GEM Near-Earth Magnetosphere Challenge

Preamble

Following discussions at 3 workshops (2 summer and one "fall" Mini-GEM Workshop), the Near-Earth Magnetosphere Focus Group is ready to proceed with formulating a GEM Challenge directed at assessing our modeling and observational capabilities relevant to a future inner magnetospheric module for GGCM. During the June 2008 GEM meeting, there was agreement among the participants in this focus group that there have been sufficient advances in development of numerical ring current-type codes that now is time to compare them both with each other and with observations using a clear set of metrics. There is also an agreement that empirical models of plasmas and fields are sufficiently realistic that they can now be used to prescribe inputs and boundary conditions to numerical codes. Below is a draft of the planned Near-Earth Magnetosphere GEM Challenge, which will be gradually finalized with community input.

Timeline

We plan to draft the details of the first 2 stages (Phases 0 and 1, see below) of the Challenge in the summer of 2008 and finalize it by fall, with input from focus group participants. We expect initial results from "phase 0" to be presented and discussed at the mini-GEM workshop at the 2008 Fall AGU meeting. At the June 2009 GEM workshop, we expect to wrap up "phase 0" results, set up "phase 1", which will then see initial and full results presented at the 2009 Mini-GEM and 2010 Summer Workshop, respectively. This is only a very general timeline, and we certainly will be as flexible as possible to stimulate collaborations within the focus group.

Information Exchange

There is a mailing list for the Challenge participants. The web page for subscribing and searching the list archives is at http://mailman.rice.edu/mailman/listinfo/gem-near-earth-l (that is a letter "l" on the end.) In addition, we will send short messages as necessary to the GEM electronic newsletter, and will post summaries of results (as agreed by the participants) on the GEM Wiki page for the focus group that can be accessed through the main GEM Wiki page (http://aten.igpp.ucla.edu/gemwiki/index.php/GemWiki). To share results among the participants, a dedicated web site has been established at http://rcm.rice.edu/~sazykin/GEM/challenge.

Participating Modelers

#	Model	Researcher(s)	Phase 0	Phase 1	Phase 2	Comments
A	RAM-SC B	Vania/Sorin (LANL)	Yes			
B	HEIDI	Mike Liemohn (UMICH)	Yes			
C	RCM±E	Stan Sazykin (Rice)	Yes			
D	CRCM	Y. Zheng (APL/JHU)	Yes			
E	MCHEN	M. Chen (Aerospace)	Yes			
F	RCM+E	C. Lemon (Aerospace)	Yes			
G	CRCM	M.-C. Fok, N.Buzulukova (Goddard NASA)	Yes			

Others?

Challenge Details

We envision the Challenge to proceed in three stages, or “phases”. The first stage, “phase 0”, is really a preliminary work done by the modelers, and should be considered as a preparation for phases 1 and 2.

Phase 0

The purpose of this phase is to establish a “baseline” for the numerical codes used in the Challenge. We recognize the fact that although there is a number of ring current or convection codes used in inner magnetospheric research, they generally differ in their assumptions, numerical methods, and the specific form of the equations they solve. Therefore, the modelers participating in the Challenge agree to bring their codes to a common level by running an idealized event simulation with the same inputs and using the same physics assumptions, to the largest possible extent.

Expected outcome. We expect that at this stage, the modelers participating in the Challenge will formulate differences among the codes, and will either reconcile them (by improving numerical methods or generalizing the assumptions) or provide a comprehensive explanation of why such differences arise.

Event. An idealized event will be simulated. We propose to run codes for 12 hours for steady-state conditions. Nominal conditions will be IMF B = (0,0,-5nT), solar wind dynamic pressure of 2 nPa, and Kp=3.0.

Initial Conditions. The initial conditions will be “an empty magnetosphere”.

Magnetic field will be assumed to be dipolar, with the dipole moment of the Earth set to the value giving B_0=31000 nT at the equator on Earth’s surface. The Earth’s magnetic dipole will be assumed to have zero tilt with respect to the rotation axis.

