

OpenGGCM transition to operations: prospects and challenges

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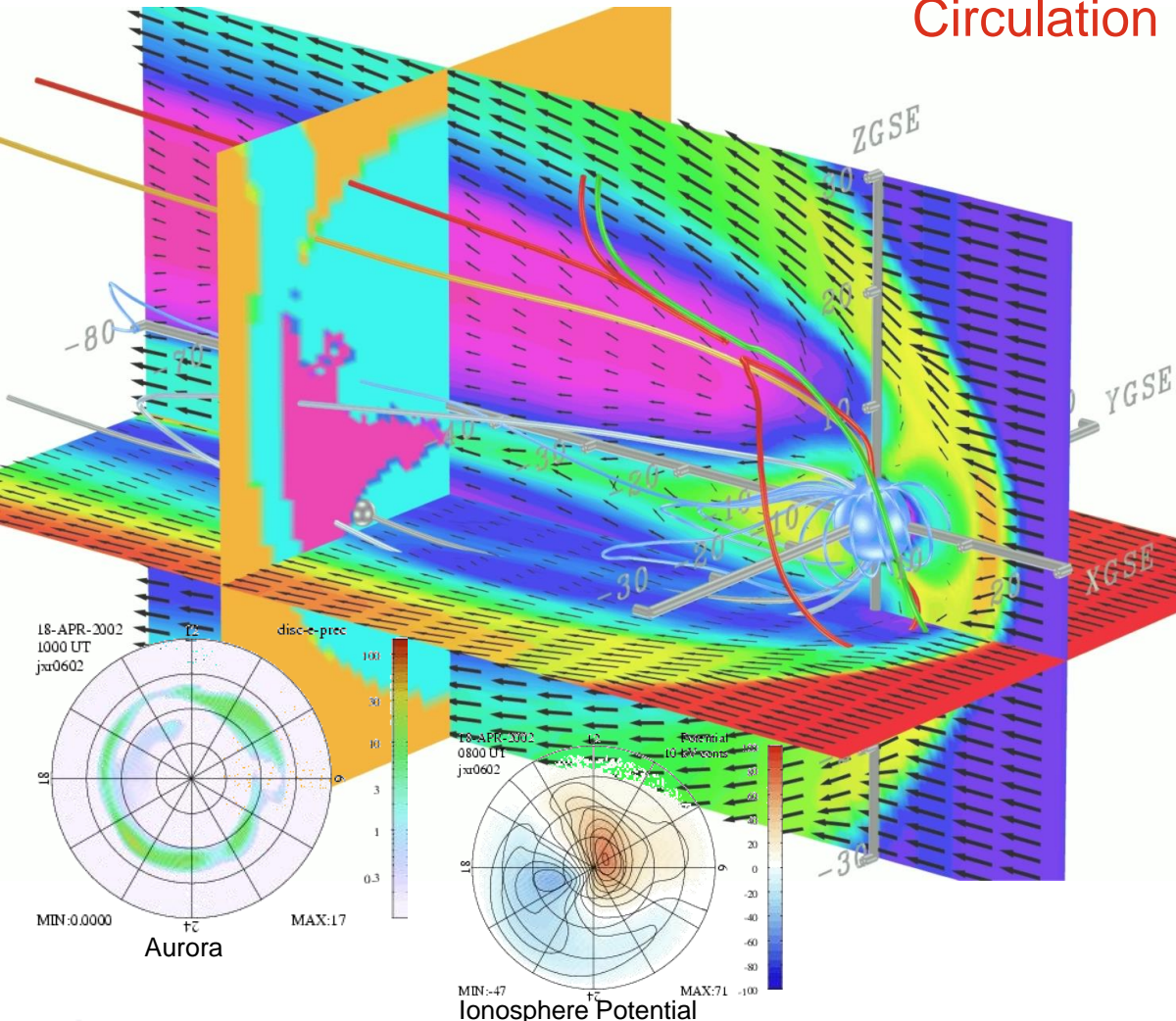
Space Weather Workshop, Boulder, CO, April 2010

Overview

- OpenGGCM Heritage
- Model outputs: Current projects
- Transition to operations in support of space weather
- Crossing the “Valley of Death”
- Operations and OpenGGCM

OpenGGCM: Global Magnetosphere Modeling

The Open Geospace General Circulation Model:



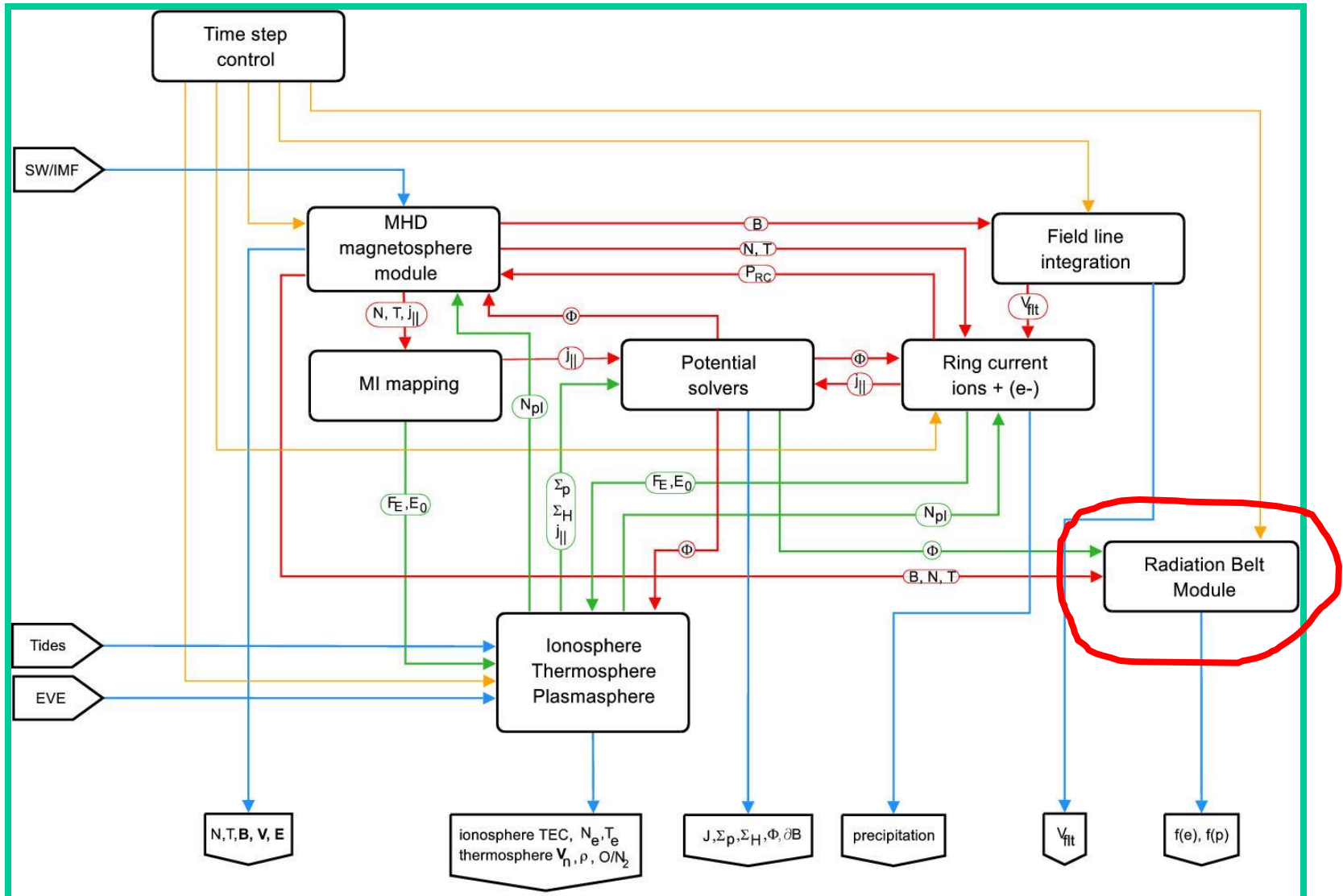
- Coupled global magnetosphere - ionosphere - thermosphere model.
- 3D Magnetohydrodynamic magnetosphere model.
- Coupled with NOAA/SEC 3D dynamic/chemistry ionosphere - thermosphere model (CTIM).
- Model runs on demand provided at the Community Coordinated Modeling Center (CCMC at NASA/GSFC <http://ccmc.gsfc.nasa.gov/>)
- Coupled with ring current models (RCM, Fok/Jordanova models).
- Fully parallelized code, real-time capable.
- Used for basic research, data analysis support, mission planning, space weather studies, and Space Weather Forecasting in the future.

