Observing Precursors to the Important Extreme Storms at the Sun

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Observing **Important Extreme Storms**

- What makes a storm at the Sun **extreme**?
- What makes a storm **important**?
- Examples of Space Weather
- A Failed Prediction
- Recommendations:
  - Decadal Survey
  - COSPAR SWX Roadmap
  - SWORM
The Corona and Wind Are Always Active
Spectacular Events Sometimes Don’t Completely Erupt
We Observe The Magnetic Field
A Curious Event in January 2014
Disk-Center X Flare of January 2014
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Giant sunspot AR1944 erupted on Jan 7th at approximately 1832 UT, producing a powerful X1-class solar flare. First-look coronagraph images from the STEREO-Ahead spacecraft appear to show a coronal mass ejection (CME). If so, the STEREO-C spacecraft is tuned for updates.

This graphic from Tamitha Skov shows the northern edge of Earth-directed solar storm. The dimming shows ejection occurred at 18:00:13 UT, followed by Earth view before X1.2 and after X1.2.

One of the biggest flares in years, the X1-class solar disk, put on an awe-inspiring show yesterday from Raybell photographer.
Predictions – FAIL!!!

CME: 2014-01-07T18:24:00-CME-001


Observed Geomagnetic Storm Params: Max Kp: 3.0

<table>
<thead>
<tr>
<th>Predicted Shock Arrival Time</th>
<th>Difference (hrs)</th>
<th>Lead Time (hrs)</th>
<th>Predicted Geomagnetic Storm Parameter(s)</th>
<th>Method</th>
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<tbody>
<tr>
<td>2014-01-09T06:35Z</td>
<td>-12.95</td>
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<td>Max Kp Range: 6.0 - 7.625</td>
<td>Average of all Methods</td>
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<td>2014-01-09T19:26Z (-10.0h, +10.0h)</td>
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<td>42.85</td>
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<td>WSA-ENLIL + Cone (GSFC SWRC)</td>
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<td>2014-01-09T04:30Z (-2.5h, +2.5h)</td>
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<td>Other (SIDC)</td>
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<td>WSA-ENLIL + Cone</td>
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<td>Expansion Speed Prediction Model</td>
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<td>WSA-ENLIL + Cone</td>
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<td>0.58</td>
<td>Max Kp Range: 3.0 - 5.0</td>
<td>Ensemble WSA-ENLIL + Cone (GSFC SWRC)</td>
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</table>
Predictions – FAIL!!!
We know a lot!

- Photospheric magnetic field on the Earth side
- Bright loops on the limb & visible disk
- Occurrence of flares and coronal dimming
- Coronal dynamics around the limb
- Some about modeling ARs, the corona & SW
- Helioseismology of the far side from Earth
- Some radio knowledge of corona and SW
- In situ measurements at various spacecraft
We know a Lot! What is Missing?

- The Sun, heliosphere, and geospace are individually global systems - we only observe parts of them and distant parts matter. (Observations)
- History counts – we need to know the past to understand energy storage, energy release, evolution and propagation, seed particles, etc. (Observation and Modeling)
- Those systems interact in complex ways – Bz and preconditioning. (Modeling and Observations)
- We know very little about the Sun’s interior – when will hazardous emergence stop? (Modeling)
- Our knowledge of the corona is limited & sparse (Observations)
What’s missing for the **Important Extreme Events**?

- Predicting eruptions is at best qualitative
- Availability of stored energy is uncertain
- Initial & evolving direction of CME B is uncertain
- Initial & evolving CME direction & speed as well
- Prior conditions are only partially known
- Flux emergence is a complete mystery
- We have very little experience with extreme events – do they behave differently?
Solar and Space Physics Decadal Survey (2012)

Separate Recommendations for Space Weather and Space Climatology

<table>
<thead>
<tr>
<th>Priority</th>
<th>Recommendation</th>
<th>NASA</th>
<th>NSF</th>
<th>Other</th>
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<tr>
<td>1.0</td>
<td>Recharter the National Space Weather Program</td>
<td>X</td>
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<td>2.0</td>
<td>Work in a multiagency partnership to achieve continuity of solar and solar wind observations</td>
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<td>2.1</td>
<td>Continue solar wind observations from L1 (DSCOVR, IMAP)</td>
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<tr>
<td>2.2</td>
<td>Continue space-based coronagraph and solar magnetic field measurements</td>
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<tr>
<td>2.3</td>
<td>Evaluate new observations, platforms, and locations</td>
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<tr>
<td>2.4</td>
<td>Establish a space weather research program at NOAA to effectively transition research to operations</td>
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<tr>
<td>2.5</td>
<td>Develop and maintain distinct funding lines for basic space physics research and for space weather specification and forecasting</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</table>
COSPAR Space Weather Roadmap

Focus is on high-priority challenges in key areas of research leading to a better understanding of the space environment and demonstrable improvement in the provision of timely, reliable information pertinent to effects on civilian space- and ground-based systems, for all stakeholders around the world.

Most Recent (2015) Comprehensive Strategic Study

cosparhq.cnes.fr/scientific-structure/cospar-scientific-roadmaps
COSPAR Space Weather Roadmap
(for solar and heliospheric only)

Maintain key capabilities (ground + space):
Solar vector B, EUV/X-ray imaging, GOES flares,
Spectral irradiance, Coronagraph(s!),
Radio observations of inner heliosphere,
“L1” SW plasma, fields & composition, SEP(s!)

Deploy new/improved instrumentation:
Binocular coronagraph, hi-res multi-height B in ARs; B at multiple viewing angles around heliosphere, more SEP locations

This all critically requires something more…
COSPAR Space Weather Roadmap
(for solar and heliospheric only)

Model Capability, Archival Research, Data Infrastructure and Expertise Development

• NRT AR models to assess destabilization sensitivity
• Data-driven models of local and global coronal field – both stable and eruptive – and of the solar wind
• Coronal magnetic field measurements and models
• Particle acceleration and propagation in heliosphere
• Ensemble models of AR to understand energy conversion
SWORM Task Force in the U.S.  
National Science & Technology Council led by OSTP

Will reduce U.S. vulnerability to SWX: Power, Aerospace, PNT

**Proposed Goals** (May) Leading to Action Plan (Summer)

- Establish Benchmarks for Space Weather Events
- Enhance Response and Recovery Capabilities
- Improve Protection and Mitigation Efforts
- Improve Assessment, Modeling and Prediction of Impacts on Critical Services
- Improve Space Weather Services through Advancing Understanding and Forecasting
- Increase International Cooperation

OSTP, DHS, FEMA, NWS, NOAA, NASA, NSF, DoD, OMB, etc.
Summary

If we are looking, the likely sources of EXTREME events are recognizable once they have emerged through the photosphere, limiting how far in advance forecasts can be made - for now.

Identifying IMPORTANT events is more problematic because details truly matter. We have some clear ideas about what must be done to improve our capabilities, and at least we can observe them from Earth.

A prominence seen over the solar limb by Hinode.