*Proposal for a GEM Focus Group*
# "Geospace Systems Science"

## 1. Topic

We propose a new GEM Focus Group that will (1) develop a fundamental understanding of the systems principles that are applicable to magnetosphere-ionosphere dynamics, (2) integrate systems-science methodologies into GEM research, and (3) develop and apply advanced data analysis tools to explore multiscale interactions in observations and simulation models.

We define "systems science" as follows: (1) system-level (global) thinking that engages a broad range of expertise to reveal the underlying system interactions controlling observed phenomena and (2) the investigation of collective system behaviors often via the application of techniques developed for analyzing dynamical complex systems. As emphasized in the NRC Decadal Survey, the magnetosphere-ionosphere system is complex and highly coupled. The expansive and uncontrolled nature of geospace presents formidable challenges to understanding this coupling. Many physical processes act simultaneously across vast interconnected regions of geospace and diverse experts are needed to study its aspects. These are classic characteristics of a system ripe for systems science.

The coupled solar wind-magnetosphere-ionosphere system involves driving of convection by the solar wind, plasma entry, ionospheric outflow, mass transport, flux transport, the generation of plasma waves and the interaction of waves with particle populations, plasma heating, particle energization, production of aurora, dayside exhaust, downtail exhaust, charge exchange, charged-particle precipitation, atmospheric ionization, and energy dissipation in the thermosphere. The solar wind drives the ionosphere; the ionosphere can drive the magnetosphere and the magnetosphere can drive the ionosphere. Activations create new particle populations. There are variable time lags and on-and-off feedback loops. Satellites, magnetometers, radars, and cameras produce diverse, multipoint observations that demand synoptic interpretations.

**The first goal of the Geospace Systems Science Focus Group is advance knowledge of the system interactions underlying geospace phenomena by coordinating research on key systems-level questions.**

Recent progress on the energization and loss of the outer electron radiation belt provides an illustration of how systems-level thinking can produce comprehensive understanding. We have learned that radiation-belt electrons are energized by high-frequency plasma waves produced by particle populations injected during substorms and by low-frequency plasma waves produced by solar-wind/magnetosphere interactions. The energization processes can only increase the radiation-belt fluxes if loss processes involving the plasmasphere, the plasma sheet, and the magnetopause are reduced. All of these energization and loss processes depend on driving by the solar wind and the time history of the magnetosphere.

Many system characteristics of geospace are not understood: e.g. polar-cap potential saturation, the substorm expansion-recovery cycle, the 3-hr periodicity of activations, the scale dependence of flow structures and entropy bubbles, plasma entry and entropy change, the role of turbulence inside and outside the magnetosphere, the consequences of the viscous interaction. Additionally, our ability to predict geomagnetic activity needs improvement. The physics underlying these and other system phenomena cross GEM research areas and advancing their understanding requires the concerted efforts of the entire GEM community. The Geospace System Science Focus Group will provide the needed cross-research coordination and planning and will nurture cross-research communication. The Focus Group will draw on both conventional and novel methodologies to reveal the system interactions controlling such phenomena.

**A second goal of the Geospace Systems Science Focus Group is to evaluate and incorporate systems-science methodologies into GEM.** Systems-science methodologies for analyzing the behavior of complicated and complex dynamical systems are evolving rapidly. There has been limited application of systems tools to the magnetosphere, mostly focused on geomagnetic indices, auroral images, and magnetotail activations. Coordinated application of new systems-analysis tools is needed to lead GEM to its goal of developing an integrated understanding of geospace dynamics. These tools will become mainstream in the GEM community when they provide improved predictions, deeper physical understanding and new insights. In one sense, the proposed focus group is a demonstration project for the value of new analysis tools.

**A third goal of the Geospace Systems Science Focus Group is the development of data-analysis tools that will enable accurate characterization of multiscale processes and transient events in observations and in numerical simulations.** Algorithms for analyzing the statistical mechanics of complex systems will be adapted for application to geospace phenomena. Some examples include (a) multiscale interactions of velocity, electric field, and magnetic field using nonstationary vector structure functions and cancellation exponent approaches, (b) transitions in unstable magnetic configurations using complex network analysis, and (c) nonlinear correlations between interacting regions with a correlation integral formalism. Such tools will enable testing of the performance and forecasting ability of global simulation models across wide ranges of scales using observational data.