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Heritage

- (Early 1980's) First global magnetosphere MHD models: LeBouef, Ogino @UCLA, Lyon, Brecht, Fedder @NRL.
- (~1993) First parallelized global MHD magnetosphere model (UCLA-MHD).
- (~2000) UCLA global MHD model + NOAA/CTIM model ==> OpenGGCM.
- (2002) Second model to be implemented at the CCMC. >415 runs on demand to date.
- (2005) Start RC coupling with RCM (NASA SR&T).
- (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.
- >45 data comparison studies in the refereed literature since 1995: tail physics, magnetopause, ionosphere, ground mags ...
- Real-time capable with modest resources.

OpenGGCM Physics Overview



Simulation Results Available for Space Weather

OpenGGCM Coupled with CRCM

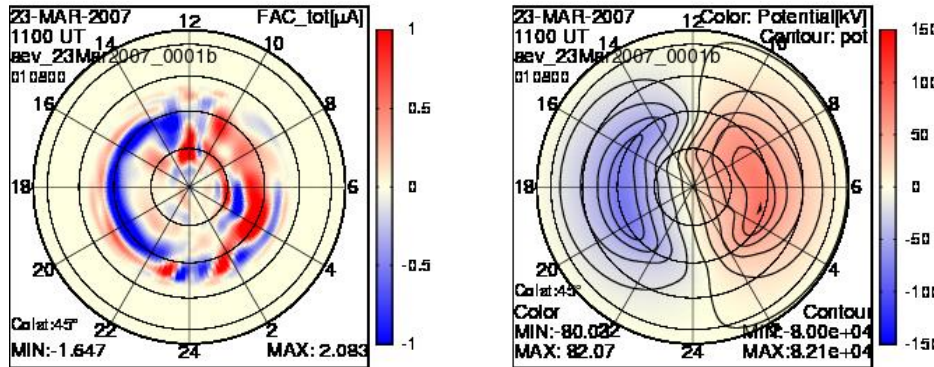
- The Comprehensive Ring Current Model (CRCM) is a combination of the Fok Ring Current Model and the Rice Convection Model (RCM).
- The CRCM is the first ring current model to self-consistently solve the magnetospheric plasma distribution considering an arbitrary pitch angle plasma distribution in the ring current.
- The CRCM computed pressure and density are mapped back onto the OpenGGCM MHD grid.
- The resources required to run the new plugin will not impact realtime space weather prediction runs.

