Response of the Earth's environment to solar radiative forcing

Ingrid Cnossen
British Antarctic Survey

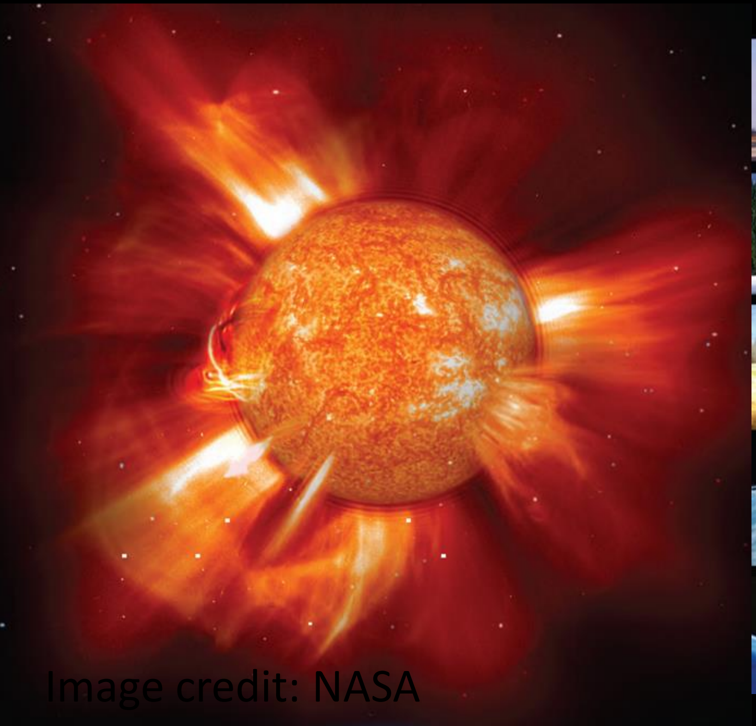
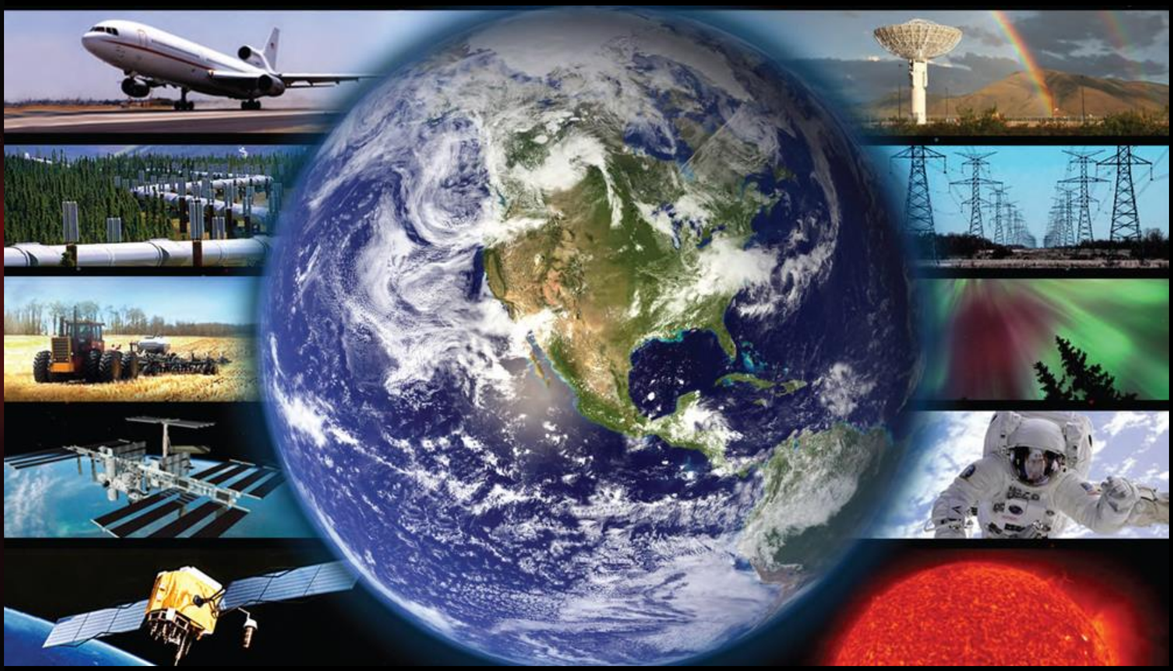


Image credit: NASA



Outline

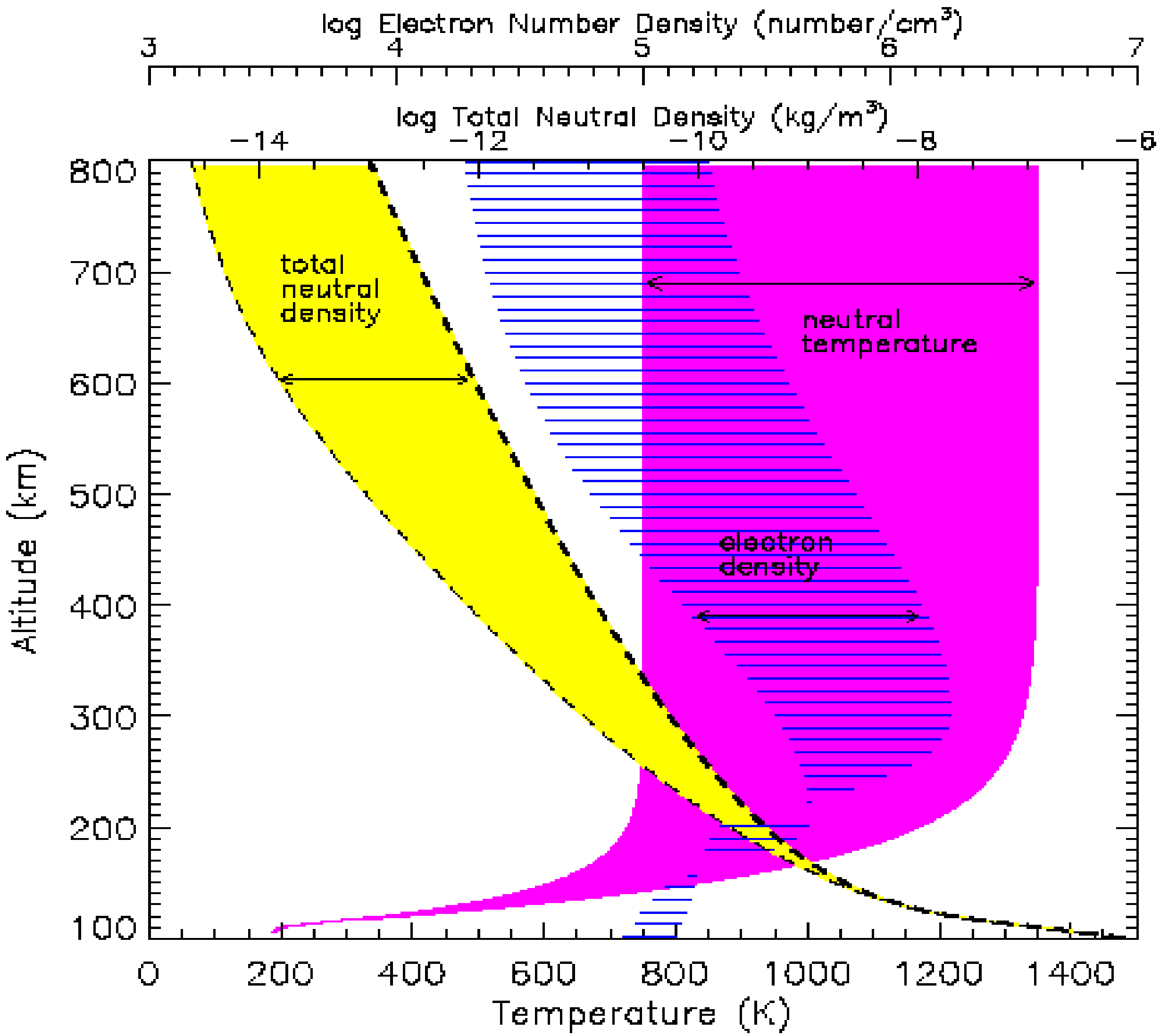
Previous lecture

- Intro to atmosphere structure and processes
- Absorption of solar radiation
- Atmosphere composition
- Energy balance
- Ionization
- Conductivity
- Low latitude currents

This lecture

- Effects of variations in solar radiative forcing (examples)
- Interactions between radiatively driven processes and
    - Solar wind-magnetosphere processes
    - Earth’s magnetic field

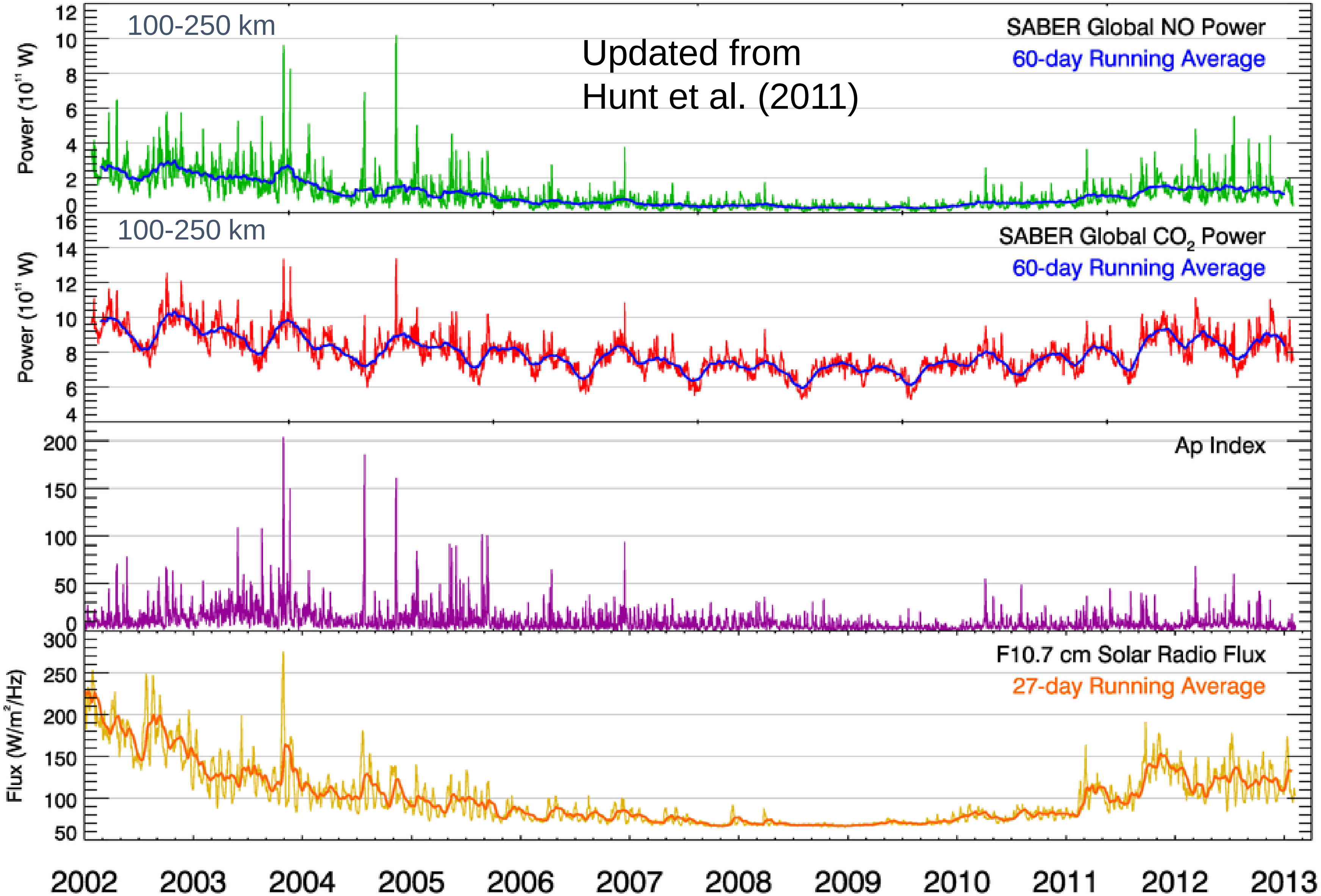
Solar cycle effects on the upper atmosphere



