

The Ionospheric Source of Magnetospheric Plasma--
Measuring, Modeling and Merging Into the GEM GGCM
Proposed GEM Focus Group
December 2010

Abstract

The Earth's ionosphere has been shown to be a significant contributor to different plasma populations of the magnetosphere. Through a variety of energization processes, the low energy ionospheric particles are transported from low altitudes upward into the magnetosphere where they can become more energized and can help create fundamentally important regions such as the plasma sheet and ring current. This focus group will drive the understanding of the role of the ionospheric outflow source by refining outflow modeling through comparison with measurements, by adjusting the outflow modeling to become a compatible input to the magnetospheric Geospace General Circulation Models (GGCM), by comparing magnetospheric modeling results with satellite measurements and by examining ways in which the dynamic magnetosphere can couple back to influence the original ionospheric outflow. This focus group contributes directly to the MI-Coupling and GGCM research areas that have been highlighted by the GEM Steering Committee and will be ideally timed to begin its activities at the combined GEM/CEDAR meeting in the summer of 2011 where the ionosphere and magnetosphere communities will meet together.

Description of the Topic

Measurements of ion outflow over the past three decades have shown that the magnitude of the total ion outflow from the ionosphere is a significant contributor to the magnetospheric plasma populations. The outflow clearly creates the plasmasphere in the inner magnetosphere and it has also been shown to contribute substantially to the more energetic plasma regions of the magnetosphere. Measurements by satellites such as Dynamics Explorer, Akebono, Polar and Cluster have shown significant fluxes of ions flowing at relatively low energies upward from the topside ionosphere, moving through the polar caps and tail lobes and entering the plasma sheet region. Ion trajectory models show that these low energy particles can be energized to levels ranging from 10's of eV to 10's of keV and can help form the plasma sheet, the ring current and the warm plasma cloak.

Although the ionospheric particles have been shown to contribute to these fundamentally important regions of the magnetosphere, this source of plasma has only recently begun to be included in the overall magnetospheric modeling being created by the GEM program. Adding this second plasma source to the solar wind source has been a difficult computational challenge for the modeling community. New modeling developments, however, have made progress in finding techniques that can add this second plasma source to the magnetospheric modeling.

It is timely, now, to convene a focus group which brings together those who are measuring the ion outflow, those who are developing the outflow modeling techniques and those who are developing the GGCM models, so that the ionospheric source can be incorporated into the overall GEM GGCM. The goals of the proposed focus group are (1) to stimulate the development and refinement of the ionospheric outflow models through comparisons with the measured outflow data, (2) to drive the successful merger of the ion outflow models with the GGCM magnetospheric models (3) to compare the magnetospheric modeling predictions with spacecraft measurements of the evolving plasma regions in the magnetosphere and (4) to identify the effects of the changing magnetospheric dynamics back on the ionospheric outflow.

Specific Goals

--Stimulate the Development and Refinement of the Ionospheric Outflow Models

There is a continuous and substantial ion outflow from the northern and southern polar regions. The outflow consists of light thermal ions (H^+ , He^+ and O^+) as well as energized ions (NO^+ , O_2^+ , N_2^+ , O^+ , N^+ , He^+ and H^+). The ion outflow that is driven by pressure gradients in the F-region and topside ionosphere is called the 'classical' polar wind, while the ion outflow that is driven by energization processes in the

auroral oval and at high altitudes in the polar cap is called the ‘generalized’ polar wind. The ion energization is associated with photoelectrons, hot magnetosphere electrons and ions, wave-particle interactions in the cusp and nocturnal oval at various altitudes, electromagnetic wave turbulence above the polar cap, and centrifugal acceleration. In addition, the ion outflow occurs in conjunction with magnetospheric convection, which causes the high-latitude plasma to drift into and out of the dayside ionosphere, cusp, polar cap, nocturnal auroral oval, and subauroral nightside ionosphere. Because of this horizontal motion, the drifting plasma is only subjected to a given energization process for a limited time, which acts to produce ionosphere structures at all altitudes and in all regions at high latitudes. Because of the complicated dynamics, various ion outflow models have been developed, including hydrodynamic (fluid), hydromagnetic, semi-kinetic, kinetic, generalized transport, and macroscopic particle-in-cell models. The first goal of this focus group is to identify and refine the ion outflow models so that they can realistically describe ion outflow during both quiet and active magnetic conditions. A second thrust of this goal is to identify the locations and altitudes where the ion energization occurs. This first goal will answer questions such as:

