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Trend Analysis of Cosmic Ray Intensity at Selected Global Stations (2020–2024)

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Abstract: This study analyses the temporal variation of CRI recorded at four geographically distinct monitoring stations—Oulu (Finland), Jungfraujoch (Switzerland), Moscow (Russia), and Rome (Italy)—over the period 2020 to 2024. The objective of this research is to identify long-term trends, inter-station variability, and possible implications related to solar modulation of cosmic rays. The results indicate a consistent declining trend in CRI across all stations, with Jungfraujoch showing the highest absolute CRI values and Rome exhibiting comparatively lower magnitudes and stronger year-to-year variability.

Keywords: Cosmic Ray Intensity, Solar Modulation, Neutron Monitor, Long-term Trend.

I. INTRODUCTION

Cosmic rays (CRs), are highly energetic charged particles originating outside the solar system, undergo significant modulation as they propagate through the heliosphere. The intensity of CRs observed near Earth exhibits a well-established anti-phase relationship with the 11-year solar activity cycle (Forbush, 1954; Hatton, 1980). Variations in solar activity modify the solar wind and interplanetary magnetic field (IMF), thereby influencing cosmic ray transport through processes such as diffusion, convection, gradient and curvature drifts, and adiabatic deceleration (Parker, 1965; Kota, 2013; Zhao, 2014).

The intensity of cosmic rays observed at Earth is not constant; instead, it exhibits significant temporal variability governed mainly by solar and heliospheric conditions. Solar magnetic activity modulates the flux of galactic cosmic rays through the heliosphere, leading to an inverse relationship between CRI and solar activity. During periods of high solar activity, enhanced solar wind turbulence and magnetic fields suppress the penetration of cosmic rays into the inner heliosphere, resulting in reduced CRI values at Earth. Conversely, higher CRI levels are typically observed during solar minimum conditions.

In addition to solar modulation, CRI measurements are strongly influenced by geomagnetic latitude, cutoff rigidity, and station altitude. High-latitude and high-altitude stations experience weaker geomagnetic shielding and reduced atmospheric absorption, allowing a larger fraction of cosmic rays to be detected. Consequently, stations such as Oulu and Jungfraujoch record significantly higher CRI values compared to mid- and low-latitude stations like Moscow and Rome.

The period from 2020 to 2024 corresponds to the ascending phase of Solar Cycle 25, a phase characterized by a gradual increase in solar activity following the solar minimum of Cycle 24. This interval provides a valuable opportunity to investigate the response of cosmic ray intensity to changing solar conditions across different geographic regions. Understanding such variations is essential not only for space weather studies but also for assessing radiation exposure risks in aviation, satellite operations, and long-duration space missions.

The present study aims to perform a detailed comparative analysis of long-term CRI trends recorded at four globally significant neutron monitor stations—Oulu (Finland), Jungfraujoch (Switzerland), Moscow (Russia), and Rome (Italy)—during the period 2020–2024. By combining graphical trend analysis with quantitative statistical methods, this work seeks to highlight both the global influence of solar modulation and the regional effects of geomagnetic and atmospheric factors. The results contribute to a broader understanding of cosmic ray variability during the rising phase of a solar cycle and provide a foundation for future correlation studies involving solar indices.

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II. DATA AND METHODOLOGY

The Oulu Neutron Monitor, located in Oulu, Finland, is operated by the Sodankylä Geophysical Observatory of the University of Oulu. The station employs a 9-NM-64 detector equipped with Chalk River tubes and is situated at a geographic latitude of 65.05° N and longitude of 25.47° E, at an altitude of approximately 15 m above sea level. The Oulu station is a key component of the global neutron monitor network and provides long-term, high-quality cosmic ray observations. Data and additional information are available at the official website (http://cosmicrays.oulu.fi).

The Moscow Neutron Monitor is located in Troitsk city, within the Moscow Region of Russia, and is operated by the Pushkov Institute of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation (IZMIRAN) of the Russian Academy of Sciences. The station is equipped with a 24-NM-64 detector and is positioned at a geographic latitude of 55.47° N and longitude of 37.32° E, at an altitude of about 200 m above sea level. The effective vertical cutoff rigidity of the station is 2.43 GV (1965 epoch), allowing it to record variations in primary cosmic ray intensity with high sensitivity. Further details are accessible at http://cr0.izmiran.ru/mosc/.

