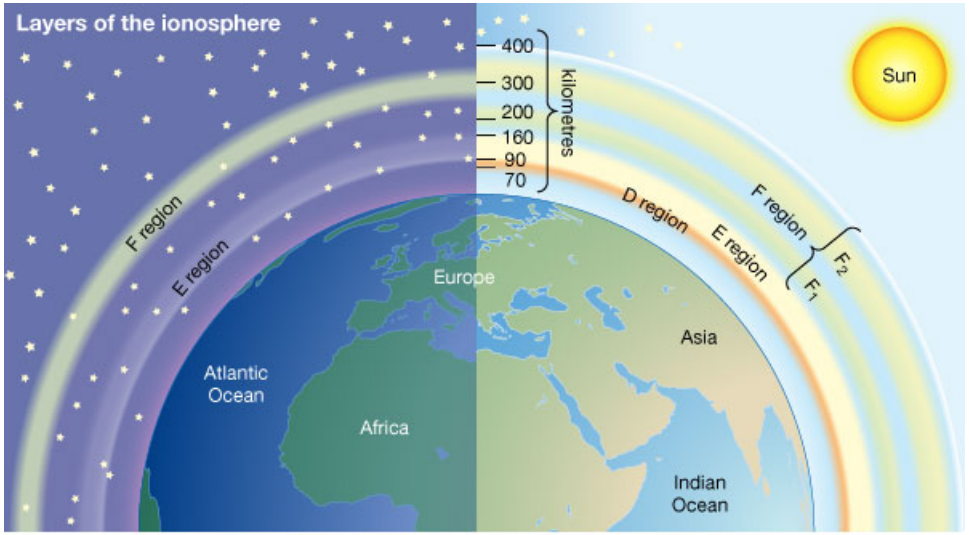
TIME CHANGES IN THE GEOMAGNETIC FIELD II-A: THE EARTH'S IONOSPHERE

Patrick Alken

Outline

- What is the ionosphere?
- Electrodynamics of the ionosphere
- Equatorial electrojet current
- Gravity current
- Pressure-gradient current

What is the ionosphere?



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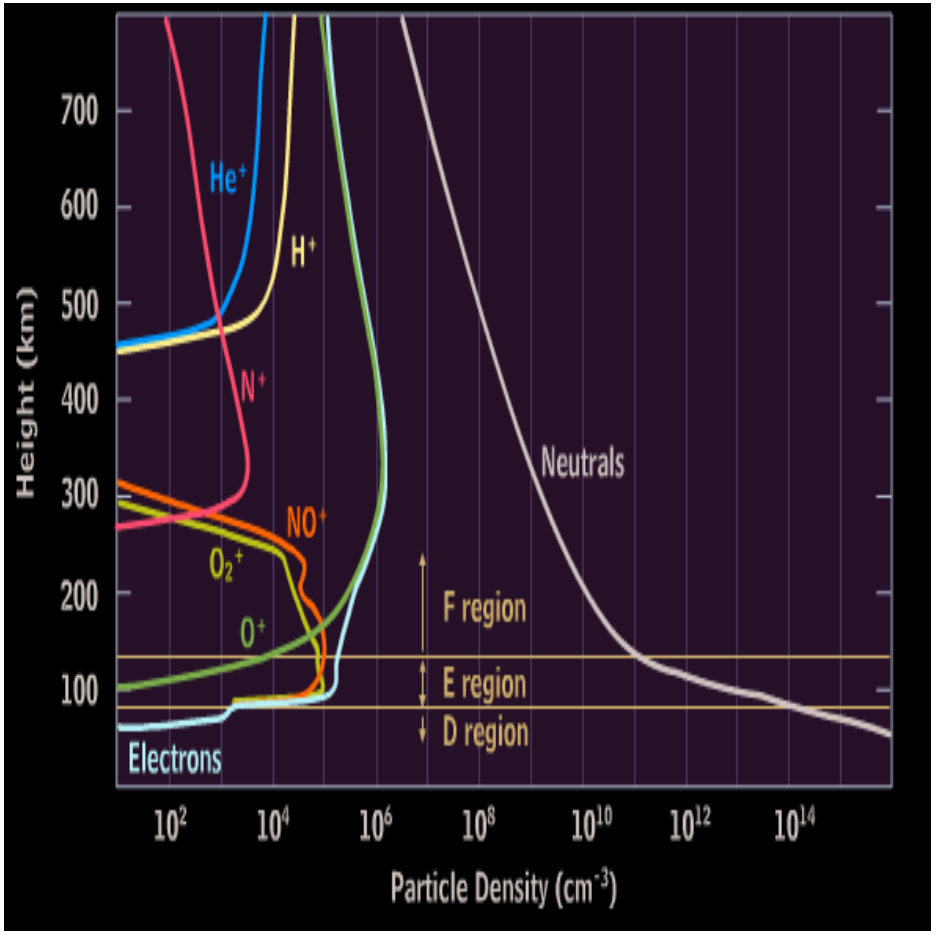
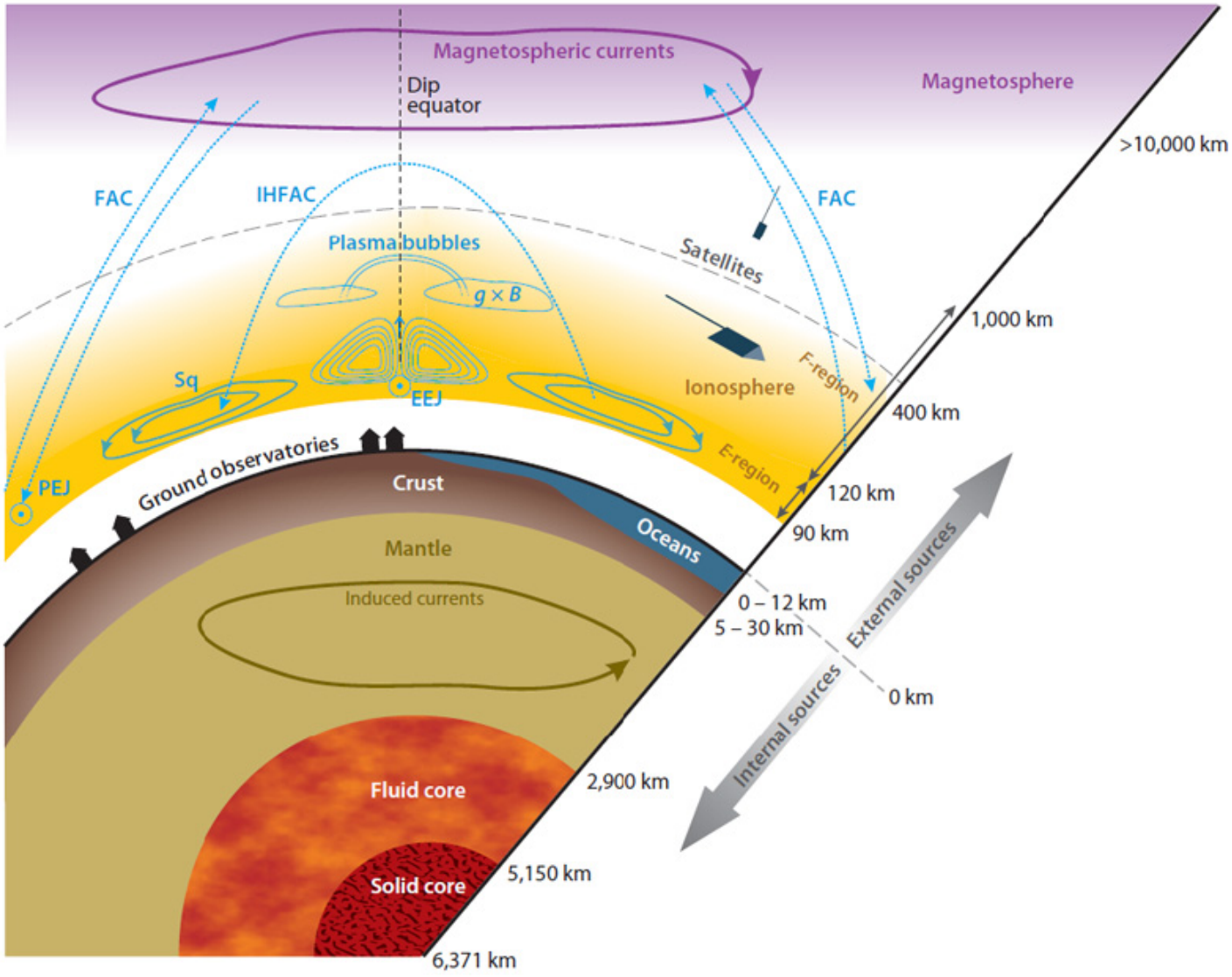


Ionospheric currents



Electrodynamics of the ionosphere

$$\mathbf{J} = \mathbf{J}_w + \mathbf{J}_g + \mathbf{J}_p + \sigma\mathbf{E}$$

Wind currents (EEJ, Sq)

$$\mathbf{J}_w = \sigma\mathbf{U} \times \mathbf{B}$$

Gravity current

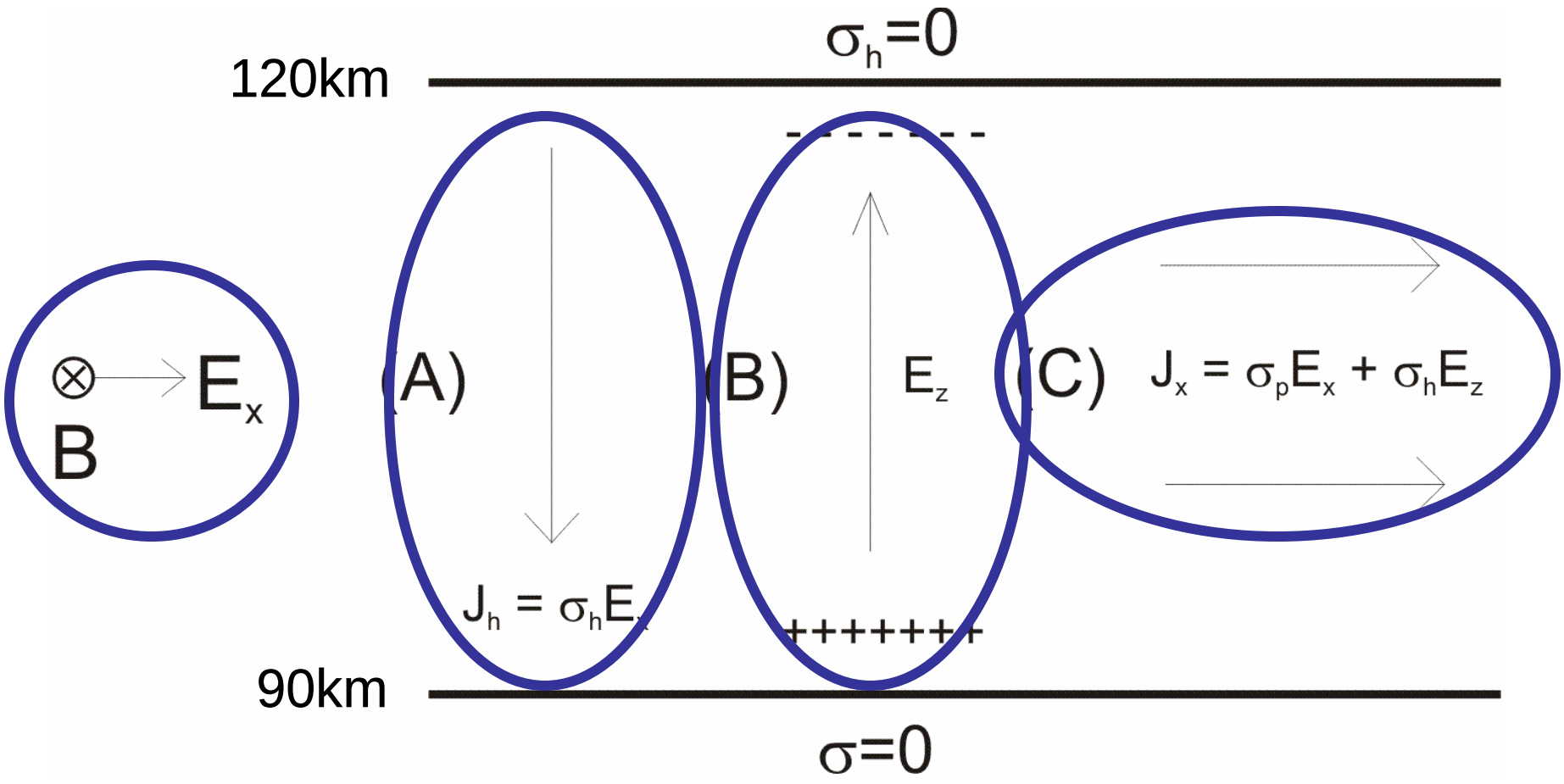
$$\mathbf{J}_g = \frac{nm_i}{B^2}\mathbf{g} \times \mathbf{B}$$

