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Solar flares associated coronal mass ejection accompanied with DH type II radio burst in relation with interplanetary magnetic field, geomagnetic storms and cosmic ray intensity

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A B S T R A C T

In this paper, we have selected 114 flare-CME events accompanied with Deca-hectometric (DH) type II radio burst chosen from 1996 to 2008 (i.e., solar cycle 23). Statistical analyses are performed to examine the relationship of flare-CME events accompanied with DH type II radio burst with Interplanetary Magnetic field (IMF), Geomagnetic storms (GSs) and Cosmic Ray Intensity (CRI). The collected sample events are divided into two groups. In the first group, we considered 43 events which lie under the CME span and the second group consists of 71 events which are outside the CME span. Our analysis indicates that flare-CME accompanied with DH type II radio burst is inconsistent with CSHKP flare-CME model. We apply the Chree analysis by the superposed epoch method to both set of data to find the geo-effectiveness. We observed different fluctuations in IMF for arising and decay phase of solar cycle in both the cases. Maximum decrease in Dst during arising and decay phase of solar cycle is different for both the cases. It is noted that when flare lie outside the CME span CRI shows comparatively more variation than the flare lie under the CME span. Furthermore, we found that flare lying under the CME span is more geo effective than the flare outside of CME span. We noticed that the time leg between IMF Peak value and GSs, IMF and CRI is on average one day for both the cases. Also, the time leg between CRI and GSs is on average 0 to 1 day for both the cases. In case flare lie under the CME span we observed high correlation (0.64) between CRI and Dst whereas when flare lie outside the CME span a weak correlation (0.47) exists. Thus, flare position with respect to CME span play a key role for geo-effectiveness of CME.

1. Introduction

Solar flare is a burst on the sun, occurred due to sudden release of magnetic energy stored in the sun atmosphere. Solar flare emits energy over a wide range of wavelength extending from Radio, Visible, EUV, X-rays and gamma-rays together with particle emission. It is known that occurrence of solar flares is not uniform and their distribution around the sun shows a strong asymmetry between the hemispheres (Rusin et al., 1979; Badrudin et al. 1983).

Coronal Mass ejections, also known as CMEs, are main source of solar activity. It is most energetic and largest phenomenon associated with the eruption of plasma and magnetic field from the Sun into the space and is main cause of GSs if CMEs are directed towards Earth (Gopalswamy et al., 2007). MacQueen and Fisher (1983) found that flare associated CMEs shows higher speed and little acceleration in the corona. A lot of work has been done in this area out of which some recent reviews on CMEs are reported in Gopalswamy (2004), 2006a, b), Kahler (2006) and Kunow et al. (2006).

CMEs associated with decameter hectometric (DH type II) radio burst are recorded in the frequency range of 1–14 MHz by the Radio and plasma wave (WAVES) experiment on board the Wind Space Craft. CMEs associated with DH type II radio burst (also known as Radio Loud) have speed 1115 km/s which is nearly 2.4 times the average speed of all CMEs (470 km/s). Lara et al. (2003) studied CMEs associated with DH type II radio burst and observed that CMEs are more energetic when they are associated with DH type II radio burst as compare to metric type II radio burst and normal CMEs. Gopalswamy et al. (2001) observed that if CMEs are associated with DH type II radio bursts then they are wider and show faster speed. Hence study of CME associated with DH type II radio burst is very crucial. Recently, Bhatt et al. (2016), has observed that the southern region with 54% events is effective in producing flare - halo CME for DH type II radio burst and for without DH type II radio burst dominance exists in the northern region with 56% events.

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CSHKP (Carmichael, Strurrock, Hirayama, Kopp and Pneuman) model requires that the flare occurs near the center of CME span. Harison (1986) and Kahler et al. (1989) examined small number of flares and found that flare position does not peak at the centre of CME span. Thus it does not fulfill the requirement of CSHKP model in which flare originate near the centre of CME span. Yashiro et al. (2008b), has done the investigation involving nearly 500 flare-CME pairs in the SOHO era and observed that the flare is typically located below the CME leading edge for limb CMEs, agreeing with CSHKP model. When flare-CME accompanied with DH type II radio burst, Bhatt et al. (2015) has observed that dominance exists in the northern region in both the cases when flare lie under the CME span or outside the CME span with 57% events and 51% events respectively.

The first explanation of storm mechanism is given by Dungey (1961). Geomagnetic storms can be defined as disturbances of Earth's magnetosphere caused by interplanetary magnetic field structures. The intensity of the storm is measured by the Disturbance storm time index (Dst) in nT, which is the average change in the horizontal component of Earth magnetic field. The Dst is based on measurement at four magnetometers near equator and depends on average horizontal component of the Earth's magnetic field (Sugiura, 1964). Earlier, it was thought that solar flares were responsible for GSs. However, recently we have seen that CMEs, not flares alone are responsible for GSs. CMEs which originate close to the centre disk of the sun arrive near the Earth thus causing GSs. The fastest (> 1000 km/s) CMEs typically cause the most intense interplanetary disturbances and in the presence of a southward component B_z at Earth's orbit, they create strongest GSs (Gosling, 1993; Tsurustani, 2001). Echer et al. (2008), analyzed the intense GSs ($Dst \leq 100\,nT$) and concluded that Magnetic cloud (MC), sheath field and corotating interaction regions are the main cause of GSs during the decay phase of solar cycle 23.

