THE COMMUNITY COORDINATED MODELING CENTER: A NEW APPROACH TO SPACE WEATHER MODELING

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ABSTRACT

The Community Coordinated Modeling Center is a US interagency activity aiming at the generation of advanced space science models specifically for space weather purposes. CCMC endeavors to support the transition of research models to operations, and to provide an independent agent for the evaluation of model performance. CCMC also provides a strong service to the research community by the provision of access to current, state-of-the-art research models.

1. INTRODUCTION

The Community Coordinated Modeling Center (CCMC) is an activity aimed at the development of advanced models for specifying and forecasting conditions in the space environment. The CCMC forms an element of US space weather plans, in particular of the National Space Weather Program Implementation plan [1], the Department of Defense (DoD) Space Weather Transition Plan, and of the Living With a Star program of the National Aeronautics and Space Administration.

The first main function of the CCMC is to provide a formal mechanism by which research models can be validated, tested, and improved for eventual operational use. The second main function of the CCMC is to be a resource to the international research community by providing access to state-of-the-art space research models.

The CCMC concept was initiated in 1998 as a result of DoD efforts to provide more effective means to transfer space physics research models to operational use. Subsequent multi-agency efforts have led to a conceptual design and management plan for the center. Participating agencies have all offered support for the CCMC including the purchase of computational assets, physical infrastructure for the center, scientific and technical support, and post-doctoral research support [2]. The CCMC front-end computers and workstations are located at Goddard Space Flight Center with a high-speed data link to supercomputing facilities. This center is staffed by scientific and technical personnel. The CCMC will host visiting students and scientists as required during the model development and testing. Access to CCMC information, model output, and run-on-request information is via the world-wide-web page http://ccmc.gsfc.nasa.gov.

Overall management of the CCMC is the responsibility of a multi-agency steering committee, with members recruited from the stakeholder agencies. These agencies are: the Air Force Office of Scientific Research [2], the Air Force Directorate of Weather, the Air Force Research Laboratory, the Air Force Space and Missile System Center, the National Aeronautics and Space Administration, the National Science Foundations, the Office of Naval Research, and the Space Environment Center of the National Oceanic and Atmospheric Administration. The Steering Committee makes decisions with the advice of a scientific working group, and an operations working group. The Steering Committee guides the implementation of ionospheric-thermospheric, magnetospheric, heliospheric- and solar physics models at the CCMC.

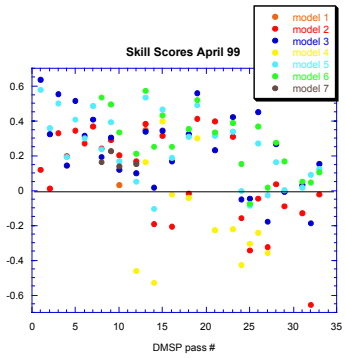

Fig. 1. Example of the first magnetospheric ionospheric metrics evaluation. Shown are skill scores for six different models obtained by comparison with DMSP cross-track ion velocities.

Models considered for ingestion into CCMC will be evaluated for their appropriateness via a standardized criteria set. Any further development of these models at the CCMC will be performed in close collaboration with the model originator, who will thereby be an immediate beneficiary of CCMC activities.

CCMC has installed a set of models, which presently address the magnetosphere-ionosphere system. Inclusion of solar and heliospheric models is planned for the near future. Presently, on-site CCMC models include the SAMI2 [3] and CTIPE [4] ionospheric models, the BATSRUS [5] and UCLA-GGCM [6] magnetospheric models, a ring current/radiation belt model [7], and the Weimer 2000 [8] polar cap potential model. Nearly all of these models are available for calculations to researchers in the international community.

2. CCMC FUNCTIONS: MODEL EVALUATIONS AND TRANSITION TO OPERATIONS

A major objective of the CCMC is to undertake and support the evaluation and capability assessment of candidate space weather models. A component of this is the maintenance and evaluation of space weather metrics as an unbiased arbiter so that improvements in specification and forecast capabilities can be tracked over time. CCMC models are also subjected to science-based validation. When models have been validated sufficiently, the CCMC will transfer them to one or both of the Rapid Prototyping Centers (RPCs) operated by the Department of Defense, and NOAA.

2.1 Model Testing and Evaluation

Before a research model can be considered for space weather operations, it needs to undergo testing and evaluation regarding numerical stability, scientific validity of model output, and of functional utility. It furthermore needs to be exposed to metrics-based testing in order to establish absolute model performance, as well as performance relative to other models with comparable outputs. This requires, at a minimum, an evaluation of model performance by an independent agent, and ideally, an evaluation of the model's performance using realistic, standardized test suites. The CCMC has, as one of its objectives, the provision of such services.

