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# The relationship between Cosmic ray intensity with Geomagnetic activity in Solar Cycle 23 and ascending phase of cycle 24

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**Abstract:** Collisions between Earth's atmosphere and cosmic rays, which originate in space, release very energetic particles. Space weather and cosmic rays from 1996–2022, influenced by solar variability are examined in this research. The modulation of cosmic rays may be either periodic or random. Forbush decline, temporary dip, and ground level enhancement (GLE) are all instances of sporadic categories. While Forbush reduction describes short-term variance, galactic cosmic ray variation describes long-term fluctuation. A long-term trend of cosmic ray strength has been observed, with a peak occurring once every eleven years. The strength of cosmic rays is inversely related to solar activity. From 22–25 solar cycles, many parametric relationships between the sun and geophysical variables were studied. Investigating the effects of several sunspot cycles on the terrestrial plasma environment via changes in the solar characteristics that matter most. Furthermore, it seeks to investigate the relationship between the sunspot maximum's impact on geomagnetic activity and its amplitude. There is a clear change in the geomagnetic activity index that lines up with the sunspot cycle, which occurs every eleven years. However, solar flare maximums do not correspond to the peak of geomagnetic activity as measured over 27 days. From 22–25 solar cycles, geomagnetic indices correlate with parameters V and B. Both Ap and Kp follow a similar pattern of variation throughout the solar cycle's peak.

**Keywords:** Cosmic Rays, Geomagnetic, Modulation, Collisions

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## INTRODUCTION

Almost as fast as light, charged particles known as cosmic rays travel from space to Earth. Most cosmic rays are made up of atomic nuclei of elements from the lightest to the heaviest group on the periodic table. A "galactic" object is one that is dispersed over the Milky Way and originates from a location outside of our solar system. Nuclei and electrons, among other energetic particles, are driven by solar flares and cosmic rays as they travel through interplanetary space and the Sun. Within the Milky Way, these particles' energy spectra span 100 MeV to 10 GeV. An interaction between the Earth's magnetic field and a solar wind shock wave, it causes a transient disruption of the magnetosphere that is called a geomagnetic storm or magnetic storm. The quick outflow of solar wind from a coronal hole is known as coronal mass ejections (CMEs) or co-rotating interaction regions (CIRs), which occur less often on Earth. Potential triggers for a magnetic storm might be any of the following.

Geomagnetic storms occur at a frequency determined by the solar cycle. During solar maximum, geomagnetic storms are more common and are mostly caused by coronal mass ejections (CMEs). As cosmic rays penetrate Earth's atmosphere, they contact with atoms there, creating a chain reaction that releases secondary particles, the most common of which are muons and neutrons at ground level. For the purpose of studying GCRs, neutron monitors and muon detectors situated at various Earth sites have been used since in the '50s. Investigations into cosmogenic isotope data found in ice cores and tree rings provide light on GCRs that happened before to the space age and the modern era of neutron and muon detectors [16]. Sunspot number and cosmic ray intensity are inversely related has been known for a long time [15-16]. Solar wind density and the number of sunspots characteristics are among the many factors that might affect the strength of cosmic rays (CRI). Within the 21st solar cycle, Mishra et al. [17] found that there is a substantial positive link between the solar wind velocity and cosmic ray intensity (CRI). According to okipii and Thomas [18], the strength of galactic ionising radiation may be significantly altered by variations in the empirical angular parameter of the heliographic equator. A solar cycle effect will be shown by the evolution of cosmic rays throughout time. The researchers looked at the relationship between the number of sunspots, the flare index, and the solar radio flux as a function of time, Yan et al. [19] use cross-correlation analysis. In their presentation, Pérez-Peraza et al. provided evidence of 30-year periodicities in cosmic ray variations.

