The GEMstone

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Focus Group Final Reports

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The Ionospheric Source of Magnetospheric Plasma—Measuring, Modeling and Merging into the GEM Geospace General Circulation Model (GGCM) Focus Group (2011-2015): Final Report

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Background

Over the past four decades, it has become progressively more obvious that the Earth's ionosphere is a significant source of the energetic plasma of the magnetosphere and a strong influence on the dynamics of the geospace environment. The ionospheric source is contributing to the formation of the plasmasphere, the plasma sheet and the ring current and through wave particle interactions is playing a major role in the formation and dynamics of the radiation belts.

Hence, the understanding of the strength and dynamics of the outflow of ionospheric particles up into the magnetosphere and their subsequent energization and movement is of critical importance to understanding how the magnetosphere is populated and influenced by these initially low energy particles. These particles are transformed in energy as they move through the magnetosphere, contributing to the different major particle regions. Our need has been to understand the origin, energization and dynamics of these particles through both measurement and merged modeling. We want to compare these two approaches in order to build and test an accurate and successful GGCM that can be used in the future to predict ionosphere-magnetosphere coupled dynamics. This goal has been the principal motivation for this GEM focus group.

Activities of the Focus Group

For the past five years, the GEM focus group on The Ionospheric Source of Magnetospheric Plasma—Measuring, Modeling and Merging into the GEM Geospace General Circulation Model (GGCM) has been actively pursuing this fundamental topic in magnetosphere-ionospheric physics. It has brought together a large international group of experimentalists and modelers to study the role of the ionospheric source in populating the magnetosphere and influencing its dynamics. It has made a significant contribution to improving our understanding of this process, including organizing 20 GEM sessions and 4 AGU sessions over this period and carrying out an AGU Chapman Conference on this topic which is leading to the publication of an AGU/John Wiley publications monograph. The focus group has stimulated many coordinated studies including the first ever mergers of generalized ion outflow models with MHD magnetospheric models. The focus group ended its period of operation at the end of 2015 but the central importance of this topic is leading to a continued focus within the GEM program with the establishment of a new focus group, Merged Modeling & Measurement of the Ionospheric Source of Magnetospheric Plasma— Plasma Sheet, Ring Current, Substorm Dynamics.

Throughout the five years of its operation, our focus group has held an active set of presentations and discussions at the GEM workshops. The sessions covered progress in merged modeling of the ionospheric outflow and magnetospheric dynamics and comparison of these merged model results with the observations for specific magnetic storm periods that had been selected by the focus group participants. The two storm periods are Sept 27- Oct 4, 2002 and Oct 22- 29, 2002. Measurements for the two selected GEM storm periods as well as for a third storm period in April 6-7, 2000 are available from instruments on Cluster, Polar, LANL and FAST spacecraft. In addition, there were continuing sessions specifically designed to do an inter-comparison between different model results. Each year there was a final general session that included an open discussion regarding the progress of the activities to date and the plans for the upcoming year.

In a general sense, there has been continued progress in both the ion outflow models and their merger with the magnetospheric MHD models, both BATS-R-US and LFM. The outflow models were completed for the two selected storm periods and there have been merged model runs for these two storms as well. The ion outflow was modeled using the Generalized Polar Wind model at Utah State University, the Polar Wind Outflow Model at the University of Michigan and Goddard Space Flight Center and the Ionosphere Polar Wind Model at NCAR. The model inter-comparisons show very interesting results, which match the observations in a variety of ways. In some instances one merged outflow model can give a better match to the Dst and the cross-polar cap potential and another can match the O+ outflow more effectively. Merging the ion outflow with the MHD model leads to the release of a plasmoid in the tail of the magnetosphere whereas the lack of explicit input from the ionosphere results in no plasmoid release.

