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Study of solar activities for long term modulation of cosmic rays for the period of Solar Cycle 23 and ascending Phase of solar cycle 24

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Abstract: We have been able to analyse solar activity (SA) development phase in cycle 24, which included variations in cosmic ray (CR) intensity over long time periods, the era of regular granulations beginning in 1951, and the very deep SA minimum between cycles 23 and 24 in the past few years, were all part of this cycle. In cycles 19–23, low ticles were measured with neutron monitors on spacecraft and in the stratosphere, and the CR density during the aforementioned period (2009) was higher than at prior CR maxima. During an exceptionally long SA minimum, the intensity maximum—whose value depends on particle energy—was observed in CR variations. When comparing the SA growth stages of the three years (2010–2012) after 2009 to previous cycles, there was a significant decrease in CR modulation. This anomaly in CR fluctuations was investigated by looking at the likely explanations, which include changes in SA features during this time and a minimum value for the CR residual modulation between cycles 23 and 24. Various solar magnetic field indices and properties, accounting for intermittent solar activity, have their contributions estimated.

Keywords: Cosmic Ray Intensity, Geomagnetic Activity, Solar Activity

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INTRODUCTION

Research on cosmic ray (CR) modification has been ongoing for as long as there have been regular CR measurements. At first, these investigations were limited to neutron monitors on the ground. The neutron monitor remains the most effective detector for studying CR modulation, even in the modern era of successful CR studies into the far heliosphere conducted by the Voyager and Ulysses spacecraft missions. One might analyse the long-term modulation of cosmic rays using the monthly data (averages) of a global network of neutron monitor stations with different geomagnetic cut-off rigidities. Neutron monitors are at their most vulnerable to cosmic rays between 0.5 and 20 GeV, which is also the energy range where solar modulation is at its most efficient. It has long been recognized that solar activity (SA) modulates galactic cosmic ray strength and energy spectrum.

Particularly intriguing are the specifics surrounding the modulation of CR and the modification of the time-lag factor. The sunspot number (SSN) is one of many measures of solar activity that have traditionally been used to characterize the sun's activity level, which typically varies every eleven years. Thus, in order to research solar-terrestrial interactions and cosmic-ray modulation, the sunspot counts are used as a typical solar indicator. Afterwards, SSN wasn't the only solar measure that was employed as a proxy for solar activity; other indices instance, solar flares, solar flux, coronal index, and so forth were also considered. Solar output and its variations impact heliosphere modulation of intergalactic cosmic rays with energies ranging from several hundred MeV to tens of Terahertz. The heliosphere controls the intensity and spectrum of cosmic rays, which are associated with a solar cycle that lasts eleven years.

The modification of cosmic rays in relation to the 22-year solar magnetic cycle reveals the charge/polarity dependency of the drift mechanism, with distinct geometries coincide with the solar cycles that are diametrically opposed. The study examines the high-energy range a global network of cosmic ray neutron monitoring stations with different geomagnetic cut-off rigidities is used to measure the average monthly data for long-term cosmic ray modulation. In the energy range of 0.5–20 GeV, where neutron monitors are most impacted by cosmic rays, optimal energy response for effective solar modulation also occurs. The anti-correlation between solar activity and the transmission of galactic cosmic rays to Earth is well-established, although its strength changes during the solar cycle. changes in cosmic rays are influenced by solar activity or a heliospheric parameter. It is anticipated that several causes would impact the procedure for adjusting cosmic rays, and the observed CR changes are integrated phenomena by definition. So, according to Belov (2000), a number of solar-heliospheric indicators will provide a more precise model of long-term modulation if they are integrated. We have tried to analyse how a series of solar-heliospheric parameters affect cosmic ray modulationin the current work, keeping the aforesaid premise in mind. To conduct this kind of research, we used the "Running multiple correlation method" to conduct a thorough correlational analysis of CRI with a separate set of SA parameters. Results from a correlational study between CRI and certain SA measures were also compared to those from this approach.