The effect of feedback when coupling with CRCM

Field aligned current and ionospheric potential

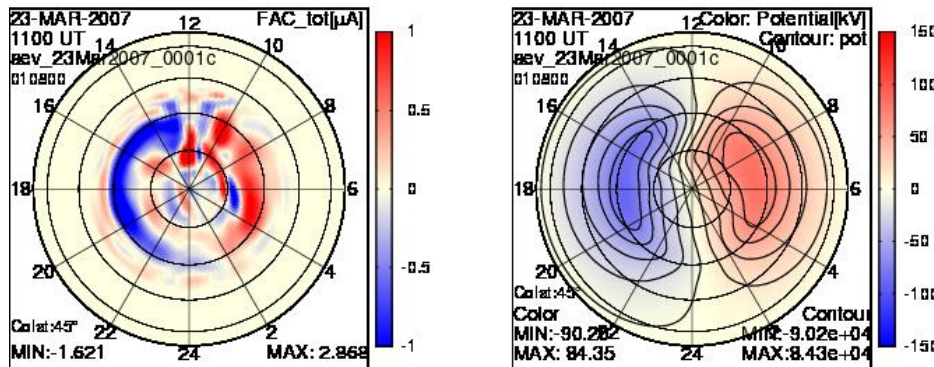
With CRCM Pressure and Density Feedback

23-MAR-2007 1100 UT



NO CRCM Feedback

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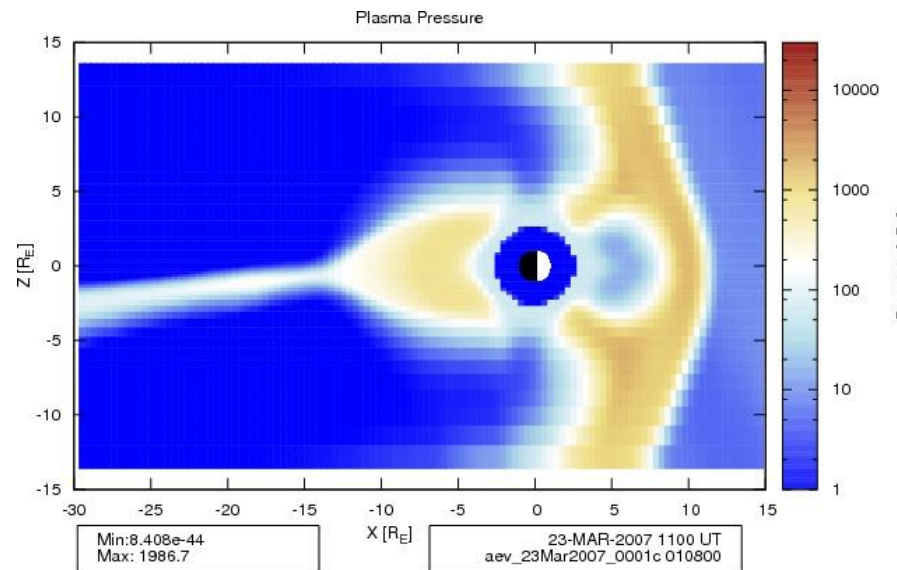
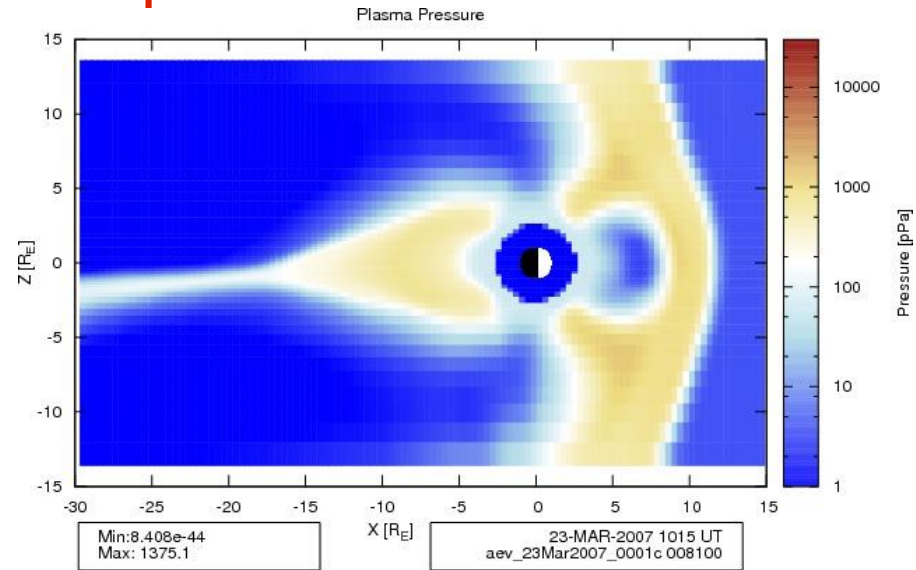
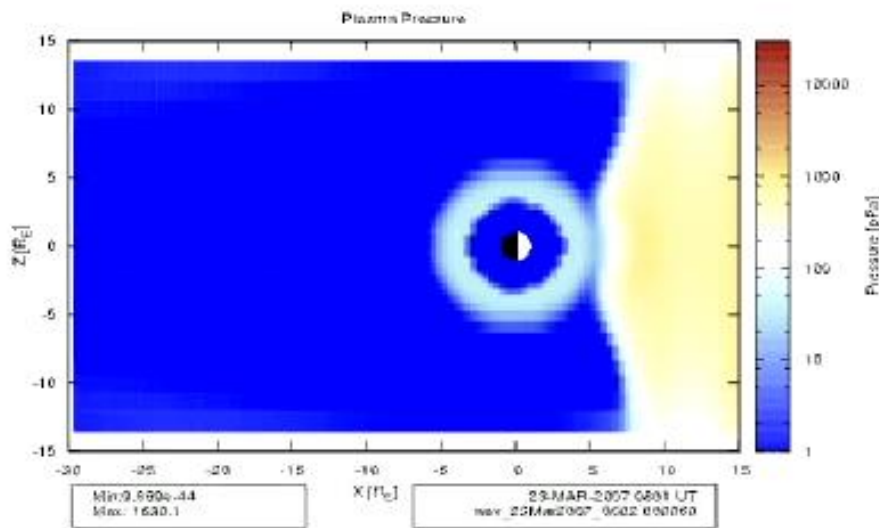
OpenGGCM two-way coupling with the CRCM Ring Current model via pressure and density feedback.

Benefits:

- Stronger Region-2 field aligned currents
- Stronger ionospheric potential shielding effect
- Realistic pressure and density distributions in the near-Earth region
- Realistic plasma distribution of the disturbed-time ring current
- The tail region is very dynamic - more elongated tail before the dipolarization of the magnetic field, the x-line is further down the tail, the dipolarization of the field is much better pronounced

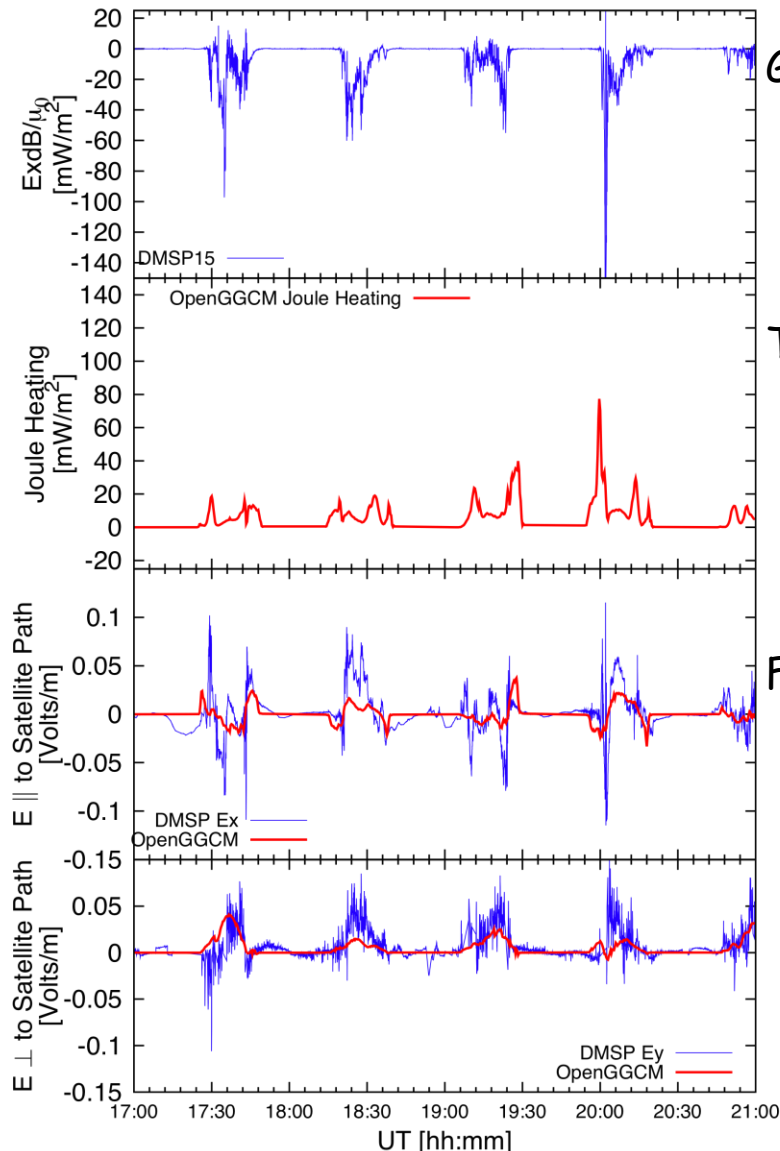
Plasma Pressure: OpenGGCM-CRCM: 23.03.2007

