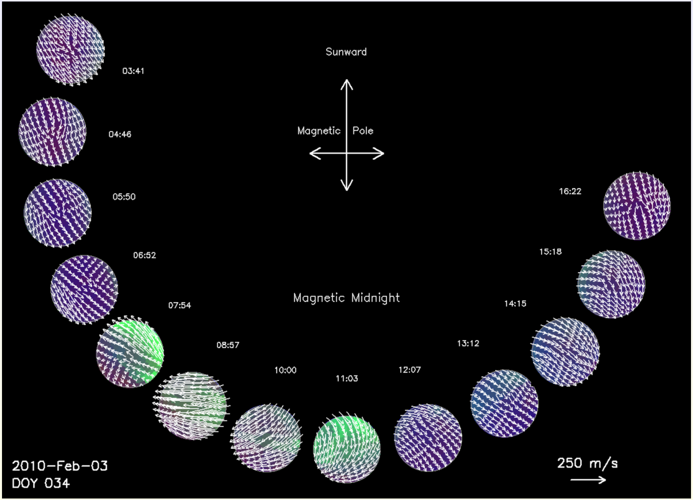
Observations of Ion-Neutral Coupling in the Auroral Thermosphere Above Poker Flat, Alaska

M. G. Conde and D. L. Hampton[1], M. Nicolls[2]



[1]Geophysical Institute, University of Alaska Fairbanks
[2]SRI International, Menlo Park, California, USA

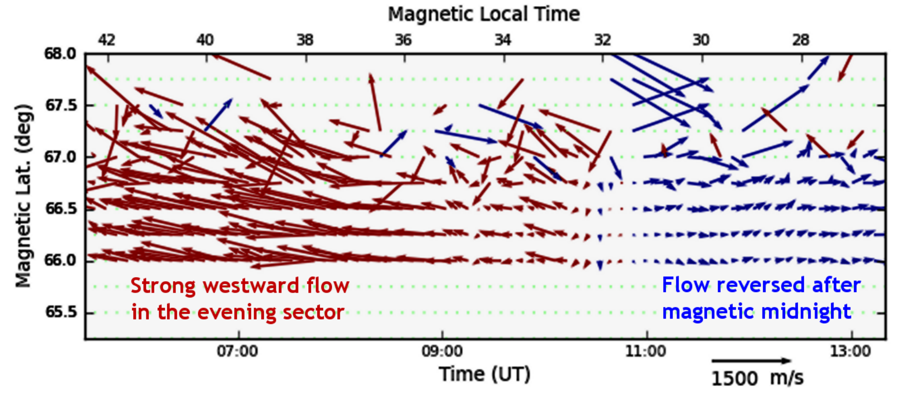
Outline

In this talk, I will describe how the PFISR radar and the Poker Flat all-sky imaging Fabry-Perot spectrometer can be used together to study energy and momentum coupling between thermospheric ions and neutrals.

The main topics that I will present are:

- A description of the imaging Fabry-Perot spectrometer and the data it produces.
- A comparison of the zonal components of the neutral and ion drift velocities at F-region heights.
- Movies showing how the neutral and velocity vectors relate to the background aurora.
- Estimates of Joule heating and ion drag forcing derived from the combined PFISR and all-sky FPS data.
- An example of how 558 nm Doppler temperatures can be used to indicate characteristic energy of the auroral precipitation.

Ion Velocities on Jan 24, 2010



Question :

PFISR routinely observes *westward ion drifts* in the evening local time sector

- How does the neutral wind field respond to these ion drifts?