Pressure gradient current

$$\mathbf{J}_p = \frac{-1}{B^2}\nabla P \times \mathbf{B}$$

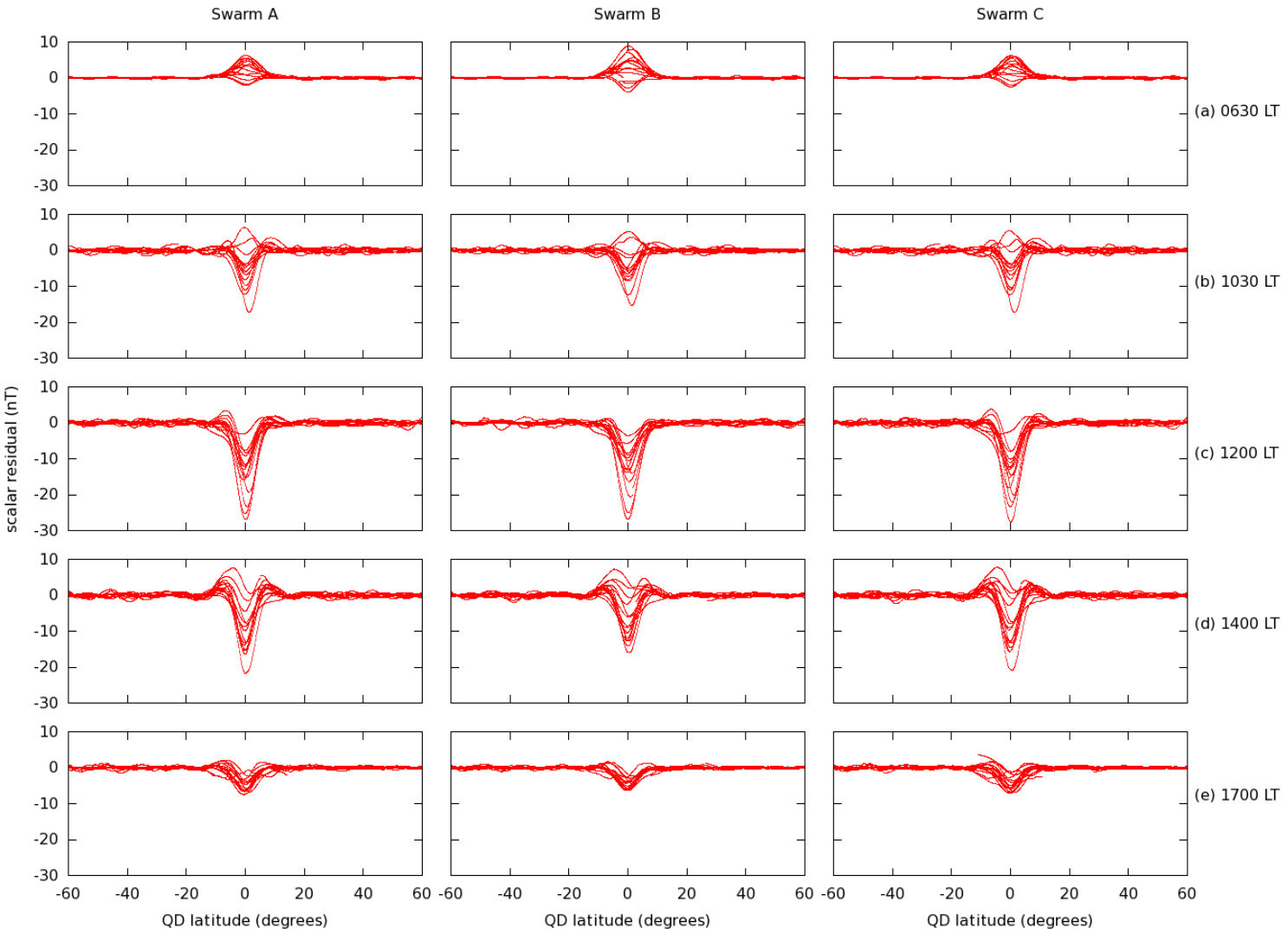
$$\sigma = \sigma_P I + (\sigma_\parallel - \sigma_P)\mathbf{b}\mathbf{b}^T + \sigma_H [\mathbf{b}]_\times$$

The Equatorial Electrojet

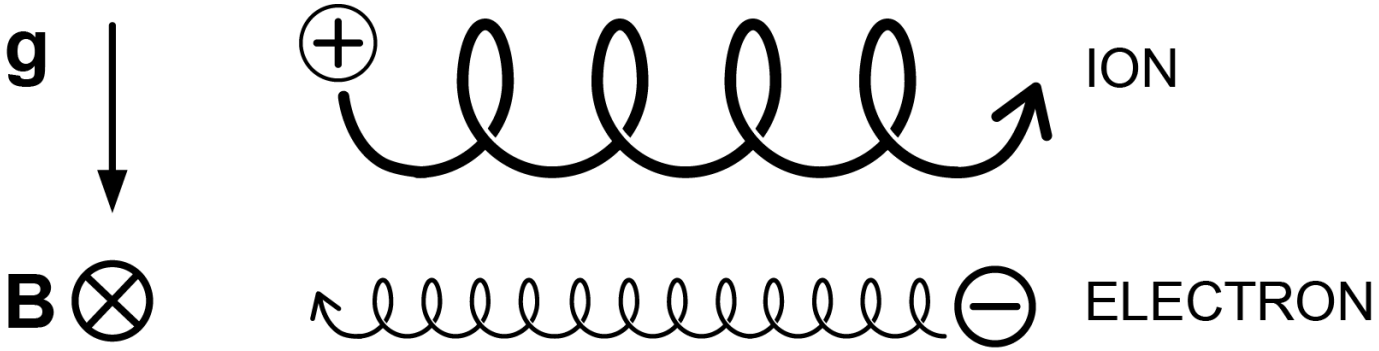


Low collision frequency: $\mathbf{V} = \mathbf{E}\mathrm{x}\mathbf{B}/B^2$

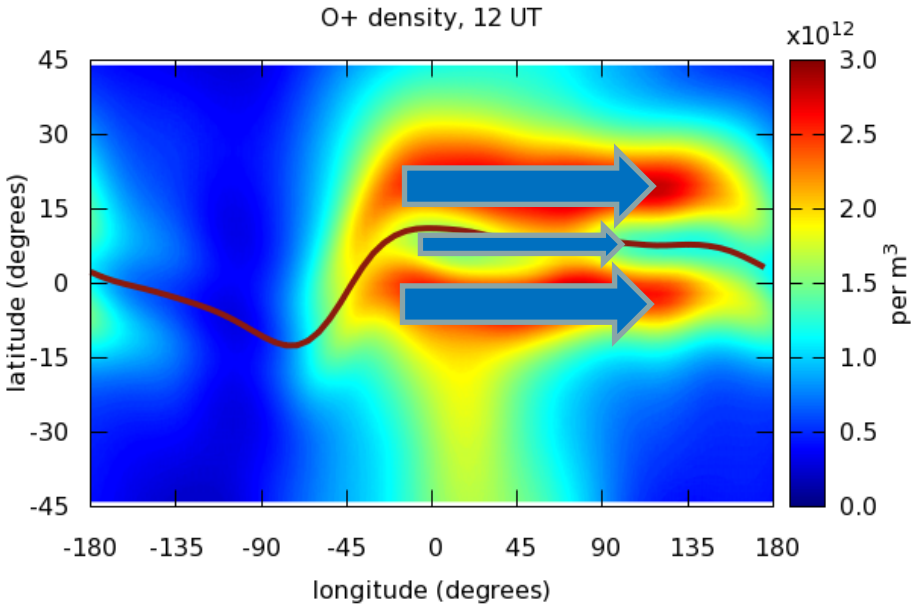
Observations of the equatorial electrojet



The gravity current



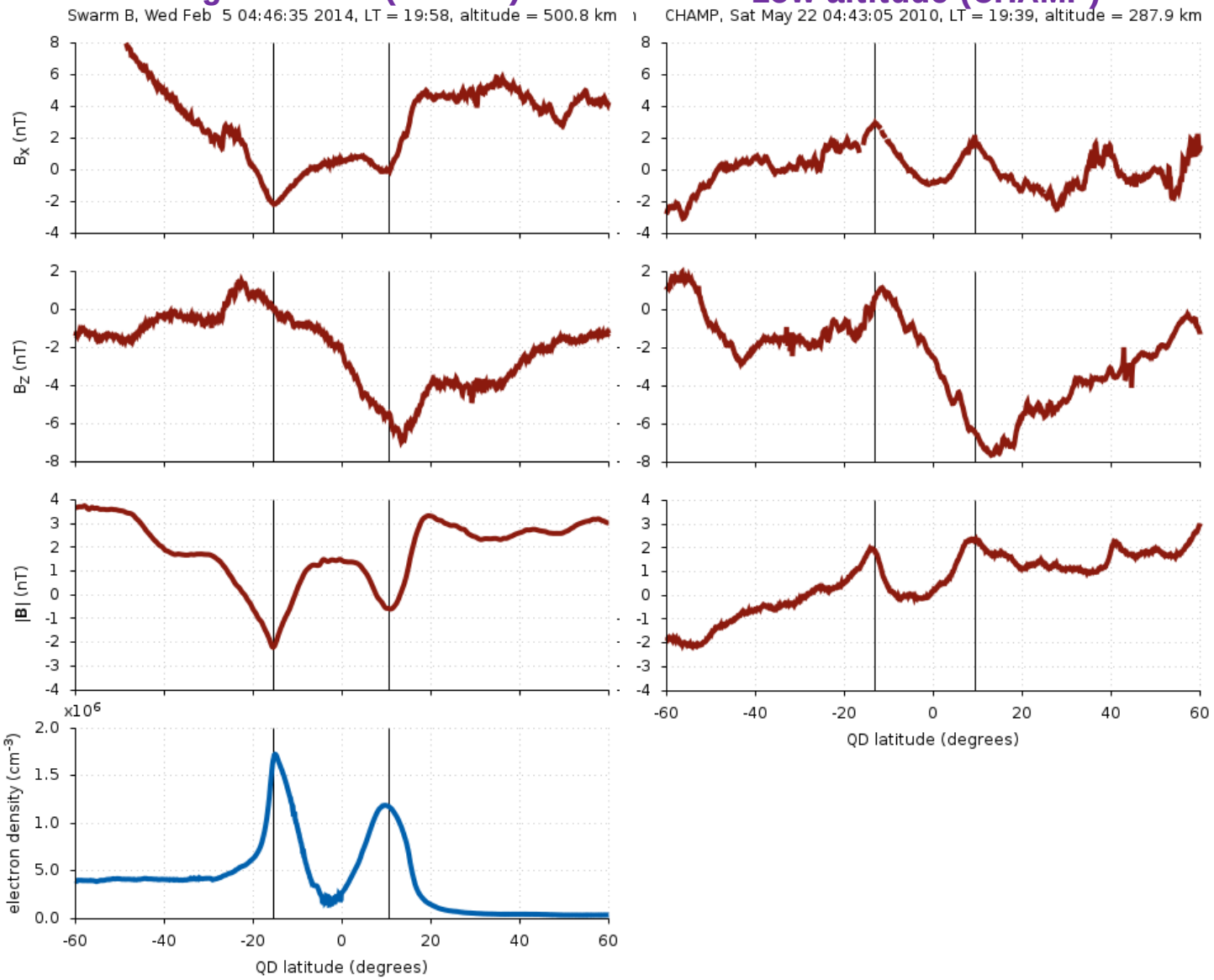
$$\mathbf{J}_g = nm_i \frac{\mathbf{g} \times \mathbf{B}}{B^2}$$



