

Geoeffective CMEs, Filaments, and Sigmoids

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Motivation

Interplanetary coronal mass ejections, particularly those with flux rope structures, have the potential to trigger geomagnetic storms, depending on the properties of the flux ropes. Eruptions of both filaments and coronal sigmoids have been implicated as important drivers of space weather, and both filaments and sigmoids have been modeled as magnetic flux ropes. However, the analysis reported by Leamon *et al.* (2002) suggested that magnetic clouds associated with filament eruptions are different from magnetic clouds associated with erupting sigmoids. In this investigation, we are exploring the differences between sigmoid-MCs and filament-MCs, with the goal of predicting the geoeffectiveness of ICMEs through analysis of the pre-eruption magnetic structures.

ICMEs from erupting sigmoids (“sigmoid-MCs”) are compared with those resulting with erupting quiescent (i.e., non-AR) filaments (“filament-MCs”). CMEs erupting from other types of progenitor structures are not considered. By analyzing the plasmas within each ICME, its

magnetic structure, and the relationship of its progenitor to the surrounding pre-eruption solar magnetic field, we hope ultimately to find an answer to the question, “*Which kind of CME-producer generates more violent space weather?*”

Method

The ICMEs studied are among those tabulated by Cane & Richardson (2003) for the period 1996—2002. *In situ* measurements of the solar wind from ACE, WIND, and Omni are downloaded from the CDAWeb Data Explorer (of ISTP, GSFC). The solar wind speed in a five-hour period immediately preceding the ICME is used as a base estimate of Sun-Earth transit speed. The ICMEs are tracked to their sources on the Sun, using images from SoHO/LASCO, SoHO/EIT, *Yohkoh*/SXT, and numerous H α observatories. The *in situ* data yield average hydrogen density, solar wind speed, temperature, and magnetic field within the ICME, as well as wind speed and temperature in the “sheath” preceding the cloud. ACE measurements of average iron charge state, for each ICME under study, are derived from data provided through the courtesy of Susan Lepri. The magnetic field of each ICME is fitted with a Bessel-function flux rope model (cf Leamon *et al.* 2004, Lepping *et al.* 1990). When the progenitor type (i.e., filament or sigmoid) for a given ICME has been identified, that

information is included in the statistical analyses, with the measurements and magnetic model. ICMEs for which the progenitor has not yet been identified are still useful for comparing the magnetic flux rope model to the Dst and cloud plasma characteristics.

Statistical Comparisons

Two kinds of statistical tests are employed, for dichotomous variables and for continuous variables. An example of the former is testing progenitor type *vs.* Dst. In this example, progenitor type is dichotomous: either sigmoid or filament. Potential relationships of this type are tested against the null hypothesis (e.g., that Dst is independent of progenitor type) via the ϕ coefficient (Daniel 1990). In addition to the ϕ result, raw averages of the two sample sets (e.g., Dst from sigmoids and Dst from filaments) are compared for consistency as a kind of sanity check.

An example of continuous-variable testing is comparison of flux rope current *vs.* Dst: both variables can take on any number of values. These relationships are examined via Spearman rank-order correlation analysis, with the linear correlation coefficient calculated as a backup sanity check.

Results

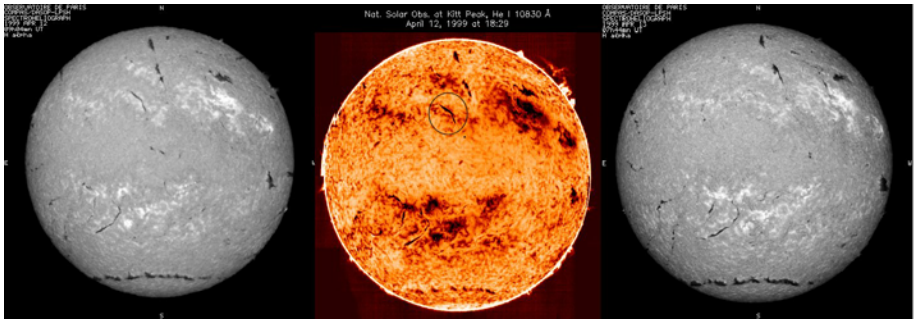
This is an ongoing project. At this stage in the analysis, an initial set of 31 ICMEs have been traced to their solar sources, and their progenitor types identified; 4 others have been analyzed, though their sources have not yet been verified (see table). The *in situ* measurements have been averaged for each ICME and the magnetic field of each has been fitted with a flux rope model. The preliminary statistical analysis indicates several features of magnetic clouds which may be related to geoeffectiveness, and also some differences between ICMEs associated with filament eruptions and those associated with sigmoid eruptions. The key question, “Which type produces more violent space weather?” has not yet been answered, but there are suggestive relationships. A summary of the relationships having at least 95% confidence is below.

