https://doi.org/10.15407/ujpe69.4.257

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SOLAR ACTIVITY AND COSMIC RAY INTENSITY VARIATION WITH GEOMAGNETIC ACTIVITY DURING 1996–2022

The average features of diurnal variation have been observed to change with different phases of the solar cycle, with the variance being substantially bigger at higher energies. The events were classified on the basis of different phases of solar cycles, i.e., the minimum solar activity time period, the maximum solar activity time period, and the declining phase of solar cycle. This research looks at the observed results and the influence of solar variability on cosmic rays and the geomagnetic field from 1996 to 2022. The occasional group includes a Forbush effect decline, transitory decrease, and a ground level enhancement (GLE). The 11-year fluctuation in Galactic Cosmic Rays is also known as the long-term variation, whereas the Forbush effect reduction is known as short-term variation. We investigated the long-term change in the cosmic ray intensity and its relationship to the number of Sun spots (Rz), solar wind speed (V), geomagnetic disturbance index (Ap), and magnetic field (B). We used Cosmic ray intensity (CRI) data from three neutron monitor sites in this study: Oulu (0.81 GeV), Moscow (2.41 GeV), and Beijing (9.56 GeV). Several properties, such as the even-odd hypothesis, the hysteresis phenomena, and the time-lag in long-term modulation, have also been explained.

Keywords: cosmic ray, geomagnetic disturbance index, solar activity cycle.

1. Introduction

The influence of solar fluctuations on cosmic rays and the geomagnetic field has previously been examined using data from ground-based detectors (primarily, the global grid of super neutron monitors) in conjunction with other solar and geophysical factors [1–4]. The interrelationship between these factors is known as the solarr–[terrestrial relationship. Long-term galactic cosmic ray changes, in addition to short-term variations in CRI (Cosmic ray intensity), remain an unresolved subject in cosmic ray investigations. Various studies have revealed that the cosmic ray flux is modulated by the 11-year solar cycle of the Sun spot activity, reaching a maximum during the quiet period of the solar cycle and a minimum near the peak of the solar cycle, i.e., cosmic ray in-

Citation: Pal M., Kumar P., Rani A., Mishra A.P., Singh Sh. Solar activity and cosmic ray intensity variation with geomagnetic activity during 1996–2022. *Ukr. J. Phys.* **69**, No. 4, 257 (2024). https://doi.org/10.15407/ujpe69.4.257.
Цитування: Пал М., Кумар П., Рані А., Мішра А.П., Сінгх С. Активність Сонця, варіації інтенсивності космічних променів та геомагнітна активність протягом 1996–2022 рр. *Укр. фіз. журн.* **69**, №4, 257 (2024).

tensity changes over the solar cycle with a time lag of 1–2 years. Ahluwalia [5] discovered that Neutron Monitor count rates are substantially linked to the tilt angle of the neutral current sheet at the start of the current modulation cycle. Bakare [6] investigated cosmic ray modification by corotating interaction zones in a paradigm that includes both drifts and diffusion. Using spherical harmonics of solar magnetic fields, Agrawal [2] attempted to improve the association of the cosmic- ray intensity with the solar activity. Forbush [8] demonstrated that the mean cosmic ray intensity has an 11-year apparent period of anticorrelation with the solar activity.

The persistent recoding of the cosmic beam strength by neutron screen technologies over recent decades has greatly promoted the exploration of features of 11-year variability. Cane [9] drew attention to the fact that the greatest reductions in la ong haul variety appear to arise after massive Forbush decreases effect, which continues for a time, followed by analogous sharp reduces decreasing general force further. Agrawal [4] postulated the occurrence of a 22-year tweak as a result of the extreme inversion of the Sun's attractive field, which occurred in 1969–1970 [10]. Many workers have outlined a few study efforts to clarify the long-term Cosmic beam strength variation with regard for a part of the time lag between sunspot numbers [10, 7, 5, 11]. An effort was made to clarify the long-term management of the astronomical beam strength using a novel balancing parameter [12, 13]. Real tests have been carried out to determine the long-range Cosmic beam power based on the collective influence of a few Geomagnetic highlights [14, 15]. They led to the conclusion that the gigantic-scale structure of the solar wind is responsible for an 11-year cycle in the Cosmic beam force diversity.

Researches proposed [16] that a 22-year-old instrument is associated with the inversion of the Sun's dipole field. They have proposed that high power states, in which the galactic attractive field and the Sun's attractive field are parallel to each other, encourage the section of Cosmic beam particles inside the heliosphere. Currently, it has been built up that galactic Cosmic beams are contrarily related to Sun spot numbers (SSN)and to its most extreme force at the base of the Sun spot cycle [17, 18] investigated the association between the long haul huge beam power variation and SSN and tilt point (TA). They discovered that Sun spot numbers and the tilt edge are extremely related to each other, whereas the cosmic beam force is hostile to connection with them. Although the long-term tuning system of a galactic inestimable beam has been widely considered both conceptually and hesitantly for more than 50 years. The long haul balancing, on the other hand, remains an unresolved topic in the Cosmic beam control research. As a result, we sought to solve the problem with the help of observational results obtained via detailed quantifiable inspection. The data used in this analysis came from low, center, and high cutoff inflexibility neutron screen sites.

The monthly mean value of Sun spot counts is employed as a solar measure of the solar activity in this study to link them with the cosmic ray intensity. Geomagnetic plasma characteristics and the geomagnetic index have also been utilized to link various outcomes of Cosmic ray long-term fluctuations. The discovered results are compared to previous Cosmic ray modulation studies' conclusions. Various long-term cosmic ray intensity variation features have been calculated and explained using accessible mechanisms. Yearly estimates of the cosmic ray intensity calculated using monthly mean values from three neutron monitor stations: Oulu, Moscow, and Beijing. For the long- term investigation, the mean data on the solar wind velocity, magnetic field, sunspot number, and geomagnetic Ap index were also obtained from the Omni website. Researcher discovered [19] that cosmic ray strength fluctuations happen 6 to 12 months behind the solar activity. In this study, we plotted yearly estimates of CRI from three different neutron screens located in Beijing, Oulu, and Moscow. In this study, we used Wolf Sunspot Numbers (SSN) as a sunlight-based metric from 1996 to 2022, spanning solar cycles. According to the findings of this analysis, the beam force lagged behind the sun-oriented cycle from 1996 to 2022. In any case, the temporal slack is not the same as different sun-oriented cycles.