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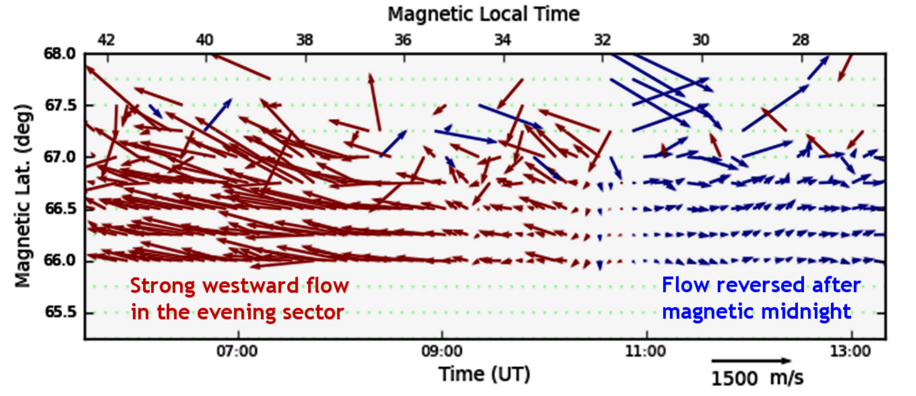


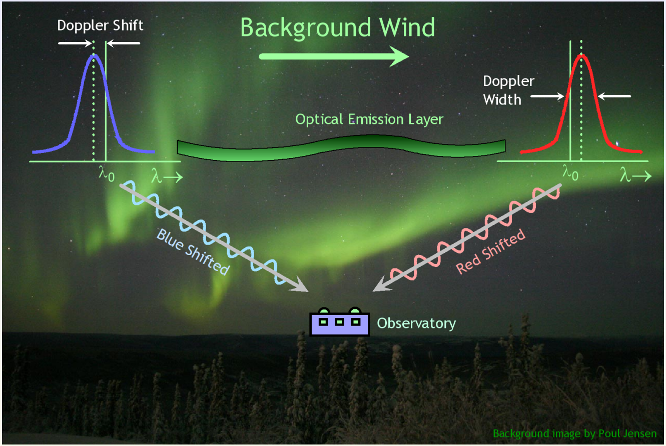
Question :

PFISR routinely observes *westward ion drifts* in the evening local time sector

- How does the neutral wind field respond to these ion drifts?

We are using data from PFISR and from the Poker Flat all-sky Fabry-Perot spectrometer to study this question.

Passive Doppler Wind Measurement



Airglow or auroral photons appear *Doppler shifted* from the ground because they are emitted by atoms and molecules that move with the thermospheric wind.

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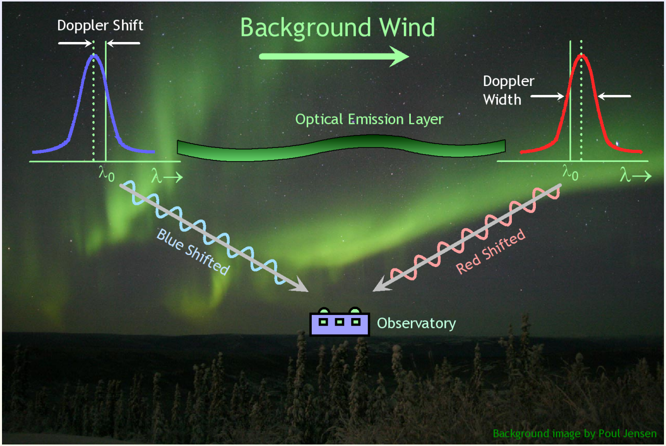

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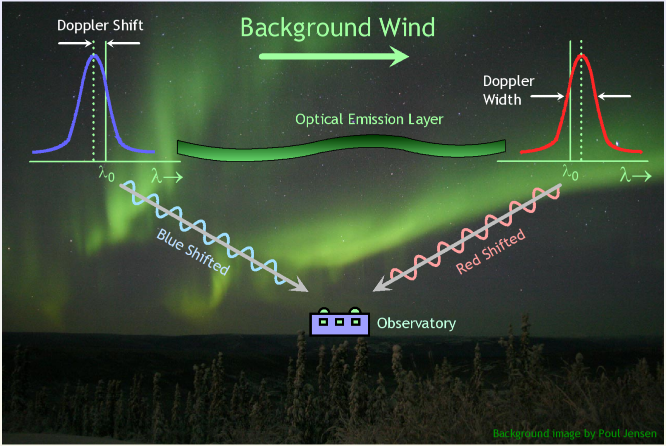

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- While the Doppler shift only measures the line-of-sight wind component, the complete wind vector can be estimated by viewing in several directions.[3]
- Further, temperatures may be inferred from the width of the Doppler spectrum.