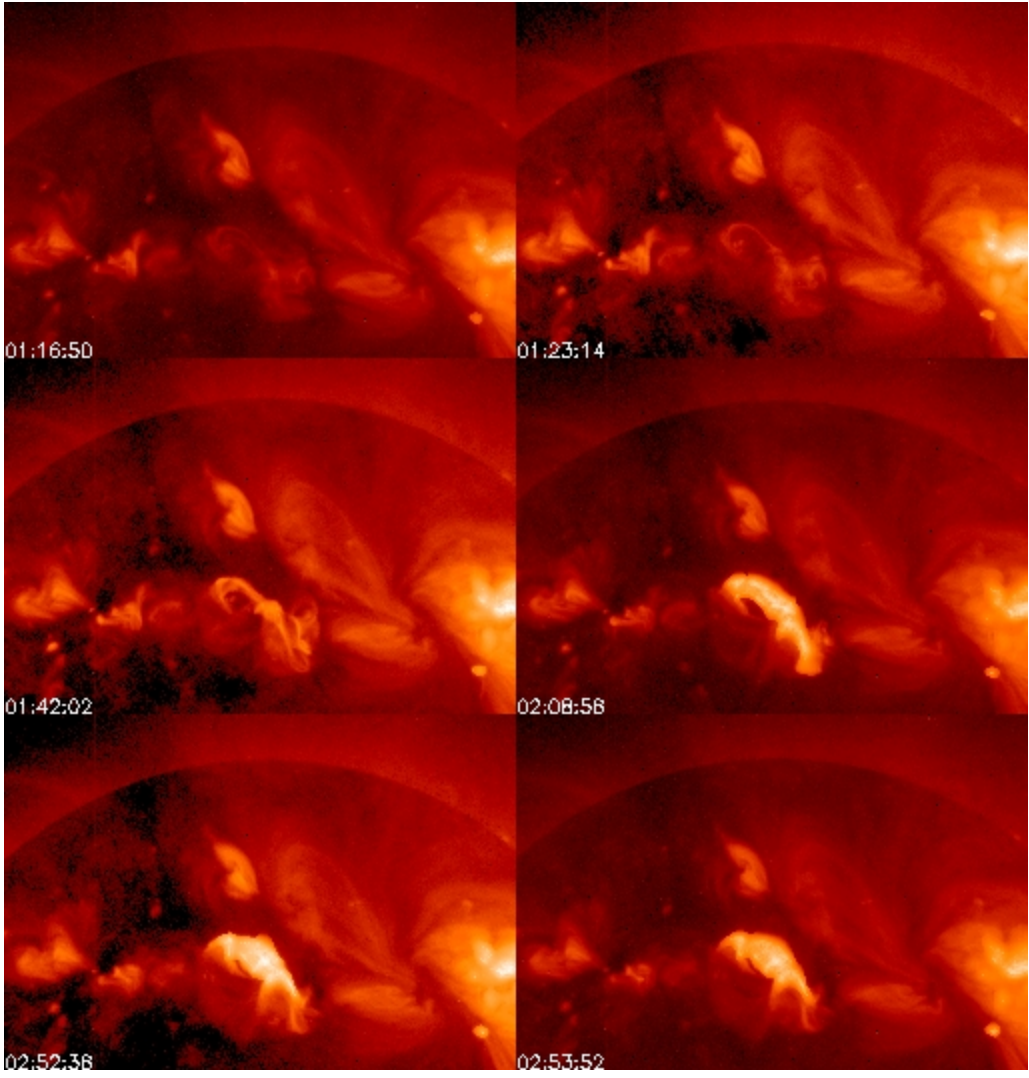
Arrival at 1 a.u.	Peak Dst (nT)	Progenitor type S=sigmoid, F=filament	Magnetic Cloud Model Flux (10¹² Wb)
10-jan-1997 04:00	-78	S	6.2
09-feb-1997 02:00	-68	S	21
11-apr-1997 08:00	-82	TBD	14
15-may-1997 09:00	-115	S	9.5
03-aug-1997 14:00	-48	F	4.6
03-sep-1997 13:00	-98	S	TBD
21-sep-1997 21:00	-36	F	9.0
10-oct-1997 22:00	-130	F	9.0
07-nov-1997 04:00	-83	S	9.6
22-nov-1997 21:00	-108	TBD	32
07-jan-1998 01:00	-83	F	TBD
17-feb-1998 10:00	-102	S	8.5
02-may-1998 05:00	-100	S	17
04-may-1998 10:00	-216	S	TBD
25-sep-1998 06:00	-234	F	TBD
19-oct-1998 04:00	-139	F	TBD
08-nov-1998 09:00	-148	TBD	22
13-nov-1998 02:00	-134	F	12
18-feb-1999 10:00	-134	S	31
16-apr-1999 18:00	-105	F	6.4
27-jun-1999 14:00	-20	F	TBD
08-aug-1999 19:00	-62	S	TBD
22-sep-1999 19:00	-164	F	0.9
21-oct-1999 08:00	-231	F	TBD
23-may-2000 10:00	0	S	12
24-may-2000 12:00	-147	S	63
15-jul-2000 19:00	-300	S	35
28-jul-2000 12:00	-74	S	7.9
10-aug-2000 19:00	-103	S	23
12-aug-2000 05:00	-237	S	26
17-sep-2000 23:00	-172	S	TBD
13-oct-2000 08:00	-110	S	TBD
28-oct-2000 21:00	-113	S	41
06-nov-2000 22:00	-159	S	15
19-mar-2002 04:00	-41	TBD	9.5

