Conductance in the Aurora: Influence of Magnetospheric Contributors

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Abstract

Estimation of the ionospheric conductance is a crucial step in coupling the magnetosphere & ionosphere (MI). Since the high-latitude ionosphere closes magnetospheric currents, conductance in this region is pivotal to examine & predict MI coupling dynamics, especially during extreme events. In spite of its importance, only recently have impacts of key magnetospheric & ionospheric contributors affecting auroral conductance (e.g., particle distribution, ring current, anomalous heating, etc.) been explored using global models. Addressing these uncertainties require new capabilities in global magnetosphere - ionosphere - thermosphere models, in order to self-consistently obtain the multi-scale, dynamic sources of conductance. This work presents the new MAGNetosphere - Ionosphere - Thermosphere (MAGNIT) auroral conductance model, which delivers the requisite capabilities to fully explore the sources of conductance & their impacts. MAGNIT has been integrated into the Space Weather Modeling Framework to couple dynamically with the BATSRUS magnetohydrodynamic (MHD) model, the Rice Convection Model (RCM) of the ring current, the Ridley Ionosphere Model (RIM) & the Global Ionosphere Thermosphere Model (GITM). This new model is used to address the precise impact of diverse conductance contributors during geomagnetic events. First, the coupled MHD-RIM-MAGNIT model is used to establish diffuse & discrete precipitation using kinetic theory. The key innovation is to include the capability of using distinct particle distribution functions (PDF) in a global model: in this study, we explore precipitation fluxes estimated using isotropic Maxwellian & Kappa PDFs. RCM is then included to investigate the effect of the ring current. Precipitating flux computed on closed field lines by RCM is compared against MAGNIT results, to show that expected results are alike. Lastly, GITM is coupled to study the impact of the ionosphere thermosphere system. Using the MAGNIT model, aforementioned conductance sources are progressively applied in idealized simulations & compared against the OVATION Prime Model. Finally, data-model comparisons against SSUSI, AMPERE & SuperMAG measurements during the March 17, 2013 Storm are shown. Results show remarkable progress of conductance modeling & MI coupling layouts in global models.

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Modern Trends in Space Weather Prediction

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Key Question

Can accurate estimation of the ionospheric conductivity in the auroral region help improve our space weather predictions?

INTRODUCTION & SCIENTIFIC BACKGROUND

How do we predict Space Weather?
Space Weather can be predicted using observational and physics-based tools. Most commonly used predictive tool are global magnetohydrodynamic (MHD) models[5,8,10].

What science problems affect predictions?
One of the major issues with global models is the inaccurate prediction of the ionospheric conductance, which causes underprediction of storm-time indices[9].

How do we know predictions are accurate?
Prediction efficiency of a given model is tested based on the accuracy of prediction of the time-varying magnetic field on the ground (dB/dt). Based on skill scores, a model's accuracy is defined[4].

What are we changing?
We propose to improve models used to predict the auroral conductance in MHD, and replace them with more physics to capture the precipitative processes more accurately.

Additional Science Questions

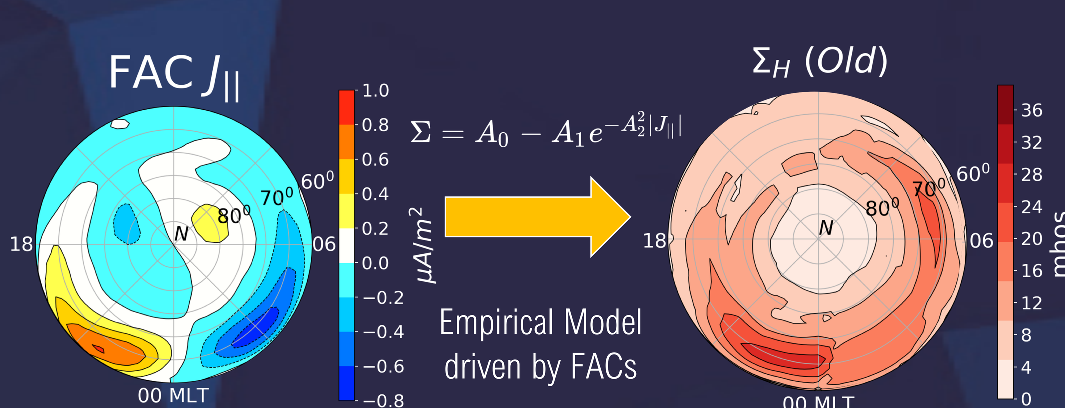
1. How do we account for all conductance sources?
2. Which source(s) is most dominant for given condition?
3. What are our present numerical capabilities and how can we improve?