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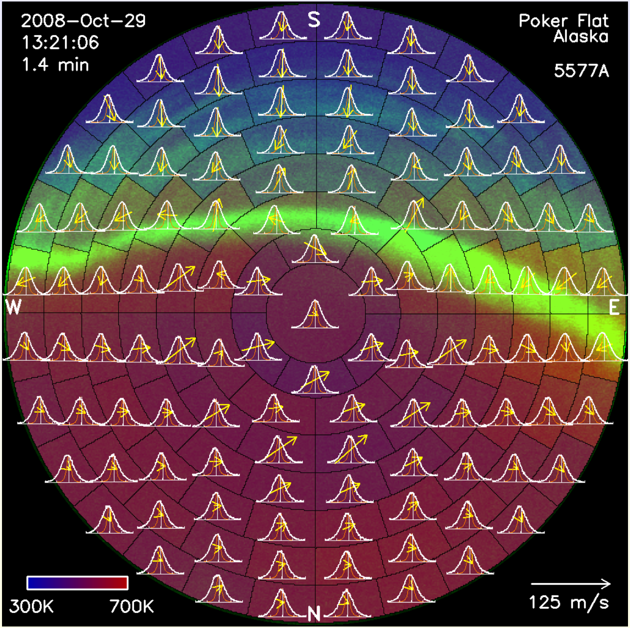
All-Sky Doppler Imaging



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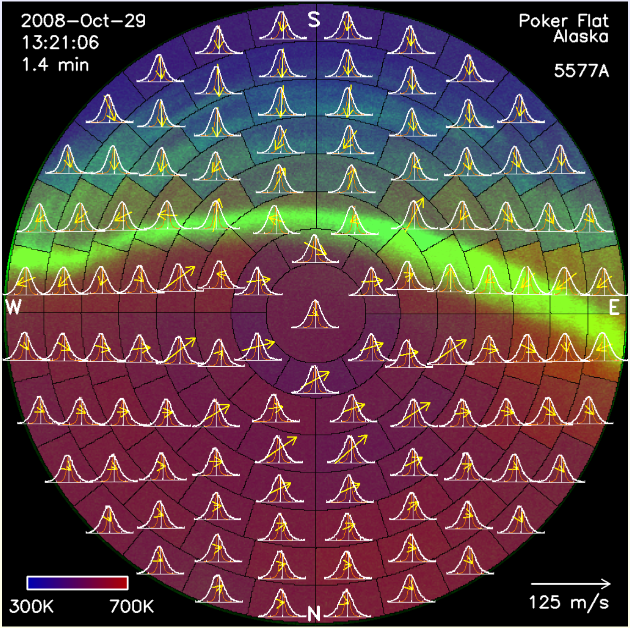

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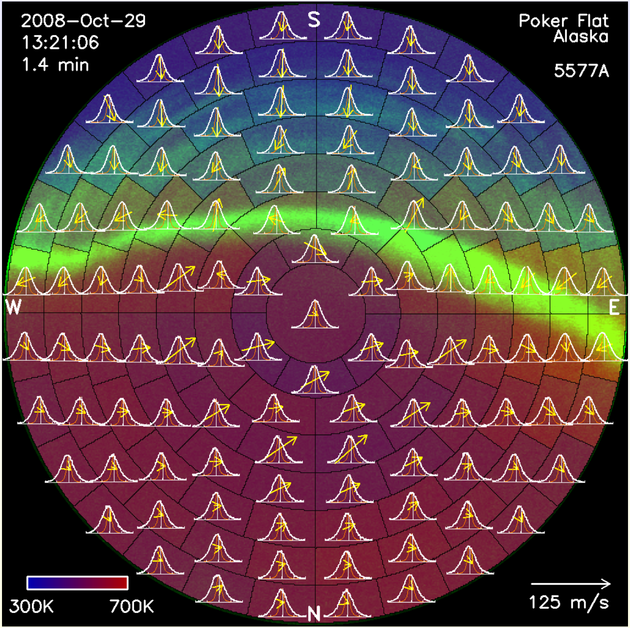

