"Long-Term Analysis Of The Diurnal Variability Of Crs Observed On Low Cut-Off Rigidity Neutron Monitors"

Rakesh Kumar Gautam[1*], Dr. Sushil Kumar Dubey[2]

[1*]Research Scholar, Rani Durgavati Vishwavidyalaya Jabalpur, MP Email: rkgautam.gpcs@gmail.com
[2] Madhya Pradesh Bhoj Mukt (Open) University, Bhopal Email: sushil.dubey.jabalpur@gmail.com

[*]**Corresponding Author:** Rakesh Kumar Gautam
*Research Scholar, Rani Durgavati Vishwavidyalaya Jabalpur,MP Email: rkgautam.gpcs@gmail.com

Abstract:
The diurnal variability of cosmic rays (CR) carries the signature of the modulation of galactic CR in the heliosphere, and in turn, it reflects the conditions prevailing in the heliosphere, which makes the study of daily variation of cosmic ray intensity important for the study of space weather and related features. In this study, the diurnal amplitude and phase of four neutron monitors with low cut-off rigidity have been studied by analyzing approximately five and a half solar cycles. This study covers the solar cycle (SC)-20 to SC-24/25, with a focus on the transition period between SC-24 and SC-25 in the context of diurnal isotropy with solar activity and polarity changes in the magnetic field of the Sun. Significant variations in the diurnal amplitude and phase of cosmic rays (CRs) are observed at low cut-off rigidity neutron monitors during both phases of solar activity in every solar cycle. The analysis also revealed significant relationships between diurnal variability and solar features. In all four neutron monitor datasets, there was a sharp and unmatched decline in amplitude and phase from 2018 to 2022 at the beginning of the 25th solar cycle. The next solar cycle is anticipated to be cooler than its predecessor and to exhibit a lower diurnal amplitude.

Keywords: Diurnal Variability, Anisotropy, Solar Activity, Polarity reversal

Introduction:
The cosmic ray flux reaching Earth significantly depends on the modulation of cosmic rays by solar wind and other solar phenomena. This modulation process can be better understood by studying the diurnal variation of cosmic rays, as the diurnal variation of cosmic rays provides a useful source for analysing CR transport in the heliosphere., McCracken and Rao 1965; McCracken, 1963) Marsden (1965), and Sarabhai (1964) used neutron monitor data to investigate the rigidity dependence of diurnal variability and confirmed that the observed diurnal variation is consistent with an energy-independent primary anisotropy that extends to approximately 100 GeV. At lower rigidity levels, the diurnal anisotropy is significantly influenced by the characteristics of both the primary spectrum and diurnal variation. The NMs in high and polar latitudes have more variation than those in middle and equatorial latitudes and the time of maximum shifts to later hours for stations with higher cut-off rigidity (Tezari et al., 2016a).

The first harmonics have low values and a phase shift towards early hours on days with low sun activity. Mishra and Mishra (2007) examined the occurrence of high-amplitude anisotropic wave train events during periods of minimum and maximum solar activity, it is noted that the amplitude and phase of cosmic ray diurnal anisotropy show a healthy and noticeable correlation with solar activity.

Ahluwalia et al. (2010) used neutron monitor data with a cut-off rigidity of 1–200 GV to explain the rigidity-dependent characteristics of the 11-year modulation of galactic cosmic rays (GCR) throughout four consecutive sunspot cycles, namely cycles 20 to 23, and found that the observed rigidity dependence can be suitably described by a power-law relationship characterised by negative exponents. Tezari et al. (2016) investigated the latitudinal and longitudinal distribution of cosmic ray diurnal anisotropy by categorising observation stations based on their geographical coordinates. This study reveals that diurnal variations are not exclusively determined by latitude but are additionally affected by the longitude of the monitoring stations.

Diurnal parameter analyses for long terms can reveal novel information about variations in cosmic rays and their links with solar activity. According to long-term investigations, the amplitude of diurnal variation correlates with the features of high- and low-amplitude days. High-amplitude occurrences related to the Sun's cycles and low-amplitude days were inversely associated with the solar cycle (Ananth et al., 1993). Diurnal amplitude variations associated with solar cycle fluctuations remain constant throughout the ascending phases of both odd and even solar cycles(A. K. Tiwari et al., 2012a). However; there seems to be a distinct variation in the time of occurrence of these oscillations during the ascending phase of odd than that of even solar cycles such as cycles 21 and 23 against those of cycles 20 and 22, the oscillations occur much earlier (Singh et al., 2011a; Tiwari et al., 2012a). The observation of (S. Thomas et al., 2017) found that in the polarity state $A < 0$ and state $A > 0$, diurnal amplitudes are similar, though not the same, in their phases, whereas diurnal anisotropy phase changes vary in transition. They proposed that the diurnal anisotropy vector may slightly change direction between the two polarity states. According to Munakata et al.,(2014), the intensity of the cosmic rays decreases for both A> 0 and A <0 polarity states, respectively, at low cut-off rigidity which comes before the solar polarity state A<0. The sun, the Earth's shock wave, and the space near Earth have less energy in the current solar cycle 24, this affects our planet's electric layer, and magnetic field (Kakad et al., 2019). The sun's activity changes every 11 years in a cycle, but it is also unpredictable and random. This makes it hard to guess what the sun will do after one cycle (Usoskin, 2017). Prolonged changes in the attributes of the Sun’s magnetic field, coupled with solar activity, have manifested a sustained decrease in Solar Activity, particularly evident after 2002(Aslam & Badruddin, 2015). The beginning of this decline became noticeable from 1995-96 (Belov A.N. et al. 1999). A pronounced reduction in solar activity was recorded during the transition from the 22nd to the 23rd solar cycle, and this decline endured throughout the 24th cycle (A. V. Belov et al. 2021). They also observed decline in solar activity continues, and such a decline has not been seen in the near history.

