From Research To Operations: Transitioning CISM Models

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Overview

• CISM
• Models in transition or being readied for transition.
  • WSA-Enlil – in transition
  • CMIT – ready for transition
  • SEPMoD – under development and testing
• Lessons Learned
• Future of Space Weather Modeling
Center for Integrated Space weather Modeling

• An NSF Science and Technology Center
• Developing a Sun-to-Earth suite of models
• A multi-institutional center led by Boston University involving 11 other institutions
• Strong partnerships and working relationships with SWPC, AFRL, CCMC
• Efforts in research, education, knowledge transfer, and increasing diversity in science.
The CISM Space Weather Summer School
This year: July 19 - 30, 2010

Students and faculty working at the CISM Summer School – a two-week school held each year.
WSA-ENLIL-Cone Transient Solar Wind

- Undergoing formal transition to NCEP operations.
- Transition now largely out of CISM hands.
- Research on cone parameter specification & sensitivities for forecast involves CISM and partners.
WSA-Enlil-Cone model

Observations
- Solar Magnetogram
- CME’s Corona-graph

Empirical Models
- Wang-Sheeley-Arge
  - Coronal B Field
  - Solar Wind speed
- Cone Model
  - CME size, initial speed and direction

MHD Model
- Enlil
  - Solar Wind speed, density, and B Field
- Earth
Wang-Sheeley-Arge Model Visualization Tool

Grey – surface magnetic field strength
Color – open mag field with solar wind speed

SOHO EIT image for comparison
CME cone geometry
CME Visualization
Intended SWx Benefits

• Provide 1-4 days advance warning of oncoming CMEs

• Provide improved warning of CIRs

• Pave the way for future generations of SWx models:
  Geospace
  Ionosphere
  Upper atmosphere
  Energetic particles
Coupled Magnetosphere Ionosphere Thermosphere model -- CMIT

- CMIT Model Overview
  - LFM, MIX, TIEGCM Components
  - Resolution and Performance

- Previous Validation efforts
  - Magnetospheric climatology
  - Regional dB/dt
CMIT – models the geospace system

Solar-wind IMF

Magnetosphere Model (LFM)

\( J_{||}, \rho, T \) \( \Phi \)

Magnetosphere-Ionosphere Coupler

\( \Phi, \varepsilon, F \) \( \Sigma_p, \Sigma_H \)

Thermosphere/Ionosphere Model (TIEGCM)

Observations

Solar EUV F10.7

Lower Atmos Forcing
**LFM Magnetospheric Model**

- Uses the ideal MHD equations to model the interaction between the solar wind, magnetosphere, and ionosphere
  - **Computational domain**
    - \(30 \, R_E < X < -300 \, R_E\) & \(\pm 100 R_E\) for YZ
    - Inner radius at \(2 \, R_E\)
  - Calculates
    - full MHD state vector everywhere within computational domain
  - Requires
    - Solar wind MHD state vector along outer boundary
    - Empirical model for determining energy flux of precipitating electrons
    - Cross polar cap potential pattern in high latitude region which is used to determine boundary condition on flow
TIEGCM

- Uses coupled set of conservation and chemistry equations to study mesoscale process in the thermosphere-ionosphere
  - Computational domain
    - Entire globe from approximately 97km to 500km in altitude
  - Calculates
    - Solves coupled equations of momentum, energy, and mass continuity for the neutrals and O$^+$
    - Uses chemical equilibrium to determine densities, temperatures other electrons and other ions (NO$^+$, O$_2^+$, N$_2^+$, N$^+$)
  - Requires
    - Solar radiation flux as parameterized by F10.7
    - Auroral particle energy flux
    - High latitude ion drifts
    - Tidal forcing at lower boundary
MIX Ionospheric Simulation

• Uses the conservation of current to determine ionospheric currents and the cross polar cap potential
  – Computational domain
    • 2D slab of ionosphere, usually at 120 km altitude and from pole to 45 magnetic latitude
  – Calculates
    • $\nabla \cdot \left( \Sigma_P + \Sigma_H \right) \nabla \Phi = J \sin(\eta)$
  – Requires
    • FAC distribution
    • Energy flux of precipitating electrons
    • F10.7 or conductance
Performance

