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# Geomagnetic Consequences of Interacting CMEs of June 13-14, 2012

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**Abstract.** We have studied the consequences of interacting coronal mass ejections (CMEs) of June 13-14, 2012 which were directed towards Earth and caused a moderate geomagnetic storm with Dst index $\sim -86$ nT. We analysed the in-situ observations of the solar wind plasma and magnetic field parameters obtained from the OMNI database for these CMEs. The in-situ observations show that the interacting CMEs arrive at Earth with the strongest ($\sim$ 150 nT) Sudden Storm Commencement (SSC) of the solar cycle 24. We compared these interacting CMEs to a similar interaction event which occurred during November 9-10, 2012. This occurred in the same phase of the solar cycle 24 but resulted in an intense geomagnetic storm (Dst $\sim -108$ nT), as reported by Mishra *et al.* (2015). Our analysis shows that in the June event, the interaction led to a merged structure at 1 AU while in the case of November 2012 event, the interacted CMEs arrived as two distinct structures at 1 AU. The geomagnetic signatures of the two cases reveal that both resulted in a single step geomagnetic storm.

**Keywords.** Coronal mass ejections, solar wind plasma, magnetic field, geomagnetic storm.

## 1. Introduction

Coronal mass ejections (CMEs) are large expulsions of matter and magnetic field from the Sun, moving with speeds ranging from few hundreds to few thousand kilometers per second. Their travel time from the Sun to the Earth ranges between 1 to 4 days. The number of CMEs launched from the Sun is about 5 per day around solar maximum (St. Cyr *et al.* 2000; Yashiro *et al.* 2004; Webb and Howard 2012). Sometimes, when CMEs occur in quick succession, particularly during solar maximum, they can interact or merge with each other if they propagate along the same direction through interplanetary space. If the successive CMEs are directed Earthward, their interaction can enhance the geoeffectiveness due to the extended period and enhanced strength of southward magnetic field causing intense geomagnetic storms (Wang *et al.* 2003; Farrugia and Berdichevsky, 2004; Farrugia *et al.* 2006).

In this paper, we present the geomagnetic consequences of interacting CMEs of June 13-14, 2012. This interaction led to the strongest SSC of solar cycle 24 and to a moderate intensity geomagnetic storm. In an earlier study, Mishra *et al.* (2015) reported a similar interaction event that occurred on November 9-10, 2012 and led to an intense geomagnetic storm. We present a comparison of the geomagnetic signatures of the two cases.

## 2. Interacting CME Events

**June 13-14, 2012 CMEs:** Two CMEs originating from the same active region NOAA 11504 were launched on June 13 and 14, 2012 separated by several hours. These CMEs has average speeds of 630 km $s^{-1}$ and 990 km $s^{-1}$ respectively and were observed to interact at a distance of 100 $R_\odot$ from the Sun. The interaction resulted in a geomagnetic storm of moderate intensity (Dst $\sim -86$ nT). The interaction phase and the interplanetary signatures have been investigated in detail and presented in an earlier paper (Srivastava *et al.* 2017, in press). From the examination of in-situ properties of these interacting CMEs, we found that it led to the Strongest Storm Commencement or SSC ($\sim$ 150 nT) of the present solar cycle. The SSC was unique because of its long duration of approximately 20 hours.

**November 9-10, 2012 CMEs:** A similar interaction event was observed in the same phase of solar cycle 24 when two CMEs with similar speeds 620 km $s^{-1}$ and 910 km $s^{-1}$ were launched a few hours apart on November 9 and 10, 2012 from NOAA AR 11608. These CMEs propagated in the same direction and were observed to interact at a distance of 35 $R_\odot$ from the Sun. The detailed study of this interaction event by Mishra *et al.* (2015) showed that it led to a strong geomagnetic storm with (Dst $\sim -108$ nT).

In the following section, we compare the in-situ and geomagnetic parameters of the interacting CMEs of June 13-14, 2012 with those of November 9-10, 2012.