Observations of gravity and pressure gradient currents

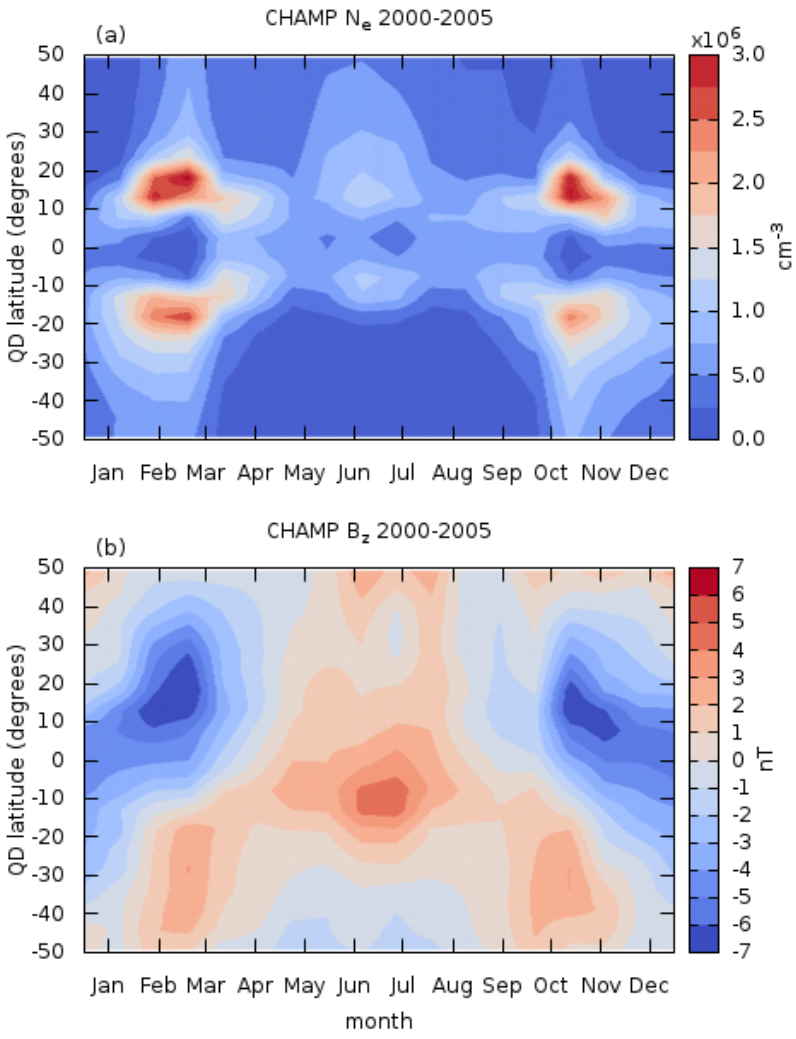
High altitude (Swarm)

Low altitude (CHAMP)

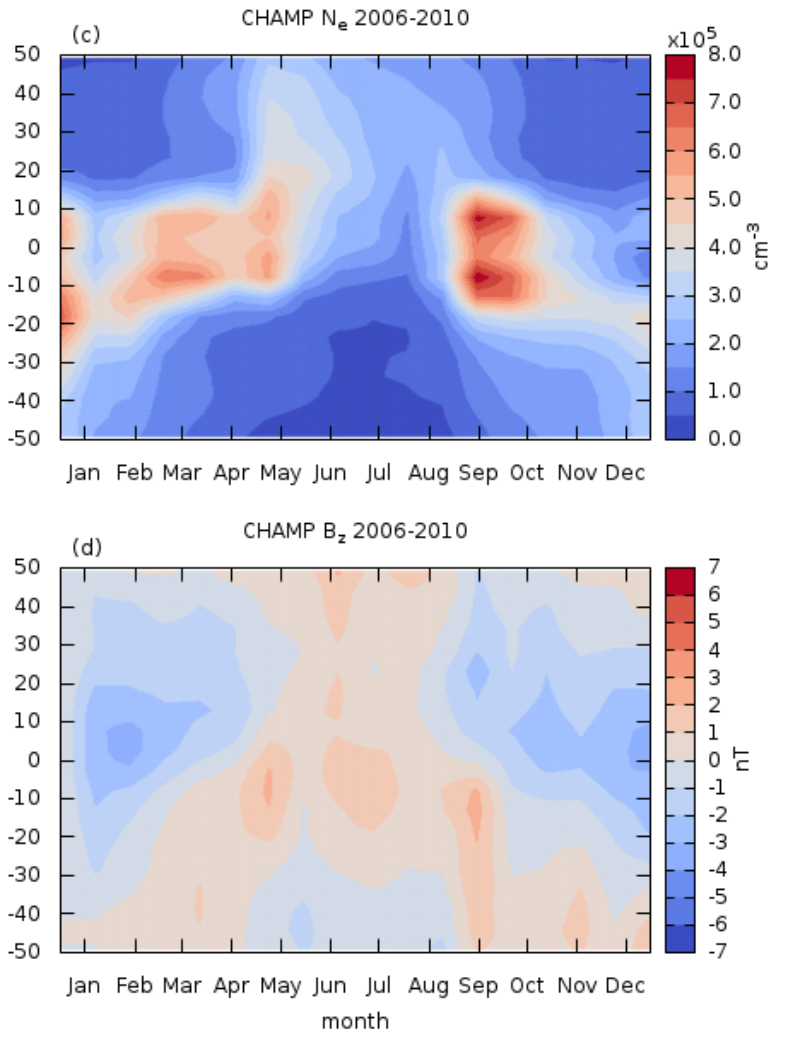


G/P currents: seasonal structure

Solar maximum



Solar minimum



Time changes in the geomagnetic field II-b: Sq and equatorial electrojet fields

GEOL/PHYS 6650
Geophysics Seminar: Geomagnetism

Arnaud Chulliat (CIRES & NOAA/NCEI)

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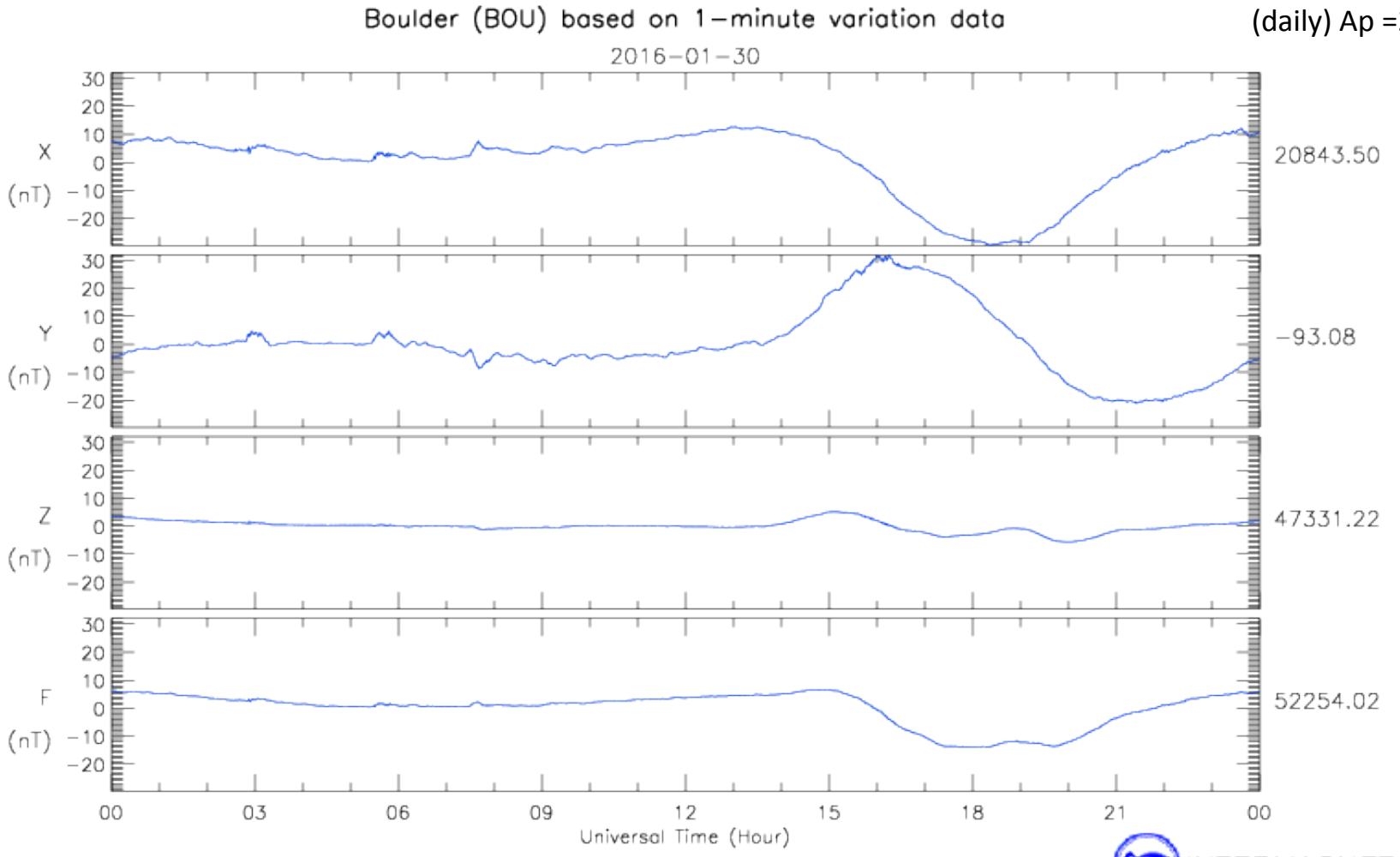
Outline

