MI coupling impact of superthermal electrons on diffuse aurora precipitation and ionospheric conductance: Missing piece in the global MHD models

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MI coupling processes in diffuse aurora regions

Khazanov et al. [2015]
\[ \beta \frac{\partial \phi}{\partial t} + \mu \frac{\partial \phi}{\partial s} - \frac{1 - \mu^2}{2} \left( \frac{1}{B} \frac{\partial B}{\partial s} - \frac{F}{E} \right) \frac{\partial \phi}{\partial \mu} + EF \mu \frac{\partial}{\partial E} \left( \frac{\phi}{E} \right) = Q + \bar{S} \]

\[ \bar{S} = \langle S_{ee} \rangle + \langle S_{ei} \rangle + \langle S_{en}^* \rangle + \langle S_{en}^+ \rangle + \langle S_{ew} \rangle \]
Auroral spectra at 800 km altitude

The MI coupling dynamics produces stronger auroral flux and stronger ionospheric conductivity.

Reproduced from Khazanov et al. [2015]
MI coupling impact on ionospheric conductance for various initial auroral spectra

We input 6 initial auroral spectra to STET:
1. Maxwellian distribution
2. Total auroral energy flux at 1 mW/m²
3. 6 auroral char. energies (400eV – 5keV)

The MI coupling processes can increase the height-integrated conductance up to 35 – 70%.

MI coupling impact can be significant during geomagnetic storm when the total auroral energy flux can go over 50 mW/m².
The MI coupling dynamics of superthermal electrons can be the physics mechanism to solve the CPCP problem by increasing ionospheric conductance.
Summary

- We examine magnetosphere – ionosphere energy interchange in the diffuse aurora region using SuperThermal electron transport code.

- Our study showed that the MI coupling processes of superthermal electrons produce stronger auroral precipitation and increase height-integrated conductance up to 35 – 70%.

- Note that we introduce 1mW/m² of total aurora flux. Geomagnetic events can produce over 50mW/m² of total auroral flux, indicating more significant MI coupling impact during storm times.

- The MI energy interchange of superthermal electrons can solve a strong transpolar cap potential problem of the global MHD models by increasing ionospheric conductance and thus decreasing the ionospheric electric potentials via a current continuity equation.
The MI coupling dynamics of superthermal electrons can be a physics-based reason to increase ionospheric conductance and thus solve the CPCP problem.
Parameterization of the MI coupling impact on the ionospheric conductance

- We investigate the MI coupling impact of superthermal electrons on the height-integrated ionospheric conductance as a function of the auroral characteristic energies ($E_0$).

- The following input conditions are introduced to a STET code.
  1. Isotropic Maxwellian energy distribution of auroral electrons.
  2. 1 mW/m$^2$ of total energy flux ($Q_0$) at 800km altitude
  3. 6 different characteristic energies ($E_0 = 400eV – 5keV$)

- We conduct 12 simulations by turning on and off the MI coupling effect inside a STEP code.
MI coupling impact for various auroral characteristic energies \((E_0)\)

The MI coupling dynamics of superthermal electrons in the diffuse auroral regions produces stronger auroral energy flux and thus increases ionospheric conductivity throughout the whole altitude.
References


**Methodology**

1. **Energy distribution of precipitating electrons**
   Robinson [1987] assumed Maxwellian distribution:
   \[
   \phi(E) = \frac{Q_0}{2E_0} E \exp\left(-\frac{E}{E_0}\right)
   \]
   where \(Q_0\): Total energy flux [keV cm\(^2\) s\(^{-1}\)], \(E_0\): Characteristic energy [keV]

2. **Ionization rate calculation**
   \[q_{tot} = \frac{Q_0}{2\Delta \varepsilon} \frac{1}{H} f\]
   where \(\Delta \varepsilon\): Mean energy loss per ion pair production (0.0035 keV)
   \(H\): Scale height [cm]
   \(f\): Energy deposition function from Fang et al. [2010]

Fang et al. [2010] parameterize the energy deposition function based on sophisticated first principal models, providing more accurate calculation for any incident auroral energies between 100 eV – 1 MeV, while Robinson et al. [1987] used the energy deposition function from Rees [1963] that is applicable for 5 – 54 keV auroral energies.

3. **Electron density calculation**
   Robinson [1987] assumed steady state conditions and neglected transport. Then, the electron continuity equation becomes:
   \[
   \frac{\partial n}{\partial t} = q - \alpha n^2 + \nabla \cdot (n \mathbf{V})
   \]
   \[\rightarrow\]
   \[n = \frac{q}{\sqrt{\alpha}}\]
   where \(n\): electron density [cm\(^{-3}\)], \(q\): ionization rate [cm\(^3\) s\(^{-1}\)],
   \(\mathbf{V}\): ionospheric plasma velocity
   \(\alpha = 2.5 \times 10^{-6} e^{-\frac{H}{51.2}}\): effective recombination coefficient [cm\(^3\) s\(^{-1}\)]

4. **Ionospheric conductance calculation**
   Robinson [1987] neglected electron-neutral collisions. Then, Pederson and Hall conductivities are:
   \[\sigma_p = (ne/B)[\Omega_i, \nu_i/(\Omega_i^2 + \nu_i^2)]\]
   \[\sigma_h = (ne/B)[\nu_i^2/(\Omega_i^2 + \nu_i^2)]\]
   where \(n\): electron density, \(e\): electrical charge, \(B\): magnetic field strength,
   \(\Omega_i = eB/m_n\): ion gyrofrequency,
   \(\nu_i [s^{-1}] = 3.75 \times 10^{-10} n_n [cm^{-3}]\): ion-neutral collision frequency
   \(m_n\): mean molecular weight, \(n_n\): total neutral number density


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**Appendix:**

**Ionospheric Conductance Calculation Details**

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