## 3. In-situ and Geomagnetic Signatures

We have analysed in-situ observations of the solar wind plasma and interplanetary magnetic field recorded during the passage of the interacting CMEs of June 13-14, 2012 as observed by the ACE and Wind spacecraft located at the L1 point. These have been plotted in Figure 1. Here S1 and S2 mark the arrival of the interplanetary shocks associated with the preceding CME of June 13 (CME1) and the following CME of June 14 (CME2), respectively. Figure 1(a), (b), (c) and (g) show the variation in density, velocity, ram pressure and horizontal component of the Earth's magnetic field near the equator. The sudden rise in density and velocity associated with arrival of shock, S2, driven by CME2 gave rise to a strong ram pressure which contributed significantly to the rise of Sym-H index. The Sym-H index increased from around 40 nT to 150 nT within less than half an hour. The details of this strongest observed SSC in the solar cycle 24 is presented in Srivastava *et al.* (2017). Figure 1(g) measures the energy content of the symmetric ring current flowing in the magnetic equatorial plane of the Earth and its decreasing value shows the main phase of the geomagnetic storm. The intensity of the geomagnetic storm reached a peak value of $\sim -86$ nT and its main phase lasted for $\sim$ 16 hrs.

The AL index in Figure 1 (h) measures the westward (midnight sector) electrojet current and captures the auroral substorm process. We note that the fluctuation in southward component (Bz) of interplanetary magnetic field (IMF) in Figure 1(d) and in the y-component of electric field (IEFy) shown in Figure 1(e) in the shock-sheath region of CME1 have not intensified the AL index significantly. Despite the large value of southward IMF Bz and positive IEFy during the arrival of shock S2, their short duration resulted in a low substorm activity. The Bz and positive IEFy are well correlated with the AL index during the passage of CME2. Figure 1(f) shows the variation in the Polar Cap (PC) index or the variation in the ionospheric electric field over the polar region. We note that the region of CME1 and shock driven by CME2 could not strongly intensify the PC index. However, the smooth variation in Bz and IEFy in the region of CME2 is reasonably well correlated with the PC index and have intensified its value. Thus, we find