The Modeling region will be defined as a circle of 6.6 Re in the magnetic equatorial plane, for the purpose of setting boundary conditions. The inner boundary location will be left up to the modelers, but it should be no farther than 3 R_E from Earth.

Electric field (convective) will be assumed to be given by the Volland-Stern model (one possibility is to use parameterization of *Maynard and Chen* [1975]). In case of Maynard-Chen parameterization, the potential in the inertial (non-rotating) frame in the equatorial plane is given by

$$\Phi = \Phi_{corot} - AR^2 \sin\phi$$
$$A = \frac{0.045}{\left(1 - 0.159Kp + 0.0093Kp^2\right)^3} \qquad \left(\mathrm{kV/R_E^2}\right)$$

where the first term on the first line is the corotation potential, R is the radial distance from Earth, and ϕ is the azimuthal angle from noon. For Kp=3, A=0.202 kV/R_E^2, implying a 17.6 kV potential drop across the modeling region.

Boundary conditions for plasma: plasma will consist of electrons and protons only, with a Maxwellian distribution function on the outer boundary, with the moments n=1.5 cm-3, T=10 keV protons, T=1 keV electrons, set uniformly along the boundary. Inner boundary conditions are likely to vary among different codes, and their roles will be clarified during the analysis.

Sources/losses: no particle sources or losses will be included except for inflow/outflow through the boundary of the modeling region.

Quantities to be compared: Initially, the focus will be on Dst (or total energy, as they are equivalent under the DPS relation for the dipole B-field), location and magnitude of the total pressure peak. An extra benchmark will be the particle flux (total and as a function of energy) at two specified locations to be agreed on, one each on the night side and day side.

If the total particle energy in the modeling region is denoted W in Joules, then the well-known Dessler-Parker-Sckopke (DPS) relation [*Dessler and Parker*, 1959; *Sckopke*, 1966] can be used to evaluate the magnetic field disturbance at the center of the Earth (SI units):

$$\Delta B(0) = -\frac{\mu_0}{2\pi}\frac{1}{B_0 R_E^3} W$$

where R_E=6375 km. If we take this quantity to represent the ring current contribution to the *Dst* index, and further express *W* in units of keV, then the quantity for comparison in [nT] is

$$Dst^* = -3.84 \times 10^{-30}\, W$$

Phase 1

Phase 1 will consist of the simulation of an idealized event (geomagnetic storm). The exact details will be resolved through communication among the Challenge participants while working on Phase 0. Below are suggested parameters for such an event.

The purpose of this phase will be to distill the roles of different model physics "components" in determining the dynamics of the storm-time ring current, while still keeping the simulation complexity tractable. Models will start from a common set of initial/boundary conditions and inputs (to be determined later, but tentatively: a Tsyganenko B-field, an E-field, etc). After one common set of runs, the modelers will start adding features (different losses, magnetic field, etc) one at a time, and will reach as much sophistication as their code formalism allows.

We expect that Phase 1 runs of the Challenge will quantify relative roles and importance of different processes that the models include. Specifically, we envision that it will lead to the quantification of the roles of:

- Magnetic field (dipole, empirical Tsyganenko fields, self-consistently computed)
- Electric fields (analytic non-consistent such as Volland-Stern or similar, empirical Weimer or similar, data-based more sophisticated with SAPS etc., self-consistently computed with and without inductive component)
- Losses (charge-exchange, Coulomb collisions, wave-particle interactions, precipitation into the atmosphere)
- Plasma boundary conditions (time-constant, time-varying, varying in time and in MLT, etc).
- Ion composition (H+ vs O+ and He+).

An idealized magnetic storm could be set up as follows. The first 24 hours will be assumed quiet-time for those models that need to run to get initial conditions, and then there will be a 6 hour main phase, followed by a long recovery phase. These conditions are quantified in Table 1, with the first two columns corresponding to solar wind density and velocity, and the third is polar cap potential drop driven by an enhanced southward IMF Bz.

