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I. General Information

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<tr>
<td>1</td>
<td>Center for Integrated Space Weather Modeling</td>
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<tr>
<td>2</td>
<td>AAMU will work with Boston University on model validation and with Florida Institute of Technology on education and increasing diversity.</td>
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<tr>
<td>3</td>
<td>Dartmouth College will lead the magnetospheric modeling effort.</td>
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<td>4</td>
<td>NCAR will lead the ionosphere/thermosphere modeling effort.</td>
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<td>5</td>
<td>PSI will work with University of California, Berkeley on the solar/solar wind effort and with Boston University on code coupling.</td>
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<tr>
<td>6</td>
<td>Stanford will work with University of California, Berkeley on the solar/solar wind effort.</td>
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<tr>
<td>7</td>
<td>University of California, Berkeley will lead the solar/solar wind effort.</td>
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<td>8</td>
<td>The University of Colorado will lead the knowledge transfer and empirical model efforts and will work closely with NOAA/SWPC to ensure our models are transitioned into the forecasting community.</td>
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<td>Institution 9</td>
<td>University of Maryland</td>
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<tr>
<td>Role of Institution at Center</td>
<td>Maryland will provide code coupling development.</td>
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<tr>
<td>Role of Institution at Center</td>
<td>Univ. Texas, Arlington will lead the diversity efforts and will work with Boston University on model validation.</td>
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<th>Institution 11</th>
<th>William Marsh Rice University</th>
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<td>Role of Institution at Center</td>
<td>Rice will work with Dartmouth College on magnetospheric physics and with Boston University on code coupling.</td>
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Executive Summary

Introduction

“Space weather refers to conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health,” (National Space Weather Program Strategic Plan, 1995). Space weather can cause satellites to fail, disrupt radio communications, cause navigation errors, overload electrical power distribution systems, and expose astronauts to dangerous levels of radiation (Lanzerotti, 2001; Baker, 2002). Mitigation of these effects requires both a better understanding of the space environment and the ability to predict and forecast conditions in space. In turn, the development and testing of physics-based models clarifies key physical processes that are currently controversial or poorly understood.

The Center for Integrated Space Weather Modeling (CISM) focuses its activities around one of the core requirements of the National Space Weather Program (NSWP) Plan, developing space weather modeling capabilities. CISM is developing a suite of ever-improving comprehensive, physics-based simulation models that describe the space environment from the Sun to the Earth. After testing and validating these models, we use them for research, make them available to the wider research community, help transition them as appropriate for use as operational specification and forecasting tools, and use them as learning tools. This shared vision and task binds the geographically distributed and scientifically diverse CISM team into a tight center with everyone doing their part towards the common goal.

The comprehensive models provide the means of achieving CISM’s overarching vision: “To understand our dynamic sun-earth system and how it affects life, and society.” Within this greater vision, CISM sees as its mission: to introduce into space physics and space weather research the first comprehensive community model suite analogous to the community models that exist in other fields such as climate research; to introduce into operational space weather prediction and forecasting the use of physics-based numerical simulation models in the same way as they are used in, for example, tropospheric weather forecasting; and to introduce in education, particularly undergraduate and graduate education, the notion that sun-earth science must be viewed as a single, unified field of research and study and not several separate disciplines.

The NSWP was formed in response to the important national need for a coordinated effort to mitigate the effects of space weather, by several Federal agencies, including NSF, representing the research, operational, and user communities. “The overarching goal of the program is to achieve an active, synergistic, interagency system to provide timely, accurate, and reliable space weather warnings, observations, specifications, and forecasts within 10 years.” (NSWP Implementation Plan, 2000; see also Space Weather Architecture Study Transition Strategy, 1999; Report of the Assessment Committee for the National Space Weather Program, 2006). The NSWP consists of six key elements – forecast and specification services, research, observations, modeling, education, and technology transition and integration. CISM substantially supports this national effort by playing a leadership role in four of these six key elements. As in CISM, the goal of the NSWP research is “to understand the fundamental physical processes that affect the
state of the Sun, solar wind, magnetosphere, ionosphere, and atmosphere, with a focus on resolving research problems that impede improvements in forecasting capability.” Similarly, “A primary goal [of the NSWP] is to develop physics-based specification and forecast models covering the forecast period out to 72 hours for solar events and 48 hours for near-Earth space weather phenomena.” The key goals of the NSWP education element are to “enhance public awareness of space weather and its impacts, help insure a sufficient supply of educated scientists and engineers to maintain expertise in all space weather related fields, and improve training of forecasters, observers, and system operators,” all three of which CISM’s education program addresses. The goal of the NSWP technology transition element is “to facilitate the transfer of tools, techniques, and knowledge from the research or commercial communities to the operational forecasting activities.” CISM’s use of observations, particularly solar observations, helps define and test the critical observational needs of the NSWP. Thus CISM is directly addressing an identified national need, and our configuration as a center provides the means to address these needs in a systematic, coordinated manner, and to provide leadership to the community as a whole.

An understanding of space weather begins with the Sun. The two solar phenomena that cause the largest space weather effects are solar flares and coronal mass ejections (CME). Both are driven by changes in the solar magnetic field. Flares give off intense bursts of ultraviolet light, X-rays, and energetic particles, while CME’s produce the interplanetary structures responsible for most geomagnetic storms and solar energetic particles (SEP). Even at quiet times the outer solar atmosphere expands and accelerates to supersonic speeds forming the outflowing solar wind that controls the structure of near-Earth space. This tenuous solar wind blows with a highly variable speed that averages about 400 km/s at Earth. The solar wind plasma and magnetic field interact with the geomagnetic field and the Earth’s atmosphere to form the magnetosphere, a large obstacle that deflects most of the solar wind flow around Earth. The boundary of the magnetosphere, the magnetopause, lies between 5 and 15 Earth radii (R_E) upstream of the Earth. On the antisunward or nightside of the Earth the magnetosphere stretches back probably 1000 R_E in a wake called the geomagnetic tail or geotail. The Earth’s uppermost atmospheric layers, the mesosphere and thermosphere, are partially ionized by the Sun’s ultraviolet and X-ray radiation to form the ionosphere. This combined system, the ionosphere, thermosphere, mesosphere (ITM), forms the earthward boundary of the region dominated by space weather, although intense electric currents flowing in the ionosphere induce large currents in the solid Earth that can affect technological systems on the ground itself.
Research

CISM’s research is focused around its unifying goal to develop a reliable and well-validated, comprehensive, physics-based numerical simulation model suite that describes the space environment from the Sun to the Earth. CISM’s research objectives, i.e., the development, improvement, and scientific use of these coupled system models, are integrated by this unifying goal. This means that CISM’s research program must be considered and managed as an integrated whole. For the purposes of research management we have divided this task into components, which we identify as our research thrusts. However, these components are all interconnected, and the boundaries between them are necessarily fluid, and in some cases not easily defined. Some thrusts are identified by areas of science, others by the capabilities needed to build the comprehensive model suite.

CISM’s modeling strategy is to build comprehensive models out of separate component models of parts of the overall system, and to couple these together using a computational framework. This approach allows each of the component models to concentrate on the physics or physical processes important to that particular piece of the system. The development of coupled models will proceed through a series of versions. Versions are distinguished by the number and type of included component models, by the improved physics within the component models themselves, and by the method and sophistication of the computational coupling technology or framework.
Core Models: The core of the CISM model suite consists of four fluid codes that form a chain from the Sun to the Earth, shown by the center row of four dark blue boxes in Figure ES1. The solar corona is modeled by MAS, a magnetohydrodynamic (MHD) model of the solar corona developed by Jon Linker, Zoran Mikic, and others at PSI, which describes solar corona dynamics from the top of the chromosphere out to a radius at which the solar wind flow is entirely supersonic and superAlfvenic. MAS couples to the heliosphere model, ENLIL, an MHD model of the solar wind developed by Dusan Odstrcil at the University of Colorado, which is optimized for supersonic and superAlfvenic plasma flow. This code models the time dependent 3-D structure of flows and fields in the solar wind from the MAS outer boundary to well beyond the orbit of Earth. When coupled together these models become CORHEL (CORona/HELiosphere). The magnetosphere model is LFM, an MHD model developed by Lyon, Fedder, and Mobarry (LFM) that models the global dynamics of the magnetosphere to a distance far enough down the geomagnetic tail (300 \(R_E\)) that all flow is again supersonic away from Earth. The magnetosphere is strongly coupled to the ionosphere and upper neutral atmosphere or thermosphere. The CISM core ionosphere/thermosphere model is the National Center for Atmospheric Research (NCAR) Thermosphere/Ionosphere Electrodynamic General Circulation Model (TIEGCM). (Our early coupled models used the Thermosphere-Ionosphere Nested Grid (TING) version of this model.) CMIT (Coupled Magnetosphere Ionosphere Thermosphere) denotes coupled versions of these models.

Other Component Models: There are several regions and particle populations in the space environment whose physics is not well described by fluid codes. So other component models, also shown as dark blue boxes in Figure ES1, must be coupled to the core fluid codes in order to properly include their physics into the comprehensive model. All these regions and populations either have important space weather effects or have a direct influence on particle populations that do have space weather effects. Some of these models are very well developed, including the Rice Convection Model (RCM) which models the ring current, the hot plasma that provides most of the pressure in the inner magnetosphere. The RCM/LFM coupling is two-way, as is the LFM-TIEGCM coupling, representing the complex physical interactions between these populations. We refer to the coupled magnetosphere/ring current/ionosphere-thermosphere model as LTR (LFM-TIEGCM-RCM). The more energetic particles trapped in the radiation belts are described by the radiation belt model developed by Mary Hudson and others at Dartmouth. Other important components of the comprehensive model, such as the solar energetic particle (SEP) module, existed only in conceptual form prior to CISM. These models are being developed as part of CISM’s research program.

Observations: The light blue circles in Figure ES1 show observations that can be used to drive or modify the model chain. The coronal model must be fed at its inner radius with parameters derived from solar observations, the most critical of which is the solar magnetic field obtained from solar magnetograms. These data are sufficient to drive the end-to-end model and provide a 3-day forecast, however its accuracy is improved with other data inputs. Observations of coronal mass ejections can be used to launch transients in the heliosphere model. The LFM code can be driven directly with solar wind data obtained from \textit{in situ} spacecraft near the L1 Lagrangian point such as WIND and ACE, which allows for more accurate short-term predictions. Observations are also used to test and validate models. The L1 observations are used to validate solar and heliospheric models, while observations made within the magnetosphere or ionosphere/thermosphere can be used to validate the geospace models. Observations also provide data that can be assimilated into models. CISM has a data assimilation plan
to apply those techniques that most effectively advance the model characterizations of the system.

**Empirical Models:** Finally the yellow boxes in Figure ES1 show how empirical or other simpler models can be coupled into the chain or used independently for comparison. For example the WSA (Wang-Sheely-Arge) solar-heliosphere model can be used in place of MAS to drive Enlil, or in place of CORHEL to drive the geospace models. Similarly, empirical geospace models can be driven by CORHEL or by WSA.

**Science Thrusts and Model Development Plan:** The research required to build, validate, and improve the comprehensive models lies in two broad areas – space science, and model development and computational science. For the purposes of management these are further divided into research thrusts. The three space science thrusts -- Solar/Heliospheric Physics led by co-director Janet Luhmann, Magnetospheric Physics led by co-director Mary Hudson, and Ionosphere/Thermosphere Physics led by co-director Stan Solomon -- are responsible for the targeted research required to bring our understanding of the fundamental physics to the level required for the CISM model suite, and for developing the component models that will incorporate this physics. The areas of physics currently recognized as needing work are particle acceleration, magnetic reconnection, and the generation, transformation, propagation, and dissipation of energy in the solar corona and heliosphere. These thrusts also study the processes responsible for coupling regions of the geospace environment, such as the photospheric control of chromospheric and coronal process, and the thermospheric control of ionospheric and magnetospheric processes, so that these processes can be appropriately included in the comprehensive model. Finally, these thrusts use the coupled models scientifically, supporting assessment and validation of model capabilities.

The code coupling thrust, led by co-director Charles Goodrich, is responsible for identifying and/or developing the computational science tools, the framework, needed for efficiently coupling the component models together and then applying these tools to coupling the models. The validation and metrics thrust, led by co-director Harlan Spence, is charged with testing and validating the functioning coupled models. This thrust performs both validation and metric or skill tests, that is, it both compares detailed model output against research data sets in order to evaluate the model against reality (validation) and makes standardized comparisons between the accuracy of the model predictions and the accuracy of predictions made by a standard or baseline model that provide a direct comparison between the effectiveness of different models or prediction schemes (metrics). This latter allows progress between generations of models to be evaluated. This thrust's first task was to define the set of metrics to be used, which was accomplished early in the second year. (See table in Validation section of report.) The validation and metrics thrust couples intellectually to the science thrusts in that studying the model outputs is one way of exploring the science questions being addressed by those thrusts. This thrust also feeds back to all the others by pointing out where the models most need improvement.

The CISM Model Development Roadmap provides details of the model development plan. It is available at http://www.bu.edu/cism/Publications/Model_Devel_Roadmap.pdf
Research Plans and Goals:

CISM’s science goals are driven both by modeling needs, which require us to develop scientific understanding in order to develop certain models, and by modeling capabilities, which allow us to study quantitatively for the first time the effects of the various couplings of the components of the solar-terrestrial system. Hence science goals are intimately coupled to the progress of model development. In this section we list our research plans and goals under broad topics.

Solar Active Region Evolution and CME Initiation: Solar active regions are the ultimate cause of almost all space weather effects. They undergo considerable evolution during their lifetime, as magnetic flux emerges, is transported by surface motions, and cancels along polarity-inversion lines. We will focus on simulating observed active region evolution within the corona model, aided by more accurate specification of the photospheric boundary conditions from sequences of vector magnetograms. These studies will lead to a better understanding of Coronal Mass Ejection (CME) initiation, which in turn will allow more accurate modeling of the evolution of CMEs in the low corona.

Particle Acceleration: Solar Energetic Particles (SEP), and the energetic particles trapped in the Earth’s radiation belts are two of the most important space weather hazards. In the solar-terrestrial system particles are accelerated: in solar flares; at shocks in the corona, in the solar wind, and standing upstream of planets; at magnetic reconnection sites and similar current sheets; by Fermi and betatron acceleration in radiation belts; and by wave-particle interactions. We will focus on particle acceleration at coronal and interplanetary shocks with the goal of developing parameterized models for the production of SEP within the global solar and solar wind models. These particles will then be transported from their shock sources within the global models to predict their distribution in geospace. Radiation belt electron modeling and SEP transport and trapping will be incorporated into the LFM code where the effects of both ULF and VLF waves will be modeled. We will incorporate the effects of the SEPs on the upper atmosphere. The SEP problem is an excellent example of a problem that needs the full range of scientific expertise available within CISM to solve, as it includes SEP generation, propagation through both the heliosphere and magnetosphere, and deposition in the upper atmosphere.

Solar Wind Physics: The solar wind stream structure is responsible for quiet to moderate space weather conditions, and also affects the propagation, evolution, and geoeffectiveness of CMEs. We will include important thermodynamic processes (e.g. radiation, coronal heating, and anisotropic thermal conduction) to more accurately model solar wind structure and parameters (velocity, density, magnetic field) based on solar magnetic field observations, and simulate its effects on our model CMEs. The shock waves generated by the CMEs in the corona and solar wind in these simulations will be better characterized (shock capture) and then used as the foundation for the coupled solar energetic particle (SEP) model. Observational tests of the solar wind/CME/SEP model will be carried out using L1 monitor observations. We will couple the solar wind model to the coupled LTR models to simulate the solar wind interaction with geospace.

Magnetic Reconnection: Reconnection occurs under different circumstances and in three distinct places in the sun-earth system: at the sun where it causes solar flares, it could well be the cause of CMEs, and may contribute to coronal heating; at the magnetopause where it controls the energy transfer from the solar wind into the magnetosphere; and in the geomagnetic tail where its energy conversion powers
substorms. In order to include reconnection explicitly in the global models, we use our expertise in reconnection physics to develop parameterized reconnection models that can be linked to the MHD models. In the magnetosphere we will extend the LFM model to include Hall physics, which has been shown to accurately capture the global aspects of reconnection.

**Outer-Inner Magnetosphere Coupling:** Important new science goals can be accomplished when the physics of the inner magnetosphere, as represented by the particle drift physics in the RCM, is embedded in the global MHD magnetospheric code. The magnetospheric component of the physics-based CISM code will be able to generate ring current and region 2 currents and associated shielding of the low-latitude ionosphere from high-latitude convection electric fields. This code will be able to resolve long-standing issues in magnetospheric physics by examining the time-dependent response and topology of the region 1 and region 2 current systems and its dependence on the interplanetary magnetic field. In order to fully incorporate these effects in the LFM code, we will incorporate multifluid physics to allow for both multiple temperatures and multiple species (heavy ions, protons and electrons). This will also permit the realistic inclusion of ionospheric outflow and the formation of a plasmasphere.

**Magnetosphere/Ionosphere Coupling:** The magnetosphere and upper atmosphere are closely coupled systems that pose a number of modeling challenges. The first order goal is to determine the role and impact of MI coupling on the establishment and maintenance of the basic state of the ionosphere and magnetosphere. Our studies will clarify the causes of the variability seen and the limitations of predictability. Using the LFM code coupled to the thermosphere-ionosphere general circulation model (TIEGCM), a host of important science studies will be undertaken. At high latitudes, the global thermospheric response to magnetospherically driven Joule heating and energetic electron precipitation will be determined, including changes in ion and neutral composition, convection, ionization, and neutral, ion and electron heating, as well as its feedback on the magnetosphere via the thermospheric “flywheel.” The evolution and spatial distribution of the auroral electrojet during storms and substorms will be simulated. Inclusion of field-aligned plasma flows, initially via empirical parameterized models, and, ultimately, using physical transport models, will enable studies of dynamic density stratification in the ionosphere and low-altitude magnetosphere and the effects of ionospheric outflow on the global magnetospheric system. Finally, precipitation-induced ionization and ionospheric outflows are significantly enhanced by collisionless ion and electron energization processes that occur in the lower magnetospheric region between the upper boundary of the TIEGCM and the lower boundary of the LFM. Empirical and physical transport models of these processes will be developed and included in the low-altitude LFM boundary conditions.

**Thermosphere/Ionosphere Physics:** The global interaction between ionization and heating induced by solar EUV and X-rays and the effects produced by M/I coupling will be determined. This interaction will have immediate applications to forecasting atmospheric drag on satellites, especially during storm-time conditions. The effects on ionospheric structuring, variations in ionospheric content along specified slant paths, and the evolution of geomagnetic induced currents affecting ground-based electrical transmission systems will be investigated. At low latitudes, where interhemispheric flows arise, studies of penetration electric fields on plasmaspheric structure and the role of light ions at and above the exobase will also be enabled when the RCM is coupled with the LFM and TIEGCM models as described above.
**Magnetic Storms:** Magnetic storms are the premier space weather events, and the cause of many catastrophic space weather incidents. Magnetospheric behavior during magnetic storms is not well understood both because it is poorly sampled since storms are relatively rare, and because the coupling between the solar wind, magnetosphere, and ionosphere is much stronger, and perhaps of different character, during storms. CISM models will let us explore this coupling under extreme conditions in ways that are just not possible presently. Determining the role of the convection electric field on the storm-time ring current is a problem of central importance to understanding magnetic storms. We will investigate the phenomenon of “undershielding” which happens when the solar wind electric field changes suddenly thereby exposing the low-latitude ionosphere to electric fields from high latitudes and modifying the ionosphere’s radio propagation properties. This is very important for understanding the erosion of the plasmasphere during storms and the location of the auroral electrojet. These are enabling issues to make substantive advances in treating storm conditions.

**Model Development:** To explore the critical space weather issues outlined above, and incorporate their effects within our models, we must continue to develop and extend the component models and add new physics within the model couplers. This will be a major part of our effort in years 6-10. Examples include thermodynamic processes in the transition region and low corona; the initiation of faster CMEs that form shocks in the low corona; refined processing of input data and the assimilation of new magnetograms into time-dependent models of the ambient corona and solar wind; adding multifluid capabilities and anisotropic pressure to the magnetosphere; including ion and electron energization in the magnetosphere/ionosphere coupling region; integration of the SEP and radiation belt models, and adding SEP effects in the upper atmosphere; auroral and cusp plasma sources and a plasmaspheric extension to the ionosphere; ionospheric data assimilation using GAIM specifications; inclusion of stratosphere/troposphere forcing using NCEP analysis; and inclusion of near-real-time solar irradiance inputs to the thermosphere and ionosphere. The component models will also be improved computationally, for example, to increase numerical efficiency or to improve modularization for easier component substitution.

**Model Coupling and Computational Science:** CISM’s model coupling technology will remain based on the InterComm and Overture software packages. The InterComm package is developed at the University of Maryland for interprocess communication, and that team provides CISM with expertise and adapts the package for our use as necessary. The Overture framework is developed at the Lawrence Livermore National Laboratory to handle translation from one code’s grid and variables to another. InterComm and Overture provide a flexible and modular approach to code coupling, allow the component models to run as separate executables, and allow the parameters of component models, such as grid resolution, to be changed without modifying the coupling software. During years 6-10, as our component models become more sophisticated and require greater computer resources, we will extend these tools to allow component models to run on a distributed network of heterogeneous computers such as the TeraGrid.

**Data Assimilation:** Data assimilation is a powerful technique that can keep real time simulations tied to observations and the true state of the system. These ideas are well developed in the meteorological community, and are commonly used in meteorological forecast models; they are beginning to be used in upper atmospheric simulations, but have yet to be widely used in space physics applications. Because of the widely varying natures of the physical regimes contained in CISM’s modeling and of the precision and
number of observations, the effective use of data assimilation requires a diverse range of approaches. CISM is developing and exploiting a variety of techniques for ingesting observational data in its numerical models. Our goal is to identify and apply those techniques for using measured data that most effectively advance the model characterizations of the system. The CISM Data Assimilation Plan is available at http://www.bu.edu/cism/Publications/Data_Assimilation_Plan_CISM.pdf

Education

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. The next generation of space physicists will come from diverse backgrounds, be capable of using the tools of computational science to study the space environment, and approach problems from an interdisciplinary viewpoint.

In order to accomplish its education mission, CISM has the following objectives: to provide graduate students with opportunities for broad-based research in CISM related fields and with professional mentoring and role models; to provide undergraduates with research opportunities (academic year and summer) as well as mentoring and role models; to provide graduate and undergraduate students with opportunities to develop professional relationships with peers and working scientists in CISM related fields; and to provide space weather resources and professional development for 6-14 teachers and provide information about space weather to the general public. The CISM Education Plan is available at: http://www.bu.edu/cism/Publications/Education_Plan.pdf

Research and education are integrated in multiple ways throughout CISM. Each component of our education plan feeds from and is integrated into our research effort. All CISM students, both undergraduate and graduate, are involved in the research program, immersing them in research at a critical time in their careers, particularly for undergraduates, and teaching them what being a scientist is all about. The graduate summer school uses the models and tools developed in our research program to prepare students to use these tools in their graduate careers and beyond. Results from our research feed directly into our teacher workshop and curriculum development programs.

The CISM Education Program has four core elements that are designed to meet the CISM Education Objectives in substantial, measurable ways. Three of these are highly specific to CISM. The fourth uses CISM content to engage the broader education and public communities through a variety of means, often leveraged with other efforts. We use appropriate methods of assessment for all elements of the CISM Education Program, and ensure alignment with national standards where applicable. The four elements are listed in order of the seniority of the students they serve.

Building a CISM Graduate Student Community: The CISM graduate students form an important cadre of the next generation of space scientists. CISM provides the means for broader professional development and peer interactions beyond what each student would normally experience at a single institution with a single mentor. Specific examples are the annual graduate student retreat, all-hands meetings, graduate student Access Grid (AG) sessions, the graduate student e-Newsletter, and taking part in cross-institutional interdisciplinary research interactions. The annual graduate student retreat
allows the CISM graduate students to share their research and build community which is reinforced throughout the year by the other activities. The rotating program at the annual retreat focuses on professional development items not normally taught in a formal graduate curriculum, such as the funding and management of research, and how to prepare research proposals, career development, science ethics, or teaching methods and physics education. The entire program provides CISM graduate students with a strong sense of community and a unique, holistic view of the Sun-Earth system. Through these close interactions the students are forging the foundation for career-long professional relationships and developing expertise that will provide a core of space weather researchers to carry forward the CISM legacy.

The CISM Summer School: Each year CISM organizes a space weather summer school. The CISM Summer School is aimed primarily at students entering graduate school in space or solar physics, or at the end of their first year of graduate study. However some undergraduates, a high school teacher, and particularly professionals entering the field have also benefited from attending. In two weeks 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. Hands-on use of space weather models is a core component of the school. The goal is to provide students with a comprehensive overview of the Sun-Earth system, space weather, and the various types and uses of models in order to provide the context for their subsequent more detailed and theoretical study in graduate school. Proven innovative teaching methods, such as interspersing concept questions in all the lectures, and a summative jigsaw learning experience, are used throughout the school.

Building a CISM Undergraduate Student Community: Academic year research projects provide undergraduates with valuable skills and experiences within the unifying CISM context. Interactions with mentors and graduate students provide a sense of belonging to a community devoted to solving a set of challenging relevant problems. Throughout the year CISM provides opportunities for undergraduates to share their research and engage in professional development. A yearly event for undergraduates as well as summer research opportunities at CISM institutions other then their home institutions solidifies a sense of membership in the CISM community.

Grade 6-14 Education and Increasing Science Literacy: CISM pursues specific contributions to grade 6-14 education and science literacy by developing partnerships with existing programs which provide both resources and training for classroom teachers, and develop highly visible programs and electronic media for the general public. For classroom teachers, CISM supports the Stanford Space Weather Monitors program that provides inexpensive equipment for monitoring space weather events in the classroom, along with curricular materials and professional development programs for the teachers using the equipment. For informal education, CISM provides content and/or support for both portable full dome planetarium shows, and a major planetarium show. Informal education is also enhanced by CISM support for the addition of space weather and CISM content to two science e-learning websites: the San Francisco Exploratorium website and the Windows to the Universe website at NCAR. Both the formal and informal education activities are integrated through shared content and resources, and the informal science education component is expected to reach millions of people over the life time of CISM.
Knowledge Transfer

The CISM knowledge transfer plan has three major objectives: transition of forecasting tools to operational environments (e.g., the NOAA/Space Weather Prediction Center, SWPC and the Air Force); providing the wider scientific community with models and visualization tools; and training and interacting with CISM’s partners within the aerospace industry, government, and others who must cope with or mitigate against space weather effects. Daniel Baker is CISM co-director for Knowledge Transfer. Our close cooperation with SWPC is strengthened by having dedicated CISM personnel at SWPC. Our strong partnership with CCMC helps us make our models available to the wider community. We have an ongoing partnership with AFRL, and are forming relationships with our industrial partners to learn their needs. Several government and industrial employees typically attend the CISM Summer Schools. The CISM’s support of its three major objectives is summarized in the Knowledge Transfer Matrix http://www.bu.edu/cism/Publications/CISM_KT_Matrix.pdf.

