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Heliospheric Effect of Sunspot Number During Ascending and Descending Phase of Solar Cycle 23 And 24

Mudasir Ayoub[1*], Santosh Sogura[2], G.N. Singh[3], C.M. Tiwari[4]
[1]Research Scholar, APS University Rewa-486001, M.P., India
[2]Research Scholar Dr. H.S. Gour University Sagar-470003, M.P., India
[3]Department of Physics Sudarshan College Lalgawan Rewa-486117, M.P., India
[4]Department of Physics APS University Rewa-486001, M.P., India
E-mail: mudasirphysics111@gmail.com
* Corresponding Author

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Abstract

The article examines the 11-year solar cycle and its impact on the variability of sunspot number and cosmic ray intensity during two recent cycles, 23 and 24. It explores how changes in solar activity affect cosmic ray intensity and how this varies over time. The solar cycle 23 has a time period of 12.3 years, while solar cycle 24 lasts for 11 years. It is evident that solar cycle 23 is prolonged than solar cycle 24. The Solar cycle 23 reached its peak with a maximum smooth Sunspot number of 180.3. on November 2001 and minimum was 11.2. In this work we investigate the heliospheric effect of cosmic rays mid-cut off rigidity neutron monitoring stations Moscow on Sunspot number. We find during ascending and descending phase for Cosmic rays and Sunspot number, the solar parameters are much faster than cosmic rays with time lag.

Keywords: - Cosmic Ray Intensity (CRI), Sunspot Number (SSN), Solar Cycle, Heliosphere..

1. Introduction

The heliosphere refers to the part of the space that is influenced by the solar magnetic field and the solar wind, a continuous stream of charged particles that are constantly expelled from the solar corona into space [1]. The heliosphere is a vast, bubble-shaped region that extends far beyond the orbit of Pluto and is shaped by the interstellar medium. Within the heliosphere, the solar wind interacts with the interstellar medium, creating a complex boundary called the heliopause, which marks the edge of the solar system. Beyond the heliopause lies the interstellar medium, which is thought to be influenced by the magnetic fields and particles ejected by other stars and supernovae [2]. The sunspot number serves as a metric to quantify the level of sunspot activity occurring on the Sun's surface. Sunspots are regions of relative darkness on the solar surface, which appear cooler compared to their surroundings and are associated with magnetic activity. The number of sunspots observable on the solar surface vary over time due to the solar cycle, which typically lasts for about 11 years. The sunspot number is determined by counting the number of sunspots observable on the surface of the Sun. and assigning a value based on the size and complexity of each sunspot. This number serves as an indicator of the activity of the sun. The sunspot number is a significant factor to determining the intensity of solar activity and its influence on the heliosphere. The researchers [3] analyses and the evolution of solar activity indicators in the ascending and descending periods in solar cycles 23 and 24 and examines their persistence. The authors find that sunspot number declines more steeply in the descending phase of cycle 24 than during the equivalent period of cycle 23. When there is high sunspot activity, the Solar magnetic field is stronger, which can cause the solar wind to be more intense and to carry a larger amount of energy and particles. This can lead to an increase in the occurrence of geomagnetic storms and auroras on Earth. Conversely, when there are fewer sunspots, the solar wind is weaker and the magnetosphere is less disturbed. This can result in a decline in the rate of geomagnetic storms and auroras.

The heliosphere plays a central role in modulating the flux of Cosmic ray's particles that initiate from beyond the boundaries of our solar system. such as distant stars or supernovae. The solar wind. that emanates from the Sun, creates a protective shield around the solar system, known as the heliospheric magnetic field that helps to deflect and reduce the incoming flux of cosmic rays. When the solar wind interacts with the interstellar medium, it creates a shockwave that further decreases the cosmic ray flux. However, heliospheric magnetic field intensity and solar wind velocity vary with the solar cycle, which has an approximately 11-year period, and can result in variations in the flux of cosmic rays. During times of intense solar activity, such as during solar maximum, both heliospheric magnetic field and the solar wind are stronger, resulting in a lower flux of cosmic rays. Conversely, during low solar activity periods, such as during solar minimum, solar wind velocity and the heliospheric magnetic field are both weaker, allowing for a higher cosmic ray flux to cross the solar system. The study of cosmic rays and their modulation by the heliosphere is important for understanding the composition and structure of the interstellar medium.

