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* Student
** Graduated Student
1 Presented by David Murr
Overview of CISM Solar/Heliospheric Modeling


1 University of California, Berkeley, 2 SAIC, 3 University of Colorado, 4 NOAA-SEC, 5 Stanford, 6 AFRL

This poster illustrates by example the approach that CISM is taking to develop a physics-based model of the corona and solar wind, including the transient disturbances known as CMEs. To force ourselves to confront the realities of actual event modeling, CISM chose a period in May 1997 that including a relatively simple CME that was well-observed at the Sun by SOHO and Yohkoh, and upstream of Earth by WIND. This CME and its ICME produced a modest SEP event and geomagnetic storm, making end-to-end simulation possibilities complete. The CISM Solar/Heliosphere modeling approach utilizes MHD simulations (see code coupling poster) based on observed boundary conditions for the coupled corona and solar wind model, and a particle code for the associated Solar Energetic Particles (SEPs).

The ambient corona is modeled
A model field is developed for studying CME initiation: Captures the essential features of AR8038 + background field

Active Region Dynamics are Introduced
The data-inspired active region vortical motions and flux cancellation at the active region neutral line are used to drive a MAS model coronal eruption. This simulation is currently run without the ambient solar wind, but will soon be augmented and coupled to ENLIL.

Cone Model Interim Approach
The Cone Model of CMEs uses coronagraph images to define the site and orientation of a cone-shaped volume that represents the coronal "channel" through which a halo CME enters the Solar wind. Odstrcil et al. incorporated this into the ENLIL model as an optional part of the inner boundary conditions.

Data Evaluation
SOHO (LASCO, EIT, MDI) and Yohkoh images, and WIND, IMP-8 and Sampex in-situ data, are used to select the May 12, 1997 well-documented halo event for CISM study. Ground-based magnetograms from MWO are used, with the MDI data, to extract boundary conditions for the models (see Liu et al. poster). The single flaring active region on the disk also produced several limb CMEs.

Geospace Connections
Local Solar Wind parameters drive the magnetosphere simulation; SEPs enter the polar caps and plasma sheet along open field lines and at low latitudes on occasion (see Kress et al. poster)

Cone Model of CMEs uses coronagraph images to define the site and orientation of a cone-shaped volume that represents the coronal "channel" through which a halo CME enters the Solar wind. Odstrcil et al. incorporated this into the ENLIL model as an optional part of the inner boundary conditions.

Illustrations re. geospace connections: SEP entry (from Kress et al. poster); solar wind driving; (Magnetosphere overview poster), relative scales of the geohelios models

Earth-Shock-connected field lines in the Cone model give shock location and a measure of SEP source strength

Nonuniform mesh: high resolution active region in a global simulation

Local correlation tracking Reveals the active region Horizontal velocities

Solar wind parameters from the Cone Model of the May 12 '97 event compared to WIND data

Flux Rope, Side View
Flux Rope and Global Field Radial Velocity

The simulated polarization brightness image illustrates one of the planned coronal model validation products (see Validation Overview poster)

SEP Model "Overlay"
The SEPs are modeled as a passive test particle (ion) population in a post-process approach that uses the MHD shock to characterize shock source "injections", and the time-dependent modeled magnetic field lines between the Sun and Earth to define the path of transport from the shock. We currently assume scatter-free propagation and an ad-hoc isotropic shock source. Ion hybrid code results will eventually be used to obtain a physics-based shock source description.

SOHO (LASCO, EIT, MDI) and Yohkoh images, and WIND, IMP-8 and Sampex in-situ data, are used to select the May 12, 1997 well-documented halo event for CISM study. Ground-based magnetograms from MWO are used, with the MDI data, to extract boundary conditions for the models (see Liu et al. poster). The single flaring active region on the disk also produced several limb CMEs.

A model field is developed for studying CME initiation: Captures the essential features of AR8038 + background field

A side view shows how an active region can produce an apparent splitting or broadening of a coronal streamer in the MHD model. (also see CORHEL poster). The simulated polarization brightness image illustrates one of the planned coronal model validation products (see Validation Overview poster)
A very challenging element for the operation of Sun-to-Earth coupled-system space weather forecasting is obtaining the solar observations that must serve as the initial and boundary conditions to drive the system. Since most solar variability is magnetic in origin, the magnetic field provides an appropriate and effective input to drive MHD simulations of the corona and solar eruptions. Deriving a self-consistent photospheric velocity field is another requirement for more realistic simulations. This poster describes how to acquire magnetic and velocity fields on the solar boundary. Several illustrations show how we incorporate this information with models to simulate solar activities.

**Observations of the Solar Boundary**
- **Synoptic maps of the magnetic field**
  - Many corrections must be applied to magnetograms (e.g. zero-level, saturation, etc.). Data are acquired by MDI, MWO, NSO, & WSO.
  - Synoptic maps can be generated in various formats. Among them are standard Carrington synoptic charts, daily update maps, and synoptic frames. The last two are typically used for purposes of real-time forecast and solar transient study.
  - Several issues must be addressed in the process of producing a synoptic map. Of great importance are: Interpolation of polar regions; Solar differential rotation.
- **Other synoptic maps**
  - Figure a: Magnetic field lines computed from a synoptic map of the magnetic field based on the PFSS model.
  - Figure b: Coronal holes, streamers, and HCS computed from a synoptic map of the magnetic field based on a PFSS model.

**Inferences of the Solar Boundary**
- **The vector magnetic field**
  - Vector magnetic field is an essential input to more realistic models of the solar corona (e.g. non-linear force free field model). SOLIS is the first to measure vector field over the whole solar disk.
  - Coronal magnetic field modeled with a force-free assumption agrees with analytical solution better than the potential field. Boundary data from the chromosphere is more appropriate than data from the photosphere.
- **The velocity field**
  - Models and algorithms have been developed recently to derive the photospheric velocity field from magnetic field data. Shown in the Figure below are velocity fields in solar quiet (left) and active regions (right) derived by applying a Local Correlation Tracking (LCT) technique to a series of MDI line-of-sight magnetograms. More rigorous schemes have been established that can be applied to a series of vector magnetograms.
  - Synoptic maps of solar magnetic field can be used for many purposes. Illustrated here are five examples: Figure c: Synoptic frames of the magnetic field and a PFSS model are used to examine change of magnetic field during a CME.
  - Figure d: Solar wind speed of three successive Carrington rotations predicted by Wang-Sheeley-Arge model. The synthetic maps were produced by MWO and NSO data. WSO data were also used. The EIT synoptic map at the bottom panel, as a comparison, shows coronal holes.
  - Figure e: IMF calculated from a synoptic map of the magnetic field. As a comparison, measurements are also plotted.

**MHD Simulation Driven by Boundary Data**
- Incorporated with solar boundary data, MHD simulations, demonstrated here by a few examples, have been carried out to study evolution of magnetic field lines and evolution of active regions. More applications can be found in our other posters.
  - Figure f: MHD simulation of an active region driven by boundary data. Shown in the panels are the initial state (upper left: velocity field at the photosphere, lower left: coronal magnetic field lines), and on the right, the end state of (short) simulation (upper right: vertical magnetic field at the photosphere, lower right: coronal magnetic field lines).

**Summary**
- We have illustrated our effort to obtain optimum boundary data of magnetic field and velocity field;
- We have also shown MHD simulations of the solar dynamic magnetic field and solar active region evolution driven by observed and inferred boundary data.

**Future Work**
- Evaluate the corrections and schemes for generating synoptic map of magnetic field;
- Compare and standardize synoptic maps of magnetic field from various observatories;
- Make use of vector magnetic field data from SOLIS and other sources;
- Analyze other data (e.g. EIT data) as possible input for MHD models.
Solar Wind Modeling of Cassini Approach Data


1. CORHEL

The CISM inner heliospheric model CORHEL is extended to 10 AU to investigate how well this solar magnetogram-based 3D MHD model describes the solar wind influence on Saturn's magnetosphere. The CORHEL model describes the steady solar wind stream structure and its origins in the corona. It has been tuned to provide a simulation of the solar wind parameters at 1 AU including plasma moments and interplanetary magnetic field magnitude and polarity in the absence of disturbances from coronal transients. Comparisons with the Cassini CAPS plasma and magnetometer field observations during Cassini’s approach to Saturn show good agreement with the model, in part because of a low solar activity and a particularly simple and steady interplanetary sector pattern during the months before the Saturn orbit insertion (SOI). It is known that Saturn’s magnetosphere responds to solar wind dynamic pressure enhancements, which are evident in this period with striking regularity. The model agreement suggests that a viable option is available to predict such enhancements from co-rotating stream interaction regions, as well as to provide an approximation to solar wind conditions when Cassini is inside Saturn’s magnetosphere. Moreover, as radial alignment with other close-in spacecraft is not required, this study illustrates the potential use of state-of-the-art numerical models to study space weather on a solar-system-wide scale.

2. HELSAT:

CORHEL extension to 10 AU

The model results for CR 2011-2012 demonstrate that the CISM model results are not limited to outer heliospheric current sheets observed at 1 AU and that the solar wind velocity is best modeled by HELSAT, and observations of the model, which have shown success, should lead to improvements in the model at 1 AU. The model results for CR 2011-2012 demonstrate the potential of CISM for 1 AU applications as the boundary conditions on the 1 AU model to understand for the first time the fate and contribution of coronal transients to the interplanetary conditions experienced by Jupiter and Saturn.

CONCLUSION

- The study demonstrates that CISM models can be extended to 10 AU with some success.
- The modeling is solar magnetogram-based and is not restricted to the cases for when Earth and Jupiter/Saturn are co-aligned.

FUTURE WORK

Introduction of transients modeled by CISM for 1 AU applications as the boundary conditions on the 1 AU model to understand for the first time the fate and contribution of solar wind dynamic pressure enhancements, which are evident in this period with striking regularity. The model agreement suggests that a viable option is available to predict such enhancements from co-rotating stream interaction regions, as well as to provide an approximation to solar wind conditions when Cassini is inside Saturn’s magnetosphere. Moreover, as radial alignment with other close-in spacecraft is not required, this study illustrates the potential use of state-of-the-art numerical models to study space weather on a solar-system-wide scale.
Introduction/Motivation
The magnetosphere responds as a coupled system to solar wind input provided by MAS-ENLIL or L1 data. The LFM code provides the single fluid MHD description of the large scale system, coupled with RCM drift physics and a TING/TIEGM ionosphere. Output from the LFM model coupled with these two large scale codes will be used to specify the time dependent fields which affect SEP and radiation belt particle dynamics. A plasmasphere boundary can be specified by RCM or inclusion of ionospheric dynamics. Mass outflow, which is important to describing the ionospheric source of magnetospheric plasma is addressed with the Mi-coupling module. Reconnection controls the solar wind coupling efficiency to the magnetosphere.

Sampled 25 MeV proton trajectories in time dependent LFM fields in solar magnetic (SM) coordinates for the 24 Nov 2001 CME-driven geomagnetic storm. The circle at 2.2RE is the inner boundary of the magnetospheric model. WIND input is used at right boundary.

An empirical model for auroral- and cusp-region ionospheric outflow has been embedded in the LFM model. The left plot shows the distribution of O+ outflow at the southern ionosphere from the LFM model (Gagne et al., 2005) and from Polar statistical data (Lennartsson et al., 2004). The % change in magnetospheric mass density, relative to a simulation without outflow, is shown in the right plot after four hours of outflow for a steady solar wind flowing at 400 km/s with IMF southward at 5 nT.
Introduction and Motivation

• The relative contributions of solar wind and ionospheric plasmas in populating the magnetosphere remains an area of intense study (e.g., see review of Moore et al., 1993). Since the ionospheric plasma is dominated by heavy ions (oxygen), it is also thought to play a unique role in several magnetospheric processes, such as the formation of the storm-time ring current.

• The majority of existing global MHD models do not currently include an ionospheric source of plasma. The model of Winglee [1998] is a multi-fluid MHD simulation and is the only published study to include ionospheric outflow.

• Observationally, ionospheric outflow has been described in climatological terms, providing global specifications for the total outflow and spatial distribution as a function of solar and geomagnetic activity. Strangeway et al. [2005] have presented the first observations that provide a physical, causal driver of outflow that can be incorporated within MHD simulations.

• As part of CISM’s Year 4 Milestones, we present the development of an initial module for ionospheric outflow within the LFM model. This module, the MORDOR Dynamic Outflow Response (MORDOR), has yielded promising results for providing LFM with an ionospheric plasma source.

Module Development

• The development of the MORDOR outflow module first required development of code to enable the use of DC Poynting flux as a diagnostic within the LFM simulation.

• The Poynting flux at the inner boundary of the simulation and used with the Strangeway et al. result to determine the outflow flux.

• The outflow flux was spatially modulated to represent the effect of ambipolar upwelling of the ionospheric source plasma. This mask effectively reduces the outflow over the polar caps.

• The final outflow was mapped back to the inner boundary of the simulation and combined with a statistical model of density to calculate the outflow velocities.

Results

• The modified version of LFM was run for 16 hours with contrived solar wind inputs: constant speed and density with four IMF clock angles, each lasting four hours. The results shown here focus on the four hour period of steady southward IMF of 5 nT.

• The first result is that the macro-scale size, shape, and dynamics of the simulated magnetosphere changed very little with the additional mass input. This indicates that the LFM simulation is able to incorporate this new plasma source and produce a more realistic magnetosphere.

• The MORDOR algorithm produced total outflow fluences similar to those predicted statistically and the spatial distribution of the outflow was reasonable except that the nightside outflow fluences seem too low.

• A control volume analysis was carried out to determine the destination of the outflow mass. Much of the mass initially accumulates in the inner magnetosphere, within geosynchronous orbit – an indication that these outflows could play an important role in ring current dynamics.

• Global ionospheric parameters were modified significantly during the period of strongest outflow. LFM’s precipitation module does not accurately track the electron precipitation source density when heavy ions are introduced in the outflow. Consequently, the precipitation-induced modifications to conductivity may be unrealistic in regions of strong outflow.

Conclusions and Future Directions

• The MORDOR module has produced a realistic, physically-driven source of ionospheric plasma within LFM. It is the first global MHD simulation of causally driven, auroral- and cusp-region ionospheric outflow and it will allow us to study the role of ionospheric plasmas in the magnetosphere.

• Future developments will include an update of the empirical driver (the Strangeway et al. result is derived from cusp observations only), particle tracing to study the destination of the ionospheric plasma, an outflow driver that is purely physical, and ultimately incorporation into a multi-fluid MHD code.
Objective

As an enterprise that depends on the collaboration of thousands of individuals from around the world, a scientist’s ability to effectively communicate ideas to others is priceless. Two-dimensional static pictures of traditional textbooks have often been stumbling blocks for new students of space physics. Fortunately, improved computer technology is allowing teachers in this field to revolutionize the way in which they communicate concepts to students.

The goals of this project are to create visualizations of the Earth’s magnetosphere, the regions defined by the magnetic field surrounding our planet. Specifically, this project attempts to illustrate the impact of the Sun on our planet as a result of the dynamic interaction between the solar wind and the magnetosphere.

These visualizations may be used in future courses at Dartmouth, an exhibit at the Montshire Science Museum, and the CISM Summer School.

CISM

The Center for Integrated Space Weather Modeling (CISM), a National Science Foundation Science and Technology Center that consists of research groups at eight universities as well as several government, private non-profit research organizations, and commercial firms, is intended to give students a comprehensive overview of space physics and space weather.

First Year Women in Science Project: Visualizing the Earth’s Magnetosphere in 3D

Emily Greenberg, David Murr, and Simon Shepherd

1 Dartmouth College, Hanover, NH

OpenDX

OpenDX, a powerful software package used for the visualization of scientific, engineering, and analytical data, has been used to create the visualizations.

Methods

OpenDX

A typical screenshot from OpenDX. Different ‘modules’ are used to import data and render it as complex images.

The GeoWall

To make these visualizations literally three-dimensional, we employed a GeoWall, an affordable stereo projection system.

How Does it Work?: Stereoscopic Principles

How Does it Work?: Stereoscopic Principles

Results

The structure of the geomagnetic field, the magnetosphere, is very similar to the pattern formed when iron filings align around a bar magnet.

1. The observer sees the Earth in front of her eye.
2. A picture of the Earth is drawn on the screen by extending lines from the eyes to the Earth. Each projector is responsible for making one image.
3. The observer sees two balls on the screen, and there is no stereoscopic effect as yet. To produce a stereoscopic effect:
   a. By polarizing the light from each projector and wearing the 3D glasses, one image is sent to one eye, and the other image is sent to the other eye.
   b. This eliminates the views represented by the dashed lines, creating the illusion of a 3D image.