Forecasting and Specification Tools: The development and transition of specification and forecasting tools is a major component of the overall CISM plan. This goal has a tremendous benefit to CISM in that it will serve to focus research into areas most relevant to society’s space weather needs. This goal is fostered through the close partnership between CISM and the NOAA Space Weather Prediction Center (SWPC). CISM-supported scientists based at NOAA/SWPC, support the primary day-to-day interaction between SWPC and CISM. They work closely with SWPC staff to affect the transfer of models into the forecasting arena.

Knowledge Transfer within the Space Physics Community: The integrated models developed by CISM can be used to test new ideas and explore the complex space environment in ways not possible using only observations. Visualization of a global model provides the best way of understanding the complex 3-D structure and dynamics of the space environment. CISM will make these models available to the space physics community, both through archives of model run results for various standard conditions, and versions of the models that are sufficiently user friendly for other scientists to run them with their own inputs to simulate particular events or conditions of interest to them. We are working closely with the Community Coordinated Modeling Center (CCMC) to provide community access to our models.

Industrial and Government Partners: Interaction with industrial and government partners occurs in various ways, including participation in the annual summer school, CISM presence at NOAA’s Space Weather Week, and a program of a series of two-day short courses whereby CISM members visit government and industrial partners to present on-site seminars and other training.

Diversity within CISM

The CISM diversity mission is to increase the diversity of participants in space weather research at all levels. All CISM components attempt to promote diversity and increase the involvement of women and underrepresented minorities in space science and help build a vigorous research program at minority serving institutions. We specifically target applications from underrepresented minorities for the graduate summer school, with a target of at least 8 women students or students from underrepresented minorities.
Similarly we target applications from underrepresented minorities for the undergraduate researcher positions, with a target of at least 5 women students or students from underrepresented minorities at all times. CISM also has a presence at the annual SACNAS and NCBPS/NSBP meetings in order to recruit students and provide information about space weather to a diverse audience. The CISM co-director for diversity is Ramon Lopez. The CISM Diversity Plan is available at http://www.bu.edu/cism/Publications/DiversityPlanCISM.pdf

CISM has the specific diversity-promoting goal of supporting the creation and development of a graduate program in space science and a vigorous space research program within the Alabama A&M University physics department. This new program provides a route for African American students to enter a field within which they are very poorly represented, and will remain a lasting legacy of CISM. AAMU hired two new tenure-track Solar Physics faculty members, Amy Winebarger and T.-X. Zhang, in 2005. AAMU graduated its first M.S. student in 2006, and initiated a Ph.D. program and recruited two students into the program.

A space weather weekend primarily for African American students considering graduate school is held annually. The Space Weather Weekend was held at AAMU each year since April 2006.

Center Management

The CISM management structure is designed to address the challenges of running a multi-institutional center that has clear integrated goals and timelines. To achieve these goals requires close communication, cooperation, and collaboration between institutions and research groups. The CISM management structure, described in the CISM Organizational Chart, is designed to achieve these goals.

CISM’s central administration consists of Director Jeffrey Hughes, Executive Director Jack Quinn, and Assistant Director Kathryn Nottingham. Jeffrey Hughes, as the Director of CISM, is ultimately responsible for the direction and management of CISM. Jack Quinn, as executive director, works closely with the director to manage the activities of CISM. Assistant director Kathryn Nottingham is responsible for all administrative functions, including budget management, overseeing the collection of management data, and maintaining the databases required for evaluation and to monitor progress.

The CISM Executive Committee, CISM’s principal executive body, consists of the CISM director, deputy director, and co-directors and three senior modelers. The executive committee confers bi-weekly by means of a telephone conference call, and meets several times a year in person, either at scientific meetings that we all attend, or in conjunction with other CISM meetings. The Executive Committee develops the strategic policies of CISM including definition of tasks and time lines, monitors progress against these goals, and develops priorities. The director, in consultation with the Executive Committee, is responsible for the allocation of resources between areas and tasks, and for resolving conflicts. Implementation of CISM policies and the day-to-day management of CISM is the responsibility of the director and executive director.

The CISM Advisory Council provides independent guidance to the CISM director. The Council meets annually in the early spring to review the activities of CISM, and to
provide guidance, advice, and oversight of Center management and all Center objectives.

**Communication within CISM:** Communication is key to the success of CISM. Frequent, efficient, and productive interaction of CISM personnel is critical to achieving our research, education, and knowledge transfer goals and to our smooth operation as a Center. CISM communications utilize periodic in-person meetings supplemented with a variety of electronic means during the periods between.

CISM holds an annual “all-hands” meeting in the early Fall to provide an occasion for the whole CISM team to meet to discuss and report progress and to develop plans for the following year and beyond. Some of the sessions are plenary at which overviews of progress are given to the entire team, other sessions are held in smaller groups at which more detailed reporting and planning can take place. This meeting also provides a venue for ethics training sessions, and for all CISM graduate students to meet.

CISM holds a series of regular meetings, including the annual Advisory Council Meeting in February or March and the annual NSF Site Visit in May or June. In addition CISM has a large presence at Space Weather Week, organized by NOAA/SWPC, which brings together space weather researchers, forecasters and end-users. CISM is also well represented at the annual SHINE, GEM, and CEDAR workshops each June or July, and at the two AGU meetings (December and May). Each of these meetings provides an opportunity for meetings of the CISM Executive Committee and/or other specialized CISM groups such as the solar, magnetospheric, or ITM teams at SHINE, GEM and CEDAR. Finally the CISM Summer School brings together another group of CISM participants each summer. A variety of topical meetings and electronic meetings are held throughout the year as described in the Management section of the annual report.

Performance and Management Indicators: The CISM Performance Indicators are drawn from a diverse set of sources that are enumerated and referenced in the Performance Indicators descriptive document, which is maintained on the CISM web site. The Performance Indicators address the Center’s performance in five overarching areas: research, education, diversity, knowledge transfer, and function of the Center.

The CISM Strategic and Implementation Plan was developed by the Executive Committee with input from the whole CISM team. The Plan defines goals and milestones for the individual thrusts within CISM and for CISM as a whole. The status of these goals and milestones, which is one of the Performance Indicators, is included as Appendix A. The director and co-directors are responsible for Center wide execution of the plan, and for engendering effective collaboration and close cooperation of the team in achieving these goals. The performance of the CISM management team, including the co-directors and local PIs, is to a large degree indicated by their ability to achieve the goals and milestones laid out in the Strategic and Implementation Plan and the other specific goals and that are reflected in the Performance Indicators for the Center.
Legacies

The lasting legacies that CISM will leave behind are:

- The development of a new interdisciplinary science that views the sun-earth system as a single closely coupled system.
- A new generation of well-trained space physicists from diverse backgrounds that is capable of using the tools of computational science to study the space environment and who approach problems from an interdisciplinary viewpoint.
- A new graduate program in space science at a historically black university.
- The introduction of community models and their validation into space physics and the use of numerical models as research tools by the broader research community.
- Advances in space science, particularly in our understanding of processes critical to the development of the global model.
- Advances in computer science brought about by our need to efficiently couple disparate numerical models and assimilate observational data.
- New models and understanding of the space environment that will lead to improved specification and forecasts at the nation’s space weather operations centers.
- Ongoing model development after STC support ends that continues to improve and augment the CISM initiated models.
- A suite of physics-based forecasting and specification tools.
- A better public understanding of the Sun and its affect on the Earth’s space environment.
Major Accomplishments During The Past Twelve Months:

- ICME-driven SEP flux profiles modeled and (favorably) compared with data for three events, using CORHEL-Cone model ICME-driven shock source and propagation in (ICME-disturbed) fields to observer position.
- "Thermodynamic" MAS model used to understand magnetic structures and shear/energization of CME initiation through comparison with observed emissions, e.g. dimming regions.
- Clarification of solar wind speed evolution during outward transit.
- Coupled CMIT simulations of magnetic storm dynamics compared with global GPS measurements and used to quantify importance of driving factors.
- MPI-LFM and TIE-GCM provided to CCMC, completing the core sun-to-earth suite for community use.
- Multi-fluid LFM scientific use.
- LFM-RCM investigations of coupling phenomena.
- CMIT 2.5 installed on NOAA SWPC wJET supercomputer.
- Preliminary ground ΔB specification product developed from CMIT in partnership with SWPC.
- InterComm-ESMF coupling compatibility demonstrated with Community Atmospheric Model and TIME-GCM.
- MIX coupler introduced as key element for coupling MHD magnetosphere, ionosphere-thermosphere, and ring current models for efficient bi-directional interactions.
- Comprehensive validation results published for solar wind predictive capabilities over an 8-year period for the WSA, WSA-ENILI, and CORHEL models.
- Validation results published for polar cap potential using the CISM end-to-end, sun-to-earth, model.
- Summer School laboratory materials made publicly available; methodology described in EOS publication.
- AAMU Space Science concentration now has three PhD students; first PhD graduate expected Summer 2009.
- Three CISM graduate students completed PhDs, bringing the total number to eleven.
- Held a successful CISM Summer School in July 2007 attended by 28 students, and organizing the next summer school for July 20–31 2009.
- Held the sixth CISM graduate student retreat on “Writing Proposals and "Balancing Personal and Professional Life" in September 2008 attended by 15 students, with Sarah Gibson and Jon Linker.
- Hosted Space Weather Weekend for likely underrepresented minority graduate student candidates in March 2009.
- Held the annual CISM “all-hands” meeting in September 2008 at which we developed detailed plans and assessed progress.
- Hosted the seventh CISM Advisory Council meeting in March 2009.
- CISM research impact growing as evidenced through nearly 400 citations in the past year, bringing total citations to over 800.

Executive Summary References


CISM Released Models as of Apr, 2009

**Coordinated Community Modeling Center**
- **MAS**  Solar Corona 1-30 solar radii
- **ENLIL**  Heliosphere beyond 30 solar radii
- **CORHEL**  Coupled MAS-ENLIL model.
- **PFSS**  Solar coronal magnetic field from magnetograms
- **WSA**  Wang-Sheeley-Arge coronal and solar wind model
- **WSA-ENLIL**  Coupled WSA-ENLIL model
- **Cone**  ICME in ENLIL domain
- **LFM**  Magnetosphere
- **TIE-GCM**  Thermosphere-Ionosphere
- **CMIT**  Coupled magnetosphere (LFM) – thermosphere-ionosphere (TIE-GCM)

**NOAA Space Weather Prediction Center**
- Daily average Ap
- Ap Forecast 3-Hr
- MeV_electron_flux
- **WSA Solar Wind Forecast Model**
- **WSA-ENLIL Solar Wind Forecast Model**
- **CMIT coupled magnetosphere(MPI-LFM) Ionosphere-Thermosphere (TIE-GCM)**
II. Research

1a. Overall Research Description
The CISM research overview is given in the Executive Summary.

1b. Performance and Management Indicators.
The CISM Performance Indicators are drawn from a diverse set of sources that are enumerated and referenced in the Performance Indicators descriptive document, which is maintained on the CISM web site. The Performance Indicators address the Center’s performance in five overarching areas: research, education, diversity, knowledge transfer, and function of the Center. The indicators are compiled and reported annually in various sections and appendices of this report. The entire set is extracted and maintained in separate binders that are available at the Site Visit.

1c. Problems.
We have not encountered significant problems.
2A. Solar/Heliospheric Thrust

Goals:

The overall science and simulation/modeling goal of the Solar thrust group of CISM continues to be the production of a physically realistic solar wind at 1 AU, into which realistic coronal mass ejections (CMEs) can be launched and propagate. The model must reproduce coronal and interplanetary magnetic fields, plasma densities and bulk velocities in 3D that can be used to both validate the Solar-Heliospheric simulations and couple to CISM magnetospheric MHD simulations. It must also provide the underlying framework for parameterized models of interplanetary shock production of Solar Energetic Particles (SEPs). The SEP event results will be used in the geospace simulations to evaluate radiation belt and upper atmosphere effects. Achievement of these goals requires increased understanding of CME initiation and the related problem of active region evolution. It also requires accurate modeling of the pre-CME corona and solar wind based on solar observations. Our work has produced the CORHEL model from the coupled corona (MAS) and solar wind (ENLIL) simulations. CORHEL is an archived CISM code that can be used in educational and knowledge transition or applied contexts.

Activities:

This past year much use was made of the CORHEL version that includes the option for launching cone model CME proxies based on coronagraph observation-derived parameters from our Stanford partners. This cone model allowed us to test and implement the SEP event code for general applications. The SAIC/PSI group continue to focus on the improvement of the MAS corona simulation of realistic CME initiations. Both the main CISM case study event of May 12, 1997, and another event in May 2005 are revealing the importance of the treatment of the energy equation in the MAS model. In addition to a much better physical description of coronal conditions, the rationale is to use the coronal diagnostics of the initiation and eruption process provided by the EUV images. The continuing challenge is to generate a sufficiently large and energetic event from the small active region of May 12, 1997, without knowledge of its detailed pre-event field structure and evolution due to lack of a time sequence of vector magnetograms. While the detailed coronal evolution of the involved active region at the early stages of eruption is still under analysis, an improved cone model version of this and other CME events is being used at UCB for ongoing SEP model development. The capability for modeling events at different observer sites, such as the STEREO spacecraft locations, will be tested as the Sun becomes more active. This provide particularly important SEP model validation data. The cone model provides a means of routinely simulating CME/ICME/SEP events with CISM’s coupled models, but the process of cone model parameter generation from coronagraph images currently remains an expert activity. Stanford is investigating possible user rules or automated generation of the cone parameters. The post-process ‘coupled’ SEP event codes have been migrated to BU computers, where they run on BU-generated cone model output from the delivered version of the CORHEL.

Inter-institutional visits and collaborations continue. Dusan Odstrcil of U of Colorado continues to work with PSI (formerly SAIC solar group) on the transmission of CME
ejecta generated in MAS into ENLIL. He is also participating with Janet Luhmann and Nick Arge, in providing mentorship to UCB graduate student Christina Lee who is carrying out solar wind research using CISM models. Janet Luhmann continues to collaborate with Nick Arge on applications of the CISM solar wind models to the observations from the STEREO mission, and with PSI on STEREO applications of MAS. Matt Owens (formerly at BU) continues to be a part of the effort to develop and test the post-process SEP code with CORHEL at BU. Brian Kress of Dartmouth has been provided with a SEP event model ‘data set’ to implement the geospace coupling step, and is in the process of computing magnetospheric access models for the May 12, 1997 event.

PSI and the University of Colorado continue to have primary responsibility for the core solar/heliospheric MHD code developments and deliveries. Stanford provides key solar observational support toward defining the models’ magnetogram-based boundary and initial conditions as well as cone model CME parameters for CORHEL. UCB continues to have responsibility for developing and delivering the SEP model code. Close CISM collaborators are located in the NCAR/HAO solar/heliosphere division, and at Air Force Research Laboratory. PSI, Stanford, and UCB regularly have student assistants helping with CISM-related work. UCB graduate student Christina Lee had her first first-author CISM paper published in Solar Physics journal, has submitted a second paper, and is working on a third. She expects to complete her PhD by late this year. She also completed a summer fellowship study with Nick Arge at AFRL.

Significant Accomplishments:

The accomplishments of the past year contribute to several solar thrust milestones:

Coupled Simulation Area:

- Generalize MAS-ENLIL coupling for transmitting arbitrary CME ejecta
- Deliver SEPMOD version that works on CORHEL results
- Provide SEPMOD results to geospace modelers

Corona and CME Model Area:

- Improve the simulated May 12, 1997 eruption.
- Carry out additional case studies

Solar Wind Model Area:

- Run cone model cases of interest for applications
- Improve and generalize cone model parameterizations

SEP Model Area:
• Experiment with modeling multipoint event detection
• Exercise and further develop SEPMOD on BU-generated CORHEL cone model outputs
• Conduct further Hybrid simulation experiments toward improving the SEPMOD shock source description

In addition, members of our group continued to:

1. Supply BU with information (e.g. cone model parameters) for the validation effort
2. Work with the validation group as needed
3. Work with the Knowledge Transfer group as needed
4. Report CISM solar/heliospheric modeling progress at a broad range of conferences and workshops

Highlights:

Highlights from some of our newest results are briefly described below.

**Latest Cone Model Developments**

The cone model is both a development vehicle for our heliophysics space weather simulations as well as a possible tool for eventual knowledge transfer. Effort is therefore being invested in its improved ability to describe the coronal transient inputs to the solar wind. By using the elliptic cone model, the radial propagation direction, speed, and the shape and size of 3-D rope-like CMEs can be derived on the basis of observed halo parameters, apparent speed of 2-D full halo CMEs, and the location of the associated flare. However, the algorithm is valid only for full halo CMEs occurring near the solar disk center, the so called disk halo CMEs. We have improved the inversion equation system for the elliptic cone model so that it can be used to invert 3-D geometrical and kinematical properties for almost all kinds of full halo CMEs, i.e., CMEs occurring not only near the disk center, but also far away from disk center.
Figure 1 Comparison of modeled halos (green and red dashed ellipses) with observed halos (white ellipses). The 2000/11/24 halo (right panel) is a so called “disk” halo for which the associated flare occurs near the disk center. The red ellipse was obtained using the original inversion equations and the green one using the improved inversion equations. The red ellipse can match the disk halo CMEs only, and the green ellipses can match both the disk and non-disk halo CMEs very well.

Modeling the May 12, 1997 CME: Latest Update

We continue to work toward a capability to model eruptions in realistic coronal magnetic fields with candidate CME initiation mechanisms. During the past year, PSI team members have continued to make further progress on the May 12, 1997 CME event with time-dependent thermodynamic MHD models. In prior work, we showed how features of our model could be directly compared with emission observations, such as EIT waves in EUV images of the Sun. We have continued to investigate emission features in the simulation. In particular, we are attempting to understand the magnetic structure of “dimming” regions - a well known feature of CMEs and a key observed attribute of the May event. This feature is considered an important diagnostic of the CME initiation process, and has been speculated to be associated with the footpoints of an erupting magnetic flux rope structure. Our simulations allowed detailed probing of the magnetic field geometry for the modeled event, as illustrated by the figures and captions below.

Figure 2 The field of the modeled version of the active region is energized by executing flux-preserving shear flows that maintain the radial field. When flux-cancelling flows toward the
extended neutral line and enhanced resistivity are introduced, a filament-like magnetic field feature emerges overlying the extended neutral line. This combination provides a good approximation to the pre-eruption conditions for the May 1997 event. (From left, observed filament and bipolar magnetic field, surface component of imposed shear flows superposed on the modeled active region, resulting model active region magnetic fields, flux cancelling converging flows, and magnetic field of the resulting filament-like structure.).

Figure 3 The simulated erupting structure for this event consists of two basic flux systems: a helical structure rooted in the strong active region fields (red field lines) and some loop-like fields rooted in quiet Sun (blue) that are carried outward by the helical fields. The blue fields map to the simulated coronal dimming in simulated soft x-ray and EUV images, while the core of the red lines form the sigmoidal bright feature. (From left, field lines of the modeled erupting flux systems, global field lines, simulated soft x-ray image showing double dimming similar to observations, zoomed-in view of the mapped footpoints of the blue field lines that coincide with the dimmings in a simulated EUV image, overhead view of the sigmoidal fields that map to the strong active region fields.)

The bottom line so far is that the structure of the magnetic field of the simulated CME ejecta is complicated and not necessarily consistent with previous paradigms for the May 1997 event. Whether the features and patterns found are generic to the initiation process for CMEs, or is specific to this case, remains to be explored. We are working on another event in May 2005 with a similarly structured active region but a different surrounding larger scale coronal field. The comparison should shed light on this question.

Further insights on the May 12, 1997 CME from homologous events

An important consideration in realistic CME modeling is whether the involved processes are common from event to event. Our May 12, 1997 case study event was actually one of a sequence of three Coronal Mass Ejections (CMEs) initiated from the same bipolar magnetic region AR8038. The first event occurred near the east limb on 1997 May 5, the well studied Halo CME occurred on May 12, and a west limb event occurred on May 16 (Figure 4). While the structure of the Halo CME was obscured by the occulting disk, the limb events were classic three part CMEs. All three CMEs had moderate speeds, and associated small flares. While the Halo CME was associated with the symmetric EUV double dimming observed adjacent to the active region (central panel of the figure), we are also able to observe double dimming associated with the two limb CMEs using wavelet enhanced EIT images and EIT difference images. Only the Halo CME excited an EUV wave with a circular wave front. A non-potential sigmoidal structure transformed to potential-like arcades during the flare in the Halo CME case. These CMEs arise from the same magnetic configuration and thus may be prone to the same energy build up
and initiation process. We investigate how the free magnetic energy was re-introduced after each release in this decaying yet still sunspot bearing region by analyzing the MDI magnetogram sequence for the Halo event. We found persistent flux cancellation over the four days analyzed. The unsigned magnetic flux of the entire AR8038 decreased monotonically by about 20% during 66 hrs prior to the flare on May 12, whereas the unsigned magnetic flux of a sub-region at the erupting neutral line was mostly increasing and up by about 16% during 36 hrs prior to the same flare. Fourier local correlation tracking (FLCT) showed converging motions toward the active region neutral line at ~40 m/s. A net shear flow northward at ~50 m/s and decreased steadily with time to zero in four days. We found little evidence for sunspot rotation-related shear. The flux distribution in AR8038 evolved to an apparently more stressed configuration as the tilt angle increased by about 15 degrees. Our observational evidence that the magnetic field became increasingly stressed at the photospheric level prior to the flare/Halo CME provides useful information for the initiation modeling.

Figure 4 (top row) SOHO LASCO Coronagraph images of the three homologous CMES associated with the same active region as the May 12, 1997 main study event. These occurred on May 5 (left), 12 (center), and 16 (right), 1997. The top center image is a difference image that brings out the faint halo signature in the images. (middle row) EIT images for the events, showing the associated EIT dimming. In this case the side images are the difference images. (bottom row) Yohkoh soft x-ray images for the events, showing the appearance of the flaring active region arcades and the common bright arcade connecting the active region to the northern polar coronal hole boundary.
CME initiation dependence on coronal field geometry

Yang Liu at Stanford is using magnetogram-based Potential Field Source Surface models to understanding the role of the surrounding coronal magnetic field geometry in CME initiation and speed. It has been suggested by some studies that the magnetic field overlying the erupting field structure decreases with height more slowly for the regions exhibiting failed eruptions than for those with successful eruptions (CMEs), and that the field strength at low altitudes in the corona is much stronger for the failed eruption cases. It has also been suggested that CMEs emerging from coronal arcades at the base of the heliospheric current sheet are significantly slower than those situated within unidirectional open field structures (see the illustration below). The average speed of the former is 883 km/s, while the latter is 1388 km/s. If the ambient magnetic field structure plays a role in determining the speed of CMEs, our models of CME initiation can explore the physics of the difference. This is important for space weather modeling because CME speed is one of the main determiners of the strengths of interplanetary and geospace effects.

![Figure 5](image-url)

**Figure 5** Two coronal field geometries associated with CME initiations include active region field arcades (black) situated under the heliospheric current sheet (left), and within a unipolar region of open coronal fields (right). The structure on the right is associated with significantly faster CMEs on average, although this geometry is rarer.

August 2008 Eclipse Prediction

The tradition of simulating total solar eclipse polarized light images with the MAS model was continued by PSI. The pictures below show the result of a remarkable simulation of what was observed in China in August, 2008. This simulation used the more accurate thermodynamic treatment of heat conduction and temperatures in the MAS model, which is expected to produce more realistic densities and solar wind speeds.
Figure 6 Magnetic field lines from a MAS MHD coronal model simulation of the corona on the day of the August 2008 total solar eclipse (left), a simulated coronagraph image from the model densities (center), and an observed eclipse image (right) obtained by Miloslav Druckmuller, Peter Aniol, and Vojtech Rusin.

Current status and proposed improvements to CORHEL

CORHEL 3.5 has greatly simplified the process of running the coupled coronal (MAS) and heliospheric (ENLIL) MHD codes. It provides a sophisticated command-line interface from which to set up and initiate runs. A wide array of user options, such as: choice of observatory, the desired resolution of the run, and a myriad of optionally-adjustable parameters. This latest release was assembled, compiled, and tested on both Mac OS X and Linux, and the package (with optional benchmark runs) fits onto a single CD that can be distributed to users, together with a user guide and installation instructions. CORHEL includes the ability to: (1) simulate simple transients, such as “cone model” CMEs; (2) run either the coronal model or the heliospheric model separately; and (3) choose either PSI’s or the ENLIL heliospheric model. Moreover, this release merges the magnetic field data from the coronal and heliospheric solutions into a single data-set to simplify visualization and analysis of the results. Finally, this release also includes many minor improvements, such as improved error checking.

CORHEL 4.0, which is undergoing final testing, but has already been delivered to both CISM and the CCMC for internal testing, has a number of enhancements over 3.5. First and foremost, both the MAS and ENLIL codes are fully parallel. The serial versions of each code can still be selected, however, which may be a more appropriate option for running on desktop computers.

CORHEL 4.1 is also under active development. For this release, we have extended the number of supported observatories to six. They are: Kitt Peak, SOLIS, GONG, MDI, WSO, and MWO. We have rewritten the pre-processing routines that smooth and extrapolate data to the poles of the magnetograms. Additionally, we have added the option for the user to specify any radial magnetic field boundary condition they choose. We are also developing a web-based magnetogram selection tool that will aid the user in choosing between the various observatories and selecting appropriate input parameters.

Proposed future enhancements to CORHEL include the following: (1) Thermodynamic solutions; (2) Incorporation of the WSA model; and (3) improved magnetogram pre-processing.
Using CISM Models to Understand this Unusual Solar Cycle Decline

The current solar cycle 23 long declining phase includes some unusual behavior such as prominent and long-lived low-to-mid latitude high speed solar wind sources, and weaker than usual interplanetary fields with atypically radial orientations accompanied by low density solar wind. There has been considerable interest in this anomalous behavior (compared to the previous two cycles) due in part to the STEREO mission. The observations of an especially weak polar field of the Sun suggest there is a connection that we can explore with the CISM models.

