

Proposal for an NSF GEM Focus Group on “Scientific Magnetic Mapping & Techniques”

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Research Area: MIC with strong overlap to IMS, Tail, GGCM, and Tail problems

Term: 5 years

Abstract

Magnetic mapping between different geospace regions is of critical importance to many of the science challenges that the GEM efforts are focused on. Recent and upcoming observational programs produce simultaneous observations from disparate geospace regions that cannot be properly interpreted without addressing the mapping issue. Global models and simulations imply mappings that need to be correct in order for the models to be as useful as possible for science and prediction. Techniques for such mapping include empirical and event-based models, simulations, utilizing auroral boundaries and phenomena, magnetoseismology, and multi-point *in situ* particle observations. There is a pressing need for taking stock of these techniques, assessing their weaknesses and adding to their strengths, and for determining how global simulations compare with reality in terms of mapping. Such an effort is highly relevant to GEM and will contribute to GGCM as well as the activities of most GEM focus groups. We are proposing a magnetic mapping focus group to spearhead this effort, and to collaborate with other GEM focus groups on the use of magnetic mapping in those activities. This focus group would have a five year term, and would deliver a review of existing mapping techniques, new metrics for assessing the validity of different techniques, quantifiable improvements of existing techniques, and provide, through community challenges, demonstrations of how those improvements will benefit GGCM, and the GEM program (e.g., other focus groups) in general.

Topic Description

The ability to "map" along magnetic field lines from the magnetosphere to the ionosphere and vice versa is tremendously important to virtually all aspects of geospace studies. When accurate, mapping enables our ability to use data from disparate regions to address a wide range of important questions. When unknown, mapping is a source of frustration in the same circumstances. Incorrect mappings lead directly to erroneous conclusions and stand in the way of science progress. Countless examples of all three situations can be found in work derived from ISTP, and more recently THEMIS, where simultaneous multi-point magnetospheric and coordinated ionospheric observations have been and are being used in attempts to bring closure to a wide range of science questions and to advance our ability to model, and thus predict, geospace phenomena and space weather.

We provide just three examples of the importance of mapping to geospace science questions. In recent substorm onset studies, it has been critically important to determine the ionospheric footprints of the THEMIS satellites *relative* to time-evolving auroral features [see e.g., *Sergeev et al.*, 2010; *Angelopoulos et al.*, 2008; *Donovan et al.*, 2008]. Recent observational studies of patchy pulsating aurora are focusing on simultaneous *in situ* observations in the inner CPS and auroral observations from the ground or from space [see e.g., *Liang et al.*, 2010], and are critically dependent on knowing whether the satellite providing the *in situ* observations is magnetically

conjugate to the aurora in question. The magnetospheric physics responsible for formation of the auroral arc remains an important and unresolved question. Closure of the arc problem will require *in situ* observations of the gradients and fields responsible for (or at least corresponding to) the lower-altitude arc, which in turn will demand an unambiguous magnetic mapping between the ionosphere and magnetosphere.

Our arsenal for making magnetic connections between the ionosphere and magnetosphere is growing, and includes empirical (general and event specific) models [see e.g., *Tsyganenko, model papers; Kubyshkina, 2010*], MHD simulations [see e.g., *Raeder et al., 2001; Angelopoulos et al., 2008*], correlation of auroral boundaries and characteristics with their magnetospheric counterparts [see e.g., *Blanchard 1995, 1996; Nishimura, 2010*], magnetoseismology [*Waters et al., 1995, 1996*], and correlations between distribution functions observed simultaneously at two locations on the same field line [see e.g., *Weiss et al., 1997*]. Still, we know that mapping is difficult, our understanding of uncertainties in all of the above listed techniques are likely large and certainly poorly understood [see e.g., *Donovan et al., 1992; Jordan, 1992*], and we can anticipate that there are techniques for mapping that have yet to be developed. An example of the latter could be the development of active experiments to “paint” field lines for unambiguous point-point mappings.

From the GEM perspective, mapping falls most directly and completely under the overarching research theme of Magnetosphere-Ionosphere Coupling (MIC). Mapping is shaped by MIC, and MIC cannot be understood without explicit understanding of mapping. Mapping is strongly relevant to the other four research areas. Significant advances in our understanding of and capacity to map between the magnetosphere and ionosphere will be of significant benefit to the GGCM effort. For example, GGCM is system-level and physics-based, so necessitates an understanding of the coupling (along magnetic field lines and otherwise) between the magnetosphere and the ionosphere. The physics driving the model(s) and the modeling techniques and framework will lead to connections between regions and phenomena *in the model*. Whether or not those predicted connections are correct will be determined by observation-based empirical mappings, which will provide important feedback to the evolution of GGCM. Ultimately, advancement of the GGCM involves incorporating new understanding of geospace physics, often relating to processes that involve the magnetosphere and ionosphere. **Magnetotail** dynamics are studied with *in situ* and ionospheric observations (see above). Such studies are enabled by mapping, but mapping brings much more to the effort than tying together observations. Knowledge of the interconnectivity between the magnetotail dynamics/processes and their ionospheric counterparts will allow ionospheric observations to be used to explore the system-level effects of those processes (e.g., how much energy is dissipated in the ionosphere? how are magnetospheric particle populations lost, energized, or transported as a consequence of these processes?). Similar arguments can easily be made regarding the importance of mapping to **dayside** and **inner magnetosphere** GEM programs.

