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Long -Term Relations of Cosmic ray Intensity with Solar Wind Plasma Parameters and Alfven mach Number During the Period of Decline phase of Solar Cycle 24 and Rising Phase of Solar Cycle 25

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Abstract

Yearly average of cosmic ray intensity (CRI) observed at Oulu super neutron monitor (NM) observed during the period of decline phase of solar cycle 24 and rising phase of solar cycle 25 has been studied with yearly average of corresponding solar wind plasma parameters interplanetary magnetic fields (IMF), solar wind plasma pressure (SWPP), solar wind plasma temperature (SWPT) also yearly average of corresponding Alfven Mach number .It is seen that yearly average of cosmic ray intensity is inversely correlated with yearly average of corresponding solar wind plasma parameters interplanetary magnetic fields (IMF) solar wind plasma pressure (SWPP) solar wind plasma temperature (SWPT) and positively correlated with Alfven mach number . We have found high negative correlation with correlation coefficient -0.90 between yearly average of cosmic ray intensity (CRI) and yearly average of interplanetary magnetic fields (IMF). High negative correlation with correlation coefficient -0.63 has been determined between yearly average of cosmic ray intensity (CRI) and solar wind plasma pressure (SWPP) and -0.51 between yearly average of cosmic ray intensity and solar wind plasma temperature (SWPT). High positive correlation with correlation coefficient 0.86 has been determined between yearly average of cosmic ray intensity and yearly average of Alfven mach number.

