E- and F-region Electric Fields, Conductivities, and Currents from PFISR

AMISR Summer School: Group 4

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Outline

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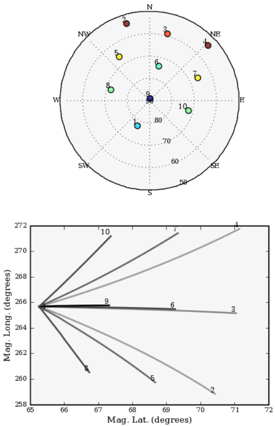
Experiment Goals

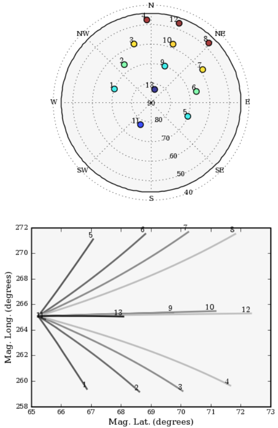
1. Measure the latitude and longitude variation of the F-region electric field and the E-region ion velocity.
2. Pulses: Combination of Long pulses and AC pulses, with a grid of 3 x 3 beams. One of the beams was pointed along B in order to get neutral winds.
3. Time of Experiment: This might be particularly interesting during auroral activity, so we requested 00 - 02 LDT or 8 - 10 UT.
4. Number of beams: 10

Beam Positions

Our Experiment:

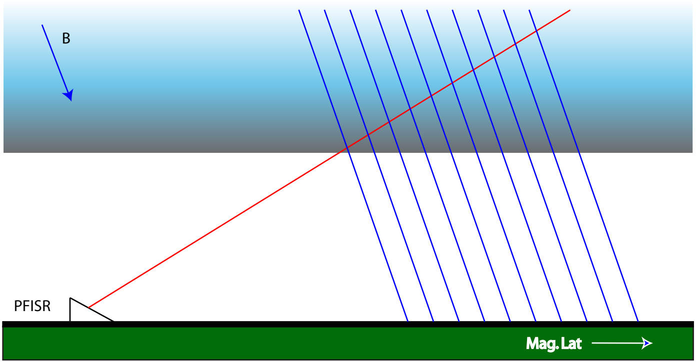


Lyons02 Experiment:



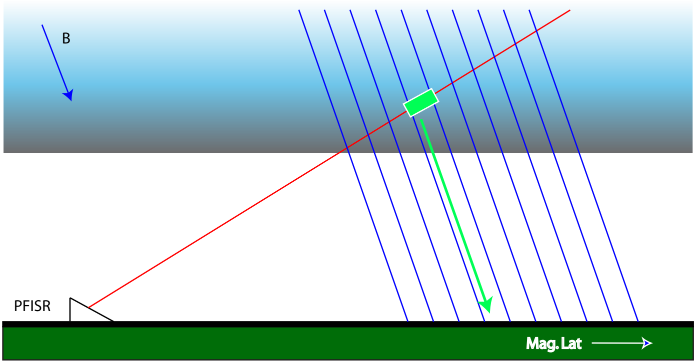
Velocities as a function of Latitude

Viewing from the East:



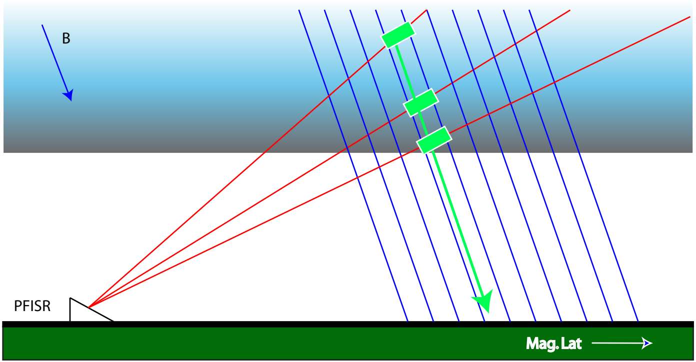
Velocities as a function of Latitude

Range bin corresponds to a latitude bin

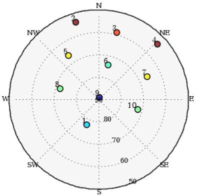


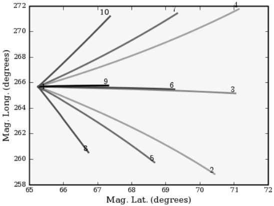
Velocities as a function of Latitude

Multiple beams give redundant measurements



Beam Positions Revisited





Extracting the Vector Velocities

$$v_{los}^i = k_x^i v_x + k_y^i v_y + k_z^i v_z = \mathbf{k}^i \cdot \mathbf{v}$$
$$\mathbf{k} = \hat{e}\cos\theta\sin\phi + \hat{n}\cos\theta\cos\phi + \hat{z}\sin\theta$$

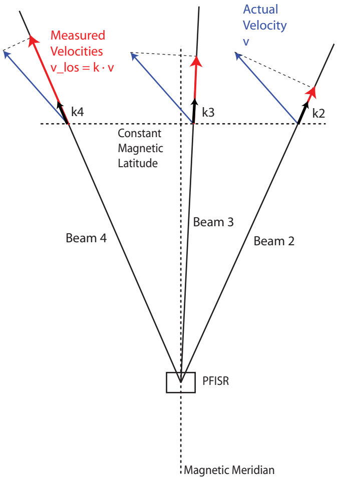
with two or more measurements:

$$v_{los}^i = \mathbf{k}^i \cdot \mathbf{v} + e_{los}^i$$

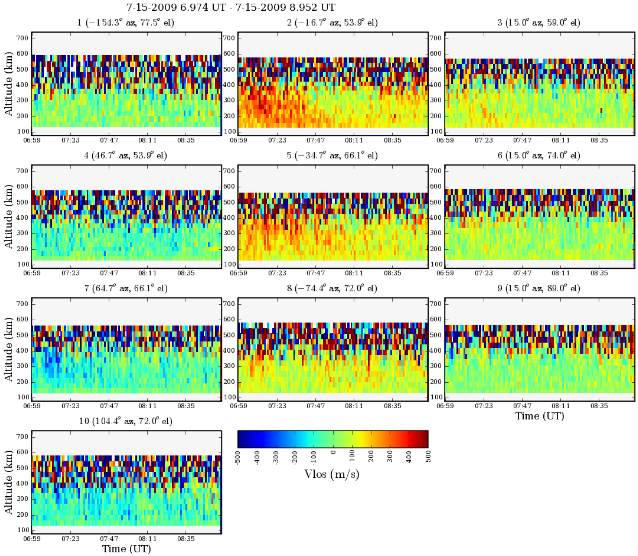
$$\begin{bmatrix} v_{los}^1 \\ v_{los}^2 \\ \vdots \\ v_{los}^n \end{bmatrix} = \begin{bmatrix} k_{pe}^1 & k_{pn}^1 & k1_{ap} \\ k_{pe}^2 & k_{pn}^2 & k2_{ap} \\ \vdots & \vdots & \vdots \\ k_{pe}^n & k_{pn}^n & k_{ap}^n \end{bmatrix} \begin{bmatrix} v_{pe} \\ v_{pn} \\ v_{ap} \end{bmatrix} + \begin{bmatrix} e_{los}^1 \\ e_{los}^2 \\ \vdots \\ e_{los}^n \end{bmatrix}$$

then, **v** is estimated as:

$$\hat{\mathbf{v}} = \Sigma_v A^T \left(A\Sigma_v A_T + \Sigma_e\right)^{-1} \mathbf{v}_{los}$$



