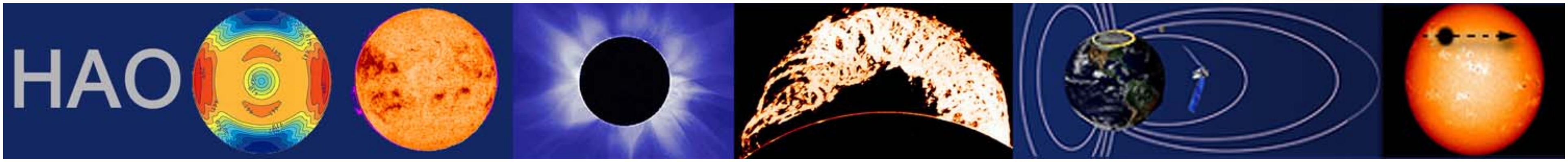


# Neutral Winds and Their Role in Ionospheric Electrodynamics

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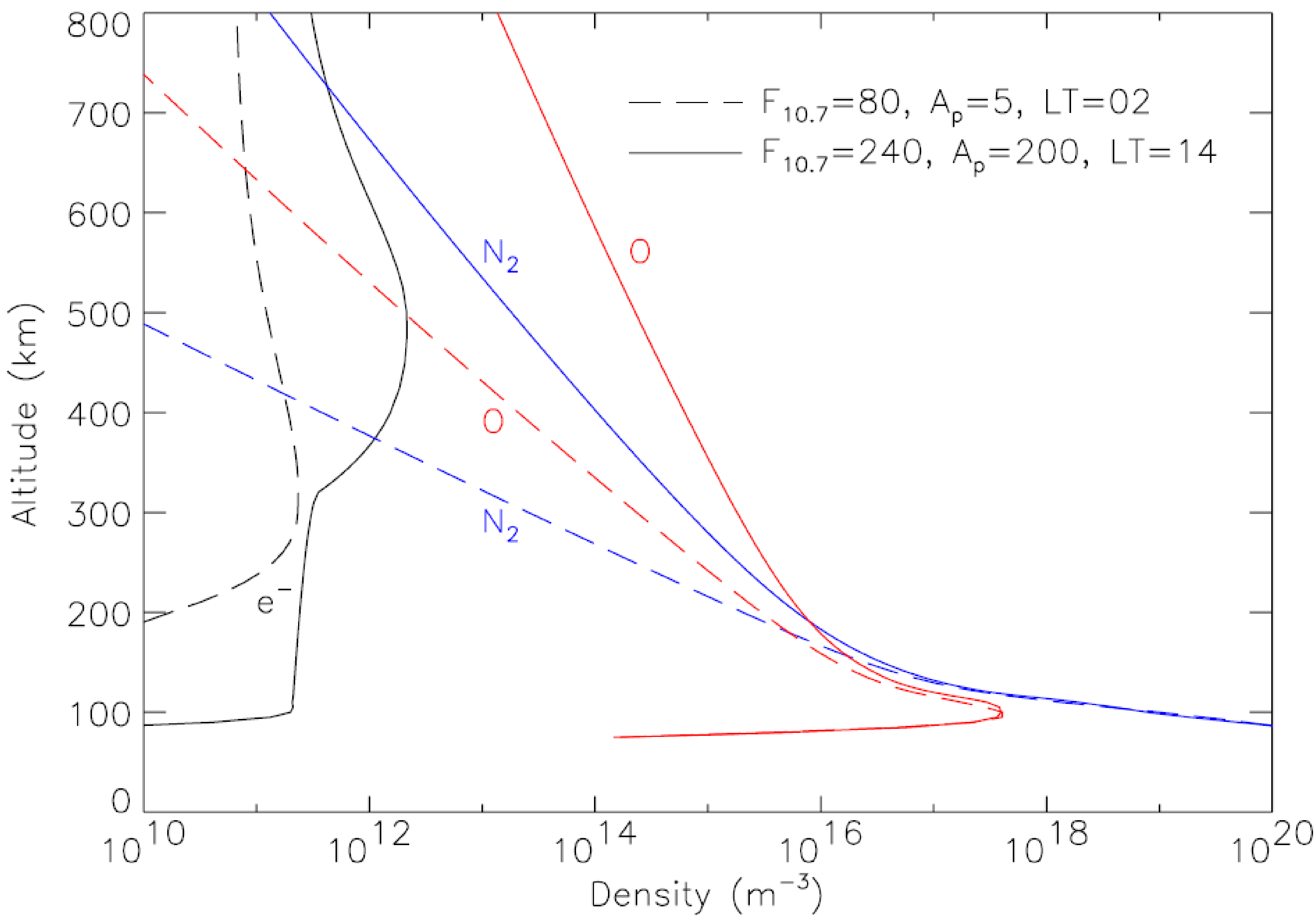
- Ion-neutral interactions

- Ion motions and Ohm’s Law

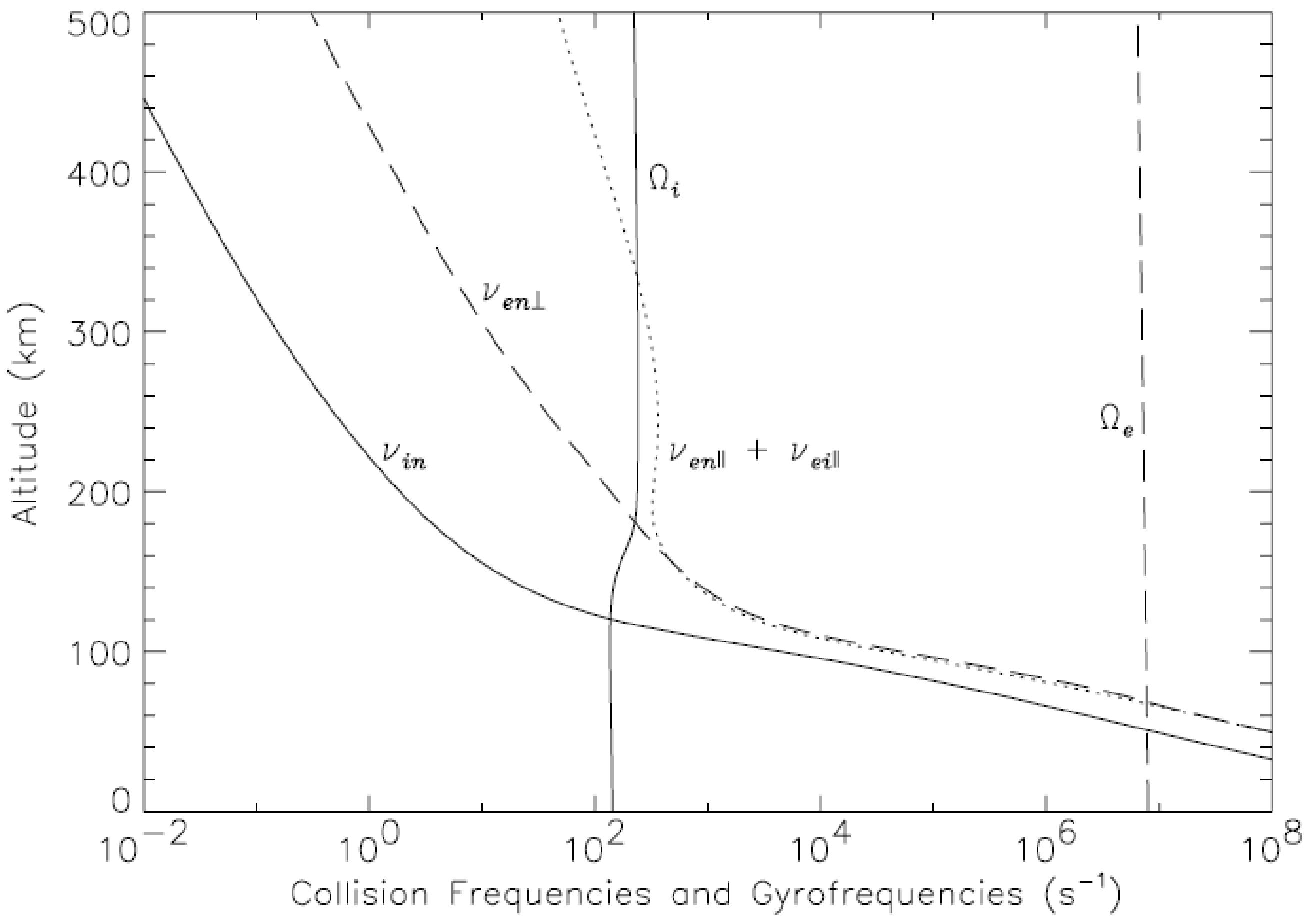
- Ion influences on neutral dynamics

- Ionospheric wind dynamo

- Interactive thermosphere-ionosphere-electrodynamics



800
700
600
500
400
300
200
100
0
Altitude (km)
$10^{10}$
$10^{12}$
$10^{14}$
$10^{16}$
$10^{18}$
$10^{20}$
Density ($m^{-3}$)
$F_{10.7}$=80, $A_p$=5, LT=02
$F_{10.7}$=240, $A_p$=200, LT=14
$N_2$
O
O
$N_2$
$e^-$



