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Extreme solar-terrestrial events

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Abstract. Extreme solar-terrestrial events are those in which very energetic solar ejections hit the earth?s magnetosphere, causing intense energization of the earth?s ring current. Statistically, their occurrence is approximately once per Gleissberg solar cycle (70-100yrs). The solar transient occurred on July, 23rd (2012) was potentially one of such extreme events. The associated coronal mass ejection (CME), however, was not ejected towards the earth. Instead, it hit the STEREO A spacecraft, located 120 degrees away from the Sun-Earth line. Estimates of the geoeffectiveness of such a CME point to a scenario of extreme Space Weather conditions. In terms of the ring current energization, as measured by the Disturbance Storm-Time index (Dst), had this CME hit the Earth, it would have caused the strongest geomagnetic storm in space era.

Keywords. geomagnetic storms, solar-terrestrial events

1. Introduction

It is well established that the interplanetary origins of geomagnetic storms are related to the southward component of the interplanetary magnetic field combined with the solar wind velocity (Gonzalez & Tsurutani (1987) , Gonzalez *et al.* (1994)). These out-of-the-ecliptic magnetic fields have several sources, the most important being the interplanetary counterparts of coronal mass ejections (ICMEs) and their related shock-sheath fields. As the intensity of the storm increases, the more predominant these ICMEs and shocks become as drivers. Current estimates show that 95% of very intense storms (Dst⩽-250nT) are cause by ICMEs or by their associated shock (Gonzalez *et al.* (2007); Echer *et al.* (2008) and Gonzalez *et al.* (2011)). Szajko *et al.* (2013) has found that all Dst⩽-200nT geomagnetic storms of solar cycle 23 have ICME-sheath origins. If we consider the level of storms as stronger than Dst⩽-400nT, we find a frequency of occurrence of once every 11 year solar cycle. Only 5 of such ?extreme solar-terrestrial events? occurred during the space era (Gonzalez *et al.* (2011)). A complete coverage of geomagnetic and interplanetary observations was available for few of these events. We highlight the November 2003 extreme storm, in which the peak Dst reached -422 nT. In July 2012, a very fast coronal mass ejection (CME) was observed at the sun by LASCO/SOHO (Brueckner *et al.* (1995)) and SECCHI/STEREO (Howard *et al.* (2008)) instruments. From the combined observations, it was possible to conclude that the event was ejected towards the STEREO A satellite, which was 120 degrees away from the Sun-Earth line. STEREO A in situ observations of this event from IMPACT (Luhmann *et al.* (2008)) and PLASTIC (Galvin *et al.* (2008)) instruments at 0.96 AU indicate an extreme scenario in which IMF peak surpassed 100nT, with considerable southward component (Russell *et al.* (2013)). The aim of this work is to estimate the intensity of the hypothetic geomagnetic storm had this

ICME hit the earth. In order to achieve this goal, we use the simple model from Burton *et al.* (1975) for the Dst estimate, which requires only interplanetary observations as input. The Dst index measures the average horizontal component of the geomagnetic field measured by mid-latitude and equatorial stations around the world. Model parameters for the Dst index were tunned using as a reference the solar-terrestrial event occurred in November 2003.

2. Model description

The approach of this work was to estimate the quantitative geomagnetic response of an interplanetary structure using Burton *et al.* (1975) model for the Dst index. This model requires as input the southward interplanetary magnetic field and solar wind velocity observations. Details on the model can be found in Fenrich & Luhmann (1988) and Dal Lago *et al.* (2015). Burton *et al.* (1975) model assumes a ring current decay time of the order of 7.7 hours. Fenrich & Luhmann (1988) found that for intense and very intense storms (-80⩾Dst⩾-300 nT) decay times ranging from 3 to 5 hours are more adequate for correctly estimate the observed Dst index. We estimate this decay time for extreme events (Dst⩽-400nT) using the November 2003 geomagnetic storm. This event originated a peak Dst of the order of -420 nT, making this geomagnetic storm the most intense of the entire solar cycle 23. Burton *et al.* (1975) formula was used to reproduce the Dst index of this event. A ring current decay time of 4.5 hours was used, in order to correctly reproduce the peak intensity of the storm. More details on this event can be found in Dal Lago *et al.* (2015).

3. The July 2012 event

The UVI instrument, aboard the STEREO A satellite, observed a solar eruption on the 23rd of July (2012), around 02h30 UT. From the earth perspective, it was a behind the limb event. A CME was observed by SOHO/LASCO C2 instrument on July 23rd (2012) at 02:36. SECCHI/COR1 A also observed this CME starting at 02:30UT. Latter on, SECCHI/COR 2 A observed a full halo CME, starting at 02:54UT. On the 23rd of July, the in situ plasma instrument aboard the STEREO A spacecraft detected an extreme event, with magnetic field intensity higher than 100 nT, 20 times stronger than the average solar wind magnetic field. Russell *et al.* (2013) presented a detailed description of this interplanetary event, classified as a magnetic cloud. They reported very high solar wind velocities, above 2000 km/s. Figure 1 shows, from top to bottom, the interplanetary magnetic field, its Bz component, plasma velocity, interplanetary electric field. The bottom panel shows the hypothetical Dst index estimated using Burton *et al.* (1975) model, had this event hit the earth. In the model estimate, a ring current decay time of 4.5 hours was used, following the estimate from the November 2003 event. The estimate peak Dst value was -1113.2 nT, which is nearly twice the strongest Dst value ever measured.

4. Summary and conclusions

In this work, we investigate the hypotetic geomagnetic response to an extreme solar-terrestrial event using the model from Burton *et al.* (1975), using as input the interplanetary observations from STEREO A on the 23rd of July 2012 CME. Results indicate that had had this CME been ejected towards the earth, it would have given rise to strongest geomagnetic storm in space era, with peak Dst values of ? 1113.20 nT. These results are

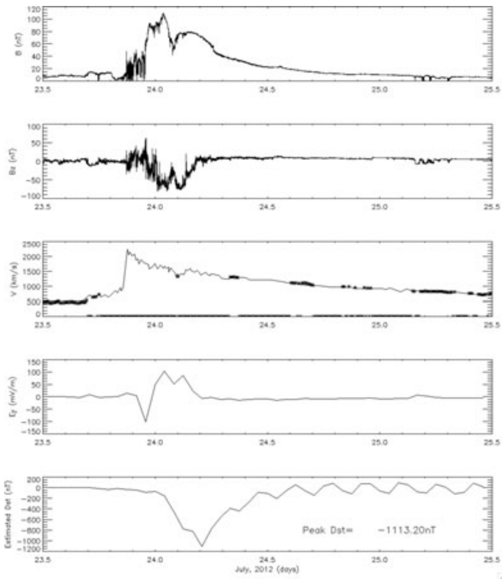

Figure 1. From top to bottom, the interplanetary magnetic field, its Bz component, plasma velocity, interplanetary electric field and the hypothetical geomagnetic Dst index estimated using Burton *et al.* (1975) model, considering a ring current decay time of 4.5 hours.

in good agreement with Baker *et al.* (2013) study of the same event, using other model approaches, in which their estimate peak Dst was -1182nT. Furthermore, the methodology presented by Gonzalez *et al.* (2011) for extreme events also would place this event in the same disturbance level.

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