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Earth–directed coronal mass ejections and their geoeffectiveness during the 2007–2010 interval

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Abstract. In this study we analyse the coronal mass ejections (CMEs) directed towards the Earth during the interval 2007–2010, using the data acquired by STEREO mission and those provided by SOHO, ACE and geomagnetic stations. A study of CMEs kinematics is performed. This is correlated with CMEs interplanetary manifestations and their geomagnetic effects, along with the energy transfer flux into magnetosphere (the Akasofu coupling function). The chosen interval that is practically coincident with the last solar minimum, offered us a good opportunity to link and analyse the chain of phenomena from the Sun to the terrestrial magnetosphere in an attempt to better understand the solar and heliospheric processes that can cause major geomagnetic storms.

Keywords. Sun: coronal mass ejections (CMEs), (Sun:) solar-terrestrial relations

1. Introduction

Coronal mass ejections (CMEs) and their implication at the geomagnetic level has been a topic for many studies in the past decades (see e.g. Gopalswamy *et al.* 2006; Echer *et al.* 2008; Zhang *et al.* 2007). All these studies have tried to give a better insight over the connection mechanisms between the CMEs and the geomagnetic storms, in a continuous attempt to build as much as possible a profile in order to predict whether a particular CME event can cause or not a strong geomagnetic storm. Thus, we know that a big number of the frontside halo CMEs are geoeffective and that the geomagnetic storms which are associated with consecutive halos are among the most intense (Gopalswamy *et al.* 2006). The intensity of geomagnetic storms has a very strong dependence to the southward component of the interplanetary magnetic field, followed by the initial speed of the CME and the ram pressure (Srivastava & Venkatakrishnan 2004).

In this perspective we investigated the geoeffectivity of the CMEs directed towards the Earth in the time interval 2007–2010, period coincident with the Sun's minimum activity.

2. Data and Analysis Methods

In this study we analyse the CMEs which arrived to the Earth in the period 2007–2010 and produced geomagnetic storms. The intensities of the storms were from minimum to moderate values (with Dst varying between –30 nT and –80 nT). We have eleven such events.

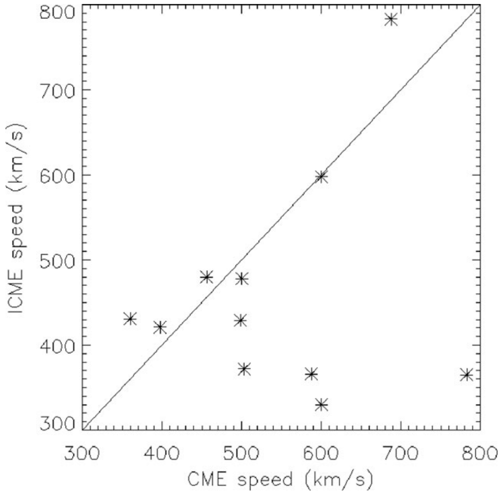

Figure 1. ICME speed versus reconstructed CME speed.

In order to select the CMEs which arrived to the Earth (ICMEs - or interplanetary CMEs) we used the data from ACE spacecraft and the data provided by Emilia Kilpua (Kilpua *et al.*, 2012). The corresponding solar sources (CMEs) were searched in a time interval up to maximum 6 days before the ICMEs, in images from LASCO (Brueckner *et al.* 1995) instrument onboard SOHO and COR instruments (Howard *et al.* 2008) onboard STEREO. The geomagnetic indices corresponding to each storm are taken from different geomagnetic stations around the globe.

Regarding the analysis methods, we derived the 3D reconstructed CMEs speeds by applying the forward-modelling (FM) technique (Thernisien *et al.* 2009) on the STEREO/COR2 and LASCO/C3 data and/or triangulation (Liu *et al.* 2010) on COR2 data. In order to investigate the behaviour of the ICMEs parameters and the impact of the ICMEs on the geomagnetic field we calculated the correlation coefficients between different ICME parameters and the geomagnetic index Dst. We also used the superposed epoch analysis (e.g. Mustajab 2011).

3. Speed analysis

Out of 21 events we have selected 11 events in the interval 2007–2010, when the STEREO separation angle was between 70 and 160 degrees and we applied the FM technique in order to derive their real (3D) speeds. Note that not all of these events produced geomagnetic storms. The calculated speeds were compared with in-situ speeds (the speeds of ICMEs recorded at ACE spacecraft). It was observed, that out of the 11 events, six were decelerated while travelling into the interplanetary space, four were accelerated and one CME kept a constant speed from the Sun to the Earth (see Figure 1). This means that the CMEs interacted with the surrounding solar wind and the drag forces accelerated or decelerated the events, depending on the speed of the solar wind.

4. ICME signatures versus Dst

From a total of 21 ICMEs observed in the interval 2007–2010, only 11 have produced geomagnetic storms (Dst<–30 nT). To understand the impact of the 11 ICMEs that arrived at the Earth on the geomagnetic field we computed the correlation coefficients of various interplanetary parameters (IP) versus the minimum Dst geomagnetic index.