UCB Graduate student Christina Lee has been working with several CISM colleagues to use the WSA semi-empirical solar wind model and the MAS/ENLIL model to investigate the effects the unusually weak solar polar field has in the ecliptic near Earth. She has compared the situation for the declining-to-minimum phase of Solar Cycle 23 to the previous solar cycle. Results from the WSA model show that the sources of this cycle’s high speed streams have been different than for the previous solar cycle. For the current cycle the main sources have been isolated low-to-mid latitude coronal holes rather than the polar coronal holes. The MAS/ENLIL global modeling results for 1 AU showed that the regions of low field magnitude in the solar wind also have a broader longitudinal extent and have been more frequent during Solar Cycle 23. Results from the MAS model results were used to illustrate how the evolution of the stream interactions can contribute to the observed weaker fields. It is suggested that higher speed contrasts during the Solar Cycle 23 period produce deeper rarefaction regions and thus lower magnetic fields in those regions. Any direct effect of the weak solar polar field is thus difficult to determine in the ecliptic.
Figure 8 These model results pertain to the outward mapping of the coronal holes supplying the declining phase solar wind (here for CR 2060) during Solar Cycle 23. (top panel) The open (color dotted areas) and closed (areas with blue-red field lines) field regions below 1.25 solar radii. (second panel) The photospheric sources mapped out to the source surface at 2.5 solar radii. The two solid gray bars mark the ecliptic plane location (between ± 7.25 degree latitudes). The thick blue curve marks the projected Ulysses trajectory. (third panel) The WSA model predictions of the coronal hole areas and the solar wind speeds arising from them. (bottom panel) The magnetic field magnitude at 1 AU modeled by the MAS coronal--solar wind model. The black curve is the magnetic neutral line.

CISM Cone Model Applications

This past year we performed validation studies of "cone-model" simulations for selected halo CMEs. ENLIL computations using the WSA maps provided the background solar wind for the cone model. Predicted arrival times were compared with ACE observations at Earth. These predictions have smaller errors than predictions made by currently used empirical shock arrival (ESA) formulas, as indicated in Figure 9.
Automatic detection of interplanetary shocks has proven to be quite challenging, especially in scenarios with large variations due to background solar wind structure and large inclinations of the interplanetary field lines to the shock front. We are developing an alternative approach which takes advantage of 3D information from numerical simulations. Figure 10 illustrates this approach on the cone model for a CME on December 13, 2006. Two simulations are carried out, one without any transient to provide the background solar wind and the other with a transient. Subtraction of these two results provides a clear picture of the actual disturbance and enables a much more reliable identification of the shock front. This approach enables us to determine the speed of the shock detected at different times and knowledge of the background solar wind parameters enable us to determine shock jump conditions using the Rankine-Hugoniot relations. The disadvantage of this approach is the large requirement for computational resources. Work is continuing to find the best and most practical alternatives for shock identification in the MHD code results.
Figure 10 Cone model simulation of the December 13, 2006 ICME. The left panel shows the distribution of the solar wind together with the field line (black-white line) passing through geospace. The right panel shows the difference from the background solar wind simulation together with the automatically detected shock front (black diamond).

SEPMOD and Tests of Multipoint SEP Event Modeling

Solar energetic particle (SEP) events are one of the primary goals of space weather forecasting modelers. We have been developing and testing our version, SEPMOD, since the cone model was adopted and implemented in CORHEL. The cone model provides a first-order solar observation-based simulation of the interplanetary shock related to a CME imaged by a coronagraph. The interplanetary shock is considered to be the primary SEP source in major SEP events.

Further work on SEPMOD has resulted in a routinely applicable sequence of codes that use high cadence outputs of the CORHEL cone model to calculate the related SEP event. The baseline approach is based on the concept of scatter-free transport along shock source-connected interplanetary magnetic fields. The current shock source is an adhoc analytical formula dependent on the cone model shock compression ratios. Future work will explore different shock source descriptions as well as modified transport assumptions.
SEP Production at Shocks: Combined Observational and Simulation Effort

Our goal is to use both observations and hybrid simulations (fully kinetic ions, fluid electrons) to better understand and quantify solar energetic particle (SEP) events, and to generate shock flux profiles that can be used in large-scale SEP transport models. Using ACE spacecraft observations, we have selected isolated ESP or local shock events to determine their energetic ion characteristics, and to evaluate if particle simulations can indeed improve our understanding of shock acceleration enough to make quantitative improvements in large-scale SEP event modeling. ESP events occur at the time the interplanetary (IP) shock arrives at the observer, presumably putting us inside the source region.

When studying the ACE data, we found that in isolated events, there is very little variation of peak energetic ion flux with shock normal angle $\theta_{Bn}$, and only a moderate variation with the Alfvén Mach number, above the theoretically expected minimum Mach number of about ~2.8. For parallel shocks, we confirmed that the observed peak fluxes and power laws agreed with our simulations. For oblique shocks, we performed much larger than usual simulations. We demonstrated that even the very dilute upstream ion beams of oblique shocks can generate compressional upstream waves, which in turn disrupt the shock surface and generate local shock properties more akin to the quasi-parallel case, augmenting the energetic ion population. This work illustrates the challenges of assigning a specific shock source property based on undisturbed upstream and downstream conditions.

Our analysis of isolated events and our simulations show that for shocks with $2.8 < M_A < 5.0$, typical peak fluxes are around $10^6$ 1/(cm²·s·sr·MeV) at ~0.05 MeV, with the flux falling off as a power law with index of between 2.0 and 2.5. Both of the above quantities show a very weak dependence on Mach number (above the limit of ~2.8, which we established many years ago) and $\theta_{Bn}$. For the very exceptional high mach numbers above about 5 in the solar wind, it is expected that the energetic ion particle environment does increase. We are currently working with experts on diffusive shock acceleration to compare our observational and simulation results of the energetic ion environment at higher Mach numbers with that of quasi-linear diffusion theory. Meanwhile, the above peak fluxes and power laws can be implemented as a zero-order...
estimate for expected local values in heliospheric MHD modeling of outward-propagating CMEs and ensuing interplanetary shocks.

A second effort is directed towards understanding at what distances the energetic ion decouple from the wave-particle environment of the shock, and can freely escape – and what their flux characteristics are, at that point. This distance evidently varies with energy, and the resulting flux profiles are sought as an input for large-scale particle transport modeling, which generally assumes little or no further scattering on the way to Earth or larger distances.

![Graph](image)

**Figure 12:** Simulation profile of the in-plane ($B_y$) and out-of-plane ($B_z$) magnetic field components as well as the density of a quasi-parallel shock ($\Theta_{Bn} = 15^\circ$) with Mach number $M_A = 4.2$ over the large distance of about ten times the distance to the moon, or about 2 hours real time in the passing solar wind.

Figure 12 shows the profile of a typical very large scale particle simulation, of the order of ten times the distance to the moon, or ~3.5 Million kilometers, or about 2 hours of real time in the passing solar wind. At this scale, even a quite extended quasi-parallel shock looks like an instantaneous shock. These new simulations are sufficiently large to show and evaluate the decoupling of the streaming energetic ions from the wave-particle environment in the proximity of the shock jump.

An interesting observation has been that lower-energy ions appear to couple strongly to the shock wave-particle environment, and thus their intensity falls off rapidly with distance from it, while higher-energy ions decouple quickly. At yet larger distances, other propagation or transport effects play a role.
Figure 13 above shows the flux profiles of energetic ion intensity versus energy for various distances upstream from the shock, resulting from our particle simulations, measured in ion inertial lengths (approximately 100 km). As seen in the observations, the simulation results show a steep fall-off with energy close to the shock, but a much flatter spectrum at large distances. The interpretation is that lower-energy ions decouple slowly from the shock, while higher-energy ions decouple quickly from the wave-particle environment of the shock, and thus show almost constant flux profiles versus distance. These results have encouraging consistency with those obtained via other approaches to the shock acceleration problem, giving us confidence that the simulation results will feed into the large scale model as planned.

Goals and Activities planned for this coming year:

Our work this coming year will emphasize several key activities including:

5. Completion of the simulation of the May 12, 1997 CME event including the SEP event

6. Development of a documented, user-oriented strategy for regular cone model parameter definition

7. Improvement of solar wind speed in MAS code and CORHEL (continuing)

8. Completion of delivery of the version 1 SEP event simulation code(s) to BU

9. Use of hybrid code shock simulations to develop an improved shock source description for the SEP code (continuing)

10. Simulation of one or more new events, including STEREO events (in work)
2B. Magnetospheric Thrust

2B1a. Parallel LFM-RCM

With the development and availability of the parallel LFM, an effort has been undertaken to couple the computational machinery to the Rice Convection Model (RCM). The original version of the coupled code used drop and lock files to exchange information, while the new version will use the INTERCOMM protocol. In January and April of 2009, the LFM-RCM core coders group (John Lyon, Slava Merkin, Pete Schmidt, Mike Wittberger, Stan Sazykin, Asher Pembroke and Frank Toffoletto) met at Rice University to begin the task of inserting and testing the software to allow exchanges between the parallel LFM and the RCM. The most challenging part of this project has been the rewrite of the interpolation machinery that passes LFM arrays, which are distributed over multiple processes, to the RCM. While the parallel LFM was being developed, RCM coding was performed by Stan Sazykin and tested using a ‘virtual LFM’ that mimicked the responses of the real LFM without using the full code.

Numerical Experiments with the LFM-RCM

While the parallel LFM was being developed, several tests were performed using the OpenMP version of the coupled code. The goal was to investigate the effect of several simple, physics-based models on the coupled code. Most of these runs were done with the help of graduate student Error! Bookmark not defined. who is currently writing a master’s thesis on these results. As a reference, Figure 14 shows a plot of the pressure contours in color, along with the velocity vectors (colored by speed) for the standalone LFM. The red line is a contour where Bz=0, which is a rough indicator of the location of the x-line in the tail. At this time, the IMF Bz has been southward for 3 hours. Note the lack of any ring current in the uncoupled code. Figure 15 shows the same configuration, but with the coupling from the RCM turned on. Note the presence of large flows on the duskside in the inner magnetosphere and the stretching of the magnetic field (as indicated by the change in the pressure contours in the tail). It is believed that these high-speed flows are caused by the inability of the LFM to obtain static equilibria with the pressure profiles imposed by the RCM. In these runs, the ring current is poorly resolved in the LFM, being confined to 3 grid cells, it is expected that higher resolution in the LFM may help resolve this problem, which motivates the effort to couple the RCM to the new parallel LFM.

1. Plasmasphere Model. Figure 16 shows the same configuration as Figure 15 except with the addition of a simple plasmasphere model. This model is based on the empirical plasmasphere model of Gallagher [2000]. Using this module to include the effect of a cold, dense plasma population in the inner region of the LFM has a substantial effect on the coupled results. Note the lack high-speed flows when the plasmasphere effects are included. The addition of the simple plasmasphere model highlights the substantial effect that a cold plasma source can have on the results; the eventual replacement of this simple model with a more realistic version suggests that such a model will be an important component of LFM/RCM coupling. The dramatic change in the results is believed to be due to the cooler temperatures which helps stabilize the system. In this
case, the run continued for another 8 hours (not shown) and eventually developed the configuration shown in Figure 16, characterized by high pressures and velocities.

2. **RCM with charge exchange.** Figure 17 shows results for the same conditions but with RCM ion charge exchange and electron precipitation turned on. The charge exchange mechanism in the RCM uses a simple sunspot dependent geocorona model, while the electron losses are based on a fraction of pitch angle scattering. In this case the pressure in the near-Earth plasmasheet is lower (and the magnetic field is less stretched). Note also the x-line location is closer to the Earth. The resulting run, which continued for a further 10 hours, stabilized into an approximate steady state. These results suggest that the configuration was similar to a steady magnetospheric convection (SMC) event. It should be noted that the specific entropy ($pV^0$) in these runs was very low, as compared to empirical estimates.

3. **Runs with a simple ionosphere outflow model.** In these runs a simple mass source was added to the polar ionosphere of the LFM. The mass was added to the nudging machinery and the density was specified as a source term that decayed exponentially with distance from the Earth. Figure 18 and Figure 19 show the configurations when the density was specified to be 0.5 and 1 particle/cc respectively. In addition a new algorithm for locating the RCM boundary was added to ensure that the flows within the RCM modeling region are consistent with the RCM's assumption of slow-flow. This new boundary algorithm has the added effect of stabilizing the LFM, although in some cases the RCM's boundary moves well inside the location of the ring current. The resulting configurations are quite different, while the input ionospheric plasma densities only differ by a factor of two. This again suggests the importance of having a reasonable ionospheric source module since the system seems to be very sensitive to these inputs. In the lower density case, the runs resembled the SMC run, while in the higher density run the system became quite dynamic with recurring substorms.

All these modifications to the coupled suggest a sensitivity to model inputs and imply a need for better physics-based modules. Current work is focused on better understanding the effects of these various additions to the model; when the coupled high resolution parallel LFM is available it is hoped that we will be able to obtain a better understanding of the physical significance of these results.
Figure 14
Pressure contours (in nPa) and velocity vectors (colored by speed in km/s) for the standalone LFM. The IMF has been southward for 3 hours.

Figure 15
Same as Figure 14 but with 2-way coupling. Note the presence of the large flows on the duskside.
Figure 16
Same as previous plot except with the addition of a simple plasmasphere model.

Figure 17
Same as previous plot except with the charge exchange in the RCM turned on. Note the inward motion of the x-line location (as marked by the red curve).
2B1b. Eulerized RCM
Research Scientist Bob Spiro has developed the Euler version of the Rice Convection Model. Formulated in terms of Euler potentials, this version of the RCM code moves
away from the rotation-axis-aligned dipole constraint of the traditional RCM to allow for more realistic internal magnetic field configurations such as the IGRF internal magnetic field model. As the initial science application of the Euler RCM code investigated how longitude and seasonal effects in the global electric conductance distribution affect the strength and distribution of prompt-penetration electric fields associated with sudden changes in the driving magnetospheric electric field. Figure 20 shows the global distribution of Hall conductance and line contours of electric potential for equinox conditions. Of special interest is the sensitivity of the post-dusk eastward electric field to longitude (UT).

![Figure 20 Equinox Hall conductance and electric equipotential distribution (1 kV spacing) following an abrupt increase in cross-polar cap potential drop. Noon is to the left. Note the varying post-dusk electric potential spacing as different longitudes move into the evening sector.](image)

**2B2. Parallel and Multi-Fluid-LFM Progress**

The multifluid version of the LFM global MHD code, MFLFM, has been used in a number of studies this past year. Although the code is still undergoing tests, a number of interesting physical studies have been performed. These fall in three distinct areas:
plasma entry to the magnetosphere, plasma outflow from the ionosphere, and the development of an MHD model for the plasmasphere.

**Ionospheric Plasma Outflow**

The multi-fluid MHD effort at BU has concentrated on two areas: the initial acceleration and transport of ionospheric oxygen from the topside ionosphere to the magnetosphere and the consequent global effects of the oxygen fluid on the magnetospheric dynamics. The former project, carried out by grad student Katie Garcia, investigates the relative contribution of the field-aligned pressure gradient and the centrifugal forces, and attempts to reconcile the fluid and the particle picture. The results so far show that the pressure acceleration for the fluid tends to dominate the final velocity, even when the initial pressure is relatively low. The latter project looks at oxygen effects on global indicators of the magnetospheric dynamics such as the cross-polar cap potential and field-aligned current patterns and magnetotail convection and geometry. This project is in its initial stages, but two conclusions are apparent: the effects of ionospheric outflow on the magnetosphere are often substantial and that even the qualitative effects depend on outflow there and where it occurs. This is borne out by the work of Mike Wiltberger at NCAR.

Figure 21 shows the comparison between the MFLFM runs with and without ionospheric outflow produced with the CISM-DX package [Wiltberger et al. 2005]. The baseline run without outflow is shown on the left with a cut through the XZ plane colored by the log10 of the proton (H+) density. The basic structure of the magnetosphere is quite apparent here with a clearly defined magnetopause and bow shock on the dayside and a plasma sheet on the nightside. In the right panels of the figure, the XZ plane is colored with the of the log10 O+ density for the run with ionospheric outflow. Since the only source of O+ is the cusp-cleft outflow region the majority of the plane is blue indicating no O+ plasma, while the expansion and tailward stream of the outflow is clear. In both cases magnetic field lines are traced from points every 5 RE along the X axis from -80 to -5 RE. After the IMF turns southward the magnetotail begins to thin and eventually a near-Earth reconnection line forms near X=-25 RE. At 02:40 ST (top panels of Fig. 1), a plasmoid is evident in the magnetic field configuration of both simulations. In the case with ionospheric outflow the visualization clearly shows that the O+ has not yet reached the central plasma sheet. In fact, it does not do so until approximately 03:10 ST. In both cases the plasmoid forms, propagates tailward, and exits into the solar wind. This evolution is typical for LFM simulations with steady southward IMF.
Figure 21 A comparison of the magnetospheric configuration for a run without (left) and with (right) O+ outflow. The top panels show the configuration during the first substorm interval. In the lower panels a second substorm is only seen in the outflow simulation.

The configurations of the two systems are shown at 04:05 ST in the bottom panels of Figure 21. In the baseline run, a typical quasisteady configuration has developed with a reconnection line persisting near X= -45 RE. In contrast, the configuration for the outflow run in the right panel is very different. A new near-earth reconnection region has formed near X= -25 RE, and a new plasmoid is evident. This plasmoid is eventually released from the magnetosphere in a fashion similar to the initial substorm sequence seen in both simulations. This cycle does not appear to repeat indefinitely. After this plasmoid is released the simulated magnetosphere reaches a new dynamic steady state with the last closed field line occurring near X= -25 RE. The ionospheric outflow lands tailwind of this reconnection line, and the bulk of the O+ ions continues to flow down the magnetotail.

Parallel LFM

The LFM global magnetospheric code has for most of the lifetime of CISM been implemented using an OpenMP framework. This has limited the scalability of the code and, with it, the resolution that can be achieved for a number of problems. As noted in the discussion of the RCM coupling, this has hindered progress. Another version of the LFM, based upon MPI message passing, has been in use for a few years, but only with the code developer. This year a concerted effort has been made to bring this version into
the main stream of the CISM Geospace suite of models. This has been largely successful with the code running routinely on a cluster at SWPC and delivered to CCMC for use in the general community for runs on demand. It has also been integrated into the general CISM coupling scheme. The enhanced resolution has been used to study plasma entry (discussed below). This has provided a useful complement to the OpenMP results also discussed there. Development plans for the coming year are to move rapidly to implement a multifluid capability in the parallel code.

Plasma Entry and Circulation

Peter Damiano has been using the MFLFM to study solar wind entry into the magnetosphere for conditions of southward IMF. The model allows for two ion species and the investigation was initialized by defining the solar wind plasma to be in excess of 99% of one ion species (where the individual mass and temperature of both species are assumed to be the same). After a quasi-steady magnetosphere was allowed to develop, the species fractions were reversed in the solar wind so that the once trace, but now dominant species could be followed into the magnetosphere. This allows for a clear visualization of the entry as is illustrated in Figure 22, which plots the log density of fluid B (the second species) in the equatorial plane (as well as the flow field) after the species fraction reversal. The red line defines the approximate magnetopause boundary. Clearly evident are quasi-periodic "finger-like" structures formed by the interaction of the entering plasma with the earthward convective flow and Kelvin-Helmoltz (KH) vortices at the flanks. Although the visualization is suggestive of flank entry for the plasma, it may not be this simple and further investigation is underway to clarify this. In addition to the solar wind entry, simulations were also carried out of the transport of cold dense plasma sheet (CDPS) material which enters during extended periods of northward IMF. A sudden reversal of the IMF to southward initiates convective flows (as evident in Figure 21) which then transports the material earthward. The overall results are qualitatively consistent with observations (e.g. Thomsen et al., JGR, 2003), but a simulation using real solar wind data would be required for a more meaningful comparison.

Figure 22 The logarithm of the density of the second (tracer) fluid in the equatorial plane. The Earth is at the center of the black circle and the Sun is off to the right. The vectors indicate flow velocity.
The high resolution permitted by use of the MPI LFM has allowed greater insight into the processes available for plasma entry and circulation in the magnetosphere. It appears now that entry of plasma from the solar wind is a multi-stage process. Plasma is first introduced to the low latitude boundary layer. Then it becomes Kelvin-Helmholtz unstable. The Kelvin-Helmholtz instability then introduces what is essentially magnetosheath plasma to the flanks of the tail magnetosphere. The entropy of this plasma is very much lower than the tail plasma. As such it tends to be interchange unstable with the existing plasma, working its way into the center and Earthward parts of the tail. This is illustrated in Figure 23 for northward IMF. Plotted are gray scale renditions of the density in the equatorial plane (left panel) and the logarithm of specific entropy ($P/\rho^\gamma$). The resolution here is double that of Damiano's studies. The low latitude boundary layer can be seen as a slightly denser (brighter) band along the flank. The K-H instability shows as ripples on this boundary. The most striking feature of the calculation is the very close anti-correlation between the density in the tail and the specific entropy. This provides a strong suggestion that interchange is responsible for plasma transport in the tail.

**Figure 23** Density and specific entropy in the equatorial plane for a simulation during Northward IMF. The left hand frame shows the density as a gray scale from 0 to 20. The Right hand frame shows the log$_{10}$ specific entropy over $\sim$ three orders of magnitude.

**Inclusion of a Dynamic Plasmasphere into the MFLFM**

The plasmasphere strongly affects all time-dependent MHD phenomena. It also affects phenomena which, though they cannot be modeled in MHD, can be modeled using LFM fields as an input; such phenomena include electromagnetic ion cyclotron waves and Whistler chorus and hiss. Furthermore, recent results for the coupled LFM-RCM system show that numerical problems associated with the coupling can be ameliorated when a plasmasphere model is included (Section 2B). Thus we consider it a high priority to include a plasmasphere. Currently, it is possible to initialize a plasmasphere in the MFLFM using the Gallagher et al. (1988) model. In order to include a dynamic plasmasphere that evolves realistically and responds to solar wind conditions, it is necessary to include corotation. In the most common paradigm, it is the balance
between corotation and convection that determines the plasmapause boundary. The physics of the interchange paradigm (Lemaire and Gringauz, 1998) is also included.

Recently, we have incorporated ionospheric corotation and gravity into the multifluid version of the LFM, the MFLFM. Corotation is implemented by adding a corotation electric field at the inner radial boundary. Inner magnetospheric regions with magnetic field lines connecting to the rotating boundary region are dragged around by the magnetic tension. Flux tubes connecting to the outer magnetosphere, the magnetopause, and the polar cap can slip at the ionosphere due to the finite conductivity. Gravity is required to overcome the centrifugal force pulling plasma radially outward at the magnetic equator. We are currently in the process of testing this new version of the code.

**LFM ULF Wave Mode Structure Studies**

We are pleased to have recent CISM PhD graduate Seth Claudepierre (University of Colorado, 2008) at Dartmouth for the 08-09 academic year as a Visiting Young Scientist, with support from CISM supplemented by the New Hampshire NASA Space Grant. He is continuing work from his thesis on the Kelvin-Helmholtz instability which used constant solar wind driving conditions at the upstream boundary of LFM, published in JGR in 2008. Further results from LFM simulations of the solar wind-magnetosphere interaction are shown in Figure 24. We use these simulations to investigate the role that solar wind dynamic pressure fluctuations play in the generation of magnetospheric ultra-low frequency (ULF) pulsations. The simulations presented in this study are driven with idealized solar wind input conditions, where we introduce monochromatic and broadband ULF fluctuations in the upstream solar wind dynamic pressure. In this numerical experiment, the idealized nature of the solar wind driving conditions allows us to study the magnetospheric response limited to a fluctuating upstream dynamic pressure, while holding all other solar wind driving parameters constant. The simulation results suggest that ULF fluctuations in the solar wind dynamic pressure can directly drive magnetospheric ULF pulsations in the electric and magnetic fields on the dayside. Moreover, the simulation results suggest that when the driving frequency of the solar wind dynamic pressure fluctuations matches one of the natural frequencies of the magnetosphere, magnetospheric cavity modes can be energized. Figure 24 shows evidence for cavity mode structure in the radial direction on the dayside at noon, described in Claudepierre et al., (GRL submitted, 2009), while Figure 25 shows evidence for harmonic shear Alfvén resonances simultaneously excited along the 15 LT meridian radial cut. Coupling between the cavity modes and the FLRs is described in a paper in preparation by Claudepierre et al. (2009).
Figure 24 Evidence for ULF cavity mode structure in the radial direction on the dayside at noon using solar wind pressure fluctuations to drive LFM, both monochromatic and broadband as indicated.

Figure 25 Radial electric field spectral density along the 15 LT meridian in the equatorial plane. The field line eigenfrequency profiles are indicated by the black dashed lines, for the fundamental and first four harmonic shear Alfven resonances. Note the n = 1, 3 and 5 toroidal mode field line resonances excited along the 15 LT meridian.

2B3. Radiation belt losses and the spatio-temporal and spectral characteristics of EMIC waves
The dynamical variations in the radiation belts are the result of a complex interplay of particle acceleration, transport, and loss. The combination of global models of the magnetosphere with test particle simulations of the radiation belts provides a physically-based means of modeling particle transport and the acceleration associated with time-changing large scale magnetic and electric fields. However, particle resonances with high-frequency waves not modeled in the MHD approximation can lead to finite particle lifetimes by scattering energetic particles into the atmosphere. In particular, electromagnetic ion cyclotron (EMIC) waves are known to effectively interact with radiation belt electrons and can lead to pitch angle diffusion into the bounce loss cone [e.g. Home and Thorne, 1994]. In this work, University of Colorado researcher Scot Elkington and CISM graduate student James McCollough have undertaken to characterize the spatio-temporal and spectral characteristics of EMIC waves with the aim of incorporating these effects into global simulations of the radiation belts.

EMIC waves are generated from temperature anisotropies of energetic ring current ions in the presence of cold background plasmas. These anisotropies may result from preferential perpendicular energization due to transport of ring current ions into regions of stronger magnetic field strength. Our approach is to use the global magnetospheric models being developed under the auspices of CISM to track the 3d motion of magnetospheric hydrogen, helium, and oxygen populations as they evolve in time-dependent electric and magnetic fields. By assuming the phase space density associated with each test particle is conserved along its trajectory in accordance with Liouville’s theorem, we are able to model the time-evolving distribution function which may then be integrated over the second moment in velocity space to calculate plasma temperatures in directions both parallel and perpendicular to the local magnetic field. With these quantities we can compute the convective wave growth rate for EMIC waves [Kozyra et al., 1984] and determine the regions of the magnetosphere where waves are likely to occur, which might then be used to constrain energetic electron lifetimes in models of the radiation belts.