Altitude (km)
Collision Frequencies and Gyrofrequencies (s$^{-1}$)
0
100
200
300
400
500
$10^{-2}$
$10^{0}$
$10^{2}$
$10^{4}$
$10^{6}$
$10^{8}$
$\Omega_i$
$\nu_{en\perp}$
$\nu_{in}$
$\nu_{en\parallel} + \nu_{ei\parallel}$
$\Omega_e$

# Ion and Electron Motion Under Force Balance

Ions

$$\mathbf{F}_i \approx 0 = ne(\mathbf{E} + \mathbf{v_i} \times \mathbf{B}) + nm_i\nu_{in}(\mathbf{v_n} - \mathbf{v_i}) + nm_i\nu_{ie}(\mathbf{v_e} - \mathbf{v_i}) - \nabla p_i + nm_i\mathbf{g} \tag{1}$$

Electrons

$$\mathbf{F}_e \approx 0 = -ne(\mathbf{E} + \mathbf{v_e} \times \mathbf{B}) + nm_e\nu_{en}(\mathbf{v_n} - \mathbf{v_e}) + nm_e\nu_{ei}(\mathbf{v_i} - \mathbf{v_e}) - \nabla p_e + nm_e\mathbf{g} \tag{2}$$

**Notation**

$\mathbf{B}$ magnetic field
$e$ magnitude of electron charge
$\mathbf{E}$ electric field
$\mathbf{F}$ force per unit volume
$\mathbf{g}$ acceleration of gravity
$m$ particle mass
$n$ number density of electrons and of ions
$p$ pressure
$\mathbf{v}$ velocity
$\nu_{en}$ collision frequency (electron-neutral)

Neglect pressure gradient, gravity, electron-ion collisions (except for electron motions parallel to **B**), and terms proportional to $m_e/m_i$.

**Ions**

$$ne(\mathbf{E} + \mathbf{v_i} \times \mathbf{B}) + nm_i\nu_{in}(\mathbf{v_n} - \mathbf{v_i}) = 0 \tag{3}$$

Parallel to **B**:

$$v_{i\|} = v_{n\|} + \frac{e}{m_i\nu_{in}}E_\| \tag{4}$$

Perpendicular to **B**:

$$\mathbf{v}_{i\perp} = \mathbf{v}_{n\perp} + \frac{\nu_{in}\Omega_i(\mathbf{E}_\perp + \mathbf{v}_n \times \mathbf{B}) - \Omega_i^2\mathbf{b} \times (\mathbf{E}_\perp + \mathbf{v}_n \times \mathbf{B})}{B(\nu_{in}^2 + \Omega_i^2)} \tag{5}$$

$$\Omega_i = eB/m_i \tag{6}$$

**Electrons**

$$-ne(\mathbf{E} + \mathbf{v_e} \times \mathbf{B}) + nm_e\nu_{en}(\mathbf{v_n} - \mathbf{v_e}) + nm_e\nu_{ei}(\mathbf{v_i} - \mathbf{v_e})_{\parallel} = 0 \quad (7)$$

Parallel to **B**:

$$v_{e\parallel} = v_{n\parallel} - \frac{e}{m_e(\nu_{en} + \nu_{ei})} E_{\parallel} \quad (8)$$

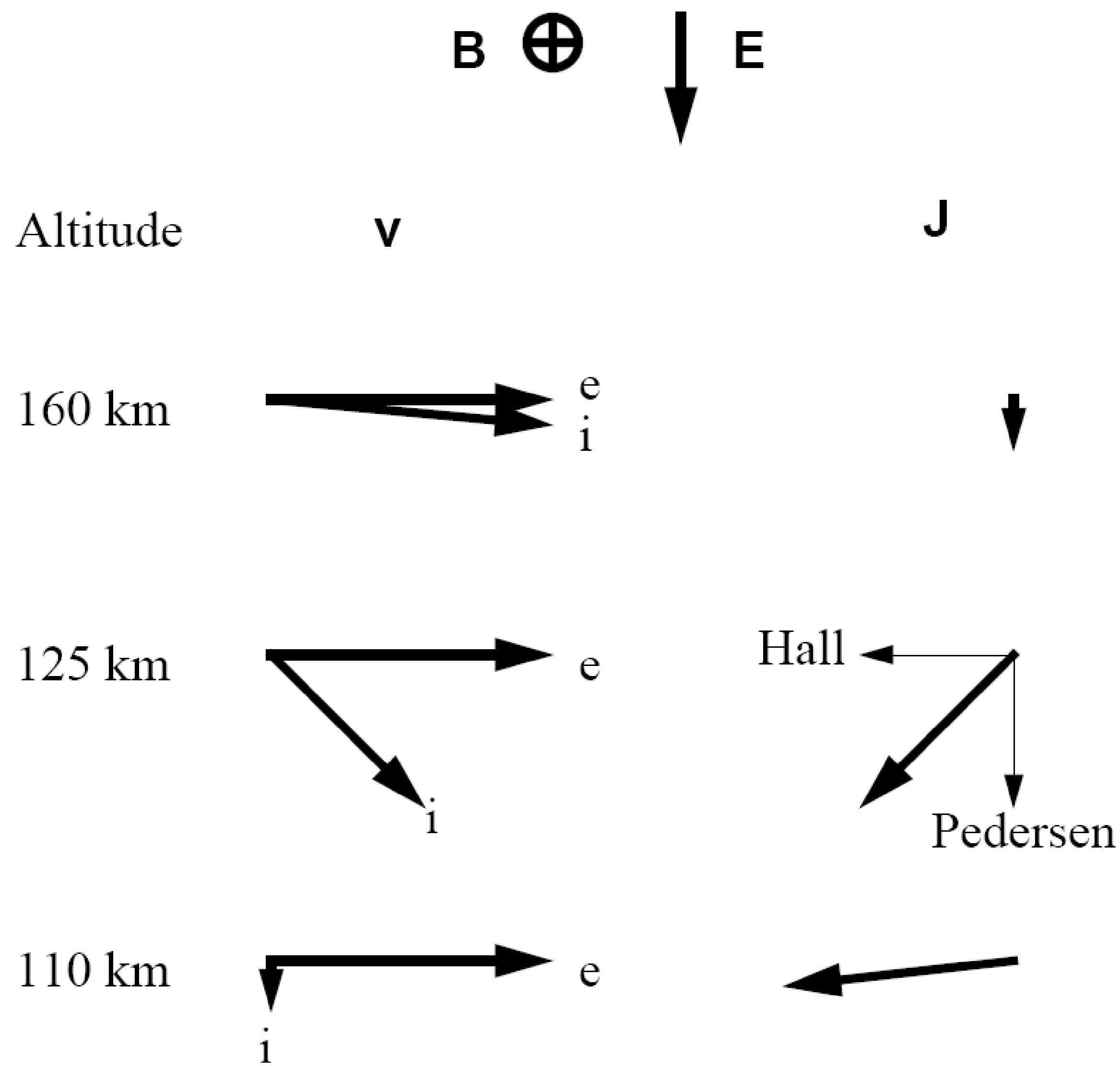
Perpendicular to **B**:

$$\mathbf{v}_{e\perp} = \mathbf{v}_{n\perp} + \frac{-\nu_{en}\Omega_e(\mathbf{E}_\perp + \mathbf{v}_n \times \mathbf{B}) - \Omega_e^2 \mathbf{b} \times (\mathbf{E}_\perp + \mathbf{v}_n \times \mathbf{B})}{B(\nu_{en}^2 + \Omega_e^2)} \quad (9)$$

$$\Omega_e = eB/m_e \quad (10)$$

Limiting perpendicular velocity ($\nu_{in}, \nu_{en}$ going to zero):

$$\mathbf{v}_{i\perp} = \mathbf{v}_{e\perp} = \mathbf{E} \times \mathbf{B}/B^2 \quad (11)$$



