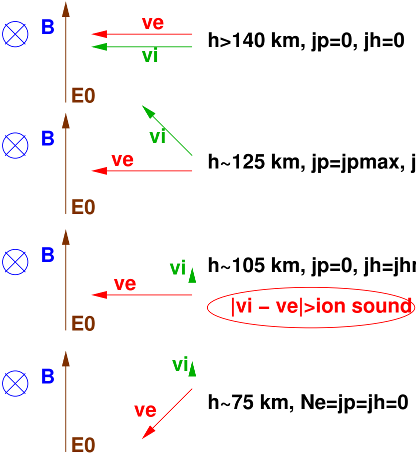
Farley-Buneman Instability

Anomalous Electron Heating

Effect of Irregularities and Energy Balance

Ion and electron motion in the ionosphere



Ion/electron motion

Ion/electron motion from

$$\frac{d\mathbf{v}_{i,e}}{dt} = \pm\frac{e}{m_{i,e}}\left(\mathbf{E} + \mathbf{v}_{i,e} \times \mathbf{B}\right) + \nu_{i,en}\mathbf{v} \approx 0$$

$\nu_{i,en}$ ion/electron-neutral collision frequency

$$\mathbf{v}_{i,e} = \pm\frac{\kappa_{i,e}}{1+\kappa_{i,e}^2}\frac{\mathbf{E}}{B} + \frac{\kappa_{i,e}^2}{1+\kappa_{i,e}^2}\frac{{}' \times \mathbf{B}}{B^2}$$

$\kappa_{i,e} = \frac{\Omega_{i,e}}{\nu_{i,en}}$, ratio between gyro and collision frequencies,
$\Omega_{i,e} = \frac{eB}{m_{i,e}}$

☞ $\kappa_e \gg 1$ everywhere in the E and F region

☞ $\kappa_i \ll 1$ below ≈ 115 km

☞ $\kappa_i \gg 1$ above ≈ 140 km

Farley-Buneman Instability

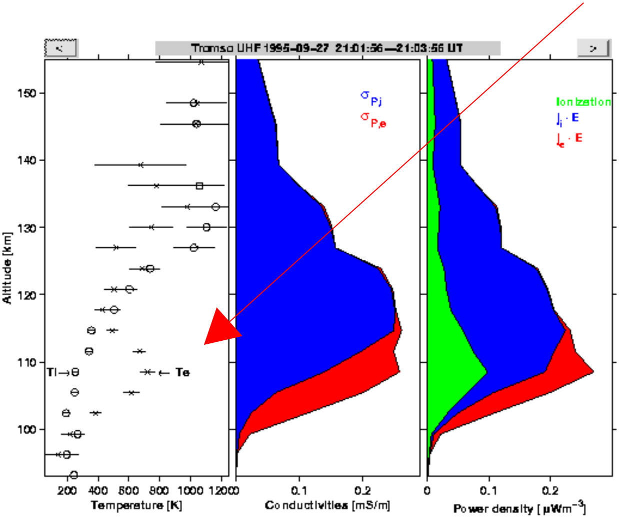
- $|\mathbf{v}_i - \mathbf{v}_e| > C_s$, supersonic speed
  - ⇨ Farley-Buneman instability (Farley, JGR, 1963; Buneman, PRL, 1963)
- VHF radio echoes from the aurora (Bowles, JGR, 1954)
- ... from the equatorial electrojet (Bowles et al., JGR, 1960)

Linear Fluid Theory ($\mathbf{V}_d = \mathbf{v}_i - \mathbf{v}_e$):

$$\omega_r = \frac{kV_d}{1+\Psi_0}\text{and}\gamma = \frac{\Psi_0}{\nu_i}\frac{\omega_r^2 - k^2C_s^2}{1+\Psi_0}, \Psi_0 = \frac{\nu_e\nu_i}{\Omega_e\Omega_i}$$

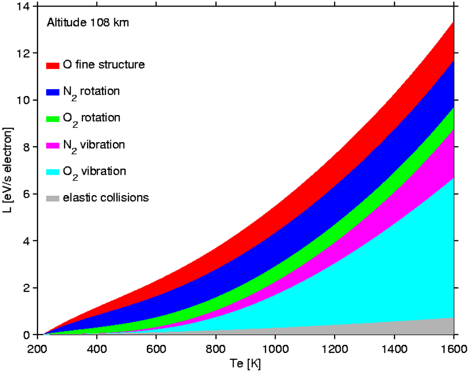
Growth for $\omega_r^2 > k^2C_s^2$ or $V_d > (1+\Psi_0)C_s$

