# Basics of high-latitude electrodynamics

# Basic equations: Ohm’s law

Generalised Ohm’s law describes the current

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

In largely collisionless plasma (in the solar wind, or in the magnetosphere above ~2,000 km), the conductivity is nearly infinite

$$\mathbf{E} + \mathbf{V} \times \mathbf{B} = 0$$

Ohm’s law is the ideal MHD approximation

= frozen-in magnetic field

# Basic equations: current continuity

Electrical coupling between the regions is described by

the current continuity:

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

And Faraday's law:

$$\boldsymbol{\nabla} \times \mathbf{E} + \partial \mathbf{B}/\partial t = 0$$

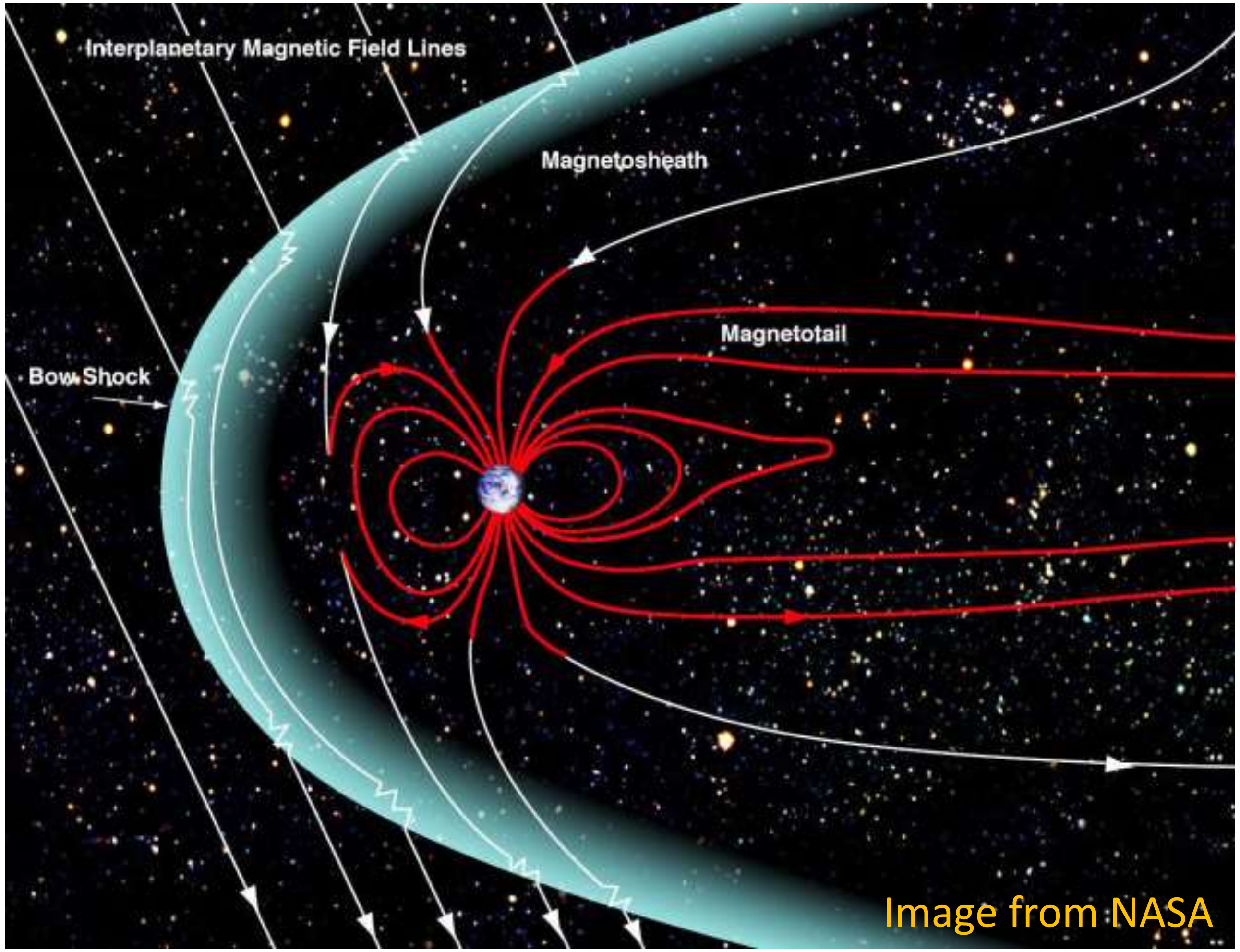
The regions considered for the high-latitude magnetosphere-ionosphere coupling:

- highly-conductive ionosphere (below 200 km);
- magnetosphere (above ~2,000 km);
- transition layer (ideal Ohm's law partially holds ).

# Magnetic field topology under southward IMF

Magnetospheric region:

- open field lines (linked to IMF);
- closed field lines (could be closed far in the tail);
- polar cap is magnetically linked to the solar wind.



# Solar wind – ionosphere coupling in the polar cap

Solar wind electric field $\mathbf{E}_{\mathrm{sw}} = -\mathbf{V}_{\mathrm{sw}} \times \mathbf{B}_{\mathrm{sw}}$

Under a southward IMF, a dawn-to-dusk $\mathbf{E}_{\mathrm{sw}}$

maps to the polar cap ionosphere:

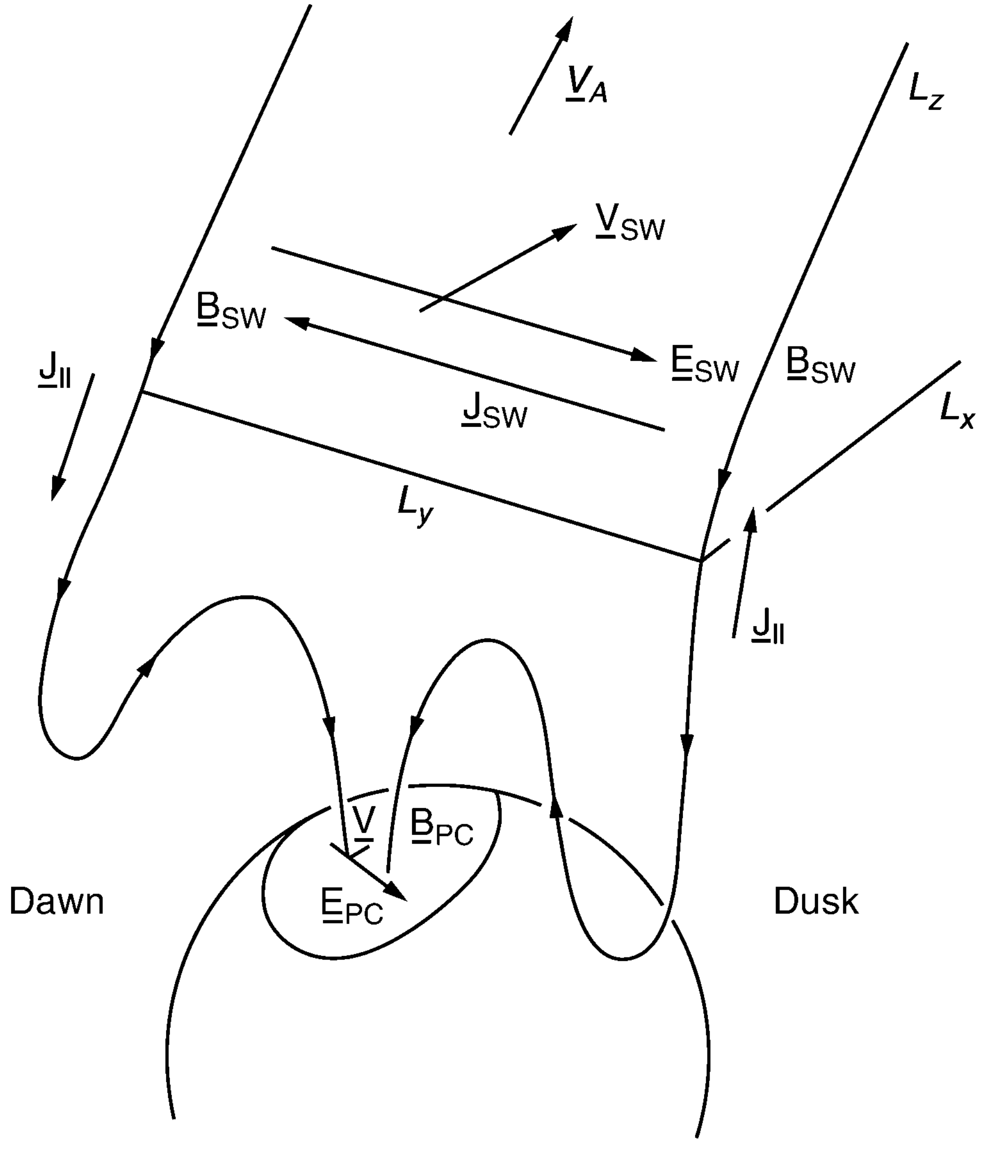
$$\mathbf{V}_{\mathrm{I}} = \mathbf{E}_{\mathrm{I}} \times \mathbf{B}_{\mathrm{I}}/B_I^2$$

Mapping factors:

$$B_I/B_{sw} = 50{,}000\,\mathrm{nT}/5\,\mathrm{nT} = 10^4$$

$$E_I/E_{sw} = 50\,\mathrm{mV\,m^{-1}}/2\,\mathrm{mV\,m^{-1}} = 125$$

$$V_I/V_{sw} = 1\,\mathrm{km\,s^{-1}}/400\,\mathrm{km\,s^{-1}} = 2.5 \times 10^{-3}$$



# Circuit energetics

Resulting ionospheric current from the mapping:

$$\mathbf{J} = \boldsymbol{\sigma} \cdot \mathbf{E}_{\mathrm{I}}$$

with the Pedersen component parallel to $\mathbf{E}_{\mathrm{I}}$

Thus $\mathbf{J} \cdot \mathbf{E} > 0$

$\Rightarrow$ Polar ionosphere is a load (=energy sink!)

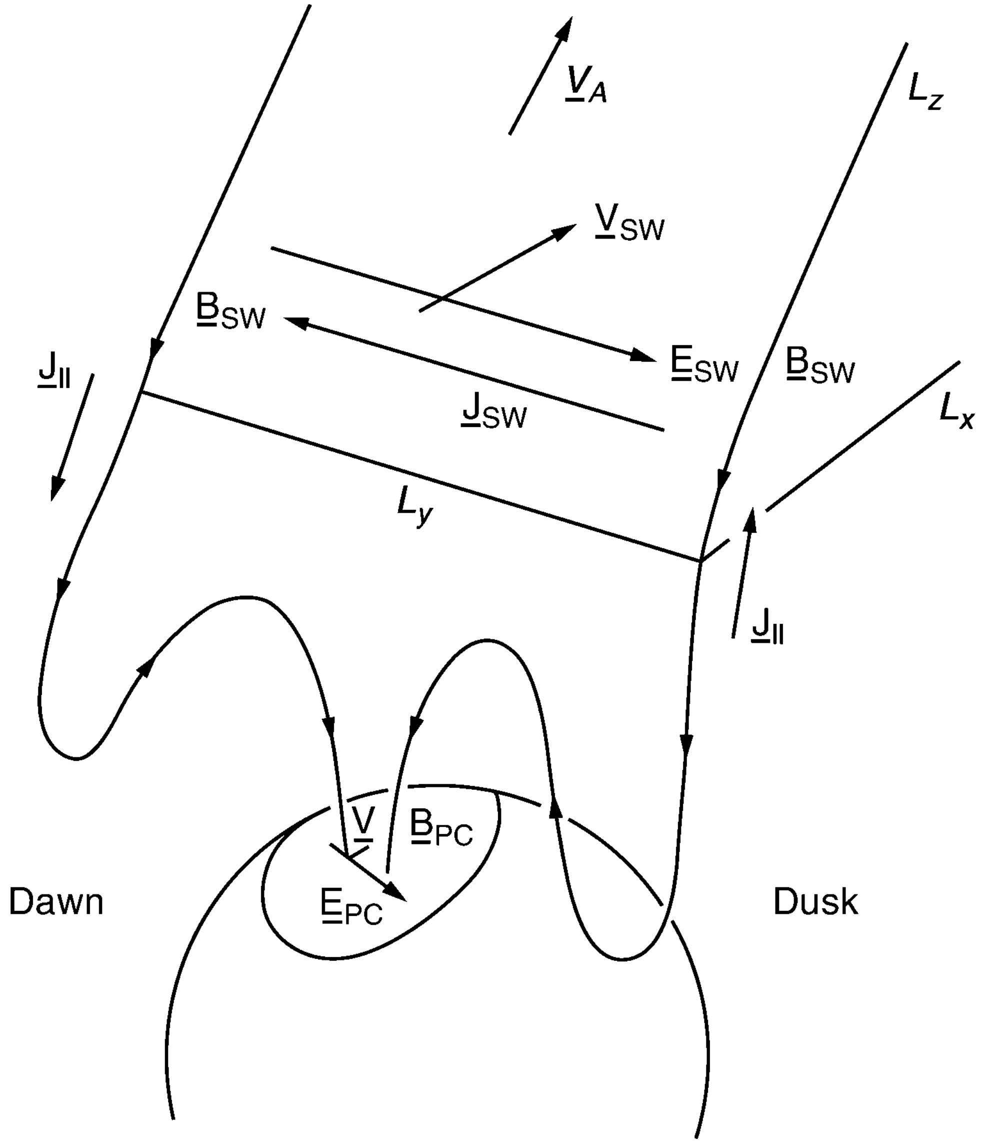
Where the electrical energy comes from?