B
E
Altitude
V
J
160 km
e
i
125 km
e
i
Hall
Pedersen
110 km
e
i

## Ohm's Law

$$\begin{aligned} \mathbf{J} &= ne(\mathbf{v}_i - \mathbf{v}_e) \\ &= \sigma_{\|}\mathbf{E}_{\|} + \sigma_P(\mathbf{E}_\perp + \mathbf{v}_n \times \mathbf{B}) + \sigma_H \mathbf{b} \times (\mathbf{E} + \mathbf{v}_n \times \mathbf{B}) \end{aligned} \tag{12}$$

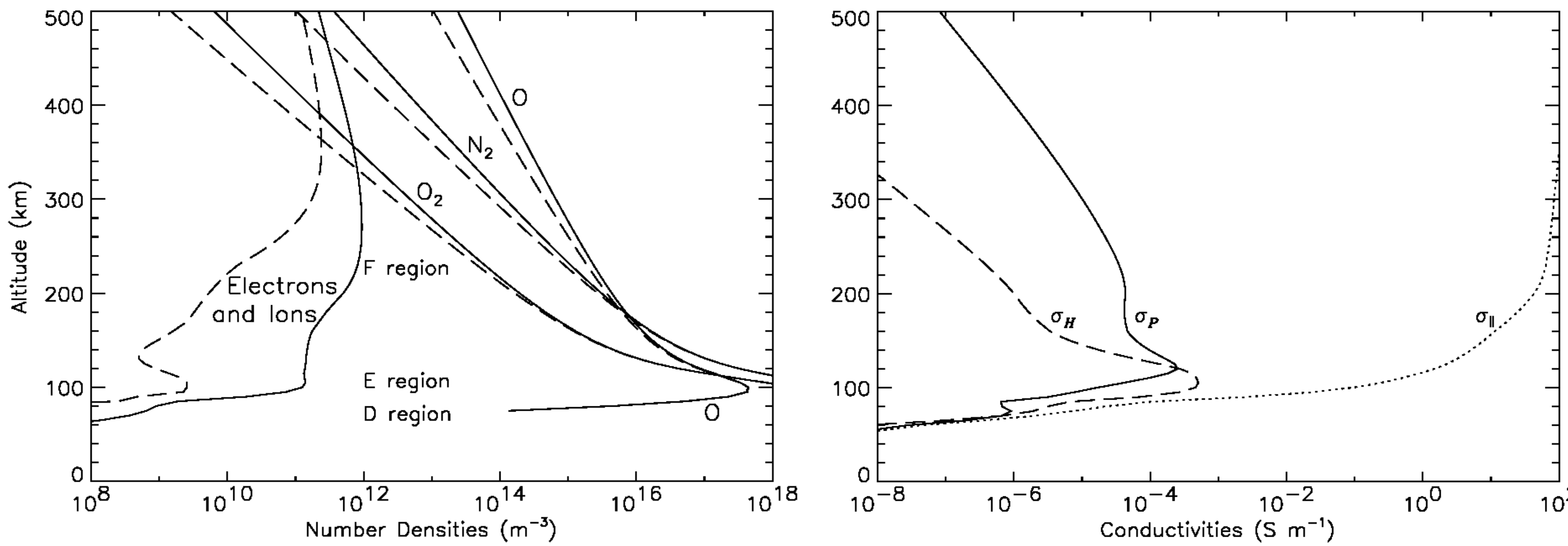
$\mathbf{J}$ electric current density

$\sigma_{\|}$ parallel conductivity

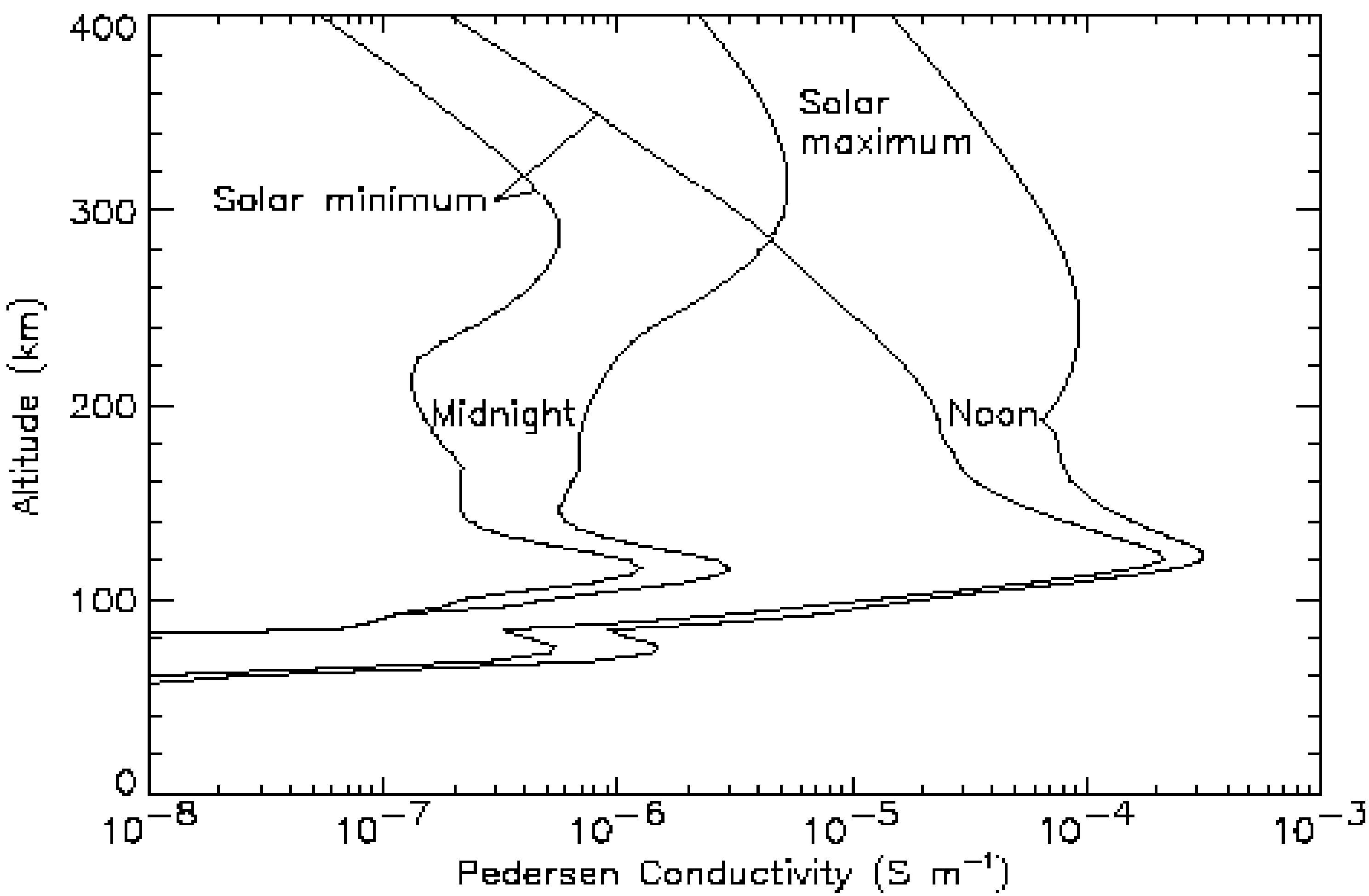
$\sigma_P$ Pedersen conductivity

$\sigma_H$ Hall conductivity

$\mathbf{b}$ unit vector parallel to $\mathbf{B}$




$$\mathbf{J} = \sigma_0\, \mathbf{E}_0 + \sigma_P\, (\mathbf{E}_p + \mathbf{u} \times \mathbf{B}) + \sigma_H\, (B/B) \times (\mathbf{E} + \mathbf{u} \times \mathbf{B})$$



400
300
200
100
0
Altitude (km)
Solar minimum
Solar maximum
Midnight
Noon
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
Pedersen Conductivity (S m^-1)

