Improvements for Operations in the Space Weather Modeling Framework

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Space Weather Modeling Framework

The SWMF is freely available at http://csem.engin.umich.edu
We have run BATS-R-US as a regional model to self-consistently model flux emergence from the convective zone through the photosphere (Manchester and Fang).

30x30x40 Mm shown
Gray scale is vertical velocity; Red lines are magnetic field lines.
Near-Earth Models of the SWMF
Magnetosphere-Ionosphere Coupling

- Global Magnetosphere - BATSRSU
- Inner Magnetosphere - Rice Convection Model
- Ionospheric Electrodynamics - Ridley Ionosphere Model

- Magnetic field integrals
- Pressure/density correction
- Electric potential
- Field aligned currents

Potentially RCM

Typically RCM

Potential

Aurora

FAC

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Testing Grids

Grid 1: 1.61M cells

Grid 2: 1.02M cells

Grid 3: 1.00M cells

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$D_{st}$ For Different Grids

April 6th, 2000 storm

Kyoto 1-hour Dst

Grid 1 (1.6M cells)

Grid 2

Grid 3 (1.0M cells)
We have noticed that the Inner Magnetosphere Model (RCM) tends to not recover after a storm.

There are many possible reasons for this:

- Plasma injected too deep into the inner magnetosphere, where MHD code can not get rid of it (inside boundary).
- Plasma close to the inner boundary of the MHD code (inside IM) could diffuse Earthward, inside the boundary of MHD.
- Flushing out of the inner magnetosphere may not be accurately modeled in the recovery phase (strong E-field, low density).
- Loss processes not adequate in IM.
  - MHD not feeding it proper O+/H+ ratio
  - MHD not feeding it proper temperature
  - Some processes not accounted for

Mimic losses artificially through a 10 hour loss process.
- Ensures that the ring current always decays back to background.
The density flowing into the inner magnetosphere is crucial. Total density can determine the energy content of the ring current. Mass and temperature determine gradient-curvature drift, so how far the particles penetrate towards the Earth. Species can set loss rates. Charge exchange.

Some of the density in the magnetosphere comes from the solar wind.

Some of the density in the magnetosphere comes from the ionosphere. Recent studies have shown that during southward IMF, significantly more density is from the ionosphere.

Density

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The BIG problem is specifying the amount of ionospheric plasma (O+ and H+) that enters the magnetosphere.

- Empirical models exist for Cusp outflow.
- First principles codes exist for outflow:
  - Computationally intensive
  - Something else to break

Decided to do something very simple:

- Background outflow (basically H+)
- Elevated outflow during strong driving (O+ outflow)
- Density = Base + CPCP*factor
Another issue!

How to tell inner magnetosphere how much is O+ and how much is H+

Should be done with a multifluid code (we have this, but not robust)

Allow it to change based on (self-consistent) Kp (Empirical relationship – Young et al.)

Simple option – hard code a ratio (worst choice, but easiest to implement and test)

We need to spend more effort on this aspect!

Density is hard!

Outflow rates? Ratios? Solar wind entry?

Need to get it all right!
Density Changes

April 6th, 2000 storm

Kyoto 1-hour Dst
H/O=7/3 rho=28/cc 2.5Re
H/O=7/3 rho=28/cc 2.25Re
H/O=4/6 rho=28/cc 2.5Re
H/O=7/3 rho=56/cc 2.5Re
H/O=9/1 rho=56/cc 2.5Re
More Density Changes

October 29th 2003 storm

<table>
<thead>
<tr>
<th>Plot Details</th>
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<tbody>
<tr>
<td>Kyoto 1-hour Dst</td>
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Dst [nT] vs time [h]
More More More Density Changes

![Graph showing density changes from Aug 31 to Sep 01, 2005 UT Hours. The x-axis represents UT hours from 09 to 09 on Aug 31 to Sep 01, 2005, while the y-axis ranges from -150 to 50. Various lines and markers represent different density change models, such as `nodecay_n28_comp7_3`, `withdecay_cpcpbc0.1_28_comp9_1_IMDensityCoupling`, and others. Each line corresponds to a specific model configuration, illustrating the density changes over the specified time period.](image)
April 6th, 2000 storm

-300 -200 -100 0 100 200 300

dst

Time [h]

H/O=9/1 rho=56/cc
cpcpbc=18,0.2
cpcpbc=28,0.1
cpcpbc=28,0.1 imcouplerho
rho=28/cc imcouplerho
rho=28/cc imrho fixpolar 28,1e5
cpcpbc=28,0.1 imrho fixpolar 56,5e4 smooth
Ground-Based Magnetometers

- The SWMF can calculate ground-based magnetometer perturbations while it is running.
- Biot-Savart integrals within:
  - The global magnetosphere
  - The ionosphere
    - Hall and Pedersen
  - Field-Aligned Currents in the gap region between ionosphere and inner boundary of MHD code.
- At high-latitudes, Hall is dominant.
- At low-latitudes, magnetosphere is dominant.
- At mid-latitudes, all are important.
Exceeding magnitude threshold (100 nT, 300 nT, 500 nT, 600 nT) predictions for the GEM Challenge events.
Exceeding dB/dt threshold (0.3 nT/s, 0.7 nT/s, 1.1 nT/s, 1.5 nT/s) predictions for the GEM Challenge events
 Synthetic $K_p$ Index

- 24 virtual magnetometers at constant latitude.
- H-component is converted to $dH$, then local $K$.
- Average of local $K$ yields $K_p$. 

$faKe_p$: 

![Graphs showing time series data for $H$-component, $dH$, and $K_p$ indices over time from 2005-08-31T09:00:00 to 2005-08-31T12:00:00]
**faKeₚ**: Synthetic $K_p$ Index

- Data-model validation for $faKe_p$ is underway.
- Provides localized $K$ data products for quick-look activity monitors.
- Can be used as inputs for $K_p$-dependent values ($D_{LL}$, Young et al. composition, etc.) for new, expanded model couplings.
Summary

- The Space Weather Modeling Framework can simulate many aspects of the Sun-Earth system.

- The SWMF has many models of the near-Earth space environment coupled together to accurately represent the magnetospheric environment.

- In order to more accurately model the magnetosphere during storms, we have:
  - Added a decay time to the inner magnetosphere model (RCM)
  - Added a cross polar cap potential dependent ionospheric outflow
  - Changed the ratio of O+/H+ for the inflow to the RCM
  - More work is needed to validate the physics!

- The magnetic field calculations in the SWMF include currents from the entire domain.
  - The ground-based perturbations are ok, but not spectacular
  - High-latitude delta-Bs are not as sensitive to numerics as Dst prediction
  - We can produce a regional Kp index
Thank You!