Solar wind current (solar wind decelerates):

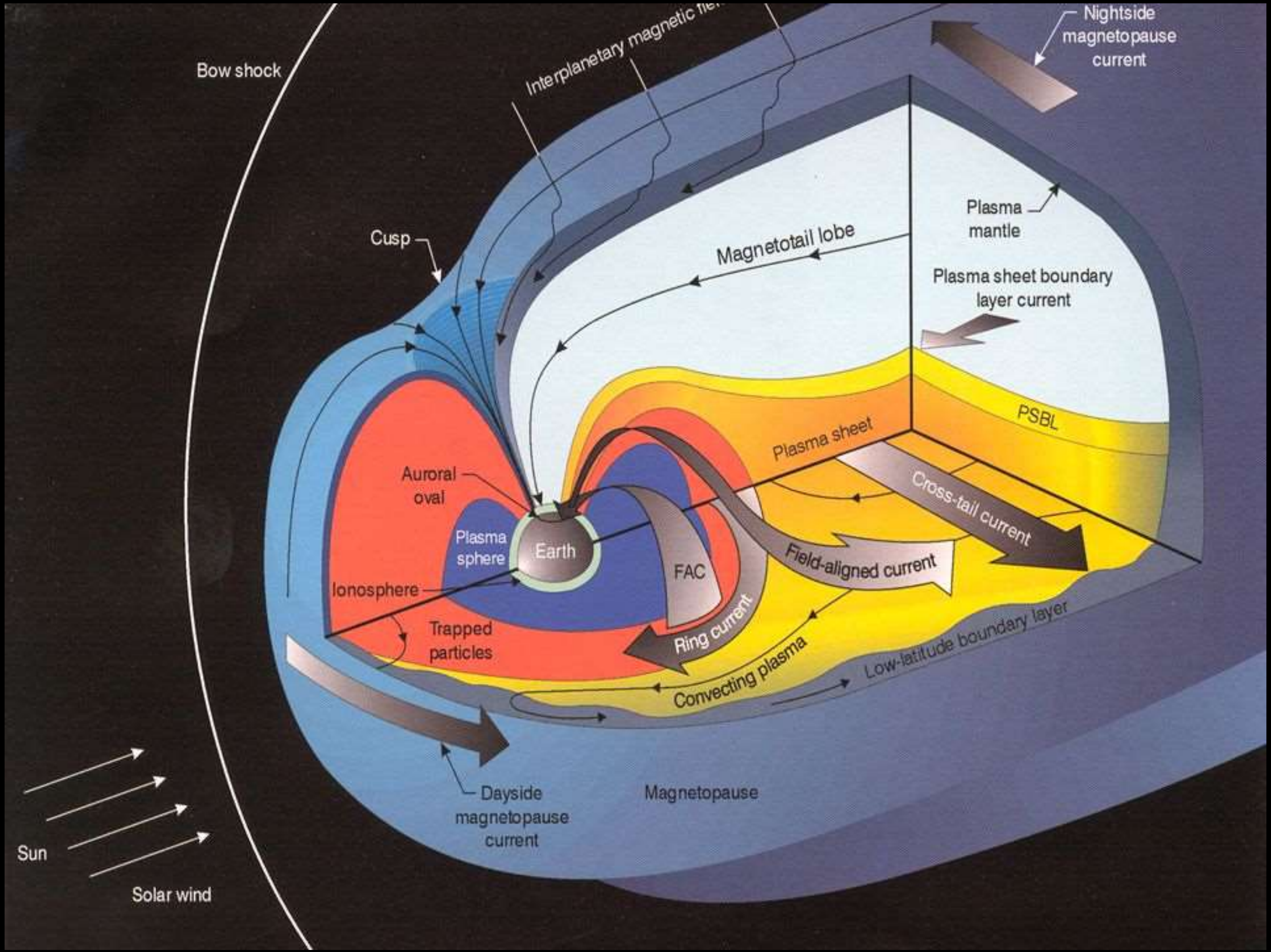
$$\mathbf{J}_{\perp} = (\rho/B^2)\mathbf{B} \times d\mathbf{V}/dt$$