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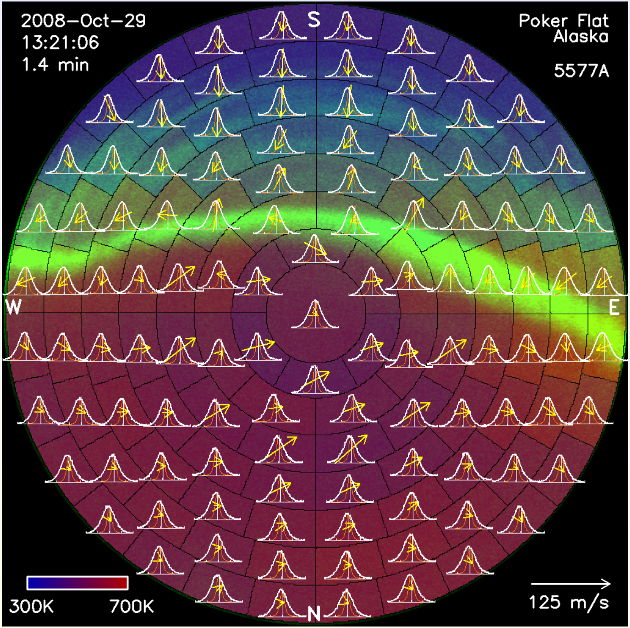

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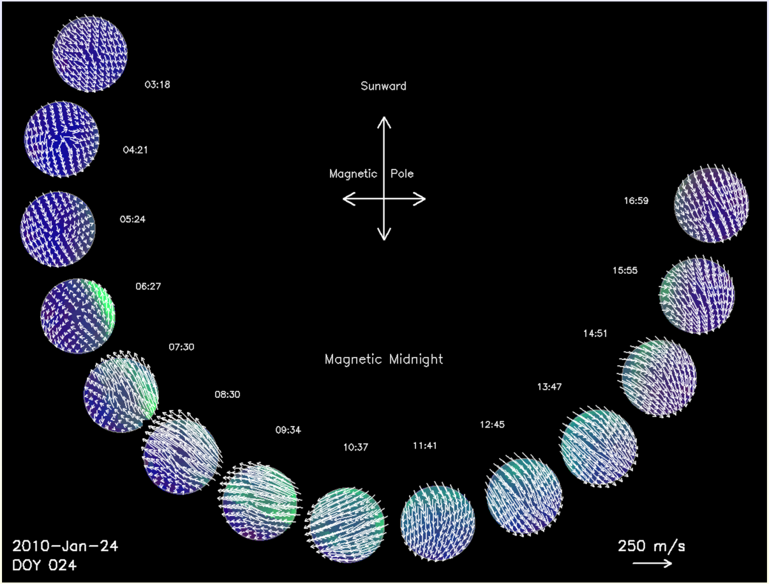
- Yellow arrows show the fitted horizontal wind field.