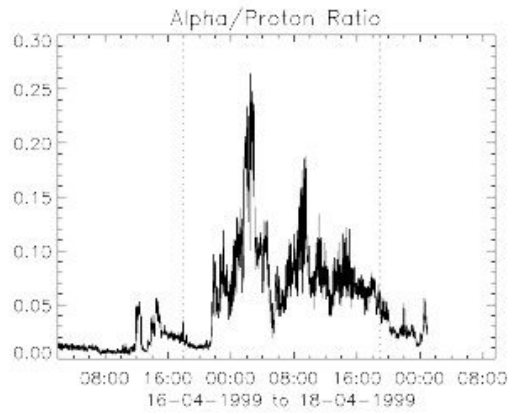
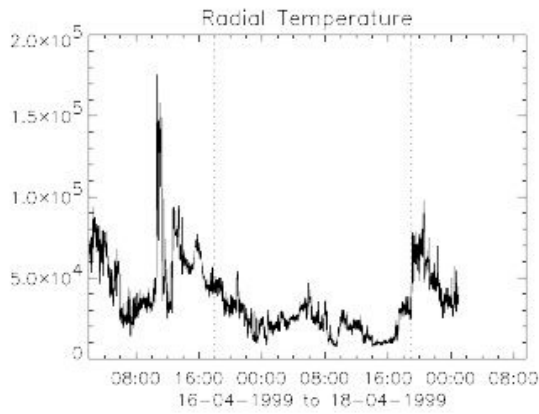
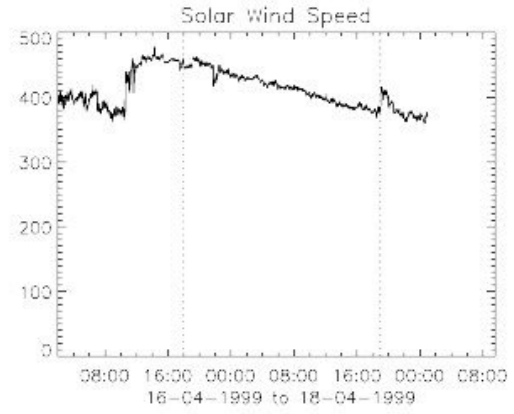
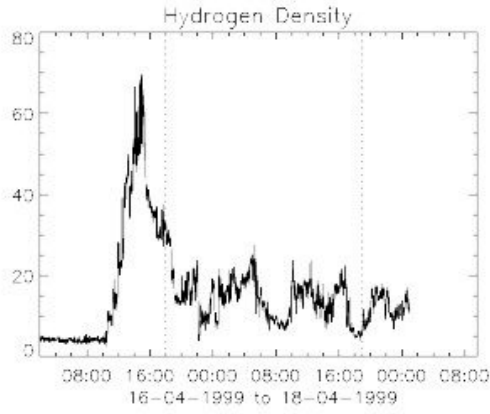
Related to Dst		Confidence
Magnetic field strength (B)	<i>Higher B → more geoeffective</i>	97.2%
Current (I)	<i>Higher I → more geoeffective</i>	99.8%
Magnetic flux (Φ)	<i>Higher Φ → more geoeffective</i>	97.2%
Hydrogen density (n)	<i>Lower n → more geoeffective</i>	98.1%
$\langle Z_{Fe} \rangle$	<i>Higher $\langle Z_{Fe} \rangle$ → more geoeffective</i>	99.0%
Velocity in sheath	<i>Higher v_{sh} → more geoeffective</i>	97.5%
Temperature in sheath (T_{sh})	<i>Higher T_{sh} → more geoeffective</i>	98.6%
Velocity in cloud	<i>Higher v_{sw} → more geoeffective</i>	99.9%
Related to Progenitor type		Confidence
Flux rope radius	<i>Sigmoid-MCs are 145% bigger</i>	95.0%
Magnetic flux (Φ)	<i>Sigmoid-MCs have 222% higher Φ</i>	97.0%
Temperature in cloud (T_{MC})	<i>Sigmoid-MCs are 36% hotter</i>	97.5%
Velocity in sheath	<i>Sigmoid-MCs have 17% higher v_{sh}</i>	96.8%
$\langle Z_{Fe} \rangle$	<i>Sigmoid-MCs have 9% higher $\langle Z_{Fe} \rangle$</i>	95.7%