1. **Sq and equatorial electrojet fields: observations**
2. Sq and equatorial electrojet fields: modeling

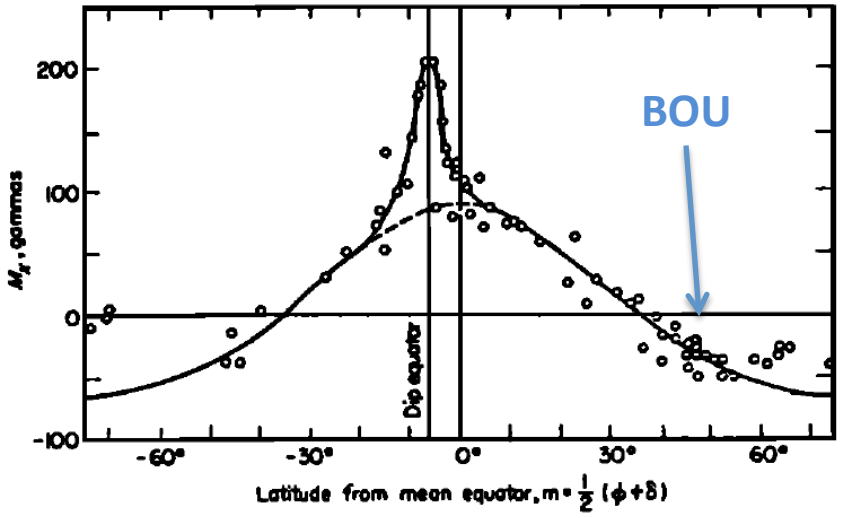
“Sq”: solar daily variation on quiet days

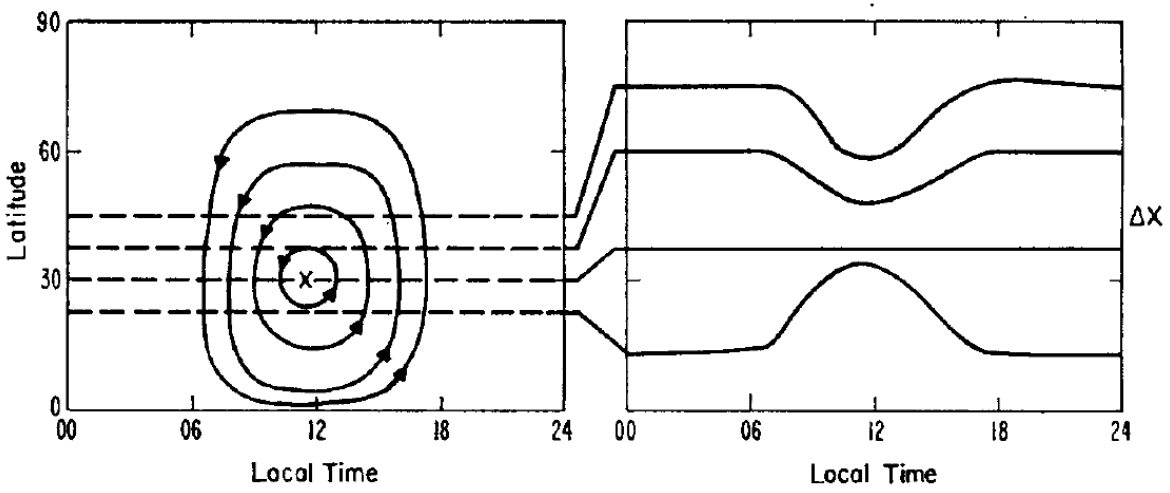
(tri-hourly) Kp ≤ 1o
(daily) Ap =2

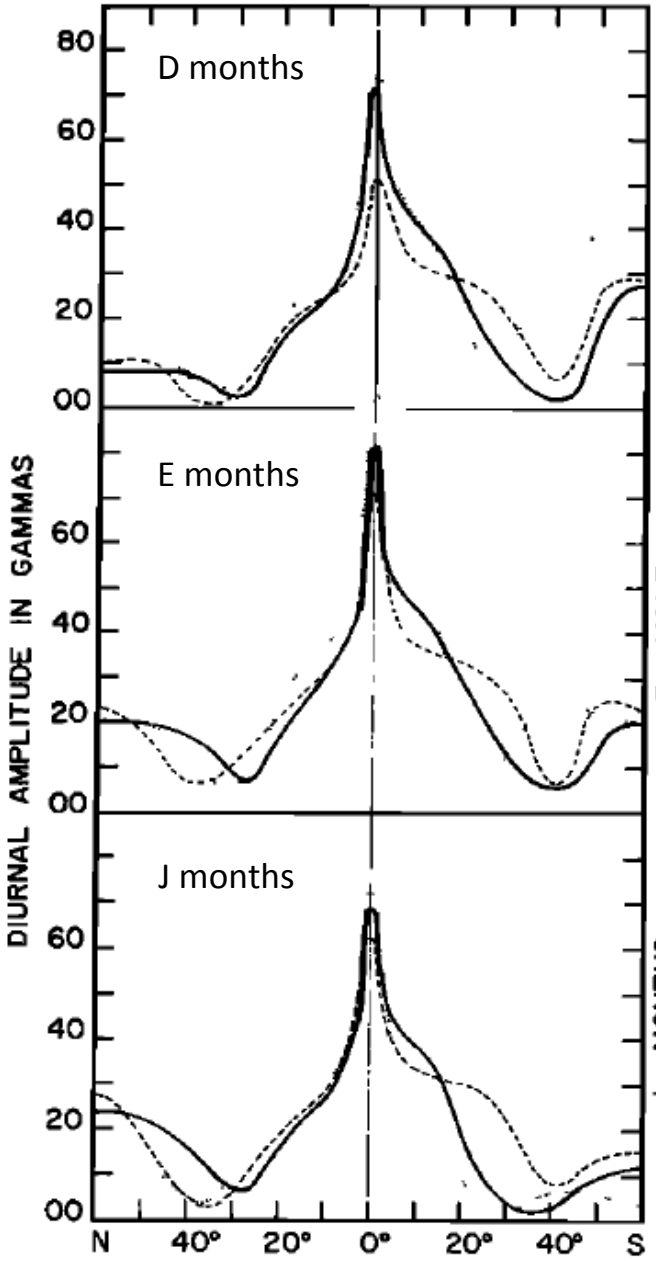


INTERMAGNET

- Sq fields vary with latitude and seasons
- They are generated by two vortex-like current systems, one in each hemisphere

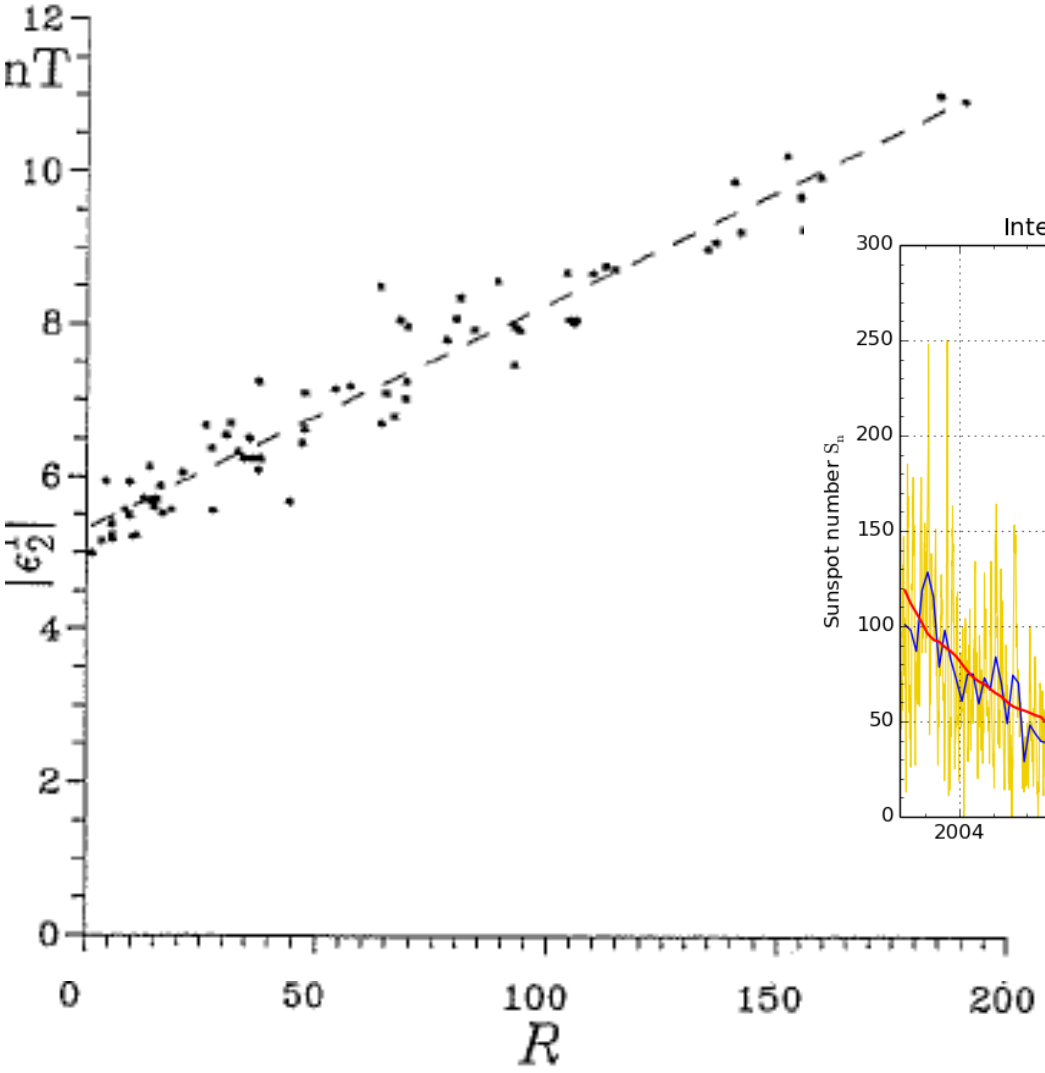


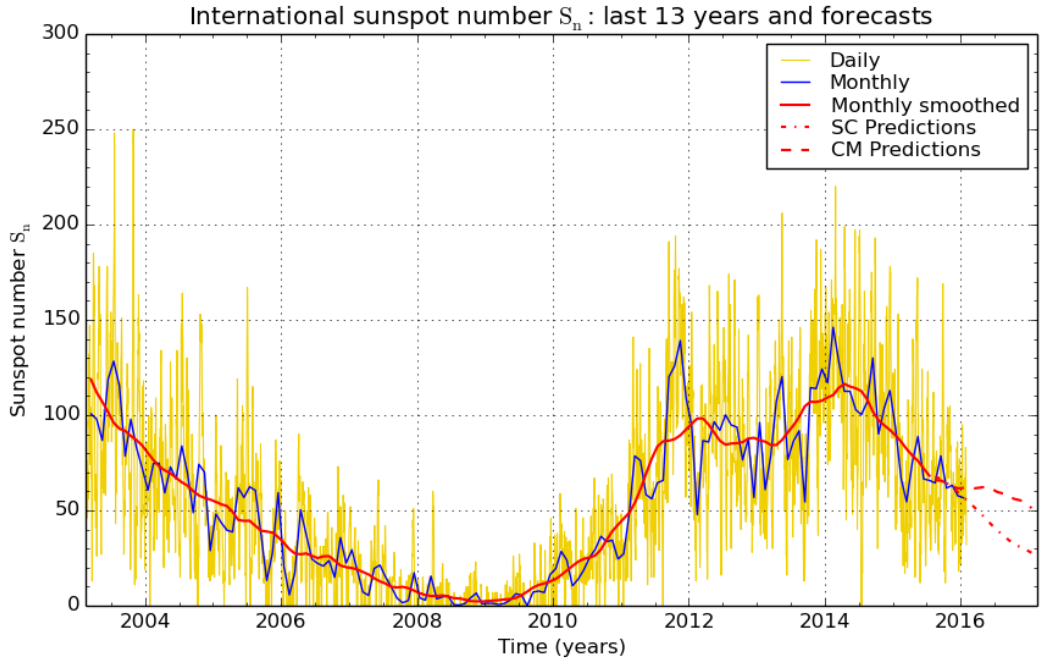




(Forbes, RGSP, 1981; Tarpley, JATP, 1973; Matsushita & Maeda, JGR, 1965)

