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### I. GENERAL INFORMATION

#### 1a. General Information:

<table>
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<tr>
<th>Date submitted</th>
<th>1 May 2003</th>
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<tbody>
<tr>
<td>Reporting period</td>
<td>1 August 2002 – 31 July 2003</td>
</tr>
<tr>
<td>Name of the Center</td>
<td>Center for Integrated Space Weather Modeling</td>
</tr>
<tr>
<td>Name of the Center Director</td>
<td>W. Jeffrey Hughes</td>
</tr>
<tr>
<td>Lead University</td>
<td>Boston University</td>
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<td>Email Address of Center Director</td>
<td><a href="mailto:hughes@bu.edu">hughes@bu.edu</a></td>
</tr>
<tr>
<td>Center URL</td>
<td><a href="http://www.bu.edu/cism">www.bu.edu/cism</a></td>
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**Institution 1 Name**: Alabama A&M  
**Address**: Ravidra B. Lal  
Department of Physics  
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PO BOX 1268  
Normal (Huntsville), AL 35762  
**Phone Number**: 256-372-8148  
**Fax Number**: 256-372-5622  
**Email Address of Center Director**: rlal@aamu.edu  
**Role of Institution at Center**: AAMU will work with Boston University on model validation and with UTEP on education and increasing diversity.  

**Institution 2 Name**: Dartmouth College  
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<table>
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<tr>
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<th>Fax Number</th>
<th>Email Address of Center Director</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dartmouth College</td>
<td>Timothy L. Killeen, PO BOX 3000, Boulder, CO 80307</td>
<td>303-497-1111</td>
<td>303-497-1589</td>
<td><a href="mailto:killeen@ucar.edu">killeen@ucar.edu</a></td>
</tr>
<tr>
<td>National Center for Atmospheric Research (NCAR)</td>
<td>Jon A. Linker, 10260 Campus Point Drive, MS E3X, San Diego, CA 92121-1578</td>
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<tr>
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<td>Stanford University</td>
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<td>510-643-8302</td>
<td><a href="mailto:jgluhman@ssl.berkeley.edu">jgluhman@ssl.berkeley.edu</a></td>
</tr>
<tr>
<td>University of Colorado, Boulder</td>
<td>Daniel N. Baker, Laboratory for Atmospheric &amp; Space Sciences</td>
<td></td>
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<tr>
<td>Institution 8 Name</td>
<td>University of Texas, El Paso</td>
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<tr>
<td>Address</td>
<td>Ramon E. Lopez</td>
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<td></td>
<td>Department of Physics</td>
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<td>Phone Number</td>
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<td>Fax Number</td>
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<tr>
<td>Email Address of Center Director</td>
<td><a href="mailto:rellopez@utep.edu">rellopez@utep.edu</a></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Role of Institution at Center</td>
<td>University of Texas at El Paso will lead the education and diversity efforts and will work with Boston University on model validation.</td>
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<table>
<thead>
<tr>
<th>Institution 8 Name</th>
<th>William Marsh Rice University</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>Frank Toffoletto</td>
</tr>
<tr>
<td></td>
<td>Department of Physics &amp; Astronomy</td>
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<tr>
<td></td>
<td>6100 Main Street, MS-61</td>
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<td></td>
<td>Houston, TX 77005</td>
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<tr>
<td>Phone Number</td>
<td>713-348-3641</td>
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<tr>
<td>Fax Number</td>
<td>713-348-5125</td>
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<tr>
<td>Email Address of Center Director</td>
<td><a href="mailto:toffo@rice.edu">toffo@rice.edu</a></td>
</tr>
<tr>
<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>
</tr>
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1b. Biographical Information for New faculty

The following faculty are new to CISM. Their biographies are in Appendix A.
Boston University: Esther Zirbel, Research Assistant Professor
Dartmouth College: Barrett N. Rogers, Assistant Professor of Physics
National Center for Atmospheric Research: Michael Wiltberger, Scientist 1
University of Colorado at Boulder: A. Xinlin Li, Associate Professor of Aerospace Engineering
2. Executive Summary.

The Center for Integrated Space Weather Modeling (CISM) has as its overarching vision “To understand our changing Sun and its effect on the Solar System, life, and society.” Within this greater vision, CISM sees as its particular missions: to introduce into space physics and space weather research the first comprehensive community model analogous to the community models that exist in other fields such as climate research; to introduce into 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.

CISM focuses its activities around the development of a series of ever-improving versions of a comprehensive, physics-based simulation model that describes the space environment from the Sun to the Earth. After having fully tested and validated these models, we will use them for research, make them available to the wider research community, transition them as appropriate into operational specification and forecasting tools, and use them as learning tools. This shared vision and task binds the CISM team into a tight center with everyone doing their piece towards the common goal even though CISM is split geographically between ten institutions spread across the country.

Much of the initial effort within CISM has been to produce a strategic and implementation plan that describes our goals and outlines a path forward to achieving them. This document lays out a series of milestones with which we will measure our progress along this path. We have also created a management structure that divides CISM into a set of overlapping teams each with an important task to perform as part of developing the comprehensive CISM model or towards achieving our goals in education, increasing diversity within space physics, and transferring tools, techniques and knowledge to the broader research and professional communities. The research teams (or thrusts) are solar/heliospheric research, magnetospheric research, ionosphere/thermosphere/mesosphere research, code coupling, validation and metrics, empirical models, and data assimilation. Each of these teams, as well as the education and knowledge transfer teams, is led by a CISM co-director. The co-directors collectively form the CISM executive committee, CISM’s principal management body.

Our plan is to produce a new version of the comprehensive model every two years. Each version will use more sophisticated coupling technology and incorporate more of the physics needed to fully describe the coupled Sun-Earth system. The science research thrusts are responsible for developing the individual models that will become component models within the coupled comprehensive model. The code coupling thrust will both develop the computational science tools required to couple the component models and use these tools to couple them into a comprehensive model. The validation and metrics thrust will not only fully test and validate the model, but also compare its performance to that of others using standardized metrics that it will develop in the first year. Models will
then be released to the wider community and, if appropriate, developed into operational and or teaching tools. Validated versions of the comprehensive model will be made accessible to the wider community with help from our partners the Community Coordinated Modeling Center (CCMC) and the National Computational Science Alliance (NCSA). In parallel to the development of the comprehensive physics-based model, the empirical modeling thrust is building a comprehensive empirical model of the Sun-to-Earth system. This model will emphasize specification and prediction and will provide both a benchmark (in terms of metrics and skill scores) by which the physics-based models can be judged, and forecasting tools that can be transitioned to operations much earlier in the life of CISM.

The first version of the comprehensive model (Ad hoc version or Version 1) will utilize ad hoc coupling technology to couple the four fluid codes that form the core of the comprehensive model as well as a fifth code that models the ring current region (the Rice Convection Model). The second version will make use of object oriented programming concepts (specifically the Meta-Chaos package and Overture framework) to provide more modular and versatile code coupling, and will include additional component codes that model the radiation belts, solar energetic particles, and possibly others if their development is sufficiently mature. The coupling technology to be used for the third version will be selected later from among options still under development in the computational science community.

Education and research will be integrated by involving all CISM students, both undergraduate and graduate, in the research effort, by using the models we develop as instructional tools, and by conducting science education research focused on measuring the effectiveness of using images in education within the education plan. We will continue to improve our already very successful space weather summer school and start programs that build community among and provide professional development opportunities for CISM graduate students. We have in place a program of training teacher interns who will help couple CISM institutions to the local education communities that will start this summer.

A major component of our diversity plan is for CISM to help and support Alabama A&M University create a graduate program in space science within their physics department. This program will provide 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 CISM knowledge transfer plan has three major components: transition of forecasting tools to the NOAA/Space Environment Center (SEC); providing the wider scientific community with comprehensive models accessible to all; 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. Our close cooperation with SEC has been strengthened with the hiring of Robert Weigel to liaise with SEC and use his understanding of SEC’s priorities to help design the comprehensive empirical model. We are formalizing our partnerships with CCMC and NCSA who will work with us to make our models available to the wider community. We are forming relationships with
our industrial partners to learn their needs. Several government and industrial employees will be attending the 2003 CISM Summer School.

The CISM Advisory Council met for the first time in March 2003 and provided very useful advice and guidance to the CISM management team.

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, and that erases the existing boundaries among space physicists.
- 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 an historically black university.
- The introduction of community models 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.
- 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.
CISM’s major accomplishments to date are:

- Developing a strategic and implementation plan that describes CISM’s goals and outlines a path forward to achieving them.
- Holding the first CISM “all-hands” meeting in September 2003 to build the CISM team and to develop and adopt the strategic plan.
- Setting-up management and administrative structures and a strong management team.
- Completing new AccessGrid facilities at Boston University and Dartmouth College; construction is underway at AA&M and UTEP, while facilities at Rice, UCB, U Colorado, and Stanford will be completed over the summer.
- Forming the CISM Advisory Council that met in March 2003.
- Successful ad hoc coupling of the 3-D coronal and solar wind global MHD models and the tracking of a 3-D CME and shock waves through the coupled system.
- Initial ad hoc coupling of photospheric flux-emerging and coronal codes.
- Successful ad hoc, two-way, coupling of the global magnetosphere (LFM) model and the global ionosphere/thermosphere/mesosphere (TING) model, and initial studies on the effects of two way coupling on ionospheric parameters.
- Initial one-way, ad hoc, coupling of the ring current (RCM) model to the global magnetosphere (LFM) model.
- Successful testing of the Overture and Meta-Chaos code coupling tools with space physics codes.
- Extending the dynamic radiation belt model to 3-D and initial coupling of it to the global magnetosphere (LFM) model.
- Constructing the initial comprehensive empirical model that includes a solar wind model, two energetic electron models, an Ap model, and a surface dB/dt model.
- Initiating an ongoing study of data assimilation techniques that are or can be used in space weather modeling.
- Successfully announcing the formation of CISM and describing its plans and program to the scientific community at scientific meetings and more broadly through the media.
II. RESEARCH

1a. Overall Research Description

The overarching goal of CISM is to develop a reliable well-validated, comprehensive, physics-based numerical simulation model that describes the space environment from the Sun to the Earth. The research goals of CISM are all directed towards achieving this goal. This means that CISM’s research program must be considered as an integrated whole, managed as a single large project. 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 processes needed to build the comprehensive model.

Figure 1 is a high-level flow chart showing our vision of the comprehensive CISM model. Along the top are icons showing schematically the path along which solar disturbances flow from the sun through the solar wind, impact the magnetosphere, and couple to the ionosphere and thermosphere. Below these icons are four boxes linked in a horizontal line which show the four fluid models that form the core of the CISM comprehensive model. The rightmost of these is the magnetohydrodynamic (MHD) model of the solar corona developed by Jon Linker, Zoran Mikic, and others at SAIC. This model describes solar corona dynamics from the base of the corona out to a radius at which the solar wind flow is entirely supersonic and superAlfvenic. The coronal model couples to the 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 successfully models the time dependent 3-D structure of flows and fields in the solar wind well beyond the orbit of earth. The solar wind impacts the terrestrial magnetic field to form the earth’s magnetosphere. Since the solar wind is highly supersonic at this point, only the upstream properties of the solar wind affect the behavior of the magnetosphere. CISM is using the model developed by Lyon, Fedder, and Mobarry (LFM), a well proven code that models the global dynamics of the magnetosphere to a distance far enough down the geomagnetic tail (300 Re) that all flow is again supersonic away from Earth. The LFM code can be driven either with results from the solar wind code or from solar wind data obtained from in situ spacecraft such as WIND and ACE, which allows the model chain to be easily split in two at the solar wind-magnetosphere boundary for the purposes of validation and testing. The magnetosphere is strongly coupled to the ionosphere and upper neutral atmosphere (thermosphere and mesosphere, or collectively ITM). As our core ITM model we are using a high resolution version of the National Center for Atmospheric Research (NCAR) Thermosphere/Ionosphere General Circulation Model (TGCM), the Thermosphere-Ionosphere Nested Grid (TING) model. The coupling between the magnetosphere and ionosphere is by far the most complicated of the core model couplings, as it acts in both directions (note the double headed arrow) and involves many processes that are not well described by fluid physics.
Below the four core models are a number of other boxes containing regions or particle populations that require other models, in most cases non-fluid models, in order to incorporate 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 inner magnetosphere and ring current by following the drift trajectories of the thermal particles in the inner magnetosphere that carry this current. The different particle populations of the inner magnetosphere cannot be treated as a single fluid, as assumed in MHD, because they all move differently. By bounce averaging the motions of these particles, the calculation can be reduced to a two-dimensional problem (i.e., in the equatorial plane). However, the RCM needs the magnetic flux tube volume threading the reference plane as well as the electric field and plasma distribution on the outer boundary. In the past these have been produced in various ad hoc ways. In the comprehensive model, the LFM will supply these needs to the RCM, while the RCM will provide more realistic plasma pressures to the LFM. 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, exist only in conceptual form and will be developed as part of CISM’s research program.
We have divided the research required to the comprehensive model into seven thrusts. The **Code coupling thrust** is at the core of our research effort. This thrust is responsible for identifying and/or developing the computational science tools needed for efficiently coupling the component models together and then applying these tools to coupling the models to produce the comprehensive CISM model. This group is charged with producing a series of ever-improving versions of functioning comprehensive models. Our plan calls for a new version every two years, with possible improvements to the existing version (that improve the physics but not the coupling strategy) being introduced at more frequent intervals.

The three science thrusts - **Solar/Heliospheric Physics**, **Magnetospheric Physics**, and **Ionosphere/Thermosphere/Mesosphere Physics** - are responsible for the targeted research required to bring our understanding of the fundamental physics to the level required for the comprehensive CISM model, and for developing the component models incorporating this understanding for the comprehensive CISM model. 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 processes, and the thermospheric control of ionospheric and magnetospheric processes, so that these processes can be appropriately included in the comprehensive model.

The **Validation and Metrics** thrust is charged with testing and validating the functioning comprehensive models they receive from the Code-coupling thrust. This thrust performs both validation and metric 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 simple model output parameters and a few selected operationally available measurements (metrics) that allow a direct comparison between the effectiveness of different models or prediction schemes. This latter allows progress between generations of models to be evaluated. One of this thrust’s first tasks is to define the set of metrics to be used. It 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 **Empirical Modeling** thrust is responsible for a parallel effort to develop a forecast and specification version of our comprehensive model. Initially this model will be formed by coupling various empirical or data-based models together to provide an end-to-end model. This initial version will provide the benchmark for metric and skill scores for all subsequent forecast and specification models as well as a benchmark to measure the performance of the physics-based comprehensive model. Future versions will incorporate new modules based on insights and understanding gained from the physics based comprehensive model. This research thrust is also closely integrated with the CISM effort in knowledge transfer to the space weather forecasting community as the models they develop are those most likely to be transitioned into operational models early in the life of CISM.
The **Data Assimilation** thrust is initially responsible for investigating ways in which the CISM research effort can make effective use of data assimilation techniques in our models. Subsequent efforts in this area will be based on the results of this initial study.

1b. **Performance and Management Indicators.**

The CISM Strategic and Implementation plan contains specific yearly outcomes/milestones for the Code Coupling, Solar/Heliospheric, Magnetospheric, ITM, and Empirical Modeling thrusts. This plan will be the primary basis for determining the success of these thrusts and of CISM research as a whole. The milestones include the projected schedules for the transfer of results from the science thrusts to our comprehensive model and for the delivery of successive versions of the comprehensive model from the code-coupling team to the validation team and subsequently through to the broader community. They further describe the incorporation of new results into the forecast and specification model developed by our Empirical Modeling thrust.

In addition to these specific indicators, we will use such standard indicators as the number and quality of journal publications and meeting presentations.

2. **Problems.**

We have not encountered any significant problems during the first several months of the project. Progress was initially slowed by administrative delays in setting up some subcontracts and by delays in making new hires.
3. Science Thrusts

3.1 Code Coupling Thrust

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<tr>
<td>PI Name</td>
<td>Charles Goodrich</td>
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Participants

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Funding (reporting year)

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Funding (anticipated for next year)

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The Code Coupling thrust is the core of CISM. The Code Coupling thrust is responsible for the developing and maintaining successive versions of the CISM comprehensive model. As such this thrust has responsibility for defining the code coupling methodology, that is the specific computational science tools that will be used to couple the component models together, and for developing or adapting, as needed, these tools for our specific use. This thrust also has responsibilities for applying these tools to produce a functioning version of the comprehensive CISM code that can then be passed on to the validation and metric thrust for testing.
The code coupling thrust interacts strongly with the science thrusts in refining and optimizing the individual codes developed by the science thrusts that become components of the comprehensive code. This thrust will work very closely with the validation and metric thrust to assure the scientific accuracy of the codes both individually and when coupled. It will also support the release of new versions of the comprehensive CISM code to the public and operational and scientific communities through our partner institutions, CCMC and NCSA, by the Knowledge Transfer team and support use of models in an educational context by the Education team.

The plan is to produce an ever-improving series of comprehensive models. Every two years a new version based on more sophisticated coupling technology and incorporating a greater number of component models, so improving and expanding the physics of the space environment the comprehensive model contains, will be produced and released to the validation team. Within each computational coupling generation (i.e. two year period) versions of the comprehensive model incorporating new or more sophisticated and comprehensive physics may be released as new component models become available from the science thrusts. Each new version will be given to the validation team for a period of rigorous testing lasting up to a year. The codes will then be released to the scientific and operational communities and the public through the efforts of the Knowledge Transfer and Education teams.

These successive generations of the comprehensive model are described briefly in the CISM Strategic Plan. The first generation will be based on \textit{ad hoc} coupling of the four core models together with the Rice convection model described in the introduction to the research section. We refer to this version as either the \textit{ad hoc} coupled version, or sometimes the Version 1 coupled model. Much of our initial work described in this report concerns the \textit{ad hoc} coupling of core models for the Version 1 Coupled Model. Our second generation model will be based on an existing general code coupling technology: Overture and Meta-Chaos. To prepare for our eventual transition to this system, we have explored the use of these packages with several versions of our fluid codes.

\textbf{3.1.1 \textit{Ad hoc} (Version 1) Coupling}

Here we describe progress on various \textit{ad hoc} couplings of pairs of component models.

\textbf{Solar/Heliosphere Coupling}
The solar corona extends outward into interplanetary space as the solar wind. There is no sharp boundary that divides the solar corona from the inner heliosphere, and in principle one calculation can cover the entire domain. However, in practice, very different physics is relevant in the lower corona and interplanetary regimes. Small scale-heights for plasma and magnetic fields in the transition region and lower corona can require grid spacing in the range of $10^{-4}$ to $10^{-2}$ Rs. These small grid sizes, coupled with high Alfven speeds in these regions, place very tight time-step constraints on explicit calculations, requiring the use of implicit methods. In contrast, the solar wind in interplanetary space is supersonic and superAlfvenic making such an approach unnecessary, as explicit methods are most appropriate for high-speed flow. Practical experience has shown that coupling separate coronal and heliospheric calculations is
the most efficient approach. The ability to optimize and update individual system components with the latest understanding also favors the use of coupled, specialized models. The natural place to divide the calculation is beyond the transition from sub to supersonic (and superAlfvenic) flow (typically 20-30 Rs). Past this critical region, the results at the upper boundary of the coronal simulation can then be fed directly into the lower boundary of the heliospheric simulation, as all information in the MHD equations propagates outward. Figure 2 shows typical grid meshes for the coupling of 2D simulation of CME initiation and propagation.

