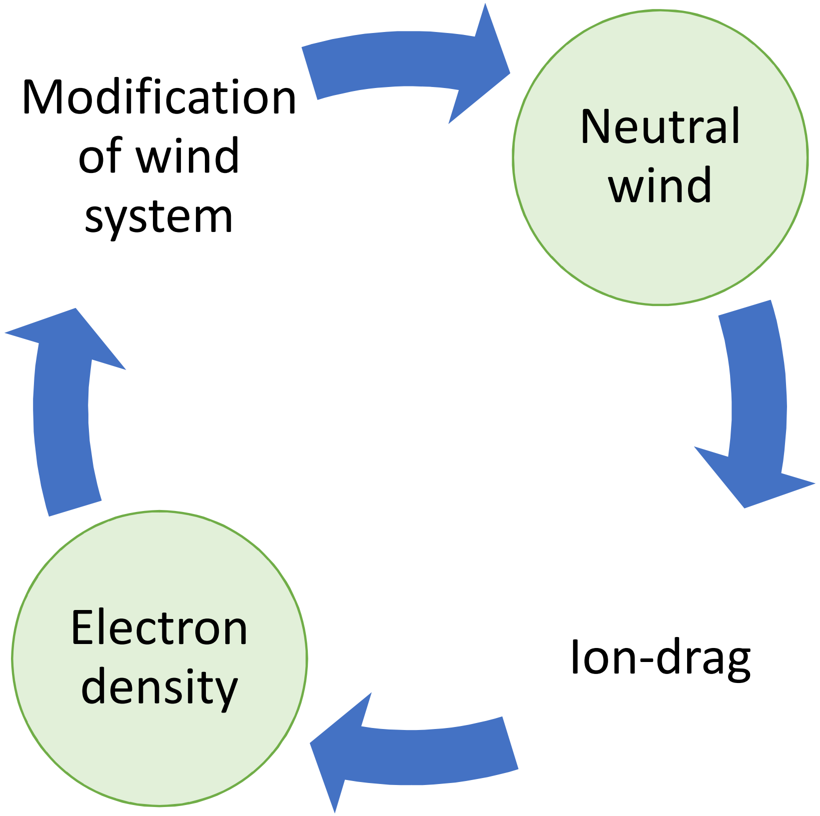
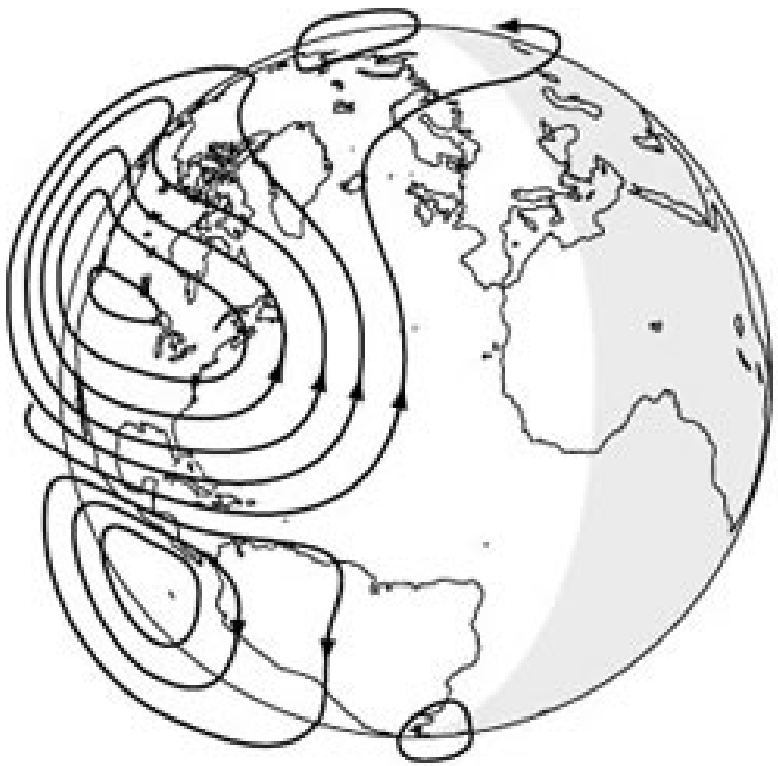
Ion-Drag



- Upper atmosphere winds → ion-drag
- bulk motions of the ions and electrons in the ionosphere are greatly influenced by the ion-drag
- Ion-drag acts as a resistance to the neutral gas flow
- Ion-drag is proportional to the electron density → variation in the electron density leads to a perturbation in the neutral gas dynamics.

Ionospheric wind dynamo



- Upper atmosphere winds
- Electrically conducting medium
- Earth’s magnetic field

→electromotive force that drives

- currents,
- electric polarization charges
- electric fields

Generalized Ohm‘s Law

$$j = \sigma(\vec{E} + \vec{v}_n \times \vec{B})$$

j: density of current flowing in the dynamo layer (E-layer)

σ: conductivity tensor

E: electrostatic field generated by the polarisation due to differential motions of ions and electrons

v_n: velocity of neutrals

B: geomagnetic flux density

The component $v_n \times B$ of E, representing the difference between the electric field in the reference frame of the moving neutrals and the electric field in the Earth reference frame, is often called the dynamo electric field.