Visualizing the Earth’s Magnetosphere in 3D

These visualizations may be used in future courses at Dartmouth, an exhibit at the Montshire Science Museum, and the CISM Summer School.

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The Scaling of Forced Collisionless Reconnection

Brian P. Sullivan¹, Barrett N. Rogers¹, Michael A. Shay²
¹Dartmouth College, ²University of Maryland

ABSTRACT: We present two-fluid simulations of forced magnetic reconnection in a collisionless two-dimensional slab geometry. In the absence of forcing, our system has $\Delta'=0$ and as expected exhibits no reconnection. Therefore, reconnection in this study is driven by a spatially localized forcing function. This function represents a generic external forcing agent such as the solar wind. We investigate the behavior of the resulting reconnection as a function of various free parameters in the system. Consistent with previous scaling studies done on systems with relatively large $\Delta$, we find that for sufficiently strong forcing the reconnection process becomes Alfvénic.

Introduction

The so-called GEM challenge studies featured a current sheet with an initial half-width of one proton inertial length without considering how this configuration had been achieved. In contrast, this study features a very wide initial current sheet. To drive reconnection, this stable system is then subjected to a spatially localized forcing function, representing a generic externally imposed forcing function, such as the solar wind.

Initial Equilibrium

Fig 1: A schematic diagram of the initial equilibrium: a system size double periodic current sheet. We seed both current sheets with x-points as shown above to create the double tearing mode. Boundary conditions are periodic in x and y. This system is stable to all linear modes ($\Delta'=0$.)

Forcing

Fig 2: $F_y(x,y)$ (dashed contours and $J_z$ (blue) The most negative current is shown in black greatest and least values of $J_z$ are shown above the figure.

Fig 3: Time dependence of the forcing function. In each simulation the forcing is ramped up at the same rate, then held fixed at a different level. In one simulation the forcing is continuously ramped for the duration of the run.

Dissipation Region

Fig 5: A schematic diagram of the current sheet and dissipation region (shaded yellow box). Magnetic fields are shown in brown, currents in red, plasma flows in blue.

Fig 6: The scaling of $V_{out}$ with $B_d$ (top) and the scaling of $E_r$ with $B_d$ (bottom.) Each cluster of data is time series data from a run with a different forcing level. The reference line of slope unity in the top plot represents Alfvénic outflow based on the upstream field. The slope of the line in the bottom plot is $\sqrt{10}$, 10 being approximately the aspect ratio of the dissipation region $\Delta/\delta$.

Fig 7: The scaling of $E_r$ with varying width of the forced region, $w_x$. Time series of the raw reconnection rates are plotted in (a). In (c) the reconnection rates are normalized to the square of the upstream field, $B_d$, shown for each simulation in (b).
Incorporating Spectral Characteristics of Pc5 ULF Waves into 3D Radiation Belt Modeling
Kara L. Perry and Mary K. Hudson
1Boston College, 2Dartmouth College

ABSTRACT
The influence of ultra low frequency (ULF) waves in the Pc5 frequency range on radiation belt electrons in a compressed dipole magnetic field is examined. A model is developed describing the magnetic and electric fields associated with poloidal-mode Pc5 ULF waves. Frequency and L dependence of the ULF wave power is included in this model by incorporating published ground-based magnetometer data. This ULF model is used as input to a three dimensional guiding center particle code from which the L, energy and pitch angle dependence of the diffusion rates are analyzed. Results from a dipole magnetic field model are compared to a compressed dipole model in the equatorial plane.

CALCULATING 3D FIELDS

+ Magnetic and electric field equations:
\[ B = B_{dipole} + B_c + B_{pol} \]
where \( B_{pol} = B_r + B_0 \)
\[ E = E_0 + E_\theta \]
value used: \( E_\theta = 0 \)

3D dipole equation
\[ B_{dip} = \frac{2\mu_0 R_e}{r} \cos(\theta) \hat{r} - \frac{2\mu_0 R_e}{r^3} \sin(\theta) \hat{\theta} \]

Compressional added to z component of magnetic fields
\[ B_z = (b_z \cos \phi)^2 \]

ULF fields given by:
\[ \nabla \cdot B = 0 \]
\[ \frac{\partial B}{\partial t} = \nabla \times E \]

Poloidal fields

- Includes both radial AND compressional components

\[ B_r = \frac{2\mu_0 F(f) H(L)(\omega, \phi, f) \cos(\theta)}{r} \left[ 1 - 0.5 L \ln(10) \right] \]
\[ B_\theta = \frac{2\mu_0 F(f) H(L)(\omega, \phi, f) \sin(\theta)}{r} \left[ 1 + 0.5 L \ln(10) \right] \]
\[ E_\phi = -u_0 \frac{F(f) H(L) \sin(\theta) \sin(m \phi - \omega t - \phi_0)}{r} \]
where:
\[ A_0 = \frac{1}{\sqrt{4\pi \eta}} \]
\[ H(L) = 10^{0.5 L L} \]
\[ F(f) = f^0 \]
\[ J(\omega, \phi, t) = \cos(m \phi - \omega t - \phi_0) \]
value used: \( m = 2 \)

Symbols:
\( P_0 \) - power of fields (nT/Hz)
\( \phi \) - longitude
\( m_0 \) - slope of line, figure 2
\( m_\phi \) - angular frequency
\( L \) - background L
\( m \) - initial phase
\( f \) - frequency
\( \theta \) - co-latitude
\( m \) - azimuthal mode

RESULTS

+ 4 case
1) \( m_0=0, m_\phi=0 \)
2) \( m_0=0, m_\phi=2 \)
3) \( m_0=1/3, m_\phi=0 \)
4) \( m_0=1/3, m_\phi=-2 \)

+ Diffusion Coefficients
- To calculate, use slope of best fit line of \( \langle DL \rangle \) vs time

\( D_{L0} = D_{L0} + 0.05 \left( \frac{L}{L_0} \right)^{0.5} \]

Figure 1:
Azimuthal wave power during a simulation of the Sept. 24-26, 1998 geomagnetic storm using the LFM MHD magnetospheric model from Elkington [2004]. Slope of total power is \( m_0 \) in H(L) equation.

Figure 2:
Ground-based magnetometer observations of power vs frequency reported by Bloom and Singer [1995]. Slope is \( m_0 \) in \( f(m) \) equation.

Figure 3:
Latitude dependence of magnetic and electric fields at \( L=6.6 \). Panel (a) is \( m_0=0 \); max of \( |B_{pol} - B_{L} + B_{r}^2 \) off equator. Panel (b) is \( m_0=1/3 \); max of \( |B| \) at equator. Panel (c) is poloidal electric field: max at equator

CONCLUSIONS

+ Frequency-dependent ULF Wave Power
- Causes \( D_{L0} \) to decrease with increasing energy (fig 4)
- Less power at higher resonances

+ L-dependent ULF Wave Power
- Changes L dependence of \( D_{L0} \) from \( n=6 \) to \( n=18 \) (fig 5)
- Produces \( D_{L0} \) max at equator \( \Rightarrow \) 2D good upper limit for space weather forecasting

+ Adding compression to dipole
- Offsets effects of additional resonances (fig 5)
Introduction

The outer zone radiation belts are comprised of energetic Electrons trapped in drift orbits encircling the Earth, lying at radial distances extending from around 2RE to 7RE or greater. This region of space is of particular significance due to the large number of spacecraft operating at these altitudes, and global society’s increasing reliance on space based technologies. As the MeV particles composing the belts represent a hazard to human activity in space, a goal of the CISM project is to provide a means for understanding and predicting changes in the radiation belts.

How well do we understand radial transport?

In this work we conduct a model-model comparison to test our understanding of the radial diffusion process during periods of enhanced geomagnetic activity. An LFM MHD simulation, driven by upstream solar wind measurements, is used to drive test particle simulations [Elkington, 2004] of the outer zone radiation belts. The results are used as a baseline for comparison in a radial diffusion study.

Radiation Belt Studies using the LFM MHD code

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September 1998 Storm

The geomagnetic storm of September 24-26, 1998 was characterized by high solar wind speeds and an order-of-magnitude increase in outer zone electron fluxes occurring over a period of less than 18 hours. The high solar wind speeds and widely-varying dynamic pressures provided a source of energy for magnetospheric ULF waves, which in turn led to efficient radial transport and adiabatic heating of the energetic electrons comprising the outer zone.

Radial Diffusion Coefficients

\[
\frac{df}{dt} = \mathbf{D} \cdot \nabla f \quad \text{or} \quad \frac{df}{dt} = \int \mathbf{D}(\mathbf{B}) \cdot \nabla f \, d\mathbf{B}
\]

Appropriate radial diffusion coefficients were developed in Fei et al. [2005], and accounted for both symmetric and asymmetric contributions to both magnetic and electric diffusion sources:

Potential Variations

\[
D_{\text{pot}} = \frac{1}{L^2} \sum \nabla^2 \left( L, m \omega_p \right)
\]

Electromagnetic Variations:

\[
D_{\text{em}} = \frac{1}{L^2} \sum \nabla^2 \left( L, m \omega_e \right)
\]

The appropriateness of these forms were verified numerically.

Diffusion results

Simple power law: \( \alpha = 0.376 \)

Symmetric only: \( \alpha = 0.325 \)

Asymmetric only: \( \alpha = 0.441 \)

Sym + Asym: \( \alpha = 0.315 \)

Summary

We have conducted simulations of the September 24, 1998 geomagnetic storm to examine the extent to which this storm could be described in terms of radial diffusion. We find the best agreement between the MHD/particle and diffusion simulations when the full compliment of symmetric and asymmetric coefficients are used. We find it necessary to include realistic descriptions of power spectral density, including information on the global mode structure. Such simulations show the utility of the CISM modeling effort as not only a means of predicting the space weather environment, but also as a means of examining fundamental physical questions about the geospace environment.

References


[Holzworth, R.H. and F.S. Mozer, Direct evaluation of the radial diffusion coefficient for MeV due to electric field fluctuations, J. Geophys. Res., 84, 2559, 1979.]
Diffusion of Radiation Belt Electrons During Magnetic Storms
- important mechanism to create MeV electrons -

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Introduction
Radial diffusion is an important mechanism to explain the dynamics of radiation belt electrons, especially during magnetic storms. In previous studies, MHD simulations are shown to be consistent with radial diffusion simulations. We use a simple radial diffusion equation, derived under assumption that the 1st and 2nd adiabatic invariants are conserved, to observe a change in phase space density (PSD) in the radial direction, L vs time (in days) using a few different radial diffusion coefficients, $D_{L1}$. Source electrons at the outer boundary of radiation belt that are transported from the tail region gain momentum when diffusing inward. Hence, radial diffusion is considered to be an effective way to increase the energy of source electrons to relativistic levels.

Outline
* Theory of Radial Diffusion
- due to excited ULF waves during storms
  - assume constant 1st and 2nd invariants
  * Various DLL Coefficients
  - numerical and empirical DLL
  * Numerical Simulation Results
    - with and without loss term
  * Future Studies

Theory
From the Fokker-Plank equation and Liouville’s theorem, a 1D diffusion equation (time and one spatial dimension) is derived. [Faithhammer 1968]
The diffusion equation at constant $\mu$ and $\nu$ is written simply as

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial \nu} \left( D_{LL} \frac{\partial f}{\partial \nu} \right)$$

During Magnetic storms, increased ULF waves of time scale $\sim 10 \text{ min}$ are observed in the magnetosphere, and the radial electric field component of these waves are considered to be responsible for moving electrons, which otherwise are drifting around the earth at constant $L$, through different $L$. We assume the 1st and 2nd adiabatic invariants are conserved during the diffusion since the time scale of the ULF waves of interest is orders of magnitude smaller than the time scale of gyration and bounce motion. Then we can use the above diffusion equation. When the source electrons that are transported from the tail region to the outer magnetosphere diffuse radially inward (stronger B field at you go inside because of earth’s dipole moment), they increase their momentum to conserve the 1st invariant.

The $D_{LL}$ Values
The diffusion coefficients $D_{L1}$ have been calculated analytically, empirically, and numerically in previous studies. We compare the resulting diffusions using some of the coefficients. Usually the diffusion coefficients are written in a form $D_{L1} = D_0 L^\alpha$. Here we compare two different Diffusion Coefficients.

I) $D_{L1} = 10^{-4} L^{10}$
[Selesnick and Blake 2000]
For compressed dipole with both freq and L dependent wave spectrum

II) $D_{L1} = 3 x 10^{-4} L^{2.3}$
[Perry et al]

Initial and Boundary Conditions
from AE8 mode
1) For a specific $\mu$, $\nu$ (pitch angle), and $L$, we can calculate the momentum of the electron from the equation $\frac{\partial}{\partial \nu} \left( D_{L1} \frac{\partial f}{\partial \nu} \right)$. Then we can also find the kinetic energy for the specific $\mu$ and $L$ by the equation.

$$E = \frac{1}{2} m \nu^2$$

Note, for now we assume a parabolic distribution so that we do not need worry about the pitch angle distribution.

2) $E \rightarrow \mu$ to convert the differential flux, $\nu$, from AE8 to PSD, $F$.

AE8 model is used for specifying the initial and fixed boundary (2.5h-9.0h) conditions for the simulation. The AE8 model gives differential electron flux (cm$^{-2}$ s$^{-1}$ MeV$^{-1}$) for given values of kinetic energy (KE), L, and B/L (B is the equatorial magnetic field strength). But our model requires to have phase space density $f$ (or PSD) (cm$^{-3}$ keV$^{-1}$), so we need to use the above equation.

Numerical Results
Numerical technique: Crank-Nicholson method

* without loss

Loss time effect
There are additional terms of the diffusion equation due to strong pitch angle diffusion. The model we use is based on [Summers et al 2004]

$$\frac{\partial f}{\partial t} = \frac{\partial}{\partial \nu} \left( D_{L1} \frac{\partial f}{\partial \nu} \right)$$

Observations
In all cases, as time goes on, PSD approaches to the steady state distribution as expected. Case II diffuses faster than case I since Case II has stronger L dependence.

Future Studies
* Use $D_{L1}$ with other equatorial pitch angle cases
* Convert $L \rightarrow L^0$ when obtaining data
* Improve loss term
* Compare the Results with Other models and Satellite data (geosynchronous)
Prompt Trapping of Solar Energetic Particles During Geomagnetic Storms
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Introduction
The formation of MeV ion belts in the Earth’s inner zone radiation belts is observed to occur during solar energetic particle (SEP) events, in conjunction with shock related enhancements in the solar wind dynamic pressure and dramatic variations in the interplanetary magnetic field [Slocum et al., 2002; Kress et al., 2004; Hudson et al., 2004]. Blake et al. [2004] address the geoeffectiveness of shocks in populating the radiation belts, focusing on the 24 March ’91, 6, and 24 Nov 01 geomagnetic storms. During these storms MeV ions were injected well into the inner magnetosphere producing new ion belts that persisted for years following these events (See Figures 1 & 2).

Störmer Theory
The Earth’s magnetic field usually shields the inner magnetosphere from direct penetration by MeV solar ions (corresponding to latitudes less than ~60°). A charged particle’s ability to penetrate a magnetic field is determined by its magnetic rigidity (m/charge). In a pure dipole magnetic field, Störmer [1895] showed that a particle with a given rigidity is bound to certain regions of space, which may be characterized by a single dimensionless parameter

\[ \gamma = \frac{M}{qv} \]

where M is the dipole moment, \( q \) is the charge, and \( \gamma \) is the azimuthal component of the generalized momentum

\[ \gamma = \frac{m}{q} \frac{d}{dt} \frac{q M}{c^2} \]

in cylindrical coordinates (\( \phi, z \)). Figure 3 shows forbidden and allowed regions for three different values of \( \gamma \). Distance is expressed in Earth radii (\( R_E \)).

Figure 3. The shaded areas show a cross section of the forbidden regions for 25 MeV particle trajectories in a dipole magnetic field \( B = 5.0 \times 10^{-6} \text{T Gauss meter}^{-1} \) for three different values of \( \gamma \). (a) \( \gamma = 1 \) is the important case where particles entering from infinity have access to the innermost L-shell. The intersection of the inner torus with the Earth’s surface, in the \( \gamma = 1 \) case, corresponds to the location of the cutoff latitude, below which solar particles of a given rigidity do not have access. Trapped orbits are possible only when \( \gamma < 1 \). Particles with \( \gamma > 0.59 \) have access to the inner trapping regions, but in these cases there is no inner trapping region, nor do these orbits have access to low L-shells.

Allowed regions for particle orbits may be determined numerically, by sampling many orbits with the same value of \( \gamma \), as shown in Figure 4.

