NOAA SWPC Needs
(Transition to Operations)

H.J. Singer
NOAA Space Weather Prediction Center
CCMC Workshop, Key Largo, Florida, January 19, 2012

- Some History and Motivation
- Model Transition to Operations: WSA-Enlil and Geospace
- High Priority Customer Needs
- Future
- Acknowledgments: Biesecker, Millward, Pizzo, Murtagh

Using Models to Support Customers  Modeling the Solar-Terrestrial System
Space Weather: Societal and Economic Impact

- March 25, 1940

- Large Geomagnetic Storm

- Western Union set up emergency circuits to re-route messages as regular lines went dead

- Telegraph lines went haywire

Community Developed Models Are in Use Today at SWPC to Warn of such Occurrences

Life Magazine, vol 8, no 15, page 38, April 8, 1940.
SWPC Customer Growth is Accelerating

Customer Growth
SWPC Product Subscription Service

- Sunspot Number
- Number of Customers

Start of Subscription Service

Customers | Solar Cycle
Geomagnetic Storm Impacts

Impacts from geomagnetic storms are wide-ranging with potentially significant consequences.

- **Satellite Operations**: Loss of mission, reduction in capability
- **Human Spaceflight**: Increased radiation risk
- **GPS**
  - Precision Agriculture, Surveying, Drilling, Military
- **Power Grid Operations**
  - Grid failure, Grid capacity, Component Failure, GPS Timing
- **Aircraft Operations**
  - Polar Flights, WAAS, NextGen, Airline Communication
WSA-Enlil Improves Geomagnetic Storm Prediction

- Provides perspective on co-rotating structures 1-27 days in advance, CME’s 1-4 days
- Reduces error in geomagnetic storm onset time from ±12 hrs to ±6 hrs
- Expected to result in improvements to SWPC GPRA
Partnerships

- NOAA / NWS / NCEP / EMC & NCO (computing) / NGDC (archive)
- DoD / AFWA
- DoD / AFRL (Nick Arge, WSA model developer)
- DoD / NRL (Cone development, STEREO) & ONR (WSA support)
- George Mason University & University of Colorado/CIRES
  (Dusan Odstrcil, Enlil model developer)
- NASA / ESA (SOHO / LASCO / STEREO)
- NASA / CCMC (Cone model development)
- NSF / CISM / NCAR / LASP
- NSF / NSO (GONG)
- Basic research community
WSA-Enlil CONOPS

NASA

SOHO LASCO data

STEREO data

NASA

SWFO

Monitor CME event
Name CME
Generate CME cone data

NSO

GONG data

Ambient & CME inputs

NGDC

Archive outputs

SWFO

Forecast products

Customers

NCEP CCS

Model results

WSA-Enlil model run

Generate CME cone data

Process model results
Generate graphical products
Inform improved forecast
**CAT (CME Analysis Tool)**

- 3D rendering of ‘lemniscate’ (tear drop) onto images from STEREO and LASCO

Tool not yet transitioned to operations as there is significant development still in progress. Meanwhile, the WSA-Enlil team can use the tool as needed.
The Results

‘Average error’ is calculated as ‘average absolute error’, which was used by CCMC in *Taktakishvili et al. 2010*.

‘RMS error’ is the community preferred measure.

The ‘community’ accepted error during Solar Cycle 23 is ±12 to ±15 hours.

<table>
<thead>
<tr>
<th>EVENT START</th>
<th>Shock at ACE</th>
<th>WSA/ENLIL NOAA</th>
<th>DIFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>02/13/2011 01:44</td>
<td>02/18/2011 00:49</td>
<td>02/17/2011 15:00</td>
<td>9:49</td>
</tr>
<tr>
<td>03/08/2011 20:14</td>
<td>03/10/2011 06:10</td>
<td>03/10/2011 08:00</td>
<td>1:50</td>
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<tr>
<td>06/02/2011 07:57</td>
<td>06/04/2011 19:58</td>
<td>06/04/2011 08:00</td>
<td>11:58</td>
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<tr>
<td>06/21/2011 03:25</td>
<td>06/23/2011 02:26</td>
<td>06/23/2011 12:00</td>
<td>9:34</td>
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<tr>
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<td>08/05/2011 17:22</td>
<td>08/05/2011 17:00</td>
<td>0:22</td>
</tr>
<tr>
<td>09/06/2011 00:00</td>
<td>09/09/2011 11:49</td>
<td>09/09/2011 17:00</td>
<td>5:11</td>
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<tr>
<td>09/14/2011 02:00</td>
<td>09/17/2011 02:56</td>
<td>09/16/2011 21:00</td>
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<td>10/05/2011 16:00</td>
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<tr>
<td>10/26/2011 10:00</td>
<td>10/30/2011 08:55</td>
<td>10/30/2011 10:00</td>
<td>1:05</td>
</tr>
</tbody>
</table>

| AVERAGE ERROR | 6:26 |
| RMS ERROR     | 7:48 |
Aug 2011

Three radio blackouts reaching the R2 (Moderate) levels, all with Earth-directed coronal mass ejections on August 2nd, 3rd, and 4th.