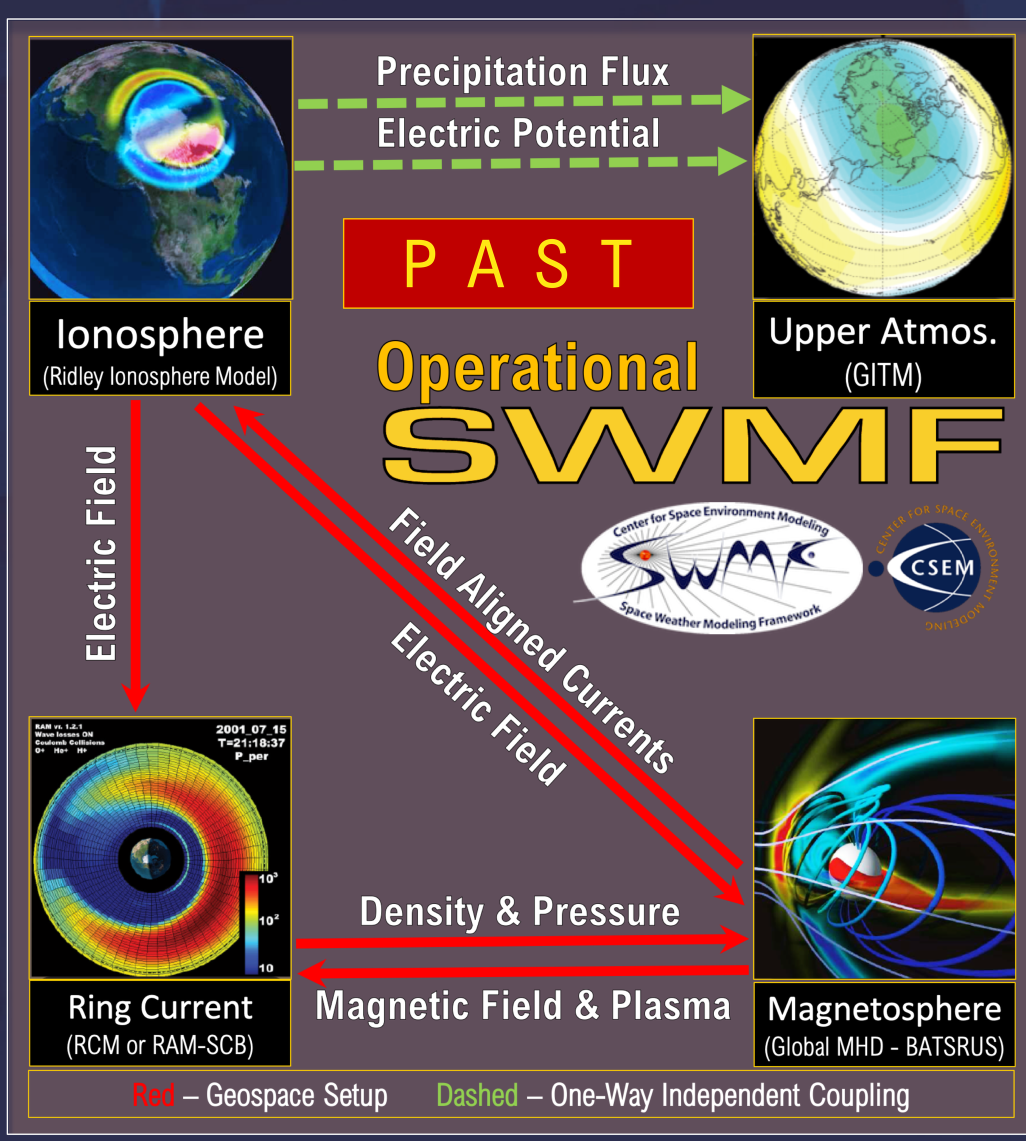
METHODOLOGY & RESULTS : M-I COUPLING IN GLOBAL MODELS

LEGACY MODEL

M-I Coupling in the SWMF (Legacy Model)

SWMF allows passage of field aligned currents (FACs) onto a 2D ionosphere to apply Ohm's Law in order to estimate the electric potential in the ionosphere. For this to work, the ionospheric conductance in the aurora is assumed dependent on FACs.

