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Symmetric cosmic ray intensity decreases with solar flares and interplanetary shocks from cycle 23 up to minimum phase of cycle 24

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Abstract
This paper presents an overview of results obtained during the solar activity cycle 23 up to minimum phase of solar cycle 24 on short term cosmic ray intensity decreases and how it relate to solar flares and interplanetary shocks. For this work we have obtained the data of cosmic ray intensity decreases and other parameters from ground-based neutron monitors (NMs) and NCEI respectively. we observed that 47 symmetric cosmic ray decreases in cosmic ray intensity in our list out of which 42 (89.36%) have been identified as being associated with X ray solar flares of different categories. Out of 42, most of the symmetric cosmic ray decreases are associated with M (42.86%) class and C (45.24%) class solar flares. Further out of 47 symmetric cosmic ray intensity decreases, 22 (46.81%) have been found to be associated interplanetary shocks. The associated interplanetary shocks are forward shocks out which arrival time of 17 (77.27%) interplanetary shocks have been found after the onset time of symmetric cosmic ray intensity decreases, The arrival time of 05 (22.72%) interplanetary shocks have been found before the onset time of symmetric cosmic ray intensity decreases. We perform a statistical analysis to find out the relation between cosmic ray intensity decreases with solar flares of different categories and obtain the correlation coefficient of 0.26, 0.14 and -0.34 for M, C and B class x-ray solar flares respectively.
Keywords: - cosmic ray intensity, symmetric cosmic rays, solar flares, interplanetary shocks.

1. Introduction

The heliosphere is a giant asymmetric bubble filled with various energetic particles due to the supersonic expansion of the solar wind. These energetic particles are the main source of space radiation environment that affects the operation of spacecraft and high altitude aircraft, and the health of astronauts and flight personnel [1]. In the interplanetary space solar energetic particles, galactic cosmic rays (GCRs) and anomalous cosmic rays are the commonly seen energetic particles. Solar energetic particles i.e. solar cosmic rays are originating from the sun with energies ranging from a few tens of keV to several GeV. They are associated with coronal mass ejections (CMEs) and solar flares. Solar energetic particles are accelerated with CME-driven shock which is widely accepted [2-5] as an essential site.
By observations and numerical simulations [6-8] believed that galactic cosmic rays originate from the supernova remnants (SNRs) and accelerated by supernova blast shocks driven by expanding SNRs. Mishev et al. 2014 [9] showed that When GCR particles (primary cosmic rays) encounter at the earth atmosphere, they interact with atmospheric atoms and generate cascades of secondary particles like neutrons and muons, can be measured by the ground-based neutron monitors (NMs) and muon detectors once arriving at the surface of the Earth. The history of neutron monitors can be traced back to the 1950s [10]. The combination of GCR count rates from NM stations and GCR intensities from in-situ spacecrafts is helpful to draw a complete picture of cosmic rays.
Since the Sun is a variable star it produces significant modulation of cosmic rays in a variety of cycles. Potgieter [11] observed that the study about the cosmic rays enlighten us about the characteristics of the Sun’s electrodynamics and about the structural features and geometry of the heliosphere including the solar wind termination shock, they influence the flux of cosmic rays in the heliosphere, up to Earth.
Leske (2013) [12] found that since last 50 years GCR intensities in 2009 (neutron monitor rates and also at ~200 MeV/nucleon) were the highest recorded. Transition from solar minima of cycle 23 to the onset of cycle 24 was different

from other solar minimum. It has been marked by a prolonged and continuing period of low solar activity that began in 2006. The first sunspot of cycle 24 marked in January 2008 which is vanished after few days [13].
Flares were observed in white light initially [14-15]; however, they have also been observed in a wide wavelength ranging from radio to gamma rays. White-light flares are responsible for flare energy release when high-energy particles from the corona precipitate to chromospheres and/or photosphere [16-18]. Badruddin and Singh (2006) argued that depression in cosmic ray density into different categories depending on the shape of the depressions like; Symmetric depressions were observed to have (i) V-shape and (ii) bowl or U-shape and Asymmetric depressions have been categorized into (i) Forbush-like, (ii) composite, and (iii) wavy depressions [19].
In the cosmic ray flux reaching at the Earth, Forbush decreases are short-term depressions and they are caused by the effects of the interplanetary counter-parts of coronal mass ejections (CMEs) from the Sun and the shocks they drive and also the co-rotating interaction regions originating from the Sun. They have been studied since their discovery in the 1930s [20-21].
The interplanetary conditions for Forbush decreases (FDs) indicate that the outward propagating interplanetary shock waves associated with the CSWSs, swept away the galactic cosmic-rays, causing the delay in the FDs recovery at 1 AU. The duration of the recovery phase of the FDs would be much longer in the lower energy galactic cosmic ray particles than in the high energy region [22]. For the increase or decrease of cosmic ray intensity (CRI), interplanetary magnetic field (IMF) shocks may be responsible [23]. However, impacts on the IMF depending on the heliospheric position as well as on the conditions in the interplanetary space are energetic solar eruptions contributors [24].
Forbush, Webber and Lockwood concluded that short-term cosmic ray modulation is very important [25-26], because short term modulation is well correlated with various solar, interplanetary parameters [27], since the accumulation of many short-term effects leads to the long-term solar modulation.
Soni and Gour reported [28] in 2017 that cosmic ray intensity decreases and CMEs are weakly correlated and also showed that cosmic ray intensity decreases are closely related with X-ray solar flares of different categories.