Derived Velocities c/o Mike Nicolls



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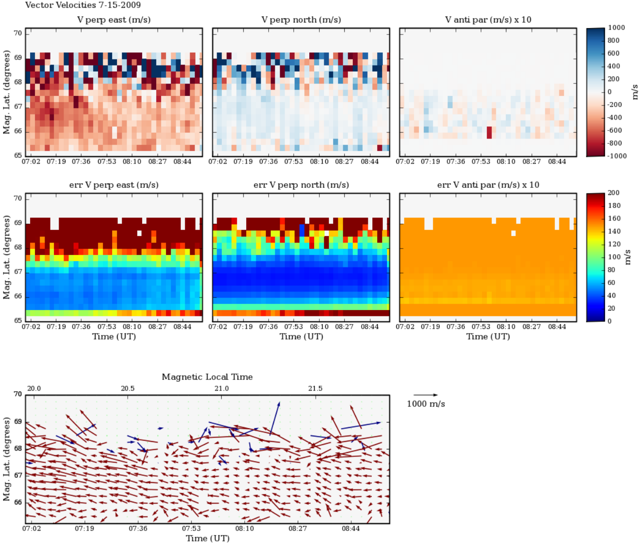
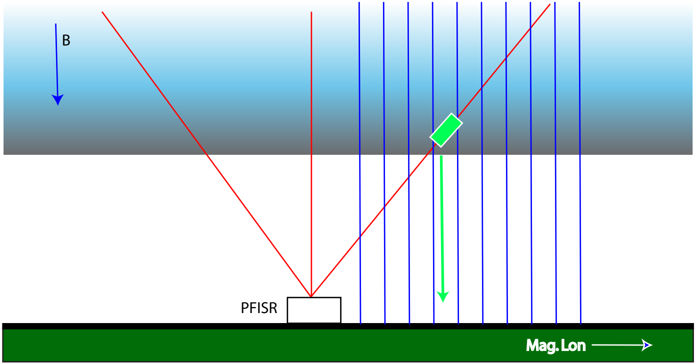


Velocity as a function of Longitude?



Simple 2-beam calculation

From *Heiselman and Nicolls*, RS, 2008; neglecting Earth curvature,

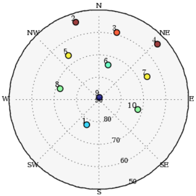
$$\mathbf{k}' = \begin{bmatrix} k_{pe} \\ k_{pn} \\ k_{ap} \end{bmatrix} = R_{geo \rightarrow gmag} \cdot \mathbf{k} = \begin{bmatrix} \cos\delta & -\sin\delta & 0 \\ \sin I \sin\delta & \cos\delta \sin I & \cos I \\ -\cos I \sin\delta & -\cos I \cos\delta & \sin I \end{bmatrix} \begin{bmatrix} \cos\theta \sin\phi \\ \cos\theta \cos\phi \\ \sin\theta \end{bmatrix}$$

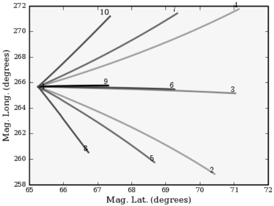
given a k for each beam, and assuming the velocity along B is negligible,

$$v_{pn}^{2,8} = \frac{v_{los}^{2} - \frac{k_{pe}^{2}}{k_{pe}^{8}} v_{los}^{8}}{k_{pn}^{2}\left(1 - \frac{k_{pn}^{8} k_{pe}^{2}}{k_{pn}^{2} k_{pe}^{8}}\right)} \qquad v_{pn}^{4,10} = \frac{v_{los}^{4} - \frac{k_{pe}^{4}}{k_{pe}^{10}} v_{los}^{10}}{k_{pn}^{4}\left(1 - \frac{k_{pn}^{10} k_{pe}^{4}}{k_{pn}^{4} k_{pe}^{10}}\right)}$$

$$v_{pe}^{2,8} = \frac{v_{los}^{8} - \frac{k_{pn}^{8}}{k_{pn}^{2}} v_{los}^{2}}{k_{pe}^{8}\left(1 - \frac{k_{pn}^{8} k_{pe}^{2}}{k_{pn}^{2} k_{pe}^{8}}\right)} \qquad v_{pe}^{4,10} = \frac{v_{los}^{10} - \frac{k_{pn}^{10}}{k_{pn}^{4}} v_{los}^{4}}{k_{pe}^{10}\left(1 - \frac{k_{pn}^{10} k_{pe}^{4}}{k_{pn}^{4} k_{pe}^{10}}\right)}$$

