International Journal of Innovative Research & Growth
A Peer Reviewed Journal
ISSN: 2455-1848
Journal homepage: http://www.ijirg.com/ijirg/
Volume: 11 Issue: 1 January 2022

Asymmetric cosmic ray intensity decreases with solar flares and interplanetary shocks

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Article Info
Received 20 October 2021
Received in revised form 16 December 2021
Accepted for publication 11 January 2022
DOI: 10.26671/IJIRG.2022.1.11.102
Citation:
Gour, P.S., Soni, S.(2022). Asymmetric cosmic ray intensity decreases with solar flares and interplanetary shocks. *Int J Innovat Res Growth*, 11, 9-13.

Abstract
This manuscript presents an overview of results obtained during the solar activity cycle 23 & 24 from 1997-2013 on short term asymmetric cosmic ray intensity decreases ≥4%, 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 have observed 74 asymmetric cosmic ray decreases in our list out of which 69(93.24%) have been identified as being associated with x-ray solar flares of different categories. Out of which 16 (23.19%) are found to be associated with X class X-ray solar flares, 36(52.17%) associated with M class X-ray solar flares, 13(18.84%) found to be associated with C class X-ray solar flares and 04(5.7%) are found to be associated with B class X-ray solar flares. Further we have found that out of 74 asymmetric cosmic ray intensity decreases 60(81.08%) have been found to be associated interplanetary shocks. The associated interplanetary shocks are forward shocks and observed that majority of interplanetary shocks following the onset of asymmetric cosmic ray intensity decreases (Fds). Out of 60 cosmic ray intensity decreases arrival time of 37(61.66%) interplanetary shocks have been found after the onset time of asymmetric cosmic ray intensity decreases, The arrival time of 20(33.33%) interplanetary shocks have been found before the onset time of asymmetric cosmic ray intensity decreases and onset time of 03(5%) asymmetric cosmic ray decreases are common to arrival time of interplanetary shocks. We perform a statistical analysis to find out the correlation between the magnitude cosmic ray intensity decreases with M and X class solar flares and obtain the correlation with correlation coefficient of 0.22, 0.77 respectively. Other B and C class flares are not correlated with Fds.
Keywords: - cosmic ray intensity decreases, asymmetric cosmic rays, solar flares, interplanetary shocks.

1. Introduction

Coronal Mass Ejections (CMEs) are plasma eruptions from the solar atmosphere involving previously closed field regions which are expelled into the interplanetary medium. Cane (2000) tells that to identify CMEs in the interplanetary medium often energetic particle effects are used, where they are usually called `ejecta'. When both the ejecta and shock effects are present the resulting cosmic ray event is called a `classical, two-step' Forbush decrease.
Coronal mass ejections (CMEs) coming out from the sun and interact with interplanetary space with great speed produce not only the magnetic disturbances in the interplanetary space but also several other effects (Gopalswamy, 2009; Lingri et al., 2016). CMEs drastically disturb the cosmic ray intensity (CRI) (Cane, 2000; Oh et al., 2008; Venkatesan & Badruddin, 1990; Zhang & Burlaga, 1988). They cause large disturbances in geomagnetic activity (Yermolaev et al., 2014; J. Zhang et al., 2007) and are responsible for other space weather effects (Kudela et al., 2000; Sanchez-Garcia et al., 2017). The study of the evolution and effects of disturbances in the heliosphere and magnetosphere are of special interest when several solar flares occur and CMEs are ejected from the sun and travel in the interplanetary space.
Geomagnetic storms (GSs) are directly related to space weather effects (Gonzalez et al., 1994; McPherron & Siscoe, 2004). Along with interplanetary magnetic field (IMF) and solar wind characteristics, the Forbush decreases (FDs) precursors can be useful for space weather prediction, (Badruddin, 2006). Thus, study of FDs and geomagnetic activity is of relevance both for a better understanding of the physics of the transient modulation of CRIs as well as for understanding possible relevance of CRI variability in space weather research. (Badruddin, 2019) showing cross correlation between time series of CRI and geomagnetic activity indices as well as with IMF and solar wind characteristics, during strongly disturbed interplanetary conditions during 4–10 September 2017. Several large solar flares, one of them of very high X-ray importance (X9.3) and three halo CMEs were detected in the solar atmosphere.

Verma,et al, 2014 found that asymmetric cosmic ray intensity decreases correlated with coronal mass ejection specifically halo CMEs. Majority of the asymmetric cosmic ray intensity decreases (Fds) are caused by halo coronal mass ejections and interplanetary shocks, disturbances in solar wind plasma parameters that they generate.

