

2015 GEM session proposal

Energy transport in the magnetosphere – ionosphere – thermosphere system

Topic: Coupling of the magnetosphere – ionosphere (MI) and of the ionosphere – thermosphere (IT) has been extensively studied in the past decades. The magnetospheric activities such as reconnection, viscous interaction, ring current energization, and tail dynamics deposit significant energy into the upper atmosphere in the form of Poynting flux and electron/proton precipitation. The subsequent high-latitude ionization and ionospheric electric field variation produce thermospheric heating, thermal expansion, high-velocity winds, traveling atmospheric disturbances, and the initiation of a new global circulation. These changes in the ionosphere – thermosphere system feed back to influence magnetospheric activities. For example, variations of ionospheric conductance and electric potential alter magnetospheric convection and magnetotail reconnection. Ionospheric outflows can influence magnetospheric dynamics via modifying magnetic reconnection rates. Although strong coupling of the magnetosphere – ionosphere – thermosphere (MIT) system are widely accepted by the space science community, study of its coupling dynamics as a whole global system has yet to be conducted comprehensively. To the 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. To the upper atmospheric scientists, simple statistical convection patterns and empirical auroral precipitation fluxes driven by indices such as Kp and HPI are adequate to infer complicated magnetospheric dynamics. In recent years, the coupled MIT models have been gradually matured to the point to revisit the extensive ground/space observations and to investigate the complex coupling 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.

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 provides plasma quantities and electromagnetic fields of the magnetosphere. DMSP, AMPERE, 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 Febyry-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. Two MI coupling FGs “*Ionospheric source of magnetospheric plasma - measuring, modeling, merging into the GEM GGCM*” and “*Scientific magnetic mapping & techniques*” will be ended this year. Their modeling tools, observational techniques, and knowledge will be integrated into our proposed FG, continuously advancing our understanding of the MIT coupling.
4. The 2016 GEM-CEDAR joint workshop will be a perfect time to inaugurate this FG since it will appeal to both the GEM and CEDAR communities, bringing interests and collaborative efforts under the auspices of this new focus group.

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 are available at our hand, it is time to move forward and put efforts on the comprehensive analysis of the MIT regions as a coupled system.

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 synergetic effects in collaboration with the following existing GEM FGs.

1. *Magnetic reconnection in the magnetosphere*: Since reconnection is a key mechanism that channels solar wind

- energy into the MIT system, their understanding of reconnection physics is complimentary to our proposed FG.
2. Transient Phenomena at the magnetopause and bow shock and their ground signatures: Our understanding of energy transport in the MIT system helps this FG to answer how the dayside transients evolve and propagate from the magnetosphere down to the IT system.
 3. Geospace System Science: We will investigate the detailed links between the magnetosphere and the IT system, advancing our fundamental understanding of geospace system science.
 4. Storm-time inner magnetosphere – ionosphere convection, Inner magnetosphere cross-energy/population interaction, and Tail – inner magnetosphere interactions: We will coordinate joint GEM sessions with these FGs to investigate the roles of the inner magnetosphere and magnetotail on the coupled MIT system and the roles of IT system on the magnetospheric phenomena.
 5. Testing proposed links between mesoscale auroral and polar cap dynamics: Since most magnetospheric energy is deposited into the high-latitude region especially near the aurora oval, collaboration with this FG bring synergetic activities to understand the role of auroral/polar cap dynamics on the MIT system.

Goals and Deliverables: The ultimate goal of this focus group is to provide more detailed understanding of global magnetosphere – ionosphere – thermosphere coupling dynamics. We specifically want to answer:

1. Where, when, and how the magnetospheric energy is deposited into the IT system?
2. How does the energy input affect the temporal/spatial distributions of neutrals and plasmas (e.g. total electron content and thermospheric densities) and thus their interactions?
3. Which energy deposition process (particle precipitation, Joule heating, or direct momentum transfer) is the major driver for the neutral and ion distribution changes? How does that develop throughout a magnetic storm?
4. How do all the interactions vary for different types of storms (CME and CIR storms) and with storm intensity (as measured by the Dst index)?
5. How does the IT variation influence the magnetosphere (through ionospheric currents and ion outflows)?

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 solar wind to the magnetosphere and down to the upper atmosphere, those of which fulfill the main objective of the GEM program.

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@jhupl.edu) Expertise: MI coupling, AMPERE observations

Research Area: Magnetosphere – Ionosphere Coupling & Global General Circulation Modeling

Term of Focus Group: Five years (2016 – 2021)

Expected activities: This focus group expects the following activities.

1. A review of magnetospheric energy input calculated from empirical models (e.g. Weimer, Heelis, and GUVI), data-assimilation model (AMIE), and physics-based models (e.g. OpenGGCM, LFM, and BATSRUS) in comparison with observations (e.g. DMSP and AMPERE)
2. Detailed investigation of the IT responses to the different magnetospheric inputs (e.g. empirical/analytical/realistic aurora precipitation and on-and-off of Region 2 currents) and of the magnetospheric responses to the different IT setups (e.g. strong/weak conductance and on-and-off of ionospheric outflows)
3. Comprehensive examination of global MIT dynamics under the different solar wind drivers (e.g. interplanetary shock and CME/CIR storms)
4. Assessment of the roles of inner magnetosphere and ionospheric outflows on the MIT coupled system by adding more physics modules to the MIT models (e.g. OpenGGCM-RCM-CTIM, LFM-RCM-TIEGCM-IPWM, BATSRUS-RCM-GTIM-PWOM)
5. Discussion of the next modeling challenges to provide reliable prediction of the MIT parameters (e.g. auroral precipitation, total electron contents, and thermospheric densities)