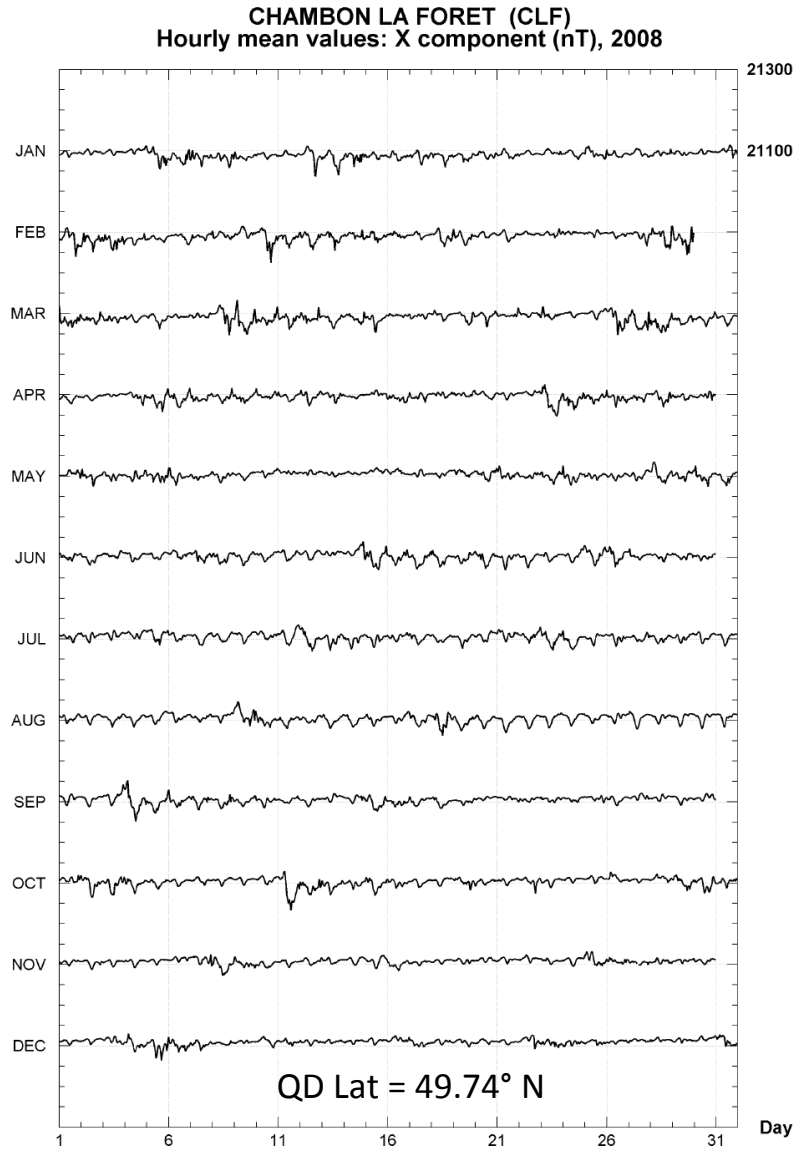
- Sq fields also vary with solar cycle

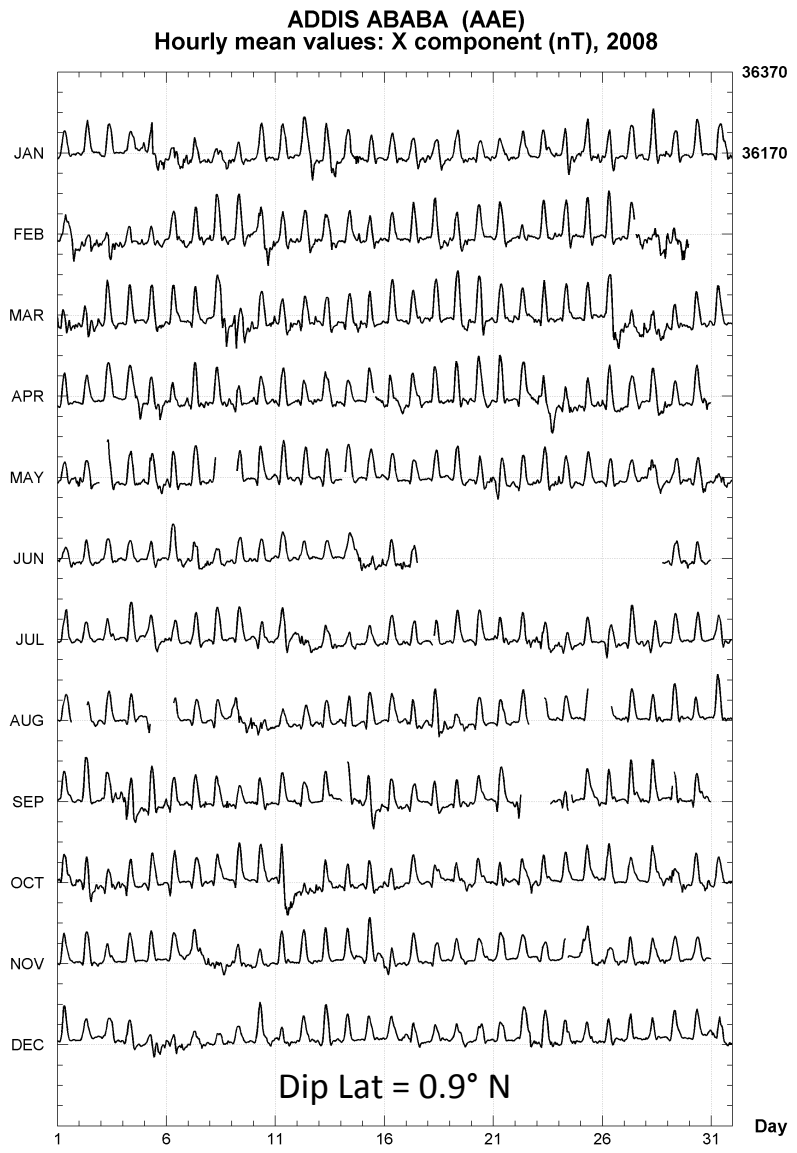




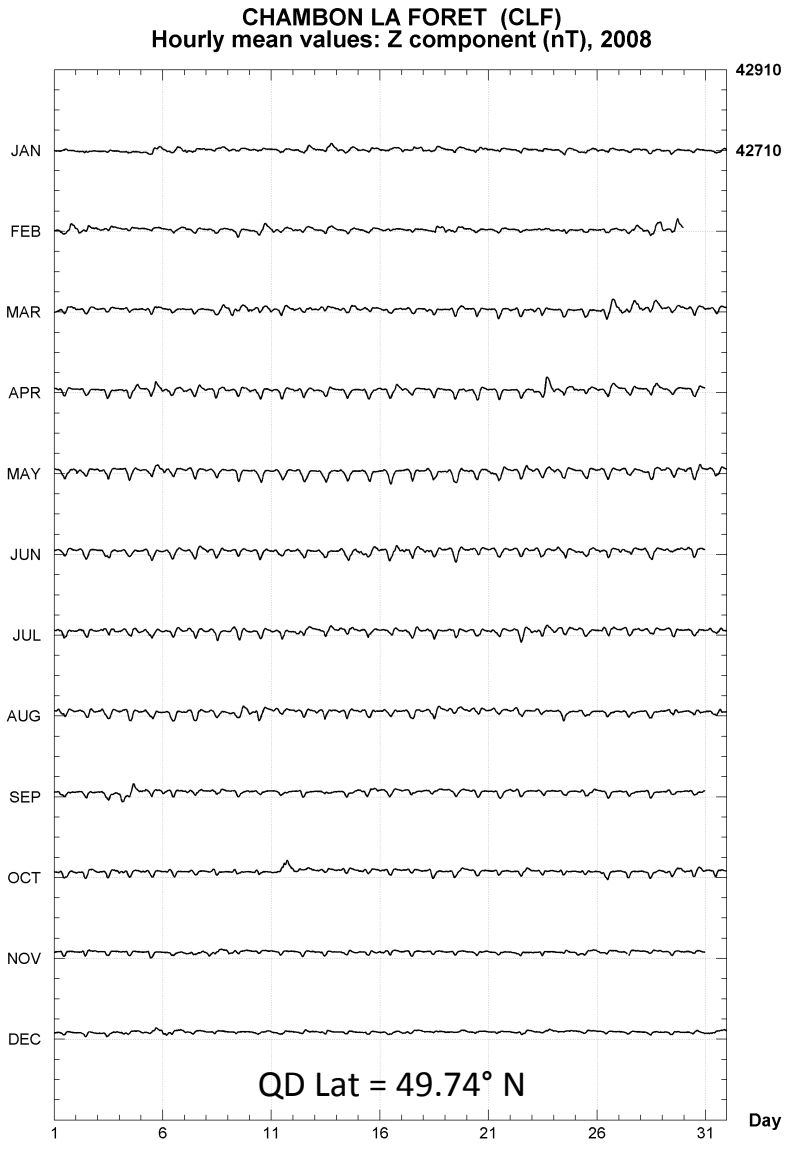
(Olsen, AG, 1993)

