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Cosmic Ray Intensity Analysis Based on the Earth's Latitude and Hemisphere

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Abstract

The interaction between cosmic rays and solar activity has been extensively investigated, particularly in relation to how solar phenomena modulate cosmic ray intensity in the heliosphere. The strength of cosmic rays absorbed by the Earth's hemisphere is not uniform across the Northern Hemisphere (NH) and Southern Hemisphere (SH). This study will include an investigation of cosmic ray intensity as recorded at various latitudes and hemispheres of the Earth. We employed nine cosmic ray stations in each NH and SH, separated into three types of latitudes: low, middle, and high. The method of percentage change in cosmic ray intensity was used, which was evaluated during the Halloween Storm phenomenon on October 29-30, 2003. The results showed that cosmic ray intensity decreased more at high latitudes than at low latitudes in both hemispheres (NH and SH). Furthermore, the reduction in cosmic ray intensity observed in the NH was approximately 1% greater than that observed in the SH. This can be attributed to the R_c value's dependence on latitude, variations in geomagnetic activity under different Interplanetary Magnetic Field (IMF) circumstances, and interplanetary space parameters such as the tilt of the Heliospheric Current Sheet (HCS).

Keywords: *cosmic ray intensity, Northern Hemisphere (NH), Southern Hemisphere (SH), Halloween Storm, geomagnetic avticity.*

1. Introduction

Cosmic rays are highly charged particles that originate from space and can impact various aspects of Earth's environment, including atmospheric processes and human health (Shea & Smart, 2000; Tomsia et al., 2024). Cosmic rays are charged particles whose energies range from 1 MeV to 10^{20} GeV and enter the Earth's atmosphere from all directions. Cosmic rays are composed of 90% protons, 9% alpha particles, and 1% heavier nuclei (Bonomi et al., 2020). Cosmic ray research has long been of interest, particularly the relationship between these particles' interactions with the Earth's magnetic field and solar activity, which also influences the planet's temperature and weather patterns (Putri et al., 2021). In reality, cosmic ray flux and solar activity (e.g. sunspot number or solar magnetic activity) are anticorrelated, with an eleven-year cycle duration—when solar activity is high, the flux of cosmic rays reaching the Earth is reduced, and vice versa (Forbush, 1958; Usoskin et al., 1998). Odd cycles exhibit a higher time lag than even solar cycles (Ross E & Chaplin W. J., 2019).

Cosmic rays that reach Earth are detected as neutron particles using Neutron Monitor (NM) detectors, which are sensitive to secondary particles emitted by cosmic rays during interaction with the Earth's atmosphere (Mangeard et al., 2018). Cosmic ray monitoring stations are distributed around the world and classified according to their geographical latitude. This classification is significant because the energy level and modulation of cosmic rays received by Earth varies depending on latitude and cutoff rigidity, particularly due to the influence of the Earth's magnetic field and atmosphere (Putri et al., 2024). It is well-established that the cosmic ray flux at Earth's surface varies with geomagnetic latitude due to the shielding effect of the Earth's magnetic field. At high latitudes (near the poles), where the geomagnetic field lines are more open, cosmic ray particles can more easily penetrate the atmosphere, resulting in higher flux. In contrast, at low latitudes (near the equator), the stronger horizontal component of the geomagnetic field provides greater shielding, thus reducing the flux of incoming cosmic rays. This phenomenon leads to a "latitude effect" where cosmic ray flux increases with increasing geomagnetic latitude (Zhang et al., 2020; Enghoff et al., 2024).

The changes in cutoff rigidities and geomagnetic field in the northern and southern hemispheres are asymmetric. The weakening of the geomagnetic field will drive the cutoff latitudes into the near-equatorial zone in the southern hemisphere, but the phenomena is not always credible in the northern hemisphere (Chu et al., 2022). One of the most significant aspects of the Earth's magnetic field is the South Atlantic Anomaly (SAA), which causes fast variations in the variation rate of geomagnetic cutoff rigidity in mid-latitudes where the SAA exerts its influence (Cordaro et al., 2019).

