Requirements for the First U.S. National Weather Service Geospace Model

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presented by

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Outline
• Space Weather Prediction Center
• R2O: From user needs to operations
• Transitioning the Geospace Model
• O2R: Plans for the future
Space Weather Prediction Center
Established 1946
First daily forecast in 1965

R & D – Space Weather Prediction Testbed
Transitioning models into operations

Operations – Space Weather Forecast Office

Specifications; Current conditions
Forecast; Conditions tomorrow
Watches; Conditions are favorable for storm
Warnings; Storm is imminent with high probability
Alerts; observed conditions meeting or exceeding storm thresholds
70 Years of Customer Growth

Critical Customers

• Electric Utilities
  • Potential for significant disruption of service due to geomagnetic storm with major financial consequences
• Aviation
  • HF Communication
  • GPS Navigation
  • Radiation Exposure
• Communication
  • HF radio
  • Satellite Communication
• GPS Navigation
  • Space Weather Introduces Errors
  • Space Weather Blocks Signal
• Space Systems
  • Satellite Anomaly Assessment
  • Space Weather Database for Satellite Design
  • Humans in Space
Meeting The Space Weather Needs of the Nation and the World

Working with key US government leadership to address the space weather threat.

- White House
- Congress
- Department of Commerce (NOAA)
- Department of Energy
- Department of Interior
- Department of Homeland Security
- Department of Defense
- NASA
- National Science Foundation
High Level Visibility

• National Risk Assessment
• Space Weather Action Plan
• Presidential Executive Order (13 Oct. 2016)
  • National policy for space weather;
  • Interagency coordination body within the National Science and Technology Council
  • Articulating roles and responsibilities with respect to space-weather research, operations, and mitigation;
  • Highlights the need to work with non-Federal entities, including international partners, to achieve national preparedness for space weather.

• Clarifying roles
  • Research to Operations
  • Operations to Research
NOAA Space Weather Prediction Center Models

Operational
Under Development

Sun:
ADAPT (USAF)
WSA (USAF/NASA)
Flare Prediction (SBIR)
Fareside Imaging (SBIR)
EUV Irradiance (GOES)

Solar Wind:
Enlil (George Mason U.)
L1-Earth Transit (U. Colorado)

Ionosphere:
IPE (U. Colorado)
US-TEC
NA-TEC
Global TEC
Equatorial Scintillation (U. Colorado)

Magnetosphere:
Space Weather Modeling Framework (U. Mich.)
GOES Magnetopause Model (U. Colorado)

Thermosphere
WAM (U. Colorado)
CTIPe

Aurora:
30 Minute Forecast (JHU/APL)
3 Day Forecast

Ground:
E-Field
Airline Radiation

Note: SBIR = Small Business Innovative Research
What is Required from a Space Weather Model or Product?

• Strategic Importance
  – Is the customer providing critical services?

• Relevance
  – Does the model or product address the customer’s needs?

• Accuracy
  – Can the model actually provide a useful improvement to the customer?

• Reliability
  – Can the model be reasonably transitioned into operations?
    • Is the model robust?
    • Does the real-time input data exist?
Developing a Model for Operations

Three possible ways to develop an operational model:

1. Develop the model at NOAA SWPC (e.g. US-TEC, D-RAP, IPE, WAM)
   - Pros: Good connection to requirements, NOAA owns the code.
   - Con: Very expensive, May not get the best model.

2. Model developer comes to work at SWPC (e.g. WSA, Enlil)
   - Pros: Good connection to requirements.
   - Cons: May not get the best model, NOAA does not own the code.

3. Open competition (e.g. Geospace)
   - Pros: Get the best model
   - Cons: Not as closely connected to requirements, NOAA does not own the code.
Strategic Importance: Societal Impacts

- Storm of 1940:
  - Telegraph wires went “haywire”
    - Western Union set up emergency circuits to re-route messages as regular lines went dead.

- "On the lines to Syltefjord and Makkaur all fuses (4 amp.) burnt through. Sparks and permanent arcs were formed in the coupling racks and watch had to be kept during the night to prevent fire from breaking out”
  - Log of the Vardø Station, Norwegian Telegraph Service, 24 March, 1940
October 31 - Sun storm causes problems for Swedish power system. The solar storm has caused technical glitches in Sweden’s power system in the past few days and may be to blame for a blackout that affected 50,000 people on Thursday, October 30.

Information Notice No. 90-42:
FAILURE OF ELECTRICAL POWER EQUIPMENT DUE TO SOLAR MAGNETIC DISTURBANCES

Specific events occurred at the Three Mile Island Unit 1, Hope Creek Unit 1, and Salem Unit 1 nuclear power plants. ...inspection of the generator step-up transformer... severe overheating, melted low-voltage service connections in phases A and C, and insulation discoloration in phase B. On September 19, at Salem Unit 2 nuclear power plant, a second solar storm damaged the generator step-up transformer.  