CCMC has therefore supported the first community-wide, evaluation of model performance. This first metrics study was applied to magnetospheric and ionospheric models. Models were driven by solar wind data and produced ionospheric flow velocities, which could be directly compared with cross-track ion flow velocities observed by the DMSP satellites. Skill scores obtained in this study, during one of the intervals considered, are shown in Figure 1. A skill score of zero denotes performance equal to a reference model (i.e., no improvement over current capabilities), whereas a skill score of unity refers to perfect match between model and measurements (perfect performance).

This first metrics study constitutes a beginning for metric-based evaluations. In the future, CCMC will support metrics-based evaluations of model runs, executed in the community, as well as in-house. In addition, CCMC will work with the research community and the operational agencies to define and utilize suitable new metrics and evaluation criteria. These will be applied to models resident on-site, as well as in community-wide studies.

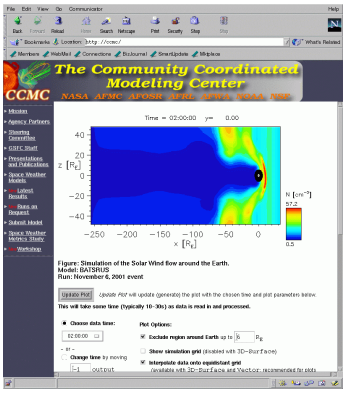

Fig. 2. Web-based (http://ccmc.gsfc.nasa.gov) access to simulation model output. The interface permits user selection of parameters, plotting modes, and volumes.

CCMC will furthermore undertake science-based validation studies of relevant space weather models. While metrics-based studies provide a normalized measure of model quality, validation studies address the logical and scientific consistency of model output. Furthermore, validation studies can focus on significant, space weather-relevant events, which lend themselves more to case studies rather than statistical analyses. An example of a validation study is a comparison between the observed size of the Earth's polar cap open magnetic flux region, and the sizes obtained from suitable simulation models.

2.2 Transition to Operations

The ultimate goal of the CCMC process is to deliver models, which have undergone suitable evaluations, to the Rapid Prototyping Centers (RPCs) at the NOAA Space Environment Center (NOAA SEC) in Boulder, Colorado, and the US Air Force Space and Missiles System Center (AF/SMC) in Colorado Springs, Colorado. In the research-to-operations transition process, CCMC forges a link between researcher and government operator. The CCMC communicates with the RPCs to facilitate an efficient transition process in which tested and improved research models fulfill the needs of operational agencies.

In September 2001, CCMC collaborated with the AF/SMC RPC to transition the University of Michigan's BATSRUS model [5] to operations. The model and a tailored visualization were successfully installed at AF/SMC, and are now being run in a quasi-operational environment. The lessons learned during this process will also simplify the transition process for future models.

3. CCMC FUNCTIONS: RESEARCH SUPPORT

The CCMC provides support to researchers in the international community in a number of different ways.

3.1 Access to State-of-the-art Research Models

The CCMC endeavors to provide a robust service to the research community through access to state-of-the-art research models. Model runs executed at CCMC, which address space weather events are routinely made available on the CCMC web site, together with suitable visualization tools (see Figure 2). In addition, CCMC now provides, since mid-2001, a new service through the execution of "runs-on-request" for specific events of interest to space science researchers. These calculations can be requested through a specific web page format, and are executed through automated scripts. Additional scripts provide post-processing of the run results, as well as notification of the requestor once the results are ready for inspection on the web. Through this activity and the concurrent development of advanced visualization tools, the CCMC provides general science community access to state-of-the-art research models.

3.2 Development of Advanced Visualization and Analysis Tools

Advanced visualization tools play a major role in the utility of model results to the research community. Both for model validation purposes and in order to provide support to the research community, CCMC has developed a set of modern visualization tools which are either already available, will be available through a web-based interface, or are available to researchers upon request. An example of such a tool was used to generate Figure 3. The figure displays magnetic field lines and plasma density (logarithmic scale) for a magnetospheric simulation. The Sun is on the right. The tool is called Space Weather Explorer (SWE) and is based on IBM's Data Explorer (OpenDX) software. It permits perspective, three-dimensional plotting of magnetic field and plasma parameters in different planes, or through virtual flights through the model volume. This tool, as well as future developments, will provide a key capability for science use and science-based validation of space weather models.

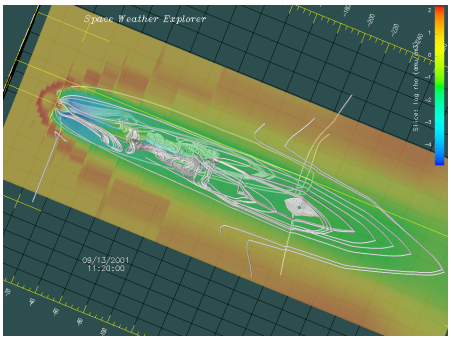

Fig. 3. Output of SWE, an advanced visualization tool developed at CCMC.

