Effects of the changing geomagnetic field on the atmosphere

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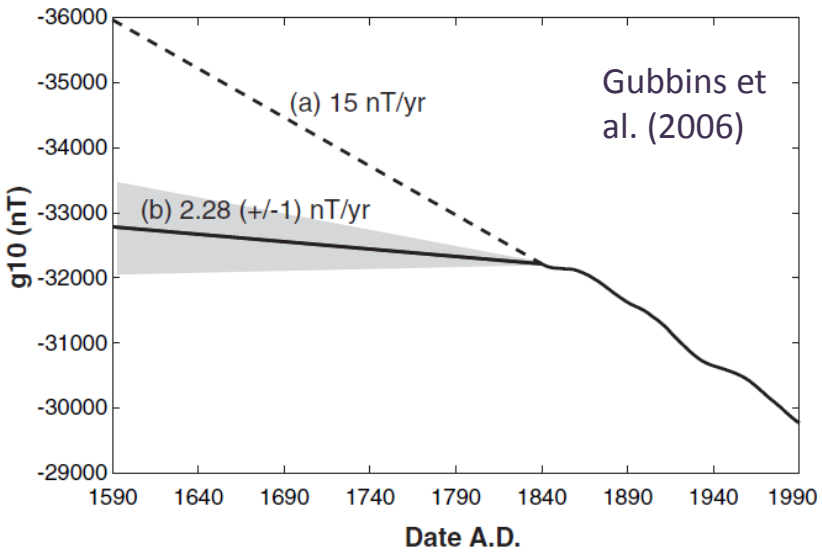
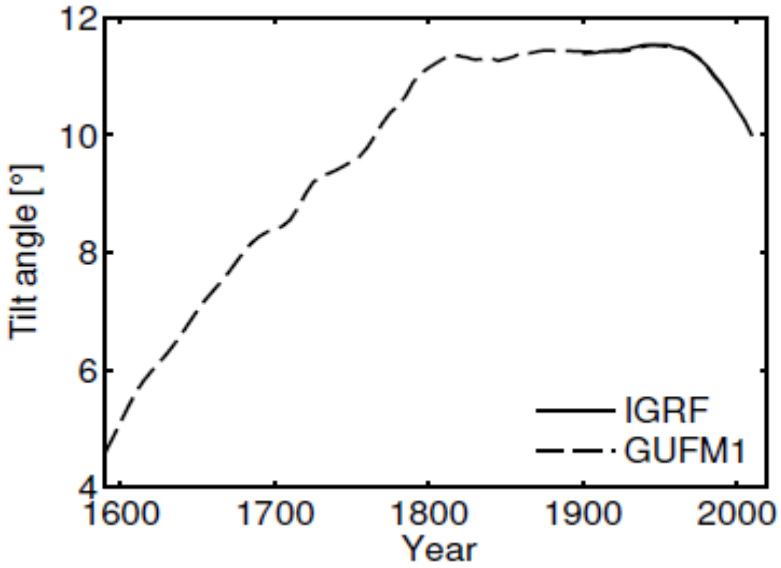
Outline

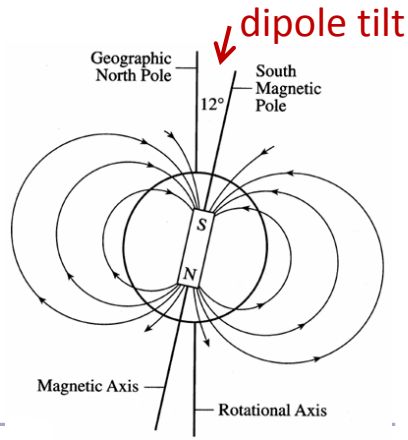
- Magnetosphere and upper atmosphere
  - Variations in dipole field *strength*
  - Variations in dipole field *orientation*