![Meshes in the coupled coronal and heliospheric simulation.](image)

Coronal Model (1 Rs - 20 Rs)  Heliospheric Model (20 Rs - 220 Rs)

SAIC (San Diego, CA): 200x300 grid points

\[ \Delta t = 0.0053 - 0.59 \text{ Rs}, \Delta \theta = 0.24 - 2.4^\circ \]

*CRIRES/SEC (Boulder, CO): 340x240 grid points

\[ \Delta t = 0.5 \text{ Rs}, \Delta \theta = 0.5^\circ \]

*NOTE: Only every 5th grid line is shown

Figure 2: Meshes in the coupled coronal and heliospheric simulation.

We have performed a 3D coupled solar-heliosphere simulation of a Coronal Mass Ejection (CME), as shown Figure 3. The interface between the two computations is shown in the upper left hand corner of the figure. Magnetic flux rope field lines in the combined calculation, extending back to the solar surface (red dot) are depicted against a translucent cut plane showing the plasma density. The shock and compressed plasma behind the shock formed by the CME are clearly visible. This calculation was used to deduce the position of the shock surface for use in calculating Solar Energetic Particle (SEP) production, as described in the Solar thrust.
Sub-photosphere-Coronal Coupling
Understanding how flux emerges from below the photosphere into the corona, and how this flux disperses during the lifetime of an active region, is an important aspect of understanding why coronal magnetic fields erupt to produce coronal mass ejections. To study the emergence of a flux tube into the corona from beneath the photosphere, we performed an MHD simulation with boundary conditions supplied from the UC Berkeley subphotospheric MHD simulation of a rising flux tube. As a prelude to testing in the global coronal code, we used a 3-D Cartesian code (suitable for localized modeling of solar active regions). For this test we also made the further simplification of using the zero-beta equations (pressure is set to zero, density is set to a constant value, and only the momentum equation and Faraday’s law are solved). This approximation is appropriate for strong magnetic field regions, where the plasma beta is typically very small.

To drive the coronal model with the results from the subphotospheric model, appropriate boundary data must be specified (using all of the MHD quantities overspecifies the problem). The tangential electric field (E_x and E_y) and vertical component of the flow velocity (v_z) from the subphotospheric simulation were extracted at the base of the corona (considered to be the plane z = 0 in our simulation). This data supplied the boundary conditions for our coronal simulation in the domain z > 0, in which we modeled the evolution of the coronal magnetic field. Figure 4 shows the emergence of the current carrying (i.e., twisted) flux tube in the corona. This exercise illustrates that a coronal code can be driven by boundary data from a subphotospheric calculation. Future plans include performing cases with larger twist, extending the calculation to the full MHD equations, and eventually studying the emergence of fields in an active region in the context of the global coronal model.
Figure 4: Four frames showing the emergence of a twisted magnetic flux tube (calculated in the subphotospheric model) into an initially field-free corona

The coupled model is not only useful for studying flux emergence, but also for testing different algorithms for using vector magnetograms. Because sequences of vector magnetograms do not explicitly define the electric field evolution (which, through Faraday’s law defines how the boundary magnetic fields will evolve), we are presently studying what the best schemes are for using sequences of vector magnetograms in MHD calculations. “Simulated” vector magnetograms can be derived from the results of the coupled model. A proposed scheme can be used to drive the MHD model with these magnetograms, and test the results against the solution obtained using the “known” electric fields from the subphotospheric model.

Magnetosphere/Ionosphere/Thermosphere Coupling (LFM/TING)
The magnetosphere and ionosphere are closely linked through electric currents and particle flows in the high latitude polar cap. This linkage is so important that global simulation codes of the magnetosphere including the LFM include simplified models of the ionosphere, and ionosphere/thermosphere codes such as TING incorporate models
for their magnetospheric inputs. We are working to couple directly the LFM and TING codes and eliminate the necessary but simplified models in each. In a nutshell the coupling between the LFM and TING model involves the LFM passing fluxes and characteristic energy precipitating particles generated in the magnetosphere as well as the high latitude convection pattern to the TING model. TING uses this information to determine new ionospheric conductivities, which are used to recalculate the high latitude electric potential. The potential is used by the LFM to advance the magnetospheric solution. The coupling is nonlinear in that calculation of the conductivities depends on the electric potential. It is further complicated by the difference in characteristic time scales of the magnetosphere (fraction of seconds) and ionosphere (minutes).

Wiltberger, Wang and Burns have completed an ad hoc one and two way coupling of the LFM and TING models. This coupling has currently been accomplished through exchange of information via a series of data and lock files. In the coupled simulations information is passed from the LFM to the TING every two minutes, about every 500 LFM time steps. During the intervening time the LFM uses the previous TING conductivities to calculate the ionospheric potential. This forces the ionosphere to be one exchange time step behind the magnetosphere, but this delay is comparable to information exchange between the ionosphere and the magnetosphere. Another complication in this model coupling is the fact that the LFM uses a grid fixed in magnetic

\[ \nabla \cdot (\Sigma \nabla \Phi + \Sigma_p \nabla \Phi) = J_{11} \]

Figure 5: Schematic diagram of the ad hoc LFM/TING code coupling.
local time for its computation while TING uses a geographic grid, which rotates in time. The exchange process completes a grid rotation and interpolation for each step. The coupling procedure is shown schematically in Figure 5.

A series of test case coupling runs between the LFM and TING have been completed. The first case involved a solar wind input stream derived from a model CME simulated from the solar surface by the Linker and Mikic coronal model and through interplanetary space by the Odstrcil solar wind model and then into the magnetosphere - ionosphere. For this interval we completed simulations with both one and two way couplings between the LFM and TING. The results were promising, but indicated a difference between the conductivities determined by the LFM and those determined by the TING in the two way coupled event. As part of a calibration study we completed coupled simulations for a magnetospheric storm and substorm interval for which there existed a wide variety of observations that can be used as ground truth for the simulation results. The initial investigations have been completed and the two way coupled simulations produced lower conductivities than the one way simulations, as shown in Figure 6. Drs Wiltberger and Wang are actively researching the physics behind these results and are comparing them with the observations.

Figure 6: Ionospheric conductivities produced by one-way and two-way coupling.

In conclusion, the mechanics of coupling the LFM to the TING models have been successfully completed and we are currently studying the results from these coupled simulations.
Now that this coupling process has been thoroughly debugged, we plan to study in depth the scientific validity of the coupled code results. We also will explore more efficient coupling methods.

- Perform several event studies using the coupled LFM/TING codes to understand the different in conductivities generated for one and two way coupling
- Use MPI for more efficient data exchange between the coupled simulations.

**Magnetosphere/Inner Magnetosphere (LFM/RCM) Coupling**

The LFM has been quite successful in describing the overall state of the magnetosphere. However, the MHD single fluid basis of the LFM is not accurate in the inner magnetosphere where the particle drifts can affect the energy population and trapping of the ring current and the degree of electrical shielding of the inner magnetosphere. The Rice Convection Model (RCM) was designed to handle the particle drifts explicitly. The major limitation of the RCM is that it is not self-consistent; it requires the specification of the magnetic field and boundary conditions for the electric potential and the plasma flowing into its domain of validity – essentially the inner magnetosphere. The MHD code self-consistently calculates these quantities. Thus, the coupling of the two models can lead to an accurate, self-consistent treatment of the inner magnetosphere and ring current.

Both codes overlap spatially and both require information from the other. The RCM is able to reduce the three-dimensional magnetosphere into a two-dimensional problem by integrating over the bounce motion of the particles. The two-dimensional problem can then be solved in any convenient reference surface, most usually the ionosphere. The important advected quantity for the RCM after this reduction is \( \eta \), essentially the adiabatic constant, \( PV^\delta \) for each energy bin carried by the RCM, where \( P \) is the pressure and \( V \) is the flux tube volume. In order to know \( V \), the magnetic field must be traced in 3D. The RCM thus needs to know the magnetic field structure and the incoming plasma distribution to get \( V \) everywhere and \( P \) on the boundary. In return, the MHD code should use the more accurate pressures produced by the RCM instead of the ones given by integrating the ideal MHD equations.

Building upon work done at Rice using equilibrium MHD models to drive the RCM, we have used the LFM code to drive the RCM in an *ad hoc* coupling scheme. The communication in this first effort is done via files with synchronization done by simulation time. The LFM writes out files containing the magnetic field and plasma data on a three-dimensional Cartesian mesh, which the RCM uses for field line tracing and the plasma input conditions. In addition, the ionospheric potential and conductance model is output from the LFM to the RCM in a separate file. The use of a Cartesian grid does involve a double interpolation (from LFM to Cartesian, Cartesian to RCM field line). However, the loss in accuracy can be minimized by fine enough gridding and the total computational effort and difficulty in parallelization of the field line trace is reduced by this technique.

As a first step, the RCM was run for period of approximately 4 hours of magnetosphere time using a single MHD snapshot. For this run, the plasma distribution was initialized from the MHD and the RCM was then run keeping the boundary conditions and the magnetic field constant. Output from the run is shown in the figures below. The left
The figure shows the initial (t=0) plot of the computed Birkeland currents and potential (contours) and the bottom figure is the input pressure distribution from the MHD. The right figure shows the same quantities at t=15000 seconds. There are several things to note from these figures: firstly the field-aligned currents form classic RCM region-2 currents resulting in the shielding of the inner magnetospheric electric field. Secondly the structured field aligned currents that appear in the tail region are the result of low content flux tubes interchanging their way from the tail boundary into the inner magnetosphere. This results in jet-like structures of plasma that may be related to bursty bulk flows. The plasma pressure shows a noticeable change at the end of the run, the pressure peak that was initially around midnight has begun to symmetrise as the result of plasma drifting in the inner magnetosphere. The results of this initial test run are very encouraging and we plan to extend the run to use time-dependent MHD data, which will result in varying plasma boundary conditions and magnetic field configurations.

Figure 7: Field aligned current and pressure distributions obtained from the one-way coupled RCM/LFM models.

The back coupling from the RCM to the MHD code is in the design phase. As a first cut, the RCM values for the plasma will be “bled” back into the MHD code and the ionospheric potential from the RCM will be used in place of the one computed by the LFM code. This procedure, however, has a number of possible pitfalls, such as anomalous numerical diffusion of the MHD solution, and spurious waves introduced by the time cadence of coupling and the inherently different time scales and physics of the codes. The investigation of these pitfalls at the very least will better define the physical domains of validity of the two codes; at best it will lead to new physical insights into the behavior of the coupled, hybrid system.
3.1.2 Object Oriented Program Modular 1 (OOP1) Model

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. This implies efficient transmission of information between codes, the translation (if necessary) of quantities between their different physical models, and a control structure to synchronize the action of all the codes. Two further, important considerations are that the resulting framework allows modularity of the integrated model, and that existing codes can be incorporated with a minimum of modification. This general software framework will be a major legacy of the CISM project.

Our approach is based on a feature of virtually all the codes within CISM, the use of spatial grids to organize their computational data. Different codes within CISM obviously have different spatial domains and, thus, different grids. The grids for these codes may be Cartesian, spherical, or even non-orthogonal. They may overlap on boundaries, such as the coronal and heliospheric codes. They may interpenetrate, such as the LFM magnetospheric code and the radiation belt codes and the LFM and the RCM. What is important is that a mechanism be provided to communicate between these grids.

After surveying the available software packages, we have decided that the Overture package is the most appropriate basis for the initial version of our framework. Overture, developed first at Los Alamos, is supported by the Center for Applied Scientific Computing (http://www.llnl.gov/CASC/) at the Lawrence Livermore National Laboratory and is freely available on the web. We have developed a good working relationship with the development team through the revision of one of our codes (LFM), which we have strengthened through CISM and a grant from the NASA Living With A Star Program. Overture is an object-oriented framework written in C++ for computation on overlapping (overset) grids. It can automatically handle the definition of overlap regions and the interpolation between data between differing grids. Overture is built upon the P++ class library, which allows Fortran90-like syntax for general arithmetic operations and does automatic domain-decomposition parallelization. P++ is an extension of the Multi-block PARTI array software developed at Maryland by one of our collaborators (Sussman). In addition, we need communications support between computational modules. We will address this problem by integrating the Meta-Chaos communication library into Overture. Meta-Chaos supports communication between different parallel components either in a single program or running as separate programs, perhaps running at different sites. Meta-Chaos also allows parallelized programs to efficiently obtain results from parallelized sensor or scientific databases.

The major limitation of generalized libraries and frameworks is, from the CISM perspective, that they require coding the problems in their own idiosyncratic language or syntax. It is not feasible to recode all of CISM's codes into a single language or meta-language, such as Overture. Our framework, combining the Overture and Meta-Chaos packages, allows us to sidestep this problem. It provides both support for simplified coding of translation routines and for inter-grid communication between distinct codes, both with minimal code modifications to the original codes. Let us emphasize this point; with these tools existing codes can be linked in most cases by modifying no more than a small amount of code.
few lines of code. There may, of course, be a substantial amount of coding to translate from one grid to another and from one physical model to another. However, that work can all be done externally to the existing codes and only a few communications calls need to be inserted in the original programs. Figure 8 shows a conceptual picture of how two codes, A and B, could be linked. The three program modules indicated in the figure could be peers running as separate programs (whether sequential or parallel), or parts of a single program, or a combination of both. Our plan allows for all three possibilities, with the specific linkages differing as required. As an example, coupling of two legacy Fortran codes is probably most easily accomplished as three peer programs.

![Figure 8: A simple example illustrating how Overture and Meta-Chaos can be used to couple two simulation codes.](image)

In our example, B is a calculation embedded in the larger simulation A. There is an overlap region for the two calculations where information needs to be passed back and forth. Array variable X in A provides the necessary information to B in the overlap region, but B requires Y for its calculation. A, in turn, requires an update on X in its overlap region with B. Beneath the code figures are text blocks showing the code fragments needed to produce the linkage. The arrows linking the blocks indicate the software tools used to do the actual communication. Since most Space Science codes are written in Fortran, we have shown the Fortran routines needed to perform the inter-program communication. Conceptually, only three calls are required: Send(X), Receive(X), and
BuildDescriptor(X). The action of the first two is obvious; the third builds the data descriptor required so that the Meta-Chaos toolkit can schedule and perform the needed communications across all processes in each program. The center of the figure shows the inter-grid and data translation program.

Another advantage with this peer process technique of coupling, beyond minimal disturbance of the original codes, is the use of object oriented coding in the translation peer. Various features of object oriented programming (OOP), such as function overloading, lend themselves to code reuse in new situations. Thus, once a coupling type is accomplished once, other similar couplings can be accomplished very rapidly. Linking codes will probably never be simple, but the interoperation strategy we are pursuing leads to as close to a modular system as is possible. Each successful coupling peer provides a template (in both the usual and the computer science meanings) for other linkages.

### OOP1 Initial Progress:

During the first year of CISM, we have concentrated on making sure that the approach is feasible, and that the proper “nuts and bolts” are available for further development. This work is also supported by a NASA grant from the Living with a Star (LWS) program, which has goals similar to those of CISM.

The lower level, “nuts and bolts”, effort has made significant progress but will require further work during the coming year. There have been three major areas of development:

The Meta-Chaos library is being redesigned and recoded to allow for communication and control between parallel (or sequential) programs. The library has been redesigned, with a new API, to allow a program to specify data distribution across processors in each parallel program in a flexible manner. The design initially supports both regular and generalized block distributions, and completely irregular distributions. This capability effectively enables support for all the space science codes that are currently intended to be coupled in CISM. Additional data distributions will be supported if additional codes are identified that need to be coupled to the existing set of codes. A prototype implementation that supports communication between programs with block distributions has been implemented and tested, and shown to perform much better than earlier versions of the Meta-Chaos library. Implementation and evaluation for other data distributions is in progress. There are several orthogonal sets of options for building communication schedules at runtime (the patterns of point-to-point communication required to communicate between parallel programs). A major goal of the prototype is to evaluate the various options, quantify the performance impact of the various choices, and enable automatic selection of the best options for a particular communication request.

Another area of effort has been in adding support for generalized block data distributions to the Multiblock Parti library. Adding generalized block distribution support for P++ via Multiblock Parti will allow for better load balancing within a P++/Overture parallel program, via the use of grid partitioning algorithms that generate generalized block distributions with good load balancing properties.
Fortran bindings for Meta-Chaos are being developed and tested. Since many of the CISM codes are written in Fortran, this is an important first step. The Fortran90 (F90) interface to Meta-Chaos is a particular challenge. As several of our codes are written in F90, we need a general F90 Meta-Chaos API to couple them to with our other codes. The major difficulty with implementing that API stems from the fact that an F90 array reference is not simply a pointer to the data for the array, but is actually a pointer to a descriptor for the array data (because of F90 support for accessing and naming subarrays). Unfortunately, the F90 standard does not mandate a specific format, or access functions, for array descriptors, and the actual implementations in existing compilers vary. Thus interpreting the descriptor and accessing the data in an F90 array in a Meta-Chaos function, which is written in C++, is a difficult problem. However, we hope to leverage work from the DOE Common Component Architecture (http://www.cca-forum.org) and Babel (http://www.llnl.gov/CASC/components/babel.html) projects, where they must solve essentially the same problem, namely language interoperability (in this case between F90 and C++). At this time, those projects have implementations for interpreting F90 data descriptors for many common compilers and machine architectures, which we plan to adopt.

A major part of the effort this year has been to familiarize a number of people with Overture. Test advection codes have been written by CISM members at Dartmouth and at NCAR in preparation for using Overture for actual coupling cases this coming year. The most extensive use of Overture has been by Drake and his colleagues at the University of Maryland. They have investigated the use of the Overture code to do the matching between two codes with grid overlap. They have carried out a study of the stability properties of the interpolation techniques, which are of interest to the general coupling problem. A concern in implementing this technique was whether the accidental near coincidence of grid points in the two grids, which inevitably will happen, would lead to Courant stability problems. This has been a problem in other techniques for dealing with irregular boundaries. The scaling of the numerical stability boundary of the code with grid spacing has been tested and has been found to be consistent with limits based on the individual grids and not the proximity of grid points from the two grids. An analytic theory has been developed which also demonstrates that stability is not sensitive to the space separation of the two grids. Thus, the interpolation of data from one grid to another effectively mitigates the problem of grid point proximity.

**OOP1 Plans for next year:**
The major goal for the upcoming year is to demonstrate the first generation OOP framework for a limited set of code couplings. Our steps include:

- Finishing the Fortran 90 bindings for Meta-Chaos.
- General testing of the recoded Meta-Chaos library and API.
- Completing tests with a simple Overture-Meta-Chaos problem. The test takes a simple Overture program with a single grid. The original grid can then be split into two overlapping, coupled grids. The computational model of Figure 2 is then used to create a calculation equivalent to the original problem, but which uses the mechanics of the full coupling framework. This work has begun during the
current year, and we expect to finish this task during the early part of the new year.

• Coupling of MHD codes together uses Overture and Meta-Chaos. Among the CISM core codes, we will couple the solar corona and heliospheric codes together using the full Overture-Meta-Chaos framework. The Maryland group will work on coupling Hall MHD codes together.

• Replacement of the internal coupling of the MHD and ionospheric parts of the LFM code with an equivalent Overture-Meta-Chaos structure. Since the LFM internal coupling has been well tested over a number of years, the performance and accuracy of the framework version can be assessed with a minimum of uncertainty. This work will also help with the design of a general ionosphere-magnetosphere interface.