4. CCMC FUNCTIONS: COUPLING OF MODELS

Because specifying and forecasting the space weather environment requires models that encompass vast spatial domains (from the surface of the Sun to the surface of the Earth), the CCMC will also address the coupling of various models to simulate the end-to-end physical system. This includes the opportunity to link together different models in order to determine optimal configurations. This becomes most important in the endeavor to model the entire domain from the Sun to the Earth's upper atmosphere. During the development and testing of these models, the output of test runs will be made available to the scientific community.

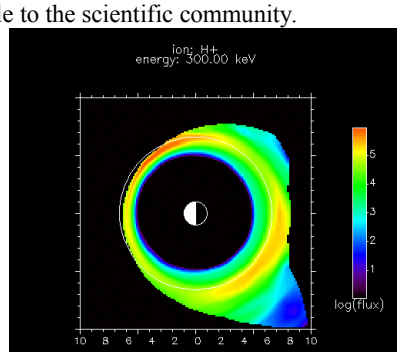

Fig. 4. Sample ring current model output, for protons of 300keV energy. In this case, the inner magnetospheric model was driven by output from a magnetospheric MHD code.

The CCMC has begun to couple models, beyond the coupling already included in the resident models. The latter typically involve the interactions of magnetospheric model with ionospheric models of different complexities. In order to experiment with coupling as well as to overcome the limitations of MHD models to describe the inner magnetosphere, CCMC interfaced the magnetospheric codes with an inner magnetospheric, ring current model [7]. At the present time,

this coupling is one way, i.e., magnetospheric model output drives the ring current model. The coupling involves a standardized translation routine, which is designed to interpolate data from one spatial grid (provided by one model) to a spatial grid required by another. This design allows maximum flexibility for future needs. A sample output from the ring current model is shown in Figure 4.

In recent years, the computational science community has embarked on a set of quests aiming at the creation of all-purpose, flexible software frameworks, which are designed to couple together individual models. These designs offer tremendous opportunities for flexible model chains such as targeted by CCMC. CCMC will therefore interact with both computational science and the space science research communities to foster the adaptation of a set of interface standards, which will then be implemented at the CCMC. Through this process CCMC will help to establish community standards. Models combined at CCMC will automatically conform to these standards. Through such frameworks, a patch-panel type approach to modeling will be enabled, by which individual modules in a chain are exchangeable. Thus model chains will not be locked-in and can be adapted to the best possible combination of modules available at any one time.

5. SUMMARY

The Community Coordinated Modeling Center constitutes a new approach to the transition of research models to space weather operations, and to the use of state-of-the-art models by the space science community. CCMC benefits from a close collaboration between a number of US government agencies, which cover basic research as well as space weather operations. CCMC provides an interface between research and operations with strategic goals.

CCMC has accepted a set of candidate space weather models, which include ionospheric and magnetospheric models. This list is soon to be expanded by solar and heliospheric models. All of these models were implemented on CCMC computers, which are based on architectures compatible with those used by the operational agencies. Model performance has and is being evaluated by CCMC staff in close interaction with the model sources. Once a model is fully implemented, it will be subjected to metrics-based evaluations, and science-based validations.

As part of its mission, CCMC has, therefore, begun independent evaluations of candidate space weather models, both based on metrics, and on detailed comparisons to space plasma measurements. CCMC performed the first, independent evaluation of a space weather metric. CCMC has undertaken a number of science-based validation studies, which establish measures of model performance. In September of 2001, CCMC transitioned the first model to the US Air Force Rapid Prototyping Center. More models are in line to follow.

Following the second part of its mission, CCMC has, for the first time, offered to the international research community direct access to state-of-the-art research models. Researchers are provided with world-wide web-based access to model output, which can be analyzed through specially designed visualization tools. Furthermore, CCMC now provides an extended service through the provision of "runs-on-request," i.e., simulations following requests from the research community. These runs can be requested through a set of simple steps via an interface available from the CCMC home page. The simulations are executed on CCMC computers, and made available on the CCMC web interface, all at no cost to the requestor. This capability provides a step toward a model policy similar to the "open data policy" instituted by NASA in the 1990s. These simulations have been used extensively by the research community.

CCMC is a new kind of activity, which is not based on experience obtained from similar but earlier programs. Therefore, CCMC has and will benefit from constant feedback from and interaction with both science and operational communities. Despite its young age, CCMC has had a number of successes, ranging from model transition to operations, to researcher access to advanced science models. In the future, CCMC will continue to communicate closely with researchers and operators in order to provide optimal service to both communities.

6. REFERENCES

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