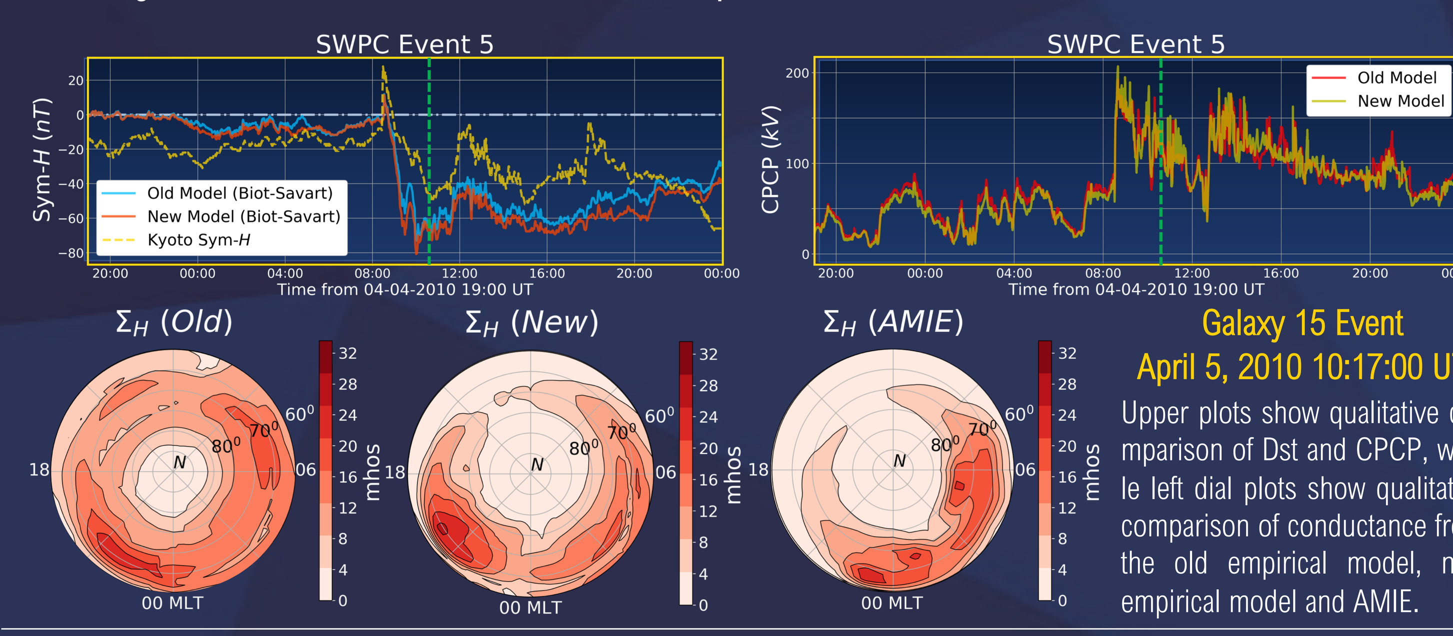




PRESENT CAPABILITIES

Conductance Model for Extreme Events (CMEE)

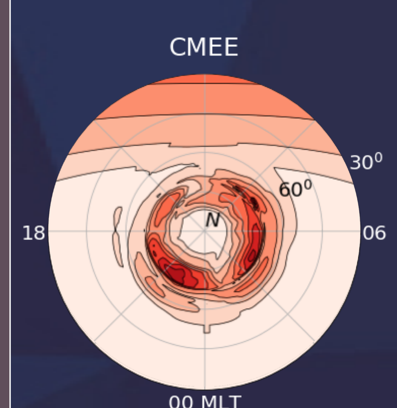
The original empirical model relating auroral conductance with FACs was based on one month of AMIE data. We improved on this work to develop another empirical model that uses one year of AMIE data, choosing the year of 2003 to include extreme space weather activities in our dataset.



