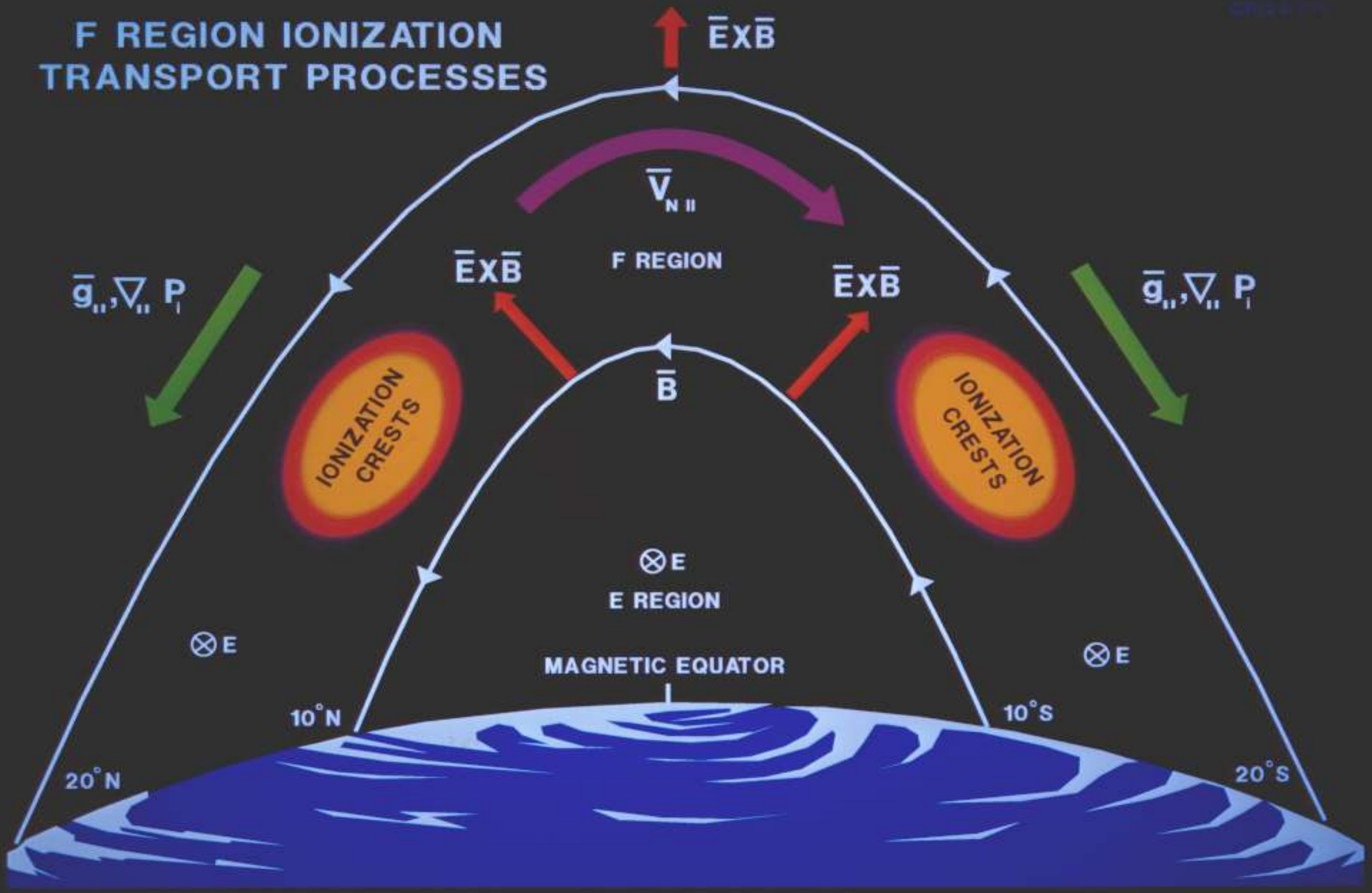
Equatorial Electrodynamics

Reading material: M. Kelley’s book, Ch 3

Lecture materials are partly compiled by
Prof Dr Jorge L Chau, Rostock University


F REGION IONIZATION
TRANSPORT PROCESSES
$\bar{E} \times \bar{B}$
$\bar{V}_{N\parallel}$
F REGION
$\bar{E} \times \bar{B}$
$\bar{E} \times \bar{B}$
$\bar{g}_{\parallel}, \nabla_{\parallel} P_i$
$\bar{g}_{\parallel}, \nabla_{\parallel} P_i$
IONIZATION CRESTS
IONIZATION CRESTS
$\bar{B}$
$\otimes$ E
E REGION
$\otimes$ E
$\otimes$ E
MAGNETIC EQUATOR
10°N
10°S
20°N
20°S