When a solar wind disturbance propagates faster than the surrounding medium, the interplanetary shocks are formed. Shocks in the inner heliosphere are generally weak, as the fast-mode MHD Mach number is typically between 1 and 2 (Volkmer & Neubauer 1985). Interplanetary shocks have two main origins, First, a shock can originate in a fast solar wind stream with a typical speed above 600 km/s, which overtakes a slower stream with a speed around 400 km/s (Balogh et al. 1999; Smith 2008). A second source of shocks is transient in nature and is associated with coronal mass ejections (CMEs).

Sheeley et al. (1985) found that at least 72% of the shocks observed in situ by Helios 1 spacecraft were associated with CMEs observed with a coronagraph. Only 2% of the observed shocks lacked an associated CME. At 1 AU and with in situ data, Berdichevsky et al. (2000) found that only 43% of shocks are associated to ICMEs during a solar minimum period. Oh et al. (2007) found that 79% of shocks are associated to ICMEs (MCs and ejecta), while 21% of shocks are associated to CIRs (or high speed streams, HSS). The presence of interplanetary shocks is typically associated with a transient variation of energetic particles abundances. In this study we studied the asymmetric cosmic ray intensity with different solar flares and interplanetary shocks during the time span of 1997-2013.

2. Experimental Data

In this work monthly and hourly data of Oulu super neutron monitor have been used to determine asymmetric cosmic ray intensity decreases. The data of interplanetary shocks have been taken from shocks arrival derived by WIND group from WIND observations, ACE list of transient and disturbances. X-ray solar flare data was collected from online catalogue of GOES (geostationary environmental satellite).

3. Analysis Result and Discussion

We have analyzed asymmetric cosmic ray intensity decreases (Fds) during the solar activity cycle 23 & 24 (1997-2013) of magnitude ≥4% with X-ray solar flares of different categories extracted from online catalogue of GOES. From the data analysis we have found 74 asymmetric cosmic ray intensity decreases (Fds) out of which 69 (93.24%) asymmetric cosmic ray intensity decreases (Fds) have been identified as being associated with X ray solar flares of different categories and majority of the associated solar flares are M-Class solar flares (52.17%). The bar diagram between types of X-ray solar flares and frequency of associated asymmetric cosmic ray intensity decreases (Fds) are shown in Figure-1. From these results it is concluded that asymmetric cosmic ray intensity decreases (Fds) are closely related with X-ray solar flares.

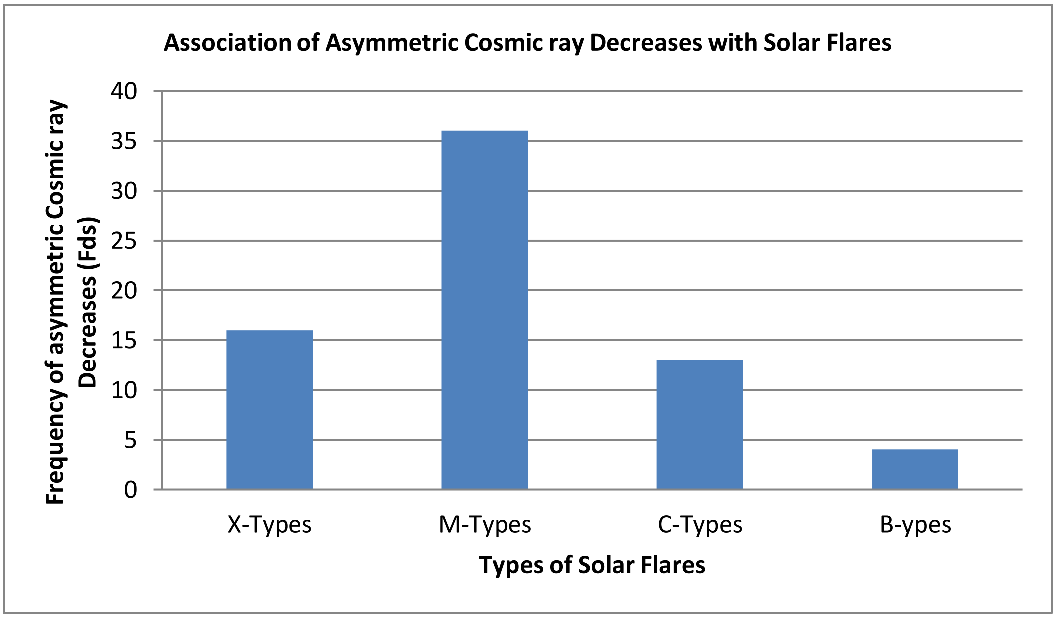

Figure-1 Bar diagram between different types of solar flares and frequency of associated asymmetric cosmic ray intensity decreases (Fds) for the period of 1997-2013.