- How different are the ion outflow rates during quiet and storm conditions and do the model predictions agree with measurements?
- What percentage of the total ion outflow is related to small-scale ionosphere structures?
- What are the dominating energization mechanisms and at what altitudes do they operate?

--Drive the Successful Merger of the Ion Outflow Models with the GGCM

Connecting ionospheric outflow to the magnetosphere opens a wealth of new research capabilities and is a necessary step for advancing our knowledge of the near-Earth space environment. Early studies connecting outflow to GGCMs have found significant impacts on magnetospheric shape, ionospheric electrodynamics, and plasma sheet conditions. These changes, through a chain of causes and effects, profoundly impact every magnetospheric regime. The second goal of this focus group is to drive the GGCMs with results from the various validated ionospheric outflow models with the intent of answering the following questions:

- How does a magnetosphere that is driven with dynamic, accurate outflow compare to a magnetosphere that is not?
- How do these differences depend on the type of outflow model used?
- How sensitive is the global system to spatial and temporal outflow dynamics of different scales?
How do small-scale features in the ionosphere map to the plasma sheet?
- What is the solar wind’s role in the relationship between outflow and the magnetosphere?

--Compare the Magnetospheric Modeling Predictions with Spacecraft Measurements

As the ionospheric outflow models are developed and used as input to the magnetospheric GGCMs, the modeling results will be compared with satellite measurements of the magnetosphere, both for general plasma population characteristics and for specific identified time periods that represent different stages of magnetospheric dynamics. These direct comparisons will serve to measure the effectiveness of the coupled ionospheric outflow and magnetospheric GGCM models. This third goal of the focus group will answer questions such as:

- How does the addition of ionospheric outflow affect the creation of the plasma sheet?
- How does the addition of the ionospheric outflow modify the modeling of the ring current?
- Is the warm plasma cloak region created by a magnetospheric GGCM that is fed by an accurate ionospheric outflow model?

--Identify the effects of the Changing Magnetospheric Dynamics on the Ionospheric Outflow

As ionospheric outflow drives changes in the global system, the magnetospheric coupling back to the ionosphere changes as well. For example, outflow of oxygen and hydrogen feed the ring current during active times, which drives region 2 field-aligned currents, which in turn change ionospheric conditions that

dictate outflow. How else is M-I coupling affected when realistic outflow is included? How does this alter the nature of the outflow in a self-consistent manner? The final goal of this focus group is to connect the cause and effect chain back to the ionospheric outflow and answer questions such as:

- What are the mechanisms through which the magnetosphere changes outflow dynamics? How do these mechanisms depend upon outflow in the first place?
- Does the interplay between outflow and the magnetosphere regulate dynamics or place limits on geomagnetic activity?
- Does the nature of the M-I relationship demand that global models and outflow models actively couple two-way, or is it enough to include outflow without direct feed back from the magnetosphere system?

Timeliness

We believe that this will be a very active and important focus group which will bring together scientists from a variety of universities and research centers. The merging of the most accurate measurements with the best ionospheric outflow modeling approaches and the application of the outflow modeling to the magnetospheric modeling will fill the plasma source gap that has existed in the GGCM models. This work will also be a timely extension of the recently concluded NASA LWS TR&T project, The Effects of Ionospheric-Magnetospheric Plasma Redistribution on Storms.

This new focus group is ideally timed for initiation at the joint GEM/CEDAR meeting planned for the summer of 2011 where both ionospheric and magnetospheric researchers will be working together.

