

High Performance Computing and Space Weather

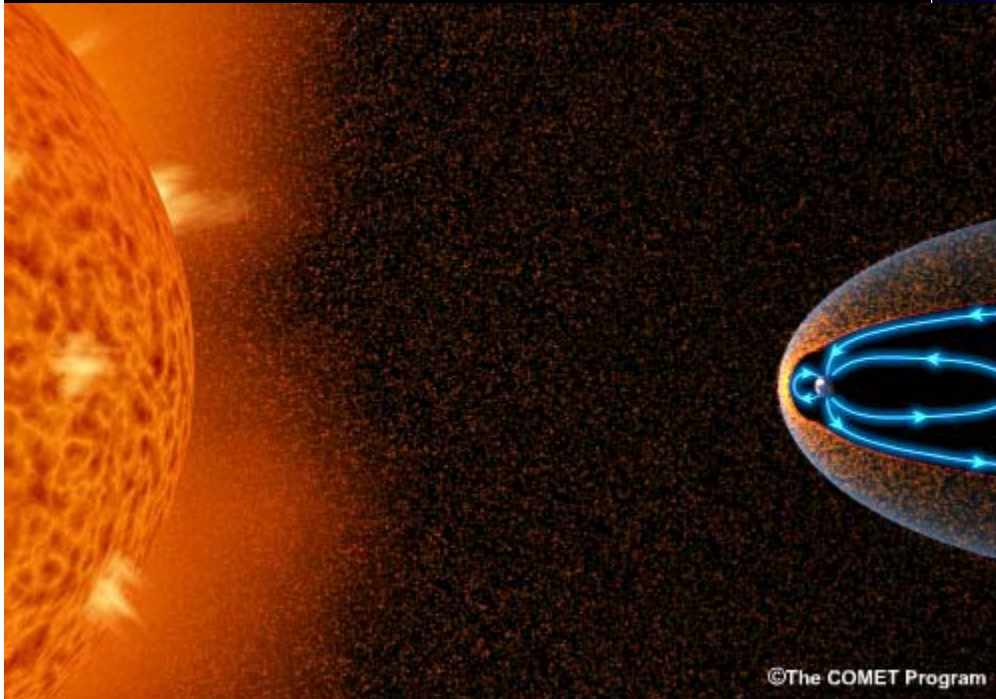
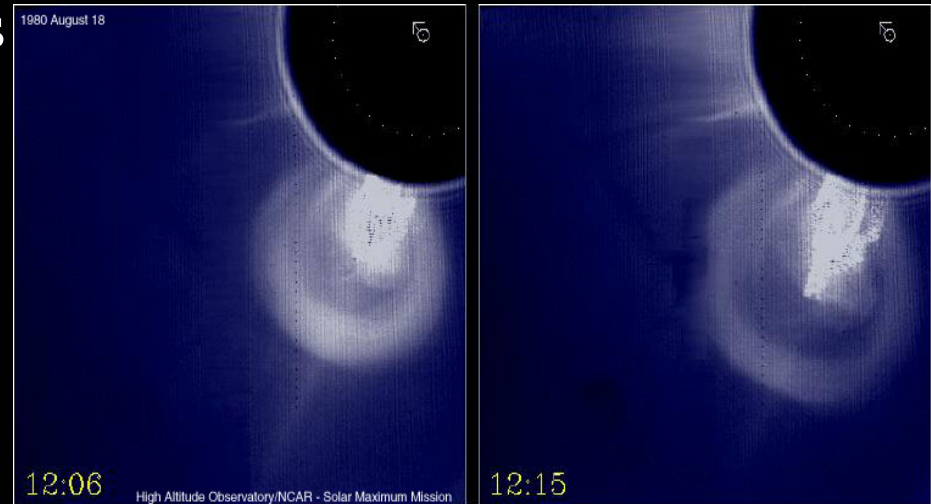
M. Wiltberger
NCAR/HAO
and the
CISM Team

Outline

- Brief introduction space weather
- CISM Numerical Modeling Chain
- Computational Infrastructure
 - Data Transfer with Intercomm
 - Grid Interpolation with Overture
 - Visualization and Analysis with CISM-DX

Space Weather

- Space weather describes events in space that effect the Earth and our technology
- Severe solar eruptions can cause disturbances which dramatically effect both the ionosphere and magnetosphere



- Coronal mass ejections send upwards of a billion tons of hot ionized gas propagating towards Earth arriving in 2-4 days
- The magnetosphere is a bubble created by the Earth's magnetic field which helps protect us from the solar wind

Earth's Magnetosphere

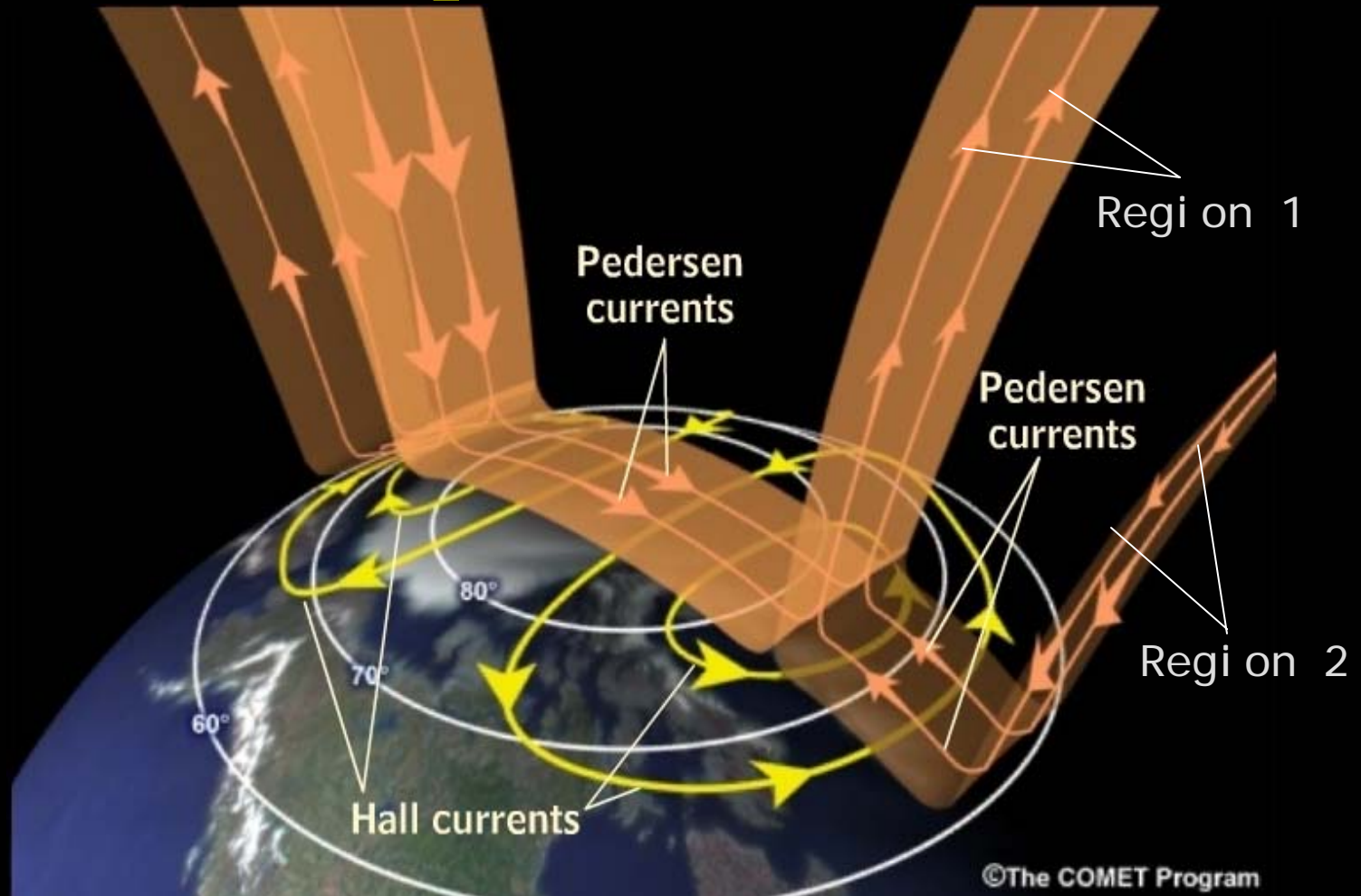


- The magnetosphere is region near the Earth where it's magnetic field forms a protective bubble which impedes the transfer of energy and momentum from the solar wind plasma