Further we perform a statistical analysis between magnitude of cosmic ray intensity decreases and solar flares. The correlation coefficient is measured on a scale that varies from + 1 through 0 to – 1 which is a degree of association of two parameters. By the analysis we observed that the solar flares of M and X class are well correlated with cosmic ray intensity decreases of correlation coefficients 0.22, 0.77 respectively. We find the linear regression equation $y = 2.8771x + 20.554$ for M class solar flares and $y = 6.2633x - 18.922$ for X class solar flares with cosmic ray intensity decreases shown in Figure-2 & 3. Gour et al. 2021 reported that coronal mass ejections (CMEs) and sunspot number also have a linear regression to each other so we can conclude that solar flares are also well related with CMEs and sunspot number. With further analysis we found that there is no correlation of B and C class flares with cosmic ray intensity decreases because they are having negative correlation.

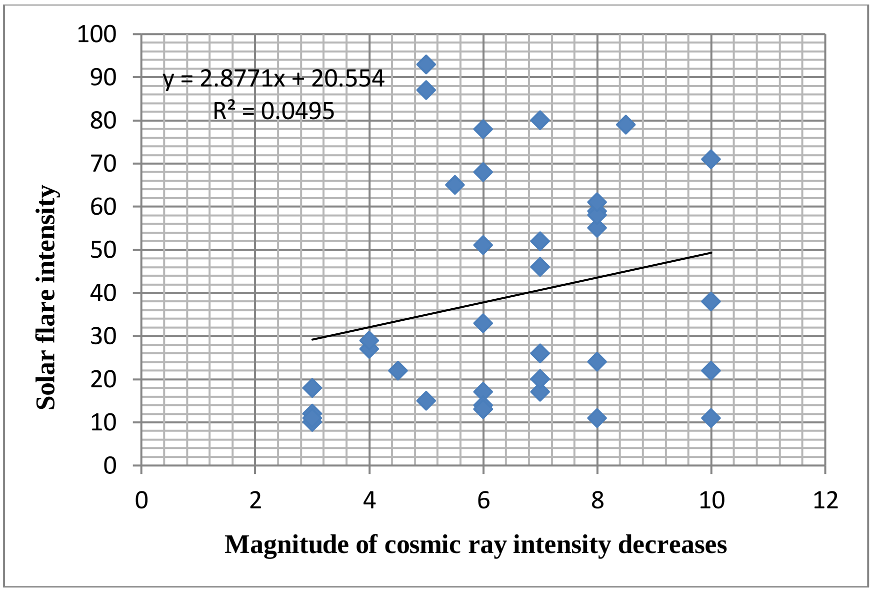

Figure-2 Correlation between cosmic ray intensity decreases and M class flare with correlation coefficient 0.22.

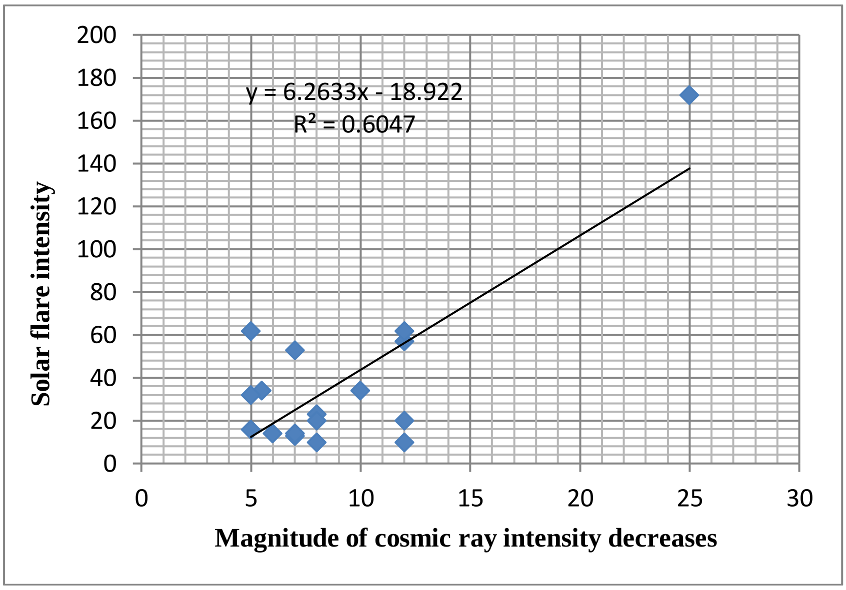

Figure-3 Correlation between cosmic ray intensity decreases and X class flare with correlation coefficient 0.77.

