Community-based Space Weather Modeling for the Future

Bob Robinson

NSF
Solar/Solar Wind Timeline

Research Observations:
- SOHO
- Yohkoh
- TRACE
- HESSI
- SOLIS II
- HFRX
- TIMED
- CCMC
- RPCs

Research Models:
- SOLIS II
- SOLIS
- HESSI
- STEREO
- Solar B
- TRACE
- SOHO
- Yohkoh
- Ulysses
- HFRX
- TIMED
- CCMC
- RPCs
- Solar Probe
- L5
- COMX

Solar Magnetic Field Extrapolation Model for Flare Prediction (S2, S5, S16, S17)

Solar Irradiance Model (S1)

Heliospheric/Mercury Mission

Basic Model for Solar Plasma (S4, S14)

Empirical Solar Cycle Model (S22)

3D MHD Dynamic Model of CME-driven Shock-related signatures (S8, S13, S16)

3D MHD Dynamic Model of Coronal Magnetic Field Region (S3)

3D MHD Dynamic Model of Coronal acceleration Region of Solar Wind (S3)

Model of CME Initiation (S8, S13, S16)

Solar Activity Forecast Model (S4, S14)

Solar Wind Dynamics Observatory

3D Magnetohydrodynamic Model of Corona and Magnetic Field (S4, S14)

LWS Solar Dynamics Observatory

Hi Resolution Coronal Magnetic Field Model

Model for Magnetic Energy Dissipation

3D Magnetic Reconnection in Active Regions (S4, S14)

Secular Change (S22)

Solar Probe Model of CME-driven Shock-related signatures (S8, S13, S16)

Solar Irradiance Model (S1)

Heliospheric/Mercury Mission

Basic Model for Solar Plasma (S4, S14)

Empirical Solar Cycle Model (S22)

3D MHD Dynamic Model of CME-driven Shock-related signatures (S8, S13, S16)

3D MHD Dynamic Model of Coronal Magnetic Field Region (S3)

Model of CME Initiation (S8, S13, S16)

Solar Activity Forecast Model (S4, S14)

Solar Wind Dynamics Observatory

3D Magnetohydrodynamic Model of Corona and Magnetic Field (S4, S14)

LWS Solar Dynamics Observatory

Hi Resolution Coronal Magnetic Field Model

Model for Magnetic Energy Dissipation

3D Magnetic Reconnection in Active Regions (S4, S14)

Secular Change (S22)
Research Observations

- SuperDARN
- Riometers
- Incoherent Scatter Radars
- Ground-based Optical Instruments
- AGOs

ARGOS
MSX
POLAR
FAST
GLO
ASTRID-2
SNOE

TIMED
TERRIERS

COSMIC

IMAGE

C/NOFS

1999

2004

2009

Ionosphere/Thermosphere Timeline
Patch-Panel Approach to Space Weather Modeling

Observations
- Ground- and Space-Based Solar Observations
- Solar Wind Observations at L1
- In situ Magnetospheric Observations
- Magnetospheric and Auroral Imaging
- Ground-based Magnetic Observations
- In situ Ionosphere and Thermosphere Observations
- Ground-based Ionosphere/Thermosphere Observations
- Scintillation Observations

Solar/Solar Wind Models
- Solar Active Region Prediction Model
- Coronal Magnetic Field Model
- Quiet and Disturbed Solar Wind Model
- Solar Irradiance Model

Magnetospheric Models
- Physics-based Hybrid Model
- Radiation Belt Energetic Particle Model
- Magnetopause Model
- Empirical Magnetic Field Model
- Magnetotail Model
- Polar Cap Potential Model
- Convection Model
- Electrodynastic Model
- Empirical Convection and Current Model
- Substorm Model

Ionosphere/Thermosphere Models
- Ionospheric Specification Model
- Empirical Ionosphere Model
- Empirical Thermosphere Model
- Physics-Based Ionosphere/Thermosphere Model
- Scintillation Model

Data Bases
- Solar
- Solar Wind
- Magnetosphere
- Ionosphere/Thermosphere

Products
- Direct Input Port
- Assimilative/Feedback Input Port
- Output Port
Space Weather Model Development

**DoD Customers and Operations Support**

**Civilian Customers and Operations Support**

<table>
<thead>
<tr>
<th>NSF/AF/ONR</th>
<th>NASA LWS TR&amp;T</th>
<th>NSF CISM</th>
<th>AF/ONR MURI</th>
<th>Core Space Science Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targeted S. W. Research</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rapid Prototyping Centers
Verification Documentation

CCMC
Model Selection Runs on Request Validation Metrics

Space Weather Research Community
Space Weather Model Development

- Research Community
  LWS, NSWP, MURI, CISM, etc.