2. Methodology

For examining outcomes, many statistical and data study methodologies are applied. Various graphs, charts, plots, and correlations have been considered for the long-term and short-term studies of cosmic ray modulationd. We shall employ regression analysis. The regression research is a technique that evaluates the relationship between a dependent variable and a set of independent factors. The regression analysis may be used as a descriptive data analysis approach without making any assumptions about the underlying processes that generate data. A basic linear regression in its most generic form is

$$y_i = \alpha + \beta x_i + \varepsilon_i,$$

where α, β, and ε_i are the intercept, slope, and are error term, which captures the unpredictability of the response variable y_i. The error term is commonly assumed to be regularly distributed. x's, and y's are sample or population data amounts, while & are unknown parameters ("constants") to be estimated from data (Draper & Smith, 1998 for more information).

We have compared the solar activity/geomagnetic activity and Cosmic Ray Intensity (CRI) for the period 1996–2022 which cover the solar cycle 22 to 24 and ascending phase of solar cycle 25. The significance of the geomagnetic Ap index in tracking long-term solar activity were [20, 21] for this purpose, we have selected Sun spots (Rz), solar wind speed (V), geomagnetic disturbance index (Ap), magnetic field (B),S and the modulation parameter ($V \cdot B$) is proportional to the product of solar wind plasma velocity (V) and strength of the interplanetary magnetic field (B). We used Cosmic ray intensity (CRI) data from three neutron monitor sites in this study: Oulu (0.81 GV), Moscow (2.41 GV), and Beijing (9.56 GV). The data on solar & geomagnetic parameters have been taken monthly averaged data from various websites: www.geomag.bgs.ac.uk/daaservice/dat, data have been taken from the National Geophysical Data Centre (htt://www.ngdc.noaa.gov/stp/SOLAR/ ftp-sunspotnumber.html).

Such data sets must depict individual 11-year cycles with a highly suitable temporal resolution for solar cycle prediction purposes. Such information has been accessible for the geomagnetic indices since 1868. From oriental naked eye sunspot records and auroral observations, attempts have been made to reconstruct the epochs and even amplitudes of solar maxima over the past two millennia [22, 23, 24]. However, these reconstructions currently have too many uncertainties to be used as the basis for predictions.

3. Result and Discussion

It is generally known that, for 11-year variability, the fluctuation in the cosmic ray intensity exhibits an inverse relationship with the number of sunspots. The highest and minimum sunspot numbers, however, are frequently found to differ from the minimum and maximum cosmic ray strengths. In order to demonstrate the relationship between the cosmic ray intensity and the sunspot cycle, Kaushik [25] reported a thorough analysis that took data on cosmic ray intensity and sunspot counts into account. In order to investigate the connection between sunspot number and the cosmic ray intensity for solar cycles 22 to 24, the correlation coefficient between the monthly mean values of these two parameters has been calculated. In September 2001, the solar cycle 23rd reached its highest value of 150.7, and, in October 2007, it reached its lowest value of 0.9. Solar cycle 24 peaked in April 2014 with a 23-month sunspot number of 81.8, while the cycle 23 started in May 1996 and peaked in September 2001. In comparison to other recent solar cycles, this maximum value was significantly lower. A striking link between geomagnetic-activity close to solar-minimum and the magnitude of the following solar-cycle was discovered in [12, 26, 27, 28, 29]. Figure 1 shows the Cosmic ray intensity from different Neutron monitor stations (Beijing, Oulu & Moscow) from years 1996 to 2021 which have the cut off rigidity as Oulu (0.81 GV), Moscow (2.41 GV), and Beijing (9.56 GV).

3.1. Inter-relation of cosmic rays with geomagnetic activity

Cosmic rays from various cutoff rigidity stations (Beijing, Oulu, and Moscow) have been linked to various solar parameters such as Sunspot numbers (Rz), Index (Ap), Solar electro jet index (Ae), Geomagnetic Magnetic field (B), Solar wind velocity (V), and $V \cdot B$ for Solar Cycles. The solar-terrestrial interaction also plays a significant role in explaining the portions of the 11- and 22-year fluctuations of Galactic Cosmic Rays. Variations in the cosmic ray strength have been observed as a function of the solar cycle (sunspot numbers (Rz), with maximum intensity occurring around seven months following sunspot minima. This, however, is not true for all solar cycles. The time gap between the solar cycle and the cosmic ray cycle varies depending on the solar cy-