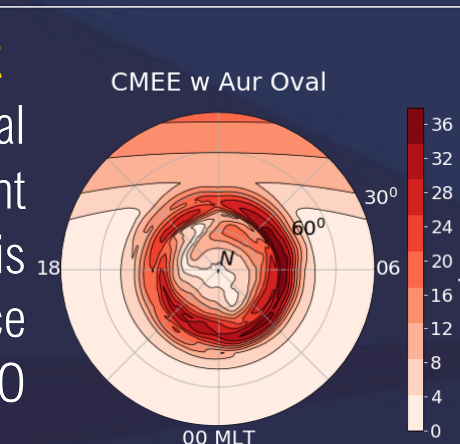
Galaxy 15 Event
April 5, 2010 10:17:00 UT

Upper plots show qualitative comparison of Dst and CPCP, while left dial plots show qualitative comparison of conductance from the old empirical model, new empirical model and AMIE.

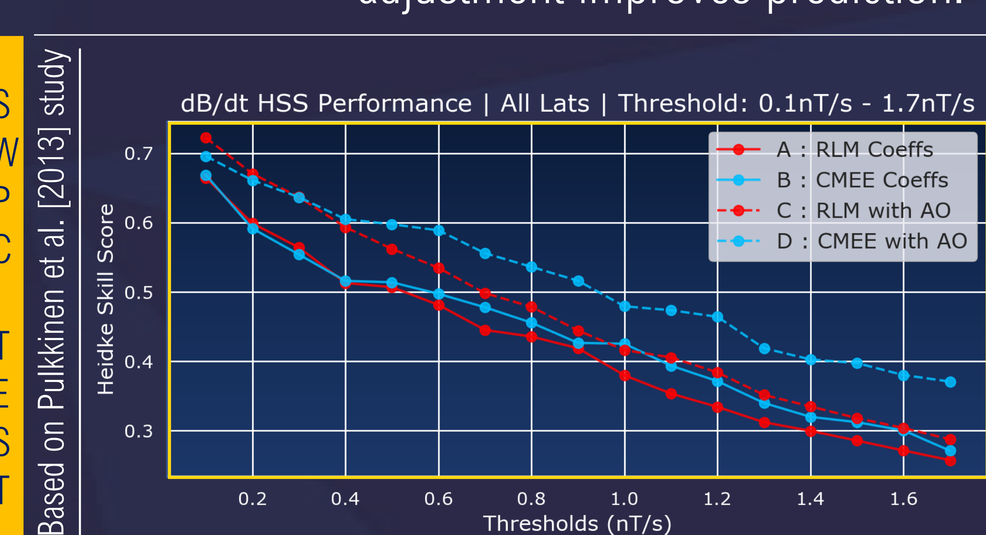
Auroral Oval (AO) Adjustment



In order to place the auroral oval accurately, an artificial adjustment function based on upward FACs is used to enhance the conductance in higher latitudinal regions. AO adjustment improves prediction.



SWPC TEST



Events[4]	Date/Time of Event	Min Dst
1	29 Oct – 31 Oct, 2003	-353 nT
2	14 Dec - 16 Dec, 2006	-139 nT
3	31 Aug - 1 Sep, 2001	-40 nT
4	31 Aug - 1 Sep, 2005	-131 nT
5	5 Apr - 6 Apr, 2010	-73 nT
6	5 Aug - 6 Aug, 2011	-113 nT

dB/dt threshold	Heidke Skill Score Old	New	Rel Diff
0.3 nT/s	0.637	0.637	+0.000
0.7 nT/s	0.498	0.556	+0.058
1.1 nT/s	0.406	0.474	+0.068
1.5 nT/s	0.318	0.397	+0.079