Richmond (1995, p. 8),Maeda (1977)

Ionospheric wind dynamo (conventional)

Dynamo equations:

$$\vec{J} = \sigma(\vec{E} + \vec{u} \times \vec{B})$$
$$= \sigma_{\parallel}\vec{E}_{\parallel} + \sigma_P(\vec{E}_{\perp} + \vec{u} \times \vec{B})$$
$$+ \sigma_H \frac{\vec{B}}{|\vec{B}|} \times (\vec{E} + \vec{u} \times \vec{B})$$

$$\vec{E} = -\nabla\Phi$$

$$\nabla \cdot \vec{J} = 0$$

Blanc+Richmond (1980)
Yamazaki + Maute (2017)
Vasiliunas (2012)

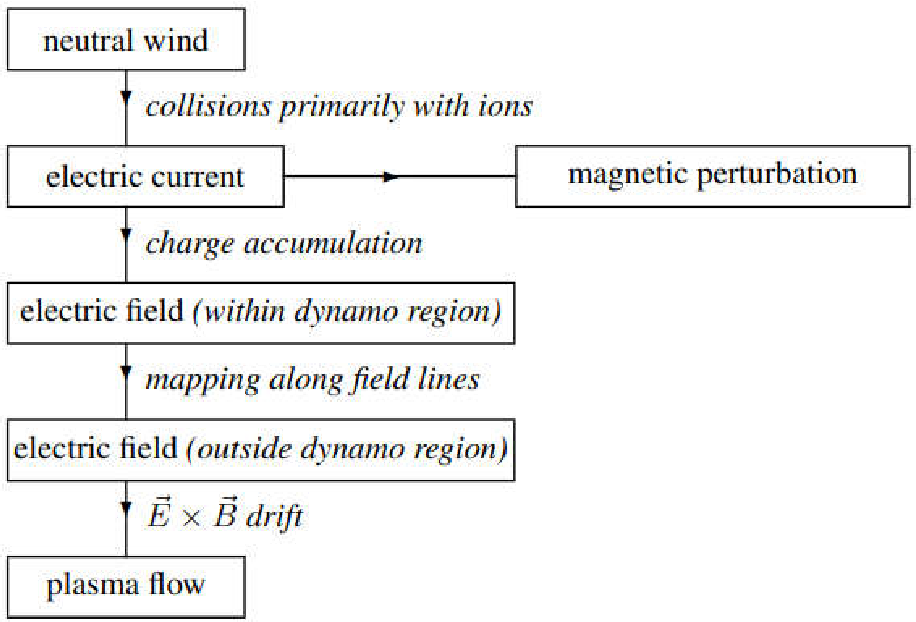


Fig. 3. Schematic diagram of how a neutral-wind dynamo develops, as understood in the conventional approach.

Ionospheric wind dynamo (physical)

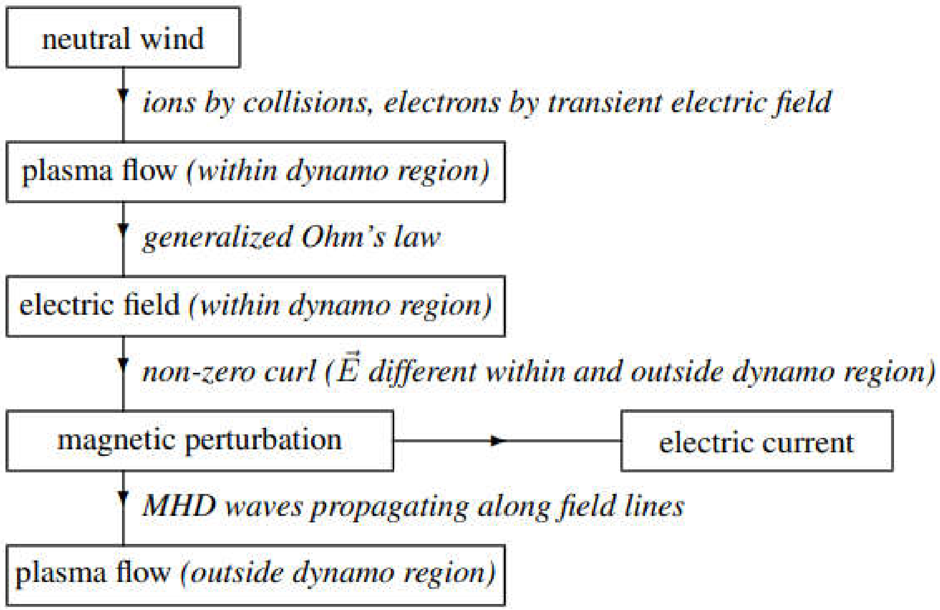
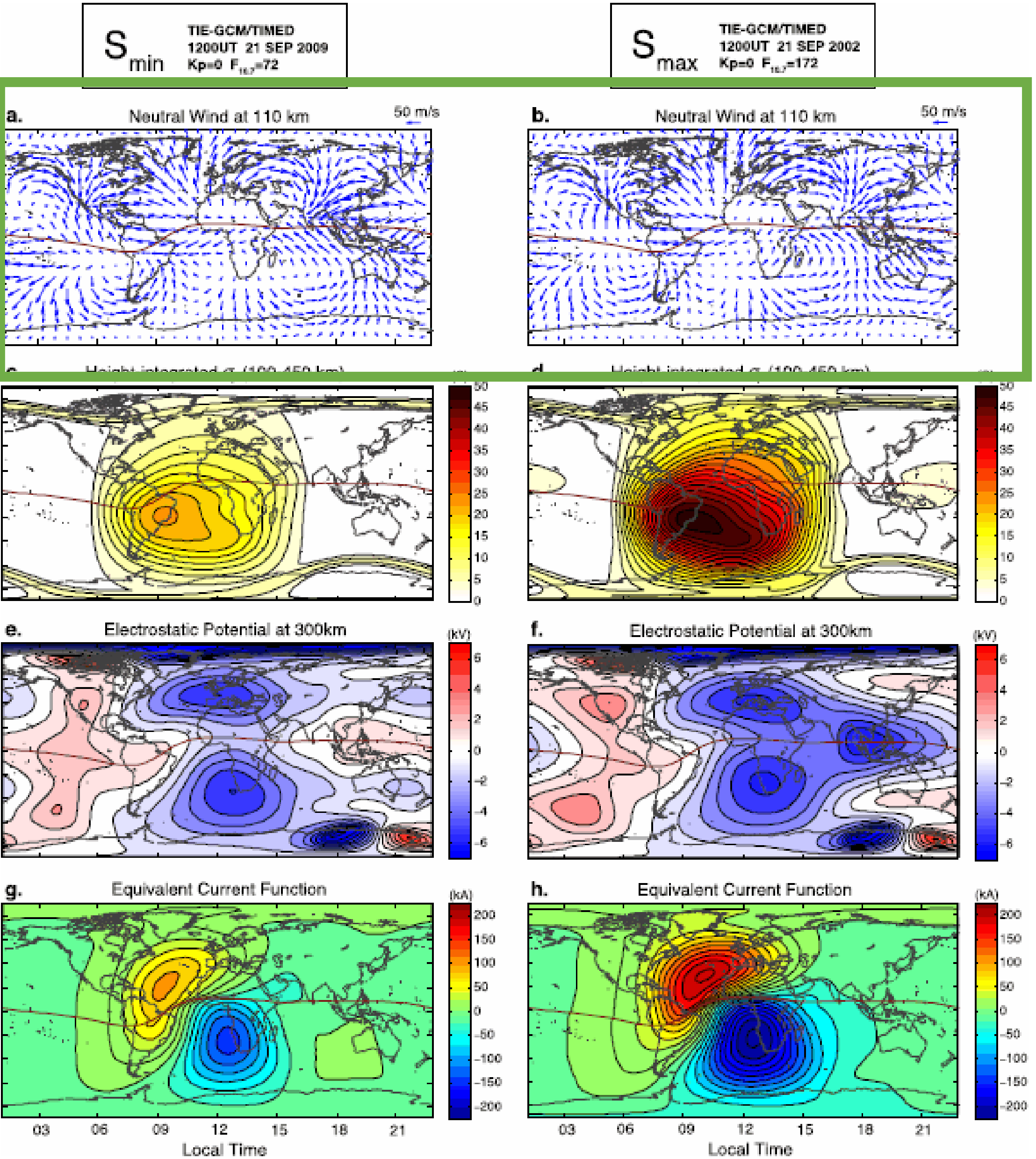


