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Geoeffectiveness of solar eruptions during the rising phase of solar cycle 24

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HIGHLIGHTS

- We have taken 33 halo CME events of the current solar cycle 24 (2009–2013).
- We analyzed statistically the different parameters responsible for the geoeffectiveness of solar eruptions.
- Big flares produce high speed CME.
- The source location of geoeffective halo CME events exhibit N-S asymmetry.
- Out of these 33 halo CME events, the majority are associated with M class flares.

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ABSTRACT

This paper presents a statistical analysis of different parameters responsible for the geoeffectiveness of solar eruptions during the rising phase of solar cycle 24. We have selected 33 halo CME events from the beginning of the current solar cycle 24 (2009–2013). The levels of geomagnetic activity are categorized into two groups based on the observed minimum Dst index, i.e., moderate ($-100\,\text{nT} < \text{Dst} \le -50\,\text{nT}$) and intense ($\text{Dst} \le -100\text{nT}$). The parameters are represented graphically and analyzed statistically. The Spearman rank correlation coefficient between Dst index and CME speed is 0.02 with a P-value 0.91 (much higher than 0.05) and between Dst index and X-ray flux of flares is 0.13 with a P-value 0.48 (higher than 0.05), which shows that high speed CMEs and big flares are not the effective and significant parameters for geoeffectiveness of these selected halo events. The Spearman rank correlation coefficient between CME speed and X-ray flux is better, i.e., 0.38 and the P-value is equal to 0.03 (less than 0.05), which clearly implies that big flares are responsible for producing high speed CMEs and both parameters share a significant relationship . The source location of geoeffective halo CME events exhibit N-S asymmetry.

1. Introduction

Coronal mass ejections or CMEs are the most energetic and largest phenomena linked with the magnetic field and plasma expelled from the Sun's corona in the heliosphere. Gopalswamy (2006) explained CMEs as large scale magnetized plasma structures that originate from closed magnetic field regions on the Sun. These regions are active regions, filament regions, active region complexes and trans-equatorial interconnecting regions. They are the major solar drivers of space-weather and are responsible for causing a significant impact on the near-Earth space environment in the form of geomagnetic storms (Baidyanath et al., 2010; Chen, 2011; Gopalswamy et al., 2005; Gosling et al., 1991; Joshi et al., 2011; Tsurutani et al., 1988; Webb and Howard, 2012). Coronal mass ejections (CMEs) occurring close to the solar disk center are important from the space-weather point of view. They are likely to affect the Earth magnetosphere and hence are effective for predicting geomagnetic storms (Cid et al., 2012; Gopalswamy, 2006; Sharma et al., 2008). Such Earth-directed CMEs are a major cause of severe geomagnetic storms (Chen, 2011; Cid et al., 2012; Gopalswamy et al., 2005; Gopalswamy, 2006; Gopalswamy et al., 2007, 2010; Gosling et al., 1991; Sharma et al., 2008; Tsurutani et al., 1988; Webb et al., 2000; Webb and Howard, 2012).

CMEs aimed at Earth are referred to as halo events (apparent angular width equal to 360^0) on account of the way they look in coronagraph images. As the expanding cloud of an Earth-directed CME emerges larger and larger, it appears to envelope the Sun, hence forming a halo around it. Thus, the halo CMEs appear as enhancements, encompassing the “occulting disk” of coronagraphs (Gopalswamy, 2009; Howard et al., 1982; Webb and Howard, 2012). These halo CMEs were first

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reported by Howard et al. (1982) on the basis of observations from Solwind on P78-1. Now a day, the images taken by the LASCO C2 and C3 instruments located on the SOHO (Solar and Heliospheric Observatory) spacecraft are put to use to be certain, whether a coronal mass ejection is directed towards Earth or not.

The solar magnetic field responsible for controlling all the cyclic changes is engendered and maintained by circulating currents in the convection zone, potentially mixed up by turbulent currents which are produced by the change in rotational speed occurring at the periphery between radiative and convective zones. Variations in the solar wind compress the magnetosphere and produce perturbations known as geomagnetic storms (Kamide and Maltsev, 2009; Nicolson, 1999)

A geomagnetic storm is a major component of space weather. According to Gonzalez et al. (1994), a geomagnetic storm is defined as an interval of time during which a sufficiently intense and long lasting interplanetary convection electric field advances through a substantial energization in the magnetosphere-ionosphere system, to an intensified ring current strong enough to surpass some key threshold of the quantifying storm time, Dst index. Dst (Disturbance Storm Time) index are the hourly values of the mean global variation of the low-latitude horizontal (H) component of the geomagnetic field caused by the changing magnetospheric ring current. These hourly values were first published by Sugiura (1964) for the International Geophysical Years. At present, these are assembled by the World Data Center C for Geomagnetism in Kyoto, Japan.

The characteristic feature of a geomagnetic storm is a depression in the horizontal component of geomagnetic field enduring more than one to a few days, given by the Dst index (Sugiura, 1964; Kamide and Maltsev, 2009).