This technique was applied to model an event occurring on June 29, 2007, in which a pressure pulse in the solar wind was associated with the onset of strong EMIC activity across the dayside at radial distances of ~5-7 $R_E$, and in a frequency band between 0.5 and 0.75 Hz [Usanova et al., 2008]. The response of hydrogen and heavy ions in the ring current (10-300 keV) to the pressure pulse was modeled using the combined MHD/particle technique, and the resulting temperature anisotropies used to calculate wave growth rates in the magnetosphere as a function of time, frequency, and location. The results of the simulation at two different times during the event are shown in Figure 26. The dashed lines indicate radial distances of 3, 5, 7... $R_E$, the solid lines contours of constant magnetic field strength, and the color scale indicates wave growth rate integrated over approximately the 0.25-1.0 Hz range. Here an empirical plasmasphere model was used to model the cold plasma density of the inner magnetosphere [Gallagher et al., 2000]; a nominal plasmapause (n~100/cc) is indicated by the solid green line in the figure. Future iterations of this technique will endeavor to incorporate a physical plasmaspheric model as elements are provided by other research teams working to provide this capability to the global models being developed by CISM.
The spectral characteristics of the waves are sensitive to the relative hot ion concentrations and the background cold plasma density. For the simulation of the 29 June 2007 compression event, initial phase space densities of energetic ring current hydrogen was taken from the AP-8 empirical model of energetic protons [Sawyer and Vette, 1991]. Helium and oxygen concentrations were then taken as a ratio relative to the hydrogen, using observations from the CRRES spacecraft as described by Grande et al. [1997]. Future iterations of this technique will take advantage of the multifluid MHD models being developed by CISM to self-consistently track the density of these three key ion species; however, since these codes may not initially employ an anisotropic pressure tensor, it is expected that the test particle approach used in this method will still be necessary to the technique.

Figure 27 shows the spectral characteristics of the waves at a point near 6 $R_E$ in the morning sector of the simulation, as a function of frequency. The solid, dashed, and dotted lines indicate the wave growth rate for three different assumed concentrations of energetic O$^+$ relative to hydrogen, showing the suppressive effects of increasing concentrations of O$^+$ on EMIC wave growth rates. The solid vertical line indicates the position of the helium gyrofrequency, where there is an associated stop band in the EMIC dispersion relation. Above this band, EMIC waves may be produced at the equator as indicated in the figure. However, as the waves propagate along the field line away from the equator, the helium gyrofrequency increases as the waves move into regions of stronger magnetic field, and the waves evanesce at successively higher frequencies. This effectively shields the waves generated at the equator in the shaded region of the figure from being observed on the ground. The range of frequencies suggested by this simulation is in good agreement with the 0.5-0.75 Hz waves observed at the Gillam magnetometer, as reported by Usanova et al. [2008].
Figure 27 Wave growth rate as a function of frequency at a point near 6 R_E in the morning sector of the magnetosphere, for three different concentrations of O^+.

The CISM Geomagnetic Cutoff Code

At low to mid-latitudes the Earth's magnetic field usually shields the upper atmosphere and spacecraft in low Earth orbit from solar energetic particles (SEPs). During severe geomagnetic storms distortion of the Earth's field suppresses geomagnetic shielding giving SEPs access to mid-latitudes. The suppression of geomagnetic shielding during storms can expose astronauts, airline crews and passengers to increased levels of harmful radiation (Golightly and Weyland, 1997; Leske et al., 2001; Dyer et al., 2003; Clucas et al., 2005). SEPs can also be damaging to electronic equipment in space and at high altitudes, causing degradation to micro electronics and single event upsets in micro electronics operations (Tylka et al., 1996).

The CISM-Dartmouth geomagnetic cutoff code models the effects of variations in geomagnetic shielding on SEP and cosmic ray fluxes within the magnetosphere by computing time-reversed Lorentz trajectories in magnetospheric model fields. Global maps of geomagnetic cutoff rigidities are used in conjunction with observed or modeled interplanetary spectra to predict energetic particle flux within the magnetosphere. The Geomagnetic cutoff code can be run using various empirical or physics based geomagnetic field models including the LFM MHD code as a stand alone model or coupled with other geospace models currently in use within CISM. The cutoff code has also been run using fields from the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model, Tsyganenko (2002) and Tsyganenko and Sitnov (2005) empirical models.

In a project recently funded by the NASA Applied Sciences Program called Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS), the CISM-Dartmouth geomagnetic cutoff code is being used in conjunction with NASA's...
High Energy and Charge transport code (HZETRN) to develop a prototype real-time data-driven prediction of atmospheric radiation for the safety of commercial airline passengers and crews. The geomagnetic cutoff rigidity code provides a critical dynamic outer boundary condition for the HZETRN atmospheric transport code. It is found that "ignoring solar wind-magnetosphere interactions during a strong geomagnetic storm in the calculation of cutoff rigidity can underestimate the total SEP dose at commercial aircraft altitudes by approximately 30% to over a factor of four" (Mertens et al., 2008). Dr. Brian T. Kress (Co-I, Dartmouth College), Dr. Michael J. Wiltberger (Co-I, NCAR/HAO), Dr. Stanley C. Solomon (Co-I, NCAR/HAO) and Dr. Christopher J. Mertens (PI, NASA/Langley) are collaborating on the NAIRAS project.

A case study of the 28-31 October 2003 solar-geomagnetic event has been used for initial tests and validation of the cutoff code using Tsyganenko and Sitnov (2005) (TS05) model geomagnetic fields. Figure 28 shows the comparison between the modeled and observed cutoff latitudes. Four cases, as SAMPEX enters and exits the north and south polar cap regions, are shown separately in the 4 subplots. The modeled cutoffs follow the variations in the observed cutoffs well. An interplanetary shock arrives at the magnetosphere on 10/29/03 at ~6 UT. The initial suppression of the cutoff is coincident with the arrival of the shock. Subsequent suppression occurs during the main phase of the storm due to weakening of the Earth's interior magnetic field caused by ring current build-up. Figure 29 shows global maps of the difference between pre-storm and storm cutoffs (storm minus pre-storm cutoffs). The maximum suppression of ~1 GV occurs during the main phase of the storm at ~21 UT on 10/29/03 at mid-latitudes on the dusk side of the Earth, presumably due an enhanced partial ring current (Fig. 10, bottom panel). The cutoff is also significantly lowered by the arrival of an interplanetary shock. The shock has the largest effect at mid-latitudes on the on the night side (Fig. 10, top panel). The maximum suppression of the cutoff produced with the arrival of the interplanetary shock is ~0.5 GV, about one half of the maximum suppression during the main phase of the storm. These results will appear in a paper to be submitted to Space Weather.

Figure 28 A case study of the 28-31 October 2003 solar-geomagnetic event is for initial tests and validation of the CISM-Dartmouth cutoff code using Tsyganenko and Sitnov (2005). Comparison
between the modeled (line plot) and observed cutoff latitudes (discrete points) are shown. Four cases, as SAMPEX enters and exits the north and south polar cap regions, are shown separately in the four subplots.

![Difference between shock arrival and quiet cutoffs](image1)

**Figure 29** An interplanetary shock arrives at the magnetosphere on 10/29/03 at ~6 UT. Global maps of the difference between pre-storm and storm cutoff rigidities (storm minus pre-storm cutoffs) are shown using the CISM-Dartmouth SEP cutoff code.

In a separate validation effort, Dr. Brian T. Kress (PI), in collaboration with Dr. Shawn Young (AFRL), is conducting an extensive validation study including SEP events from 1992 to present. In addition to SAMPEX observations, to measure the performance of the model against earlier work, the geomagnetic cutoff model will be compared with the Smart and Shea model (Smart et al., 2006) which is included in the AF-GEOSpace models.

**Radial Diffusion of Radiation Belt Electrons**

Work is underway by Dartmouth graduate student Feifei Chu to quantify diffusive radial transport of radiation belt electrons, including a model for pitch angle scattering losses to the atmosphere. The radial diffusion model conserves the first and second adiabatic invariants and breaks the third invariant. For the radial diffusion coefficient, $D_{LL}$, the Brautigam and Albert (JGR, 2000) diffusion coefficient parameterized by $K_p$ is used, which provides an ad hoc measure of the power level at ULF wave frequencies in the range of electron drift (MHz), breaking the third invariant. A two-month period of recurring high speed streams following the prompt injection of electrons on March 24, 1991 is modeled, computing both electron flux and phase space density (PSD) enhancement inside of geosynchronous orbit, incorporating LANL geosynchronous
spacecraft measurements of the outer boundary phase space density. The March 31-May 31, 1991 radial diffusion calculation is initialized with a computed phase space density (PSD) profile using differential flux values from the CRRES High Energy Electron Fluxmeter instrument, covering 0.65 - 7.5 MeV along with the LANL geosynchronous measurements at each subsequent time step. Results are compared with SAMPEX measurements. It is found that the radial diffusion code does a very good job of reproducing three recurring high speed stream enhancements in flux, where IMP8 data was available in the solar wind to compare with the three geosynchronous flux enhancements seen by the LANL spacecraft. An fourth moderate change in PSD seen in Figure 30 on day 138 during the largest Dst storm of the two-month interval (Dst = -105 nT), when IMP8 was inside the magnetosphere for the preceding week and no solar wind data is available, was not seen in LANL or CRRES measurements, indicating that both an increase in Kp, hence the radial diffusion coefficient AND an increase in flux at the geosynchronous outer boundary of the radial diffusion calculation (absent in the LANL data incorporated) are both necessary conditions for flux and PSD increase. The absence of this fourth enhancement in the CRRES measurements simultaneous with a broadening of the slot region around L = 3.5 is indicative of a significant ‘Dst effect’ for this storm, causing outward transport and drop in flux at the geosynchronous outer boundary incorporated from the LANL measurements. Thus the strongest storm of the two-month interval shows the weakest radiation belt electron enhancement, while the three recurring high speed streams on average increase outer zone flux levels. This result is consistent with the observation that highest average outer zone flux levels occur during the declining phase from solar maximum, rather than on the ascending phase when CME driven storms are the more common solar disturbance signature in the solar wind.

Figure 30 Radial diffusion results are shown with every time step of PSD expressed by the color. Each time step is 1/6 hour. The unit is log [c/ (cm^2 MeV)]^3, the size of the log PSD is
expressed using different colors indicated by the color bar. The March 31-May 31, 1991 two month interval follows $M=100$ MeV/Gauss particles. Different first adiabatic invariants phase space density must be calculated to covers the range of $M=50-6000$ Mev/gauss in order to interpolate the flux at a fixed energy.

2B4. Simulating Locally Forced Collisionless Magnetic Reconnection

A key question in the computational magnetospheric physics community concerns magnetic reconnection at the magnetopause. Since reconnection is believed to be a major plasma transport process in the magnetosphere, discerning its properties is the top priority of the upcoming NASA MMS mission. Specifically, research is focused on determining where on the magnetopause reconnection is concentrated, at what rate does it proceed, what are the predicted magnetic shear angles, and to what degree do these properties depend on global parameters such as the orientation of the solar wind magnetic field versus local parameters such as diffusion.

CISM graduate student Jeremy Ouellette along with his advisor Barrett Rogers and collaborators Mike Wiltberger and John Lyon have been investigating these questions using the LFM code. Using a set of idealized solar wind conditions, they have discovered that the dayside reconnection rate increases linearly with IMF clock angle from 45 to 135 degrees with a more modest increase from 135 to 180 degree IMF, a robust trend that holds for multiple measurement techniques (Figure 31). The reasons for this trend are currently under investigation, but are suspected to be connected to differences in magnetospheric geometry under these solar wind conditions. Additionally, they have uncovered two distinct reconnection processes. The first process can be categorized as three-dimensional topology merging, where solar wind field lines merge with Earth's dipolar field lines. For IMF clock angles below 90 degrees this merging is concentrated around null regions in the magnetic cusps, regions where the solar wind magnetic field and geomagnetic field are oppositely directed. For larger clock angles the merging occurs along a line that crosses the subsolar point and is more broadly distributed (Figure 32).

Additionally, these investigations have revealed a second reconnection process fitting the description of virtual field line motion as described by Priest, Hornig, and Pontin (2003). In this process, a field line passes through a diffusion region and decouples from the plasma velocity. This process occurs for clock angles below 90 degrees and occurs over larger swaths of the magnetopause, often in conjunction with the previously mentioned instances of topology merging. The coupling of this type of reconnection with the topology merging may serve to complicate the way that energy is transferred from the magnetic field to the plasma so that the actual energy conversion occurs over an area different from what the distributions of these two processes might suggest individually.
Figure 31 The dayside reconnection rate measured using three techniques using data from LFM simulations of the magnetosphere under four constant solar wind conditions. The rates were measured at seven half-hour time intervals, with the data points indicating the mean value and error bars showing maximum and minimum measurements.

Figure 32 The above plot shows the distribution of topology merging along separator lines at the magnetopause, with light copper regions that indicate where the process occurs most often.

2B5. Magnetosphere-Ionosphere Coupling – Power Flow, Precipitation and Outflow
We continue to investigate concepts for embedding collisionless dissipation and particle energization processes of MI coupling into the LFM and CMIT global models. Among the most pressing issues are development of 1) models of electron precipitation, associated collisionless Joule dissipation, and multispecies superthermal ion outflow in Alfvénic regions – essentially the auroral/polar cap boundary and cusp regions located at the ionospheric footpoints of magnetospheric reconnection activity; 2) a model for thermal outflows including polar wind outflow; and 3) a model for collisionless Joule dissipation, upward field-aligned electron flow and energy flux in downward field-aligned currents.

With synergistic funding from the NASA LWS TR&T program, the effects of causally regulated ionospheric outflow based on the Gagne (2005) algorithm is being investigated for two storm intervals: 7-12 Nov 2004 and 31 Sep-1 Oct 2005. The Gagne algorithm is based on an empirical relation (Strangeway et al., 2005) between the Poynting flux flowing into the ionosphere and outflowing ion flux. As discussed in our previous annual report, the accuracy of the algorithm depends crucially on the accuracy of the simulated Poynting flux derived from the LFM model (Melanson et al., 2008). We continue to benchmark this feature of the model, and our provisional conclusion is that dc Poynting flux, even when convolved with precipitating electron flux, is too indiscriminate in regulating outflow. Thus we are also exploring models based on the ac (Alfvénic) Poynting flux derived from LFM, and this summer we will also use CMIT model to causally regulate the source population of the ionospheric outflow.

Despite the existing deficiencies in the outflow model, we seemed to have discovered a robust and previously unknown effect of ionospheric outflow: magnetospheric inflation and associated blunting of the dayside boundary (Figure 33). When this effect acts alone it diverts a portion of the upstream magnetic flux around the flanks of the magnetosphere, thereby reducing the dayside reconnection potential and the transpolar potential. However, as discussed in previous CISM annual reports, we have also found that the outflow increases the density at the low-altitude simulation boundary, and this effect reduces the precipitating electron energy flux into the ionosphere, thereby reducing the ionospheric conductance relative to a simulation without outflow. The lower

![Figure 33](image-url) Magnetospheric, equatorial plane density distributions from LFM simulations of an encounter with an IMF B_z = -50 nT magnetic cloud at 02:50UT on 8 Nov 2004. At this time, Dst ≈ -250 nT, on its way to the storm minimum of -380 nT at 06:15 UT during the first of two superstorms of the 7-12 Nov 2004 interplanetary event. Left panel: without outflow. Right panel: with outflow included.
conductance also reduces the net field-aligned current flow and its closure in the magnetosphere-ionosphere system. Evidently this effect deflates the magnetosphere, which tends to increase the dayside reconnection potential. Thus, ionospheric outflow gives rise to two competing effects in the solar wind-magnetosphere-ionosphere interaction, both of which are observed in LFM simulations of first storm of the 7-12 Nov 2004 double superstorm.

In subsequent years, we will continue to develop the new model features identified as items 1) – 3) above with leveraged funding from the NASA Heliophysics Theory and Living With a Star Programs. We are investigating alternative outflow boundary conditions based on an empirical outflow model derived from the DyFK convecting-flux tube model for superthermal outflows (Zeng and Horwitz, 2007). Thermal outflows representative of the polar wind are under development by Dartmouth doctoral student Oliver Brambles, Dartmouth doctoral student Binzheng Zhang is pursuing development of improved electron precipitation models. Mr. Zhang will visit NCAR CISM Co-Is W. Wang and M. Wiltberger to begin using and modifying CMIT to improve the fidelity of
2C. Ionosphere-Thermosphere Thrust

The ionosphere-thermosphere modeling segment of CISM is primarily housed at the National Center for Atmospheric Research, but with affiliations to the Space Environment Center at NOAA, the University of Colorado, Utah State University, and Space Environment Technologies. In addition, partnerships with the Air Force Research Laboratory for studies of ionospheric scintillations and use of satellite drag measurements for neutral density validation have been initiated. Primary modeling tools include the NCAR Thermosphere General Circulation Models, auroral particle and photoelectron transport models, middle-atmosphere tidal and planetary wave models, and the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure for analyzing auroral region currents and conductances. The particular model component currently being used for CISM coupled model development is the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM).

The ionosphere, that small percentage of the upper atmosphere that exists as charged particles, is created and maintained mostly by solar extreme-ultraviolet radiation. However, its variability on daily and shorter time scales is largely driven by processes controlled by the solar wind and magnetosphere and coupled to the ionosphere through the auroral regions. Many other small-scale forms of ionospheric variability, such as irregularities in the equatorial region and traveling disturbance waves, are also important, but are less accessible at this time to global-scale thermosphere-ionosphere models. Therefore, the goal of the CISM project for the geospace regions is to create a coupled model of the magnetosphere and ionosphere that includes magnetospheric dynamics, upper atmosphere circulation, solar irradiance variation, and forcing by the lower atmosphere. This Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model is currently released as v. 2.5.

Year-Seven Goals

The following milestones were identified as primary objectives for the Ionosphere-Thermosphere modeling thrust during the seventh year of the CISM project. It is anticipated that most of these will be completed by the conclusion of Year-Seven (7/31/09).

- Release TIE-GCM v. 1.9 (1.91, 1.92) as a community model completed
- Transition TIE-GCM v. 1.92 to BU, SWPC, and CCMC completed
- Include measured solar irradiance in TIE-GCM and CMIT completed
- Release CMIT v. 2.5 completed
- Transition CMIT v. 2.5 to BU, SWPC, and CCMC completed
- Perform verification and test studies of CMIT v. 2.5 in progress as of 4/09
- Complete work on global potential solver in progress as of 4/09
- Complete inclusion of static plasmasphere model in TIE-GCM completed
- Complete and test high-resolution (2.5° grid) TIE-GCM in test as of 4/09
- Extend upper boundary of the TIE-GCM tested, currently on hold
- Continue validation and metrics studies continuing

Plans for Year-Eight

The following milestones are the tentative goals for Year-Seven, subject to
Magnetosphere-Ionosphere Coupling
Coupling between the magnetosphere and ionosphere was implemented during previous years through an exchange of auroral boundary conditions using the InterComm framework. Grid rotation and interpolation is handled by the magnetosphere-ionosphere coupling module. During Year-Seven, CMIT v. 2.5, which includes the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) v. 1.92 in the coupling framework, was released. User guides and other documentation have been completed. Validation studies for the coupled model are continuing. The TIE-GCM is an MPI parallel code that incorporates model-generated electric fields at low latitudes, and uses Apex magnetic coordinates based on the International Geomagnetic Reference Field (IGRF) for electrodynamical calculations. CMIT v. 2.5 is also being transitioned to the Community Coordinated Modeling Center, including stand-alone capacity for running TIE-GCM v. 1.92.

Ionosphere-Thermosphere Model Development
The TIE-GCM ionosphere/thermosphere component model (version 1.9) was released as a community model in June, 2008 (http://www.hao.ucar.edu/modeling/tgcm/). This release was announced at the 2008 CEDAR meeting. Two subsequent releases of updated versions of the model have been made available since that time: version 1.91 in December 2008 and version 1.92 in February 2009. All of these versions of this code are robust and well tested. Intercomm connections have been included in the latest release, which enables coupling to the LFM model and brings version control between TIE-GCM and CMIT into alignment. Extensive documentation is available on line as well as release notes and a wiki, which allows users to update model information as needed. A number of users have downloaded the code since it was publicly released.

The double-resolution version of the TIE-GCM (2.5° horizontal and H/4 vertical) has been tested, and this capability is included as an option in v. 1.92, but will not yet be switched on for CMIT implementation until verification and stability studies are complete. Coupling of the Global Ionosphere Plasmasphere (GIP) module to the TIE-GCM has been completed and test runs successfully conducted.

Highlights of Ionosphere-Thermosphere Scientific Studies
Wang et al. (J. Geophys. Res., submitted, 2009) studied the ionospheric response to the initial phases of three geomagnetic storms: April 2-5, 2004; November 7-9, 2004, and December 13-16, 2006, using both ground-based GPS TEC data and Coupled Magnetosphere Ionosphere Thermosphere (CMIT) model simulations. The onset times for these storms all occurred at local daytime in the North American sector. This similarity of onset times and other factors resulted in some common features in their ionospheric response. These common features included: 1) Enhanced TEC (positive response) at low and middle latitudes in the daytime; 2) Depleted TEC (negative response) around the geomagnetic equator in the daytime; 3) A north-south asymmetry in the positive response as the northern hemispheric response appeared to be more pronounced; and 4) Negative response at high latitudes as the storms progressed. The
CMIT model reproduced these features reasonably well. The model showed that storm-time enhancements in the eastward electric field were the primary cause of the observed positive storm effects at low and middle latitudes in the daytime and the negative response around the geomagnetic equator in electron density. These eastward electric field enhancements were caused by the penetration of high latitude electric fields to low latitudes during southward IMF periods, when IMF $B_z$ oscillated between southward and northward directions in the initial, shock phase of storms. Consequently, the ionosphere was lifted up at low and middle latitudes to heights where recombination was weak. In addition, the CMIT model showed that high-latitude negative storm responses were related to the enhancements in molecular nitrogen seen in TIMED/GUVI observations.

![Figure 34](image)

**Figure 34** Global maps of differential GPS TEC (left panels) and CMIT simulated TEC (right panels) between the disturbed day and quiet for the November 2004 (a) and December 2006 storms.

In another study, Burns et al. (J. Geophys. Res., 2008) used observations by the six-satellite Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) mission. These satellites make routine ionospheric measurements over the entire globe using GPS occultation. These observations were used in this study to develop global-scale climate maps of $NmF_2$ and $hmF_2$ during the southern (northern) summer (winter). Enhanced electron densities that appear to be associated with the southern, Equatorial (Appleton) anomaly was displaced far southward at dusk and, within about an hour, form the Weddell Sea anomaly. Coincidentally, the height of the $F_2$ peak increased on the northern boundary of this anomaly. This height increase was also displaced southward as the enhanced electron densities were displaced southward, suggesting that the electron density increases were associated with the $F_2$ peak rising. As well as being an interesting phenomenon in its own right, this behavior may shed new light on the formation of the Weddell Sea anomaly. No unambiguous explanation for this behavior can be determined from the data presently available, but an examination of
some possibilities suggested that an evening downward flux of plasma from the plasmasphere might be at least partly responsible for the phenomenon.

![Global maps of NmF2](image)

**Figure 35** Global maps of $NmF2$ calculated from COSMIC data for four local time bands: a) 1700-1800 local time; b) 1800-1900 local time; c) 1900-2000 local time; d) 2000-2100 local time.

Luan et al. (*J. Geophys. Res.*, 2008) used ionospheric electron density profiles retrieved from COSMIC measurements from November 2006 to February 2007 to study the ionospheric nighttime electron density enhancements under winter, solar minimum and geomagnetically undisturbed conditions. The global morphology and local time dependence of these nighttime enhancements were investigated at magnetic mid-latitudes (20-60°). The results showed that the enhancements of electron density were evident near the F2-layer peak at most latitudes and longitudes, and there were significant latitudinal and longitudinal dependences of both their occurrence time and their net magnitude. Three patterns of nighttime enhancements were seen at different longitudes: 1) Enhancements of NmF2 occurred predominately at ~30-50° magnetic latitude with a magnitude of 0.2-0.4×10^5 cm^-3, mostly after midnight, occurring from Europe to Asia, the Pacific Ocean, and the western part of the North American sector; 2) Enhancements of NmF2 dominated at latitudes lower than ~35° around midnight with a magnitude of 0.3-0.6×10^5 cm^-3, occurring in the North Atlantic Ocean sector; and 3) Enhancements of NmF2 showed combined features of the first two patterns, with two dominant latitude belts separated by a few degrees around 35°, occurring in the east part of the North American sector. Furthermore, NCAR TIE-GCM simulations indicated
that a combination of downward plasma flux and nighttime changes of $1/[N_2]$, which were related to the variations of recombination rate, caused these post-midnight enhancements.

Figure 36 a) Altitudinal-latitudinal variations of electron density (Ne) during night time around 120°E sector. The solid white line shows $h_m F_2$ obtained from the profile analysis. b) The TIE-GCM simulation results at 130°W for the $F_2$-layer peak density (top panels) and $1/[N_2]$ ratio (middle panels) from 2000 to 0400 LT, and electron density profile (bottom panels) at 0300 LT.

A modeling study was undertaken to study the effects of CO$_2$ increases on the $F_2$ region dynamo by Qian et al. (J. Atmos. Sol.-Terr. Phys., 2009). They studied the effect of carbon dioxide (CO$_2$) cooling on trends of $h_m F_2$ and $N_m F_2$ using a coupled thermosphere and ionosphere general circulation model. These and previous model simulations indicated that CO$_2$ cooling not only caused contraction of the upper atmosphere and changed neutral and ion composition but also changed the dynamics and electrodynamics of the thermosphere-ionosphere. These changes determined the altitude dependence of ionospheric trends and complex latitudinal, longitudinal, diurnal, seasonal, and solar cycle variations of trends of $h_m F_2$ and $N_m F_2$. Under CO$_2$ cooling, trends of $N_m F_2$ were negative with a magnitude from 0 to $-40\%$ for doubled CO$_2$, depending on location, local time, season, and solar activity. The corresponding trends of $h_m F_2$ were mostly negative with a magnitude from 0 to $-40$ km, but could be positive with a magnitude from 0 to $-10$ km at night, with maximum positive trends occurring after mid-night under solar minimum conditions.
Figure 37 Changes of \( h_mF_2 \) and \( N_mF_2 \) (double CO\(_2\) – base CO\(_2\)) at 3:00am for solar minimum (upper panels) and solar maximum (lower panel) conditions. Changes of \( h_mF_2 \) are absolute changes in km while changes of \( N_mF_2 \) are percentage changes. Solar minimum: \( F_{10.7} = \langle F_{10.7} \rangle = 70 \); Solar maximum: \( F_{10.7} = \langle F_{10.7} \rangle = 200 \). Geomagnetic K\(_p\) index is 1, i.e., under geomagnetic quiet condition. The black line in each figure is geomagnetic dip equator.
2D. Code Coupling Thrust

The Code Coupling Thrust is responsible for developing and maintaining successive versions of the CISM coupled model suite, which simulates the entire solar terrestrial system. We are responsible for defining the code coupling strategy, adapting specific computational science tools to implement this strategy, and applying these tools to couple our component codes to create versions of our coupled models. We further perform an initial pre-Validation test of the coupled codes before freezing them for evaluation by the Validation and Metric Thrust. Finally we are responsible for developing and implementing the code and data handling plans for CISM and for maintaining the CISM code repository.