Figure 4. Randomly sampled 25 MeV, \( \gamma = 1 \), proton orbits in a pure dipole magnetic field. \( B = 10^{-5} \text{T Gauss meter}^{-1} \), with distance in Earth radii (\( R_E \)). All particle orbits enter and exit from infinity.

Although Störmer’s analytic result is derived in a pure dipole magnetic field, well defined but non-axis symmetric SEP magnetic ray cutoffs are found in previous experimental and numerical geometric results [e.g., Leske et al., 2001; Smart and Shea, 2001] suggesting that Störmer theory may be, in some approximation, generalized to a time dependently perturbed dipole field.

Modeling Geomagnetic cutoffs
A cutoff surface is located by testing points in space successively outward in small L-shell increments for SEP access. A point in space is tested by launching many particles of uniform rigidity from that point with their velocities distributed isotropically over all directions. Each trajectory is followed backwards in time. If a particle escapes the magnetosphere then its trajectory is a viable inward trajectory, indicating that we have reached the inner cutoff. An efficient search algorithm has been developed to find and follow this surface. Figure 5 shows the inner cutoff at two snapshots in time from the LFM 24 Nov 2001 storm simulation.

Figure 6. Randomly sampled 25 MeV proton orbits with approximately the same value for \( \gamma \) launched throughout an ~5 minute interval from the 24 Nov 2001 LFM storm simulation, in solar magnetic (SM) coordinates. The orbits are sampled only within the volume defined by \( \gamma < 1 \) in order to show a cross section of the Stömer boundaries. At 7:05 UT the inner cutoff is most compressed due to a large solar wind density enhancement, evident by the color scale, moving from far right to left toward the magnetopause which is compressed inside of geomagnetic. The circle at \( \gamma = 2.2 \) \( R_E \) is the inner boundary of the magnetospheric model.

SEP Geomagnetic Trapping
While cutoffs may be calculated by computing reverse Lorentz trajectories in static field snapshots, geomagnetic trapping is studied by computing forward trajectories in time dependent fields. In Figure 5, we illustrate the dynamics of Stömer boundaries during a severe compression of the magnetopause, by randomly sampling ~ 1.5 million forward particle trajectory orbits followed in time dependent fields, from the 24 Nov 2001 LFM storm simulation. We use initial conditions numerically determined to have \( \gamma = 1 \) in the 7:05 UT snapshot. The same set of initial conditions is used to launch particles repeatedly throughout the ~5 minute interval, thus we obtain Stömer boundaries for a time dependent \( \gamma \). A cross section of the allowed orbital region is obtained by randomly sampling orbits in a volume defined by \( \gamma < 1 \). Although most particles can pass through the computational domain in a fraction of a second, and are sample once on average, the time sequence of sampled orbits in the simulation show the comparatively slow (~minutes) evolution of Stömer like boundaries in the magnetosphere. When the magnetopause is most compressed at 7:05 UT, particles of a given rigidity are given access to an otherwise closed innermost trapping region, and subsequently trapped there by the retreating magnetopause.

Summary and Future Work
For a particular SEP event, the final distribution is a function of the initial SEP distribution, solar wind bulk parameters, resulting magnetospheric dynamics, and the subsequent effects of radial diffusion and losses. In future work we will study the trapped L-shell, pitch angle, and energy distributions resulting from an initially isotropic solar wind distribution. Some conclusions from this work are:

- In MHD magnetospheric model fields, we find well defined surfaces of constant cutoff rigidity that exhibit dynamic behavior in response to solar wind conditions.
- We demonstrate a mechanism for prompt trapping of SEPs that can be understood as a generalization of Störmer theory, to a time dependently perturbed dipole field.
- SEPs with access to the innermost L-shells enter through the magnetopause on the day side.
- Trapping occurs on the time scale of the global evolution of the magnetosphere.

Acknowledgments
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Figure 1. Proton Fluxes with \( E > 25 \text{ MeV} \) from the HEO 1997-068 spacecraft for the month of Nov 2001 [Slocum et al., 2002]. Note that the fluxes in the inner zone MeV ion belts are predominantly determined by a few violent storms occurring throughout the year.

Figure 2. Solar 1-754.2 MeV/nucleon Fe ions, measured using the LEICA instrument on SAMPEX, provide direct evidence of geomagnetic SEP trapping in the inner zone radiation belts [Slocum et al., 2002].

The processes by which solar ions gain access to the inner magnetosphere, producing long lived stably trapped populations, remain poorly understood. In the work presented here, we study injections of energetic solar ions into the magnetosphere by computing Lorentz trajectories in Lyon-Feder-Mobarry (LFM) global MHD magnetospheric model fields. Our goal is to better understand how the interaction of an interplanetary shock with the magnetosphere traps MeV solar particles in the Earth’s radiation belts. In order to model these events, some questions we need to answer are: what is the physical mechanism for SEP geomagnetic trapping, is it contained in our models, and what time scales do we need to include?
Overview of CISM Ionosphere-Thermosphere Modeling
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Abstract
The Ionosphere-Thermosphere modeling component of the CISM project is responsible for development of general circulation models of the upper atmosphere system and their coupling to the magnetosphere. Initial construction of the Coupled Magnetosphere-Ionosphere-Thermosphere model (CMIT) was accomplished using the NCAR Thermosphere-Ionosphere Nested Grid (TING) model; transition to the more complex NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) is underway. Several improvements are being made to the TIE-GCM and it is now in transition to community model status. Additionally, we are working on extending ionospheric models into the plasmasphere, collaborating with data assimilation activities, conducting an extensive validation effort, and including ion outflow in the feedback to the magnetosphere.

The Coupled Magnetosphere-Ionosphere-Thermosphere Model (CMIT)

The CMIT model has progressed from one-way to two-way coupling, and now includes neutral wind feedback to the magnetosphere. Transition to the TIE-GCM is represented by the simplified schematic diagrams below. See poster in Code Coupling section, M. Wiltberger et al.

New Developments for the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM)

Several areas of current development improve the model and facilitate coupling with the magnetosphere.

- Self-consistent global electrodynamics
- Plasmasphere extension using IGRF/APEX coordinates
- New solar module and photoelectron parameterization
- Ionosphere and neutral atmosphere validation program

(see poster in Validation section, A. Burns et al.)

Key solar wind parameters at L1 as a function of model time, and the simulated global response (NH). Top to bottom: solar wind density, cm⁻³; solar wind velocity x-component, km s⁻¹; IMF y, z components, nT; cross-tail potential, kV; hemispheric Joule heating, GW; hemispheric power, GW; simulated AU and AL indices, nT. Vertical lines are times of model output (at right).

Configuration of the magnetosphere at 6, 12, and 22 UT as simulated by the LFM/TING coupled model. Plasma density is plotted as a color image with the “last closed field line” surface superimposed. Inset: ionospheric conductance as calculated by the TING model.

Response of the thermosphere/ionosphere system calculated by the LFM/TING coupled model at 6, 12, and 22 UT. (a,b,c): E-region electron densities at ~120 km with the ion drift pattern superimposed. (d,e,f): F-region neutral temperatures at ~250 km with the neutral winds superimposed.

Ionosphere-Thermosphere Coupling in an End-to-End CISM Simulation

These figures illustrate the geospace response to a simulated coronal mass ejection conducted as part of an end-to-end CISM model run. Calculations from the coupled MAS-ENLIL description of the corona and solar wind are used as input to the CMIT model, similar to upstream solar wind data such as from ACE. Other runs, such as for the May 1997 event, have also been conducted. (See poster, W. Wang et al.)

Ionospheric Data Assimilation

A collaborative effort in ionosphere modeling with the USU GAIM group is underway.

(see poster in Data Assimilation section, A. Burns et al.)

Future Directions

- Link ionosphere/plasmasphere model with RCM (see poster, N. Maruyama et al.)
- Extend T/I models to lower altitude
- Include high-energy particles in atmospheric models
- Use OOP-2 framework in coupled codes
- Provide solar EUV forecast capability
- Improved auroral acceleration model in CMIT
- Supply outflowing ion flux to magnetosphere
Abstract

A 3D simulation of the May 14-17, 1997 CME event was made using the CISM Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model. In this paper, we describe the response of thermospheric winds to this event. It is found that a strong westward zonal wind jet occurs in the middle and low latitudes. A diagnostic analysis is carried out to study the mechanisms that are responsible for causing this neutral wind jet and its temporal variations.

**The CMIT Model**

The LFM code solves ideal MHD equations in the magnetosphere using the Partial Interface Method on a distorted spherical mesh and Yee type grid. The TING model solves time dependent, 3-D, coupled equations of momentum, energy, and mass continuity for neutrals, and O+ on both global coarse and local fine grids.

**May 14-17, 1997 Event**

Solar wind and IMF data from the WIND satellite that are used to drive the CMIT model.

The CMIT simulated polar cap potential (top), Joule heating (middle) and particle precipitation hemispheric power (bottom) in response to the solar wind and IMF data on May 14-17, 1997.

Significant westward acceleration occurs after about 18 LT for all longitudes. The westward zonal wind speeds maximize usually around local midnight, followed by decelerations in the morning sector.

Zonal (left) and meridional (right) winds at 0° longitude. There are significant altitude variations of neutral winds during both storm and recovery periods. Strong westward zonal winds occur in the lower thermosphere (around 180 km) at middle and lower latitudes.

Zonal momentum advection transports westward wind momentum from high latitudes to lower latitudes.

Neural zonal and meridional winds on pressure level 2.0 (~180 km, bottom). Strong westward zonal winds occur immediately after IMF Bz turned northward at about 21 UT on May 15.

Summary

A westward zonal neutral wind jet occurs in the lower thermosphere in low latitudes during a major geomagnetic storm. The wind speed here is larger that in the upper thermosphere. The advection of westward momentum from the high latitude dusk cell to lower latitudes is the primary driving force for this jet. The recovery of this westward flow takes about 18 hours and is also caused by the momentum advection. The poleward Coriolis force is balanced by equatorward pressure gradient and momentum advection. This produces very small meridional winds in the middle and low latitudes.
A New Model of the Earth’s Ionosphere and Plasmasphere

A new high-resolution ionosphere-plasmasphere model has been developed in a collaboration between HAO and UCL. In the new model, the magnetic field is taken directly from the full International Geomagnetic Reference Field (IGRF) using the Apex coordinate system. The plasmaspheric component of the model along closed field lines follows the approach used by the SUPIM and CTIP models. The new model is modular in design to facilitate coupling to existing general circulation models.

Abstract

Motivation

A vital requirement for space weather modeling is the accurate representation of the global ionosphere and plasmasphere. Previous ionospheric models, while providing powerful frameworks for research, have been limited in a number of ways. One such limitation has been the requirement of using a Dipolar representation for the Earth’s magnetic field. At certain locations on the planet (most notably the US sector), the field differs considerably from a Dipole, leading to modeled ionospheric features which are in the wrong place.

To address this deficiency, a new high-resolution ionosphere-plasmasphere model has been developed in a collaboration between HAO and UCL. In the new model, the magnetic field is taken directly from the full International Geomagnetic Reference Field (IGRF) and the ionospheric equations are solved within an ‘Apex’ magnetic field coordinate system (Richmond, 1995).

Results

The new model yields much improved, global high-resolution ionospheric parameters, such as the peak ionospheric electron density (NMF2) and the total electron content (TEC) shown opposite in the upper and lower panels respectively.

Model development is proceeding along a ‘modular’ route such that the new ionosphere-plasmasphere model can be easily coupled into existing atmospheric models, such as the NCAR Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM) and other components of the CISM system.
Abstract. The direct penetration of the high-latitude electric field to lower latitudes and the disturbance dynamo, both play a significant role in restructuring the storm-time equatorial ionosphere and thermosphere. Although the fundamental mechanisms generating each component of the disturbance electric field are well understood, it is difficult to identify the contribution from each source in a particular observation. In order to investigate the relative contributions of the two processes, their interactions, and their impact on the equatorial ionosphere and thermosphere, the response to the March 31, 2001 storm has been modeled using the Rice Convection Model (RCM) and the Coupled Thermosphere-Ionosphere-Plasmasphere-Electrodynamics (CTIPe) model. The mid- and low-latitude electric fields from RCM were imposed as a driver of CTIPe, in addition to high latitude ion convection and auroral precipitation. During daytime, and at the early stage of the storm, the penetration electric field is dominant; at night, the penetration and disturbance dynamo effects are comparable. Our results also demonstrate that the mid- and low-latitude conductivity and neutral wind changes initiated by the direct penetration electric field preferentially at night are sufficient to alter the subsequent development of the disturbance dynamo.
Abstract

A hemispherically asymmetric electric potential solver for the ionosphere is developed. At low geomagnetic latitudes the electric potential $\Phi$ is forced to be hemispherically symmetric, but at high latitudes, where the field-aligned current from the LFM model is specified, the electric potential can be hemispherically asymmetric. In addition, the precipitating electron flux $F$ and energy $\varepsilon$ is given by the LFM. The global electric potential is determined iteratively by solving on each domain, i.e. northern and southern hemisphere high latitudes and low latitudes, until the electric potential across the boundaries between the high and low latitude domain is continuous.

As a first step, presented here, the field-aligned current, precipitating electron flux and energy from the LFM from one time step is used to test the solver, without any feedback to the LFM. The next step in the development will be to test with a time series of LFM output, and then feed back TIE-GCM conductances to the magnetosphere.

Domains

Electric potential $\Phi - B_z < 0$

Precipitating electron flux $F$ & energy $\varepsilon$: $\Sigma_{\text{hall}}$

Precipitating electron flux $F$ & energy $\varepsilon$: $\Sigma_{\text{hall}}$

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Domains

Electrodynamo equation

$\nabla \cdot (\nabla \phi) = R \left( \nabla \cdot \nabla \phi \right) + \frac{\partial}{\partial \phi} \left( \cos \lambda_m \phi \right) + R^2 \cos \lambda_m J_m$

Constraint: continuity of $\phi$ across high / low latitude boundaries $\Rightarrow$ continuity of $K_{m\lambda}$ with $u$, $\Sigma$ continuous

Precipitating electron flux $F$ & energy $\varepsilon$: $\Sigma_{\text{hall}}$

Precipitating electron flux $F$ & energy $\varepsilon$: $\Sigma_{\text{hall}}$

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Domains

Electric potential $\Phi - B_z > 0$

Precipitating electron flux $F$ & energy $\varepsilon$: $\Sigma_{\text{hall}}$

Precipitating electron flux $F$ & energy $\varepsilon$: $\Sigma_{\text{hall}}$

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Domains

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Domains

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Domains

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM

Precipitating electron flux $F$ & energy $\varepsilon$ from LFM
Overview of CISM Data Assimilation

1 High Altitude Observatory, NCAR, 2 University of Colorado, 3 UC Berkeley, 4 NASA/GSFC, 5 Utah State University

Abstract
The Center for Integrated Space Weather Modeling includes a new component focused on preparing prognostic numerical models for data assimilation methodologies. This element is most developed in the ionosphere/thermosphere area, where a collaboration with the GAIM development group at Utah State has been initiated. Other disciplines within CISM are pursuing data assimilation in different ways, particularly in radiation belt physics. Due to the differences between physical regimes and modeling methods, the analogy with meteorological and oceanographic techniques has strong application in some areas and limited validity in others. CISM therefore plans a pragmatic approach where application of data to numerical models may be adopted using the most effective means to address particular problems.

Which Geophysical Systems are Most Amenable to Data Assimilation Techniques?

— To what extent do future states depend on present states?
— To what extent do future states depend on variable boundary conditions?
— To what extent are the future boundary conditions known?
— What are the timescales for which we will desire a forecast?
— Are there lags between observables and effects that can be exploited?
— Is the system persistent or compliant?

Here, persistence means that a combination of the current state plus our knowledge of physics can adequately describe future states, regardless of how boundary conditions change, and compliance means that the system responds rapidly to changing boundary conditions. Of course, a largely stationary system has the greatest persistence and is easiest to forecast, but not all persistent systems need be stationary. But it is also important to consider to what extent we can know what the boundary conditions will do in the future, particularly in the case of compliant systems.
Abstract
The Thermosphere Ionosphere Nested Grid (TING) model was initialized using Global Assimilation of Ionospheric Measurements (GAIM) model electron densities to test the feasibility, advantages and limitations of using these assimilated data to initialize the TING model for forecasts. The procedure used in this study was to replace the TING model electron densities at a specific time and to then run the TING model for a number of hours to see how long the effects of the changed electron densities would last. The main results of this study were: 1) the TING model could be successfully run without problems when TING electron densities were replaced with GAIM ones; 2) The effects of this replacement were still strong after 1 hour, considerably diminished after 3 hours and virtually non-existent after 6 hours.