Forbush decrease (Fd) is a rapid depression in the observed galactic cosmic ray intensity followed by a gradual recovery typically lasting about a week (Forbush, 1938). It occurs when the sun releases large burst of matter and magnetic disturbance. Cosmic ray decrease is usually associated with CMEs and ICME (Cane et al., 1996, 1997, 2000). Cane in 1996, studied that 86% of Fd are associated with CMEs and interplanetary shocks. Verma et al. (2009) concluded that halo CME associated with X-ray solar flare and related to interplanetary shocks, magnetic clouds or combination of both are mainly responsible for Fd and GSs. Mishra et al. (2008), analyzed the data during the period 1996–2006 and found that Fd $\geq 4\%$ is due to bright solar flare (importance $\geq$ 1B) in the northern hemisphere. They also observed that almost 88% Fd is associated with halo CME and most of the flares are produced in the $10^\circ - 30^\circ$ latitudinal and longitudinal belts. Recently Kovalyov et al. (2014) have observed that both the solar activity and cosmic rays have one to one correspondence. Cane et al. (2000) found a high correlation coefficient (0.74) between Dst index and B_z.

The interplanetary magnetic field (IMF) is a part of Sun magnetic field that is carried outward by the solar wind. The southward component of IMF (B_z) stresses the Earth magnetic field. Tsurutani et al. (1997) observed that there is one to one relationship between Dst index and strength of IMF and concluded that intense storm ($Dst \leq -100nT$) were caused by large southwardly directed magnetic fluid, where $B_z \leq -10nT$. The ability of a CME or any IP structure to produce a geomagnetic storm is known as geo effectiveness and such a structure is said to be geo effective. Many authors have studied the geo effectiveness of CMEs directed to Earths (Tsurutani et al. 1997; Farrugia et al., 1997). Kharayat et al. (2016) found a very good correlation coefficient between CRI and Dst index. Thus CME is most effective in causing FD when it is closest to Earth.

2. Data analysis and identification method

For the present study we have chosen the data from period 1996 to 2008 (i.e. solar cycle 23) downloaded from the website http://cdaw.gsfc.nasa.gov/CME_list/radio/waves _type2.html. This website provide the type II bursts data observed by the Radio and Plasma Wave (WAVES) experiment on board the Wind spacecraft and the associated CMEs observed by the Solar and Heliospheric Observatory (SOHO) mission. The type II burst catalogue is derived from the Wind/WAVES catalogue available at http://lep694.gsfc.nasa.gov/waves/waves.html by adding a few missing events. The CME sources (flare position and classes) are also listed, as derived from the Solar Geophysical Data listing or from inner coronal images such as Yohkoh/Soft X-ray Telescope (SXT) and SOHO/Extreme ultraviolet Imaging Telescope (EIT). Excluding those events for which solar flares position angle, class and CMEs properties is not given we found total 114 events. We investigate the flare position with respect to the CME span by using the following formula

$$r_3 = \frac{\phi_F - \phi_3}{0.5\omega_3} \tag{1}$$

where γ_3 is flare position under the CME span, θ_F is position angle of flare, θ_3 is central position angle (CPA) of CME and ω_3 is angular span of CME. If $\gamma_3 = \pm 1$ then the solar flare is located at either leg of CME frontal structure and if $\gamma_3 = 0$ then the flare is located at the center of the CME span (Yashiro et al., 2008). Solar flares position angle is determined by the formula

$$\phi_F = \tan^{-1}\left(\frac{\sin\beta}{\tan\gamma}\right) \tag{2}$$

where β is flare heliographic longitude and γ is heliographic latitude.

Using the above formulas we found that out of 114 events only 43 flares are under the CME span and 71 are outside the CME span. This is contrary to the result as suggested by CSHKP. Now we have two sets of data:-

(i) Flare under the CME Span (i.e. 43) and
(ii) Flare outside the CME Span (i.e. 71).

We apply the Chree analysis by the superposed epoch method to both sets of data to investigate the relationship of these events with IMF, GSs and CRI. The occurrence day of CME is used as zero days. The daily mean values of the Dst index and IMF is taken from the Omniweb data centre (omniweb.gsfc.nasa.gov/form/dx1.html). The pressure-corrected daily mean CRI data were taken from the Moscow Neutron Monitor Station (cr0.izmiran.rssi.ru/mosc/main.htm).

3. Result and discussion

In 2008, Yashiro and Gopalswamy studied the position of flare with respect to CME span during 1996–2008 and found the most of the solar flare lie under the CME span. Their result follows the CSHKP flare-CME model but our result does not as 71 (62%) out of 114 lie outside the CME span. Thus we can say that DH type II radio burst play a major role in context of flare position with respect to CME span. Now we discuss the relationship of Flare-CME with Interplanetary parameters.

3.1. Flare-CME and IMF

We have studied the relationship between flare-CME and IMF for both the case during 1996 to 2008. We observed that in case when flare lie under the CME span, the ascending phase and descending phase of solar cycle 23 show maximum increase in IMF within 3 to 6 and 2 to 5 days after the CME onset, respectively. Whereas in case when flare lie outside the CME span, the ascending phase and descending phase of solar cycle 23 shows maximum increase in IMF within 1 to 5 and 1 to 4 days after the CME onset, respectively. From the above we conclude that in arise and decay phase of solar cycle the time leg between CME onset and IMF on its peak is almost same for both cases.