The Jungfraujoch IGY Neutron Monitor, Switzerland, is installed at the Sphinx Observatory on the Jungfraujoch high-altitude research station. Its operation is supported by the Physikalisches Institut of the University of Bern and the International Foundation for High Altitude Research Stations Jungfraujoch and Gornergrat (HFSJG), Bern, Switzerland. The detector consists of a standard 18-IGY neutron monitor comprising three units of six counters each. The station is located at a geographic latitude of 46.55° N and longitude of 7.98° E, at an altitude of 3570 m above sea level, with an effective vertical cutoff rigidity of 4.5 GV (epoch 2010.0). Owing to its high elevation, Jungfraujoch is particularly sensitive to cosmic ray variations. Station information is available via http://cr0.izmiran.ru/jung.

The Rome Neutron Monitor, operated at the SVIRCO Observatory in Italy, joined the worldwide neutron monitor network to investigate temporal variations in primary cosmic rays and their modulation within the heliosphere. From July 1957 to April 1997, continuous measurements were carried out at the Physics Department “G. Marconi” of La Sapienza University of Rome. In May 1997, the neutron monitor was relocated to the Physics Department “E. Amaldi” of Roma Tre University, where the SVIRCO Observatory (INAF/IFSI–UniRomaTre collaboration) has been operating continuously since then. The station uses a 20-NM-64 detector consisting of three 3-counter units, one 5-counter unit, and one 6-counter unit. It is situated at a geographic latitude of 41.86° N and longitude of 12.47° E, near sea level, with an effective vertical cutoff rigidity of 6.27 GV (epoch 1995.0). Additional information can be found at http://cr0.izmiran.ru/rome/main.htm.

A. Mathematical Formulation

The long-term CRI trend was quantified using linear regression analysis. The regression model is defined as:

$$CRI(t) = mt + c$$

where m is the linear trend slope (CRI units per year), t represents time (year), and c is the intercept. The percentage change in CRI over the study period was calculated as:

$$\%\Delta CRI = [(CRI_{(2024)} - CRI_{(2020)}) / CRI_{(2020)}] \times 100$$

The strength of the temporal relationship was evaluated using the Pearson correlation coefficient:

$$r = \Sigma[(t - \bar{t})(CRI - \overline{CRI})] / \sqrt{[\Sigma(t - \bar{t})^2 \, \Sigma(CRI - \overline{CRI})^2]}$$

III. RESULTS & DISCUSSION

Figure 1 shows the temporal evolution of Cosmic Ray Intensity (CRI) from 2020 to 2024 across all four neutron monitor stations. A coherent and monotonic decline in CRI is observed at each location, demonstrating the expected inverse modulation of galactic cosmic rays by increasing solar activity. This behavior is consistent with the ascending phase of Solar Cycle 25, during which intensified heliospheric magnetic fields and solar wind turbulence progressively suppress cosmic ray penetration into the near-Earth environment.

Linear regression and correlation analyses confirm statistically robust negative trends at all stations. Oulu exhibits a 13.97% decrease in CRI, characterized by a trend slope of −254 CRI units yr^{-1} and a strong negative temporal correlation ($r = -0.98$). Jungfraujoch shows the most pronounced decline (−793 CRI units yr^{-1}) with an overall reduction of 13.41%, reflecting its enhanced sensitivity to solar modulation owing to high altitude and reduced atmospheric attenuation (r =