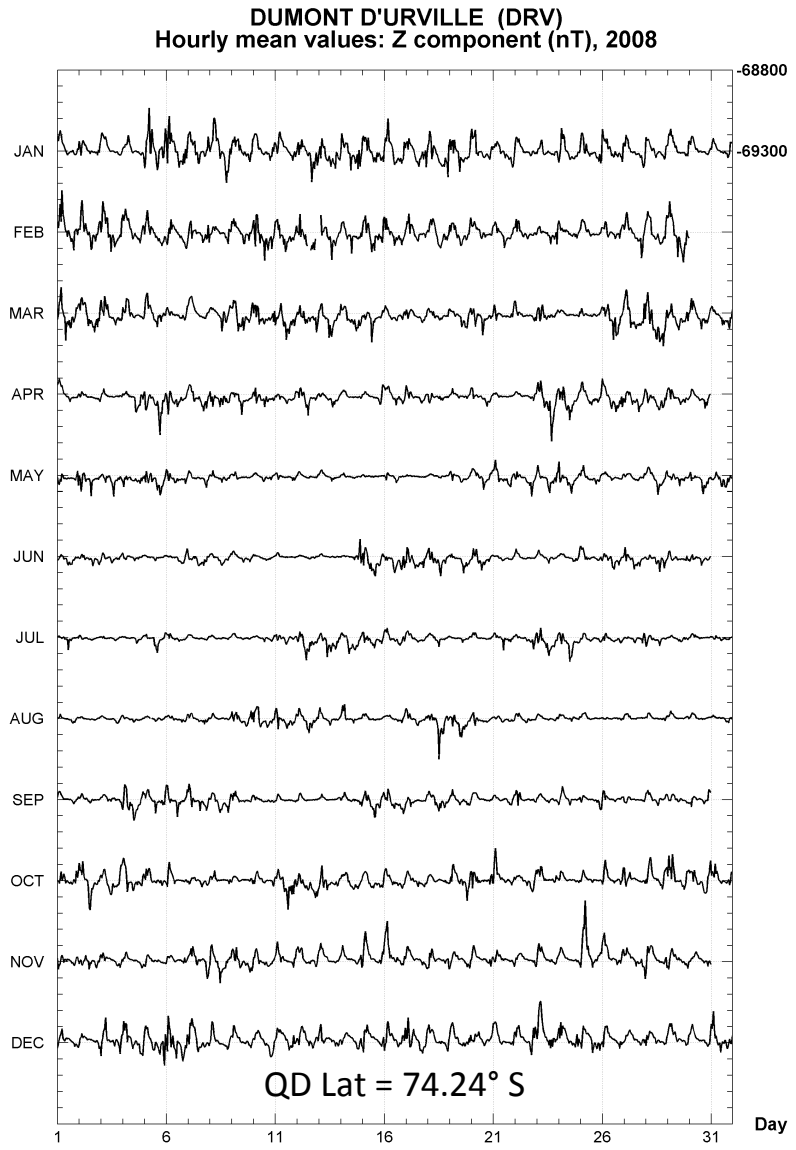
Equatorial electrojet along the dip equator

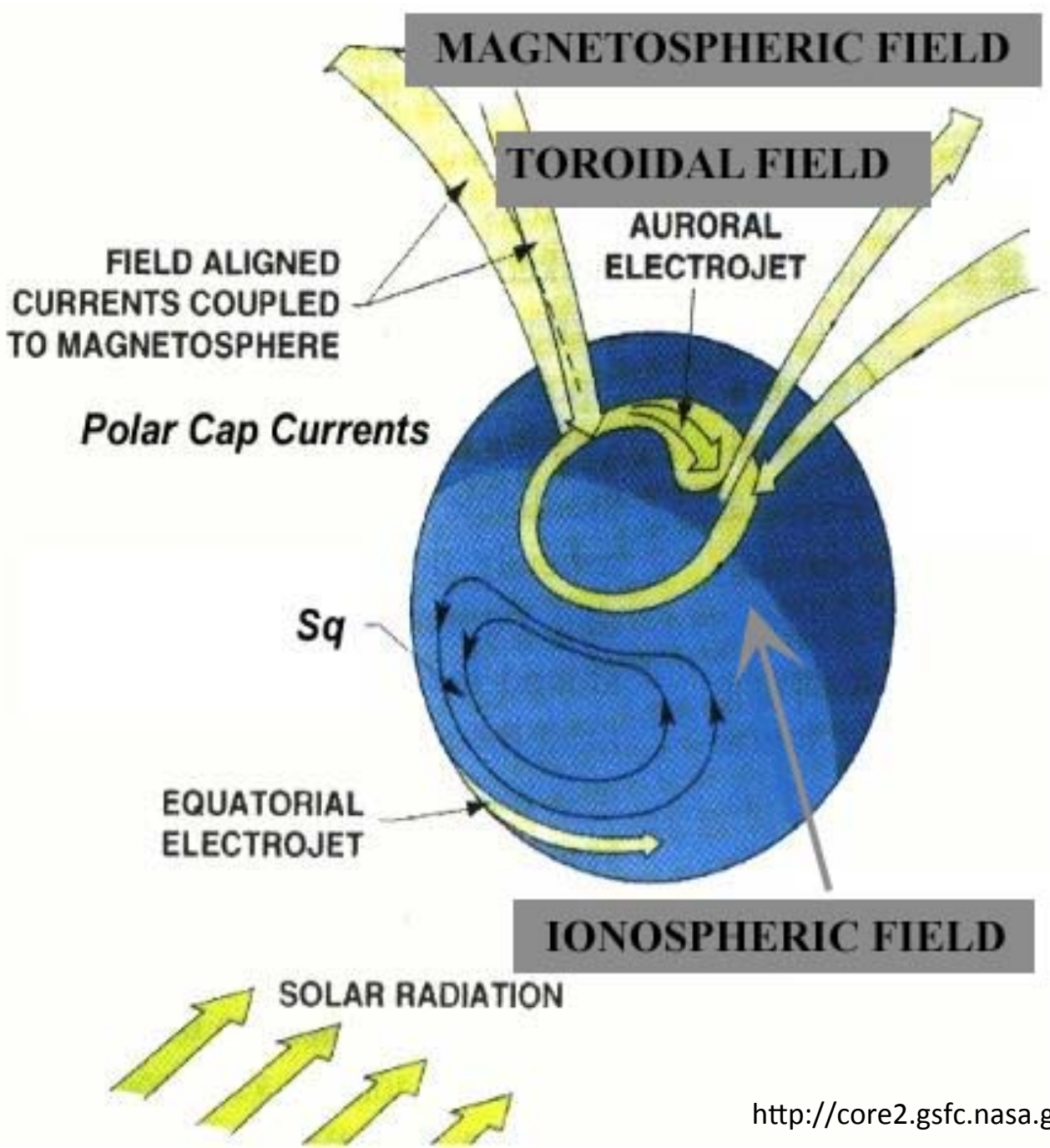




High latitude ionospheric fields



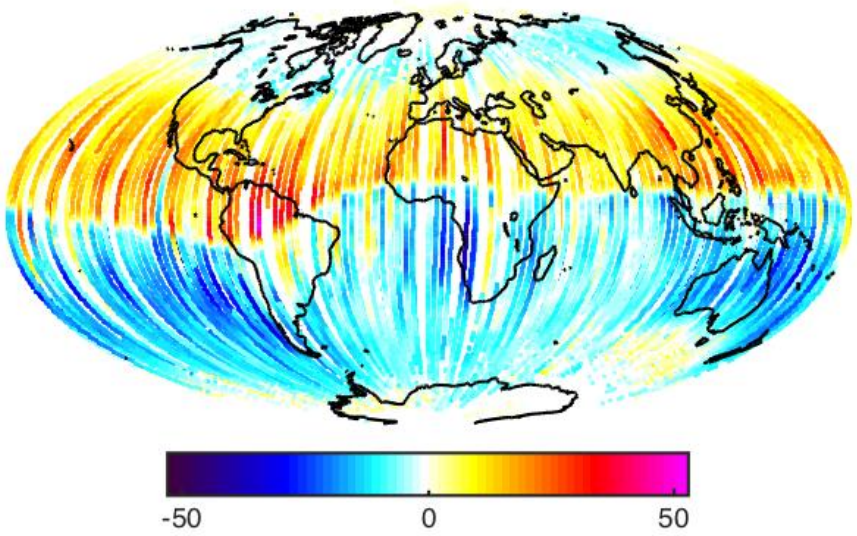




http://core2.gsfc.nasa.gov/CM/

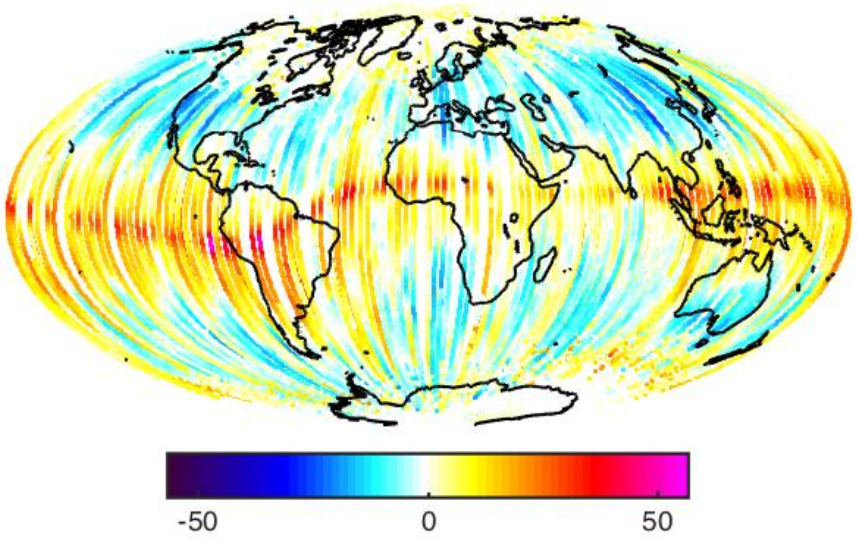
LT = 12 to 15

B_r

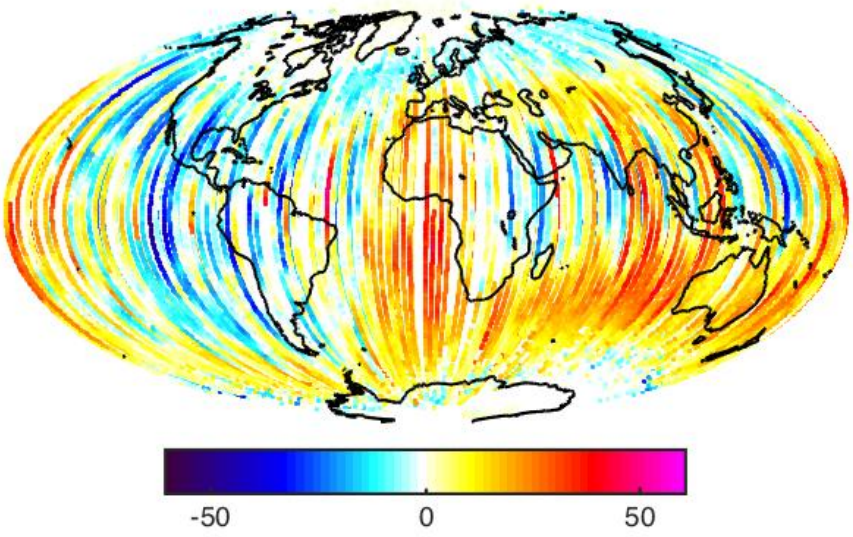


- Magnetic satellites measure the Sq and EEJ fields *above* the E-region of the ionosphere
- Multi-satellite constellations such as Swarm can make simultaneous measurements at different local times