It has been noted that during 11-year activity cycle, solar activity and galactic cosmic rays have an inverse relationship, with a time lag between them. During the peak of galactic cosmic ray intensity, solar activity reaches a minimum while as minimum of galactic cosmic ray there is a maximum of solar activity [4, 5, 6, 7, 8, and 9]. Figure 1 depicts the long-term relationship between the number of sunspots with monthly cosmic ray intensity count rates measured at the Moscow Neutron monitor from 1996 to 2020. When the polarity is positive (A>0) in the drift scenario of charged particle propagation within the solar heliosphere, positively charged particles are observed to enter the heliosphere through its polar regions and During periods of negative solar polarity (A<0), the inner heliosphere experiences the entry of galactic cosmic rays through the equatorial region, specifically along the heliospheric current sheet. [10,11,12].

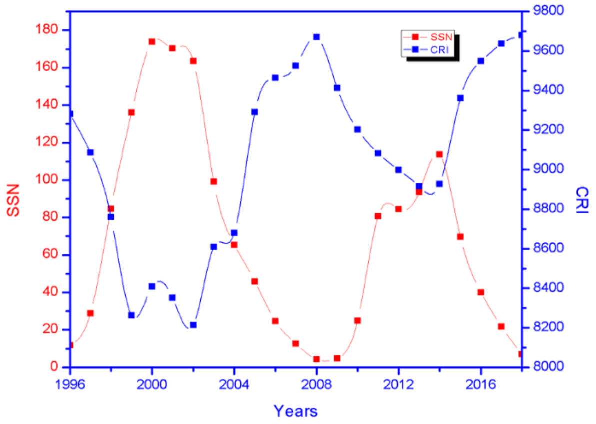

Figure-1 Illustrating the correlation between Cosmic Ray Intensity and Sunspot number in solar cycle 23 and 24.

Forbush observed the first solar cosmic ray occurrence with BeV energy in 1942. Solar flares can have an impact on the flux of cosmic rays. During a solar flare, significant amounts of energy are emitted as electromagnetic radiation and charged particles, such as protons and electrons. When a solar flare occurs, it can accelerate charged particles, including cosmic rays in the proximity of the solar flare. This can result in an increase in cosmic ray flux, particularly those with lower energies. However, the overall impact of a solar flare on cosmic ray flux depends on various factors, such as the magnitude and orientation of the interplanetary magnetic field, the energy spectrum of the cosmic rays, and the location and timing of the solar flare. Solar flares are a common occurrence in the sun, but only a few of these particles possess sufficient energy to produce solar cosmic rays. After being produced by solar flares, cosmic rays are released into space and eventually make their way to Earth.

2. Data and Method of Analysis

To investigate the time-lag between fluctuations in galactic cosmic rays (GCR) and solar activity, a time-lag cross-correlation analysis was conducted. This analysis was carried out separately for each station Moscow, following the approach of [13] and involved comparing the monthly average GCR intensity with the monthly average sunspot number (SSN). We utilized a time window of width T, centered at time t, spanning from t − T/2 to t + T/2. For this analysis, T was defined as 50 months. The window was shifted in 1-month intervals across this period. The lag between GCR and SSN was calculated by locating the maximum correlation coefficient within the time range T. Our investigation focused on examining the heliospheric impact of the sunspot number during both the ascending and descending phases of solar cycle 23 and 24. We looked at the time lag observed for the entire solar cycle and specifically during the two magnetic epochs of the cycle (A<0 and A>0).

We obtained monthly data on sunspot numbers from the web https://oomniweb.gsfc.nasa.gov/form/dxl.html and monthly data on galactic cosmic rays from the Moscow neutron monitor, which we accessed from the web http:/cr0.izmiran.ru/mosc/. We analyzed the relationship between the galactic cosmic rays (GCR) intensity and different parameters of solar activity and identified the time lag between them.