This article will study cosmic ray flux at various latitudes (low, middle, and high) using The Neutron Monitor Database (NMDB). NMDB has a real-time database for measuring cosmic ray intensity at high resolution. The information provided is critical for gathering the data required to understand cosmic ray behavior and its connection with the Sun's activity in interplanetary space. In addition to analyzing the variation with latitude, this study also investigates the distribution and behavior of cosmic ray intensity across the Earth's hemispheres which can also provide about the structure and dynamics of the Earth's magnetic field. This study's findings are expected to reveal new insights into hemisphere variations in cosmic ray exposure, with significant consequences for atmospheric physics, space weather effects, and radiation risk assessment at high altitudes.

2. Methodology

Long-term modulation data for cosmic ray intensity detected on Earth were obtained from the Neutron Monitor Database (NMDB) (http://www01.nmdb.eu/). Pressure and efficiency corrected cosmic ray intensity data were collected at seventeen stations with varying altitudes, latitudes, and cutoff rigidity. Data on cosmic ray intensity resolution are also used on monthly basis. The cosmic ray data distinguishes two types of cosmic ray station locations: Northern Hemisphere (NH) and Southern Hemisphere (SH). Each cosmic ray station location collects data on cosmic ray strength in a variety of latitudes, including low (0^o-30^o), mid (30^o-60^o), and high (60^o-90^o). Table 2-1 shows information from each station.

Table 2-1 displays data on R_c, or cutoff rigidity, which is the minimal quantitative threshold of the Earth's magnetic field used to forecast the energy of charged particles that can penetrate the magnetosphere and reach a specific place (Gvozdevsky et al., 2019). R_c calculation based on the geometry of the magnetic field. When cosmic rays encounter the Earth's magnetic field, lower-energy particles are deflected, reducing the number that can reach the surface. Only cosmic rays with sufficient energy to overcome this geomagnetic shielding are able to penetrate the atmosphere and reach the Earth's surface. The R_c number decreases with increasing magnetic latitude, indicating that higher magnetic latitudes would get cosmic rays with a wider energy range than lower latitudes.

In this study, we calculate the percentage decrease in cosmic ray intensity in extreme circumstances such as storms that exhibit the Forbush Decrease phenomena, which is characterized by a significant decrease in cosmic ray intensity (Sierra-Porta, 2024). Calculation the percentage decrease in cosmic ray intensity is shown in equation:

$$Percentage\ decrease\ (\%) = \frac{\overline{x_i} - \overline{x_f}}{\overline{x_i}} \times 100\% \quad (1)$$

where $\overline{x_i}$ and $\overline{x_f}$ are average of initial and final value.

3. Result and Analysis

Figures 3-1 show the cosmic ray intensity profiles in NH and SH from low to high latitudes with x-axis is Universal Time (UT) and y-axis is cosmic ray intensity in count/s. Table 3-1 shows the standard deviation for each station throughout the chosen time span. The amplitude of cosmic ray intensity variations is significantly influenced by the geomagnetic environment of the observing station. However, there is an anomaly at the low latitude station namely TSMB and MXCO stations, which is most likely related to the station's geographical placement near SAA, which influences the distribution of cosmic rays (Zhou et al., 1991). The PAMELA experiment detected far more antiprotons than expected as it went through the SAA. This implies that the Van Allen belts include antiparticles produced by the interaction of the Earth's upper atmosphere with cosmic rays (Adriani et al, 2011). In the southern hemisphere also shows greater fluctuations compared to the northern hemisphere.