Cradle-to-Grave Example

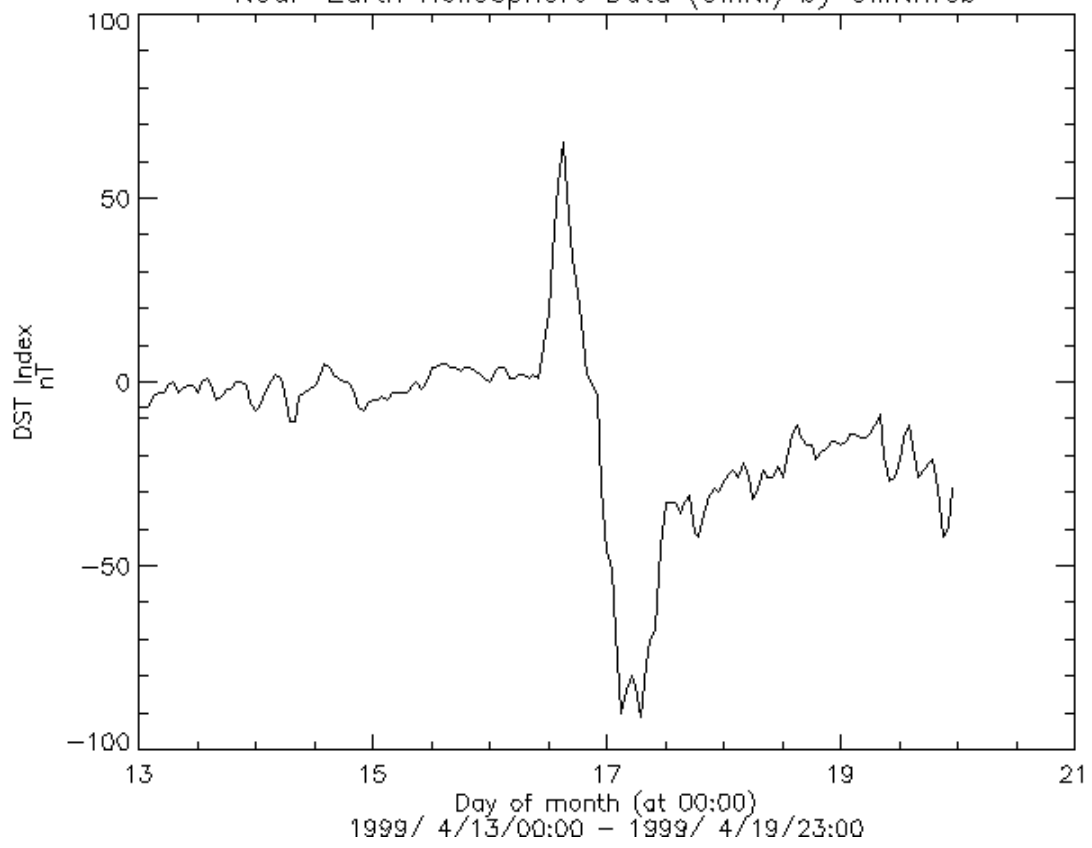
Early on 13-April-1999, a filament on the northern central meridian erupted. The H α and He I images below demonstrate the disappearance of the filament, while the sequence of SXT images display the ensuing post-eruption arcade. SoHO/LASCO recorded a halo CME at 03:30 UT (not shown here), with a plane-of-sky speed of 293 km/s. The ICME arrived at 1 a.u. on 16-April-1999 (see *in situ* time profiles). The Dst peaked at -105 nT. The flux-rope fit to the magnetic field is shown by the red dashed line in the final figure.