Relationship to Existing Focus Groups

This focus group is directed toward furnishing the fundamental input from the ionospheric plasma source to the modeling of the magnetospheric plasma populations and dynamics. As such, it is an ideal contributor to the other GEM focus groups and will specifically match the needs of the MI-Coupling and GGCM research areas that have been identified by the GEM Steering Committee. By including the ionospheric plasma source, the magnetospheric modeling will become more accurate and many of the other GEM focus groups can be expected to benefit. For example, this proposed focus group will be valuable to FG 4 (Plasma Entry and Transport) as the ionospheric plasma outflow adds to the magnetospheric plasma and changes plasma transport by affecting convection patterns and field configurations. The ionospheric outflow studied in this proposed focus group will also have significant effects on the work of FG 8 (Inner Magnetosphere) as the outflow has profound effects on the magnetic and electric fields and plasma sheet conditions that influence the inner magnetosphere.

Specific Goals and Deliverables

The four goals listed above will lead to the following deliverables:

- a generalized ion outflow model that will produce an ion outflow output that is compatible with the existing magnetospheric GGCMs
- an improved magnetospheric GGCM that has been refined through the addition of the generalized ion outflow model input and through the direct comparison with in situ spacecraft data from satellites such as the LANL geosynchronous spacecraft, Polar and Cluster
- a magnetospheric-ionospheric feedback model that adjusts the ion outflow model through electric field, current and plasma pressure effects from the dynamic magnetosphere
- an enhanced understanding of ionospheric-magnetospheric-ionospheric coupling effects
- a concluding GEM modeling challenge to evaluate to-date progress of outflow models and coupled GGCMs
- a journal special section to summarize the model development and scientific findings made over the lifetime of the focus group

Proposed Co-Chairs

Co-chairs for this focus group would be Bob Schunk, Utah State University (ionosphere modeling), Rick Chappell, Vanderbilt University (low energy ion dynamics measurements in topside ionosphere and magnetosphere), and Dan Welling, Los Alamos National Laboratory (modeling of the magnetosphere including ionospheric sources). We anticipate important participation in the planning and guidance of the focus group from scientists who are involved in developing the ionospheric outflow and GGCM models as well as scientists involved in ionospheric and magnetospheric particle and field measurements.

Research Areas

This focus group will make significant contributions to both the GGCM and the MI-coupling research areas. Its goals are directly supportive of these two areas. It is also anticipated that the sessions and research fostered by this working group will be valuable to the Inner Magnetosphere, the Plasma Entry and Transport and the Tail research areas.

Term

The significance of incorporating the ionospheric source of plasma into the magnetospheric models is expected to be of such fundamental importance that a period of 5 years of activity would be appropriate. As the ionospheric outflow modules are refined and their effects both on the magnetospheric GGCM models and the magnetospheric-ionospheric coupling models are realized, the resulting understanding will need to be coupled throughout most of the other GEM focus groups. Hence a 5 year period of activity will be very important to permit this penetration throughout the GEM activities.

Expected Activities

Sessions created by this focus group will initially concentrate on the four major goal areas listed above. As the understanding and coupled modeling advance, the session topics will broaden as the influence of the more comprehensive models is connected to many of the other focus group topics.

Activities in year one of this focus group will concentrate on establishing the group in the community and elucidating future plans. Workshop sessions that review current modeling and measurement capabilities, assess current and past research in this area, establish collaborations with the CEDAR community, and plan for the future of the focus group will be emphasized. Sessions that target the specific science questions listed above in more detail will take place during years two through four, as will cross-model comparisons, data-model investigations, and other research activities. We expect the work to culminate in year 5 with a GEM modeling challenge and a potential journal special section as mentioned in the goals and deliverables above.

Because of the far-reaching implications of ionospheric outflow, cross-focus collaborations will be a hallmark of this focus group. Joint sessions are easily envisioned, especially with FG4 (Plasma Entry and Transport), FG8 (Near-Earth Magnetosphere), FG11 (Plasmasphere-Magnetosphere Interactions), FG10 (Diffuse Aurora) and FG13 (Modes of Solar Wind-Magnetosphere Energy Transfer). This proposed focus group will actively seek to interface with other focus groups throughout its lifespan.