Our basic plan, as described in Goodrich et al. (2004), is to build our comprehensive model suite from individual component codes representing different physical regimes and processes. Incremental versions of coupled models incorporate new or more sophisticated and comprehensive physics as new component codes become available. This approach allows us easily to improve or tailor versions of the coupled model suite by adding new components, and replacing existing ones with minimal modification. In practice, we have pursued two complimentary development paths. First, the initial coupling of all code combinations was done using the most convenient methods available, which generally were ad hoc ones commonly using transfer of data by files. As the ad hoc coupling codes are completed, tested, and transferred to the Validation team, we then implement them using our framework software, based on the Overture and InterComm packages, as appropriate to improve computational efficiency and flexibility.

The goals for the Coupling Thrust are outlined in the CISM Goals and Milestones and in the CISM Model Timeline. The goals are developed in more detail each year at our All Hands Meeting. Our major accomplishments in the last year are:

- **Framework Technology Development**
  - Release of InterComm 2.0, incorporating dynamic timestamp matching of data export and input requests through data caching.

- **Implementation of CMIT 2.5**
  - Couples MPI-LFM, MIX, and TIE-GCM via Intercomm
  - Allows for concurrent execution of models for improved performance
  - Refactored code to facilitate maintenance

- **Supported LFM-RCM Coupling**
  - Developed parallel interpolation method within MPI-LFM
  - Began work on coupling MPI-LFM, MIX, and RCM

- **Intercomm-ESMF Inter-operatability Project**
  - Completed integration of Intercomm calls in the ESMF
  - Conducted test project coupling CAM with TIME-GCM

Framework Technology Development
The long-term goals of CISM require a software framework in which codes can be coupled together efficiently and with a maximum amount of flexibility for adding new physics and new simulation models. Our current software framework is based on the combined functionality of the InterComm and Overture packages, as described in Goodrich et al (2004). InterComm provides an intelligent data channel between independently executing codes (programs). Overture provides the data and grid manipulation functions we need to make meaningful the exchange of data between codes.

**Release of InterComm 2.0**

InterComm is a programming environment and runtime library for coupling distributed memory parallel components. It enables efficient data transfer between different programs in the presence of complex data distributions and controls the efficient data redistribution when data transfers occur.

InterComm 2.0 which provides dynamic matching of exports and imports through the use of timestamps was released during this year. Dynamic timestamp matching further loosens the coupling between communicating application components compared to earlier InterComm versions, by relaxing the current restriction that an export operation for an object in a component correspond to exactly one import operation in the importing component for each connection for that exported object. With timestamp matching, the policy for matching timestamps on a connection between the importing and exporting components is specified in the XJD file. The runtime library then determines at runtime the best match for a given import operation, from the exports executed in the exporter component for that connection, based on the specified policy provided that a match is possible. This functionality was developed as part of a graduate student's recently completed Ph.D. dissertation work.

**Implementation of CMIT 2.5**

CMIT 2.5 couples the recently completed parallel version of the LFM with TIE-GCM via the Magnetosphere-Ionosphere Coupler/Solver using Intercomm to handle the passing of information between the component models. This development effort accomplished several significant objectives beyond the completion of a major modeling milestone. In particular we restructured the coupling between MIX and TIE-GCM to allow for concurrent execution of LFM-MIX and TIE-GCM. This feature improves the computational performance of the coupled model and will become increasingly important as we increase the resolution of the component models and need to run effectively on large processor counts. In addition, to restructuring the coupling schedule we refactored the coupling code within the component models to make it more transparent and easier to maintain. We also worked hard on improving the quality of the documentation available via the CISM Wiki and streamlining the model installation process. We believe this will facilitate the transfer of CMIT 2.5 to the CCMC and the SWPC.

**Support of LFM-RCM Coupling**
The Code-Coupling thrust worked closely with the Geospace thrusts on the coupling of the LFM-RCM. A significant outstanding question that remains to be answered is the role of increased resolution within the LFM computation domain in improving the stability of the coupled LFM-RCM model. Since this coupling requires the computation of numerous field lines we currently use a high resolution rectilinear grid for passing data between the LFM and RCM. The coupling efforts have focused on creating and parallel method for interpolating data from the non-orthogonal LFM computation grid onto this rectilinear grid using Intercomm to complete the data transfer to the RCM where this grid is utilized. In addition, we have begun developing the needed infrastructure to include MIX within the coupled model. This is needed because is where the cross polar cap potential is computed which is required by the RCM. This development work is being conducted in fashion to assure compatibility with CMIT.

**Intercomm-ESMF Inter-operatability Project**

Working with the ESMF development team at NCAR members of the code-coupling thrust have completed a demonstration project in which an ESMF component, the Community Atmosphere Model (CAM) was coupled to the TIME-GCM. As part of this development work calls were added to ESMF to allow it to directly utilize InterComm functionality. Since an ESMF array object already contains information about how the array is distributed across multiple processes, we were able to extract that information directly from the ESMF array object and use it to move a subarray into or out of another program using InterComm with only two function calls in the ESMF program (one to build the required InterComm data descriptor from the ESMF array object, and one to export or import the data). This functionality enables any ESMF component to be used in a coupled simulation with other, non-ESMF, components. In the demonstration project temperature and geopotential height are passed from a region near the upper boundary of CAM into TIME-GCM at a region near the model’s lower boundary. This one way model coupling required simultaneous execution of both parallel component models and successfully illustrated the driving of the thermosphere by mesoscale structures in the upper atmosphere. The InterComm function calls are already part of the ESMF contributed code repository, and we anticipate that the rest of the development work conducted on ESMF will shortly become part of the standard release of ESMF.
2E. Model Validation and Metrics Thrust

Activities

The core of the V/M team is centered at Boston University and led by Harlan Spence. Other BU members include principally: W. Jeffrey Hughes, John Lyon, Slava Merkin, Mathew Owens (recent former member), and Jack Quinn. These scientists meet periodically via the Access Grid and via email and phone with other V/M team members from CISM partner institutions, including: UT Arlington (Ramon Lopez), NCAR (Alan Burns, Sarah Gibson, Giuliana deToma, Stan Solomon, Wenbin Wang, Michael Wiltberger), AFRL (Nick Arge), CU Boulder (Michael Gehmeyer, George Millward), SAIC (Pete Riley, Jon Linker), and UC Berkeley (Janet Luhmann, Steve Ledvina). These scientists plus their associates and students are well integrated with the other CISM thrusts so cross-communication is assured.

Significant Accomplishments

Top-level accomplishments of our model validation/metrics effort are:

- By the end of this year’s reporting cycle, over a dozen different model versions were considered delivered to the CISM repository, “frozen”, and considered to be in pre-validation; another handful were informally pre-delivered for validation pre-assessment.
- Continued systematic assessment of delivered models using a suite of quantitative metrics and baseline models for skill score evaluations of models.
- Continued validation studies of core component models as well as coupled models leading to new scientific insights and model improvements.
- Focused on publication of validation/metrics studies with increasingly large number of papers submitted or in draft form for publication in the Journal of Geophysical Research, Geophysical Research Letters, Journal of Atmospheric and Solar-Terrestrial Physics, and Spaceweather Journal.

A major center-added component of our activities is a systematic, independent model validation process. We have established a formal process by which completed models are delivered by the modelers to the validation team. Once a model has been delivered, the validation team runs metric tests, computing a skill score for a particular parameter by comparing the prediction capability of the model with the prediction capability of a baseline model. The model validation work also provides important guidance to the development of future model generations. This process is establishing a community expectation and approach to evaluating space weather models and is fostering a community clarification of “what’s important” to characterize model performance.
Metrics Summary:

The rationale for CISM metrics selection was developed and a list of 29 metrics, along with the baseline models, first-generation physics models, and the data sets needed to compute skill scores, were established by Spence et al. (2004). Every metric consists of four elements: a parameter, a “baseline” model (herein typically empirical) used to predict that parameter, an observation of that parameter for “skill score” computation, and finally, a predictive physics-based model.

The table to the right (adapted from Spence et al., 2004) is colored coded to show progress in the two main metric focus areas (operational and science metrics), for the different regions where space weather effects are created or manifested. Green indicates parameters for which formal metrics have been or are being evaluated. Yellow indicates parameters for which metrics are being defined or refined. During the past year, we note that this chart no longer possesses red coloring, indicating pending activity. All areas identified initially in 2004 for metric computation are currently underway. New model metric activities this year include SEP cutoffs (operational) and radiation belt energetic particle fluxes (both operational and science metrics)

In the past year, significant progress was made on defining, refining, and computing skill scores for a number of key CISM metrics, especially coronal white light structure. The results of these studies are documented in five main publications either published, in press, submitted, or in draft form.

Representative Validation/Metrics Studies

Though too numerous to summarize in full detail, the following section highlights several validation/metrics studies completed or significantly advanced this year. A common theme is that by comparing model outputs with observations, two outcomes are typical: model improvements are identified and quantified, and, new physical insights emerge. Both outcomes are valuable and are leading to significant publishable results.

Validated Polar Cap Flux Saturation in the LFM

For low values of the solar wind electric field, the response of the polar cap potential is essentially linear, but at high values of VBs, the polar cap potential saturates and does not increase further with increasing VBs. On the other hand, the ring current injection rate does increase linearly with VBs and shows no evidence of saturating. If enhanced
convection is the origin of the ring current, this poses a paradox. How can the polar cap potential, and thus convection, saturate when the ring current does not?

![Figure 38](image)

**Figure 38** Magnitude of the ring current injection rate in nT/hour as a function of VBs in mv/m during periods when the magnetosphere is in the main phase of magnetic storms with a peak Dst <-75 nT (taken from Lopez et al., 2009).

We examined a possible explanation based on the reexamination of the Burton equation by Vasyliunas (2006). Using the LFM, we show that this explanation is not a viable solution to the paradox since it would require a changing polar cap flux, and we demonstrate that the polar cap flux saturates (at around 1 GWb) as the polar cap potential saturates. Instead, we argue that during storms a quasi-steady reconnection region forms in the tail near the Earth. This reconnection region moves closer to the Earth for higher values of solar wind Bs, although the polar cap potential, the dayside merging and nightside reconnection rates, and the amount of open flux do not change much as a function of Bs once the polar cap potential has become saturated. As the neutral line moves closer, the volume per unit magnetic flux in the closed field line region is less. Flux tubes leaving the reconnection region in general have lower PV’ as Bs increases, and lower PV’ flux tubes can penetrate deeper into the inner magnetosphere, leading to a corresponding greater injection of particles into the inner magnetosphere. Thus a reconnection region that is closer to Earth is more effective in creating a strong ring current. This leads to a continued dependence of the ring current injection rate on VBs (see Figure 38), although the polar cap potential has saturated. In addition to validating that the polar cap flux in the LFM saturates, this study also explored new understanding of magnetospheric dynamics.
Validated Substorm Signatures in LFM Simulations

Through comparison with standard ground-based observations, we validated against several events the ability of the LFM to reproduce classic substorm signatures. We then used LFM to determine variation of energy content in tail, thereby using the validated and modeled substorm to obtain key physical information not otherwise available from point measurements. This work was completed by CISM graduate student, Sandra Brogl as part of her Ph.D. She graduated last summer and is now working for DLR in Munich as the Operations Manager for the Columbus space station module.

We have shown that our simulations using the Lyon-Fedder-Mobarry magneto-hydrodynamic code can reproduce the characteristics of substorms, in particular, for these events, they do an outstanding job in reproducing the ground signature of substorm onset and substorm current-wedge structure (see Figure 39). We examine the distribution and propagation of energy in the plasma sheet and lobes using observations and simulations for three substorms. The substorms occurred on 9 March 1995, 10 December 1996, and 27 August 2001 and have been simulated using the Lyon-Fedder-Mobarry magneto-hydrodynamic code. All three events occur over North America and show a clear substorm current wedge over the ground magnetometer chains of Alaska, Canada, and Greenland. The three simulations show the thinning of the plasma sheet during the growth phase of the event and an increase in the relative amount of thermal energy due to the compression of the plasma sheet. Generally, the total lobe energy, polar cap flux, and lobe magnetic field strength simultaneously increase during the growth phase, and polar cap flux and total lobe energy only start dropping at substorm onset, as measured by the CANOPUS magnetometer chain. Starting at time of onset and continuing throughout the expansion phase a transfer of magnetic energy from the lobes into the plasma sheet occurs, with the increase in the plasma sheet energy ranging from 30–40% of the energy that is released from the lobes.
Figure 39 Substorm expansion phase onset (vertical line) on 27 August. The actual CL index is in the bottom panel and the simulation index is in the top panel (from Brogl et al., 2009).
We address the question of how mid- and low-altitude ionosphere affects the global magnetosphere by using the Magnetosphere-Ionosphere Coupler/Solver (MIX) simulation code. MIX was developed primarily to provide the Lyon-Fedder-Mobarry (LFM) global MHD model with the ionospheric electrostatic potential solution and for coupling of the LFM model to different models of the ionosphere-thermosphere. The MIX code is highly flexible in two aspects: 1) due to the use of generic grid-independent interpolation tools it allows ready coupling to different models of the ionosphere-thermosphere; and 2) the code allows virtually arbitrary choice of boundary conditions.

Aside from purely scientific interest, the importance of this question is also dictated by reasons that are twofold. Firstly, it is important to understand physical limitations of global MHD simulations based on assumptions that were made to essentially ease their implementation but without significant scientific foundation. Secondly, as global MHD models are proving to be more and more robust tools for prediction of magnetospheric phenomena and space weather, their validation has become essential. Understanding numerical reasons for discrepancies between simulations and data is crucial for being able to discern the models’ scientific limitations.

We have presented results of numerical simulations of the magnetosphere using the LFM global MHD model. Our simulations differed only in the treatment of the boundary condition imposed on the ionospheric electrostatic potential at the low latitude boundary of the simulation. We found that this boundary condition may influence the global magnetospheric configuration considerably in terms of the global plasma convection (see Figure 40), pressure distribution and magnetotail geometry (see Figure 41 and Figure 42). Although our model did not include an inner magnetosphere, the numerical experiments performed are suggestive that details of the inner magnetospheric and mid- and low-latitude ionospheric convection may have important global effects.

Figure 40 The temporal evolution of the cross polar cap potential for three LFM simulation runs with different ionospheric boundary conditions. The time starts at 4 hours at which time the IMF Bz turned southward (from Merkin and Lyon, 2009)
Figure 41  Plasma pressure in the meridional plane of the LFM simulation. The snapshots are taken at the end of the 4-hour simulation period driven by southward IMF Bz, at a time when the cross-polar cap potential is approximately the same for each three conditions, but which results in very different global magnetospheric configurations (from Merkin and Lyon, 2009).
Figure 42 Plasma velocity x-component in the equatorial plane of the LFM simulation. The snapshots are taken at the end of the 4-hour simulation period driven by southward IMF Bz, at a time when the cross-polar cap potential is approximately the same for each three conditions, but which results in very different global flow properties (from Merkin and Lyon, 2009).
Developed metric to assess the capability of coronal MHD models.

In the interest of quantitatively assessing the capabilities of coronal MHD models, we developed a metric which compares the structures of the white light corona observed with SOHO LASCO C2 to model predictions. The MAS model is compared to C2 observations from two Carrington rotations during solar cycle 23, CR1913 and CR1984 (see Figure 43), which were near the minimum and maximum of solar activity respectively, for three radial heights, 2.5 R\textsubscript{Sun}, 3.0 R\textsubscript{Sun}, and 4.5 R\textsubscript{Sun}. In addition to simulated polarization brightness images, we create a synthetic image based on the field topology along the line of sight in the model. This open-closed brightness is also compared to LASCO C2 after renormalization. In general, the model’s magnetic structure is a closer match to observed coronal structures than the model’s density structure. This is expected from the simplified energy equations used in current global corona MHD models.

Figure 43 Max/min normalized Carrington maps for CR1913 and CR1984. CR1913 west limb at 3.0 R\textsubscript{LASCO} pB (a), simulated pB (b), and open-closed brightness (c). CR1913 occurred between August 28, 1996 and September 25, 1996. CR1984 East Limb at 3.0 R\textsubscript{LASCO} pB (d), spB (e), and ocB (f). CR1984 occurred between December 3-31, 2001 (from Schmit et al., 2009).

Valideated Heliosphere Model and Used it to Explore Solar Wind Sources/Evolution

The relative abundances of helium and hydrogen in the solar wind vary on solar cycle time scales as well as with solar wind speed. Kasper et al., 2007 demonstrated further that, during solar minimum, the relative helium abundance correlated with the heliographic latitude of the observer. They also found a linear relationship between the
solar wind speed and relative helium abundance for slow (less than 550 km/s) solar wind. Mapping the in situ measurements back to the solar wind source region allows us to relate helium abundance to conditions at the Sun.

We investigated the coronal sources of the relative helium abundance variations using the WSA-ENLIL model. Improvements to the WSA-ENLIL model have led to better solar wind predictions. Using these improved simulations of the connection between the corona and interplanetary space, we determine the source regions for several time periods during solar minimum when the predicted solar wind speed yields good results as compared with observations. We investigated helium abundance as a function of source region properties such as distance to the current sheet, magnetic expansion factor and the distance to the edge of a coronal hole (see Figure 44).

![Figure 44](image)

**Figure 44** Two-dimensional distribution of mapped data plotted versus distance from mapped open flux boundary and versus expansion factor. Contours of solar wind speed are overlaid (from McGregor et al., 2008).

In the slow solar wind, for speeds greater than 530 km/s, the alpha-to-proton abundance ratio is proportional to speed; solar wind speed is a function of the distance to the edge of the open flux region for slow wind, producing slower wind (lower alpha-to-proton ratio) closer to the boundary. For speeds between 350 and 530 km/s, the ratio varies with heliographic latitude; for a given solar wind speed observed at 1 AU, initial speeds (mapped back to 0.1 AU) vary with Earth's heliographic latitude, with average initial speeds at higher heliographic latitudes.
In validating the back-mapping from 1 AU to 0.1 AU, the ENLIL results demonstrate that the simplistic technique of ballistic propagation, even during the relative quiet and order of solar minimum, only works in a highly averaged sense. Figure 45 shows how back-mapped solar wind plasma in the model evolves in speed between 0.35 AU and 0.1 AU. Slower solar wind plasma tends to be accelerated over this range while faster solar wind tends to be decelerated. Plasma at intermediate speeds typical of the most probable speeds, have a wide range of initial speeds at 0.1 AU. The use of this validated model is allowing us to quantify how well arrival times of solar wind features based on simple ballistic models can be expected.

Figure 45 Model solar wind speeds at 0.4 AU backmapped in the model to their source region at 0.1 AU. (from McGregor et al., 2008).
2F REFERENCES


Sawyer, D. and J. Vette (1991), AP-8 trapped proton environment for solar maximum and solar minimum, National Space Science Data Center, Report 76-06, Greenbelt, Maryland.


Tsyganenko, N., A model of the near magnetosphere with a dawn-dusk asymmetry, J. Geophys. Res.


III. Education

The primary mission of the CISM education program is to prepare the next generation of space physicists and imbue them with an understanding of the Sun and Earth as a system. Our goal is to instill in them a holistic view of the Solar Terrestrial environment that is unusual in our fragmented field. The core elements of our education program are:

1. The CISM Summer school
2. Building a graduate student community
3. Enhanced Undergraduate Research
4. Grade 6-14 education and increasing science literacy

The first three elements are highly specific to CISM and are tightly coupled with CISM’s research. The fourth element uses CISM content to engage the broader audience in formal and informal education settings, often leveraged with other efforts. Details of the CISM Education program, its objectives and assessments are given in the CISM Education Plan, which is available on our web site. During the past year we have continued to build on the highly successful aspects of our education program. Progress in the four CISM Education elements during the past year are summarized below.

Significant Accomplishments in the Last Year:

- Held another successful CISM Summer School attended by 28 participants out of 56 applicants including: 19 graduate students, 2 undergraduates, 3 Space Weather Forecasters, and 4 other space weather professionals.
- Held the seventh graduate student retreat attended by 15 CISM graduate students from six institutions.
- Ongoing graduate student professional development through mentoring, multi-institutional student research and CISM graduate student gatherings at professional development meetings.
- Two graduate students completed their Ph.D. degrees bring the CISM total to 10 since the beginning of CISM.
- Involved 25 undergraduates in CISM related research projects.
- Involved several teachers and undergraduates in summer internships in continued support of the Space Weather Monitors program at Stanford.
- Continued support of 300 SID monitors distributed world wide since 2005.
- Publication of two papers related to the CISM Education program.
Programs

The CISM Summer School:

The summer school is a two-week course in space weather and space weather models. It is intended primarily for first-year graduate students; however it is taught at a level and in a manner suitable for well-prepared upper division undergraduates, and also space weather professionals. Last summer there were 28 participants drawn from 56 applicants. This is the largest applicant pool we have ever had. The participants included: 19 graduate students, 2 were undergraduates, 3 forecasters, and 4 other space physics professionals. The next Summer School will be held July 20 – June 31st, 2009 at Boston University. The faculty and students of the 2008 school are listed in Appendix F.

The basic structure of the summer school includes three series of morning lectures on the space environment (“reality”), its effects on technological systems and humans (“harsh reality”), and models used to specify or predict the space environment (“virtual reality”). In afternoon computer labs students use results from these models and data to explore the concepts discussed in the morning sessions. The pedagogy of the summer school is active and hands-on. Lectures use a “Peer-Instruction” format where during a lecture students are given a conceptual question that they must discuss with their peers and report back on. Employing another technique, at the end of each mornings lectures students write questions on index cards that are collected; answers to the questions are provided just prior to the start of the labs. On the last day of the summer school the students engage in an event study that challenges them to integrate disparate data sets and simulations into a “concept map” that describes the event.

During the summer school there is explicit reflection on the pedagogy being used. Summer school participants may be future teachers, so a goal of the summer school is to inculcate some familiarity with active learning techniques in the participants. Moreover, it is a goal that CISM faculty will also gain familiarity with these techniques and use them in their regular classes.

Summer School materials are being adopted for a variety of uses. We are also disseminating information about the summer school to the professional community. Along with presentations on the CISM Summer School at professional meetings, we have published a descriptive paper on the summer school. We have had several inquiries about adopting the summer school materials and are working closely with those institutions interested in doing so. We are creating a summer school version of the CISM-DX Live disk (a bootable Knoppix disk with a version of CISM-DX, our custom designed visualization package, on it). With this disk, any PC can boot into a Linux system with CISM-DX and the summer school labs can be run. The labs are currently being revised based on pre-defined objectives to increase their effectiveness for use during the
summer school and in other settings such as a graduate or undergraduate classroom.

Graduate Student Community

With graduate students distributed among eight CISM institutions, the Center employs a variety of activities to develop a sense of community among the students. Each year we hold a Graduate Retreat and invite all CISM researchers to send their graduate students. The retreat is intended for students who are or will be engaged in CISM research and who we expect to be within CISM for a few years, completing their thesis or dissertation on a CISM topic. The 2008 graduate student retreat was held at the Breckenridge Resort in New Hampshire on September 13-14. 15 graduate students from six institutions participated in the retreat, which was led by J. W. Hughes with additional mentoring support from Sarah Gibson and John Linker. This year’s special topic was: “Balancing work and life”. These meetings allow the CISM graduate students to share their research and build community. The rotating program has focused on professional development items not normally taught in a formal graduate curriculum, such as: the funding and management of research, how to prepare research proposals, ethics in science research, or publishing papers.

Graduate students also interact as a CISM-wide group via all-hands meetings, CISM graduate student luncheons at professional meetings, and through cross-institutional interdisciplinary research. In the past, CISM graduate student have also interacted through: Access Grid (AG) sessions, a graduate student website, and a graduate student run Wiki. These interactions provide CISM graduate students with a strong sense of community and a unique, holistic view of the Sun-Earth system. Through these close interactions the students are forging the foundation for career-long professional relationships and developing expertise that will provide a core of space weather researchers to carry forward the CISM legacy. In the last year, 2 students working on CISM related projects earned Ph.D.’s bringing the total to 10. Six others earned terminal masters degrees mainly from the Thayer Engineering School at Dartmouth and the Masters program at AAMU.

Support for Undergraduate Research

Academic year research projects provide undergraduates with valuable skills and experiences within the unifying CISM context. Throughout the year CISM provides opportunities for undergraduates to share their research and engage in professional development. During the past year, 25 undergraduates, including 11 women and 12 students who belong to underrepresented minority groups, participated in CISM projects.

Undergraduate participation in CISM research provides a diverse group of students with experience and personal connections that kindle and support their
interest in scientific careers in general, and in space weather specifically. Because of the distributed nature of CISM, undergraduates working on CISM projects at various institutions have diverse goals, backgrounds, and schedules. Under these circumstances we find that the Center can best support these students by providing individualized experiences for students where it is appropriate.

During the lifetime of CISM, 14 undergraduate students who have worked on CISM related projects have entered graduate programs. Of those, 12 entered departments with strong space physics research programs.

The CISM Education program works closely with the Diversity program. For example, in March of this year an undergraduate event targeting minority recruitment for graduate programs, Space Weather Weekend, was held at AAMU. Nine undergraduates from historically black institutions or institutions that serve the Latino community, all of whom intend to go to graduate school, attended. Space Weather Weekend was organized by CISM Co-Director for Diversity R. Lopez and hosted by CISM researcher and AAMU faculty members Amy Winebarger and M. Schamshula. CISM co-Director for Education, Nicholas Gross was also involved. The weekend was spent discussing with the students various aspects of space weather research and opportunities for graduate study. One of the most popular sessions is the discussion about applying to graduate school. Students are given an opportunity to discuss what is important to them in a graduate program and ask about application issues and hurdles they might face.

Because of his background in physics and his experience with curriculum development and education research, the co-Director of Education, Dr. Nicholas Gross, is in a unique position to inform the space physics community about the latest techniques prescribed by education research. Using the methodology of education research, Dr. Gross has worked to identify concepts that students at the undergraduate and graduate level have difficulty with. With these concepts identified Dr. Gross will develop curricular materials that can foster conceptual change in those students and test them during the CISM summer school. For example, there is now evidence that some students believe that the solar wind flows in a spiral pattern out from the sun rather then a radial direction. Evidence shows that this belief can persist into graduate school and can be strengthened (rather then dispelled) by direct instruction regarding the spiral structure of the interplanetary magnetic field. This year saw the publication of that work co-authored by Dr. Gross and Prof. Ramon Lopez. An addition activity has been added to the solar wind lab to address this issue.