B_θ



B_ϕ

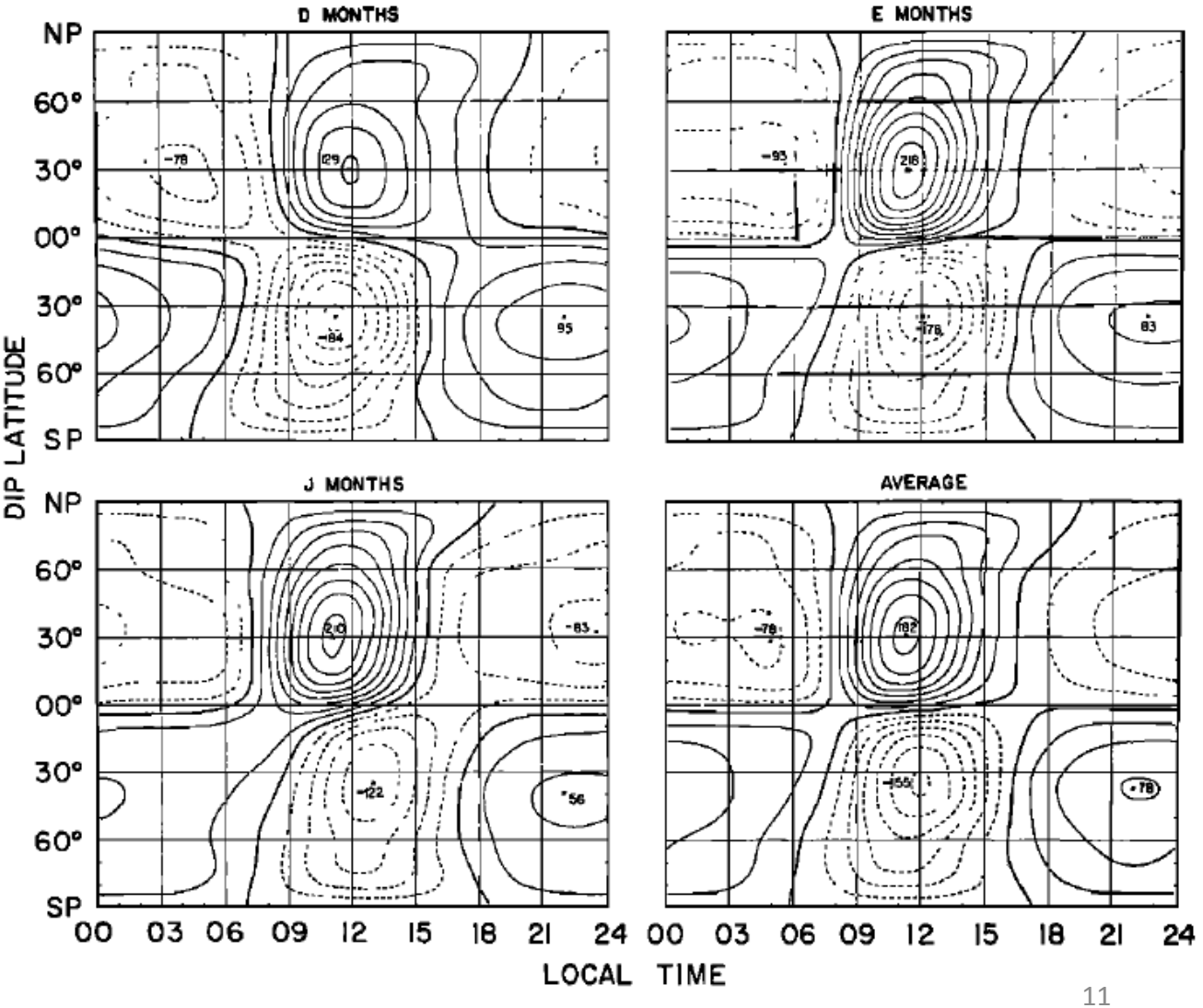


Outline

1. Sq and equatorial electrojet fields: observations
2. **Sq and equatorial electrojet fields: modeling**

Early modeling studies

- Spherical Harmonic Analysis naturally separates internal/ external sources
- Used by Schuster (1889) to infer external origin of Sq
- Until the early 2000s, SH modeling focused on local time vs. latitude due to sparse ground data coverage



(Matsushita & Maeda, JGR, 1965)

Satellite-based models

Q matrix (induction)

a < r < a+h:

$$V^m_{nsp}(t, t_{\mathrm{mut}}, \mathbf{r}) = \Re\left\{\iota^m_{nsp} S^m_{nsp,\mathrm{i}}(t, t_{\mathrm{mut}}, \mathbf{r}) + \epsilon^m_{nsp} S^m_{nsp,\mathrm{e}}(t, t_{\mathrm{mut}}, \mathbf{r})\right\}$$

Continuity relationship (B_r)

r > a+h:

$$(V')^m_{nsp}(t, t_{\mathrm{mut}}, \mathbf{r}) = \Re\left\{\left[\iota^m_{nsp} + (\epsilon')^m_{nsp}\right] S^m_{nsp,\mathrm{i}}(t, t_{\mathrm{mut}}, \mathbf{r})\right\}$$

$$S^m_{nsp,\mathrm{i}}(t, t_{\mathrm{mut}}, \mathbf{r}) = a\left(\frac{a}{r}\right)^{n+1} P^m_n(\cos\theta_{\mathrm{d}}) \times \exp i(m\phi_{\mathrm{d}} + \omega_s s t + \omega_p p t_{\mathrm{mut}})$$

$$S^m_{nsp,\mathrm{e}}(t, t_{\mathrm{mut}}, \mathbf{r}) = a\left(\frac{r}{a}\right)^{n} P^m_n(\cos\theta_{\mathrm{d}}) \times \exp i(m\phi_{\mathrm{d}} + \omega_s s t + \omega_p p t_{\mathrm{mut}})$$

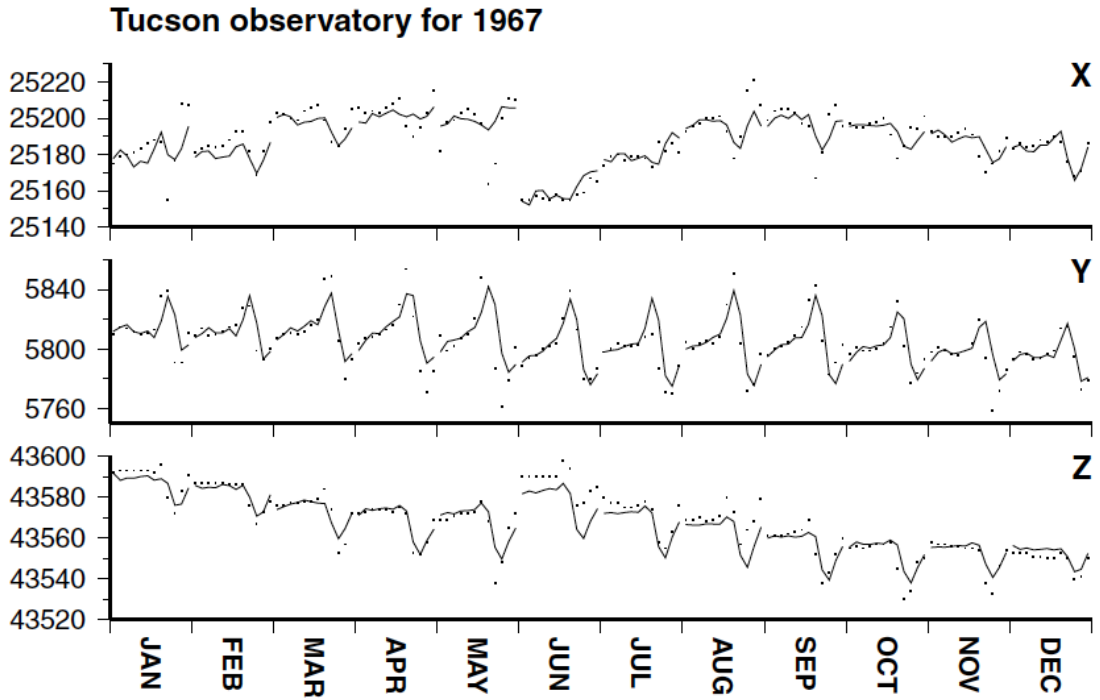
n, m: degree and order
s, p: seasonal and diurnal wavenumbers
ε, ε', ι: model complex coefficients

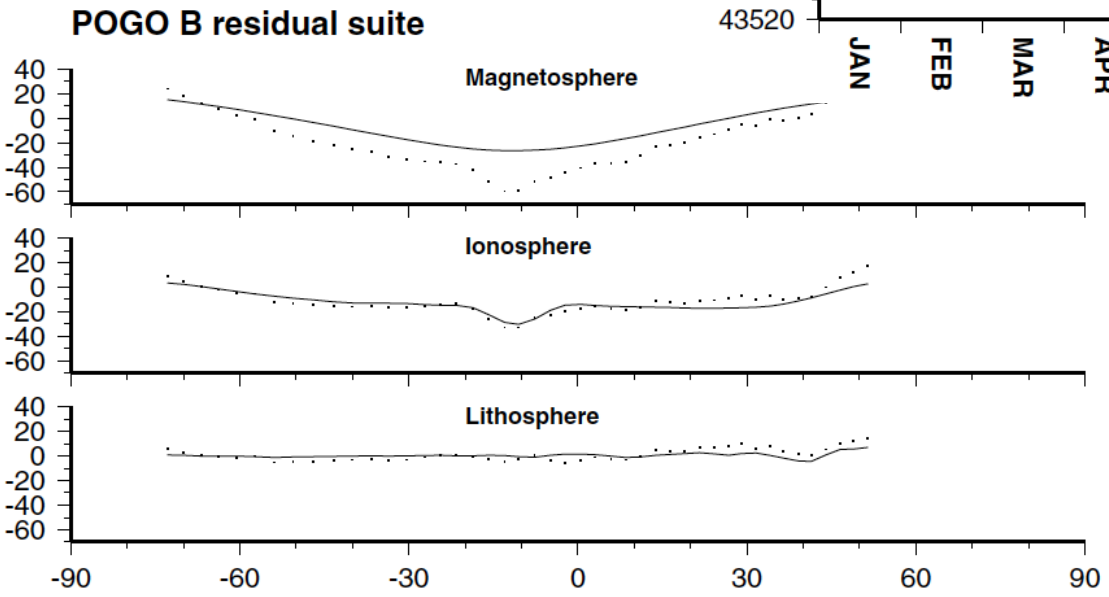
(Sabaka et al, GJI, 2002; Chulliat et al., EPS 2013)

The Comprehensive Model

- Simultaneous modeling of Sq +EEJ fields and other fields (core, lithosphere, magnetosphere)