LITERATURE REVIEW

Opm, Aslam & Badruddin, B(2012). While the sun is at its lowest point in its 23rd year, a period known as the profound solar minimum, we examine the solar modulation of galactic cosmic rays (GCRs) and contrast the outcomes of this exceptional era with those achieved during comparable stages of solar cycles 20, 21, and 22. The field of magnetic fields in the solar heliosphere, which is north polar region, has two epochs of positive and negative polarity, respectively, throughout these eras. We use data from cosmic-ray sources in conjunction with data from the sun, interplanetary plasma/field, and the heliospheric current sheet tilt angle simultaneously. We examine the link between the concurrent variations in solar/interplanetary parameters and cosmic ray intensity across the decades lowest and decreasing stages of cycle 23. These relations are compared to those that were established for the identical stages in the three solar cycles before to this one. While solar cycle 23 is near its lowest, we see unusual cosmic ray modulation characteristics, such as the highest GCR strength ever recorded. Despite a weak correlation (R=0.41) during this unusual minimum, the interplanetary magnetic field (R=0.66), solar wind velocity (R=0.80), and the tilt angle of the heliospheric current sheet (R=0.92) all show a marked improvement over the previous three variables. The maximum GCR intensity ever recorded occurred during solar cycle 23's deep low was likely caused by solar wind convection and not diffusion or drift alone.

Sharma, Aradhna & Verma, S. (2013). Sunspots, solar flares, coronal mass ejections, and any other solar phenomena are all examples of solar activity. The dynamo process and the turbulence of fluid flows within the sun are the origins of these phenomena. The solar magnetic field's cyclicity is the primary force behind it. From January 2009 through December 2011, this article analyses the correlation between several solar variables. Similar origins are indicated by a high connection between several metrics.

Biswas, Akash & Karak, Bidya &Usoskin, I. & Weisshaar, Eckhard. (2023). The interannual fluctuation of solar activity is mostly governed the Schwabe cycle, which lasts for around eleven years and cyclical character. From very active grand peaks to almost pristine grand minima, the duration, shape, and amplitude of solar cycles are substantially modified. The direct sunspot-number dataset, which spans around 400 years, has uneven quality and is insufficient for studying reliable characteristics of solar variability over the long period. The cosmogenic isotope proxy, which extends the era to twelve millennia, provides crucial observational limits on the long-term modulation of the solar dynamo. Current solar activity fluctuations from the centennial to the millennial timescales are summarized in this article. There are also discussions of grand minima and maxima, in addition to the centennial Gleissberg, 210-year Suess/de Vries, and 2400-year Hallstatt cycles. The sun's cycles don't exhibit clock-like phase locking, which is indicative of poor memory retention, and the presence of a significant random component are shown. Within the context of dynamo models, including nonlinearity and stochastic fluctuations, a concise but thorough overview of the theoretical viewpoints that attempt to account for the observed phenomena is offered. As we get more familiar with new data and build new models, our understanding of the mechanisms underlying solar variability continues to grow.

Kumar, Pawan & Pal, Mahender & Rani, Amita & Mishra, A. & Singh, Sham. (2022). We are estimating the strength and start times of future 11-year cycles using a mechanism that predicts solar activity, a flawless event. Historically, it was used for the purpose of predicting the maximum amplitudes and onset periods of cycles ranging from 19 to 24. What follows is a synopsis of the comforting results achieved over all of these iterations: Earlier, a revised version of the suggested approach was used to forecast the characteristics that would define cycle 24. In order to validate the initial predictions for the features of cycle 24, we use the observed values of spotless events. It is also possible to use this approach to forecast the 25th solar cycle's maximum amplitude and ascent period. The next cycle 25 has been predicted using the stacking LSTM forecasting model. Results from our investigation show that our model successfully anticipates data patterns and long-term interdependence. With a sunspot amplitude of 171.9 3.4, when compared to solar cycle 24, the maximum intensity of cycle 25 will be 47% higher.

