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Study of the geoeffectiveness of interplanetary magnetic clouds

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ABSTRACT

Magnetic clouds are mass ejections observed in the interplanetary space with specific field structures. These structures have been observed in the interplanetary data and through spacecraft in near-earth space. These magnetic clouds have north-south or south-north magnetic field orientations. Some of them are associated with shock/sheath region preceding them. Their speed is not the same; they move with different velocities in the interplanetary space. The magnetic clouds observed in the near-earth space have different field orientations, move with different speed, and different features are associated with them. As the field orientations in them, their speed and associated features are likely to influence the geo-effectiveness of magnetic clouds, we consider the magnetic clouds with distinct properties and study their relative geo-effectiveness. We also investigate the solar wind plasma/field parameters that play important role in influencing the geo-effectiveness of magnetic clouds. The implications of this study on the solar wind-magnetosphere coupling are also examined.

1. Introduction

Interplanetary magnetic clouds are plasma and magnetic field structures of radial dimension ~0.25 AU at 1 AU. The magnetic field of these structures is enhanced, there is a large rotation in the direction of the field, their plasma temperature and density (compared to the ambient plasma) is lower and plasma 'beta' is significantly lower than 1 (Burlaga et al., 1981). Some of the magnetic clouds are associated with interplanetary shock waves (Klein and Burlaga, 1982; Gopalswamy et al., 2008, 2009; Richardson and Cane, 2010).

Magnetic clouds are a subset of interplanetary coronal mass ejections (ICMEs). In near-earth space, as observed by the spacecraft, some of them are isolated flux rope structures while some other are found to be associated with shock/sheath structure. In the sheath region, the magnetic field is high as well as turbulent, while in the magnetic clouds, the magnetic field, although high, is magnetically quiet and smooth.

Magnetic clouds are not only the potential source geomagnetic storms in the geo-magnetosphere (*e.g.* Zhang and Burlaga, 1988; Lepping et al., 1991; Badruddin, 1998; Fenrich and Luhmann, 1998; Webb et al., 2000; Kudela and Brenkus, 2004; Zhang et al., 2004; Li and Luhmann, 2004; Echer et al., 2005; Wu et al., 2006 Gopalswamy et al., 2008; Badruddin and Singh, 2009; Yermolaev et al., 2014; Wu and Lepping, 2015, 2016) but they can also disturb the ionosphere (*e.g.,* Marcz, 1992) and produce drastic changes in galactic cosmic ray intensity during their passage in the heliosphere (*e.g.,* Badruddin et al., 1986, 1991; Zhang and Burlaga, 1988; Iucci et al., 1989; Venkatesan and Badruddin, 1990; Lockwood et al., 1991; Cane, 1993; Yu et al., 2010; Kumar and Badruddin, 2014; Parnahaj and Kudela, 2015; Badruddin and Kumar, 2015, 2016; Lingri et al., 2016). Thus from space weather perspective, these structures are of significant importance.

The magnetic clouds as observed during their passage in the near-Earth space may have northward to southward (NS) turning, southward to northward (SN), full northward (FN) or fully southward (FS) magnetic fields (*e.g.,* Zhang et al., 2004; Gopalswamy et al., 2008, 2009). It is known that the southward magnetic is crucial for the geomagnetic disturbances to occur (*e.g.* Gosling et al., 1991; Tsurutani et al., 2004; Gopalswamy et al., 2007; Kane and Echer, 2007; Richardson and Cane, 2011; Mustajab and Badruddin, 2013; Badruddin and Falak, 2016; Paouris and Mavromichalaki, 2017 and references therein). Many studies on the geomagnetic effect of magnetic clouds have been done in the past (*e.g.,* Zhang and Burlaga, 1988; Zhang et al., 2004; Gopalswamy et al., 2008; Badruddin and Singh, 2009; Alves et al., 2011; Wu et al., 2006; Lepping and Wu, 2007; Wu and Lepping, 2015) and significant results have been obtained from these studies. However, a comparative study of geomagnetic response, regarding both the amplitude and the recovery characteristics of resulting geomagnetic disturbances, due to magnetic clouds of different field orientation (NS/SN/FS/FN) and associated structures (shock/sheath) is still required.