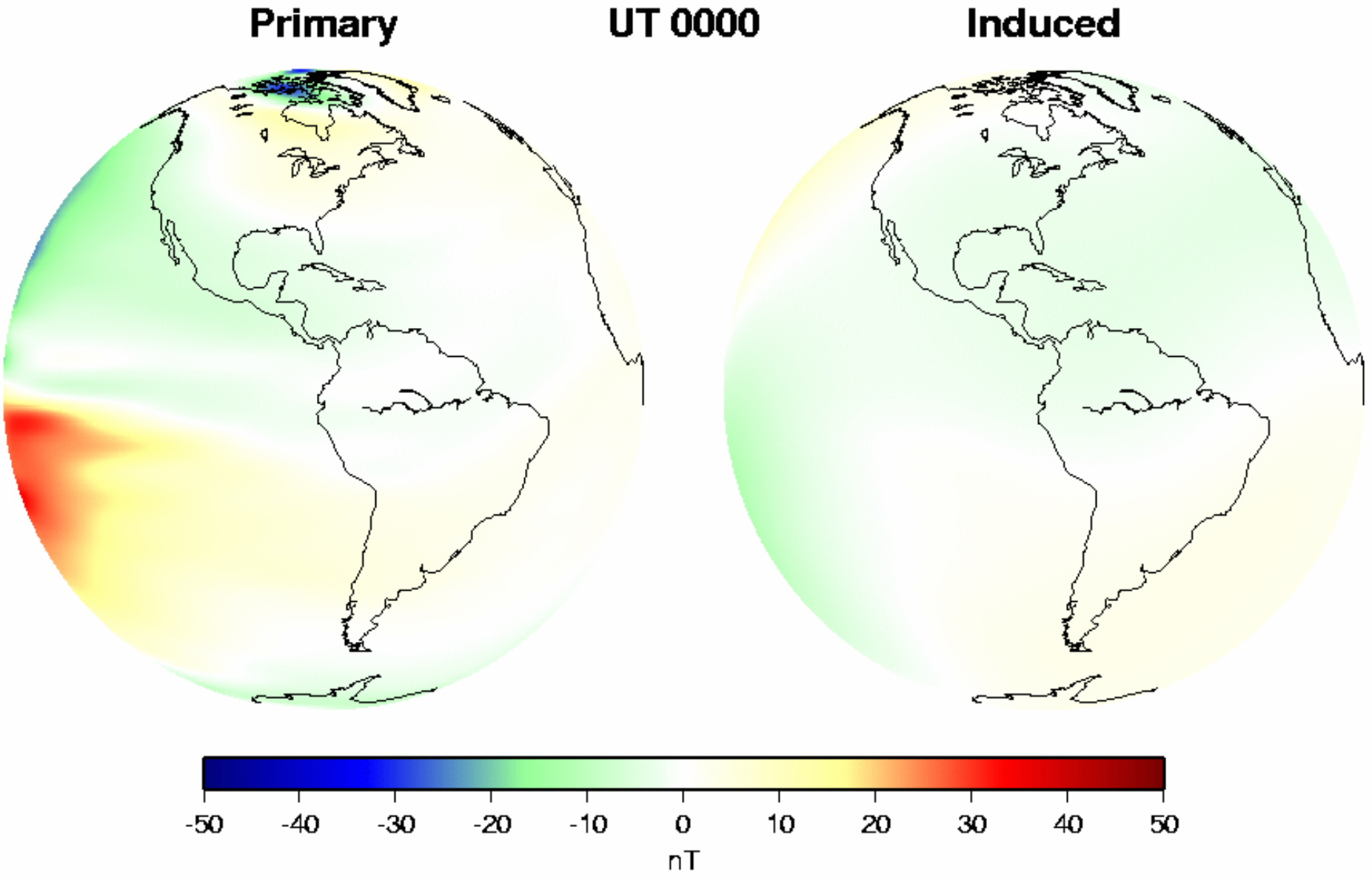
- 1D mantle conductivity model
- Linear dependence upon F10.7 cm solar flux index





- Includes data from ground observatories and satellites (POGO, Magsat, Oersted, CHAMP)

(Sabaka et al., GJI, 2002)



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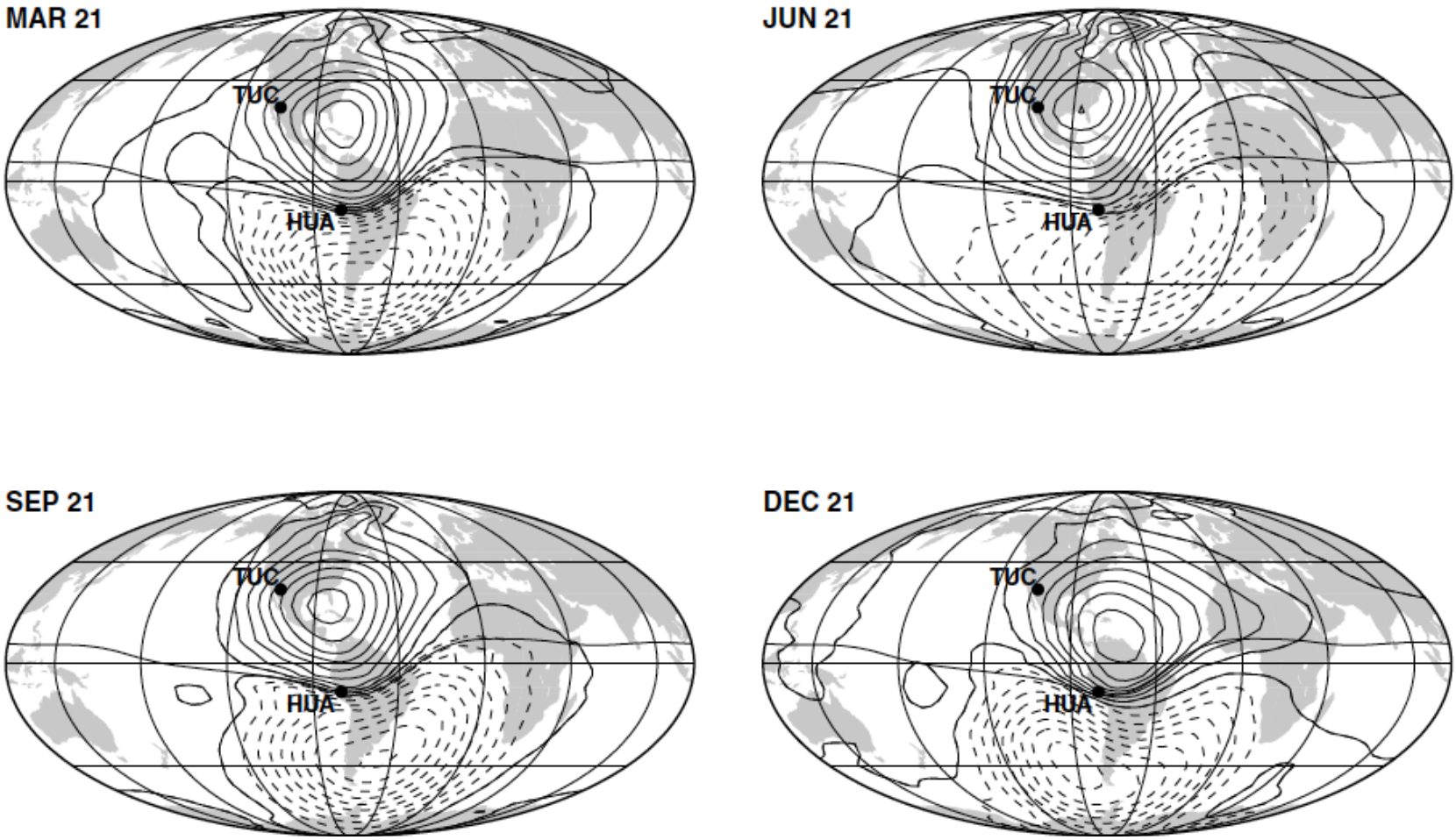


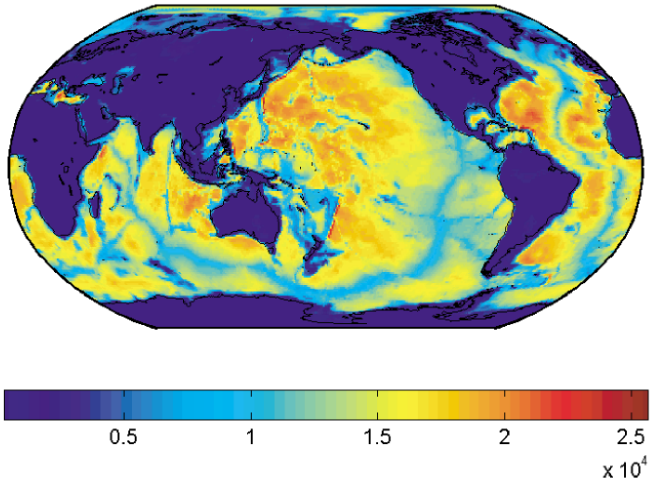
- CM3 ionospheric E-region equivalent current function (external field only)
- A 20 kA current flows between the contours

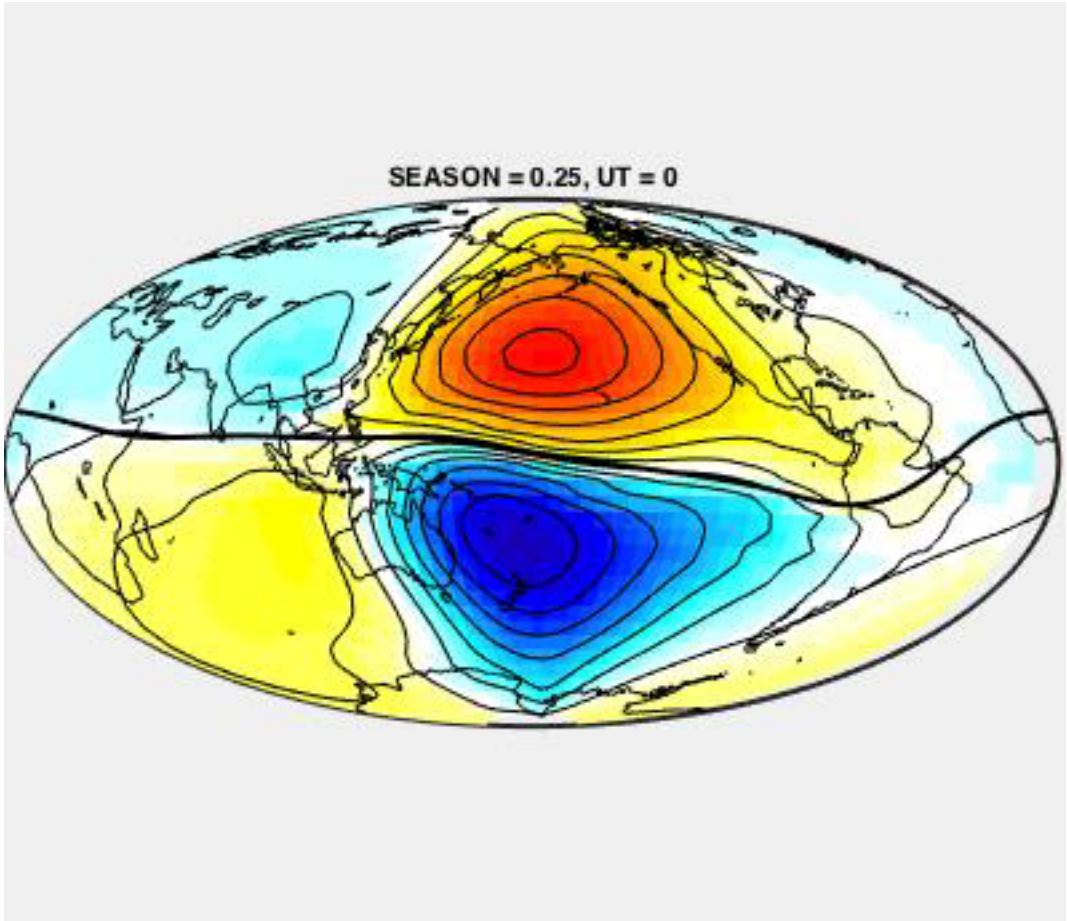
(Sabaka et al., GJI, 2002)

Swarm-based model

- DIFI-2015b ionospheric E-region equivalent current function (external field only)
- A 13.1 kA current flows between the contours

- 3D mantle conductivity model: 2D surface shell + 1D profile underneath





(Chulliat et al., AGU, 2015; Manoj et al., EPS, 2006)

Self-assessment questions

1. How does the ΔX (northward) component of the Sq+EEJ field vary with latitude?

2. What are the approximate latitudes of the northern and southern foci of the Sq current system?

3. How does the equatorial electrojet vary with season?

4. How does the Sq field vary with solar activity?

5. Assuming the (primary) Sq+EEJ field is generated by a thin current sheet at 110 km altitude, how is the (primary) field at satellite altitude related to the (primary) field at ground?