Fig. 4. Schematic diagram of how a neutral-wind dynamo develops, as understood on the basis of the complete physical equations.

Vasyliūnas (2012)

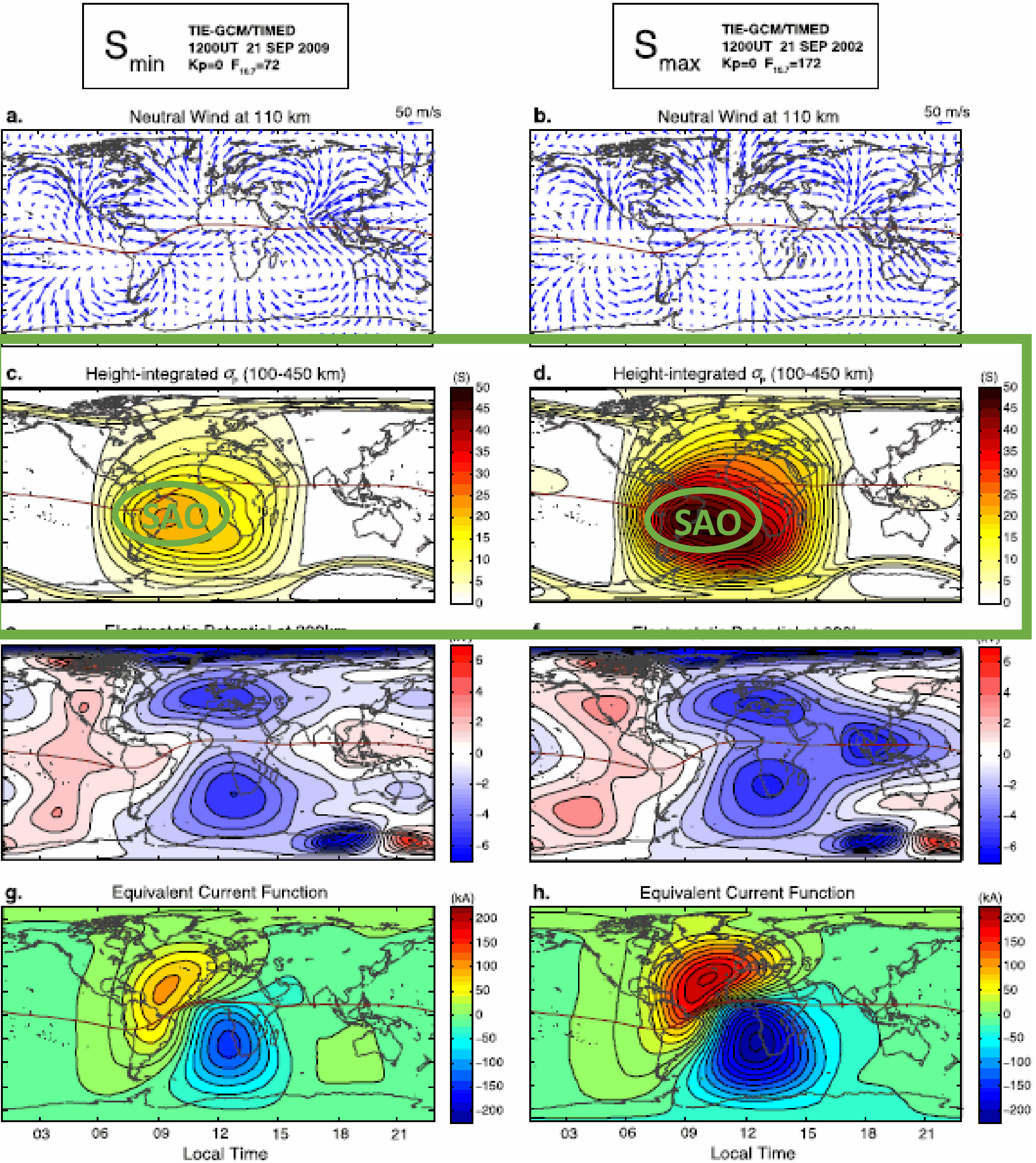
- Electric fields do not produce plasma flows; they are a consequence of plasma flow and other terms in the generalized Ohm's law.
- The electric current is determined, in a quasi-steady state, by the requirement that the magnetic stress balance the mechanical stress (specifically for the ionosphere, the collisional friction between plasma and neutrals).
- There is no "mapping" process along magnetic field lines; changes of plasma flow and electric field are propagated by appropriate (mostly MHD) wave
- Neutral winds do not create electric currents directly; they create plasma motions, which then deform the magnetic field, and the current arises to match the curl of the deformed field