• Interface design for the general ionospheric-magnetospheric coupler. Among the core CISM codes, the LFM, the RCM, and the TING codes all need to be coupled together. All of these codes need the solution for the ionospheric electrodynamics, and they all have information that is needed for that solution. Using the knowledge gained from the LFM exercise above, we will start the development of an Overture module that will solve the electrodynamic problem and handle the necessary inputs and outputs from the CISM codes.
3.2 Solar/Heliospheric Thrust

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### Participants

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### Affiliates

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### Goals:

The overall science and simulation/modeling goal of the Solar-Heliospheric thrust of CISM is to produce realistic predictions of the solar wind and fluxes of solar energetic particles (SEPs) at 1 AU, which incorporate the effects of solar transients such as coronal mass ejections (CMEs). The model must reproduce interplanetary magnetic fields, and solar wind plasma densities and bulk velocities in 3D. These are needed to
both couple to CISM magnetospheric MHD simulations and validate the Solar-
Heliospheric simulations. We will also develop parameterized models for the production
of SEPs at shock waves generated within the global coronal and solar wind models. In
the global models these particles will then be transported from their shock sources to
predict their distribution in geospace. Achievement of these goals requires increased
understanding of CME initiation and the related problem of active region emergence and
evolution. It also requires routine modeling of the corona and solar wind based on solar
observations.

Activities:
Our activities in the first half of our first year have centered around the integration of the
diverse partners in the solar-heliosphere effort into a coherent team. Janet Luhmann at
UCB has responsibility for co-directing and reporting for the CISM Solar thrust area. The
lead contacts at the other core solar-heliosphere funded institutions are Jon Linker
(SAIC), Dusan Odstrcil (University of Colorado), and Philip Scherrer (Stanford
University). As originally proposed, we have also established collaborative connections
with NCAR/HAO and NRL. The HAO collaboration has been initiated through Nick Arge
at U. of Colorado, who is working with Sarah Gibson and B.C. Low on CISM-related
research. A new UCB research assistant, Tetsuya Magara, has been hired to work at
NRL with Spiro Antiochos’ CME simulation group. These CISM-funded positions bring
expertise and concepts to the Solar thrust from other key groups active in the CME
initiation and simulation area. A UCB CISM senior fellow position aimed at SEP model
development is in the process of being filled. Two UCB CISM graduate students,
Christina Lee and Camron Gorguinpour will start work and attend the CISM School this
summer.

To focus our team efforts, two principal meetings were held at UC Berkeley and SAIC.
The first was a 1-day solar CISM workshop held at Berkeley in December, 2002, that
brought together members of our core institutions as well as our affiliates and unfunded
partners to discuss and refine the goals of our effort. A 3-day meeting of members of
our core institutions (Berkeley, Colorado, SAIC, and Stanford) occurred in March 2003 at
SAIC to discuss issues regarding photospheric vector magnetic field data, appropriate
boundary conditions for the models, and to initiate coupling of the Berkeley
subphotospheric model and the SAIC coronal model. As a result of the discussions in
these meetings, the May 12, 1997 CME event was selected as the first target for an
event study. This CME was selected because it occurs when the photospheric field is
relatively simple, and because it displays exceptionally clear signatures in a range of
solar and interplanetary data. Vector magnetograph data is available for this event, but
unfortunately it is of poor quality. To offset this problem, the time period in early May,
1998 will also be investigated, (when several CMEs occurred) because much better
vector data is available, and will be useful for testing different ideas on the best way to
formulate boundary conditions for MHD simulations using the vector field. In addition to
these meetings, two other splinter meetings were held at Berkeley and HAO.
Interactions with the MURI centers at UCB (Solar Eruptive Events) and the University of
Michigan (Space Environment Modeling) have occurred through common members and
at several workshops.
Significant Accomplishments:

The goals in the first year of CISM focus on the integration and further development of computational tools and data sets necessary for achieving our overall science goal. The principal computational models are the heliospheric model of Dusan Odstrcil (University of Colorado/CIREs) and the SAIC coronal model. In addition, the U.C. Berkeley subphotospheric model is being used to study flux emergence into the corona with the goal of modeling its effects in the coronal and solar wind simulations. Stanford’s scheme for calculating global force-free coronal field models using vector magnetograms is being used to assess initial and boundary condition approaches. The modeling accomplishments in the first year include:

- Simulated a 3D mass ejection in the coupled coronal-heliospheric model
- Tracked the three-dimensional shock wave in the coupled coronal-heliospheric model
- Performed a preliminary simulation of the coupled subphotospheric model and coronal model
- Constructed global force-free models, incorporating vector magnetograms, for the selected event studies
- Developed visualization tools for the coupled models
- Presented first results for the new, massively parallel version of the coronal code at the AGU/EGS meeting in April 2003.

While we are still in the midst of building and refining our tool set, significant science results were achieved from these studies, including:

- Further analysis of the flux cancellation mechanism for coronal mass ejections (Linker et al., 2003)
- Investigation of the limitations of the force-free field approaches used for modeling in situ solar wind signatures of CMEs in interplanetary space (Riley et al. 2003).
- Evaluation of photospheric magnetic field observations for use as boundary conditions in event studies
- Investigation of coronal and solar wind context of the May 12, 1997 event (to be reported at the ’03 SHINE Workshop)
- Investigation of the source regions of ICMEs using in-situ observed solar cycle changes as an indicator

Some highlights of our results are described briefly below.

Figure 1. Magnetic field lines and an isosurface of the scaled plasma density from a 3D CME simulation are shown (see Linker et al., 2003, for details). The figure shows the structure of the CME flux rope when the ejecta is near 20 solar radii.
Coronal mass ejections are a key aspect of space-weather. We have used the combination of the SAIC coronal code and the University of Colorado solar wind code to model CME initiation and propagation, starting at the Sun and continuing out to 1 A.U. Figure 1 shows magnetic field lines and the dense portion of the 3D simulated CME as it propagates in the corona. The coupling of this model to the heliospheric model is described in the Code-Coupling thrust. Using the coupled models, our investigations have uncovered some important aspects of CME propagation.

The coupled simulations also provide a capability to test the assumptions of methods used to interpret interplanetary data, such as flux rope fitting techniques and the use of electron heat flux to infer solar connections of field structures. For example, some results described in detail by Riley et al. (2003) suggest that non-cylindrical and/or non-force free fitting techniques may be more accurate than the cylindrical flux rope assumption.

Tracking the location of the CME-driven shock in the solar-interplanetary computation is essential for eventual space weather applications, particularly for modeling the shock acceleration and transport of solar energetic particles. We have developed a method for tracking the evolving interplanetary shock in the coupled model results, using gradients in the density. Figure 2 (left frame) shows a visualization of the shock surface in the 3D CME calculation obtained by plotting an isosurface of the normalized density gradient. In the right hand frame, the field lines with different topologies in relation to the shock are shown. The SEP propagation and transport algorithm, to be started in the coming year, will require a rapid magnetic field line tracing algorithm together with a description of the shock source.

Goals and Activities planned for Next Year:

- Develop two-state (fast and slow) solar wind background for CME simulations
using Alfvén wave pressure term to drive the fast wind

- Begin development of the solar energetic particle code, using the computed shocks and interplanetary field in MHD CME simulations as a background
- Use the coupled subphotospheric-coronal model to investigate the effects of flux emergence in an active region on the corona
- Use the new MPI coronal MHD code to simulate a 3D CME initiated from an idealized active region; couple to the heliospheric model
- Continue investigations of best techniques for using vector magnetograms in MHD simulations; use May 1, 1998 vector magnetograms.
- Perform a more detailed analysis of vector magnetograms prior to the May 12, 1997 event to assess whether reliable quantitative estimates can be obtained.
- Perform initial coronal and solar wind simulations of the May 12, 1997 event
3.3 Magnetospheric Thrust

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The CISM Magnetosphere research thrust is focused on model development in the earth's magnetosphere. Specifically, we aim to develop computational models addressing all aspects of the Earth's magnetosphere, from its global structure to small scale plasma diffusion and magnetic reconnection that nevertheless have important global consequences. Our models will focus inner plasma sheet, ring current, and Birkeland, or
magnetic field aligned, currents which couple the magnetosphere to the ionosphere. The LFM code, which simulates the global structure of the magnetosphere, the RCM code, which models the inner magnetosphere and ring current, and the TING code, which models the ionosphere and thermosphere, are all well established models that have been described in the Code Coupling thrust section. The Coupling thrust is working actively to couple these codes. Here we focus on our effort to develop computational modules addressing new and important aspects of magnetospheric physics including the radiation belts, the auroral acceleration region, and magnetic reconnection.

3.3.1 Dartmouth Radiation Belt Code

Figure 1: Schematic showing the 3 dimensional structure of the electron radiation belts. The lines are magnetic field lines. The red lines are open field lines; the yellow are closed field lines starting at a constant ionospheric latitude. The colored plane shows the intensity of the radiation in that plane.

The Dartmouth Radiation Belt Code is a relativistic trajectory-tracing code which extracts electric and magnetic fields from the LFM-MHD simulation of the magnetosphere and advances the position of guiding center test particles. The goal is to simulate the time dependent fluxes of outer zone relativistic electrons (the blue population indicated on the dayside, or left, in the accompanying figure) as well as the access and trapping of Solar Energetic Particles (SEPs), which accompany interplanetary shocks, entering the magnetosphere through the high latitude cusp region. With gyroradii comparable to the radius of curvature of the magnetic field, SEPs can become trapped and contribute to the inner zone (red population in the near-earth equatorial plane) when the magnetosphere is perturbed by the arrival of an interplanetary shock, originating at the sun as a coronal mass ejection. While significant progress has been made in modeling equatorial plane dynamics of radiation belt electrons, and radial transport and trapping of SEPs, extension to 3D is essential for modeling the balance between source and loss processes. Incorporation of an injection boundary condition from the nightside plasmasheet region (indicated in green) is in progress. Furthermore, Lorentz integration of particle trajectories using the LFM-MHD fields is under development, as required for modeling SEP access from high latitudes, and subsequent radial transport and trapping.
In Year 1, work on 3D modeling of relativistic electron dynamics was pursued by PhD student Kara Perry, and MS student Alicia Eccles. Kara has extended the 2D modeling work of Scot Elkington, now at LASP/CU, and continuing collaboration, to 3D for a specified ULF wave field, modeling the poloidal mode effect on electron transport, with azimuthal electric field component in the equatorial plane, and a parallel wave mode structure taken from Li et al. (JGR, 98, 215, 1993), along with a compressed dipole magnetic field analogous to that used by Elkington et al. in 2D (GRL, 26, 3273, 1999). Kara also investigated the toroidal mode effects, which Elkington et al. (JGR, 108, 1116, 2003,) has recently shown contributes less to radial transport and energization than does the poloidal mode. The 2D dependence on energy and L-value of the radial diffusion coefficients calculated by Elkington in his PhD thesis (Dartmouth, 2001) and recent JGR paper, and synoptic parameter survey carried out by Alicia Eccles for her MS thesis, are generally preserved in the 3D model, while the first 3D results show greater radial diffusion for equatorially mirroring particles, as expected (Schulz and Lanzerotti, Particle Diffusion in the Radiation Belts, 1974). Preliminary results on model fields and individual particle trajectories were presented by Kara at the GEM Workshop in Telluride in June, while more recent results were presented at a radiation belt workshop organized by The Aerospace Corporation in Maui in January, 2003.

Progress has been made on simulations of Solar Energetic Particle (SEP) trapping during CME-driven storm events using the Lyon-Fedder-Mobary 3D global MHD code to advance guiding center test particle trajectories in the equatorial plane. Results for two storms in November 2001, which produced newly trapped Fe+11 as well as proton belts, were presented at Fall AGU by Hudson. She also participated, along with Dartmouth postdoctoral researcher Paul Haines, in a NASA CDAW workshop on Solar Cycle 23 SEP events in August, which led to a fruitful exchange of relevant data for the simulations. Discussions with Janet Luhmann at the UC Berkeley Space Sciences Laboratory, where Hudson visited over the summer and gave a seminar on these results, led to further exchange with Richard Leske at Caltech, who has shown a correlation between the magnitude of Dst and the energetic ion cutoff latitude, possibly related to the minimum L-value of the final trapped population. However, Hudson has since found that the strength of the interplanetary shock, significantly greater in the case of the 6 Nov 01 than the 24 Nov 01 storm, is the key factor in determining the minimum L-value. In both cases, there is clear evidence for the same type of drift-time scale transport of SEP ions to low L-values ~2.5 as seen in the famous March 24, 1991 storm (Hudson et al, JGR, 102, 14807, 1997). Michael Wiltberger provided the MHD simulations for the two event studies using the LFM-code, while Paul Haines performed the particle simulations and post processing. Hudson presented an overview of recent modeling of radiation belt dynamics during geomagnetic storm periods at a one-day workshop at UC Berkeley Space Sciences Laboratory in March 03, organized by the IMAGE team scientists.

3.3.2 Magnetosphere-Ionosphere Coupling

CISM research into magnetosphere-ionosphere coupling is currently following two trajectories that are expected to intersect within 1-2 years. One trajectory, as described in more detail elsewhere in this report, is proceeding initially as a numerical effort to
couple the existing LFM, RCM and TING codes. The second trajectory is a scientific investigation with the primary objective of developing simple, lumped transport models to be embedded within the coupled large-scale models. These transport models characterize collisionless plasma processes that arise in the topside ionosphere and low-altitude magnetosphere, which impact the large-scale dynamics and energetics of the coupled MI system by converting electromagnetic power into field-aligned beams of electrons and upward flows of ions. The formation of parallel electric fields in the low-altitude magnetosphere produces electron beams that carry large energy fluxes into the ionosphere and magnetosphere. The downgoing beams, in particular, cause aurora and modify the ionospheric conductivity and the electrodynamics of MI coupling. Topside collisionless ion heating causes massive outflows from the ionosphere. The stratification of the ionosphere is modified in the process, and an inertial coupling is imparted to the MI interaction. The effects of these processes either are neglected or, as currently implemented, are of limited applicability in the existing large-scale models of the magnetosphere and ionosphere. The near-term goal of this work is to improve the existing electrodynamic coupling between the LFM, TING and RCM models and, for the first time, to implement inertial coupling between the models.

CISM researchers at BU (Goodrich, Hughes, Spence), Dartmouth (Lotko, Lyon, Shepherd, Streltsov and Murr), NCAR (Burns, Killeen, Solomon, Wang, Wiltberger) and Rice
Figure 2: Flow chart diagram of the coupling between the LFM, RCM and TING, illustrating how an M-I coupler module would link these code together.

(Toffoletto) have formed a MI Coupling working group to coordinate development and validation of the empirical and physical transport models and code couplings that are required to address this set of problems. Monthly meetings of this working group occur via the Access Grid (see http://thayer.dartmouth.edu/spacescience/wl/cism-mi-wg/ for meeting notes and related materials). The group is currently addressing a wide variety of issues. They include:

1) Facilitating cross-disciplinary understanding of the physical bases of the LFM, RCM and TING models, including their implementation as numerical algorithms both as uncoupled and coupled models;
2) Identification of thermospheric and MHD variables to be used as causal inputs in lumped models of collisionless plasma transport (enhanced energy fluxes carried by electrons, ion heating and mass outflow), together with identification of the thermospheric and MHD variables to be modified by the resulting lumped models;
3) Relaxation of artificial boundary conditions at code interfaces;
4) Streamlining and improving the MI coupling algorithm at the heart of all three models (the "MI coupler" in the above flowchart);
5) Interpretation of coupled model results, code validation and validation of model results against measurements;
6) Identification of candidate products and metrics for eventual transition to CISM partners at NOAA/SEC;
7) Development of software and data protocols for exchanging variables and data streams between the LFM, RCM and TING codes and for visualizing and interpreting results; and
8) Scientific investigations into MI coupling enabled by new modeling capabilities arising from the coupled codes.

3.3.3 Reconnection Code Development

A significant physics discovery over the past several years is the importance of including the coupling to dispersive whistler and kinetic Alfven waves in boundary layers where magnetic reconnection takes place. The complication is that the correct treatment of these waves requires the resolution of small scales, which are normally not treated in global simulations. On the other hand, the resolution of small scales is only required in rather small regions of space. The computational challenge is therefore to develop "adaptive physics" techniques in which adaptive mesh refinement is combined with the inclusion of a kinetic physics model as small scales develop in large-scale MHD modeling.

Several codes are being utilized in the development of these "adaptive physics" techniques. The set of sister codes, which are based on similar algorithms, include a two-fluid (Hall MHD with electron inertia) model, a hybrid model (particle-in-cell ions), and a fully electromagnetic pic-simulation of electron and ion dynamics. The magnetic field lines and electrical currents in color code shown below were derived from a reconnection simulation using the two-fluid code.

![Magnetic reconnection simulated by a two fluid code. The colored background shows the intensity of the electrical current. The lines are magnetic field lines. The reconnection flow is in from the top and bottom and out to the right and left from the center point.](image)

MS student Nathaniel Ferraro will complete his dissertation research on this project in June at Dartmouth, working with Barrett Rogers, while PhD student Paul Cassak at U Md is working with Jim Drake and Michael Shay on use of Overture software to imbed a Hall reconnection simulation into an MHD simulation of geomagnetic tail reconnection geometry.
3.3.4 Ground-Induced Current Simulations

Large-scale currents flowing overhead in the ionosphere induce electric and magnetic fields on the surface of the Earth. So-called Geomagnetically Induced Currents (GICs) can in turn be induced in conducting networks located underneath these currents, such as railroads, power transmission lines, and pipelines. During electromagnetic storm periods caused by the Sun these GICs can be large, often exceeding several hundred Amperes, and cause catastrophic consequences to the system in which they flow.

Simon Shepherd, supervising undergraduates, is attempting to predict the occurrence of GICs using physics-based models of the global magnetosphere, ionosphere, and Earth conductivity together with input from a satellite located in the upstream solar wind. The electric (and magnetic) field at the surface of the Earth over North America will be determined with 30-90 minutes warning, allowing an advance warning of GICs to be calculated for specific conducting networks. This research project has provided undergraduate research opportunities for two students from Dartmouth’s Women-in-Science Program and one summer intern.
3.4 Ionosphere-Thermosphere Thrust

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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 and the University of Colorado. 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 using a variety of measurement data. The particular model currently being used for CISM studies is a high-resolution version of the NCAR-TGCM known as the Thermosphere-Ionosphere Nested Grid (TING) model.

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 initial goal of the CISM project for the geospace regions is to create a coupled model of the magnetosphere and ionosphere that includes upper atmosphere circulation, solar irradiance variation, and forcing by the lower atmosphere.

3.4.1 Magnetosphere-Ionosphere Coupling

The joint efforts towards the ad hoc coupling of the TING and LFM codes have been described in the Code Coupling thrust section.

3.4.2 Ionosphere-Thermosphere Model Development

The polar cap model is a new version of the TING model that has been developed to study trans-polar-cap plasma transportation processes that are important to space weather, such as polar cap patches and boundary blobs. The polar cap model removes zonal boundaries that exist in the regular TING Model. Thus the zonal boundary conditions for the nested grid domain of the polar cap model are now periodic boundary conditions, instead of being specified by the global coarse grid. In the polar region, periodic boundary conditions are also used in the meridional direction for the nested grid, so the cross polar cap transportation is calculated self-consistently. The time dependent lower latitude boundary is still specified by the global 5° coarse grid. The simulation domain for the polar cap model is –180° to 180° in longitude and from a prescribed latitude to 87.5°. Currently the polar cap model uses one level of nesting with a nested grid resolution of 1.67 in both latitude and longitude. Multiple levels of grid nesting are also under development. Figure 1 illustrates the difference between a standard coarse grid calculation of auroral region plasma and a polar cap model simulation.