Geomagnetic activity has been known for a long time to be characterised by solar parameters. The variation in current systems within the magnetosphere and ionosphere gives rise to geomagnetic activity. These systems are shaped by the interaction between the solar wind and the magnetosphere. In contrast, solar activity is characterised by a well-defined 11-year periodic variation, commonly known as a solar cycle. Changes in solar activity can significantly affect geomagnetic activity(Reyes et al., 2021). Even small changes in solar activity can have dramatic and complex effects on the magnetic field of the Earth. Being a periodic variate, the solar activity, we can expect periodicity in the geometric activities. Variations in the electromagnetic environment of the Earth during the 11-year solar cycle have been investigated in recent decades (Li et al., 2018).

Our study aims to investigate the daily fluctuations in cosmic ray intensity during the transition from Solar Cycle 24 to Solar Cycle 25. By comparing our findings with those of previous studies, we anticipate the characteristics of the forthcoming solar cycle and make predictions related to space weather.

Data and Methodology:

In this study, we examined the diurnal amplitude and phase of cosmic rays observed at a low cut-off rigidity of Rc ≤ 1.14 GV over approximately 59 years. Hourly pressure-corrected data were obtained online from four neutron monitor stations with cut-off rigidities ranging from 0 to 1.14 GV for the period of study; period spanning 1964 to 2022. These stations were chosen to provide broad coverage of the polar region of the Earth. This study employs various statistical methods to analyse the data, including Fourier transforms. These techniques are used to identify the periodicity and amplitude of diurnal variations in cosmic ray flux and their long-term trends and variations. Harmonic analysis was conducted on the data using Fourier analysis to determine the amplitude (in percentage) and phase (in hours) of the neutron monitor data. The specifications of the six stations used in the analysis are summarised in Table 1.

Table 1 Specifications of low cut-off rigidity neutron monitors.

Neutron Monitor	Geographic Latitude	Geographic Longitude	Cut-off Rigidity	Span
Apatity	67.57 N	33.4 E	0.65 GV	1964 to 2022
Inuvik	68.35 N	-133.72 W	0.17 GV	1964 to 2022
Oulu	65.05 N	-25.47 E	0.8 GV	1964 to 2022
Thule	76.60 N	-68.80 W	0.0 GV	1964 to 2022

Results and Discussion:

This study used NM data from Apatity (APT), Inuvik (IVK), Oulu (OLU), and Thule (THL). Table 1 details the specifics of the stations and years of observations employed in this analysis. Days with significant ground-level enhancements (GLE) due to solar flares and coronal mass ejections (CMEs) were excluded from the dataset during observation. The yearly averages of the daily amplitude (in per cent) and phase (in hours) are shown separately for neutron monitor (NM) stations over 59 years based on the availability of data.

Figure 1 illustrates changes in cosmic ray diurnal amplitudes (DAs), as observed with n NMs, and demonstrates the annual variation in solar activity levels measured by the number of sunspots. Figure 1 clearly shows that all NMs display almost the same behaviour. The diurnal amplitude (DA) shows approximately an 11-year sunspot cycle variation, with minima occurring near the sunspot minimum in 1964, 1976, 1986, 96, 2002, 2008, and 2019 with some deviation and maxima occurring near the sunspot maximum in 1970, 1981, 1989, 2001, 2014.

Based on data availability, the Thule NM had very low diurnal amplitudes in 1976 , and 2020, and Apatity, Invik, and Oulu had low diurnal amplitudes in 1996 and 2019. Note that the diurnal amplitude decreased in 1995-1997, which is the transition period of Solar Cycles 22 and 23. Similarly, 2018–2021 represents the transition period of Solar Cycles 24–25, but the decline during this period is the first time it has occurred.

Fu et al. (2021) observed that the environment affecting the modulation of galactic cosmic rays during the solar minima of cycles 24 and 25 differed significantly from the previous solar minima. They stated that the period was characterised by extremely low solar activity a weak interplanetary magnetic field and turbulence. From 2018 onwards, there has been a noticeable plateau in the flux of cosmic rays during the minimum of cycle 24/25, which supports the drift theory of modulation when the Sun’s global magnetic field is in a positive direction (Yanke et al., 2021, 2022). These conditions make it possible to reduce the level of solar modulation, which could explain the unprecedented high GCR intensity in interplanetary space. Belov A.V. et al. 1999) examined a similar anomaly and found an unusual diurnal anisotropy behaviour that occurred in early 1996 during Solar Cycle 22. This behaviour is exceptionally small and has an unusual amplitude and phase distribution. The diurnal anisotropy amplitude varied over an 11-year cycle, with the lowest values occurring at the solar maxima and the highest values occurring near the solar minima of the declining phase.

