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Relative geo-effectiveness of coronal mass ejections with distinct features in interplanetary space

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ABSTRACT

Coronal mass ejections launched from the Sun into the interplanetary space (called ICMEs) are observed in the near-earth space with distinct structures, features and properties. We utilise geomagnetic and interplanetary data to study the relative geoeffectiveness of these ICMEs with distinct features and properties, and compare their geoeffectiveness with associated solar and plasma/field properties. We use two geomagnetic indices and various solar wind parameters, and analyse them using the method of superposed epoch analysis with reference to ICMEs of different features and properties. We observe differences in relative geoeffectiveness of ICMEs with distinct features. Differences in plasma/field properties have also been found. We examine critically the observed differences in ICME features, their relative geoeffectiveness and plasma/field behaviour. In addition to superposed epoch analysis, we perform statistical analysis and also adopt best fit approach to study, (a) the dependence of the geoeffectiveness of ICMEs with different features and properties, on solar wind parameters, and (b) the recovery characteristics of geomagnetic storms due to ICMEs with distinct features/properties. We discuss the relative importance and the geoeffectiveness of various structures and features associated with ICMEs in producing geomagnetic disturbances.

1. Introduction

The geoeffectiveness of various solar and interplanetary phenomena such as interplanetary shock/sheath, CMEs, corotating high speed streams from coronal holes, and interaction region/stream interfaces have been of considerable interest to solar-terrestrial physics community and the geomagnetic impacts of these interplanetary structures have been investigated in the past by several authors (e.g., see Gosling et al., 1990, 1991; Bothmer and Schwenn, 1995; Richardson et al., 2000; Sabbah, 2000; Srivastava and Venkatakrishnan, 2002; Borovsky and Funsten, 2003; Echer et al., 2005; Kudela and Storini, 2005; Koskinen and Huttunen, 2006; Denton et al., 2006; Richardson et al., 2006; Gopalswamy et al., 2007; Kane, 2005, 2007; Kershengolts et al., 2007; Zhang et al., 2007; Borovsky and Denton, 2008; Gupta and Badruddin, 2009; Alves et al., 2011; Gonzalez et al., 2011; Mustajab and Badruddin, 2011; Richardson and Cane, 2011a; Tsurutani et al., 2011; Yermolaev et al., 2012 and references therein).

An important subset of ICMEs contains magnetic flux rope with large-scale smoothly rotating magnetic field is known as magnetic cloud (Burlaga et al., 1981). The geoeffectiveness of magnetic clouds and their associated features has also been studied in the past (e.g., Zhang and Burlaga, 1988; Wilson, 1990., Lepping et al., 1991; Badruddin, 1998; Fenrich and Luhmann, 1998; Webb et al., 2000; Echer and Gonzalez, 2004; Kudela and Brenkus, 2004; Zhang et al., 2004; Echer et al., 2005; Wu and Lepping, 2005; Gopalswamy et al., 2008; Badruddin and Singh, 2009; Yermolaev et al., 2010; Alves et al., 2011; Hidalgo et al., 2011). However, study

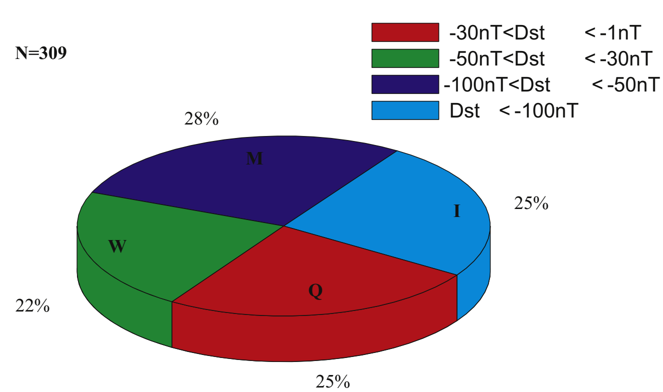

Fig. 1. Distribution of ICMEs (in %) producing geomagnetic disturbances of different range; quiet (Q), weak (W), moderate (M) and intense (I) storms.

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of the geoeffectiveness of ICMEs with magnetic cloud structure as compared to no-magnetic cloud ICMEs is still required.

The Sun–earth interaction depends on the solar wind and various solar phenomena. Thus, in addition to identify the relative geoeffectiveness of various interplanetary structures, it is also challenging and important to quantitatively predict the dynamics of the magnetosphere from measured solar wind and interplanetary magnetic field conditions. In order to search for the causes of geomagnetic disturbances and to develop models for predicting the occurrence of geomagnetic storms important for space weather prediction, a number of correlative studies between various geomagnetic indices and interplanetary plasma/field parameters have been carried out (e.g., Snyder et al., 1963; Hirshberg and Colburn, 1969; Crooker et al., 1977; Holzer and Slavin, 1982; Echer et al., 2005; Alves et al., 2006; Singh et al., 2006; Kane, 2007; Dwivedi et al., 2009; Gupta and Badruddin, 2009; Ontiveros and Gonzalez Esparza, 2010; Joshi et al., 2011; Mustajab and Badruddin, 2011; Richardson and Cane, 2011a; Singh and Badruddin, 2012). However, a unique relation is still lacking which may ultimately lead to unambiguously understand the phenomena and to predict their occurrence, intensity and space weather consequences.