- CCMC
  Validation
  Runs-on-Request
  Metrics

- Selection

- Rapid Prototyping
  Centers
  Verification
  Test
  Documentation

- Space Weather
  Operations and
  Customers

Model Flow
### NSF Contributions to Space Weather Activities

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Proposal Competitions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CISM Research</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SuperDARN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMPERE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PolarDARN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-Latitude SuperDARN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSMIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMISR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CubeSats</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CISM Model Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NASA/NSF Strategic Partnership</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space Weather Week</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CISM Educational Activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Space Weather Journal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FDSS Awards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CISM Knowledge Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Zermatt Discussions

• The workshop included four panel sessions covering the following topics:
  – Lessons learned from existing community programs,
  – Lessons learned from current modeling activities,
  – Interest by modelers in a community program, and
  – Perspectives from the space weather user community.
Zermatt Conclusions

- Space Weather modeling is good
- General support for a community modeling program
- Disagreement about the role of a center with sustained support
- Where should new funding go? Targeted toward space weather modeling or enhancement of SHINE, GEM, and CEDAR
- Targeted SW modeling should be for model development, test, validation, and use.
- Need balance between individual investigator awards and center-type modeling activities.
CISM Lessons Learned
(From Quinn and Hughes, SW 2009)

• Coupled models capture important “system” aspects of space weather.
• Component model development is essential.
• A single Sun-to-Earth model does not meet all needs; a flexible suite of models that can be coupled and driven in different combinations is more practical and effective.
• For models with future application to operations, sustained interaction between forecasters and model developers is essential.
• “Center” synergy encourages collaborations, stimulates research, enables valuable educational and outreach opportunities.
CISM suggestions on the way forward:

- Keep the component model pipeline primed.
- Integrative activities (coupling models, building frameworks, implementing new software and hardware technologies) must be supported.
- Community-directed model development that transcends institutional and disciplinary boundaries is essential.
- Transitioning research to operations requires extended collaborations among all stakeholders.
- Systematic validation of models provides the foundation for understanding fundamental processes and model capabilities.
Recommendations from discussions on the Space Weather Prediction Testbed (SWPT) in January and March 2009

- Protection of intellectual property
- The importance of in-house research at NOAA SWPC
- Participation of model developers in transitioning
- Competitive bidding of SWPT implementation
- Composition of the SWPT Executive Board
- Public distribution of metrics results
- Multiple paths from research to operations
- Fair and open selection process for models
- Strong participation from the private sector
- Importance of interagency participation
- Importance of including different types of models
- Accounting for the staffing and computing limitations of the operational centers
Space Weather Community Model Transitioning

SW Modeling Team

Research

Operations

Individual Investigator Awards

Space Weather Model Consortium

DoD MURIs

Space Weather Community Model Transitioning Operational Agencies CCMC

SW Model Development

NRL AFRL SW Model Development

Research Agencies

CCMC

For Space Weather Research And Model Development (NSWP, LWS, GEM, CEDAR, SHINE, etc.)
## Distribution of Space Weather Community Modeling Activities

<table>
<thead>
<tr>
<th></th>
<th>Individual Investigator Projects</th>
<th>Space Weather Modeling Consortia</th>
<th>DoD MURIs</th>
<th>NRL, AFRL Model Development</th>
<th>Science Team</th>
<th>CCMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Targeted Basic Research</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component Model Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-to-End Model Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model Validation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education and Outreach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge Transfer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrative Activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Runs on Request</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Web-enabled Access</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

How to Move Forward

• Develop a plan that captures what we are already doing.
• Emphasize communication and coordination.
• Justify redundancy of effort or eliminate it.
• Emphasize how strongly coupled the Sun–Earth system is.
• Stay on the same page.