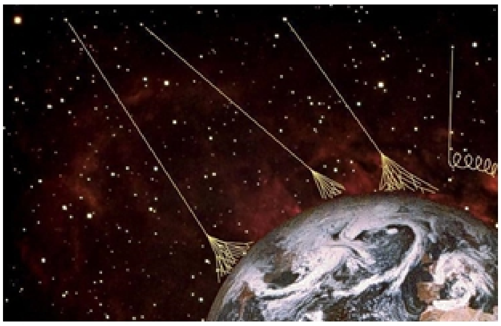

**Fig 1: Cosmic rays travelling to earth from the sun**

## COMPOSITION AND ABUNDANCES

A basic question in high-energy astrophysics is where cosmic rays (CRs) come from, and this remains a mystery. A primary goal in developing the satellite arrays was to determine the path that cosmic rays would take after colliding with Earth. Unfortunately, nobody knows where the CR came from. The problem is that CRs have an electric charge. There is no such thing as a linear trajectory for cosmic rays. Particles have their courses diverted by the magnetic fields that exist between galaxies and stars. Still, as the distance from the Sun increased, the strength of galactic cosmic rays (CRs) climbed, as pointed out by Bultena et al. (1990) and Weekes et al. (1989), suggesting that the Sun is a CR source. Cosmic rays (CRs) are 100 times more variable during solar flares, according to research. These outbursts may last for days.

**Fig 2. Solar flare captured by nasa**

By comparing the results of prior cycles with those of current ones, the findings show the trend. In addition, the study looks at the long-term changes in various solar activity parameters over the last three solar cycles —22, 23, and 24—including solar flares, Ap index, sunspot numbers, solar wind velocity, coronal mass ejections, Forbush Decreases, and solar abrupt commencements. It has been discovered that all of these indicators have correlations.

## REVIEW OF LITERATURE

**Shalaby, S. et al. (2023).** During solar cycles 24 and 25, six significant Forbush drop (FD) occurrences were observed between 2008 and 2021 at the Rome, Moscow, Fort Smith, Oulu, and Thule neutron monitoring sites. The specific dates that were noted are: March 7, 2012, July 15, 2017, June 21, 2015, September 11, 2014, November 3, 2021, and September 6, 2017. In order to understand what may have caused the major FD to happen, an investigation has been carried out. Several major the inquiry looked at solar and planetary events. Counts of sunspots, the Ap index, and the disturbance storm time (DST) index are a few examples. Furthermore, we investigated the solar wind-related interplanetary magnetic field (IMF) parameters including speed, density, temperature, and BZ component. Over the course of the event, the DST index falls sharply, falling on par with the Forbush drop in magnitude. Sunspot activity peaked just before the FD began, suggesting a possible relationship between sunspots and solar flares—which affect cosmic ray variability—through which this event may have originated. There was a notable drop in the BZ component as one moved southward, the speed and temperature of the solar wind rapidly increasing, and no discernible effect on the density of any large FD.

**Papailiou, M. et al. (2020).** The wide variety of Forbush reductions is mostly due to the large number of sun sources that are associated with them. Focussing on notable drops in Forbush occurrences and their association with solar causes, this research investigates all the features and facets of Forbush reductions. Various occurrences from an institute of the Russian Academy of Sciences known as the Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation" were originally included in the research. But in subsequent iterations, it zeroed down on a select group of noteworthy Forbush drops. Located at 21 helio-longitude in the west, 60 helio-longitude in the east, and 20 helio-longitude in the centre were the three subcategories into which the observed occurrences were divided using the solar source's helio-longitude for reference. The chosen occurrences occur between 1967 and 2017. "Global Survey Method" information on solar flares, the speed of the solar wind, geomagnetic indices (KP and DST), and the field between the planets' magnetic fields analyse the previous Forbush declines. To show the time series of the chosen events, we used the epoch-superimposition technique. This comprehensive research deals with the characteristics of cosmic-ray spills as a function of solar sources' helio-longitude which yields interesting results. Enhanced geomagnetic activity and significant Forbush dips are associated with elevated anisotropy, which includes anisotropy be, unrelated to the helio-longitude of the sun. As contrast to Forbush reductions linked to western solar sources, those in the middle or eastern areas are more often identified, have a bigger amplitude and show slower development. The latter are less common, smaller in size, and less long-lasting.