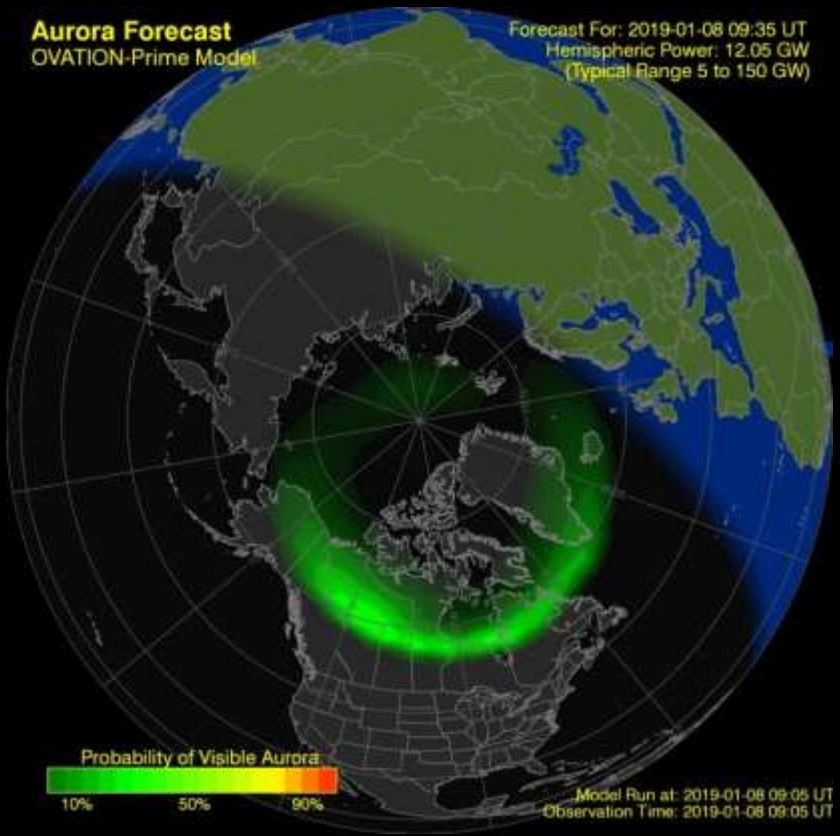
Thus $\mathbf{J}_{\mathrm{sw}} \cdot \mathbf{E}_{\mathrm{sw}} < 0$

$\Rightarrow$ Solar wind is the generator, feeding the ionosphere as a load!