Table 1: Cosmic Ray Station Information at NH and SH

	Station	Geographic Latitude (°)	Geographic Longitude (°)	Magnetic Latitude (°)	Magnetic Longitude (°)	Altitude (m)	R_c (GV)	Interval time
Northern Hemisphere (NH)								
Low magnetic Latitude	PSNM	18.59	98.49	11.38	170.53	2,565	16.8	2007 – now
	MXCO	19.8	-99.18	28.81	-30.48	2,274	8.28	1990 – now
Middle magnetic Latitude	NEWK	39.68	-75.75	50.15	0.61	50	2.4	1964 – now
	KIEL	54.34	10.12	50.49	87.60	54	2.36	1957 – now
	MGDN	60.04	151.05	53.72	-140.25	220	2.1	1971 - now
High magnetic Latitude	OULU	65.05	25.47	61.47	104.880	15	0.81	1964 – now
	APTY	67.57	33.39	63.77	112.86	181	0.65	1965 - now
	THUL	76.5	-68.7	83.14	25.23	26	0.3	1957 – now
Southern Hemisphere (SH)								
	Station	Geographic Latitude (°)	Geographic Longitude (°)	Magnetic Latitude (°)	Magnetic Longitude (°)	Altitude (m)	R_c	Interval time
Low magnetic Latitude	HUAN	-12.03	-75.33	0.46	-3.31	3,400	12.92	1952 – now
	TSMB	-19.2	17.58	-30.97	87.77	1,240	9.15	1976 – now
	PTFM	-26.68	27.09	-37.00	94.87	1,351	6.98	1971 – now
Middle magnetic Latitude	HRMS	-34.43	19.23	-42.63	83.25	26	4.58	1957 – now
	KERG	-49.35	70.25	-58.38	122.40	33	1.14	1957 – now
High magnetic Latitude	SNAE	-71.67	357.15	-61.29	43.87	856	0.73	1964 – now
	SOPO	-90	0	-73.96	18.66	2,820	0.1	1964 – now
	MCMU	-77.9	166.6	-79.81	-32.23	48	0.3	1960 – 2017
	TERA	-66.65	140	-80.41	-124.69	32	0.01	1967 – now

PSNM: Princess Sirindhorn Neutron Monitor (Thailand); MXCO: Mexico City (Mexico); NEWK: Newark (USA); KIEL: University of Kiel (Germany); MGDN: Magadan (Russia); OULU: University of Oulu (Finland); APTY: Apatity (Russia); THUL: Thule (Greenland); HUAN: Huancayo (Peru); TSMB: Tsumeb (Namibia); PTFM: Potchefstroom (South Africa); HRMS: Hermanus (South Africa); KERG: Kerguelen (Antarctica/France); SNAE: South African National Antarctic Expedition (SANAE, Antarctica); SOPO: South Pole (Antarctica); MCMU: McMurdo (Antarctica); TERA: Terre Adelie (Antarctica/France)

Table 2: Standard Deviation of Cosmic Ray Station

Northern Hemisphere (NH)			**Southern Hemisphere (SH)**		
Latitude position	Station	Standard deviation	Latitude position	Station	Standard deviation
Low magnetic Latitude	PSNM	4.33	Low magnetic Latitude	HUAN	1.02
	MXCO	8.40		TSMB	10.42
	average	6.37		PTFM	2.96
				average	4.80
Middle magnetic Latitude	NEWK	5.06	Middle magnetic Latitude	HRMS	5.11
	KIEL	9.88		KERG	13.29
	MGDN	14.84		average	9.20
	average	9.93			

Northern Hemisphere (NH)			Southern Hemisphere (SH)		
Latitude Position	Station	Standard Deviation	Latitude Position	Station	Standard Deviation
High magnetic Latitude	OULU	6.10	High magnetic Latitude	SNAE	10.08
	APTY	9.18		SOPO	26.89
	THUL	6.95		MCMU	15.67
				TERA	36.71
	average	7.41		average	14.87