The diurnal amplitude also shows a difference between even and odd-numbered solar cycles, with lower values for even cycles. Although all solar minima such as 1964–65, 1976, 1986, 2008–09, and 2019–20 have small amplitudes of diurnal variability of cosmic rays, our observations found a much lower diurnal amplitude in 1996 than other solar minima. However, in SC 24–25 (2019–20), the daily amplitude is less than that in 1996. As such the lowest diurnal amplitude for the Thule NM station occurred in 1976. In 2019-20, the diurnal amplitude was found to be 50%–60% less than the overall average amplitude of the entire observation. In the transition period of SC 24–25 (2019–20,) not only the amplitude is less than the previous results, but the diurnal phase is also less than that of the entire 59 years of observations.

Notably, periodic enhancements in amplitude occurred during the declining phases of solar cycles 20, 21, 22, 23, and 24 in 1971, 1974, 1984-1985, 1990, 1994, 2002–2005, and 2018–19, respectively. A remarkable fall in amplitude appeared in 2019 for Apatity, Inuvik, and Oulu and in 2020 for Thule station in the minimum of 24/25 solar cycles. A surprisingly sharp peak occurs for the Inuvik NM station in 2021, which declines again in 2022, while the remaining three stations display relatively slow recovery until the end of 2022 in this observation.

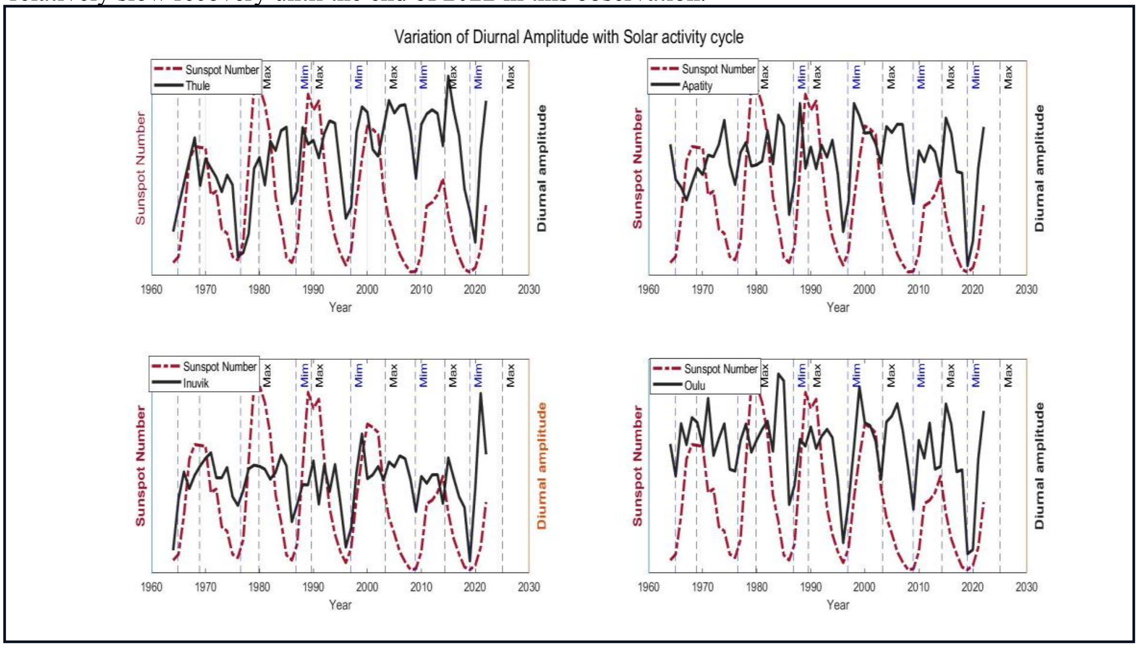

Figure 1 shows the variation of the amplitude of diurnal isotropy with the solar activity cycle at Thule, Apatity, Inuvik and Oulu NM stations.