3. Results and Discussion

The reason for the time lag between sunspots number and the cosmic ray intensity is that the cosmic rays are modulated by the heliosphere. The solar magnetic field shields the solar system from cosmic rays originating from beyond the solar system, but this shield varies with the strength and location of the sun's magnetic field, which in turn is affected by the sunspot number. A high sunspot number indicates that the solar magnetic field is stronger and more concentrated, and therefore provides a stronger shield against cosmic rays. This results a decrease in the observed intensity of cosmic rays. Conversely, when the sunspot number is low, the solar magnetic field is weaker and more dispersed; this stronger magnetic field allows an increased influx of cosmic rays into the solar system leads to an increase in the recorded cosmic ray intensity. This inverse relationship between Sunspot Number (SSN) and Cosmic Ray Intensity (CRI) observed during solar cycles 23 and 24 is shown in figure 2.

However, it takes time for the cosmic rays to travel through the heliosphere and reach the Earth, which results in the time lag between changes in the sunspot number and changes in the cosmic ray intensity observed at Earth. The exact time lag depends on the cosmic ray energy and the distance between the earth and the sun. For lower energy cosmic rays, the time lag can be several months to a year, while for higher energy cosmic rays, the time lag is shorter, typically on the order of weeks to a few months.

The coefficient of correlation between galactic cosmic rays and sunspot number during the ascending and descending phases of solar cycle 23 and 24 as a function of time lag can provide insights into the relationship between these two variables over a longer period of time. As solar cycle 23 entered its ascending phase (A>0) during 1996-1998, the sun's magnetic field strengthened, leading to a decrease in the intensity of galactic cosmic rays. The coefficient of correlation between the galactic cosmic rays and sunspot number may have been negative during this phase, indicating that as sunspot number increased, the intensity of galactic cosmic rays decreased. As solar cycle 23 peaked and started to decline (A<0) during 2001-2008, the solar magnetic field weakened, which allowed more galactic cosmic rays to enter the solar system. The correlation coefficient representing the relationship between galactic cosmic rays and sunspot number. may have been positive during this phase, indicating that as sunspot number decreased, the galactic cosmic ray’s intensity increased. A time lag correlation analysis was conducted for each polarity epoch (A>0 and (A<0) separately (refer to figure 3 and 4). The relationship between SSN and CRI during solar cycle 23 and 24 is supported by multiple studies. The analyses of data from neutron monitors located around the world found a strong negative correlation between SSN and CRI during solar cycle 23 and 24 [14]. Another investigation demonstrated a strong negative correlation between SSN and CRI during these solar cycles, using data from the PAMELA satellite [15].

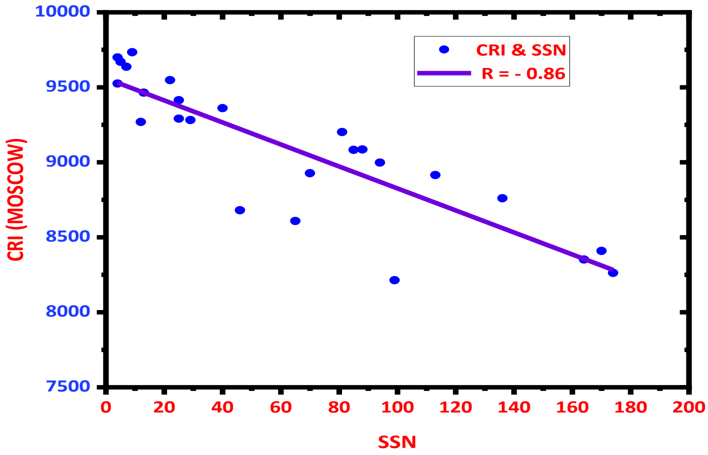

Figure-2 Displays an inverse correlation between Sunspot Number (SSN) and Cosmic Ray Intensity (CRI) observed during solar cycles 23 and 24.