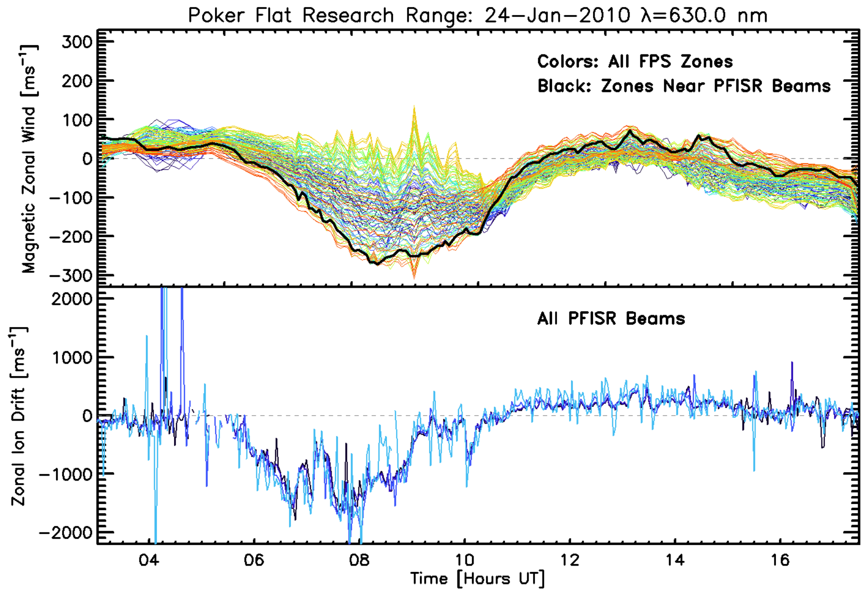
Neutral Winds on Jan 24, 2010



This figure shows neutral winds;[4] *Arrows pointing clockwise indicate westward flow.*

[4] At a degraded time resolution of ∼ 1hour. The true time resolution of the data is as short as a few minutes.

Ion and Neutral Zonal Velocity Components on Jan 24, 2010



Neutral Winds and Ion Convection on Feb 03, 2010

- The left panel shows PFISR convection (cyan arrows), FPS neutral winds (yellow arrows), digital all-sky camera images at $558\,\mathrm{nm}$ (green), and $630\,\mathrm{nm}$ images from the FPS (red).
- The right panel shows the wind summary (dial) plot for this night, together with an updating "time index" arrow.

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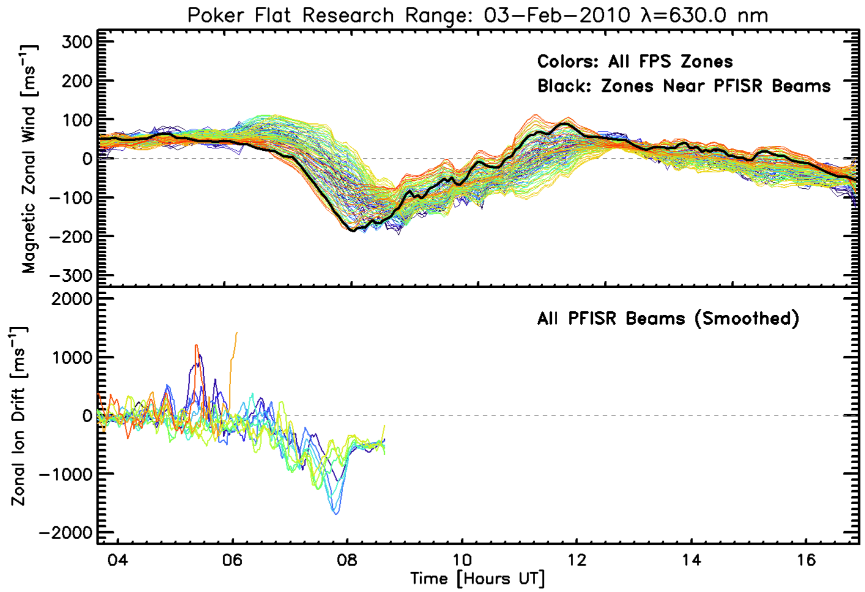

Neutral Winds and Ion Convection on Feb 03, 2010

- This movie is in the same format as the previous one (which was for Jan 24.)
- Note that *so far* I only have ion convection data for the early part of the night – but additional data is avaliable from later in this night, although it was recorded using a different radar mode.

Ion-Neutral Coupling: Ion Drag & Joule Heating

Joule Heating

The volumetric power density deposited at heat into the atmosphere by *Joule heating* may be calculated from

$$\frac{\partial Q_J}{\partial t} = \mu_{ni}\overline{v}_{ni}n_n\left(\overrightarrow{\mathbf{u}}_n - \overrightarrow{\mathbf{u}}_i\right)^2 \quad \left[\text{units of } \mathrm{W\,m^{-3}}\right]$$

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where
$$\begin{cases} n_n = \text{neutral number density} \\ \overrightarrow{\mathbf{u}}_n = \text{velocity vector of neutral bulk motion} \\ \overrightarrow{\mathbf{u}}_i = \text{velocity vector of ion bulk motion} \\ \overline{\nu}_{ni} = \text{mean frequency at which a neutral particle collides with ions} \\ \mu_{ni} = \text{ion/neutral reduced mass} = \frac{m_i m_n}{m_i + m_n} \end{cases}$$