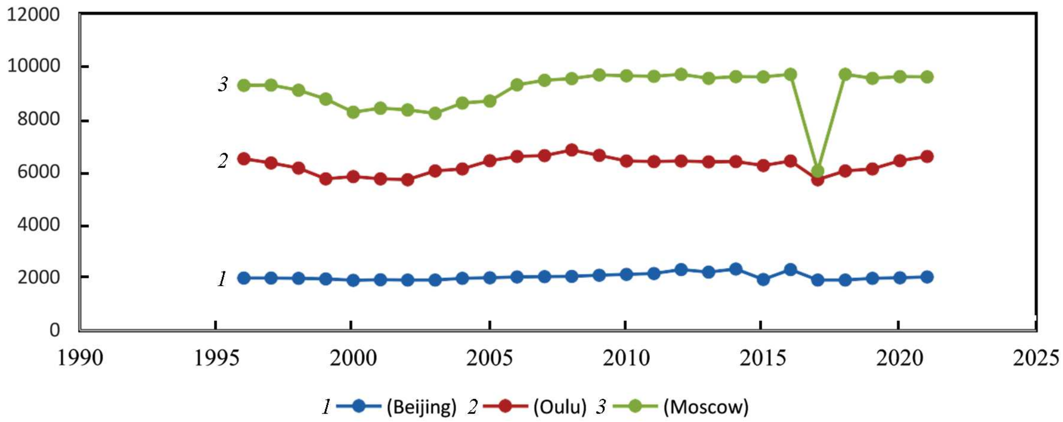

Fig. 1. Neutron monitor stations Beijing, Oulu & Moscow from years 1996 to 2021

Table 1. **Shows yearly values of various parameters for a long-term study**

S.N.	Years	(Oulu)	(Beijing)	(Moscow)	B	(Km/s)	SSN (Rz)	Ap	$V \cdot B$
1	1996	6494	1987	9266	4.29166667	351.9833	6.7153846	8.52727273	1673.27462
2	1997	6335	1986	9279	4.60833333	316.7	16.623077	7.71818182	1616.63154
3	1998	6137	1978	9083	5.73333333	341.7667	49.353846	10.9363636	2170.48154
4	1999	5731	1956	8757	5.75	364.8333	71.669231	11.4363636	2323.70769
5	2000	5821	1898	8260	5.975	373.1083	91.976923	13.7272727	2469.40308
6	2001	5735	1918	8406	5.75833333	354.525	85.3	11.7818182	2261.32385
7	2002	5705	1908	8349	6.36666667	365.825	80.061538	11.9454545	2579.91077
8	2003	6039	1912	8211	6.31666667	451.4667	48.923077	19.7818182	3158.87769
9	2004	6107	1978	8606	5.44166667	375.8417	31.1	12.2	2265.45769
10	2005	6426	1991	8677	5.2	392.0917	22.907692	12.2909091	2258.44769
11	2006	6578	2026	9288	4.18333333	357.7583	11.684615	7.75454545	1657.79692
12	2007	6620	2042	9461	3.73333333	366.3	5.7538462	6.84545455	1514.79154
13	2008	6825	2049	9522	3.525	374.05	2.1692308	6.35454545	1460.52154
14	2009	6624	2089	9667	3.26666667	303.8083	2.3615385	3.60909091	1099.31846
15	2010	6406	2123	9639	3.9	335.8333	12.684615	5.46363636	1450.8
16	2011	6387	2153	9610	3	341.8333	5.2307692	12.2727273	1007.92308
17	2012	6412	2303	9687	3.175	352.9167	5.5384615	7.72727273	1215.53846
18	2013	6382	2208	9539	3.50833333	354.45	5.0307692	9.63636364	1400.5
19	2014	6390	2327	9602	4.725	359.0417	5.3384615	10.4636364	1084.96154
20	2015	6239	1929	9589	4.15	365.4167	5.2846154	8.14545455	1447.36154
21	2016	6412	2303	9687	3.9	335.8333	12.684615	5.46363636	1450.8
22	2017	5705	1908	6039	3	354.45	5.0307692	9.63636364	1400.5
23	2018	6039	1912	9687	3.175	352.9167	5.5384615	7.72727273	1215.53846
24	2019	6107	1978	9539	3.50833333	354.45	5.0307692	9.63636364	1400.5
25	2020	6426	1991	9602	4.725	359.0417	5.3384615	10.4636364	1084.96154
26	2021	6578	2026	9589	4.15	365.4167	5.2846154	8.14545455	1447.36154

cle. Furthermore, it fluctuates with the phases of the solar cycle. A number of previous studies have investigated the temporal fluctuations of the cosmic ray strength and sunspot counts [16, 30, 31, 32]. They discovered an inverse relationship between the cosmic ray intensity and the sunspot counts. A correlation analysis was performed between the astronomical beam force (CRI) and sunspot numbers (Rz) for

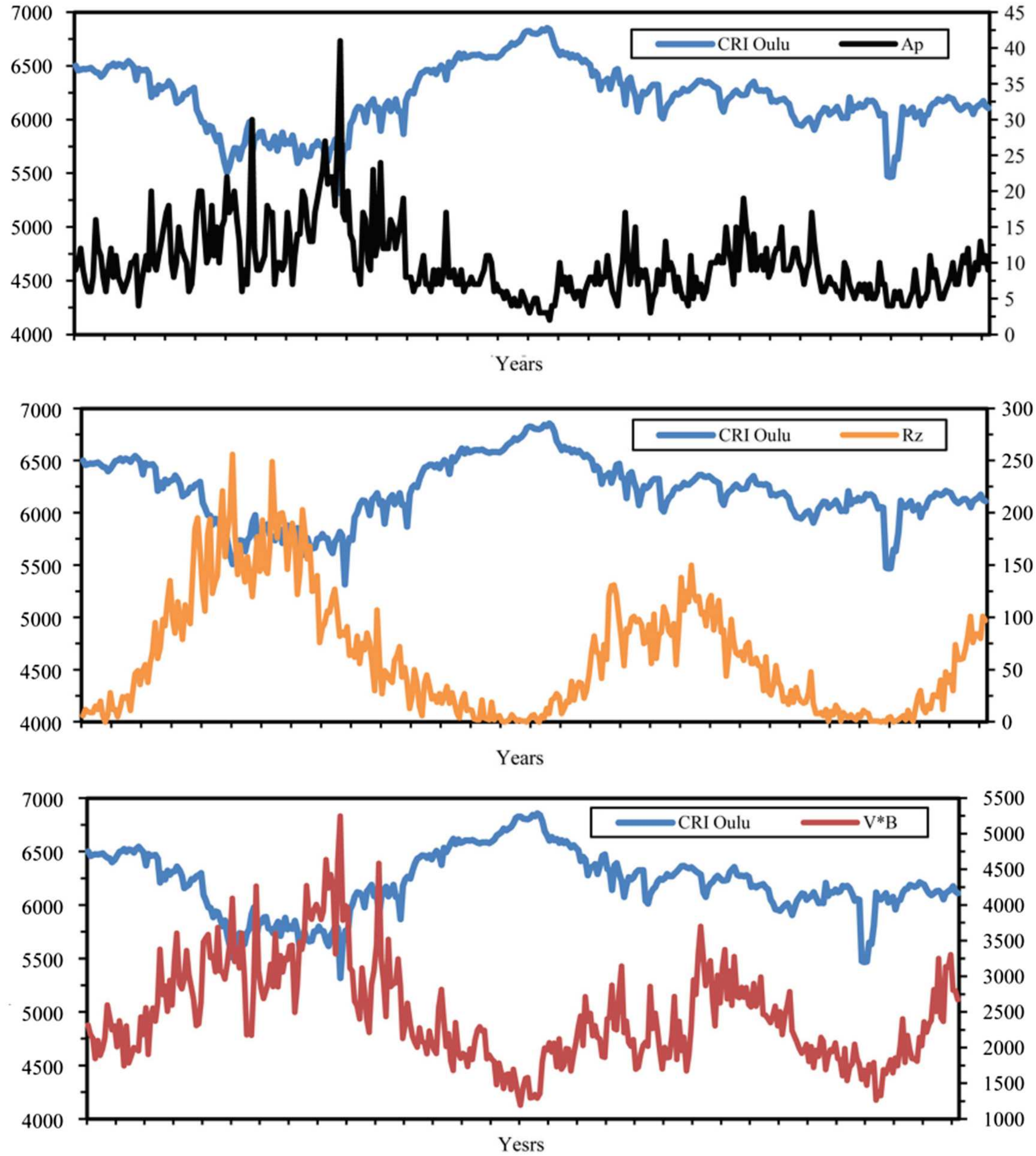

Fig. 2a. Yearly values of cosmic rays intensity for Oulu stations along with geomagnetic solar index (Ap), vector magnetic field ($V \cdot B$) & sunspot number (Rz) for years 1996–2021

sunlight-based cycles 23 and 24 [33]. In correlative research, the annual mean benefits of Beijing, Oulu, and Moscow super-neutron screens were used. For continuing time periods, hostile to correlative behavior between infinite beams and sunspot counts is confirmed during (1996–2022). Using yearly mean estimations of sunspot counts (Rz) and the infinite beam force, a relationship coefficient was derived for the time period 1996 to 2022, spanning sun-based cycles 22 and 24. In which we computed the correlation coefficient, which demonstrates that the shape of the curve for the even solar cycle is similar to the next even solar cycle and the shape of the curve for the odd solar-cycle is similar to the other odd solar-cycle. Figure 2, *a* shows the