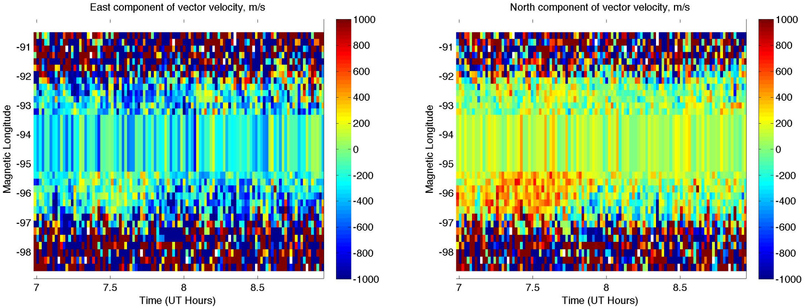
Beam Positions Revisited





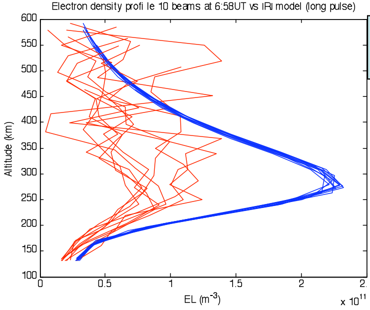
Results

Mean velocities: -246.8 m/s East, 66.3 m/s North, or 255 m/s at -75° azimuth

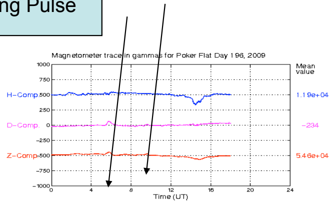


NOTE: We haven't done any calculations of errors!

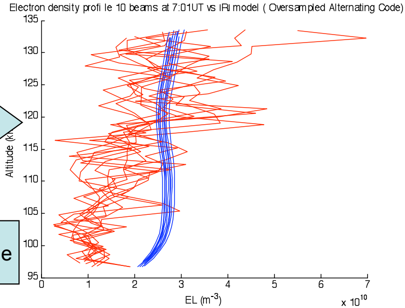
Outline



Long Pulse



Quiet time
Still big differences compared with IRI



Alternating Code

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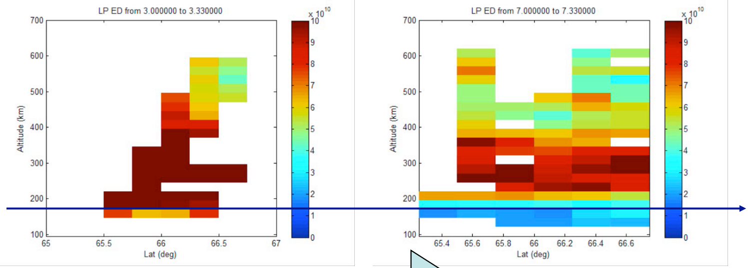
Long Pulse (E F)

Group 2

Group 4



At low altitude, EL enhancement appears during disturbed peridod

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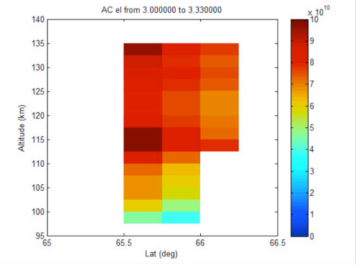
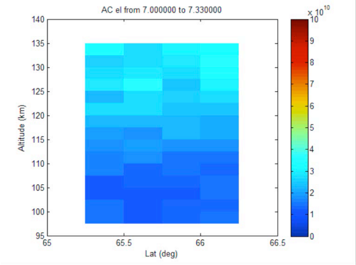
Alternating code (E)