The ICMEs parameters considered for this analysis were: the interplanetary magnetic field (IMF) magnitude (B), Z component of the IMF (Bz), Bs·V (where Bs=|Bz|when Bz<0 and Bs=0 when Bz⩾0), the plasma speed (V), the plasma temperature (T) and the proton density (ρ). Furthermore, we computed the correlation coefficient between the minimum Dst and the total energy injected into Earth's magnetosphere (eq. 2), which was found using the Akasofu coupling function (eq. 1) (Akasofu 1983). The Akasofu coupling function takes into consideration the processes of reconnection within the magnetosphere, as being the principal source of the injected energy (De Lucas *et al.* 2007).

$$\varepsilon = 10^7 V B^2 l_0^2 \sin^4(\frac{\theta}{2}), [J/s] \tag{1}$$

where: V and B are the physical units defined above, θ is the IMF clock-wise angle in the plane perpendicular to the Sun–Earth line, l_0 is the magnetopause radius ($l_0 = 7\mathrm{R}_E$), $\theta = \tan^{-1}(\frac{B_y}{B_z})$.

$$W_\varepsilon = \int_{t0}^{tm} \varepsilon dt, [J] \tag{2}$$

where: W_ε is obtained by integrating ε over the main phase of each geomagnetic storm, from t_0 to t_m. All the measured units are given in International System.

We also computed the correlation coefficients between the IPs measured at the same time (t_0), one hour earlier (t_{-1}), two hours earlier (t_{-2}) and three hours earlier (t_{-3}) than the minimum Dst and the minimum Dst value. The computed coefficients show a poor correlation between the IPs and the minimum Dst index value. The best correlations were found for ICME speeds taken at two hours (r=-0.57) and three hours (r=-0.58) before the minimum Dst and for Bs·V taken at three hours (-0.55) before the minimum Dst. W_ε had a rather low correlation coefficient of -0.51, although an important amount of energy was injected into the magnetosphere in the main phase of each geomagnetic storm.

We think that the poor correlation of the interplanetary structures parameters with the Dst index were due to the little number of geomagnetic storms occurred in the 2007–2010 interval. Also, the high speed streams (HSS) had an important implication in the disturbances at the geomagnetic level, taking in consideration that the geomagnetic storms produced by the ICMEs were, in some cases only contributions overimposed to already incipient geomagnetic disturbances produced by the HSS (Maris & Maris 2010).

5. Superposed epoch analysis

For a better understanding of the importance of the ICMEs parameters we used the superposed epoch analysis. In this analysis we considered as origin (t = 0) the time when the minimum Dst was observed. The period of the superposed epoch analysis was 24 hours before and 48 hours after this minimum. Then, the mean values of the interplanetary and geomagnetic parameters (the Bz component of the IMF, the Dst geomagnetic indexes and the Akasofu coupling function) at a given time, over the 11 events, were computed (Figure 2).

From Figure 2 we can see a better dependence between the Bz, the Akasofu coupling function and the Dst index than we observed in the case of the correlation coefficients computation. Bz is deacreasing on the main phase of the geomagnetic storms up to two hours before the minimum Dst value and then it starts to increase. The energy injected into the magnetosphere is increasing during the main phase of the storm. Even so, it can be observed that before the beginning of the main phase of a geomagnetic storm the Akasofu coupling function shows an increasing trend, meaning that for some reasons an

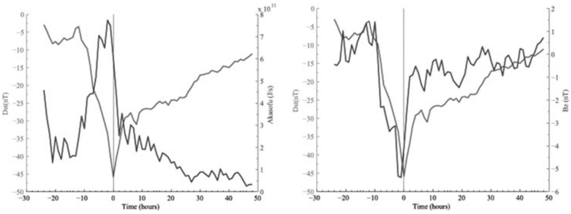

Figure 2. Plots of the mean values of: Dst and Akasofu coupling function (left), Dst and Bz (right).

important amount of energy was already injected into the magnetosphere at an earlier time. A possible explanation is the perturbations caused by the HSS in this 2007–2010 interval.

6. Summary

In this paper we studied the ICMEs manifestations from the 2007–2010 interval. In this period a number of 21 ICMEs were observed at ACE, from which only 11 caused weak and moderate geomagnetic storms (Dst<−30 nT).

Majority of the 11 events in the interval 2008-2009 for which the 3D speeds were calculated were decelerated while travelling into the interplanetary space, and four were accelerated. This suggests different kinds of their interaction with the ambient solar wind.

The correlation between different ICME parameters and Dst was very weak. A slightly better correlation was observed between the minimum Dst and the ICME speed measured three hours earlier than minimum Dst.

The highest energy was injected into the magnetosphere on the main phase of the geomagnetic storm. HSSs played also an important role to the production of the storms.

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