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Helicity of Magnetic Clouds and Solar Cycle Variations of their Geoeffectiveness

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Abstract. Coronal mass ejections (CMEs) are sources of the strongest geomagnetic disturbances. From sunspot minimum to sunspot maximum, the intensity of storms associated with CMEs increases but the degree of association decreases. We divide the CMEs in the last solar cycle (1996–2002) into magnetic clouds (MCs)and CMEs which are not magnetic clouds. MCs are much more geoeffective than non-MC CMEs, and the portion of CMEs which are MCs is maximum in sunspot minimum and minimum at sunspot maximum, corresponding to the net helicity transferred from the solar interior into the corona. The smaller portion of the more geoeffective MCs is the explanation of the smaller degree of association of CMEs with geomagnetic disturbances in sunspot maximum.

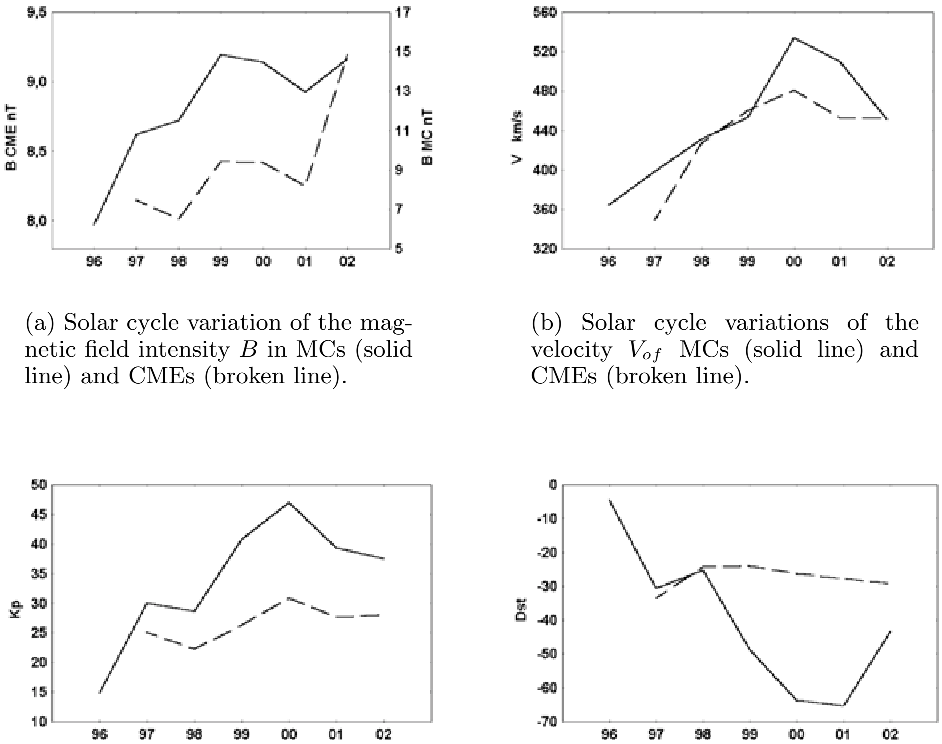
Keywords. Sun: coronal mass ejections (CMEs), magnetic fields, solar-terrestrial relations.

1. Introduction

Coronal mass ejections (CMEs) are large-scale bubbles of plasma and magnetic fields expelled from the Sun. When they hit the Earth's magnetosphere, CMEs often produce intense geomagnetic disturbances. From sunspot minimum to sunspot maximum, the intensity of storms associated with CMEs increases, however the degree of association between CMEs and storms decreases. Several possible explanations have been proposed for this solar cycle dependence (see for example Webb (2000), and the references therein), but the question remains open. A special class of CMEs are magnetic clouds (MCs) which are distinguished by the smooth rotation of the magnetic field (Lepping, Jones & Burlaga 1990). Here we study a list of 202 CMEs in the last solar cycle (1996–2002), which we divide into MCs, i.e. CMEs with magnetic field rotation (74 cases) compiled from several sources: Fenrich & Luhmann (1998); Leamon, Canfield & Pevtsov (2002); Vilmer, *et al.* (2003); SOHO LASCO CME catalog; WIND MFI magnetic cloud list, and 124 cases of CMEs without magnetic field rotation which hence are not MCs - what is left from the Richardson & Cane 2003 list of CMEs after removing all cases identified as MCs.