Group 2



Group 4

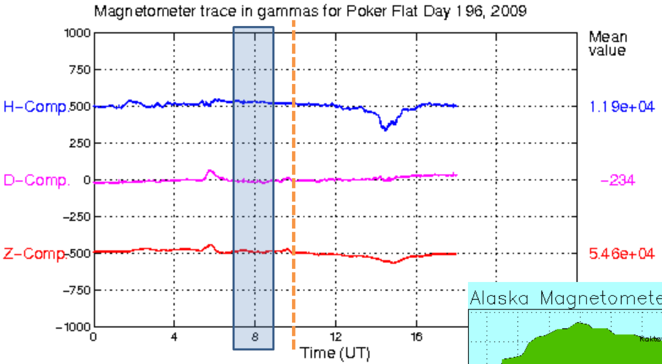


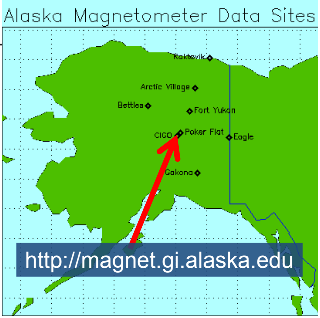
Summary of this part

- IRI model has great differences compared with the real measurement by ISR
- F region peak can be observed by both groups data
- ED is higher at “slightly” disturbed period for E region
- Validation needed to use the “seriously” disturbed period comes after G4 period
- ISR is capable of observing a certain area ionosphere continuously

Outline

Magnetometer Data



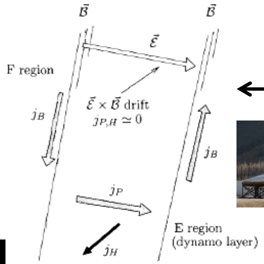


15 July 2009 experiment:
07:00 – 09:00 UT
(23:00 – 01:00 LDT)

Fairbanks magnetic midnight is ~10:00 UT

Methodology

1. Measure F-region $\mathbf{V}_{i\perp}$ with PFISR long pulse
2. Assume **ExB** drift to infer **E**
3. Estimate σ_P from PFISR n_e and MSIS model n_n
4. Calculate j_P and Joule heating rate



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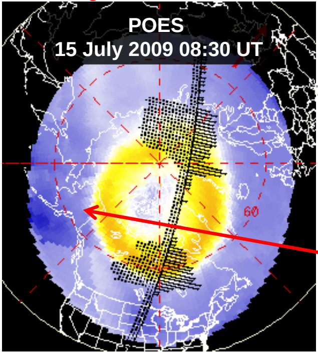
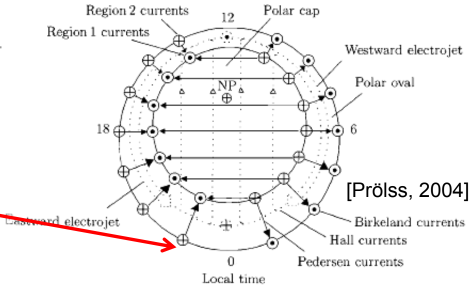
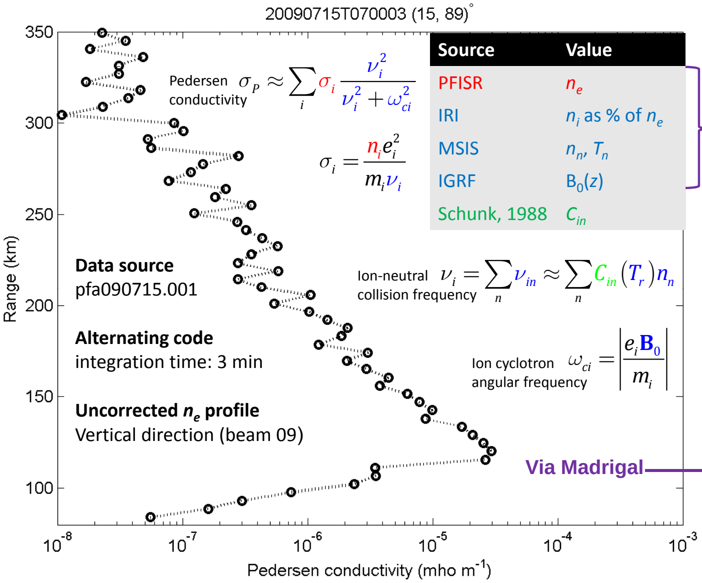