Coupling between the global MHD model, BATS-R-US, and the Generalized Polar Wind model, the GPW, has proceeded successfully overall. The merging occurs in a one-way manner, i.e., output of the GPW is used to drive outflow in BATS-R-US; however, the MHD does not provide feedback to the outflow code. The coupling has flexibility in terms of what version of BATS-R-US is being used: single fluid, multi-fluid, and multi-species can all be coupled. It is important to note, however, that stability limitations have prevented the full implementation of the multi-fluid version of BATS-R-US.

In addition to the two real world storm periods mentioned above, the merged GPW-MHD model has been used to study an idealized storm as well. The idealized storm allowed for the exercise of the new coupling and comparison of the impact on magnetospheric dynamics of no-outflow, classical polar wind outflow via the Polar Wind Outflow Model (PWOM), and the generalized polar wind. The two real-world storm events allowed for an exploration of outflow dynamics when the complications of real solar wind drivers were considered. Extensive data-model comparisons have been made using the Polar and Cluster spacecraft. In general, we found reasonable agreement with observations. Total number density comparisons improved with the inclusion of GPW, but O+ composition was over-predicted by the merged GPW-MHD model. Dramatic impacts on the inner magnetosphere and tail dynamics were observed when GPW driven outflow was included. These results were presented at GEM workshops and AGU Fall Meetings.

Additional discussion of modeling results and observations from these two real world storm events has led to a short list of key features that must be investigated in the future. Cluster observations of outflow in the northern and southern hemispheres showed strong asymmetry in terms of density and composition. Further studies will be required to determine if this feature manifests in the model results. Throughout the merged modeling activities many noted that the lack of an embedded ring current model in the MHD models might be an important limitation, especially when performing data-model comparisons within geosynchronous distances. Finally, initial results from the LFM model when many fluids were used illustrates the necessity for 3 or more dedicated fluids in order to properly capture the complicated outflow dynamics throughout the magnetosphere and to be able to separate the ionospheric source from the solar wind contribution. These additional modeling steps will very likely be pursued in the follow-on focus group activities.

Modeling results for GPW, BATS and merged GPW/BATS are available to the community at the following website: http://aoss-research.engin.umich.edu/projects/outflowmmm/. Contact Dan Welling for information on obtaining or sharing your modeling results on the website (dwelling@umich.edu).

Based on the focus group discussion in the fourth session of our final focus group meeting, we planned and carried out a special session at the Fall 2015 AGU meeting. The session title was Ionospheric Outflow from Earth and Other Terrestrial Planets and It's Importance as a Source of Plasma for Magnetospheres. Our goal was to continue the momentum of the focus group with presentations addressing both the merged modeling results and the observations that are now in progress for the Earth and extending this merged activity by considering other planets.

Research Accomplishments

There has been an extensive number of publications in the space research literature related to the research topics encouraged and fostered by our focus group. The list of specific publications is too long to be included in this final report.

As mentioned above the focus group was involved in creating the Yosemite Chapman Conference on Magnetosphere-Ionosphere Coupling in the Solar System in 2014. An AGU/John Wiley monograph has been written based on the papers given at that Yosemite conference and will be published later in 2016. An HD video of the Yosemite conference is available online at Utah State University. In order to view the Yosemite video go to http://digitalcommons.usu.edu/yosemite_chapman/2014/.

A second book on the focus group topic, "Plasma Sources of Solar System Magnetospheres," based on an International Space Science Institute conference held in Bern Switzerland in October, 2013 was published in February, 2016. This combination of GEM sessions, AGU sessions, JGR papers and two books represents a comprehensive collection of material that captures the new research results that have been stimulated by our GEM focus group over the past 5 years.

Thanks to all of the focus group members who have contributed to the merged modeling activities and to the analysis of the spacecraft measurements that are being used for comparisons with the modeling results. Please plan to join the activities of the successor focus group on Merged Modeling & Measurement of the Ionospheric Source of Magnetospheric Plasma— Plasma Sheet, Ring Current, Substorm Dynamics beginning at the GEM meeting in Santa Fe in June, 2016.

It has been a distinct pleasure for us to have the opportunity to work with all of you.

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