The entire period of solar cycle 24 consists of two distinct heliospheric polarity states (A<0 and A>0) due to the reversal of the Sun’s magnetic field around the solar maximum. During the increasing phase of the solar cycle (2009–2013), the northern solar polar field was directed inward while the southern polar field was outward, representing the A<0 polarity epoch. As the solar cycle entered its declining phase (2014–2019), the polarity reversed, with the northern polar field pointing outward and the southern polar field inward, marking the A>0 polarity epoch. In the A<0 epoch, cosmic rays, primarily composed of positively charged particles, predominantly entered the inner heliosphere through the equatorial region. After the polarity reversal, during the A>0 epoch, cosmic rays mainly entered through the polar regions. To investigate whether this change in the entry path of cosmic rays into the heliosphere between the A<0 and A>0 epochs influenced the time lag, we conducted a time lag correlation analysis for each epoch separately (refer to Fig. 5and 6). The results showed that the time lag was longer during the A<0 epoch, whereas it was shorter during the A>0 epoch.

The beginning of solar cycle 24 was characterized by a prolonged period of low solar activity, with few sunspots observed. During this time, a weak and disorganized solar magnetic field was observed, which allowed more galactic cosmic rays to enter the solar system. The coefficient of correlation between the galactic cosmic rays and the sunspot number may have been positive during this phase, indicating that as sunspot number increased from a low value, a decrease of galactic cosmic ray intensity was observed. As solar cycle 24 progressed and reached its maximum, the solar magnetic field became stronger and more organized, resulted a decrease in the galactic cosmic ray intensity. The coefficient of correlation between the galactic cosmic rays and sunspot number may have been negative during this phase, indicating that as sunspot number increased, the galactic cosmic ray intensity decreased. We computed the correlation between the monthly average counts of

Galactic Cosmic Rays (GCRs) and Sunspot Numbers (SSN) at various time lags, specifically for Cycles 23-24. Figure 3 revealed that for each solar cycle, there exists a particular time-lag where the highest degree of anti-correlation between the of Galactic cosmic ray (GCR) intensity and Sunspot numbers is observed. This time-lag point was identified as the peak of the anti-correlation.

Our analysis focused on examining the changes in the time lag between Galactic Cosmic Ray (GCR) intensity (MOSCO) and Sunspot Number (SSN) during both the ascending and descending phases of solar cycle 23 and 24. In the study, it was found that throughout the descending phase of the solar cycle (A<0), there is a negative time lag between the recovery of Galactic Cosmic Ray intensity and Sunspot Number. This negative time lag indicates a recovery of GCR intensity which is faster than the sunspot number during this phase. This observation is consistent with previous findings in cycles 20 and 23. However, a positive time lag was observed between the two factors. [16, 17, 18]. The study found that a lag is observed in the modulation of Galactic Cosmic Ray intensity in relation to Sunspot Number. which is more pronounced during odd-numbered solar cycles [19, 20] than in even number cycle [21, 22]. The galactic cosmic ray decreases its maximum value in 4-5 years and retrieves in 5-6 years [22, 23]. There has been speculation regarding the characteristics of Solar Cycle 24 by comparing to the preceding even and odd cycles. The analysis reveals that during the ascending phase of solar cycle 23, the time lag is 11 months, and for solar cycle 24, it is 12 months. In contrast, during the descending phase of solar cycle 23, the time lag is 23 months, and for solar cycle 24, it is 12 months. This gives the idea that the researchers have confirmed that there is a consistent agreement between the time lag difference for cosmic rays and sunspot number during even and odd solar cycles. This suggests that a consistent and significant time lag exists between the two parameters, which can be used to better understand solar activity (25,26). The time lag and the corresponding correlation coefficients of the positive and negative polarity epochs (A>0 and A<0) during the ascending and descending phases of solar cycle 23 and 24 are presented in table 1.

Table.1 Cross Correlation Coefficient and Time Lag.

Sunspot number	**Solar cycle phase**	**CC 95% Significance**	**Time Lag (months)**
Solar cycle 23	Ascending phase	0.800-0.816	11
	Descending phase	0.699-0.711	23
Solar cycle 24	Ascending phase	0.798-0.811	12
	Descending phase	0.786-0.800	09

The cross-correlation coefficient between Galactic Cosmic Rays (GCRs) and Sunspot Numbers (SSN) was examined at various time lags during both the ascending and descending phases in solar cycle 23 and are illustrated in fig.3 and fig.4.