**Grade 6-14 Education and Science Literacy**

*Class Room Material and Teacher Professional Development*
A centerpiece of the CISM Grades 6-14 formal education program is the Sudden Ionospheric Disturbance (SID) Monitor (http://solar-center.stanford.edu/SID/) developed by the Stanford Solar Group (http://solar2.stanford.edu/) under the guidance of Deborah Scherrer. The SID monitor is an inexpensive ($250) Very Low Frequency (VLF) radio receiver that is tuned to one of several VLF transmitters around the country. VLF radio signal strength is sensitive to the state of the ionosphere. Changes in the signal strength indicate changes in the ionosphere, which can be due to solar activity. This is a leveraged program with CISM providing support for the development period and is currently supporting an engineer and students who support the monitor program at Stanford. NASA grants provide the funds for distribution. For some locations, CISM researchers have been acting as mentors for some of the SID monitors. In addition to the 100 monitors distributed through out the US, an additional 200 have been distributed world wide through IHY programs including 50 in Africa. Each monitor can be connected to an Internet ready computer and the provided software can automatically collect data and post it in daily to a central server. Thus, students in the US can access data from around the world.

In addition to the monitors themselves, Stanford has developed high quality teacher training and classroom materials. To do this, Stanford worked with the Chabot Space and Science Center in Oakland, CA and Master Teachers, along with NCAR. A draft of these materials is currently available at (http://www.chabotspace.org/vsc/solar/spaceweather/) This draft has been piloted by two classroom teachers and the results are being professionally accessed.

In an initiative that involves both undergraduate students and middle school students, last year Dr. Gross worked with the BU chapter of the Society of Physics Students (SPS) to develop an outreach program that they can present at local schools. Last year the BU physics students adapted materials and activities first developed as part of the CISM Summer School. The students piloted this presentation in an 8th grade classroom at the Peabody School in Cambridge. This year the SPS students at BU are using a similar model with different material, but again are working with Dr. Gross to develop grade appropriate materials to present to middle school students.

**Informal Science Education Resources**

In 2006 CISM simulation results were incorporated into a major planetarium show, “Cosmic Collisions”, produced and presented at the Haydan Planetarium at the American Natural History Museum in New York City. Five CISM researchers were involved in this effort including two graduate students from separate institutions who collaborated on generating the visualization. The show continues to run to millions of viewers.

Our web based efforts continue to play a key role in our outreach program. By providing content and modest resources to existing science and space science
web efforts we have been to successfully leverage the contribution we have made to reach a large and broad population. First, the UC Berkeley and Stanford education teams in partnership with the San Francisco Exploratorium have developed a Space Weather website based on CISM-related topics, imagery, and materials. It can be found at http://www.exploratorium.edu/spaceweather/. The Exploratorium space weather site is interlinked with the NCAR, Stanford, and Rice University websites. It contains background information about space weather, visualizations of space weather models, and video clips of CISM scientists explaining concepts in space weather.

The education group at NCAR, has been leading development of web-based resources on space weather for students ranging from elementary through to undergraduate students, leveraging the expertise in informal science in the “Windows to the Universe”, http://www.windows.ucar.edu/. This website exists in both English and Spanish editions. Hundreds of thousands of people visit the site every year to learn more about space weather and its impacts on the Earth. The number of pages visited and unique visitors for this website are reported on the Education Metrics in Appendix J.

Another CISM sponsored web resource is the real time space weather prediction based on a neural net model that takes the Boyle Index as input. This webpage is developed and hosted at Rice Univ. and can be seen at http://space.rice.edu/ISTP/wind.html. Based on this model, alerts are generated that can be distributed to a subscriber list. This list is not intended for operations, but is meant for education and outreach purposes. It is advertised through teaching networks and conferences.

**Education Support for other CISM components**
The CISM education program works closely with other aspects of the program, both to support the education goals, and also to further the goals of the other thrusts. For example, the Space Weather Summer School makes use of the CISM-DX visualization tools developed for the research program. This allows participants in the summer school to explore space weather phenomena as exemplified by the simulation results. Labs developed for the summer school are then used as part workshops run by the Knowledge Transfer program and as a recruitment tool for the Diversity program. The education program will continue to build closer ties with the research program, as students are trained in research and as new research materials are adopted for curricular use.

**Evaluation and Program Performance**
Where appropriate, each of the individual program elements has an evaluation component as part of that programs development. For example, the Space Weather Summer School conducts both formative and summative evaluation. In addition, for the program as a whole, we have defined and reported on metrics that are listed in Appendix J.
IV. Knowledge Transfer (KT)

In addition to the normal dissemination of research results within the scientific community (achieved through publishing papers in journals and reporting results at meetings) the CISM Knowledge Transfer plan has three distinct objectives:

1. Facilitate the transfer of validated models to an operational environment at relevant government agencies;
2. Provide models and visualization tools to the broad research community; and
3. Train and interact with government agencies, the aerospace industry, and others who must cope with space weather.

These three objectives are supported through five program elements as indicated in the CISM Knowledge Transfer Matrix that is in the CISM Strategic Plan.

The KT work is broadly distributed throughout the Center and also involves close partnerships with the Community Coordinated Modeling Center (CCMC), Space Weather Prediction Center (SWPC), and Air Force Research Laboratory (AFRL). A stage has been reached where very substantial progress is being achieved in transitioning complex, coupled models for use by the research community (through CCMC) and the operational community (through SWPC and AFRL). A list of released models is provided in Appendix G.

To provide a flavor of the model transition work, we focus below on the development of realtime forecast tools using CISM models at SWPC.

**SWPC Real-Time Prediction of the Ambient Solar Wind Parameters**

The 3-D magnetohydrodynamic numerical code ENLIL is a research tool for simulating the corotating ambient solar wind structures and the transient solar wind disturbances. The physical model is based upon an ideal magnetohydrodynamic (MHD) description while the numerical scheme is an explicit high-resolution TVD Lax-Friedrich scheme. A real-time Solar Wind Model has been implemented at NOAA/SWPC where the ENLIL application is driven by the empirical Wang-Sheeley-Arge (WSA) model. This model uses daily observations of the photospheric magnetic field (solar magnetograms) to compute a potential field source surface at 2.5 Rs, and a Schatten current sheet model extends the magnetic structures out to 5 Rs or 21.5 Rs, which constitutes the boundary for the MHD code. An empirical formula derives the radial solar wind speed from the radial magnetic field configuration. ENLIL uses this as the daily specification of the inner boundary (at 0.1 AU) of the computational domain which reaches out to 1.1 AU. Note that a single, corotating map is used to drive the simulation.
Figure 46 Visualization of the solar wind velocity from the experimental real-time prediction model. Results of the heliospheric computations are shown between 0.1 and 1.1 AU for a −/+ 5 day span about the beginning of the day with the most recent solar wind source data. Date (yyyy-mm-dd hh:mm:ss UTC) at the top center corresponds to displayed results. Date (yyyy-mm-dd UTC−/+ days) at the top right gives time relative to beginning of the day with the most recent solar wind source data. Negative (positive) values are for times prior (subsequent) to that reference date. Three slices passing through Earth show the radial component of the solar wind velocity using the color scale given at the top left. The white line shows the heliospheric current sheet which represents a magnetic sector boundary. The polarity of magnetic sectors is indicated by blue or red color at boundaries of the computational region. The blue is for negative (toward the Sun) and the red is for positive (away from the Sun) polarity. The black-and-white dashed line shows the interplanetary magnetic field (IMF) line which passes through the Earth. Planets and spacecraft are denoted by symbols shown at the bottom right.

The following additional data sets are applied to the daily runs: (1) Trajectories of planets and several spacecraft of interest are used during ENLIL computations to store values of the solar wind density, velocity, temperature, and magnetic field, and they are also displayed on the global solar wind plots; and (2) ACE real time solar wind and magnetic field (SWEPAM, EPAM) data are used to ascertain the accuracy of the numerical simulation of those parameters at Earth.

Daily runs have been provided (since early 2007) with the first coupled versions of WSA+ENLIL. Dusan Odstrcil has developed a web site to display the daily results at the following NOAA/SWPC website: [http://helios.swpc.noaa.gov/enlil/latest-velocity.html](http://helios.swpc.noaa.gov/enlil/latest-velocity.html), specifically for the CISM project, see Figure 46. The computations were carried out in low resolution, i.e. 4°x4° in heliographic latitude and longitude. The first daily products were in the form of the so-called spiral plots, meridional cuts at the Sun-Earth line, and 1 AU sphere, together with line plots of 5 day forecasts of the solar wind parameters. These were delivered from the latest available NSO/SOLIS magnetograms. Later in 2007, SOLIS experienced a black out period due to extended maintenance, so that it
was decided to switch over to the latest available Mount Wilson magnetograms. Again, in January and February 2008, all US American solar observatories were subjected to weeklong outages due to severe winter storms passing over from the Sierras. In March 2008 it was decided to switch over to the reliable GONG magnetograms, which do not rely on a single observatory and are generated with hourly cadence. At the same time the once-daily runs were upgraded to medium resolution, i.e. 2°x2° in heliographic latitude and longitude, which allows for a much better specification of the ambient solar wind and resulting solar wind parameter forecasts.

A new experimental product was introduced in late 2007 in the form of a comparison between the daily-generated coronal hole (CH) map that is derived from a WSA run and the SOHO/EIT image indicating the CH structures on the solar disk. This tool has been refined by Leslie Mayer and is now made available on the NOAA/SWPC website: [http://helios.swpc.noaa.gov/WSA/](http://helios.swpc.noaa.gov/WSA/). The purpose of this tool, see Figure 47, is to provide the forecaster with a quick visual representation to show the reliability of the WSA generated boundary conditions that are propagated outward by ENLIL. A reasonable agreement between the remotely observed CH structures with the model derived ones can build confidence in the trustworthiness of the 5 day prediction of the corresponding solar wind parameters, and vice versa.

Figure 47. Visualization of the coronal hole structures from the experimental real-time prediction model. The right hand image displays the SOHO/EIT remote observation for a specified date (yyyy/mm/dd hh:mm:ss UTC) of the central meridian. Black structures are indicative of coronal holes which translate into ambient solar wind structures, white regions are flares from underlying sun spots. The left hand image displays the WSA computed coronal holes in color (scale according to field strength) which is overlaid over the GONG magnetogram in gray scale upon which was used as the input to the computation. In this magnetogram the sun spots show up as white/ black dipoles. The computed image is specified by the Carrington rotation number and the longitude of the center meridian.
An autoregressive prediction of the solar wind speed, based on real-time ACE SWEPAM data, has served successfully as a back-up during the times of data gaps in the solar observatory magnetograms. This empirical model has been running in the current experimental mode reliably for over 5 years now. This model is less accurate than the WSA+ENLIL method as it provides forecasts of the daily-averaged solar wind speed only, but is highly useful in the prevailing solar minimum conditions because it successfully captures the recurrence of the solar wind streams. At the request of the forecast personnel, the display was modified slightly to print the predicted speeds for the next days, see Figure 48.

We have recently developed tools for real-time validation. Best suited for this purpose is the currently available 5 years of daily 1 to 7 day predictions of the solar wind speed from the autoregressive model. Aside from a straightforward calculation of the prediction efficiency of a forecast, we have used comparisons of the histograms between predicted and observed data; and also characterized the joint distributions. A more advanced level is to repeat such a study for threshold crossings of the solar wind speed, or for functions of the forecast, such as the Heidke skill score, forecast ratio, true skill score, that are derived from dichotomous categories. Results of this validation work are being prepared for publication.

**Forecasting of Transient Solar Wind Disturbances**

A key new element is the addition of transient impulsive disturbances emanating from a localized region in the Sun’s corona. Such modeled disturbances can emulate coronal mass ejections which cause the largest and most significant geomagnetic storms at Earth. The so-called “cone model” has been added to the WSA-ENLIL framework in order to model transient solar wind disturbances (see Figure 48).

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Figure 48. Display of the predicted daily averages of the solar wind speed (black bars) from the experimental autoregressive model that is driven by real-time ACE solar wind data (underlying blue bars) together with a visual validation of the 1-day forecasts over the past solar rotation (indicated by the gray stripe).
Figure 49). It is a very high priority for SWPC to have a formal transition of the cone model to NCEP operation. The CISM team is working aggressively toward this goal, but the team also realizes that significant research is needed on cone parameter specification and also on sensitivities in the model that may be present as we seek to achieve accurate forecasts.

![Image](image_url)

**Figure 49.** WSA-ENLIL-Cone Transient Solar Wind. SWPC priority for formal transition to NCEP operations. Significant research is needed on cone parameter specification and sensitivities for forecast use.

**Development of a prototype regional ΔB product from the Geospace Model CMIT**

The first forecast product to be derived from the global magnetospheric code used by CISM (LFM) or, more generally from the global geospace model (CMIT), is the regional specification of the magnetic activity at Earth’s surface. George Millward’s work has been concerned with calculations of the ground magnetic perturbation response to ionospheric currents, as modeled by CMIT. The technique used is a Biot-Savart integration of the horizontal currents within the ionosphere to calculate the resulting ground-level horizontal perturbation (ΔB) of the Earth’s magnetic field.

The present ΔB product in development is shown in Figure 50. The visualization concept of the product is to show concurrently both the spatial and temporal changes in ground magnetic perturbations. In the example shown, the magnetic perturbation ΔB is represented by a green/yellow/red - “traffic light” - scale, in a similar way to the global kp index currently in use at SWPC. The present work is concerned with calculating the ΔB perturbations from suitable historical periods and comparing these to the relevant magnetogram data to assess the
effectiveness of using the CMIT code as a forecast tool for $\Delta B$ products. Animations of the modeling results allow forecasters and scientists to visualize the rapidly evolving regional magnetic disturbances.

Figure 50: Forecast products in development.

**MPI build of LFM on the NOAA/SWPC wJET computer**

An important step for CISM’s geospace modeling goals with SWPC is to port the CMIT magnetosphere-ionosphere code to run on NOAA parallel processor computers. The major hurdle to be addressed in this effort is get the LFM magnetospheric component of CMIT (by far the most computationally intensive part) running in a distributed MPI mode. Development of the parallel LFM has been on IBM Power5 architecture, very different from the Intel-based LINUX cluster available at NOAA. Recent work has resulted in the LFM now running in parallel on wJET, the NOAA distributed computer. This is a significant development as wJET represents a typical LINUX cluster, a computer architecture that will be come increasingly important for cost-effective computing in the near future. Building the parallel LFM on wJET provides a solid basis for replicating this on other LINUX systems such as those at CCMC where CMIT is being ported. CMIT is currently running at about 2.5 times real-time. It is using InterComm coupling and is in a higher resolution testmode running on 32 processors.

**Development of advanced space weather visualization products**

In addition to “traditional” visualization such as classic line plots and color contour maps we have begun to develop a full 3D visualization environment which would allow a forecaster to view multiple space weather parameters concurrently. An early example is shown in Figure 51, namely in form of a colored mesh which represents global Total Electron Content (TEC).
The partnership with CCMC seems to be progressing well. The CISM versions of CORHEL and WSA-EMLIL have been available at CCMC for some time and many runs of these models have been made. The overall suite of CISM models is shown here in Figure 52. As noted above, progress has been made on the MPI version of LFM and an 8-processor version is running presently at CCMC. The Run-on-Request procedures for processing and visualization are being finalized. In addition, a standalone version of TIEGCM is beginning the transition process that will be followed by the coupled CMIT 2.5 model. A preparatory step is to get standalone components running well in the CCMC environment prior to running the fully coupled model.
Lessons Learned From SWPC Transition Efforts

The CISM team has, we believe, learned valuable, widely applicable lessons about transitioning complex models to an operational government agency. These lessons hinge on the key point that models cannot simply be thrown “over the wall” to the government partner. It is quite clear that modelers – no matter how well intentioned and how interested – do not fully know what forecasters really need. On the other hand, even the best forecasters do not know what models can (or possibly could) do. It is a challenging matter to define what is needed and to develop appropriate solutions. The CISM-SWPC experience shows that several iterations are necessary to derive a good forecast product.

From the CISM experience to date, we would argue that a “transition team” approach is desirable and workable. This entails having a project team that is comprised of developers (modelers), forecasters, computation and software engineering experts, and managers. We recommend and strongly urge that the National Space Weather Program provide mechanisms and funding support for such collaborations.
V. External Partnerships

CISM has partnerships with the following organizations:

NOAA/Space Weather Prediction Center (SWPC) [formerly Space Environment Center (SEC)]: SWPC is the government agency charged with providing the civilian community with space weather information, specifications, and forecasts. CISM and SWPC have a close partnership. CISM views SWPC as a principal client or customer for space weather forecast models. Liaison between SWPC and CISM is facilitated through the CISM knowledge transfer team with substantial participation by the CISM model developers. This is discussed further in the Knowledge Transfer section of this report.

Community Coordinated Modeling Center (CCMC): The mission of CCMC is to provide space physics researchers with access to models, to provide an independent evaluation of space physics models both for research purposes and as potential forecast tools, and to facilitate the selection and ultimate transition of research models into operational forecast models. CCMC is based at NASA/Goddard and staffed through NASA, but is funded jointly by NASA, various Air Force agencies, and NSF. CCMC and CISM have a partnership in order to provide community access to numerical models developed by CISM, to collaborate in evaluation of coupling frameworks, and to provide further robustness through independent model validations. CCMC currently has versions of the Source Surface (PFSS), MAS, and ENLIL models available for community runs on request. The LFM, TIE-GCM, and CORHEL models are in-house at CCMC.

Air Force Research Laboratory: AFRL and CISM collaborate in three areas of model development. The WSA (CISM baseline) and WSA-ENLIL model development is supported by Nick Arge, as is ongoing work toward operational transition and use of these models. Kara Perry works with radiation belt modeling using fields from CISM physics models. Keith Groves and John Retterer are supporting a collaboration in which regional scintillation modeling is driven by the CISM CMIT specification of the global ionosphere. The AFRL Space Weather Center of Excellence is CISM’s primary interface to the DoD operational modeling community.

TeraGrid supercomputing Centers. NSF-funded supercomputer centers provide high performance computing resources for CISM model development and scientific use through the TeraGrid program. CISM is currently working with the National Center for Supercomputing Applications (NCSA), Texas Advanced Computing Center (TACC), and the National Institute for Computational Sciences (NICS).

The Exploratorium of San Francisco: The Exploratorium is the leading science museum in the San Francisco Bay area. They have worked with CISM to make the results of CISM research available to the public in the form of simulations, animations, and interpreted data. In conjunction with CISM partners, they have developed a Space Weather website based on CISM-related topics, imagery, and materials.

In addition to these established partnerships, CISM researchers have many informal collaborations with research scientists at other government labs, research centers and universities.
VI. Diversity

The CISM diversity mission is to increase the diversity of participants in space weather research at all levels. All CISM components attempt to promote diversity and increase the involvement of women and underrepresented minorities in space science and help build a vigorous research program at minority serving institutions. The CISM Diversity Plan is available at http://www.bu.edu/cism/Publications/DiversityPlanCISM.pdf and the CISM co-director for diversity is Ramon Lopez. Our recruitment of women and minority graduate and undergraduate students has been very successful, with 30% of U.S. graduate students coming from underrepresented minorities. This is on par with the proportion of these groups in the population as a whole and far above their representation in science as a whole. Similarly, the percentage of CISM graduate students who are women (40%) is well above the level of participation of women in physics as a whole. Our numbers for diverse undergraduate participation (52% minority and 48% female) are equally impressive.

CISM sponsored a session “Frontiers in Physics and Space Science” at the October 2009 SACNAS meeting in Salt Lake City and three students presented papers on CISM research at the February 2008 joint NSBP/NSHP meeting, in order to recruit students and provide information about space weather to a diverse audience.

CISM has the specific diversity goal of supporting the creation and development of a graduate program in space science and a vigorous space research program within the Alabama A&M University physics department. This new program provides a route for African American students to enter a field within which they are very poorly represented, and will remain a lasting legacy of CISM. The AAMU Ph.D. program has now recruited three Ph.D. students and one M.S. student into the program. One of the AAMU M.S. graduates (female, African-American) is now pursuing a Ph.D. at the University of New Hampshire in space physics. Dr. Amy Winebarger (hired into a tenure track position at AAMU with partial CISM support) was awarded a CAREER grant in 2006 by the NSF and is well on her way to tenure. CISM is also providing support to the newly formed department of Department of Atmospheric & Planetary Sciences at Hampton University by providing spaces for their students to attend both the Summer School and Space Weather Weekend.

A space weather weekend for students from minority-serving institutions or students attending either the SACNAS or NSHP/NSBP meeting and who are considering graduate school is held annually. The Space Weather Weekend was held at AAMU in April 2009.
MAJOR ACCOMPLISHMENTS DURING THE PAST TWELVE MONTHS:

- Held Space Weather Weekend for likely minority graduate student candidates.
- AAMU space science graduate program now has 3 Ph.D. students and one M.S student enrolled in that program.
- CISM is expanding collaboration with Hampton U.
- Continued a multi-year trend in maintaining a high level of participation by women and minority students in CISM research.
VII. Management

A1. Organization

The CISM management structure is designed to address the challenges of running a multi-institutional center that requires close cooperation and collaboration between research groups in order to achieve its goals. The CISM management structure is shown in the organizational chart in Appendix B.

The management and administrative core is Director Jeffrey Hughes, Executive Director Jack Quinn and Assistant Director Kathryn Nottingham. Jeffrey Hughes, as the Director of CISM, is ultimately responsible for the direction and management of the Center. Jack Quinn works closely with the Director on day-to-day management functions and coordination of Center activities at the many geographically separate locations. Kathryn Nottingham is responsible for all administrative functions, including budget administration, overseeing the collection of management data and maintaining the databases required for evaluation.

The Center is divided into eight focused management areas, each led by a Co-Director. The Co-Directors, together with the Director, Executive Director, and four senior modelers (Jon Linker, John Lyon, Mike Wiltberger and Frank Toffoletto) form the CISM Executive Committee, CISM’s principal executive body. Charles Goodrich has responsibility for code coupling and computational aspects of the center. Harlan Spence is responsible for CISM model validation. Ramon Lopez leads our efforts in Diversity. Daniel Baker has lead responsibilities for the Knowledge Transfer component and for development of forecast models. Nicholas Gross is Education Co-Director. The research thrusts in solar/ heliospheric, magnetospheric, and ionosphere/thermosphere/mesosphere physics and modeling are the responsibility of co-directors Janet Luhmann, Mary Hudson, and Stan Solomon. Because of the Center’s integrative nature there is extensive interaction between these areas as they address the center’s shared objectives. However this thrust division represents a logical and effective management breakdown for the key aspects of CISM’s functions.

The CISM Executive Committee confers bi-weekly by means of a telephone conference call, and meets several times a year in person, either at scientific meetings that we all attend, or in conjunction with other CISM meetings. The Executive Committee develops strategic policies including definition and prioritization of tasks and time lines, monitors progress against these goals, and monitors overall activities with respect to overarching objectives. The director, in consultation with the Executive Committee, is responsible for the allocation of resources between thrusts and tasks. This overall management plan provides the structure, depth, and breadth needed to manage our complex center. Our management team has, both individually and collectively through our working together, the experience and resolve required to effectively manage CISM.

A significant challenge to the management of CISM is that there are 11 CISM core institutions: 9 universities, a national research center, and a commercial research company, that receive NSF funds. At each CISM site, the local principal investigator is responsible for managing activities and finances at that site and for coordinating with the appropriate co-directors to ensure that local activities are aligned with the overall CISM plan. Each site has a designated administrative contact who interacts directly with Assistant Director Kathryn Nottingham on all administrative and reporting issues, with
Ms Maureen Rodgers (BU Office of Sponsored Programs) regarding contractual issues, and with the BU Office of Grant and Contract Accounting regarding fiscal reporting issues.

The CISM Advisory Council provides independent guidance to the CISM director. It meets annually, in the early spring, to review the activities of CISM, and to provide guidance, advice, and oversight of Center management and all Center objectives. The Advisory Council membership is shown in Section D, below.

A2. Performance and Management Indicators

The CISM Performance Indicators are drawn from a diverse set of sources that are enumerated and referenced in the Performance Indicators descriptive document, which is maintained on the CISM web site. The Performance Indicators address the Center’s performance in five overarching areas: research, education, diversity, knowledge transfer, and function of the Center. The indicators are compiled and reported annually in various sections and appendices of this report. The entire set is extracted and maintained in separate binders that are available at the Site Visit.

The CISM Strategic and Implementation Plan was developed by the executive committee with input from the whole CISM team. The Plan defines goals and milestones for the individual thrusts within CISM and for CISM as a whole. The status of these goals and milestones, which is one of the Performance Indicators, is included as Appendix A. The director and co-directors are responsible for Center wide execution of the plan, and for engendering effective collaboration and close cooperation of the team in achieving these goals. The performance of the CISM management team, including the co-directors and local PIs, is to a large degree indicated by their ability to achieve the goals and milestones laid out in the Strategic and Implementation Plan and the other specific goals that are reflected in the Performance Indicators for the Center.

B. Progress, Problems, and Changes

The coronal modeling group that is responsible for one of CISM’s core models (MAS) has moved from SAIC to form a new company, Predictive Science, Inc. (PSI). The entire scientific and technical group involved in CISM work moved to PSI, where they continue to fulfill the same roles within CISM. The appropriate subaward and funding agreements between Boston University and PSI were completed in January and work is proceeding very satisfactorily.

C. Communication within CISM

CISM is a collaboration of faculty, research professionals, students, and staff at 11 core institutions and several partner sites. Frequent, efficient, and productive interaction of CISM personnel is critical to achieving our research, education, diversity, and knowledge transfer goals and to our smooth operation as a Center. For this reason we have developed a comprehensive set of communication methods that consist of periodic in-person meetings supplemented with a variety of electronic communications.

All-hands Meeting: The annual CISM All-Hands Meeting, held in September each year, is a principal management tool by which CISM goals and plans are developed, refined,
and adopted by the entire CISM team. The 2008 All-Hands meeting was held at the NCAR Center Green facility in Boulder on September 15-17. About 70 CISM team members attended (they are listed in Appendix E). The agenda, which is also contained in Appendix E, consisted of a series of plenary meetings together with many splinter meetings of the different groups and topical subjects within CISM. While the plenary meetings allowed for feedback and exchange within the whole group, most of the detailed work was done in the splinter sessions. One product of the all-hands meeting is a review and status of well-developed milestones that serve as one of the principal performance indicators for all aspects of CISM.

The 2009 All-Hands Meeting will be held in Boulder, hosted by NCAR, on September 14-16.