A variety of different phenomenon

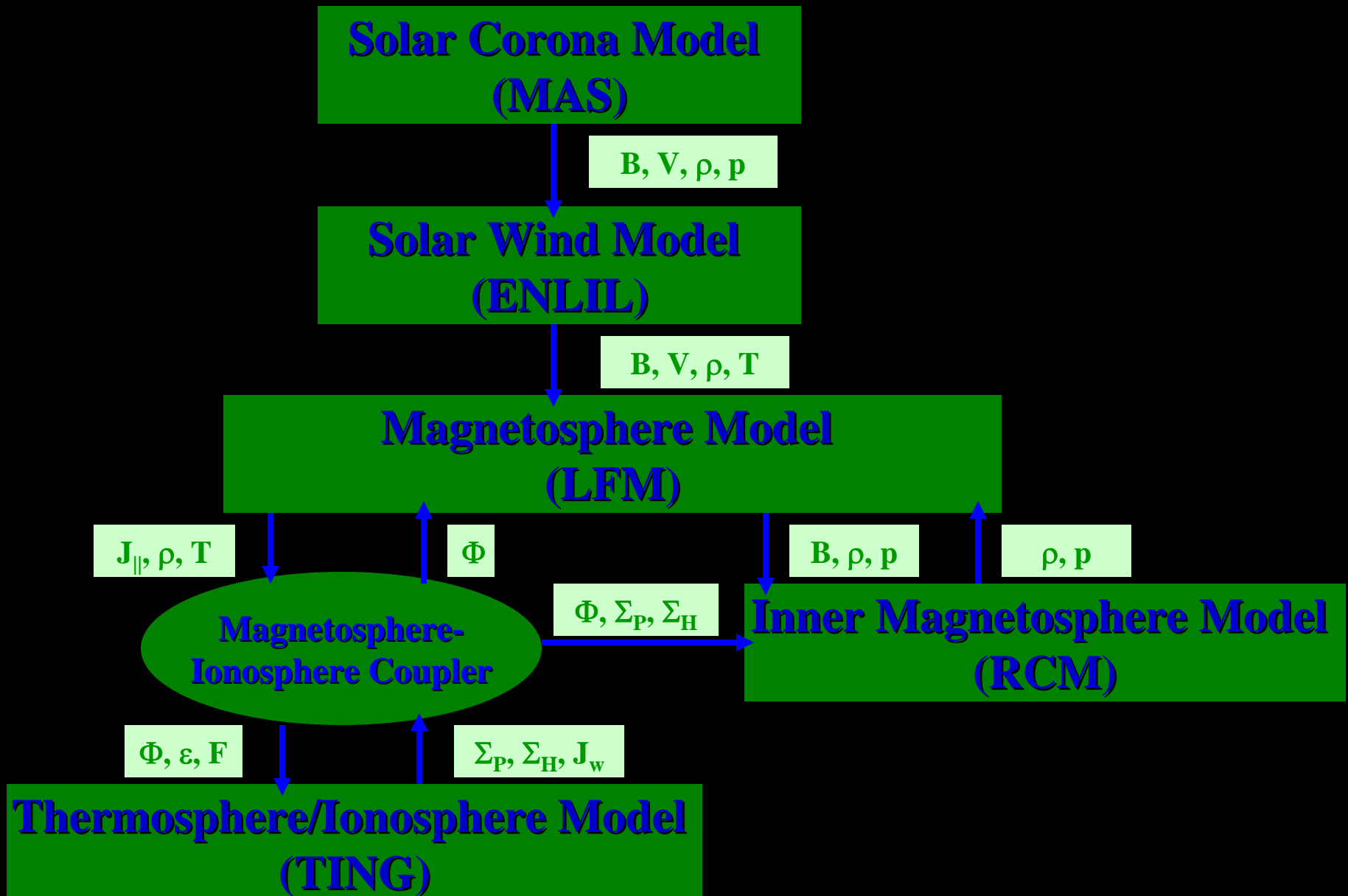
- **Substorms**
 - impulsive energy release over hours
- **Storms**
 - globally enhanced activity over days
- **Radiation belts**
 - trapped particles which are omnipresent

Ionospheric Currents



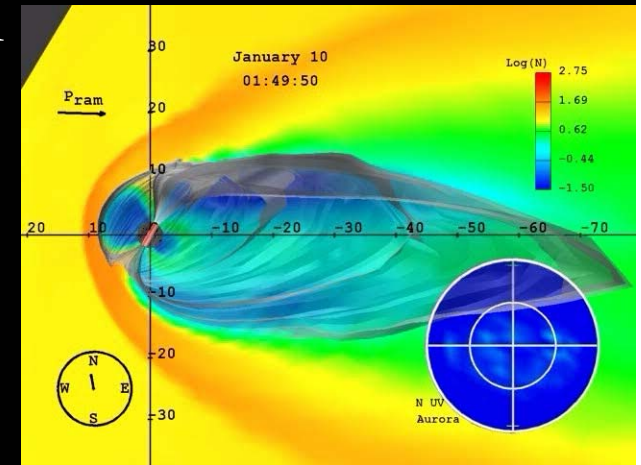
- FAC from the magnetosphere close though Pedersen and Hall Currents in the ionosphere

Numerical Model Chain



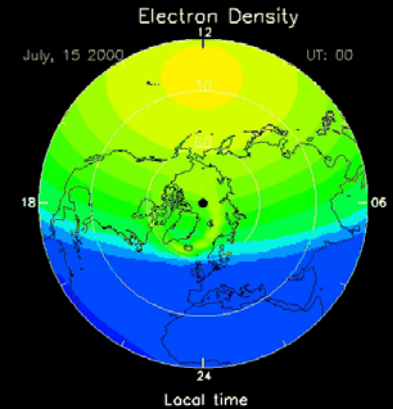
LFM Magnetospheric Model

- 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



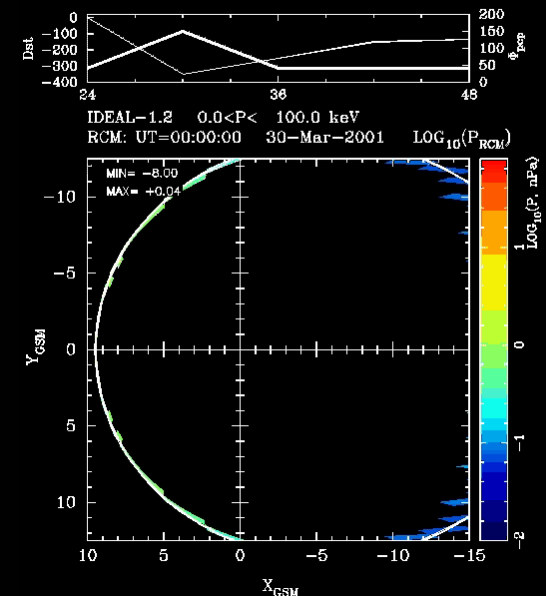
TING Model

- 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

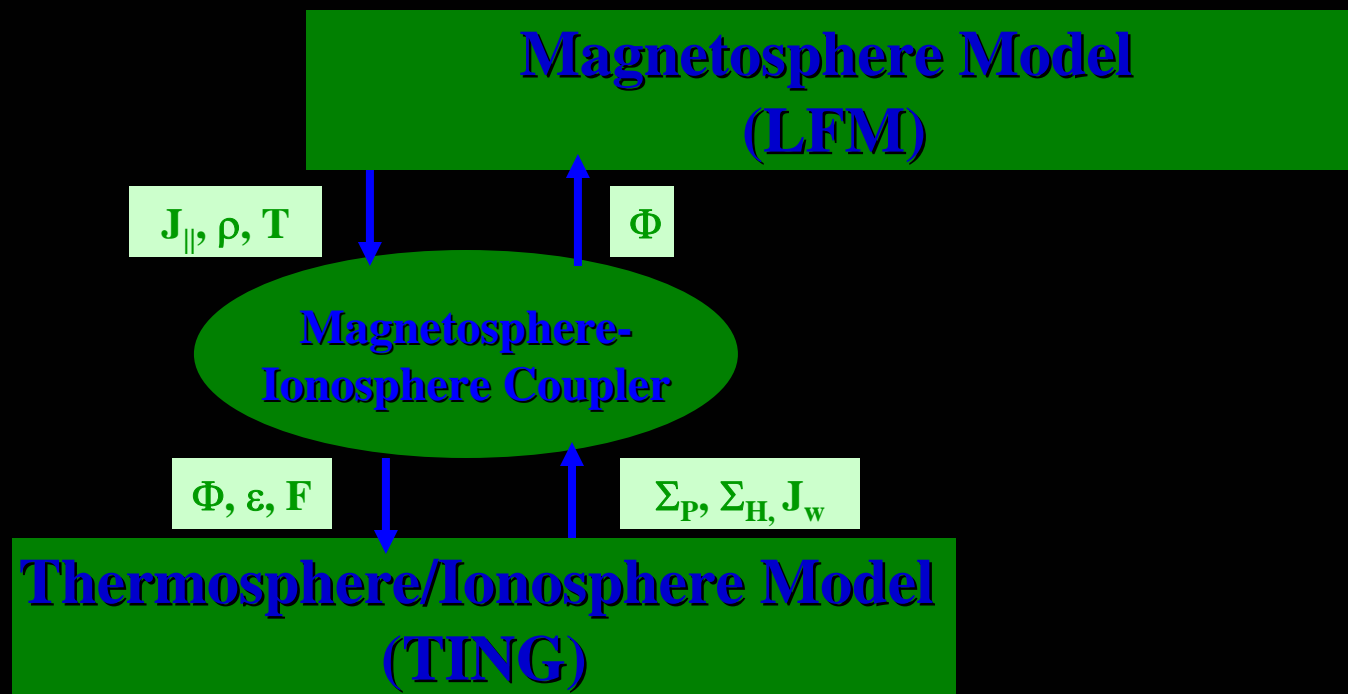


Rice Convection Model

- Uses drift and current conservation equations to determine the plasma motion, currents, and electric fields in the inner magnetosphere
 - Computational domain
 - Closed slow flow field region of the magnetosphere
 - Calculates
 - Distribution functions of electrons and ion species on flux tubes
 - Requires
 - Magnetic field model
 - Electric field along high latitude boundary
 - Initial and boundary values for plasma
 - Ionospheric conductance