Low-latitude ionosphere electrodynamics have been incorporated into the TING Model using the 5° grid, and work is in progress to include it in the nested grids. This will enable coupling of TING Model electrodynamics self-consistently with the LFM and RCM to study some important magnetosphere-ionosphere coupling processes such as the penetration electric field and its global effects. At present the three main geospace models each solve parts of the electrical potential problem individually. Initial discussions have taken place to develop a common solver for the potential, which will have the advantage of making the calculation more self-consistent and rigorous. Work is also in progress on an MPI version of the TING Model to better exploit massively parallel computational facilities.

The NCAR TGCM models do not yet include the plasmasphere, other than as a parameterized upper boundary condition. A study of possible approaches for development of a plasmasphere model for CISM has been initiated, and a post-doctoral visiting scientist (Naomi Maruyama) with expertise in this area has been hired to assist with this problem.

New measurements of solar extreme-ultraviolet irradiance variability and associated modeling efforts are being exploited to improve the solar ionization and heating
specification to global models. Predictability of solar irradiance variability on timescales of a few days using rotational modulation is also being investigated, in partnership with external collaborators.

Figure 1. Auroral region electron density at the +2 pressure level (near the peak of the F\textsubscript{2} layer at \~250 km) calculated using the standard 5° grid model (left) and the polar cap model (right). The increased resolution is apparent, but additionally features not present in the standard model appear.
3.5 Validation and Metrics Thrust

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Funding (anticipated for next year)

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Validation of our models is as important to the success of CISM as their development, as a model is only useful to the extent we know it simulates reality. Thus model validation and metrics is its own research thrust, led by CISM co-director Harlan Spence. He will coordinate and direct validation and metrics studies within CISM. Validation will be a two-pronged effort: science validation and “end-user” validation. These two aspects are outlined below. While each element is described discretely as a sequence of operations,
we do recognize that both activities will be ongoing concurrently throughout the CISM effort. Access Grid meetings have allowed the CISM team to begin the important work of formulating and implementing this plan.

Science validation occurs during the major development period for each code version. The distributed validation team will work with the code developers to: (1) identify key aspects of codes or code coupling that require scientific validation; (2) compile and use extant data sets to exercise and explore the ranges of validity of the codes; and (3) iteratively feedback the knowledge gained into the ongoing development of scientifically robust models. While led and overseen by BU, this part of model validation will be distributed throughout the CISM teams and institutions. The goal of this effort is to assure that the primary science outputs of the models will be understood early enough in the process, through comparisons with the most relevant observations, so that developers will be able to adjust their codes to better model the desired regions or processes.

Once each major version of the coupled model is completed, it will be released internally to the CISM Validation Team for a second regimen of validation, so called “end user” validation, before the code is released to the Knowledge Transfer team and thus to the wider community. This second level of validation will continue the scientific validations from the initial phase and introduce other targeted science validations identified from this first iteration. Another important element of this second phase of validation will be to exercise the codes as broadly as possible, thus to fully explore their ranges of validity and operability. Such information will be important to establish before they are made available to the wider community. This element of the second validation stage (the “operational” or “end-user” validation) will be centered at BU assisted by teams from UTEP and AA&M, institutions without a vested interest in any of the component models. For “end-user” validation, it is critical to have primary responsibility in the hands of those who have not played an integral role in the code or code coupling development. During this second phase of validation, BU will work with the broader validation and development team to fine-tune and document the codes before each version is officially released.

We describe next several examples of science validation efforts that are currently under way at member institutions, started during the first six months of the CISM effort. Additional validation efforts are highlighted in other sections of the report. We note that these sorts of efforts are excellent vehicles for involving graduate and undergraduate students in CISM science.

**Magnetotail Transport** – Establishing the flow of mass, momentum, and energy throughout the magnetosphere remains an overarching problem in magnetospheric physics. One aspect of this question is how magnetotail flows, textured in both space and time, contribute to the overall transport. Current sparse spacecraft data provide only a glimpse of this transport, while physical models hold out the hope for establishing a global quantitative view. While the LFM code has been shown to possess features which mimic observed flow bursts, work is now underway at UTEP and BU to establish their validity in the LFM code and, respectively, to study the role the modeled flow bursts
play during magnetic storms and during substorms and inter-substorm intervals. These validation efforts are drawing heavily on both case studies of multi-spacecraft data (UTEP) as well as statistical analyses of long duration single spacecraft data sets (BU).

Ring Current Structure and Dynamics – One key code-coupling effort is the integration of the RCM into the LFM. This coupling is critically needed for a robust modeling of the ring current region which is vitally important for understanding and predicting the effects of magnetic storms. In order to validate codes’ abilities to model this region, an effort at BU is in place to develop the data sets and tools needed to compare magnetic fields throughout the inner magnetosphere and on the ground with model outputs. In this effort, we have established a large empirical data set, which we are comparing with semi-empirical models (i.e., Tsyganenko) as well as with the physics-based LFM and coupled LFM-RCM codes.

Validation Studies at UTEP - The UTEP magnetosphere team has been engaged in a variety of validation and research activities, all of which involve students to a significant degree. The major thrust has been to examine the response of the Lyon-Fedder-Mobary magnetosphere model to magnetic clouds that result from Coronal Mass Ejections (CMEs originating at the sun. These have been shown to produce magnetic storms via the coherent organization of the interplanetary magnetic field, typically characterized by a rotation, which can produce an extended interval of southward IMF enhancing reconnection and magnetospheric convection.

For example, the model, when strongly driven, develops a quasi-steady reconnection region near the Earth, located at 20 to 25 Re downstream, and a rough balance develops between dayside and nightside reconnection so that the total polar cap flux remains fairly steady. During such periods, variations in the solar wind kinetic energy flux have a significant impact on ionospheric joule heating, with large solar wind kinetic energy flux correlating with high levels of joule heating, but only weakly impacting the polar cap potential. Also during these periods of strong driving, the inner magnetosphere inflates, so that a combination of a quasi-steady, near Earth reconnection region and large flux tube volumes in the inner magnetosphere allows for quasi-steady convection. Finally, during periods of enhanced solar wind energy input, fast plasma flow channels form in the simulation. These look much like the flow bursts previously discussed in substorm simulations, but they are not associated with the loading-unloading sequence characteristics of substorms.

Having identified these behaviors we can ask "Does the magnetosphere really do this?". For example, does the actual magnetospheric configuration of the tail resemble the configuration produced by the simulation, with features such as inflated flux tube volumes in the inner magnetotail? UTEP students are collecting a database of magnetotail magnetic field observations during the main phase of large (Dst<-100) magnetic storms to test this. Similarly, we are comparing our calculations of ionospheric joule heating to the AlME-model to benchmark the simulations results. We are also looking for examples of bursty bulk flows of plasma in the tail during magnetic storms to see if the simulation results showing such features is supported by observations.
Working with the UTEP team is the Alabama A&M University group. Magnetospheric modeling is new to AAMU, but Professor M. Schamschula is working with a graduate student to begin a program of model validation. Staff from UTEP has visited AAMU to set up required software for reading and displaying magnetosphere simulation results. AAMU students and faculty will attend the CISM summer school to learn more about space weather and build additional connections with Center staff. AAMU has been initially tasked to develop a statistical map of the storm-time magnetotail magnetic field from the simulation to compare to the stormtime magnetotail magnetic field observation database being assembled by UTEP.

3.5.1 Metrics
Metrics will be developed, fixed, and then computed routinely to quantify, through skill scores, our progress toward overall CISM modeling goals. CISM has already benefited from the several studies of modeling metrics established by the science community, including documents resulting from National Space Weather Program and CCMC studies. From these comprehensive documents, CISM is in the process of extracting a small subset of the highest priority metrics from the very long lists of possible metrics identified therein. Finalizing our list will be a task to be completed by the end of the first year. That effort is well underway. Because CISM will work with the CCMC in metrics studies, a close collaboration and memorandum of understanding is being established with them. Dr. Michael Hesse, the CCMC Director, will play a key role in helping to define CISM metrics.

Several factors influence the ultimate selection of CISM space weather metrics. These include: (1) must be a reasonably small collection to be able to feasibly track; (2) on the other hand, must be comprehensive enough to robustly measure the wide realm of CISM models; (3) must be based on direct measurements or derived quantities that will be continuously and reliably available in the foreseeable future; (4) must be quantities related to key space weather effects that we are trying to predict; and (5) must be parameters that are recognized to be important by the space physics science community and/or the operational user community.

Currently, CISM envisions selecting only a handful of key space weather metrics that will continuously track our progress. While the final list is not yet decided, these may include measurements or indices such as: (1) solar wind speed, density, and interplanetary magnetic field at 1 AU; (2) fluxes of energetic particles at geostationary orbit; (3) low-altitude, cross-track plasma flow measurements over the polar cap; (4) polar cap size; (5) radar and ionosonde measurements of E and F region peak electron densities and heights; (6) dB/dt at a few key ground magnetometer stations; and (7) global magnetic activity indices such as Dst. Neutral atmosphere metrics may be neutral densities from satellite drag, and possibly FPI red line neutral temperatures.
3.6 Empirical Modeling Thrust

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<tr>
<th>Thrust Name</th>
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<tr>
<td>PI Name</td>
<td>Daniel Baker</td>
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Participants

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<tbody>
<tr>
<td>1. Goodrich, Charles (BU)</td>
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<td>6. Elkington, Scot (CU)</td>
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<td>7. Rigler, Josh (CU)</td>
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<td>8. Vassiliadis, Dimitris (GSFC)</td>
<td>Staff</td>
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<td>9. Li, Xinlin (CU)</td>
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Affiliates

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<td>1. McPherron, Robert, (UCLA)</td>
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<td>2. Arge, Nicholas (CU)</td>
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<td>3. Alex Klimas</td>
<td>Staff</td>
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<td>4. Terry Onsager (NOAA/SEC)</td>
<td>Staff</td>
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<td>5. Howard Singer (NOAA/SEC)</td>
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Funding (reporting year)

| NSF                   |
| Other                |

Funding (anticipated for next year)

| NSF                   |
| Other                |

The empirical modeling’s thrust is lead by co-director Dan Baker, who also heads the Knowledge Transfer group. The empirical modeling group consists of approximately 16 individuals who participate regularly in weekly or bi-weekly teleconferences or on-site meetings. At LASP, the participants include Xinlin Li, Bob Weigel, Scot Elkington, and Josh Rigler. From BU the participants are George Siscoe, Chuck Goodrich, Harlan Spence, and Nancy Crooker. Alex Klimas and Dimitris Vassiliadis participate from NASA/Goddard along with Bob McPherron of UCLA. Terry Onsager, Howard Singer, and Nick Arge from NOAA/SEC are also regular participants and provide significant guidance and feedback.

Significant Accomplishments

The primary accomplishment of EM research in the first year was the establishment of a sun-to-Earth empirical model chain. The chain includes models from a diverse set of researchers written in a diverse set of programming languages. The chain has contributions from the solar/heliospheric magnetospheric and ionospheric communities.
The chain includes a solar-wind propagation model, the Wang-Sheeley-Arge (WSA) model that is driven by solar observations. The output of this model can be used to drive magnetospheric and ionospheric models. The magnetospheric models include several well-established energetic electron models. The Earth end of the chain now has an Ap index model and a surface dB/dt model. In the near future, the chain will include a ground magnetic field model that can provide predictions of the local geomagnetic field on sub-hourly time-scales. The model currently under consideration (by D. Weimer) is one that is of great interest to the SEC and is thus the most logical choice for a starting point.

A typical output from the WSA model is shown in the figure to the left. The WSA model is driven by Mt. Wilson Solar Magnetogram measurements and is currently available with a lead time of 2-3 days at a cadence of three predictions per day. Arge has been participating in the bi-weekly empirical modeling telecoms, and has provided CISM with a 5 year history of predictions. These data are currently being used to drive the energetic electron models and the Ap model, both of which require one-day averages of the solar-wind velocity.
The CISM empirical model chain includes two energetic electron models, a finite-impulse response model developed by Vassiladis et al., [2002] and a threshold-prediction model developed by Weigel et al., [2003]. These two models work together in a complementary way. The FIR model provides a day-to-day forecast of the amplitude of the MeV flux in the L-shell range of [2,8]. The threshold model provides a prediction for the days in which a large-event in the MeV flux is expected. In the figure to the left, the predictions of both models are shown for a 100 day interval in 1994. Both models are driven by the WSA solar-wind model, and can thus provide a 2-3 day lead time in predictions. One of the reasons these models were chosen for development is that they both require only the magnitude of the solar-wind velocity as an input.

The Ap model developed by McPherron, [1998] also provides predictions on a daily time scale. Moreover, the model was developed to use only the solar-wind velocity as an input, and thus we have integrated it with the output of the WSA model. In the following figure, the filter coefficient values of the model are shown. Under validation using historical measurements of the solar-wind velocity at the L1 point, the model was able to provide prediction at the same level or higher than those provided as SEC. The next step in development of this model will be to compute its performance using the WSA velocity.
On sub-daily time scales, the empirical model chain can provide a forecast of the average value of |dB/dt| in a 30-minute time interval. Provided ACE data, which is available at lead times of 62 minutes on average, this model can provide a prediction with an average of 32-minutes lead-time. As shown by Weigel et al., [2002], the model performance does not depend on the north-south component of the IMF in the pre-noon sector. For this reason, when solar-wind propagations models move down to the sub-hourly timescales, predictions with 3 day lead times may be possible. In the figure to the left, the model output is shown at UT = 20:00, after a steady increase in the magnitude of the solar-wind velocity. The model predicts a large level of activity in the pre-noon sector.

**Goals, Activities, Outcomes, and Impacts**

The establishment of a systematic empirical model framework will allow us to meet many of the empirical modeling science goals. These goals include (1) the computation of benchmarks for a set of models that were previously tested using inputs that were measured, as opposed to using inputs from a separate empirical model in the chain, (2) an understanding of how predictable various parts of the sun-to-Earth system are; such knowledge will be used to determine where modeling efforts are most needed and will guide future spacecraft missions, and (3) an ability to do inverse modeling of the propagation dynamics of disturbances from the sun to Earth; an understanding of these dynamics with empirical models provides information on which plasma process have the most influence on the system.

The impact of this work extends from the scientific to operations communities. From the scientific community perspective, this will be the first extensive sun-to-Earth model chain that includes the best empirical models from a diverse set of modeling communities. From the operational perspective, the empirical model chain has the potential to be used to provide forecasts at lead times much greater than the usual L1-Earth solar-wind propagation time (~1 hour). Because it is a sun-to-Earth chain, we should have lead times of 2-3 days.

**Goals and Plans**

We will continue our work in bringing in other models to the empirical model chain. To simplify this process, we have developed a basic framework that researchers can follow if they want to have their model included in the currently-established chain. Our goal is to have this basic framework become widely used so that that the resources required for
learning a new model or integrating it, and preparing it for operations will be reduced. The framework was developed so that it is both simple and general enough to be easily integrated with the physics-based model framework, which is more general and will eventually be the standard CISM framework. We plan to integrate many of the existing models from participants into the empirical model framework. For example, Xinlin Li and Alex Klimas have real-time predictors of Dst available on-line. Dan Moorer and Dan Baker have developed a 4-D data assimilation for the radiation belt that Ph.D. student Josh Rigler will continue work on.

A second major effort in the following year will be the integration of the empirical models with the physics-based models. Each modeling approach has its strengths and weaknesses with respect to the goal of optimal forecasts. For example, one of the current strengths of the physics-based models is their ability to provide global forecasts, something that empirical models are not able to do, because of the lack of data in many parts of the magnetosphere. At ground levels, where long records of geomagnetic measurements are available, empirical models currently out-perform the physics-based models. Using both approaches to provide forecasts increases the volume of space where forecasts can be made.

Now that the core set of models for the EM chain has been established, we will begin extensive testing and benchmarking. Dialog has already begun with the researchers participating in the MHD modeling thrust for the eventual integration with physics-based models for data assimilation and testing.
The primary goal of CISM during its first five years is to construct a physics-based comprehensive model of the solar-terrestrial system. However, recognizing the importance of data assimilation in improving model predictions in many fields, the CISM team decided that during the first year of the Center, it would study both the extent to which data assimilation was already happening within the work of the CISM team, whether under the auspices of CISM or not, in the wider community, and the feasibility of introducing data assimilation into the core CISM modeling activity. These activities and the preliminary results of this study are collected and reported here as the Data Assimilation thrust, though no funding was explicitly allocated to this activity. Our plan is to use the next CISM all-hands meeting as a venue to discuss and form a plan for data assimilation within CISM.

The activities that CISM team members have initiated or helped in are:

- Organizing a special session on data assimilation at the fall AGU meeting in San Francisco
- Organizing a special 1-day meeting on data assimilation to be hosted by Dan Baker in Boulder on the day following Space Weather Week. CISM advisory committee member J. Sojka, and Bob Schunk from Utah State have agreed to attend and share their considerable expertise.
- Organizing a GGCM campaign tutorial at the 2003 GEM Workshop in Snowmass on data assimilation to be given by Ludger Scherliess of Utah State. This tutorial will be followed later on the same day by a breakout session on data assimilation to be chaired by Mary Hudson.
- Holding many less formal discussions on data assimilation within the CISM
research groups, to determine what is currently happening and how data assimilation may be usefully employed. The results of these discussions are outlined below.

**Background**

Every measurement made of a physical system has an associated uncertainty. A numerical model of such a system also has a separate associated uncertainty. Data assimilation is, in the most general sense, any technique that uses measured data and model output to provide an improved estimate of the state of a system given both sets of uncertainties. Mathematical theory for providing these optimal estimates has been developed, so the only remaining obstacle should be determining what these uncertainties are. This is far from a simple matter, however, and can require considerable experimentation before usable model output is attained. Data assimilation has been used for decades to combine large meteorological data sets with various atmospheric and oceanographic models in efforts to specify and forecast terrestrial weather. Recently, similar techniques have been applied to the auroral region electric potential and to global models of the ionosphere (see below).

There are several areas where incorporation of measurements into the CISM model is already part of the Center strategy. Whether these applications are boundary conditions or true data assimilation is to some extent a matter of semantics. In other cases, experiments using specification models that employ data assimilation to provide initial conditions, and perhaps continuous updates, that were outside the original scope have been identified. These will be incorporated in the updated Center strategic plan as resources permit. The following sections discuss existing and potential uses of data assimilation methods in the various scientific areas.

**Solar Photosphere**

Realistic models of the corona and heliosphere require the assimilation of solar photosphere magnetic field data as a lower boundary condition. Magnetograms of the line-of-sight photospheric field are now routinely made several times daily by a number of ground-based and space-based solar observatories. To realistically model the structure and time evolution of the corona and ultimately the solar wind, the line-of-sight photospheric field measurements must be updated frequently with new observations. This is especially true when the field is changing rapidly, as occurs during solar maximum. The photospheric field may be continuously updated via the assimilation of new full-disk magnetograms into global (i.e., synoptic) maps of the magnetic field distribution assembled from the most recent ~27 day time series of magnetograms. A collaborating project at the NCAR High Altitude Observatory is in progress to produce routinely highly reliable, uniformly constructed, synoptic maps using this method. These maps will be used to drive both the coupled empirical models (e.g., Wang-Sheeley) and advanced numerical Sun-to-Earth models, and they will also be made publicly available to the scientific community this coming year. A future improvement will be the incorporation of a photospheric field diffusion/convection algorithm that “evolves” fields on the far side of the Sun and through periods without observations.
Coronal Observations

For transient events such as coronal mass ejections, CISM models could incorporate key observations of the lower corona, such as coronagraph and X-ray/EUV observations, and radio observations. These contain information on the source region, trajectory, size, morphology, and acceleration profile of the coronal mass ejection, all of which will affect the interaction of the CME with the Earth’s environment. Radio and X-ray observations are already used to parameterize blast wave simulations of CMEs in certain semi-empirical models. The manner in which these can be used in the CISM models will be explored in the coming year. Ultimately, the assimilation of such observations in real time could be used to aid in predicting the timing and geoeffectiveness of CMEs.