From the data analysis we have found total numbers of asymmetric cosmic ray intensity decreases (Fds) during the period 1997-2013 are 74. Out of 74 asymmetric cosmic ray intensity decreases (Fds), 60 (81.08%) asymmetric cosmic rays intensity decreases (Fds) have been found to be associated with interplanetary shocks. The associated interplanetary shocks are forward shocks. From the further analysis it is observed that majority of interplanetary shocks following the onset of asymmetric cosmic ray intensity decreases (Fds). We have 60 asymmetric cosmic ray intensity decreases which are associated with interplanetary shocks out which arrival time of 37(61.66%) interplanetary shocks have been found after the onset time of asymmetric cosmic ray intensity decreases (Fds), The arrival time of 20(33.33%) interplanetary shocks have been found before the onset time of asymmetric cosmic ray intensity decreases (Fds) and onset time of 03(5%) asymmetric cosmic ray decreases are common to arrival time of interplanetary shocks (Figure-4).

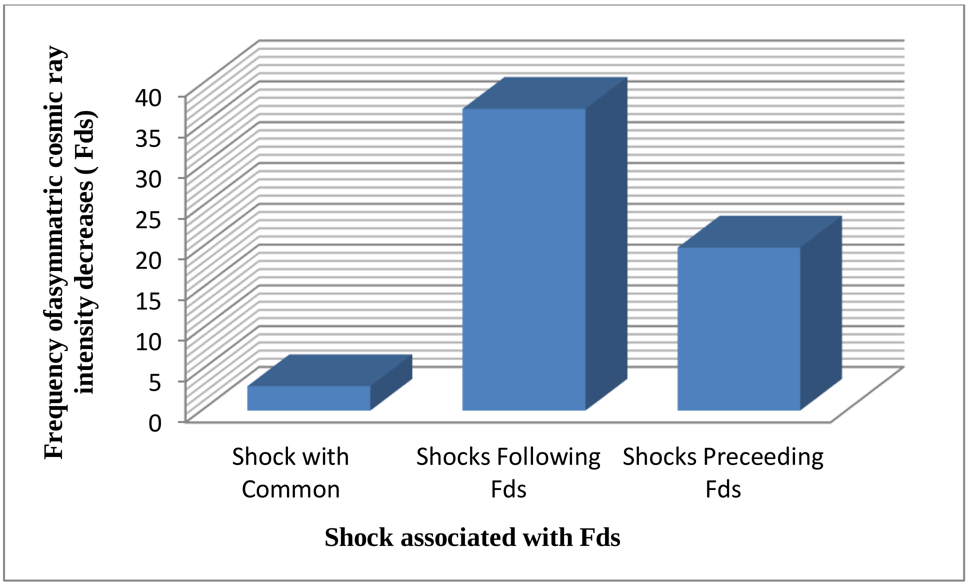

Figure-4 Frequency of asymmetric cosmic ray intensity decreases (Fds) associated with common onset, preceding and following the onset time of asymmetric cosmic ray intensity deceases (Fds).

4. Conclusion

In this investigation we have studied short term asymmetric cosmic ray intensity decreases of magnitude ≥4% during the solar activity cycle 23 & 24 (1997-2013) with different solar parameters. We have seen that asymmetric cosmic ray intensity decreases are closely related with X-ray solar flares particularly M and X class X-ray solar flares. By the statistical analysis we have concluded that asymmetric cosmic ray intensity decreases and flares have linear relationship with linear regression equations between them. Asymmetric cosmic ray intensity decreases are also well related with interplanetary shocks, most of the shocks are forward shocks. Further this study may continue with U and V shape cosmic ray intensity decreases.

Acknowledgement

We are very thankful to Oulu super neutron monitor, WIND group and online catalog of GOES for making the data freely available.

Conflict of Interest

In this manuscript the authors declare that there is no conflict of interest.

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