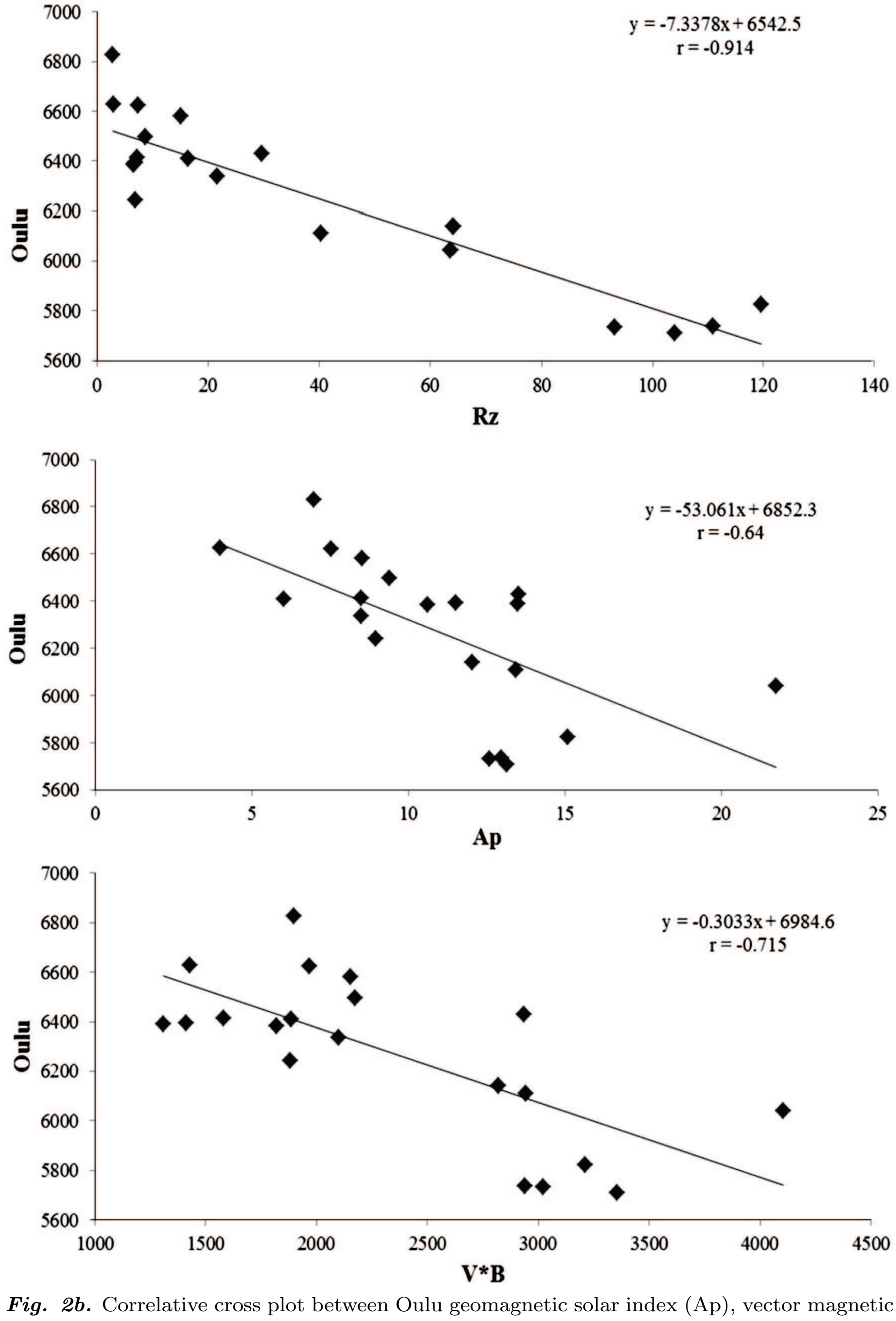

Fig. 2b. Correlative cross plot between Oulu geomagnetic solar index (Ap), vector magnetic field ($V \cdot B$) & sunspot number (Rz) for years 1996–2021

relationship between the cosmic ray intensity (Oulu) with sunspot number, geomagnetic indices Ap, and the product of $B \cdot V$ for the solar cycle 23 to 24 and ascending phase of solar-cycle 25. It is apparent from the figure that the inverse relationship and opposite variational profile. When CRI is increases during high solar-activity period the Ap indices, sunspot number and $B \cdot V$ shows negative variation for the