Coupled vs Un-Coupled



Comparing DMSP F15 data to simulation

Event of Jan. 21, 2005



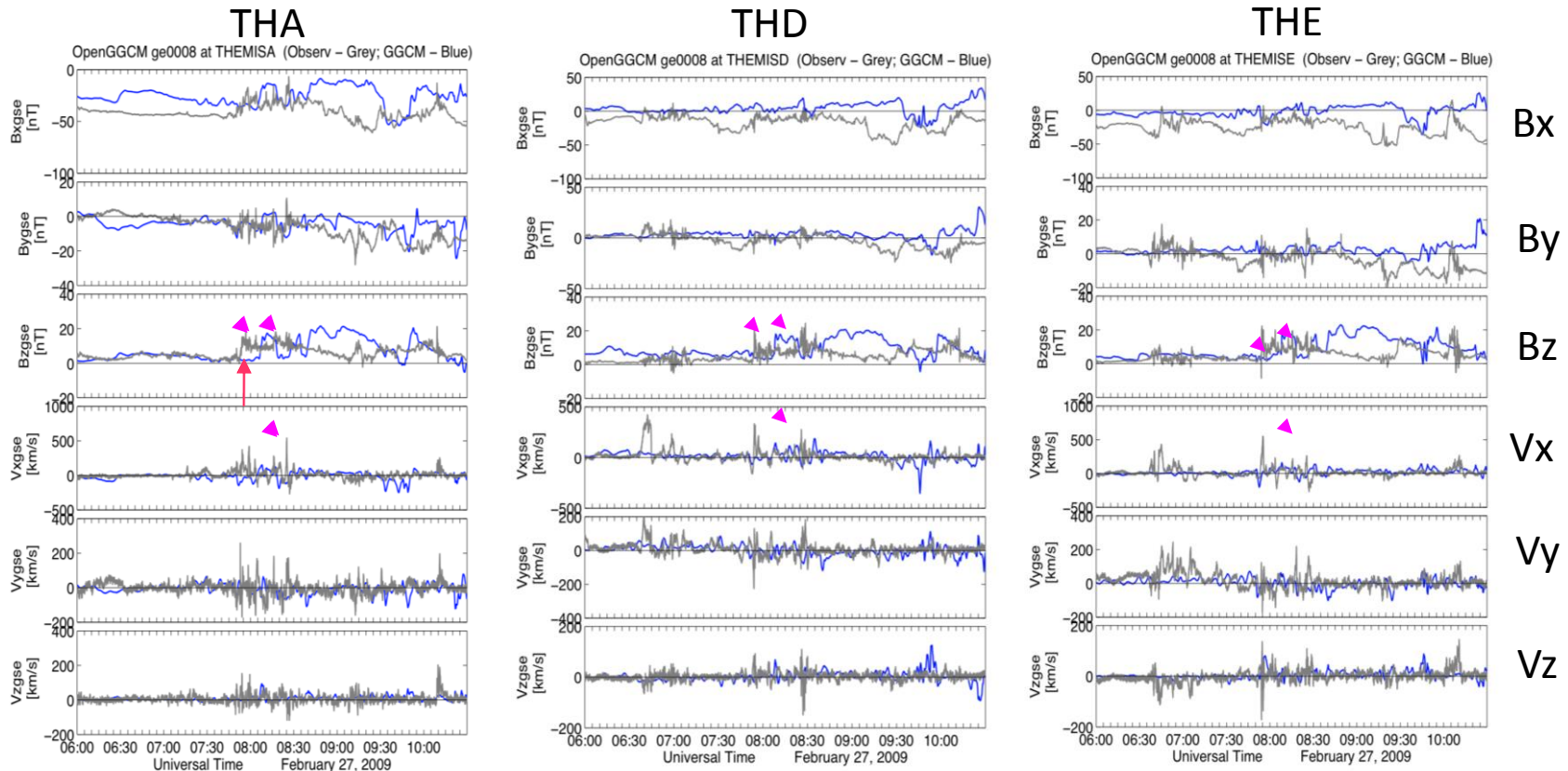
Goal: Explain strong localized heating in the ionosphere and associated thermosphere disturbances during northward IMF periods. These disturbances are not predicted by empirical models.

The OpenGGCM, when run with the CTIM ionosphere model, simulates large Poynting flux events when IMF is northward and IMF B_y is large. These events are reported by D. Knipp using DMSP data.

From top to bottom; Poynting flux, Joule heating, electric field along satellite track, electric field across satellite track. Overall, the simulation agrees very well with DMSP data. Computed Joule heating agrees with the observed Poynting flux.