Equatorial F region ion drifts

- ISRs measure the ion velocity which in the F region is given by:

$$(\mathbf{V}_i)_\perp = [\mathbf{E} - (k_B T_i / q_i)\nabla n / n + (M / q_i)\mathbf{g}] \times [\mathbf{B} / B^2]$$

$\kappa_i >> 1$
Collisionless case

But,

1 m/s ~ 25 microvolt/m, B = 0.25 G

$$\mathbf{E}_\perp = -\mathbf{V}_i \times \mathbf{B}$$

kT/eL ~ 0.01 mV/m

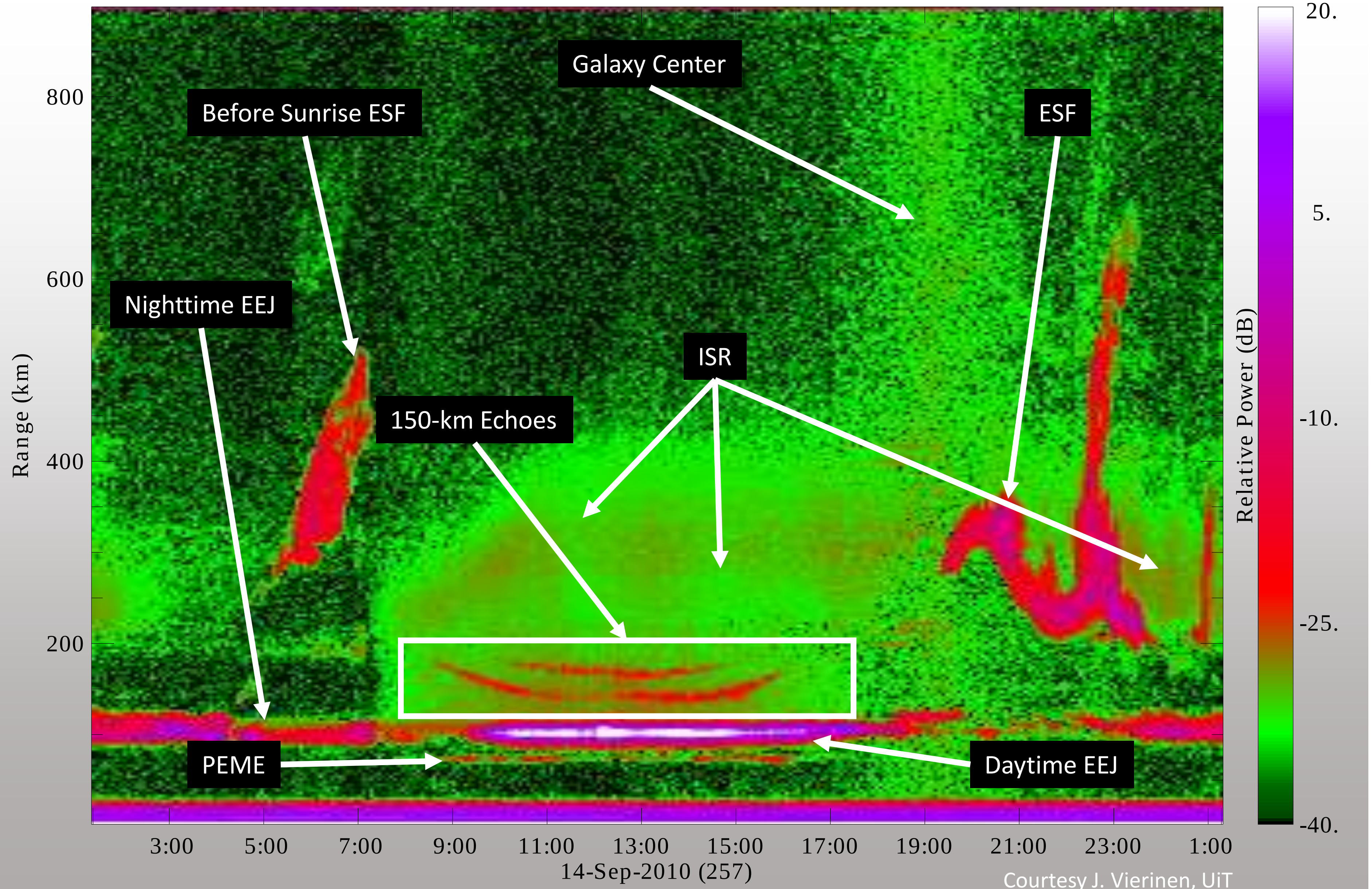
~ 0.25 m/s Not enough

Mg/e ~ a few microvolt/m

So, in this equation the electric field term dominates

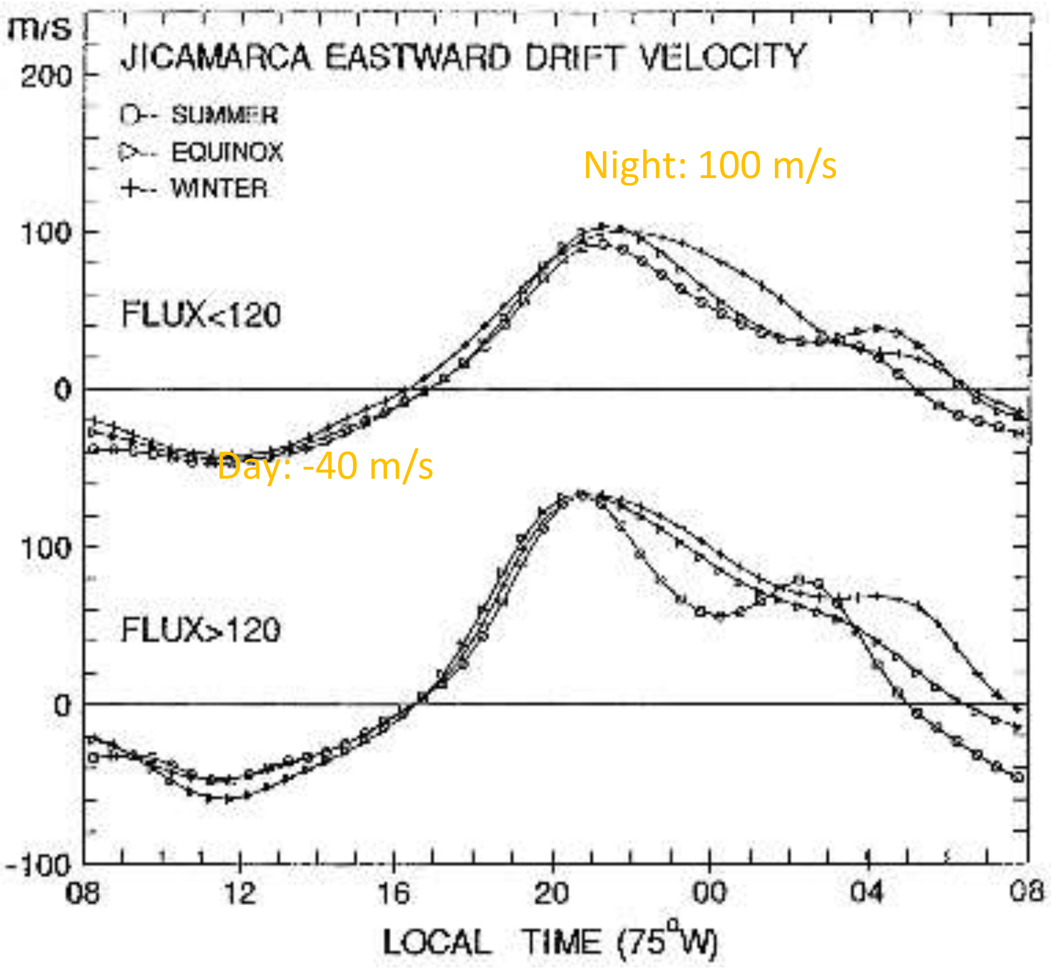
- Most of our equatorial electric field data/information has come from the Jicamarca Radio Observatory