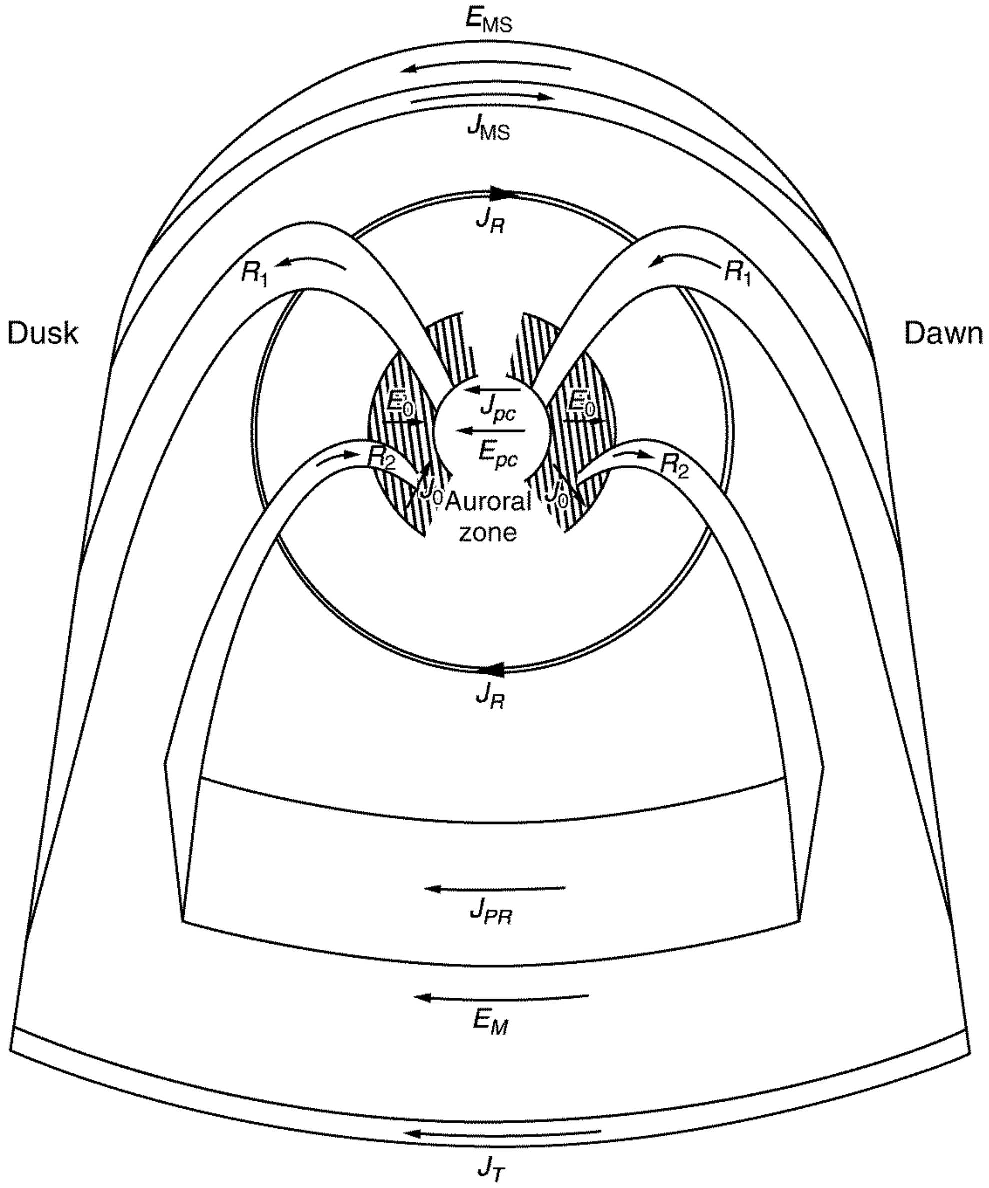
# Auroral precipitations and the oval

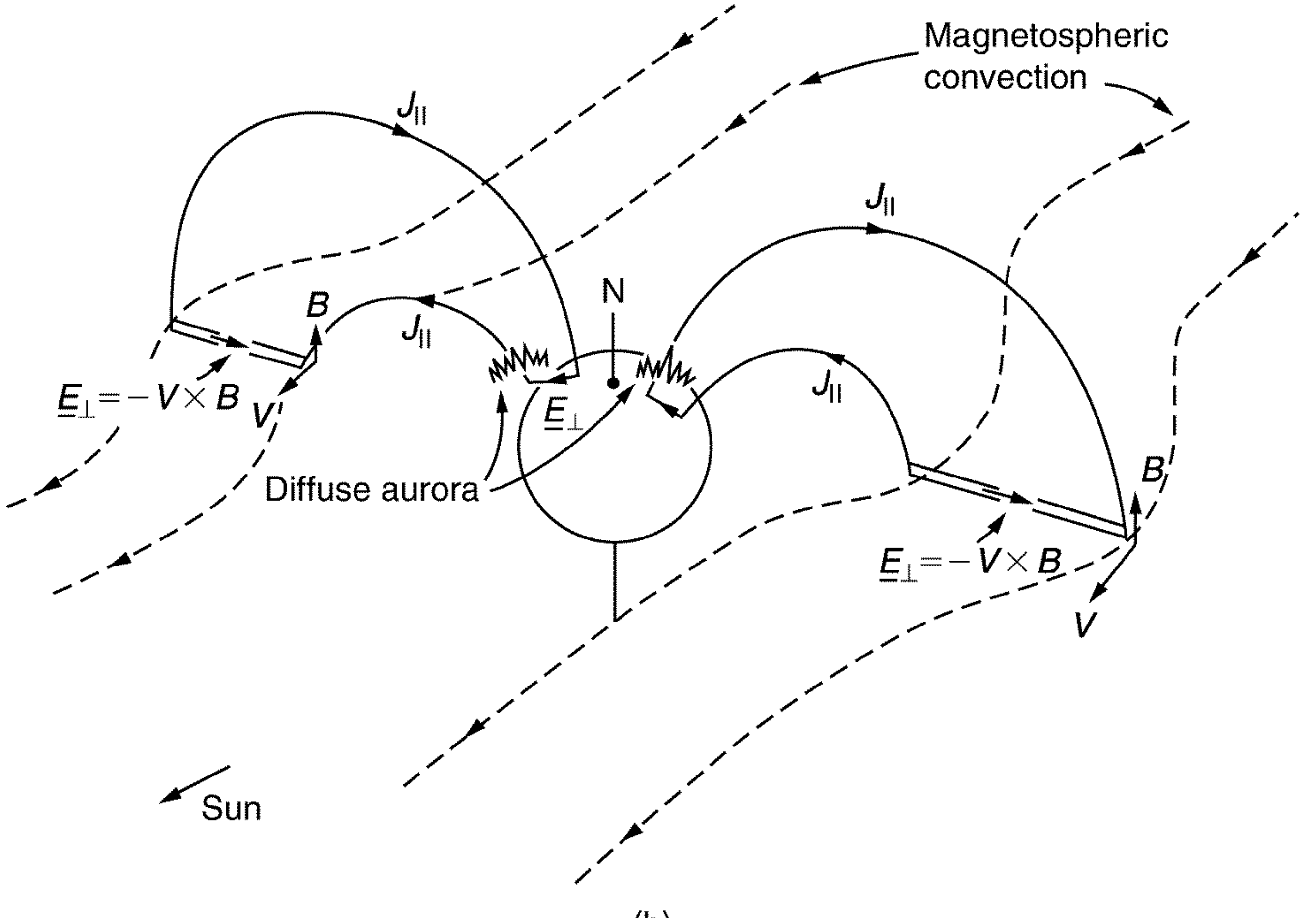


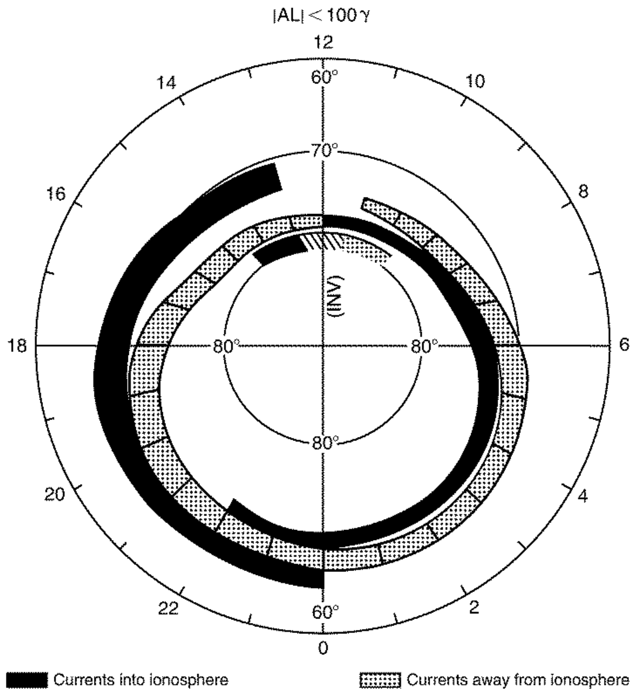