“Storming levels are expected to attain G3 (Strong)”

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SWPC performance reviewed at NERC (North American Electric Reliability Corp.) in Atlanta.

NERC, FERC, DOE, NASA, USGS, and multiple industry types in attendance

“SWPC forecasts were spot-on” - PJM

Excellent job by SWPC Operations and supporting staff
Future Plans

• For FY12
  – Tool development continuing
  – Forecaster Training
  – Modify WSA-Enlil to enable continuous updating mode
    • Should provide better estimate of evolving background flow
    • Will ‘fix’ inconsistencies that result when more than 1 CME
    • Should eliminate 10 simulation days of ENLIL startup, cutting CCS runtime to ~45 minutes
  – V&V and enhanced performance tracking

• Beyond FY12
  – Improved inputs
    • especially as regards CME parameterization
  – Improved products
    • 3D rendering, estimates of storm strength and duration, Bz
  – Ensembles
    • Enabled through improved CCS runtime and results of V&V
Geospace Model
Transition to Operations

- Metrics
- Selection Considerations
- Plans

Geospace Models
Protecting Power Grids (and other services)

Howard Singer and Terry Onsager
NOAA Space Weather Prediction Center
Masha Kuznetsova, Antti Pulkkinen, Lutz Rastaetter
NASA Community Coordinated Modeling Center

Safeguarding Our Nation’s Advanced Technologies
High-level government response...

Coordinating on ways forward to develop and implement mitigation strategies to safeguard critical infrastructure from the impacts of severe space weather.

• The Shield Act (H.R. 668) (Feb 2011)
  To amend the Federal Power Act to protect the electric infrastructure geomagnetic storm (and EMP)

• Meeting at White House with National Security Staff and OSTP (18 Feb)

• Op Ed in NY Times on space weather by Holdren and Beddington (10 Mar)

• Electric Infrastructure Security Summit (EISS) in Washington D.C. (11 Apr)
Geospace Model Project Goals

• **Goal:** Evaluation of Geospace prediction models to determine which model or models should begin transition to operations process beginning about Q4 2012.

• **Focus:** Models that can predict regional geomagnetic activity

• **Process:** CCMC leads evaluation; Build on GEM Storm Challenge; Establish partnerships; Select metrics; Conduct evaluation, Model(s) selection

• **Community Discussions:** GEM, AGU, and CCMC Meetings; Geomagnetic activity products documents circulated, Geospace Model Validation Workshop…
Models at CCMC Participating in Geospace Evaluation

MHD Models:

• Space Weather Modeling Framework (SWMF) - U. of Michigan (delivered to CCMC)

• The Open Geospace General Circulation Model (Open GGCM) - University of New Hampshire (delivered to CCMC)

• Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) - BU CISM, Dartmouth, NCAR (delivered to CCMC)

• Grand Unified Magnetosphere-Ionosphere Coupling Simulation (GUMICS) - Finnish Meteorological Institute (recently parallelized, not ready for full evaluation for selection process)

Empirical Models:

• Weimer Empirical Model, Va. Tech (delivered to CCMC/may update)

• Weigel Empirical Model, George Mason (delivered to CCMC)
Regional dB/dt Prediction

Observations, Models

<table>
<thead>
<tr>
<th>Observed dB/dt</th>
<th>MHD Model dB/dt</th>
</tr>
</thead>
<tbody>
<tr>
<td>At ground station</td>
<td>At ground station</td>
</tr>
<tr>
<td>(Regional)</td>
<td>(Regional)</td>
</tr>
</tbody>
</table>

Compute skill (or other metric) for each model and compare

Model dB/dt / Observed dB/dt
dB/dt Evaluation

Event x Model \( y_i \)
- (Kp, Dst, LT of storm main phase...)

High Latitude
- (repeat for mid-latitude)

Max 1-min \( \text{dB/dt} \)
- (10 minute window)

Contingency Table
- (for different thresholds - e.g. 1 nT/s, 1.5 nT/s...)

Skill metrics
- (e.g. POD, Heideke, CSI, ETS, ...)