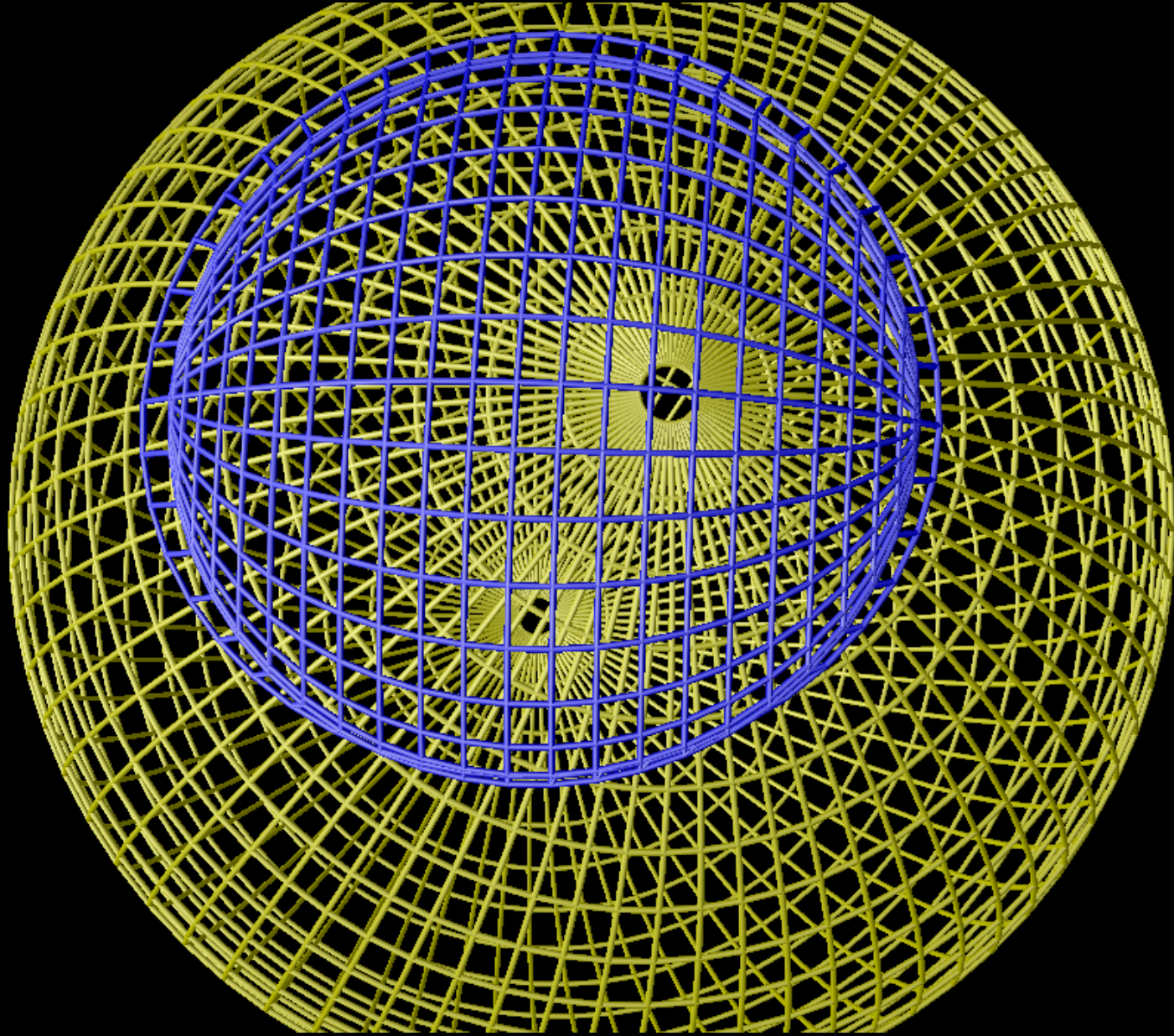


CMIT Coupling



CMIT Coupling

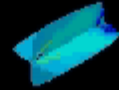
- Since ionosphere is part of magnetospheric boundary condition both models must run at the same time
- Magnetosphere Ionosphere Coupler handles communication between regions
 - Handles coordinate system rotations and grid interpolations
 - Potential and electron flux information passed to TING every two minutes with conductivities held constant during interim ionospheric updates within LFM
 - Two methods for interprocess communication
 - Via a series of lock and data transfer files
 - Intercomm portion of the CISM Coupling Framework
 - Very closely associated with LFM



CMIT Coupling

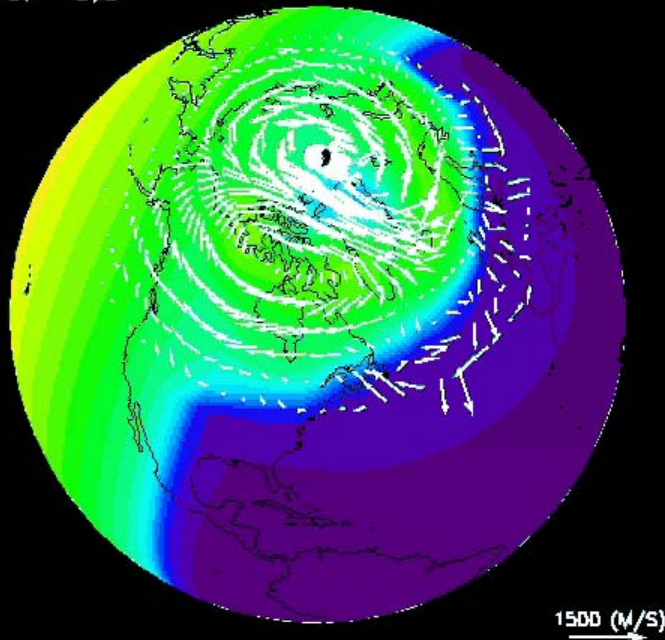
- Since ionosphere is part of magnetospheric boundary condition both models must run at the same time
 - Two way coupling is now operational
- Magnetosphere Ionosphere Coupler handles communication between regions
 - Handles coordinate system rotations and grid interpolations
 - Potential and electron flux information passed to TING every two minutes with conductivities held constant during interim ionospheric updates within LFM
 - Two methods for interprocess communication
 - Via a series of lock and data transfer files
 - Intercomm portion of the CISM Coupling Framework
 - Very closely associated with LFM