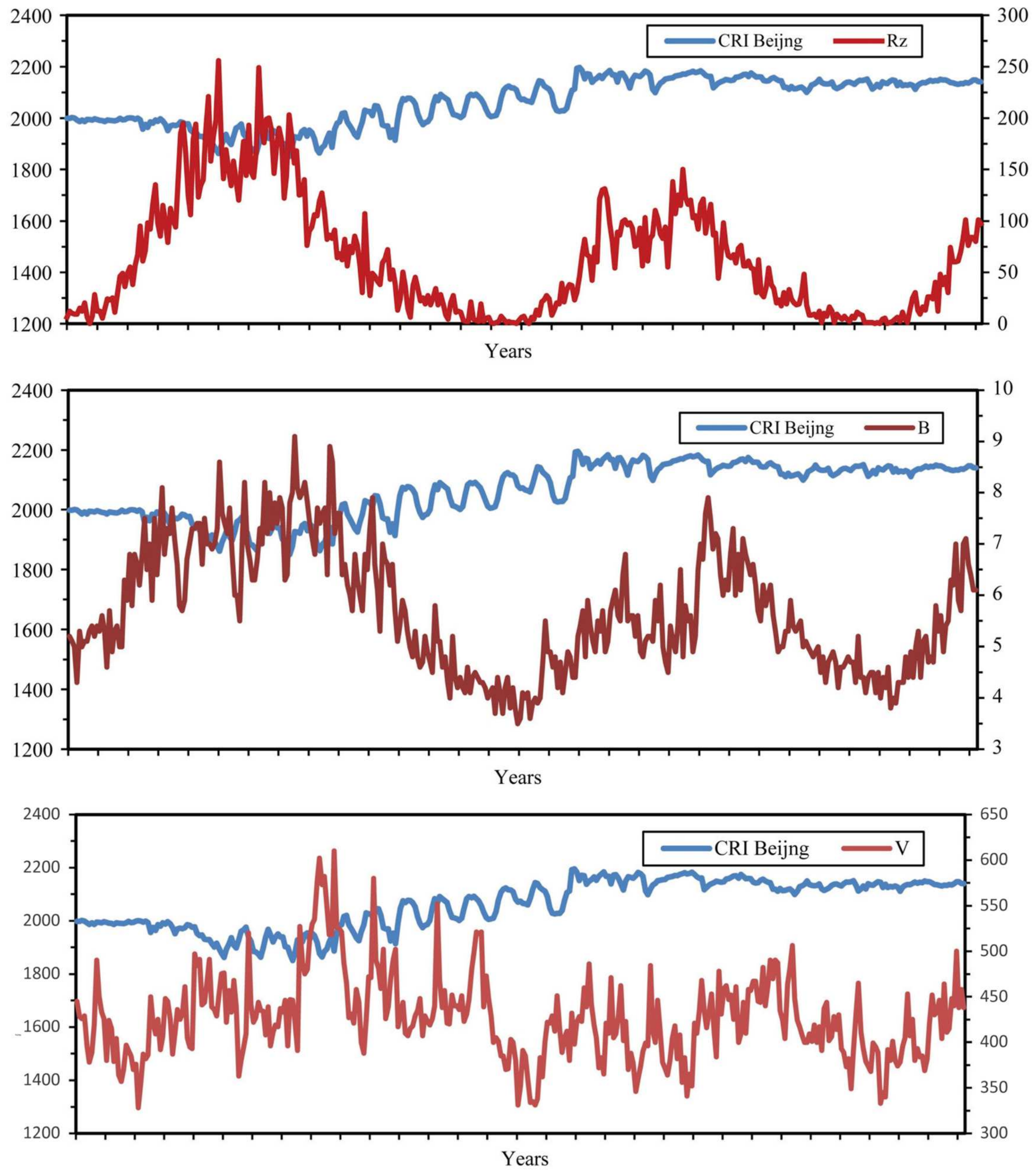

Fig. 3a. Cosmic rays intensity for Beijing stations along with geomagnetic magnetic field (B), solar wind velocity (V) & sunspot number (Rz) for years 1996–2021

solar-cycle 22 to 24. The long-term correlation coefficient between CRI and sunspot number Rz, Ap index and $B \cdot V$ found to be –0.9, –0.6 and –0.7 respectively in (Fig. 2, *b*). It is observed from Fig. 3, *a* that the CRI from Beijng is intensifications during high solar- activity period the sunspot number, B and solar wind velocity shows negative variation for the solar-cycle 22 to 24 anti-correlation among CRI and Rz, B, V found to be –0.60, –0.3 & –0.3, respectively. We noticed that solar cycle 24's ascending sequence roughly differs from solar cycle 22's. It is apparent from the (Fig. 4, *a*) that the opposite relation-

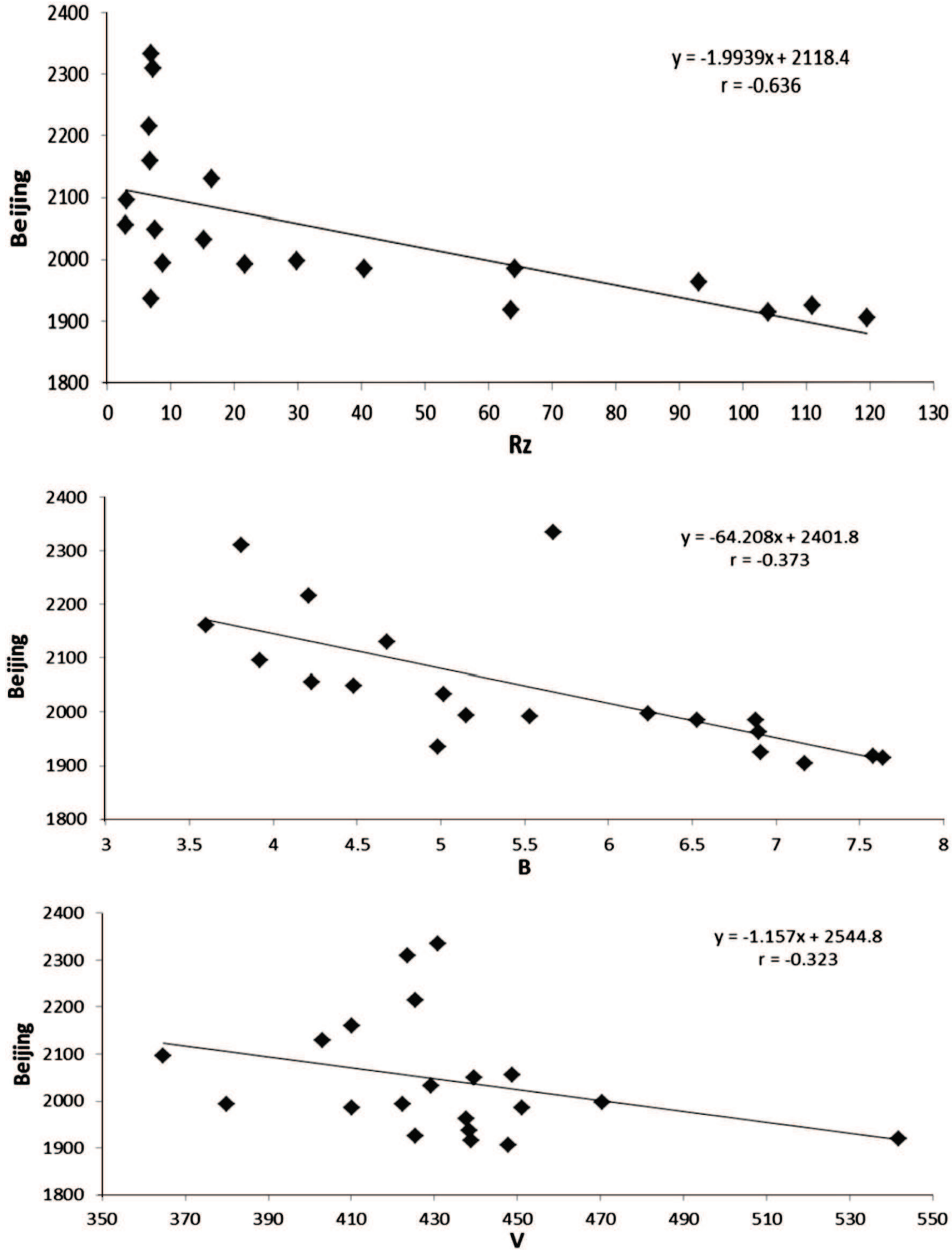

Fig. 3b. Correlative cross plot between Beijing & Geomagnetic magnetic field (B), solar wind velocity (V) & sunspot number (Rz) for years 1996–2021

ship and contradictory variational profile CRI from Moscow station with Rz, B & $B \cdot V$. The correlation-coefficient among CRI and B, Ap, $B \cdot V$ for the cycle 24 found to be –0.9, –0.8 & –0.7, respectively in (Fig. 4, *b*).