Procedure
1) Run GAIM for the event
2) Run TING for the event
3) Replace TING electron densities with GAIM
4) Compare Results
5) Run TING using GAIM initialization

Discussion
The influence of initialization with the GAIM specification is nearly gone after 6 hours. This rapid regression is somewhat surprising. Studies as far back as 1959 [e.g., Matsushita, J. Geophys. Res., 64, 305, 1959] have indicated that electron density recovery times after storms are considerably longer. Why are these recovery times not reflected here? It is notable that TING model results also find long recovery times in the May, 1997 period, so the problem is not inherent in the model. In this study only electron densities were perturbed. The source of the long recovery time may lie in the neutral atmosphere. If so, forecast models will benefit most if routine data sets of critical neutral parameters are available for assimilation.

Conclusions
1) The TING model was successfully run when initialized with electron densities from the GAIM model.
2) The effect of the initialization was strong after 1 hour, weak after 3 hours, and virtually gone after 6 hours.
3) This “relaxation” time was far shorter than recovery times noted in the literature for electron densities
4) This last point implies that the persistence of disturbances in electron densities after a geomagnetic storm is caused by other parts of the thermosphere/ionosphere system, such as the neutral atmosphere.
Abstract

We use the extended Kalman Filter (EKF) to simultaneously estimate the physical state and the time-varying linear coefficients of an adaptive state-space model that describes the impulse response of the Earth's electron radiation belts (as measured by the SAMPEX satellite) to multiple solar wind inputs. Space-weather implications of this novel combination of space physics and empirical engineering models are evident in the high quality short-term electron flux predictions generated. Additionally, high time-variability in the data-derived response functions to fluid-like solar wind parameters, in contrast to the time-stationary response to electromagnetic solar wind inputs, raises interesting questions regarding the physics that govern energetic coupling between the solar wind and Earth's magnetosphere that deserve further consideration.

1. State Space Model with Innovations

State-space models offer a compact dynamical modeling framework capable of describing the (potentially) coupled multi-input, multi-output linear response of geophysical systems like the Earth's electron radiation belts. If recent observations of the modeled system are available to calculate prediction errors, or innovations, an optimized gain matrix \( K \) may be applied to further refine model output:

\[
\begin{align*}
\mathbf{x}(t+1) &= \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t) + \mathbf{K}\mathbf{e}(t) \\
\mathbf{y}(t) &= \mathbf{C}\mathbf{x}(t) + \mathbf{e}(t)
\end{align*}
\]

This additional stochastic component helps account for persistent correlated structure in the output (DC offsets, seasonal and diurnal variations, etc.) that might otherwise lead to a biased estimate of the radiation belt’s deterministic response (i.e., \( \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t) \)). The \( \mathbf{C} \) matrix is just a linear transformation of the state (\( \mathbf{x}(t) \)) into something comparable to the available observations \( \mathbf{y}(t) \).

A simple block diagram, illustrates the elegant dynamical structure of this modeling technique. Each input, output, and block represents an appropriately sized matrix.

2. The Extended Kalman Filter

The Kalman Filter is a linear state-estimation algorithm commonly used in data assimilation. If the concept of a system’s “state” is extended to include adjustable parameters for a particular model, a system identification technique can estimate the optimal set of linear coefficients and the current physical state of the system simultaneously.

If the model parameters are assumed to vary as a random walk with a specified “step-size”, the EKF can be tuned to track non-linear dynamics that manifest as non-stationary (i.e., locally-linear in time) model parameters, thus serving as an adaptive linear state-space model.

\[
\begin{bmatrix}
a_1 \\
a_2 \\
\vdots \\
a_n
\end{bmatrix}
\begin{bmatrix}
h_1 \\
h_2 \\
\vdots \\
k_n
\end{bmatrix}
\]

The upper panels shown below serve to illustrate initialization of the state during the training period. The state (\( \mathbf{x} \)) and parameters (\( \theta \)) start as vectors of zeros. As data is ingested, large errors near the beginning of the process gradually shrink, until the algorithm converges on an optimal solution for the state and model parameters. Impulse response functions derived from the final set of coefficients are shown below on a time-lag vs. L-shell surface.

3. Adaptive Models of Nonlinear RB Dynamics

The coefficients obtained in the model training period described in section 2 are used to re-seed the EKF adaptive state-space model, then allowed to vary as random walks as the solar wind inputs and SAMPEX data are reprocessed. The now time-varying coefficients are saved for each time step. One-year averages are shown below:

4. Conclusions

It is generally understood that radiation belt electrons are extremely variable and sensitive to changes in observed solar wind parameters, especially the plasma bulk speed. The results shown above indicate that: 1) other solar wind inputs contribute significantly to electron flux dynamics; and 2) if variation in state-space model coefficients is truly indicative of nonlinear dynamics, nonlinear behavior often noted in prior radiation belt studies seems to be attributable more to the fluid-like (\( V_{sw} \) and \( B_{sw} \)) than electromagnetic (\( \mathbf{B} \)) interactions between the solar wind and Earth’s magnetosphere.
Overview of CISM Code Coupling
C. Goodrich and the CISM Coupling Team

The CISM Comprehensive Models

The functionality of our comprehensive models come from two sources:
1. Strengths of the individual component codes
2. End to end coupling, which eliminates boundary conditions and other limitations of the individual codes

CISM 1.0 …
Ad hoc coupling of the MAS, ENLIL, LFM, and TING codes
Following 1.x versions incorporate improved versions of these codes, additional codes, and the replacement of TING by TIE-GCM code

 Archived in the CISM code repository

CISM 1.5 …
Added Capabilities:
•Physical Inputs for ENLIL, LFM, and ITM
•Accurate Ionosphere F (Particle precipitation from LFM and Conductances from ITM)

CISM 2.0 …
Added Capabilities:
•2nd Generation Coupling
  •SEP and Radiation Belt modeling
  (energetic ion and electron fluxes near earth,
  SEP generation, propagation, and penetration into the magnetosphere)

CISM 3.0 …
Added Capabilities:
•3rd Generation coupling
  •Physical CME initiation (CME initiation from coronal active regions)
  •Kinetic scale physics (MI coupling, reconnection, …)

Model Coupling Approach

Introduction
The Code Coupling Thrust is responsible for the developing and maintaining successive versions of the CISM comprehensive model, including:
•Defining our code coupling approach
•Selecting the computational science tools needed
•Applying these tools with our scientific codes to create the CISM comprehensive models

Coupling Requirements:
– Truly minimal code modification
– Efficient data transfer between codes
– Data translation (physics) and interpolation (grid)
– Control of independently executing codes

Model Coupling Approach

Generation 1
– Code developers use Ad Hoc hardwired linkages
– Test scientific validity and refine codes

Generation 2
– Computational framework based on Object Oriented Programming (OOP) using existing packages
  •Intelligent Data Channels, Program Control (InterComm)
  •Data Manipulation and Interpolation (Overture)

Generation 3
– Next generation framework to be developed in partnership with the Earth Systems Modeling Framework (ESMF) project

Generation 2 Framework

Data Manipulation and Interpolation - Couplers:
Couplers make data from one code useful to another by:
– Interpolation between disparate grids
  •Requiring: knowledge of grid structures of all codes
  •Conversion of data between disparate physical models
  •Requiring: knowledge of code data and conversion methods

Overture is a set of C++ classes providing:
(www.llnl.gov/CASC/Overture/)
– Interpolation between (moving, static) overlapping grids
– Powerful syntax for data manipulation including array arithmetic and (numerical) differential operations
– Registration and archiving of grids, coordinate mapping, and state variables in HDF database(s)
– Seamless interaction with IC (common data libraries)

CISM Geospace coupling in terms of our 2nd Generation Framework. The red arrows indicate data communication and the yellow oval indicates data manipulation

Results of prototype Overture versions of the Magnetosphere-Ionosphere Coupler for the October 2003 Magnetic storm

Intelligent Data Channels and Program Control:
InterComm is a programming environment (API) and runtime library that provides functions for:
(www.cs.umd.edu/projects/hpsl/chaos/ResearchAreas/ic/)
– Transferring data efficiently between programs
  •Direct (MxN) processor to processor transfer between parallel programs
  •Support for FORTRAN, C, and C++
– Controlling when data transfers occur
  •Nonblocking exports – IC caches data until it is requested
  •Codes export data (with timestamp) and keep going
  •Synchronization of execution through timestamps on data transfers
– Deploying multiple coupled programs
  •IC demons read config files – launch codes and set up data paths

CISM Geospace coupling in terms of our 2nd Generation Framework. The red arrows indicate data communication and the yellow oval indicates data manipulation

Results of prototype Overture versions of the Magnetosphere-Ionosphere Coupler for the October 2003 Magnetic storm

October 2003 Storm Data

Courtesy of the ACE SWEPAM
And GEOTAIL PWI Teams

Full S with $S_e=50$ mho
Full S with $E=0$
LFM solution

Magnetic Storm Results Data

18:55 UT

Full S with $S_e=50$ mho
Full S with $E=0$
LFM solution

Magnetic Storm Results Data

18:55 UT
CORHEL: A Coupled MHD Model for Routine Calculation of the Corona and Inner Heliosphere

Pete Riley(1), Dusan Odstrcil(2), Jon Linker(1), and the rest of the CISM team

(1) SAIC, San Diego, California. (2) NOAA/SEC, Boulder, Colorado.

The goal of CORHEL (CORona-HELiosphere) is to provide a physics-based description of the of the solar corona and inner heliosphere for scientists who are not computational experts. CORHEL combines SAIC's coronal MHD model (MAS) with NOAA/SEC heliospheric MHD model (ENLIL) to calculate a steady-state description (in the rotating frame of the Sun) of the corona and solar wind for specific Carrington rotations. For a given Carrington rotation number, CORHEL 1.0, performs the following tasks. First, it automatically downloads the appropriate magnetogram from the Kitt Peak observatory and preprocesses the data. Second, it runs SAIC's coronal MHD model using these inputs. Third, it post-processes the output for input into the heliospheric model. And fourth, it runs the NOAA/SEC heliospheric MHD model. CORHEL couples the models as well as pre- and post-processing codes via a c-shell script and file transfers. CORHEL will be transitioned to the OOP1 coupling framework over the next year.

CORHEL 1.2 has improved upon the ease of installation of the MHD model while CORHEL 1.0 provided the initial proof of concept for code coupling using file I/O, it still required some knowledge on the part of the user to be able to: compile the various FORTRAN modules on their system; install a number of system libraries; and debug possible errors in several languages. CORHEL 1.2 has considerably simplified this process by providing a standalone distribution that can be disseminated on a CD, with pre-compiled modules will run on any standard Linux system. All that is required of the user is to copy the folder to their hard drive and run the program.

CORHEL 2.0 (release date: August 2005) promises some major improvements in capability and usability. In particular, the simple command-line driven script will be replaced by a platform-independent Java application, which will give the user greater control over the input parameters, as well as the ability to choose input data from several Solar observatories. CORHEL has been released to the CISM validation team and the component models to the CCMC.
Introduction
An important step towards developing a comprehensive model of the Sun-Earth environment is the coupling of the Lyon-Fedder Mabry (LFM) global MHD model with the Rice Convection Model (RCM) drift physics code. In this poster, we present some initial results from the coupled model. It is expected that the coupled LFM-RCM model will provide a more realistic and physically consistent model of the inner magnetosphere than either model alone and is expected to address several important and outstanding science questions such as:
- The role of a self-consistent magnetic field and the plasma sheet on ring current formation.
- The effects on the inner magnetospheric electric field.
- Insight on the role of the inner magnetosphere on the global magnetospheric structure and dynamics.

Methodology
The codes are run asynchronously, exchanging data and coordinating their timings through files.
- Future versions will use the INTERCOMM software package, the transition to is expected to be straightforward.
- The RCM modeling region is confined to an ellipse in the equatorial plane (+10x<8 R_e, |y|<8 R_e).

Over a specified time interval (1 minute) the LFM interpolates time averaged MHD magnetic field, pressure and density onto a rectilinear grid.
- Figure 1 shows the LFM (in red) and intermediate grid (in green) used for exchanging data between the LFM and the RCM.

Test Runs
For a set of tests, 4 runs were performed. For the LFM, the solar wind was held steady with a velocity of 400 km/s and particle density of 5 particles/cc. The IMF direction was flipped from $B_z = +5$ nT to -5 nT at $t=4$ hours when the RCM was turned on.

The 4 runs consisted of:
1. LFM-only, constant pederson conductance of 5 s.
2. LFM-RCM, constant pederson conductance of 5 s.
3. LFM-only, constant pederson conductance of 8 s.
4. LFM-RCM, constant pederson conductance of 8 s.

The hall conductance was set to zero in all the runs. For a set of tests, 4 runs were performed. For the LFM, the solar wind was held steady with a velocity of 400 km/s and particle density of 5 particles/cc. The IMF direction was flipped from $B_z = +5$ nT to -5 nT at $t=4$ hours when the RCM was turned on. The 4 runs consisted of:

1. LFM-only, constant pederson conductance of 5 s.
2. LFM-RCM, constant pederson conductance of 5 s.
3. LFM-only, constant pederson conductance of 8 s.
4. LFM-RCM, constant pederson conductance of 8 s.

The hall conductance was set to zero in all the runs.

Summary
- LFM-RCM code produces a ring current that consists of a region of trapped plasma near the inner boundary of the LFM.
- The values of $\Delta B_z$ in the LFM-RCM shows a substantial reduction in the inner region as compared to the LFM-only run.
- Periodic behavior in the coupled code appears to be as a result of the buildup of the inner magnetosphere that causes the LFM to release plasma down the tail.
- Periodic oscillations also show up in the RCM as flow-jets that inject plasma into the inner magnetosphere.
- The stronger driving case ($\Sigma=5$) results in oscillatory behavior in the potential, possibly related to recurring substorm-like flows that occur in the coupled code. No such behavior is seen in the LFM-only runs.

Sample results for $\Sigma=5$s

<table>
<thead>
<tr>
<th>Initial</th>
<th>Final-LFM-only</th>
<th>Final-LFM-RCM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Pressure</td>
<td>Log Pressure</td>
<td>Log Pressure</td>
</tr>
<tr>
<td>$\Delta B_z$</td>
<td>$\Delta B_z$</td>
<td>$\Delta B_z$</td>
</tr>
</tbody>
</table>

Flow vectors and $B_z=0$

1. LFM-RCM code produces a ring current that consists of a region of trapped plasma near the inner boundary of the LFM.
2. The values of $\Delta B_z$ in the LFM-RCM shows a substantial reduction in the inner region as compared to the LFM-only run.
3. Periodic behavior in the coupled code appears to be as a result of the build up of the inner magnetosphere that causes the LFM to release plasma down the tail.
4. Periodic oscillations also show up in the RCM as flow jets that inject plasma into the inner magnetosphere.
5. The x-line location (as measured by the line of $B_z=0$) is more dynamic and moves further out in the LFM-RCM run.
6. RCM results show a lack of shielding in the inner magnetosphere, that results from a hot, tenuous plasma distribution entering the RCM from the LFM’s plasmasheet. This hot plasma comes from an x-line in the LFM that is reconnecting lobe field lines.
Abstract

The Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model is designed to model the interaction between the solar wind and the close magnetosphere – ionosphere – thermosphere system. We begin by providing an overview of the model development plans in geospace including how the CMIT will be coupled with the Rice Convection Model to form the LTR model. In the first stage of development the current model is covered in the next section. The poster concludes with a brief overview of results from the model.

Model Development Plans

In the first stage of development the current version of CMIT, with the LFM and TING models, is coupled with the two LFM-RCM model to form LTR.

Currently communication between the separate executables which make up CMIT is handled using the Intercomm library. After and initial series of setup calls which describe how the data is laid out in memory information is passed between the two codes using calls very similar to MPI send and receives.

Model Results

The CMIT model is working well in the queued computational environment at NCAR and is currently undergoing extensive testing with idealized and real world solar wind conditions.

Neutral wind driven FACs persist well after magnetospheric FACs are reduced by the northward turning of the IMF. Effects of this feedback on the magnetosphere is currently under investigation.
**Introduction**

Overture is a set of C++ classes providing two main functionalities: 1) A high level programming environment for writing PDE solvers in complex geometries that hide intrinsic details of the numerical algorithms from the user yet leaving the possibility of low level control, and 2) Interpolation between overset grids (moving and static). InterComm is a runtime library (with Fortran, C, and C++ interfaces) that provides means for controlled data transfers between separate running executables and easy (automatic) access to distributed data on both ends of the communication channel. We show examples of Overture PDE solving capabilities applied to the plasma sheet and ionosphere, as well as interpolation and data transmission (InterComm) between these codes and the Lyon-Fedder-Mobarry global MHD model.