CMIT Animation



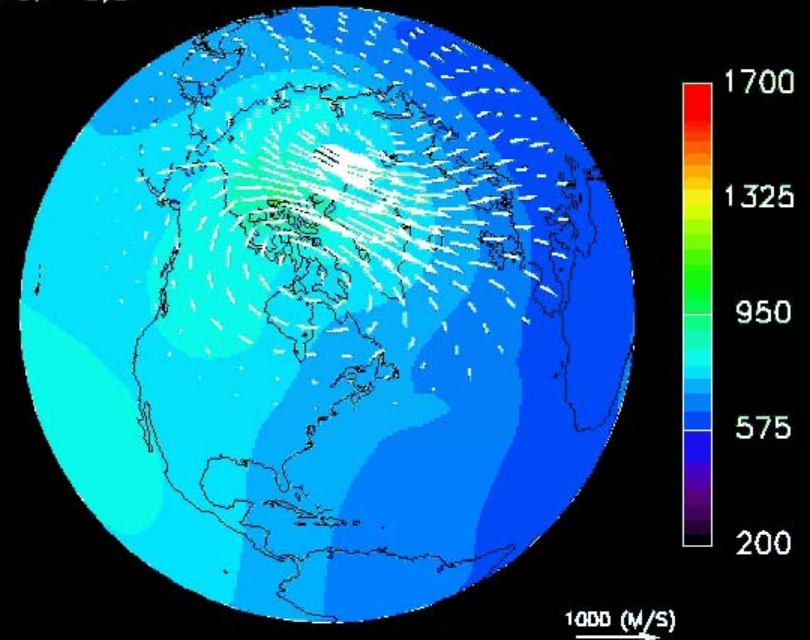
Ionosphere-Thermosphere Coupling

Time: 0,8



E-region ionosphere and ion drifts

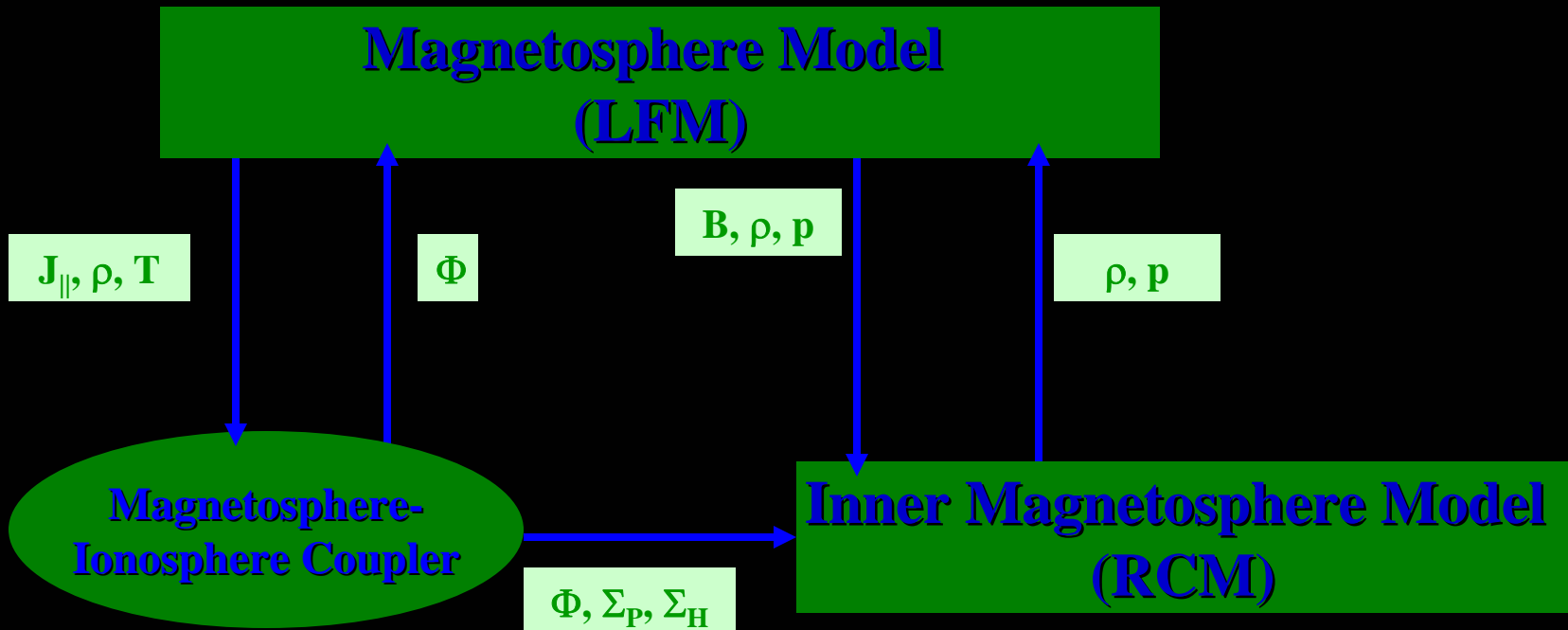
Time: 0,8



F-region temperature and neutral winds

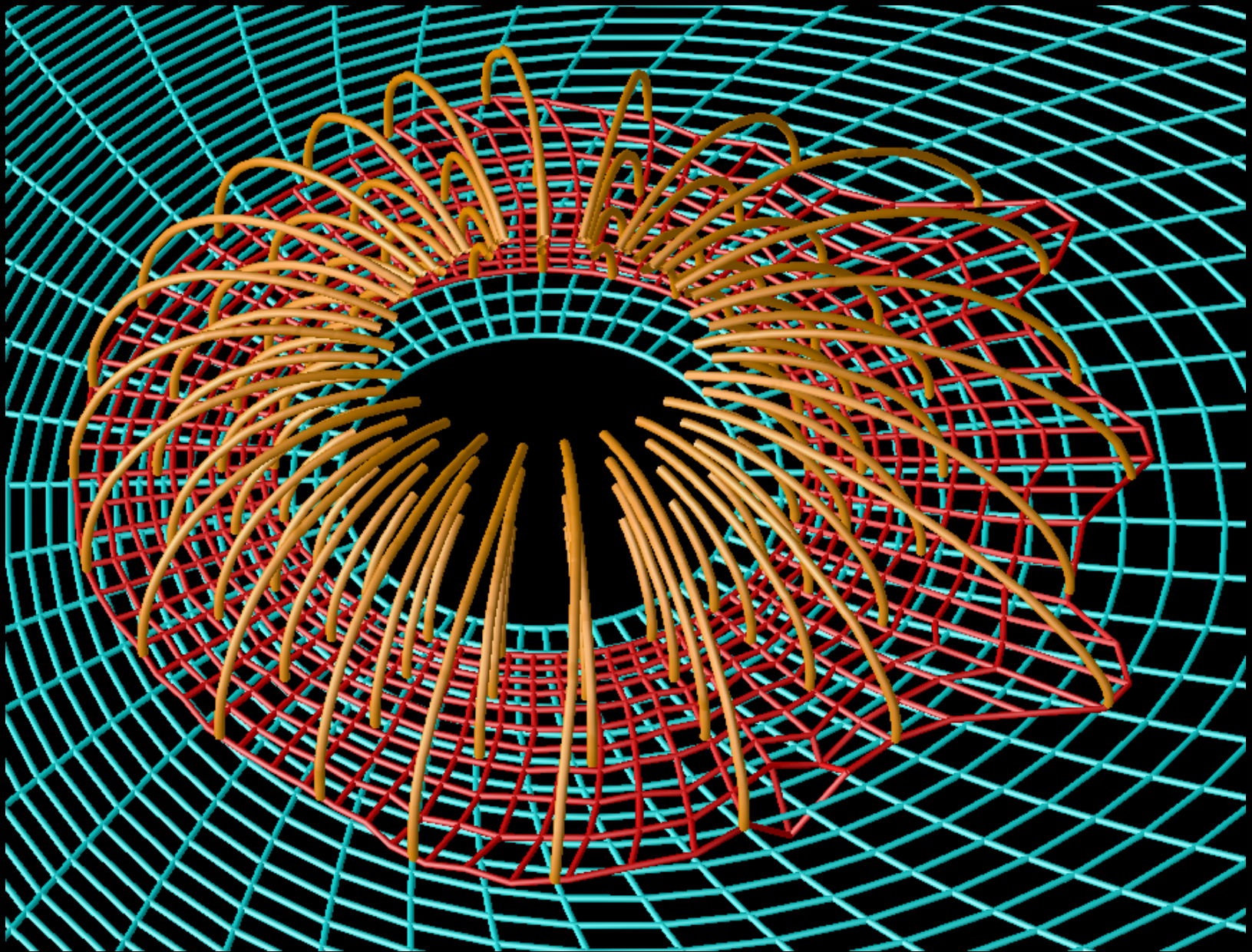
Thanks to W. Wang and S. Solomon

LFM-RCM Coupling



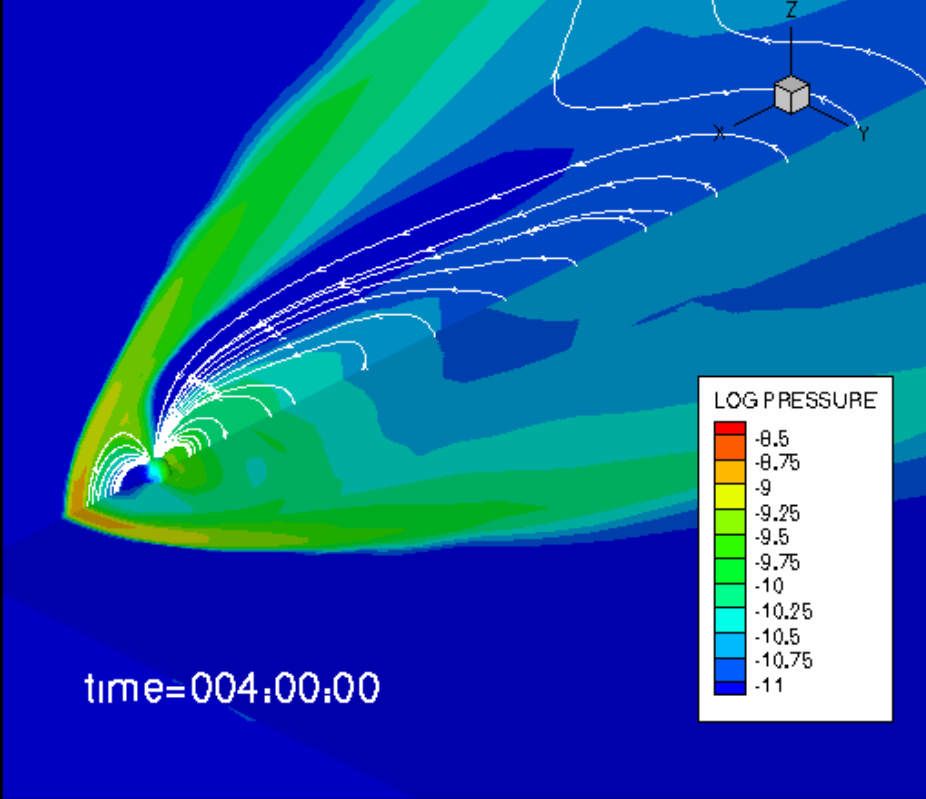
Implementation of LFM-RCM Coupling

- Two way coupling requires concurrent execution of the LFM and RCM
- Transfer of information between codes requires magnetic field line tracing
 - RCM uses 'flux tube volume' to compute solution
 - Process uses an intermediate rectilinear grid because it allows for parallel field line tracing
 - LFM pressure and density are determined by assuming that there is no variation along a given flux tube

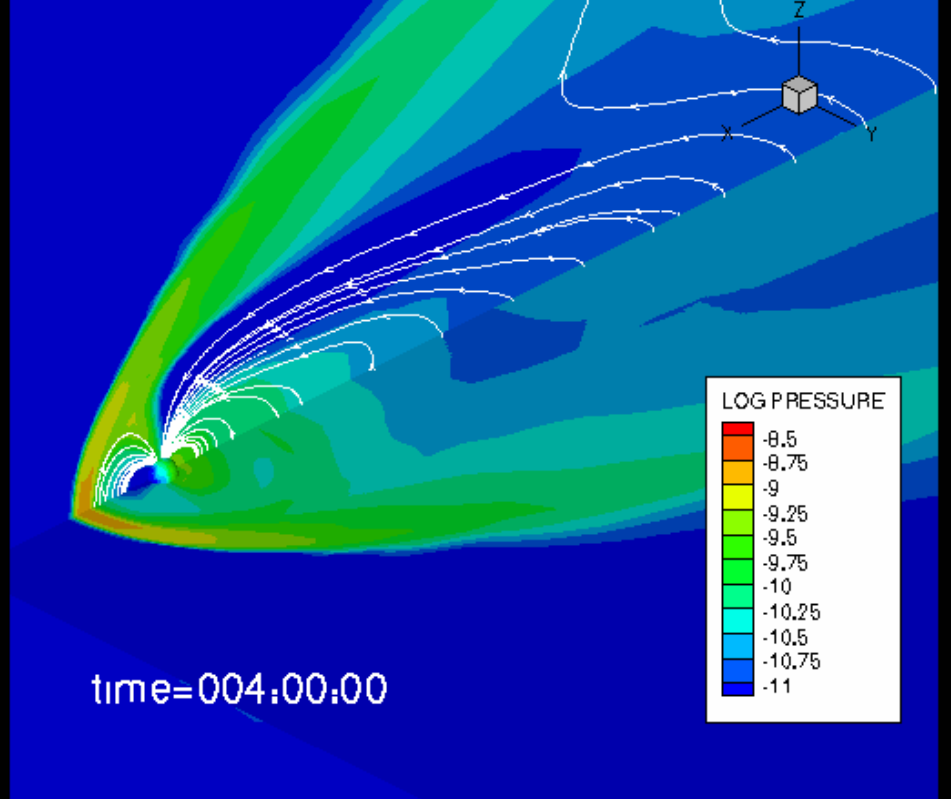
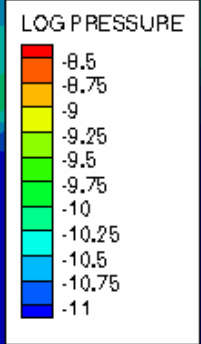