Upstream Solar Wind Measurements

Measurements of the interplanetary magnetic field, plasma density, and speed are routinely performed by spacecraft in orbit about the first libration point (L1) of the Sun-Earth gravitational system, particularly by the ACE spacecraft. Real-time measurements can be used to adjust parameters used in the CISM solar wind model such as the heating that determines the solar wind speed. The boundary conditions derived from the photospheric magnetograms, described above, can also be modified to obtain a better fit (e.g. by adjusting the assumed solar polar field strength).

The L1 measurements have been employed for some time to drive magnetosphere and ionosphere models, including direct incorporation into the LFM model to study magnetospheric disturbances, and continuous real-time ingestion by the TING model, using empirical relationships to estimate auroral precipitation and convection. The Center strategy for model development is that the magnetosphere-ionosphere coupling project will progress more or less independently of the solar-heliospheric coupling effort for the first few years, using solar wind measurements at L1 to drive the coupled model, until improved forecast skill is obtained by the solar-heliospheric model. This will give us short-term (~30 minute) magnetosphere-ionospheric forecasts and “nowcasts” to show for our efforts while forecasts on the order of 1-2 days are under development. We now need to derive a strategy for transitioning from measured solar wind parameters at a particular time to heliospheric model forecasts. Since there are few parameters involved (one vector and two scalars), a fairly simple spline transition could be used that would enable the magnetosphere-ionosphere model to retain its response over immediate time scales to the measured solar wind, and adding the capability for a more speculative longer-term forecast.

Radiation Belts

Formal data assimilation techniques have been applied to the problem of radiation belt specification by Moorer and Baker at the University of Colorado. This model combines data from NOAA GOES satellite particle detectors and LANL geostationary satellite sensors, and uses the empirical CRRESELE electron model as a baseline. It provides
sub-daily resolution estimates of relativistic electron fluxes at geostationary orbit that reproduce up to 90% of the variance in the measured data. This is a tremendous improvement over previous specification models, where dynamic range and resolution were limited to climatological scales.

During initial attempts to improve and extend the Moorer-Baker data assimilation model, it became clear that at least two significant hurdles remain before the model will be operationally viable: consistent high-quality electron data from non-geostationary regions of the radiation belts, and dynamical equations relating electron flux variations to variations in solar wind parameters to provide short-term forecasts. These issues are currently being addressed by Rigler and Baker through continuing studies at CU using SAMPEX data in conjunction with linear and non-linear prediction filters to provide short-term (0-2 day) predictions of 2-6 MeV electron fluxes from L = 1.1 to 8. Preliminary results are very encouraging, and include time-adaptive, multi-channel response functions at 100-minute time scales. Weigel, an expert in non-linear dynamics and neural networks, has recently joined CU to work on the CISM project, which promises to improve the space weather forecasting capability of these empirical models.

**Assimilative Mapping of Ionospheric Electrodynamic**

The Assimilative Mapping of Ionospheric Electrodynamic (AMIE) procedure, developed by CISM co-investigator Richmond and co-workers, is a data assimilation model that specifies high-latitude electric potential and convection, and ionospheric conductance, using a variety of measurement sources. These include ground-based magnetometer data, DMSP and NOAA auroral particle data, auroral images from the POLAR UVI and IMAGE FUV instruments, incoherent scatter radars, and Superdarn HF radars. AMIE combines the available data with constraints from an empirical auroral oval to obtain a time-dependent best-fit estimate of auroral ionization and convectional forcing, suitable for use as the high-latitude inputs for TIE-GCM runs. AMIE is also of significant utility to magnetospheric modeling because it can provide a global comparison between model predictions and observations. However, initial attempts to constrain global magnetospheric MHD models to the AMIE auroral conductances and convection were unsuccessful. The vast scales of connectivity in these models makes them resistant to local constraints, and is the most daunting aspect of data assimilation faced by CISM investigators. Rather than attempt to drag the magnetosphere by its feet, our use of the AMIE procedure during the first five years of Center activities will be for ionosphere-thermosphere response, comparison with auroral predictions, and validation.

**Ionospheric Data Assimilation**

The most promising area for direct incorporation of measurements into CISM model segments is in the ionosphere-thermosphere system, where the meteorological analogy is most valid. Global ionospheric density measurements using ground-based and, increasingly, space-based GPS receivers are available, and models such as the Global Assimilation of Ionospheric Measurements (GAIM) developed by R.W. Schunk and co-workers at Utah State are of considerable utility for describing the current state and short-term future of the ionosphere, particularly the non-auroral ionosphere. Rather than
duplicate this effort, we suggest a collaboration with the Utah State group to investigate the possibilities of combining this assimilative approach with the CISM theoretical modeling approach. As an initial experiment, we propose to employ a GAIM ionospheric specification as the initial condition for an coupled magnetosphere-ionosphere model run, and quantify the differences between nominal and measured initial conditions, and the time scales on which ionospheric features persist in the model during magnetically active periods. We have conducted discussions on these collaborations with CISM advisory committee member J. Sojka, and Schunk and Sojka have agreed to attend the data assimilation discussion during Space Weather Week and to further discuss collaborative work.

Neutral Atmosphere

Although there are insufficient continuous global measurements of the thermosphere above ~100 km to perform the same type of comprehensive data assimilation as is now possible in the ionosphere, there are two areas where data are used to improve the validity theoretical and empirical models that could be extended to inclusion in the CISM models. The first is the use of National Center for Environmental Prediction (NCEP) global stratospheric pressure fields to provide the lower boundary forcing for the TIME-GCM. This greatly enhances the variability of model predictions when compared simple forcing models, and presumably provides a more realistic representation of the upper atmosphere. Although the full (mesosphere included) TIME-GCM is not currently employed in the CISM modeling suite, future developments could utilize it. The second possibility is the use of satellite drag measurements of the global atmospheric density field. Work by F. Marcos and colleagues at AFRL has shown that incorporation of selected satellite drag measurements into empirical models of thermospheric neutral densities greatly improves the ability of these models to predict orbital decay of other satellites. This result, while perhaps not surprising, indicates the utility of these measurements for adjusting model parameters to correspond to the gross state of the thermosphere. Since satellite orbit decay is one of the metric targets of the CISM program, tuning the model using drag measurements is a sensible approach.

Solar Ultraviolet Radiation

Finally, the solar radiation component of upper-atmosphere and ionosphere forcing must be addressed by the CISM project. Initially, this will use empirical models of solar far-ultraviolet, extreme-ultraviolet, and X-ray irradiance based on past and current measurements. For middle-term (<~2 day) forecasts, a simple persistence assumption would be employed. The next step in development will be to use daily measurements (e.g., by the TIMED solar EUV experiment) of the solar irradiance in the model, and following that, techniques developed by W.K. Tobiska to perform a several-day extrapolation of solar proxy indices based on the 27-day periodicity will be utilized. Since the thermosphere-ionosphere system responds sluggishly to (non-flare) solar irradiance variations, this approach should be adequate. For flare events, it would be necessary to employ real-time observations, e.g., from the GOES X-ray monitors, as available.
III. EDUCATION

Overall objectives:
The overall objectives of the CISM education program are to integrate the training of the next generation of space physicists into the research program of the Center, increase diversity in space physics, to provide space physics-based educational resources to secondary and post-secondary teachers, and to generate resources for communicating the importance of space weather to the general public. In the past year, as a result of continuing conversations with other STC education professionals, the NSF, and our own Advisory Committee, we have decided to make some change of emphasis in these areas of concern. In particular, we are scaling back the amount of professional development that the center will provide to secondary teachers. That professional development we undertake will focus primarily on long-term internships, beginning during the summer but continuing during the school year. On the other hand, we are shifting resources to strengthen the program at Alabama A&M University as will be described below.

Challenges and solutions:
The major challenge in the past few months has been in fashioning a coherent education group out of the distributed education staff of the Center and bringing new staff on board. We have made considerable progress in this direction. Boston University has hired Dr. Esther Zirbel, an astronomer who is changing careers to science education. She will be conducting summative evaluation and physics education research.

At UTEP we are hiring an education coordinator, Jana Martinez, who has a background in science and who has been working in another UTEP education program doing coordination and evaluation. Another UTEP staff member, Robert Bruntz, will be added beginning this fall after he completes his M.S. degree working on a CISM project. He will provide computer and AG node support, as well as assist in mentoring undergraduates doing research. UTEP has also advertised for a Post-Doc. We have also begun to have semi-regular teleconferences, one every two to three weeks. These teleconferences, along with additional communication (such as weekly telephone meetings between Lopez and Zirbel) have allowed us to more sharply define the roles of the various groups. As our AG Nodes become operational we will be able to even better coordinate our activities. Regular Center-wide education group AG telecoms will be scheduled every three weeks.

Distribution of CISM Education Activities and Responsible Individuals:

Boston University:
Lead Institution for organizing Summer School (Hughes, Zirbel, Nottingham)
Physics Education Research/Curriculum Development (Garrick, Zirbel)
Summative evaluations (Zirbel)
Teacher interns/professional development (Zirbel, Garrick)
Undergraduate research (Hughes, Spence)
Graduate research meeting (Hughes, Zirbel, Nottingham)
Ethics training (Hughes)

**University of Texas, El Paso:**
Summer school organization and execution (Lopez, Bruntz, Turner)
Teacher intern/professional development (Lopez, Hamed, Turner, Bruntz, Martinez)
Physics Education Research/Curriculum Development (Lopez, Hamed, Turner, Bruntz, Martinez)
Undergraduate research (Lopez, Hamed, Turner, Bruntz)
Formative Program Evaluation (Hamed, Martinez)
Graduate research meeting (Lopez)
Ethics training (Lopez)

**Stanford University:**
Space Weather Monitor development (Scherrer, Morefield)
Teacher intern/professional development (Scherrer)

**Rice University:**
Teacher intern/professional development (Reiff)
Undergraduate research (Reiff, Tofolotto)
Full-dome planetarium show development (Reiff)

**National Center for Atmospheric Research:**
Teacher intern/professional development (Johnson)
Web-based materials (Johnson)

**University of Colorado:**
Undergraduate research (Baker)

**Dartmouth College:**
Teacher intern/professional development (Hudson)
Undergraduate research (Hudson, Lotko)

**Education Programs:**

Ethics training

The CISM Executive Committee is in the process of developing a “rules of the road” document that covers the principal ethical questions we believe arise in the conduct of our science. This document will describe the proper use of models and data developed or collected by others, the proper conduct of research, especially in a large collaborative effort, and general rules of authorship and acknowledgement on papers either published or presented at meetings, with the particular rules for CISM related papers. These rules and guidelines will be communicated to all CISM members as a special session at our annual all-hands meeting. Each year, all new CISM members will be required to attend
this session, or a similar one presented over the AccessGrid for those not able to attend the all-hands meeting.

We do not yet have a means of evaluating this activity, though certainly formative evaluation will be developed to learn if participants find the sessions clear and useful. This is an important juncture between research and education since we need to establish clear rules that regulate our research in this distributed and diverse center, and make certain that all members fully understand these rules.

The Summer School:

Description:
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 taught at a level and in a manner suitable for well-prepared upper division undergraduates, and also space weather professionals. This year we are also inviting 3-4 high school and/or community college physics teachers who are working long-term with CISM sites to the summer school. The summer school has been held for two years, beginning before the official start of the center. The next one will be held this summer, from July 28 through August 8 at Boston University.

The basic structure of the summer school is three series of lectures on the space environment (reality), its effects on technological systems and humans (harsh reality), and on models used to specify or predict the space environment (virtual reality) during the morning, and afternoon computer labs in which students explore these models, and also gain familiarity with IDL and OpenDX (two core CISM software packages). In addition leading professionals in space weather are invited to present after-lunch talks on their professional lives to give students a better grasp of the various sides to the profession of space weather beyond research. The pedagogy of the summer school is active and hands-on. Lectures use a Peer-Instruction format (Mazur, 1997). At the end of the morning lectures students write questions on index cards that are collected; answers to the questions are provided at 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 a simulations into a “concept map” that describes the event.

During the summer school there is explicit reflection on the pedagogy being used, as well as a special session on physics education. Summer school participants might at some point be teachers themselves, so a goal of the summer school is to inculcate some familiarity with active learning techniques in the participants. Moreover, it is also a goal that CISM faculty will also gain familiarity with these techniques and use them in their regular classes. We also will disseminate information about the summer school to the professional community. A paper describing the summer school will be presented at the 2003 Summer AAPT meeting.

Evaluation:

Formative –
The summer school has daily formative assessments of lecture sessions and labs, using a modified Likert scale ranging from 0 to 5 (as opposed to a typical 1-5 scale in order to emphasize that the low end of the scale is a negative evaluation). Previous evaluations have scored 3.6 to 4.8 on this scale, which we consider to be successful. There is also a summary evaluation of the summer school at the end of the event. Those scores and comments have also been quite positive, with most students ranking the summer school as “very good” or “excellent”. Another element of formative evaluation is to ensure that the summer school serves a diversity of students. The 2001 and 2002 summer school had a total of 53 students; 36 white males, 12 white females, 2 black males, and 3 Hispanic males, so there is scope for improving diversity.

Summative –
We are currently developing a set of questions for past participants in order to judge the long-term effects of the summer school. Evaluation will examine how the summer school has impacted the participants’ space weather careers. It will also examine how the use of active engagement educational techniques in the summer school has affected the participants’ teaching (if they have teaching duties). Finally, we will survey the summer school faculty to determine the impact on their own teaching. We have not determined what would qualify as success, but that determination will be made this summer.

Integration with Research –

The summer school provides a critical support to the research program through the creation of a shared resource that all CISM institutions can use to educate incoming center members about space weather and models. It also provides a forum for testing and evaluating teaching techniques in an advanced educational setting.

Graduate Student Meeting

Each year we will hold a meeting of all the graduate students engaged in CISM research. These meetings will allow the CISM graduate students to share their research and build community. A rotating program will focus 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, or teaching methods and physics education. Once our AccessGrid is fully operational we will also experiment with special CISM graduate student AccessGrid meetings as a way of building community among our dispersed student population, and as a way to bring issues of special concern among our graduate students to the fore.

Evaluation –
Formative evaluation will focus on student perception of usefulness. Summative evaluation will consist of interviews in succeeding years. Success will be defined if interviewed students identify the meetings as “very useful” or “extremely useful” on a five-point scale.

Integration with Research –
The AG node meetings will provide needed cross-center communication among the graduate students and thus enhance their research. The annual meetings will provide important professional development to students as they prepare to become professional scientists and faculty. Also, such a professional development program might prove attractive to students and aid recruitment.

**Undergraduate research**

CISM has an active, distributed undergraduate research program. We have already recruited 14 students. To promote a sense of “CISMness”, we will hold two undergraduate research conferences over the Access Grid each year.

**Evaluation –**

Students will be interviewed to determine how they feel about their research experience. We will also examine student demographics, with success defined as at least 30% of participants being women or members of underrepresented minorities.

**Integration with Research –**

Undergraduates can provide significant research support to CISM while at the same time such research can be used to recruit and retain students in physics.

**Physics Education Research/Curriculum Development**

CISM will have an active program of physics education research that will act in concert with a program of curriculum development that uses space weather concepts and CISM visualizations to enhance undergraduate teaching of physics and astronomy. Currently we have initiated a research program in how students at a variety of levels interpret visuals such as solar images in extreme ultraviolet (a commonly used image). Preliminary results of this study were presented at the winter AAPT meeting in January 2003. We consider such research to be essential if we are to use CISM visualization products effectively in education.

We have also developed materials for a lecture in introductory astronomy about space weather. These materials were field-tested at UTEP, with both attitudinal surveys and pre- and post- content exams. The results showed a significant impact on attitudes and considerable gains in content knowledge. These materials have been disseminated to 100 institutions around the country. Evaluation will begin this summer and continue in the fall to determine teacher satisfaction with level of use of the materials.

**Evaluation –**

Assessment and evaluation are an important part of the research process but to determine the overall effectiveness of the research and curriculum development program we will use a mix of traditional metrics (papers presented at professional meetings, publication of results) and measures to determine use of CISM-developed materials by non-CISM institutions. In that sense we consider materials to be successful if at least 5 non-CISM institutions use them more than one semester.

**Integration with Research –**
The physics education component of CISM will focus on research problems that are directly related to CISM science. Our results will be used to increase the effective use of CISM resources like visualizations in the research realm, such as helping students acquire the basic content and conceptual knowledge they need to contribute to the center.

Teacher Interns/Professional development

Six sites (Boston, Dartmouth, Rice, UTEP, NCAR, Stanford) will have teacher interns this summer. The role of these teacher interns is to work with the CISM sites and connect CISM resources to the area education community and/or engage in summer research experiences as a means of professional development. We envisage that these teachers will become long-term members of the center. The exact nature of the activities are site-dependent, as described below. Evaluation will generally consist of post-intern interviews, with one measure of success defined as all interns rating the experience as being important to their professional development. Also, since building long-term relationships is one of our goals, we will also define success as having 2/3 of our summer interns still involved in CISM activities at the end of 3 years.

Boston – A major consideration is to provide CISM resources over time to Boston Public Schools (BPS). A teacher from BPS will join CISM as a summer intern in July and attend the summer school. This individual will then work with the BU education team and the Director of Science for BPS (Marilyn Decker) to identify resources that can be integrated into BPS in a systemic manner. The BU team will also work with the UTEP and other CISM sites to refine the summer school labs, especially in response to evaluation results. In addition to the teacher from BPS, we are looking to bring on another high school or community college teacher from the Boston area. Thus the internship program will serve both internal and external education activities, and through the improvements to the summer school, the research effort will be strengthened by providing a better introduction to space weather for CISM graduate students.

Dartmouth -- Dartmouth College, in partnership with Montshire Museum of Science, will offer a three-day teacher workshop for kindergarten through eighth grade teachers in astronomy and space weather education. This mini-institute will be designed to provide participating teachers with a basic understanding of astronomical concepts related to celestial mechanics and descriptive astronomy, and an introduction to space weather. In addition, the program will provide teachers the tools, resources, and appropriate techniques needed for introducing these ideas to their students. The summer teacher intern will play an important role in working with the CISM scientists and teacher participants to ensure a successful workshop. Templates for inquiry-center, standards-based sessions on sunspots and phases of the Moon have been developed at UTEP and will be provided to Dartmouth. We plan to conduct followup evaluation with participants over the coming year in order to determine the effectiveness of the activities.

Rice – Rice will hire a teacher intern to assist in summer continuing education and to help incorporate space weather material into a course offered in the fall for Houston teachers as part of the MS in teaching offered by Rice. The intern will also assist in the
development of evaluation instruments for the planetarium shows being developed by Rice. This teacher intern will deepen the systemic partnership already in place between the Rice space science education group.