**Embedded Plasma Sheet Code**

The code uses the PDE solving capabilities of Overture to solve the 3 dimensional ideal MHD equations in a cartesian grid embedded within a volume of the LFM grid.

**Ionospheric Solver**

The solver solves the usual Poisson’s equation in the high latitude ionosphere:

\[ \nabla \cdot (\Sigma \nabla \Phi) = j_z \]

**Overlapping Plasma Sheet and LFM grids**

APEX grid is earth bound. LFM grid is fixed in SM coordinate system.
Future Directions for the CISM Code Coupling and Framework Effort

John Lyon and Alan Sussman

Loose Coupling with CISM/LWS Framework

Where we’re going – Matching is OUTSIDE the components (codes, modules)

Matching information is specified separately – at run time –

by the person running the codes

Runtime match is by simulation time stamps

CISM/LWS framework differs from ESMF and Michigan frameworks in implementing s modules as

separate executables linked by couplers, which may also be separate executables.

This has a number of advantages:

1. Maintainability – codes can be developed/updated individually
2. Flexibility – change participants/components easily
3. Functionality – support for variable-sized time interval
4. Algorithms or visualizations
5. Individual codes can operate asynchronously – more

properly loosely synchronous
6. Communication between codes can be demand driven
7. Distributed (Grid) computing is greatly simplified
8. Possibility of modifying number and type of modules

(codes) running during the course of a calculation

Challenges:

1. Command and control
2. Addition of new components (Plug and Play)
3. Timing between codes

Separate codes from matching

Directions in Couplers

Adding new Models to our Framework:

Toward Plug and Play

1. Understand Physical Model (inputs, outputs)
2. Register Computational Grid
3. Create a ModelGrid (interface) object (same code) for new model
4. Store the ModelGrid object and auxiliary data in

HDF database with appropriate name tags
5. Supply Couplers with grid and data tags

Overture HDF database Structure

Possible Organizations

• Federation, Plug and Play
• Federation, non-Plug and Play

Data Assimilation is not just for data?

The plot to the right shows the effect of a strong very shock hitting the magnetosphere.

During the period, both the LFMI (global IMF) and RCM (River Convection Model) have significant errors.

The RCM depends on the consistency of the second advection invariant, which is dramatically

violated during this and weaker events. The LFMI suffers from the lack of proper drift physics in the

inner magnetosphere.

Data assimilation – as applied, for example, in weather forecast codes – attempts to incorporate

both simulation results and observational data, taking the account that both have errors. This

may be the best strategy for coupling codes like the LFMI and RCM together.

Coupling by combining data and model

The diagram to the left shows schematically a coupler that uses both results from

ENLIL (LFMI) and data from ACE.

While the data observed at L1 (ACE) are much more detailed than anything likely

to be produced by simulations in the foreseeable future, these data are only a time slices

at a single point. ENLIL can not follow small scale structure but does provide a global picture.

A hybrid coupler could use the 3-D data in ENLIL to resolve the ambiguities in

the 1-D time series at ACE into a picture of the 3-D solar wind hitting the magnetosphere.

Distributed (Grid) Computing With

InterComm

Our approach is motivated by:

1. Developers have to deal with...

Multiple logons
2. Manual resource discovery and allocation
3. Application run-time requirements
4. Processes for launching complex applications with multiple components

• Repetitive
• Time-consuming
• Error-prone

Deploying components

• We want a single environment for running coupled applications in the

high performance, distributed, heterogeneous Grid environment.

• We will provide:

• Resource discovery: Find resources that can run the job, and

automate how does model code finds the other model codes that it

should be coupled to

• Resource Allocation: Schedule the jobs to run on the resources –

without you dealing with each one directly

• Application Executions: Start every component appropriately

and monitor their execution

Possible Organizations

Resource Discovery

Resource Allocation

Application Launching

Possible Organizations

Long-Term Goal

Multiple logons
Manual resource discovery and allocation
Application run-time requirements
Processes for launching complex applications with...
Knowledge Transfer to SEC: First results with Ap (Michael Gehmeyr)

The CISM Forecast Model Chain contains empirical and semi-empirical models. As the science models develop, parts will be integrated into the Forecast Model Chain by member of KT and based on feedback from the community.

A key measure used to compare geomagnetic storms is the Dst index. In this poster the status of a semi-empirical model is described.

Prediction of MeV electrons (Manny Presicci)

MeV electron flux is one of the more difficult magnetospheric measurements to predict, and physics-based model predictions are on the far horizon of CISM numerical model capabilities. In this poster prediction of MeV electrons using Kalman filter methods are described.

Integrating Research Results with CISM_DX (Bob Weigel)

The CISM_DX software package was developed to facilitate knowledge transfer between members within CISM and to the community that is interested in CISM results.
Knowledge Transfer to SEC: First results with Ap, future plans

Michael Gehmeyer, Robert Weigel, Dusan Odstrcil, Leslie Mayer, and Nick Arge

University of Colorado, Boulder CO, 2Air Force Research Laboratory, Hanscom, NH

The Daily Ap Forecast Model

1-7 Day Ap Time Series Prediction:
- index constructed from world-wide ground-based magnetometers
- persistent & recurrent features of observed Ap
- "xenogeneous" solar wind speed input (from ACE)
- uses McPherron (1996) autoregressive scheme

Importance for Space Wx Forecasting:
- "end-of-day" summary of geomagnetic activity
- alerts for geomagnetic activity watch levels
- quick outlook of anticipated geomagnetic activity
- driver for other empirical methods (Kp, MSIS90)

Continuously running at SEC Test bed since May 2004

Model Validation

Forecast Model Transfer Process

CISM ↔ SEC

Importance for Space Wx Forecasting:
- constitutes most of the solar wind
- recurrent activity
- path for CMEs
- carries "killer" electrons

Projected to be implemented at SEC Test bed in Spring 2006
Objectives
- Present up-to-date information on CISM research and availability of models or products.
- Teach how CISM modelers and researchers analyze and interpret their data.
- Teach how to run CISM models or view and analyze CISM model output.
- Learn from attendees what would help them improve their job performance.
- Address and focus on specific subjects of interest to the attendees.

Audience
- Non-academic spaceWx professionals
- Forecasters
- Software engineers who transition research models into operation
- Leadership concerned with space environment prediction

Instructors
- Members of the CISM FM/KT group
- A CISM Expert on the selected topic

Available Topics
- Thermo/Ionosphere
  (e- densities, scintillation, aura boundary)
- Magnetosphere
  (radiation belts, ring current, relativistic e-)
- Solar Wind
  (ambient and transient components)
- Solar Surface
  (coronal holes, flares)
- Magnetic Indices
  (Ap, Kp, Dst, AE)

Format
- Hands-on Learning
  - Visualize and analyze time-series residing in CISM_DX_DATA
  - Run a CISM_FM and compare with observations
  - Apply CISM_DX to analyze and interpret simulations

- Group Interactions
  - Import and prepare data sets
  - Run a model
  - Validate the model

- Scenario-based Education
  - Forecasting: Ap index, MeV e- events, dB/dt
  - Simulation: Holes in the corona, Ambient solar wind structure, ULF waves of the magnetopause

- Real-World Experience
  - Bastille Day storm
  - Halloween storm
  - Solar cycle seasons
  - Quiescent times

Deliverables
- Hand-outs of Lecture notes
- Hand-outs for Computer labs
- Implementation of CISM_DX
- Implementation of CISM_DX_DATA
- Short course evaluation form

AFWA Short Course, August 1-2
Syllabus:
1. Overview over CISM activities, research and model development efforts
2. Analyzing and Interpreting Data
   Introduction to CISM_DX_DATA
3. Using Empirical Models:
   Predicting Ap index
   CISM Ap Forecast Model, Model Validation
4. Using Numerical Models:
   Predicting Solar Wind
   CISM WSA and ENLIL Models
Introduction/Motivation

The Dst index is based on 4 magnetometers, which are widely spaced in longitude and also located away from the equator to avoid the magnetic perturbations from the equatorial electrojet, see Figure below. They are adjusted to remove the quiet time Sq ionospheric current perturbations and the secular variation of the magnetic field due to changes in the internal currents of the Earth.

The Dst index is widely used to determine the onset and strength of magnetic storms

It has been known since the work of Burton et al.[1975] that the Dst can be well modeled and predicted using the solar wind as input. Since then, many scientists have tested and improved the prediction.

The motivation for attempting such improvements is usually a combination of a practical desire to make a better prediction, a desire to understand which features of the interaction between the solar wind and the magnetosphere are most important in producing magnetospheric current systems, and the desire to understand which features of the solar wind density in additional to the dynamic pressure.

The solar wind parameters and the magnetic perturbations from the equatorial electrojet are widely spaced in longitude and also located away from the equator to avoid the perturbations from the equatorial electrojet. The solar wind measurements are therefore a tool, study the detailed physical processes governing the large scale responses of the magnetosphere to solar wind variations.

Model Description

\[ \text{Dst} = \text{dst}_1 + \text{dst}_2 + \text{dst}_3 + \text{(pressure)} + \text{(direct IMF) b}_2 + \text{offset} \]

\[ \text{dst}_1(t+dt) = \text{dst}_1(t) + \text{(driver term)} + \text{(decay term)}, \text{the driver term is similar for all three, which are a strong function of } V_x, B_z, N_t, \text{the clock angle and the angle between } V_x \text{ and the dipole axis. The decay terms are quite same.} \]

\[ (\text{pressure}) = [p_b^4 + n(p_v^2 / \sin^2 \Phi) + p_v^2]^{1/2}, \text{includes IMF pressure and a term proportional to the solar wind density in additional to the solar wind variation.} \]

\[ (\text{direct IMF) b}_2 = 0.478 \text{sin}^3(\Phi), \text{is a small term with an average magnitude of 0.7 nT and sometimes over 10 nT (IT cannot be eliminated).} \]

\[ \text{offset} = s_1 + s_2 \text{sin}(2nt/yr + s_3) + s_4 t + s_5 t^2, \text{may compensate for a portion of the secular variation that may not have been removed in Dst.} \]

Results

The 2003 ‘Halloween’ storm

The 1859 Carrington Storm

Summary

Given solar wind conditions, large-scale magnetospheric activities are predictable; the magnetosphere has an organized way to respond.

For reliable and accurate forecast of magnetospheric activities, reliable and accurate solar wind measurements are absolutely necessary.

Based on our model, a very fast solar wind with a very large negative IMF Bz can produce a super magnetic storm with minimum Dst less than -1600 nT

Future Work

Using the Dst prediction model as a tool, study the detailed physical processes governing the large scale responses of the magnetosphere to solar wind variations.

References:


Acknowledgments:

WIND: 3-D Plasma and Energetic Particle (R. P. Lin) and Magnetometer (R. Lepping); ACE: SWEPAM (R. Skoug, D. J. McComas) and Magnetometer (C. W. Smith, N. F. Ness); WDC for Geomagnetism, Kyoto University, Japan.
Abstract

Linear state space techniques have been successful for modeling many natural nondeterministic systems. In this study, four daily averaged electron flux measurements from SAMPEX are used to predict the daily averaged measurement as long as ten days after the last measurement. The electron flux is predicted assuming an autoregressive (AR) model with four constant coefficients, which are estimated by a four-state Kalman filter. The measurement vector in the filter consists of the previous four measurements, and the state vector consists of four coefficients in the (AR) model. The Kalman filter calculates the optimal solution for the state vector (the four coefficients) using a least squares (minimum variance) criteria. Prediction consists of using the model with the optimal determined coefficients to calculate the electron flux at the desired day as a weighted sum of the coefficients with the previous measurements or predictions at the four most immediate earlier days. This identification technique has been extended to six and eight state Kalman filters.

The SAMPEX Satellite in High Elevation Orbit Samples Many L-Shells.

The Kalman Filter Estimates the AR Coefficients to Minimize the Variance.

The Leading Coefficients Agree in 4th and 6th Order Kalman Filters

Conclusions

Both fourth and sixth order filters agree on the values of the median coefficients plotted versus L-Shell. This conclusion demonstrates diminishing returns in going to higher AR order.

The leading AR coefficient (1) is nearly linear when plotted against L-shell in the interval [3-10]. (Agreement Using 4th and 6th order.)
The CISM Model & Data Explorer, CISM_DX, is a collection of models and data from space science, together with tools for their analysis and visualization.

- used by space science researchers, students, and forecasters
- written in open source software OpenDX, Octave, Perl, C, FORTRAN

CISM_DX is a community-developed collection of:
- Codes for side-to-side visualization and analysis of the output of space physics numerical models
- Data sets put into standard file format and form, and provided with code for display in OpenDX, Octave, Matlab, IDL
- Tools – with examples of their usage – for space physics research, including coordinate transformation codes, and scripts that transform the data from many providers into a standard format and form
- Codes for running the CISM Forecast Model (FM), and codes for carrying out the validation of the CISM FM using comparison data in the data sets as distributed with CISM_DX

All codes in the package have been tested on computers running Red Hat Enterprise or Fedora Core, many components can be run also on different operating systems (Windows, Mac OS)

### CISM_DX – OpenDX Codes
- intro tutorials: OpenDX and space science networks
- intro tutorials: collection of CISM space physics networks
- intro tutorials: codes for running the CISM Forecast Model (FM), tools with detailed documentation and many examples
- intro tutorials: sides-to-side visualization and analysis of the output of space physics numerical models
- intro tutorials: regression tests all OpenDX networks

### CISM_DX – Octave Codes
- intro tutorials: introduction to Octave, empirical models, data processing functions
- intro tutorials: unit drivers for CISM macros & SPDX modules
- intro tutorials: regression tests all Octave functions

### CISM_DX DATA Sets
- data used in tutorials
- data from observations
- data from simulations
- real-time data & predictions

### CISM_DX Utilities
- PDF manual, online web reference, image collection
- documentation
- engineering: OpenDX, Octave, Matlab
- convenience: 2 NCAR/HAO, 0120950 and by NASA LWS grant NAG5-12652

**Acknowledgements**

CISM_DX is tested upon work supported by CISM, which is funded by the NSF STC Program under Agreement Number ATM-0120950 and by NASA LWS grant NAG5-12652.

Developers & Contributors


Distribution available on web site lasp.colorado.edu/cism/private/CISM_DX

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CU/LASP, NCAR/HAO
Overview of CISM Validation and Metrics
Harlan E. Spence¹ on behalf of the Validation and Metrics Thrust Team
¹Boston University, Boston MA

Overarching Validation/Metric Thrust Goals:
The goals of the Validation/Metrics (V/M) thrust are twofold:
• to identify and document integrated model strengths and weaknesses comprehensively, systematically, and quantitatively through the detailed comparison of model output with observations (Validation); and,
• to measure objectively, using a small set of targeted benchmarks, the long-term trends in model improvement (Metrics).

Validation Plan:
• “Validation” refers to the broad assessment of a model’s output through comparison with observations.
• What motivates these comparisons?
  • Do models possess all the most important physics and also the algorithms needed to solve the governing equations?
  • Do computational limitations lead to simplifying assumptions that are unjustifiable?
  • Do poorly specified boundary conditions and initial values compromise model predictability?
• To quantify and understand these shortcomings and to guide a developer’s path to eliminating or reducing them, model validation is an essential element of CISM.

Validation Philosophy and Procedure:
• Independent code validation essential for a robust coupled model
• Independent validation efforts will:
  • Fully exercise models to establish physical range of usefulness:
    • Comprehensive event studies — large number of detailed point comparisons
    • Statistical studies — do codes have correct climatology?
    • Note: this is something that has never been attempted systematically in space physics and is a CISM novelty
  • Provide feedback to code/coupling developers
  • Contribute to overall CISM documentation:
    • Internal feedback to code developers: Can the code be run easily with the provided User Manual?
    • Produce community report identifying range(s) of validity of CISM models

Metrics Plan:
• CISM, with inputs from science and user communities, selected a limited number of key metrics that will be used to continuously measure progress over the lifetime of the Center.
• Several factors influenced (and continue to influence) CISM metrics:
  • must be a reasonably small collection to feasibly track;
  • must be comprehensive to measure wide range of models;
  • must be based on direct measurements or derived quantities that will be continuously and reliably available in the foreseeable future;
  • must be quantities related to key space weather effects that we are trying to predict;
  • must be recognized to be important by the space physics science community and/or the operational user community.

Metrics Selection:
• Metrics objectively measure a model’s overall improvement with time (Skill Score—SS)
• Operational (top) and science (bottom) CISM metrics are shown in the left-hand column.
• Baseline models, data sets, and physics models from which SS’s are computed shown in other columns.
• Metric studies currently underway to identify most useful SS and prediction efficiency measures.