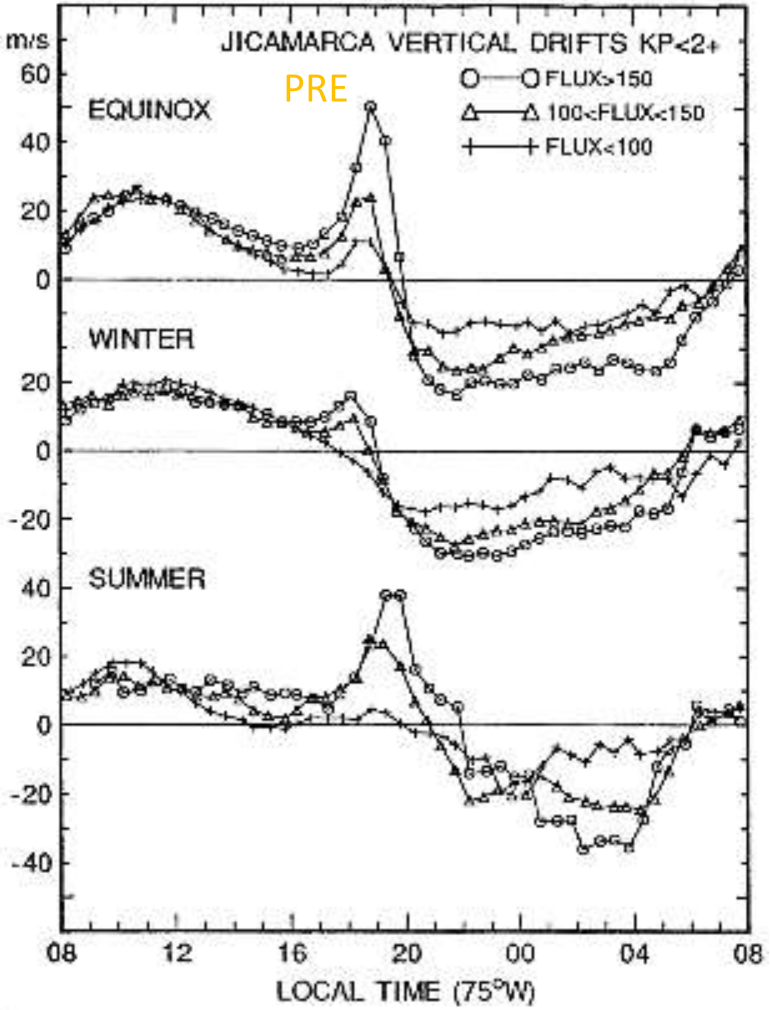
Example of equatorial ISR radar data



Courtesy J. Vierinen, UiT

Equatorial Drifts/Electric Fields from Jicamarca ISR





Equatorial drifts summary

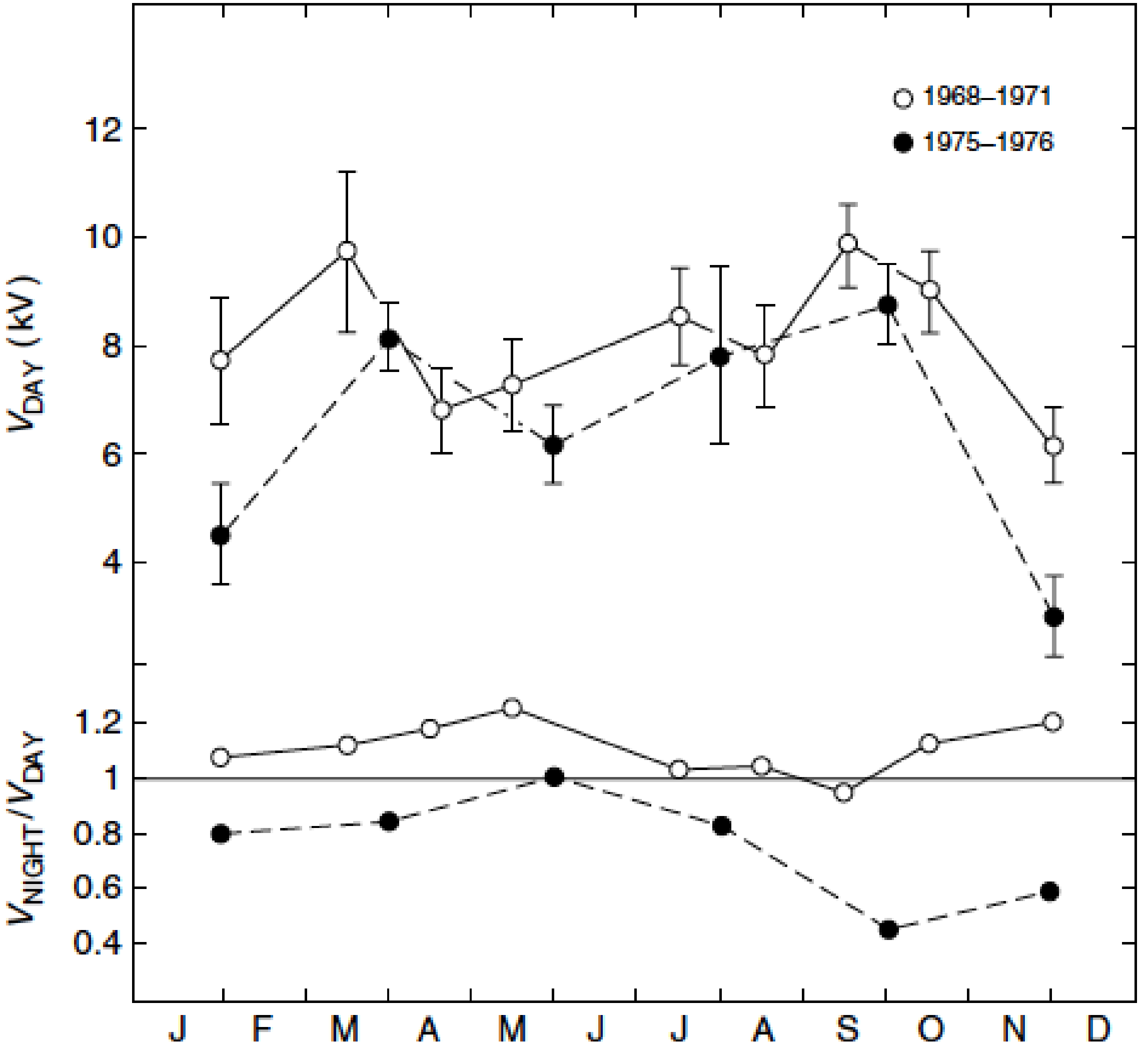
- The peak eastward drift at night is twice as great as the peak westward drift during the day
- The zonal drifts are much larger than the vertical velocities
- The vertical drift is often strongly enhanced just after sunset but shows no comparable feature near sunrise
    - This is termed the pre-reversal enhancement of the vertical drift or, equivalently, of the eastward electric field component
- There are strong solar cycle effects in the vertical drifts and moderate seasonal effects in both data sets

