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Ionosphere-thermosphere models at the Community Coordinated Modeling Center

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[1] One of the ways to address the science needs of the research community and to enable science progress is to provide community access to modern space science models. The Community Coordinated Modeling Center (CCMC) is a multiagency partnership based at the Goddard Space Flight Center that hosts a set of state-of-the-art space science models ranging from the solar atmosphere to the Earth's upper atmosphere. The CCMC provides a Web-based, no-cost, Runs on Request system, by which the interested scientist can readily request simulations for time intervals of interest. CCMC also provides a tailored Web-based visualization interface for the model output, including near-real-time results from select models. Model outputs have been specifically tailored for easy comparison with observational data to facilitate data analysis and model validation. This paper provides an overview of CCMC activities, with an emphasis on the ionosphere-thermosphere models residing there.

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1. Introduction

[2] In recent years the number of space science computer simulation models has grown dramatically, encompassing virtually every aspect of space science from the Sun to the Earth and beyond. However, these space science models have often resided in the hands of the authors at their home institutes and, as such, have not been easily accessible by other researchers in the wider scientific community. This has limited the use of the models by other researchers. Furthermore, potentially considerable effort can be required by the model's authors if they attempted to set up the model at another institution for researchers there to use. The keeping of models "in house" by developers restricts the opportunities for the wider scientific community to test the models and determine possible scenarios where they could fail in one regard or another. Independent testing provides one of the best ways to give feed back to the model's authors to help them to improve their model and to, therefore, make it a better model. Better models are, obviously, more desirable by the wider scientific community as they directly enables science progress.

[3] One of the ways to address these issues and to provide for the science needs of the research community is to provide community access to these modern space science models. This means making the space science models available through independent organizations, which can be freely access by members of the scientific community whenever they need. The Community Coordinated Modeling Center (CCMC) is a multiagency partnership based at the Goddard Space Flight Center with just such a goal.

2. Community Coordinated Modeling Center

[4] In 2000, the CCMC was established in response to a request from a multiagency consortium, of which specifically NASA and NSF are the major supporters, seeking to find an effective way to bring space research results to bear on space weather operational needs. The CCMC hosts a set of state-of-the-art space science models ranging from the solar atmosphere to the Earth's upper atmosphere, and provides a tailored Web-based visualization interface for the model output, including

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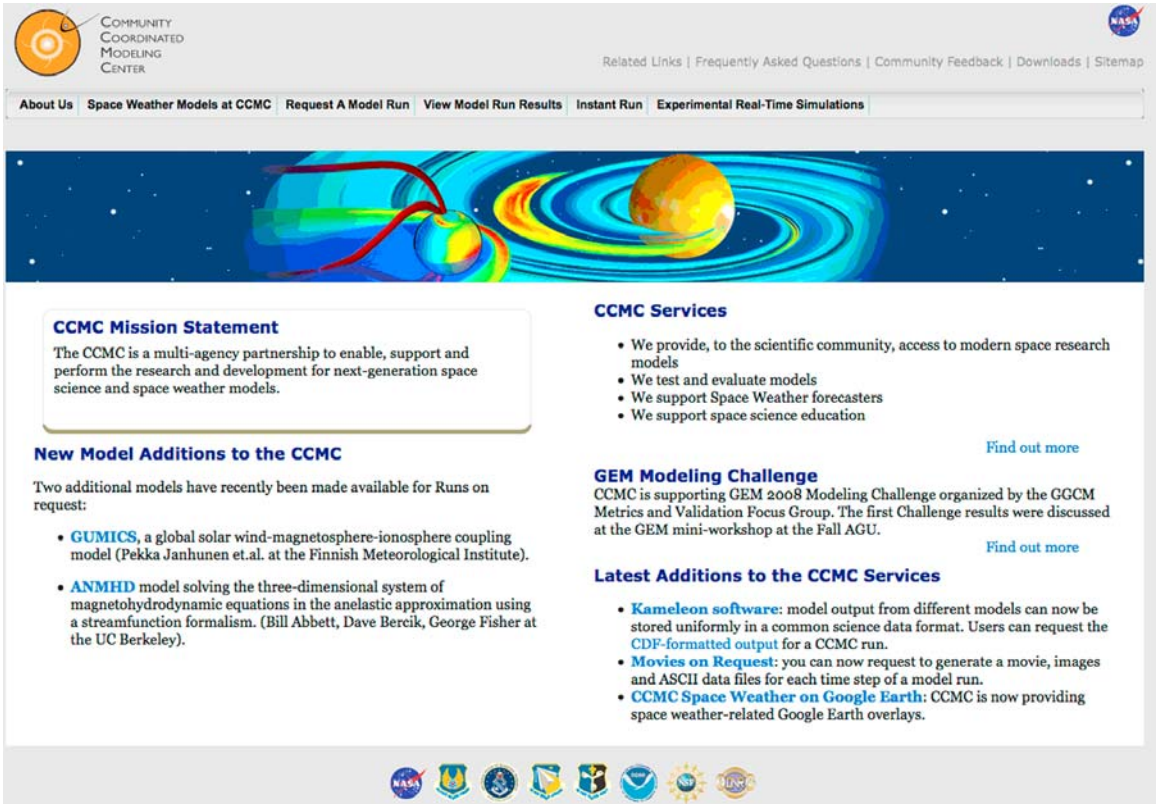