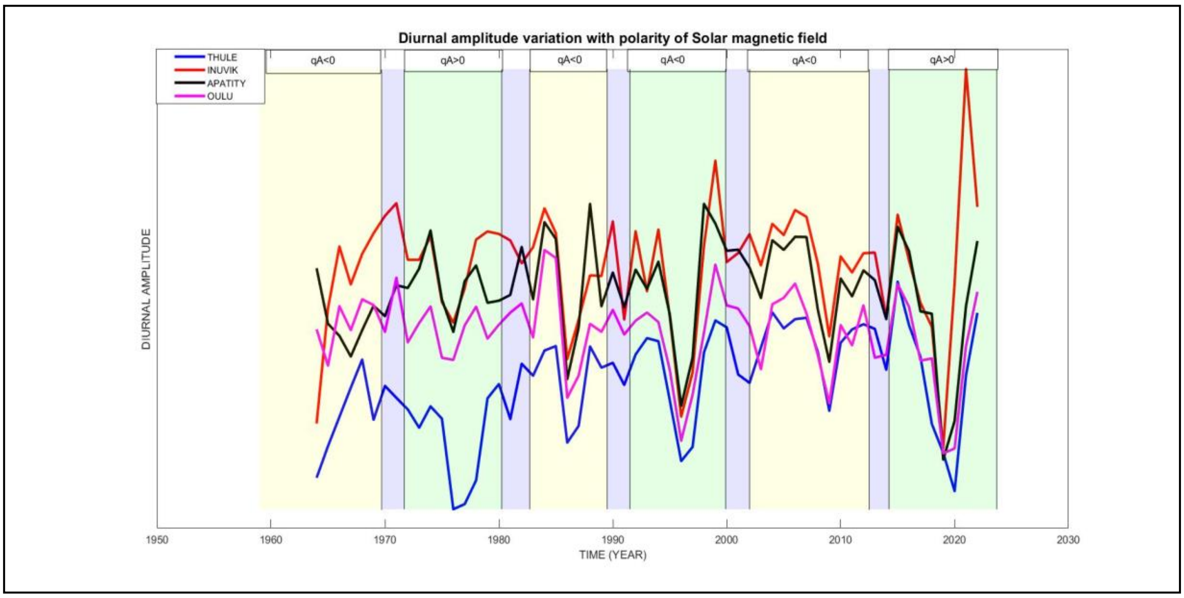

Figure 2 shows the variation of the amplitude of diurnal isotropy in solar polarity epoch (qA<0) and (qA>0) at Thule, Inuvik, Apatity and Oulu NM stations.

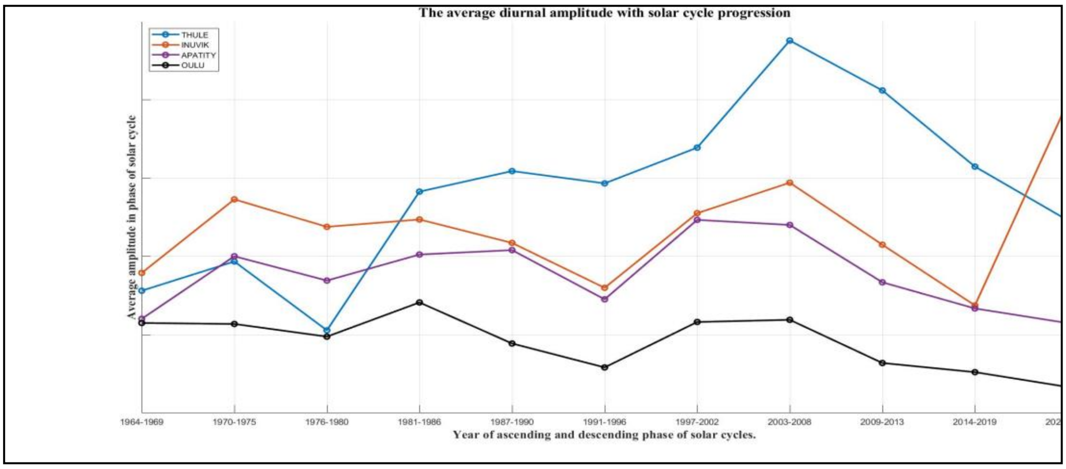

Figure 3 shows the amplitude of diurnal isotropy averaged over the ascending and descending phases of the solar cycle at the Thule, Inuvik, Apatity, and Oulu NM stations.

Figure 2 shows the periods of the magnetic field reversals highlighted by vertical lines. During qA<0, the interplanetary magnetic field (IMF) points towards the Sun in the northern hemisphere and away from the Sun in the southern hemisphere. The diurnal amplitude is also influenced by the polarity of the solar magnetic field, with larger values during negative polarity states; however, a clear disparity is observed in solar cycle 22. On the other hand, during qA>0, the IMF points towards the Sun in the southern hemispoalaphere and away from it in the north (Sabbah, 2013). The intervals of positive and negative magnetic states were 1971–1980 1992–2000 and 1959–1969, 1981–1991, and 2002–2010, respectively. The amplitude enhancement is greater in the positive polarity states (A>0) of the Sun.

The amplitude was the lowest during the minima of solar cycles 23 and at the beginning of 25 when the IMF was directed away from the North Pole. However, at the beginning of the solar cycle 25 it is historically low. When the solar polar field reverses from qA>0 to qA<0, DA is almost flat during maximum solar activity. However, DA was enhanced during the declining phase of solar activity, particularly in SC-24. This confirms the results of (A. K. Tiwari et al., 2012b). The amplitudes of these enhancements are higher than the maximum solar activity for cycles 20-23.

The change in the average value of DA is shown with the progression of SC in Figure 3. It is clear that the average value of DA is found to be less in the ascending phase and more in the descending phase of SC 20, 21 and 23, but this fact is seen to be the opposite in SC 22 and SC 24. In the observation of Tiwari et al., 2012) the vector mean diurnal amplitude for the falling phases of the even-numbered sunspot cycles (20 and 22) was much lower than those of the vector mean for the falling phases of the odd-numbered sunspot cycles (21 and 23). From here, it becomes clear that not only does the value of the diurnal phase depend on the odd and even solar cycles, but the average DA also varies with the odd and even solar cycles.

The time of maximum diurnal anisotropy exhibits a ~22-year variation that corresponds to the solar magnetic cycle (Kóta, 2013; Laurenza et al., 2014; Potgieter, 2014; S. R. Thomas et al. 2014). It is seen in Figure 4 that the diurnal phase (DP) variation, changes approximately following the Hell cycle. However, an anomaly was observed for the Apatity station in 1991–1992 and a similar pattern was found for the Inuvik station in 2011, and the correlation for Apatity was weak in our observations. The diurnal phase also appeared to shift to the early hours in 1995–1996 and 2018–2021. The largest phase shift (decline in time of maximum) in the entire observation is seen in 2019–20, which is less than that of the phase in 1995–1996.