- CMIT Performance is a function of resolution in the magnetosphere ionosphere system
  - Low resolution
    - 53x24x32 cells in magnetosphere with variable resolution smallest cells ½ RE
    - 5° x 5° with 49 pressure levels in the ionosphere-thermosphere
    - On 8 processors of an IBM P6 it takes 20 minutes to simulate 1 hour
  - Modest resolution
    - 53x48x64 cells in the magnetosphere with variable resolution smallest cells ¼ RE
    - 2.5° x 2.5° with 98 pressure levels in the ionosphere-thermosphere
    - On 24 processors of an IBM P6 it takes an hour to simulate and hour
Magnetospheric Climatology

- Comparison of time-averaged Geotail (top row) and LFM (bottom row) thermal pressure (a,d), magnetic pressure (b,e), and perpendicular flows (c,f) in magnetotail equatorial plane.
- Millions of data samples comprise each average map.
- Similarities and differences in magnetotail climatology reveal strengths/weaknesses of model

(Details described in Guild et al., 2004)

Equatorial cross-section showing snapshot of LFM magnetotail, Sun to right, solar wind blows from right to left. Color coding indicates plasma flow velocity (Red/Yellow = sunward flow, Green/Blue = antisunward flow).
CMIT dB/dT analysis at an observatory

Event 2 (Dec 14–18/2006), ABK: Horizontal dB model results

Event 2 (Dec 14–16/2006), ABK: Horizontal dB data

LFM, threshold: 200 nT  CMIT, threshold: 200 nT  Data, threshold: 300 nT

Kp, threshold: 5  Kp-estimated, threshold: 5  Data, threshold: 300 nT
Regional dB Forecast

Project: CISM
Model: CMIT 2.5.0
Input: Real-Time ACE
Method: Biot-Savart1

4/14/2006 10:40 UT

Map of regional dB forecast with data from various locations such as YKC, MEA, NEW, FRN, IOA, SNK, OTT, and FRD. The map also shows the time frame from Apr 14 2006 to Apr 15 2006 and a specific time of 10:40 UT.
Solar Energetic Particle Model – SEPMOD

- Models the SEP’s created at the shock waves generated by Interplanetary Coronal Mass Ejections (ICME) in the heliosphere.
- SEPMOD uses as input a ICME in a heliospheric model such as WSA-Enlil-Cone
- SEPMOD relies on a sufficiently accurate description of the underlying solar wind and ICME shock structure. This is needed to determine:
  - Shock source strength and attributes
  - Shock connectivity to an observer
  Both of which are time dependent
Earth field line traced at 5 time different times

WSA-Enlil-Cone run showing ICME

SEPMOd traces field lines to find how the earth is connected to the interplaneary shock then populates that field line with a particle spectrum that depends on the shock properties.
Comparison of model SEP fluxes with observations for three ICME events: May 1997; Nov 1997; Dec 2006.
Lessons Learned from SWPC Transitions*

• Sophisticated models can’t be “thrown over the wall”. A sustained interaction is needed.
  – Modelers don’t know what forecasters need.
  – Forecasters don’t know what models can (or could) do.
  – Defining & developing what’s needed is non-trivial.
  – Iteration is required to derive good forecast products.

• A “transition team” approach is workable (forecasters, developers, computation experts, scientists, managers).

• As an STC, CISM has unique opportunity as pathfinder.

• NSWP needs mechanisms that support such collaborations.

Future of Space Weather Modeling

An unfortunate coincidence of end dates:

- NSF: CISM Science and Technology Center ends July 2012
- NASA: Living With a Star Strategic Capabilities projects end in 2012
- DoD: Space weather related MURIIs end in 2012
- Approximately $9 million less funding per year into space weather model development and validation after 2012 (Tamas Gombosi – informal communication)