2016 GEM session proposal

3D ionospheric electrodynamics and its impact on the Magnetosphere – Ionosphere – Thermosphere coupled system

1. Topic

The magnetosphere is one of the major energy sources that drive the Earth's upper atmosphere. During geomagnetic storms, the magnetosphere transmits significant energy and momentum into the upper atmosphere via field-aligned currents, Poynting flux, and auroral precipitation. In response, the ionospheric electric potentials and conductances increase, the thermosphere heats and expands, and the global atmospheric circulation changes. The ionosphere – thermosphere feedback can also influence magnetospheric dynamics. The heated thermosphere can enhance ionospheric outflows and change magnetic reconnection rates. The modified global circulation redistributes plasmas and neutrals, alters the ionospheric conductance and electric field, and thus changes the magnetospheric convection and reconnection. Although strong coupling of the magnetosphere – ionosphere – thermosphere (MIT) system are widely recognized by the space science community, studying this coupling dynamics as a whole global system has yet to be conducted comprehensively. To magnetospheric scientists, the ionosphere is treated as a two-dimensional, low-altitude boundary. The mass and momentum exchanges between the magnetosphere and the IT system are often ignored. More realistic calculation of upper atmospheric dynamics is necessary in the global magnetosphere - ionosphere models. To upper atmospheric scientists, simple statistical convection patterns and empirical auroral precipitation fluxes driven by the Kp and hemispheric power indices are commonly used to infer complicated magnetospheric dynamics. As a consequence, global IT models (e.g. CTIPe, TIEGCM, and GTIM) cannot sufficiently capture the spatiotemporal dynamics of magnetospheric energy sources during strong geomagnetic activities, thus limiting the predictive capability of these models when it is most needed. More realistic calculation of magnetospheric energy input is necessary. In recent years, the coupled magnetosphere – ionosphere – thermosphere (MIT) models (e.g. OpenGGCM-CTIM, LFM-TIEGCM, BATSRUS-GTIM, and AMIE-TIEGCM) have been gradually matured to the point to revisit the extensive ground/space observations and to investigate the complex coupling processes of the MIT system. It is thus the proper time to build on and expand these recent efforts. For the next five years, this new focus group (FG) will address, via modeling and observational approaches, 1) where, when, and how magnetospheric energy contributes to the IT system and 2) how the IT system feeds back to the magnetosphere.

2. Timeliness

This new focus group is timely because

1) The physics-based, two-way coupled MIT models are mature enough to test the coupling dynamics. Recent studies showed that OpenGGCM-CTIM and LFM-TIEGCM (a.k.a. CMIT) improve the predictability of the magnetospheric and the upper atmospheric responses especially during storms. BATSRUS coupled with GITM and PWOM is also a useful MIT model, particularly for investigating the ionospheric outflow impact on the magnetospheric dynamics. The IT only models can be driven using empirical or data-assimilated energy input from the Weimer/Heelis or AMIE, providing good comparison tools to analyze the MIT behaviors.
2) Extensive datasets from the ground to the upper atmosphere and to the magnetosphere are

available to validate the model results and to understand the coupling physics. MMS, THEMIS, and Cluster spacecraft measure plasma characteristics and electromagnetic fields in the magnetosphere. DMSP, AMPERE, SWARM, GRACE, and CHAMP spacecraft provide the upper atmospheric data such as aurora precipitation, magnetic perturbations, electric fields, field-aligned currents, and neutral densities. The ground instruments such as Febry-Perot interferometers, GNSS receivers, and incoherent scatter radars provide thermospheric wind and temperature, total electron content, and the altitudinal profile of ionospheric density, temperature, and ion drift.

3) The 2016 GEM-CEDAR joint session titled "Magnetospheric energy/momentum input and its role in the Magnetosphere – Ionosphere – Thermosphere Coupling" was a very popular session with 27 speakers and over 120 participants, demonstrating the growing need in space science community to understand the MIT coupling dynamics.
4) One of the two MI coupling FGs "*Storm-time inner magnetosphere – ionosphere convection*" will be ended in 2017. Their modeling tools, observational techniques, and knowledge can be integrated into our proposed FG to ensure continuity in our understanding of the MIT coupling dynamics.

MI coupling and IT coupling studies are traditionally conducted separately by the magnetospheric and upper atmospheric scientists. Now that the MIT modeling tools and the extensive data sets become widely available to us, it is time to move forward and put efforts on the comprehensive analysis of the MIT regions as a coupled system.

3. Fit/Relevance to Existing GEM Focus Groups

Our proposed focus group is unique since the full MIT coupling dynamics is not addressed in any of the current GEM focus groups. We expect to bring synergies to collaboration with the following existing GEM FGs.