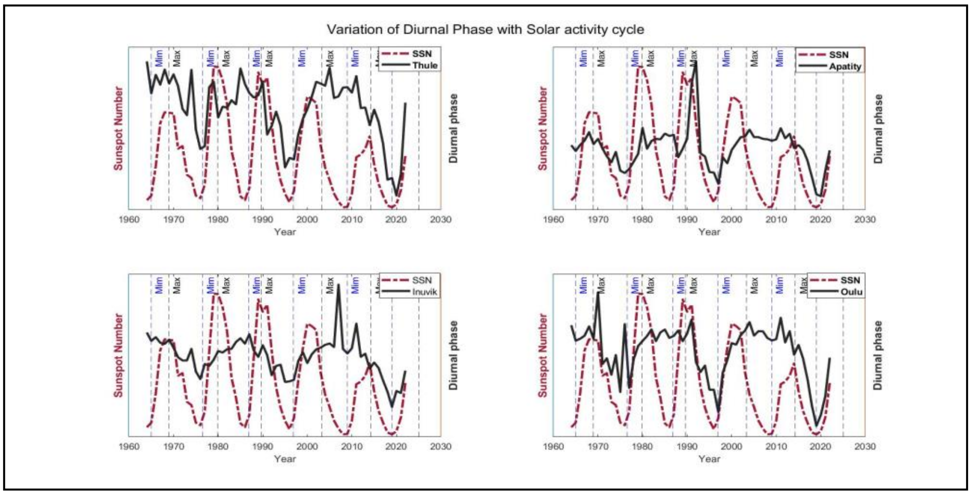

Figure 4 shows the variation of the phase of diurnal isotropy with the solar activity cycle at Thule, Apatity, Inuvik and Oulu NM stations.

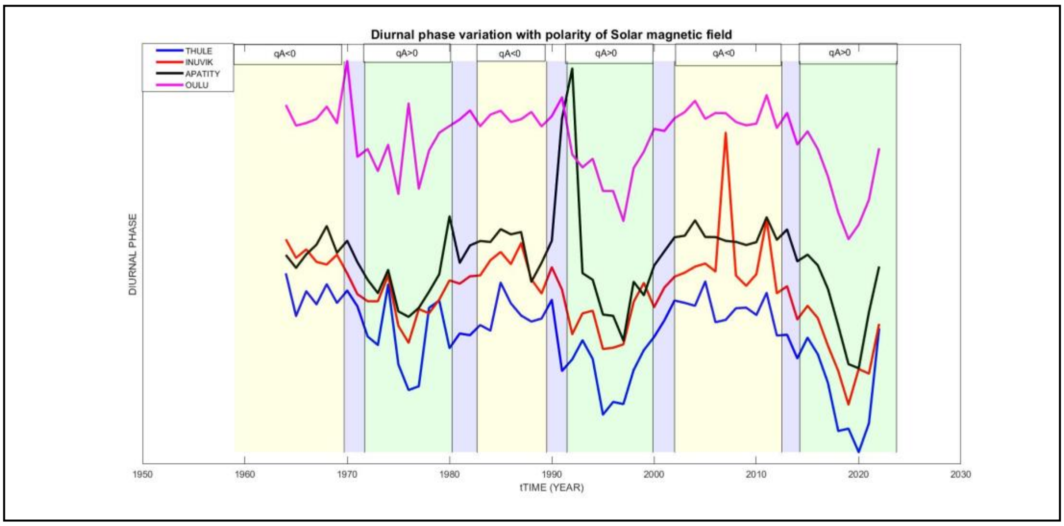

Figure 5 shows the variation of the phase of diurnal isotropy in solar polarity epoch (qA<0) and (qA>0) at Thule, Inuvik, Apatity and Oulu NM stations.

An anomalous behaviour of the diurnal phase at the Oulu station during 1976 was observed, which requires further investigation. The diurnal phase shifts to earlier hours after the polarity reversal reaches its minimum value near the solar minimum, and then recovers to its pre-reversal level.

The observations indicate that the diurnal phase is more sensitive to the orientation of the solar magnetic field than to the solar activity progression. Figure 5 illustrates the phase variation with polarity reversal of the Sun's magnetic field. The diurnal phase is low when qA < 0, i.e., the Phase shifts towards earlier hours and phase shifts to later hours when qA > 0 (Sabah I, 2013; Modzelewska et al., 2019), although anomalies were observed at the Oulu station from 1971 to 1980. Observations show (Figure 5) that the diurnal time of the maximum is less in the positive polarity state of the Sun, i.e., shits towards earlier hours than recovery, and it is found more in the negative polarity state, i.e. Shift towards later hours than down. However, there are some anomalies in the observations, such as a trough found at the Oulu NM station during the (1972–80) positive polarity state, the high peak found at Inuvik station during the (2002–14) negative polarity state of Sun's magnetic field and in the Apatity NM station at the time of polar reversal (1980–82) also gets a high peak.