Solar cycle changes at 700 km:

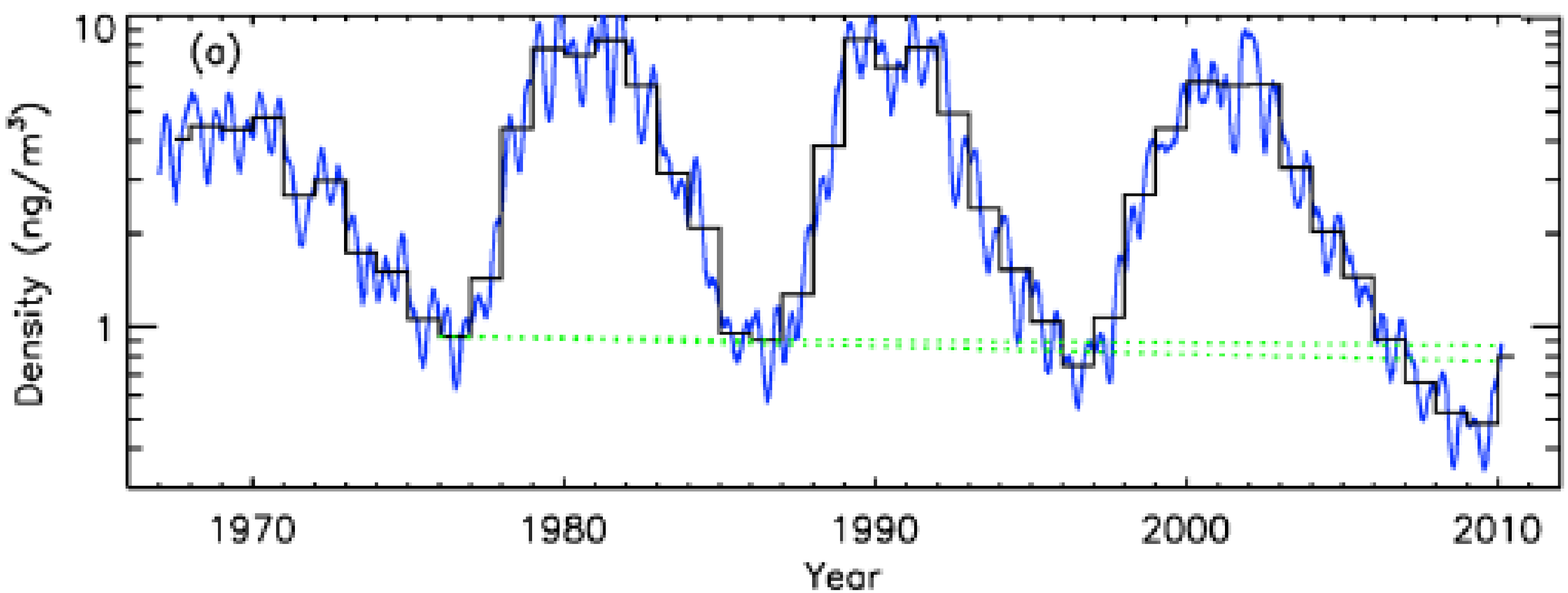
- Neutral Temperature: 2 times
- Neutral Density: 50 times
- Electron Density: 10 times

Radiative balance



Long-term mass density variations

Global mean density at 400 km altitude



81-day centred running mean

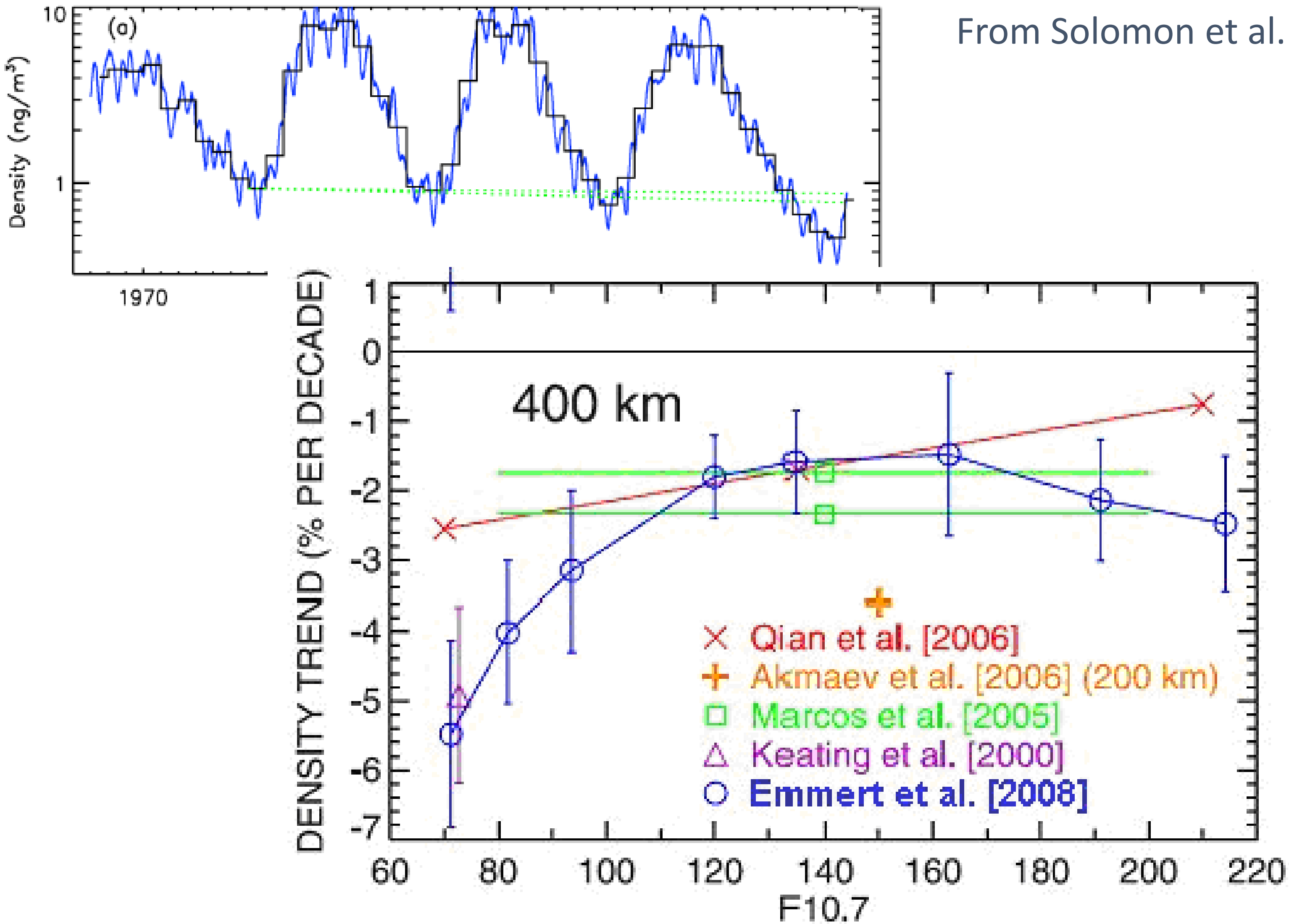
annual average

envelope of expected decline due to increased CO_2

From Solomon et al. (2010)

