Metrics Studies, Verification & Validation

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CCMC Workshop, 2005

http://ccmc.gsfc.nasa.gov
CCMC Function

- Evaluate scientific research models to address National Space Weather needs.

- Perform independent and unbiased model testing and validation.
Model Testing and Validation Components

• **Science-based validation**
  – Test model validity
  – Address natural events or model capabilities
  – Detailed analysis for selected events
  – Broad feedback to code developers
  – Essential for further model improvement

• **Metrics studies**
  – Measure model usefulness for operations in comparison with some simple standard model.
  – Create simple measure of model capabilities (“one number”).
  – Allow objective comparison between models with comparable output.
  – Measure the improvement of model capabilities over time (usefulness of model upgrades).
  – Focus on parameters useful for operations
  – Based on repeatable comparison between model output and measurements.
  – Blind studies
Outline

- Examples of Science-Based Validation Studies
- Role of Runs on Request System Users in V&V
- Examples of Current Metrics
- Other Metrics Opportunities
- Future Plans
Radiation Belt Model Improvement

Particle Fluxes at Geosynchronous Orbits

- **50 - 75 keV**
- **75 - 105 keV**
- **105 - 150 keV**
- **150 - 225 keV**
- **225 - 315 keV**
- **315 - 500 keV**
- **500 - 750 keV**
- **0.75 - 1.1 MeV**
- **1.1 - 1.3 MeV**

**Flux Increase**

**Flux Decrease/Flat**

**Original Model**

**Improved Model**

**Los Alamos National Laboratory Satellite Data**
Role of Spatial Resolution in Modeling Magnetopause Position and Structure

Spatial resolution 1/4 Re

Time = 05:20:00 z = 6.00R_E

Magnetopause

Spatial resolution 1/16 Re

Time = 05:20:00 z = 6.00R_E

Kuznetsova et al., 2005
Magnetopause Structure Validation

Time = 04:08:00 $z = 6.00R_E$

$v \ [\frac{\text{km}}{\text{s}}]$
Min: 0.0
Max: 3.33

$B \ [\text{nT}]$
Min: 0.0
Max: 30.0
Flux Transfer Event seen by Cluster
Testing the Ability of Global MHD Models to Simulate Flux Transfer Events

Spatial resolution 1/4 Re

Spatial resolution 1/16 Re
Role of Spatial Resolution and Grid Orientation

55 minutes after southward ($\theta = 180^\circ$) IMF turning, $y = 0$

- **Dipole Tilt = 0°**
  - $V_x = V = -300$ km/s
  - $V_z = 0$
  - Resolution: 1 / 4 Re

- **Dipole Tilt = 0°**
  - $V_x = V = -300$ km/s
  - $V_z = 0$
  - Resolution: 1 / 16 Re

- **Dipole Tilt = -10°**
  - $V_x = V \cos (10°)$
  - $V_z = V \sin (10°)$
  - Resolution: 1 / 16 Re
Role of RoR Users in V&V

2001 – 2003: ~ 200 requests, 10 publications/presentations

2004 – 2005: ~ 400 requests, > 30 publication/presentations

Informal feedback from users
• An output **parameter** from a model.
• A **measurement** that can be used for comparison (satellite or ground-based).
• **Model Score**: assesses the difference between the parameter from the model and the measurement.
• **Standard model** for comparison
  - mean (no perturbations)
  - persistence (use previous measurements as prediction)
• **Skill Score** (M): model score vs. standard model score.
  
  \[
  \begin{align*}
  M < 0 & \quad \text{worse than standard} \\
  M = 0 & \quad \text{as good as standard} \\
  0 < M < 1 & \quad \text{better than standard} \\
  M = 1 & \quad \text{perfect score}
  \end{align*}
  \]
Heliosphere Metrics

- **Data**
  - ACE velocity and density.

- **Models**
  - Heliospheric Tomography (B. Jackson and P. Hick).
  - ENLIL (D. Odtrcil)

- **Standard Models:** mean, persistence

- **Metrics**
  - Model score: $D_i = \sqrt{\frac{\sum |\Delta H_{\text{model}} - \Delta H_{\text{data}}|^2}{\text{npts}}}$. 
  - Skill score: $M_i = 1 - D_i / D_s$
Heliospheric Tomography: Model and Data Comparison

ACE Data (averaged every 6 hours)

HelTomo Model output every 6 hours

Mean

- **Density**
  - Period 1 (27 days)
  - Period 2 (27 days)

- **Velocity**
  - Period 1 (27 days)
  - Period 2 (27 days)
Heliospheric Tomography Skill Score

Scores for Density

Scores for Velocity
ENLIL: Model and Data Comparison

D. Odstrcil, P. Macneice
Polar Cap Size Metrics

Boundary between open and closed field lines (BATSRUS, OpenGGCM)

VIS Earth Camera 15 July 2000 20:20 UT

Polar cap boundary observed by POLAR

Lutz Rastaetter, 2005
Polar Cap Size Metrics

Polar cap from field-aligned currents pattern

(Weimer 2K, BATSRUS, OpenGGCM)

Positions of the maximum or minimum of the field-aligned current in each of the 16 sectors of local time.