*Credit: NOAA*

# Field aligned current (FAC) system

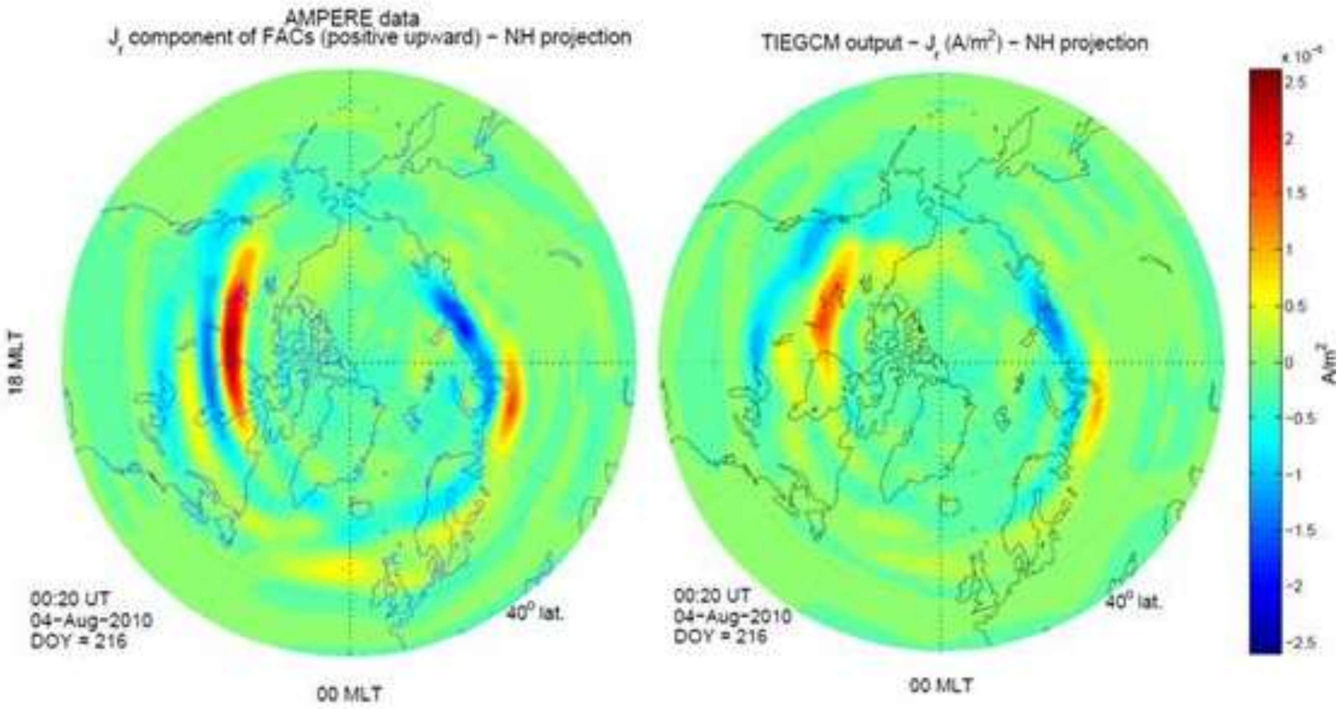


# Satellite observations of FACs