## Horizontal momentum equation for neutrals

$$\rho \frac{D\mathbf{v}_{nh}}{Dt} + 2\rho\Omega\cos\theta\mathbf{z}\times\mathbf{v}_{nh} = -\nabla_h p + \frac{\partial}{\partial z}\left(\mu\frac{\partial \mathbf{v}_{nh}}{\partial z}\right) + \rho\nu_{ni}(\mathbf{v}_{ih} - \mathbf{v}_{nh}) \tag{13}$$

$$\nu_{ni} = (n_i m_i/\rho)\nu_{in} \tag{14}$$

$\mathbf{v}_{nh}$ horizontal neutral velocity

$\Omega$ angular rotation rate of Earth

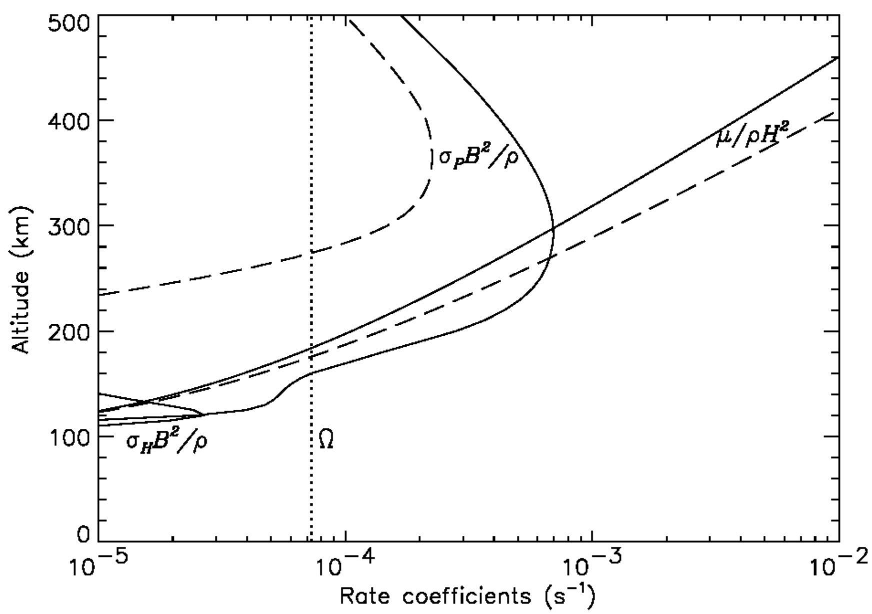
$z$ altitude

$\mathbf{z}$ unit vertical vector

$\mu$ viscosity coefficient

$\rho$ mass density

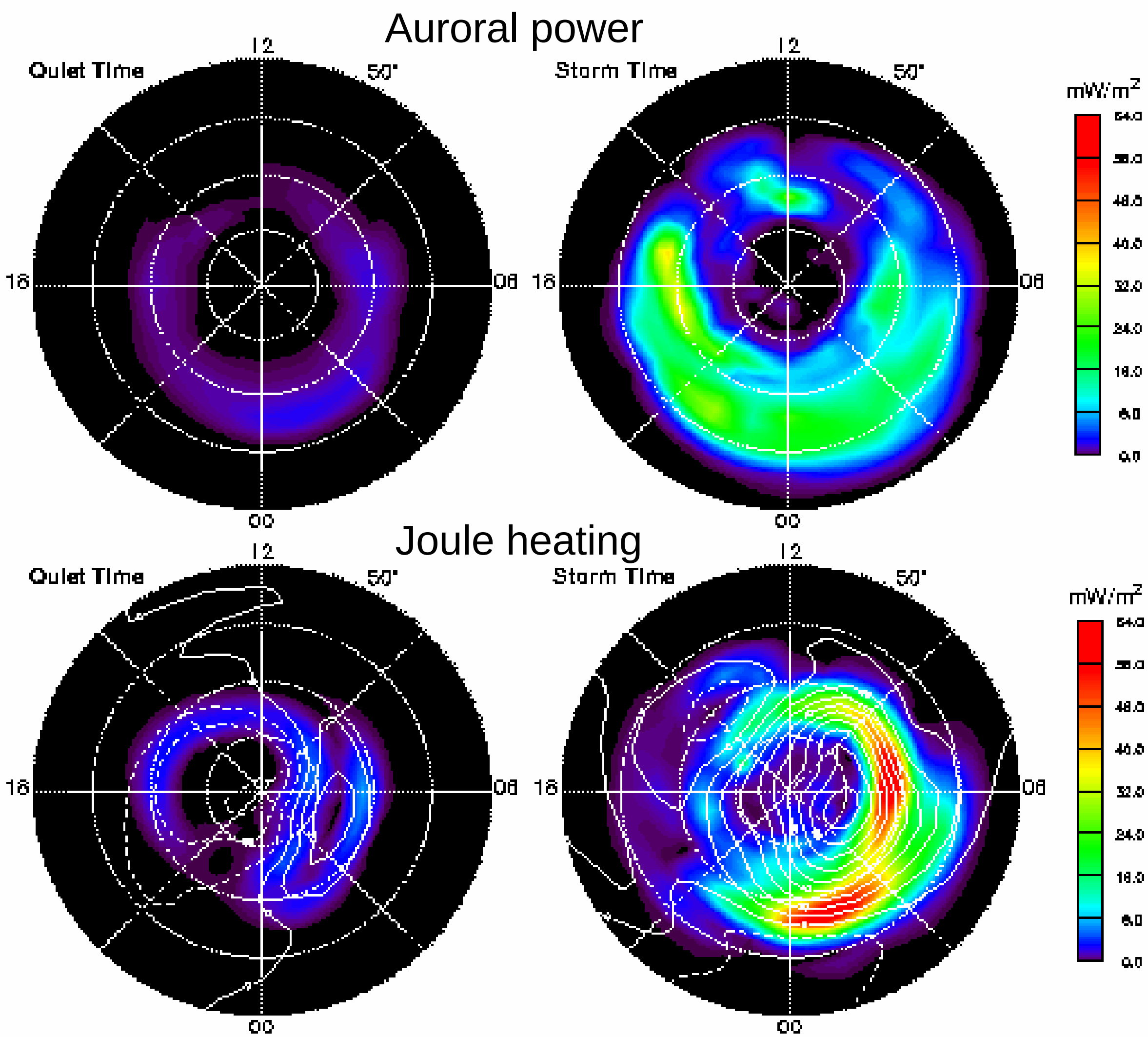
$\theta$ colatitude

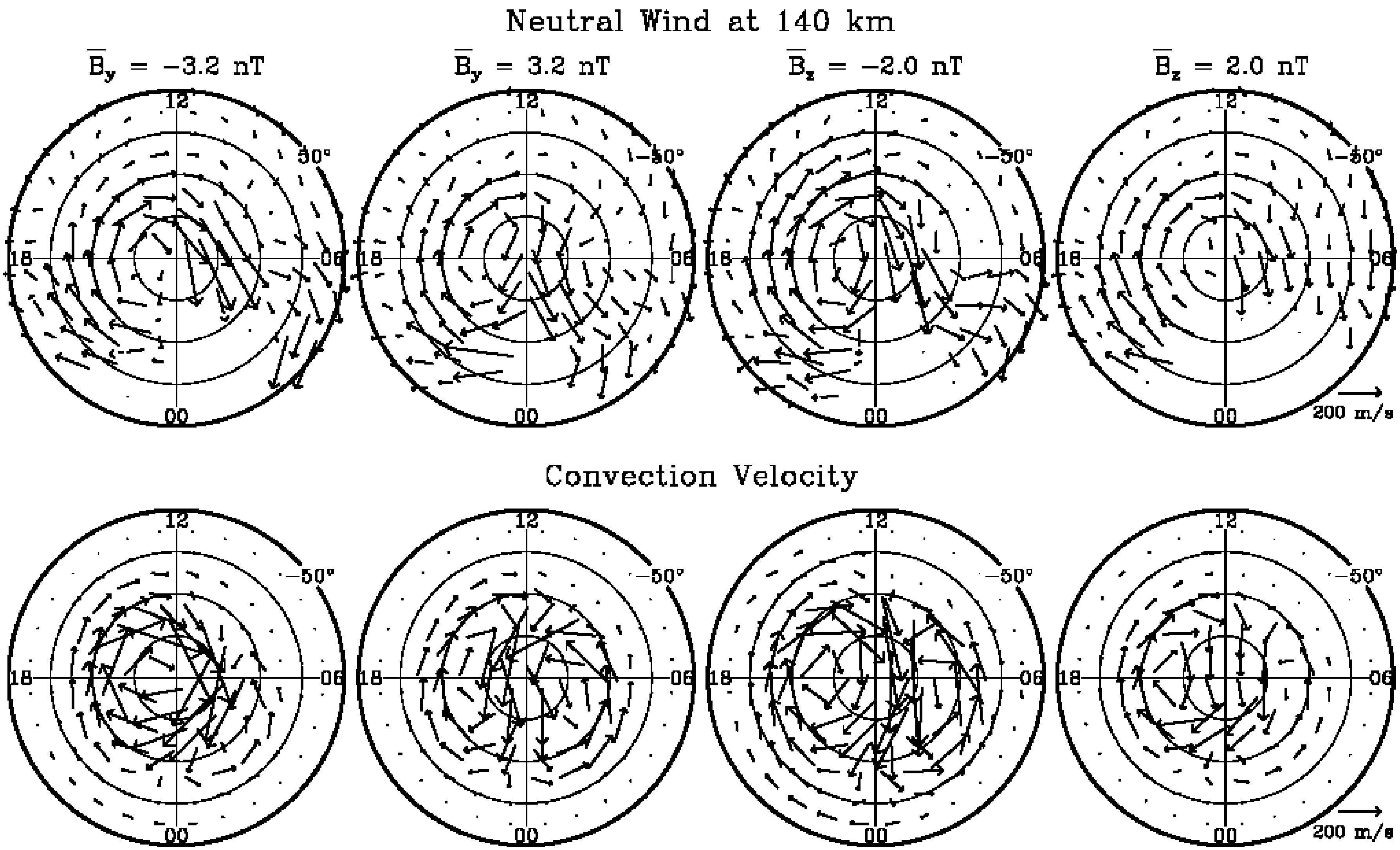



$$\text{Ion drag acceleration} = \left(\frac{\sigma_P B^2}{\rho}\right)\left(\frac{\mathbf{E}\times\mathbf{B}}{B^2} - \mathbf{u}_\perp\right) + \left(\frac{\sigma_H