Other Annual Meetings: The annual CISM calendar is punctuated by a series of regular meetings. These include the annual Advisory Council Meeting in February or March and the annual NSF Site Visit in May or June. In addition CISM has a large presence at Space Weather Workshop, which is organized by NOAA/SWPC, usually in April, and brings together space weather researchers, forecasters and end-users. CISM also participates in the annual SHINE, GEM, and CEDAR workshops each June or July, and at the two AGU meetings (December and May). Each of these meetings provides an opportunity for meetings of the CISM Executive Committee and/or other specialized CISM groups such as the solar, magnetospheric, or ITM teams at SHINE, GEM and CEDAR. Finally the CISM Summer School brings together many CISM participants each summer.

Electronic Communication: Physical meetings cannot be held often enough nor include all the appropriate CISM members to provide the desired level of close communication in support of the integrated activities of the Center across multiple organizations. Thus much of our communication and interaction must be done electronically.

We use three forms of electronic communication: real-time video conferencing via the AccessGrid (inSors/IOCOM), telephone conferencing, and e-mail including a large number of topical mailing lists. The executive committee and various groups within CISM have regular meetings via these means.

AccessGrid meetings are held by several groups, either regularly or as-needed, including the Magnetosphere-Ionosphere Coupling Group (led by Bill Lotko), the Solar/Heliospheric Thrust (led by Janet Luhmann), the Validation and Metrics Thrust (led by Harlan Spence), the Magnetosphere Thrust (led by Mary Hudson), and CISM graduate students. During the academic year a series of CISM Science Seminars are conducted, led by Jeffrey Hughes. In addition the AccessGrid facilities are used for many ad hoc meetings by smaller groups and as a means of increasing participation in other meetings.

Telephone Conferences: Some groups within CISM make use of regular telephone conferences. These include the Executive Committee, Knowledge Transfer group and Education.
D. CISM Advisory Council

The CISM Advisory Council is chaired by Dr. Gregory Ginet; the full membership is given in the table. The Council held its 2009 meeting on March 3-4 at Boston University. The Council's report is included in Appendix C.

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gregory Ginet, Chair</td>
<td>Air Force Research Laboratory</td>
</tr>
<tr>
<td>2. Terry Forbes</td>
<td>University of New Hampshire</td>
</tr>
<tr>
<td>3. Cherilynn Morrow</td>
<td>Georgia State University</td>
</tr>
<tr>
<td>4. Janet Kozyra</td>
<td>University of Michigan</td>
</tr>
<tr>
<td>5. Jan Sojka</td>
<td>Utah State University</td>
</tr>
<tr>
<td>6. James Stith</td>
<td>retired, American Institute of Physics</td>
</tr>
<tr>
<td>7. Jerry Brackbill</td>
<td>retired, Los Alamos Nat'l Laboratory</td>
</tr>
</tbody>
</table>

Former Advisory Council members are:
- Joe Hollweg (UNH) 2003 - 2005
- Lisa Hunter (UC Santa Cruz) 2003 – 2004
VIII. Center Wide Outputs and Issues

1A. Center Publications

*Indicates Center participant, indicates student author


1B. Conference Proceedings

* Indicates Center Member, Indicates Student


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Pacific at dusk during quiet summer conditions from COSMIC data, CEDAR Workshop, Zermatt, UT, June 2008


24. Chu, F., M. Hudson*, B. Kress*
Dynamic Modeling of Radiation Belt Electrons: Radial Diffusion Model of Injection Into the Slot Region, GEM, Midway UT, June 2008


46. Fang, T-W., Wind dynamo effects on ground magnetic perturbation and vertical drifts, CEDAR Workshop, Zermatt, UT, June 2008
47. Farr, N.L., D. N. Baker*, and M. Wiltberger* The formation and evolution of a plasmoid flux rope using a global MHD simulation of an actual substorm event
48. 37th COSPAR Scientific Assembly. Held 13-20 July 2008, in Montréal, Canada
57. Hayashi*, K, An MHD simulation model of the global solar corona with the time-varying boundary magnetic field based on the measurement data, Spring AGU Meeting, Ft. Lauderdale, 2008
58. Hayashi*, K., M. Tokumaru, M. Kojima, K. Fujiki The MHD simulation of interplanetary space and heliosphere by using the boundary conditions of time-varying magnetic field and IPS-based plasma, Fall AGU Meeting, San Francisco, 2008
64. Hughes*, W. J., Predicting the Space Environment: Recent Results from CISM and Where Do We Go from Here, Space Weather Week, Boulder, April 2008
65. Huttunen E., Luhmann* J., J. Gosling, Small-scale transients in the slow solar wind during solar activity minimum, Joint GEM/Shine Meeting, Zermatt, UT, June 2008
activity and the connection to the large-scale coronal structure during the solar activity minimum, Spring AGU Meeting, Ft. Lauderdale, 2008


72. K. Kabin, R. Rankin, A. Degeling and S. Elkington*, Frequencies and polarizations of ULF waves in the magnetosphere: effects of ionospheric Pedersen and Hall conductances, Fall AGU Meeting, San Francisco, 2008


75. Krauss-Varban* D., Li Y., Luhmann* J.G., Oblique CME-driven Shocks: SEPs, and Upstream and Downstream Waves, Joint GEM/Shine Meeting, Zermatt, UT, June 2008

76. Krauss-Varban*, D., Y. Li*, S. Ledvina, and J.G. Luhmann*, Hybrid Simulations of ion Acceleration at Interplanetary Shocks: Decoupling From the Wave Turbulence on Large Scales and Resulting Flux Profiles, Fall AGU Meeting, San Francisco, 2008


81. Lai, P., Chin S. Lin, William J. Burke, New Hardy Auroral Flux Model for Driving TIEGCM , CEDAR Workshop, Zermatt, UT, June 2008


87. Li*, Xinlin Myths and Mysteries of Solar Wind Speed and MeV Electrons in the Magnetosphere, Presented by Xinlin Li at AGU at San Francisco, December of 2008.


105. Liu* Y., Hoeksema* J.T., Scherrer*, P.H., MDI/SOHO Level 1.8 Magnetograms, Joint GEM/Shine Meeting, Zermatt, UT, June 2008


121. Lyon*, J.G., Multi-Fluid MHD Simulations Invited Presentation at the Spring AGU Meeting, May 2008
123. Lyon*, J.G., On how the solar-wind plasma enters into the Earth’s plasma sheet, Invited Presentation at Non-linear Magnetosphere Workshop, Vina Del Mar, Chile, January 2009
137. Millward*, G. Transitioning the CMIT Magnetosphere-Ionosphere-Thermosphere model for Real-Time Space Weather Forecasting
143. Odstrcil* D., Heliospheric Simulations by ENLIL, Joint GEM/Shine Meeting, Zermatt, UT, June 2008


174. Schwadron* N.A., McComas D., Particle Acceleration at the Blunt Termination. Shock, Joint GEM/Shine Meeting, Zermatt, UT, June 2008

175. Schwadron*, N, INVITED, Coronal Loops as the Sources for Solar Wind, Spring AGU Meeting, Ft. Lauderdale, 2008

176. Siscoe* G., Hesse M., Kuznetsova M., Substorms and CMEs: A Search for a Common Onset MeChan*ism,Joint GEM/Shine Meeting, Zermatt, UT, June 2008


179. Suessmann, P., A Winebarger*, D Falcone, Correlation of STEREO\EUVI Luminosity and Active-Region Non-potentiality, Spring AGU Meeting, Ft. Lauderdale, 2008


190. Tokumaru, M. M. Kojima, K. Fujiki, K. Hayashi*, Unusual solar wind structure observed during the 2008 sunspot minimum, Fall AGU Meeting, San Francisco, 2008
201. Weigel, R.S., E. Kihn, D.N. Baker*, et al., The Virtual Radiation Belt Observatory: Progress and Plans, Fall AGU Meeting, San Francisco, 2008


Appendix A:  CISM Year 6-10 Goals and Milestones

(established October 2007)
Status as of April, 2008

**Annual Milestones:**

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Yr-6</th>
<th>Yr-7</th>
<th>Yr-8</th>
<th>Yr-9</th>
<th>Yr-10</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hold all-hands CISM meeting in early Fall.</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Sep 17-19, 2007</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>Sep 15-17, 2008</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>(Sep 14-16, 2009)</td>
</tr>
<tr>
<td>Hold Summer School for at least 25 students, of which at least 8 are</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Jul 23 – Aug 3, 2007</td>
</tr>
<tr>
<td>women or underrepresented minorities and 3 are from non-graduate school</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Jul 21 – Aug 1, 2008</td>
</tr>
<tr>
<td>settings.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Jul 20 – 31, 2009)</td>
</tr>
<tr>
<td>Hold annual meeting for CISM graduate students.</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>Sep 14-17, 2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sep 12-14, 2008</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(Sep 11-13, 2009)</td>
</tr>
<tr>
<td>Hold Space Weather Weekend for students from minority-serving institutions</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>April 4-6, 2008</td>
</tr>
<tr>
<td>Provide research opportunities for at least 10 undergrads of diverse</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>backgrounds.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
### Year 6 Milestones (July 2008):

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeze CORHEL 4.0, incorporating MPI MAS and (domain decomposition) ENLIL.</td>
<td>X</td>
</tr>
<tr>
<td>Freeze LTR 2.0: MPI LFM, TIE-GCM, RCM coupled geospace model.</td>
<td></td>
</tr>
<tr>
<td>Solutions to prior LFM-RCM coupling issues identified and being coded. MIX coupling model implemented and running with parallel LFM and TIE-GCM in CMIT 2.5. LTR 2.0 follows further testing of these two elements.</td>
<td></td>
</tr>
<tr>
<td>Provide community access to COHEL 3.4 (coupled MAS, ENLIL, CONE models).</td>
<td>X</td>
</tr>
<tr>
<td>Perform initial validations of SEPMOD runs with cone model.</td>
<td>X</td>
</tr>
<tr>
<td>Submitted to JASR Space Weather Modeling special issue.</td>
<td></td>
</tr>
<tr>
<td>Identify and develop test forecast products for CMIT at SEC. [SEC is now SWPC]</td>
<td>X</td>
</tr>
<tr>
<td>Interactive ground delta-B display with arbitrary point forecast and comparison with magnetometer chains. CMIT 2.5 (with MPI-LFM) installed on SWPC wJET cluster. Testing and event analyses proceeding in coordination with SWPC personnel.</td>
<td></td>
</tr>
<tr>
<td>Report on validations of WSA-ENLIL running as realtime solar wind forecast model at SEC.</td>
<td>Ongoing</td>
</tr>
<tr>
<td>WSA-ENLIL running daily since March 2008; displays used in SWPC (formerly SEC) morning forecaster briefing. Forecaster and CISM assessments of realtime performance continuing.</td>
<td></td>
</tr>
<tr>
<td>Hold community modeling workshop.</td>
<td>X</td>
</tr>
<tr>
<td>Community workshop held June 22 with NSF sponsorship in conjunction with CEDAR, GEM, SHINE.</td>
<td></td>
</tr>
</tbody>
</table>
**Year 7 Milestones (July 2009):**

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provide Summer School labs and supporting materials for community use.</td>
<td>X</td>
<td>Web access provided. Announced and described in: Gross et al., EOS, V90, 2, p13, 2009.</td>
</tr>
<tr>
<td>Freeze CORHEL 5.0, adding “thermodynamic” MAS.</td>
<td></td>
<td>Now expected Spring, 2010</td>
</tr>
<tr>
<td>Provide community access to CMIT 2.5 (coupled MPI LFM, TIE-GCM)</td>
<td>On Track</td>
<td>CMIT components (MPI LFM and TIE-GCM) provided to CCMC for standalone. Coupled version next.</td>
</tr>
<tr>
<td>RADBELT and SEP Cutoff codes running in LTR fields with SEPMOD input.</td>
<td></td>
<td>Pending LTR. Codes running in LFM fields as interim measure.</td>
</tr>
<tr>
<td>Freeze LTR with capability for initialization using a data-assimilated ionosphere, solar forcing, and asymmetric RCM.</td>
<td></td>
<td>Solar forcing implemented in TIE-GCM (CMIT 2.5). Asymmetric RCM in development. Initial tests performed with data assimilated ionosphere in TING, but not yet implemented in TIE-GCM.</td>
</tr>
<tr>
<td>Complete realtime test system for CMIT at SEC.</td>
<td>Ongoing</td>
<td>Systems for realtime processing of input Solar wind data and output displays/products are in place. Development of CMIT code for full realtime operation to follow after the satisfactory completion of testing and event analyses.</td>
</tr>
</tbody>
</table>
**Year 8 Milestones (July 2010):**

<table>
<thead>
<tr>
<th>Milestone</th>
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<tbody>
<tr>
<td>Freeze SEPMOD 2.0, adding x-ray based flare source option.</td>
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<tr>
<td>Freeze RADBELT and SEP Cutoff codes for LTR fields.</td>
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</tr>
<tr>
<td>Freeze LTR version with TIME-GCM, multi-fluid LFM.</td>
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<tr>
<td>Identify institution(s) and structure for post-STC “integrator” functions.</td>
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### Year 9 Milestones (July 2011):

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<tbody>
<tr>
<td>Complete development of time-dependently driven MAS; ready for CORHEL implementation.</td>
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<tr>
<td>Freeze LTR adding high resolution TIME-GCM and inductive coupler for MI gap region.</td>
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### Year 10 Milestones (July 2012):

<table>
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<tbody>
<tr>
<td>Freeze CORHEL 7.0, adding thermodynamic MAS driven by flux-evolution model</td>
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<tr>
<td>Graduate first Ph.D. student from new AAMU program.</td>
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<tr>
<td>Complete transition of model repository and “integrator” functions.</td>
</tr>
<tr>
<td>Comprehensive validation/metrics report.</td>
</tr>
</tbody>
</table>
Appendix B: Organizational Chart
Appendix C:  Advisory Council Report
Center for Integrated Space Weather Modeling
Advisory Council Summary
10 Apr 2009

The Advisory Council (AC) to the Center for Integrated Space Weather Modeling (CISM) met at Boston University on 3-4 Mar 2009. Present were Gregory Ginet (Chair), Terry Forbes, Cherilynn Morrow, Jan Sojka, James Stith, Jeremiah Brackbill and Janet Kozyra.

The AC applauds the continuous effort, scientific focus and broad composition of the CISM team. Essential difficulties previously reported in several parts of the project have been indentified, and new directions for component development and model coupling have emerged. CISM models are beginning to show the interesting features that result from two-way coupling between geospace regions. It is likely that many new scientific discoveries will be found in the details of this two-way coupling in addition to the expected improvement in forecasting accuracy and the ability to track back to the sun and identify geoeffective elements of solar eruptions and large-scale interplanetary field and particle structures. With a robust cadre of graduate students, the summer school and an aggressive campaign to promote minority involvement in space weather, among other projects, CISM is developing a diverse population of space physicists and related professionals well-educated in and actively exploring the coupled-domain nature of space weather. To further progress the AC offers the comments below in the spirit of independent and constructive analysis.

General

As CISM progresses it is becoming clearer what can and cannot be achieved in modeling the coupled heliosphere-magnetosphere-ionosphere-thermosphere system within the timescale and resources of the program and the limits of current data and theory. There are over three years left for CISM as an NSF Science and Technology Center (STC) and the time has come to develop the “critical path” to complete a coupled model capable of propagating disturbances from the solar surface down through the thermosphere with a sufficient description of the environment to be useful for scientific analysis and forecasts of space weather impacts. This is CISM “End-State” model according to the CISM Strategic Plan. Such a critical path should be based on the six years of knowledge gained to date concerning team capabilities and the critical space physics and computational issues. The End-State model should be realistically achievable, which means compromising on capabilities originally envisioned, and completed with enough time to do sufficient validation. Undoubtedly the model will not be complete and miss certain features completely, but it will exist and be
useable as the first of its kind and serve as a foundation for space weather forecasting.

In the final few years of the STC funding, with a few carefully focused studies, CISM can demonstrate the breakthrough science that begins to fulfill the promise and justify the expense of the developing cyber infrastructure, distributed ground- and space-based observatories, STC's and open data policies of the last few decades. Interdisciplinary investigations of the end-to-end space weather system generally require teams of people from multiple discipline areas contributing a wide variety of data sets, models and expertise. These teams are difficult to pull together and fund within the current program structure at the agencies and CISM is probably the only team of this kind already in existence. CISM can demonstrate the need for a system-level approach that pushes us away from traditional modes of carrying out scientific research and in the process, will likely help to revolutionize the very way in which collaborative scientific research is done in the future.

Research

Good progress has been made in predicting the properties and occurrence of Solar Energetic Particle (SEP) events given the properties of the Coronal Mass Ejection (CME) shock as a function of time and space. However, the current lack of a working CME model within the region of the corona below 30 solar radii greatly limits the ability to make useful predictions of the onset and early stages of an event, a period when the generation of the highest energy particles occurs. Given that the SEP event work in the context of the CISM model will comprise one aspect of the project that is both valuable and successful it is recommended that this gap be filled whether by a CISM-generated model or adaptation of an existing model. The prediction accuracy for the early stage should be no worse than existing techniques and for the later stage will be significantly better.

The work with the MAS code modeling the solar corona continues to produce exciting new results as the ramifications of the consistent thermodynamics and variation of boundary conditions are explored. It's apparent that the vector magnetogram data and hard X-ray images of the corona impose incomplete constraints on the dynamics, and that flow maps often can't be devised to reproduce observed magnetic field topologies. Progress seems to occur by exploring the boundaries of what is possible within the constraints of the data. In the spirit of the critical path an assessment needs to be conducted with the goal of moving MAS beyond single event studies to determine what a reasonable set of internal parameters might be and whether existing data can be used in some manner to trigger the onset. If MAS cannot be configured to produce a shock profile within 30 solar radii as needed by the SEP model, then an alternative must be chosen for the CISM End-State model.
Results on RCM/LFM coupling are encouraging and studies of the type presented by Toffoletto should serve as a guide for the RCM-LFM-TIEGCM integration effort. In addition to the better understood LFM spatial resolution issues generated by RCM pressures, it has been found that the location of the RCM domain boundary and inclusion of plasmasphere, charge exchange, and polar outflow models all have significant effects on the solutions – not just on numerical stability but also on fundamental physical features such as substorms and Region-2 currents. The coupling of the RCM to the parallel LFM is rightly the highest priority and will provide for quantification of the resolution issues when completed. Studies on the component models should be continued and a priority list developed based on what gives the most effect and can be integrated into the model within the scope of the program. A stable RCM-LFM-TIEGCM with realistic outputs, albeit perhaps in a limited parameter regime, will be a major accomplishment of CISM and something the space physics community have waited over 20 years to see! Identification of the limits of current models in terms of what is really important for magnetosphere-ionosphere coupling will drive future research efforts.

The development of the MIX module is an important new development for CISM that enables independent code developers to efficiently interact and implement their magnetosphere-ionosphere-thermosphere coupling needs. With the successful integration of the TIEGCM into CMIT 2.5 the focus should turn to coupling studies of the type demonstrated with RCM-LFM but using MIX to push into the ionosphere-thermosphere regime. Several good metrics have been identified for the ionosphere/thermosphere (e.g. \(\Delta\)TEC maps, cross polar cap potential data and satellite drag measurements) which can be used to shake out the priorities for what needs to be added to the MIX. Some intriguing results were shown from runs of the coupled Community Atmospheric Model (CAM) – TIEGCM. It would be interesting to see if the effect is strong enough on the ionosphere/thermosphere metrics compared to the standard space weather drivers to warrant further effort in this direction.

The CISM team is encouraged to look at Co-rotating Interaction Regions (CIRs) as a phenomena that can be examined to demonstrate and validate the CISM 2.0, 4.0 and End-State models. Though not the most dramatic of space weather events, CIRs do have measurable impacts on the CISM metrics to include the L1 solar wind parameters, magnetospheric particle fluxes (both low and high energy) and field-aligned currents. CIR modeling would not exercise all components of CISM (e.g. certainly not the SEP or shock models) and shouldn’t be the totality of the validation efforts. However, the frequency of occurrence throughout the solar cycle and substantial associated data sets make CIRs attractive for validating the coupled CORHEL, LTR and RADBELT components in a relatively gentle but meaningful way.
**Education and Diversity**

The CISM Education program is making good progress along the lines of its stated mission to recruit and train the next generation of space physicists who will have new capacity to realize and carry on the scientific benefits of understanding the Sun & Earth as an integrated system. The Education program’s elements appropriately address all educational levels (from graduate & professional to middle school) and engage CISM scientists, data, and facilities in support of creating a powerful, positive impact on diverse audiences and participants.

There is also laudable progress in increasing the diversity of participants in CISM programs and in enhancing the participation of historically underrepresented minorities and women in space weather research in numbers that are significant with respect to the current participation by such groups. While progress has been made in articulating the role of various CISM institutions in supporting diversity goals, the AC continues to call for an institution-by-institution inventory of diversity efforts/results. While we are pleased with your overall numbers and experience, the committee would like to see evidence of buy in from the full range of CISM institutions.

The progress of the AAMU program continues to be impressive, and this element of the Diversity program stands to be an important part of the legacy of CISM. The AC would like to see a plan for the overture to Hampton University that has been mentioned at the past two meetings of the AC.

Overall, the Education and Diversity managers are doing a good job and are evidently well coordinated with the CISM PI and each other (e.g. the Education and Diversity managers have collaborated on education research and co-authored peer-reviewed papers on space weather education and CISM’s exemplary program elements.)

The AC recommends that the Education manager take advantage of CISM being the host for the upcoming STC Directors’ meeting and also of his new AGU leadership role (i.e. as Vice Chair and Chair-Apparent of AGU’s SPA Education and Public Outreach (EPO) committee) to help elevate the visibility of space weather education efforts around the nation, and in particular the visibility of the CISM Education and Diversity programs as exemplars among STC’s. These efforts have a noteworthy integration with the research and knowledge transfer elements of the Center, and this accomplishment should be communicated along with other programmatic successes via sessions at AGU and other appropriate professional occasions. The appointment of CISM’s EPO manager to this AGU leadership position is in itself a notable achievement for CISM since he had had no contact with the AGU prior to coming to work with CISM.
The AC suggests that future presentations of CISM's Education program be framed in terms of the objectives and indicators cited in the CISM Education Plan, and that appropriate attention be given to the national STEM education frameworks and agendas to which CISM is contributing. Detailed comments on each of CISM’s Education Programs is provided in Appendix A.

**Knowledge Transfer**

CISM continues to excel in transitioning models to the operational and application-oriented space weather agencies. It is obvious that the team has been working hard with NOAA/SWPC, NASA/CCMC and AFRL and there is much progress to show, e.g. the CMIT and WSA-ENLIL-Cone projects at SWPC. CISM has done an admiral job indentifying and minimizing the many issues impeding the transition of models from research to operations, successfully navigating a narrow but productive path. The AC urges the team to continue the often tedious and unglamorous but vitally important transition effort. CISM forecast models spanning the regime from sun-to-ionosphere are in the pipe at SWPC and, when they become fully operational, will be a huge CISM legacy and go far in justifying NSF’s STC investment.

Systematic validation of the heliospheric components of the CISM models for high speed enhancements is going well. This comprehensive analysis covering over 250 events spanning a solar cycle has provided both error bars for the forecasters and information needed to improve the model. Similar validation campaigns should be carried out on other high priority metrics (e.g. SEP profiles, ΔTEC, LEO & GEO particle fluxes, cross polar cap potential and field-aligned currents). A comparison of the magnetospheric and ionospheric metrics from the complete CISM model driven by solar and heliospheric observations vs. the LTR component model driven by L1 data will illuminate the tradeoffs between accuracy and lead-time and help identify which physical processes are the most responsible for driving the dynamics of concern.

**Management**

As the critical path for the last 3.5 years becomes clear, resources will likely have to be shifted to meet the revised goals. Tremendous progress on many fronts has been made and it is clear to the AC that CISM can produce the integrated Sun-to-thermosphere model the community expects. That said, some components of the CISM program are of higher priority. For example, one high priority area where CISM has already taken action is M-I-T coupling where the MIX concept has been implemented and a coupling expert (M. Wiltberger) has been added to the CISM Executive Committee. Other areas that are considered high priority in the eyes of the AC are indicated in this report. CISM leadership
should evaluate the current program plan in light of the critical path to the CISM End-State model and make any changes necessary to ensure a successful outcome.

**CISM needs to identify and label its contribution to models at every step and promote the distribution of the coupled set.** Credit needs to be given where credit is due. For example, much was made of the completion of TIE-GCM V1.92 and the connection to CISM should be displayed (it is not on the TIE-GCM website). In another example, on the CCMC web page “CCMC Hosted Models at a Glance” there are several CISM component models listed, but no listing of CISM itself. It is important that users begin to think of CISM as the suite of coupled models comprising CORHEL, SEPMOD and LTR. As was demonstrated with the LFM-RCM coupling studies of Toffoletto running the uncoupled models could easily be more “incorrect” than “correct”.

Advisory Report Appendix A: Detailed Comments on the CISM Education Program

Building a CISM Graduate Student Community

CISM’s emphasis on building community and nurturing students is laudable. So far, ten students have received PhD’s via their participation in CISM-funded research, and it is anticipated that as many more will complete their doctorates before CISM’s funding runs out. This indicates that the team is well on its way to accomplishing this task of populating the space physics community with new scientists who treat the system as a whole not as merely individual heliospheric, magnetospheric or ionospheric components.

The annual graduate student retreat (attended by 15 students in 2008) and convened in conjunction with CISM all-hands meetings continues to foster cross-institutional, interdisciplinary research interactions and to provide CISM graduate students with a strong sense of community and a unique, holistic view of the Sun-Earth system. For next year, the AC requests a more detailed update on the status of the “off-shoot” graduate student activities cited in the CISM Education Plan (August 2006). It would also be useful to survey the graduated students to identify what he/she is currently involved in. This kind of information is often viewed as a first level assessment of a program’s education “product”.

The CISM Space Weather Summer School

The 2-week CISM Summer School remains a flagship element of the CISM Education program with an inquiry-based, conceptually rich pedagogical approach and faculty from five different CISM-affiliated institutions. Participants have diverse backgrounds that are mutually enriching (e.g. graduate students, space physics professionals, and the occasional undergraduate or educator who may be a close associate of CISM efforts). The AC finds the publication of a peer-reviewed article on the Summer School’s pedagogy laudable, and recommends that further formative analysis and research be conducted to provide a base of scholarship to which Summer Schools in other disciplines can refer. This may be considered a key element of CISM’s legacy.

Undergraduate Research Opportunities

The AC finds the broad spectrum of outreach and opportunities for undergraduates praiseworthy. There are 25 undergraduates involved in CISM-related projects at 5 institutions. Thus far, 12 CISM undergraduates have entered graduate programs with a strong space physics emphasis.