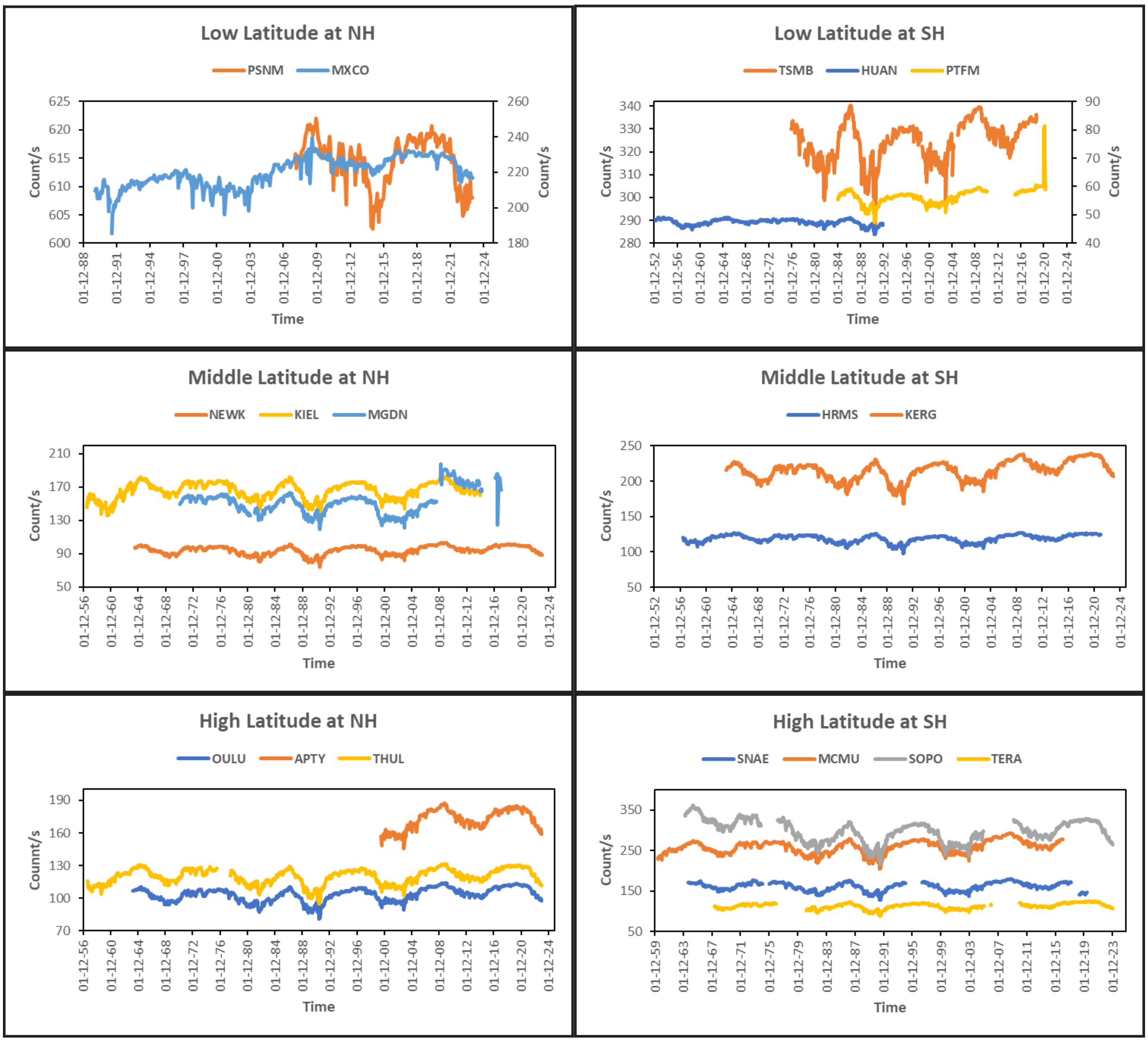

Figure 1: Cosmic ray intensity profiles at NH (left) and SH (right) for low (top), moderate (middle), and high (bottom) latitudes. At low latitudes for NH, the left y-axis is the PSNM station and the right y-axis represents the MXCO station. While, at low latitudes for SH, the left y-axis is the TSMB station and the right y-axis represents the HUAN and PTFM stations.

To better understand the amount of fluctuation or decrease in cosmic ray strength at each latitude and hemisphere of the Earth, we consider one extreme case: a geomagnetic storm caused by intense solar activity. High geomagnetic storms generate a sharp and sudden reduction in cosmic ray intensity known as the Forbush Decrease. In particular, the magnetic latitude and associated L-shell value determine the station's geomagnetic cutoff rigidity (Smart & Shea, 2005). The L-shell is the set of magnetic field lines that intersect the geomagnetic equator at a specific distance from the Earth's core, as measured in Earth radii (Soni et al., 2020). Station located at higher magnetic latitudes (closer to the magnetic poles) are situated on higher L-shells and have lower cutoff rigidities. These stations are more sensitive to lower-energy cosmic rays and generally observe larger Forbush Decreases during geomagnetic disturbances. One of the greatest geomagnetic storms occurred on October 29 – 30, 2003, known as the Halloween Storm, with a storm Kp index of 9 (Figure 3-2).