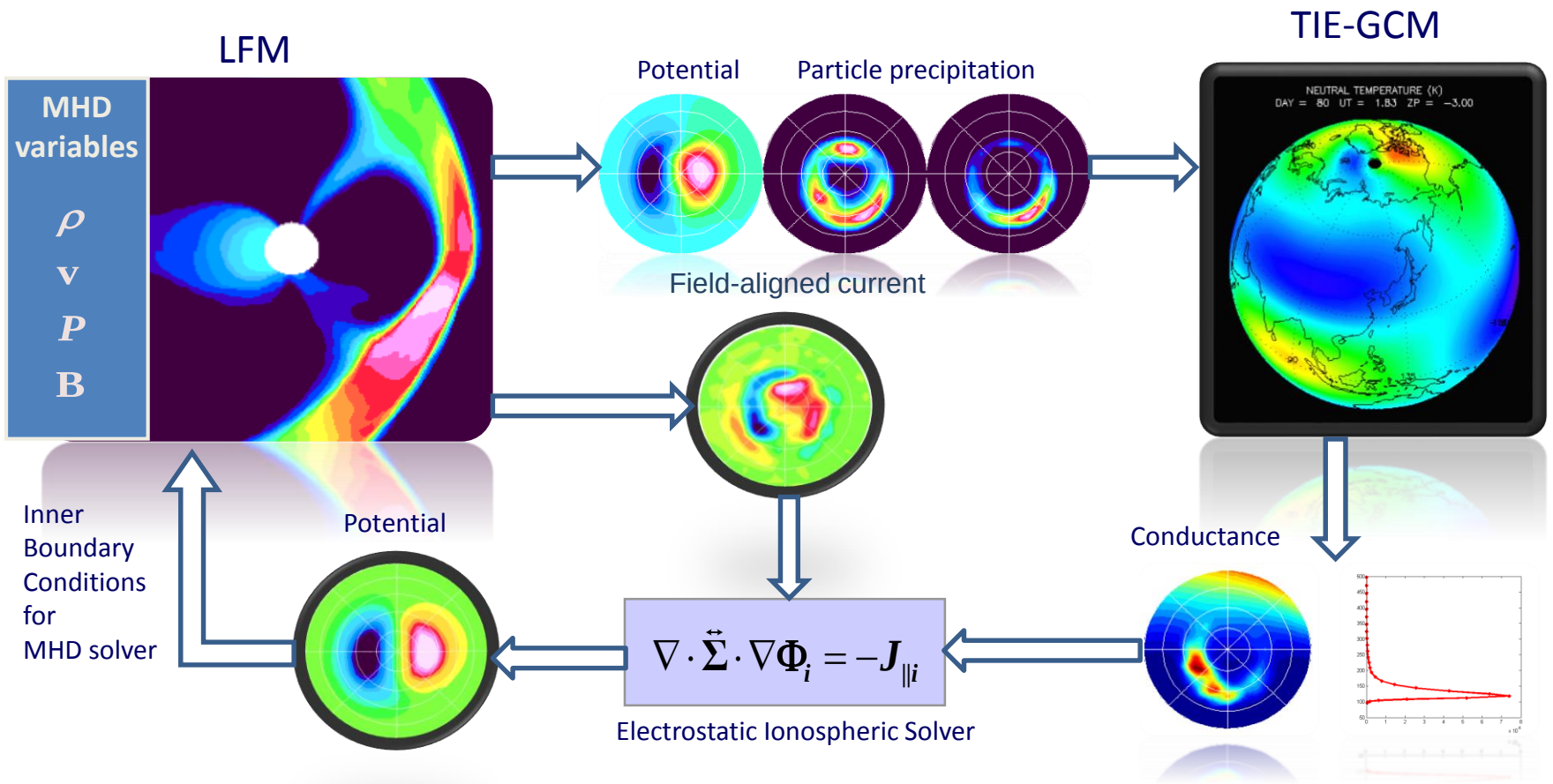
  - Realistic magnetic field changes 1908-2008
  - Contrasted with effects of CO_2 increase

- Lower and middle atmosphere
  - Realistic magnetic field changes 1900-2000



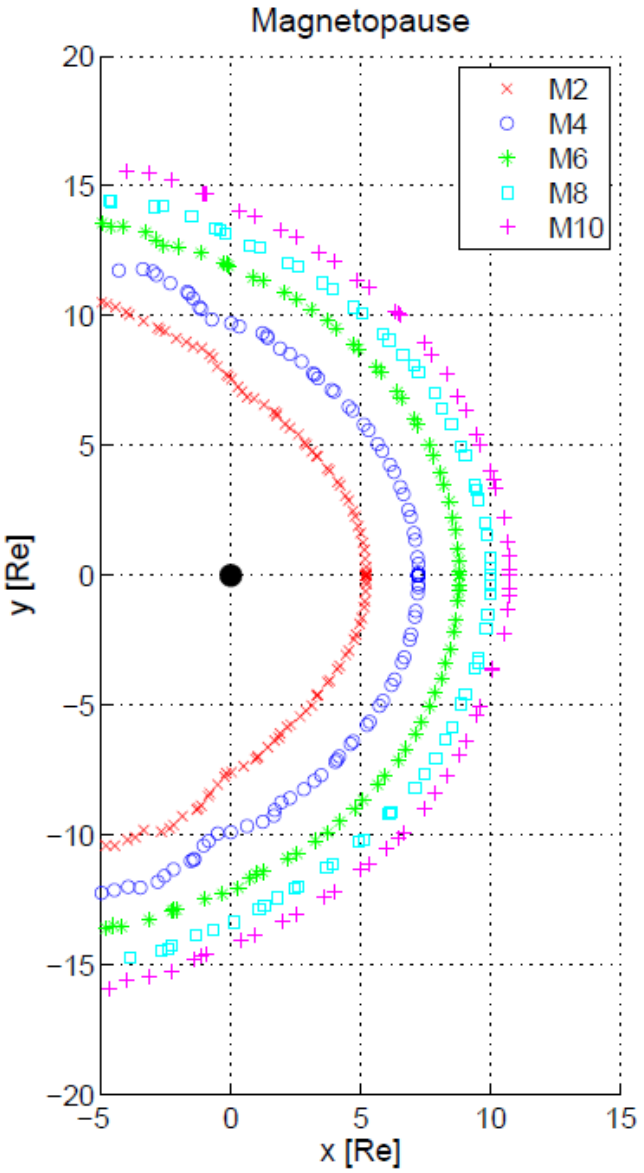
Coupled Magnetosphere-Ionosphere-Thermosphere model

