Space Weather Mission to L5
Setting the Operational Context

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National Weather Service
What does “Operational” mean?

- National Weather Service standards
  - 24/7/365 staffing of forecasting office.
  - 99+% reliability of observing, processing, and dissemination systems.
  - Redundant power, cooling, and networking at all facilities.
  - Contingency plans for outages of all forecast-critical system elements: e.g. alternate processing sites, backup instruments for observations and backup computers for model runs, etc…

- Space weather forecasting has yet to achieve fully operational status, primarily because of the observing systems.
Characteristics of Operational Weather Satellites

- Systems designed for 10—15 year mission.
- Continuous high cadence data collection and transmission.
- Redundant communication systems.
  - Backup Command/Control and downlink channels.
- Robust and resilient ground-station coverage.
  - Backup stations for C/C and data downlink.
- Data latency to forecast center measured in seconds or minutes.
- Backup satellites in ‘on-orbit’ storage.
- Operational data processing and dissemination systems.
1. **Geomagnetic Storm Watch**
Issued upon coronagraph detection of Earth-directed CME and WSA-Enlil model run
   - 15 – 72 hour lead-time

2. **Geomagnetic Storm Warning**
Issued upon detection at the ACE (soon DSCOVR) spacecraft at the L1 Lagrange point
   - 15-60 minutes lead-time
   - First time we get measurement of Bz

3. **Geomagnetic Storm Alert**
Issued when geomagnetic storm is detected on USGS magnetometers
   - Current condition
Space-based Data for Space Weather Ops.
Space-based Operational Systems...

NOAA GOES

Eumetsat METOP

NASA ACE

(Data Availability)

(Data Dissemination)

(Data Latency)
Ground-based data for Space Weather Ops

Magnetometer Network

Air Force SEON Network

USGS CORS Network

NSF GONG Network

Neutron Monitor Network
Ground-based Operational Systems...

Magnetometer Network

Air Force SEON Network

(Data Dissemination)

(Data Latency)

(Program viability)
Current Operational Systems: GOES 13—15

- On-orbit spares.
- Back-up ground stations.
- 7 communications antennas!
  - 2 S-band dipole, 1 UHF, 2 L-band dipole, 1 omni, 1 S-band horn.
- Continuous data transmission.
- XRS data latency to SWPC forecast office 10—12 sec!
Current Operational Systems: ACE*

• NOAA continuous real-time data beacon.
• RTSW ground-receiving station backed up by AFSCN network.
• Data ingest, processing, and dissemination systems are fully operational at SWPC.
• Data latency to SWPC forecast office ~ 1 min.

* DSCOVR is replacing ACE for operational forecasting in 2015 (on-orbit spare).
Current Operational Systems: DSCOVR*

- Continuous very high cadence data stream.
- *On-orbit spare (ACE).
- RTSW ground-receiving station backed up by AFSCN network.
- Data ingest, processing, and dissemination systems fully operational at SWPC.
- Data latency to SWPC forecast office < 1 min.

NOAA DSCOVR
Arriving at L1 on June 7—8, 2015!
Real-time Solar Wind Network (RTSW)

- 24/7 reception from one L1 deep space satellite (ACE \(\rightarrow\) DSCOVR)
- Backup via USAF AFSCN network

- National Institute of Information and Communications Technology (NICT) in Tokyo, Japan
- Korean Space Weather Center (KSWC) in Jeju, Korea
- German Aerospace Center (DLR) in Neustrelitz, Germany
- Wallops Command and Data Acquisition Station (WCDAS) in Virginia
- Space Weather Prediction Center (SWPC) in Boulder
Future Operational Systems: GOES-R

- EXIS – high dynamic range X-ray and EUV photometry.
- SEISS – high dynamic range energetic particle measurements.
- SUVI – new UV solar imager.
- MAG – high sample rate magnetometer.
- Extensive S/C discharge protection.
- Continuous real-time data stream.
- Operational data processing at SWPC with 10—12 sec latency.