Background and Motivation:
• Appeal to tropospheric meteorology – metrics such as 36-hr, 500-mb forecast provide assessment of long-term improvement to models
• Routine calculation of important operational- and scenario-motivated metrics permits us to measure objectively the ability of CISM models to predict essential space weather quantities
• Rationale for CISM metrics selection has been developed and the list of 29 metrics, along with the baseline models, first-generation physics models, and the data sets needed to compute skill scores, are outlined — work ongoing to define/refine metrics
• While metrics provide a means for the objective assessment of long-term model improvement, model validation—the comprehensive, systematic quantitative comparison of model output with observations—is required for identifying and documenting model strengths and weaknesses
• One CISM goal/outcome is to introduce the process of model evaluation to the space physics community.

Cross-Thrust Integration:
• V/M team works cooperatively with the model developers and the knowledge transfer thrust

CISM Validation and Metrics Status:
• Validation efforts underway with all core models as well as with their available coupled versions
• Detailed studies to define and refine metrics are underway (green), pending (yellow), and future (red)
• Both Operational and Scientific Metrics are being worked
• Examples of activities represented in remaining V/M posters
ABSTRACT: The coronal magnetic field is exceptionally complex and exceedingly difficult to measure. Several models have been put forth which generate solutions for the coronal fields based on photospheric field measurements. Here we examine and compare the underlying structures and topologies of the solar coronal magnetic field and the heliospheric current sheet derived from two very different coronal models, SAc's MAS model and the coupled potential field source surface/Sheehley-Arge (WSA) model. The MAS model solves the three-dimensional resistive MHD equations using a semi-implicit finite difference scheme utilizing staggered meshes. The WSA model uses the values at the outer boundary or "source surface" (R=2.5Rs) as the input for the SCS model.

Summary & Conclusions: At all locations, the heliospheric current sheet from the two models agree fairly well with each other. The same structures are present however, in the case of the WSA results, the current sheet appears to be smoothed out more than what is calculated from the MAS model. Especially in the case of cr1961, the current sheet protrusion is much more blunt and rounded than that derived from the MAS model. Thus, for solar minimum case the WSA and MAS models have a high degree of commonality, but the comparison is weaker for the solar maximum case.

Using both an out-to-in and in-to-out method of field line tracing for coronal hole derivation we calculate good degree of comparison between both the MAS and the WSA model, 94% for the solar minimum case and 87% for the solar maximum case. With, in both cases, the disagreement coming largely from MAS deriving a larger pixel-area for the open flux region than the WSA model. Some of this can be attributed to a stretching at the poles, so the discrepancy may lessen by using the different method which includes the latitude of the open flux region. Upon a visual inspection of the comparison between the two models, we can see that overall they appear to match, and in most cases the discrepancy is in one model creating a slightly larger region than the other. Although this is not always the case.

Radial Magnetic Field Projections:
Merkurov projections of the radial magnetic field through surfaces at 2.5 solar radii (top row) and at 29 solar radii (bottom row). Magnetic field is measured in gauss in all images except the 29 solar radii representations of the WSA model, which show polarity only. The radial magnetic field can be used as a locator for the heliospheric current sheet, indicated here by black line.

Differences in Open Flux Calculations:
The implementation of this dual tracing program has only a minor affect on the pixel-area of open flux regions calculated by the model. Most of the area's calculated overlap, as can be seen by the green open flux regions below. However there are some differences between the open flux regions calculated from out-to-in and in-to-out. To see this we compare the pixel-area calculated for the two different tracing routines for both the MAS and the WSA models.

CR1912 Solar Minimum

CR1961 Solar Maximum

CR1912 Solar Minimum

CR1961 Solar Maximum

Below we calculate pixel-areas contained by each of the regions. These percent are calculated by the total number of pixels pertaining to each area divided by the total number of pixels. In both cases MAS derives a greater pixel-area than the WSA. Although overall the two are within an 94% (Solar Minimum) and 87% (Solar Maximum) agreement.

Open flux regions

Closed flux regions

WASA

In-Out trace

Out-to-In trace

CR1912

30.6% 5.1% 2.6% 61.8%

Open flux regions

37.0% 4.6%

Closed flux regions

1.2% 57.2%

CR1961

13.3% 10.7%

Open flux regions

2.0% 73.9%

Closed flux regions

35.5% 5.7%

Open flux regions

0.3% 58.4%

Closed flux regions

14.9% 8.7%

Open flux regions

0.7% 75.6%

Closed flux regions

References:
An event-based approach to validating solar wind speed predictions
M.J. Owens1, A. Pembroke1, H.E. Spence1, C.N. Arge2.
1Boston University, Boston MA, 2 AFRL, Hanscom AFB, MA.

Abstract
One of the primary goals of the Center for Integrated Space-weather Modeling (CISM) effort is to assess and improve prediction of the solar wind conditions in near-Earth space, arising from both quasi-steady and transient structures. We compare 8 years of L1 in-situ observations to predictions of the solar wind speed made by the Wang-Sheeley-Arge (WSA) empirical model. Using the standard method of measuring prediction accuracy (i.e. by calculating the mean-squared error, MSE, between the observed and model values) we test the 8 years of WSA predictions, and reach a number of useful conclusions. However, some potential problems with the interpretation of MSE are highlighted, leading to the development of an additional, complementary, event-based analysis technique using high speed enhancements (HSEs).

The model

The Wang-Sheeley-Arge model (WSA) (e.g. Arge and Pizzo, 2000)

Potential field solution to photospheric boundary condition gives coronal field configuration Solar wind speed determined by empirical relation with magnetic field strength (Wang et al. 1992). Daily updated synoptic maps of the line of sight photospheric magnetic field from the Mount Wilson Observatory. Predictions of WSA are kinematically projected out to 1 AU (accounting for stream – stream interactions).

Interpretation of MSE

• Whilst it is extremely useful to have a single number (skill score) to monitor performance of a predictive model during its development, it gives little/no information about why the predictive accuracy has changed.
• Furthermore, MSE (and correlation, r^2) can be misleading in quantifying model performance:
  - For the hypothetical situation below we might conclude model B is doing a better job of predicting the observed behaviour of the solar wind speed than model A. However the MSE for model B is significantly higher than for model A.

Mean Square Error

• WSA uses daily updated synoptic maps. The figure on the left shows the effect of using maps updated 1 to 7 days prior to the prediction on the skill (using the average MSE for all 7 predictions as the baseline).
  - In general, predictions using 3 to 4 day old maps are better than those using the very latest maps. Predictions using maps older than 6 days are significantly worse.
• The plots on this poster are the 3 day advance prediction (the most accurate).

Event-based approach

• Select High Speed Enhancements (HSEs):
  - Include both coronal fast wind and high speed ICMEs
  - Events will be different in observed, empirical and MHD model time series, therefore use very simple criterion:
    - Require dV >= 100 km/s for dT >= 2 days
  - Apply criterion to observations and model time series
  - Produce 2 lists of events

• Associate HSEs in observations and model data using the algorithm show in the above figure.
  - If the model predicts a fast stream arrival within a set time (t_{GAP}) of an observed one, register a "hit".
  - If there is no model stream to coincide with an observed stream register a "miss".

Summarize

• Three day-old synoptic maps are optimal for solar wind prediction models.
  - They allow the most accurate reconstruction of corona at time the solar wind left the Sun.
  • MSE can be easily misleading
  - Use event-based approach using high speed enhancements (HSEs)

Key to the plots

• Comparing the 3 day WSA prediction to data for the whole 8 years, the RMS error in the radial speed is 91.7 km/s
• Offsetting the predictions in time shows no systematic lag (see figure on the left).

Input Corona Heliosphere

• Potential field solution to photospheric boundary condition gives coronal field configuration
• Solar wind speed determined by empirical relation with magnetic field strength (Wang et al. 1992).

WSA fast streams

• There are 264 (208) high speed enhancements (HSEs) in the ACE/Wind (WSA) data, shown as pink (light blue) panels in the two long time series plots.
  - A pair of events is a "hit" if any part of the event occurs within t_{GAP} = 12 days of the other. Accounting for data gaps, we find:
    - WSA: 166 HSE, 36 No HSE
    - CORHEL: 64 HSE, - No HSE

• The bottom left plot shows:
  - Histogram of the timing and maximum speed errors between the observed and predicted HSEs for the WSA.
  - There is systematic offset in the predicted timing of HSEs.
  - There is some underestimate of their magnitude.
  - All false HSE predictions are small.
  - There are two missed HSE predictions – small magnitude, and fast ICMEs.

• The bottom right plot shows:
  - Multi-posed epoch analysis for the HSEs.
  - MHD models should better capture these properties.

• Out of ecliptic predictions (r^2 2.5^2) used to generate expected error in V(t).
• By defining discrete events, can estimate error in HSE timing.
• Right hand figure shows expected error in HSE timing as function of solar cycle (red line).
• Black dashed line shows average heliospheric current sheet (HCS) tilt angle.
• Anti-correlation between timing uncertainty and HCS inclination.

• Most of the false HSEs are small
• Large missed HSEs: mainly transients (ICMEs)
• Timing of HSEs shows no offset.
• Small underestimation of magnitude of fastest events – probably due to transients.
• Out of the ecliptic:
  - Allow estimate of uncertainty of HSE timing

References
Cane and Richardson (2003), J. Geophys. Res., 108, p1156

Mean Square Error

• WSA predicts the ambient solar wind speed, it does not include speed enhancements resulting from ICMEs.
• Both the WSA and observed solar wind speed might be expected to track with solar cycle.
• Maximum error during 1995 (solar minimum).
• Looking at time series, prediction for 1995 seems to capture the large-scale structure of the solar wind speed better than for e.g. 1998.

Interpretation of MSE

• Why the predictive accuracy has changed.

• Out of ecliptic:
  - By defining discrete events, can estimate error in HSE timing.
  - Right hand figure shows expected error in HSE timing as function of solar cycle (red line).
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  - Anti-correlation between timing uncertainty and HCS inclination.

References
Cane and Richardson (2003), J. Geophys. Res., 108, p1156
Introduction

Geosynchronous orbit is one of the most important orbits for commercial spacecraft. During large storms like the 2003 Halloween storms, satellites on this orbit will cross the magnetopause, making them vulnerable to loss of orientation if they depend on Earth’s northward field to guide them.

We present an accuracy study of the predictions made by three empirical models of the magnetopause location (Roelof and Sibeck [1993], Petrinec and Russell [1993], Shue et al. [1998]) along with predictions made by a magnetic field model from which the magnetopause can be inferred (Tsyganenko [2003]) and by the Lyon-Fedder-Mobarry numerical simulation of the magnetosphere that is one of the four core models in the CISM portfolio.

The predictions are compared against actual solar wind observations made by GOES 10 & 12 during a particularly intense period of time, the Halloween 2003 storms. Skill scores were developed against which future models or improvements can be compared.

Numerical Simulation

- We use the Lyon-Fedder-Mobarry (LFM) code
- The simulation uses solar wind data as an outer boundary condition (the inner boundary being a 2-D semi-empirical ionosphere model)
- LFM is one of the basic building blocks of the CISM code coupling effort
- Used successfully in the past to model periods of strong driving like during large magnetic storms.

Empirical Models Used

- Roelof and Sibeck [1993] (RS93)
  -6 nT < IMF Bz < 5 nT
  -0.5 nPa < SWP < 8 nPa
- Petrinec & Russell [1993] (PR93)
  -10 nT < IMF Bz < 10 nT
  -0.5 nPa < SWP < 8 nPa
- Shue et al. [1998] (S+98)
  -18 nT < IMF Bz < 18 nT
  -0.5 nPa < SWP < 8 nPa
- Tsyganenko [2003] (T+03)
  dst, VB, and sw pressure as input
  Storms → -350 nT < dst < -100 nT

Magnetopause Location

Predicted by the Empirical Models

<table>
<thead>
<tr>
<th>Model</th>
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<th>GOES 12</th>
<th>Total</th>
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<tr>
<td></td>
<td>Oct 29</td>
<td>Oct 30</td>
<td>Oct 29</td>
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<tr>
<td>S+98</td>
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<td>S+98</td>
<td>46</td>
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Magnetopause crossings

<table>
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<th>Table 2</th>
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<tr>
<td>F - % of time the model correctly predicted the satellite was outside the magnetosphere</td>
</tr>
<tr>
<td>P - % of time the model correctly predicted the satellite was inside the magnetosphere</td>
</tr>
</tbody>
</table>

Summary

- We have examined how well a variety of models are able to predict whether the GOES spacecraft will be in or out of the magnetosphere during the Halloween storms of 2003.
- We have also presented several quantitative measures of the quality of those predictions.
- The LFM simulation provides the best overall prediction.
- These results will allow us to benchmark future improvements in the LFM code.
- The comparisons have been done for southward IMF. Northward IMF magnetopause crossings should be rare in any case.
**Introduction/Motivation**

The terrestrial plasma sheet is a large volume of plasma which can globally alter its state in a short time period. The plasma sheet is also subject to localized fast flows within it’s volume. Because of the multi-scale nature of plasma sheet phenomena, previous plasma sheet studies have used two general methods:

- **Individual Event Analyses & Long Baseline Time Averages**
- **Long Baseline Time Averages** provide a global, statistical picture of the plasma sheet, averaging over dynamical fluctuations (Baumjohann et al. 1993; Angelopoulos et al. 1993; Huang and Frank, 1994; Wing and Newell, 1998; Kaufmann et al. 2002).

We would like to understand the connection between the localized high speed flows and the global convection pattern of the plasma sheet. We plan to use a global MHD model as a tool to bridge the time and spatial scale gap that exists between these two methods.

**But First:** We must validate the global MHD model with respect to the major features of the plasma sheet.

**Science Question:** Does the Lyon-Fedder-Mobarry (LFM) model correctly describe the observed plasma sheet on large spatial scales and time scales?

**Geotail Study**

Geotail data from the LEP [Mukai et al., 1994] and MGF [Kikubun et al., 1994] instruments were collected over a ~3.5 year period from 1996 to mid-1999. We select only those measurements with plasma parameters that are representative of the central plasma sheet (criteria at right). The B_y filter is the same as that used by Baumjohann et al. [1990].

Plotted at right is the total number of samples where Geotail measured the plasma sheet in the XY plane and Y > Z and Z > Y planes, according to the above criteria. We further limited our database according to the distance from a model neutral sheet [Hammond et al., 1994] (within the red lines in the XZ, YZ planes).

**Long Baseline Time Averages** provide a global, statistical picture of the plasma sheet, averaging over dynamical fluctuations (Baumjohann et al. 1993; Angelopoulos et al. 1993; Huang and Frank, 1994; Wing and Newell, 1998; Kaufmann et al. 2002).

**Fluid Comparisons**

- Density, Thermal Pressure, and Temperature are plotted below for Geotail (top row) and the LFM model (bottom row). The model yields a slightly over-dense inner plasma sheet, but the other results agree well.

**Velocity Fluctuation Comparisons**

- The median values of perpendicular flows simulated by the LFM in the equatorial plane are close to those observed by Geotail (as seen on left).
- *Largest (|V| > 5 km/s) flow direction discrepancies are apparent in the pre-midnight sector.*
- Energy-dependent gradient-curvature-drifts are important in this region of the plasma sheet, and are not included in the MHD model.

**Summary**

- We have performed a statistical comparison of Geotail data with the LFM MHD model in the central plasma sheet.
- The statistical behavior of the model is largely consistent with the measurements, with the exception of the plasma flow speed and the flow direction primarily on the plasma sheet dusk side.

**Future Work**

- Perform Climatology comparison with the LFM coupled to the Rice Convection Model (RCM)
- Extend the LFM flow channel analysis of Wittberger et al. (2000) to tie the localized dynamics of the model to the global convection pattern presented here.

**References**

Storm Time Configuration of the Inner Magnetosphere:
LFM MHD Simulations, Tsyganenko Models, and GOES Observations

Chia-Lin Huang¹*, Harlan Spence¹, John Lyon¹,², W. Jeffrey Hughes¹, Charles Goodrich³ and Howard Singer³
¹Boston University, Boston MA, ²Dartmouth College, Hanover, NH and ³NOAA, Boulder, CO

Motivation:
What are the physics describing the evolution of inner magnetosphere magnetic fields and plasma during magnetic storms? How well do LFM MHD simulations perform during storm times? Under what limits is it a sufficient tool to study magnetospheric dynamics?

Goal of Study:
To understand the structure and dynamical evolution of inner magnetosphere B-fields and plasma during magnetic storms, we present comparisons between LFM MHD simulations, Tsyganenko models, and observations of the geostationary environment.

Lyon-Fedder-Mobarry (LFM) codes are global three-dimensional MHD simulations of Earth’s magnetosphere.