To reduce influence of currents near the pole use \( \text{FAC}*\sin(\text{co-latitude}) \)

Disregard 7 degrees near low-latitude boundary of patterns (for Weimer-2K)

VIS Earth Camera 15 July 2000 20:20 UT

Polar cap boundary observed by POLAR

Lutz Rastaetter, 2005
July 15, 2000 – Bastille Day Storm:
Time period: 14:00 – 24:00

Mean Skill Score

**BATSRUS FL tracing:** 0.226
**BATSRUS FAC:** 0.149
**OpenGGCM FL tracing:** -0.137
**OpenGGCM FAC:** -0.252
**Weimer-2K FAC:** -0.473

Lutz Rastaetter, 2005
Inner Magnetospheric Metric

- Data
  - Proton fluxes from LANL geosynchronous satellites
- Model
  - For K Ring Current model driven by a MHD model
- Skill Score using the Root Mean Square Deviation
Ring Current Metrics

Log(Pitch Angle-Averaged Differential Flux (#/cm²/s/sr/keV))

Energy Skill Score
Band (keV)
50-75 -0.995
250-400 0.232

Geosynchronous proton flux data was provided by the Energetic Particle team at Los Alamos National Laboratory, Richard Belian (PI).

K. Keller
Prediction of Daily-Averaged MeV Electron Intensity at Geostationary Orbit (UPOS, APL)

Skill score: 0.08

A. Chulaki
Other Metrics Opportunities.
Solar Wind, Energetic Particles Forecasting.

Connection to active region

Model: ENLIL
Electron Density Parameters: Vertical Profiles, NmF2, TEC

Observations:

- Incoherent Scatter Radars, GPS, Ionosonds

Models:

- CTIP, SAMI2, GITM2, GAIM
Ionosphere Electrodynamics Metrics:
Ground Magnetic Perturbations (H component).

Skill Scores for Weimer Models

Score Averaged over 6 Days
Averaged over 10 Stations in Greenland Chain

Weimer 2K Electric Potential Model
Weimer Electric Potential Model Version 5
Weimer Electric Potential Model Version 5 with MV delay
Weimer FAC Model Version 1
Weimer FAC Model Version 2
Weimer FAC Model Version 5
Weimer FAC Model Version 5 with MV delay

Model and Version

K. Keller, 2003
Future Plans

• Continue to follow National Space Weather Program Implementation Plan guidelines.

• More models (GAIM, AbbyNormal,…), model chains, frameworks. Focus on physics-based models with operation benefits.

• Focus on parameters most useful to operations that CCMC models can provide. Work with operators to identify suitable metrics.

• Priority evaluations for operations
• Development of reusable V &V and metrics software.
• Expand RoR System to benefit V&V studies
• Continue working with model developers to improve model performance.

We are open to suggestions!
Other Metrics

• Ionospheric forecasting (CTIP, GAIM)
  Electron density parameters
  (vertical profiles, TEC, NmF2)

• Solar Wind Forecasting, Energetic Particles
  Plasma and magnetic field parameters
  Connection to active region
Ionospheric metrics

• Data
  – Ground magnetic perturbations measured at 10 stations in the Greenland chain using the H component of the data.

• Models
  – Weimer electric potential model (2 different versions).
  – Weimer field-aligned current model (3 different versions).

• Standard model: no perturbations

• Metrics
  – Model score: \( D_i = \sum |\Delta H_{\text{model}} - \Delta H_{\text{data}}| / \text{npts} \).
  – Skill score: \( M_i = 1 - D_i / D_s \)
Comparison of Model Results to Data

Black: Data from ground magnetometers
Orange: Model results from Weimer 2k Electric Potential Model
Blue: Model results from Weimer Electric Potential Model Version 5

Magnetometer data was provided by the Danish Meteorological Institute (Dr. Jurgen Watermann, Project Scientist)
Sample of Ring Current Metric

<table>
<thead>
<tr>
<th>Energy Band (keV)</th>
<th>Energy Skill Score</th>
<th>Cross Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-75</td>
<td>0.135</td>
<td>.59</td>
</tr>
<tr>
<td>113-170</td>
<td>-0.02</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Time

Black is LANL data. Blue is the model results.
Methods of polar cap determinations

• **Field line tracing:**
  Polar cap boundary is between open and closed field lines as traced through the magnetosphere. Field lines start in the high-latitude region at the near-Earth boundary.
  Models: **BATSRUS, OpenGGCM**

• **Polar cap from field-aligned current (FAC) pattern:**
  Positions of the maximum or minimum of the field-aligned current in each of the 16 sectors of local time form the cap.
  Models: **BATSRUS, OpenGGCM, Weimer-2K FAC**
  Use FAC*sin(co-latitude) to reduce influence of currents near the pole (e.g., NBZ currents).

• **Weimer-2K FAC:** disregard 7 degrees near low-latitude boundary of patterns.
Future Plans

• Global magnetosphere, Inner magnetosphere
  – Extend polar cap study
  – Comparison with GOES magnetic field data
  – Extend ring current study
  – Perform similar analysis for Fok Radiation Belt Model
  – Prediction of MeV Electron Intensities at geostationary orbit.

• Global magnetosphere models
  – Comparison with GOES magnetic field data

• Solar, Heliosphere
  – Extend metric to new models

• Ionosphere
  – GAIM, Absorption model
  – Total Electron Content, NmF2