Transformers exit-lead overheating
Electric power companies take actions to mitigate geomagnetic storm impacts

**Procedure: Implement Solar Magnetic Disturbance Remedial Action**

**Process Name:** Implement Emergency Operations

**Procedure Number:** RTMKTS.0120.0050

**Revision Number:** 6

**Effective Date:** March 29, 2005

**Procedure Owner:** Steve Weaver

**Approved By:** VP Operations

1. Discontinue maintenance work and restore out of service high voltage transmission lines. Avoid taking long lines out of service.
2. Maintain system voltages within acceptable operating range to protect against voltage swings.
3. Review the availability of the Chester SVC and Orrington capacitor banks to respond to voltage deterioration if necessary.
4. Adjust the loading on Phase 1 or II, the Cross Sound Cable and Highgate HVdc ties to be within the 40% to 90% range of nominal rating of each pole.
5. Reduce the loading…

**U.S. Nuclear Regulatory Commission**

**Power Reactor Status Report for October 30, 2003**

**Reason or Comment**

- REDUCED POWER DUE TO SOLAR MAGNETIC DISTURBANCES
- REDUCED POWER DUE TO SOLAR MAGNETIC DISTURBANCES
- COASTDOWN TO REFUELING OUTAGE
- VIEWING SYSTEM PLANNING OPERATING GUIDE FOR SOLAR FLARE RESPONSE
- HOLDING OFF ON SWITCHYARD MAINTENANCE FOR SOLAR FLARE
- OFF LIMITS TAKING EXTRA READINGS PLANT COMPUTE DUE TO SOLAR FLARE
- CANCELLED D/G SURVEILLANCE DUE TO SOLAR FLARE RESPONSE

**UPDATE 2-NextEra cuts N.H. Seabrook output due to solar activity**

*First time Seabrook reduced for solar activity*
*Solar activity peaks about every 12 years*
*2013 expected to be the peak of the solar storm*

By Scott DiSavino

July 16 (Reuters) - NextEra Energy Inc said it expects to be able to increase power at the 1,247-megawatt Seabrook nuclear power plant in...
## Example of Specific Customer Requirements

### Electric Utilities

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification and Short-Term Forecasts</th>
<th>Regional Electric Power Grid Operators</th>
<th>Regional Space Weather Information for Improving Grid Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geoelectric Field Vector</td>
<td>6 hr. forecast, updated hourly</td>
<td>Various Power Companies</td>
<td>To know the key ingredient that plays into the GIC at selected points, is a critical parameter for the industry. To do this requires local dB/dt and geologic conductivities.</td>
</tr>
<tr>
<td>K-7 Geomagnetic Storm Warnings</td>
<td>Minutes to hours Operators want as much lead time as possible, but any lead time is considered useful</td>
<td>North America Electricity Reliability Corp.</td>
<td>The Midwest Independent System Operator receives the K-index forecast. If the index is K-7 or higher, MISO notifies all NERC reliability coordinators concerning the level and expected duration of the specific event. These forecasts are shared with all power system operating entities throughout North America so that those power systems that are particularly susceptible.</td>
</tr>
<tr>
<td>Regional Specification: Local impacts of geomagnetic storms</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Why Regional Forecasts? October 2003 Example

Long intervals of high Kp, yet...effects regional

- GIC impacts were more significant in Northern Europe where heating in a nuclear plant transformer was reported and a power system failure occurred on 30 October in Malmo, Sweden
- A representative from the North American Electric Reliability Corporation (NERC) commented:
  - “Although the bulk electric system was not significantly affected by the solar activity, some systems reported higher than normal GIC’s that resulted in fluctuations in the output of some generating units, while the output of other units was reduced in response to the K-index forecast.”
Geospace Model: Test, Evaluation, Selection

- **Goal:** Evaluate Geospace models (MHD and empirical) to determine which model(s) are ready for transition to operations
- **Focus:** Regional K and dB/dt (important to electric utilities)
- **Partnership:** Evaluation at NASA/Goddard CCMC working with SWPC, modelers and science community

SWPC Selection FY 14: U. Of Michigan (MHD); VT (Weimer Empirical) based on CCMC reports, internal and external advice, and following considerations:

- Strategic Importance
- Operational Significance
- Implementation Readiness
- Cost to Operate, Maintain, and Improve
Establishing Operational Value
Will this meet user requirements?

- Demonstrate model value – Value to customers must exceed cost to transition and to run model operationally

Geospace models evaluated: Regional K and dB/dt

CCMC, modelers, SWPC, and science community

Distribution of observed mid-latitude K values for modeled K values of 4, 6, and 8

K = 4  K = 6  K = 8

Observed K (Newport Station)

Modeled K

Univ. of Michigan
SWMF

ESWW 2016
University of Michigan Geospace Model
Part of the Space Weather Modeling Framework

**Input:** Solar wind speed, density, IMF at L1 (DSCOVR/ACE)

**Output:** 10-30 min forecast of the spatial and temporal variations of dB calculated on the ground
- via Biot-Savart integration
- BATS-R-US solves the ideal Magnetohydrodynamic (MHD) equations (similar to the Navier-Stokes equations in fluid dynamics but including magnetic properties of an electrically conducting fluid)
- Coupled to kinetic Rice Convection Model (RCM) and Ridley Ionosphere Model (RIM)