Longitudinal behavior of the observed equatorial electric fields

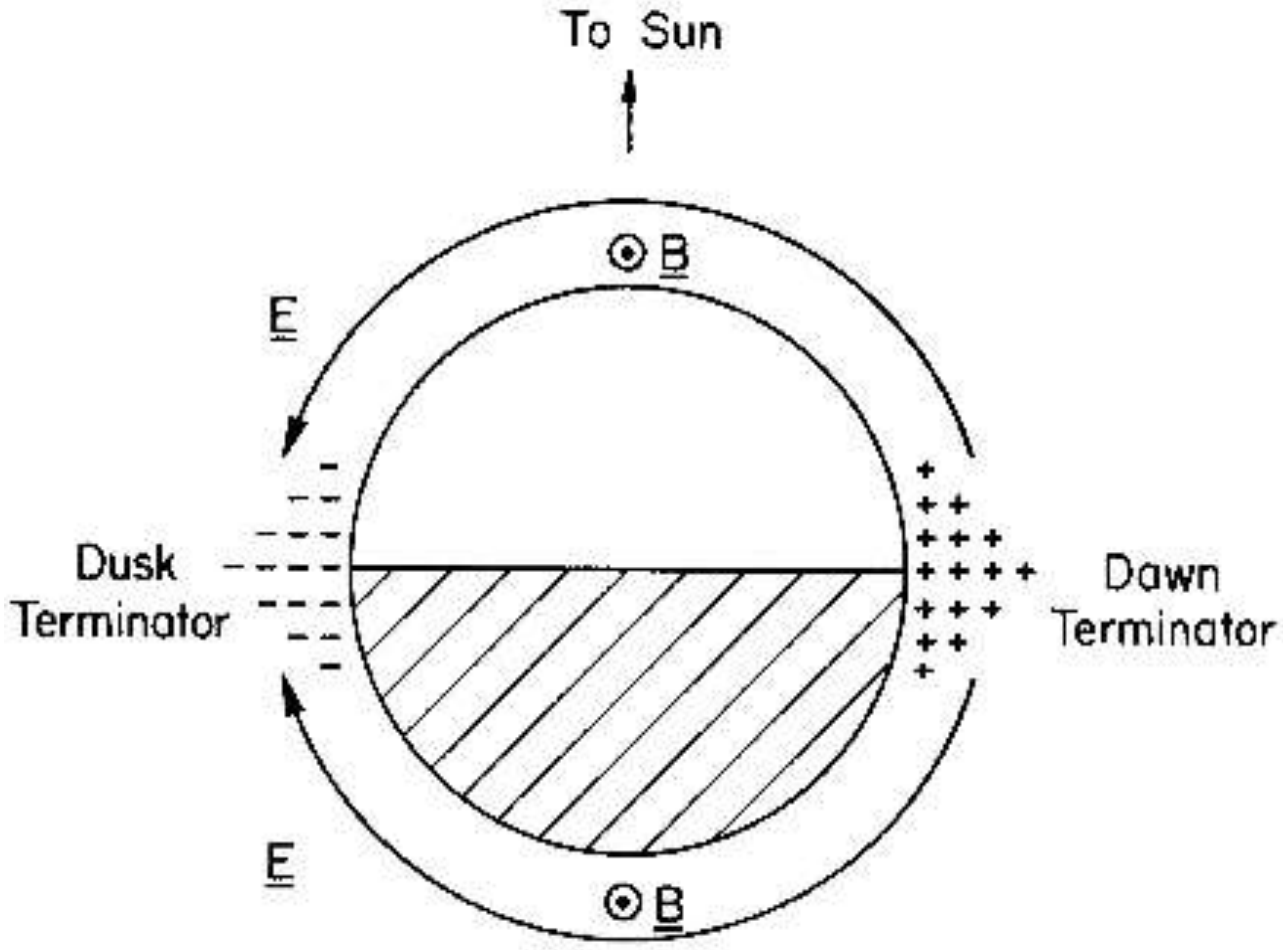
Maxwell's equations to understand the observed electric fields