1. Introduction

Solar modulation of cosmic rays is primarily driven by the 11-year solar activity cycle, which is characterized by variations in sunspot numbers, solar magnetic field strength, and solar wind properties (Balogh A et al 2009). As solar activity increases, the interplanetary magnetic field (IMF) becomes more turbulent and the solar wind more energetic, creating a more effective barrier against incoming cosmic rays (Strauss R D et al 2013). Conversely, during solar minima, the heliosphere becomes more permeable to GCRs, leading to increased cosmic ray flux at Earth (Petrie G J D 2024). This cyclical variation in cosmic ray intensity provides a valuable tool for studying the long-term evolution of solar activity and its impact on the heliospheric environment. The study of cosmic ray modulation has a rich history dating back to the 1950s, with ground-based neutron monitors serving as the primary tool for continuous, long-term measurements of GCRs intensity (Forbush S E 1954). These detectors have provided invaluable data on the temporal variations of cosmic ray flux, revealing clear anti-correlations with solar activity cycles (Simpson J A 2000). However, the relationship between GCRs intensity and solar parameters is not straightforward, as it involves complex processes of particle transport, diffusion, and drift within the heliosphere. The exact mechanisms of cosmic ray transport through the heliosphere remain a topic of ongoing research. Ground-based neutron monitors networks remain essential for studying the modulation of GCRs, even after six decades of operation. These networks provide continuous, high-precision measurements of cosmic ray intensity variations in the energy range from approximately ~500 MeV to ~30 GeV, complementing space-based detectors. The global network acts as a giant spectrometer, allowing researchers to observe cosmic ray variations across different rigidity cut-offs (Mishev A and Usoskin I 2020). This capability is crucial for understanding long-term trends in cosmic ray modulation, solar cycle effects, and transient phenomena such as Forbush decreases. Real-time data accessibility through platforms like the Neutron Monitor Database (NMDB)6 has further enhanced the network's value for space weather applications and radiation exposure assessments (Mishev A L 2023). Galactic cosmic rays (GCRs), are affected by the heliospheric magnetic flux as they propagate inward from the heliospheric boundary at about 120 AU (Krimigis et al. 2013). Since decades ago, we have learned that GCR fluxes are constantly affected by variations of the heliospheric magnetic fields, both on short and long-time scales. In the short term of days or months, the GCR flux can be altered in the form of Forbush decreases (Forbush 1937) due to transient heliospheric structures with more turbulent and intensive magnetic fields such as interplanetary coronal mass ejections (ICMEs, Cane 2000) and stream interaction regions (Richardson 2004). As galactic cosmic rays can interact with Earth's atmosphere via ionization processes, such disturbed galactic cosmic ray variations have also been argued to be the link of Sun-climate correlations (Pittock 1978) via changing the global electric circuit and modifying cloud properties (Harrison et al. 2011; Laken et al. 2012; Laken & Calogovi´c ˇ 2013). In the long term of a few years, the galactic cosmic ray flux was first observed to anti-correlate with sunspot variations (Forbush 1958) since the transport of galactic cosmic rays is modulated by heliospheric field strength and irregularities that evolve following the quasi-11-year solar cycle (Parker 1965; Potgieter 1998). Specifically, enhanced magnetic flux is more efficient in preventing charged galactic cosmic ray particles from deeply penetrating into the heliosphere, causing decrease of galactic cosmic ray fluxes towards solar maxima. The variation of galactic cosmic ray fluxes at Earth has been correlated with various solar and heliospheric parameters, such as the Sunspot Number (SSN), the strength and turbulence level of heliospheric magnetic field (HMF), the heliospheric current sheet (HCS) tilt angle, the open solar magnetic flux, the solar polarity, and so on (Usoskin et al. 1998; Cliver & Ling 2001; Rouillard & Lockwood 2004; AlankoHuotari et al. 2007; Potgieter 2013, etc.), and empirical functions describing the galactic cosmic ray dependence on different solar cycle parameters have been proposed (e.g., Dorman 2001; Usoskin et al. 2011; Guo et al. 2015). In particular, when correlating the galactic cosmic ray and sunspot number temporal variations, the strongest anti-correlation appears when the galactic cosmic ray profile is shifted backward in time, suggesting a delay of the GCR variation with respect to the solar activity evolution. The classic picture to explain this time lag involves the solar wind convection and the GCR transport in the heliosphere (Parker 1965; Van Allen 2000; Dorman 2001; Usoskin et al. 2001; Cliver & Ling 2001; Thomas et al. 2014). That is, GCRs propagate inward throughout the heliosphere and are affected by the magnetic field carried by the outward solar wind during their journey. In this work, we have analyzed cosmic ray intensity variation with different solar wind plasma parameter interplanetary magnetic fields, pressure, temperature, Alfven Mach number, observed during the period of Decline phase of Solar Cycle 24 and rising phase of solar cycle 25.

2. Data Reduction and Analysis

In this work yearly data of solar wind plasma parameters, interplanetary magnetic fields (IMF), solar wind plasma pressure (SWPP), solar wind plasma temperature (SWPT) and Alfven Mach number and cosmic ray intensity count rates over the period of decline phase of solar cycle 24 and rising phase of solar cycle 25 have been used to determine possible correlation between these parameters and relation between cosmic ray intensity variations and these parameters. Yearly data of Oulu super neutron monitors over the period of decline phase of solar cycle 24 and rising phase of solar cycle 25 have been used to determine the cosmic ray intensity variation. Yearly data of solar wind plasma parameters, interplanetary magnetic fields (IMF), solar wind plasma pressure (SWPP), solar wind plasma temperature (SWPT) has been taken from Omni web data.

3.1 Long-Term Cosmic Ray Intensity Variation (Oulu) With Interplanetary Magnetic Fields During Decline Phase of Solar Cycle 24 And Rising Phase of Solar Cycle 25

Interplanetary magnetic field is key parameter to study the cosmic ray variations. In this study, long-term cosmic ray intensity variation (Oulu) with Interplanetary magnetic fields during Decline Phase of solar cycle 24 and rising phase of solar cycle 25 has been studied. We have made correlative analysis between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of interplanetary magnetic fields (IMF) for the Decline Phase of solar cycle 24 and rising phase of solar cycle 25. We have plotted a liner graph and a bar between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values of interplanetary magnetic fields shown in fig. [1, 2]. From the figures it is observed that cosmic ray intensity variation is anti-correlated with yearly average values of interplanetary magnetic fields for the Decline Phase of solar cycle 24 and rising phase of solar cycle 25. Large negative correlation with correlation coefficient -0.90 has been found between yearly average values of cosmic ray intensity variation and yearly average values of interplanetary magnetic fields for the Decline Phase of solar cycle 24 and rising phase of solar cycle 25 .