**Melkumyan, Anaid et al. (2019).** Two kinds of Forbush declines (FDs) have been compared during sun cycles 23 and 24, along with their apexes: periodic FDs, associated with high-velocity streams emanating from coronal holes, and occasional FDs, brought about by ICMEs. Around 1700 one-time FDs, 350 recurring FDs, and 207 FDs picked at random with a high degree of certainty were included in the Forbush Effects and Interplanetary Disturbances database, maintained by IZMIRAN, allowed statistical methodologies to be used. At the lowest points between cycles, recurrent FDs were more prevalent, but at the peaks of cycles, random FDs were more common, according to the data. In particular, during the cycle peaks, the features of FD (size, decay rate, and anisotropy) stand out more when dealing with one-time occurrences as opposed to recurrent ones. The FD is largely consistent for repeated events, but its magnitude is larger at its peak and lowest points for irregular occurrences. Regular events usually have faster solar wind velocity than rare ones. The velocities of sporadic coronal mass ejections are greater during times of maximum activity, whereas those of recurrent coronal hole stream structures are higher during periods of minimal activity. During the peaks, when it comes to random FDs, the magnetic field is greater compared to recurrent ones. However, when they are at their weakest, the magnetic fields of the two kinds of catastrophes are almost identical. When compared to the preceding solar cycle, Interplanetary Coronal Mass Ejections (ICMEs) no longer have as strong of a magnetic field. Both types of occurrences initially featured flares of shorter length during their peaks. In particular, near the peak of cycle 23, the durations of sporadic flares developed at a much higher rate than recurrent ones.

**Pandey, Achyut &Ghuratia, Rani &Dhurve, Lt. Arvind. (2022).**Analysis of monthly data obtained from 2008–2019, i.e. Solar Cycle 24, allows us to investigate the periodic behaviour and correlation between cosmic ray strength and sunspot counts. The data on intensity of cosmic rays measured by the Oulu neutron monitor with a one-month auto-resolution and adjusted for pressure were used in this investigation. Sources for the sunspot number include the sunspot index and solar observations throughout the long haul. Evidence from studies of cosmic ray intensity, it is modulated every eleven years by solar activity in the heliosphere. During solar cycle 24, the average cosmic ray strength, after accounting for frequency and pressure, was 6475.58 counts/min. There is a substantial negative correlation between the intensity of cosmic rays and the quantity of sunspots; statistical investigation corroborated this, showing a correlation value of -0.86 and a connection between phases that is not synchronous.

## RESEARCH METHODOLOGY

This research examines the impact of cosmic ray modulation on solar activity via the use of data science and statistical methods. The research covers solar cycles 22–24 and the upturn portion of cycle 25, and it uses regression analysis to compare from 1996 to 2022, solar and geomagnetic activity correlated with cosmic ray intensity (CRI). Solar wind speed, geomagnetic disturbance index, magnetic field, sunspots, and other characteristics were examined geomagnetic Ap index being of paramount importance for long-term monitoring of solar activity. The modulation parameter grows in direct proportion and multiplying the plasma velocities of the solar wind and their multiplicative powers. Three neutron monitoring sites' cosmic ray intensity data and other websites' monthly averaged data were used in the research. For optimal temporal accuracy in forecasting solar cycles, the records should show individual 11-year cycles precisely. For the last two thousand years, scientists have been trying to deduce the length and strength of the solar maximum using geomagnetic indices, which have included this data since 1868. Nevertheless, the current reconstructions cannot be used as a basis for prediction because to the uncertainty they include.

## RESULT

The inverse correlation between the number of sunspots and cosmic ray intensity for the last eleven years power is well-known. However, the times when cosmic-ray intensity is at its lowest and highest, which correlate to the highest and lowest sunspot activity, are not always the same. Popielawska (1992) performed extensive research to demonstrate sunspot frequency as a function of cosmic ray intensity! The investigation included both the quantity of sunspots and the strength of cosmic rays. For solar cycles 22–24, she used monthly averages for sunspot abundance and cosmic ray intensity to determine the correlation coefficient to look for a relationship between the two. The Rz value for solar cycle 23 was at its highest point in September 2001 at 150.7 and its lowest point in October 2007 at 0.9

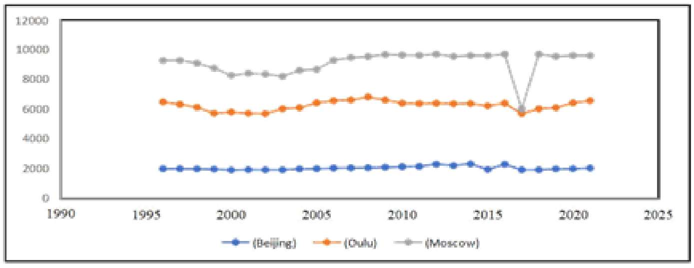


**Fig. 3. From 1996 until 2021, Neutron will be monitoring stations in Beijing, Ulu, and Moscow.**

In April 2014, the sunspot number peaked at 81.8 during the 24th solar cycle, which lasted for 23 months. The 23rd solar cycle, on the other hand, run from May 1996 all the way through September 2001. That is different from solar cycles past that are still active, its maximum was much lower. Gupta and Badruddin (2010), Kaushik and Srivastava (2000), and Brown and Williams (1969) all found that the amplitude of the solar cycle that followed was significantly related to the geomagnetic activity that occurred during the solar minimum.