3.2. Correlative study of cosmic ray intensity & plasma temperature

For solar cycles 23 and 24, a correlation analysis was conducted between the cosmic ray intensity and plasma temperature (T). Correlative study used an-

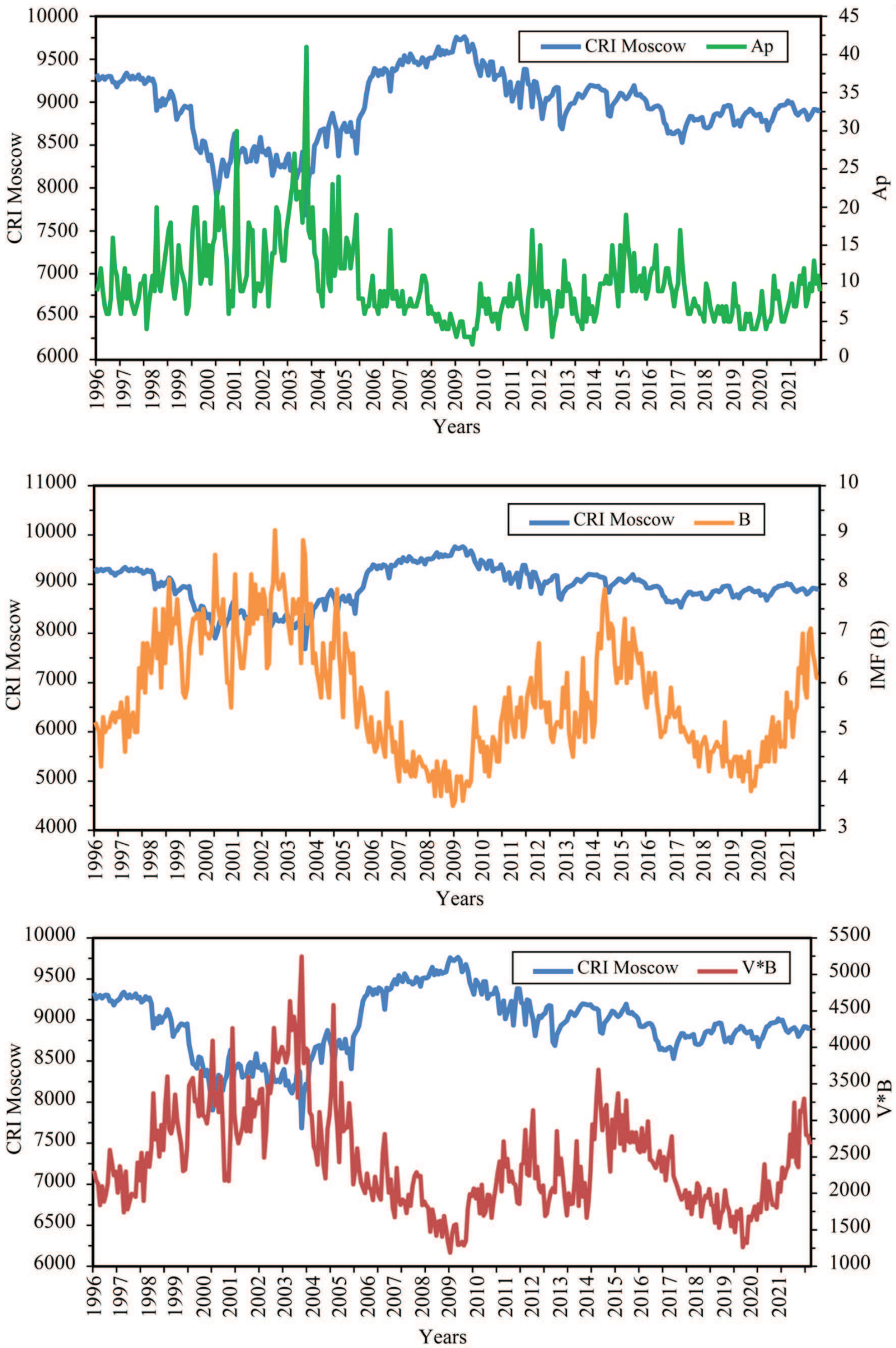

Fig. 4a. Yearly values of cosmic rays' intensity for Moscow stations along with Geomagnetic solar index (Ap), vector magnetic field $(V \cdot B)$ & sunspot number (Rz) for years 1996–2021