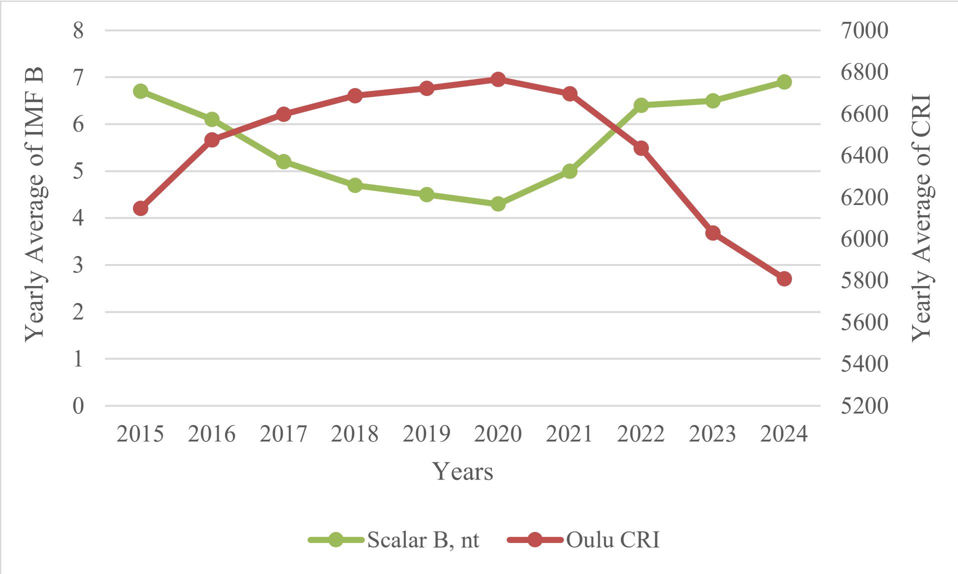

Fig.1 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of interplanetary magnetic fields during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

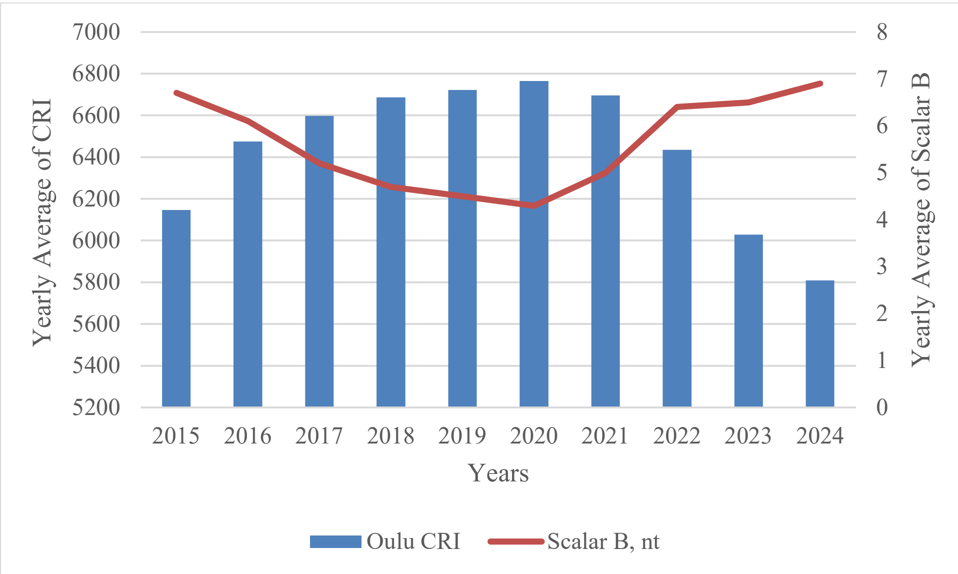

Fig.2 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of interplanetary magnetic fields during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