Figure 1. CCMC Web site home page (April 2009).

near-real-time results from select models. Figure 1 shows the current (April 2009) WWW home page of the CCMC (http://ccmc.gsfc.nasa.gov).

[5] Since its establishment, the CCMC has progressed from a one-model and three-workstation enterprise to become an internationally recognized center hosting 26 state-of-the-art space weather models and providing services to the science and operational communities. The majority of models residing at the CCMC are computationally intensive, comprehensive, physics-based or first-principle models. The models at the CCMC, as of April 2009, are displayed in Figure 2. They cover the entire domain from the solar corona to the Earth's upper atmosphere: four solar models, six heliosphere models, nine global and inner magnetosphere models, seven ionosphere/thermosphere models, and one Space Weather Modeling Framework (SWMF). CCMC offers a variety of visualization and output analysis tools to aid scientists in the interpretation of simulation results from these models. Detailed model descriptions are available on the CCMC Web site.

[6] Model output has been specifically tailored for easy comparison with observational data, to facilitate data analysis and model validation. As an indication of the success that the CCMC has had so far in achieving this goal, the following numbers are the public usage of the CCMC in February 2009, for example, which consisted of (1) 50,000 interactive visualization requests, (2) 240 unique visualization users, (3) 3700 unique Web visitors, (4) 590,000 pages viewed, and (5) 2.12 million Web site hits.

[7] These statistics can and do vary from month to month depending on factors such as the amount of outreach effort CCMC makes.

3. Runs on Request

[8] One of the main functions of the CCMC is to provide researchers access to space science models for research purposes: even if these researchers are not model owners themselves. For this purpose, a unique Runs on Request (RoR) system has been employed by the CCMC. This system essentially allows the execution of space plasma simulations via the Internet upon customer request. The rapid growth in the number of RoR completed by the CCMC between 2002 and 2008 is shown in Figure 3.

