

Effect of Halo Coronal Mass Ejection on Cosmic Ray Intensity and Disturbance Storm-Time index for the Ascending Phase of the Solar Cycle 24

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Abstract

The aim of this paper is to study the effect of halo coronal mass ejections (CME) on cosmic ray intensity (CRI) and disturbance storm-time (Dst) index for the ascending phase of solar cycle 24. A Chree analysis by the superposed epoch method has been done for the study. From the present analysis, we have found that the maximum decreases in CRI and Dst index takes place within five days after the onset of halo CMEs. Also, solar flare associated halo CMEs are found to be most effective in producing maximum decreases in CRI and Dst index in comparison to non-flare associated halo CMEs. Halo CMEs which are associated with X-class of solar flares are found to be most effective in producing maximum decreases in CRI in comparison to those halo CMEs which are associated with M and C- class flares while these entire halo CMEs have almost similar effect on the Dst index. These results of our analysis may reflect a very good idea of scientific community in the field of solar physics.

Keywords: Coronal mass ejection, Cosmic rays, Disturbance storm-time index, interplanetary medium, Solar flare

1 Introduction

Cosmic rays are high energy radiations and are modulated by solar activities. Forbush decrease (FD), a transient and rapid decrease in cosmic ray intensity (CRI) followed by a slow recovery, is one of the most occurring phenomena in cosmic ray intensity modulation process and was first discovered by Forbush in 1938. After the discovery of FDs in cosmic ray intensity, many investigators have investigating the cause of these decreases. It is well known that the intensity and energy spectrum of the cosmic rays are modulated by solar activity. Lockwood and Webber (1992) have found an inverse correlation between CRI and solar activity. Solar flare release vast amount of matter and radiations together with particle emission (Prasad & Joshi 2008) in a short



time, hence they play an important role in the study of cosmic ray intensity modulation process. The association of solar flares with the decrease in cosmic ray intensity has been studied by many researchers (Hotton 1980, Badruddin et al. 1982, Shrivastava 2003, Singh et al. 2004). Shrivastava (2003) reported that flares occurring between 15° to 30° north and between 0° to 30° east are most effective in producing FD events. It was suggested by Jothe & Shrivastava (2011) that a strong solar flare alone is capable of producing FDs. It was believed that during an explosive solar flare, a gas is ejected from the flaring region of the Sun in the form of plasma cloud. When this plasma cloud arrives at the earth, it produces the decrease in cosmic ray intensity. Recently, it has been suggested that not only flares but coronal mass ejections (CMEs) also may produce variations in cosmic ray intensity (Shrivastava and Jaiswal, 2003). A CME is a dynamically evolving, most energetic and largest phenomenon in association with the eruption of plasma and magnetic field from the solar surface. These CMEs adds magnetic flux to the interplanetary magnetic field (IMF, which also produces geomagnetic storms, GSs and FDs in CRI, Kharayat et al., 2016) and produces major disturbances in the interplanetary medium. These disturbances in the interplanetary medium are the primary causes of geomagnetic storms and forbush decreases in cosmic ray intensity. Geomagnetic storm is a temporary disturbance in the Earth's magnetosphere. The strength of a GS is measured by the disturbance storm-time (Dst) index (Gonzalez et al., 1994). The Dst index is the measure of ring current intensity and energy observed at earth's surface over low and moderate latitudes. The FDs are strongly associated with CMEs (Cane, 2000; Shrivastava and Singh, 2008). The major solar flares occurring in western hemisphere of the sun in association with halo coronal mass ejection produce large number of FD events (Shrivastava et al., 2011). In 2014, Parsai and Singh noted that the solar flares in association with CME occurring in northern hemisphere are more effective in producing FD events in cosmic ray intensity. Badruddin (2002) have demonstrated that Halo CMEs are more effective transient modulator of cosmic ray intensity than other CMEs and produce significant FDs. Earth directed CMEs are known as halo CMEs and was first observed by Howard et al. (1982). Full halo CMEs have an apparent width (W) of 360°, while partial-halo CMEs have $120^{\circ} \le W < 360^{\circ}$. Halos with their sources within $\pm 45^{\circ}$ of the Central Meridian Distance (CMD) are known as disk halos, while those with central meridian beyond ±45° but not beyond ±90° are known as limb halos. Gopalswamy et al. (2007) suggested that disk halos are likely to arrive at the Earth and causes GSs, while limb halos are less geo-effective. Fast halo