Ionospheric wind dynamo



- Winds are created by
  - daily absorption of solar radiation in the thermosphere
  - upward-propagating solar and lunar tides,
  - ion-drag acceleration at high latitudes
  - Joule heating at high latitudes
- when plasma collides with a flowing neutral medium, different bulk velocities are imparted to ions and to electrons

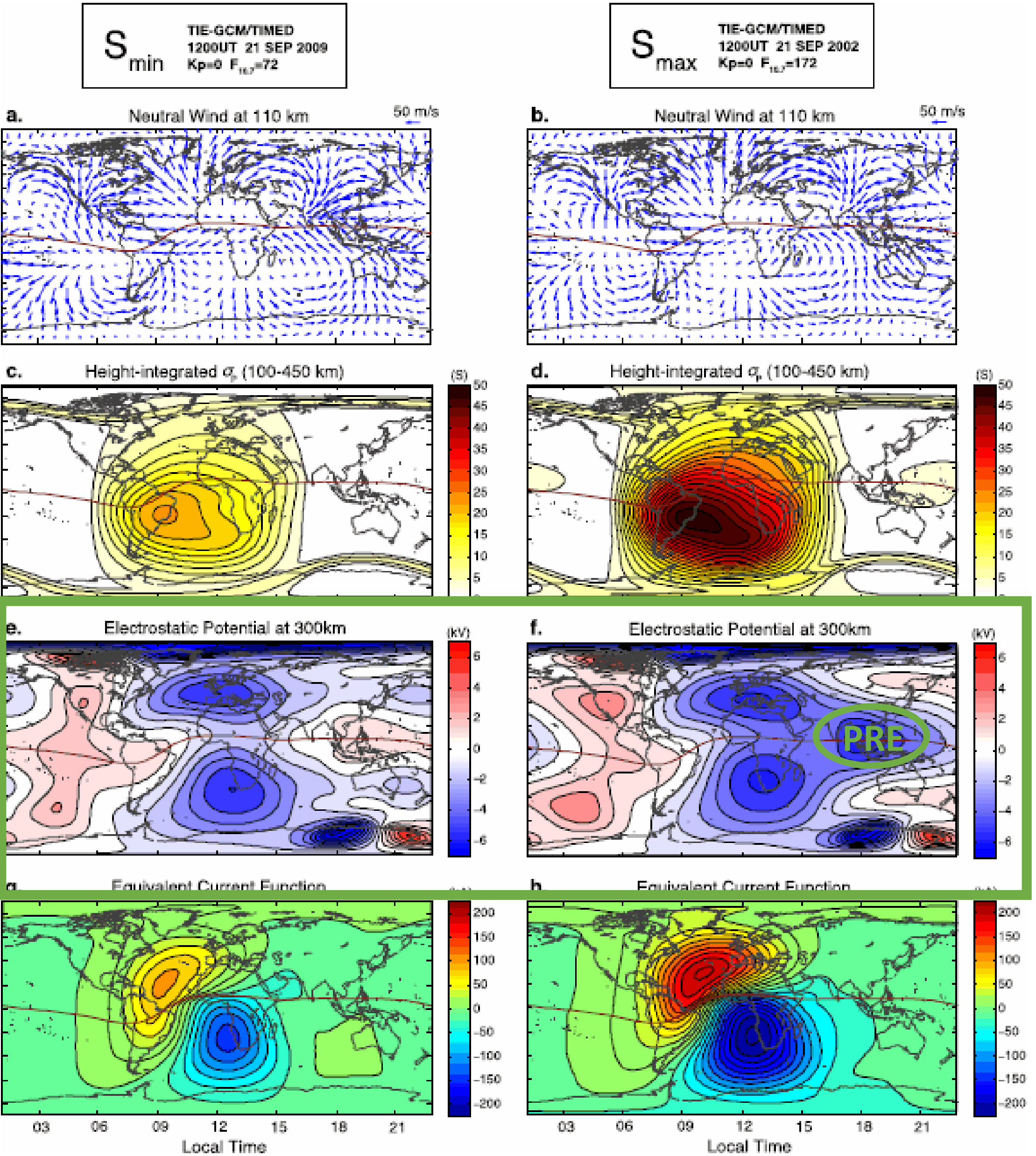
Yamazaki and Maute (2017)