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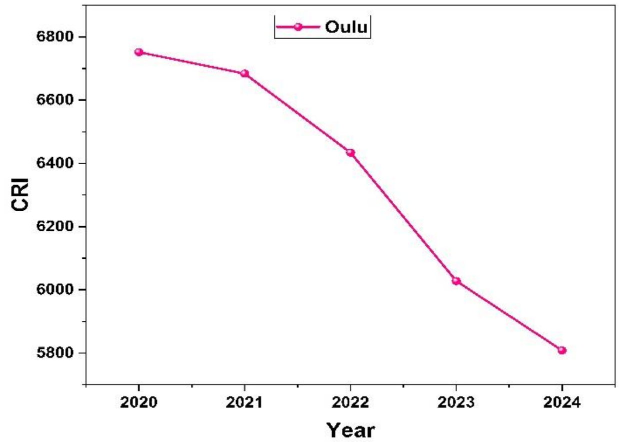
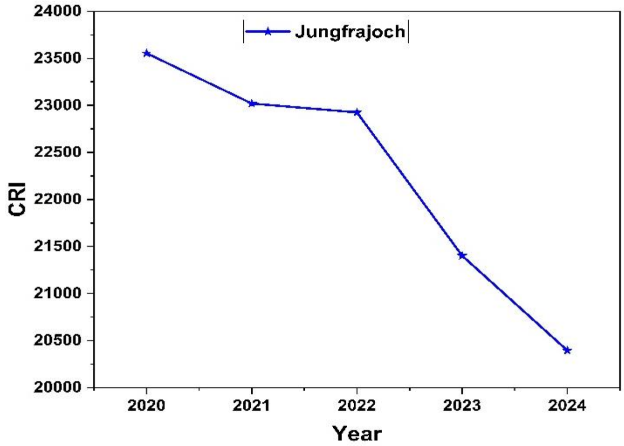
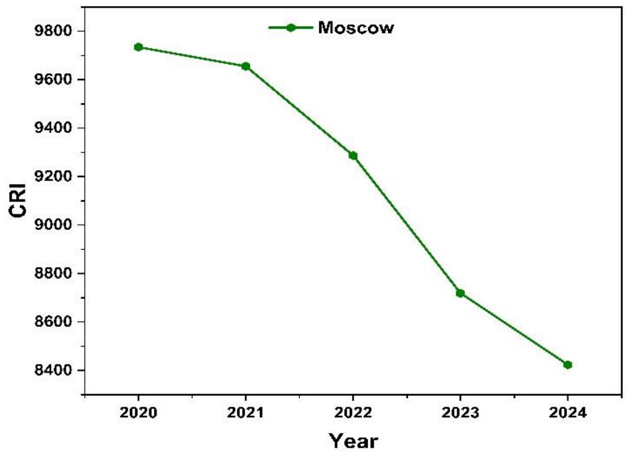
−0.95). Moscow similarly records a 13.46% decrease with a slope of −356 CRI units yr^{-1} and a strong correlation (r = −0.98). In contrast, Rome displays a weaker decline of 6.32% and a modest correlation (r = −0.57), indicating a greater influence of geomagnetic cutoff rigidity and regional atmospheric effects at lower latitudes.

These results confirm a statistically significant decreasing CRI trend at high-latitude and high-altitude stations. The observed decline in CRI across all stations can be attributed to increased solar magnetic activity, which suppresses the influx of galactic cosmic rays into the inner heliosphere. Jungfraujoch's consistently high CRI values reflect altitude effects, while Rome's lower values are influenced by higher geomagnetic cutoff rigidity.







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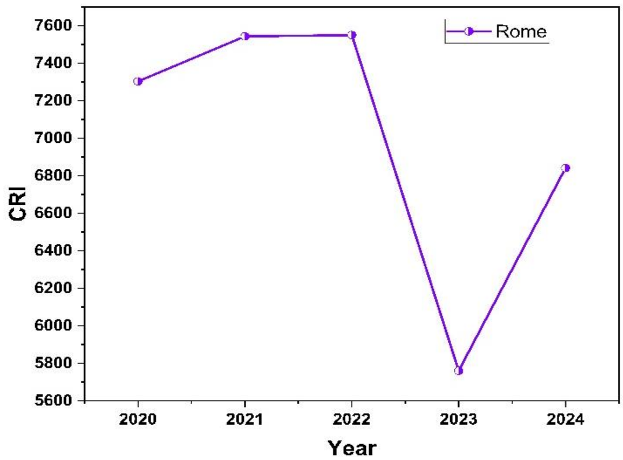

Fig. 1 shows the temporal variation of cosmic ray intensity from 2020 to 2024 across all four neutron monitor stations.

IV. CONCLUSION

This study confirms a clear decreasing trend in Cosmic Ray Intensity from 2020 to 2024 across four global monitoring stations. The uniformity of the trend highlights the dominant role of solar modulation, while magnitude differences emphasize the influence of local geomagnetic and atmospheric factors.

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