CMEs associated with flares originating from the central and mid latitude of the Sun can possibly be used for predicting intense geomagnetic activity (Tsurutani et al., 1990; Shea and Smart, 1996). Cane et al. (1996) have studied FD events with CME for 30 years period and found that 86% FDs are associated with CMEs and interplanetary shocks that they produce. The long term variation of cosmic ray intensity is still an unsolved problem. Therefore, study of long term variation in CRI is one of the major fields of study. The details of the CRI modulation as well as variation of time lag factor are still a matter of great interest. Here, we have studied the effect of halo CMEs on CRI and Dst index. We have not included the non-halo CMEs because the main focus of this work is to determine the association of CRI and Dst index with halo CMEs.

2 Data and Method

For the present study, we have used Chree analysis by the superposed epoch method. The onset days of halo CMEs with speed $\geq 500 \text{ km}\text{-s}^{-1}$ is taken as zero days for the analysis. The halo CME SOHO/LASCO halo data are taken from the CME catalogue from http://cdaw.gsfc.nasa.gov/CME list/halo/halo.html for the period 2009 - 2015 (ascending phase of solar cycle 24). The pressure-corrected daily mean data of CRI are taken from the Moscow Neutron Monitor Station (cr0.izmiran.rssi.ru/mosc/main.htm). The daily mean values of the disturbance storm-time index (Dst index) are taken from the Omniweb data center (omniweb.gsfc.nasa.gov/form/dx1.html). We have excluded those events from the study whose speed is either less than 500 km-s⁻¹ or not given in the catalogue. Halo CMEs of the same day are assumed to be equally effective in producing decreases in CRI and Dst index.

3 Results and discussion

In this article, we have studied the effect of halo CMEs on CRI and on Dst index for the period 2009-2015 (ascending phase of solar cycle 24). We have plotted daily mean values of CRI for the period studied as illustrated in fig.1. As we have not found any halo CME with speed \geq 500 km-s⁻¹ in 2009, so figure 1 contains the plots for period 2010-2015. It is clear from figure 1 that the maximum decrease in CRI takes place within five days after the occurrence of the event. A sharp decrease in CRI is found in 2011 and 2013, while in 2014, the variation of CRI is quite different.





Fig.1: The result of Chree analysis from -6 to +10 days with respect to zero epoch days. The variation of CRI is shown. Zero day corresponds to the starting day of occurrence of the halo CME event during 2010-2015.

Further, as it is well known that not all the halo CMEs are associated with solar flares, so their effect on CRI should be different. We have divided halo CMEs in two categories: i) flare associated halo CMEs and ii) non-flare associated halo CMEs. The variations of CRI and Dst



index under the influence of flare associated halo CMEs and non-flare associated halo CMEs are shown in fig.2 and 3 respectively. It is clear from the figures that the flare associated halo CMEs produces maximum decreases in CRI and Dst index in comparison to non-flare associated halo CMEs. This may be due to the fact that halo CMEs in association with flares become more energetic and magnetized which may cause larger disturbances in interplanetary medium and hence, results more decreases in CRI and Dst index. These decreases in CRI and Dst index, due to the flare associated halo CMEs are found to be four and three days after the onset of the event, which also confirms the result of fig.1.



Fig.2: Variation of CRI under the influence of flare associated halo CME (HCME) and non-flare associated halo CME depicted by different symbols.





Fig.3: Variation of Dst index under the influence of flare associated halo CMEs (HCME) and non-flare associated halo CMEs depicted by different symbols.