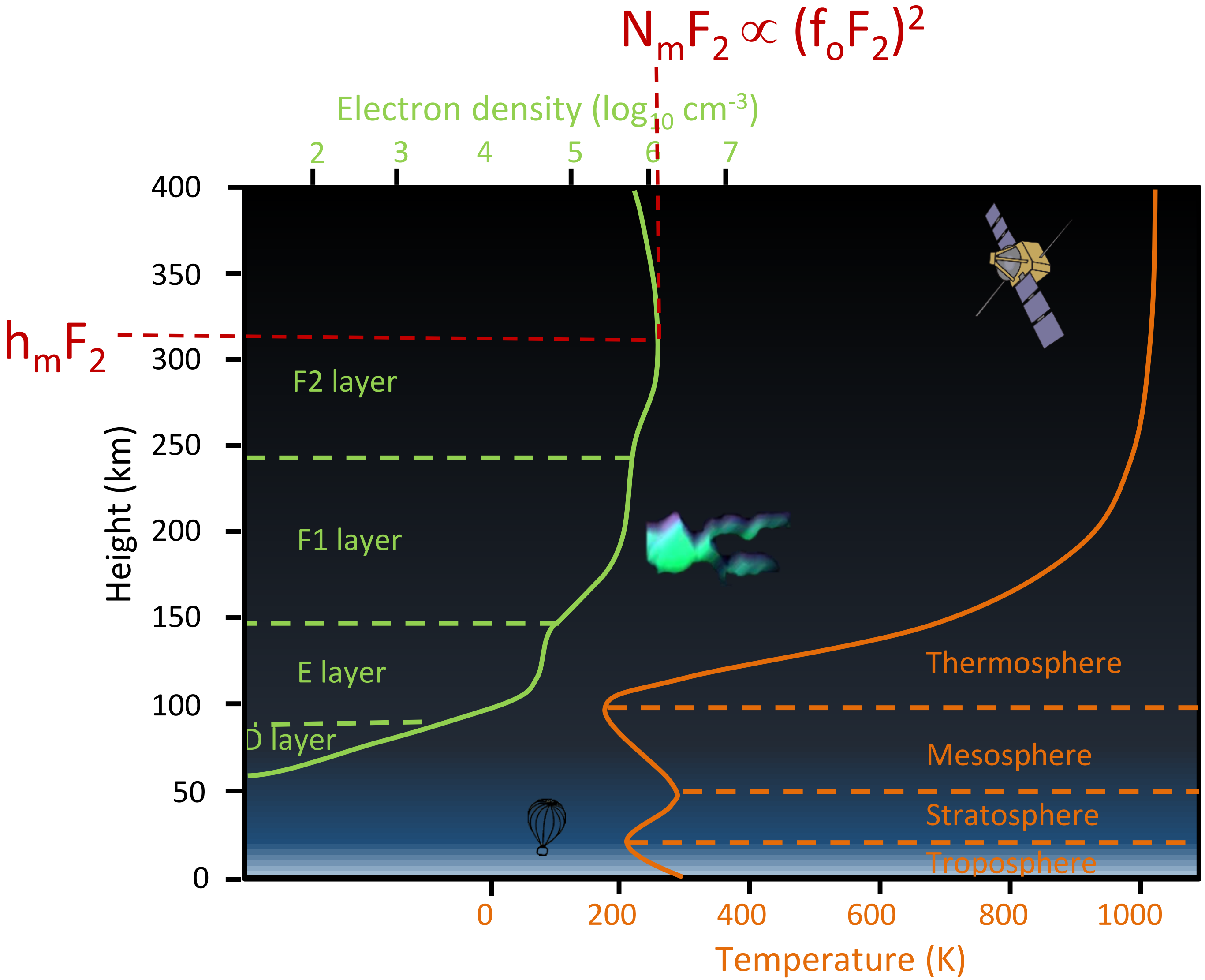
Long-term mass density variations

Global mean density at 400 km altitude

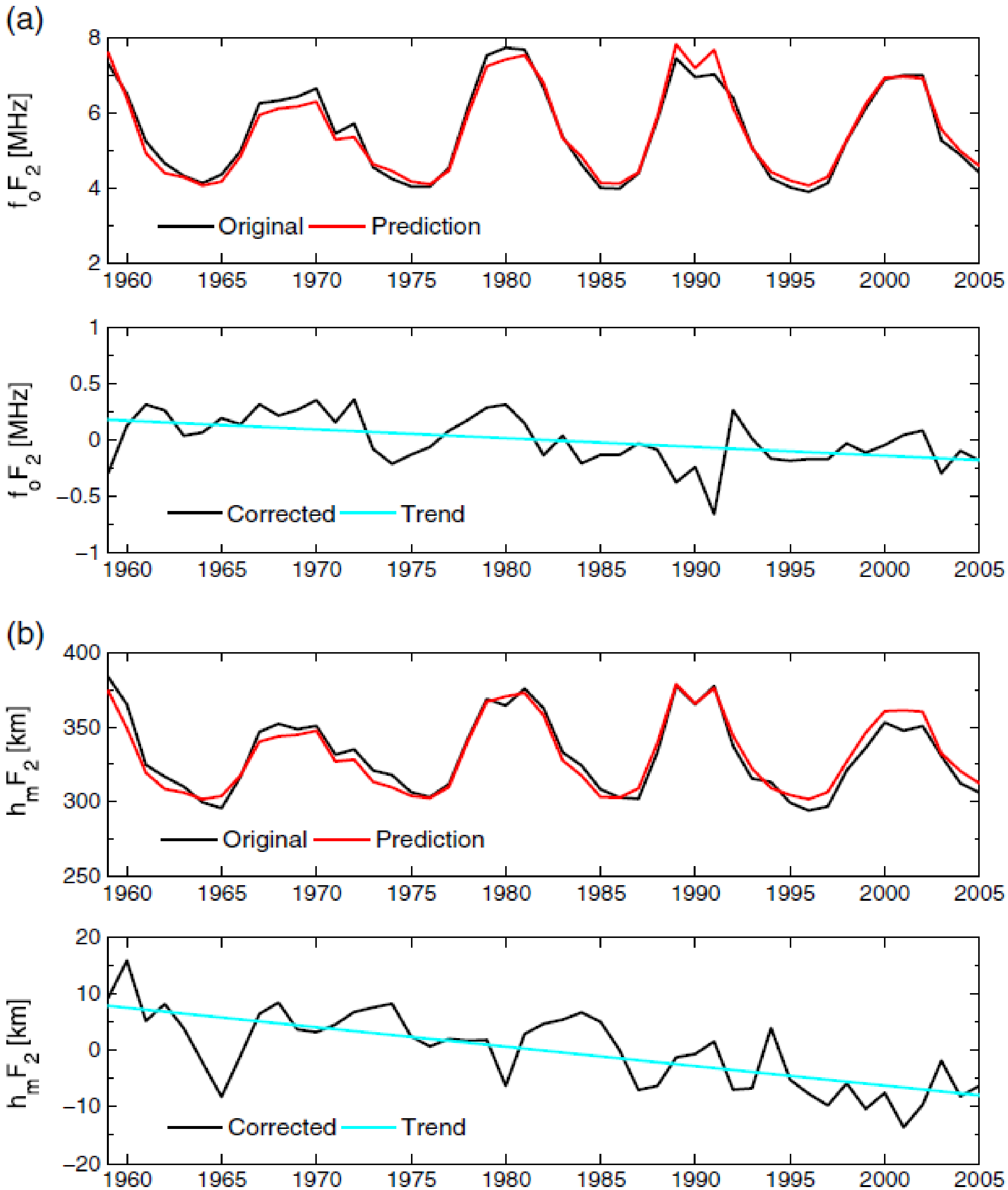


From Solomon et al. (2010)

Vertical structure of the atmosphere



Long-term variations in f_oF_2 and h_mF_2

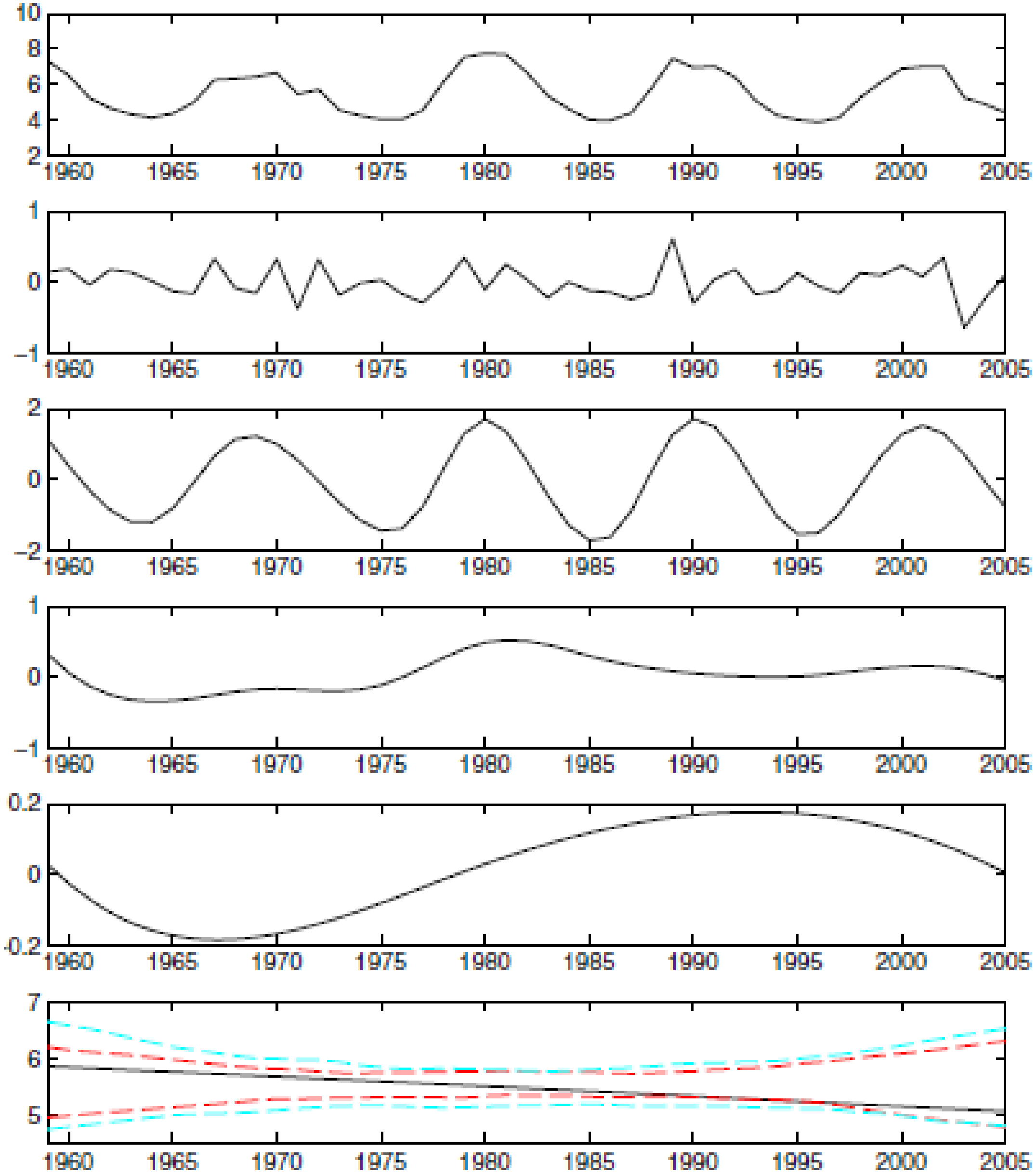


Observations from Juliusruh/Rugen, Germany

Prediction = a*F10.7 + b

From Cnossen and Franzke (2014)

Long-term variations in f_oF_2 (EEMD analysis)



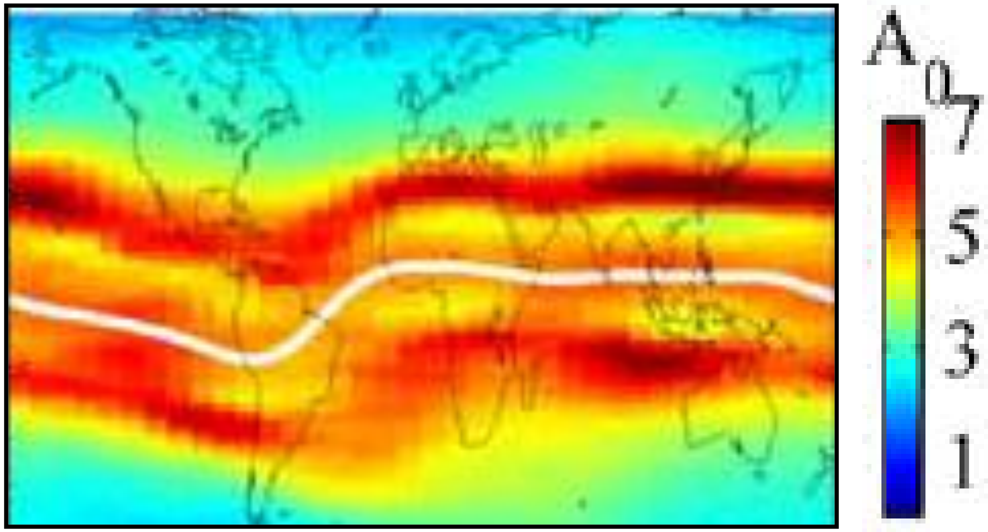
Observations from Juliusruh/Rugen, Germany

Ensemble Empirical Mode Decomposition

From Cnossen and Franzke (2014)

Spatial electron density variations

250 km



x 10^5 cm^{-3}

Annual mean electron density

Observations from COSMIC

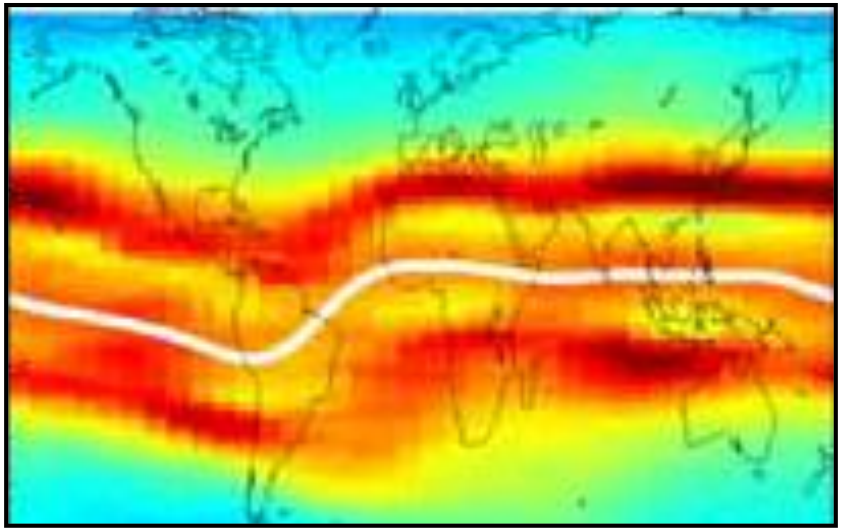
From Liu et al. (JGR, 2009)

Equatorial ionization anomaly:

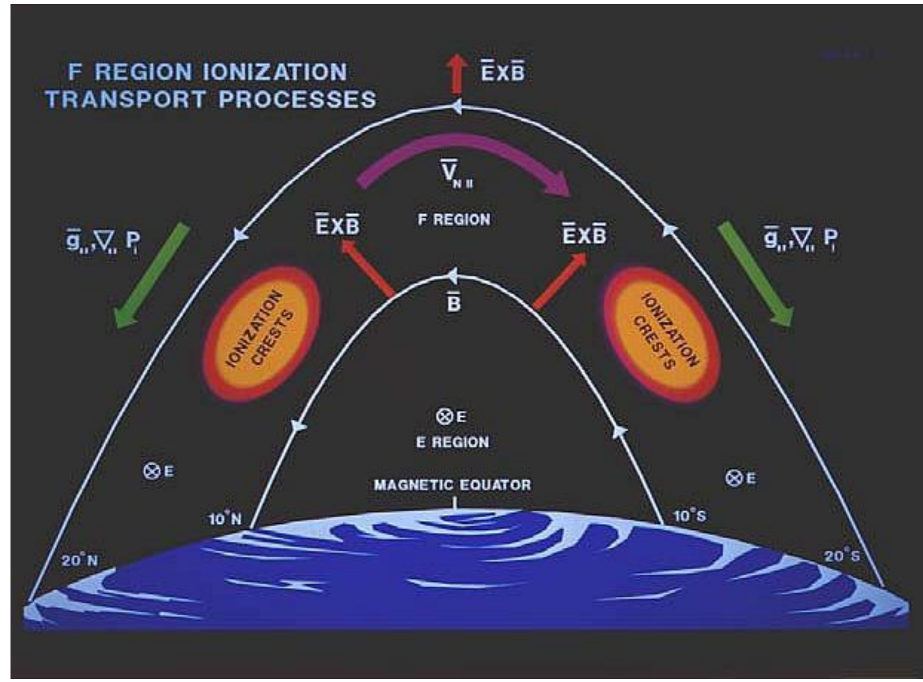
Peaks on either side of magnetic equator in afternoon

