UNH-CCMC Collaboration

J. Raeder, D. Larson, W. Li, A. Vapirev
Space Science Center, University of New Hampshire
T. Fuller-Rowell, N. Maruyama
NOAA & Cires
M.-C. Fok, A. Glocer
NASA/GSFC
F. Toffoletto, B. Hu, S. Sazykin & A. Chan
Rice University
A. Richmond & A. Maute
NCAR/HAO

CCMC Workshop, Key Largo, FL, January 25, 2010

Overview

- What is OpenGGCM, where does it come from?
- OpenGGCM at CCMC.
- OpenGGCM use:
  - Tail instability (Siscoe et al.)
  - Ionosphere currents (Vennerstroem et al.)
  - THEMIS support.
  - Metrics.
  - Other science.
- Development under LWS / Strategic Capabilities.
- Development under NSF/PetaApps.
- Other Developments.
- Future Releases (v4.0).
OpenGGCM: Global Magnetosphere Modeling

The Open Geospace General Circulation Model:

- Coupled global magnetosphere - ionosphere - thermosphere model.
- 3d Magnetohydrodynamic magnetosphere model.
- Coupled with NOAA/SEC 3d dynamic/chemistry ionosphere - thermosphere model (CTIM).
- Coupled with inner magnetosphere / ring current models: Rice U. RCM, NASA/GSFC CRCM.
- Model runs on demand (>300 so far) provided at the Community Coordinated Modeling Center (CCMC at NASA/GSFC).
- Fully parallelized code, real-time capable. Runs on IBM-datastar, IA32/I64 based clusters, PS3 clusters, and other hardware.
- Used for basic research, numerical experiments, hypothesis testing, data analysis support, NASA/THEMIS mission support, mission planning, space weather studies, and Numerical Space Weather Forecasting in the future.
- Funding from NASA/LWS, NASA/TR&T, NSF/GEM, NSF/ITR, NSF/PetaApps, AF/MURI programs.

Aurora
Ionosphere Potential
Heritage

- (early 80’s) First global magnetosphere MHD models: LeBouef, Ogino @UCLA, Lyon, Brecht, Fedder @NRL.
- (~2000) UCLA global MHD model + NOAA/CTIM model == OpenGGCM.
- (2002) Second model to be implemented at the CCMC. >300 (?) runs on demand at CCMC to date.
- (2006) NASA/NSF “Strategic Capabilities” funding for CTIpe/RB/RCM/CRCM coupling and V&V.
- Current uses: mission planning (THEMIS, Swarm, Mag-Con), complement data analysis, study fundamental processes, numerical experiments.
- >30 data comparison studies in the refereed literature since 1995: tail physics, magnetopause, ionosphere, ground mags ...
- Real-time capable with modest resources.
Example of OpenGGCM use: Investigation of tail instability by George Siscoe

Fig. 1. Three frames from the output of CMC run UCLA2.UCLA2.00105.3 showing magnetic field lines and contours of plasma pressure in the midnight meridian plane from 10 $R_E$ to 25 $R_E$ down the tail. The contours and field lines are changing in time in response to an IMF flip from south to north, which reached the magnetopause at time 2:06. Magnetic reconnection in this plane commenced between 2:22 and 2:24. In the last frame, blue blobs are coiled-up plasmoid field lines. Solar wind conditions for the run are density $n = 5$ cm$^{-3}$, speed $v = 600$ km/s, temperature $T = 100,000$ K, and field strength $B = 5$ nT.

Siscoe et al., Annales Geophys., 27, 3141, 2009

Example of OpenGGCM use: Investigation of tail instability by George Siscoe

Imbalance of grad(p) and $J \times B$ forces occurs before substorm onset. Points to an ideal MHD instability such as bollooning.

Siscoe et al., Annales Geophys., 27, 3141, 2009

Fig. 2. Corresponding to Fig. 1, this figure shows profiles along the tail axis of the magnetic force ($J \times B$) and the pressure-gradient force (with signed changed for easier comparison) nine minutes prior to reconnection onset (red) and one minute prior to reconnection onset (black). In the gray region the pressure gradient force, which is pushing the plasma away from the Earth, is greater than the magnetic force pulling the plasma toward the Earth.
Follow-up with study of observed THEMIS substorm of March 23, 2007

Aurora and Westward Traveling Surge

Force balance breakdown before tail reconnection onset

Example of OpenGGCM use:
Field-aligned currents by Susanne Vennerstrom

How do FACs react to changes in the IMF direction?