MAGNIT Physics-Based Conductance Model

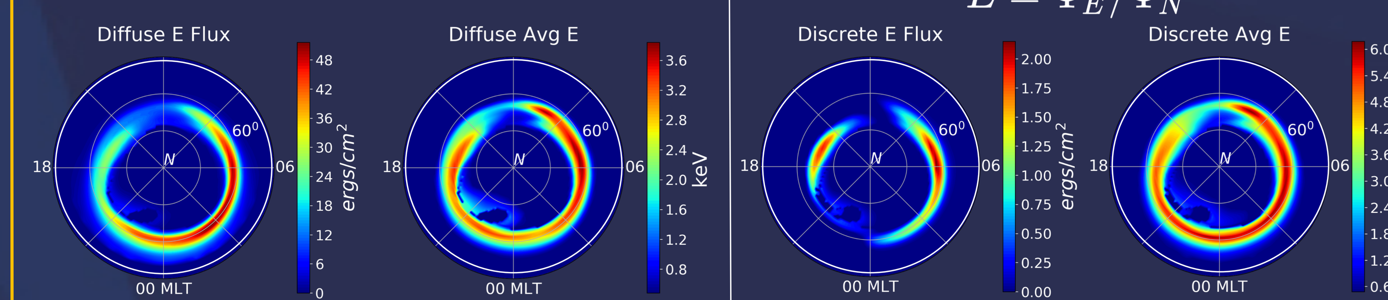
Using elementary kinetic theory, we derive the diffuse and discrete particle flux and energy flux for a *Maxwell-Boltzmann distribution*. The total energy flux divided by the particle flux gives us the average energy. Using the average energy and the energy flux, we derive the conductance using the relation from [11].