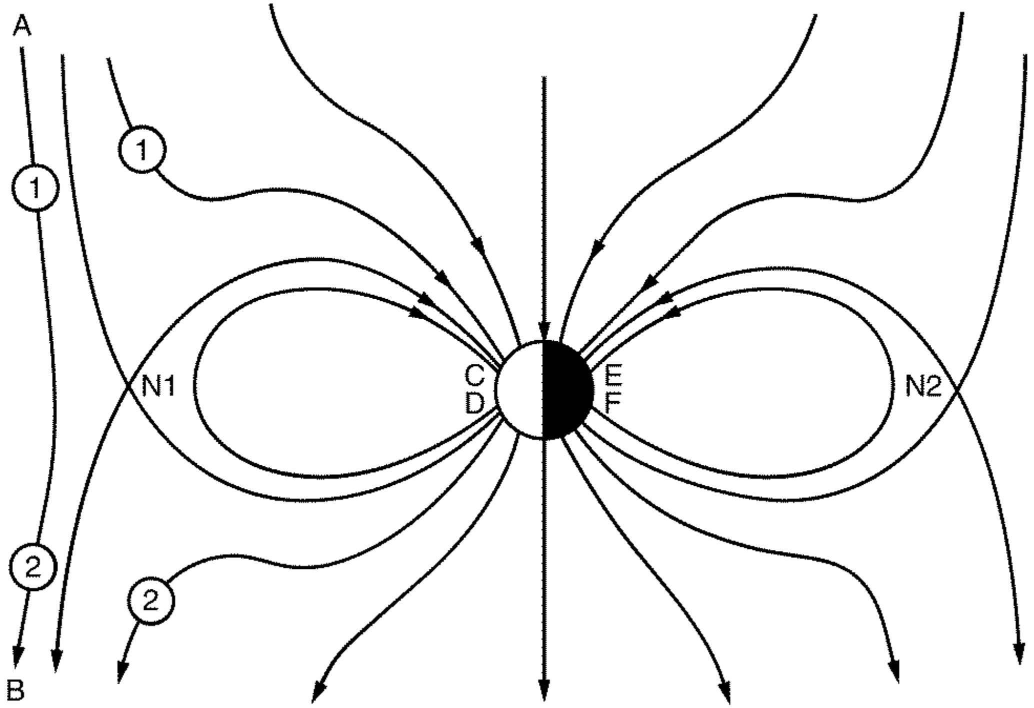


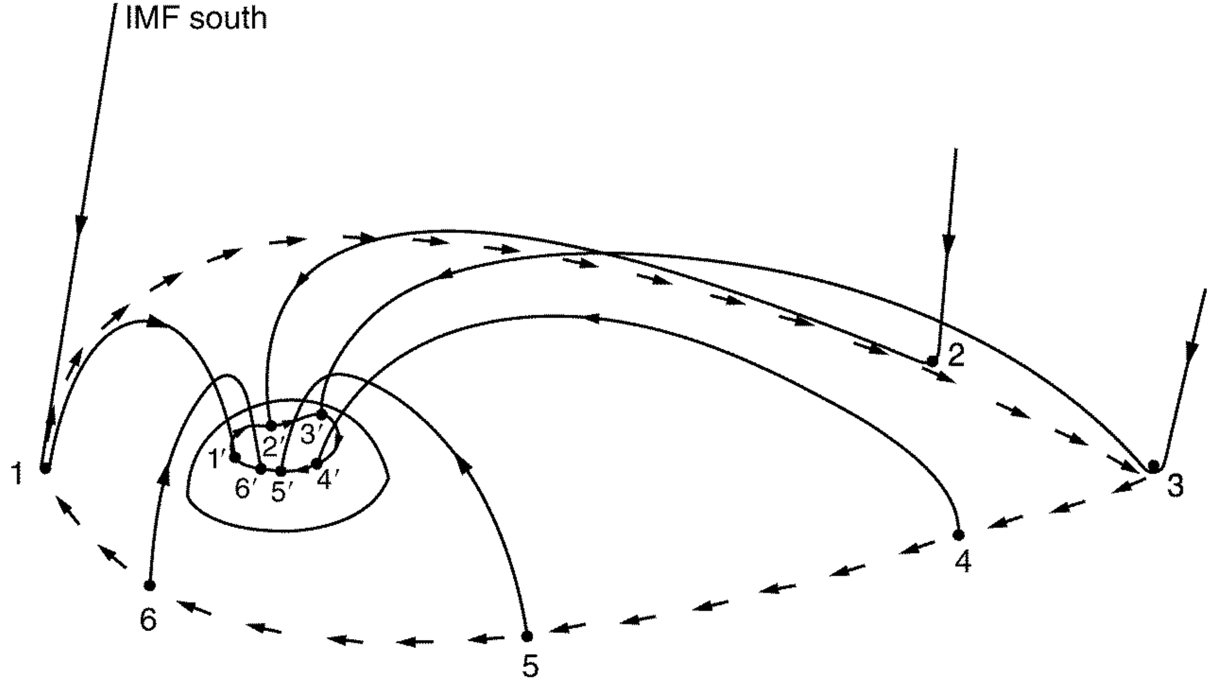

First satellite observations by
*Ijima and Potemra* (1976).