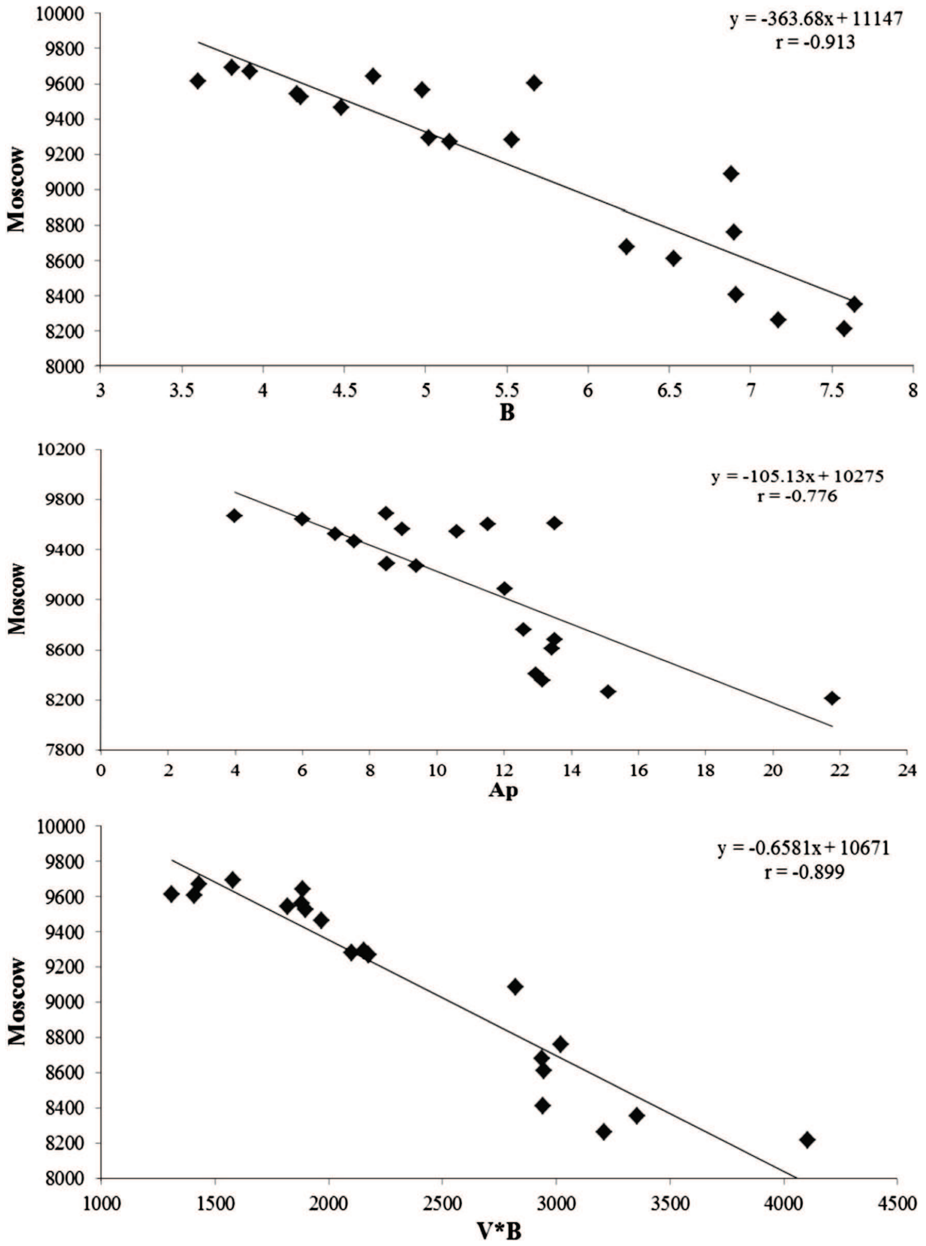

Fig. 4b. Correlative cross plot between Moscow Geomagnetic solar index(Ap), vector magnetic field ($V \cdot B$) & sunspot number (Rz) for years 1996–2021

nual mean readings from the Oulu and Moscow super neutron monitors. The anti-correlation between cosmic rays and T has been verified over recent times. In this analysis, we used annual averages of T & cosmic ray neutron intensity from Kiel and Moscow high latitude neutron monitor sites from 1996 to 2021. The correlation coefficient was calculated using yearly mean values of T and the cosmic ray intensity from 1996 to 2021, covering solar cycles. In most cases, the coefficient of correlation is determined to be negative and high. We created a cross plot for the annual value of cosmic rays and T, which shows a similar shape to the even solar cycle and a similar fluctuation trend to the odd solar cycle [34].

3.3. Correlative study of disparity of the cosmic ray force & plasma concentration

A correlation analysis was conducted between the cosmic ray intensity and the plasma density (D) during solar cycles. Correlative study used annual mean readings from the Oulu and Moscow super neutron monitors. The anti-correlation between cosmic rays and D has been verified over recent times. In this analysis, we used annual averages of D & cosmic ray neutron intensity from the Oulu and Moscow neutron monitor stations from 1996 to 2021. The correlation coefficient for the period 1996 to 2021, which covers solar cycles 23 and 24, was calculated using monthly mean values of D and cosmic ray intensity. In most cases, the coefficient of correlation is determined to be negative and high. The annual value of cosmic rays, which shows a similar shape to the even solar cycle and a similar fluctuation trend to the odd solar cycle. A substantial Forbush decline of 11 percent was reported by a ground-based neutron monitor at Oulu on 11 April 2001. The commencement of Fds occurred on 11 April at 16:00 hour and reached its peak on 12 April at 9:00 hour. The recovery will take place on April 15 at 14:00. M-79 solar flare was responsible for the event, which was followed by a halo (BA) Coronal Mass Ejection (CME) with a peak speed of 1103 km/sec, an average solar wind velocity of 670 km/sec, and a southbound magnetic field (B_z) of −11.8 nT. In this occurrence, the geomagnetic index Dst indicates a very extremely big reduction (−269 nT) and the geomagnetic Ap index was 207, with Fds being the major contributor. In the Fds event, the CME began on 11 April 2001 at 13.31.48 (HH:MM: Sec), whereas the storm began 15 hours later. The highest decreasing duration of Fds in this occurrence was 17 hours, whereas the recovery time of Fds was 4 days. Storm recovery, on the other hand, was far faster than Fds, which took two days. These findings back up previous findings [35]. It has also been noticed that the drop in cosmic rays (Fds) begins 11(16) immediately after the arrival of shocks 11(13) on Earth [36]. This study shows that Fds of 10% or more are related to Dst in the –200 to –300 nT range. This Fds event was caused by the most intense solar flare M-79, which was followed by a high-speed coronal mass ejection and shock. Because of these solar and Geomagnetic events, the geomagnetic index has dropped to –269 nT, signifying a severe geomagnetic storm. As a result, solar flares linked with CMEs are far more successful at creating huge Fds.

Table 2. **Correlation coefficient among cosmic rays on other solar & Geomagnetic parameters**

Beijing with Rz $r = -0.636$	Oulu with Rz $r = -0.913$	Moscow with B $r = -0.913$
Beijing with B $r = -0.373$	Oulu with Ap $r = -0.64$	Moscow with Ap $r = -0.776$
Beijing with V $r = -0.323$	Oulu with $V \cdot B$ $r = -0.715$	Moscow with $V \cdot B$ $r = -0.899$

4. Conclusions

We have presented the long-term aspects of the daily change. To investigate the effect of solar cycle variations (on high- and low-amplitude wave train incidents). The occurrences were classified according to the several stages of the solar cycle, including the minimum solar activity time period, the maximum solar activity time period, and the falling phase of the solar cycle. Only low-amplitude wave train episodes are seen at the minimum solar activity time period in both solar cycles. A substantially longer minimum CRI period is included in Cycle 24. Brown and Williams [37] identified a strong correlation between the geomagnetic activity and the size of the upcoming solar cycle. The number of geomagnetic abnormally quiet days and the size of the upcoming solar cycle were shown to be strongly correlated. When we combined solar cycles 23 and 24 with solar cycle 25, we came to the conclusion that solar cycle 25 was more active and had an impact on the space weather. According to statistical models, the monthly sunspot count will probably reach its high in 2013 between 50 and 70. Models based on the strength of the solar polar magnetic field suggest that the peak might happen as early as in 2012. It is of interest to follow the evolution of cycle 25 by comparing it to more recent cycles.