2. Geoeffective parameters and geoeffectiveness of CMEs and MCs

The main factor for the geoeffectiveness of an interplanetary structure is the prolonged period of southward magnetic field ($B_z < 0$) providing coupling with the Earth's magnetic field (Gonsalez, Tsurutani & Clua de Gonsalez, 1999). Additional factors are the total magnetic field magnitude B and the velocity V. MCs, because of the magnetic field rotation, do have prolonged periods of $B_z < 0$. Our data show that MCs also have significantly higher B than CMEs.



(a) Solar cycle variation of the magnetic field intensity B in MCs (solid line) and CMEs (broken line).

(b) Solar cycle variations of the velocity V_{of} MCs (solid line) and CMEs (broken line).

(c) Solar cycle variations of MC-associated (solid line) and CME-associated (broken line) K_p index.

(d) Solar cycle variations of MC-associated (solid line) and CME-associated (broken line) D_{st} index.

Figure 1. Solar cycle variations of MC associated properties

B in both MCs and CMEs follows the sunspot cycle, and B in MCs is persistently higher than in CMEs in all phases of the solar cycle (figure 1a), the difference between them also being solar cycle dependent. V of both MCs and CMEs is higher in solar maximum than in solar minimum, and in all phases of the sunspot cycle it is higher for MCs than for CMEs, or equal (figure 1b). The geomagnetic disturbances caused by MCs as measured by K_p index are greater than the ones caused by CMEs (figure 1c), and for both are solar cycle dependent. MC-associated D_{st} index is much greater than the CME-associated, and shows strong solar cycle variations for MCs but no solar cycle variations for CMEs (figure 1d). This means that solar cycle variations of CME-related D_{st} index reported by previous studies (Webb, 2002) in which CMEs haven't been divided into MCs and non-MCs, are due to the solar cycle variations of the MC-related D_{st}.

3. Occurrence frequency of MCs and CMEs

It has been noted that the occurrence frequency of CMEs follows the sunspot cycle (Gopalswamy *et al.* 2003) while the occurrence frequency of MCs follows neither the sunspot cycle nor the occurrence frequency of CMEs (Wu *et al.*, 2003). Different estimations have been made about what portion of CMEs are MCs: 30% (Gosling 1990), 50% (Bothmer 1996), 60–70% (Webb 2002), until it was finally realized that this ratio

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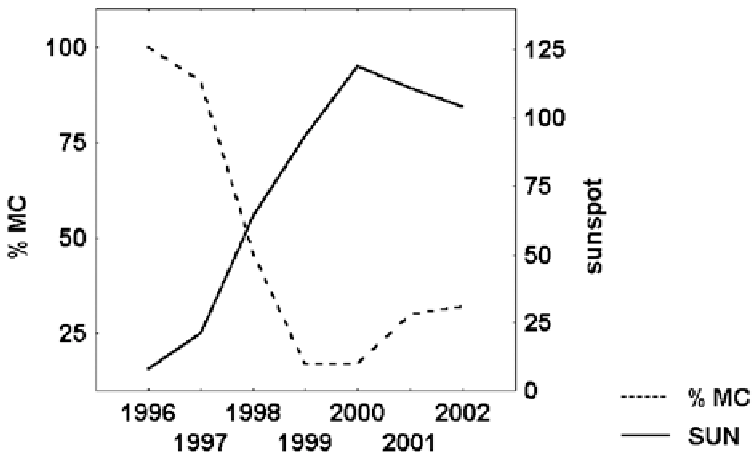

Figure 2. Solar cycle variations of the percentage of CMEs which are MCs.

varies with the sunspot cycle - from 100% at solar minimum though with poor statistics, to 15% at solar maximum (Richardson & Cane 2003). Our data confirm this conclusion (figure 1). A possible explanation of this solar cycle dependence is the solar cycle variation in the net helicity transferred from the solar interior to the surface (Berger & Ruzmaikin 2000): it is maximum in sunspot minimum and minimum in sunspot maximum. It could be speculated that the greater amount of helicity is contained in the solar corona, the greater part of CMEs expelled from it will contain helical, or twisted, magnetic fields and will be registered at the Earth's orbit as MCs.

4. Conclusion

MCs are significantly more geoeffective than CMEs which are not MCs. In sunspot maximum the portion of MCs among CMEs is small which is the reason for the lower degree of association of CMEs with geomagnetic storms than in sunspot minimum when practically all CMEs are MCs. The reason for this solar cycle variation of the ratio between MCs and CMEs is the solar cycle variation of the helicity transferred from the solar dynamo region into the corona.

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