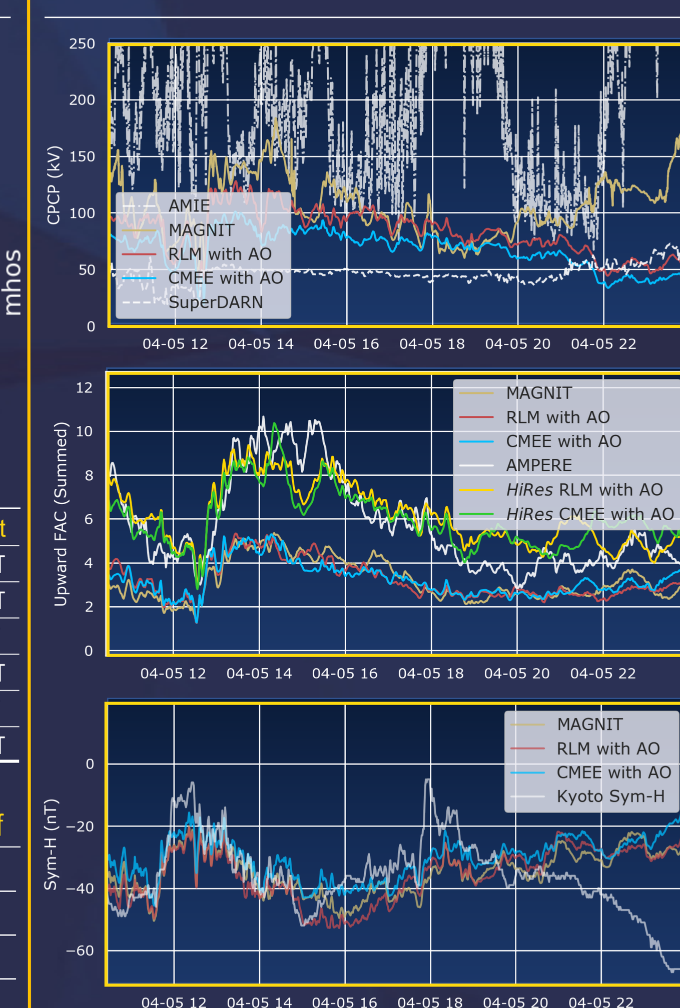
1 - Diffuse Flux Calculations

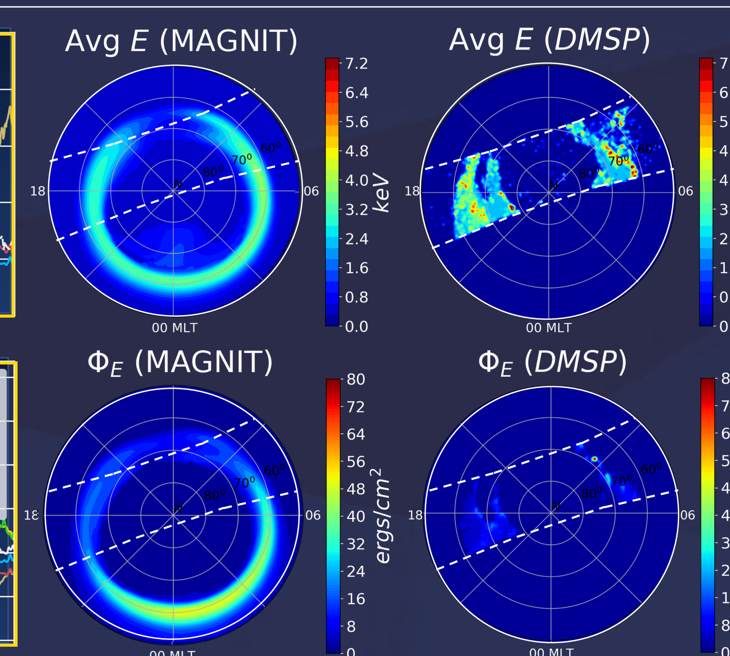
$$\Phi_E = \int_0^\infty dv \int_0^{2\pi} d\phi \int_0^1 \mu\, d\mu\, v^3 (\tfrac{1}{2} m v^2) f(v)$$
$$\Phi_N = \int_0^\infty dv \int_0^{2\pi} d\phi \int_0^1 \mu\, d\mu\, v^3 f(v)$$
$$\bar{E} = \Phi_E / \Phi_N$$

2 - Discrete Flux Calculations

$$\mathcal{E}_I = \mathcal{E}_S + eV$$
$$\Phi_E = \int_0^\infty d\mathcal{E} \int_0^{2\pi} d\phi \int_0^1 \mu\, d\mu\, v\, \mathcal{E} f(\mathcal{E})$$
$$\Phi_N = \int_0^\infty d\mathcal{E} \int_0^{2\pi} d\phi \int_0^1 \mu\, d\mu\, v f(\mathcal{E})$$
$$\bar{E} = \Phi_E / \Phi_N$$







Galaxy 15 Event (SWPC Event 5)
April 5, 2010 10:40:00 UT

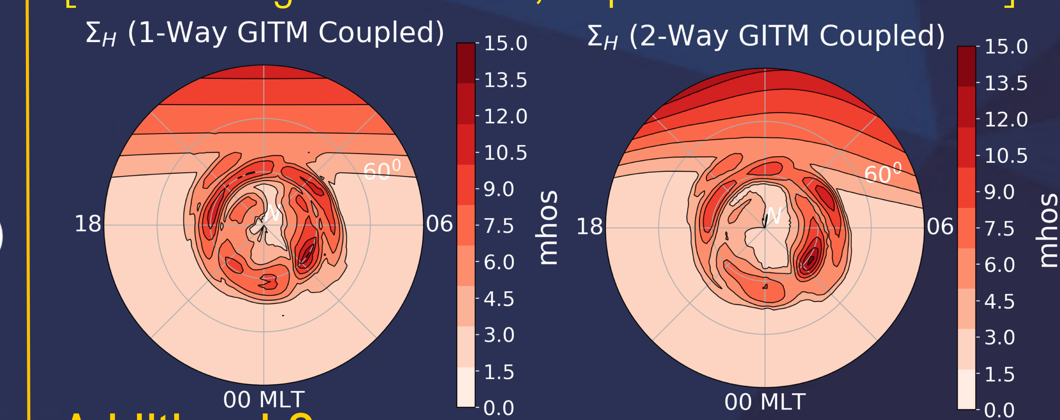
Upper plots show comparison of average energy and energy flux with DMSP F16 observations against MAGNIT precipitation estimates. The precipitation is converted into conductance using the Robinson Relation [11]. Plots on the left show CPCP, Integrated FACs and Sym-H comparisons for MAGNIT results along with the RLM and CMEE results against observations from SuperDARN, AMIE, AMPERE and Kyoto Observatory.