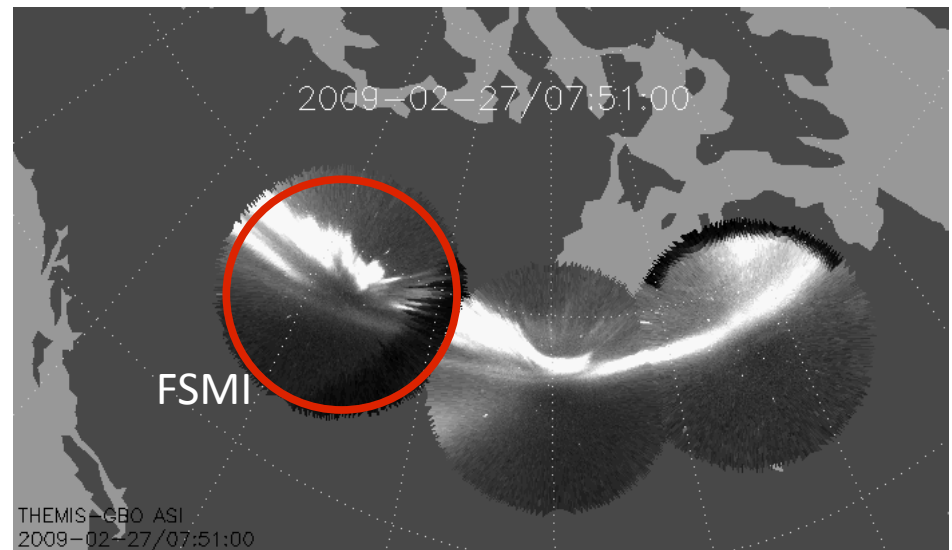
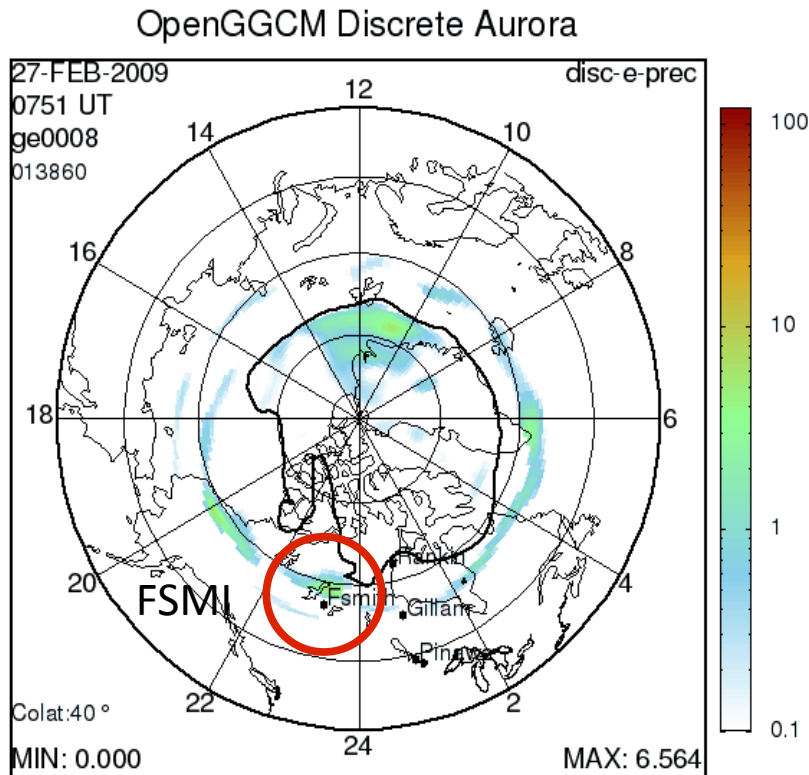
OpenGGCM & THEMIS: Dipolarizations

- Goal: Understand the physical processes that trigger substorms.
- OpenGGCM observed dipolarizations at the inner THEMIS spacecraft (P3,4,5) 10 minutes after the in-situ observations of the February 27, 2009 substorm.
- Sharp dipolarizations are accompanied by the earthward flows in the OpenGGCM, while the flow speeds are smaller than the observations.
- OpenGGCM reproduces the growth phase (tail stretching) before dipolarizations.



THEMIS All-Sky-Images and Simulated Aurora

- OpenGGCM observed aurora breakup at 07:51 UT north of the zenith of Fort Smith station on February 27, 2009 substorm.
- At 07:51 UT, THEMIS All-Sky-Image at Fort Smith Station also caught the auroral onset of February 27 substorm, which is also slightly poleward of the zenith of FSMI.



Modeling the cusp ion structure with OpenGGCM

Goal :

To understand the relation of cusp ion structure with dayside reconnection under various solar wind and IMF conditions

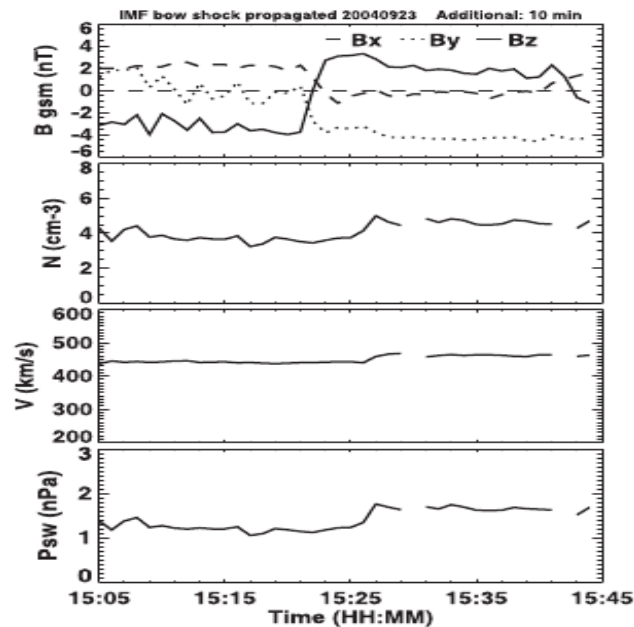
Motivation :