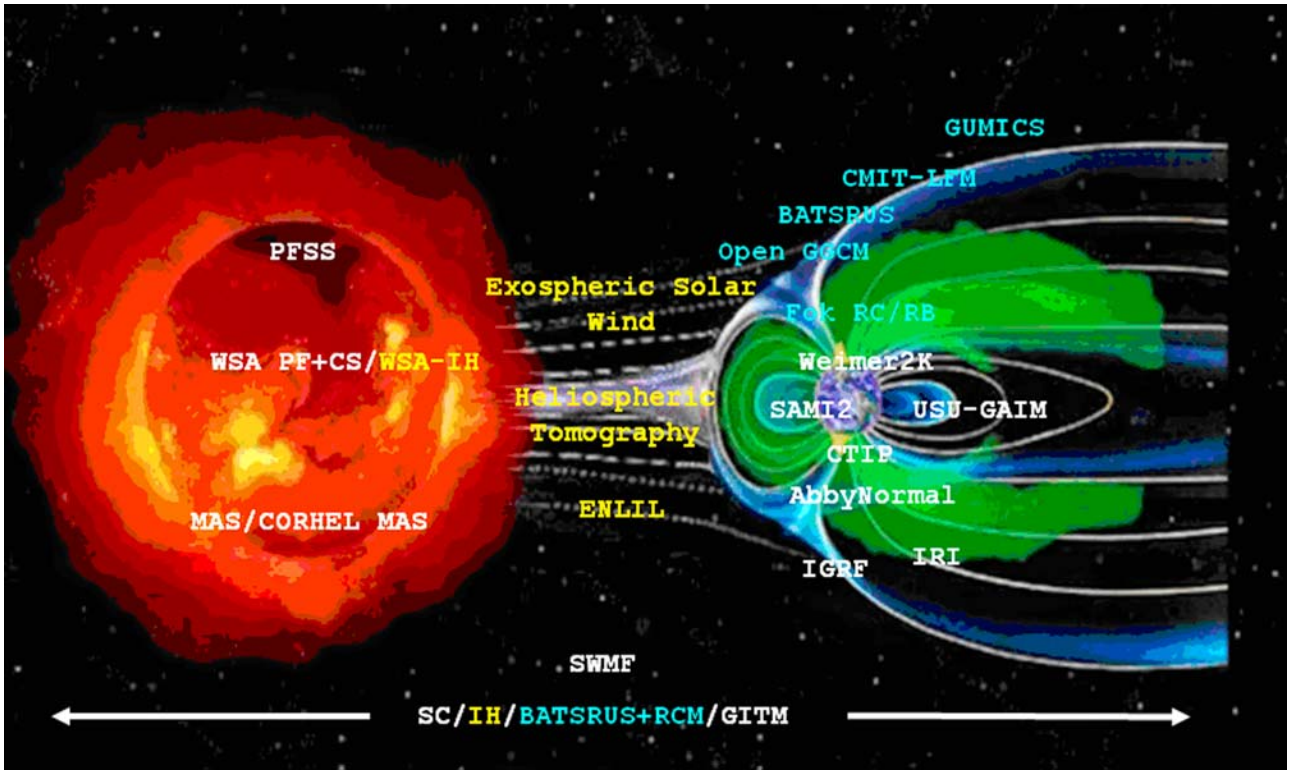

Figure 2. Space science models currently at the CCMC (April 2009).

[9] The CCMC Web site provides users with access to 17 often competing models and model combinations covering the entire domain from the solar corona to Earth's upper atmosphere. For every request, the CCMC configures the model, execute the simulation, and provide the user with science-quality visualizations of the run results, as well as archived output for future analyses. This service is unique in the world. Through this activity,

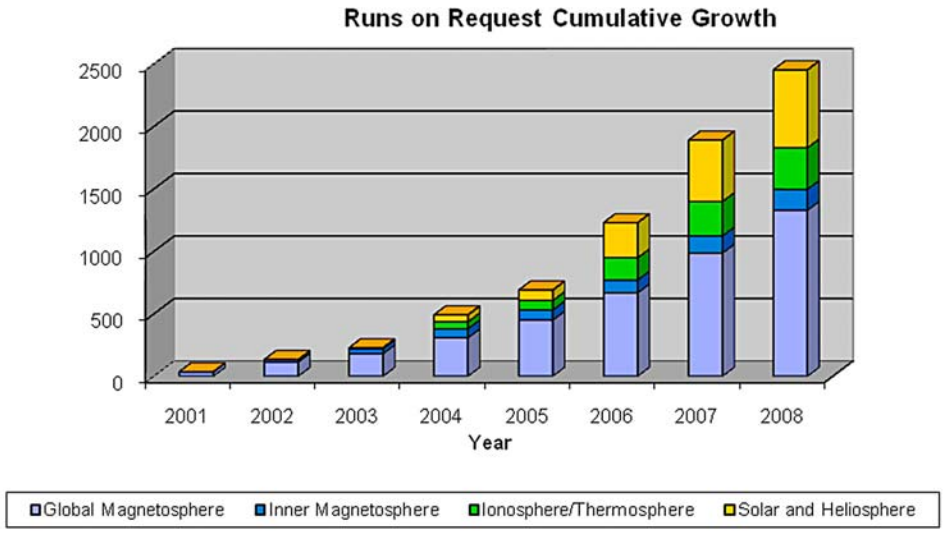

Figure 3. Growth in Runs on Request (RoR) at the CCMC.