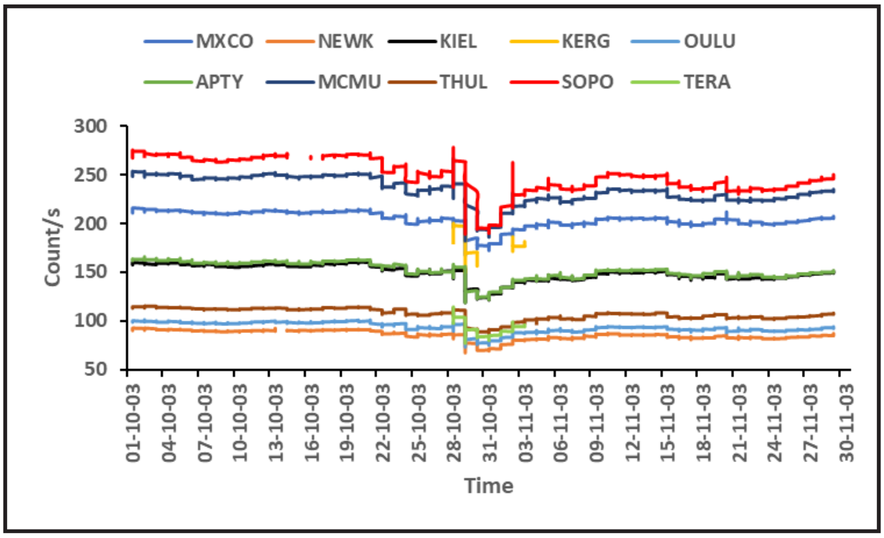

Figure 2: Cosmic ray strength decreased (Forbush Decrease) at various latitudes during the Halloween Storm on October 29-30, 2003.

Table 3-2 shows the percentage drop in cosmic ray intensity during the Halloween storm. Calculation in Table 2 exclude the PSNM and HUAN stations because they were not operational in 2003. The greatest percentage drop occurs at high magnetic latitudes, while the smallest percentage decline occurs at low magnetic latitudes in both NH and SH. This is conceivable because high latitudes have a lower R_c value, resulting in larger energy fluctuations (Danilova et al., 2019). Our analysis also indicates a clear trend between L-shell value and the amplitude of cosmic ray decrease during the Halloween 2003 geomagnetic storm. For examples at the NH, stations with higher L-shell such as THUL and OULU observed greater decreases in neutron monitor counts, while stations with lower L-shell such as NEWK showed smaller variations for the same interval time, consistent with their higher geomagnetic rigidity thresholds. MGDN station has higher percentage decrease due to this station use shorter interval time than the others. The comparison of the two hemispheres (NH and SH) also shows how the magnetic latitudes and the L shell respond to the drop in cosmic ray intensity. For example, the KIEL at the NH shows greater decreases than HRMS at the SH where KIEL has higher magnetic latitude and L-shell than HRMS.

Table 2 further demonstrates that the amount of the decline in cosmic ray intensity is comparatively unequal in the NH and SH. This can occur due to the asymmetry of the Earth's north and south magnetic poles, which can cause differences in current and magnetic field disturbances (Laundal et al., 2017). Particle drift is strongly influenced by the polarity of the Sun's magnetic field. As long as $qA > 0$, positively charged particles (such as protons) enter the solar system primarily via the poles while $qA < 0$, they pass past the equator (Potgieter, 2013; Rankin et al., 2022). This creates a hemispheric asymmetry in the distribution of cosmic ray intensity on Earth. The Halloween Storm occurs in negative polarity conditions ($qA < 0$), indicating increased geomagnetic activity in NH. In contrast, geomagnetic activity in SH increases under positive polarity conditions ($qA > 0$) (Thomas et al., 2014).

Table 3: Cosmic Ray Intensity Decrease at Several Stations During the Halloween Storm (October 29 – 30, 2003)

Latitude Position	Northern Hemisphere (NH)		Southern Hemisphere (SH)	
	Station	Intensity Decrease (%)	Station	Intensity Decrease (%)
Low Latitude	PSNM		HUAN	
	MXCO	9.19	TSMB	7.80
			PTFM	9.23
	Average Decrease	9.19	Average Decrease	8.52
Middle Latitude	NEWK	12.78	HRMS	10.24
	KIEL	12.30	KERG	12.42
	MGDN	14.69		
	Average Decrease	13.26	Average Decrease	11.33
High Latitude	OULU	13.85	SNAE	13.84
	APTY	13.59	SOPO	16.26
	THUL	15.47	MCMU	14.20
			TERA	14.40
	Average Decrease	14.30	Average Decrease	14.68