Tsyganenko Models are empirical magnetic field models, based on satellite magnetic field measurements, that provide flexible and parameterized global average views of dynamic states of Earth’s magnetosphere.

* LFM MHD Simulations over-estimate the geosynchronous B-fields during storm main phase, especially at the night side.

Comparison of Tsyganenko 1996, 2001 and 2003 Models

<table>
<thead>
<tr>
<th>Field Sources</th>
<th>T96</th>
<th>T01</th>
<th>T03</th>
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<td>Same as T96, plus new 6 B Sources</td>
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<td>Model Inputs</td>
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<td>Skill Score</td>
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<td>Brm’s B96 / Brm’s T96 x 100%</td>
<td>Brm’s B96 / Brm’s T96 x 100%</td>
</tr>
</tbody>
</table>

*1 MPa, HEDS, ISSE ½
*2 Geotail, Polar, ISSE 2, AMPTE/CECE, AMPTE/IRM, CRRES and DE 1
*3 GOES 8, 9, and 10, Polar, Geotail, Equator-S

GOES Data v.s. Tsyganenko Model Outputs:

Magnetic island configurations predicted near Earth due to strong ring current (T96) and tail current (T01).

* Early Tsyganenko models cannot reproduce the correct B-field for extreme storm events.

GOES Data, Tsyganenko 2003 Model and MHD Simulations for Sep98 Storm

B-Field Line Configurations of T03 and LFM

T03 works very well at geosynchronous orbit; we assume next that it works well elsewhere to compare field line configurations with LFM.

Compare the Current Profiles During Storm Main Phase

Skill Score Analysis for LFM MHD Simulations Using Tsyganenko 2003 Model as Baseline Model

To measure how well the MHD model predicts the B-field observation as compared to Tsyganenko model prediction of the same quantity we define a skill score:

\[
\text{Skill Score (SS)} = \left(1 - \text{Brms(MHD)} / \text{Brms(T03)} \right) \times 100\%
\]

Brms is the root-mean-square between the model outputs and the observed B-field. This is a first attempt at defining optimal parameters for a skill score for geostationary magnetic fields.

* Contact: hcl@bu.edu
A study of low latitude electron densities using CMIT
A. G. Burns¹, W. Wang¹, T. L. Killeen¹, S. C. Solomon¹, H. Spence², and M. Wiltberger¹
¹High Altitude Observatory, National Center for Atmospheric Research, ²Boston University

Abstract
The coupled thermosphere-ionosphere magnetosphere (CMIT) and thermosphere ionosphere nested grid (TING) models have been run for the May 15, 1997 CME. Initial validation using middle latitude ionosondes is shown here. The quality of agreement between data and model varies from stations-to-station, with the agreement ranging from good at some stations and times to poor at others. Some reasons for this agreement and disagreement are discussed in the conclusions.

The May 1997 Geomagnetic storm

Stations

Auroral Oval Size

CMIT
TING

Boulder

At 7 UT on the 15th of May TING electron densities were enhanced compared with those seen in the data at Boulder and Wallops Island but CMIT ones were not. The TING auroral oval covers these stations. The TING auroral oval occurs at too low a latitude.

High Latitude Forcing

CMIT
TING

Irkutsk

Chilton

TING calculations of NmF² are much better than those of CMIT in the middle of May 15 at both Chilton and Irkutsk. As small changes in geographic location cannot explain this effect, CMIT must overestimate negative storm effects.

Skill Scores

<table>
<thead>
<tr>
<th></th>
<th>Boulder</th>
<th>Wallops Island</th>
<th>Puerto Rico</th>
<th>Chilton</th>
<th>Irkutsk</th>
<th>Petropavlovsk</th>
<th>Hobart</th>
<th>Learmonth</th>
<th>Grahamstown</th>
</tr>
</thead>
<tbody>
<tr>
<td>14th</td>
<td>-0.253</td>
<td>-0.123</td>
<td>-1.099</td>
<td>-0.926</td>
<td>-0.623</td>
<td>-0.988</td>
<td>1.624</td>
<td>0.916</td>
<td>-0.450</td>
</tr>
<tr>
<td>15th</td>
<td>-0.123</td>
<td>-1.697</td>
<td>-0.059</td>
<td>-0.246</td>
<td>0.571</td>
<td>0.503</td>
<td>-0.334</td>
<td>0.228</td>
<td>0.944</td>
</tr>
<tr>
<td>16th</td>
<td>0.628</td>
<td>0.121</td>
<td>0.295</td>
<td>-3.722</td>
<td>-8.947</td>
<td>-11.65</td>
<td>0.507</td>
<td>0.741</td>
<td>0.670</td>
</tr>
</tbody>
</table>

Some ideas that can be drawn from these results are: 1) IRI is doing a very good job of reproducing NmF² values during quiet time and its smooth nature contributes to low mean square errors during the storm days; 2) skill scores that are calculated using mean square errors tend to reflect spiky extremes rather than trends in the data; 3) skill scores are particularly bad if the model predicts negative effects when positive effects occur in data and vice versa.

Conclusions
• Both versions of the model can vary considerably from both the data and each other. These differences illustrate the need to validate the high latitude inputs.
• The TING model overestimates electron densities at several high middle latitude stations during the main phase of the storm as the modeled auroral oval is overhead.
• CMIT overestimates the strength of the storm.
• There are weaknesses in the skill scores as they are currently estimated.
CISM Education Objectives:
1. Provide graduate students with opportunities for broad-based research in CISM related fields and with professional mentoring and role models.
2. Provide undergraduates (2 and 4 year) with research opportunities (academic year and summer) as well as mentoring and role models.
3. Provide graduate and undergraduate students with opportunities to develop professional relationships with peers and working scientists in CISM related fields.
4. Provide space weather resources and professional development for 6-14 teachers and provide information about space weather to the general public.

The CISM Education Mission
The CISM Education Mission is to recruit and train the next generation of space physicists and imbue them with an understanding of the Sun & Earth as a system.

Measures of Success: Objectives to Outcomes

<table>
<thead>
<tr>
<th>Objective</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Graduate research, mentoring, and role models</td>
<td>A thriving, diverse community of graduate students actively engaged in CISM research and related activities.</td>
</tr>
<tr>
<td>2. Undergraduate research, mentoring, and role models</td>
<td>A thriving, diverse community of undergraduate students actively engaged in CISM research and related activities.</td>
</tr>
<tr>
<td>3. Graduate &amp; undergrad prof. &amp; peer relationships</td>
<td>Both CISM and non-CISM students interacting with peers and working scientists throughout CISM related fields.</td>
</tr>
<tr>
<td>4. Resources for grades 6-14 and general public</td>
<td>Teachers using CISM materials in their classes. Teaching professionals participating to CISM sponsored activities. Members of the general public participating in CISM sponsored programs and accessing CISM provided materials.</td>
</tr>
</tbody>
</table>

Connecting Program Elements to Objectives

<table>
<thead>
<tr>
<th>Program Element</th>
<th>Objectives</th>
<th>Goal</th>
<th>Year-3 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Build a Graduate Community</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. CIM Summer School</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Build an Undergraduate Community</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Grade 6-14 Education &amp; Science Literacy</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measures of Success: Assessing the Outcomes

Outcome 1: A thriving, diverse community of graduate students actively engaged in CISM research and related activities

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-3 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of graduate students engaged in CISM research each year</td>
<td>5 underrepresented US citizens</td>
<td>27, including 12 women and 15 men</td>
</tr>
<tr>
<td>Number of CISM PhDs</td>
<td>12 per year</td>
<td>21 in 2004</td>
</tr>
<tr>
<td>Number of graduate student first-author publications at professional conferences</td>
<td>21 per year</td>
<td>20 in 2004</td>
</tr>
<tr>
<td>Year-3 Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percentage of students mentored by CISM graduate students</td>
<td>12 graduate students, 9 faculty, and 8 undergraduates</td>
<td>20 teachers trained per year</td>
</tr>
<tr>
<td>Percentage of students participating in CISM sponsored activities</td>
<td>12 students participating in CISM sponsored activities</td>
<td>10 students from five institutions</td>
</tr>
<tr>
<td>Number of students attending the graduate retreat</td>
<td>12</td>
<td>Not yet available</td>
</tr>
</tbody>
</table>

Outcome 2: A thriving, diverse community of undergraduate students actively engaged in CISM research and related activities

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-3 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of undergraduates engaged in CISM research each year</td>
<td>20</td>
<td>0 in 2005</td>
</tr>
<tr>
<td>Number of CISM undergraduate co-authors from other institutions</td>
<td>12</td>
<td>Not yet available</td>
</tr>
<tr>
<td>Percentage of students engaged in CISM sponsored activities</td>
<td>20%</td>
<td>Not yet available</td>
</tr>
<tr>
<td>Number of undergraduate/co-authored papers in space weather journals</td>
<td>5 per year</td>
<td>2 in 2004</td>
</tr>
</tbody>
</table>

Outcome 3: Both CISM and non-CISM students interacting with peers and working scientists throughout CISM provided means

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-3 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students identified as CISM alumni participating in CISM related activities</td>
<td>12</td>
<td>Not yet available</td>
</tr>
<tr>
<td>Number of students attending the undergraduate retreat</td>
<td>12</td>
<td>2 in 2004</td>
</tr>
<tr>
<td>Number of students presenting at CISM related conferences</td>
<td>12</td>
<td>Not yet available</td>
</tr>
</tbody>
</table>

Outcome 4: Teachers using CISM materials in their classes. Teaching professionals participating in CISM sponsored activities. Members of the general public participating in CISM sponsored programs and accessing CISM provided materials.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-3 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers incorporating CISM materials into their Space Weather Monitor (SWM) lessons</td>
<td>20 teachers trained through multiple workshops</td>
<td>20 teachers trained through multiple workshops</td>
</tr>
<tr>
<td>Students using the Space Weather Monitor (SWM)</td>
<td>10 per year</td>
<td>10 per year</td>
</tr>
</tbody>
</table>

CISM Education Program Elements

1. Building a Graduate Student Community

- The 2003 CISM Graduate Student Retreat

2. The CISM Summer School

- The CISM Graduate Space Weather Summer School is a two week intensive program run each summer. It is aimed at beginning graduate students but has proved to be equally valuable to others entering the space weather field in industry, government or the military. The summer school is described in detail in an accompanying poster.

3. Building a CISM Undergraduate Student Community

- Providing undergraduates with research opportunities is a proven method of engaging and retaining them in science. Currently 31 undergraduates spread among 9 CISM institutions are engaged in research with CISM researchers. These research projects provide undergraduates with valuable skills and experiences. To build on and enrich this experience CISM will provide opportunities for undergraduates to share their research and engage in professional development throughout the academic year. The capstone event, the undergraduate retreat, will solidify a sense of membership in the CISM community following the pathfinder model of the successful graduate student retreat. The undergraduate retreat will be a 3-day program where students share their research, learn about cutting-edge CISM research, meet other students and representatives of CISM graduate schools, and engage in other professional development activities. Undergraduate professional development will include a series of AG meetings for CISM undergraduate researchers that will provide information on various topics, including basic research skills such as how to look up, use, and reference previous work and how to write for a scientific audience.

4. Grade 6-14 Education and Increasing Science Literacy

This element comprises specific focused activities, under the leadership of several CISM institutions, most of which are heavily leveraged. The goals are to provide materials and training for grade 6-14 educators and high visibility exhibits and information for the general public.

- Stanford Sudden Ionospheric Disturbance (SID) Monitor
- Berkeley/Stanford/San Francisco Exploratorium Space Weather Web Site
- New Windows to the Universe section on space weather (See separate poster)
- Rice Solar Plantarium show
- Physics of HAM Radio course at Rice University
- Secondary curriculum development, and teacher workshops
The CISM Graduate Space Weather Summer School

W. Jeffrey Hughes and the CISM Team
Boston University, Boston MA,

Introduction:
The CISM Summer School is an intensive two-week program aimed primarily at students receiving graduate school in space or solar physics, and an early stage in such a program. However, others entering the space weather field, particularly in industry, government or the military, have also benefited from attending. The school provides an overview of the space environment, space weather hazards, and models that are used to understand, specify, and predict the space environment – Reality, Harsh Reality, and Virtual Reality. Hands-on use of space weather models is a core component of the school. The goal is to provide students with the Sun-Earth system context for their subsequent more detailed and theoretical study in graduate school, and their thesis research topic. The school is introducing innovative pedagogy at the graduate level. The school receives excellent reviews from participants.

The Curriculum:
The summer school curriculum is divided into 5 courses that are taught concurrently. Most meet each day. A typical day is constructed so that the opening class deals with some region of the space environment. The second class discusses how this region produces a space weather hazard, the third class discusses how phenomena can be modeled, and the afternoon session has the students using a model of this part of the sun-earth system. Some afternoons a guest lecturer from government or industry presents a seminar on some aspect of space weather operations or policy. Through the two-weeks the topics move from the Sun to the upper atmosphere. The two-week schedule of lectures, seminars, and labs from 2004 is given below.

The Faculty:
The Summer School faculty are drawn from throughout the CISM team and beyond. Below are listed those scientists who participated in teaching the 2004 summer School. The CISM team members are also identified by their primary theme, showing that they are drawn from all CISM threats. We also give special recognition to outside CISM, particularly to those from industrial side and for those topics (such as ionospheric scintillation) not within CISM's models.

CISM Team Members (Thrust)

<table>
<thead>
<tr>
<th>Name</th>
<th>Course (Title)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Arge</td>
<td>SW 102: Effects &amp; Fundamentals</td>
</tr>
<tr>
<td>Robert Sheeley</td>
<td>SW 105: Space Weather Laboratory</td>
</tr>
<tr>
<td>Al Swisdak</td>
<td>SW 103: Ionospheric Modeling</td>
</tr>
<tr>
<td>John Lyon</td>
<td>SW 104: Seminar: Space Weather Operations and Policy</td>
</tr>
<tr>
<td>Patricia Doherty</td>
<td>SW 101: Overview of the Solar-Terrestrial System</td>
</tr>
<tr>
<td>W. Jeffrey Hughes</td>
<td>SW 106: Space Weather Effects and Conditions</td>
</tr>
<tr>
<td>Michael Wiltberger</td>
<td>SW 107: Introduction to Modeling of CME</td>
</tr>
</tbody>
</table>

Non-CISM

<table>
<thead>
<tr>
<th>Name</th>
<th>Course (Title)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dr. John Drake</td>
<td>SW 108: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. John Vittori</td>
<td>SW 109: Themodynamics and the Corona</td>
</tr>
<tr>
<td>Dr. Brian Murphy</td>
<td>SW 110: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Montes</td>
<td>SW 111: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Axford</td>
<td>SW 112: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Argo</td>
<td>SW 113: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Smith</td>
<td>SW 114: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Jones</td>
<td>SW 115: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Kent</td>
<td>SW 116: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Hargreaves</td>
<td>SW 117: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Allred</td>
<td>SW 118: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Gross</td>
<td>SW 119: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Golightly</td>
<td>SW 120: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Wiltberger</td>
<td>SW 121: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Hughes</td>
<td>SW 122: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Mathews</td>
<td>SW 123: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Nohr</td>
<td>SW 124: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Onsager</td>
<td>SW 125: Space Weather Hazards</td>
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<tr>
<td>Dr. Brian Arge</td>
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<td>Dr. Brian Sheeley</td>
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<td>Dr. Brian Lyon</td>
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<td>Dr. Brian Hargreaves</td>
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<td>Dr. Brian Hughes</td>
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<td>Dr. Brian Mathews</td>
<td>SW 135: Space Weather Hazards</td>
</tr>
<tr>
<td>Dr. Brian Nohr</td>
<td>SW 136: Space Weather Hazards</td>
</tr>
</tbody>
</table>

The Students:
The students who attend the summer school are drawn in several respects, gender, employment, and institutional location. Approximately 30% of those attending are employed by government, industry or the military. They benefit from a knowledge of space weather. These usually young professionals have different perspectives to space weather that shape the majority of questions when students are beginning their graduate studies, showing from the non-research aspects of space weather. We also deliberately include a few students from overseas to add diversity to the course and school. The two tables to the right show how the the students who attended the 2003/2004/2005 summer schools split demographically and by current professional or student status.