1) *Geospace system science, Modeling methods and validation*: We will investigate the detailed links between the magnetosphere and the IT system using the theoretical, numerical and observational approaches, advancing our fundamental understanding of geospace system science. Thus, our FG is complementary to the two GEM FGs.
2) *Inner magnetosphere cross-energy/population interaction, Merged modeling & measurement of injection ionospheric plasma into the magnetosphere and its effects*: We will coordinate joint GEM sessions with these FGs to investigate impact of the magnetospheric energetic particles on the IT system and the roles of IT dynamics in regulating magnetospheric dynamics.
3) *ULF wave modeling, effects, and applications, Testing proposed links between mesoscale auroral and polar cap dynamics*: ULF waves can contribute to the auroral precipitation, which subsequently modifies the ionosphere - thermosphere dynamics. Additionally, mesoscale auroral and polar cap dynamics in the high-latitude regions are important to understand spatiotemporal variations in the IT dynamics. Collaboration with theses FGs bring synergetic activities to understand the role of ULF waves and auroral/polar cap dynamics on the MIT system.

4. Goals and Deliverables

The ultimate goal of this focus group is to advance our physics-based understanding of global magnetosphere – ionosphere – thermosphere coupling dynamics. We are particularly interested in the following topics:

1) *Momentum/Energy input from the magnetosphere to the upper atmosphere*: The small and large-scale patterns of field-aligned currents, auroral precipitation, and Poynting flux during various geomagnetic events will be carefully examined using observations, theoretical calculations, and numerical simulations.
2) *Responses of three-dimensional IT system to the magnetospheric input*: This FG will investigate the impact of magnetospheric momentum/energy inputs on the three-dimensional IT system using global MIT models and/or global IT models coupled with AMIE. We will address how the spatiotemporal dynamics of magnetospheric input modifies the altitudinal profiles of electron density, ionospheric conductivity, and Joule heating. We will also study how this modification influences global ionospheric electrodynamics.
3) *IT feedbacks to the magnetosphere*: Variations in global ionospheric electrodynamics can influence the magnetospheric convection patterns and modify the magnetic reconnection rates. The coupled magnetosphere – ionosphere – thermosphere models can be a good tool to investigate the IT dynamics and their impact on the magnetospheric phenomena. Additionally, strong Joule heating and enhanced ionospheric temperature can produce ion outflows and modulate the reconnection rates. The outcome from this FG can be a good asset for the ion outflow modelers.

The main deliverables of this focus group will include the development, refinement, and application of more comprehensive and self-consistent, physics-based models that cover from the magnetosphere to the upper atmosphere, those of which fulfill the main objective of the GEM program.

5. Co-Chairs

Two young and two senior scientists will co-chair this focus group.

- Hyunju Connor (hyunju.k.connor@nasa.gov) Expertise: MIT coupling, OpenGGCM – CTIM
- Bin Zhang (binzheng.zhang@dartmouth.edu) Expertise: MIT coupling, LFM – TIEGCM
- Gang Lu (ganglu@ucar.edu) Expertise: IT coupling, TIEGCM – AMIE
- Haje Korth (haje.korth@jhuapl.edu) Expertise: MI coupling, AMPERE observations

6. Research Area

Magnetosphere – Ionosphere Coupling & Global System Modeling

7. Term of Focus Group

Five years (2017 – 2021)

8. Expected activities

This focus group expects the following activities:

1) *Data analysis*: Multiple datasets (e.g. MMS, THEMIS, Cluster, DMSP, AMPERE, SWARM, GRACE, GOCE, SuperDARN, and AMISR) provide a good coverage of the Earth's MIT system. This focus group will encourage the data analysts to join our session and provide the observational insights to MIT coupling dynamics.
2) *Modeling challenges*: This focus group will select a few geomagnetic storms when the multiple datasets are available throughout the MIT system. We will encourage the GEM community to investigate the MIT coupling dynamics during the selected events using

various modeling tools (e.g. OpenGGCM-CTIM, LFM-TIEGCM, and BATSRUS-GTIM). The model-to-model and model-to-observation comparisons will help to advance our understanding and prediction of the storm-time MIT dynamics.

3) *Dissemination of our focus group results to CEDAR community*: Our FG activities will be shared with the upper atmospheric science community in the following ways. First, we will encourage participation of the CEDAR scientists to our mini-GEM sessions held near the fall AGU conference sites. Second, we will organize web seminars at least once per year by inviting speakers who present their MIT coupling studies in our GEM session. These seminars will be advertised on both GEM and CEDAR newsletters. Last, we will post our FG session reports on the GEM and CEDAR newsletters.
4) *Collaboration with other GEM Focus Groups*: We will organize several joint sessions with other GEM focus groups mentioned in section 3. The collaborative efforts will foster discussions and advance our understanding of the near-Earth space environments.
5) *Student-friendly tutorials and presentations*: We will start our GEM session each year with a student-friendly tutorial. Additionally, we will encourage our speakers to provide 1-2 slides of introduction at the beginning of their talk so the students can be familiar with the basics.