3.2 Long-Term Cosmic Ray Intensity Variation (Oulu) With Solar Wind Plasma Pressure (SWP) During Decline Phase of Solar Cycle 24 And Rising Phase of Solar Cycle 25

In this study, correlative analysis between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of solar wind plasma pressure for the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.has been carried out. We have plotted a liner graph and a bar graph between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values of solar wind plasma pressure shown in fig. [3,4.]. From the figures it is observed that these parameters are negatively correlated for the decline phase of solar cycle 24 and rising phase of solar cycle 25. From the further analysis large negative correlation with correlation coefficient -0.63 has been found between cosmic ray intensity variation yearly average values of solar wind plasma pressure during Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

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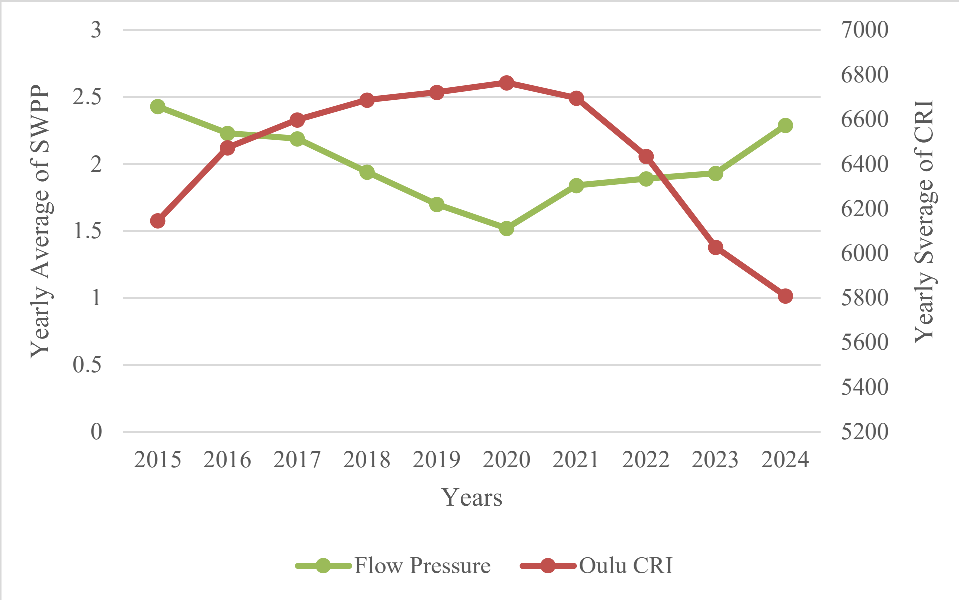

Fig.3 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of solar wind plasma pressure during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