Parameters Passed between Component Models

\[
\begin{align*}
\frac{\partial p}{\partial t} + \nabla \cdot (\rho u) &= 0, \\
\frac{\partial \rho u}{\partial t} + \nabla \cdot \left[ \rho uu + I(p + \frac{1}{2}B^2) - BB \right] &= -B \nabla \cdot B, \\
\frac{\partial B}{\partial t} + \nabla \cdot (uB - Bu) &= -\nabla \cdot B, \\
\frac{\partial c}{\partial t} + \nabla \cdot \left[ u(c + p + \frac{1}{2}B^2) - u \cdot BB \right] &= -u \cdot B \nabla \cdot B,
\end{align*}
\]
Geospace Model Transition

Year 1

- Port the code to the NOAA super computer
  - National Weather Service (NWS) NCEP Central Operations Weather (NCO) Weather and Climate Operational Supercomputing System
  - SWMF is F90, MPI code + various scripts for a variety of tasks. Model runs continuously on 144 cores - 6 nodes

- Get the model to run in real-time
  - Geospace modeling system is controlled by a master control script (ecFLOW, python, bash) which runs every minute. Master control script deals with all aspects of model control:
    - Jump upwards in SW speed (requires model STOP/RESTART)
    - SW data outage (model shuts down after 15 mins with no input data)
    - WCOSS switch from Tide <-> Gyre
  - Output results (1 minute cadence) rsync back to SWPC [5GB data/day]
  - Develop Products

  At this point, the model is now ready for transition

Year 2

- Hand the computer off to NCEP Central Operations to run operationally
30-Day Model Evaluation Overview (March 15- April 14 2016)

- Magnetic Field (nT), Bz (nT)
- Density (p/cm³)
- Speed (km/s)
- Temperature (K)
- Kp – SWMF prediction, SWPC real-time Kp
- DST – SWMF prediction, KYOTO ground truth
Early Test: Real-time operations on NWS supercomputer in 2015.
Working with U. Mich, NCEP/NCO, and NASA/CCMC
Product: Local Time K Predictions

Real-Time SWMF Geospace [St. Patrick's Day Storm]

2015-03-17 00:00:00

Bz Total 7.6
Bz 3.1
Density 11.5
Speed 421.4
SWMF predicted Kp 3.0

Space Weather Prediction Center

ESWW 2016
Geospace Model Displays for Forecasters and Customers (Public)

Predicted Delta B’s due to Ionospheric and Magnetospheric Current Systems

Operational October 1, 2016
Geospace Model
St. Patrick’s Day Storm 3/17/2015 (demo)
Predicted delta B’s
Future Geospace Model Products

Improved Products:
• Feedback from customers and users

Drive Other Models:
• Ionosphere, Aurora,

Electric Field Maps:
• Provide real-time regional geomagnetic storm impacts for electric power industry
  – Based on the USGS ground magnetometer network
• Partner with USGS, NASA CCMC, NRCAN to develop a real-time model of regional Electric Field
• Status: Test products available soon
• In parallel: work with CCMC on Solar Shield initiative for complementary E-field forecast capability
Additional User Needs:
High-Latitude Navigation and Communication

A Shortcut Across The Top of the World

The Northeast Passage, across the Arctic Ocean, provides a shorter alternative for cargo vessels travelling between Europe and Asia than using the Suez Canal. It is shorter than the Panama Canal route for some voyages between the North American west coast and Europe.

LENGTH OF A VOYAGE TO ROTTERDAM FROM:

YOKOHAMA, JAPAN
12,894 miles via Suez Canal,
8,452 miles via Northeast Passage

SHANGHAI, CHINA
12,107 miles via Suez Canal,
9,297 miles via Northeast Passage

VANCOUVER, CANADA
10,282 miles via Panama Canal,
8,038 miles via Northeast Passage
Distant Future: Longer (1-3 day) Forecast: Drive Geospace Model with WSA-Enlil

Still need a forecast of Bz
Operations to Research (O2R): Improving models after transition to operations

Geospace Model Development after Handover:
- How low densities were handled in the inner magnetosphere
- Different numerical solver to run continuously in real time
- Driving the model with solar wind when high-speed streams overtake slow

Operational Models in General
- Incorporating the latest research results.
- Adding improvements and new physics (in ways that are different from scientific studies)
- Establishing benchmarks for model performance validation

Model “Ownership” and Intellectual Property Issues
Conclusions

- Transitioning a model/product into operations requires consideration of a number of critical factors;
  - Strategic Importance of Customer
  - Relevance to Customer
  - Accuracy During Critical Events
  - Reliability, Supportability, Robustness

- The Geospace model meets these requirements;
  - Strategic: Impact-based decision support services for the electric power industry
  - Relevance: Regional specification and forecasts of geomagnetic activity and major geomagnetic storms
  - Accuracy: Improvement over current capabilities
  - Supportability: A robust modeling environment with continued support
  - Future Improvements: Expansion to other products and services and coupling to other models