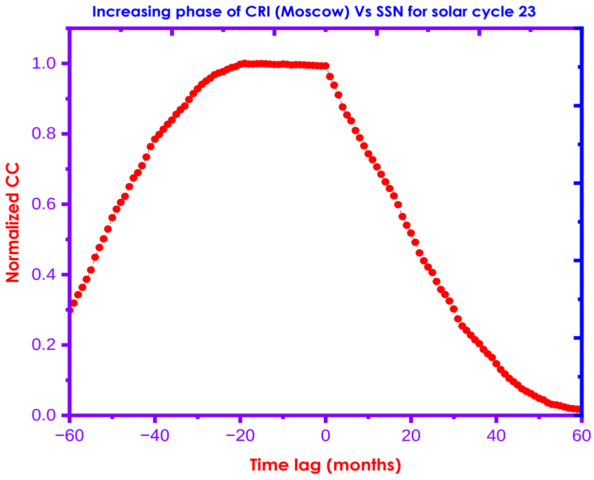

Figure-3 Increasing phase of cosmic ray intensity verses sunspot number SSN during (A>0) epoch for solar cycle 23.

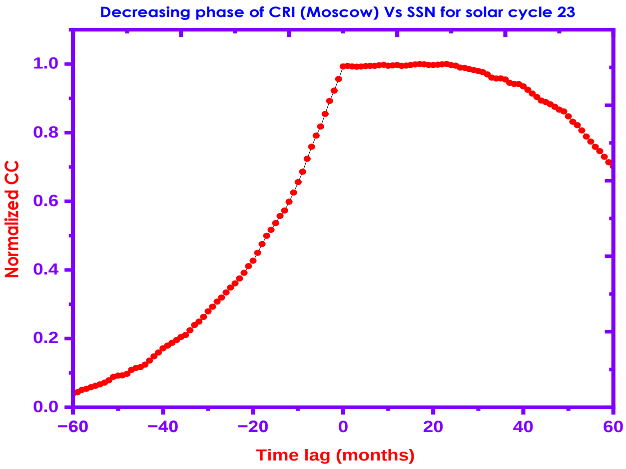

Figure-4 Decreasing phase of cosmic ray intensity verses sunspot number (SSN) during (A<0) epoch for solar cycle 23.

The cross-correlation coefficient between Galactic Cosmic Rays (GCRs) and Sunspot number (SSN) at different time lags throughout the ascending and descending phases of solar cycle 24 are depicted in fig.5 and fig.6.

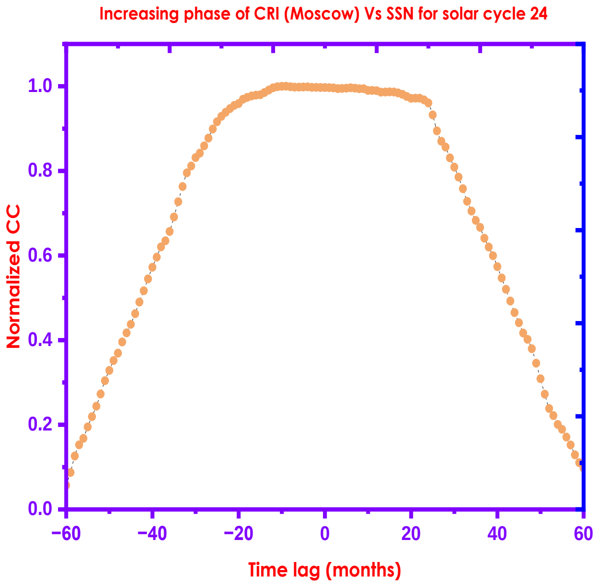

Figure-5 Increasing phase of cosmic ray intensity (CRI) verses sunspot number SSN during (A>0) epoch for solar cycle 24.