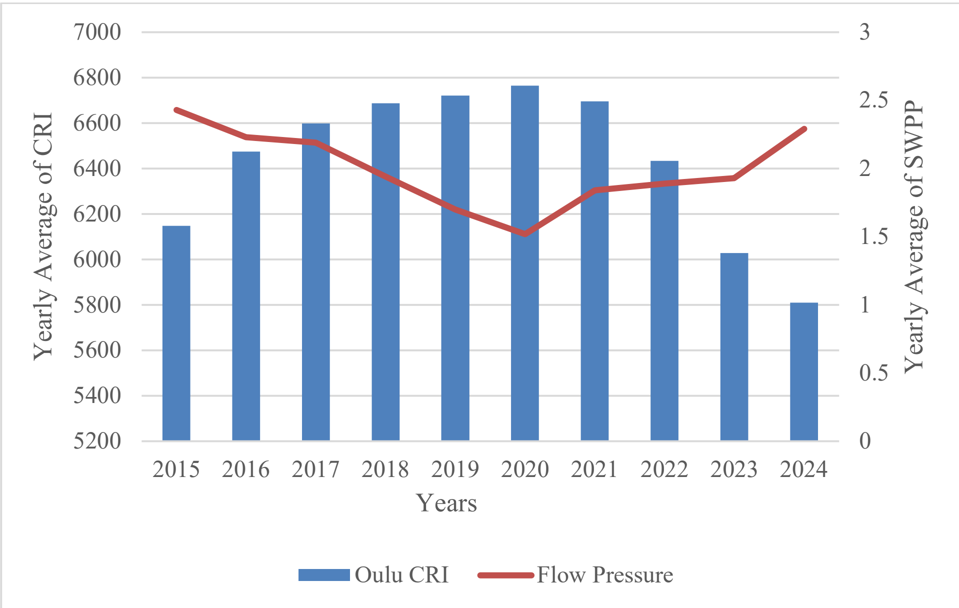

Fig.4 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of solar wind plasma pressure during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

3.3 Long-Term Cosmic Ray Intensity Variation (Oulu) With Solar Wind Plasma Temperature (SWPT) During Decline Phase of Solar Cycle 24 And Rising Phase of Solar Cycle 25

In this study, correlative analysis between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of solar wind plasma temperature for the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.has been carried out. We have plotted a liner graph and a bar graph between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values of solar wind plasma temperature shown in fig. [5, 6]. From the figures it is observed that these parameters are negatively correlated for the s period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25. From the further analysis large negative correlation with correlation coefficient -0.51 has been found between cosmic ray intensity variation yearly average values of solar wind plasma temperature during Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

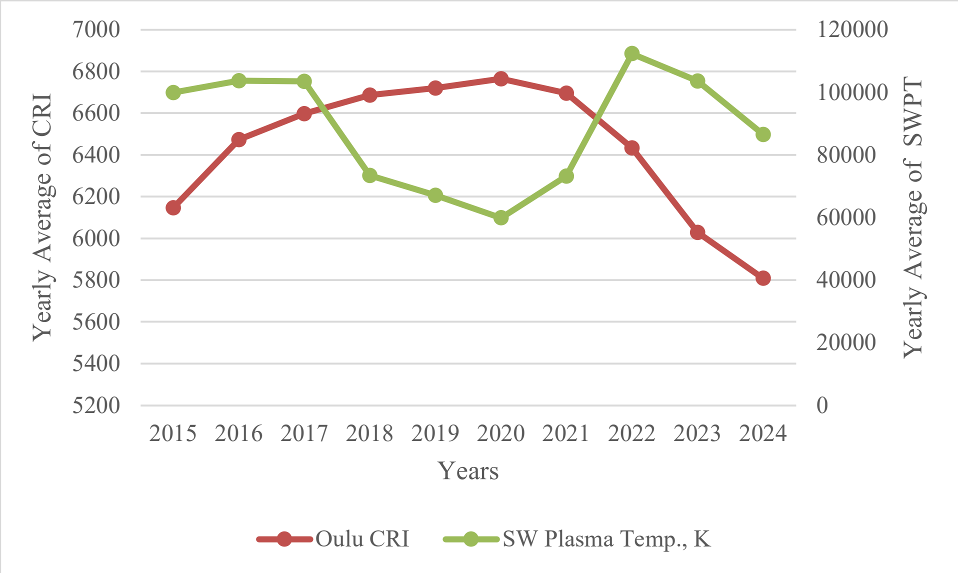

Fig.5 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of solar wind plasma temperature during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