Ionospheric wind dynamo

- Hall and Pedersen conductivities vary with
  - Electron density
  - Strength and background geomagnetic field

Yamazaki and Maute (2017)



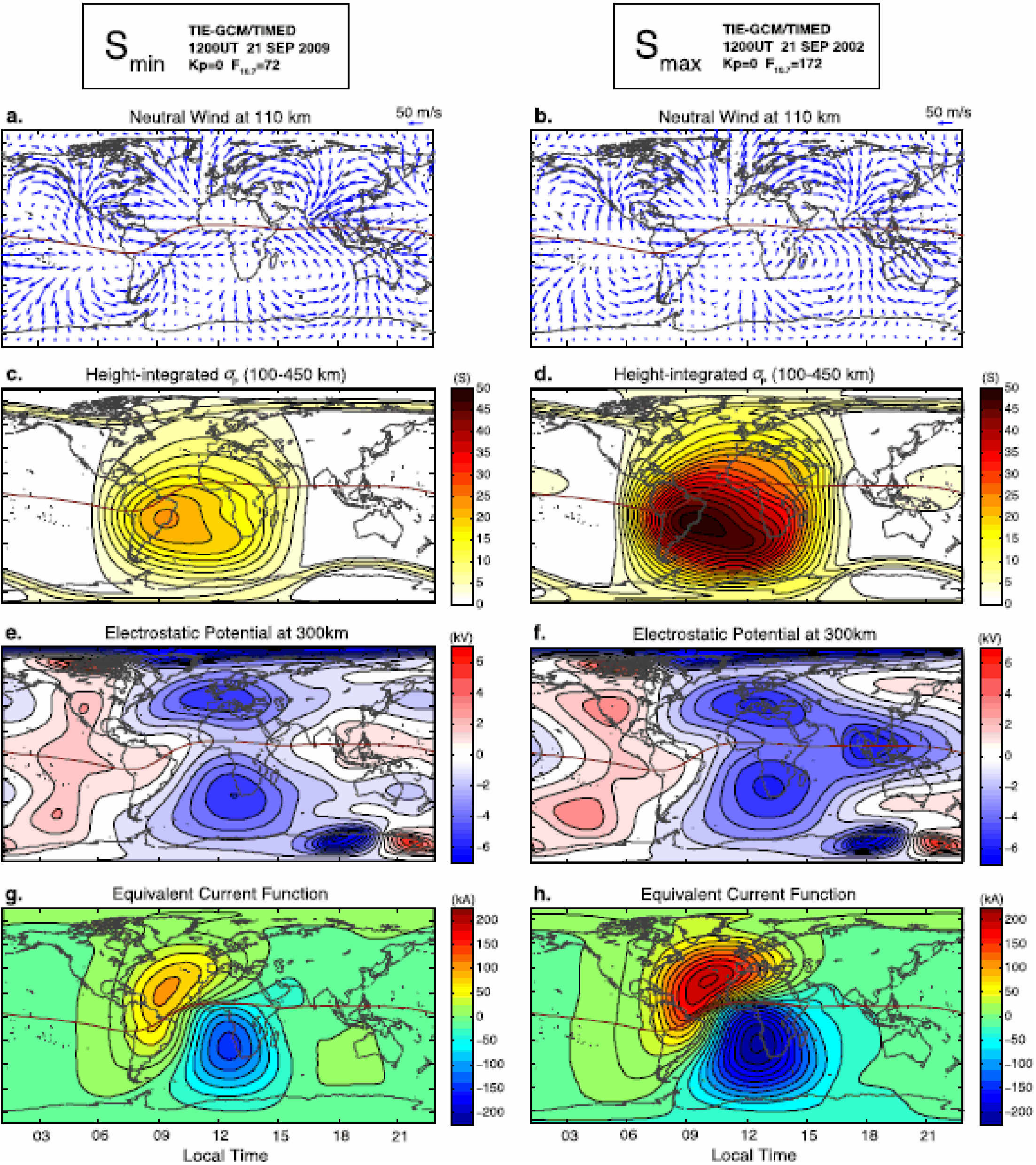
Ionospheric wind dynamo

- Dynamo equations can be combined to calculate the potential

$$\nabla \cdot \sigma \cdot \nabla \Phi = \nabla \cdot \sigma \cdot (\vec{u} \times \vec{B})$$

- The electric potential (Figs. 8e and 8f) is symmetric about the magnetic equator at middle and low latitudes
- largely independent of solar activity
- except that during solar maximum there is a rapid potential drop at the magnetic equator around the sunset (pre-reversal enhancement)

Yamazaki and Maute (2017)



Ionospheric wind dynamo

- Dynamo currents are created by charge separation at the terminators
- Westward current develops in mid-latitudes
- It closes at the equator with an eastward current

Yamazaki and Maute (2017)