4. Conclusions

The intensity of cosmic rays received by the Earth fluctuates. Latitudinal and hemispherical dependence of cosmic ray intensity is investigated to estimate the extent of modulation caused by a dip in cosmic ray intensity in extreme scenarios. We used 17 cosmic ray stations spread over three latitudes (low, middle, and high) in both NH and SH. Our results reveal that cosmic ray strength fluctuates more significantly at high latitudes than at low latitudes. However, we observed anomalies at the TSMB and MXCO stations due to their proximity to the SAA. Extreme cases are also utilized to demonstrate a quantitative decline in cosmic ray intensity. The Halloween storm, which occurred on October 29-30, 2003, was a geomagnetic event that caused the Forbush Decrease. The examination of the Halloween storm also indicated that stations at higher latitudes shows the highest decrease in cosmic ray intensity when compared to lower latitudes. This is conceivable because lower R_c values at high latitudes. The non-uniformity between the NH and SH is generated by geomagnetic activity, which is affected by the Sun's polarity conditions and other interplanetary space properties such as the tilt of the HCS.

Contributorship Statement

ANIP is the single author.

References

Adriani, O., Barbarino, C., Bazilevskava, G. A., Belloti, R., Boezio, M., Bogomolov, A., Bongi, M., Bonvicini, V., Borisov, S., & Bottai, S. (2011). The Discovery of Geomagnetically Trapped Cosmid-Ray Antiprotons. The Astrophysical Journal Letters. 737. https://doi.org/10.1088/2041-8205/737/2/L29.

Badruddin, S. M. & Singh, Y. P. (2007). Modulation loops, time lag, and Relationship Between Cosmic ray Intensity and Tilt of The Heliospheric Current Sheet. *Astronomy and Astrophysics.* 466. https://doi.org/10.1051/0004-6361:20066549.

Bonomi, G., Checcia, P., D'Ericco, M., Pagano, D., & Saracino, G. (2020). Applications of Cosmic-Ray Muons. *Progress in Particle and Nuclear Physics.* 112. https://doi.org/10.1016/j.ppnp.2020.103768.

Chu, W., Yang, Y., Xu, S., Qin, G., Huang, J., Zeren, Z., & Shen, X. (2022). Study on Long-Term Variation Characteristics of Geomagnetic Cutoff Rigidities of Energetic Protons Caused y Long-Term Variation of Geomagnetic Field. *Frontiers in Earth Science*. 10. https://doi.org/10.3389/feart.2022.818788.

Cordaro, E. G., Venegas-Aravena, P., & Laroze, D. (2019). Variations of Geomagnetic Cutoff Rigidity in The Southern Hemisphere Close to 70ºW (South-Atlantic Anomaly and Arctic Zones) in The Period 1975-2010. *Advances in Space Research*. 63 (7). https://doi.org/10.1016/j.asr.2018.12.019.

Danilova, O. A., Demina, I. M., Ptitsyna, N. G., & Tyasto, M. I. (2019). Mapping of Geomagnetic Cut-off Rigidity of Cosmic rays During the Main Phase of The Magnetic Storm of November 20, 2003. *Geomagnetism and Aeronomy.* 59. 147-154. https://doi.org/10.1134/S0016793219020051.

Enghoff, M. B., Svensmark, J., Becker, H. N., Jørgensen, J. L., Kotsiaros, S., Herceg, M., Alexander, J. W., Florence, M. M., Connerney, J. E. P. (2024). Cutoff Rigidities, Galactic Cosmic Ray Flux, and Heavy Ion Detections at Jupiter. *Journal of Geophysical Research: Planets.* 129 (2). https://doi.org/10.1029/2023JE008085.

Forbush, S. E. (1958). Cosmic-Ray Intensity Variations During Two Solar Cycles. *Journal of Geophysical Research*. 63. 651-669, 1958. https://doi.org/10.1029/JZ063i004p00651.

Laundal, K. M., Cnossen, I., Milan, S. E., Haaland, S. E., Coxon, J., Padatella, N. M., Förster, M., & Reistad, J. P. (2017). North-South Asymmetries in Earth's Magnetic Field. *Space Science Review*. 206. 225-257. https://doi.org/10.1007/s11214-016-0273-0.

Mangeard, P. S., Clem, J., Evenson, P., Pyle, R., Mitthumsiri, W., Ruffolo, D., Sàiz, A, & Nutaro, T. (2024). Distinct Pattern of Solar Modulation of Galactic Cosmic ray Above a High Geomagnetic Cutoff Rigidity. *The Astrophysical Journal*. 858 (43). https://doi.org/10.3847/1538-4357/aabd3c.