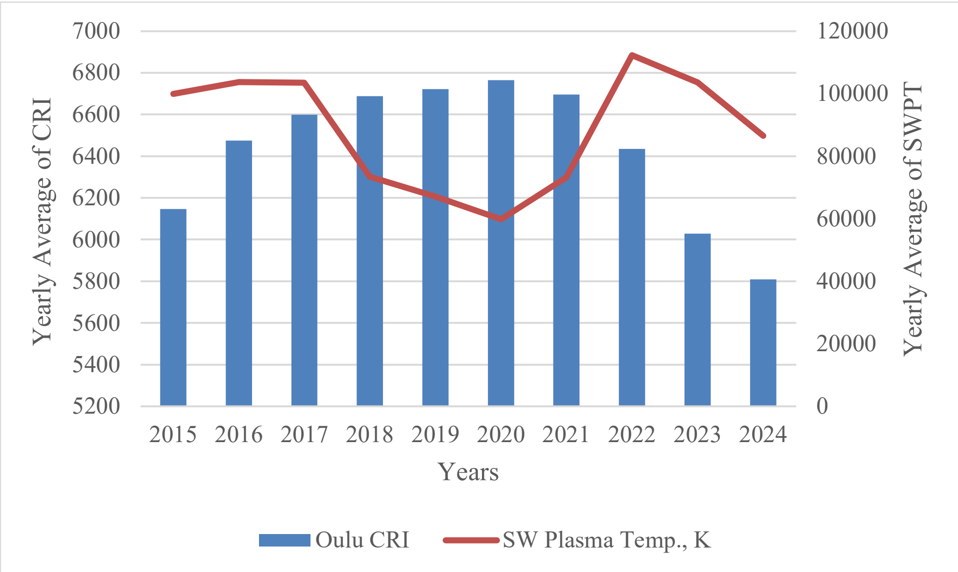

Fig.6 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of solar wind plasma temperature during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

3.4 Long-Term Cosmic Ray Intensity Variation (Oulu) With Alfven Mach Number During Decline Phase of Solar Cycle 24 And Rising Phase of Solar Cycle 25

In this part of the study, we have a correlative analysis has been performed between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of Alfven Mach number for the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.We have plotted a liner graph and a bar graph between yearly average values of cosmic rays' intensity (CRI) variation and yearly average values Alfven Mach number of shown in fig. [7, 8]. From the figures it is observed that positive correlation has been found between yearly average values of cosmic ray intensity (CRI) variation and yearly average values of Alfven Mach number for the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.Large positive correlation with correlation coefficient 0.86 has been found between yearly average values of cosmic ray intensity variation yearly average values of Alfven number during Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