Magnetic field signature

- Geomagnetic Sq variations can be observed at any location on the globe
- The pattern of the Sq variation systematically changes with latitude
- Impossible to derive currents from ground observation – more than one solution of 3-D current system is responsible for the observed Sq variations
- concept of “equivalent” Sq current system → a two-dimensional current system which flows in a spherical thin shell (typically assumed at 110 km)

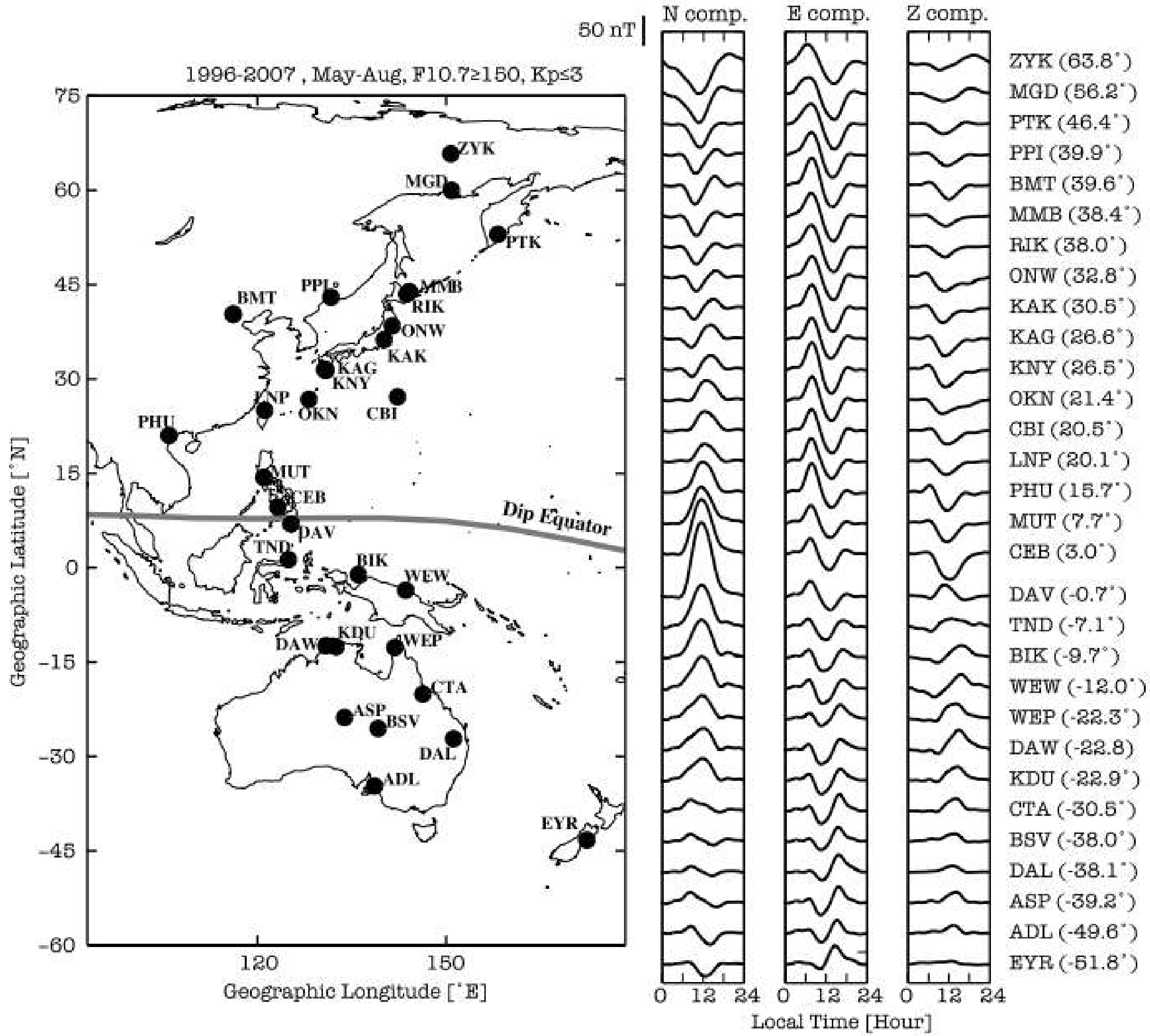


Fig. 2 Average geomagnetic daily variations in the magnetic-northward (N), magnetic-eastward (E), and vertically downward (Z) components during May–August of 1996–2007. From Yamazaki (2011)

Equatorial Eastward Electric Field

- Ionospheric dynamo action that generates westward currents will tend to polarize the dawn and dusk terminators such that a low latitude eastward electric field and current result
- Zonal component of the global electric field is usually eastward during daytime → EEF
- primary driver of many ionospheric phenomena
- Particularly important at the equator