Mishra, V. & Mishra, A(2016). From Oulu (Cut off Rigidity = 0.8 GV) and Moscow (Cut off Rigidity = 2.3 GV), neutron monitors (NM) collected monthly data on cosmic ray intensity (CRI), sunspot number (SSN), and sunspot area of entire disc (SSA). During cycles 23 and 24, researchers examined the pattern of fluctuating solar activity and modification by cosmic rays. For an abnormally extended period (July 2008–August 2009), the SSN have maintained their minimal level. During the last solar minimum in April 1964, ground-based detectors at Oulu NM detected the strongest galactic cosmic rays ever seen. When compared to other solar cycles, Similarly, the highest SSN value in this cycle is rather low (19–23). Using regression analysis, we have assessed and studied the correlation coefficient between SSN and CRI during solar cycle 24 (January 2008–December 2015) both without and with a time lag. Based on the highest correlation coefficient, the current solar cycle has a 4–10 month lag at both locations; cycle 23 has a 13–14 month lag. Researchers have also looked at how the running cross correlation function behaves throughout this solar cycle and discovered that, unlike in past cycles, it stays at its maximum value of about -0.8 to -0.9 for a very long time. Additionally, for both cycles, there is a strong correlation between the fluctuation of SSN and SSA (r >.92). The unusual behaviour of solar cycle 24 has prompted a discussion and comparison of cosmic ray modulation trends with previous cycles.

RESEARCH METHODOLOGY

In a previous set of publications, such as, the multi-model was used to characterize long-lation, with SA features being linearly connected to the amplitude of CR fluctuation. This study builds on that work. The first set of information needed to simulate fluctuations in CR comes from measurements of CR intensity, sun activity statistics, and features of the solar magnetic field on a worldwide scale. Using the previously suggested approach (Belov et al., 1993), the CR variation spectra from 1953 to 2012 were computed. Using all this method was used to determine the CR isotropic component using data on CR strength collected from the ground NM network (~40 monitors) and three instances when the stratosphere was audible (Stozhkov et al., 2007). Additional analysis was carried out utilising the average monthly changes in the intensity of CRs with 10 GV stiffness (A10 in percent compared to 2009) and the data obtained from the aforementioned procedure: For particles with a stiffness of 10 GV, the energy at which NMs are most sensitive, the amplitude of nonvariations is denoted as A10. A trustworthy empirical model for explaining CR fluctuations should include many solar indices, since CR variations seen close to Earth represent the sum of many solar processes. (Belov et al., 2002, 2005; Gushchina et al., 2008) provides justification for the selection of the solar microwave radiation characteristics used in the empirical description of cycles in CRs.

For the purpose of determining global solar processes, indicators such as the field utilised, along with the magnitude and orientation of polar solar magnetic fields (Hpol), the squared radial magnetic field component averaged over a set source surface (Bss), and the heliospheric current sheet inclination (). On a weekly basis, these figures were averaged outside the solar wind generator. Direct observations at solar observatories starting in May 1976 and continuing (Obridko and Shelting, 1999; Vanyarkha, 1995) up to the current day, with the addition of indirect magnetic field data made before 1976 and analysed using the techniques outlined in form the basis of the field characteristics.

The impact of passing solar events on CRs was accounted for in the performed study using several indexes. The Xy flare power (defined as flares with a magnitude of ≥M1) was used by Belov et al. (2007) when calculating the solar flare index (xf). After adding solar flare activity to the description of longariations from 1976 to 2012, the CR modulation model was shown to be specified (the shortariations are provided in this model). The subsequent stage in correctly representing SA in the CR longariation model was the incorporation of the Pi index, which was calculated by taking into consideration the monthly average plasma velocity and the number of coronal mass ejections (CMEs) (Paouris et al., 2012). The formula for finding the Pi index is as follows: The equation Pi = a [Nc/Nc(max) + b [Vp/Vp(max)] is valid during the time period 1996–2012 when data on CME is available from the SOHO satellite. Here, a and b are non-negative integers. The maximum values of the parameters Nc(max) and Vp(max) are defined here; Nc is the monthly CME count and Vp is the average CME velocity. Using the Pi index to determine the expected CR fluctuations from 1996 to 2012 provides a far more accurate description of the CR variations throughout cycles 23 and 24's growing phase.

We may build Given that the aforementioned indices respond differently in solar cycles, the model may be expected to create a full CR modulation pattern in SA cycles by employing complementing indices (Fig. 1). Presented here are the anticipated and observed alterations for a particle stiffness of 10 GV during cycles 19–24, along with the relative contributions of several indicators to CR modulation. We used multi-analysis to build the CR modulation model. The overall pattern of CR fluctuations from 1957 to 2012 is relatively well-represented by this model, which exhibits the following features of the regression model: a mean squared deviation of 2.79% and a correlation value of ρ = 0.86.