UTEP – UTEP will hire two teacher interns for the summer, one to work in space science research, and the other in physics education research. The latter position will be filled by a high school physics teacher who last semester took a graduate course in physics education research. She will assist in developing protocols and evaluation instruments for the physics education effort at UTEP. The intern to work in research has yet to be indentified, but we will hire a high school physics teacher who will assist in the construction of a small Beowolf cluster. The involvement of these teachers, while providing them with valuable professional development experience, will also materially aid both the space physics and physics education research program at UTEP.

NCAR – NCAR will hire one, perhaps two, teacher interns this summer to assist in work on an undergraduate website on space weather. Those teachers will support planned workshops this summer.

Stanford – Stanford will hire two interns, one high school physics teacher and one community college physics teacher, to assist in the development of an inexpensive space weather monitor. The basic idea is to monitor ionospheric disturbances with existing VLF signals. It is expected that detectors could be built for about $200 each. Proof of concept tests are currently being conducted, and this summer will allow for long-term data collection and analysis. If the tests prove successful, we will be able to deploy many of these to high schools around the country, following the model of Project Inspire, and have a central website where students can share data and analysis. In a recent research project at UTEP we conducted in-depth interviews with all the physics majors to determine why they had chosen physics. About 50% said that they decided to study physics because of positive experiences in middle or high school. Thus by providing real-world data experience we hope to impact high school students. Students at schools where the space weather monitor is deployed will be surveyed to measure the effect on their attitudes about science. This summer we will determine specific metrics for success.

Informal Science Education

This summer NCAR will begin developing web-based materials for undergraduates about space weather models, leveraging the expertise in informal science in the “Windows to the Universe” group. These materials will be used both inside CISM to provide our undergraduates with basic space physics content and as a public outreach tool for undergraduates or advanced high school seniors. The NCAR and UTEP teams will jointly develop evaluation instruments to determine the effectiveness of the materials. We also will use these materials as a research tool to study student interpretation of images and visualizations. What we learn will be utilized to improve the summer school, thus directly supporting the research effort by better preparing center students.
Two other informal science efforts are centered on the creation of materials for planetarium shows. At one end of the spectrum, Stanford is creating a space weather show for the Starlab planetarium (Starlab is a small, inflatable planetarium used widely in schools). At the large-scale end of the spectrum, Rice University is developing content for an immersive, full-dome planetarium show in conjunction with the Houston Museum of Natural Science. Success in each case will be measured by number of viewers of the show. More specific measures of success will be determined this summer.

New graduate program at Alabama A&M University

Alabama A&M University is proposing to its governing bodies the formation of a masters-level graduate concentration in space science within their physics graduate program. CISM will act as a key partner and resource to help AA&M establish this new concentration and build an active research presence in space science with space weather as a research focus that will be integrated with the new degree concentration. Establishing these new programs will require a stronger space physics expertise within the AA&M faculty. CISM is currently identifying funds gained from scaling back short-term teacher workshops to provide partial support for a new tenure-track position at AAMU in space physics. Building a stronger program at AAMU will provide that institution with increased ability to contribute to CISM research as a whole. A new tenure-track position and a new MS concentration represent significant institutional legacies that will continue after the center and provide a new route for increasing the number of African Americans in space physics.
IV. KNOWLEDGE TRANSFER

Objectives
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. Transition of forecasting tools to NOAA/Space Environment Center. The transition will be facilitated through a close partnership and interaction with SEC including a CISM staff member to specifically be the liaison with SEC. We anticipate that the first models to be transitioned will be components from the end-to-end empirical model. Later we anticipate transition of models from the comprehensive numerical model.

2. Providing the scientific research community access to CISM models. Access to the empirical models will be provided through a web site based at LASP. In the longer term, we plan to provide access to the CISM physics-based models through our partnerships with CCMC and NCSA.

3. Training and interaction with industrial partners and government labs and agencies. This will be achieved both through industrial or government employees attending the summer school and through specific programs that will be developed in conjunction with industrial partners.

The management and performance indicator for (1) is the transition of community-developed end-to-end models from the sun to earth to operational forecasts at NOAA/SEC. The initial performance indicator for (2) is the development of a KT web page that disseminates the forecasting advances of CISM to the scientific community. The indicators for (3) are a strong CISM presence at NOAA’s Space Weather Week (in May), an industrial sponsorship of “Space Weather Fellowships” for graduate students and post-docs, a program of a seminar series whereby CISM member visit industrial partners to present on-site seminars and other training, and participation of government and/or industrial employees at the 2003 Summer School.

Problems Encountered

The goal of the transition of forecasting tools to NOAA/SEC has not been fully realized at the end of the first year reporting period because the KT liaison has been in place for 4 months. However, progress towards this goal has advanced considerably in this short time, and the transition of at least one model will be completed after 8 additional months.

The original plan was for Dimitris Vassiliadis to be the KT liaison. However, for personal reasons he was not able to move to Boulder. He is still participating in CISM KT activities from his office at NASA/GSFC, which is also the location of the CCMC. Bob Weigel was hired in February, 2003 and has taken on the many of the KT liaison tasks.
Additional essential indicators for reaching those objectives are quantitative evaluation via feedback from NOAA/SEC and the broader space weather community. At present NOAA/SEC representatives participate in the planning meetings of CISM/KT. In the future, feedback from space weather users and scientists will be sought in a) direct collaborations and in meetings that CISM/KT will participate in and launch; and b) indirectly through the electronic (web- and e-mail-based) communication channels.

Knowledge transfer activities

The following is a list of knowledge transfer activities that serve to meet the Knowledge Transfer goals of (I) transition of forecasting tools to NOAA/SEC; (II) dissemination of community models to the scientific community; (III) training and interaction with industrial partners and government labs and agencies.

1. Interaction at SEC/NOAA, CO. The KT liaison Bob Weigel spends at least one day a week in an office at NOAA/SEC. He has been interacting with both Terry Onsager and Howard Singer and assessing their forecasting needs.

2. Interaction with CCMC, MD. Dr Michael Hesse, the CCMC director, visited Boston University in April, and discussed collaboration between CCMC and CISM with the Hughes, Goodrich and Spence. Dimitris Vassiliadis is located at NASA/GSFC remains in close contact with Dr. Hesse.

3. CISM presence at the NATO Conference on the Effects of Space Weather on Technology Infrastructure (ESPRIT), Rhodes, Greece, March 25-29, 2003. Bob Weigel and Dimitris Vassiliadis met with John Kappenman, of Metatch, one of CISM’s industrial partners and got feedback about the recent changes in forecasting needs of the electric power industry. Bob Weigel met with Kristy Keller of the CCMC and had extensive discussions on metrics and on how CISM can efficiently transfer its models to the CCMC. Dimitris Vassiliadis gave an invited talk on new results on relativistic electron modeling which are of direct interest to scientists and space weather modelers. Dan Baker was a Key Speaker at this meeting and will continue to play a role in the meeting organization. Bob McPherron gave the opening presentation at this meeting and introduced the meeting participants to CISM and its goals. Bob Weigel gave an invited talk on prediction of geomagnetically induced currents.

4. Janet Luhmann ran a joint MURI/CISM solar workshop at UCB SSL in December 2002

5. Dan Baker has been meeting with Dr. Dan Moorer of Ball Aerospace (Military Space Systems)

6. Dan Baker is chairing the Boulder Space Matrix, a consortium of all major organizations (commercial, governmental, and educational) that are doing space-related work.

7. Jeffrey Hughes gave an invited paper on the CISM modeling effort at the AAS meeting in Denver in February to an audience containing many science writers.

8. Dan Baker has been appointed as point of contact for Space Weather activities with the Boulder Chamber of Commerce.


10. LASP sent a representative to the National Space Symposium in Colorado
12. Jeffrey Hughes will give the main address the Massachusetts Chapter of the AIAA on May 14.
14. Development of the KT web page. This page has been developed by Bob Weigel with input from all KT members. The web page and is hosted at CU/LASP and is linked to from the main CISM page at BU.
15. Boeing Corp representatives visited to CU/LASP on 26-27 March 2003
16. Dan Baker joined the Editorial Board of the new journal “Space Weather”.
17. Dr. Noel Hinners (former Vice President of Lockheed-Martin) was hired as a LASP Senior Research Associate.
18. Dan Baker is the chair of the Satellite Review Panel at the Air Force Technical Application Center (Patrick Air Force Base, FL) and helps bring space weather expertise to Air Force programs.
19. Presentations will be made at the CEDAR, GEM and SHINE workshops on the CISM program by Tim Killen, Jeffrey Hughes and Janet Luhmann respectively.

In addition to these activities many of the senior members of the CISM team serve on various advisory or steering committees advising various government agencies and programs and/or serve in leadership roles in professional societies and in NSF programs such as SHINE, GEM and CEDAR.

**Other outcomes and impacts**

The primary application of the CISM efforts in the first year has been in preparing community-developed empirical models for transition to the Space Environment Center. From this experience, we will then be prepared to transition the CISM physics-based models to the SEC. We anticipate that our efforts will lead to a model standardization and methodology that will be used to both close the communication gap between research and applications and to decrease the amount of time for model transition to application.
V. PARTNERSHIPS

CISM has no specific partnership objectives, rather CISM seeks out partnerships with organizations that share some or all of our objectives and will be able to assist us in meeting our objectives. CISM examines each potential partnership to evaluate if the arrangement will help CISM achieve one or more of its goals and be mutually beneficial. CISM has or is forming partnerships with the following organizations:

NOAA/Space Environment Center (SEC): SEC is the government agency charged with providing the civilian community with space weather information, specifications, and forecasts. CISM and SEC have a close partnership. CISM views SEC as its principal client or customer for space weather forecast models. Liaison between SEC and CISM is facilitated through the CISM knowledge transfer team, and in particular through a CISM staff member (still to be hired) who’s principal task will be understanding SEC’s most pressing needs, communicating them to the CISM community, and working with CISM and SEC scientists (in particular Howard Singer and Terry Onsager) towards solutions to these needs.

National Center for Supercomputing Applications and the National Computational Science Alliance (both NCSA): NCSA is one of two NSF-funded supercomputer partnerships that support the supercomputing needs of the research community. NCSA has agreed to work with CISM to both provide computing resources that CISM needs and to work with CISM to provide community access to CISM numerical models. CISM is one of the ten projects in the NCSA Platinum User Program, which provides extraordinary service to selected research groups responsible for the most significant breakthroughs in computational science and engineering. NCSA director Daniel Reed has assigned NCSA staff member Bruce Loftis as the NCSA Liaison with CISM. He works closely with Charles Goodrich.

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 funded jointly by various Air Force agencies, NASA, and NSF, and based at NASA/Goddard Space Flight Center. CCMC director Michael Hesse has agreed to partner with CISM in order to provide community access to numerical models developed by CISM. Currently CCMC is in the process of accepting CISM’s coronal MHD model in order to provide community access. Charles Goodrich, Janet Luhmann, and Nick Arge are current members of the CCMC Science Working Group, which advises the CCMC Steering Committee.

Naval Research Laboratories: The solar research group at NRL headed by Spiro Anitochos is developing MHD models of solar active regions in order to understand how CME’s are initiated. In a partnership with CISM, he hosts a CISM post-doc (funded through UC Berkeley) to work in his group with the ultimate goal of incorporating these models in the comprehensive CISM model.
Lockheed-Martin Advanced Technology Center: The Lockheed solar research group headed by Alan Title is a leader in the development of space-borne solar instruments and in the analysis of solar data. CISM has formed a partnership with this research group that provides CISM with access to various solar data sets. Moreover the Lockheed Martin Advanced Technology Center has agreed to support CISM through the partial financial support of a post-doc at UC Berkeley.

The Exploratorium of San Francisco: The Exploratorium is the leading science museum in the San Francisco Bay area. They have agreed to help CISM make the results of CISM research available to the public in the form of simulations, animations, and interpreted data via their museum displays and on-line programs. They provide in-kind support.

Daniel Baker and the Knowledge Transfer team are developing contacts with various potential industrial partners including Ball Aerospace (Dr Dan Moorer), Metatech (Dr John Kappenman), and Boeing Corporation.

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

**Overall Objectives:**
The Center has a strong and integrated effort to promote diversity within the Center and to increase diversity in the space physics community. Space physics has historically been located at relatively few universities with a much larger presence at government labs and other research institutes. An important element of the CISM strategy is to include large minority-serving institutions in the basic research of the center, and to use that research to build the programs at these institutions. The leadership of the Center itself is quite diverse, with the eight-person Executive Committee including two women and one Hispanic scientist. Several members of the Executive Committee (e.g. Hudson, Killeen, Lopez) are well known for their work in promoting diversity. Diversity is also reflected in the diversity of institutions involved, which include both public and private universities, urban comprehensive and Research I institutions.

**Plans and programs:**
Two of the institutions in the Center, UTEP and AAMU, are minority-serving institutions where space science has not historically had much of a presence. Their contribution to Center scientific activities, focusing on model validation and comparison between simulation results and observations, will provide a strong research focus that can involve both undergraduate and graduate students. AAMU has recruited a graduate student to begin working on model validation. And as described in the section of Education, the AAMU program will be significantly expanded to include a new M.S. degree and a new faculty member is space physics. At UTEP, seven undergraduates, four of them Hispanic or female US citizens, were recruited this year to begin doing research as part of CISM. And four students decided to become physics majors in large part because of the research opportunities.

The CISM summer school likewise provides an exceptional educational resource for preparing UTEP and AAMU students to engage in space weather research. Needless to say, without a Center to provide such a shared resource, the ability of these schools to provide cutting edge education in space physics would be much reduced. For example, the summer school will prove crucial to the AAMU student, who currently is learning how to use packages like IDL and OpenDX. AAMU cannot on its own produce a graduate space science course to provide him a tutorial of the space environment. Two upper division undergraduates from UTEP will attend the school as well, as will Paul Ontiveros, a former UTEP student who is now in graduate school at Rice University and part of the Center there.

Another goal of the Center is to recruit more women scientists into the field. Historically, space physics has attracted more women scientists that physics generally, perhaps because as a relatively young field space physics did not have as entrenched an “old boys” network as older fields. (Though listening to Dr Peggy Shea, a pioneering woman in space physics now retired after a long career in research, talk informally after her lecture to the young women at the last summer school, would lead one to think otherwise.) Many of these women have achieved positions of leadership in the
community, providing excellent role models. Dartmouth has had a very active program of recruiting and retaining women (Women In Science Program – WISP), while the Boston University student body has a significant female majority. The majority of BU students who have participated in the two summer schools are women, and both our recruitment for the summer school and participation in undergraduate research emphasize the recruitment of female students. These opportunities should prove effective in recruiting and retaining female students.

Some K-12 activities that are part of the general education program are also designed to increase a diverse participation in Center activities. The solar group at Stanford will be hosting 2-3 summer teacher interns who will work with the group to develop a VLF space weather monitor. However, 1-2 of those will be physics teachers from a local community college. Similarly, UTEP is recruiting a summer intern from El Paso Community College. By building partnerships with faculty in 2-year institutions we hope to strengthen their science programs and gain access to bright students who can materially aid the research of the Center. Such students will be encouraged to pursue science careers by an exposure to research opportunities and excitement about space weather as conveyed by their teachers. Another diversity-promoting activity is a CISM presence at the annual SACNAS and NSBP meetings. The upcoming SACNAS meeting in Albuquerque will feature CISM participation in both the scientific sessions and the K-12 workshops. Communicating to a broad audience the opportunities in space science generally, and CISM specifically, is an important part of broadening participation in this scientific enterprise.

**Impact of programs/activities:**

Although CISM has just begun, there have already been some significant effects and impacts. As stated above, a number of Hispanic students have been recruited as undergraduate researchers. Previous experience with undergraduate physics majors at UTEP lead us to believe that all of these students will complete their degrees, and most, if not all, will go on to graduate school. At AAMU, the Center has produced a significant move to build infrastructure in space science. This summer a new M.S. concentration in space science will be proposed to the AAMU graduate council, and there is strong support from individuals (including the provost) for this proposal. We are also reorganizing funding to partially support a new faculty member at AAMU in a tenure-track position, which will significantly add to AAMU’s capability to engage in space science research and provide students with research opportunities. Finally, the summer school has proved very successful in recruiting a diverse set of students. This diversity is not only in areas of ethnicity and gender, but also in background and institution, since the summer school has also recruited space weather forecasters (including NOAA and Air Force personnel).
VII. MANAGEMENT

1a. Organizational Strategy

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 clear project oriented goals and timelines. The CISM management structure is described in the organizational chart in Appendix B.

The administrative core is provided by Director Jeffrey Hughes, Deputy Director Charles Goodrich, and Assistant Director Kathryn Nottingham. Jeffrey Hughes, as the Director of CISM, is ultimately responsible for the direction and management of the project. Charles Goodrich, as deputy director, manages the daily activities of CISM, working closely with Prof Hughes. The CISM assistant director Kathryn Nottingham reports directly to the director and is responsible for all administrative functions, including budget management, and for overseeing the collection of management data and maintaining the databases required for evaluation and to monitor progress against milestones.

The Center is divided into seven focused management areas, each led by a co-director, who together form the CISM Executive Committee, CISM’s principal executive body. Charles Goodrich has direct responsibility for the computational science and code coupling aspects of the center. Ramon Lopez is co-director for Education and Human Resources and also leads our efforts in Diversity. Co-director Daniel Baker has direct responsibility for the Knowledge Transfer component and for development of the empirical model chain. The space science research efforts in solar, magnetospheric, and ionosphere/thermosphere/ mesosphere physics are the responsibility of co-directors Janet Luhmann, Mary Hudson, and Timothy Killeen. Co-director Harlan Spence is responsible for CISM model validation. Whereas there is significant overlap in these areas, and in some cases the boundaries between them can be hard to define, each area has a distinctly different role to play in the development of the CISM comprehensive model and in its use and dissemination. Some of the overlap, or integration, of these areas is indicated in the organizational chart by individuals’ names appearing in more than one area.

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 the strategic policies of CISM including definition of tasks and time lines, monitors progress against these goals, resolves conflicts arising within CISM. The director, in consultation with the Executive Committee, is responsible for the allocation of resources between areas and tasks. Implementation of CISM policies and the day-to-day management of CISM is the responsibility of the director and deputy director. 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 10 CISM core institutions, 8 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 coordinated with the overall CISM plan. They have also designated administrative contacts at their site, who interact 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 Ms Rhoda Clayton (BU Office of Grant and Contract Accounting) regarding fiscal reporting issues.

The management of the CISM education effort, under the direction of co-director Ramon Lopez, includes full-time education coordinators at both Boston University and UTEP. The Boston University education coordinator Esther Zirbel works closely with Prof Lopez and assists him in the day-to-day management of this effort. She has primary responsibility for program evaluation and liaison with NSF. Jana Martinez, the UTEP education coordinator, has primary responsibility for scheduling the education program, and coordinating events.

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.