Further we have divided the flare associated halo CME events with the class of solar flares and studied their effect on CRI and Dst index. The results are shown in fig.4 and 5. It is clear from the fig.4 that halo CMEs associated with X- class solar flare produces maximum decrease in CRI than the M and C-class flare associated halo CMEs. Since X-class solar flares are most energetic flares of the solar surface, so the halo CMEs becomes more energetic in association with X- class of solar flares. Hence, its effect on CRI is very high. However in case of Dst index, all the flare associated halo CMEs have almost similar effect. Although, decreases in CRI and Dst index have a common origin in interplanetary space but magnitude of both the decreases are not proportional to each other. The Dst variations depends on the local characteristics of the solar wind flowing around the Earth's magnetosphere whereas CRI decreases in Dst index is found to be three, four and five days after the event due to M, X and C- class flare associated halo CMEs respectively which also confirms the result indicated by fig.1. This result of our study is in good agreement with the result of Prasad et al. (2013) who have suggested that the GSs occur within five days after the onset of event.





Fig.4: The variation of CRI under the influence of Halo CMEs associated with M, C and Xclass solar flares is shown by different symbols.



Fig.5: Variation of Dst index under the influence of Halo CMEs associated with M, C and X-class solar flares is shown by different symbols.

4 Conclusions



We have examine following conclusions

- 1- A maximum decrease in CRI and Dst index is found within five days after the onset of halo CMEs.
- 2- Flare associated halo CMEs produces larger decreases in CRI and Dst index than that of without flare associated halo CMEs.
- 3- More decrease in CRI is found due to those halo CMEs which are associated with Xclass solar flare.
- 4- Halo CMEs associated with X, M and C-class of solar flares has similar effect in Dst index.

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References

Badruddin B. 2002, Solar Physics, 165, 195206.

Badruddin B. and Yadav, R. S. 1982, Indian J. Physics, 68, 588.

Cane H.V. 2000, Space Sci. Rev., 93, 55-77.

Cane H.V., Richardson I.G. and Von Rosenving T.T. 1996, J. Geophys. Res. 101, 21561.

Forbush, S.E.: 1938, Phys. Rev. 54, 975

Gonzalez, W.D., Joselyn, J.A., Kamide, Y., Kroehl, H.W., Rostoker, G., Tsurutani, B.T., Vasyliunas, V.M.: 1994, *J. Geophys. Res.* **99**, 5771.

Gopalswamy, N., Yashiro, S., Akiyama, S., 2007, J. Geophys. Res., 112, A06112.

Hotton, C. J. 1980, Solar Phys., 66, 159.



Howard, R.A., Michels, D.J., Jr. Sheeley, N.R., Koomen, M.J., 1982, Astrophys. J. Lett., 263, L101.

Jothe, M. K. and Shrivastava, P. K. 2011, Ind. J. of Radio & Space Phys., 40, 179-182.

Kane, R.P., 1977, J. Geophys. Res., 82, 561.

Kharayat, H., Prasad, L., Mathpal, R., Garia, S., Bhatt, B.: 2016, Solar Phys. 291, 603.

Lockwood, J.A. and Webber, W.R., 1992, J. Geophys. Res., 97: 8221-8230.

Parsai, N. and Singh, N. 2014, Int. J. Theoretical & Applied Sci. 6(2), 10-12.

Prasad, L., Joshi, V. K., 2008, Physics Education, 25, 267.

Prasad, L., Garia, S., Bhatt, B., 2013, Int. J. Phys. Appl., 5(2), 77-81.

Singh, N., Tiwari, D. P., Tiwari, C. M. & Shrivastava, P. K. 2004, *Acta Ciencia Indian*, **XXXP** (2), 209.

Shea, M.A., Smart, D.F., 1996, Adv. Space Res., 17, 4-5.

Shrivastava, P.K. 2003, Proceedings of the 28th International Cosmic ray Conference, 3595.

Shrivastava, P.K. and Jaiswal, K. L. 2003, Solar Physics, 214, 195-200.

Shrivastava P.K., Jothe M.K. and Singh M., 2011, Solar Physics, 269, 401-410.

Shrivastava P.K and Singh G. 2008, Indian J. of Radio & Space Physics, 37, 244-248.

Tsurutani, B.T., Goldstein, B.E., Smith, E.J., Gonzales, W.D., Tang, F, Akasofu, S.I., Anderson, R.R., 1990, *Planet Space Sci.*, **38**, 109.