Vennerstrom et al., JGR, 110, A06205, 2005
THEMIS Support

- THEMIS has an OpenGGCM modeling component.
- THEMIS researchers bring problems forward and we run the model.
- Example: Plasma entry into magnetosphere under northward IMF:
  
  * Oieroset et al., GRL, L17S11, 2009:
  
  * Li et al., JGR, 114, A00C15, 2009:

Metrics

- We participate in CCMC’s metrics and evaluation efforts.
- Antti will say more….

Lpulkkinen et al., JGR, in press, 2010:

Figure 4. Spectra of the modeled and the observed geostationary magnetic field fluctuations in Fig. 5 for storms events (panels a-d corresponding to events 1-4) given in Table 1. Different colors indicate power associated with different models. Black error bars indicate the observed spectra. The color codes corresponding to different models are given in Table 3.
Other science: FTEs

- Flux Transfer Events during east-west IMF, May 8, 2004 Cluster event.
- FTEs for in subsolar region, only move towards dawn, observed at dawn MP.
- OpenGGCM predicts dawn-dusk asymmetry depending on IMF By sign and tilt.

OpenGGCM development under LWS/SC

- Collaboration with:
  - NASA/GSFC (M.-C. Fok, A. Glocer): CRCM/RBM coupling.
  - NCAR/HAO (A. Richmond, A. Maute): Asymmetric potential solver.
- Runs through 09/2011, just passed mid-term review.
- Accomplishments:
  - RCM coupling basically finished.
  - CRCM coupling basically finished.
  - Potential solver tested.
  - ....
Model Data Flow

Development under PetaApps: Tuning for CBE

**Computing: The Old Days...**

15 years ago one would have needed something like a Cray YMP:
- 8 processors
- ~1 GB memory
- ~8 x 0.2 GHzips
- ~$10M
- 200 kW power/cooling
- ~$1M/yr operations.

First global models ran on such machines.

**Computing: Cray on a Chip**

Cell chip versus YMP processor: board (2 ft wide)

**Computing: Enter the Cell Chip**

1992 YMP block diagram:

2006 Cell Broadband Engine (CBE) chip (IBM/Sony/Toshiba):

**Computing: Comparing the Vitals**

<table>
<thead>
<tr>
<th>YMP</th>
<th>Cell chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processors</td>
<td>8</td>
</tr>
<tr>
<td>Memory</td>
<td>0.25-1.5 GB</td>
</tr>
<tr>
<td>Peak speed</td>
<td>~2 GHzips</td>
</tr>
<tr>
<td>Memory bw</td>
<td>2 GB/s</td>
</tr>
<tr>
<td>Clock</td>
<td>0.333 GHz</td>
</tr>
<tr>
<td>Power</td>
<td>150 kW</td>
</tr>
<tr>
<td>OS</td>
<td>UNIX/9</td>
</tr>
<tr>
<td>Price</td>
<td>$10M</td>
</tr>
<tr>
<td>Computers</td>
<td>Cray back then</td>
</tr>
</tbody>
</table>
Development under PetaApps: 40 PS3 Cluster

- 40 PS3 from Best Buy + GB Ethernet switch + PC head node + cables + monitor – games ~$24k.
- New firmware, Linux, MPI libs etc.
- Uses 5 kW of power, though.
- Motivates middle-schoolers, newspaper writers.

Weak scaling on 40 PS3 cluster: Not perfect. Too much time spent on inter-node communication (GB Ethernet switch). New QS22 IBM Cell blade cluster should be much better. Cluster (42 nodes / 84 CBE, NSF CISE funding + IBM donation) delivered November 2009.
Scaling for PS3 cluster: Event of 31 August, 2001

Latest results: ~ factor 1.8 better!

Other developments

- Code now completely under subversion control.
- Bug reporting system: http://fishercat.sr.unh.edu/trac/openggcm
- Compiling with autoconf/make.
- Ultra-high resolution runs for ballooning (1200x600x600, Ping Zhu, U. Wisconsin).
- Include Hall physics (LWS grant, Bhattacharjee).
- Particle tracing / reconstruction of f(v) (for now cusp ion structures, grad student project).
- Calculating proton aurora (grad student project).
- Moving dipole (grad student project).
- Version 4.0: not so soon. Still many loose ends that need to be tied up.