It is broadly accepted that storms are times with a Dst(min) less than -50nT. Consequently, 20 to 50 storm events occur annually, depending upon solar activity. When the horizontal component of geomagnetic field attains a negative value of about 25–30 nT, Dst(min) occurs in a range of 200–600 nT (Kane, 2012). Dst decrease or Dst index attaining a negative value, which is the main manifestation of geomagnetic storms, is caused by the ring current enclosing the Earth. Large negative value of Dst index indicate an increase in the intensity of the ring current. A ring current is an electric current conveyed by charged particles caught in a planet's magnetosphere. Geomagnetic storm is only an enhancement of this ring current.

The capacity of CMEs to cause geomagnetic storms is known as geoeffectiveness, and we measure it regarding a geomagnetic index such as disturbance storm time or Dst index (Gopalswamy, 2006; Gopalswamy et al., 2007; Gonzalez et al., 1994; Loewe and Prolss, 1997; Zhang et al., 2006).

Loewe and Prolss (1997) categorized geomagnetic storms into five groups which were based on the minimum value of Dst: weak (-30 nT to -50 nT), moderate (-50 nT to -100 nT), strong (-100 nT to -200 nT), severe (-200 nT to -350 nT), and great (< -350 nT).

In general, we classify CMEs with Dst (≤ -100 nT) as strongly geoeffective and the other category as moderately geoeffective (-100 nT $<$ Dst ≤ -50 nT).

Loewe and Prolss (1997) also calculated the median Dst values for weak, moderate and strong storms as -36 nT, -68 nT and -131 nT respectively.

Gopalswamy et al.(2007) studied halo CMEs of solar cycle 23(1996–2005) and found that out of all frontside CMEs, a larger fraction i.e., about 75% of disk halos are most geoeffective, limb halos are moderately geoeffective and backside CMEs are not at all geoeffective.

Cid et al. (2012) also found that disk center CMEs are more geoeffective and when the source heliographic longitude moves away from the central meridian the geoeffectiveness decreases.

Zhang et al. (2007) studied and explored the origin of all major geomagnetic storms (Dst ≤ -100 nT) happening amid the time period 1996–2005 and found that the associated CMEs showed up as a full halo CMEs in 68% of the cases. They also concluded that in 86% of the cases, the origin of the geoeffective CMEs was situated less than 45° from the central meridian position.

As described above, Dst is one of the significant parameter to define geoeffectiveness. All previous studies show that it depends on several parameters of the solar eruptions such as – CME source locations, speed etc.

In this paper, we have presented the analysis and results of CME source locations, CME speed, flare class (X-ray flux) and geomagnetic storms Dst index. The aim of the present study is to understand the different parameters (as mentioned above) responsible for the geoeffectiveness of solar eruptions. We have considered 193 halo events from the beginning of the current solar cycle 24 (2009–2013). Since during this rising phase of the solar cycle not much solar activity is observed on the Sun and also the solar cycle 24 is observed to be extremely weak as measured by the sunspot numbers (Gopalswamy et al., 2015), it gives us a better opportunity to understand the association between geoeffectiveness and its source location on the solar surface.

We have grouped the levels of geomagnetic activity into two groups on the basis of observed minimum Dst index i.e., moderate (-100 nT $<$ Dst ≤ -50 nT) and intense (≤ -100 nT). We studied the Spearman rank correlation among Dst index, CME speed and X-ray flare class. The significance of the relationship among these is studied with the help of P-value using Chi-square statistic (If P-value < 0.05, relationship is taken as significant). We have focused on the characteristics of CMEs with respect to their speed and heliographic longitude.

2. Data sources and analysis

1. We have considered all the 193 halo CMEs observed by SOHO/LASCO from 2009 to 2013. These are extracted from the

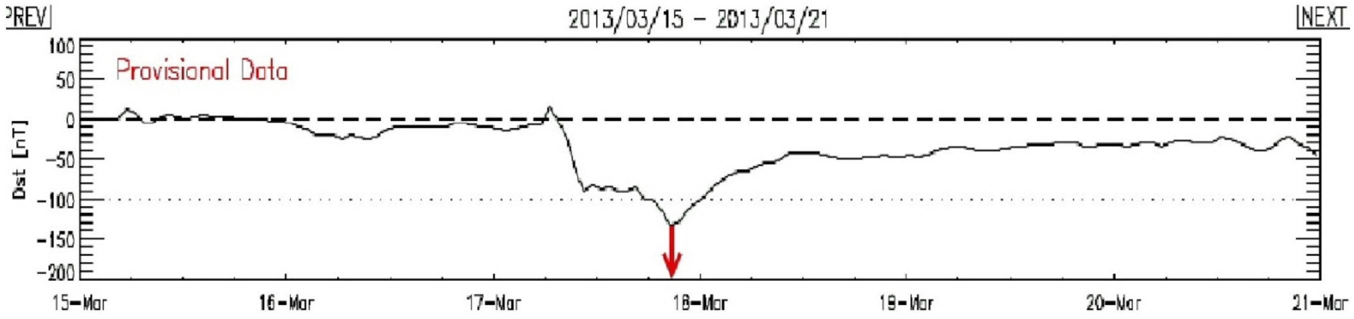

Fig. 1. Dst variation on 15 march 2013.