Space Weather: Modeling and Forecasting

Lauren Woolsey
Harvard-Smithsonian Center for Astrophysics
SHINE Student Day
22 June 2014
Definitions

Wikipedia: “the fluid environmental conditions of space, especially near-Earth space [...] the description of changes in the ambient plasma, magnetic fields, radiation, and other influences in space.”

SOHO: “Conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health.”
Faraday's Law

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]
Faraday's Law

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]
CURRENT CONDITIONS
Space Weather Prediction Center

- Find at [http://www.swpc.noaa.gov](http://www.swpc.noaa.gov)
- Part of National Weather Service!
- Many data and products available...

Lauren Woolsey  22 June 2014
Top News of the Day:

2014-06-10 14:15 UTC  Multiple R3 (X2) Solar Flares

An R3 (NOAA Scale - Strong) solar flare (X2.2/Sf) was observed this morning at 10/1142 UTC. The event was produced from newly numbered Region 2087 near the SE limb of the solar disk. Short lived impacts to HF communications should be expected. The flare was short lived in duration and initial analysis does not favor an additional associated coronal mass ejection (CME).

An additional R3 (NOAA Scale - Strong) solar flare (X1.5/11) was observed at 10/1252 UTC, approximately an hour after the previous R3 event. The source location for this second flare was also Region 2087 (S16E79). More analysis is underway at this time, so stay tuned for more details.

NOAA's Space Weather Prediction Center is pleased to debut the beta version of its new website.

New Space Weather Education and Outreach Resources - NOW AVAILABLE! Follow this link. Sign up for Emails of Space Weather Alerts, Warnings, Watches, and Forecasts.

Current Space Weather Conditions

Latest GOES Solar X-ray Image

NOAA Scales Activity

<table>
<thead>
<tr>
<th>NOAA Scale</th>
<th>Range 1 (minor) to 5 (extreme)</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomagnetic Storms</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Solar Radiation Storms</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Radic Blackouts</td>
<td>R3</td>
<td>none</td>
</tr>
</tbody>
</table>

GOES Solar X-ray Flux
In Situ Data: ACE

Available:
1) Bt, Bz
2) Phi
3) Density
4) Speed
5) Temp
MODELING & FORECASTING
**Community Coordinated Modeling Center**

**CCMC mission statement**

The CCMC is a multi-agency partnership to enable, support and perform the research and development for next-generation space science and space weather models.

**SHINE Modeling Challenge**

CCMC is now supporting the SHINE modeling challenge. At the SHINE Workshop in the summer of 2011 the community decided to establish a systematic effort to compare corona and inner heliosphere models and evaluate their absolute and relative performance.

*The next SHINE workshop session on this validation will be held, Tuesday June 24, 2014, at the SHINE workshop in Telluride, Colorado.*

**CCMC Services**

- We provide, to the scientific community, access to modern space research models
- We test and evaluate models
- We support Space Weather forecasters
- We support space science education

**CME Arrival Time Scoreboard**

*CME arrival time predictions from the research community*

- Access the [CME Arrival Time Scoreboard](#)
- See the list of available CME propagation models

The space weather scorecard (developed at the CCMC) is a research-based forecasting methods validation activity which provides a central location for the community to:
- submit their forecast in real-time
- quickly view all forecasts at once in real-time
- compare forecasting methods when the event has arrived
CCMC Domain


Coupled Solar-Heliosphere:

1. CORHEL
2. AWSoM
3. ASSA
1. CORHEL

Developed by J. Linker, Z. Mikic, R. Lionello, P. Riley, N. Arge, D. Odstrcil

CORHEL is a software package that:

(1) obtains and processes magnetograms

(2) runs coronal model (MAS or WSA)

(3) processes results to generate boundary conditions for heliospheric code

(4) runs heliospheric model (MAS or ENLIL)
WSA–Enlil

- 25th anniversary of WSA Model! Sheeley, Jr. was at AAS 224: History of Solar Physics

- Expansion factor and wind speed are anti-correlated
  - Levine, Altschuler & Harvey 1977
  - Y.-M. Wang: August 17, 1989
  - Wang & Sheeley 1990

- C. N. Arge was their post-doc: made website and improved relation (Arge & Pizzo 2000)

- In 2011, connected WSA and Enlil: first ever official (NWS) space weather prediction!

Lauren Woolsey
\[ f_s = \left( \frac{R_\odot}{R_s} \right)^2 \left[ \frac{B^P(R_\odot)}{B^P(R_s)} \right]. \]

Once all the expansion factors are determined, the solar wind speed is assigned to each point on the source surface by using the following empirical relationship between solar wind velocity and expansion factor:

\[ v(f_s) = 267.5 + \left[ \frac{410}{(f_s)^{2/5}} \right]. \quad (4) \]

This equation applies strictly near the solar equator, since it was derived from low latitude in situ data. We

- Wind speeds at source surface act as boundary conditions on the MHD code


Lauren Woolsey

22 June 2014
2. AWSoM / SWMF

Developed by Bart van der Holst, Igor Sokolov, Ward Manchester, Gabor Toth, Darren DeZeeuw and Tamas Gombosi

The Alfven–Wave driven SOlar wind Model (AWSOM) is part of the Space Weather Modeling Framework (SWMF).

Center for Space Environment Modeling team led by Tamas Gombosi at U. Michigan (Toth et al. 2012).

AWSOM uses the solar corona and inner heliosphere components of the SWMF, based on the BATS–R–US 3D MHD block–adaptive code.
BATS-R-US

Block-Adaptive-Tree-Solarwind-Roe-Upwind-Scheme

• Developed at University of Michigan (for more info: http://csem.engin.umich.edu/)

• Solves 3D MHD equations in finite volume form using numerical methods related to Roe's Approximate Riemann Solver

• Uses an adaptive grid composed of rectangular blocks arranged in varying degrees of spatial refinement levels

Lauren Woolsey

22 June 2014
3. ASSA

Developed by Sangwoo Lee, Sunhak Hong, KiChang Yoon, JaeHun Kim, YungKyu Kim, JeongDeok Lee, SeungJun Oh

The Automatic Solar Synoptic Analyzer (ASSA) provides real-time monitoring and identification of key solar phenomena such as:

- sunspot groups
- coronal holes
- filaments

Outputs: images and list of identified features above with McIntosh classification and Mt. Wilson magnetic classification of each active region
Other Models!

- ForeCAT (Kay, Opher, & Evans 2013; Kay & Opher, *in prep.*)
- TEMPEST (Woolsey & Cranmer 2014)
Conclusions

• Space weather caused by flares and CMEs as well as high-speed wind streams

• SWPC is an official part of the National Weather Service, best for getting observations & measurements

• CCMC is awesome for running a wide variety of models spanning the domain of the Sun–Earth connection

• Ongoing work is improving our understanding of the physical processes and forecasting ability

Lauren Woolsey
22 June 2014