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Ion Drag

The corresponding rate of acceleration of the neutral gas by *ion-neutral collisions* is

$$\vec{\mathbf{a}}_{\text{ion-drag}} = \overline{\nu}_{ni}\left(\vec{\mathbf{u}}_i - \vec{\mathbf{u}}_n\right) \tag{2}$$

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$$\overline{\nu}_{ni} \simeq n_i \times 3.42 \times 10^{-17}\,\mathrm{m}^3 \sqrt{\frac{T}{1\,\mathrm{K}}} \times \left[\begin{array}{c} 1.08 - 0.139 \log_{10} \frac{T}{1\,\mathrm{K}} \\ +4.51 \times 10^{-3} \left(\log_{10} \frac{T}{1\,\mathrm{K}}\right)^2 \end{array} \right] \mathrm{Hz} \qquad (3)$$

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Combining data from PFISR and the all-sky FPS provides almost all the key parameters needed to estimate the rates at which ion convection is depositing energy and momentum into the neutrals:[a]

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Ion Velocity: Obtained from PFISR.

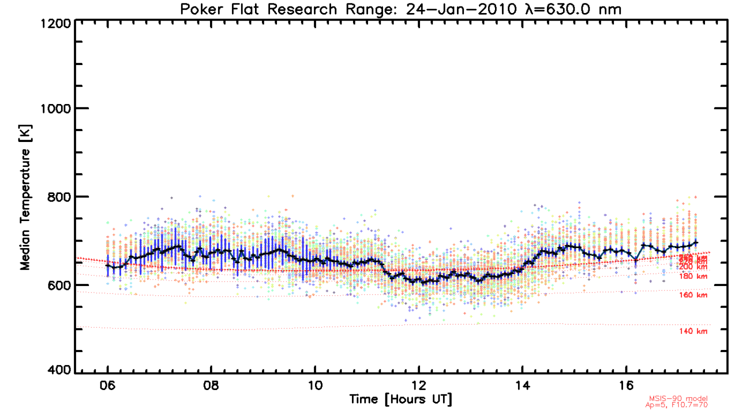
Neutral Velocity: Obtained from the all-sky FPS.

Temperature: Obtained from the all-sky FPS.

Electron Density: Obtained from PFISR.

[a] Neutral densities must still be obtained from MSIS.

Temperature Measurements



- To calculate $\overline{v}_{ni}$ we can use $630\,\mathrm{nm}$ Doppler temperatures *recorded by the all-sky FPS* . Small dots show *all individual temperature measurements*,[5] color-coded by viewing zone number.

[5] Excluding those rejected either because the signal/noise ratio of the original spectrum was too low, or the chi-squared value of the spectral fit was too high.

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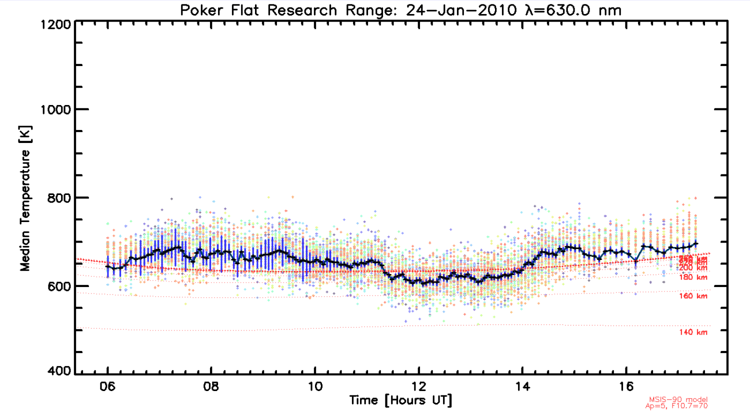

- To calculate $\overline{\nu}_{ni}$ we can use $630\,\mathrm{nm}$ Doppler temperatures *recorded by the all-sky FPS* . Small dots show *all individual temperature measurements*,[5] color-coded by viewing zone number.
- The heavy curves show the all-sky median temperature obtained from each successive exposure; error bars indicate the uncertainty in the mean.