B^2}{\rho}\right)\frac{\mathbf{B}}{B}\times\left(\frac{\mathbf{E}\times\mathbf{B}}{B^2} - \mathbf{u}_\perp\right)$$

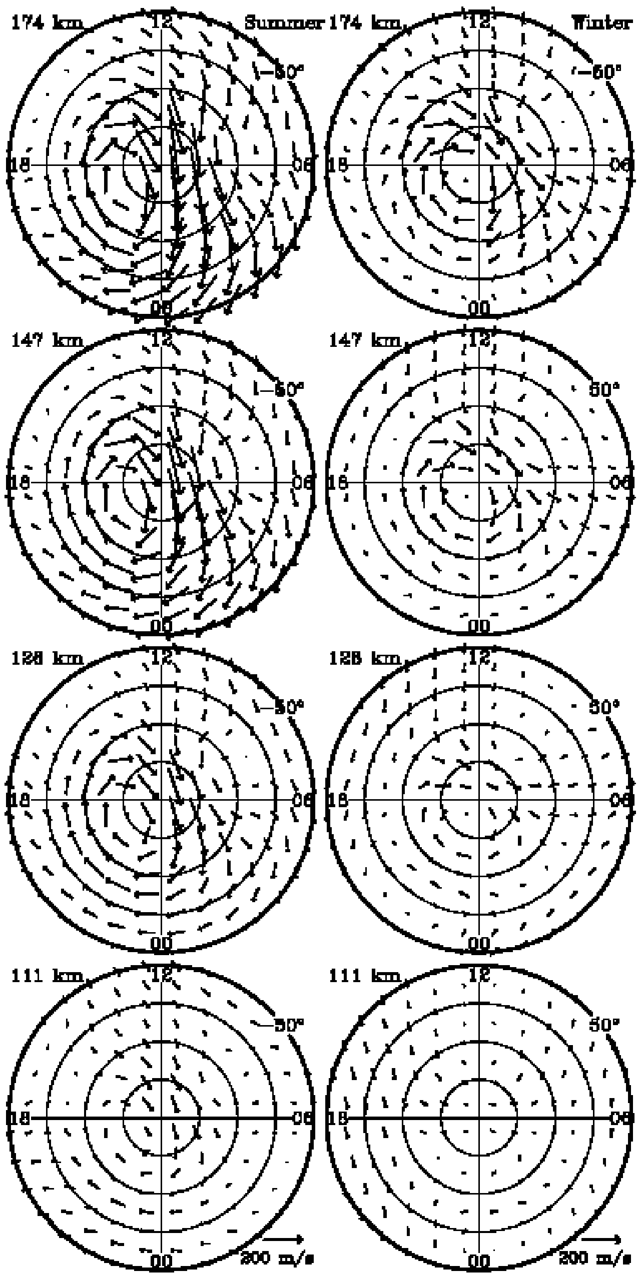
$$\text{Joule heating per unit mass} = \left(\frac{\sigma_P B^2}{\rho}\right)\left(\frac{\mathbf{E}\times\mathbf{B}}{B^2} - \mathbf{u}_\perp\right)^2$$

$\mathbf{B}$ = Magnetic field
$\mathbf{E}$ = Electric field
H = Scale height
$\mathbf{u}_\perp$ = Wind component perpendicular to $\mathbf{B}$
$\mu$ = Molecular viscosity coefficient
$\rho$ = Mass density
$\sigma_H$ = Hall conductivity
$\sigma_P$ = Pedersen conductivity
$\Omega$ = Earth rotation

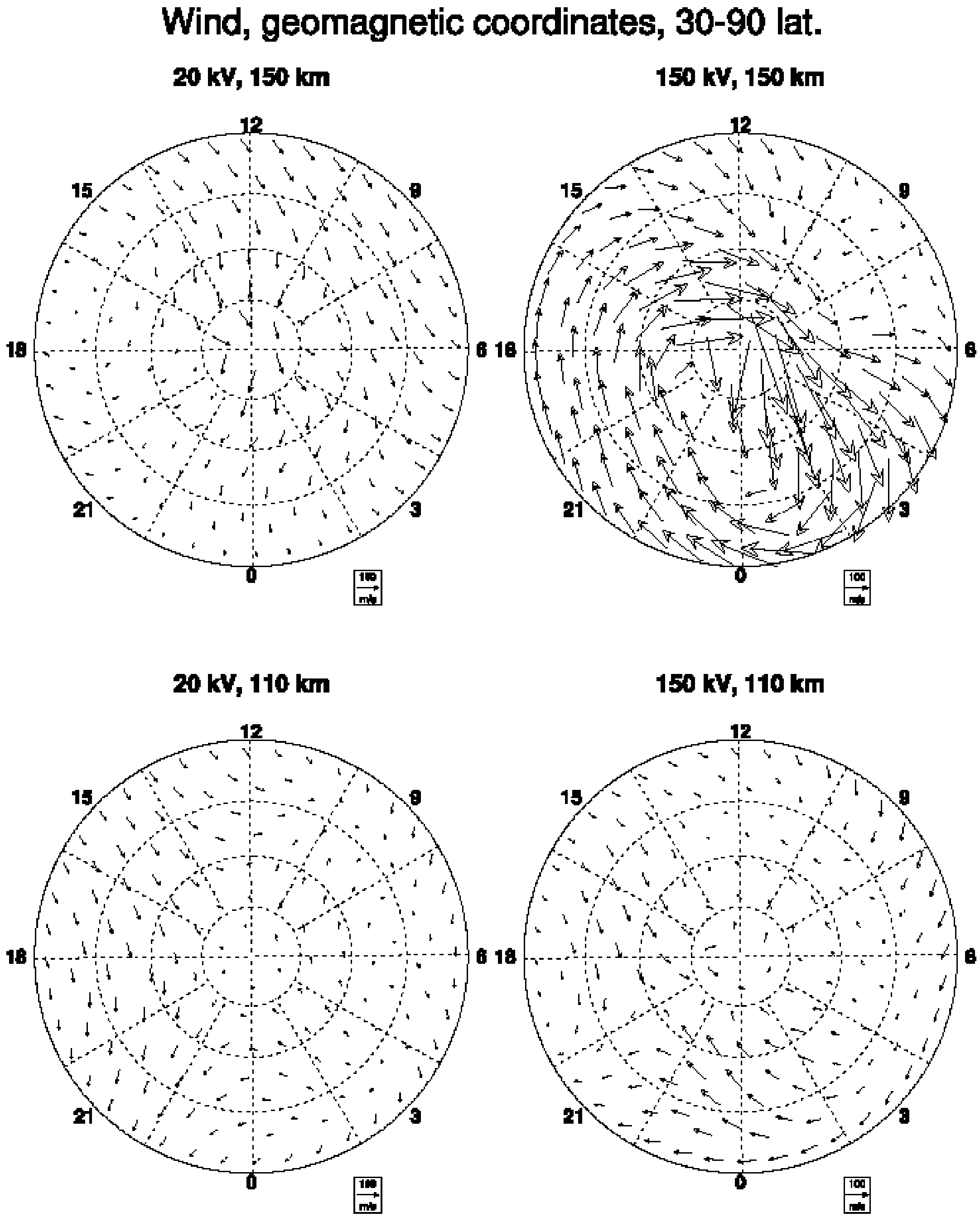

Auroral power
Quiet Time
Storm Time
12
50°
18
06
00
mW/m2
Joule heating
Quiet Time
Storm Time
12
50°
18
06
00
mW/m2