Figure 6 shows the variations in the phase (time of maximum) of the average diurnal anisotropy with the progression of solar cycles from 1964 to 2022. In the ascending phase of solar cycles 20, 22, and 24, the diurnal phase is greater, i.e.Shift towards later hours, and in the descending phase it is less, i.e., Shift towards the early hour, whereas in solar cycles 21, 23, and the beginning of 25, the opposite phase variation is observed. These results are consistent with those of Singh A. et al. 2011; Tiwari et al., 2012) In this observation, a variation was observed in the results of Apatity NM from 1991 to 1996. The most important thing is that after the DP falls in the descending phase of Solar Cycle 24, it falls continuously at the beginning of Solar Cycle 25 and becomes historically low in the transition period of Solar Cycles 24–25, with the recovery of phase starting in 2021. It was found that during even solar cycles, the time of the diurnal phase at the solar activity minimum shifts towards earlier hours. Conversely, during odd solar cycles, a shift towards later hours was observed, which corresponds to (C. M. Tiwari & Tiwari, 2008). These results regarding diurnal amplitude and phase changes are consistent with those of Thomas et al. (2017). The diurnal vector of each NM was oriented towards the co-rotational direction at ground level, subsequently exhibiting a systematic shift in alignment concurrent with changes in the

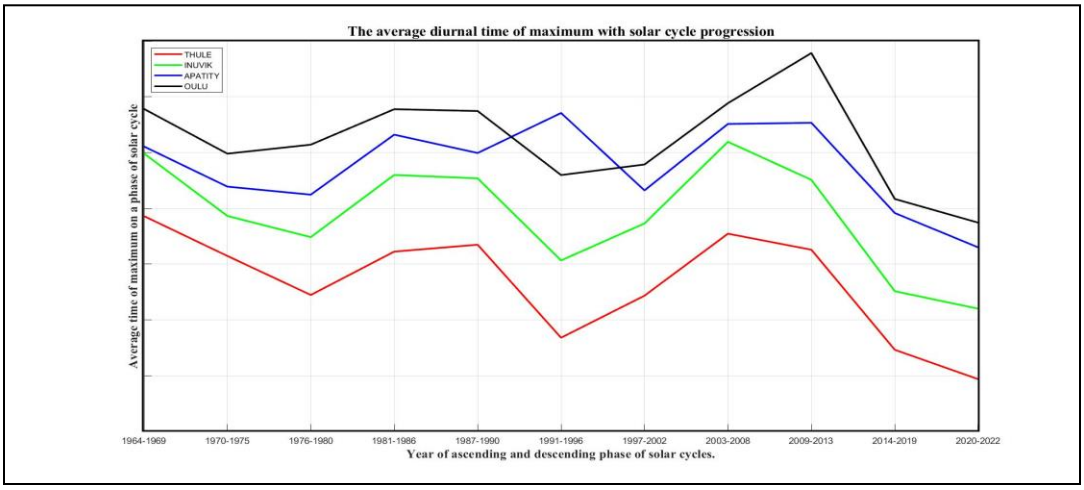

Figure 6 shows the phase of diurnal isotropy averaged over the ascending and descending phases of the solar cycle at the Thule, Inuvik, Apatity, and Oulu NM stations.

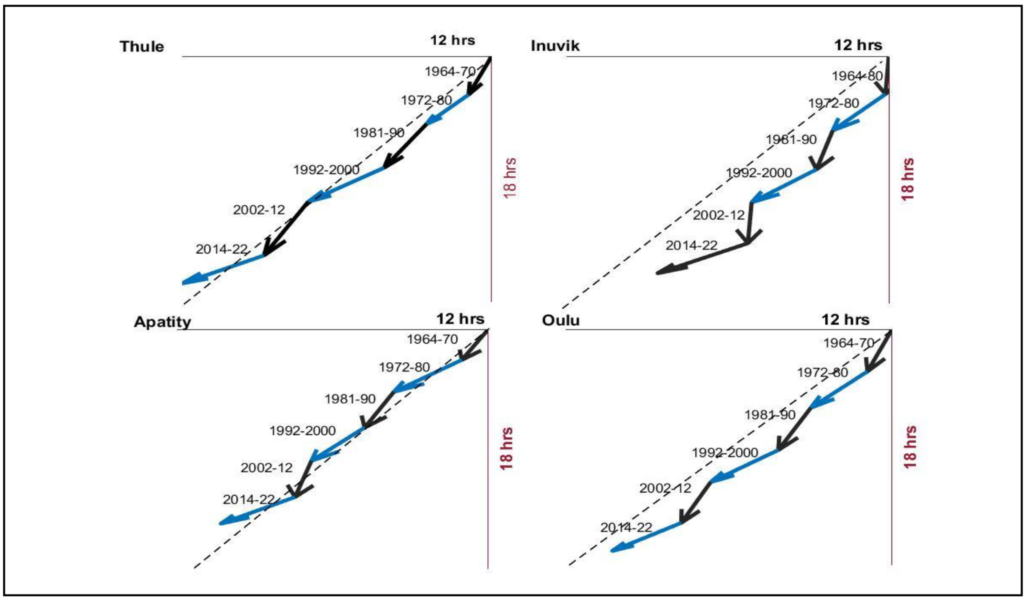

Figure 7 shows vector addition representations of the diurnal anisotropy averaged over solar polarity epochs (A > 0 and A < 0) for NM stations Thule, Inuvik, Apatity and Oulu.