NOAA GOES-R
Launching to Geosynch in early 2016
GOES-R will not go into on-orbit storage...
Future Operational Systems: “SWx Follow-On”

- L1 Lissajous orbit.
- Compact Coronagraph (CCOR).
- Solar Wind plasma.
- Solar Wind magnetic field.
- Solar photospheric magnetic field?
- NASA/Earth Science contribution?
- Continuous real-time data stream.

NOAA SWx Follow-On
Launching to L1 in 2020—2021
NRL Compact Coronagraph

- 50% shorter and 30% lighter than STEREO/COR2 heritage
- Replaces SOHO/LASCO
What’s Missing?

- “The second umpire”.
- Key inputs to the operational WSA/Enlil CME model: location (lat, long), angular width, and radial velocity.

From MOSWOC forecast 29/08/2014:

“SOHO LASCO C3 image showing an almost full halo CME. However it looks highly likely that this is from a back sided filament eruption, and so this CME is headed almost directly away from Earth.”

Thanks to Markos Trichas!
Case Study: St. Patrick’s Day Geomag Storm

- “Glancing blow” CME predicted with G1 magnitude.
- Actual arrival 15 hours early. Magnitude G4!
- What happened??
St. Patrick’s Day Storm: CME parameter sensitivity

Run 1: Lat=-21°, Lon=45°, ω=41°
A glancing blow to miss

Run 2: Lat=-14°, Lon=21°, ω=40°
A definite hit and on time arrival
The More Subtle Problem

For same plane of sky (POS) projection, slower and wider CME has same signature as faster and narrower CME.

Most challenging parameter fit from “L1 only” observations is accurate CME angular width.

\[ V_1 = \frac{\Delta r_1}{\Delta t} \]

\[ V_2 = \frac{\Delta r_2}{\Delta t} \]

\[ \frac{V_2}{V_1} = \frac{\tan(w_2)}{\tan(w_1)} \]

11-Sep-2014 “Double CME” Example

- Fit to the 1st CME (M5 flare on 10-Sep-2014).
- Width decrease $\rightarrow$ faster $\rightarrow$ earlier arrival time

**CAT derived parameters**

- Lat = 24°
- Lon = -23°
- Width = 43°
- Speed = 767 km/s

**Model run predicted arrival:** 2014-09-12 00:00

**Actual shock at ACE arrival:** 2014-09-11 22:58

**Error:** 1:02 (very good)
11-Sep-2014 “Double CME” Example

- Fit to the 1st CME (M5 flare on 10-Sep-2014).
- Width decrease → faster → earlier arrival time

CAT derived parameters

Lat = 16°
Lon = -12°
Width = 36° (-6.5)
Speed = 1271 km/s

Model run predicted arrival: 2014-09-11 02:00

Error: -20:58 (horrible)
Can we use radio bursts to constrain CME speed?

- Study of Type II radio bursts by S. Park, Korea RRA, 2015.
- LASCO vs. Type II CME speed correlation coefficient = 0.54.
- Short answer: No.
Additional operational considerations for L5

- Gives ~3 days forecast of Parker spiral solar wind conditions that will effect Earth.
- Can give several days to one week forecast of active regions rotating onto Earth-facing disk.
Additional operational considerations for L5

- Integration of Heliospheric Imaging (HI) could give “data assimilative” corrections to CME propagation models.

Courtesy Craig DeForest
National Space Weather Strategy

Nov 2014 – Space Weather Operations, Research, and Mitigation (SWORM) Task Force is established

Tasked to develop:

• National Space Weather Strategy
• Space Weather Action Plan

Open for public comment on the federal register:
www.dhs.gov/national-space-weather-strategy
Conclusions

• Operational space weather missions have distinct requirements
  - Continuous high cadence data collection rate.
  - Robust and resilient S/C and instrument design.
  - Continuous data downlink and transmission to forecast center.
  - Data latency to forecast center measured in seconds or minutes.
  - Operational data processing, associated models, and input tools.
  - Back-up instrument, data collection, and processing/dissemination systems.

• Operational space weather mission to L5
  - Makes the most sense in the context of an operational mission to L1 with similar (or ideally identical) instrumentation and capabilities.
  - Need “two umpires”!
  - Added advantage: with two coronagraphs on deep-space operational satellites, the coronagraph capability gains “on-orbit” spare status.