Ranking

Contingency Table

<table>
<thead>
<tr>
<th>Event Observed</th>
<th>Event Forecast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>
Models will be evaluated on four criteria:
- Strategic Importance
- Operational Significance
- Implementation Readiness
- Cost to Operate, Maintain, and Improve

Evaluation team will consist of internal and external participants

Modelers to review and comment on draft Recommendation Report prior to delivery to SWPC Director

The final Recommendation Document will be made public

Selection will be made by SWPC Director
Possible Findings/Recommendations

• One (and only one) MHD model has sufficient value to justify transition and operation costs – Recommend transition

• Multiple MHD models have sufficient value – Recommend one model based on highest long-term value and lowest cost

• No MHD model has sufficient value, but near-term improvements could be made – Recommend SWPC support for additional development and testing

• One or both empirical models have sufficient value – Recommend either or both for transition

• No model has sufficient value – Recommend no SWPC action
Geospace Model Transition:
Recent Activities and Current Schedule
(draft under discussion with CCMC)

- 4/25/11: Geospace modeler meeting focused on evaluation metrics, selection process and initiate discussion to understand resource requirements
- May-June 2011: Spatial, temporal, and window sensitivity testing at CCMC to refine and iterate on metrics, event selection, verification measures
- June 26 – July 1 2011: GEM-CEDAR Workshop including Modeling Challenges and discussions with modelers on sensitivity tests and schedule
- July – Nov 2011 : Empirical model tests, gathering data for additional events, tool to integrate currents, comparisons of db/dt calculated by CCMC and modelers (SWMF and GGCM)
- Dec: Presentations and discussions with modelers at Metrics and Validation Session at Geospace Modeling Workshop (day before AGU meeting)
- Jan 2012: Runs and post processing
- Feb – March 2012: Analysis and Report Writing
- April-May 2012: SWPC circulate draft report for comments
- June 2012 - : Model Selection at SWPC
New Test Product Example
Newell Auroral Model

Aurora Forecast
OVATION-Prime Model
Test Product

Movie

Forecast For: 2011-10-25 01:10 UT
Hemispheric Power: 84.36 GW
(Typical Range 5 to 150 GW)

Model Run at: 2012-01-12 17:36 UT
Observation Time: 2011-10-26 00:40 UT

Probability of Visible Aurora
10% 50% 90%
Highest Priority Needs for SpWx Operations 1.  
(An evolving list with some topics for improvement)

1. Improved forecasts of Geomagnetic storms  
   1. Requires better CME specification and parameterization.  
   2. Requires better specification of the background solar wind.  
   3. Requires improved modeling of heliospheric magnetic fields and fields within CMEs (Bz).

2. Forecasts of geomagnetic activity, including spatially resolved variations in electromagnetic fields and Geomagnetic Induced Currents (GICs)  
   1. Requires magnetospheric models driven by solar wind observations.  
   2. Requires improvements to magnetosphere-ionosphere coupling and the generation of electromagnetic fields on the ground.

3. Prediction of ionospheric scintillations and gradients in the Total Electron Content (TEC) of the ionosphere.  
   1. Requires modeling of all ionospheric drivers including solar EUV, geomagnetic storms, and waves/tides from the troposphere.  
   2. Requires better understanding of the small-scale physics of ionospheric scintillation.
Highest Priority Needs for SpWx Operations 2.
(An evolving list with some topics for improvement)

4. Forecasts of the location and intensity of the Aurora
   1. Requires research on coupling WSA-Enlil output to the OVATION Prime model and significant improvement in predicting Bz and other field components

5. Forecasts of the magnitude and timing of solar flares
   1. Flares are the precursor to all large space weather storms
   2. Flare forecast would provide predictions of HF radio blackouts

6. Forecasts of Solar Energetic Particle events and Radiation Storms
   1. Research required to insert energetic particles and electromagnetic shock physics into heliospheric models such as WSA-Enlil

7. Forecasts of the geospace energetic particle radiation environment
   1. Requires understanding of sources and losses of energetic particles
Transfer of Models to Operations: Some Key Lessons Learned

• Demonstrating customer benefit – whether a new product or showing improvement of an existing product

• Model validation is essential to demonstrate readiness for transition and user metrics need to be established (as well as the scientific metrics).

• Evaluating Cost/Benefit

• Importance of iterative development between SWPC (forecasters, scientists, managers, IT..) and model developers—bringing together partners with different expertise and perspectives to find solutions and develop products

• Focus on limited set of model products at any one time

• Model transition needs to involve and support model developers
Future

• Evaluate where there is match between customer needs and research models available at CCMC and in the scientific community
• Invest in those models where there is a significant customer benefit

Research to Operations – Operations to Research

• On-going activity supporting NOAA SWPC is also extremely beneficial to CCMC Runs-on-Request users [models have been updated]
• NASA/GSFC Space Weather Desk supporting NASA Robotic Missions
• GEM Community

-- M. Kuznetsova