## THE INTERPLAY BETWEEN COSMOLOGICAL RAYS AND GEOMAGNETISM

Several criteria were used to analyse the cosmic rays from observatories in Beijing, Oulu, and Moscow, including solar wind speed, geomagnetic field strength (B), solar electric jet exponent (Ae), sunspot number (Rz), and exponent (Ap). These characteristics were contrasted with the conventional solar parameters. You may think of the solar cycles as (V) and V.B. To make sense of the galactic cosmic ray fluctuations of 11 and 22 years, interactions between the Sun and Earth are crucial. According to observations, the solar cycle affects the strength of cosmic rays., and more especially with the sunspot number Rz. It takes around seven months after the sunspot minimum before the intensity reaches its peak. However, not every solar cycle follows this pattern. The solar cycle determines the relative timing of solar cycles and cosmic ray cycles. As the solar cycle progresses, it also changes. Many studies have looked at how cosmic ray strength and sunspot number have changed over time; among of them are Forbush (1957), Mishra and Mishra (2018), Sham and Mishra (2019), and Ross and Chaplin (2019). The amount of cosmic rays was discovered to be inversely proportional to the number of sunspots.

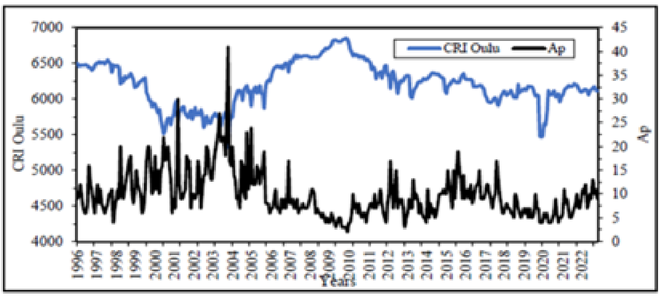


**Fig 4: Oulu Stations' Annual Values of Cosmic Ray Intensity and Geomagnetic Solar Index (Ap) for 1996–2021.**

During solar cycles 23 and 24, the link found a relationship between solar radiance (Rz) and cosmic ray intensity (CRI) that was examined using a correlation analysis (Draper and Smith, 1998). The correlation analysis made use of the average annual growth rates of super neutron detectors in Moscow, Oulu, and Beijing. There is a negative correlation with relation between the sunspot count and the number of limitless rays from 1996 to 2022. Sunspot number (Rz), infinite radiance, and solar cycles 22 and 24 were all factors in the calculation of the connection coefficient, which covered the years 1996–2022. From this group, we can see that it's easy to see similarities between the even and odd solar cycle curves, as well as between them and the ones that come after them. A correlation coefficient that indicates been calculated by us. At the ascending stages of solar cycles 23–24 and 25, The correlation between cosmic ray intensity (owl), geomagnetic index (Ap), B*V, and the multiplication of sunspot number (Rz) is shown in Figure (2). You can see the presence of an inverse connection and varied profile in Figure (2). While CRI rises with intense solar activity, Between 22 and 24 solar cycles, the Ap index, sunspot number, and B*V all converge.