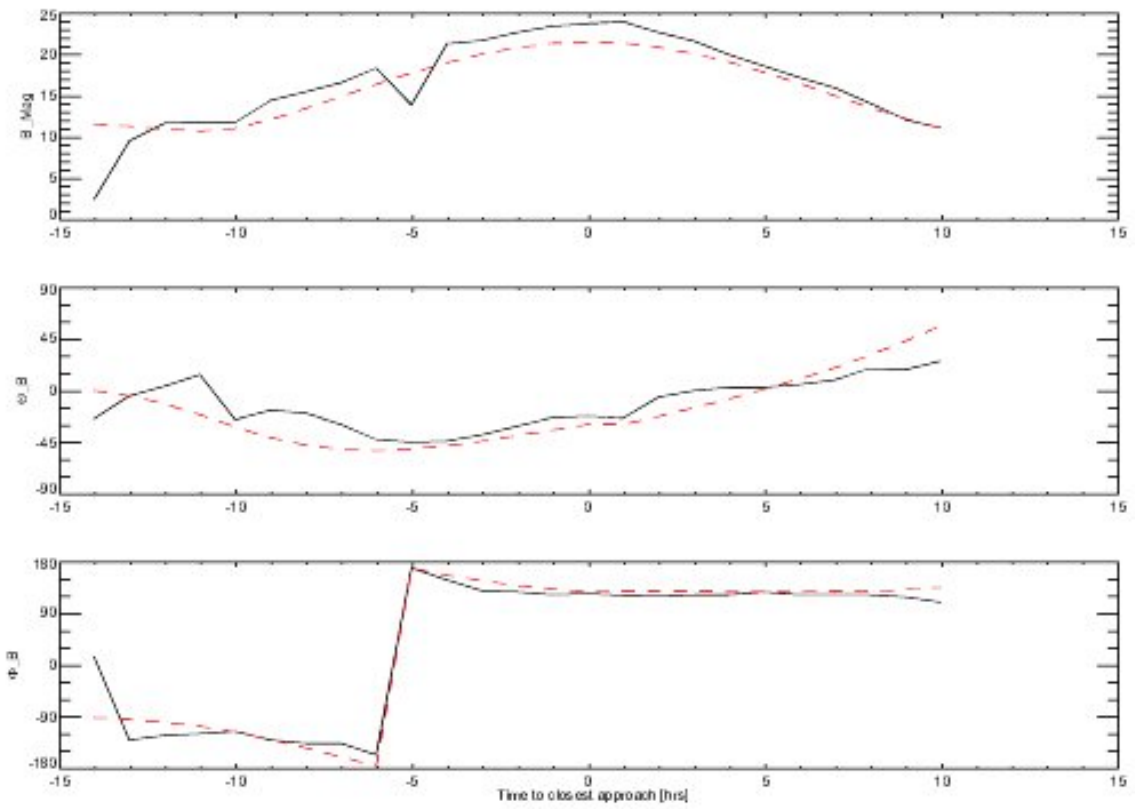






Near-Earth Heliosphere Data (OMNI) by OMNIWeb





Future

1. Continue identifying solar sources and progenitor types, add to the statistical sample.
2. Generate models of magnetic structure of progenitors, from pre-eruption magnetograms.
3. Compare progenitor magnetic models to flux rope models of clouds at 1 a.u.
4. Relate progenitor magnetic models to surrounding pre-eruption solar magnetic field (global dipole, hemispheric trend, potential field source surface, e.g.)

Works Cited

- Cane, H.V., and Richardson, I.G. “Interplanetary Coronal Mass Ejections in the Near-Earth Solar Wind During 1996—2002”, *JGR*, **108**, 1156 (2003).
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