[Prölss, 2004]

MLT

Extracting the Conductivity



Pedersen conductivity $\sigma_P \approx \sum_i \sigma_i \frac{\nu_i^2}{\nu_i^2 + \omega_{ci}^2}$

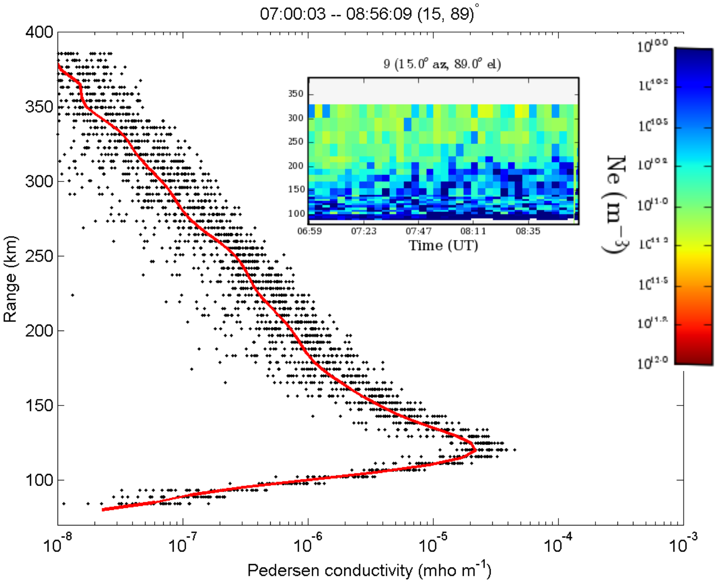
$$\sigma_i = \frac{n_i e_i^2}{m_i \nu_i}$$

Ion-neutral collision frequency $\nu_i = \sum_n \nu_{in} \approx \sum_n C_{in}(T_r) n_n$

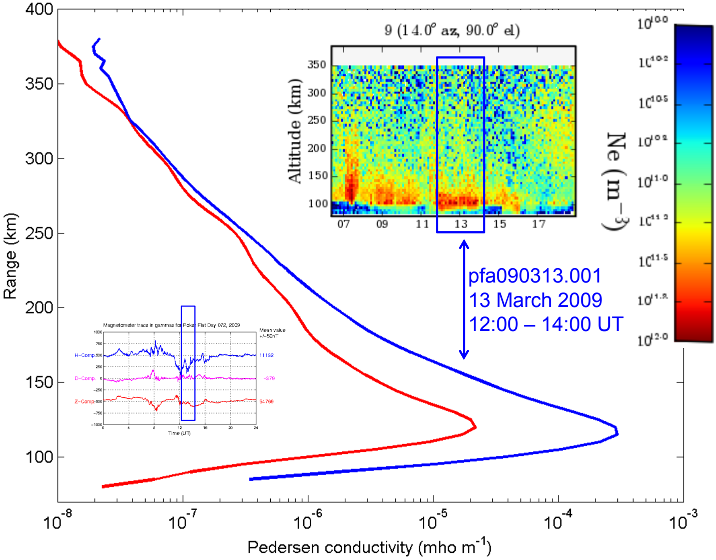
Ion cyclotron angular frequency $\omega_{ci} = \left| \frac{e_i \mathbf{B}_0}{m_i} \right|$