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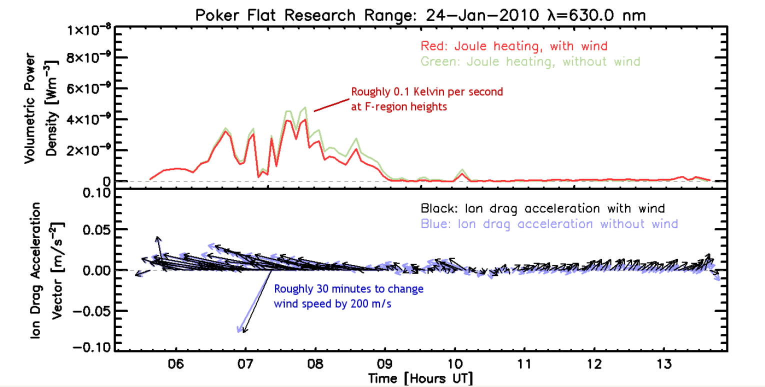
Ion Neutral Coupling



- This figure shows the result of using combined PFISR[6] and all-sky FPS data to estimate rates at which ion convection deposited energy and momentum deposition into the neutral atmosphere on the night of Jan 24, 2010.
- The fainter background data in each panel indicate the results that would be obtained by assuming zero neutral wind.

[6] Note that I did not have the PFISR electron densities in digital at the time I made this plot. So for illustration purposes I just approximated that $n_e \sim 10^{11}\,\mathrm{m}^{-3}$.

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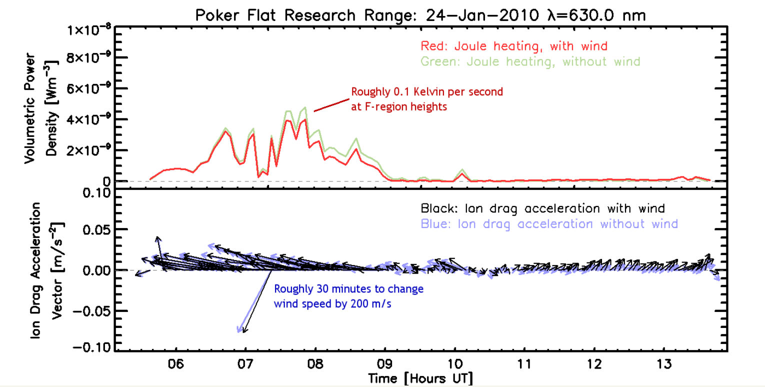

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- The fainter background data in each panel indicate the results that would be obtained by assuming zero neutral wind.
- Note that these data are for F-region heights (around $250\,\mathrm{km}$ altitude.)

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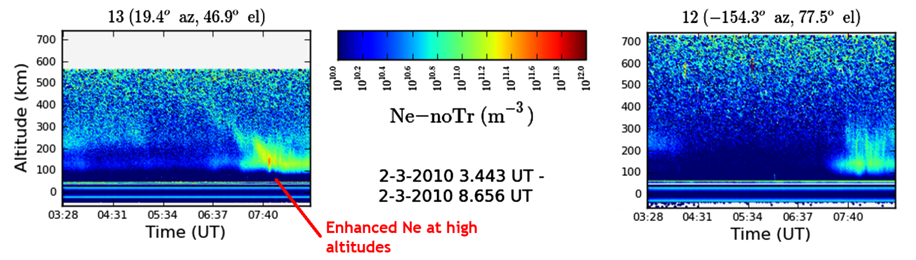
Electron Densities on Feb 03, 2010



- The Fabry-Perot has a filter wheel, and can execute arbitrary sequences of exposures through up to six different filters. Typically it alternates between 630 nm and 558 nm during full darkness.[7]

[7] The normal night time mode cycles repeatedly through the sequence "red, green, red, green, laser". During dusk and dawn twilights an alternate sequence is used: "sodium, sodium, laser".

