# Ring Current-Ionosphere Coupling: Electron Scattering Rates and Electrodynamics

N. Perlongo[1], A. Ridley[1], M. Liemohn[1],
R. Katus[1], S. Sazykin[2]
1. University of Michigan 2. Rice University

## Abstract

The ring current is an integral component of the magnetosphere-ionosphere (M-I) electrodynamic system. Pitch angle diffusion caused by waves in the inner magnetosphere is the primary source term for the diffuse aurora, especially during storm time. A number of empirical models have been developed to define the subsequent scattering rate of ring current electrons. This study investigates the magnetic local time (MLT) and storm dependent electrodynamic impacts of the diffuse aurora using a comparison between hot electron ion drift integrator (HEIDI) with varying electron scattering rates and real geomagnetic storm events. HEIDI was updated to include a self-consistent auroral model and compared with Dst and hemispheric power indices, as well as auroral electron flux and electric field observations. The results are used to investigate the electrodynamic impact of an accurate description of the diffuse aurora on the M-I system.

## Introduction

- Diffuse aurora provides an important source for conductance in the ionosphere, which regulates the electric fields both locally and those which map back to the magnetosphere
- The rate of electron loss in the ring current due to pitch angle diffusion from whistler and chorus waves is still relatively poorly constrained, leading to a poor description of the diffuse aurora in coupled models
- The electron scattering rate is known to be dependent on L-shell, with stronger scattering towards the tail and weaker scattering near the Earth

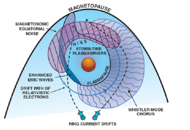
## Purpose

- This study investigates the impacts of electron scattering rate on the ring current-ionosphere electrodynamic system
- Four moderate storms (DST ~ -100 nT) were modeled, 2 of which are CME's and 2 are CIR's
- 4 different weak diffusion limits were imposed to control the maximum lifetime of ring current electrons. These are 2, 4, and 8 hours, as well as an energy dependent relationship

## Model Description

We employ the hot electron and ion drift integrator (HEIDI) [Liemohn et al., 2001a]

- Solves time-dependent, gyration, bounce averaged kinetic equation for $H^+$, $O^+$, and $e^-$ species
- Includes convective and magnetic drift, losses due to Coulomb collisions, charge exchange and atmospheric precipitation
- Electron scattering rates from Chen et al., [2005] are included with an imposed maximum loss rate (Tau_max) within L = 4.5



- Conductances are calculated using the Robinson et al., [1987] formula from the average energy and electron flux

$$\Sigma_P = \frac{40\overline{E}}{16+\overline{E}^2}\Phi_E^{1/2}$$

$$\frac{\Sigma_H}{\Sigma_P} = 0.45\left(\overline{E}\right)^{0.85}$$

- These are used with field aligned currents to calculate the electric potentials

$$\nabla \cdot (-\overline{\Sigma}\phi) = J_{\parallel} \sin I$$

- OVATION SME aurora is used during times when the auroral oval is outside the HEIDI boundary

## New Electrodynamic System

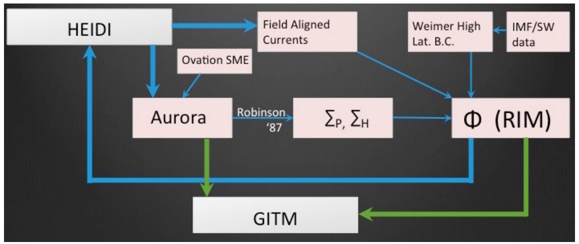


*Figure 1 – Overview of the new self-consistent aurora within HEIDI, as well as the coupling with GITM*

## DST and Hemispheric Power Results

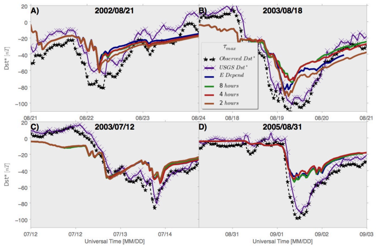


*Figure 2 – DST for each Tau max plotted with the Kyoto DST* in black and USGS DST* in purple. DST* is the ring current contribution to the DST index.*

- The model consistently over-estimates DST*, but agrees very well with the timings
- Electron scattering rate has a positive correlation with storm intensity
- The difference in DST* between simulations is larger when the response to the storm is greater

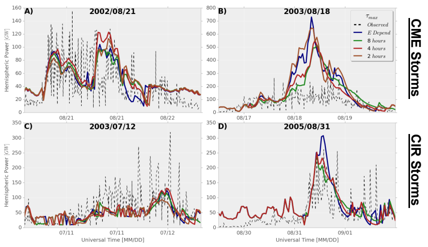


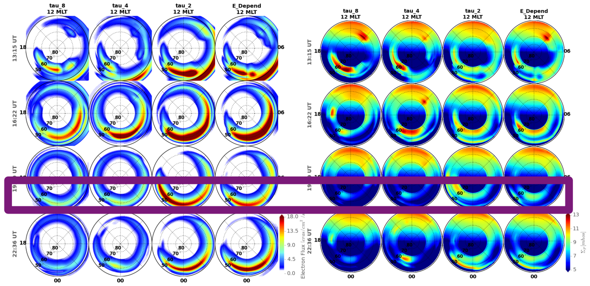
*Figure 3 – Hemispheric power for each Tau (colored lines) against NOAA POES (dotted black line).*

