A Coupled Ionosphere-Raytrace Model for High Power HF Heating

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Does the HF Heating Location Change?

- HF radio waves refract in the presence of horizontal electron density gradients.
- Observations from an Arecibo experiment indicate that the zonal neutral wind can change the location of HF heating.
• photoionization
• full chemistry (21 reactions and recombination)
• ion inertia parallel to B
• ExB drifts (vertical and longitudinal)
• Solves the ion continuity, momentum and temperature equations (H\(^+\), He\(^+\), N\(^+\), O\(^+\), N\(_2\)^+, NO\(^+\), O\(_2\)^+)
• Solves the electron momentum and temperature equations

• nonorthogonal, nonuniform fixed grid
• 3D, but limited to 4° longitude (4 km longitudinal resolution)
HF Heating Model in SAMI3

- **Electron Temperature Equation**

\[
\frac{\partial T_e}{\partial t} - \frac{2}{3} \frac{1}{n_e k} b_s^2 \frac{\partial}{\partial s} \kappa_e \frac{\partial T_e}{\partial s} = Q_{en} + Q_{ei} + Q_{phe} + Q_{source}
\]

- **Source Term**

\[
Q_{source} = \left(\frac{dT_e}{dt}\right)_0 \exp\left[-\left(z - z_0\right)^2 / \Delta z^2\right] \exp\left[-\left(\theta - \theta_0\right)^2 / \Delta \theta^2\right] \exp\left[-\left(\varphi - \varphi_0\right)^2 / \Delta \varphi^2\right]
\]
Density Depletion Drifts with the Zonal Wind
1. SAMI3 calculates the electron density (including HF heating) from first principles
2. MoJo uses the electron density to determine the new path of the heater beam
3. SAMI3 uses the HF propagation path to determine a new location for HF heating
The Snapback Effect: Observations and Simulations

Simulation with 60 m/s zonal wind
Original Snapback Theory

60 m/s zonal wind
Physical Mechanism for Snapback Effect

60 m/s zonal wind

Altitude (km)

Longitude (degrees)
Effect of Zonal Wind Speed on Heating Location

- 40 m/s, 4.2 MHz
- 60 m/s, 4.4 MHz
- 80 m/s, 4.5 MHz

LT Hour

Heating Longitude
Effect of Heating Rate/Frequency on Heating Location

- 2000 K/s
- 1000 K/s
- 500 K/s

- 4.5 MHz
- 4.4 MHz
- 4.3 MHz
Summary

• The location of HF heating can change as a function of time
• The coupled model successfully simulates the result of the 1988 Bernhardt experiment
• The heating region snaps back, not the ray as originally expected
• The frequency of snapback increases as a function of zonal wind speed
• To suppress the snapback effect one can lower the heating rate and/or the heating frequency