ONGOING

Two-Way Coupling to GITM

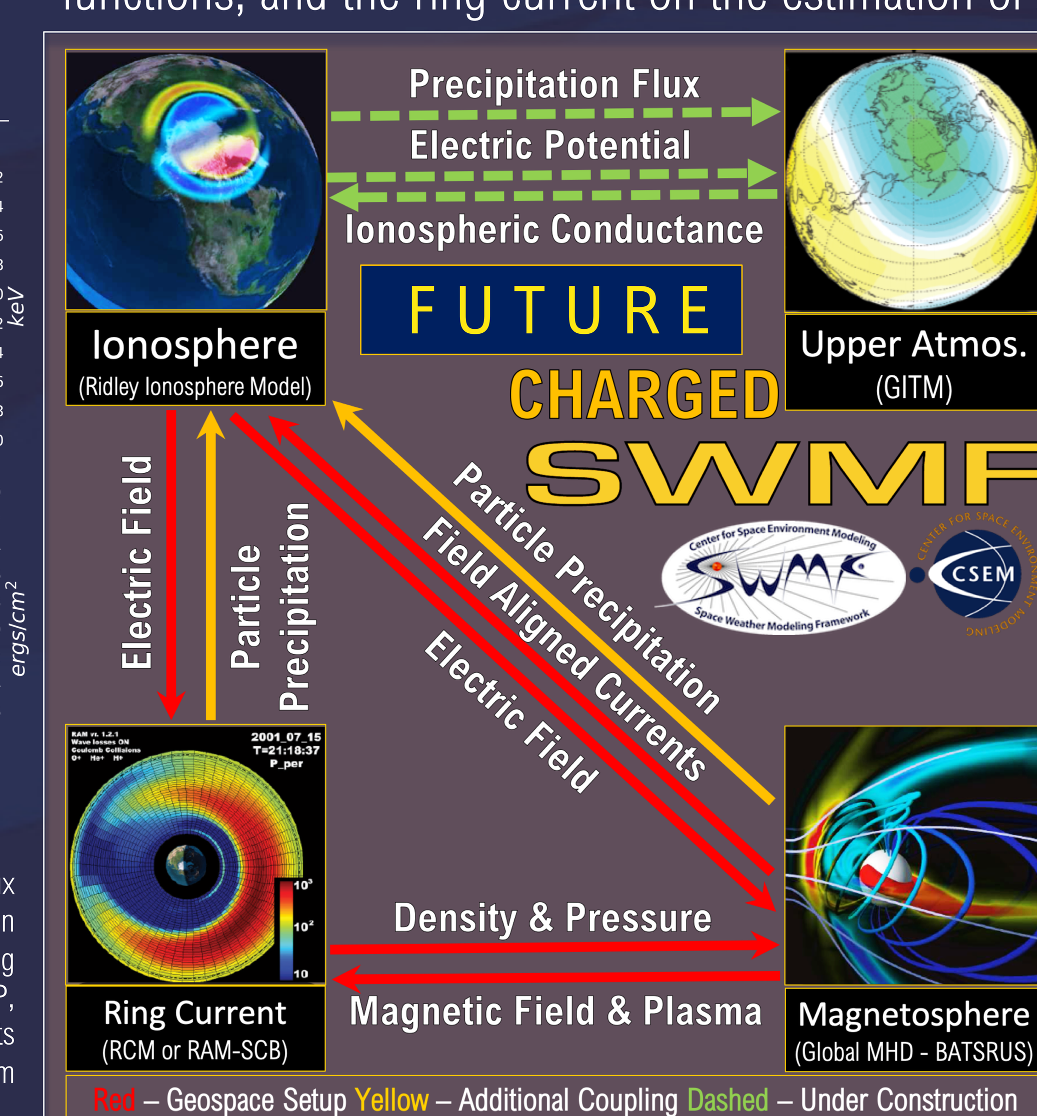
Conductance Input from the Global Ionosphere Thermosphere Model (GITM) will help us get realistic ionospheric dynamics.

[See Burleigh et al. 2019, Paper No. SA41B-3168]



Additional Sources

Investigate the effect of broadband precip, distribution functions, and the ring current on the estimation of Σ.



Conclusions

The impact of the ionospheric conductance on our space weather results are significant enough to cause physical as well as predictive improvements.

- We have completed development of a new empirical model (CMEE) using 1 year's worth of AMIE data. This model will be operationally available soon. Compared to the legacy model, CMEE improves dB/dt predictions significantly for the 6 SWPC events.
- Development of the MAGNIT model is ongoing. The model is being used to study the contribution of magnetospheric precipitation sources during space weather events. High Resolution runs might yield improved results in discrete fluxes.

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