Table 1. Ionosphere-thermosphere models at the CCMC in April 2009

Model Name	Authors	Institution	Model Type
SAIM2	Joseph Huba, Glenn Joyce, Marc Swisdak	NRL and Icarus Research, Inc.	Physics based
CTIP	Timothy Fuller-Rowell et al.	NOAA SEC	Physics based
AbbyNormal	J. Vincent Eccles et al.	Space Environment Corporation	Physics based
USU-GAIM	R.W. Schunk, L. Scherliess, J.J. Sojka, DC.Thompson, L. Zhu	Utah State University	Physics-based data assimilation
IRI	D. Bilitza, NASA/GSFC	URSI/COSPAR Working Group on IRI	Statistical
Weimer	Daniel R. Weimer	Solar Scientific Inc.	Statistical
MSISE	A. E. Hedin	Retired from NASA/GSFC	Statistical

and the concurrent development of advanced visualization and data dissemination tools, the CCMC provide the general science community access to a large number of state-of-the-art research models.

4. Model Validation

[10] Additionally, the CCMC collaborates with individual model owners as well as major modeling programs, such as CSEM and CISM, to bring in new models and also maintain, enhance and evolve models that currently reside at the CCMC. When model owners supply their models for use in the CCMC's RoR facility, the models are exposed, usually for the first time, to a quasi-operational environment. Thus, CCMC's utilization provides valuable feedback to modelers regarding model robustness and performance. It is also of real value for model developers to provide access of their models to other scientists, not only to help validate the model but also to maximize the science return from their coding investment. The CCMC provides an independent and neutral location to test the emerging software framework designs for end-to-end modeling of the Sun-Earth system.

[11] Furthermore, the CCMC provides a formal mechanism by which research models can be validated, tested, and improved for eventual use in space weather operations. Models that have progressed through their developmental stages and passed both metrics-based evaluations as well as science-based validations are then available for transition to operations at NOAA's Space Weather Prediction Center and at the United States Air Force Weather Agency for space weather applications.

5. Ionosphere-Thermosphere Models at the CCMC

[12] The ionosphere-thermosphere (IT) element forms the essential end of the Sun-to-Earth modeling chain. The IT models currently (April 2009) residing at the CCMC are listed in Table 1. These models are either physics based or statistical, and outputs from them are either available via RoR from the CCMC, such as the USU-GAIM model [*Schunk et al.*, 2004] or, in the case of less computationally intensive models such as the IRI [*Bilitza and Reinisch*, 2008], through the instant run interface on the WWW site.

[13] CCMC offers a variety of visualization and output analysis tools to help in the interpretation of the IT model's output. In the case of less computational intensive models, users can obtain results directly from the CCMC Web site by inputting temporal and spatial information plus the output parameters required and the results or plots requested will be automatically displayed and/or be made available for download from the CCMC. In the case of models that need to be run via RoR, the user can submit the request online and once the run is complete (could be several days later depending on the particular model and the specifics the required run) the results can be downloaded and visualized using the CCMC Web site. Furthermore, all RoR results are stored at the CCMC in a database so that other public users can browse and use them as if they had submitted the RoR. This has the advantage of not needing to repeat runs that have been previously undertaken and also allows a new user to get an idea of the types of results that could be obtained from a given model without having to wait for a RoR request to be completed. Figure 4 shows an example of a plot from the USU-GAIM global ionosphere model from a RoR. Users can also request via the Web site a GIF movie from a completed RoR – the movie will be automatically generated and made available for download when completed.

[14] The CCMC has recently started to experiment with Real Time (RT) model runs. Achieving "real time" results depends on the availability of data required to drive the given model. In general, the time lag is of order of 5–10 min. The RT results are displayed directly on the CCMC Web site, with the pages been refreshed with new plots as they become available. One IT example is the AbbyNormal model [*Eccles et al.*, 2005], which calculates total vertical high-frequency (HF) absorption.