2. Data Selection and Analysis

In this study the data of cosmic ray intensity decreases adopted from Oulu super neutron monitor 9-NM-64 having cutoff rigidity ~0.8 GV [29] over the 1997 to 2013 time period (cycle 23 & 24). The data of X-ray solar flares are taken from STP solar data (http://www.ngdc.noaa.gov/stp/solar/solardataservices.html). The data of interplanetary shocks are taken from shocks arrival derived by WIND group from WIND observations. I perform the statistical analysis also to find out the relation between these parameters. By the analysis found that 47 cosmic ray intensity decreases are there, out of which 42 associated with X-ray solar flares of different categories. Furthermore cosmic ray intensity decreases associated with interplanetary shocks, 22 cosmic ray intensity decreases associated with shocks most of the shocks are forward shocks (17 shocks).
Figure-1 shows the variation of cosmic ray intensity obtained from Oulu NM over the 1997 to 2013 time period, in 2010 the solar activity was in minimum phase (i.e. minimum phase of cycle 24) but correspond variation in cosmic ray intensity was maximum. An M-class flare erupted in active sunspot region 1093, peaking at 1824 UTC on August 7, 2010. The eruption hurled a coronal mass ejection (CME) into space. The CME is not fully directed toward Earth, but some of the plasma cloud may glance the magnetosphere between August 9 and August 10, causing a geomagnetic disturbance and possible aurora.
On October 16, 2010, Fast-growing sunspot 1112 is crackling with solar flares. The three strongest of this 24 hour period: an M3-flare at 1910 UT on Oct. 16th, a C1-flare at 0900 UT and another C1-flare at 1740 UT on Oct. 17th. So far, none of the blasts has hurled a substantial CME toward Earth (figure-2).

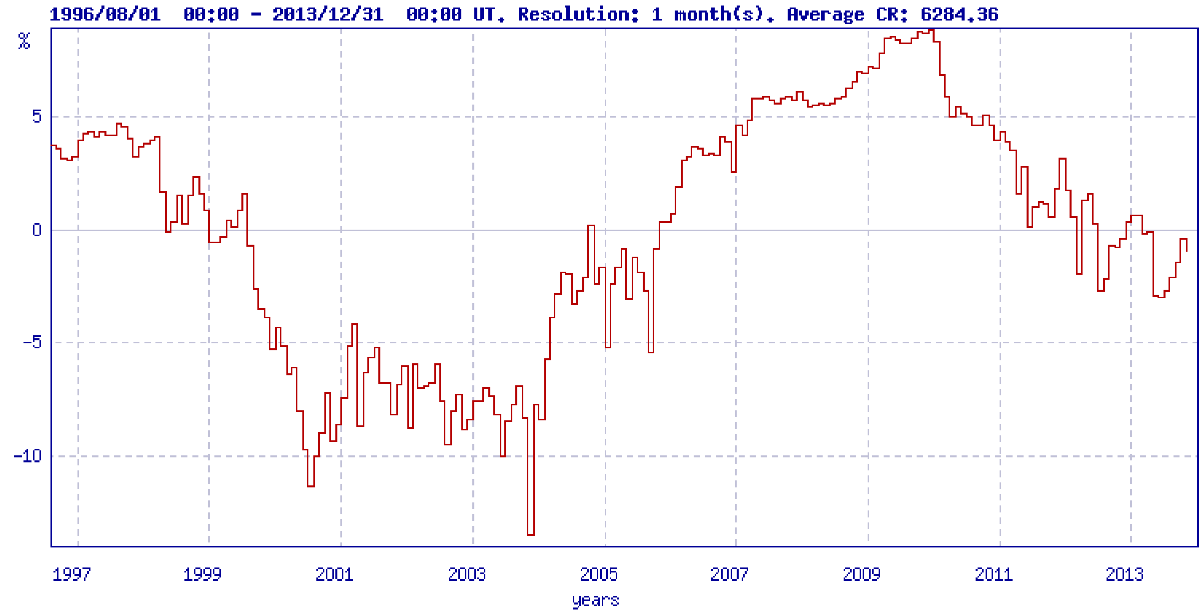

Figure-1 Variation of cosmic ray intensity in respect of years from 1997-2013.

