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The geospace environment is controlled largely by events on the Sun, such as solar flares and coronal mass ejections, which generate significant geomagnetic and upper atmospheric disturbances. The study of this Sun-Earth system, which has become known as space weather, has both intrinsic scientific interest and practical applications. Adverse conditions in space can damage satellites and disrupt communications, navigation, and electric power grids, as well as endanger astronauts.

The Center for Integrated Space Weather Modeling (CISM), a Science and Technology Center (STC) funded by the U.S. National Science Foundation (see http://www.bu.edu/cism/), is developing a suite of integrated physics-based computer models that describe the space environment from the Sun to the Earth for use in both research and operations [*Hughes and Hudson*, 2004, p. 1241]. To further this mission, advanced education and training programs sponsored by CISM encourage students to view space weather as a system that encompasses the Sun, the solar wind, the magnetosphere, and the ionosphere/thermosphere. This holds especially true for participants in the CISM space weather summer school [*Simpson,* 2004].

This summer school is a 2-week intensive program targeted to first-year graduate students, although undergraduates and space weather professionals have also benefited from attending. Since its inception in 2001, the school has had more than 200 participants. The daily schedule of the summer school includes a series of three morning lectures delivered by experts in the field and an afternoon laboratory session where participants use data and computer simulation results to further explore the topics covered in the morning. An example syllabus can be found on the CISM Web site (http://www.bu.edu/cism/SummerSchool/timetable.html).

The lab activities are a unique aspect of the summer school. The goals of these activities are to gain insight into space physics phenomena, experience with visualizing model results and relating them to observations, and experience using model results and observations to make both short-term and climatological forecasts. The labs utilize results from CISM models, publicly available data, and readily available visualization software, ensuring that summer school participants gain experience in working with actual and up-to-date data sets to learn more about current issues in space weather modeling. The goal of this article is to outline the content of the lab materials for instructors who may want to use them in a variety of educational settings.

Descriptions of the Specific Labs

To provide students with a way to explore the concepts discussed in the morning session, summer school leaders have adapted research materials collected from models used by CISM into laboratory exercises. To that end, the first CISM lab provides students with experience using the visualization software CISMDX (http://www.bu.edu/cism/cismdx/) [*Wiltberger et al.,* 2005], used by many CISM researchers to analyze model results. The lab introduces the students to the various space physics models used during the summer school and the techniques used to analyze the results. Following this is a series of eight labs—four solar/heliosphere labs and four geospace labs—that trace the evolution of space weather from the Sun to the Earth.

In the first of the solar labs, participants use both Solar Heliospheric Observatory (SOHO) magnetogram data (http://soi.stanford.edu/magnetic/index6.html) and model results from the magnetohydrodynamics around a sphere (MAS) model [*Hughes and Hudson,* 2004, p. 1243] to explore the three-dimensional (3-D) structure of the solar magnetic field at various points in the solar cycle. In the next solar lab, participants explore 2-D synoptic maps of derived coronal holes generated from results of the Wang-Sheeley-Arge (WSA) model [*Hughes and Hudson,* 2004, p. 1297] and compare these results with the 3-D magnetic field structure as generated by the MAS model. Participants are also asked to compare the WSA results with direct observations of coronal holes using SOHO extreme ultraviolet images of the Sun (http://sun.stanford.edu/synop/synoptic_eit.html). The WSA model is used at the NOAA Space Weather Prediction Center (SWPC) for forecasting (http://www.swpc.noaa.gov/ws/), affording the participants hands-on experience with a state-of-the-art forecasting tool.

The third and fourth solar labs use the Enlil model [*Hughes and Hudson,* 2004, p. 1311] to study the structure and evolution of the solar wind. In the third solar lab, the participants use slices through volumetric data along with field lines to explore the 3-D structure of the solar wind at various times during the solar cycle. In the fourth solar lab, students first predict the arrival time of a coronal mass ejection (CME) at Earth by analyzing coronagraph images [*Owens and Cargill,* 2004], and then use the CME-cone model [*Hughes and Hudson,* 2004, p. 1311] to explore the global evolution of a CME.