Incoherent Scatter Observations of Enhanced T_e



Incoherent Scatter Observations of Enhanced T_e

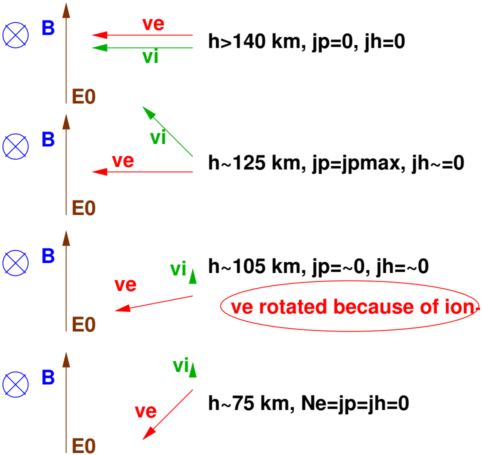
- ☞ Electron temperature T_e enhanced where FB instability
- ☞ in spite of strong cooling by inelastic collisions:



Empirical Estimate of Anomalous Conductivities and Dissipation

- ☞ From observed T_e get cooling rates L_e (Schunk and Nagy, Ionospheres, 2000)
- ☞ This energy must come from above, quasi-stationary.
- ⇨ $L_e(T_e) = j_{P,e} \cdot \mathbf{E}_0 = \sigma_P E_0^2$
- ☞ $j_{P,e}$ “electron Pedersen current”
- ☞ we don’t care for now how the electron Pedersen current emerges microscopically

Anomalous electron motion in the ionosphere



h>140 km, jp=0, jh=0

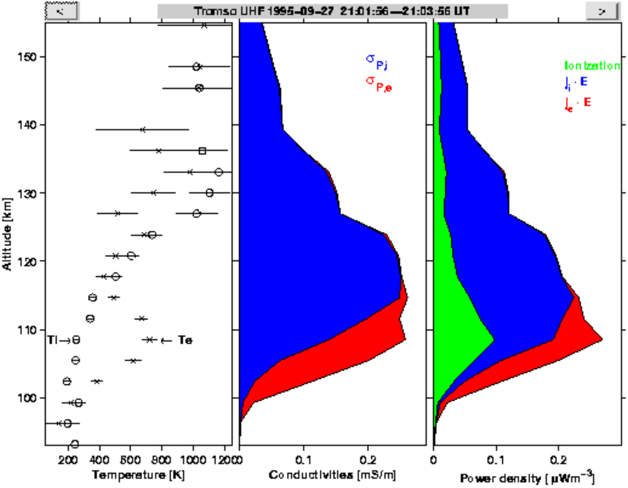
h~125 km, jp=jpmax, jh~=0

h~105 km, jp=~0, jh=~0

ve rotated because of ion-

h~75 km, Ne=jp=jh=0

Empirical Estimates of Conductivities and Dissipation



Conclusions so far

- ☞ Electron Pedersen current can locally be the strongest dissipation mechanism
- ☞ 10-20 % of the height integrated conductivity
- ☞ the ionosphere responds weakly non-linear to slowly varying electric fields
  - ▸ enhanced T_e isotropic → there is even an anomalous effect along the geomagnetic field, $sigma^{*}_{\parallel}$.

Comments:
Total energy $<\mathbf{j}\cdot\mathbf{E}>=\mathbf{j}_0\cdot\mathbf{E}_0+<\mathbf{j}_1\cdot\mathbf{E}_1>$
Energy for e^{-} heating comes from 2nd term (waves)

Effect of Irregularities

$$\begin{aligned} <\overline{\mathbf{j}(\mathbf{r},t)}> &= -eN_0\mathbf{v}_0 \\ &+ \left(\frac{1}{2\pi}\right)^3 \frac{e}{VT}\iiint d(\mathbf{k})\mathbf{A}\frac{\mathbf{k}\cdot\mathbf{v}_0}{1+\Psi_0}\frac{<|N_1(\mathbf{k},\omega_r)|^2>}{N_0} \end{aligned}$$

where the vector **A**

$$\begin{aligned} A_x &= \frac{k_x}{k^2} + \frac{M}{m}\left(\frac{\nu_i}{k^2}\right)\frac{k_x\nu_e - k_y\Omega_e}{\Omega_e^2+\nu_e^2} \\ A_y &= \frac{k_y}{k^2} + \frac{M}{m}\left(\frac{\nu_i}{k^2}\right)\frac{k_y\nu_e + k_x\Omega_e}{\Omega_e^2+\nu_e^2} \\ A_z &= \frac{k_z}{k^2} + \frac{M}{m}\left(\frac{\nu_i}{k^2}\right)\frac{k_z}{\nu_e} \end{aligned}$$

Effect of Irregularities and Energy into waves

- ☞ Ion-acoustic waves do have an effect on $< \mathbf{v}_e >$!
- ☞ Energy into waves even more complicated,
- ☞ but the result is (of course?) $\mathbf{j}_0 \cdot \mathbf{E}_0 = - < \mathbf{j}_1 \cdot \mathbf{E}_1 >$
- ☞ assumptions: negligible dissipation from collisions

where $\mathbf{j}_0 =< \mathbf{j} >$, $< \mathbf{j}_1 >=< \mathbf{E}_1 >= 0$
T. Hagfors, S. Buchert, and J. McKenzie, submitted to JGR

Power into waves