# Ion Upflow Dependence on Ionospheric Density and Solar Photoionization

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## Introduction

Ion outflow plays an important role in magnetospheric physics, since the addition of ionospheric plasma (particularly $O^+$) into the tail can alter the reconnection rate and affect a range of magnetospheric processes. Furthermore, *Lessard et al.* [2015] showed that EMIC wave frequencies depend on heavy ions and exhibit a solar cycle dependence.

This broadly termed "ion outflow" of light thermal ions ($H^+$, $He^+$) and light and heavy energized ions ($H^+$, $He^+$, $O^+$, $N^+$, $NO^+$, $O_2^+$ , $N_2^+$) can be attributed to multiple processes occurring in the polar and auroral ionosphere (e.g. classical polar wind, photoelectrons, cusp ion beams and conics, polar rain, etc.); these include both bulk flows affecting the full ion distribution and flows where only portions of the distribution are energized.

With the exception of $H^+$, these ions require a secondary energization source to achieve escape velocity. This creates the distinction between *"ion upflow"* processes, which initially move ions to higher altitudes, and secondary *"ion outflow"* processes that provide sufficient energy for the ions to escape Earth's gravity.

*Wahlund et al.* [1992] first separated TUI into two types: thermal plasma upflows (Type-1) and upflow due to enhanced field-aligned electric fields (Type-2).

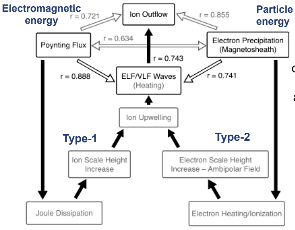


**Figure 1**. From *Strangeway et al.* [2005], this figure breaks down the two types of ion upflow based on the flow of energy. It also underscores the secondary processes (here WPI) that are necessary to achieve escape velocities, hence differentiating ion upflow from ion outflow.

Type-2 upflow is believed to result from a vertical ambipolar field created by the deposition of energy from soft electron precipitation. Simply, precipitating electrons heat ionospheric electrons and create electron pressure gradients that establish the field-aligned ambipolar electric field, which accelerates ions and generates upflow.

## Model Description

The single field line ionosphere/polar wind model introduced by *Varney et al*. [2014] solves the dynamics of thermal ions, thermal electrons, and suprathermal electrons on a single open field line between 97 and 6300 km altitude. To investigate the effect of ionospheric density on upflow, six simulations were run using initial density profiles with F-peaks ranging from $6.8\times10^{10}$ to $2.16\times10^{11}$ $m^{-3}$ (see Figure 2).

In all six simulations, the model was allowed to run for 48 hours starting at 09:00 UT on 17 February 2012 (near the launch of the MICA rocket) to establish "normal" ionospheric conditions over Poker Flat. The parameters established by that run at 05:48 UT on 19 February 2012 were then used as initial conditions for the runs presented here. Each run then introduced 360 seconds of constant Maxwellian precipitation with a characteristic energy of 1750 eV and a number flux of $2.6\times10^{12}$ $m^{-2}s^{-1}$ mapped to 6300 km altitude.

## Model Results

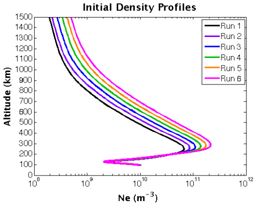
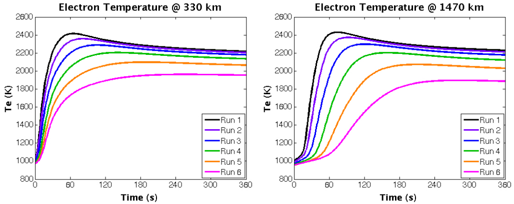
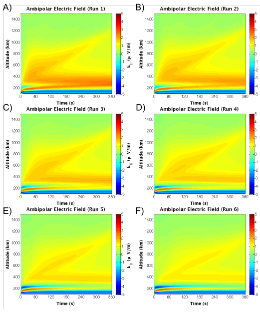


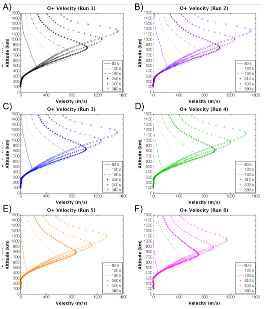
**Figure 2.** Initial ionospheric density profiles for the six simulation runs.