Most of the earlier works involving magnetic clouds were limited in

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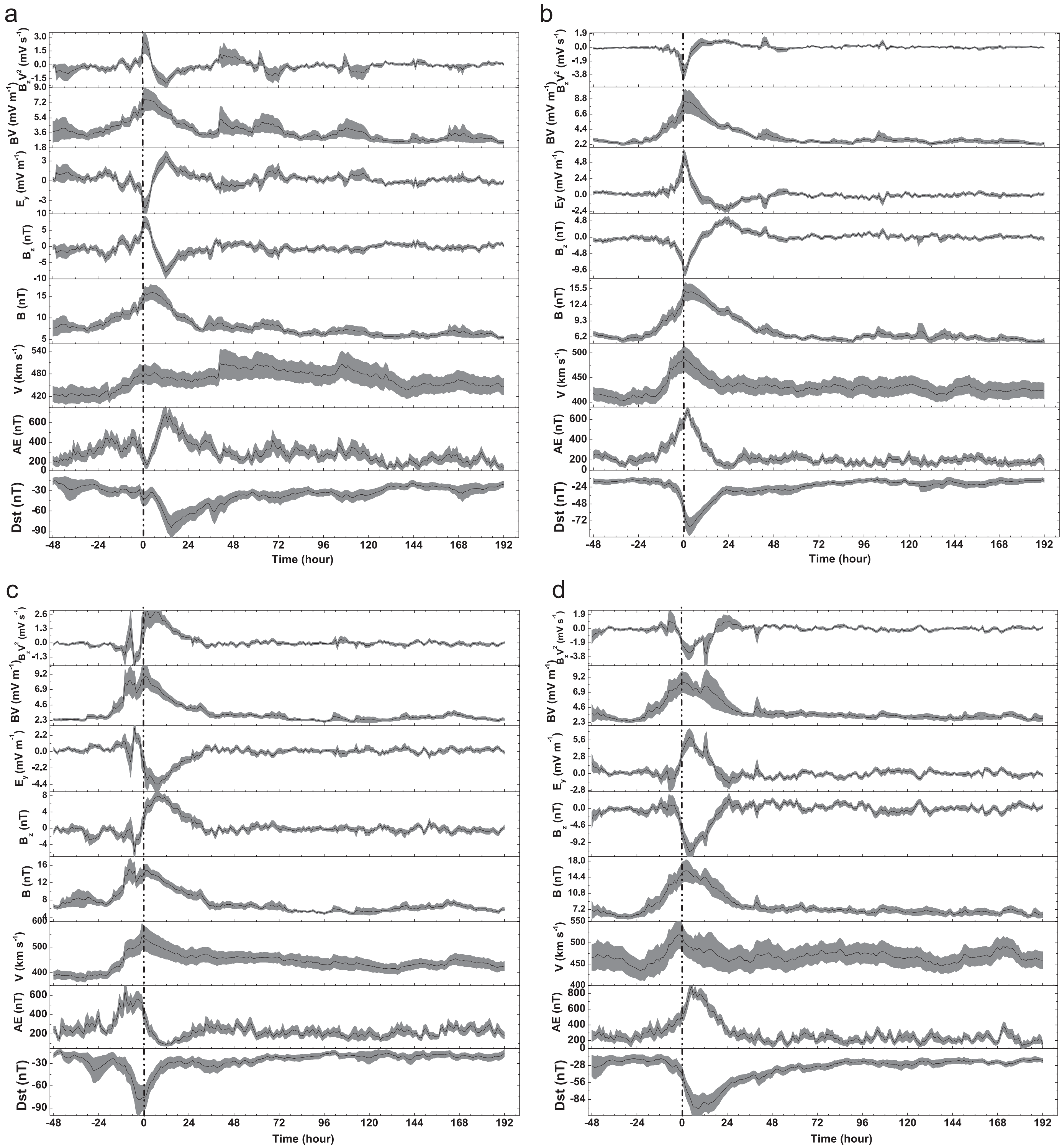

Fig. 1. A: Superposed epoch analysis of hourly data of Dst index, AE index, solar wind velocity (V), interplanetary magnetic field (B), its north-south component (B_z), dawn-dusk electric field (E_y), the products BV and B_zV^2 during the passage of NS magnetic clouds; zero hour corresponds to start time of NS magnetic clouds (N = 21). B: Same as (A) for SN magnetic clouds (N = 39). C: Same as (A) for FN magnetic clouds (N = 20). D: Same as (A) for FS magnetic clouds (N = 19).

their studies focused mainly on the geomagnetic response of individual magnetic clouds or their statistical studies. In this work, we have adopted the method of superposed epoch analysis (see also, Badruddin and Singh, 2009; Mustajab and Badruddin, 2013) to study and compare the average geomagnetic response, both on the amplitude as well as the recovery characteristics, due to magnetic clouds of different field orientation and associated features. We further extend our work to study the influence of shock/sheath region by comparing the geoeffectiveness of magnetic clouds of different field orientation, with or without associated shock/sheath region.

2. Data and analysis

Spacecraft based solar wind plasma and field observations in the near-earth space led to identification of magnetic clouds (Burlaga et al., 1981; Klein and Burlaga, 1982; Lepping et al., 2006). The ACE/Wind