Spatial electron density variations

250 km



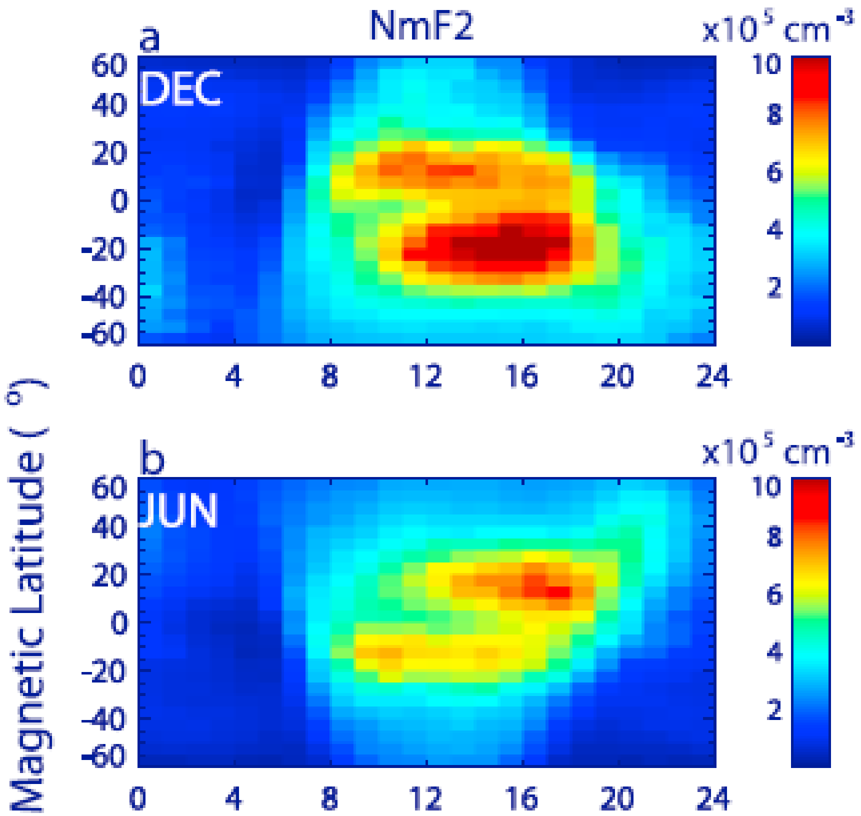
From Liu et al. (JGR, 2009)



Equatorial ionization anomaly:

Peaks on either side of magnetic equator in afternoon

Diurnal/seasonal electron density variations



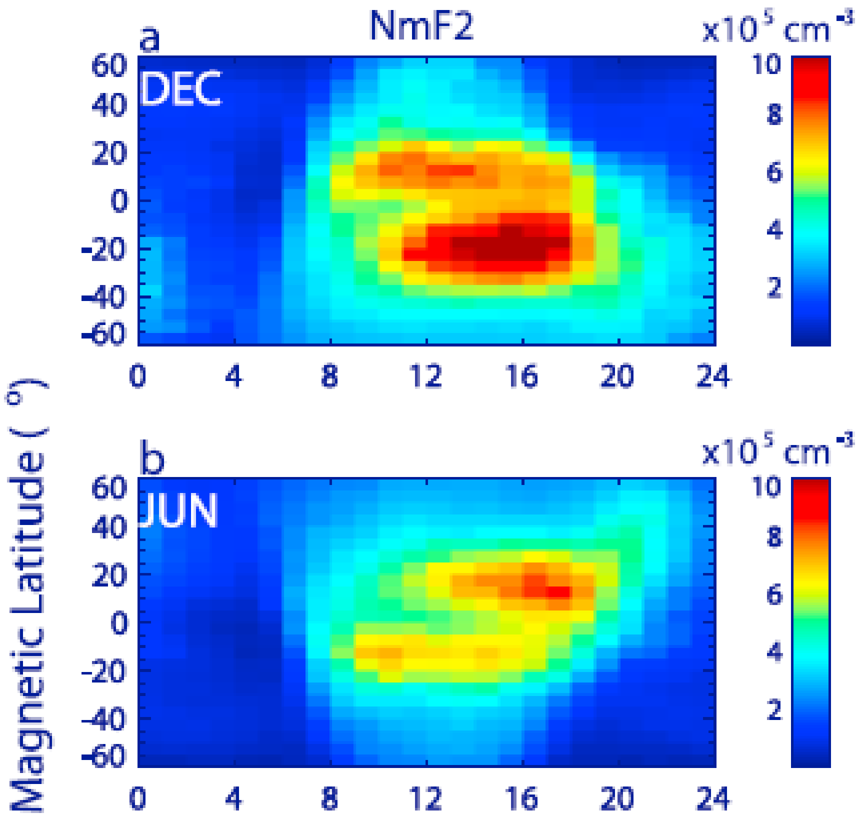
From Lee et al. (JGR, 2011)

Observations from COSMIC

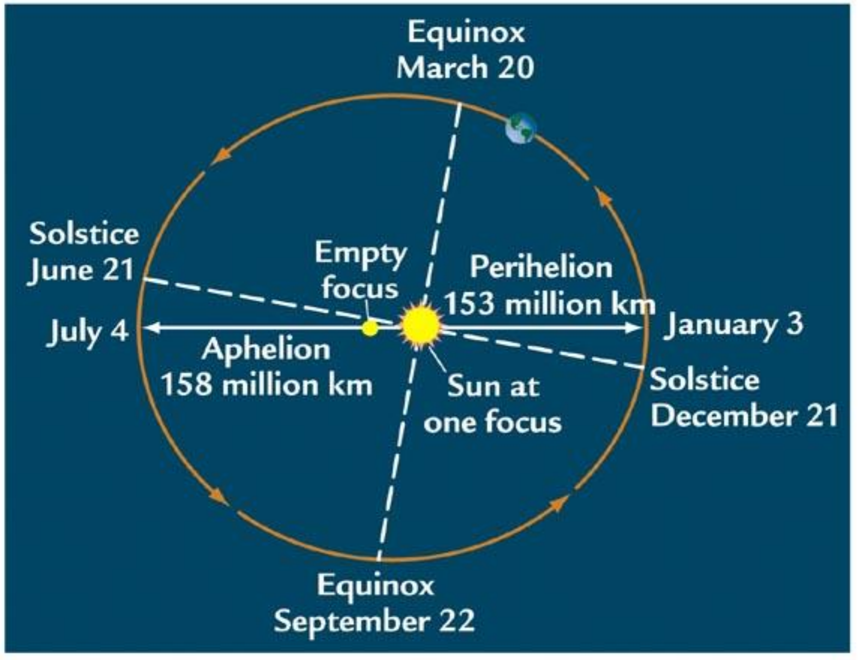
- Annual anomaly:

  Electron density Dec > Jun

Diurnal/seasonal electron density variations



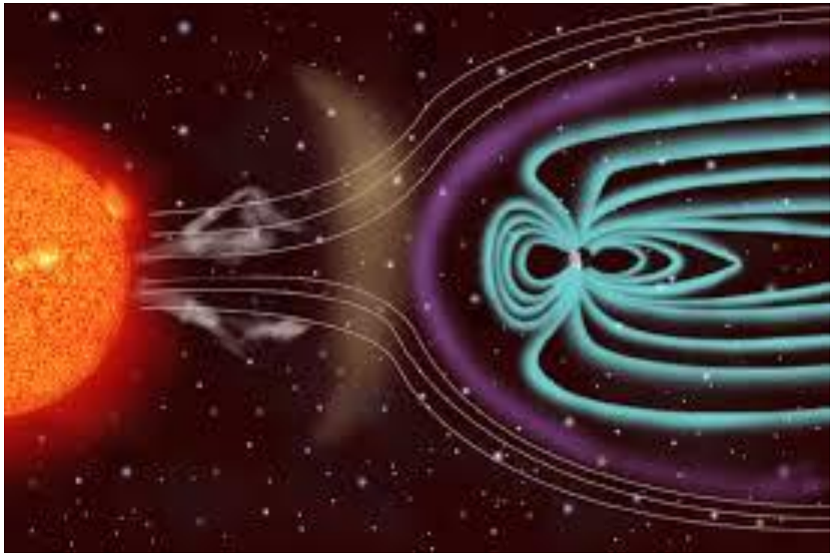
From Lee et al. (JGR, 2011)