Neutral Wind at 140 km
$\overline{B}_y$ = −3.2 nT
$\overline{B}_y$ = 3.2 nT
$\overline{B}_z$ = −2.0 nT
$\overline{B}_z$ = 2.0 nT
12
18
06
00
−50°
200 m/s
Convection Velocity
200 m/s



174 km
Summer
174 km
Winter
147 km
147 km
128 km
128 km
111 km
111 km
12
18
06
00
50°
200 m/s
200 m/s


Wind, geomagnetic coordinates, 30-90 lat.
20 kV, 150 km
150 kV, 150 km
20 kV, 110 km
150 kV, 110 km
12
15
9
18
6
21
3
0
100
m/s

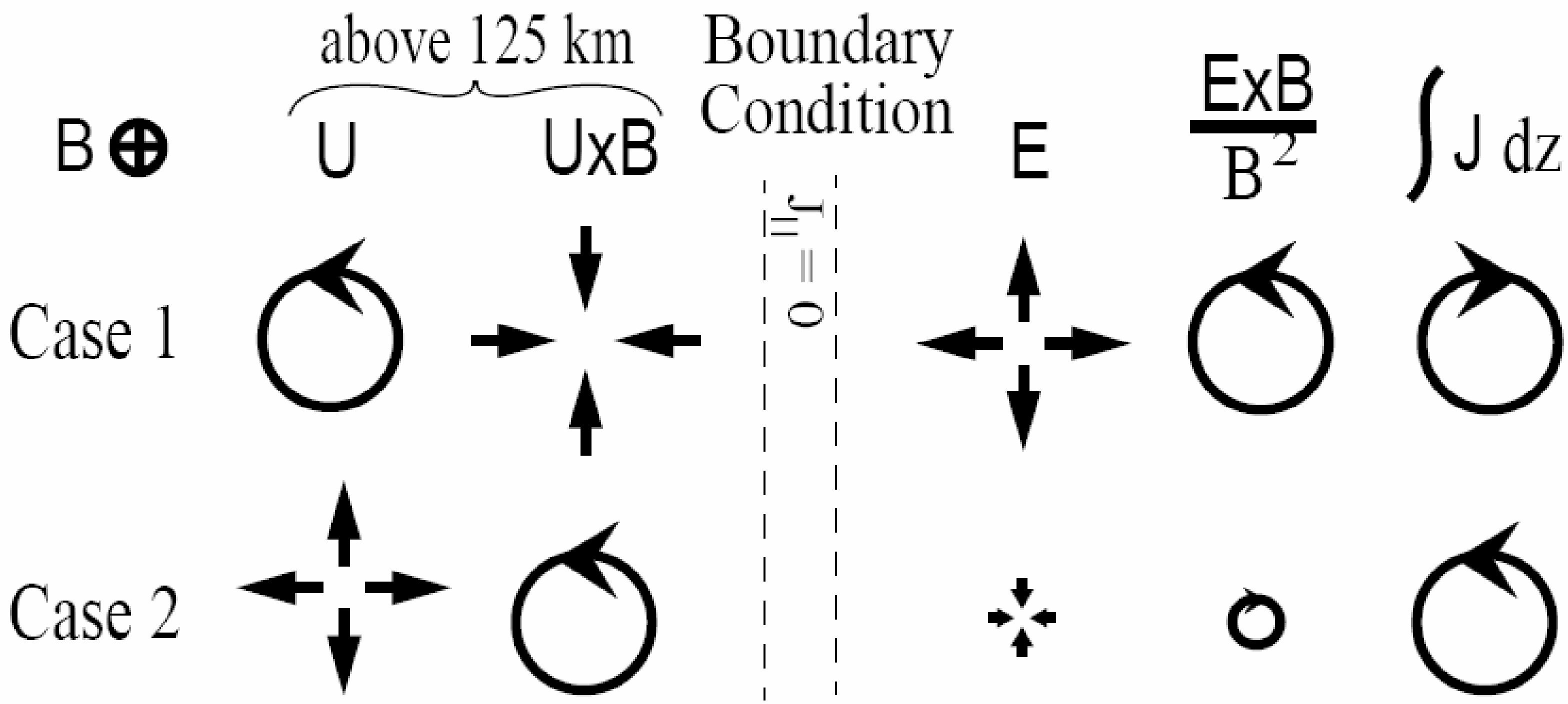
## Dynamo Equations

$$\mathbf{J} = \sigma_{\|}\mathbf{E}_{\|} + \sigma_P(\mathbf{E}_{\perp} + \mathbf{v}_n \times \mathbf{B}) + \sigma_H \mathbf{b} \times (\mathbf{E} + \mathbf{v}_n \times \mathbf{B}) \tag{12}$$

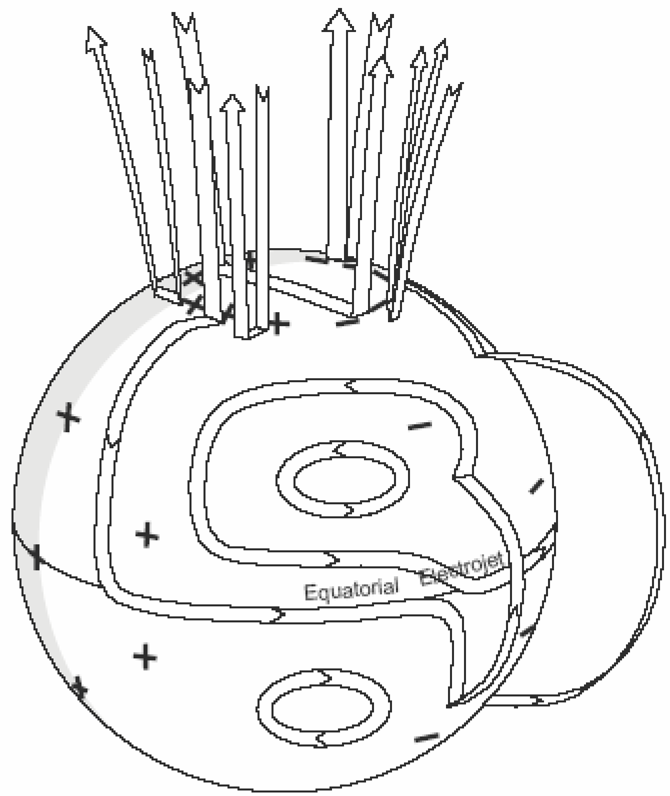
$$\nabla \cdot \mathbf{J} = 0 \tag{15}$$

$$\mathbf{E} = -\nabla\Phi \tag{16}$$

plus boundary conditions



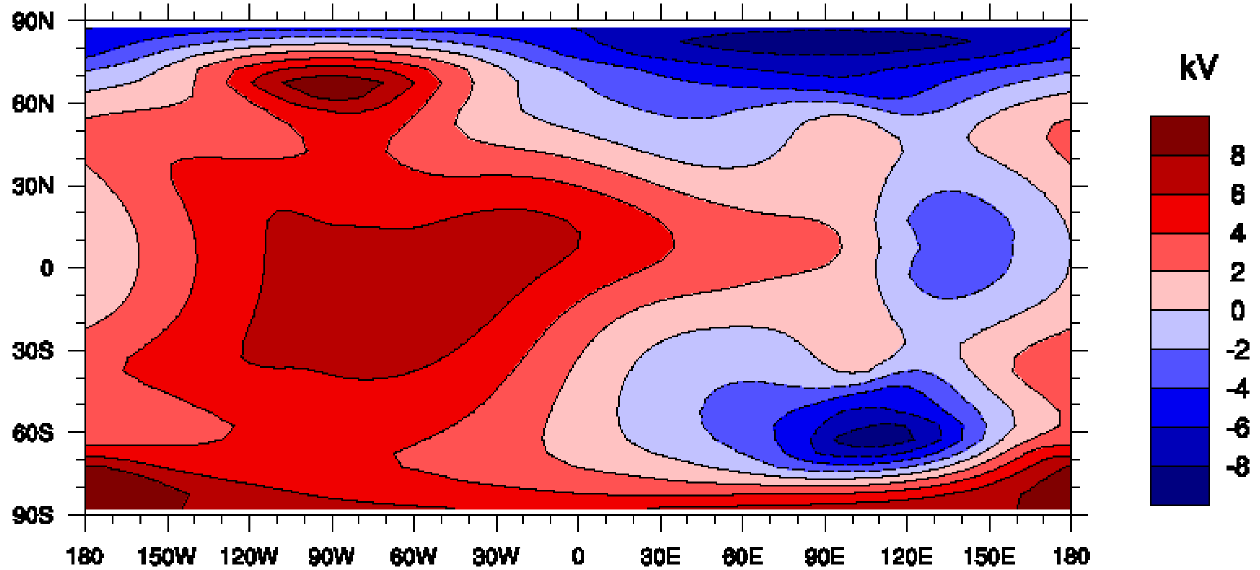
above 125 km
Boundary
Condition
B
U
UxB
E
ExB
B 2
J dz
J|| = 0
Case 1
Case 2