Implementation of LFM-RCM Coupling

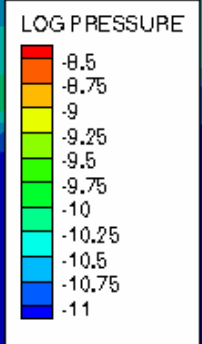
- Two way coupling requires concurrent execution of the LFM and RCM
- Transfer of information between codes requires magnetic field line tracing
 - RCM uses ‘flux tube volume’ to compute solution
 - Process uses an intermediate rectilinear grid because it allows for parallel field line tracing
 - LFM pressure and density are determined by assuming that there is no variation along a given flux tube
 - Two methods for interprocess communication
 - Via a series of lock and data transfer files
 - Intercomm portion of the CISM Coupling Framework



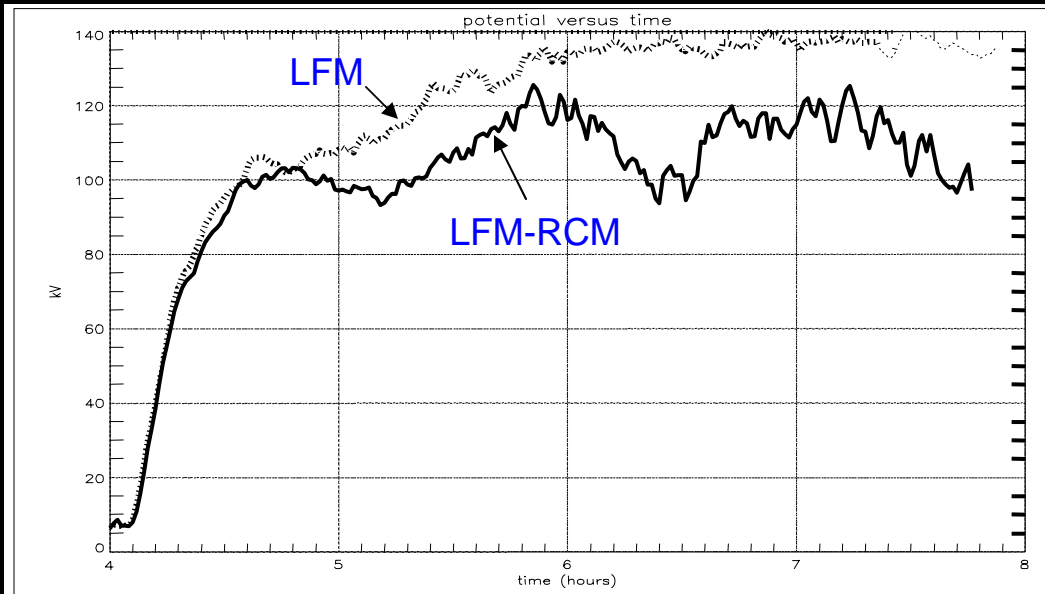
time=004:00:00



time=004:00:00



LFM



LFM-RCM

Code Construction



CISM Coupling Framework

- Need to develop programming paradigm which allows for efficient coupling of models and is flexible enough to allow adding new physics and models
 - efficient transmission of information among codes
 - interpolation of data between grids
 - translation of physical variables between codes
 - control mechanisms to synchronize execution and interaction between codes
 - minimal modifications to existing code base
- Intercomm – University of Maryland – A. Sussman
 - Solution to the MxN problem in coupling parallel codes
 - Will address the control issues
- Overture - LLNL – B. Henshaw & D. Quinlan
 - C++ framework for solving differential equations on overset grids
 - Used to handle interpolation between model grids

What is InterComm?

- A programming environment and runtime library
 - For performing efficient, direct data transfers between data structures (*multi-dimensional arrays*) in different programs
 - For controlling *when* data transfers occur
 - For deploying multiple coupled programs in a Grid environment
 - won't talk about this much today – subject of future work on developing a Grid services framework

Data Transfers in InterComm

- **Interact** with data parallel (SPMD) code used in separate programs (including MPI)
- **Exchange** data between separate (sequential or parallel) programs, running on different resources (parallel machines or clusters)
- **Manage** data transfers between different data structures in the same application
- CCA Forum refers to this as the **MxN** problem

InterComm Goals

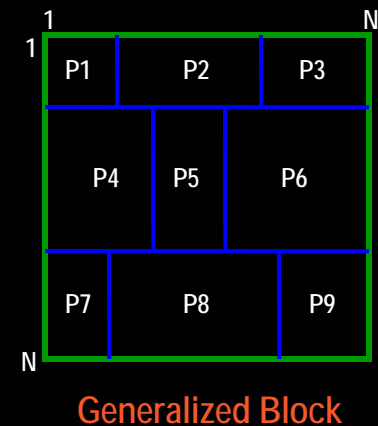
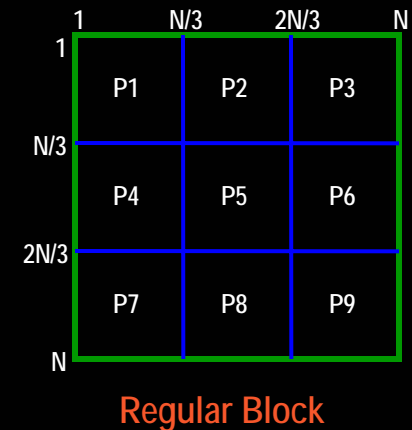
- Main goal is **minimal modification** to existing programs
 - In scientific computing: plenty of legacy code
 - Computational scientists want to solve *their* problem, not worry about plumbing
- Other main goal is **low overhead** and **efficient data transfers**
 - Low overhead in *planning* the data transfer
 - Efficient data transfers via customized all-to-all message passing between source and destination processes

Coupling OUTSIDE components

- Separate coupling information from the participating components
 - Maintainability – Components can be developed/upgraded individually
 - Flexibility – Change participants/components easily
 - Functionality – Support variable-sized time interval numerical algorithms or visualizations
- Matching information is specified separately by application integrator
- Runtime match via simulation time stamps
 - Not in current software distribution

Issues in Coupling Codes

- To enable a program to be coupled to others, we need to:
 - Describe data distribution across processes in each parallel program
 - Build a *data descriptor*
 - Describe data to be moved (imported or exported)
 - Build set of *regions*
 - Build a communication schedule
 - What data needs to go where
 - Move the data
 - Transmit the data to their proper locations



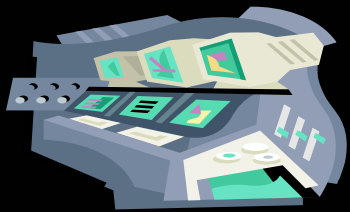
Data Transfer

- It all starts with the **Data Descriptor**
 - Information about how the data in each program is distributed across the processes
 - Usually supplied by the program developer
- **Compact** or **Non-Compact** descriptors
 - **Regular Blocks**: collection of offsets and sizes (one per block)
 - **Irregular Distributions**: enumeration of elements (one per element)
- InterComm uses a *linearization* (L_{S_1}) of the data to be moved (the *regions*) to determine the best method to move data from set of regions in P_1 (S_1) to a set of regions in P_2 (S_2)

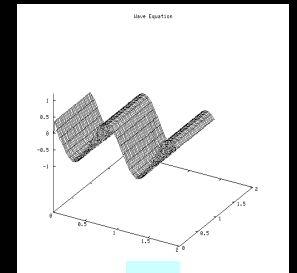
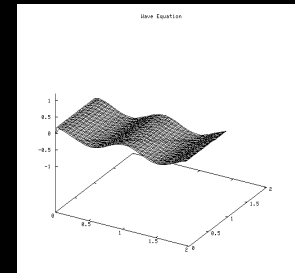
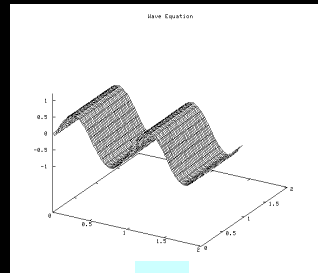
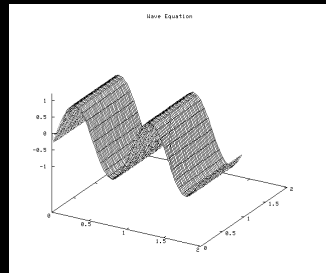
Controlling Data Transfers

- A flexible method for specifying *when* data should be moved
 - Based on matching **export** and **import** calls in different programs via **timestamps**
 - Transfer decisions take place based on a separate **coordination specification**
 - Coordination specification can also be used to deploy model codes and grid translation/interpolation routines (how many and where to run codes)

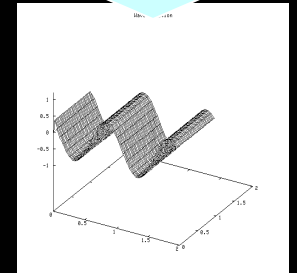
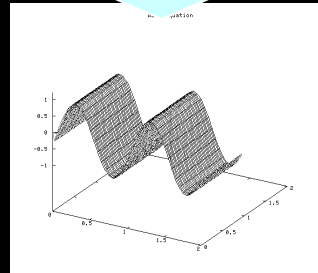
Example



Simulation Cluster



Visualization station



- Simulation **exports** every time step, visualization **imports** every 2nd time step