1b. Performance and Management Indicators

The CISM Strategic and Implementation Plan is developed by the executive committee with input from the whole CISM team. The Plan defines the goals, indicators of success, and milestones for individual areas within CISM and for CISM as a whole. This document provides the principal performance indicators for CISM. The director and deputy director are responsible for Center wide execution of the plan, and for engendering close collaboration and cooperation of the teams. Their effectiveness of the entire CISM management team, including the co-directors and local PIs, will be determined by their ability to achieve the goals and milestones laid out in the strategic and implementation plan, and to undertake any adjustments or restructuring required to do so. Specific management performance indicators include:

- Timely submission of reports and documentation to NSF
- Participation of the director and/or deputy director in all CISM meetings
- Convening Advisory Council meetings at least yearly, with timely response to them recommendations
- Encouraging cross-thrust meetings

2. Progress and Problems

During the first 7 months of funding significant management effort was spent in setting up subcontracts for the core CISM institutions and in establishing fiscal and management reporting mechanisms and protocols between institutions that would ensure the efficient collection of all the required management data. CISM received
valuable help from NSF in resolving some of the contractual issues. At this point all reporting structures are in place and appear to be working satisfactorily.

Considerable effort has also been expanded in developing communication systems (particularly the AccessGrid facilities at each core CISM institution) and in developing plans for communication, as well as in developing the strategic and implementation plan. These topics are described in more detail below.

3. Communication within CISM

CISM is a collaboration of faculty, students, and staff at 10 core institutions and several partner sites. 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. For this reason we have developed a comprehensive CISM communication plan that consists of periodic in-person meetings supplemented with electronic communication during the periods between.

All-hands Meeting: CISM will hold an annual “all-hands” meeting in the early fall. This meeting will be the 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 will be plenary at which overviews of progress will be given to the entire team, other sessions will be held in smaller groups at which more detailed reporting and planning can take place. This meeting will also provide a venue for ethics training sessions, and for all CISM graduate students to meet.

The first all-hands meeting was held September 16-18, 2002, at Boston University and was attended by about 50 scientists and others. The principal purpose of this meeting was to further develop the CISM Strategic and Implementation Plan, with the particular emphasis of involving as broad participation as possible from within the CISM team so that the team as a whole takes ownership of the plan.

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 will have a large presence at Space Weather Week, which is organized by NOAA/SEC, usually in April, (though being held in May this year because of a conflict with the Spring AGU meeting) and brings together space weather researchers, forecasters and end-users. CISM will also be 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 will bring together another group of CISM participants each summer.

Electronic Communication: Physical meetings cannot be held often enough nor include all the appropriate CISM members to provide the needed frequent communication required to manage and organize a complex organization such as CISM.
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, telephone conferencing, and asynchronous communication via e-mail. The executive committee and various groups within CISM have set up regular meetings via these means.

**AccessGrid:** We have selected the AccessGrid (www.accessgrid.org) system to provide CISM’s video conferencing needs. The AccessGrid (AG) is a system combining state of the art software and network technology with commodity computer and audiovisual equipment to support distributed group-to-group interaction. It uses the high-speed networks (Internet2/Abilene) that already connect almost all of the CISM institutions to support large-scale distributed meetings, collaborative work sessions, seminars, lectures, tutorials, and training. To our knowledge, the AccessGrid system is the only system that provides a video-conferencing system supporting multiple independent video feeds from each connected site. Developed and supported by Argonne National Laboratory, it is an ongoing research project whose capabilities are constantly expanding.

With supplemental support from NSF, we are developing AccessGrid facilities at each of the core CISM institutions. The facilities at Boston University and Dartmouth are now operational. NCAR has a convenient existing facility. Nodes are being installed presently at Alabama A&M and UTEP. Installation at the other core sites will follow this summer. Rice, NCAR, and Berkeley have campus AG nodes that our colleagues can schedule to use while preceding with installation of their CISM nodes. In addition, NSF and our computational partner NCSA have their own AG nodes.

Because of existing AccessGrid facilities at Boston, Dartmouth and NCAR, the CISM magnetosphere-ionosphere coupling group, which primarily consists of people at these locations, began regular monthly AccessGrid meetings in January. Meetings were held on Fridays January 17, February 14, March 14, and April 18. The latest meeting included Boston University, NCAR, Rice, and two nodes at Dartmouth. As well as providing a useful meeting format for this group, these sessions have also provided an important opportunity to explore the mechanics of holding electronic meetings, as well as useful lessons in understanding the different social dynamics and meeting protocols that an electronic meeting requires. We also made use of the AccessGrid for the Advisory Council meeting, with presentations being made from Boulder and Dartmouth.

In the future we anticipate very frequent use of the AccessGrid by many groups within CISM. Our goal is to connect the members at all levels from regular executive committee meetings, working meetings of the thrust teams, and frequent *ad hoc* small group meetings. This greatly facilitates management by enabling the director and/or deputy director to take part in all the CISM meetings without travel. We hope finally to enable the graduate students throughout CISM to participate in these working meetings, and through informal multi-site “bull” sessions with or without CISM faculty.
Telephone Conferences: Until our AccessGrid facilities are fully functional, various groups within CISM have been making use of regular telephone conferences. These include the Executive Committee (biweekly meetings), the Knowledge Transfer group (monthly meetings) the Education group (monthly meetings), and the Solar group.

4. CISM Advisory Council
The CISM Advisory Council held it’s first meeting on March 4/5 2003. The Council is chaired by Dr. Gregory Ginet; the full membership is given in the table. All members except Professor Mechoso were present at the March meeting. Much of this meeting was spent educating the Council about CISM, its vision and goals. However, the Council provided very useful criticism and feed back to the CISM management team both orally during the meeting and in its report prepared following the meeting. The Council also adopted a charter.

The CISM Advisory Council Charter, the Council meeting agenda, and the Council’s report are included in Appendix C.
5. **The CISM Strategic and Implementation Plan.**

The CISM Strategic and Implementation Plan provides the primary guide to CISM visions, goals, plans, and milestones by which progress can be measured. It is included as Appendix E to this report.
VIII. CENTER-WIDE OUTPUTS AND ISSUES

1. Publications


2. Conference Presentations

2. Baker*, D.N., Space weather: specifying and forecasting threats to human technology, Key Speaker: NATO Advanced Research Workshop on Effects of Space Weather on Technology Infrastructure
6. Baker*, D.N., The recent past and future prospects for research at the Laboratory for Atmospheric and Space Physics, Invited talk presented at the 50th Anniversary of the CU Space Program Celebration, CU Heritage Center, Boulder, CO 12 December 2002
14. Hughes, W.J., Storms in Space; Understanding the Sun-Earth connection, joint AGU/EGS Meeting, Nice, France, April 2003
21. Lopez*, R. E., Storms from the sun: The emerging science of space weather, AAPT Announcer, September, 2002


32. McPherron, R.L., Empirical studies of solar wind-magnetosphere coupling, Key Speaker: NATO Advanced Research Workshop on Effects of Space Weather on Technology Infrastructure


36. Riley,* P., D. Odstrcil,* J. A. Linker,* and Z. Mikic*, Modeling CMEs: From the Sun to Earth, SHINE Workshop, Banff, Canada, August, 2002


3. **Dissemination activities.**
Nothing to report.

4. **Awards and Honors**

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<td>Dartmouth College</td>
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8. **Summary Table**

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Appendix B: Center Organizational Chart
Appendix C: Advisory Committee

Center for Integrated Space Weather Modeling

Advisory Council Summary

14 Mar 03

The Advisory Council to the Center for Integrated Space Weather Modeling (CISM) met at Boston University on 4-5 Mar 03. Present were Gregory Ginet (Chair), Joseh Hollweg, Lisa Hunter, Janet Kozyra, Jan Sojka, James Stith and Richard Vondrak. Absent was Carlos Roberto Mechoso.

Being the first meeting of the council, which includes several members whose scientific discipline is not space weather, the CISM team presented thorough "sun-to-mesosphere" scientific, education, and knowledge transfer briefings. It was abundantly clear CISM comprises enthusiastic and talented scientists who are committed to the success of the center. Strong management keenly focused on producing an integrated product was also obvious. The council offers the following observations and recommendations in the spirit of strengthening what is already a world class effort. Comments are categorized according to the reporting categories mandated by NSF.

General

- Why a Science & Technology Center? The value added of being a center versus a collection of world class PI's performing weakly-coupled research needs to be emphasized upfront and throughout all presentations. Emphasis should be placed on the code coupling and validation tasks as being the glue binding the research into a coherent set of products.

- Define the scope of the CISM research and products more clearly with realistic assessments of what can be done in 5 years for $20M. CISM does not want to be held accountable for unrealistic expectations. For example, is it realistic to assume that a model to forecast the onset of a flare/CME will be available for inclusion in any of the deliverable codes (V0 - V3) in the first five years? Perhaps a summary of environment features (e.g. electron density profiles) to be forecast with relative space-time scales as a function of CISM code version could be included in the overview.

- Define expectations for progress both short and long term (e.g. science codes, software products, education partnerships) consistent with CISM goals and objectives. This should take the form of a roadmap with milestones and an implementation plan. Expectations should be defined for each team element. The draft implementation plan given to the council chair at the end of the first meeting is a good start.

Research
- **Validation procedures and metrics need to be established and emphasized starting early on.** Metrics should be a mix of both scientifically and operationally relevant quantities to track forecasting progress and diagnose modeling limits. Specific events or intervals of time with sufficient ground truth data should be determined at the outset and serve as the benchmarks throughout CISM development.

- **More focus needs to be put on data ingestion both for nowcasting (initial conditions) and assimilation (updating the progress of time dependent codes).** Plans should be developed for each model showing what data is required and how it will be used. Often an algorithm to create an initial condition from a data set is a useful product in itself. Each of the three science team leads should evaluate the maturity of formal data assimilation in their fields and identify on the CISM Roadmap where formal data assimilation may be considered.

- **Use common data file structures, formats, and interfaces when building and coupling codes.** This will pay off in terms of savings in time and attention from center scientists as CISM deals with issues of data ingestion and knowledge transfer. It will also enable CISM to more easily leverage useful technologies and models under development in the community.

**Education**

- **Refine and articulate the education goals in the spirit that it is better to do a few things well than to touch the base in all education categories.** NSF indicated that they are looking for an education legacy lasting beyond the center's lifetime that takes advantage of the specific resources of CISM. Be careful of the "feel good" programs that when you look back have had limited effect. The strategic plan should clearly articulate goals, the activities that will be implemented to achieve goals, and how the center will report on reaching goals. As CISM moves beyond their initial year, it will be increasingly important to show that all activities are supporting a set of cohesive goals.

- **Great summer school initiative.** This has already put CISM on the space weather education map. Teaching graduate level material using current pedagogical techniques is unusual, and needed. It would be valuable to put more resources into this project, including a long-term assessment of the project’s goals. For example, if the goal is to change faculty teaching practice, an assessment could determine whether the faculty who tried new teaching strategies actually implemented them in their university courses. Continue to pursue with legacy in mind.

- **Explore partnership opportunities at Alabama A&M University.** Establishing a space weather program at a minority institution would have the kind of lasting effect that NSF is looking for in education and diversity. If the center were to work with AAMU to develop a new degree at AAMU that fed students into CISM institutions, that would be a significant Center contribution. This sort of partnership will be complex, take time, and involvement of CISM members. It could be an ideal match in terms of a project that
really takes advantage of the "center mechanism," if CISM leadership decides that this type of effort is aligned with the overall CISM EHR goals.

- **Educational partnerships, collaborations, and existing projects.** Given the intent of STC funds to develop new, innovative education projects, CISM will need to clearly demonstrate that they are developing new education projects rather than existing efforts funded through other mechanisms. It will also be important to show CISM stakeholders and advisors specifically how funds are spent on EHR. For example, how much is spent on summer school, undergraduate research support, etc.

- **Physics education research.** The incorporation of physics education research into CISM EHR is a very strong element, and is well aligned with NSF goals. This could be an area to be expanded and emphasized in the future.

- **Teacher workshops.** The planned implementation of teacher workshops should be looked at carefully. There is a lot of evidence that indicates teacher professional development should be a long-term process, not short workshops (even with a few follow-ups). As described, the teacher workshops don’t align well with current national reports on teacher professional development. Long-term teacher involvement could be an interesting direction for the Center given the longevity of the Center, if CISM leadership determines this type of work to be aligned with EHR goals.

**Knowledge Transfer**

- **Effective knowledge transfer to NOAA/SEC at the level of products running in their Rapid Prototyping Center will require a full time CISM person at SEC.** This might not be the same person for the full five year period but someone needs to work the details at SEC on a daily basis. Identification of the transition products, presumably subsets of Versions 1-4 of the CISM codes, as early as possible will facilitate transition.

- **What is industry looking for in CISM?** Forecasting has typically not been the highest space environment priority for the satellite construction and operations community. With industry slated to support Space Weather Fellowships to CISM, albeit perhaps not exclusively satellite builders, it is important that they buy into the forecasting goals and not expect other products.

**Partnerships**

- **Clarify external partnership structure.** It is recommended that the strength of a partnership be quantified to some degree. A possible set of metrics might be (a) CISM core: funded directly by CISM, (b) strongly-coupled: relations vital to but not directly funded by CISM, (c) weakly-coupled: collaborations of opportunity which can appear and disappear as the winds of science blow where they may. When a partnership is in category (b) a written agreement should exist that clearly identifies the relevant roles and responsibilities of both CISM and its partner.

**Diversity**
- Need to explicitly identify diversity, both within CISM and in the education efforts. There seemed to be significant initiatives but it was hard to pull them out of the education briefing. See also the comments concerning AAMU in the Education section. As CISM moves beyond the initial year, it will be important to report what CISM is doing to increase the diversity at the Center.

Management

- Recommend "all hands" CISM annual retreat. The Access Grid is nice but there is nothing like getting the whole group together under one roof for several days to review progress, strategize on the future, and informally discuss any and all aspects of CISM. Community workshops can be held after significant milestones reached (e.g. a Version release).

- Need clear lines of accountability for effective management. Though not as rigorous as a satellite project, the CISM Science and Technology Center is building a product according to a schedule and budget. The success of the Center will depend critically on delivering a coherent, validated set of coupled models. It should be understood by all team members that products are expected and personnel and resources could be shifted if performance levels are not met.

Budget

- A summary of the budget should be presented at a level one lower than the current functional break-out. It is difficult, especially for people outside the space weather community, to determine what fraction of the money is spent towards solar research, magnetospheric research, validation, summer school, etc.

For future Advisory Council meetings it is recommended that time be allocated equally between presentation and discussion, and that all CISM leaders attend the entire meeting at least by Access Grid.
CISM Advisory Council Meeting
4/5 March 2003

Agenda

Tuesday, March 4

8:30: Continental Breakfast
9:00: Introductions and Welcome
9:15: Introduction from NSF:
    Dragana Brzakovic, Office of Integrative Activities, NSF
9:45: Overview of CISM – Goals of this meeting.
    Jeffrey Hughes, CISM Director
    Janet Luhmann, CISM Co-director
10:45: Break
11:00: Research Plan and Progress: Magnetospheric Physics.
    Mary Hudson, CISM Co-director
11:30: Research Plan and Progress: Ionospheric Physics
    Stan Solomon
12:00: Research Plan and Progress: Code Coupling and Computational Science
    Chuck Goodrich, CISM Deputy Director
12:30: Open discussion.
1:00: Lunch
2:00: Knowledge Transfer and Empirical Models:
    Daniel Baker, CISM Co-director
3:00: Education Plan and Progress:
    Ramon Lopez, CISM Co-director
4:00: Break
4:15: Management Plan and Issues:
    Jeffrey Hughes, CISM Director
4:45: Open Discussion
5:30: Wine and Cheese reception
7:00: Dinner

Wednesday, March 5

8:30: Advisory Council, private working breakfast.
9:30: Advisory Council meets with CISM Director.
10:00: Advisory Council meets with CISM Executive Committee.
11:00: Advisory Council drafts initial report.
12:00: Adjourn and Lunch.
Charter of the Center for Integrated Space Weather Modeling Advisory Council

**Mission:** The Center for Integrated Space Weather Modeling (CISM) Advisory Council provides advice and guidance to the CISM director on all components of CISM including research, education, knowledge transfer, and management.

**Membership:** The Advisory Council is composed of a chairman and at least seven other members chosen by the CISM director in consultation with the CISM Executive Committee and the Chairman of the Advisory Council. Representatives of academia, government, and industry with expertise in the Center's activities will be chosen for council membership.

**Meetings:** The Advisory Council will meet at least annually to review the Center's programs. The Council will address the focus, structure, operations and effectiveness of CISM programs and management and provide oral and written feedback. Council meetings (except for executive sessions) are open to all members of CISM. A written summary of Council meetings will be provided to the CISM director.

**Member Responsibilities:** Members of the Advisory Council will commit to attending Council Meetings, to invest the time needed to understand the goals of CISM, and to provide straightforward advice and opinions on CISM activities. Individual council members may be consulted by the CISM director or by a CISM co-director for advice on a particular issue at other times.
Appendix E: Strategic and Implementation Plan

The Center for Integrated Space Weather Modeling (CISM)
An NSF Science and Technology Center

Strategic and Implementation Plan (Version 0, May 2003)

VISION AND MISSION

As defined by the National Space Weather Program, “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.” 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. Mitigation of these effects requires both a better understanding of the space environment and developing the ability to predict and forecast conditions in space.

The Center for Integrated Space Weather Modeling (CISM) will focus its activities around building a comprehensive physics-based numerical simulation model that describes the space environment from the Sun to the Earth. This model will achieve three complementary goals: we will do fundamentally new science, increasing our understanding of the complex, closely coupled Sun-Earth system; in partnership with NOAA’s Space Environment Center we will convert the results of our research into robust and operationally useful forecasting tools to be used by both civilian and military space weather forecasters; and in our education programs we will make the geospace environment accessible to understanding through models and visualization tools.

In order to achieve these goals we will need to:

- Foster interdisciplinary research between solar physicists, magnetospheric physicists, aeronomers, and computational scientists.
- Develop a better physical understanding of processes in the space environment.
- Develop the computational and analysis tools needed to couple models efficiently.
- Transfer our new understanding and the products of our research into useful forecasting and specification tools.
- Integrate research and education in order to effectively train the next generation of diverse space weather scientists.
CISM Legacies

We foresee the legacies of the Center to be:

- The development of a new interdisciplinary science that views the Sun-Earth system as a single closely coupled system, and that erases the existing boundaries among space physicists.
- 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 an historically black university.
- The introduction of community models 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.
- A suite of physics-based forecasting and specification tools.
- A better public understanding of the Sun and its effect on the Earth’s space environment.
RESEARCH PLAN

Introduction

The overarching goal of CISM is to develop a reliable well-validated, comprehensive, physics-based, numerical simulation model that describes the space environment from the Sun to the Earth. CISM’s research goals are all directed towards achieving this overarching goal. This means that CISM’s research plan must be considered as an integrated whole. Although, for the purposes of research management, we have divided our research into components, these components are all interconnected, and the boundaries between them are necessarily variable, and in some cases not easily defined.

The core of the comprehensive CISM model consists of four fluid codes that form a chain from the Sun to the Earth. The magnetohydrodynamic (MHD) model of the solar corona developed by Jon Linker, Zoran Mikic, and others at SAIC describes solar corona dynamics from the base of the corona out to a radius at which the solar wind flow is entirely supersonic and superAlfvenic. The coronal model couples to the 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 well beyond the orbit of earth. We use the code developed by Lyon, Fedder, and Mobarry (LFM) to model 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 LFM code can be driven either with results from the solar wind code or from solar wind data obtained from in situ spacecraft such as WIND and ACE, which allows the model chain to be easily split in two at the solar wind-magnetosphere boundary for the purposes of validation and testing. The magnetosphere is strongly coupled to the ionosphere and upper neutral atmosphere (thermosphere and mesosphere, or collectively ITM). The core ITM model we are using is a high resolution version of the National Center for Atmospheric Research (NCAR) Thermosphere/Ionosphere General Circulation Model (TGCM), the Thermosphere-Ionosphere Nested Grid (TING) model. The coupling between the magnetosphere and ionosphere is by far the most complicated of the core model couplings, as it acts in both directions and involves many processes that are not well described by fluid physics.