$$\nabla \times \mathbf{E} = 0$$

$$\oint \mathbf{E} \cdot d\mathbf{l} = 0$$



The simple charged terminator model



$$\oint \mathbf{E} \cdot d\mathbf{l} = 0$$

Equatorial conductivity tensor

- New conductivity tensor for equatorial work

$$\boldsymbol{\sigma} = \begin{pmatrix} \sigma_P & 0 & \sigma_H \\ \boxed{0 \quad \sigma_0 \quad 0} \\ -\sigma_H & 0 & \sigma_P \end{pmatrix}$$

- In the F region $\sigma_P >> \sigma_H$ and the conductivity tensor is diagonal, although it still holds that $\sigma_P << \sigma_0$
- To a very good approximation,

$$\sigma_P = \frac{ne^2 \nu_{in}}{M\Omega_i^2}$$

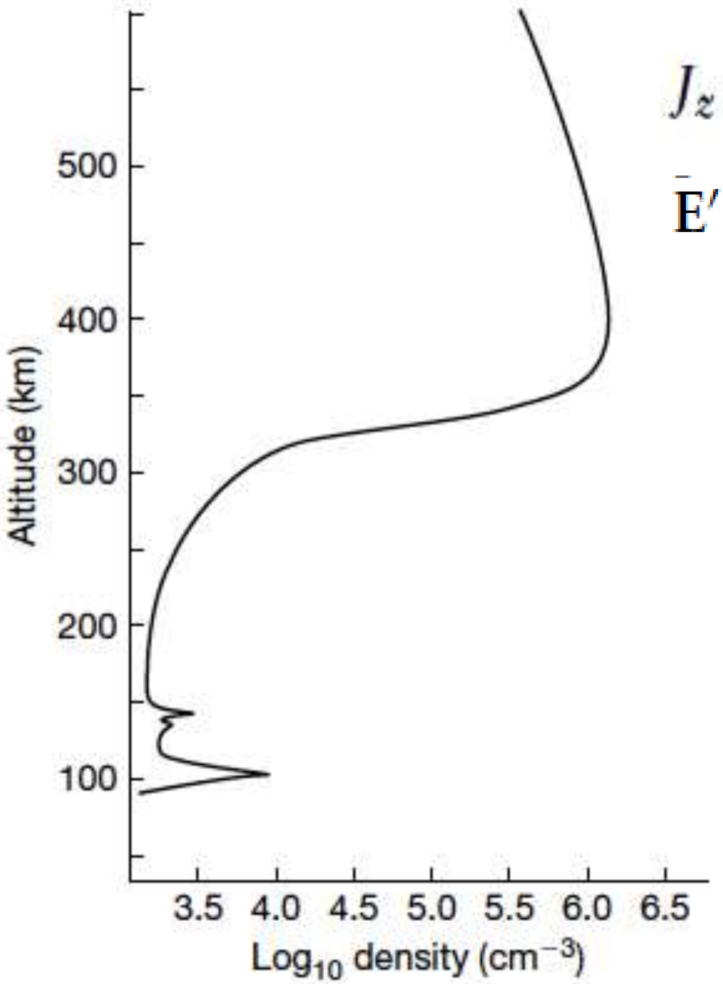
- For a wind only the current is

$$\mathbf{J} \simeq \boldsymbol{\sigma} \cdot (u\mathbf{a}_x \times \mathbf{B})$$