**Figures 3 & 4.** Simulation results of the electron temperature evolution during the period of precipitation at 300 and 1470 km, respectively. The colors correspond to the runs of varying ionospheric density, as shown in Figure 2.

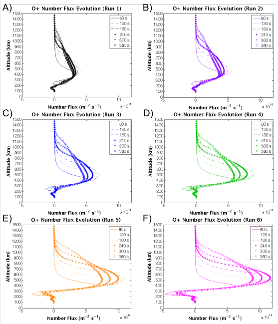
The simulation was able to generate realistic upflows in response to the precipitation, with all of the characteristics indicative of Type-2. Most importantly it generated enhanced electron temperatures (see Figures 3 & 4). Although much heating was not seen at very high altitudes, two effects of enhanced ionospheric density were apparent: decreased electron temperatures and longer heating timescales.





**Figures 5** (left) shows simulation results of the strength of the field-aligned ambipolar electric field versus altitude over time during the precipitation. It clearly shows that the field weakens in runs with higher ionospheric density. **Figure 6** (right) shows the evolution of the O+ upflow velocity at 1 minute intervals during the precipitation period. The colors correspond to initial ionospheric density profiles shown in Figure 2.

The simulations also showed that enhanced ionospheric density decreases the strength of the field-aligned ambipolar electric field, which plays an important role in the acceleration of ions in the Type-2 upflow process. Subsequently, the weakened ambipolar field results in lower upflow velocities in runs with higher ionospheric density.

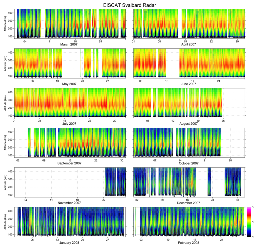


However, despite the weakened ambipolar field and lower upflow velocities, the simulations still show enhanced ion fluxes in runs with enhanced ionospheric density (Figure 7). This is most likely due to the fact that there are more ions present to be accelerated.

**Figure 7** (left) shows the evolution of the O+ upflow flux at 1 minute intervals during the precipitation period. The colors correspond to the initial ionospheric density profiles shown in Figure 2.

## The Role of Solar Photoionization

The simulations suggest that ionospheric density plays an important role in ion upflow. So what affects ionospheric density? *Solar photoionization!*



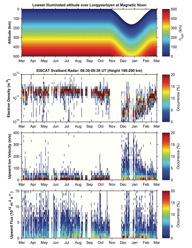


**Figure 8** (left) shows data taken from the EISCAT Svalbard radar during the International Polar Year (IPY). It clearly shows the seasonal increase (an order of magnitude) in ionospheric density during the summer months. **Figure 9** (right) shows IPY data supporting the results of the simulations presented here. The observations clearly show decreased upflow velocities and increased fluxes during the summer months when electron density is enhanced due to solar photoionization.

## Conclusions

A new simulation based on the model of *Varney et al*. [2014] was run for six cases with peak ionospheric density varying from $6.8\times10^{10}$ to $2.16\times10^{11}$ $m^{-3}$.

The simulation results generated realistic ion upflows in response to the auroral precipitation, generating electron temperatures in good agreement with rocket observations at F region altitudes (300 km).

The simulations demonstrate that enhanced ionospheric density yields:

- Lower ionospheric $T_e$
- Longer heating timescales
- Weaker ambipolar electric field
- Lower ion upflow velocities
- Longer upflow timescales
- Larger ion upflow fluxes

New EISCAT data from the International Polar Year (IPY) clearly shows the seasonal effect of solar UV ionization on ionospheric density, with observations that support the simulation results

Previous studies (observationally)
i.e. *Ogawa et al.* [2011], *Yau et al.* [1985]

Summer ➔ Increased upflows

New understanding from this study

Summer ➔ Increased photoionization from solar UV ➔ Increased ionospheric density ➔ Increased upflows

### References

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