1. R. M. Jacklyn. The apparent sidereal and anti-sidereal daily variations of cosmic ray intensity. *Nuovo Cimento.* **24**, 1034 (1962).
2. S.P. Agrawal, L.T. Lenzerolti, D. Venketnsan, E.J. Hansen. Solar polar coronal holes and galactic cosmic ray intensities. *J. Geophys. Res.* **85**, 6845 (1980).
3. S.P. Agrawal, P.K. Shrivastava, R.P. Shukla. Study of cosmic ray daily variations during quiet periods at neutron monitor energies. In: *Proceedings of 24th International*

Cosmic Ray Conference, Calgary (Canada), July 19–30 (1993).
4. S.P. Agrawal. Solar cycle variations of cosmic ray intensity and large-scale structure of the heliosphere. *Space sci. Rev.* **34**, 127 (1983).
5. H.S. Ahluwalia, C. Lopate. Long term residual modulation of lower energy galactic cosmic rays. In: *Proceeding of 27^{th} Int. Cosmic Ray Conf., Hamburg, Germany, August 8–15* (2001).
6. O.N. Bakare, V.U. Chukwuma. Relationship Dst and solar wind conditions during intense geomagnetic storms. *Indian Journal of Radio & Space Physics.* **39**, 150 (2010).
7. J. Chum, M. Kollárik, I. Kolmasová, L. Ronald, J. Rusz, D. Saxonbergova, I. Strharsky. Influence of solar wind on secondary cosmic rays and atmospheric electricity front. *Earth Sci.* **9**, 671801 (2021).
8. Badruddin, D. Venkatesan, A. G. Ananth. Types of interplanetary shocks and forbush decreases. *Sol. Phys.* **134**, 395 (1991).
9. H.V. Cane. Coronal mass ejections and forbush decreases. *Space Sci. Rev.* **93**, 55 (2000).
10. M. Calisto, E. Usoskin, Rozanov, T. Peter. Influence of galactic cosmic rays on atmospheric composition and dynamics. *Atmos. Chem. Phys.* **11**, 4547 (2011).
11. N.R. Draper, H. Smith. *Applied Regression Analysis* (Wiley, 1998).
12. S.E. Forbush. World-wide cosmic-ray variations 1937–52. *J. Geophys. Res.* **59**, 525 (1954).
13. S.E. Forbush. Large increase of cosmic-ray intensity following solar flare on February 23, 1956. *J. Geophys. Res.* **62**, 169 (1957).
14. S.E. Forbush. Cosmic-ray intensity variations during two solar cycles. *J. Geophys. Res.* **3**, 6510669 (1958).
15. M. Gupta, V.K. Mishra, A.P. Mishra. Long-term modulation of cosmic ray intensity in relation to sunspot numbers and tilt angle. *J. Astrophys. Astron.* **27**, 455 (2006).
16. V. Gupta, Badruddin. High-speed solar wind streams during 1996–2007: Sources, statistical distribution, and plasma/field properties. *Sol. Phys.* **264**, 165 (2010).
17. J. Kóta, J.R. Jokipii. The role of corotating interaction regions in cosmic-ray modulation. *Geophys. Res. Lett.* **18**, 1797 (1991).
18. J.A. Lockwood. Forbush decreases in the cosmic radiation. *Space Sci. Rev.* **12**, 658 (1971).
19. J.A. Lockwood. An investigation of the Forbush decreases in the cosmic radiation. *J. Geophys. Res.* **65**, 3859 (1960).
20. S. Mori. Cosmic-ray modulation ground-based observations. *Il Nuovo Cimento C* **19**, 791 (1996).
21. M. Jakimiec, M. Storini, A. Antalova. Multivariate daily sequence analyses of GCR/solar X-ray parameters. *Advances in Space Res.* **20**, 111 (1997).
22. A. Prasad, S. Roy, K. Ghosh, S.C. Panja, S.N. Patra. Investigation of hemispherical variations of soft X-ray solar flares during solar cycles 21 to 24. *Sol. Sys.t Res.* **55**, 169 (2021).
23. R. Baral, B. Adhikari, A. Calabia, M. Shah, R.K. Mishra, A. Silwal, S. Bohara, R. Manandhar. Spectral features of Forbush Decreases during geomagnetic storms. *J. Atmos. Sol. Terr. Phys.* **242**, 105981 (2023).
24. S. Singh, D. Shrivastava, A.P. Mishra. Effect of solar and interplanetary disturbances on space weather. *Indian J. Sci. Res.* **3**, 121 (2012)
25. S. Kaushik, P. Shrivastava. Influence of magnetic clouds on interplanetary features. *Indian J. Phys.* **74**, 159 (2000).
26. S. Singh, A.P. Mishra. Cosmic ray intensity increases during high solar activity period for the solar cycles 22 and 23. *Indian J. Phys.* **93**, 139 (2019).
27. S. Singh, A.P. Mishra. interaction of solar plasma near-earth with reference to geomagnetic storms during maxima of solar cycle 24. *Indian J. Phys.* **89**, 1227 (2015).
28. S. O. Ifedili. Forbush decrease of June 8, 1969: Causes of the unusually long recovery. *Earth, Planets and Space.* **53**, 993 (2001).
29. I.G. Usoskin, H. Kananen, K. Mursula, P. Tanskanen, G.A. Kovaltsov. Correlative study of solar activity and cosmic ray intensity. *J. Geophys. Res.* **103** 9567 (1998).
30. V.K. Mishra, A.P. Mishra. Long-term modulation of cosmic-ray intensityand correlation analysis using solar and heliospheric parameters. *Sol. Phys.* **293**, 141 (2018).
31. D.F. Webb, T.A. Howard. Coronal mass ejections: Observations. *Living Rev. Sol. Phys.* **9**, 3 (2012).
32. M. Lee, L. Fisk. The role of particle drifts in solar modulation. *Astrophys. J.* **248**, 836 (1981).
33. E. Ross, W.J. Chaplin. The behaviour of galactic cosmic-ray intensity during solar activity cycle 24. *Sol. Phys.* **294**, (2019).
34. R.P. Kane. Hysteresis loops of cosmic ray intensity decreases versus solar and interplanetary parameters. *Ann. Geophys.* **25**, 2087 (2007).
35. L. Burlaga, F. McDonald, M. Goldstein, A. Lazarus. Cosmic-ray modulation and turbulent interactionregions near 11 AU. *J. Geophys. Res.* **90**, 12027 (1985).
36. B. Popielawska. Components of the 11- and 22-year variation of cosmic rays. *Planet Space Sci.* **40**, 811 (1992).
37. G. Brown, W. Williams. Some properties of the day-to-day variability of Sq(H). *Planet. Sp. Sci.* **17**, 455 (1969).

Received 16.06.23

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АКТИВНІСТЬ СОНЦЯ, ВАРІАЦІЇ ІНТЕНСИВНОСТІ КОСМІЧНИХ ПРОМЕНІВ ТА ГЕОМАГНІТНА АКТИВНІСТЬ ПРОТЯГОМ 1996–2022 рр.

Вивчається вплив змін на Сонці на космічні промені і геомагнітне поле у період з 1996 р. до 2022 р. Розглянуто довгострокові зміни інтенсивності космічних променів та її зв'язок з кількістю сонячних плям, швидкістю сонячного вітру, індексом геомагнітних збурень та магнітним полем. Для космічних променів взято дані спостережень в Оулу (0,81 ГеВ), Москві (2,41 ГеВ) та Бейджінгу (9,56 ГеВ). Знайдено пояснення гіпотезі парного-непарного, явищу гістерезису та затримці у часі довгострокової модуляції.

Ключові слова: космічні промені, індекс геомагнітного збурення, цикл сонячної активності.