RELATING GEOEFFECTIVE INTERPLANETARY CORONAL MASS EJECTIONS TO THE GLOBAL SOLAR FIELD

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- Interplanetary coronal mass ejections (ICMEs) occur when the Sun’s magnetic field becomes twisted and unstable
- Magnetic fields are carried away from the Sun at high speeds
- Geoeffectiveness describes the impacts Earth

Credit: Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA. [source].
Earth’s magnetic field protects us from harmful radiation

Geoeffectiveness depends on orientation
RECONNECTION AND GEOEFFECTIVENESS
WHY STUDY ICMES?

- Disruption to modern technologies
  - GPS
  - HF communication
  - Electrical grid
- Need to understand how they originate and evolve over time.

Bloomberg Bloomberg via Getty Images

https://www.youtube.com/watch?v=FU_pY2sTwTA

Magnetic cloud criteria:

- Increase in magnetic field magnitude
- Continuous rotation of magnetic field direction over a large angle
- Lower proton temperature than surrounding medium

Well defined structure and predictability allows for better modeling

Magnetic clouds = geoeffective

Burlaga, 1998
THE MODEL

- Developed by Lynch et al., 2005 based on the solution to the equation describing force-free magnetic fields discovered by Lundquist in 1950.

- Described by a constant and five parameters, three of which appear in the equation:

\[ HB_0 J_1(\alpha \rho) \hat{\phi} + B_0 J_0(\alpha \rho) \hat{\rho} \]

- Goal: fit this model to 218 magnetic cloud events using solar wind and interplanetary magnetic field measurements at 1 AU.
\[ HB_0 J_1(\alpha \rho) \hat{\phi} + B_0 J_0(\alpha \rho) \hat{\rho} \]

- **\( H \): Helicity**
- **\( B_0 \): Axial Field Strength**
- **\( \rho_0 \): Distance from spacecraft to cylinder axis upon closest approach**
- **\( \theta_0 \) and **\( \phi_0 \) (not in equation): Angles specifying the orientation of the magnetic cloud**
- **\( \alpha \): Constant determined by the first zero of \( J_0(x) \) for \( x = \alpha \times \rho \)**

Lynch et al., 2005
Using the model to calculate field components

\[ B_x = H B_0 J_1(\alpha\rho) \times \cos{\phi} \]
\[ B_y = H B_0 J_1(\alpha\rho) \times \sin{\phi} \]
\[ B_z = B_0 J_0(\alpha\rho) \]

Where \( \phi \) is the angle specifying the position of the spacecraft with respect to the cylindrical axis.

- Field components were calculated at each point during the event
X, Y, and Z components of magnetic field strength were obtained from the NASA Omni Database, which is a collection of data from many spacecraft.

Mean square error (Lynch et al., 2005):

\[ X^2 = \frac{1}{N} \sum_{i=1}^{N} \left( B_x - B_x^M \right)^2 + \left( B_y - B_y^M \right)^2 + \left( B_z - B_z^M \right)^2 \]

Minimized for each of the 218 magnetic clouds in our sample using the downhill simplex method.
MAGNETIC CLOUD ORIENTATIONS – BIPOLAR BZ

NWS

Negative Helicity
$H = -1$

SEN

SWN

Positive Helicity
$H = +1$

NES
MAGNETIC CLOUD ORIENTATIONS – UNIPOLAR BZ

ENW

WSE

WNE

ESW

Negative Helicity
\( H = -1 \)

Positive Helicity
\( H = +1 \)
SN AND NS ORIENTATIONS

SN clouds

SEN

SWN

Leading field

NS clouds

NWS

NES

Leading field
USING MODEL FITS TO DETERMINE ORIENTATION

SEN
USING MODEL FITS TO DETERMINE ORIENTATION

ESW
7/31/18: SN dipolar field
DIPOLE TILT
WHAT REALLY INFLUENCES THE ORIENTATION OF A MAGNETIC CLOUD THROUGHOUT THE SOLAR CYCLE?

- Opposing opinions on what affects orientation:
  1. The streamer belt (Mulligan et al., 1998)
  2. Individual active regions (Marubashi et al., 2015)
  3. High-latitude opposing-flux interactions near pole reversal
HOW MIGHT THE ORIENTATION OF A MAGNETIC CLOUD RELATE TO THE GLOBAL FIELD?

Crooker and Horbury, 2006
LIMITATIONS OF PAST RESULTS

- Conclusions may be incomplete due to a small data set and lack of magnetic context
- Magnetic cloud orientation does not always line up with dipole tilt (Mulligan et al., 1998)
- Bipolar Bz peaks do not match the global dipole (Mulligan et al., 1998)
- Active regions cannot always explain MC orientation as suggested by Marubashi et al., 2015
To analyze the orientation of the magnetic clouds most descriptively, we defined an orientation angle as:

$$\text{Orientation angle} = \tan^{-1} \frac{B_y}{B_z}$$

- Clear changes occur at solar minimum
DENSITY PLOTS: ORIENTATION ANGLES OVER SOLAR CYCLES 23 AND 24

Positive helicity orientation angle over time

Negative helicity orientation angle over time
ANALYZING DENSITY PLOTS

Positive helicity orientation angle over time

Negative helicity orientation angle over time
ANALYZING DENSITY PLOTS

Key:  
- Yellow = SN dipole  
- Green = NS dipole  
- Purple = Active regions  
- Black = High latitude filament eruptions
IDENTIFYING DOMINATING STRUCTURES

Orientation angle

- Positive \( B_z \) = NS dipole dominates

Leading \( B_z \) over time

Positive \( B_z \) = NS dipole dominates
COMPARING BZ AND THE STREAMER BELT

December 31, 2007

December 31, 2012
COMPARING ORIENTATION TO GLOBAL FIELD AND ACTIVE REGIONS

Date
Cycle 23
Cycle 24
Latitude (degree)
SN dipole dominates
Active regions dominate
NS dipole dominates
Active regions dominate
Influence from high-latitude interactions
Influence from high-latitude interactions

90 60 30 0
-30
-60
-90
CONCLUSIONS

- At solar minimum, the global field has the greatest influence on magnetic cloud orientation

- During more active periods, the magnetic structure and local context of active regions complicate the orientations of magnetic clouds

- A minority of magnetic clouds seem to be due to high-latitude filaments
FUTURE WORK

- Expand data set to include more magnetic clouds from the Richardson Cane ICME list
- Explore the velocities and other parameters of magnetic clouds over solar cycles 23 and 24
- Continue to examine the relationship between magnetic cloud orientation and geoeffectiveness
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