Figure 7 illustrates the diurnal anisotropy vector addition for the Apatity, Inuvik, Oulu, and Thule NM stations for the study period 1964–2022. These vector addition diagrams illustrate the mean diurnal anisotropy over a heliospheric polarity state for each negative (1964–1970, 1981–1990, 2002-2012) and positive (1972–1980, 1992–2000. 2014-2022) polarity epoch. Here, we have drawn the average of the diurnal amplitude and the corresponding time of maximum in each positive and negative polarity state of the solar magnetic field. The average value in the polarity state of the diurnal amplitude (in %) represents the length of the vector, and the maximum time (in hours) represents the direction of the corresponding vector. The vector shifts to an earlier hour during 1972–1980, 1992–2000, and 2014–22 when the Sun is in its positive polarity state and shifts towards a later hour during 1964-70, 1981–1990, and 2002–12 when the Sun is in its negative polarity state. (Modzelewska et al. 2019 2021) concluded that the shift depends on the sign of the SMF polarity (qA), and can be understood by the theory of GCR modulation that involves diffusion and drift processes. They also confirmed that radial component of the anisotropy reflects the global drift caused by the gradient and curvature of the heliospheric magnetic field. The resultant vector direction for the entire period is observed to be in the early hour's direction.

Conclusion:

This study investigates the daily variations of cosmic ray intensity concerning sunspot numbers (SSNs) and the inversion of the solar magnetic field (SMF) across solar cycles 20 to early 25. It reveals significant changes in the amplitude based on the Sun's 11-year activity cycle with some lagging. A 22-year periodicity in the phase of diurnal anisotropy, with minimums in 1976, 1996, and 2019 is also evident. The diurnal amplitude and phase tended to be more stable during or around the solar minima of cycles 20–21 (1976-77), 21–22((1986-87) and 23-24 (2007–09) but decreased around the solar maximum within two subsequent periods 22–23 (1996–1997) and 24–25 (2018–2018). Stronger dependence of diurnal anisotropy on solar variability during the ascending phase of Solar Cycle 24, has also been observed.

Record low levels of SSN and interplanetary magnetic field were observed at the end of solar cycle 23 (Fu et al., 2021b), continuing to 2022. In this series, the current investigation reveals a remarkable decline in the amplitude and time of maximum diurnal anisotropy during the transitional phase between solar activity cycles 24 and 25. This observation substantiates the gradual attenuation of the Sun's magnetic field and the stagnation of the ongoing solar cycle. Furthermore, the diurnal anisotropy parameters of cosmic rays exhibit distinct variations based on the polarity of the Sun's magnetic field, particularly during periods of polarity reversal, as exemplified by occurrences in 1975–1977, 1995–1997, and 2007–2009. Notably, a phase shift towards earlier hours is evident for positive SMF polarity, while negative SMF polarity corresponds to a delayed phase. These findings align with the GCR modulation theory, encompassing phenomena like diffusion and drift, and significantly contribute to our comprehension of the 22-year cyclic variation in GCR anisotropy.

References:

1. Ahluwalia, H. S., Fikani, M. M., & Ygbuhay, R. C. (2010). Rigidity dependence of 11-year cosmic ray modulation: Implication for theories. *Journal of Geophysical Research: Space Physics*, *115*(A7). https://doi.org/10.1029/2009JA014798
2. Ananth, A. G., Venkatesan, D., & Pillai, S. (1993). Long-term changes in the cosmic-ray diurnal anisotropy. *Solar Physics*, *143*(1), 187–196. https://doi.org/10.1007/BF00619104
3. Aslam, O. P. M., & Badruddin. (2015). Study of Cosmic-Ray Modulation During the Recent Unusual Minimum and Mini-Maximum of Solar Cycle 24. *Solar Physics*, *290*(8), 2333–2353. https://doi.org/10.1007/s11207-015-0753-5