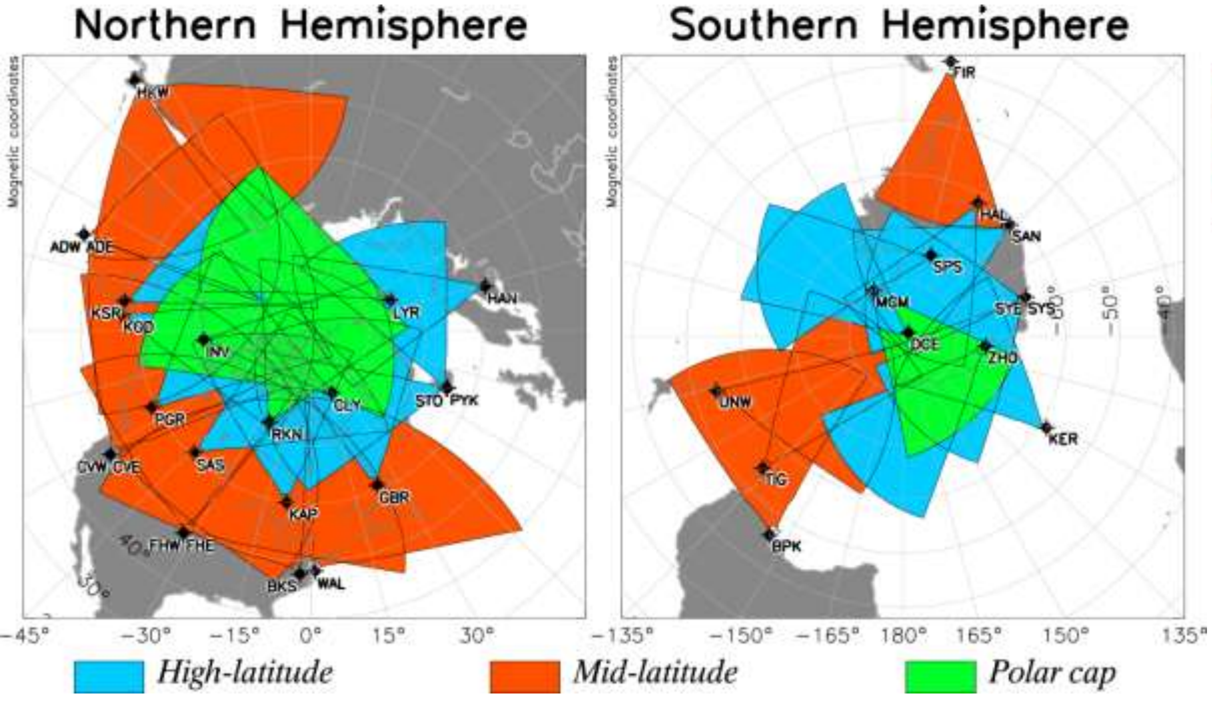

*Credit: AGU*

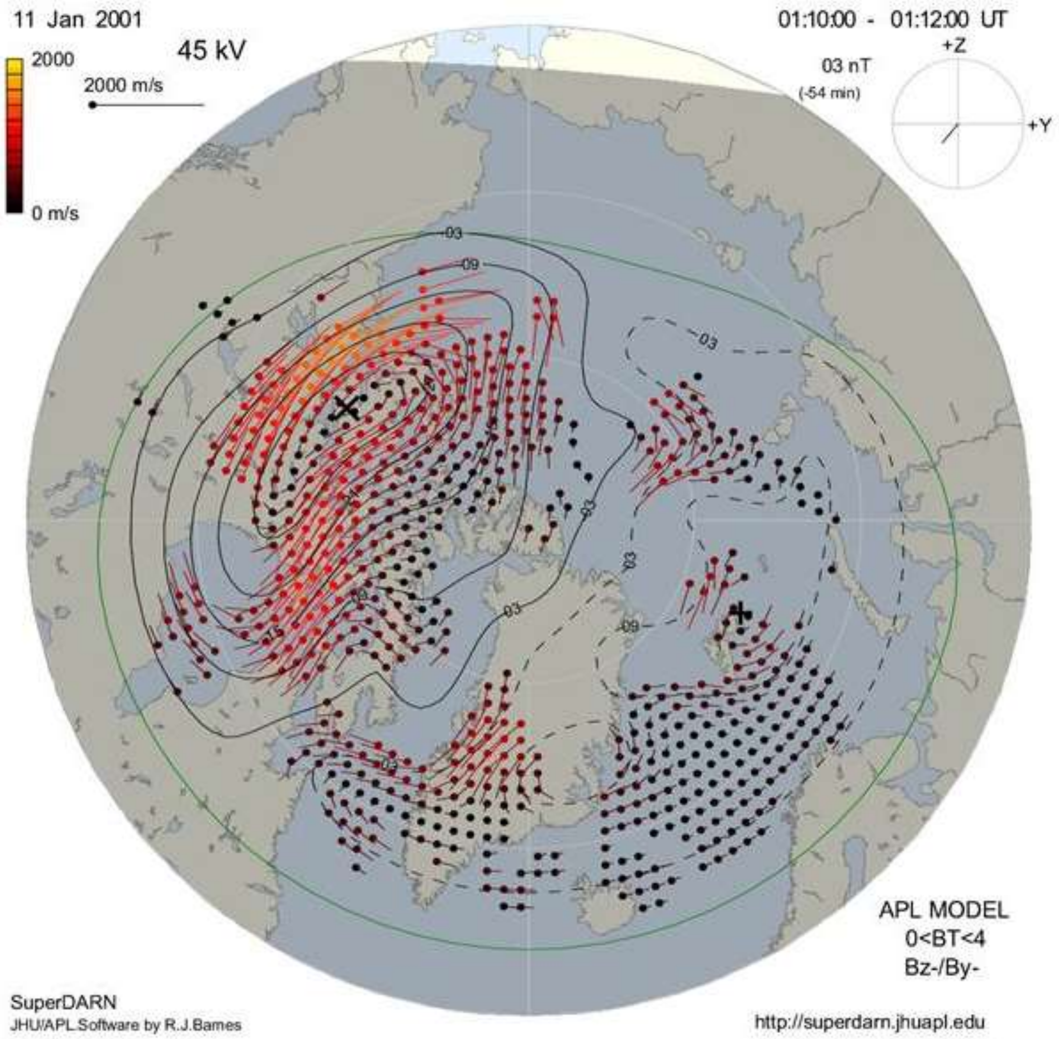
# Plasma convection under southward IMF



# Observations of plasma convection: radar networks

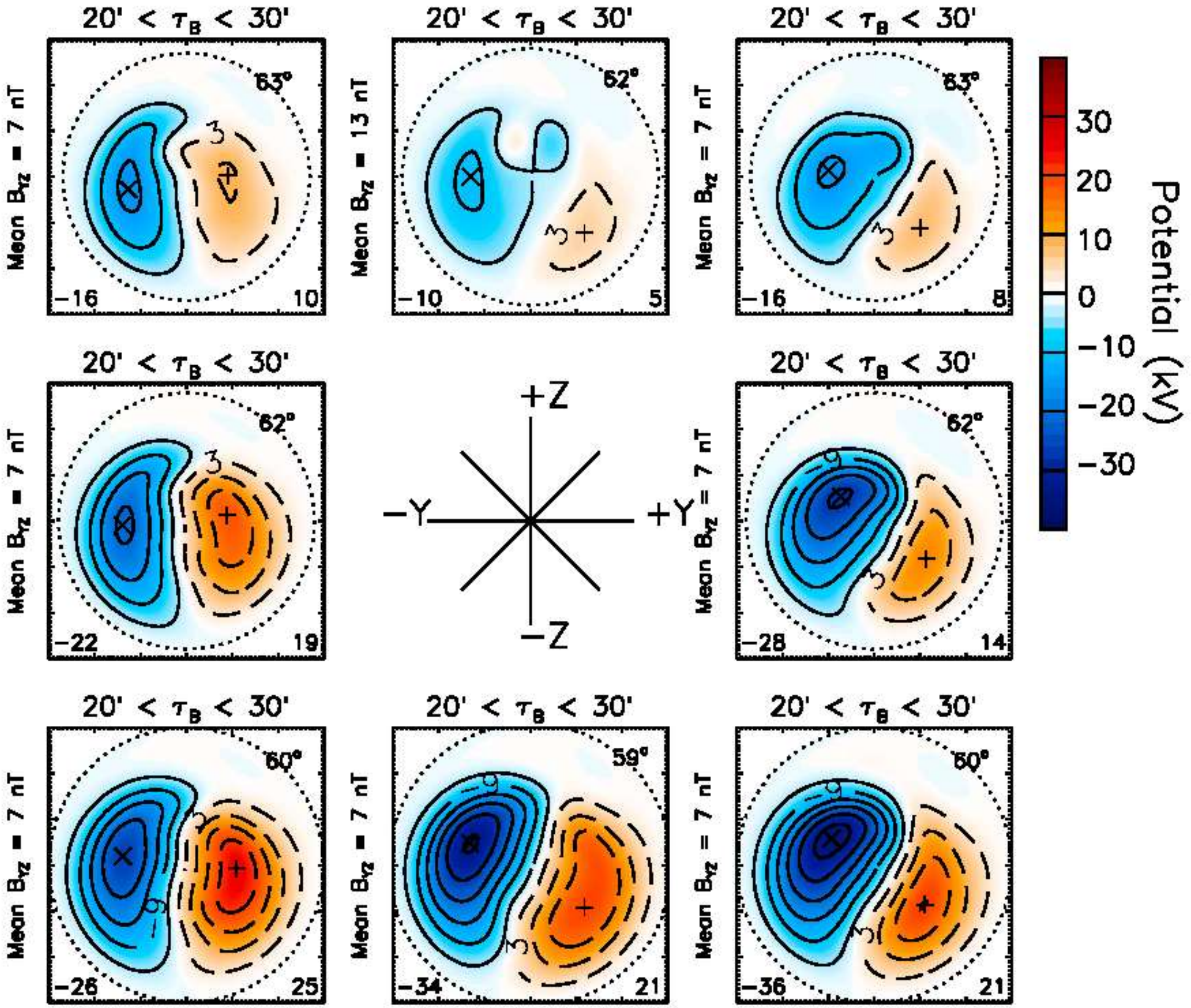




- Incomplete/patchy coverage
- Satellite and model data can be added

# IMF control of plasma convection




From Grocott and Milan, 2014
Credit: AGU

- Clear convection patterns under southward (Bz) IMF.
- Complex/weak convection under northward IMF.
- East-west IMF (By) causes asymmetries.