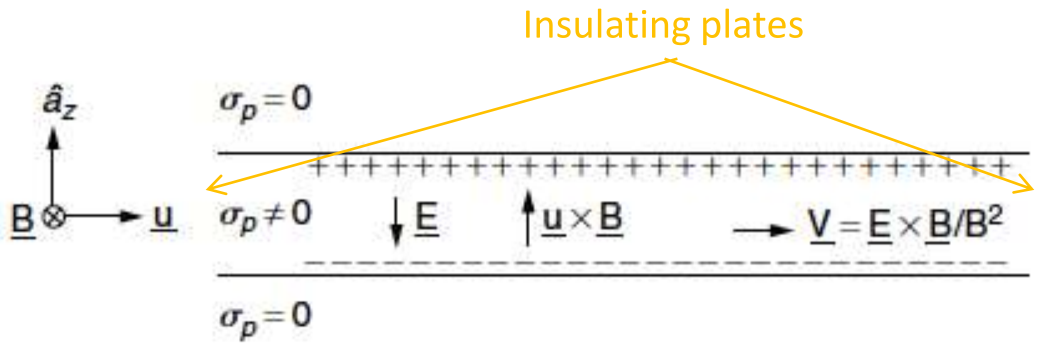
Simple F region model without E region

$$J_z = \sigma_P E_z + \sigma_P u B = 0 \qquad E_z = -uB$$

$$\mathrm{E}' = \mathrm{E} + \mathrm{U} \times \mathrm{B} \qquad \mathrm{J} = \mathrm{J}' = \sigma_P \mathrm{E}' = 0$$



(a)

