Coronal Mass Ejections and Space Weather

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Mass Chain:
- CMEs
- Solar Wind
- SEPs

Aspects of CMEs related to Space Weather:
- Ability to cause Geomagnetic storms (geoeffectiveness)
- Ability to drive shocks that accelerate SEPs (SEPeffectiveness)

~1/2 day lead time for storms
almost no lead time for SEPs
Type II bursts may provide some warning
A CME headed Earthwards
SEPs acceleration starts when the
CME is close to the Sun (a few Rs)

SEPs reach SOHO (located along the
SUN-Earth line at L1) in 10s of minutes

SOHO detectors blinded by SEPs

SOHO’s performance in imaging the corona
is temporarily affected

Sometimes fatal
The spikes in the CME rate & mean speed (averaged over Carrington Rotation periods) plots are indicative of super events. Higher mean speed enhances the chance for geoeffectiveness.
AR 486
Transequatorial connection to AR 488
Largest active region of cycle 23
Largest SEP event of cycle 23
SEPs from many backside events
Sun-Earth shock transit in < 20 h
Two super storms
Significant ozone depletion due to SEP impact on the atmosphere
Reached the edge of the heliosphere in ~ 6 months

Tri-journal (JGR, GRL, SW)
special issue (Sep 2005) on the October-November 2003 storms
70+ papers
Statistical Properties

Speed, Width & Acceleration

• < 20 km/s to 3000 km/s (avg = 480 km/s)

• Apparent width ranges from a few deg to 360 deg

• Average width of non-halo CMEs (W < 120 deg): 47 deg

• Full halos: ~3%

• Wide (W > 120 deg) events: ~11% - implications for CMEs in the heliosphere

• Acceleration negative for fast CMEs

CMEs at the tails of these distributions are important for space weather

1996-2004.5 CMEs

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Storms and CMEs

- Dst – Vcme correlation is moderate
- Dst – B correlation is good
- In addition to CME speed, the magnetic field and its orientation are also important. For example, the Dst-VB correlation ($r=0.81$) is much better than the Dst-V correlation ($r = 0.55$)
- Bz and total B have similar correlation with Dst
Geoeffective CMEs – A subset of Halo CMEs

- Front-sided halos are likely to impact Earth.
- Halo CMEs originating from close to the Sun center definitely impact Earth.

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Frontside vs Backside Halos

LASCO/C2

EIT

Kp

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CMEs need to originate close to the disk center for geoinfluence.

October-November 2003 Geomagnetic Storms

X17  X10


-363 nT  -401 nT  -84 nT  Only SC

DST Index [nT]

28-Oct  30-Oct  01-Nov  03-Nov  05-Nov  07-Nov

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Direct Impact of CME plasma at Earth needed for storms

1 Shock only

2 shock + sheath

3 shock + sheath + MC

4 MC Only (slow)
Longitudes of Storm-related CMEs

Larger storms (Dst < -200 nT) seem to occur close to the disk center (±15 deg)
Electron & Ion acceleration by shocks

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Type II Bursts

All CMEs: 487 km/s

- **m** 610 km/s
- **km** 539
- **DH** 1115 km/s
- **m-to-km** 1490 km/s

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SEP & m-to-km Events

- Similar number of SEP and m-to-km events → same shock accelerates electrons and protons
- Difference due to connectivity for particle and wider beam for bursts
- 33.8% of m-to-km events to the east of W10; only 13.8% of SEP events to the east of W10

<table>
<thead>
<tr>
<th>CME Property</th>
<th>All</th>
<th>m</th>
<th>DH</th>
<th>mkm SEP</th>
<th>km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (km/s)</td>
<td>487</td>
<td>610</td>
<td>1115</td>
<td>1490 1524</td>
<td>539</td>
</tr>
<tr>
<td>Width (deg)</td>
<td>45</td>
<td>96</td>
<td>139</td>
<td>171 186</td>
<td>80</td>
</tr>
<tr>
<td>Halos (%)</td>
<td>3.3</td>
<td>3.8</td>
<td>45.2</td>
<td>71.4 72</td>
<td>17.2</td>
</tr>
<tr>
<td>Acceleration(m/s²)</td>
<td>-2</td>
<td>-3</td>
<td>-7</td>
<td>-11 -11</td>
<td>+3</td>
</tr>
</tbody>
</table>

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Geoeffective & SEPEffective CMEs

Disk center source for plasma impact; western events for SEPs

Ip < 50 pfu

Ip ≥ 50 pfu

Eastern 33%
Western 67%

55 Geoeffective CMEs
Average 955 km/s

343 Halo CMEs
Average 1012 km/s

72 SEPEffective CMEs
Average 1524 km/s
CMEs Relevant for Space Weather

CMEs of heliospheric consequences $V \geq 1000$ km/s
Other considerations

• CME interaction (merging, deflection)
• Interacting events take longer to arrive at Earth (Manoharan et al. 2004)
• Presence of coronal holes nearby
• Ambient medium (density, flow speed)
Interaction Event

Feature = All
Position Angle = 334.
Velocity = 2093.6 km/s

2005/01/17 09:54  EIT: 2005/01/17 09:48
Summary

- CMEs are responsible for intense geomagnetic storms and large SEP events
- Different requirements for SEP effectiveness and geoeffectiveness
- More lead time for geomagnetic storms (≥0.5 day) than for SEP events (tens of min.)
- Halos, Fast and wide Western CMEs are most relevant for space weather (~10% of all CMEs, typically V>1000 km/s)
- CME interaction affects SEP intensity & Geomagnetic storms
- Identification of super active regions is very important: Only a handful in each cycle
- Publications can be downloaded from http://cdaw.gsfc.nasa.gov/publications