Objectives

Our goal for this focus group is to identify the best practices, advance our understanding of the critical science that depends on and facilitates mapping, and enhance the value of existing assets (such as auroral observations) for the larger GEM initiative. Our specific objectives are organized as themes under which the activities outlined below will be carried out. These objectives are

1. Survey of Mapping Techniques: Our first objective is to produce an inventory of the state-of-the-art of mapping, including empirical models, simulations, auroral boundaries, auroral features, magnetoseismology, and satellite conjunctions on the same field line
2. Assessment and Development of Techniques: Our second objective is to develop quantitative metrics for mapping and identify new innovative new technique. This will involve assessment of existing techniques, identification of areas for improvement of existing techniques, and identification of new techniques such as active experiments.

3. Relevant Science Questions: Our third objective is to identify specific questions where closure would be facilitated by improved magnetic mapping. Identification of these questions will serve as a guide for where the focus group should direct efforts to maximize our impact on GEM. Example questions include mapping in time changing topology, ionospheric source/magnetospheric destination of low-energy ion outflow, and how macroscopic fields map between the equatorial region and the ionosphere.
4. Applications of Results to GGCM and GEM and Vice-Versa: We believe that we will succeed in assessing existing techniques, developing metrics for some, and improving mapping techniques, but we wish to achieve something more meaningful for GEM. Our overarching objective is to contribute to GGCM and GEM as a whole by applying the results of the focus group. These applications could include the use of mapping to assess global circulation model results, the use of mapping to assess system-level consequences of geospace processes and phenomena, the use of GGCM output to guide improvements to empirical and event-specific models, and improvement of simulation-based mapping. In addition, we hope to contribute to education of the community, and in particular students, on the limitations of all mapping techniques and the validity of various techniques under different circumstances.

Deliverables

The deliverables will be

1. A review of existing mapping techniques.
2. New metrics for assessing the validity of different techniques.
3. Quantifiable improvements of existing techniques.
4. Demonstration of how those improvements will benefit GGCM, and the GEM program (e.g., other focus groups) in general.

We anticipate that deliverable 1 will be met by a review paper prepared by the focus group leaders, and that deliverables 2 and 3 will be met through publications by community members who will contribute to the focus group activities. The demonstration of how improved mapping benefits GEM and GGCM will be achieved through one or several community challenges.

Timeliness & Relation to other Focus Groups

This proposed focus group is timely for a number of reasons. Recent observational programs have produced a wealth of data obtained simultaneously from disparate geospace regions. It is more and more the case that optimum use of these simultaneous observations requires an understanding of the mapping along magnetic field lines between different regions, of how electric fields map between different regions, and how ionospheric phenomena such as convection and aurora are connected to their magnetospheric counterparts. This is the ideal time to delve deeper into this challenging and interesting problem. This focus group will serve existing efforts to use these data sets thereby extending the impact of current and past missions, and meaningfully impact the definition of future missions and models. The efforts of our group will be especially useful and timely for THEMIS investigators, and will be central to the upcoming RBSP mission, in particular for studying the distribution and dynamics of loss processes through the radiation belts. The BARREL experiment will use a flotilla of balloons to measure electron precipitation in conjunction with THEMIS and RBSP. Accurate field line mapping is crucial for directly connecting equatorial measurements of waves and particles to low altitude measurements of precipitation. The combined measurements will provide a unique opportunity to quantitatively test models of wave-particle interactions thought to be responsible for causing relativistic precipitation. Applying the best practices from this focus

group will enable timely and definitive progress when RBSP is launched in 2012 and the BARREL campaigns in early 2013 and 2014.

Without question, a mapping is highly relevant for numerous GEM focus groups, in particular, the GGCM groups, FG12 Substorm Expansion Onset (joint sessions are highly likely), Radiation Belts, FG8 Near-Earth Magnetosphere, and FG11 Plasmasphere-Magnetosphere Interactions. This focus group would be a natural follow on to the successful work of FG10 Diffuse Auroral Precipitation. By focusing on mapping as a critical tool for scientific analyses, the precision of global modeling, inherently reliant on mapping the magnetic field, can be improved and quantified. In organizing our focus group sessions and carrying out the activities they represent, focus group leaders and participants will interact closely with other focus groups to ensure the potential synergies with other GEM activities and benefits to GEM are realized.

Expected Activities

In order to achieve our goals for the focus group we will carry out activities corresponding under the themes identified in the above objectives section. In that list, we included illustrative examples that correspond to possible specific focused activities and corresponding sessions. First (1), we will survey current mapping techniques and relevant problems. This will build on the results of the special session on mapping that we organized for the GEM 2010 summer workshop. It will involve at least one session where the community will provide input on the different mapping techniques. From these we can identify and prioritize the scientific topics to focus on. Second (2), we will further develop the techniques for mapping and advance metrics to evaluate these techniques. For example, how reliable are empirical or event-based models? We envision challenges, for example challenging theorists and modelers to map a specific boundary or type of event and then comparing to observations (comparing physics-based mappings with those inferred from empirical models or simulations). This will involve sessions at the GEM summer and min-workshops. This activity will include the identification of new experimental and modeling methods that should enable new advances towards closure of significant problems. Third (3), we will organize a coordinated effort to identify, and apply advanced tools to solving, science questions. This will involve GEM community input through sessions during at least three successive summer workshops. These (1-3) focused activities are expected to advance our knowledge of mapping problems and solutions within the community. By the end of year two, our goal is to have identified clear avenues where focused activity would enable mapping to contribute significantly to GGCM and GEM as a whole. In years 3-5 our activities will shift from the details of mapping to its application in system-level geospace science, and to the use of system-level tools to improve the utility of various mapping techniques. Overall, we anticipate 3-4 GEM summer workshop sessions, during each of the five years of the focus group, as well as one session during each GEM mini workshop.