4. Belov A. V. et al. (1999). Anomalous Behaviour of Cosmic Ray Anisotropy in the Last Minimum of the Solar Activity. *1999ICRC*, 7-268B.
5. Belov, A. V., Gushchina, R. T., & Yanke, V. (2021). About long-term modulation of cosmic rays in the 23-24 solar activity cycles (pp. 23–29). https://doi.org/10.38072/2748-3150/p3
6. Fu, S., Zhang, X., Zhao, L., & Li, Y. (2021a). Variations of the Galactic Cosmic Rays in the Recent Solar Cycles. *The Astrophysical Journal Supplement Series*, *254*(2), 37. https://doi.org/10.3847/1538-4365/abf936
7. Fu, S., Zhang, X., Zhao, L., & Li, Y. (2021b). Variations of the Galactic Cosmic Rays in the Recent Solar Cycles. *The Astrophysical Journal Supplement Series*, *254*(2), 37. https://doi.org/10.3847/1538-4365/abf936
8. Kakad, B., Kakad, A., Ramesh, D. S., & Lakhina, G. S. (2019). Diminishing activity of recent solar cycles (22–24) and their impact on geospace. *Journal of Space Weather and Space Climate*, *9*, A1. https://doi.org/10.1051/swsc/2018048
9. Kóta, J. (2013). Theory and Modeling of Galactic Cosmic Rays: Trends and Prospects. *Space Science Reviews*, *176*(1–4), 391–403. https://doi.org/10.1007/s11214-012-9870-8
10. Laurenza, M., Vecchio, A., Storini, M., & Carbone, V. (2014). Drift effects on the galactic cosmic ray modulation. *The Astrophysical Journal*, *781*(2), 71. https://doi.org/10.1088/0004-637X/781/2/71
11. Li, K., Lin, L., Bui, X., & Liang, M. (2018). The 11-Year Solar Cycle Response of the Equatorial Ionization Anomaly Observed by GPS Radio Occultation. *Journal of Geophysical Research: Space Physics*, *123*(1), 848–861. https://doi.org/10.1002/2017JA024634
12. McCracken, K. G. & R. U. R. (1963). A survey of the diurnal anisotropy. *Proceedings of the 9th International Cosmic Ray Conference*, 213.
13. Mishra, R. K., & Mishra, R. A. (2007). Cosmic Ray Anisotropy and Solar Activity. In *Brazilian Journal of Physics* (Vol. 37, Issue 4). http://spidr.ngdc.noaa.gov/NeutronMonitor
14. Modzelewska, R., Iskra, K., Wozniak, W., Siluszyk, M., & Alania, M. V. (2019). Features of the Galactic Cosmic Ray Anisotropy in Solar Cycle 24 and Solar Minima 23/24 and 24/25. *Solar Physics*, *294*(10). https://doi.org/10.1007/s11207-019-1540-5
15. Modzelewska, R., Krasińska, A., Wawrzaszek, A., & Gil, A. (2021). Scaling Features of Diurnal Variation of Galactic Cosmic Rays. *Solar Physics*, *296*(8). https://doi.org/10.1007/s11207-021-01866-6
16. Munakata, K., Kozai, M., Kato, C., & Kóta, J. (2014). Long-term variation of the solar diurnal anisotropy of galactic cosmic rays observed with the Nagoya multi-directional muon detector. *Astrophysical Journal*, *791*(1). https://doi.org/10.1088/0004-637X/791/1/22
17. Potgieter, M. S. (2014). The charge-sign dependent effect in the solar modulation of cosmic rays. *Advances in Space Research*, *53*(10), 1415–1425. https://doi.org/10.1016/j.asr.2013.04.015
18. Reyes, P. I., Pinto, V. A., & Moya, P. S. (2021). Geomagnetic storm occurrence and their relation with solar cycle phases. *Space Weather*, *19*(9). https://doi.org/10.1029/2021SW002766
19. Sabbah, I. (2013). Solar magnetic polarity dependency of the cosmic ray diurnal variation. *Journal of Geophysical Research: Space Physics*, *118*(8), 4739–4747. https://doi.org/10.1002/jgra.50431
20. Singh, A., Tiwari, A. K., & Agrawal, S. P. (2011a). Study of the diurnal variation of cosmic rays during different phases of solar activity. *Proceedings of the 32nd International Cosmic Ray Conference, ICRC 2011*, *6*, 120–132. https://doi.org/10.7529/ICRC2011/V06/0072
21. Singh, A., Tiwari, A. K., & Agrawal, S. P. (2011b). Study of the diurnal variation of cosmic rays during different phases of solar activity. *Proceedings of the 32nd International Cosmic Ray Conference, ICRC 2011*, *6*, 120–132. https://doi.org/10.7529/ICRC2011/V06/0072
22. Tezari, et al. (2016a). Latitudinal and longitudinal dependence of the cosmic ray diurnal anisotropy during 2001–2014. *Annales Geophysicae*, *34*(11), 1053–1068. https://doi.org/10.5194/angeo-34-1053-2016
23. Tezari, et al. (2016b). Latitudinal and longitudinal dependence of the cosmic ray diurnal anisotropy during 2001–2014. *Annales Geophysicae*, *34*(11), 1053–1068. https://doi.org/10.5194/angeo-34-1053-2016
24. Thomas, S., Owens, M., Lockwood, M., & Owen, C. (2017). Decadal trends in the diurnal variation of galactic cosmic rays observed using neutron monitor data. *Annales Geophysicae*, *35*(4), 825–838. https://doi.org/10.5194/angeo-35-825-2017
25. Thomas, S. R., Owens, M. J., & Lockwood, M. (2014). The 22-Year Hale Cycle in Cosmic Ray Flux – Evidence for Direct Heliospheric Modulation. *Solar Physics*, *289*(1), 407–421. https://doi.org/10.1007/s11207-013-0341-5
26. Tiwari, A. K., Singh, A., & Agrawal, S. P. (2012a). Study of the Diurnal Variation of Cosmic Rays during Different Phases of Solar Activity. *Solar Physics*, *279*(1), 253–267. https://doi.org/10.1007/s11207-012-9962-3
27. Tiwari, A. K., Singh, A., & Agrawal, S. P. (2012b). Study of the Diurnal Variation of Cosmic Rays during Different Phases of Solar Activity. *Solar Physics*, *279*(1), 253–267. https://doi.org/10.1007/s11207-012-9962-3
28. Tiwari, C. M., & Tiwari, D. P. (2008). Characteristics of high energy cosmic ray diurnal anisotropy on a day-to-day basis. *Cosmic Research*, *46*(5), 465–468. https://doi.org/10.1134/S0010952508050134
29. Usoskin, I. G. (2017). A history of solar activity over millennia. *Living Reviews in Solar Physics*, *14*(1), 3. https://doi.org/10.1007/s41116-017-0006-9
30. Yanke, V. G., Belov, A. V., & Gushchina, R. T. (2021). Long-Term Modulation of Cosmic Rays in Solar Cycles 23–24. *Bulletin of the Russian Academy of Sciences: Physics*, *85*(9), 1045–1048. https://doi.org/10.3103/S1062873821090355

31. Yanke, V. G., Belov, A. V., & Gushchina, R. T. (2022). Variations of Cosmic Rays with Various Energies in the Minima of Solar Activity Cycles. *Geomagnetism and Aeronomy*, *62*(4), 347–355. https://doi.org/10.1134/S001679322204017X