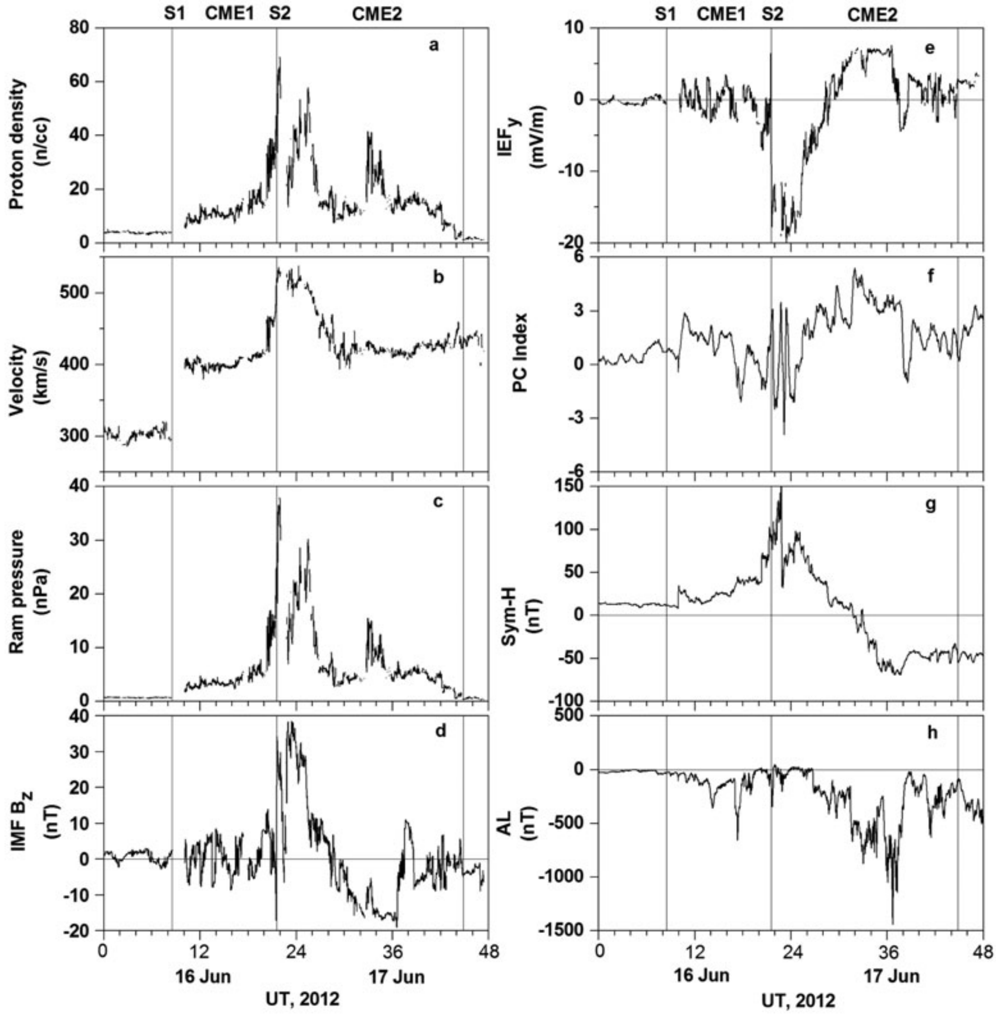


**Figure 1.** Variation of the in-situ solar wind and geomagnetic field parameters associated with the passage of interacting CMEs of June 13-14, 2012, obtained during June 16-18, 2012. Left panels show, (from top to bottom): Proton density (n/cc), Velocity (km $s^{-1}$), Ram pressure (nPa) and Bz component (nT). Right panels show, (from top to bottom), the 'y' component of the interplanetary electric field IEFy (mV/m), polar cap (PC) index, Sym-H (nT) and AL index (nT).

that the preceding CME did not strongly influence the triggering of substorms nor in the perturbation of the ionospheric electric field over the polar region. Figure (1) also shows that when the terrestrial magnetosphere encounters the passage of the trailing edge of the following CME, i.e. CME2 (excluding its rearmost part), intensification of the AL and PC indices took place.

In our earlier study of interacting CMEs of 2012 November 9-10 (Mishra *et al.* 2015), we found that the trailing edge of CME1 (November 9) and the interaction region identified between the preceding and following (November 10) CMEs played a direct role in the storm-time AL intensification. In this case, the peak amplitude of the PC index was nearly the same in the shock-sheath region of the preceding CME as in the interaction region. Therefore, comparing the interaction events of June 2012 CMEs and November

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2012 CMEs, we suggest that it is not always true that the trailing portion of the preceding CME and leading portion of the following CME gives rise to intense perturbations in the Earth's magnetosphere. In the case of the June 2012 CMEs, the following CME with its shock probably pierced through the preceding CME at 21:40 UT on June 16 and led to compression and intensification of the pre-existing magnetic field and density. Due to this, a large amplitude of northward component of magnetic field is noted. This implies that the magnetic field parameters responsible for the main phase of the geomagnetic storm did not pre-exist at the rear edge of preceding CME. Therefore, the following CME was geo-effective in the case of June 2012 event. In case of the November 2012 CMEs, the following CME did not have a strong influence on the geomagnetic storm or substorms because the magnetosphere perhaps encountered the flank of this CME.

## 4. Summary and Discussion

Our study suggests that the June 2012 CMEs which interacted at a distance of $\sim 100$ $R_{\odot}$ from the Sun, arrived at the Earth as a merged structure leading to a moderate and single step geomagnetic storm. In this case, we find that the persistence of the southward component of the magnetic field is more important than its amplitude in driving the geomagnetic storm and substorm activity. The part of the CMEs which has a pre-existing southwardly directed magnetic field is responsible for perturbing the magnetosphere. On the other hand, the November 2012 CMEs which interacted at a distance of $\sim 35$ $R_{\odot}$ from the Sun, arrived at the Earth as separate structures but led to an intense and single step geomagnetic storm. It is therefore, worth investigating why in some interaction events an interaction region between preceding and following CMEs is formed, while in others a merged structure is formed. As the distance at which the CMEs interact are different in the two cases, our study suggests that the location of the site of interaction may play a decisive role in enhancing Bz in the preceding CME and also in the formation of the interaction region between the two CMEs. The June 13-14, 2012 event is unique as it highlights the role of interaction of CMEs in enhancing the SSC, as compared to previous studies which focussed on the development of the main phase of the resulting geomagnetic storm.

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