Limited satellite resources to gather lots of cusp crossing data

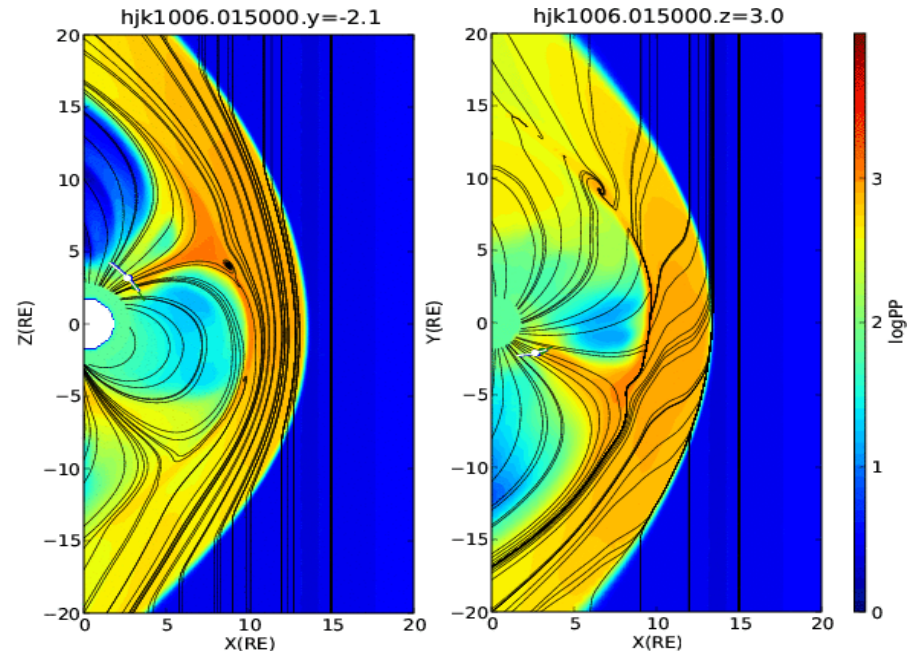
Ambiguities in the satellite observations because of satellite motion

Cluster's cusp crossing event on Sep 23, 2004

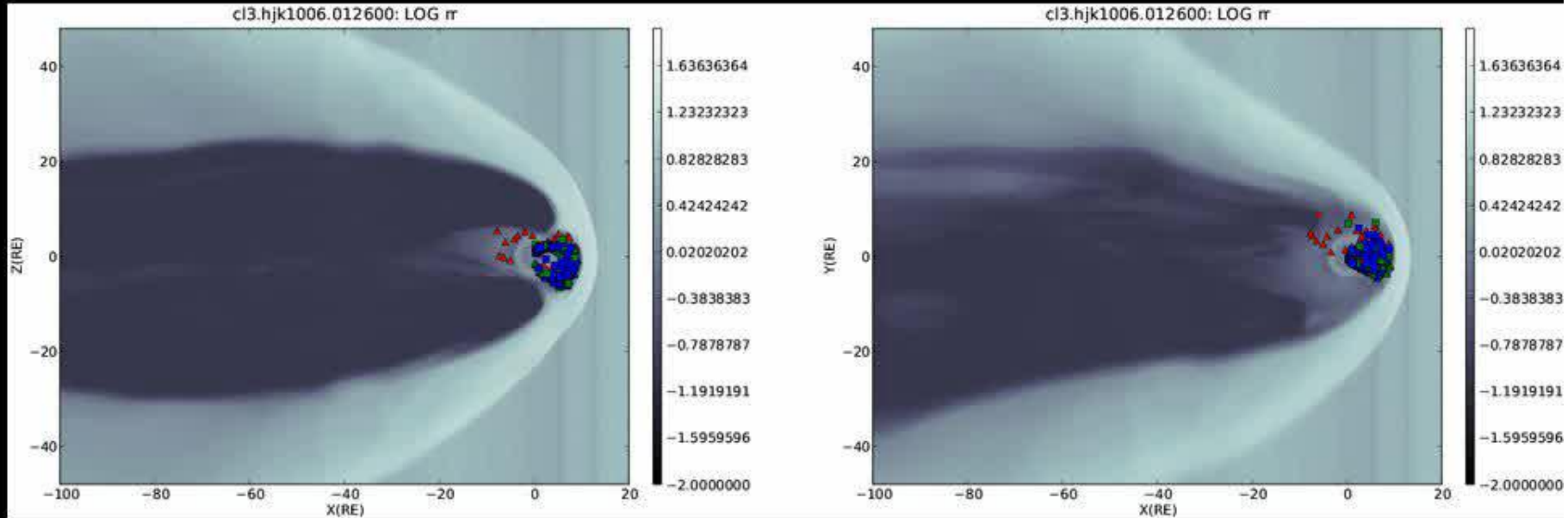
SW/IMF input



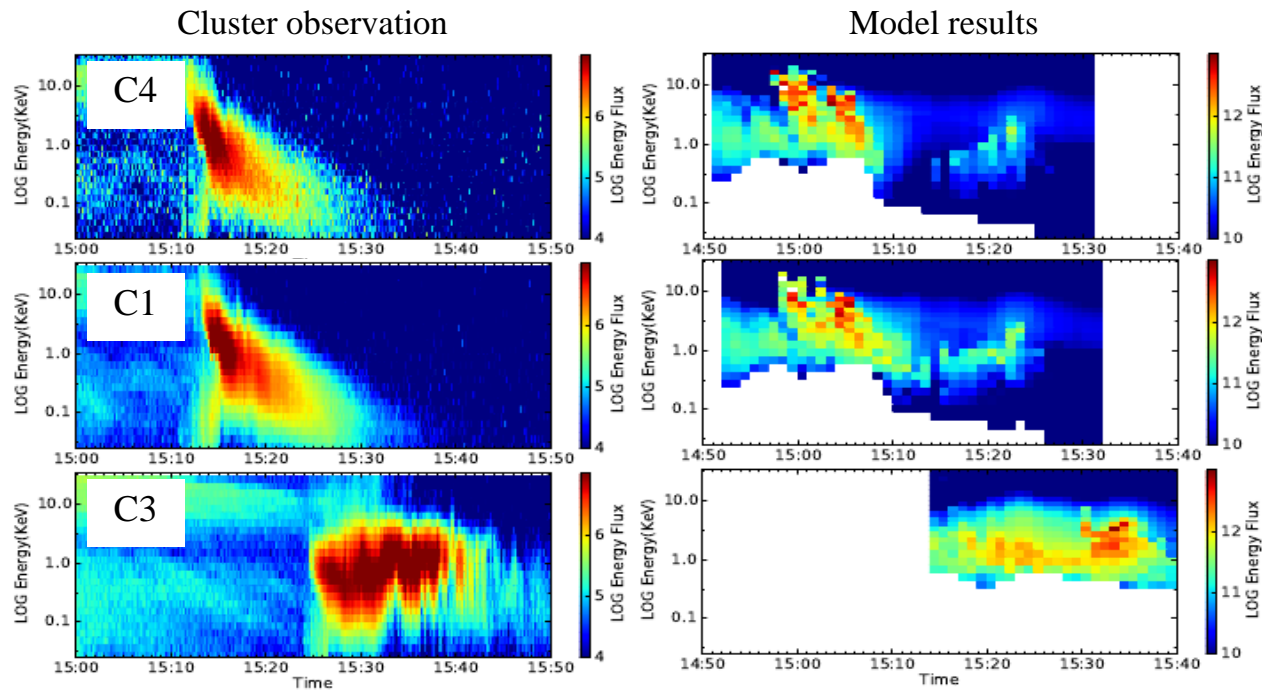
OpenGGCM Results



Step 2. Trace cusp-ions back to space



Step 3. Calculate densities and display them into a energy-time spectrogram



Research to Operations: What does it take?