There are several regions and particle populations in the space environment whose physics is not well described by fluid codes. So other models 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 inner magnetosphere and ring current. 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, exist only in conceptual form and will be developed as part of CISM’s research program.
We have divided the research required to build the comprehensive model into 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, Magnetospheric Physics, and Ionosphere/Thermosphere/Mesosphere Physics - are responsible for the targeted research required to bring our understanding of the fundamental physics to the level required for the comprehensive CISM model, and for developing the component models that will incorporate this physics into the comprehensive model. 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.

The model development and computational science thrusts are responsible for constructing and testing the comprehensive model. The code coupling thrust is at the core of our research effort. This thrust is responsible for identifying and/or developing the computational science tools needed for efficiently coupling the component models together and then applying these tools to coupling the models to produce the comprehensive CISM model. They will produce a series of ever-improving versions of functioning comprehensive models. The validation and metrics thrust is charged with testing and validating the functioning comprehensive models they receive from the code-coupling thrust. 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 simple model output parameters and a few selected operationally available measurements (metrics) that allow a direct comparison between the effectiveness of different models or prediction schemes. This latter allows progress between generations of models to be evaluated. One of this thrust’s first tasks is to define the set of metrics to be used. It 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 empirical modeling thrust is responsible for a parallel effort to develop a forecast and specification version of our comprehensive model. Initially this model will be formed by coupling various empirical or data-based models together to provide an end-to-end model. This initial version will provide the benchmark for metric and skill scores for all subsequent forecast and specification models as well as a benchmark to measure the performance of the physics-based comprehensive model. Future versions will incorporate new modules based on insights and understanding gained from the physics based comprehensive model. This research thrust is also closely integrated with the CISM effort in knowledge transfer to the space weather forecasting community as the models they develop are those most likely to be transitioned into operational models early in the life of CISM.

Space Science Goals
Space 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 the space science goals and plans under broad topics.

**Solar Active Regions and Flux Emergence:** The emergence of magnetic flux from below the photosphere as active regions, and its evolution, is the ultimate cause of space weather. We will focus early in the life of CISM on simulating active region emergence and evolution within the corona model to develop a better understanding of Coronal Mass Ejection (CME) initiation. The results will lead to better predictions of CMEs based on solar observations.

**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. Early in the life of CISM 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. In the global models these particles will then be transported from their shock sources to predict their distribution in geospace. Radiation belt electron modeling and SEP transport and trapping will be incorporated into the LFM code used to advance guiding center test particle and Lorentz trajectories of respective source populations. Ultra low frequency (ULF) wave transport will be included self-consistently and VLF wave loss rates via pitch-angle scattering will be incorporated.

**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 routinely 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 used as the foundation for a 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 LFM and TIEGCM 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 will use
our expertise in reconnection physics to develop parameterized reconnection models that can be linked to the MHD models.

**Outer-Inner Magnetosphere Coupling:** Important new science goals can be accomplished when the physics of the inner magnetosphere, as represented by the drift physics in the RCM, becomes embedded in the global MHD magnetospheric code. Then the magnetospheric component of the comprehensive 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.

**Magnetosphere/Ionosphere Coupling:** 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 shed light on the causes of the variability seen and the limitations of predictability. Once the LFM code is 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. 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. 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. The global electrodynamic interaction between the thermospheric winds and magnetospheric convection and, in particular, the “flywheel” feedback of thermospheric winds on magnetospheric convection will be characterized.

**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 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. Reaching closure on these issues is important if CISM is to make substantive advances in treating storm conditions.

**Model Development and Computational Science Goals**

Model development will both lead to models that will be used to better our scientific understanding of the space environment, and be enabled by our better understanding. The development of the comprehensive model will be based on a concept of generations. Each model generation will use more sophisticated and/or comprehensive physics, and more advanced or sophisticated computational tools. Model generations will be developed on a two-year cycle.

**Empirical Modeling:** During the first year, the first end-to-end model will be built using existing empirical and semi-empirical models as components. This initial version will provide the benchmark for metric and skill scores for all subsequent forecast and specification models as well as a benchmark to measure the performance of the physics-based comprehensive model. Future versions of the empirical model will incorporate new modules based on insights and understanding gained from the physics-based comprehensive model. This research effort is closely integrated with the CISM knowledge transfer goal of developing a forecast and specification version of our comprehensive model for the space weather forecasting community as empirical models are the most likely to be transitioned into operational models early in the life of CISM.

**Ad hoc (Version 1) Coupled Model:** The first generation physics-based model will couple the existing physics based codes on an ad hoc basis. Codes will be coupled together in whatever way makes sense for the particular codes with little eye for generality. This is extremely valuable for the development of a more general coupling scheme or “framework.”

**OOP [Object Oriented Programming] Modular I Model:** The second generation physics-based model, the first to use OOP techniques, will use the Meta-Chaos package developed at the University of Maryland for interprocess communication and the Overture framework being developed at Livermore to handle translation from one code’s grid and variables to another.
**OOP Modular II Model**: Development of the third generation of physics-based model will begin in the fourth year of the project if we have identified substantially improved coupling technology. OOP II will make use of the latest developments in code coupling technology developed by others in the meantime. One candidate technology is the NCAR Earth Sciences framework that will be developed during the first three years of this project. During the first two years we will monitor and assess progress of the Earth Sciences Framework project, as well as any other suitable framework projects.

**Validation and Metrics**: Each generation of model will undergo a period of up to a year of validation and assessment using observational data and metrics. The metrics will be defined during the first year and will include some selected from among those adopted by the National Space Weather Program and others developed specifically by CISM. We will perform both validation and metric tests, that is, both compare detailed model output against research data sets in order to evaluate the model against reality (validation) and make standardized comparisons between simple model output parameters and a few selected operationally available measurements (metrics) that allow a direct comparison between the effectiveness of different models or prediction schemes. These metrics studies will be used to measure the progress of model development. Validation couples intellectually to the space science goals in that studying the model outputs is one way of exploring the science questions being addressed. The results of validation studies will also guide further modeling efforts by pointing out where the models most need improvement.

**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. The technical problems of introducing observational data into the middle of numerical calculations in order to update predictions and correct simulation errors are significant. During the first year of CISM we will carefully study what has been learned and the methods used by other communities, and use this knowledge to develop a plan for adapting these techniques so that they can be used in space physics applications.
EDUCATION PLAN

The goals of the CISM education plan are twofold: training the next generation of space physicists, who 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; and a better public understanding of the Sun and its affect on the Earth's space environment. The CISM education plan will integrate the training of the next generation of space physicists with the research program of the Center, provide opportunities for K-12 teachers to learn about space weather and the research process and provide them with materials to incorporate space weather topics into their teaching, increase the opportunities for women and other underrepresented groups in science, and educate the general public about space weather.

Integrating Research and Education: Research and education will be integrated in multiple ways throughout CISM. Integration of education and research means researchers being educators, it means educators and students being researchers, it means including the results of research in what is taught, and it means using the results of education research to improve instruction. Each component of our education plan feeds from and is integrated into our research effort. The graduate summer school will make use of results from and models and tools developed in our research program, and prepare students to make use of these tools in their graduate careers and beyond. Our undergraduate research program immerses undergraduates in our research program at a critical time in their careers, teaching them what being a scientist is all about. Our teacher interns will similarly be immersed in our research program, learning first hand about the research process, and using this to help inspire their colleagues. Results from our research will feed directly into our teacher workshop and curriculum development programs. Furthermore we will institute an education research program using pre and post program student evaluations to evaluate thoroughly the effectiveness of our education programs. The results of this research will be used to improve and strengthen our education programs.

Graduate Students: The CISM graduate students will form an important cadre of the next generation of space scientists. CISM will provide the means of supplementing their normal academic graduate education. Each year we will hold a meeting of all graduate students engaged in CISM research. These meetings will allow the CISM graduate students to share their research and build community. A rotating program will focus 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, or teaching methods and physics education.

To introduce new students to space weather modeling, a two-week summer school aimed at beginning graduate students will be held each summer. The school will introduce space weather concepts treating the solar-terrestrial system in a unified fashion and will teach the use of models in space weather research, prediction, and education. Although the school will be targeted at beginning graduate students, it will also be appropriate for advanced undergraduates or young professionals new to space weather.
Undergraduate Students: Research opportunities provide a proven means of retaining undergraduate students in science and preparing them for graduate school or the workplace. We will have two related programs. During the academic year opportunities for undergraduates will be available at those CISM sites that teach undergraduates. A coordinated summer program will allow more interactions between students and an opportunity for them to spend time at other institutions.

Undergraduate Education Research and Curriculum Development: CISM will have an active program of physics education research and curriculum development that focuses on undergraduate science students. Since visualization plays a key role in CISM research and education, we will study how students interpret visualization images and how such resources can be used effectively in education settings. The results of this research will be used to update the summer graduate school and to aid the development of undergraduate teaching materials for both science majors and science literacy courses like introductory astronomy. We will develop web-based educational materials for undergraduates providing a resource for educating undergraduates about space weather and for bringing undergraduate researchers more quickly up to speed.

K-12 Education: CISM will contribute to K-12 education primarily by hosting teacher summer interns and developing an inexpensive “space weather monitor” that will allow students and teachers to collect data about the disturbance level of the ionosphere. Partnerships between some of the CISM institutions and their local school districts will provide important local involvement and a testing ground for educational products. Teacher interns at some CISM sites will spend the summer gaining research experience. They will also help develop and test classroom materials, and assist with running local teacher workshops, such as for disseminating the space weather monitor. Teacher workshops also will be held at the national SACNAS meeting as a means to exposing a greater diversity of teachers and students to space weather.

Promoting Diversity: All components of the CISM education plan will be used to promote diversity and increase the involvement of women and underrepresented minorities in space science and help build vigorous research programs at minority serving institutions. Using our predominantly minority institutions, U. Texas El Paso, and Alabama A&M U., we will 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 will 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 will have 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.

Space Science Graduate Program at AA&M: CISM will support the introduction of a new graduate program in space science within the physics department at Alabama A&M University. This program will provide a new pathway for African American students to enter space physics, a field within which they are very poorly represented.
KNOWLEDGE TRANSFER PLAN

The CISM knowledge transfer plan will promote the exchange of information, tools, and techniques between CISM and other communities, particularly the broader space science research community, the space weather specification and forecasting operational community, and the aerospace engineering and other user communities. The plan has three distinct components: provision of forecasting tools to NOAA/SEC; dissemination of community models to the wider scientific community; and training and interaction with industrial partners and government labs and agencies.

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. We will facilitate this goal through the close partnership between CISM and the NOAA Space Environment Center (SEC).

A highly experienced and highly motivated CISM-supported scientist will be based at NOAA/SEC and become the primary means of information transfer between SEC and CISM. SEC and CISM recognize that model transfer can only be effected by a close working partnership between the scientist(s) who developed the model and the operators who will use it. The CISM liaison will provide this connection, becoming an integral member of the SEC Rapid Prototyping Center (RPC) team, aiding the transfer of CISM-generated models into SEC operations, and consulting daily with the SEC forecasters, programmers, and scientists. This scientist will be a catalyst for getting evaluation and development work done at SEC. But, even more importantly, by working this closely with SEC personnel, the CISM liaison will develop a profound understanding and insight into the pressing needs of SEC and its customers. The liaison will transfer this knowledge to CISM team members and also transfer knowledge about model development within CISM back to SEC.

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. These resources will be made available over the internet. We will also work closely with the Community Coordinated Modeling Center (CCMC), and the National Computational Science Alliance (NCSA) to provide community access to our models.

Industrial and Government Partners: Interaction with industrial and government partners will occur in various ways, including participation in the annual summer school, CISM presence at NOAA’s Space Weather Week, industrial sponsorship of “Space Weather Fellowships” for graduate students and post-docs, and a program of a seminar
series whereby CISM members visit industrial partners to present on-site seminars and other training.

**Ethics Training:** We will develop a “rules of the road” document that covers the principal ethical questions we believe arise in the conduct of our science. This document will describe the proper use of models and data developed or collected by others, the proper conduct of research, especially in a large collaborative effort, and general rules of authorship and acknowledgement on papers either published or presented at meetings, with the particular rules for CISM related papers. These rules and guidelines will be communicated to all CISM members as a special session at our annual all-hands meeting. Each year, all new CISM members will be required to attend this session, or a similar one presented over the AccessGrid for those not able to attend the all-hands meeting.
Management Plan

The CISM management structure is designed to address the challenges of running a multi-institutional center which has clear project oriented 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.

Management Structure: CISM’s central administration consists of Director Jeffrey Hughes, Deputy Director Charles Goodrich, and Assistant Director Kathryn Nottingham. Jeffrey Hughes, as the Director of CISM, is ultimately responsible for the direction and management of CISM. Charles Goodrich, as deputy director, works closely with the director to manage the daily activities of CISM. Assistant director Kathryn Nottingham, who reports directly to the director, 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 Center is divided into seven focused management areas, each led by a co-director. Charles Goodrich has direct responsibility for the computational science and code coupling aspects of the center. The research efforts in solar, magnetospheric, and ionosphere/thermosphere/mesosphere physics are the responsibility of co-directors Janet Luhmann, Mary Hudson, and Timothy Killeen. Co-director Harlan Spence is responsible for model validation. Ramon Lopez is co-director for Education and Human Resources and also leads our efforts in Diversity. Co-director Daniel Baker has direct responsibility for the Knowledge Transfer component and for development of the empirical model chain. Whereas there is significant overlap in these areas, and in some cases the boundaries between them can be hard to define, each area has a distinctly different role to play in the development of the CISM comprehensive model and in its use and dissemination. Some of the overlap, or integration, of these areas is indicated in the organizational chart by individuals’ names appearing in more than one area.

The CISM Executive Committee, CISM’s principal executive body, consists of the CISM director, deputy director, and the co-directors who lead the seven management areas. 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 resolves conflicts arising within CISM. The director, in consultation with the Executive Committee, is responsible for the allocation of resources between areas and tasks. Implementation of CISM policies and the day-to-day management of CISM is the responsibility of the director and deputy director.

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 coordinated with the overall CISM plan. They have designated administrative contacts at their site who interact 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 Ms Rhoda Clayton (BU Office of Grant and Contract Accounting) regarding fiscal reporting issues.

The management of the CISM education effort, under the direction of co-director Ramon Lopez, includes full-time education coordinators at both Boston University and UTEP. The Boston University education coordinator has primary responsibility for program evaluation and research. The UTEP education coordinator has primary responsibility for scheduling the education program, and coordinating events.

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. The comprehensive CISM communication plan consists of periodic in-person meetings supplemented with electronic communication during the periods between.

CISM will hold 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 will be plenary at which overviews of progress will be given to the entire team, other sessions will be held in smaller groups at which more detailed reporting and planning can take place. This meeting will also provide a venue for ethics training sessions, and for all CISM graduate students to meet.

CISM will hold 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 will have a large presence at Space Weather Week, which is organized by NOAA/SEC, usually in April, (though being held in May this year because of a conflict with the Spring AGU meeting) and brings together space weather researchers, forecasters and end-users. CISM will also be 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 will bring together another group of CISM participants each summer.

Physical meetings cannot be held often enough nor include all the appropriate CISM members to provide the needed frequent communication required to manage and organize a complex organization such as CISM. 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, telephone conferencing, and asynchronous communication via e-mail. The executive committee and various groups within CISM have set up and will run regular meetings via these means.
The Center for Integrated Space Weather Modeling (CISM)  
An NSF Science and Technology Center

5-Year Goals and Milestones (Version 0, May 2003)

Annual Milestones:

- Hold all-hands CISM meeting in early Fall.
- Hold Summer School for at least 25 students, of which at least 8 are women or underrepresented minorities and 3 are from non-graduate school settings.
- Run Summer Teacher Intern program for at least 4 teachers.
- Hold annual meeting for CISM graduate students.
- Provide research opportunities for at least 10 undergraduates, of which at least 5 are women or underrepresented minorities.

Year 1 Milestones (September 2003):

- Complete construction and coupling of the end-to-end empirical model.
- Develop metrics and begin developing skill scores using empirical models.
- Link (ad hoc) pairs of codes: LFM and TING, 2D Radiation Belt and LFM, and 3D solar corona and heliosphere.
- Include solar rotation and magnetogram boundary conditions in corona code.
- Test use of the coupled corona-solar wind code to drive LFM.
- Begin developing and testing Object Oriented Program I coupling protocols.
- Develop ethics training materials (rules-of-the-road).
- Develop plan for data assimilation within CISM.
- Provide end-to-end empirical model chain to NOAA/SEC.

Year 2 Milestones (September 2004):

- Validate coupled LFM/TING and corona/heliosphere codes.
- Link (ad hoc) RCM to LFM.
- Develop generalized electrodynamic magnetosphere/ionosphere interface.
- Develop 3D radiation belt code.
- Incorporate "localized" CME module in coupled corona/solar wind code.
- Begin active use of Object Oriented Program I coupling protocols.
- Begin development of Object Oriented Program II coupling protocols.
- Implement code documentation and version control, and data management plans.
- Establishment of seminar series and training for industrial partners.
- Create, test, and disseminate to institutions beyond CISM space weather teaching and curriculum materials for undergraduates, 2-yr colleges, and high schools.
Year 3 Milestones (September 2005):

- Provide community access to coupled LFM/TING and corona/heliosphere codes.
- Link RCM, TING, and LFM codes forming the coupled geospace model (CGM).
- Begin to validate ad hoc coupled geospace model.
- Transition coupled codes from ad hoc coupling to OOP I.
- Include lower atmosphere effects in TIEGCM/TING models.
- Link 3-D radiation belt code to LFM.
- Couple flux emergence and filament eruption models to coronal code.
- Complete SEP code that uses coupled corona/solar wind code as input.
- Add improved thermodynamics to corona and heliospheric codes.
- Develop second generation of forecast and specification model.
- Establish new M.S. concentration in Space Science at AAMU.
- Establish Aerospace Fellowships for Graduate Students and Postdocs.
- Develop planetarium materials using CISM content and visualizations for both full-dome and StarLab.

Year 4 Milestones (September 2006):

- Provide community access to ad hoc coupled geospace model.
- Begin developing skill scores using ad hoc coupled model.
- Develop plasmasphere model for coupled geospace model.
- Link reconnection codes to LFM.
- Include losses in radiation belt models.
- Integrate SEP code with corona/solar wind code.
- Complete development of OOP Modular II CISM framework.
- Validate second generation of forecast and specification model.
- Create, test, and disseminate 2nd generation space curriculum materials.

Year 5 Milestones (September 2007):

- Validate OOP Modular I model.
- Begin developing skill scores using OOP Modular I model.
- Transition coupled codes from OOP Modular I to OOP Modular II.
- Study techniques for "routine" incorporation of CME initiation into routine coronal and solar wind model.
- Include reconnection physics in magnetospheric and coronal codes.
- Develop strategy for embedding transient simulations in coupled solar/heliospheric code.
- Provide second generation of forecast and specification model to NOAA/SEC.
- First graduate of new AAMU graduate space science concentration.
- Develop 2nd generation planetarium materials using CISM content and visualizations for both full-dome and StarLab.
- Create, test, and disseminate 3rd generation space weather curriculum materials.