Time	n_{sw} (cm^{-3})	V_{sw}(km/s)	Φ_{PC}(kV)	*Dst*	*Kp*
00:00	5	450	40	0	3
24:00	25	430	40	0	3
30:00	25	680	150	–250	6
36:00	30	630	40	–150	4
42:00	15	630	40	–100	3
60:00	5	630	40	–050	2+

Table 1. Conditions for the idealized intense magnetic storm to be modeled in Phase 1.

Initial conditions could be either start with an empty magnetosphere and run for 24 hours prior to the main phase, or empirically prescribed fluxes (e.g. from CRRES or POLAR). The initial conditions might not matter that much - in our experience with storm simulations, they quickly become "washed out" in the main phase.

Magnetic field: one possibility is to start with a T89 Kp-driven magnetic field for those codes that can handle it. The magnetic tilt will be set to zero.

Modeling region will be defined as a circle of 10 Re in the magnetic equatorial plane, except where the magnetopause is closer to the Earth. The exact inner boundary location will be left up to the modelers, but it should be no farther than 3 R_E from Earth.

Electric field: We propose to start with a prescribed electric field. The Volland-Stern model has a simple parameterization and is one option. Another one might be an MSM-based E-field model that includes shielding (S. Sazykin will supply it to everybody else). When the stage of a self-consistent electric field is reached, conductance model details will also be needed. A suggestion is that one of the modelers could compute a time-dependent E-field and supply it to the others (S. Sazykin could provide this as well).

Boundary Conditions on Plasma: prescribe n and T on the outer boundary, and assume a kappa (e.g. kappa=6) distribution function, which is more realistic than a Maxwellian. Initially, keep n and T constant in MLT and time. Later, empirical plasma models could be used. Initially, set ion composition to be 100% H+ (include electrons too). Later, move on to statistically-based ion composition, include anisotropies.

Losses/Sources: Start with none, and add charge exchange and wave particle interactions (for the models that have this capability).

Quantities to be compared: same as in Phase 0. Initially, the focus will be on Dst and total energy (the relationship between the two will be discussed based on generalized DPS formulation for non-dipole B-field), location and magnitude of the total pressure peak. An extra benchmark will be the particle flux (total and as a function of energy) at two specified locations to be agreed, one each on the night side and day side.

Phase 2

Phase 2 will consist in simulations of a real event (or more than one if agreed on), after Phase 1 is wrapped up (a very general timeline for this phase would be starting at the 2010 Summer Workshop). This phase will involve, besides modelers, observers as well. Besides providing data for comparison with model results, they will provide up-to-date empirical models (statistical or event-based) of plasma and fields for input into the physics-based models (at the boundary for the self-consistent models, and everywhere for the others). Below is a very brief outline of this phase, with the details to be added after focus group discussions at upcoming workshops.

The purpose of this phase is to apply the full variety of model features to study the roles of different physics processes in inner magnetosphere dynamics, and also to validate the codes vs. observations. A clear and quantitative understanding of these relative roles will be permitted by the knowledge gained from phases 0 and 1.

The setup will be similar to that in Phase 1 (i.e. start with a common set of inputs/boundary conditions, and start adding features one at a time), but will relax all simplifying assumptions (e.g. the zero dipole tilt) for the comparison with observations.

Quantities to be compared: same as in phase 1, but will also include the higher time resolution SYM-H, in situ measurements of electric and magnetic fields, particle fluxes, magnetic field signatures on the ground (for those models that can do it), and ground-based radar measurements of convection.

Summary

This is a first draft of the GEM Near-Earth magnetosphere focus group challenge. Its primary purpose is to stimulate phase 0 model runs (for the December Mini-GEM session and 2009 Summer GEM), and also to start a discussion among the participants of Phase 1 and 2 work.

References

Sckopke, N. (1966) A general relation between the energy of trapped particles and the disturbance field near the Earth, *J. Geophys. Res., 71*, 3125-3130.

Dessler, A. J. and E. N. Parker (1959) Hydromagnetic theory of geomagnetic storms, *J. Geophys. Res., 64*, 2239-2252.

Maynard, N. C. and A. J. Chen (1975), Isolated cold plasma regions: Observations and their relation to possible production mechanisms, *J. Geophys. Res., 80*, 1009-1013.