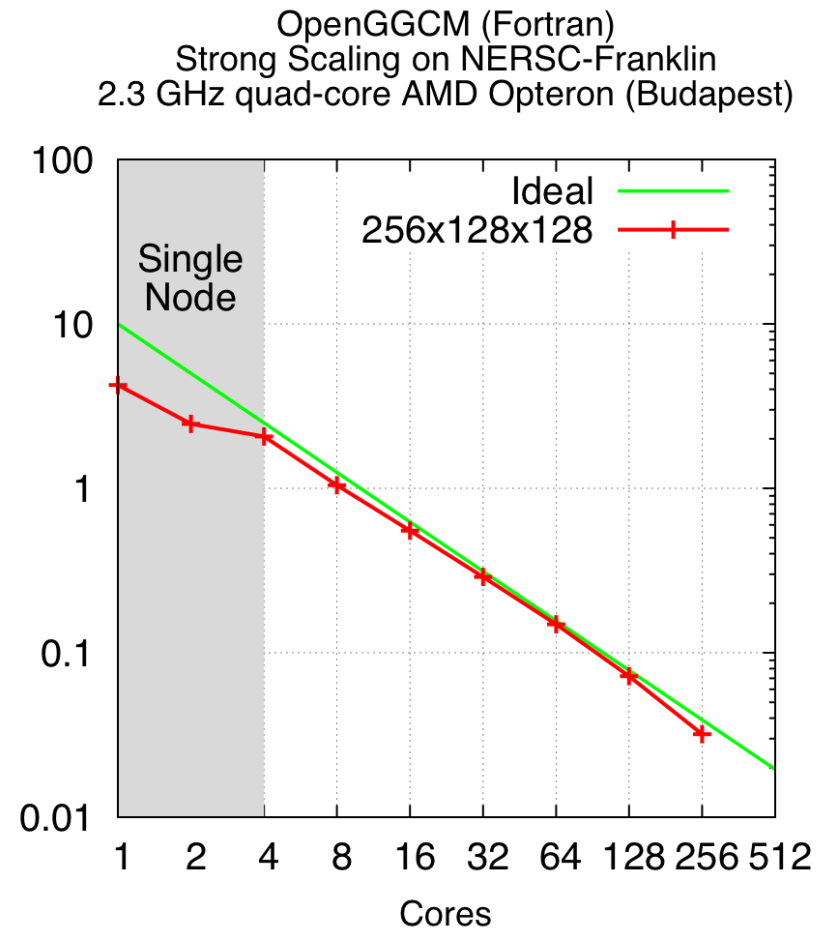
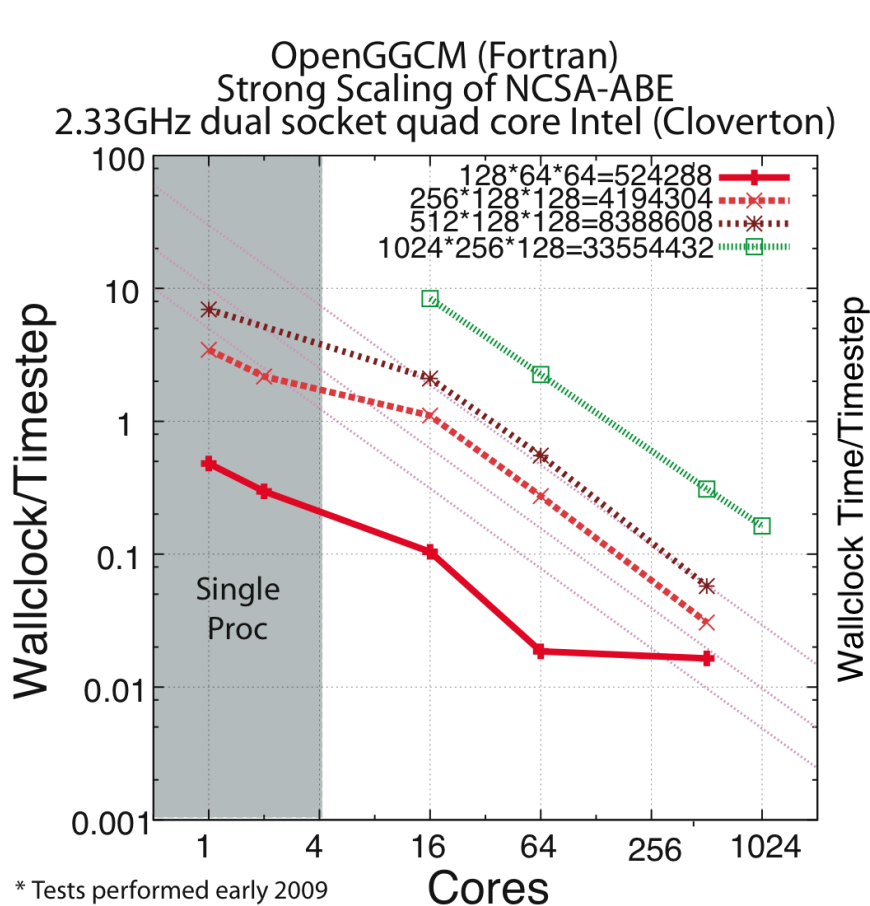
- 1) A time tested model that successfully captures the physics and produces simulation results of space weather relevance.
- 2) Computers fast enough to run multiple instances of the model, and trained personnel. Our group is part of the high performance computing initiative, PetaApps. We are actively restructuring OpenGGCM code internals to take advantage of new architectures.
- 3) All models are approximations. Data are often inaccurate and incomplete. What are we to do? More validation in an operational setting. More formal code verification and ensemble predictions.

Strong Scaling of OpenGGCM

Goal: Get answers quickly using more resources.

Scenario: Fortran branch comparing Intel vs AMD Opteron

This branch is heavily memory bandwidth bound and relies on MPI blocking for communications (MPI_Send/MPI_Recv waits for buffer empty/full)



OpenGGCM on Meerkat, our PS3 Cluster



- Playstation 3 has gigabit ethernet and OpenGGCM is MPI based, so it made sense to create a cluster.
- Inexpensive! \$23K for 40 Cells. IBM charges \$8k for a single QS22 blade.
- Better resolved with more PS3's, but SONY has closed the door to Linux.
- Faster than realtime (256x128x128)
- Limited memory (256MB shared, 256kB per SPE)
- OpenGGCM remains in fortran, but with the MHD core recoded into C to use the SPEs.
- Initial port of MHD core took Kai about three months. Ongoing work involves a rhs code generator that can target more than just the Cell.