Separate codes from matching

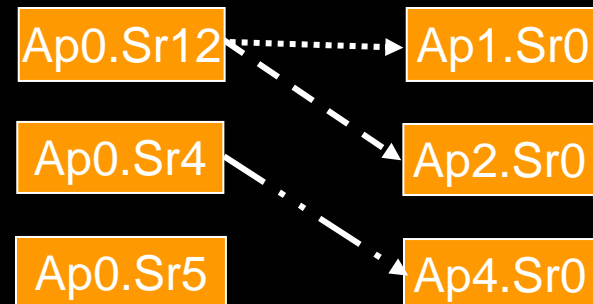
```
define region Sr12
define region Sr4
define region Sr5
...
Do t = 1, N, Step0
    ... // computation jobs
    export (Sr12, t)
    export (Sr4, t)
    export (Sr5, t)
EndDo
```

Exporter Ap0

```
define region Sr0
...
Do t = 1, M, Step1
    import (Sr0, t)
    ... // computation jobs
EndDo
```

Importer Ap1

```
# Configuration file
Ap0 cluster0 /bin/Ap0 2 ...
Ap1 cluster1 /bin/Ap1 4 ...
Ap2 cluster2 /bin/Ap2 16 ...
Ap4 cluster4 /bin/Ap4 4
#
Ap0.Sr12 Ap1.Sr0 REGL 0.05
Ap0.Sr12 Ap2.Sr0 REGU 0.1
Ap0.Sr4 Ap4.Sr0 REG 1.0
#
```

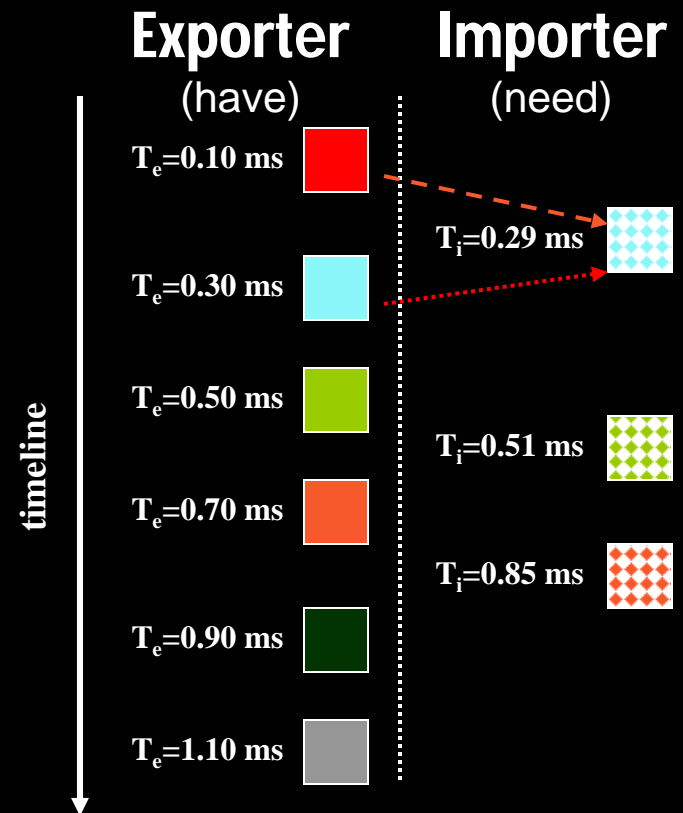


Approximate Matching

- Exporter Ap0 produces a sequence of data object A at simulation times 1.1, 1.2, 1.5, and 1.9
 - $A@1.1, A@1.2, A@1.5, A@1.9$
- Importer Ap1 requests the same data object A at time 1.3
 - $A@1.3$
- Is there a match for $A@1.3$? If Yes, which one and why?

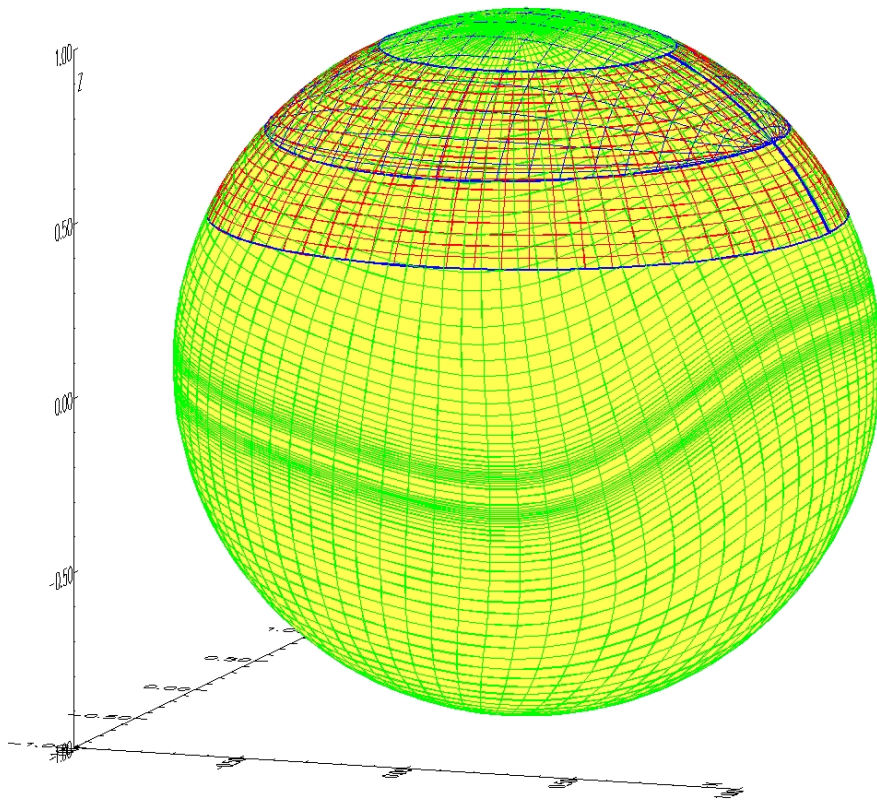
Controlling Data Transfers

- *Import* and *Export* operations are time-stamped (T_i and T_e)
- Issues in designing *Decision Functions*
 - **Matching Policy**
 - Does the import timestamp *match* any of the exported timestamps, subject to a particular policy?
 - **Precision**
 - Which of the exported data most closely matches what is requested to be imported?
- Decision functions directly affect InterComm buffering decisions!