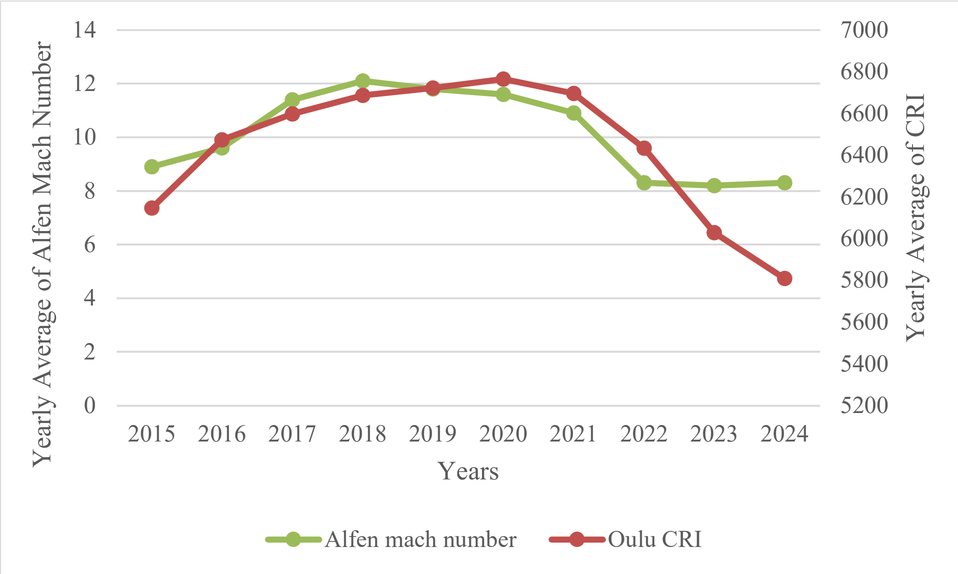

Fig.7 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of yearly average values of Alfven number. during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

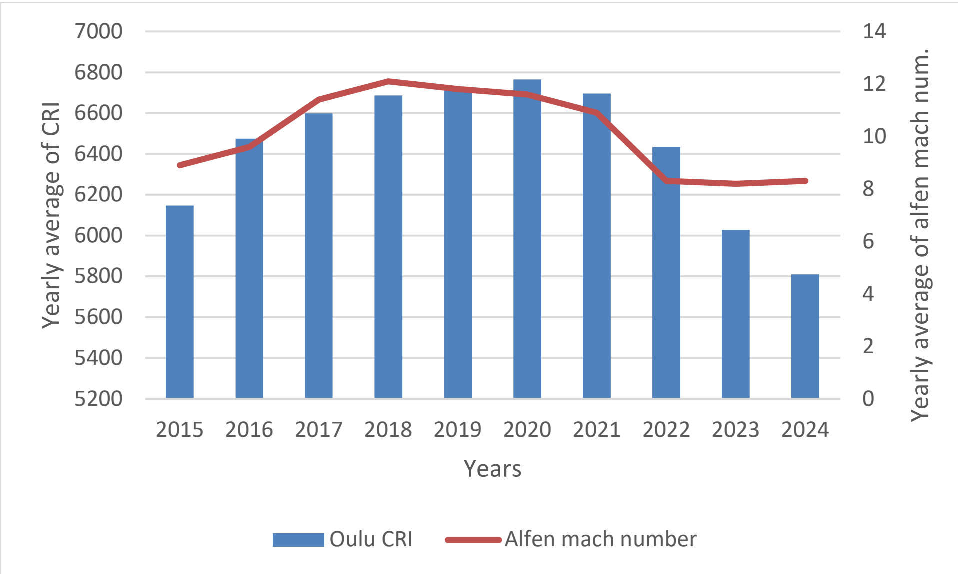

Fig.8 Shows the relationship between yearly average value of CRI (Oulu) and yearly average of yearly average values of Alfven number. during the period of Decline Phase of solar cycle 24 and rising phase of solar cycle 25.

4 Conclusions

The study confirms that the yearly average of interplanetary magnetic field and yearly average of cosmic ray intensity (CRI) are negatively correlated and anticorrelations observed are highly significant. As the correlation coefficient -0.90 has been found between yearly average of cosmic ray intensity variation and yearly average of interplanetary magnetic fields during decline phase of solar cycle 24 and rising phase of solar cycle 25.
The study also confirms that the yearly average of cosmic ray intensity (CRI) and solar wind plasma pressure and temperature is anti-correlated as the correlation coefficient -0.63 has been found between yearly average of cosmic ray intensity variation and yearly average of solar wind plasma pressure and -0.51 are determined

between yearly average of cosmic ray intensity and yearly average of solar wind plasma temperature during the period of decline phase of solar cycle 24 and rising phase of solar cycle 25.
Further the yearly average of Alfven mach number and yearly average of cosmic ray intensity is positively correlated. From these results it is concluded that cosmic ray intensity variations are closely related with solar wind plasma parameter interplanetary magnetic fields, solar wind plasma pressure, solar wind plasma temperature also Alfven mach number.

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Conflict of Interest

The authors declare no conflict of interest.

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