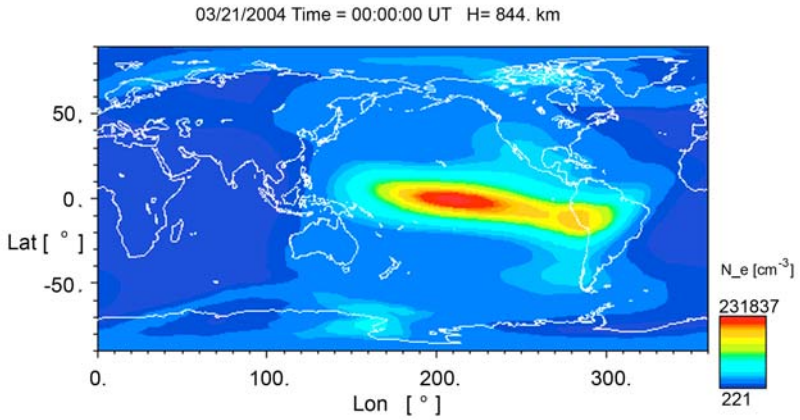

Figure 4. CCMC Web site example of USU-GAIM ionosphere model RoR results.

Figure 5 shows an example of the RT output from AbbyNormal.

[15] *Horvath* [2007] and *Andreeva et al.* [2009] are two examples of published scientific publications that used results generated from running IT models at the CCMC. *Horvath* [2007] made use of the CTIP model [*Codrescu et al.*, 2008, and references therein] to study the nighttime response of ionosphere to geomagnetic storms, focusing on the Weddell Sea Anomaly. By combining results from CTIP with multiinstrument data measurements, it was shown that equatorward winds generated downwellings and the O/N_2 ratio showed changes in the neutral atmospheric composition. *Andreeva et al.* [2009] compared USU-GAIM model [*Schunk et al.*, 2004] results with ionospheric radio tomographic cross sections in Alaska during an October 2003 geomagnetic storm, with one of the main results being that GAIM was observed to diverge from the observed tomographic data with increasing strength of ionospheric disturbances. It should also be noted that the authors of *Andreeva et al.* [2009] are based in Russia, which highlights the international aspect of CCMC user base, whom are not solely restricted to the United States, where the CCMC is located.

[16] One of the future goals of the CCMC is to use the IT models to undertake metrics studies that are consistent with the National Space Weather Program Implementation Plan guidelines. To determine suitable metrics, the

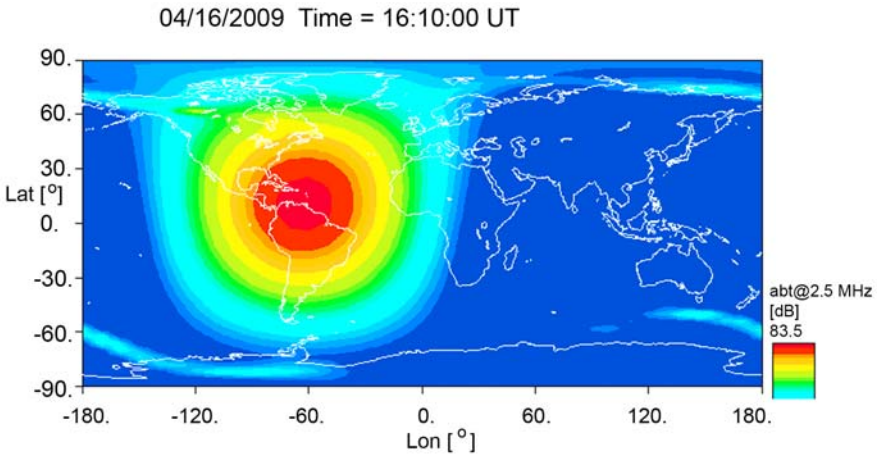

Figure 5. CCMC Web site example of Real Time AbbyNormal model high-frequency absorption results, also showing accompanying output information presented to user.

CCMC will focus on IT parameters most useful to operations that resident models can provide, such as electron density and total electron content (TEC).

6. Summary

[17] While the CCMC was originally designed primarily to support the transition of research models to space weather operations, our role has evolved to include research support for the science community as one of our main activities. CCMC is a means by which the broad science community can benefit from the development of modern space science models. CCMC activities are driven by customer input, allowing us to provide strong support to the science community and to apply modern space science research models to the needs of Space Weather applications. CCMC also provides a tailored Web-based visualization interface for the model output, including near-real-time results from select models. Included in the CCMC are a number of IT models including USU-GAIM, AbbyNormal, and the IRI. CCMC offers a variety of visualization and output analysis tools to aid scientists in the interpretation of simulation results from these IT models.

[18] **Acknowledgments.** CCMC is an interagency activity. We gratefully acknowledge interagency support and, specifically, support from our main sponsors: NASA and NSF.

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