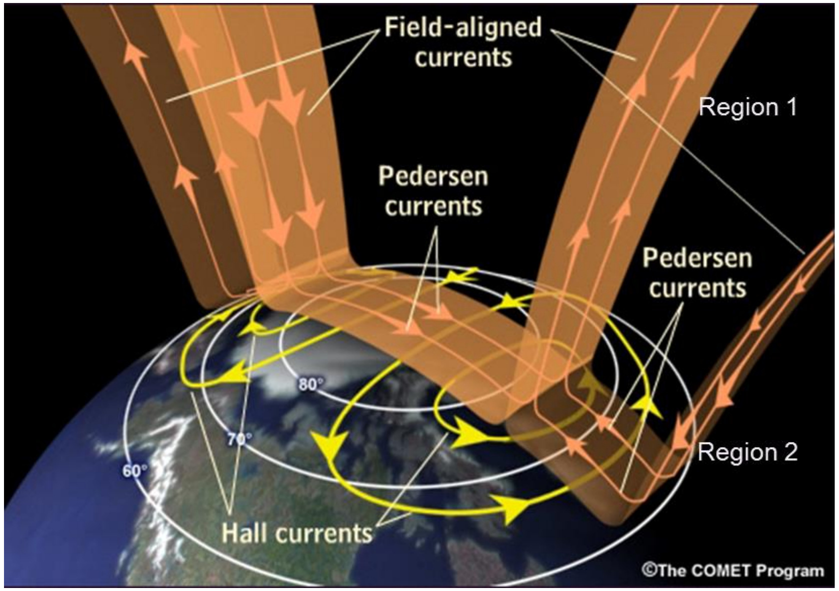


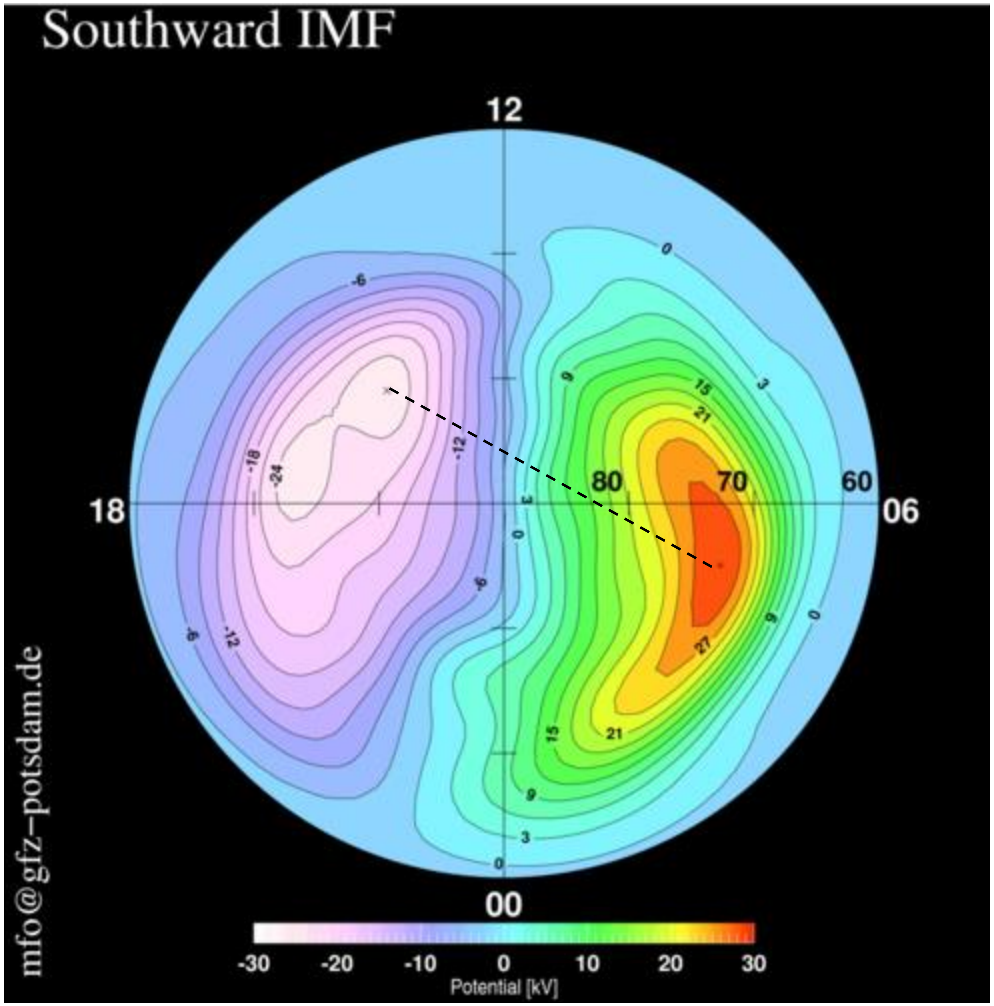
- Annual anomaly:

  Electron density Dec > Jun

Solar wind-magnetosphere-ionosphere coupling

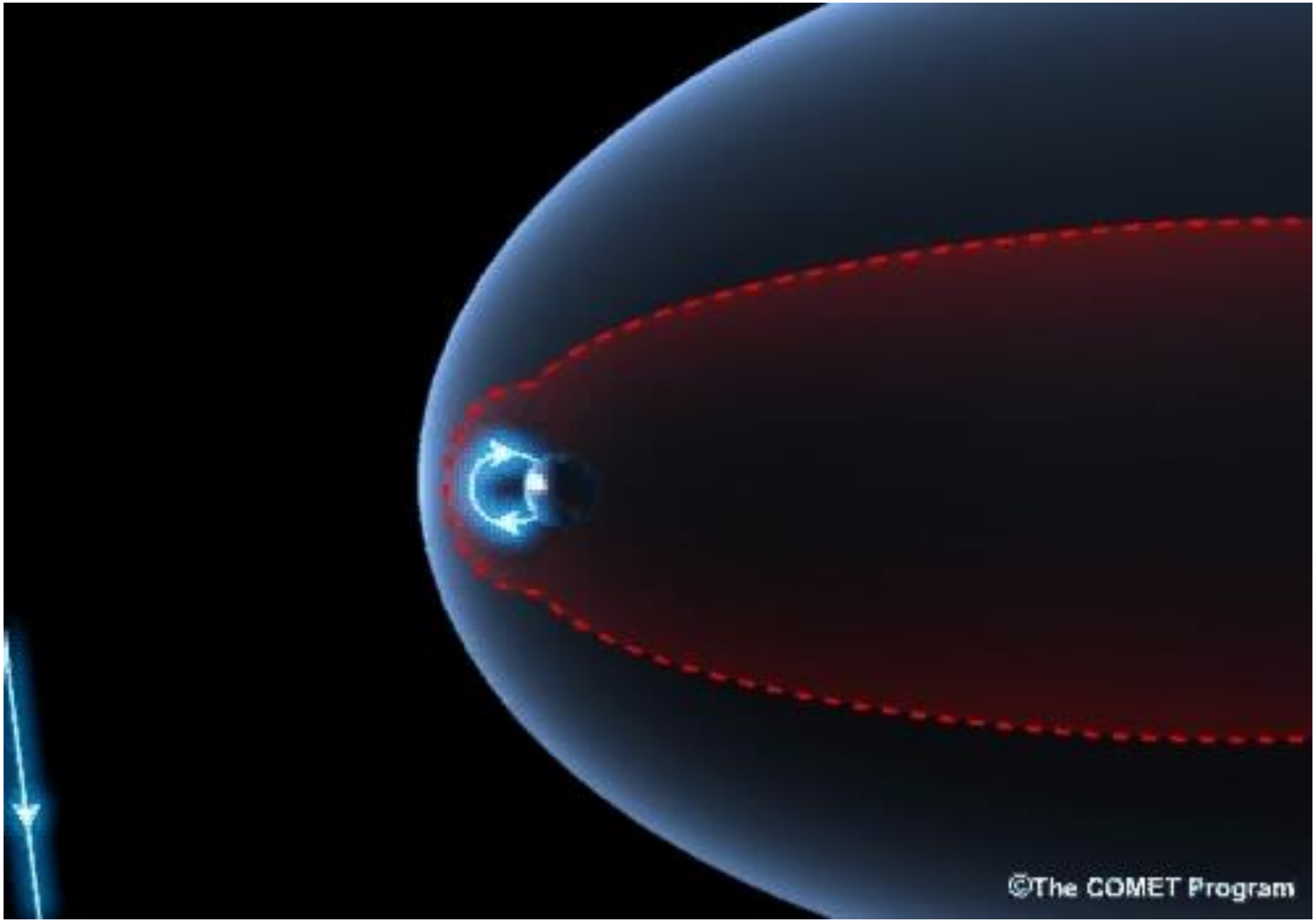




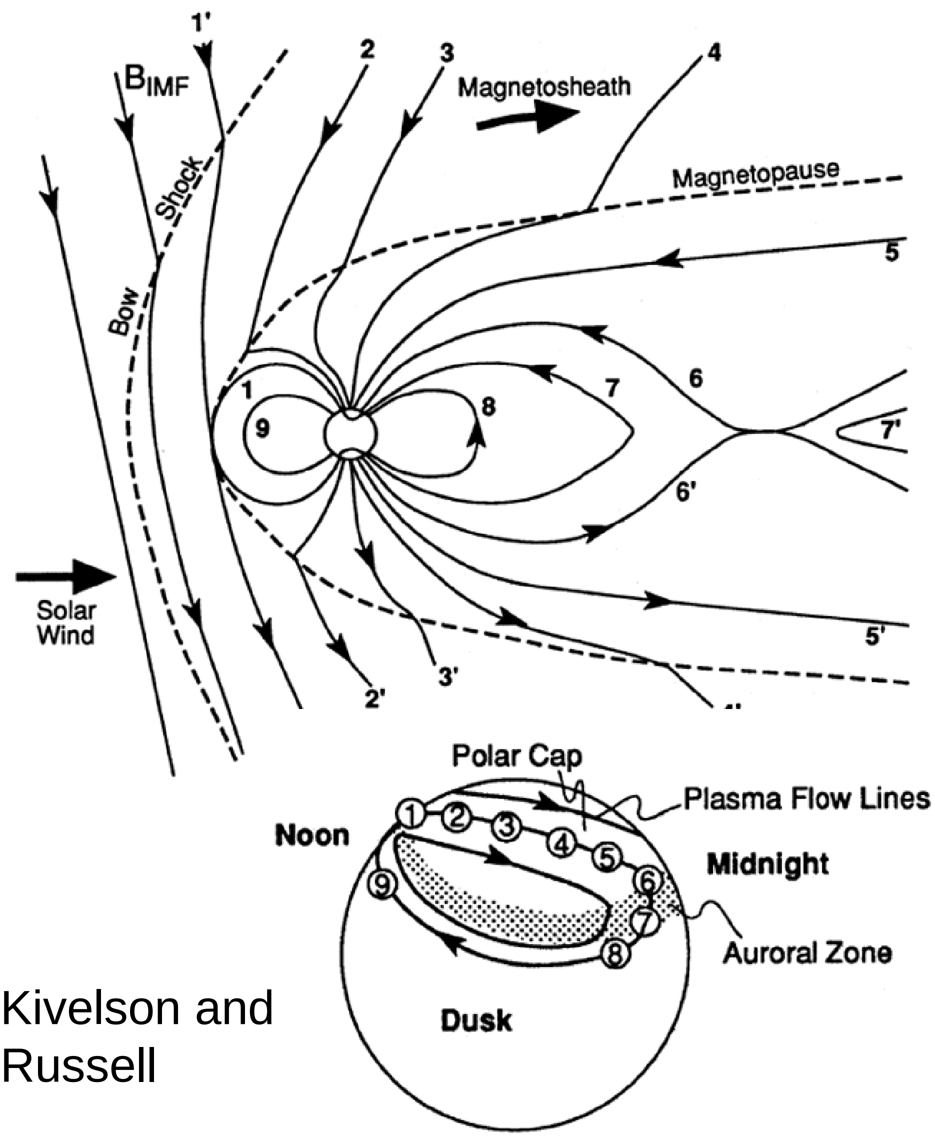


created by Matthias Förster from EDI/Cluster data

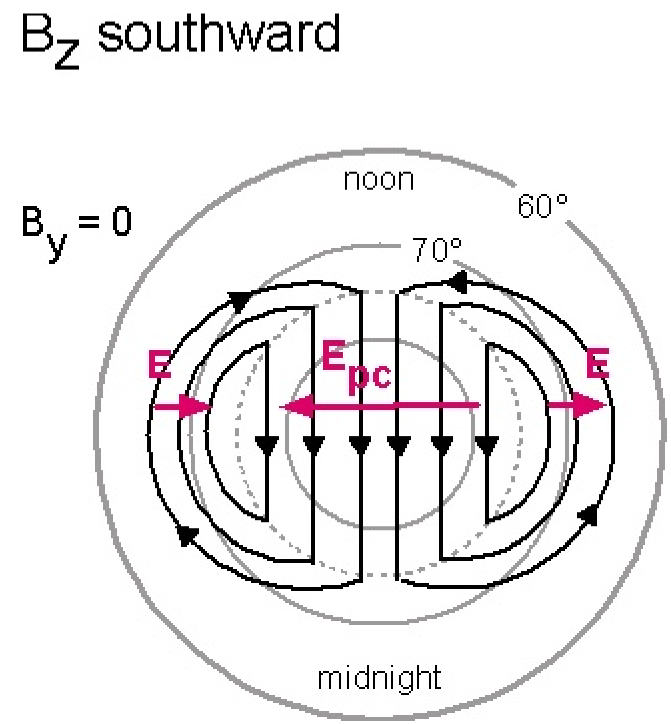
Magnetosphere convection



Ionospheric convection

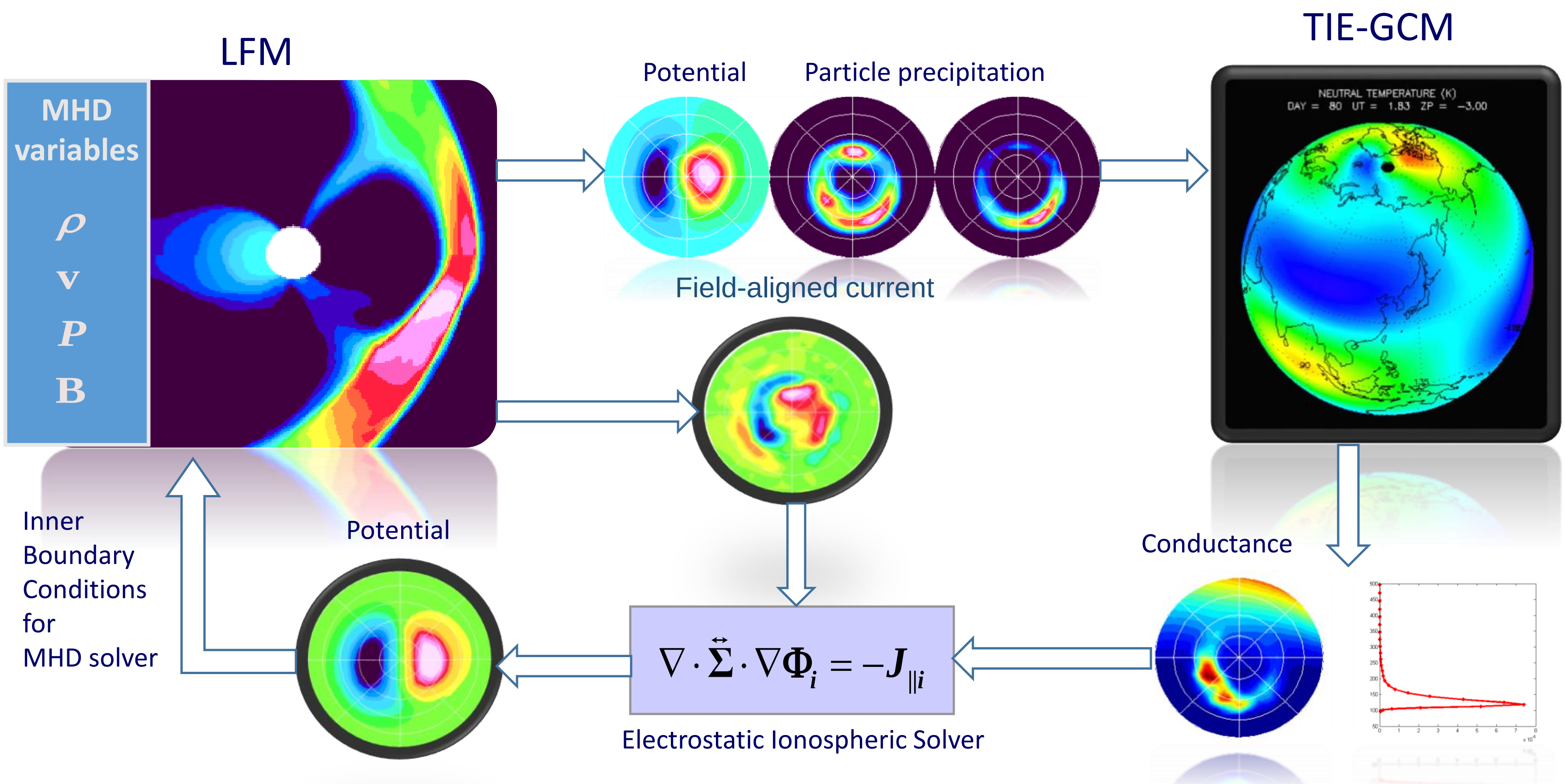


Kivelson and Russell



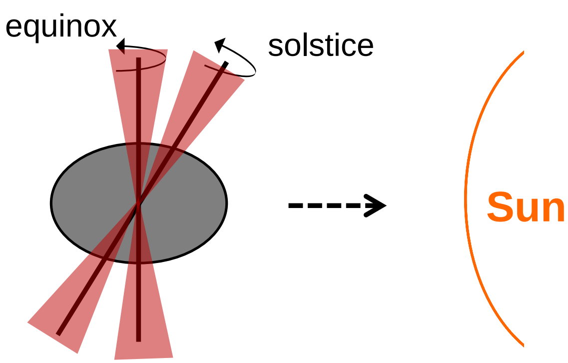
Coupled Magnetosphere-Ionosphere-Thermosphere model

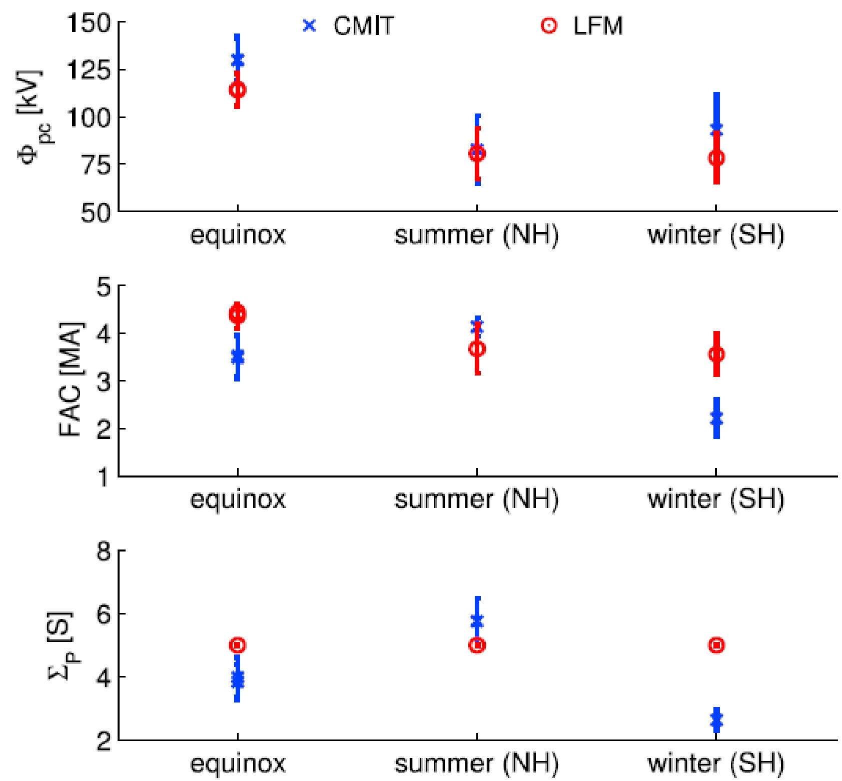
- CMIT = LFM + TIE-GCM
- LFM = Lyon-Fedder-Mobarry MHD code (magnetosphere model)
- TIE-GCM = Thermosphere-Ionosphere-Electrodynamics General Circulation Model