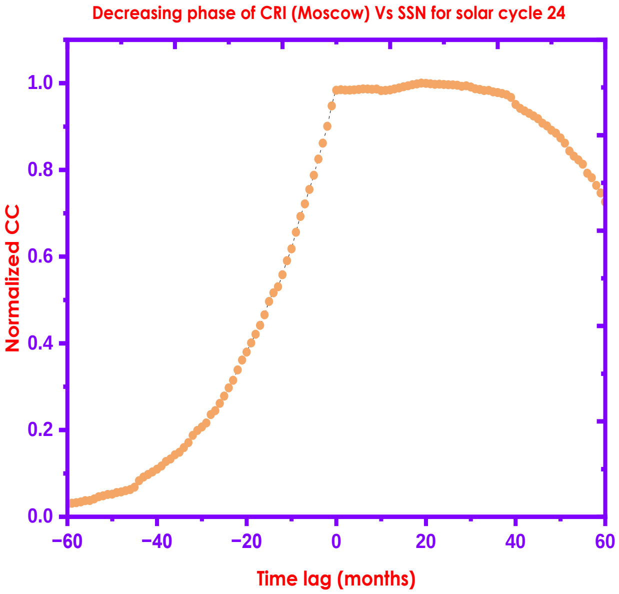

Figure-6 Decreasing phase of cosmic ray intensity verses sunspot number SSN during (A<0) epoch for solar cycle 24.

The variations in solar activity and GCR intensity indicate a visible time lag between the two, which is more clearly observed in the simultaneous plots. These plots suggest that the time lag in solar cycle 24 is likely shorter compared to that in solar cycle 23.

4. Conclusions

The occurrence of sunspots (SSN) and the time delay between the onset of solar cycle-related indicators (CRI) exhibit variations during both the ascending and descending phases of the solar cycle 23. In the ascending phase of the solar cycle, there is usually a relatively short time lag between the appearance of sunspots (SSN) and CRI. This is because the magnetic fields associated with sunspots are still relatively simple and weak during the early stages of the cycle, making it easier for the solar magnetic field to become unstable. During the descending phase of the solar cycle 23, the time lag between SSN and CRI is typically longer with other solar activity appearing later in the cycle, even after the sunspot number has begun to decline. This is because the magnetic fields associated with sunspots become more complex and stronger as the cycle progresses, making it more difficult for the Solar magnetic field to become unstable.

Previous solar cycles have been the subject of research regarding the influence of the heliosphere on the modulation of cosmic rays throughout the 11-year solar cycle. The main objective of this research was to examine the characteristics of galactic cosmic rays during the periods of solar activity in Cycles 23 and 24. For solar cycles 23 and 24, which occurred between 1996-2008 and 2008-2019 respectively, we have presented the analysis of the time-lag between the intensity of galactic cosmic rays (GCR) and sunspot numbers (SSN) during the declining phase of solar cycle 23, showed a remarkably long delay of about 23 months. In contrast, during solar cycle 24, the time-lag was relatively shorter, with duration of approximately 9 months. In ascending phase, the time lag for solar cycle 23 is 11 months while as in solar cycle 24 the time lag is 12 months. It has been observed consequently there is high cross correlation between sunspot number and galactic cosmic rays with the duration ranging from approximately 9 to 23 months.

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Conflict of Interest

The authors of this document affirm that they have no conflicts of interest.

References

[1] Parker, E. N. (1958). Dynamics of the Interplanetary Gas and Magnetic Fields. The Astrophysical Journal, 128, 664. https://ui.adsabs.harvard.edu/abs/1958ApJ...128.664P/abstract.

[2] Frisch, P. C., and Mueller, H.R. (2013). Time-Variability in the Interstellar Boundary Conditions of the Heliosphere: Effect of the Solar Journey on the Galactic Cosmic Ray Flux at Earth. Space Sci Rev,176, 21–34. https://doi.org/10.1007/s11214-011-9776-x

[3] Lockwood, M., Barnard, L., and Owen, M. J. (2011). The persistence of solar activity indicators and the descent of the sun into Maunder Minimum conditions. Geophysical Research letters, 38, L22105. https://doi.org/10.1029/2011GL049811

[4] Forbush, S. E. (1958). Cosmic-ray intensity variations during two solar cycles. J. Geophys. Res., 63, 651.

[5] Parker, E.N. (1965). The passage of energetic charged particles through interplanetary space. Planet. Space Sci. 13, 9.

[6] Usoskin, I. G., Kananen, H., Mursula, K., Tanskanen, P., and Kovaltsov, G.A. (1998). Correlative Study of Solar Activity and Cosmic Ray Intensity. J. Geophys. Res., 103, 9567.