Tomsia, M., Cieśla, J., Śmieszek, J., Florek, S., Macionga, A., Michalczyk, K., & Stygar, D. Long-term Space Missions Effects on the Human OrganismL What We Do Know and What Requires Further Research. *Sec. Environmental, Aviation, and Space Physiology*. 12. https://doi.org/10.3389/fphys.2024.1284644.

Gvozdevsky, B. B., Belov, A. V., Guschina, R. T., Eroshenko, E. A., Kobelev, P. G., & Yanke V. G. (2018). Long-Term Changes in Vertical Geomagnetic Cutoff Rigidities of Cosmic Rays. *Physics of Atomic Nuclei.* 81. 1382-1389. https://doi.org/10.1134/S1063778818090132.

Potgieter, M. S. (2013). Solar Modulation of Cosmic Rays. *Living Reviews in Solar Physics*. 10. 3. https://doi.org/10.12942/lrsp-2013-3.

Putri, A. N. I., Herdiwijaya, D, & Hidayat, T. (2021). Studi Hubungan Intensitas Sinar Kosmik Terhadap Variasi Parameter Aktivitas Matahari dan Plasma Ruang Antarplanet. *Prosiding Seminar Fisika 7.0*, 301-306.

Putri, A. N. I., Herdiwijaya, D, & Hidayat, T. (2024). On the Correlation of Cosmic-Ray Intensity with Solar Activity and Interplanetary Parameters. *Solar Physics*, 299(12). https://doi.org/10.1007/s11207-023-02249-9.

Rankin, J. S., Bindi, V., Bykov, A. M., Cummings, A. C., Torre, S. D., Florinski, V., Heber, B., Potgieter, M. S., Stone, E. C., & Zhang, M. (2022). Galactic Cosmic Rays Throughout the Heliosphere and in the Very Local Interstellar Medium. *Space Science Reviews*. 218. 42. https://doi.org/10.1007/s11214-022-00912-4.

Ross, E & Chaplin, W. J. (2019). The Behaviour of Galactic Cosmic-Ray Intensity During Solar

Activity Cycle 24. *Solar Physics*. 294 (8). https://doi.org/10.1007/s11207-019-1397-7.

Sierra-Porta, D. (2024). A Multifractal Approach to Understanding Forbush Decrease Events: Correlations with Geomagnetic Storms and Space Weather Phenomena. *Chaos, Solitons, & Fractals*. 185. https://doi.org/10.1016/j.chaos.2024.11508.

Shea, M. A., & Smart, D. F. (2000). Cosmic Ray Implication for Human Health. *Space Science Reviews*. 93. 187-205. https://doi.org/10.1023/A:1026544528473.

Smart, D. F., & Shea, M. A. (2005). A review of geomagnetic cutoff rigidities for earth-orbiting spacecraft. *Advances in Space Research*, 36, 2012–2020. https://doi.org/10.1016/j.asr.2004.09.015.

Soni, P. K., Kakad, B., & Kakad, A. (2020). L-shell and Energy Dependence of Magnetic Mirror Point of Charged Particles Trapped in Earth's Magnetosphere. *Earth, Planets, and Space*. 72. 129. https://doi.org/10.1186/s40623-020-01264-5.

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. 407-421. https://doi.org/10.1007/s11207-013-0341-5.

Usoskin, I. G., Kananen, H., Mursula, K., Tanskanen, P., & Kovaltsov, G. A. (1998). Correlative Study of Solar Activity and Cosmic Ray Intensity. *Journal of Geophysics Research*. 103. 9567-9574. https://doi.org/10.1029/97JA03782.

Zhang, L., Tinsley, B., & Zhou, L. Low Latitude Lightning Activity Responses to Cosmic Ray Forbush Decreases. *Geophysical Research Letters*. 47 (4). https://doi.org/10.1029/2020GL087024.

Zhou, H., Li, C., Zong, Q., Parks, G. K., Pu, Z., Chen, H., Xie, L., & Zhang, X. (2015). Short-term Variations of The Inner Radiation Belt in The South Atlantic Anomaly. *Journal of Geophysical Research: Space Physics*. 120 (6). 4475-4486. https://doi.org/10.1002/2015JA021312.