- Electron scattering rate has a positive correlation with storm intensity
- Hemispheric power is likely artificially low due to absence of polar rain, cusp precipitation, and discrete auroral arcs in HEIDI
- Simulations converge during quiet times when empirical models are used

## Electron Loss & Electrodynamics

### Electron Flux

### Pedersen Conductance



### Electric Potential

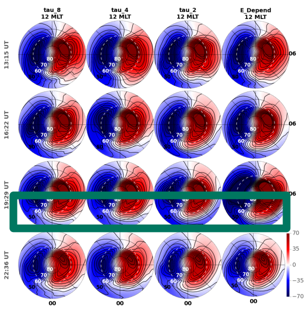


*Figure 4 – For each Tau_max - HEIDI electron energy flux (left) , Pedersen Conductance (right), and electric potential (bottom) for the August 18th, 2003 storm.*

- The description of Tau_max controls how many electrons are lost in the premidnight sector, and how many make it to, or past the dayside
- This leads to significant changes in Pedersen conductance, the gradient of which is greatest on the nightside
- Subsequently, the nightside electric fields are stronger for smaller tau_max's
- Though times exist where the conductance on the dayside exceeds the background (first and second rows), this was the only event in which that occurred

## GUVI and DMSP Comparison

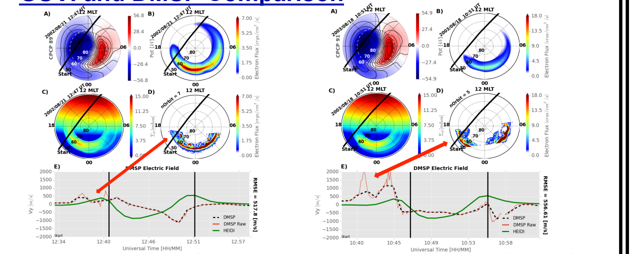


*Figure 5 – HEIDI potentials, electron flux, and Pedersen conductance in plots A-C. Plot D is the GUVI aurora for the orbit closest to the DMSP flyby time. The black line on each plot is the DMSP F15 orbit path. Plot E shows the DMSP cross-track plasma velocity in the dashed and red lines, as well as the HEIDI value calculated interpolated to those times and locations. The vertical black bars in plot E and white dashed line in plot A signify the outer boundary of HEIDI where self-consistent calculations give way to empirical models. The left Figure is from the August 2002 event and the right is from August 2003.*

- Location matters! The plots demonstrate how drastic the cross-track plasma velocity can be off if the aurora is not in the correct place or has a different magnitude
- When the nominal dayside conductance supercedes auroral conductance, the additional electrons on the dayside are insignificant to the electric fields. This suggests a strong seasonal effect may be possible
- Discrete auroral arcs are very important drivers of conductivity gradients and subsequent electric fields. They should be included in future models

## GUVI Location and Strength Comparison

### Tau_max = 8 hrs

### Tau_max = 2 hrs

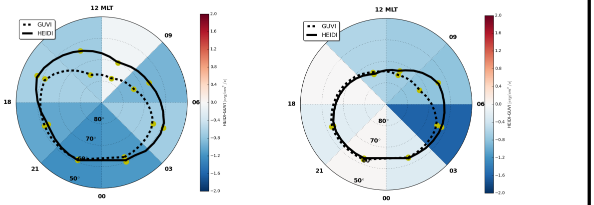


*Figure 6 – An aggregate comparison of the GUVI aurora and location compared to HEIDI simulations for all storms. The left plot shows tau_max of 8 hours, the right for 2 hours. The colors shows the difference between the average HEIDI and GUVI electron flux in each MLT sector. The yellow dots are the average locations of the aurora for all times. The dashed and solid lines are a first order spline interpolation of the GUVI and HEIDI auroral locations respectively.*

- When Tau_max is larger, electrons persist longer in the ring current and are lost more equatorward and towards the dayside
- The magnitude of the electron flux from 18-03 MLT, and the location of the aurora from 00-15 MLT is much closer to observed values for smaller tau_max

## Conclusions

- Small adjustments in electron scattering rates in the ring current have a profound effect on the agreement between the ring current model and the observed aurora
- A limit on the weak scattering rate (tau_max) of 2 hours was found to generate the best agreement
- Times when the aurora fit well with observations are much more likely to produce realistic ionospheric electric fields, which then map back to the magnetosphere

## References

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**Contact:**
nperlong@umich.edu