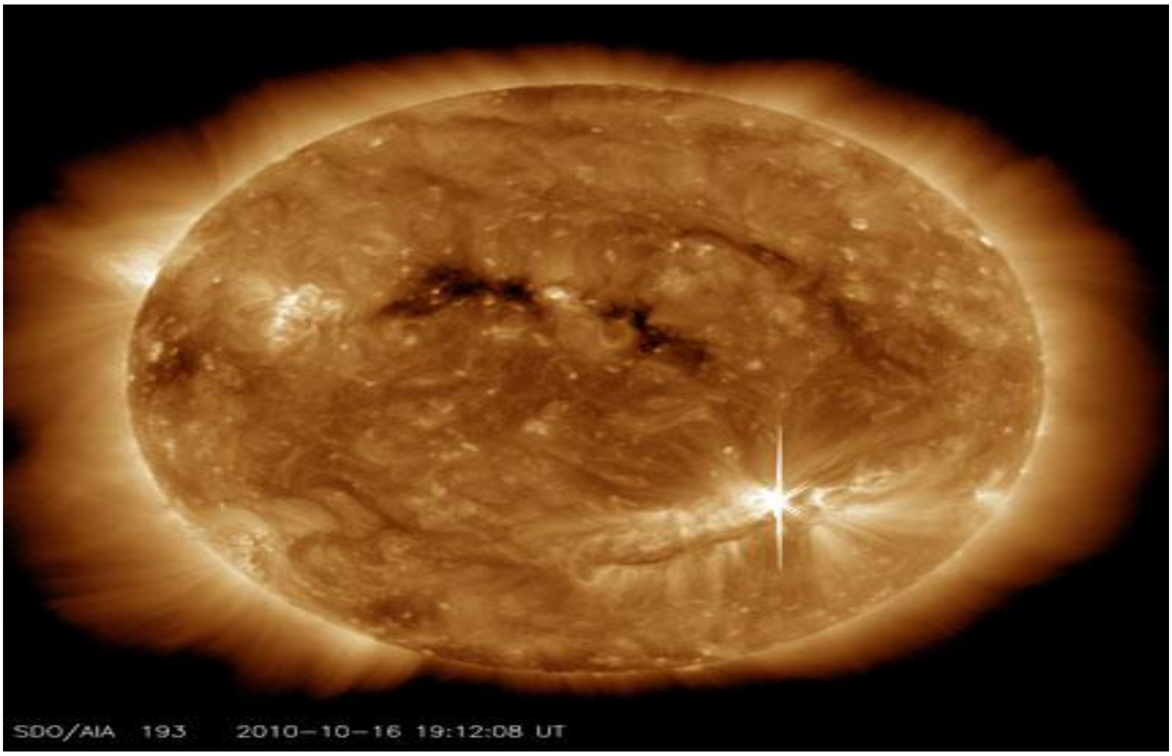

Figure-2 most intense M-class solar flare on October 16, 2010 (Image credit: NASA/SDO/AIA).

3. Result and Discussion

By the analysis of the data we have found that 47 symmetric cosmic ray decreases in cosmic ray intensity in our list out of which 42 (89.36%) have been identified as being associated with X ray solar flares of different categories. Out of 42 symmetric cosmic ray intensity decreases, 01(2.38%) symmetric cosmic ray intensity decreases are found to be associated with X class X-ray solar flares, 18(42.86%) symmetric cosmic ray intensity decreases are found to be associated with M class X-ray solar flares, 19(45.24%) symmetric cosmic rays intensity decreases are found to be associated with C class X-ray solar flares and 04(9.52%) are found to be associated with B class X-ray solar flares. The bar diagram between different categories of solar flares and frequency of associated symmetric cosmic ray decreases in cosmic ray intensity is shown in Figure-3.