Source	Value
PFISR	n_e
IRI	n_i as % of n_e
MSIS	n_n, T_n
IGRF	$B_0(z)$
Schunk, 1988	C_{in}

Conductivity Profiles



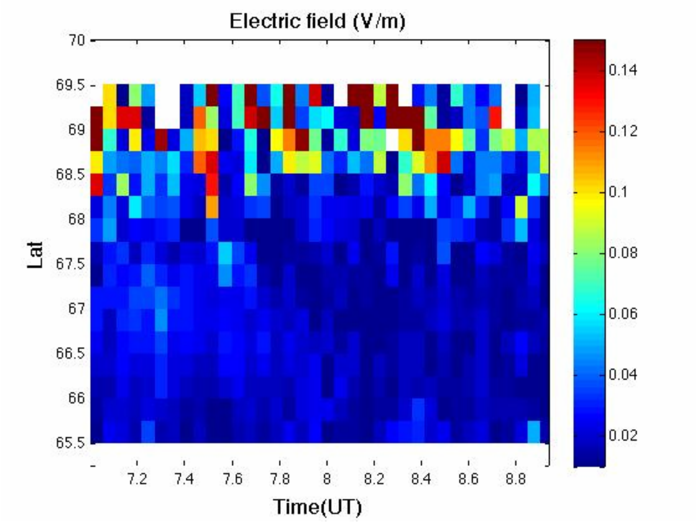
Comparison with Storm-time Data



Outline

Electric Fields

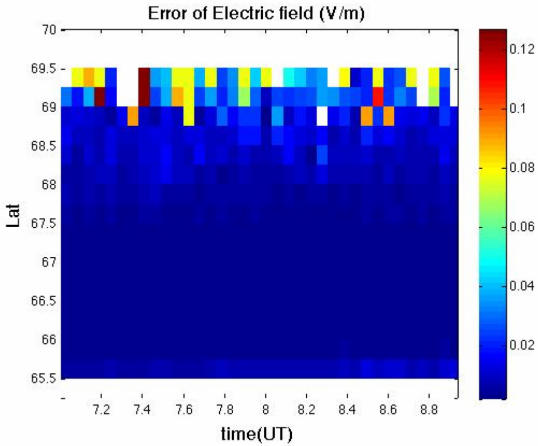
Calculated electric field: $|E|=|V_i||B|$



Errors in Electric Field

Propagated errors of electric field:

$$\sigma_E{}^2 = \left(\frac{\partial E}{\partial V_{\perp N}}\right)^2 \sigma_{V_{\perp N}}{}^2 + \left(\frac{\partial E}{\partial V_{\perp E}}\right)^2 \sigma_{V_{\perp E}}{}^2$$



Outline

Calculating Current Density

Method to calculate current density

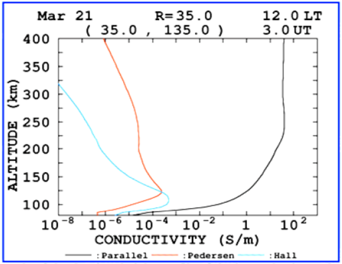
Method 1:

$$\mathbf{j}' = n \cdot e \cdot (v_i' - v_e') = n \cdot e \cdot \left(v_i - v_n - (v_e - v_n)\right) = n \cdot e \cdot (v_i - v_e)$$

Method 2:

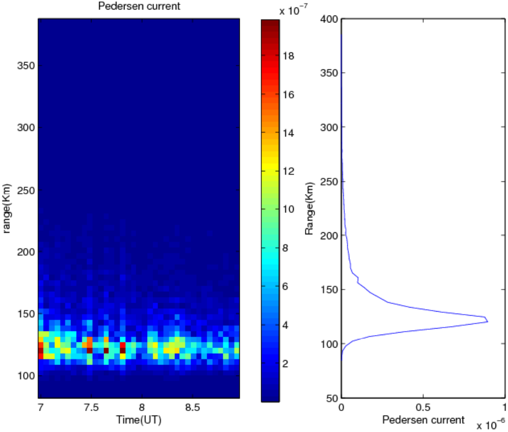
$$\mathbf{j}' = n \cdot e \left\{ \left(\frac{k_e}{1+k_e^2} + \frac{k_i}{1+k_i^2} \right) \frac{\mathbf{E}'}{B} - \left(\frac{k_e^2}{1+k_e^2} - \frac{k_i^2}{1+k_i^2} \right) \frac{\mathbf{E}' \times \mathbf{B}}{B^2} + \left(\frac{k_e^3}{1+k_e^2} - \frac{k_i^3}{1+k_i^2} \right) \frac{(\mathbf{E}' \cdot \mathbf{B})\mathbf{B}}{B^3} \right\}$$

$$= \sigma_p \mathbf{E}_\perp' - \sigma_H \frac{\mathbf{E}' \times \mathbf{B}}{B} + \sigma_\parallel \mathbf{E}_\parallel{}'$$



Pedersen Currents vs. Altitude and Time

Pedersen current



Method for Calculating Joule Heating

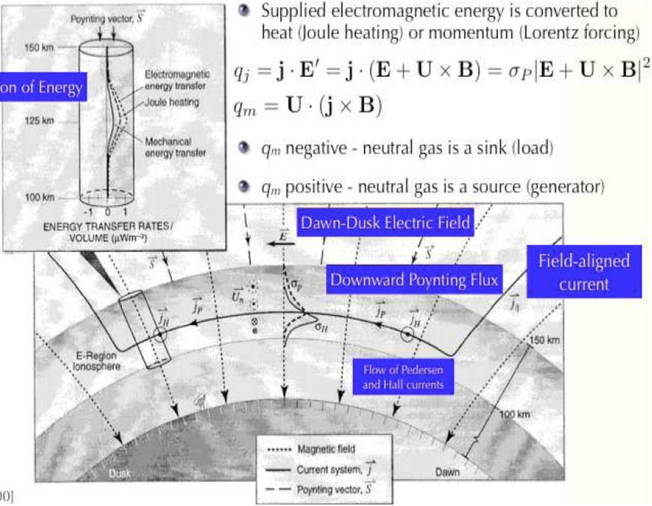
Joule heating

- Supplied electromagnetic energy is converted to heat (Joule heating) or momentum (Lorentz forcing)

$$q_j = \mathbf{j} \cdot \mathbf{E}' = \mathbf{j} \cdot (\mathbf{E} + \mathbf{U} \times \mathbf{B}) = \sigma_P |\mathbf{E} + \mathbf{U} \times \mathbf{B}|^2$$

$$q_m = \mathbf{U} \cdot (\mathbf{j} \times \mathbf{B})$$

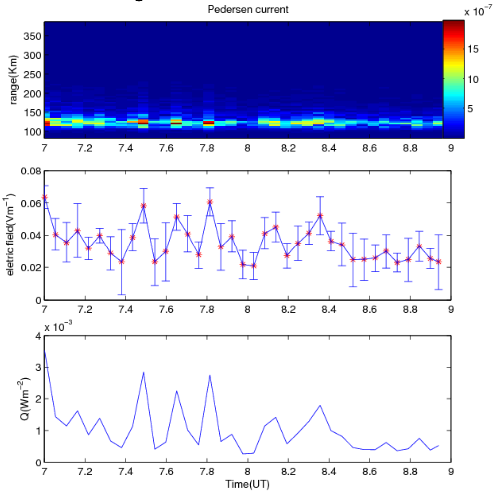
- q_m negative - neutral gas is a sink (load)
- q_m positive - neutral gas is a source (generator)



Thayer [2000]

Joule Heating vs. Time

Height Integrated Joule heating rate



Thanks!

Mike, Craig, Asti,
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Shelley, Mary, John K.