SOLAR ACTIVITY GROWTH PHASE IN CYCLE 24 AND CR MODULATION DURING THIS PERIOD

With the Wolf number rising again in April-May 2013, the first and perhaps most significant maximum of the current solar cycle (cycle 24) occurred in February 2012. Although the CR modulation achieved its peak during the present solar cycle, it is far from the highest point ever recorded, and very near to the lowest point in cycles 20 and 22, when the solar magnetic field was at its weakest. The CR variations throughout cycle 24's development and maximum phases were compared to the longariations in different epochs of cycles 19–23. Every cycle is unique because its CR variation average value changes. In cycle 22, the modulation was most pronounced (-7.3%), while cycle 20 had the least impact on CRs (-3.1%). Cycles 19, 21, and 23 all saw a decline in modulation of -7.0%, -6.3%, and -4.6%, respectively. Cycle 24's modulation was negligible all the way up to December 2012. It is possible that low SA and tiny values of account for the lowest solar activity during the CR observation period, cycle 24modifying features, which also have a reduced influence on CRs.

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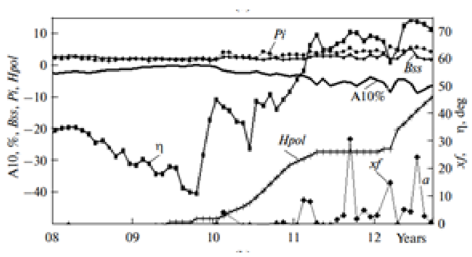
A



B

2008–2012

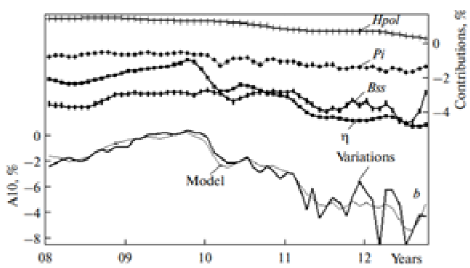


Fig. 1. The regulation of CRs throughout SA cycles 19–24. In the bottom part, you can see the model and the data on CR variations (rigidity 10 GV). On the top part, you can see the factors that were used to build the model, such as Hpol, η, Bss, and Nsss.

A crucial component of the solar magnetic field (CR) modulation model over an extended period of time has been the heliospheric current sheet's inclination (). The inclination is an essential component of the solar magnetic field index (SA index) and may be used in conjunction with sunspot counts and other comparable indices, such as the mean solar magnetic field. A number of models also take drift into account, which is a method of charged particle transmission.

One of the most significant magnetic inhomogeneities in the heliosphere that CRs interact with is the Helio spheric current sheet. A drift path is amplified and new kinds of magnetic inhomogeneities are generated as the angle of attack is raised. Model CR density values compared to observed ones show that maintaining the same index efficacy over the last two years would have resulted in a greater modulation depth. But there was a period when CR modulation was affected differently by the heliospheric current sheet inclination because the contribution of this factor to CR modulation decreased. Regression coefficient for present sheet inclination in cycle 24 model is 0.05%/°, 2-3 times less than coefficient for earlier periods of preceding cycles. The solar magnetic field's structural characteristic is thus shown, which changed from 11.5° at the start of the cycle to >70° between April 2012 and 2013, had a less effective impact on CR intensity compared to earlier cycles. At cycle 24's maximum, η fluctuations contribute around 4.5% to overall modulation, which is twice as little as the contributions from earlier cycles when the same variations were present.