The geospace labs pick up the story with effects of varying solar wind conditions on the magnetosphere. The first geospace lab uses results from the Lyon-Fedder-Mobarry (LFM) model [*Hughes and Hudson,* 2004, p. 1243] to explore the structure of the magnetosphere under varying interplanetary magnetic field (IMF) conditions. First, ideal cases are studied, after which students are asked to consider what happens under realistic solar wind conditions. In the next lab, students explore the motion of high-energy charged particles in the inner magnetosphere using a variety of approaches including a preexisting Web application that was designed for outreach to the general public (http://www.spaceweathercenter.org/our_protective_shield/01/minigolf.html) and simulation results from research models that move charged particles within a dynamic LFM magnetosphere [*Hughes and Hudson,* 2004, p. 1371].

The third geospace lab was adopted from one developed at the U.S. Air Force Academy to explore changes in satellite drag when the upper atmosphere is disturbed by space weather [*Knipp et al.,* 2005]. The final lab uses results from the thermosphere-ionosphere electrodynamics general circulation model (TIE-GCM) [*Hughes and Hudson,* 2004, p. 1425] to look at the global and vertical structure of the ionosphere as it is driven by either fluctuations in the magnetosphere or changes in the solar extreme ultraviolet flux.

After completing the labs, students will have not only delved into the details of the various components of the Sun-Earth system but also explored the connections between these components.

The Road Forward

The labs continue to evolve in response to several factors: research advances, identification of students' needs and misconceptions, and feedback from student evaluations and other evaluation data. The student evaluations ask participants to rate their interest in the material, whether they were engaged by the different presentations and activities, and their personal learning experience. Typical average scores for these activities are above 4 on a five-point scale. When a particular lab does not score well, it is considered for improvement. For example, the first lab exercise, in which the students become familiar with the visualization tools, originally was not relevant to space physics modeling, and in the evaluations the students expressed their disappointment. As a result, the lab was modified to include examples from models studied in later labs and favorable evaluations increased dramatically.

Other evidence for the success of the approach taken by CISM is the number of advisors and organizations that repeatedly send their students and employees to the summer school. A review of previous applications shows that 12 advisors from within CISM and 13 other advisors and organizations (including the NASA Space Radiation Group from the Johnson Space Center, SWPC, the U.S. Air Force Research Laboratory, and the U.S. Air Force Weather Agency) have sent students in multiple years. Students from these advisors now account for more than one third of our participants each year.

Although activities are still evolving, the summer school team considers the labs sufficiently mature for use by other instructors for training students. These materials can be used in a variety of approaches, from supplementing a lecture course to being the centerpiece of an independent study course in space physics. Some of these materials have already been adapted as introductory material for NSF-sponsored Research Experience for Undergraduates (REU) programs, and selected activities have been adapted for use in middle-school Earth science classrooms. As part of CISM's NSF-funded mandate, summer school instructors are making the labs generally available for those who wish to use them.

A Web index page with more detailed descriptions of these activities along with the student lab manuals can be found under the Education link at the CISM Web site (http://www.bu.edu/cism/SummerSchool/Labs/Lab_Index.htm). Anyone interested in adapting these materials is encouraged to contact CISM education coordinator Nicholas Gross (gross@bu.edu).

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References

Hughes, W. J., and M. K. Hudson (Eds.) (2004), Towards an integrated model of the space weather system, *J. Atmos. Sol. Terr. Phys., 66*(15–16), 277 pp.

Knipp, D. J., E. T. Patterson, A. Franz, J. H. Head, T. A. Summers, and E. L. Zirbel (2005), Simulating realistic satellite orbits in the undergraduate classroom, *Phys. Teach., 43,* 452–455.

Owens, M. J., and P. J. Cargill (2004), Predictions of the arrival time of coronal mass ejections at 1 AU: An analysis of the causes of errors, *Ann. Geophys., 22,* 661–671.

Simpson, S. (2004), A Sun-to-mud education in two weeks, *Space Weather, 2,* S07002, doi:10.1029/2004SW000092.

Wiltberger, M., R. S. Weigel, M. Gehmeyr, and T. Guild (2005), Analysis and visualization of space science model output and data with CISM-DX, *J. Geophys. Res., 110,* A09224, doi:10.1029/2004JA010956.

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