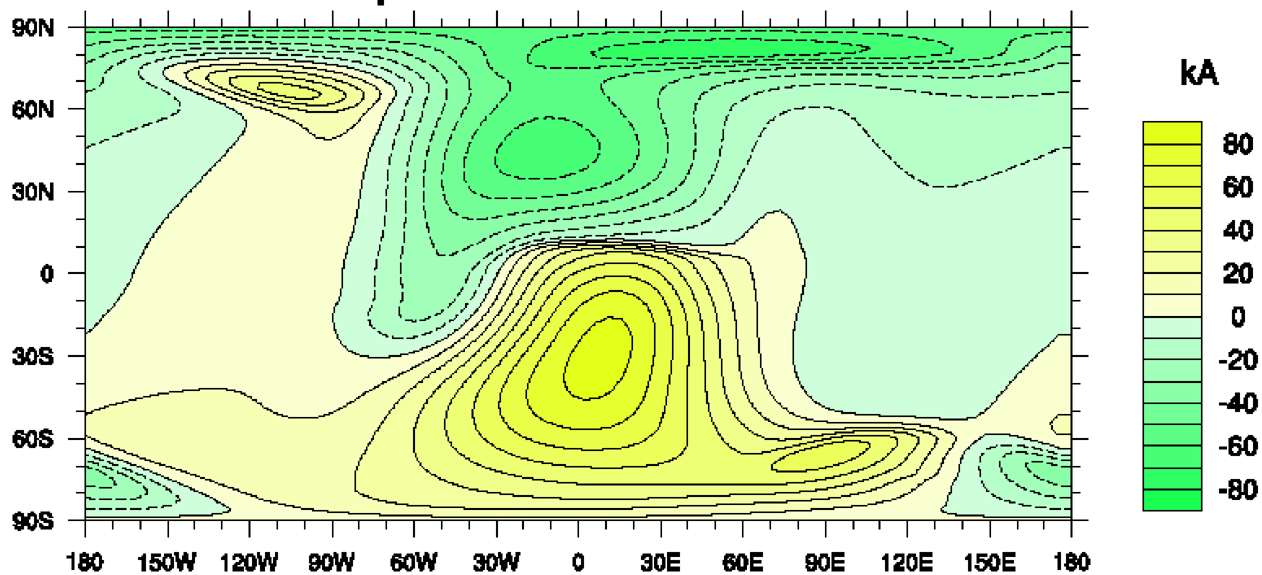
Equatorial
Electrojet

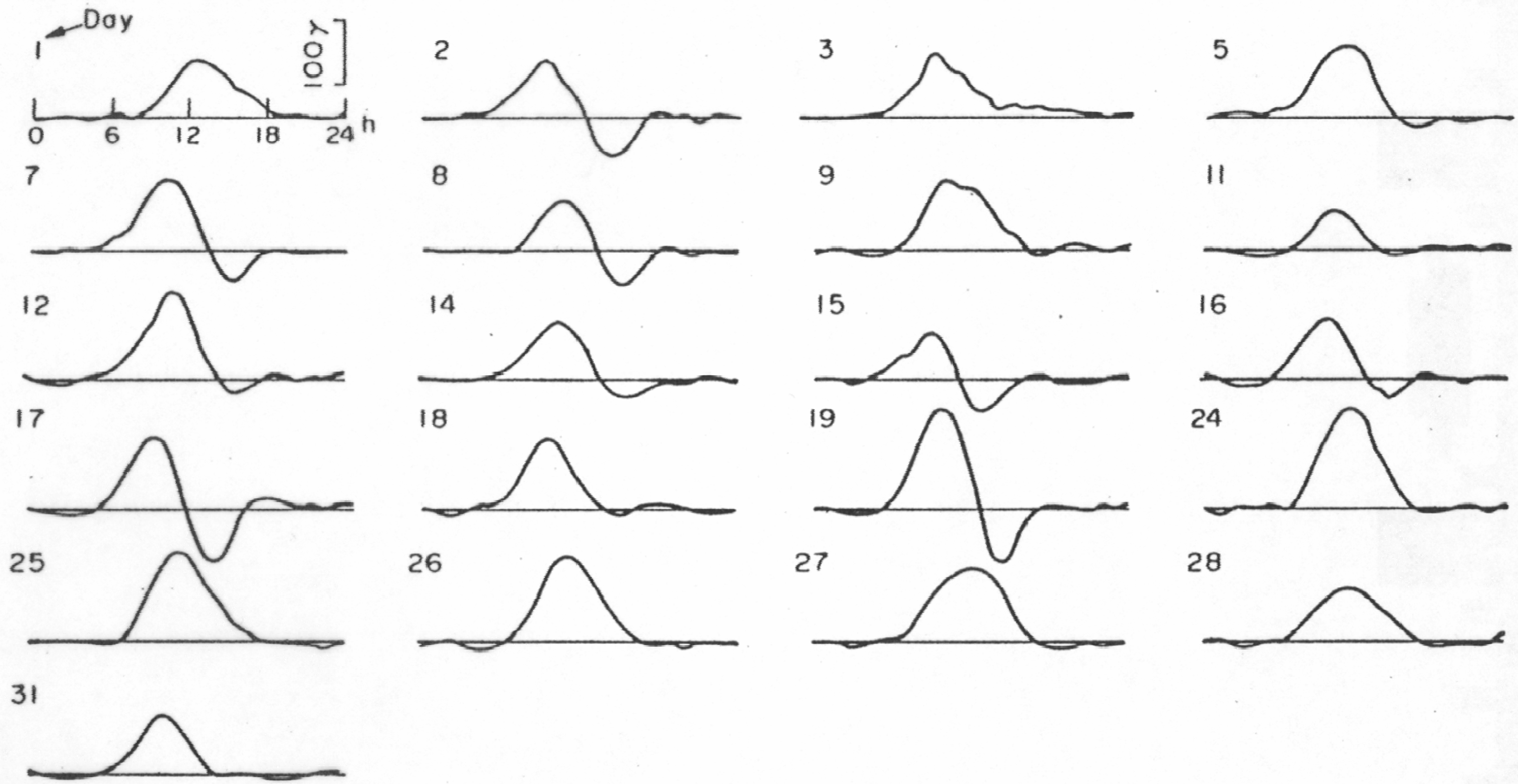
## With migrating tides, 12 UT, March

### Electric potential



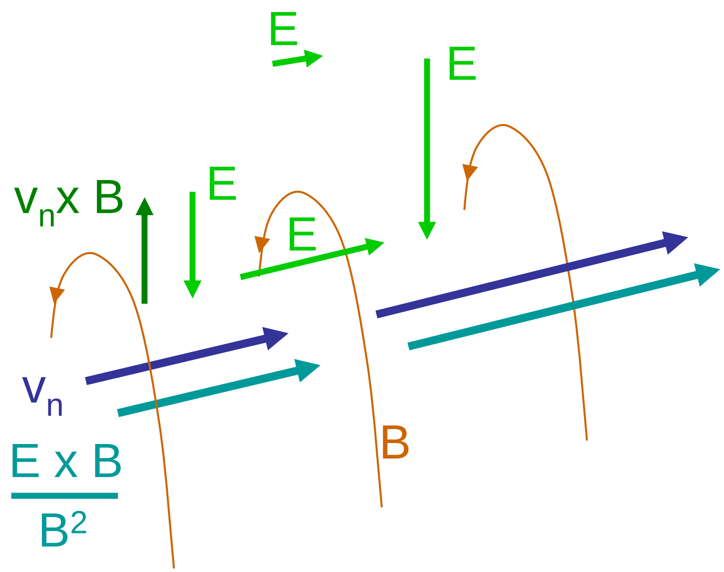

### equivalent current function

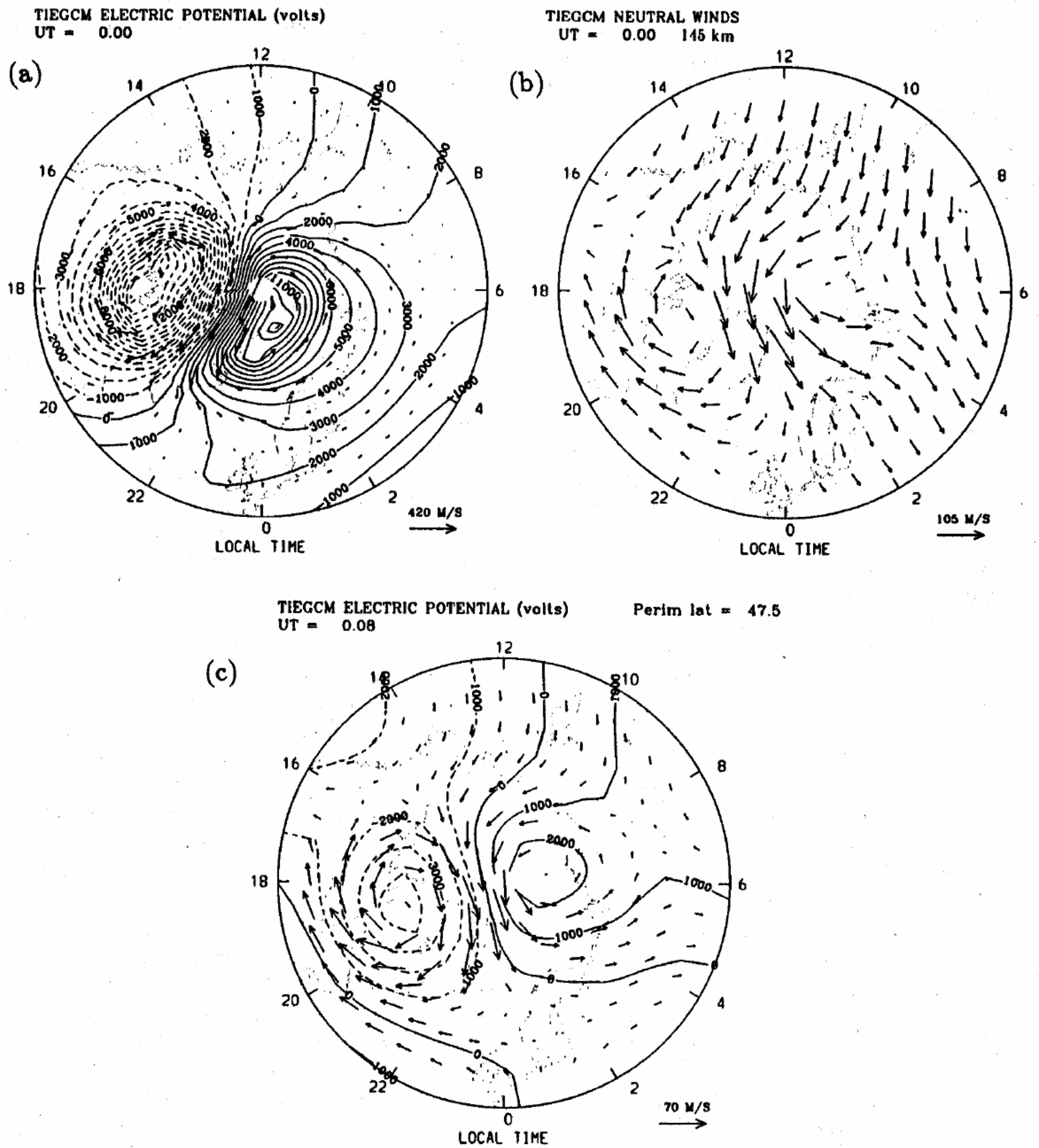




Day
100γ
0
6
12
18
24
h
1
2
3
5
7
8
9
11
12
14
15
16
17
18
19
24
25
26
27
28
31

# Evening F-region Dynamo



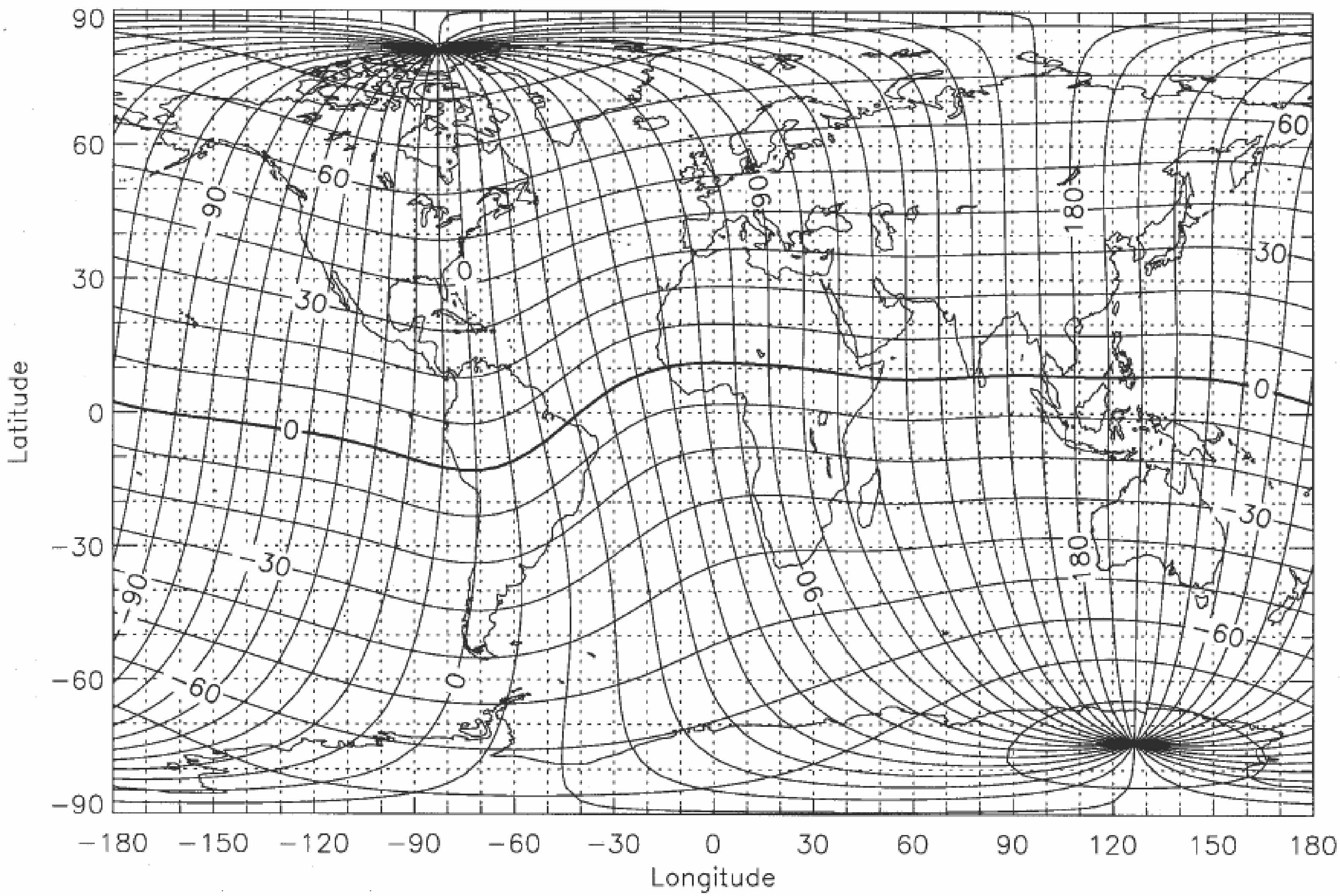


TIEGCM ELECTRIC POTENTIAL (volts)
UT = 0.00
(a)
LOCAL TIME
420 M/S
TIEGCM NEUTRAL WINDS
UT = 0.00 145 km
(b)
LOCAL TIME
105 M/S
TIEGCM ELECTRIC POTENTIAL (volts)
UT = 0.08
Perim lat = 47.5
(c)
LOCAL TIME
70 M/S

# Summary

- Ion-neutral interactions strongly influence both ion and neutral dynamics.
- High-latitude thermospheric winds are often dominated by ion convection.
- Ionospheric wind dynamo usually dominates low-latitude electric fields.
- Mutual coupling of thermosphere and ionosphere dynamics is important.

M(110) Coordinates at 110 km for 1995.0



# Wind, 12 UT, March