Thermospheric Wind Impacts on Ionospheric Upflow and Outflow
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Introduction

- Thermospheric winds can arise from solar forcing, plasma convection, gravity waves, etc. 
- These neutral winds interact with the ionospheric plasma, through collisions, driving upflow or perpendicular motion.
- Other ion upflow drivers, such as electric potentials and auroral precipitation, may also be present.
- Ions may then undergo further acceleration from transverse heating.
- At high altitudes the mirror force propels the ions to escape velocities, resulting in outflow to the magnetosphere.

Modeling the Ionosphere

The 2D multi-fluid ionospheric model developed here is based on a modified 16-moment transport description of the evolution of mass, momentum, parallel and perpendicular energy. The main equations are:

\[
\begin{align*}
\frac{\partial p_i}{\partial t} + \mathbf{v} \cdot \left( p_i \mathbf{u}_i \right) &= -\frac{\partial E_i}{\partial x} + \frac{\partial \left( \rho_i u_i E_i \right)}{\partial x} + \frac{1}{2} \left( \frac{\partial \left( p_i u_i v^2 \right)}{\partial x} + \frac{\partial \left( p_i u_i v^2 \right)}{\partial y} \right) \\
\frac{\partial \rho_i}{\partial t} + \mathbf{v} \cdot \left( \rho_i \mathbf{u}_i \right) &= -\frac{\partial \left( \rho_i u_i \mathbf{u}_i \right)}{\partial x} + \rho_i \mathbf{u}_i \mathbf{u}_j \cdot \nabla \mathbf{u}_j + \frac{\partial \left( \rho_i u_i \mathbf{E}_i \right)}{\partial x} + \frac{1}{2} \left( \frac{\partial \left( \rho_i u_i v^2 \right)}{\partial x} + \frac{\partial \left( \rho_i u_i v^2 \right)}{\partial y} \right) \\
\frac{\partial E_i}{\partial t} + \mathbf{v} \cdot \left( E_i \mathbf{u}_i \right) &= -\frac{\partial \left( E_i u_i \mathbf{u}_i \right)}{\partial x} + \frac{\partial \left( E_i u_i \mathbf{E}_i \right)}{\partial x} + \rho_i \mathbf{u}_i \mathbf{u}_j \cdot \nabla \mathbf{u}_j + \frac{\partial \left( \rho_i u_i \nabla E_i \right)}{\partial x} + \frac{1}{2} \left( \frac{\partial \left( \rho_i u_i v^2 \right)}{\partial x} + \frac{\partial \left( \rho_i u_i v^2 \right)}{\partial y} \right)
\end{align*}
\]

For the momentum equations above, the main terms are:

\[
\begin{align*}
\frac{\partial \mathbf{v}}{\partial t} &= -\nabla \mathbf{p} + \nabla \cdot \left( \rho \mathbf{u} \right) + \frac{\partial \left( \rho \mathbf{u} \mathbf{u} \right)}{\partial x} - \frac{1}{2} \left( \frac{\partial \left( \rho \mathbf{u} \mathbf{u} \right)}{\partial x} + \frac{\partial \left( \rho \mathbf{u} \mathbf{u} \right)}{\partial y} \right) \\
\frac{\partial \rho \mathbf{u}}{\partial t} &= -\nabla \cdot \left( \rho \mathbf{u} \mathbf{u} \right) + \frac{\partial \left( \rho \mathbf{u} \mathbf{u} \right)}{\partial x} - \frac{1}{2} \left( \frac{\partial \left( \rho \mathbf{u} \mathbf{u} \right)}{\partial x} + \frac{\partial \left( \rho \mathbf{u} \mathbf{u} \right)}{\partial y} \right)
\end{align*}
\]

Thermospheric Wind Impacts

Left: 50 m/s neutral winds parallel to the field lines coupled with transverse heating and an applied 50 mV/m electric potential. Large neutral winds along the geomagnetic field lift the F-region density peak. Both field aligned neutral winds and frictional heating upflows increase ion densities at higher altitudes feeding source populations for transverse heating. The more ions that are available at higher altitudes, the larger the net effect of the transverse heating.

Right: 100 m/s neutral wind perpendicular to the magnetic field lines with transverse heating and an applied 90 mV/m electric potential. This direction of neutral winds increases the frictional heating of ions from fast convection through the neutral atmosphere creating pressure-driven ion upflows. This upflow also feeds source populations for transverse heating resulting in outflow.

Conclusions & Future Work

- Anisotropic multi-fluid models can capture important features of ionospheric upflow and outflow.
- Neutral wind can play a significant role in ion upflow individually or by combining with other upflow mechanisms and enhancing flux rates. There was a 50% increase of O\(^+\) flux when 50 m/s field aligned neutral winds were added to a 50 mV/m electric potential and transverse heating. A 10% increase in O\(^+\) flux was seen, centered around the leading edge of the propagating disturbance, when 100 m/s perpendicular winds were added to an applied 90 mV/m electric potential and transverse heating.
- The choice of heat flux and stress 'equations of state' greatly impact the results. Work is currently being done to quantify these values so that features of observed ion outflows can be correctly and efficiently recreated. One future goal is to use this model to reproduce observations that contains low altitude wave heating.

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