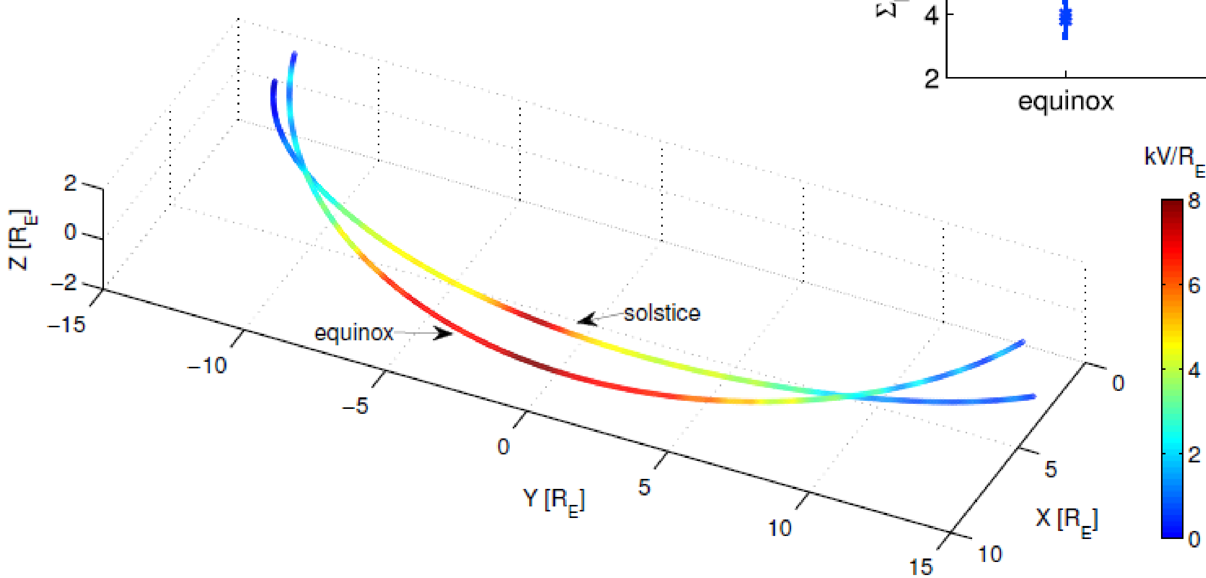
Graphics courtesy of Binzheng Zhang

Magnetosphere-ionosphere coupling: seasonal effects

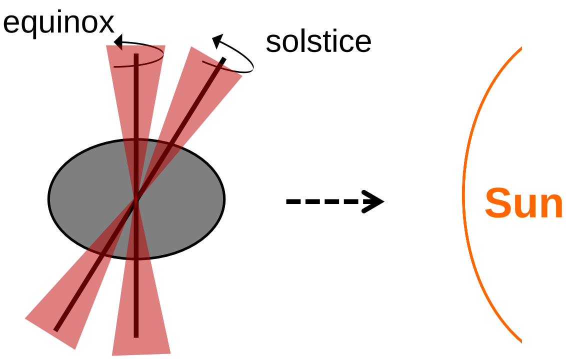


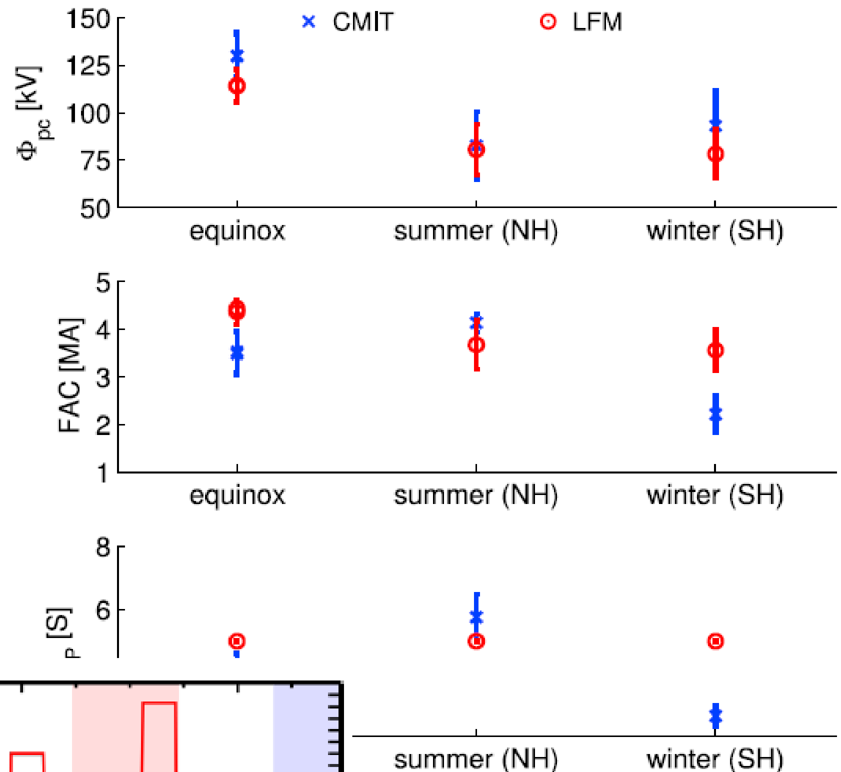


From Cnossen, Wiltberger and Ouellette, JGR, 2012

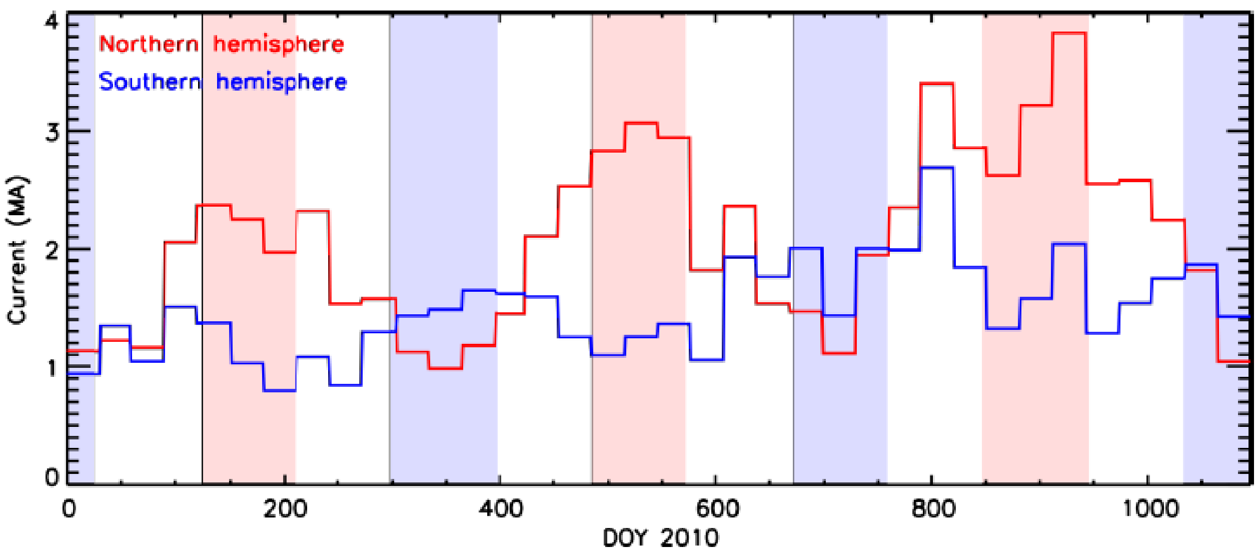


Magnetosphere-ionosphere coupling: seasonal effects



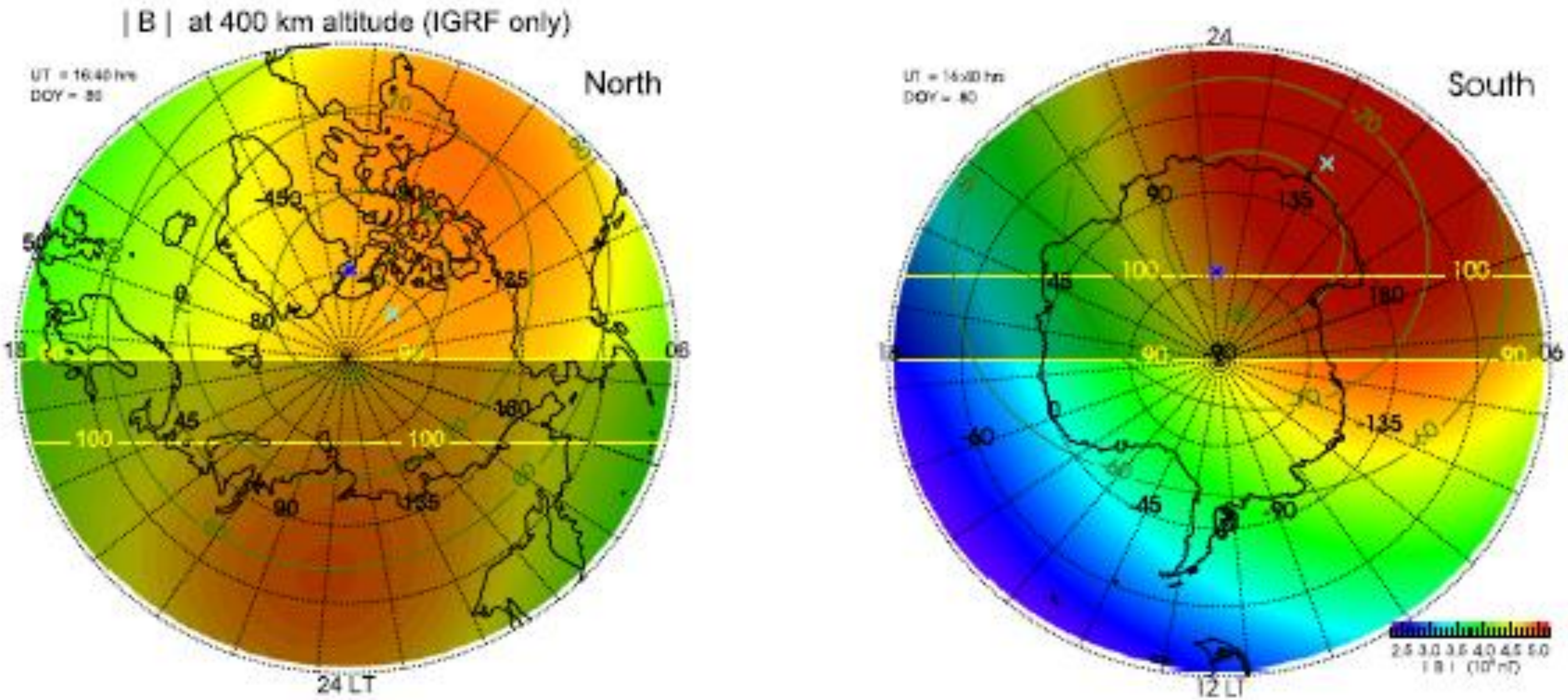


From Cnossen, Wiltberger and Ouellette, JGR, 2012



Created by Steve Milan from AMPERE data

North-South asymmetries in magnetic field

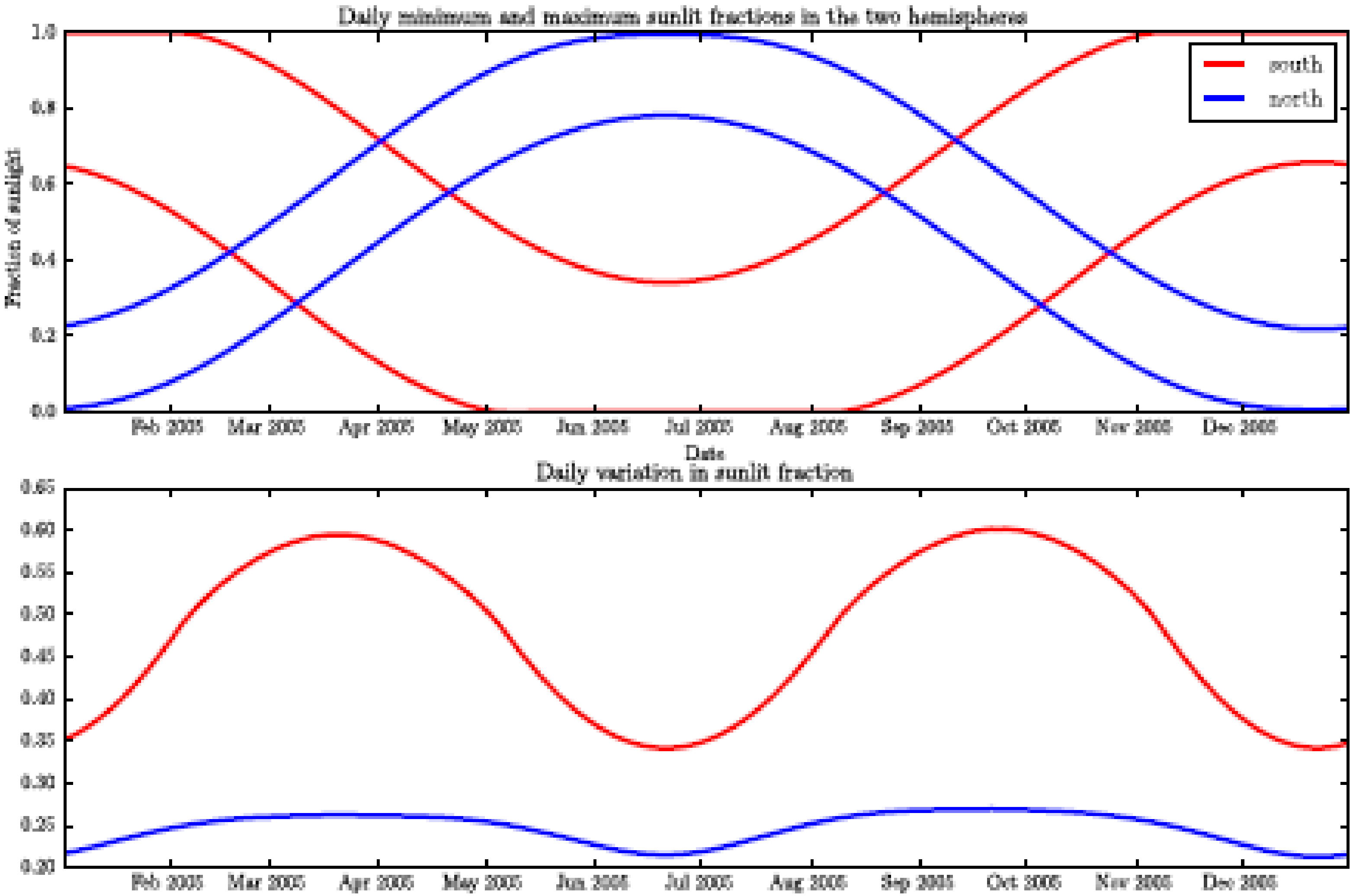


Magnetic field in Northern high latitudes is weaker

Offset between geographic and magnetic pole in the North is smaller

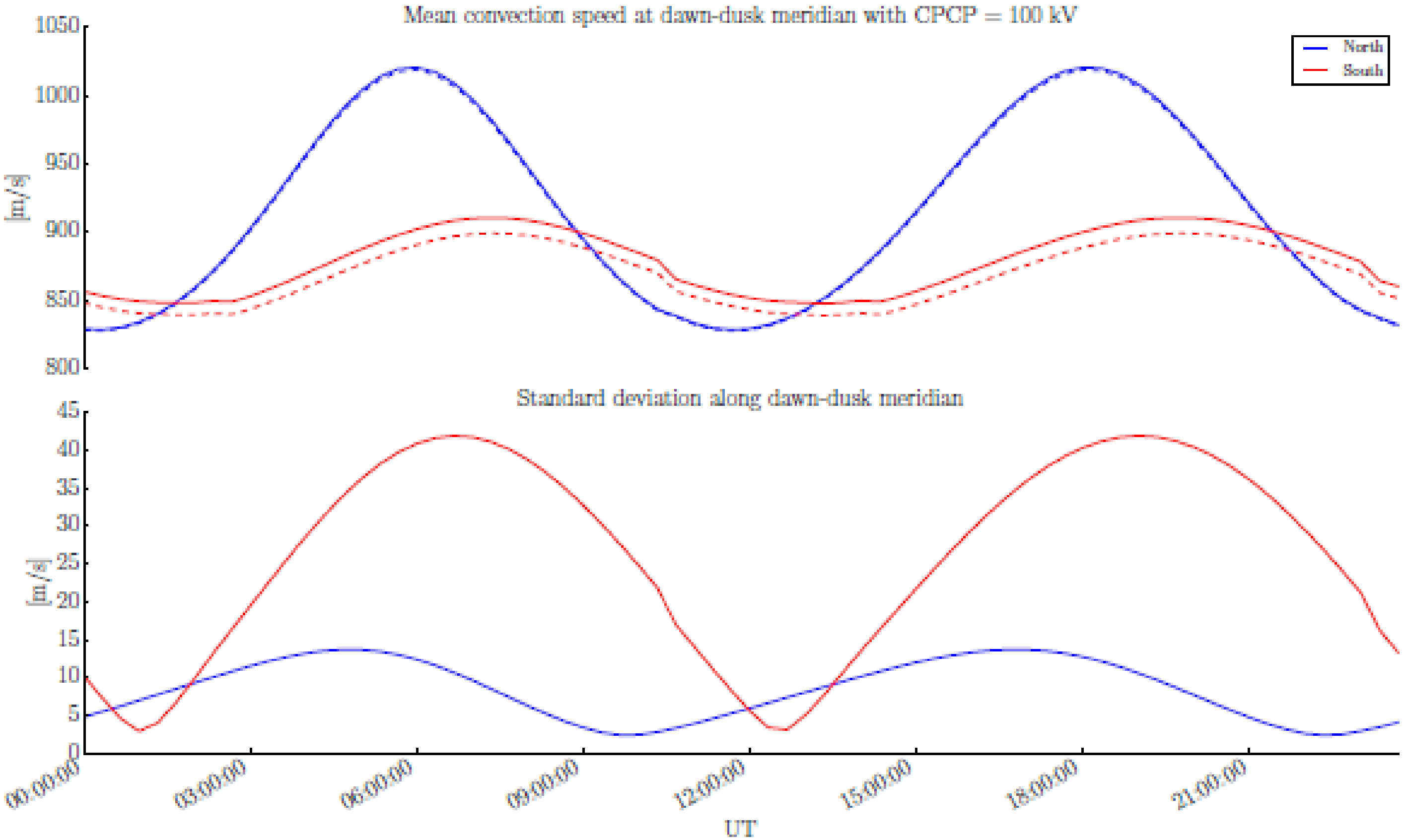
From Förster and Cnossen (2013)