RESIDUAL CR MODULATION AT SA MINIMUMS

Garcia Munoz et al. (1977), Segashima and Morishita (1980), and Sirotina (1989) were among the publications that calculated the residual modulation at various intervals around the minimums of cycles 19 and 22. With the latest SA minimum and a record high CR density close to Earth, residual modulation (δ0) may be calculated. Close to the mother plants from cycles 19–24, we calculated the δ0 value for separate intervals lasting 8–10 years. Remaining modulation was thought to be defined via the correction equation's free term. We identified a parameter δ0 = 3.7 ± 0.6% for the time period close to the 1964 minimum in our model, which is similar to the value found in (Sirotina, 1989), where δ0 = 3.6 ± 0.5%. Our results show that residual modulation is 7.6 ± 0.3% in the years close to the 1976 minimum, while in Sirotina (1989), it was 4.1 ± 0.8%. We lean towards accepting a novel finding, keeping in mind while the modulation value was not specified by Garcia Munoz et al. (1977), it was also noted that modulation is important at the 1976 minimum. Our simulation indicates that at the minimums in 1986 and 1996, δ0 = 9.8 ± 0.3 and 5.2 ± 0.3%, respectively. Our finding that δ0 = 9.2 ± 0.2% for the final minimum of cycle 24 is in close agreement with the value determined for cycle 22 (δ0 = 9.8 ± 3.3%) and with Nagashima and Morishita (1980).

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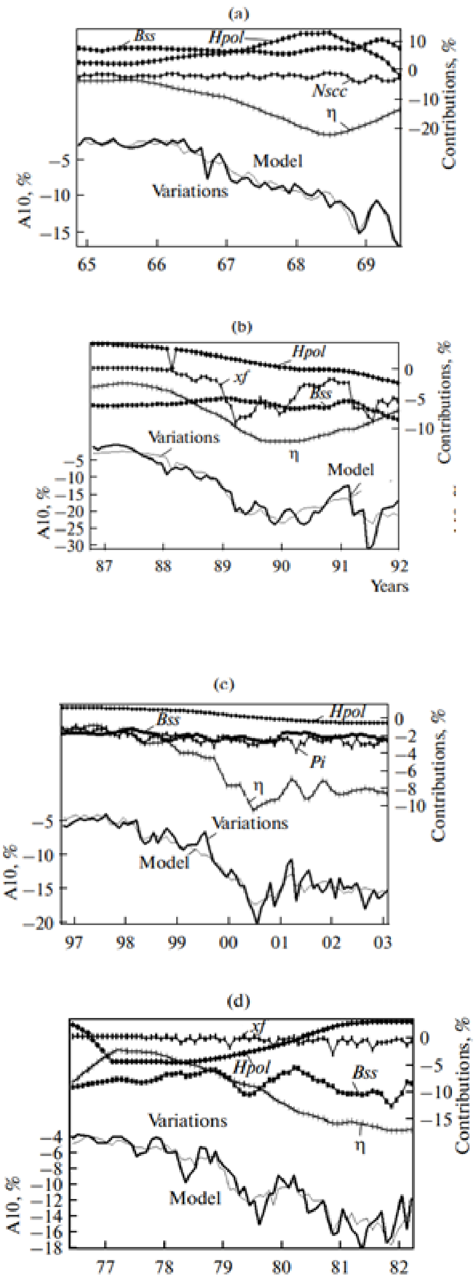

Fig. 3. When it comes to the SA development phase, the CR fluctuations (both in terms of the model and the data) in cycles 20 and 22 and (c) and (d) are relevant. In panels (a)–(d), the top plots show the contribution of several indices to modulation.

When SA is very low, the heliosphere has a proportionally large impact because to the undesirable residual modulation that occurred during the time of abnormally high CR density. During the present cycle's minimum, it is quite probable that the heliosphere will display residual modulation from both the previous and current cycles. The real character of the correlation between CR intensity and SA characteristics demands attention may vary from our modulation description, which was made under the premise that this relationship is linear. Lastly, it should be mentioned that the residual if the entire solar magnetic field is polarized, then the modulation value should be as well, but no clear effect has been seen so far. Because of these factors, we can't trust existing definitions in terms of the value of residual modulation, and the results are very standard.

CONCLUSIONS

This current SA cycle (cycle 24) is unique because of recent solar and heliospheric anomalies, most notably a weakening of solar magnetic fields, which has led to very weak CR modulation. During the activity rise stage in cycle 24, many SA observations corroborate a similar finding. Furthermore, it was shown that between 2009 and 2012, the current sheet inclination had a less severe effect on CR modulation. Similar to previous cycles, the inclination fluctuates within a narrow range, but this influence has a far less impact.

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