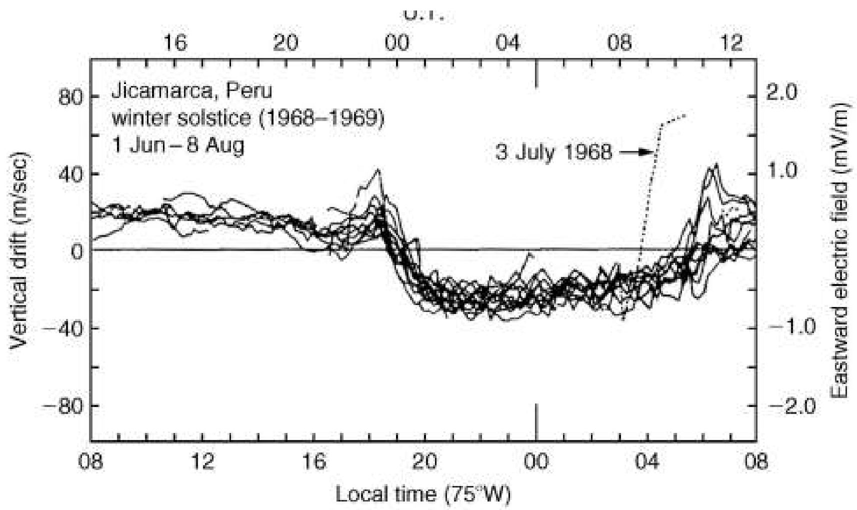
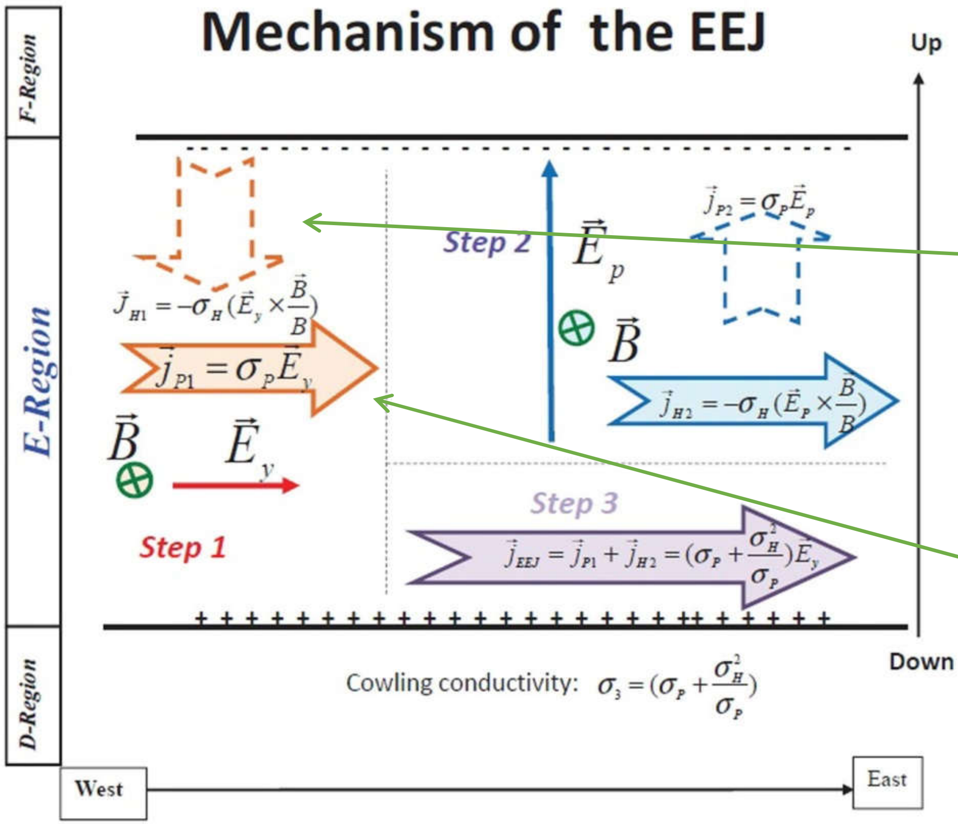


Figure 1. Superimposed vertical drifts (eastward electric fields) measured at Jicamarca, Peru. (After Woodman, 1970. Reproduced with permission of the American Geophysical Union.)

Kelley+ (2014, https://doi.org/10.5194/angeo-32-1169-2014)

Equatorial Electrojet



$\boldsymbol{\sigma_p < \sigma_H}$ Grodji et al. (2017)

Step 1: In the dynamo region of the ionosphere near the dip-equator, the **horizontal northward geomagnetic field $\vec{B}$** and **zonal electric field $\vec{E}_y$**, produce an

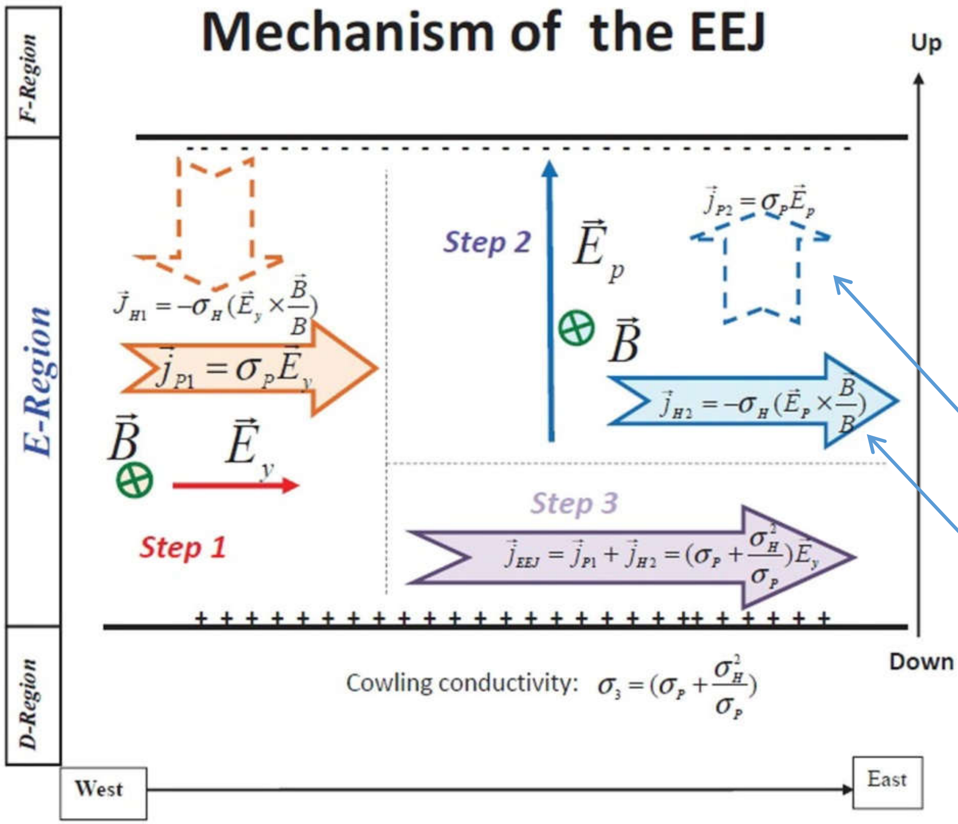
- a vertical downward Hall current $\vec{J}_{H1}$ associated with electrons upward vertical drift