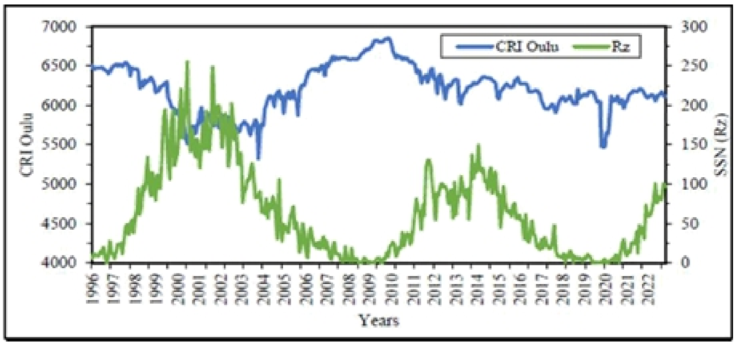


**Fig 5: Results of the Cosmic Ray Intensity, the Geomagnetic Solar Index, the Vector Magnetic Field, and the Sunspot Number for the Years 1996–2021, as Measured Annually at the Oulu Stations.**

The CRI, sunspot number Rz, Ap index, and B*V are shown with long-term correlation coefficients of -0.9, -0.6, and -0.7, respectively. Furthermore.

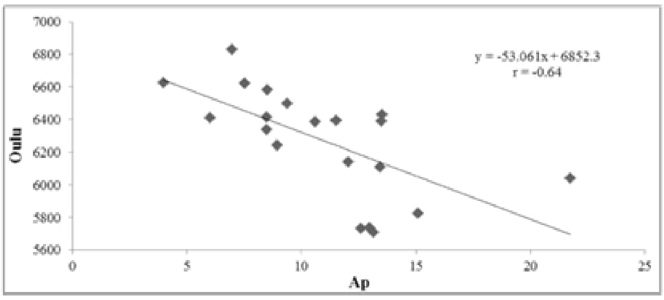

**Fig 6: Analysis of the Oulu Geomagnetic Solar Index (Ap), Vector Magnetic Field (V*B), and Sunspot Number (Rz) from 1996 to 2021 in a Correlation Cross Plot.**

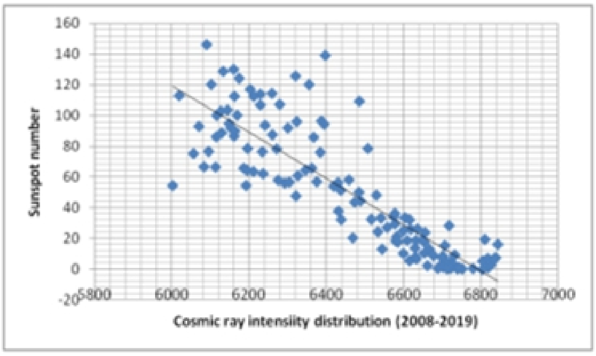

**Fig 7. Anticorrelation with a coefficient of -0.86 is shown by the scatter plot of SSN and CRI from 2008 to 2019.**

## CONCLUSION

We have performed an exhaustive study that considers the use of modern methods and scientific papers to investigate the correlation between cosmic rays and various measures of solar activity throughout the last four solar cycles. Through our study, we have identified the several solar and interplanetary elements that impact cosmic ray activity fluctuation throughout the long run. To achieve this goal, we have collected geomagnetic, cosmic ray, and solar interplanetary data from many neutrons monitor stations' websites and the Solar Geophysical data books. The results of this systematic examination are based on the use of several statistical methods. In this study, the authors delved into the long-term effects of everyday variations. I study how variations in the sun's cycle affect events with trains of waves of varying amplitudes. The events categories based on the sun's yearly cycle, which include periods of inactive sunshine, high solar activity, and decreasing phases. Under both solar cycles, low-amplitude wave trains are the only things that can be seen when the sun isn't shining. In cycle 24, the minimum CRI period is much longer than in previous cycles. Brown and Williams's (1969) study demonstrated a robust relationship between geomagnetic activity and the amplitude of future solar cycles. According to the study, the severity of the next solar cycle is strongly correlated with the number of days with an unusually calm geomagnetic field. In a combination with solar cycles 23 and 24, solar cycle 25 was shown to be the most active and impactful on space weather. Sunspot monthly counts are expected to reach a high of 50 to 70 in 2013, according to statistical models. The solar pole magnetic field is expected to reach its peak as early as 2012, according to models that take its intensity into consideration. Cycle 25's development in comparison to more recent cycles is fascinating to see. We have used linear regression analysis techniques to study the fluctuations comparing CRI and SSN during solar cycle 24. Solar activity is thought to significantly affect CRI inside the heliosphere on an 11-year cycle. Solar minimum is the highest point in the cycle, and vice versa. A negative correlation between sunspot counts and CRI was also verified by the current investigation. Significant anti-correlation is seen in the cycle.

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