The GEM Workshop is the ideal venue for coordinating the necessary diverse collaborations and GSM is the appropriate research area for this Focus Group because it requires coordination with all other Focus Groups.

## 2. Timeliness

The NRC Decadal Survey is emphatic: "Throughout this report, the committee emphasizes the necessity of adopting a systems approach to achieve appropriately balanced progress in understanding an interconnected solar-heliospheric-terrestrial and planetary system." The Survey is even more explicit in pointing out that the "coupled magnetosphere-ionosphere …

system exhibits characteristic non-linear, chaotic dynamics, or 'emergent' behavior that could never have been predicted without knowledge of the coupling physics." The 2013 GEM White Paper emphasizes system-level understanding, identifying system-level problems, and holistic treatment of the coupled system. This proposed Geospace Systems Science Focus Group will directly advance the GEM Program Goal "Develop an integrated physical understanding of the geospace dynamical system". The importance of systems science in physics and the geosciences is now paramount and the GEM community is poised to advance system understanding of geospace. This Focus Group will integrate systems science into our research discipline.

## 3. Fit

The Geospace Systems Science Focus Group will complement and collaborate with all ongoing GEM Focus Groups, with CEDAR, and with SHINE to attack select systems-level problems. All current GEM Focus Group leaders were consulted in the drafting of this Focus Group proposal and topics for joint sessions with 7 ongoing Focus Groups have been outlined. Two members of the CEDAR community will act as coordinators between this Focus Group and CEDAR; one of the Focus-Group co-chairs (JB) is the GEM-SHINE Liaison and he will act as a coordinator with SHINE. Participation and coordination of the diverse GEM community will be crucial in selecting session topics that will be most effective: to ensure the broadest participation, every year at the GEM Workshop an assessment-and-planning session for the Geospace Systems Science Focus Group will be scheduled.

## 4. Goals and Deliverables

The goals of this Focus Group are
(G1) to develop a fundamental understanding of the systems principles that are applicable to magnetosphere-ionosphere dynamics
(G2) to evaluate and integrate systems-science methodologies into GEM research
(G3) to develop and apply advanced data analysis tools to explore multiscale interactions in observations and simulation models.

The deliverables of this Focus Group include:
(D1) identification of the dynamic couplings, time lags, and feedback processes that control observed phenomena
(D2) likely development of new indices characterizing the state of the M-I system
(D3) new systems-science tools for analyzing the solar-wind-driven M-I system
(D4) data-analysis guidelines and libraries of data-analysis codes
(D5) validation of the multiscale performance of computational models of the magnetosphere
(D6) a journal special issue on systems science of the geospace.

## 5. Co-Chairs

Joe Borovsky (jborovsky@spacescience.org)
Bill Lotko (William.Lotko@dartmouth.edu)
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**Coordinators with CEDAR:**
Aaron Ridley (ridley@umich.edu)
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## 6. Research Area

GGCM / GSA

## 7. Term

5 years beginning in the Summer of 2014.

## 8. Expected Activities

Proposed Year-1 Plenary Talk and Workshop Sessions:

Plenary Talk: *Systems Science in CEDAR*
Session: *What Is Systems Science for the Magnetosphere?*
Session: *Timescales, Time Lags, and Feedback Loops in the M-I System*
Session: *Long-Running Measurements of the State of the System: What Can Be Done?*
Session: *Planning Session for the Systems Science Focus Group*

Seven active GEM Focus Groups have expressed interest in coordinating joint workshop sessions with the proposed Geospace Systems Science Focus Group. The focus groups and the potential joint topics under discussion are:

Magnetic Reconnection in the Magnetosphere:
*How Do Large-Scale Magnetospheric Geometry, Ionospheric Conductivity, and Ionospheric Outflows Influence Reconnection Rates?*
Storm-Time Inner Magnetosphere-Ionosphere Convection:
*The Physics of Shielding and Its Impact throughout the Geospace System*
The Ionospheric Source of Magnetospheric Plasma:
*Can we create an ionospheric-outflow index or an oxygen-fraction index?*
The Magnetosheath:
*Origins of Non-Adiabatic Heating from Magnetosheath into Magnetosphere*
Metrics and Validation:
*Novel Validation Techniques*
Transient Phenomena at the Magnetopause and Bow Shock:
*Impulse Response of the Magnetosphere*
Tail-Inner Magnetosphere Interactions:
*Transport Bubbles: Scale Invariance and Large Events*