Demographics of Summer School Students

<table>
<thead>
<tr>
<th>Summer School Attendees</th>
<th>Summer 2003</th>
<th>Summer 2004</th>
<th>Summer 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>13</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>Asian</td>
<td>Native</td>
<td>Asian</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>Industry</td>
<td>Private</td>
<td>Government</td>
<td>Private</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>5</td>
<td>23</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>33</td>
<td>14</td>
</tr>
<tr>
<td>US/Globally</td>
<td>US</td>
<td>Global</td>
<td>US</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Research</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
<td>11</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>County</td>
<td>Urban</td>
<td>Rural</td>
<td>Urban</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
<td>20</td>
<td>18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Professional Status of Summer School Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer School Attendees</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Employment</td>
</tr>
<tr>
<td>Total</td>
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<td>Industry</td>
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<tr>
<td>Total</td>
</tr>
<tr>
<td>US/Globally</td>
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<tr>
<td>Total</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Research</td>
</tr>
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<td>Total</td>
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<td>Total</td>
</tr>
<tr>
<td>County</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

The Capstone Integrative Project:
The final day of the summer school is dedicated to a capstone project designed to allow the students to use the knowledge they have gained during the two weeks. Students analyze real observational data from several days around a significant space weather event using expert and jaguar collaborative learning techniques. The projects are designed to take advantage of the jaguar collaboration tools: expert and jaguar collaborative learning techniques. The projects are designed to take advantage of the jaguar collaboration tools: expert and jaguar collaborative learning techniques. The projects are designed to take advantage of the jaguar collaboration tools: expert and jaguar collaborative learning techniques. The projects are designed to take advantage of the jaguar collaboration tools: expert and jaguar collaborative learning techniques.

The tables below show the student responses to the first three questions averaged for each day and for each lecture series. (The SW104 seminars on operations and policy were not evaluated.)

Evaluations

<table>
<thead>
<tr>
<th>Question</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
<th>Day 9</th>
<th>Day 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q.1: Did you find the material presented easy?</td>
<td>4.3</td>
<td>4.4</td>
<td>4.4</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Q.2: What was the lecture engaging?</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Q.3: Rate your personal experience [1-5 scale]</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Q.4: Was it the best part of the lecture?</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Q.5: Which aspects could be improved?</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

These groups must then piece together what happened in the Sun-Earth system during these period. They are asked to produce a web-chart (using messygraph and markers) to illustrate their findings, and also to show what models might have been helpful in predicting the outcomes expected during this time. The students are asked to give their best answer. There is usually an array of Such processes and learning how to discern the correct one.

The students are asked to give their best answer. There is usually an array of models that are used to understand, specify, and predict the space environment – Reality, Harsh Reality, and Virtual Reality. Hands-on use of space weather models is a core component of the school. The goal is to provide students with the Sun-Earth system context for their subsequent more detailed and theoretical study in graduate school, and their thesis research topic. The school is introducing innovative pedagogy at the graduate level. The school receives excellent reviews from participants.
The Space Weather Weekend: A new CISM Diversity Initiative

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**CISM Diversity: Goals and Objectives**

- To involve historically underrepresented minorities and women in space weather research
- Increase number of underrepresented space weather professionals
- Focus both on recruitment and retention
- The Space Weather Weekend is a means to meet our goals and objectives

**Space Weather Weekend: Our Objectives**

- Use the excitement of space weather to recruit students from Minority-Serving Institutions to apply to CISM graduate schools - just a few students will significantly impact demographics of field
-Expose participants to a new field of science in an innovative teaching environment.
- Establish personal connection with participants

**Recruitment Strategy**

- The recruitment was done in a very short time - We started recruiting on 3/21 for the 4/22 event
- We used existing networks in the African-American and Hispanic Physics Communities, along with the NASA/MUCERF network
- Faculty at minority-serving institutions were contacted directly and asked to recruit students
- Students had a financial incentive - $300 stipend plus expenses
- A brochure was produced to aid recruitment
- 11 students participated, from AAMU, Fisk U., Grambling State U., Howard U., NC A&T State U., U. of Houston (Downtown), and UT Browsville
- A professor from NC A&T, Abede Kebede, also attended

**Who did what?**

- AAMU hosted the event, handled local logistics, stipend, and travel, and arranged visit to Rocket Center
- Ft Tech designed the program, recruited students, and produced the CISM_DX Live CD
- Scientists and staff from AAMU, Boston U., Ft Tech, and Marshall Space Flight Center made presentations and ran the labs
- CISM staff at NCAR and AFRL contributed material

**Schedule**

- Held April 23-24 at AAMU
- Loosely based on the CISM Summer School
- Saturday - Lectures (w/ peer instruction) on Sun, Magnetosphere, Ionosphere, CISM, and space weather: Visit to Huntsville Space and Rocket Center; Special session on applying to graduate school
- Sunday - Working with CISM_DX and tracing a space weather event from Sun to Earth
- All meals eaten together, including Saturday night dinner at the Olive Garden, to build sense of community

**Evaluation and Outcomes**

- Formative evaluation shows 4 or greater on 1-5 Likert scale for useful/valuable
- Student comments indicate positive impact on choice of space physics as a career - 6 indicated new interest in applying to CISM grad school
- "Space science is now among my top 3 options for graduate school. It is much more interesting than I initially thought it would be. Now I will definitely consider this field for graduate school.
- "Very likely that I will apply for graduate study in space physics since this workshop.
- "...This program was the single factor influencing my decision. Before this workshop I was completely unaware of this field, but now I see it as a possible research career.”

**CISM_DX Live CD**

- This new CISM product was developed specifically for the Space Weather Weekend, but it has much broader utility
- Based on KNOOPPIX Linux distro in bootable CD format plus stripped-down version of standard CISM_DX installation
- Non-essential packages and datafiles were removed, libraries needed for CISM_DX added, and a light-weight Xwindow manager (IceWM) is used
- CD contains data and DX networks for exploring MAS, ENLIL, LFM, TING
- All students got a copy

**Summary**

- The first CISM Space Weather Weekend was organized and conducted in Spring 2005
- Initial evaluation indicates that it was a great success
- A new resource, the CISM_DX Live CD was produced
- Participants who apply to CISM graduate schools will have personal contacts to help them
- A new connection with NC A&T program was established
- Further evaluation will determine long-term impact
Graduate students meet, work, and interact across institutions through CISM:

Shared Research
Students at different institutions work together on several research areas of CISM. The CISM Graduate Student Forum, monthly Access Grid meetings and the Graduate Student list server are used for a general call out for help or information, while phone calls and emails to individuals are a common occurrence.

CISM email list server and forum
The CISM graduate student forum provides a simple way to keep an ongoing dialogue between CISM students, while the email list server provides a means to send out reminders and distribute our monthly newsletter. Topics discussed on the forum range from programming problems to the location of the next Graduate Student Retreat.

Conference Support
CISM students can provide mutual support to each other at conferences. Graduate students make a point to attend each other’s presentations and posters. With this support, students find it easier to integrate within the scientific community.

Access Grid
Monthly access grid meetings allow CISM Graduate students to share research, practice presentations, discuss meetings, and ask any questions of each other.

Graduate Student Retreat
Each year we hold a retreat for all CISM graduate students. The retreat is intended for students who are or will be engaged in CISM research and whom we expect to be within CISM for a few years, completing their thesis or dissertation on a CISM topic.

The first retreat was held in September 2003. Seven students participated in the meeting, which was led by J. Hughes. The main topic of discussion was Ethical Behavior in the Context of Science. Two recent Ph.D.s, David Murr (Dartmouth) and Niescja Turner (UTEP) also participated. Sessions included “The Goals of CISM”, “How to survive graduate school”, and “Getting along with your advisor”.

The second annual CISM Graduate Student Retreat was held September 17-19, 2004. Ten CISM PhD students from five institutions participated with CISM Director Jeffrey Hughes and two early-career scientists, Genene Fisher (American Meteorological Society) and Michael Wiltberger (NCAR) (pictured below-left with J. Hughes). The 2004 topic was “Careers in Space Physics” and “How to find a job after Graduate School”. The students also used this meeting as an opportunity to organize themselves better, initiating the Access Grid, Newsletter, Webpage and Forums.

The Graduate Retreat not only allows the Graduate Students to meet each other face to face and to discuss important issues facing the scientific community, but also to share experiences with each other, such as Yong Gong and Christina Lee’s first feel of the Atlantic Ocean.

Graduate Student Webpage
A Graduate Student Webpage is currently under construction. The site contains (or will contain) Access Grid minutes, a gallery of photos from the Graduate Retreat and scientific meetings, links to every student’s homepage, a list of student presentations and publications.

http://sprg.ssl.berkeley.edu/~clee/CISM/cism_student.html

Graduate Student Newsletter
Every month a newsletter is sent out to the entire Graduate Student community. This Newsletter provides, among other things, the minutes for the Access Grid that month and reminders of important dates and deadlines.

Each newsletter also includes a section devoted to a brief summary of each Graduate Student’s work (both research and scholastic) over the past month.

Broader Experiences
Beyond their individual research areas and those emphasized in their own institutions, CISM graduate students

• gain familiarity and experience with problems of the whole the sun-earth system
• work with established scientists at other institutions
• form relationships with peers that will continue past graduate school
Objectives

- Provide space weather resources & professional development for teachers of grades 6-14
- Integrate CISM research and education
- Leverage off Center concept and engage CISM scientists with the educational program
- Respond to diversity needs
- Enhance CISM coherence – interconnection with multiple partners & varied programs

CISM Interconnections

- Teachers, students, partners in space science
- Space Weather Monitor Program
- Centralized data repository, software for data analysis
- Educational, professional formative & summative assessment
- Professional development for teachers of grades 6-14

Intended Outcomes

- Over 100 monitors placed in underserved high schools and community colleges
- Teachers trained in Standards-based, hands-on, inquiry-driven use of monitors in the classroom to study space weather
- CISM scientists, as partners to the schools, become engaged with teachers, students, and the CISM educational program
- Potential space weather students become actively involved early in their careers
- Data from the monitors is returned to scientists for further research

The United Nations and organizers of the International Heliophysical Year, 2007, have designated these Space Weather Monitors as official IHY instruments, to be placed in 191 countries around the world.

Highlighting the Space Weather Monitor Program

Teacher interns working in collaboration with CISM researchers have developed inexpensive space weather monitors targeted for under-served high school and community college use. The monitors track disturbances to the Earth’s ionosphere caused by solar activity. The teacher interns worked with scientists to design and develop the monitors. The interns tested by incorporating the monitors into classrooms, and are providing supporting documentation, curricula, and activities. Students from high schools and community colleges participated by developing software and beta-testing the systems.

- 2 versions of monitors –
  - SID, for wide distribution (~$150)
  - AWESOME, research quality (~$3000)
- Monitors placed in schools most likely to reach under-represented students, esp. community colleges – where bulk of under-represented students are found
- Leverage from CISM Education Partners –
  - Teacher workshops, incl. online (NCAR)
  - University application (Alabama A&M)
  - Integration into teacher-training courses (Rice U.)
  - Development of web-based training (NCAR, Exploratorium, Stanford)
- Engagement from CISM Science Partners:
  - Distribute in a Partnership model, to encourage scientist-teacher-student collaborations
  - Return data to CISM and other researchers
  - Professional formative & summative assessment
  - All materials standards-based
  - Supplemental funding obtained from NASA

Web-based Training Resources

- Exploratorium –
  - Space Weather Research Explorer
  - Produced in conjunction with CISM partners at UC Berkeley & Stanford
  - Includes CISM imagery, interviews with CISM scientists, pointers to “live” CISM data

- NCAR’s Windows to the Universe –
  - Space Weather
  - http://www.windows.ucar.edu/resource/space_weather

- Stanford Solar Center –
  - Space Weather Monitors
  - http://solar-center.stanford.edu/32

NCAR will be incorporating the monitor project into their professional development program for middle – high school educators and Rice University will be incorporating it into their Ham Radio Course for teachers – thus using professional development opportunities to improve educators’ understandings of space weather concepts and providing them and their students with a hands-on tool to track this phenomena.

Incorporating the Space Weather Monitor into Teacher Coursework

Rice University supports formal training courses for teachers. Their Physics of Ham Radio course covers electromagnetic waves, basic electronics, antennas, the ionosphere, ionospheric propagation, the Sun and CMEs, and the magnetosphere. The Space Weather Monitors will be incorporated into the course and students/teachers will be taught how to directly monitor and exchange data about the solar influences on their radio transmission.

Extending the Space Weather Monitors into the University Environment

Professor Marius Schamschula of Alabama A&M will experiment with incorporating both monitors into their undergraduate space science programs. To what extent can these be useful in training future space scientists? Are they effective as teaching aids or as tools to spark an interest in space science? Do they help encourage a diversity of fields? How will their functions need to be extended to work effectively for undergraduate space science majors? To what extent does the use of an AWESOME for space science undergrads differ from the use of a SID as an enthusiasm-builder for a more general student population?
Introduction

The CISM Education Program includes an objective to provide space weather resources and professional development for grades 6-14 teachers and provide information about space weather to the general public. This poster summarizes CISM Education Program activities focused on science literacy, to bring resources and information to the public, students, and educators outside of the professional development context.

Implementation Strategies:

- Leveraging existing programs at the University Corporation for Atmospheric Research (UCAR), Rice University, and Stanford.
- Collaboration with external partners, in recognition of need for effective large-scale efforts with limited funding.
- Internal collaboration, ensuring that higher impact is attained than would be possible without the STC.

Web-Based Science Literacy

Multiple CISM Education Program partners are working to bring CISM space weather content to the public, students and teachers through the web, building on the strengths of their existing programs for maximum impact.

At UCAR, Windows to the Universe (http://www.windows.ucar.edu) project staff are working to develop a new, updated, and comprehensive Space Weather website that:
- Highlights CISM science results and work of education program partners,
- Consolidates and expands our existing extensive Space Weather content, currently dispersed through the website into one comprehensive, up-to-date, and multilevel section (including entry-level undergraduates),
- Takes advantage of the large audience the website
  - 8.2 million visitors over past year,
  - 25% visit Space Weather content

The CISM Education Team is working together to increase science literacy about space weather with the public, students, and teachers, in addition to our professional development efforts described elsewhere. Our science literacy efforts focus on leveraging existing programs and collaboration, where possible, to ensure the most efficient and effective use of the limited funding resources available, given the large scope of our intended audience – the general public. Over the next two years, we will complete and evaluate the impact of our current web- and museum-based programs.

The new CISM Space Weather interface will consolidate and expand upon the existing space weather content on Windows to the Universe, including a new undergraduate level and new sections on Modeling and Monitoring space weather, Fundamental Physics, and Activities and Problems

Rice University also participates in web-based efforts:
- CISM research is highlighted through “e-teacher” emails, to over 2800 teachers nationwide (with support from IMAGE).
- Updated their “real time space weather” pages at http://space.rice.edu/CISM/ with links to real-time space weather prediction pages (linked to from the Windows to the Universe Space Weather section).

Stanford has collaborated with the Exploratorium Science Museum in San Francisco and researchers at UC Berkeley to develop a Space Weather website (http://www.exploratorium.edu/spaceweather/ ) including:
- Imagery and animations from CISM,
- Interviews with CISM scientists, and
- Ready access to live CISM and other solar data.

Museum-Based Science Literacy

The museum-based science literacy effort has two parts:
- Upgrading museum kiosks and CD-roms to include CISM science and animations (Rice), and
- Planetarium show development (Rice and Stanford)

Kiosks/CD-roms
With crucial CISM support for programming staff, Rice is updating their “Space Weather” CD-ROM that has nearly 600 MB of images, animations, and games, to include CISM science and CISM animations.
- Over 9,000 disks were distributed in 2004-05
- 1000 funded by CISM and 8000 by IMAGE
- Distributed at teacher meetings this year including NSTA, CAST, SACNAS, AMS, and AAPT, and workshops given by CISM partners.
- Also distributed at multiple other venues, including on Sun-Earth Day and Earth Day at the Houston Museum of Natural Science.

- Full-dome digital planetarium shows
  - Small portable systems
  - Major high resolution multiple-projector theaters
    - Rice is currently working on three projects
      - One solar show headed by Stanford;
      - One high resolution major production with the American Museum of Natural History, NY;
      - A remake of “Solar Max” with John Weiley of Australia, called “The Heart of the Sun”;
    - Rice provides animations or connections so that we reach millions with a very modest investment.
  - Stanford is working to develop a solar planetarium program on Space Weather and Sun as a Magnetic Star, in conjunction with the Lawrence Hall of Science in San Francisco. This show is designed for small, interactive planetaria such as the StarLab.

Summary

The CISM Education Team is working together to increase science literacy about space weather with the public, students, and teachers, in addition to our professional development efforts described elsewhere. Our science literacy efforts focus on leveraging existing programs and collaboration, where possible, to ensure the most efficient and effective use of the limited funding resources available, given the large scope of our intended audience – the general public. Over the next two years, we will complete and evaluate the impact of our current web- and museum-based programs.

Links to our web-based resources and information about our education and public outreach program is available at http://www.windows.ucar.edu/CISM/literacy.html