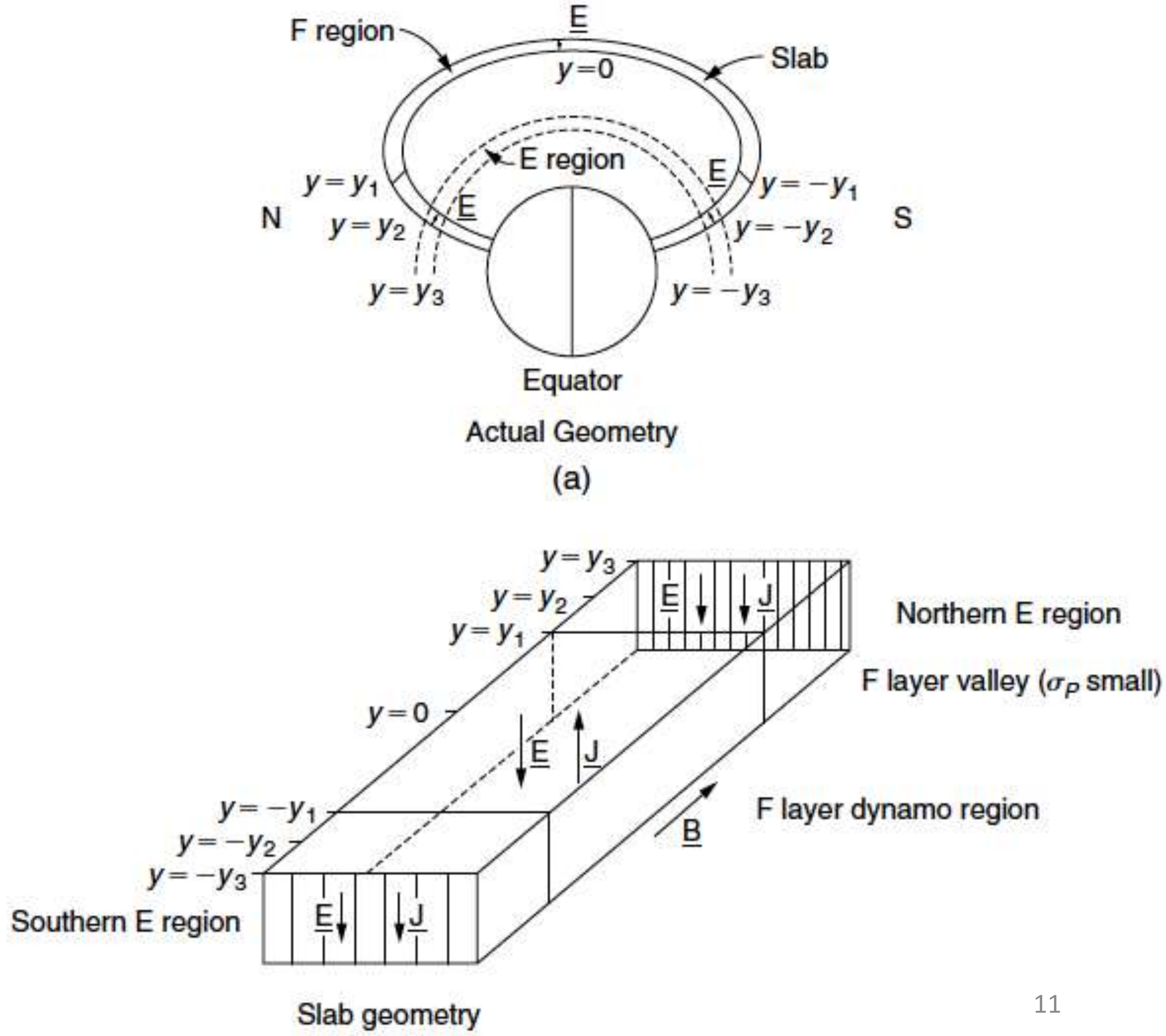


(b)

Modified F region model including E region

- We model the system as shown below since the magnetic field lines are nearly equipotentials due to the high ratio of σ_0 to σ_P ($\geq 10^5$)
- The electric field is thus mapped down to the E-region altitudes, where we have assumed that the neutral wind vanishes in order to study just the F-region dynamo

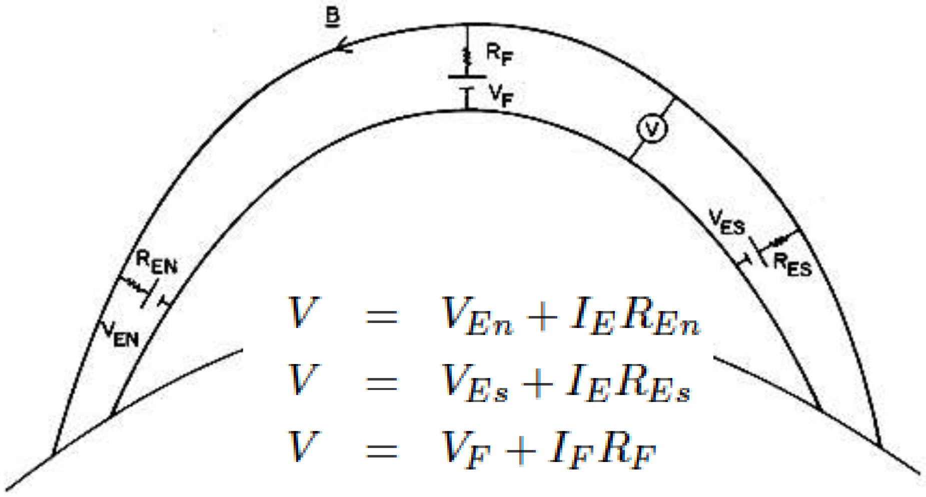
$$\mathbf{J} = \sigma \cdot (\mathbf{E} + \mathbf{U} \times \mathbf{B})$$



Electric Circuit Analogy

- If we include an E region dynamo there are three regions opting for control but only one electric field/voltage can exist
  - In the daytime the E region wins most of the time but at night its conductivity drops dramatically and the F region dynamo can win

$$
\begin{aligned}
V &= \left(\frac{V_E}{R_E}+\frac{V_F}{R_F}\right)\left(\frac{1}{\frac{1}{R_F}+\frac{2}{R_E}}\right)\\
V &= (\sigma_E V_E+\sigma_F V_F)/(\sigma_F+2\sigma_E)
\end{aligned}
$$



$$
\begin{aligned}
V &= V_{En}+I_E R_{En}\\
V &= V_{Es}+I_E R_{Es}\\
V &= V_F+I_F R_F\\
I_F &= -2I_E
\end{aligned}
$$