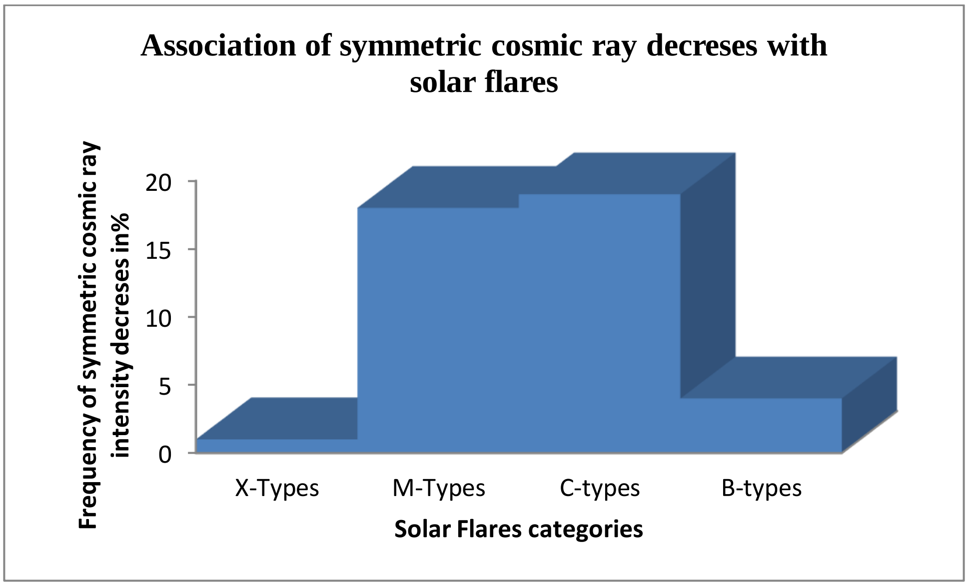

Figure-3 shows Bar Diagram between Different types of Solar flares and frequency of associated symmetric cosmic ray intensity decreases.

From the data analysis it is concluded that majority of the symmetric cosmic ray intensity decreases are associated with X-ray solar flares and most of the symmetric cosmic ray decreases in cosmic ray intensity are associated with M class and C class solar flares. perform a statistical analysis to find out the relation between cosmic ray intensity decreases with solar

flares of different categories and obtain the correlation coefficient of 0.26, 0.14 and -0.34 for M, C and B class x-ray solar flares respectively. B class flare having weak negative correlation with CRI.
From the further analysis it is observed that majority of interplanetary shocks following the onset of symmetric cosmic ray intensity decreases. We have 22 symmetric cosmic ray intensity decreases which are associated with interplanetary shocks out which arrival time of 17(77.27%) interplanetary shocks have been found after the onset time of symmetric cosmic ray intensity decreases, The arrival time of 05(22.72%) interplanetary shocks have been found before the onset time of symmetric cosmic ray intensity decreases (figure-4).

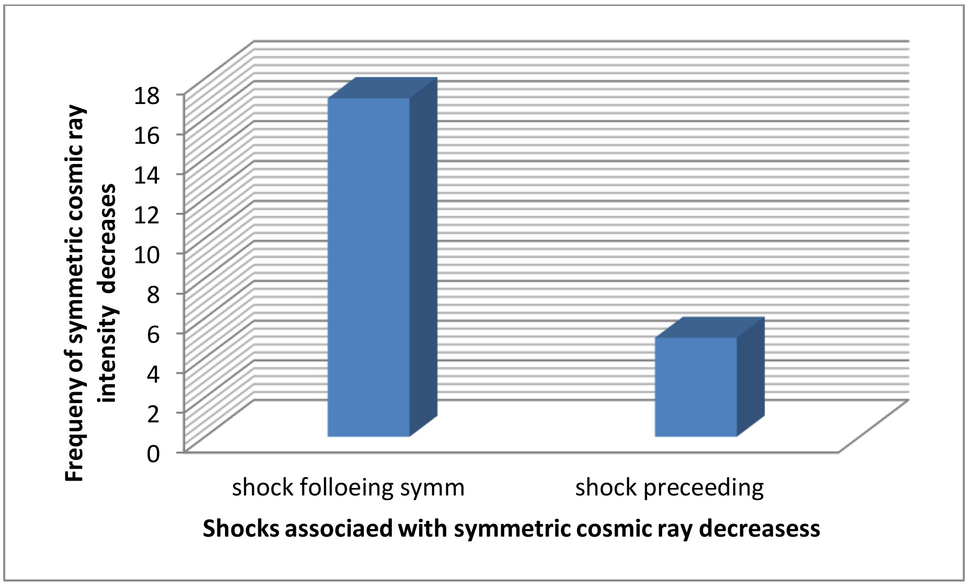

Figure-4 Shows Frequency of symmetric cosmic ray intensity decreases associated with common onset, preceding and following the onset time of symmetric cosmic ray intensity deceases.

4. Conclusion

In this study I have analyzed the CRI depressions with different parameters such as solar flares and shocks. At the end I found that at the maximum solar activity the depressions are minimum and vice versa. During this study CRI connected with solar flares mostly to the M and C class flares and also to the interplanetary shocks which are driven during eruptions from the sun most of them are forward shocks over this time period. Firoz et.al. 2010 [30] also did the correlative analysis of CRI with solar activity and found that they are having anti-correlation even with the solar flux. I recommend that this work will be extended for CRI collected from different ground based NM and relation with different parameters.

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Conflict of interest

The Author declares that no conflict of interest in this manuscript.

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