and

- eastward Pedersen current

and are respectively Pedersen and Hall conductivities.

Equatorial Electrojet



$\boldsymbol{E_y < E_P}$ Grodji et al. (2017)

Step 2:

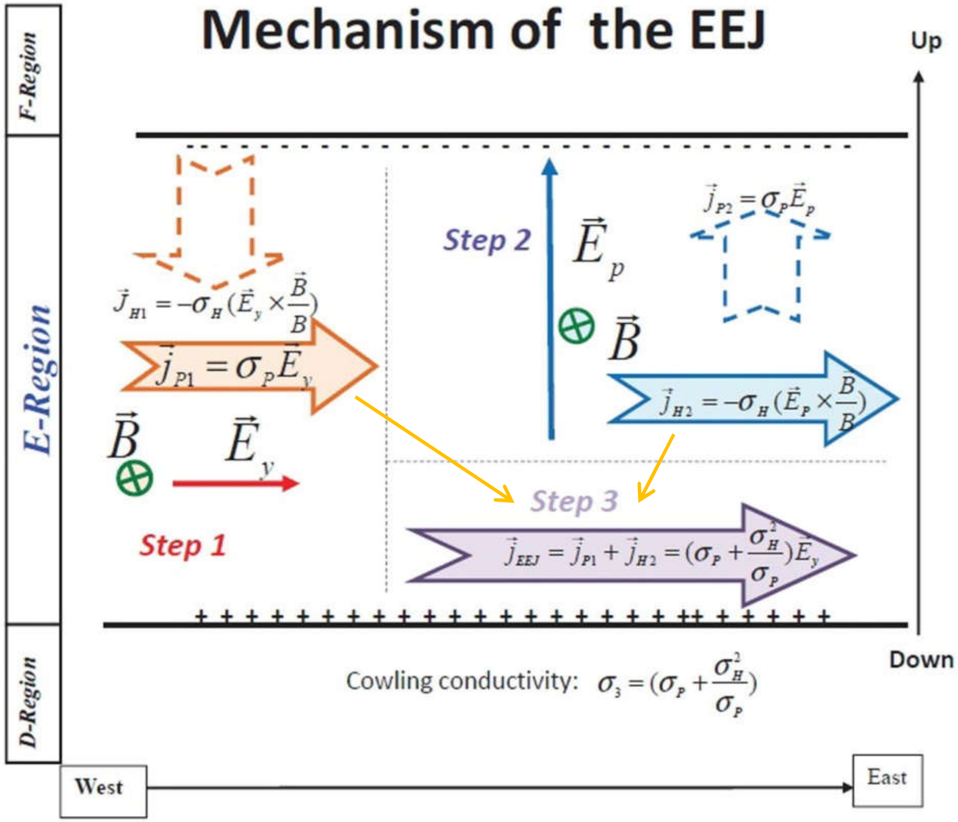
On the one hand:

- ions $\vec{E} \times \vec{B}$ drift is impeded in the E-region due to collisions with neutral particles
- electrons are relatively free to move
- the resulting charge separation gives rise to an upward vertical polarization electric field $\vec{E}_p$.

On the other hand:

- $\vec{E}_p$ gives rise to an **upward vertical Pedersen current $\vec{J}_{p2}$**
- And the westward electron drift gives rise to an **intense eastward Hall current $\vec{J}_{H2}$**

Equatorial Electrojet



Grodji et al. (2017)

Step 3: When the polarization process is complete:

- the upward vertical Pedersen current counter-balances the downward Hall current → then the net **vertical current becomes nil**

$$\boldsymbol{\sigma_p \vec{E}_p - \sigma_H \left(\vec{E}_y \times \frac{\vec{B}}{B}\right) = 0}$$

- The eastward Hall current $\overrightarrow{J_{H2}}$ **superimposes** the primary eastward Pedersen current $\overrightarrow{J_{P1}}$. Thus the total eastward current density is:

$$\vec{j}_{EEJ} = \boldsymbol{\sigma_p \vec{E}_y - \sigma_H \left(\vec{E}_p \times \frac{\vec{B}}{B}\right)} = \left(\boldsymbol{\sigma_p + \frac{\sigma^2{}_H}{\sigma_p}}\right)\boldsymbol{\vec{E}_y}$$

- The net eastward conductivity known as **"Cowling conductivity"**

$$\sigma_c = \left(\boldsymbol{\sigma_p + \frac{\sigma^2{}_H}{\sigma_p}}\right)$$