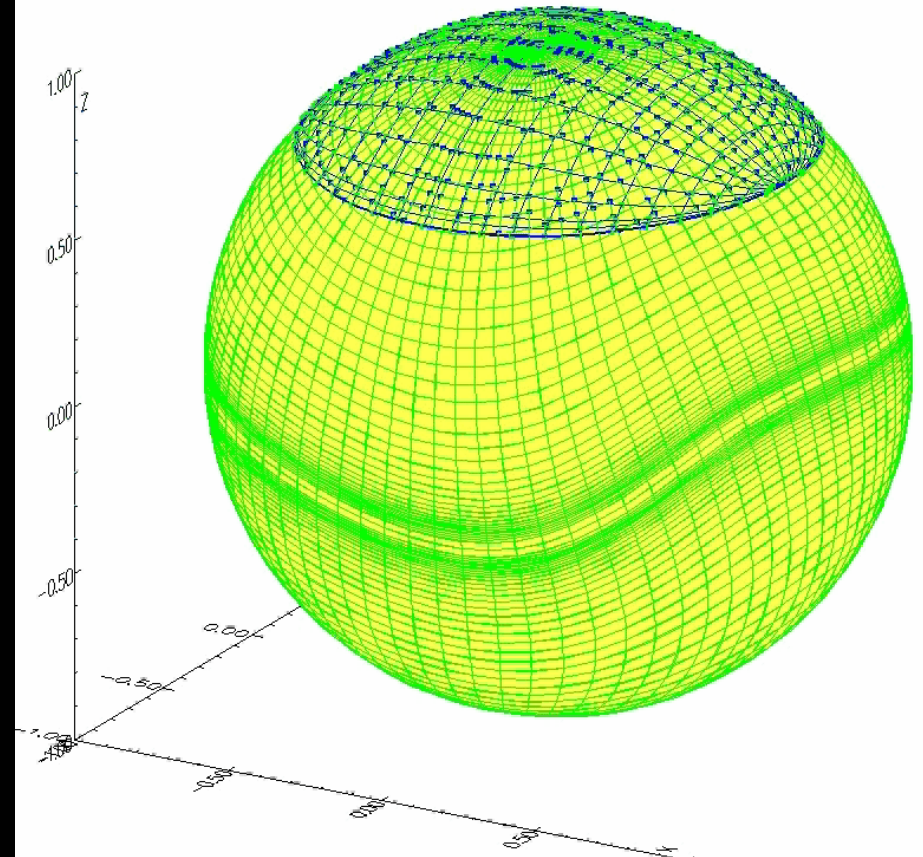


Ionospheric Grids in Overture

Apex, LFM, and RCM grids

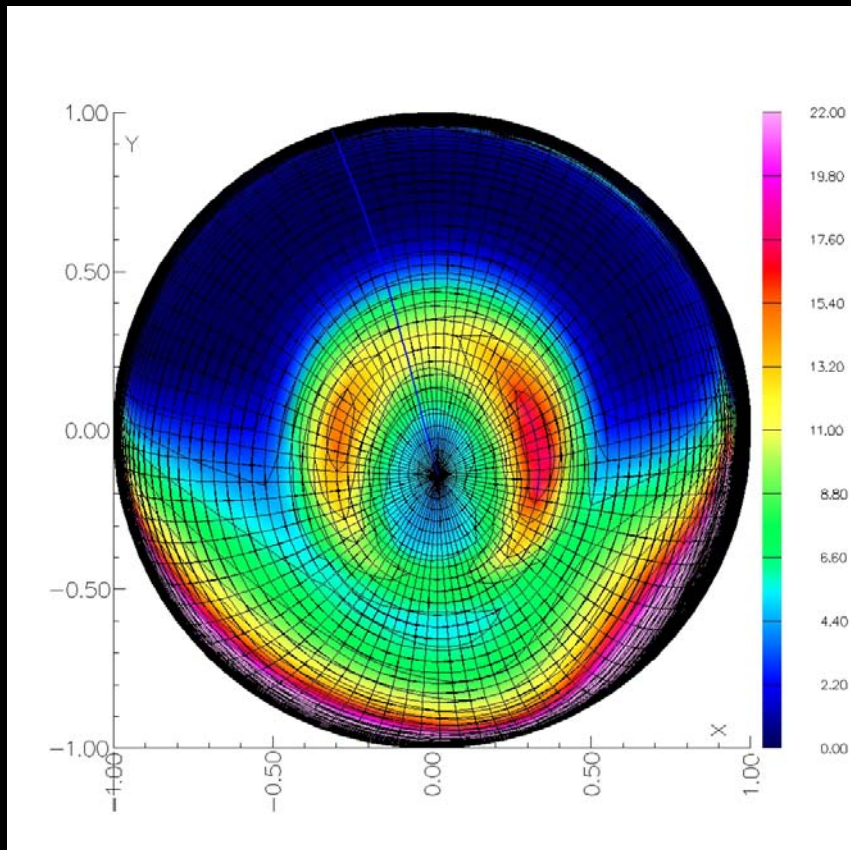


Year 2006, Day 90, Time 00:00:00

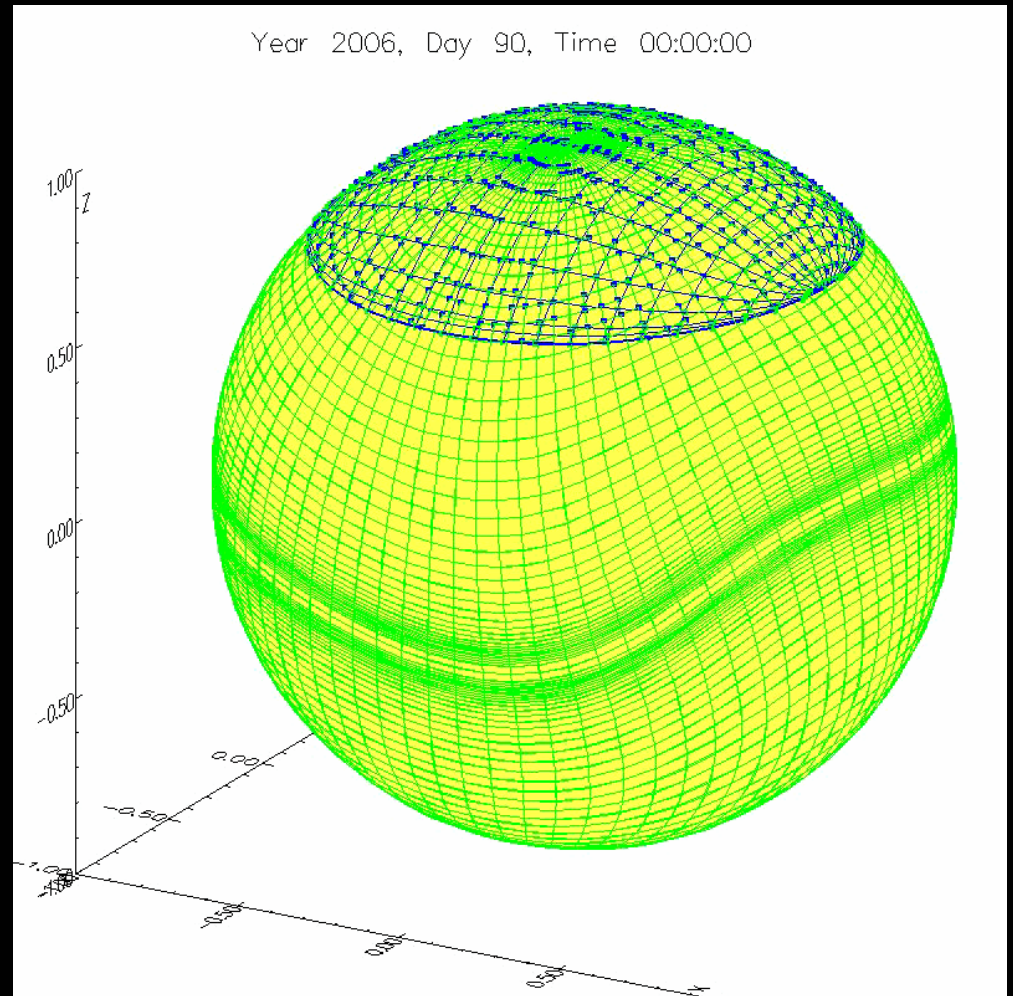


We have found establishing geospace grid in Overture the largest barrier. Once done, and stored in HDF database for reuse, the data import is simple. It is also straight forward to include coordinate system rotations.

Mapped Grids in Coupler(s)



TIE_GCM Conductivity
on the Apex grid



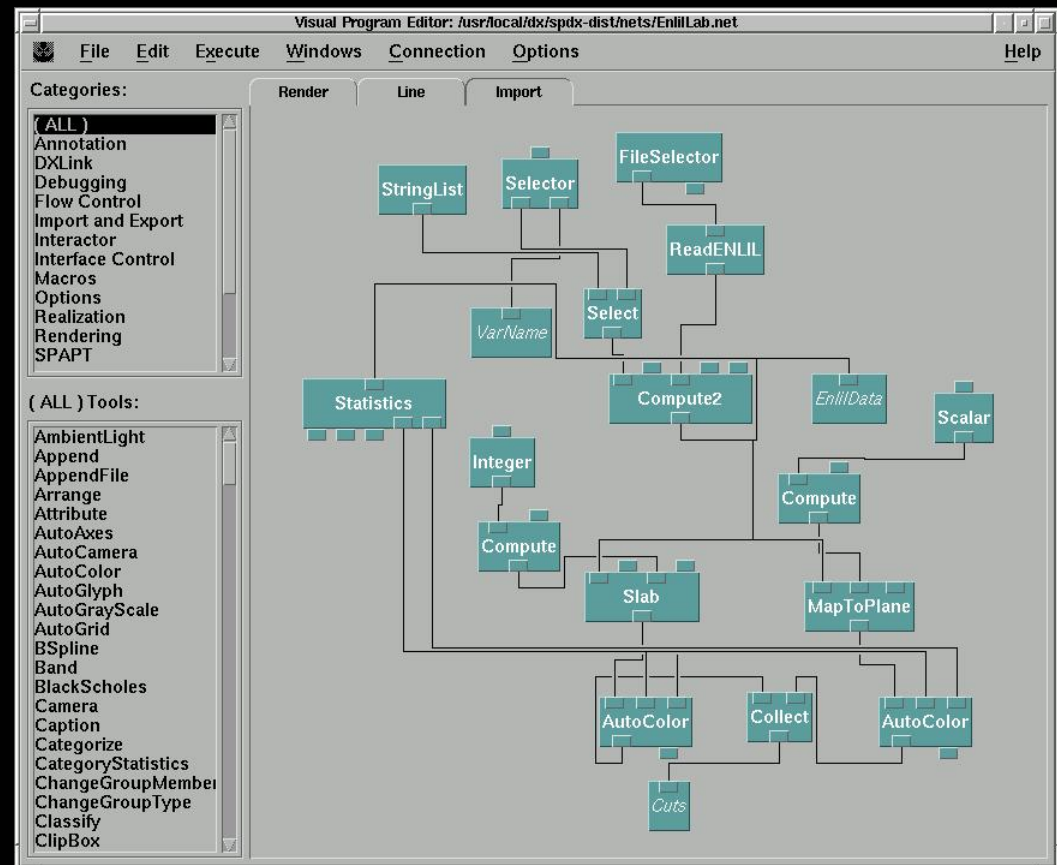
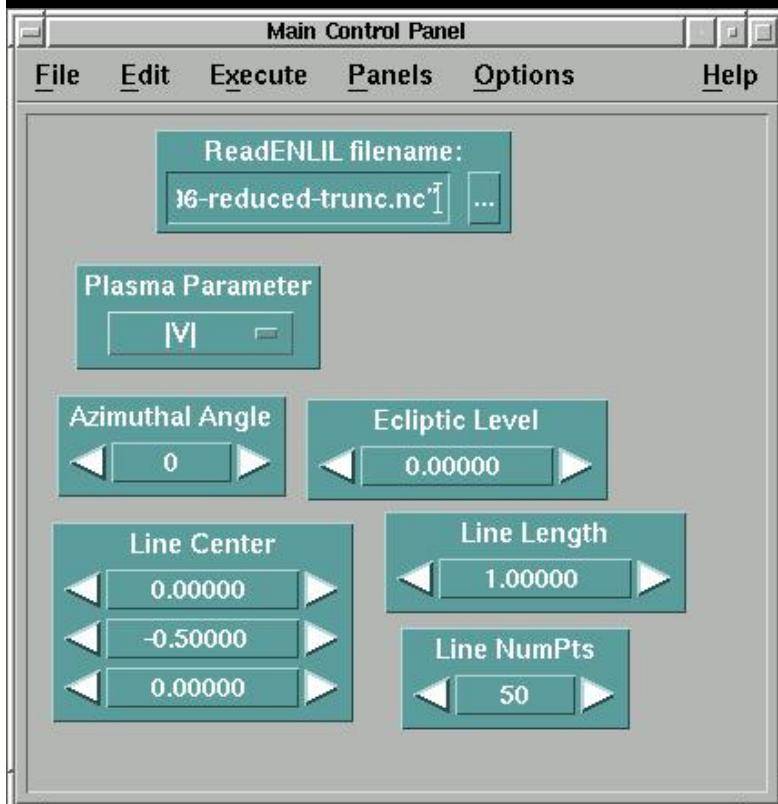
Rotation of earth bound Apex grid
against LFM grid

