Update - Solar Mass Ejection Imager and Implications for Space Weather

November 2006

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Detection and tracking of coronal mass ejections (CMEs) from the Sun to the Earth to improve space weather forecasts
SMEI Status/Success

- Launched Jan 2003 on the Coriolis S/C with Navy Windsat
- Designed mission life 3-5 years
- Operating in “normal” observing mode - ~85% of the time
- Obtains full sky image every orbit (100 minutes)
- Data latency: Quicklook image < 8 hours

SMEI has observed > 200 CMEs in 3 years
Including ~30 geoeffective CMEs
SMEI Observations

Instruments

- Three 3°x60° fields of view heliospheric imagers
- Total field: fan survey 155° wide
- Images faint CMEs to a level less than 1% of the background (visible) sky brightness

Top to bottom right: high altitude aurora, limb coronal mass ejection, asteroid Vesta
Statistical Results Summary*: SMEI CMEs First 1.5 Years

- SMEI has observed 139 CMEs in 1.5 years and 204 CMEs in 2.5 yr
  Estimated observation rate = 0.3 CMEs/day
  (LASCO: >3 CMEs/day)

  - Brightness: Mean = 1.7 S10 units (range = 0.4 - 10 S10)
    Helios-2: Mean = 2.3 S10 (range 1.5 - 2.95; 1976-1979)
  - Spans (detected): Mean > 40°; Range = 3° – 113°
    LASCO: Mean = 60° (median = 42°)
    Helios-2: Mean = 53° (1976-1979)
  - Durations: Mean 16.3 hr; Range = 3.5 – 70 hr
    Helios-2: Mean = 37 hrs (1976-1979)
  - Speeds: Angular Mean = 1.1°/hr P-approx. mean = 473 km/sec, range 51-1611 km/sec
    LASCO: Mean = 507 km/sec
    Helios-2: Mean = ~500 km/sec (1976-1979)

SMEI detected ~20 halo CMEs at ~1/3 of Sun to Earth distance. Can detect CMEs 10 hours to 1+ days before Earth arrival

* LASCO results courtesy S. Yashiro & N. Gopalswamy; Helios-2 results from Webb & Jackson, JGR, 95, 1990.
Why Discrepancy in Numbers?

- Duty cycle
- Obscured regions – particle hits, shutters, auroras…
- Fade out, backsided distances (e.g. distance to first entry into SMEI FoV of backsided 120° span CME is 1.35 AU)
- LASCO multi–events episodes evolving into single SMEI features (!Ongoing research!)

Often multiple events in LASCO appear as a single event in SMEI - Do one or more of the events fade? Does a later event “catch up” to and merge with an earlier event?

SMEI composite all-sky image with LASCO coronagraph field (blue) overlaid and CME superimposed.

Earth-directed CME (white arrows). Blue arrows - obscured data from particle enhancements, SAA, auroras, zone of exclusion and shuttered areas.
SMEI Observes CME Evolution and Dynamics

- Concave-outward CME Structures

- Comet tail disconnections
Point-for-Point Tracking
(Circular Loop Structure)

Top: LASCO movies – FoV limited to < 8° from Sun

Bottom: All-sky SMEI movie – starting from 20° outward from the Sun

Distance from the Sun vs. Time

450 km/sec
Point-for-Point Tracking
(Wedge)

LASCO

610 km/sec

Angular Width
Point-for-Point Tracking
(Erupting Prominence)

540 km/sec

(15-16 Feb 2004)
Using SMEI in Space Weather Forecasts
A “Mid-Course” Correction

HAFv2 is a solar wind model, providing real-time forecasts of CME position and interplanetary shock arrival time (SAT) at Earth.
Halo CME
Howard et al. (2006) studied 20 CMEs observed by SMEI that were associated with geomagnetic storms.

Computed height-time profiles to determine CME speed, and predicted shock arrival time at Earth.

For the 20 observed CMEs:
- HAFv.2 made 13 correct predictions: 9 shocks, and 4 no-shocks (correct nulls).
- SMEI observations led to 14 correct predictions: the 9 HAFv2 shocks, and 5 additional shocks.

Real-time SMEI observations would have increased the HAFv2 correct forecast rate by 38% (5/13).

Howard et al. (in press, JGR, 2005)
Does SMEI Miss Any Geoeffective CMEs?

- Study of all *intense* storms (peak $Dst < -100nT$), Feb. 2003 - Jan. 2005; 2 years
  - Of 16, 87.5% (14/16) storms had associated SMEI CMEs
  - All CMEs were at large elongations ($> 60^\circ$) at storm onset
  - All 16 storms had associated SMEI aurora

- Study of all *moderate* storms (peak $Dst < -60nT$), Mar. 2003 – Feb. 2005; 2 years
  - For 85% (39 of 46) SMEI saw a CME within 2 days prior

(Johnston, *et al.* 2004)
Concluding Remarks

- SMEI has successfully demonstrated the capability of an all-sky white light imager to detect and track CMEs
- Improvements to space weather forecasting using SMEI data are currently being explored and quantified
- AFWA currently pursuing incorporation of SMEI data in operational forecasting

- It is possible to track structures, point for point, from LASCO into the SMEI FoV – in simple cases
- The evolution of distinctive features entering the gap region between SOHO and SMEI for complicated, multiple events is open to speculation, however long distance range CME tracking (20° to >1 A.U.) holds potential for understanding physical processes occurring en route
- With luck, the Stereo mission will overlap SMEI’s operation, adding a more dimensional understanding of CMEs
Future

• SMEI-OV
  Modified, operational version of SMEI hardware

• CDATE (CME Detection and Tracking Experiment)
  Combined coronagraph/heliospheric imager

• COVI (Compact, Orbit-Versatile Imager)

• SEEMS (Space Environmental Monitoring System)
http://smei.nso.edu/

LASCO Coronagraph data courtesy SOHO (ESA & NASA)
http://sohowww.nascom.nasa.gov

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Most recent running difference movie

The Solar Mass Ejection Imager (SMEI)

Whole-Sky Images
Current image
Most recent movie (3943 Kb)
Archived images

Running Difference Images
Current Running Difference Image
Most recent movie (4821 Kb)
Archived images
Back up
SMEI CMEs – Study First 1.5 Years

- Study (Webb, et al submitted to JGR) used SMEI Orbital difference movies
- Observation period searched:
  - 6 February 2003 – end August 2004
  - Statistical study over first 1.5 years

<table>
<thead>
<tr>
<th>Categories by Fractions of CMEs Observed by SMEI</th>
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<tbody>
<tr>
<td>A) Limb CMEs</td>
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<tr>
<td>B) Erupting prominences with CMEs</td>
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<tr>
<td>C) Multiple CMEs</td>
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<td>D) Distant wide arcs</td>
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<tr>
<td>E) Concave-outward V-shaped CMEs</td>
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<td>F) Earthward (“halo”) CMEs</td>
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