The Space Weather Weekend for undergraduates is a laudable strategy for recruitment of underrepresented students. The AC believes that it is very
important to recruit such students from BOTH Minority Serving Institutions (MSI’s) and majority institutions.

The use of Summer School activities for training undergraduates beyond CISM is also highly praiseworthy (e.g. LASP Research Experience for Undergraduates, and the prospective adoption into undergraduate labs at the Air Force Academy).

The work with BU’s SPS chapter to develop an outreach program for local schools is very exciting, particularly in light of enhanced support NSF has been providing to programs that promote the cultivation of secondary physics teachers. This program (which needs a good name) provides physics majors with an opportunity to test the waters of education as a potential career path, and this is as valuable an output of CISM’s education effort as physics majors who go on to graduate school. In furtherance of this program, the CISM Education Manager should become well apprised of BU’s options and tracks toward teacher certification as well as toward graduate school.

Grade 6-14 Education and Increasing Science Literacy

CISM’s efforts at the 6-14 educational level is well leveraged via collaboration with high-profile programs at CISM partner institutions. The strategy of high impact for modest investment is laudable. The AC requests more specific information on CISM’s contributions to these elements and evaluative data wherever possible. For example, it is noteworthy that CISM contributed to the development the Stanford Sudden Ionospheric Disturbance Monitors because this educational version of a research-grade instrument is now distributed throughout the world via a UN-sanctioned element of the IHY. CISM’s role in helping to seed this now shining program led by Deb Scherrer should be elevated. Also, the CISM animation contributed to the famous and highly-acclaimed Cosmic Collisions space show developed by the American Museum of Natural History should be made available for public presentations by CISM scientists and educators. Web data should be provided annually for the CISM-supported sections of two prominent websites: Windows to the Universe, and the Exploratorium site on Space Weather.
Appendix D: Media Publicity

None
Appendix E: All Hands Meeting

CISM All-Hands Annual Meeting
NCAR, Boulder, Colorado
September 15-17, 2008

☑ Baker, Dan, U. Colorado
☑ Balch, Chris, NOAA
☑ Bogdan, Tom, NOAA
☑ Bruntz, Robert, U. Texas, Arlington
☑ Burkepile, Joan, NCAR
☑ Burns, Alan, NCAR
☑ Crown, Misty, NOAA
☑ Damiano, Peter, Dartmouth College
☑ de Toma, Giuliana, NCAR
☑ des Roziers, Edward Burin, U. Colorado
☑ Dryer, Murray, NOAA
☑ Elkington, Scot, U. Colorado
☑ Emery, Barbara, NCAR
☑ Fang, Tzu-Wei, NCAR
☑ Fang, Yuhong, NCAR
☑ Farr, Nathan, U. Colorado
☑ Garcia, Katie, Boston U.
☑ Goodrich, Charles, Boston U.
☑ Gross, Nicholas, Boston U.
☑ Hagan, Maura, NCAR
☑ Hayashi, Keiji, Stanford U.
☑ Hudson, Mary, Dartmouth College
☑ Hughes, Jeffrey, Boston U.
☑ Knipp, Delores, USAFA
☑ Krauss-Varban, Dietmar, U. California
☑ Landivar, Jorge, U. Texas, Arlington
☑ Lee, Christina, U. California
☑ Lei, Jiuhou, U. Colorado
☑ Li, Xinlin, U. Colorado
☑ Lecinski, Alice, NCAR
☑ Lin, Wenlong, U. Colorado
☑ Linker, Jon, SAIC
☑ Liu, Hanli, NCAR
☑ Liu, Yang, Stanford U.
☑ Lopez, Ramon, U. Texas, Arlington
☑ Lotko, Bill, Dartmouth College
☑ Luan, Xiaoli, NCAR
☑ Luhmann, Janet, U. California
☑ Lyon, John, Dartmouth College
☑ Mayer, Leslie, CIRES/NOAA
☑ McGregor, Sarah, Boston U.
☑ McInerney, Joe, NCAR
☑ McCollough, James, U. Colorado
☑ Merkin, Viacheslar, Boston U.
☑ Millward, George, U. Colorado
☑ Mitchell, Betsey
☑ Oudstrcil, Dusan, NCAR/U. Colorado
☑ Ouellette, Jeremy, Dartmouth College
☑ Pembroke, Asher, Rice U.
☑ Perry, Kara, AFRL
☑ Pizzo, Vic, NOAA
☑ Prested, Christina, Boston U.
☑ Quinn, Jack, Boston U.
☑ Rastaetter, Lutz, CCMC
Reinard, Alysha, NOAA
Russell, Randy, UCAR/E&O
Schamschula, Marius, Alabama A&M
Scherrer, Deborah, Stanford U.
Schmit, Don, NCAR
Schmitt, Peter, NCAR
Singer, Howard, NOAA
Smith, Zdenka, NOAA/SWPC
Solomon, Stan, NCAR
Steenburgh, Rob, NOAA/SWPC
Sun, Xudong, Stanford U.
Sussman, Alan, U. Maryland
Tu, Weichao, U. Colorado
Wang, Wenbin, NCAR
Wilson, Erik, Boston U.
Wiltberger, Mike, NCAR
Winebarger, Amy, Alabama A&M U.
Woods, Tom, U. Colorado
Young, Shawn, AFRL
CISM All-Hands Meeting, 2008 Agenda

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<th>MON, Sep 15</th>
<th>TUE, Sep 16</th>
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<td><strong>8:30</strong></td>
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<td><strong>Intro &amp; Welcome</strong> Hughes, Solomon</td>
<td><strong>Model Mechanics</strong>&lt;br&gt;* InterComm &amp; HPCALE: needs for future development&lt;br&gt;* documentation, geo wiki example&lt;br&gt;* open source plans, TIEGCM exper.&lt;br&gt;* model delivery experience, test suites, etc.&lt;br&gt;* CVS-to-SVN transition</td>
<td><strong>SPLINTERS</strong>&lt;br&gt;1) Plasmasphere&lt;br&gt;2) Solar-Helio (contin.)&lt;br&gt;3) Ethics training session</td>
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<td><strong>SCIENCE MODELING</strong>&lt;br&gt;Thermodynamic MHD Coronal Modeling Linker</td>
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<td>Multifluid LFM Results Lyon</td>
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<td><strong>Modeling Storms with CMIT</strong> Wang</td>
<td><strong>SPLINTERS</strong>&lt;br&gt;1) RCM-LFM Coupling&lt;br&gt;2) Corona, CME initiation, Cone parameters&lt;br&gt;3) Atmosphere-ionosphere coupling</td>
<td><strong>Plenary Wrap-Up</strong>&lt;br&gt;Splinter reports as needed and general discussion</td>
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<td><strong>Radiation Belt Electron Transport &amp; Energization</strong> Hudson</td>
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<td><strong>Discussion</strong> All</td>
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<td><strong>FORECAST MODELING</strong>&lt;br&gt;High Speed SW Streams McGregor</td>
<td><strong>1:30</strong></td>
<td><strong>SPLINTERS</strong>&lt;br&gt;1) Multi-Fluid LFM &amp; related&lt;br&gt;2) Heliosphere, ICMEs, SEPs</td>
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<td>3:20</td>
<td>Geomagnetic Variations</td>
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<td>Thermosph. Neutral Density</td>
<td>Solomon</td>
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<td>4:00</td>
<td>Model Validation</td>
<td>Wiltberger</td>
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<td>4:20</td>
<td>Panel Discussion</td>
<td>Balch, Bogdan, Young</td>
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<td>5:30</td>
<td>CISM Reception</td>
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**MON, Sep 15** | **TUE, Sep 16** | **WED, Sep 17**

Numbered items (1, 2, 3) are parallel breakout sessions;
Appendix F: CISM Summer School 2008

Faculty Profiles

Alan Burns is a scientist at the High Altitude Observatory (HAO) at the National Center for Atmospheric Research. He is expert in ionosphere/thermosphere simulations.

Patricia Doherty is a research scientist at Boston College. She works closely with the Federal Aviation Administration (FAA) and with Air Force scientists on ionospheric space weather effects.

Michael Golightly is a research scientist at Boston University. He was previously with the human space flight program at NASA/Johnson Space Center, where he had responsibility for Astronaut Safety.

Nicholas Gross is the CISM Co-Director for Education. A physicist, he is an expert in physics education and curriculum development.

Michael Hesse is the Director of the Coordinated Community Modeling Center at NASA/Goddard Space Flight Center. He is an expert on magnetic reconnection and magnetospheric physics.

Jeffrey Hughes is a professor of astronomy at Boston University. He is an expert in magnetospheric physics, and is director of CISM.

Delores Knipp is professor emerita of physics at the Air Force Academy where she teaches a course on space weather. She is an expert on magnetosphere-ionosphere coupling.

Sarah McGregor is a Ph.D. candidate at Boston University. Her thesis research involves extensive coronal magnetic field modelling using the Wang Sheely Arge Model. She is a CISM summer school alumna.

Terry Onsager is a scientist with the NOAA Space Weather Prediction Center (SWPC) with responsibilities for transitioning models from research to operations. He is a magnetospheric scientist.

Kara Perry is a research scientist at Boston College. She works closely with Air Force Research Laboratory scientists on the radiation belts and their space weather effects. She is a graduate of the first CISM Summer School in 2001.

John Retterer is a physicist with the Air Force Research Laboratory. He is an ionospheric physicist expert in modelling ionospheric scintillations.

Margaret Shea and Don Smart are solar physicists, now both retired from the Air Force Research Laboratory. They have been active in research of solar effects on communications for many years.

Stan Solomon is a scientist at the High Altitude Observatory (HAO) at the National Center for Atmospheric Research. He is an expert in ionosphere and thermosphere physics.

Harlan Spence is a professor of astronomy at Boston University. He is an expert in magnetospheric particle physics and in spacecraft systems.

Robert Steenburgh is with the 2nd Weather Squadron, US Air Force. He is currently on detail as a space weather forecaster with NOAA/SWPC. He is also a CISM Summer School alumnus.

Michael Wiltberger is a scientist at the High Altitude Observatory (HAO) at the National Center for Atmospheric Research. He is expert in MHD simulations of space plasmas.
<table>
<thead>
<tr>
<th>Student</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katherine Baldwin</td>
<td>Naval Research Laboratory</td>
</tr>
<tr>
<td>Oliver Brambles</td>
<td>Dartmouth College</td>
</tr>
<tr>
<td>Thiago Brito</td>
<td>Dartmouth College</td>
</tr>
<tr>
<td>Michele Cash</td>
<td>University of Washington</td>
</tr>
<tr>
<td>Jeff Chancellor</td>
<td>Lockheed Martin</td>
</tr>
<tr>
<td>Ho-Sung Choi</td>
<td>Korean Air Force</td>
</tr>
<tr>
<td>Brian Curtis</td>
<td>George Mason University</td>
</tr>
<tr>
<td>Serena Dalena</td>
<td>University della Calabria, Italy</td>
</tr>
<tr>
<td>Yaxue Dong</td>
<td>Rice University</td>
</tr>
<tr>
<td>Nathaniel Frissell</td>
<td>Virginia Tech University</td>
</tr>
<tr>
<td>James Groth Olson</td>
<td>U.S. Air Force</td>
</tr>
<tr>
<td>Naoshin Haque</td>
<td>Stanford University</td>
</tr>
<tr>
<td>Lyndell Hockersmith</td>
<td>Virginia Tech University</td>
</tr>
<tr>
<td>Robert Junod</td>
<td>Millersville University of Pennsylvania</td>
</tr>
<tr>
<td>Kamen Kozarev</td>
<td>Boston University</td>
</tr>
<tr>
<td>Xin Liu</td>
<td>Rice University</td>
</tr>
<tr>
<td>Trey Mack</td>
<td>Fisk University</td>
</tr>
<tr>
<td>James McCollough</td>
<td>University of Colorado</td>
</tr>
<tr>
<td>Tess McEnulty</td>
<td>University of California Berkeley</td>
</tr>
<tr>
<td>Erica Morgan</td>
<td>Fisk University</td>
</tr>
<tr>
<td>Anna Mytyk</td>
<td>Embry Riddle Aeronautical University</td>
</tr>
<tr>
<td>Donald Norquist</td>
<td>U.S. Air Force</td>
</tr>
<tr>
<td>Soon Tae Park</td>
<td>Korean Air Force</td>
</tr>
<tr>
<td>Luke Rogers</td>
<td>U.S. Air Force</td>
</tr>
<tr>
<td>Nicholas Stoffle</td>
<td>Lockheed Martin</td>
</tr>
<tr>
<td>Jian Yang</td>
<td>Rice University</td>
</tr>
<tr>
<td>Binzheng Zhang</td>
<td>Dartmouth College</td>
</tr>
<tr>
<td>Liheng Zheng</td>
<td>Rice University</td>
</tr>
</tbody>
</table>
Appendix G: Released Models

CISM Released Models
Status as of Apr, 2009

Coordinated Community Modeling Center
MAS
  Solar Corona 1-30 solar radii
ENLIL
  Heliosphere beyond 30 solar radii
CORHEL
  Coupled MAS-ENLIL model.
PFSS
  Solar coronal magnetic field from magnetograms
WSA
  Wang-Sheeley-Arge coronal and solar wind model
WSA-ENLIL
  CCMC Assessing realtime runs in collaboration with SWPC
Cone
  Included in CORHEL 3.4 and later
LFM
  MPI LFM running at CCMC. Runs-on-request procedures being finalized by CCMC
TIE-GCM
  Thermosphere-Ionosphere General Circulation Model
CMIT
  Coupled magnetosphere (LFM) – thermosphere-ionosphere (TING, TIE-GCM)
(CMIT 1.0 to CCMC January; CMIT 2.5 with MPI LFM and TIE-GCM in transition)

NOAA Space Weather Prediction Center
Daily average Ap
  SWPC testbed in April, 2004; running in Development Environment.
Ap Forecast 3-Hr
  Running in SWPC Development Environment
MeV_electron_flux
  SWPC testbed in April, 2004; running in Development Environment
WSA Forecast Model
  Running in real-time in SWPC Development Environment. (CISM baseline model)
WSA-ENLIL Solar Wind Forecast Model
  Daily runs with forecaster displays since Spring 2008.
CMIT
  CMIT 2.5 with MPI LFM now running on NOAA/SWPC wJET supercomputer.

Other releases
CISM_DX analysis and visualization suite.
  Released for public use and continuing community development.

There is a lag of approximately one year between the date of a publication and the appearance in print of the first citations, due to the time required for a citing publication to be written, reviewed, and published. We therefore report here citations to-date for publications in 2003 – 2007. Each annual report will add citations for one additional year of publications (e.g., first reporting citations for 2008 in next year’s report) and update citations of previously reported citation years.

The citations reported here are only for publications that explicitly acknowledge CISM support. Publications of CISM-related work, and publications that do not explicitly acknowledge CISM, are not included.

To date, there are 814 citations of CISM publications from 2003-2006. (Last year’s number was 427.) The top-cited publications as of April, 2009 are:

<table>
<thead>
<tr>
<th># of citations</th>
<th>Publication Details</th>
</tr>
</thead>
</table>


* Center personnel.
## Appendix I: Statistics of Outside Participants

### CISM Summer School:

<table>
<thead>
<tr>
<th>Year/# Students</th>
<th># of Applications</th>
<th>Male</th>
<th>Female</th>
<th>Students</th>
<th>Non-Students</th>
<th>Hispanic/Latino</th>
<th>Race of Students</th>
<th>U.S. Citizens</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003: 31 Students</td>
<td>43</td>
<td>24</td>
<td>7</td>
<td>25</td>
<td>6</td>
<td>1</td>
<td>Asian 1, Black 8, White 22</td>
<td>21</td>
</tr>
<tr>
<td>2004: 32 Students</td>
<td>41</td>
<td>23</td>
<td>9</td>
<td>23</td>
<td>9</td>
<td>4</td>
<td>Asian 2, Black 4, White 26</td>
<td>21</td>
</tr>
<tr>
<td>2005: 36 Students</td>
<td>47</td>
<td>20</td>
<td>16</td>
<td>22</td>
<td>14</td>
<td>5</td>
<td>Asian 5, Black 2, White 29</td>
<td>23</td>
</tr>
<tr>
<td>2006: 32 Students</td>
<td>41</td>
<td>24</td>
<td>8</td>
<td>27</td>
<td>5</td>
<td>1</td>
<td>Asian 8, Black 2, White 22</td>
<td>19</td>
</tr>
<tr>
<td>2007: 31 Students</td>
<td>40</td>
<td>19</td>
<td>12</td>
<td>24</td>
<td>7</td>
<td>1</td>
<td>Asian 8, Black 1, White 22</td>
<td>16</td>
</tr>
<tr>
<td>2008: 28 Students</td>
<td>56</td>
<td>20</td>
<td>8</td>
<td>21</td>
<td>7</td>
<td>0</td>
<td>Asian 8, Black 2, White 18</td>
<td>17</td>
</tr>
</tbody>
</table>

### Space Weather Weekend

<table>
<thead>
<tr>
<th>Year/# Students</th>
<th>Male</th>
<th>Female</th>
<th>Students</th>
<th>Non-Students</th>
<th>Hispanic/Latino</th>
<th>Race of Students</th>
<th>U.S. Citizens</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004: 10 Participants</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>0, 7, 0, 2</td>
<td>8</td>
</tr>
<tr>
<td>2005: 10 Participants</td>
<td>6</td>
<td>4</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>0, 4, 0, 5</td>
<td>7</td>
</tr>
<tr>
<td>2006: 9 Participants</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>0, 5, 0, 4</td>
<td>8</td>
</tr>
<tr>
<td>2007: 9 Participants</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>0, 5, 0, 4</td>
<td>5</td>
</tr>
<tr>
<td>2008: 9 Participants</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>0</td>
<td>4</td>
<td>0, 5, 0, 4</td>
<td>5</td>
</tr>
<tr>
<td>2009: 9 Participants</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>0</td>
<td>1</td>
<td>0, 7, 1, 0</td>
<td>9</td>
</tr>
</tbody>
</table>
Appendix J: Education Assessments

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-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of graduate students engaged in CISM research each year.</td>
<td>20 each year, including 8 women and 4 underrepresented</td>
<td>32 students including 13 women and 6 underrepresented US citizens</td>
</tr>
<tr>
<td>Number of CISM PhDs.</td>
<td>5 after five years; 25 after 10 years, including 12 women and 5 underrepresented</td>
<td>Interim progress: 10 after Six years Murr, Perry, Fei, Rigler, Guild, Hernandez, Huang, Qian, Claudepierre, Brogl, Fang 5 woman</td>
</tr>
<tr>
<td>Number of graduate student first-author presentations at professional scientific meetings related to CISM research.</td>
<td>12 per year</td>
<td>30 first author presentations 16 co-author presentations</td>
</tr>
<tr>
<td>Number of graduate student first-author papers in scientific journals.</td>
<td>5 per year</td>
<td>9 first author paper 5 co-author papers</td>
</tr>
<tr>
<td>Graduate student enrollment in Summer School.</td>
<td>24 each year</td>
<td>19 graduate students of 28 attendees</td>
</tr>
<tr>
<td>Formative evaluations of Summer School.</td>
<td>an average of &quot;4&quot; on a five-point Likert scale</td>
<td>4.01 average daily evaluation</td>
</tr>
<tr>
<td>Summative evaluations by graduate students of the Summer School contribution to professional development.</td>
<td>“4” on a 5-point scale</td>
<td>2007: 4.19 Average Evaluation</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-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of undergraduates engaged in CISM research each year.</td>
<td>20, including 10 women and 5 underrepresented</td>
<td>25, including 11 women and 12 underrepresented U.S.</td>
</tr>
<tr>
<td>Number of CISM undergraduates entering graduate school in Space Weather related programs.</td>
<td>3 each year.</td>
<td>0</td>
</tr>
<tr>
<td>Number of undergraduate co-authored presentations at professional scientific meetings related to CISM research.</td>
<td>5 per year</td>
<td>2</td>
</tr>
<tr>
<td>Number of undergraduate co-authored papers in scientific journals.</td>
<td>5 per year</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of student first-author presentations with co-authors from other institutions at professional conferences.</td>
<td>8 each year</td>
<td>13 first author presentations 11 co-author presentations 7 first author paper</td>
</tr>
<tr>
<td>Number of students representing different institutions attending the CISM all-hands meeting.</td>
<td>12 students representing 6 institutions each year</td>
<td>13 graduate students representing 8 institutions</td>
</tr>
<tr>
<td>Students from most CISM institutions participating in regular CISM AG sessions</td>
<td>students from 6 institutions participating</td>
<td>Graduate AG meeting not regularly held this year. Students from 5 institutions regularly present at CISM AG seminars</td>
</tr>
<tr>
<td>Number of students attending the graduate retreat.</td>
<td>12</td>
<td>15 students from 6 Institutions</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-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teachers trained in use of CISM curriculum modules (such as the Space Weather Monitor System) at middle school, high school and community college level.</td>
<td>20 teachers trained per year.</td>
<td>Module is in the summative evaluation stage.</td>
</tr>
<tr>
<td>Space Weather Monitor suitable for widespread classroom use developed and tested with teacher interns and students by end of year 3.</td>
<td></td>
<td>Done.</td>
</tr>
<tr>
<td>100 Space Weather Monitor systems (SIDs) and 15 research-quality monitors (AWESOME) distributed, with at least 80% incorporated into classroom curriculum or activities, by end of year 5.</td>
<td></td>
<td>Distribution Completed: 100 SID monitors placed nationally; 300 monitors placed world wide including 50 in Africa</td>
</tr>
<tr>
<td>Presentations and workshops on CISM science, classroom relevance, and pedagogical approaches at professional meetings for educators and scientists.</td>
<td>10 per year</td>
<td>15 Workshops serving 663 teachers</td>
</tr>
<tr>
<td>Teachers report using CISM curriculum modules in the classroom.</td>
<td>25% of previous year’s cohort after 5th year</td>
<td>Not Tracked</td>
</tr>
<tr>
<td>CISM content accessed by the public via the web or in person.</td>
<td>1 million visitors per year after 5th year</td>
<td>Interim progress for past year: Windows to the Universe: 960K visits with 1.3 million page served Exploratorium CISM Site: no explicit tracking data Haydan Planetarium: No explicit tracking data</td>
</tr>
</tbody>
</table>

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**Appendix K. Diversity Assessments**

**Objective 1:** Recruit undergraduates from groups who are underrepresented in science to attend graduate school in space science at CISM institutions

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of minority and female graduate students engaged in CISM research each year.</td>
<td>30 % of US total are women</td>
<td>Current number is 40% (8/20)</td>
</tr>
<tr>
<td></td>
<td>20% of US total are minority</td>
<td>Current number is 30% (6/20)</td>
</tr>
<tr>
<td>Formative evaluation of the 2009 Space Weather Weekend</td>
<td>Overall score of “4” on a 5-point Likert scale.</td>
<td>Both objectives met</td>
</tr>
<tr>
<td></td>
<td>1/3 of participants indicate likelihood of applying to CISM graduate schools</td>
<td></td>
</tr>
<tr>
<td>Summative evaluation of the Space Weather Weekend</td>
<td>Over the 5 years, 7 students will begin study at CISM (or other space physics) graduate schools</td>
<td>From 2005 – 2009, 2 students have joined CISM, two have applied to other Space Physics programs, and two others (from the 2009 Space Weather Weekend) have stated that they now want to do graduate study in space physics.</td>
</tr>
<tr>
<td>Number of women and minority students involved in CISM undergraduate research</td>
<td>40 % of US total are women</td>
<td>Current number is 48% (11/23)</td>
</tr>
<tr>
<td></td>
<td>25% of US total are minority</td>
<td>Current number is 52% (12/23)</td>
</tr>
<tr>
<td>Number of minority students involved in CISM undergraduate research who go to CISM (or other space weather related) graduate schools</td>
<td>7 students over 5 years</td>
<td>8 CISM minority undergraduate researchers since 2002 have begun graduate work in space science. Every CISM minority undergraduate researcher who could graduate has done so and gone to graduate school.</td>
</tr>
</tbody>
</table>
**Objective 2:** Work with existing programs that aim to improve diversity in science

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory of Diversity programs at CISM campuses</td>
<td>CISM creates inventory of programs and find mechanisms by which CISM can contribute</td>
<td>Inventory done. Undergraduate research programs identified as high leverage activity as CISM campuses.</td>
</tr>
</tbody>
</table>

**Objective 3:** Ensure that participants in Center activities and programs represent a diverse population

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-7 Performance</th>
</tr>
</thead>
</table>
| Number of minority and female graduate students engaged in CISM research each year. | 30% of US total are women  
20% of US total are minority | Current number is 40% (8/20)  
Current number is 30% (6/20) |
| Number of minority and female participants at the CISM summer school. | 1/3 of US participants are women and/or minorities | 24% in 2003 (5/21)  
41% in 2004 (9/22)  
52% in 2005 (12/23)  
37% in 2006 (7/19)  
33% in 2007 (4/12)  
29% in 2008 (5/17) |
| Number of women and minority students involved in CISM undergraduate research | 40% of US total are women  
25% of US total are minority | Current number is 48% (11/23)  
Current number is 52% (12/23) |
| Grade 6-14 programs target women and minorities | 30% of teachers involved CISM professional development represent diverse populations | TBD |
**Objective 4:** Support the establishment of a viable space science program at Alabama A&M University, which is a leading producer African-American physics degrees

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Degree programs at AAMU.</td>
<td>Establish new B.S. and M.S. space science degrees at AAMU</td>
<td>New M.S. and Ph.D. space science concentrations for the Physics degree now in place at AAMU.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two M.S. degrees awarded so far. First Ph.D. degree expected in coming year.</td>
</tr>
<tr>
<td>New tenure-track positions at AAMU in space science; CISM-sponsored faculty gets tenure</td>
<td>Hire a tenure-track space physicist with partial CISM support and provide support network</td>
<td>Drs. Amy Winebarger and TianXi Zhang have been hired with partial CISM and NASA support.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dr. Winebarger was awarded a CAREER grant from the NSF in 2006</td>
</tr>
</tbody>
</table>

**Objective 5:** Integrate the new AAMU program into the research and education programs of the Center

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Goal</th>
<th>Year-7 Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>CISM-wide participation in a mentoring/support role for AAMU</td>
<td>At least 3 CISM institutions are actively engaged in joint research/mentoring with AAMU</td>
<td>Boston, NCAR, and PSI are working with AAMU students</td>
</tr>
<tr>
<td>Provide CISM-sponsored colloquia with outside speakers at AAMU</td>
<td>AAMU will participate regularly in Access Grid Session. 2 CISM colloquium visitors/yr</td>
<td>AAMU regularly attends AG sessions. One CISM visit to AAMU last year</td>
</tr>
</tbody>
</table>