CISM DX

- Needed to create a visualization and data analysis tool which could be used by validation team as well as model developers
 - Used Open DX and Octave as a basis
- Import modules currently implemented
 - MAS, ENLIL, LFM, TING, and WSA
 - RCM and TIEGCM are under development
- Also includes an extensive collection of observations and tools for calculating metrics and skill scores
- Includes ‘push button’ installation process
 - extensive examples and documentation
 - Available for download from <http://cism.bu.edu/cism/cismdx>
- User group with mailing list and ‘network’ archive

ENLIL – Solar Wind Model

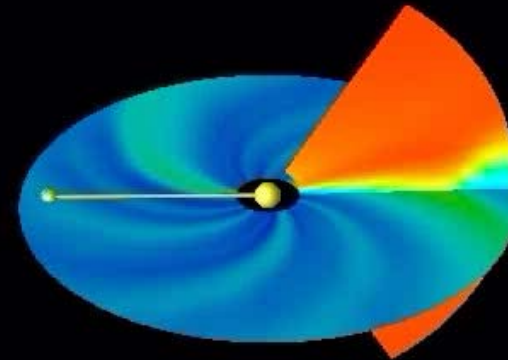
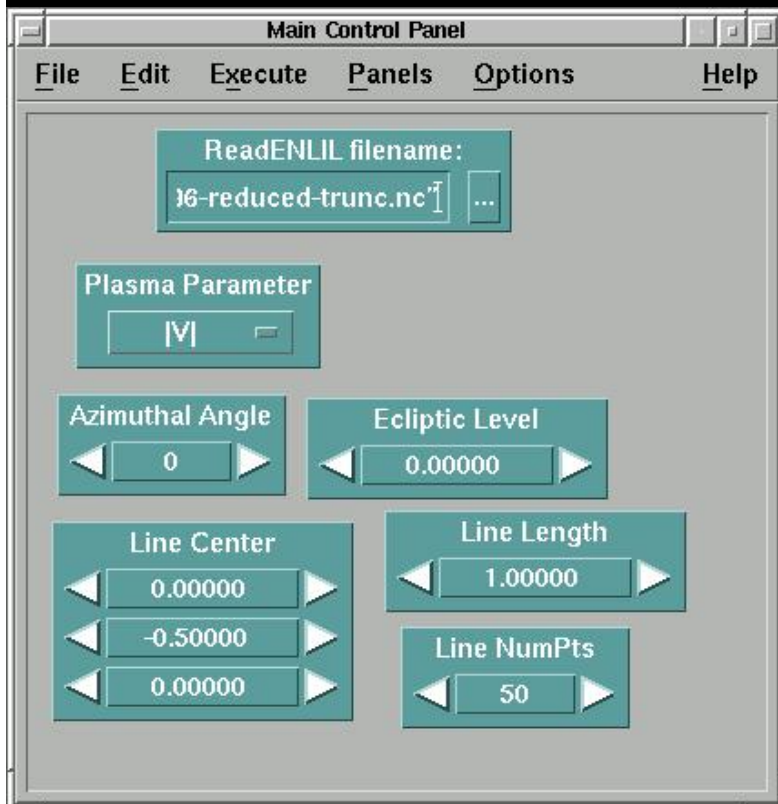
- Network was used as basis for graduate student lab in CISM Summer School



Thanks to D. Odstrcil and N. Arge

ENLIL – Solar Wind Model

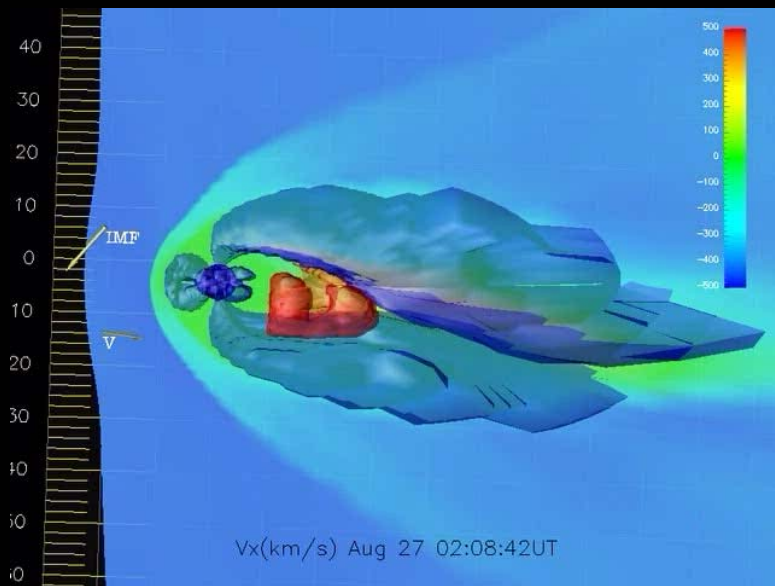
- Network was used as basis for graduate student lab in CISM Summer School



M

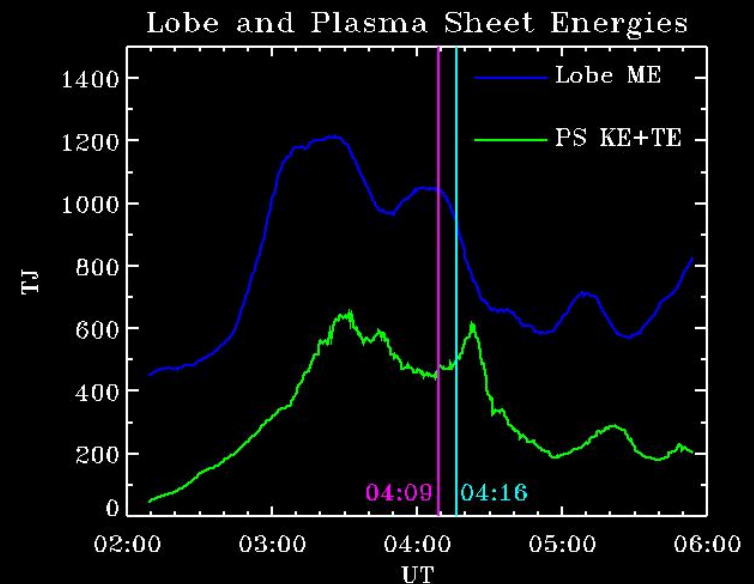
Thanks to D. Odstrcil and N. Arge

LFM – Energy Partitioning



- Lobes
 - $P < 0.01$ nPa and $\rho < 0.2$ #/cc
- Plasma Sheet
 - $\beta < 0.5$ and $T > 1$ keV

- MHD energy densities inside each region are integrated to examine the transfer of energy from the lobe to the plasma sheet
 - Energy transfer appears to precede substorm onset as determined by CL
 - Results are very preliminary because regions may include domains outside the closed field domain



Thanks to T. Guild

Journal of Atmospheric and Solar-Terrestrial Physics
Volume 66, Issues 15-16, Pages 1241-1517 (October-November 2004)
Towards an Integrated Model of the Space Weather System
Edited by W.J. Hughes and M.K. Hudson
<http://www.sciencedirect.com/science/journal/13646826>

Luhmann, J.G., S.C. Solomon, J.A. Linker, J.G. Lyon, Z. Mikic, D. Odstrcil, W. Wang, and M. Wiltberger, Coupled Model Simulation of a Sun-to-Earth Space Weather Event.

Odstrcil, D., V.J. Pizzo, J.A. Linker, P. Riley, R. Lionello, and Z. Mikic, Initial Coupling of coronal and heliospheric numerical magnetohydrodynamic codes.

Riley P., J.A. Linker, R. Lionello, Z. Mikic, D. Odstrcil, M.A. Hidalgo, C. Cid, Q. Hu, R.P. Lepping, B.J. Lynch, and A. Rees, Fitting Flux Ropes to a Global MHD Solution: A Comparison of Techniques.

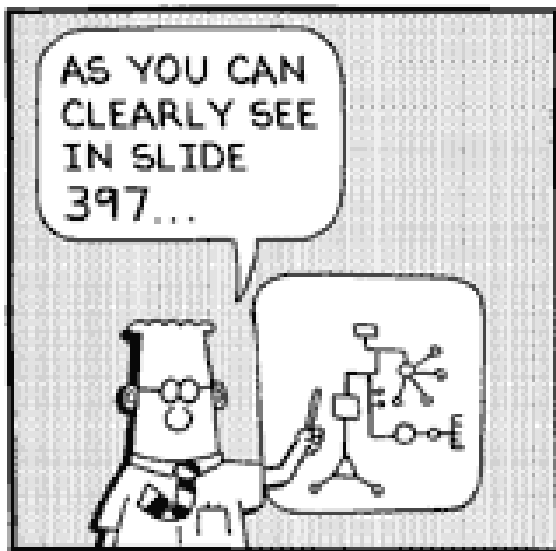
Lyon, J.G., J.A. Fedder, and C.M. Mobarry, The Lyon-Fedder-Mobarry (LFM) Global MHD Magnetospheric Simulation Code.

Toffoletto, F.R., S. Sazykin, R.W. Spiro, R.A. Wolf, and J.G. Lyon, RCM meets LFM: Initial results of one way coupling.

Wiltberger, M., W. Wang, A.G. Burns, S.C. Solomon, J.G. Lyon, and C.C. Goodrich, Initial results from the Coupled Magnetosphere-Ionosphere-Thermosphere Model: Magnetospheric and Ionospheric responses.

Wang, W., M. Wiltberger, A.G. Burns, S.C. Solomon, T.L. Killeen, N. Maruyama, and J.G. Lyon, Initial results from Coupled Magnetosphere-Ionosphere-Thermosphere Model: Thermosphere-Ionosphere responses.

Goodrich, C.C., A.L. Sussman, J.G. Lyon, M. Shay, and P. Cassak, The CISM Code Coupling Strategy.



www.dilbert.com scottadams@aol.com



slide © 2009 United Features Syndicate, Inc.