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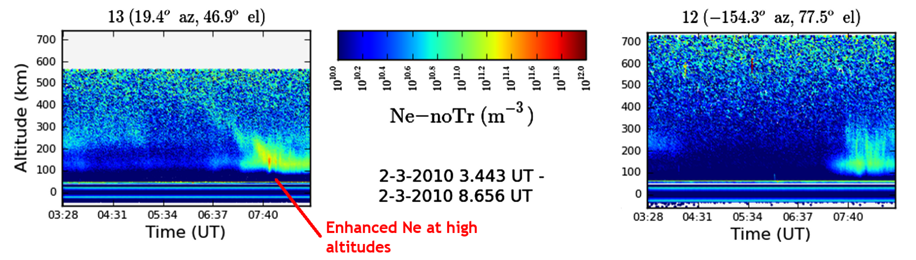

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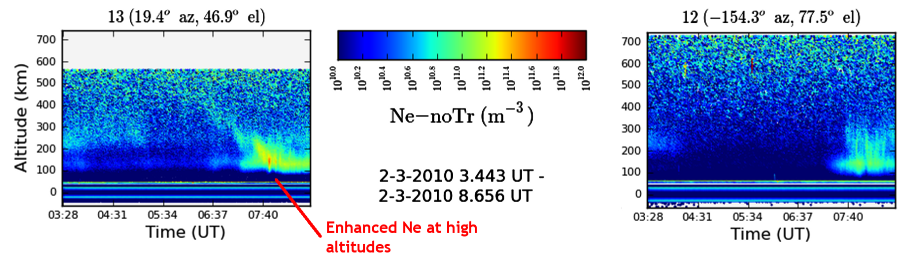

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- The 558 nm Doppler temperature data provide a useful proxy for the characteristic energy of auroral electons; high temperatures indicate low energies, and vica versa.
- Note the elevated electron densities that appear in the lower F-region at around 07:40 UT in the PFISR data shown here. Presumably this indicates soft precipitation, for which *we'd expect elevated 558nm Doppler temperatures.*

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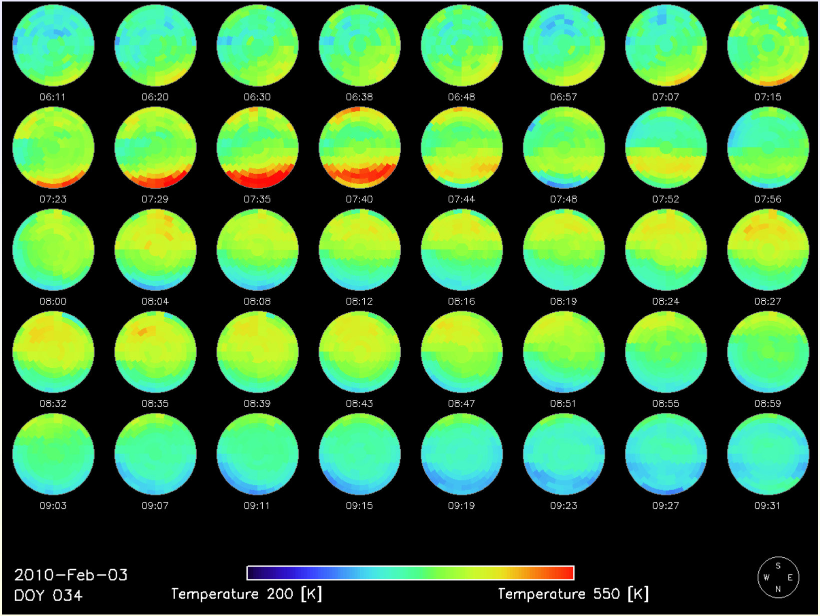
558 nm Doppler Temperatures on Feb 03, 2010



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- Comaprison with PFISR indicates that westward neutral flows (and their associated meridional shear) are due to momentum deposited in the neutrals by westward ion convection.
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I have only touched briefly on what is produced by the all sky FPS – *there are MANY more data products available:*

- Summary plots of each night's all-sky FPS data are freely available on the web, and may be browsed at:

  http://fulcrum.gi.alaska.edu/conde/sdi_arc.asp

- Multiple near-real-time plots are also available (with around 15 min latency) at:

  http://fulcrum.gi.alaska.edu/conde/pkr_realtime_sdi_plots.asp