OpenGGCM on New Architectures

Goal: Refactor for speed and flexibility with new platforms.

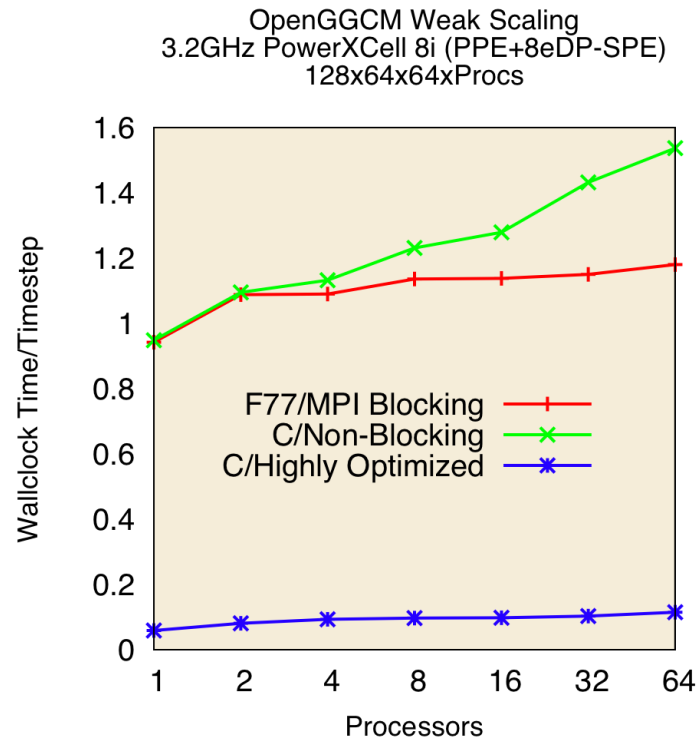
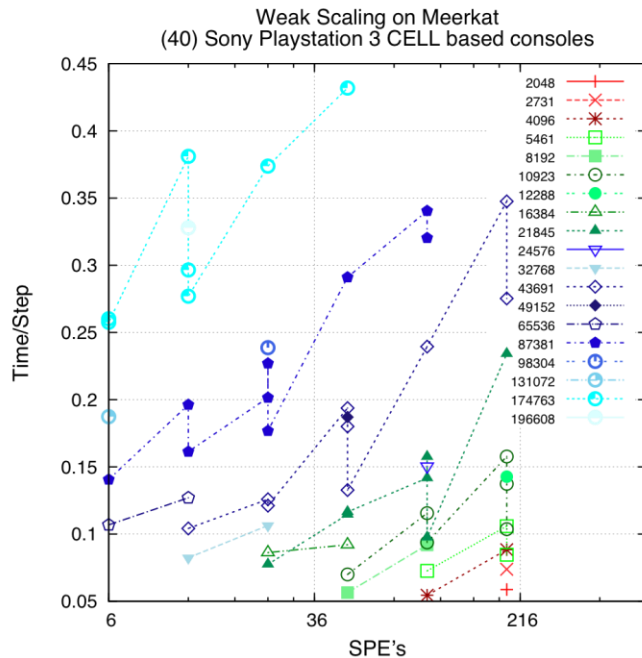
The original PS3 cluster is a frugal entry to Cell and was a success as a testbed.

Latest branch uses a generator for the MHD (rhs) solver.

The Generator is in python and produces code in C.

The rhs generator may eventually evolve to use GPU cards, another frugal choice.

Exploring Non-blocking MPI calls that can efficiently handle larger messages.



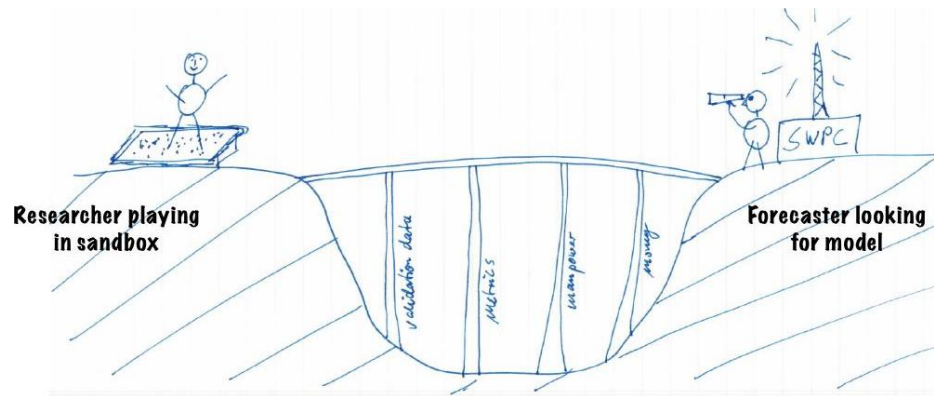
R2O: What '2' do

Criteria being met to aid transition from research to operations

- Software Engineering: Leverage open source tools
Svn + git, autotools, bug tracking with Trac, wiki, gnuplot, python.
wiki: <http://openggcmsr.unh.edu/>
- Verification and validation is already being done.
Test event runs, unit tests, and validation efforts in collaboration with CCMC. (Look for the GEM 2008-2009 Challenge paper submitted to Space Weather by Pulkkinen et al.)
- Performance modeling including I/O. This is important for planning resource requirements.

Canteens we will fill before crossing the "Valley of Death"

- CCMC's CDF output format is implemented and undergoing tests. In the future developers should be able to upload test runs for CCMC to compare against as their resources change.
- HDF5 has already been implemented in the development branch.
- Realtime ingest of ACE or other satellite data. We will implement a software workflow, but forecasts require quality SW/IMF data. L1 measurements only give ~30-60 min lead time; less when it gets interesting.
- Ensemble prediction capability; multiple run instances are easily possible with current hardware, the key is meaningful variations.



Operations Requirements:

'O' you have a lot of work ahead!

- Agency funding for research groups to host visitors for immersion in a specific model. Transition team members can gain invaluable experience from direct observation of the code development workflow and how researchers really use their own codes.
- Installation & Operations manual with simple tests to verify software installation. Since the interpretation of results will be subjective, it will be up to the R2O team to develop criteria for using the code.
- Network security configurations necessary to provision the models with realtime data from satellites.