[7] Van Allen, J. A. (2000). on the modulation of galactic cosmic ray intensity during solar activity cycles 19, 20, 21, 22 and early 23. Geophys. Res. Lett. 27, 2453.

[8] Mishra, A. P., Gupta, M., and Mishra, V. K. (2006). Cosmic Ray Intensity Variations in Relation with Solar Flare Index and Sunspot Number. solar Phys., 239, 475-491.

[9] Singh, P. R., Saxena, A. K., and Tiwari, C. M (2018). Mid-term periodicities and heliospheric modulation of coronal index and solar flare index during solar cycles 22–23. J Astrophys Astron, 39, 20.

[10] Potgieter, M. S. and Ferreira, S. E. S (2001). Modulation of Cosmic Rays in the Heliosphere from Solar Minimum to Maximum: A Theoretical Perspective. Adv. Space Res., 27, 481.

[11] Gupta, M., Mishra A. P., and Mishra, V. K. (2006). Correlation of long-term modulation of cosmic ray intensity variation with sunspot numbers and tilt angle. Indian space J Rad. and Space Phy., 35, 167-173.

[12] Alanko, Huotari, K., Usoskin. G. I., Mursulak., and Kovaltsov. A. G. (2007). Cyclic variations of the heliospheric tilt angle and cosmic ray modulation. Adv. Space Res., 40, 1064-1069.

[13] Usoskin, I. G., Kananen, H., Mursula, K., Tanskanen, P., and Kovaltsov, G. A. (1998). Correlative study of solar activity and cosmic ray intensity. J. Geophys. Res. 103, 9567.

[14] Mishra, A. P., Mishra, N. B., Gupta, M., and Mishra, V. K. (2006). Study of cosmic ray intensity variations in relation to solar activity for sunspot cycles 19 to 23. Indian space J Rad. and Space Phy., 37, 237-243.

[15] Usoskin, I. G., Mursula, K., Kananen, H., and Kovaltsov, G. A. (2001). Dependence of cosmic rays on solar activity for odd and even solar cycles. Adv. Space Res. 27, 571.

[16] Chowdhury, P., Dwivedi, B. N., and Ray, P. C. (2011). Solar modulation of galactic cosmic rays during 19-23 solar cycles. New Astron. 16, 430.

[17] Chowdhury, P., Kudela, K. and Dwivedi B. N. (2013). Heliospheric modulation of galactic cosmic rays during solar cycle 23. Solar Phys., 286:577-591.

[18] Burlaga, L.F., and McDonald, F.B., Ness, N. F. (1993). Cosmic ray modulation and the distant heliospheric magnetic field. J. Geophys. Res. 98, 1.11.

[19] Parker, E. N. (1963). Interplanetary Dynamical Processes. Journal of the Royal Astronomical Society of Canada, 58, 235.

[20] Dorman, L.I. (1959). In Proc. 6th Int. Cosmic Ray Conf. 4, 328.

[21] Okipii, J. R., Thomas, B. (1981). Effects of drift on the transport of cosmic rays. IV - Modulation by a wavy interplanetary current sheet. Astrophys. J., 243, 1115-1122.

[22] Aslam, O. P.M., and Badruddin (2012). Solar Modulation of Cosmic Rays during the Declining and Minimum Phases of Solar Cycle 23: Comparison with Past Three Solar Cycles. Sol. Phys., 279, 269-288.

[23] Kane, R. P. (2011). Hysteresis of Cosmic Rays with Respect to Sunspot Numbers During the Recent Sunspot Minimum. Solar Phys., 269, 451-454.

[24] Chowdhury, P., Gokhale, M. H., Singh, Jagdeo, and Moon, Y. J. (2016). Mid-term quasi-periodicities in the CaII-K plage index of the Sun and their implications. Astrophys Space Sci, 361, 54.

[25] Usoskin, I. G., et al. (2017). Cosmic Ray Intensity during the Recent Cycle 23. Journal of Geophysical Research: Space Physics, 122(10), 10,602-10,617.

[26] Munini, R., et al. (2015). Solar Cycle Variations of the Cosmic Ray Intensity Observed by the PAMELA Experiment. Solar Physics, 290(1), 23-36.