From space weather perspective, several major advances are needed (Schwenn, 2006) in order to understand the way that geomagnetic storms affect the space environment. For example, it is important to understand (a) the relative geoeffectiveness of CME, with distinct features, (b) to understand the solar wind input to the magnetosphere and their time variations better and to know how changes in the solar wind plasma and field conditions influence the energy transfer in the geospace environment, and

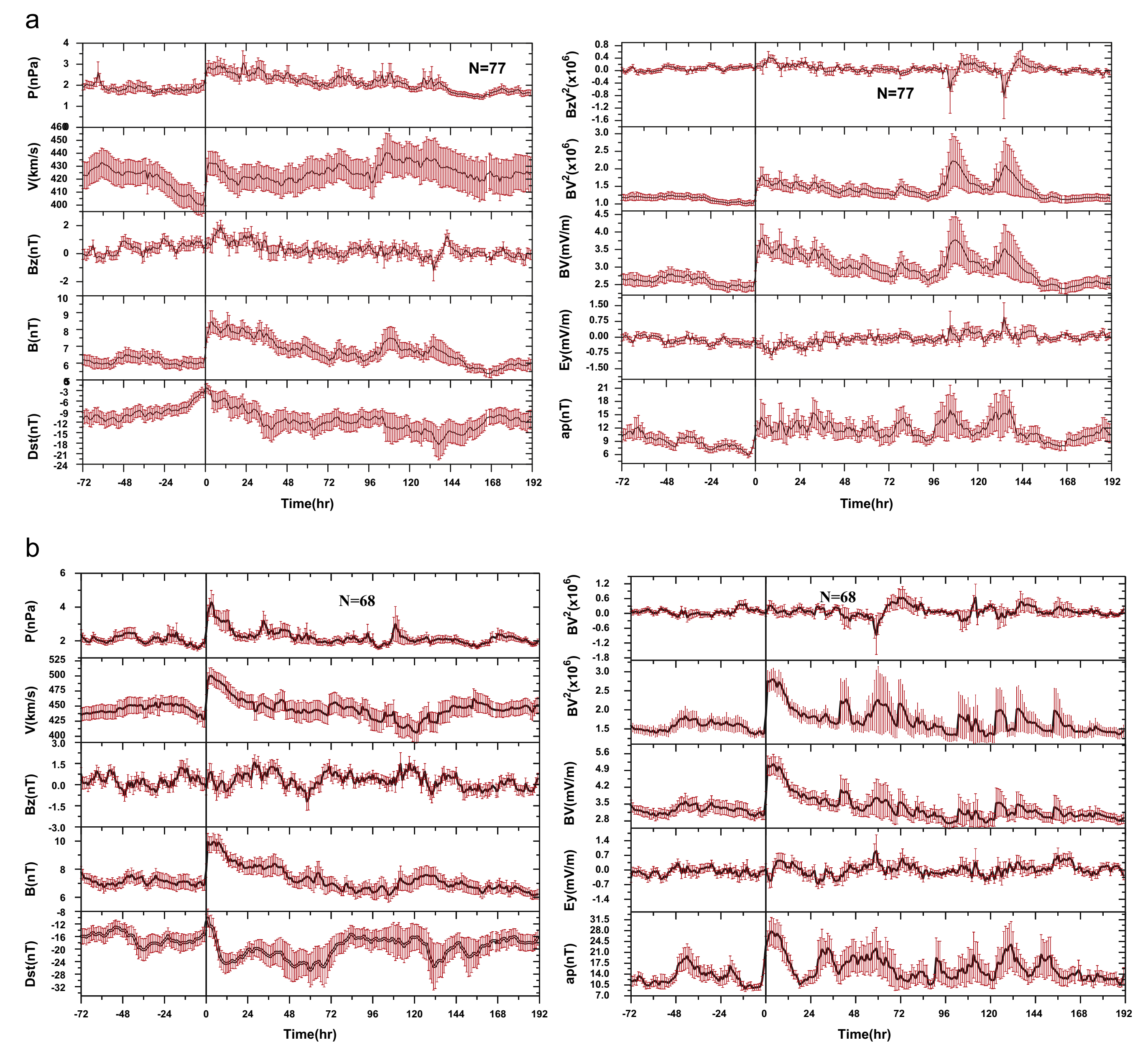

Fig. 2. (a) Superposed epoch analysis of geomagnetic and interplanetary plasma/field parameters; epoch (0 h) corresponds to arrival time of ICMEs producing quiet (−30 nT < Dst≤−1 nT) geomagnetic activity. Standard error of mean is also shown at each hour. (b). Superposed epoch analysis of geomagnetic and interplanetary plasma/field parameters; epoch (0 h) corresponds to arrival time of ICMEs producing weak (−50 nT < Dst≤−30 nT) geomagnetic activity. (c) Superposed epoch analysis of geomagnetic and interplanetary plasma/field parameters; epoch (0 h) corresponds to arrival time of ICMEs producing moderate (−100 nT < Dst≤−50 nT) geomagnetic activity. (d) Superposed epoch analysis of geomagnetic and interplanetary plasma/field parameters; epoch (0 h) corresponds to arrival time of ICMEs producing intense (Dst≤−100 nT) geomagnetic activity.