North-South asymmetries in sunlit fraction of high magnetic latitude region

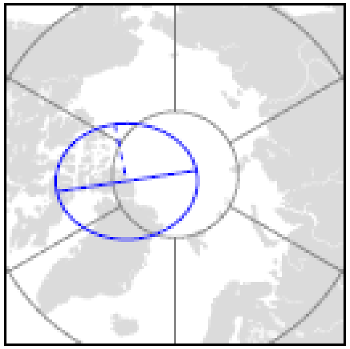


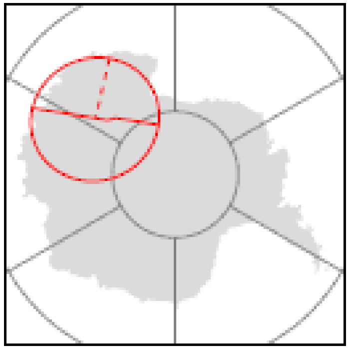
Laundal et al. (in preparation)

North-South asymmetries in ExB drift speeds



0 UT

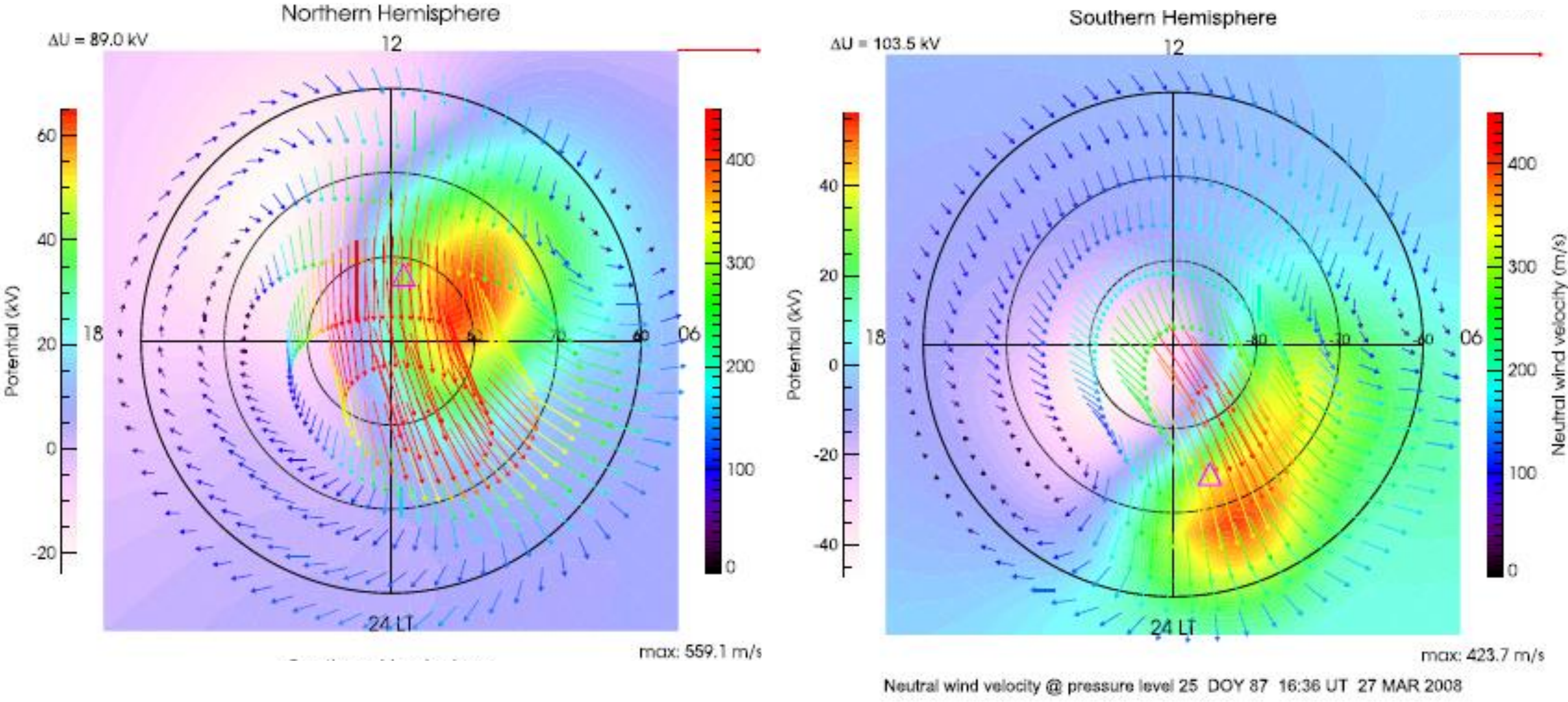




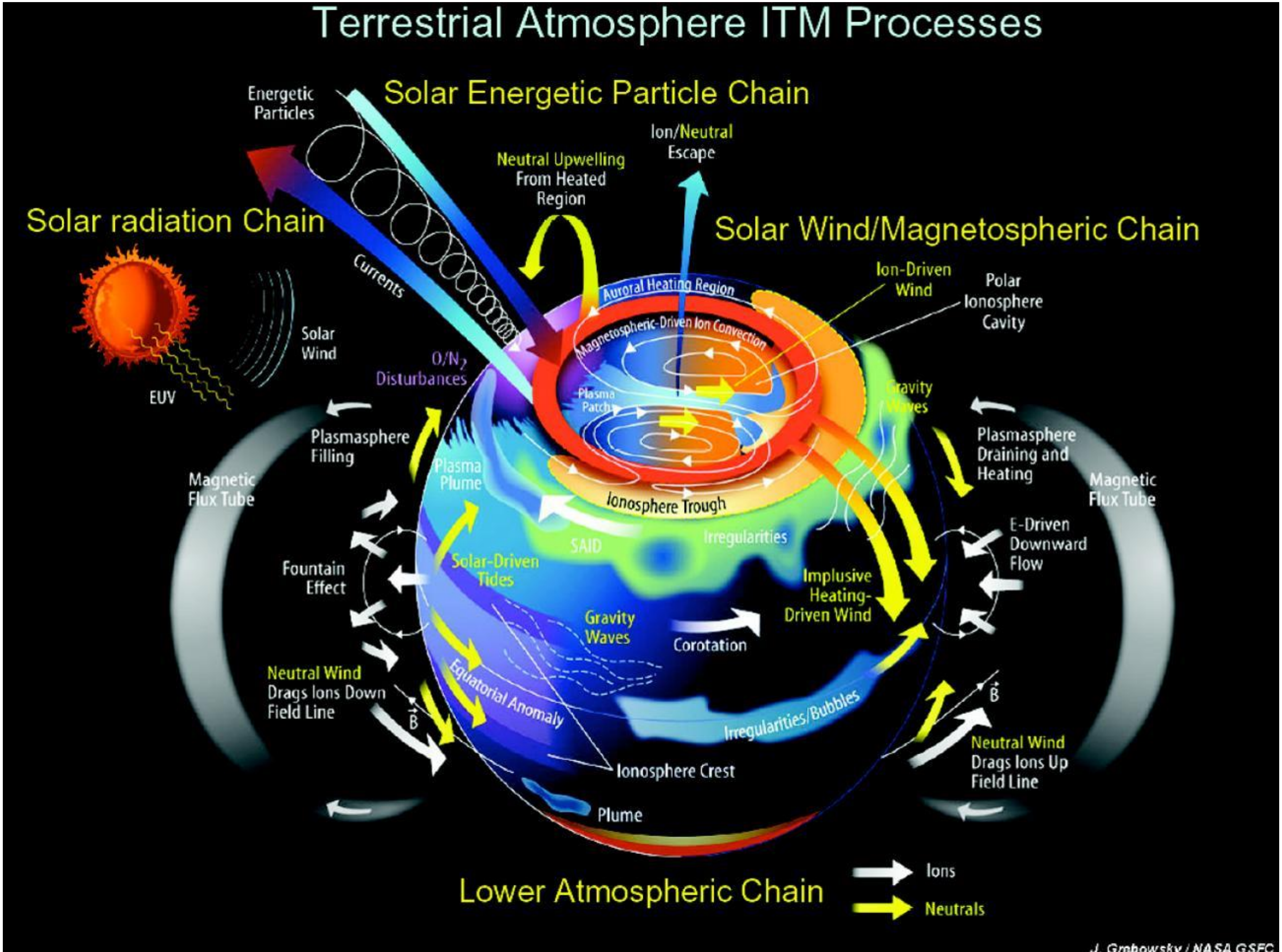
Ex**B** drift speed scales as E/B

Laundal et al. (in preparation)

Neutral winds at high latitude



From Förster and Cnossen (2013)


Terrestrial Atmosphere ITM Processes
Solar Energetic Particle Chain
Energetic Particles
Solar radiation Chain
Currents
Ion/Neutral Escape
Neutral Upwelling From Heated Region
Solar Wind/Magnetospheric Chain
Solar Wind
EUV
O/N2 Disturbances
Auroral Heating Region
Magnetospheric-Driven Ion Convection
Ion-Driven Wind
Polar Ionosphere Cavity
Plasma Patch
Gravity Waves
Plasmasphere Filling
Plasma Plume
Magnetic Flux Tube
Ionosphere Trough
Plasmasphere Draining and Heating
Magnetic Flux Tube
SAID
Irregularities
E-Driven Downward Flow
Fountain Effect
Solar-Driven Tides
Implusive Heating-Driven Wind
Gravity Waves
Corotation
Neutral Wind Drags Ions Down Field Line
Equatorial Anomaly
Irregularities/Bubbles
Neutral Wind Drags Ions Up Field Line
Ionosphere Crest
Plume
Lower Atmospheric Chain
Ions
Neutrals
J. Grobowsky / NASA GSFC

Summary

- Solar radiative forcing varies with…
  - Latitude
  - Time of day
  - Season
  - Solar cycle
- This introduces corresponding variations in many upper atmosphere variables, e.g.,
  - Temperature
  - Neutral mass density
  - Electron density
- Solar radiation also affects ion-neutral coupling and solar wind-magnetosphere-ionosphere coupling processes

Spare slides, additional info

Conductivity equations

$$\sigma_{\parallel} = \frac{N_e e^2}{m_e(\nu_{en\parallel} - \nu_{ei\parallel})}$$

$$\sigma_P = \frac{N_e e}{B}\left(\frac{\nu_{in}\Omega_i}{\nu_{in}^2 + \Omega_i^2} + \frac{\nu_{en\perp}\Omega_e}{\nu_{en\perp}^2 + \Omega_e^2}\right)$$

$$\Omega_i = \frac{eB}{m_i}$$

$$\Omega_e = \frac{eB}{m_e}$$

$$\sigma_H = \frac{N_e e}{B}\left(\frac{\Omega_e^2}{\nu_{en\perp}^2 + \Omega_e^2} - \frac{\Omega_i^2}{\nu_{in}^2 + \Omega_i^2}\right)$$