT at observation 8. It then becomes less negative, reaching approximately −15 nT by observation 13. Left vertical axis: Shows CRI values, approximately 5,900–6,900. Right vertical axis: Shows Dst values, from 0 to −90 nT.

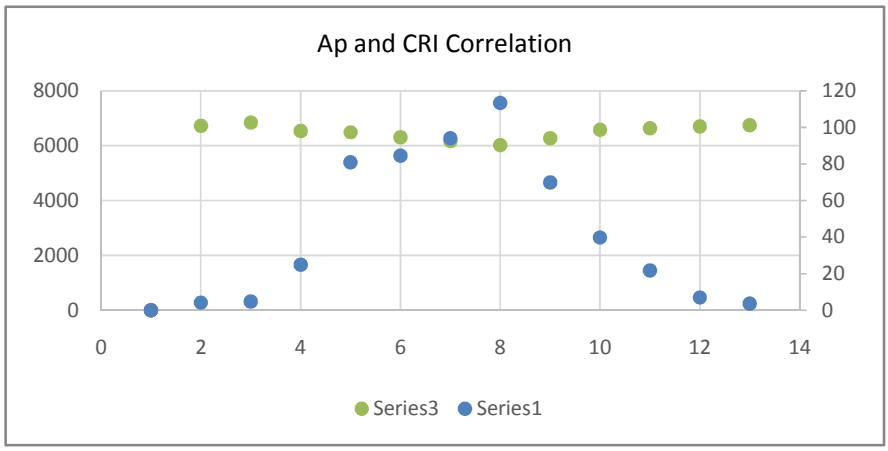


Figure:5 Show the Ap and Cosmic Ray Intensity Correlation

The AP values fluctuate substantially. They start very low, increase sharply from observations 4–8, reach their highest point at about 7,500 at observation 8, and then generally decline. There are particularly low AP values again around observations 11–13.

In contrast, the CRI values are relatively stable, mostly remaining between approximately 90 and 103. There is only a modest dip around observations 6–8 before CRI rises again.

Ap and CRI Relation:

The graph does not show a clear strong correlation between AP and CRI. Large changes in AP are accompanied by only small changes in CRI. For example, AP rises dramatically from observation 3 to 8, while CRI changes only moderately.

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