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

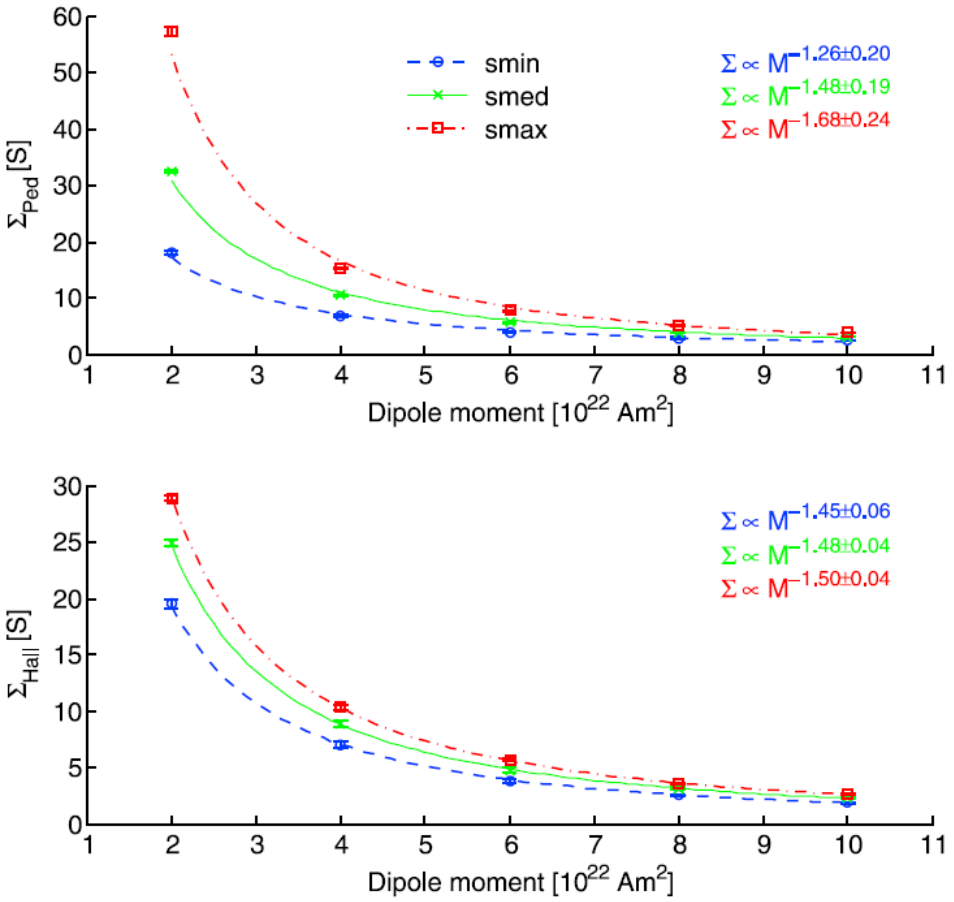


Graphics courtesy of Binzheng Zhang

Influence of magnetic field strength



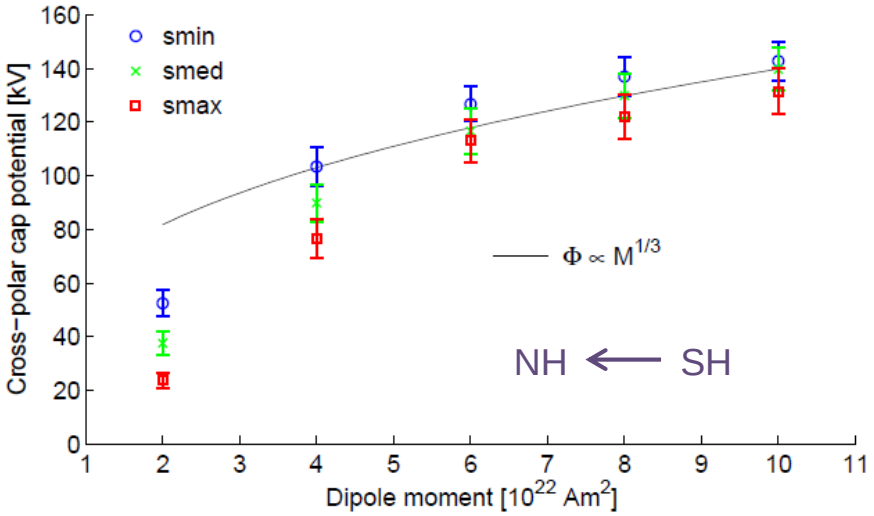
Ionospheric conductance



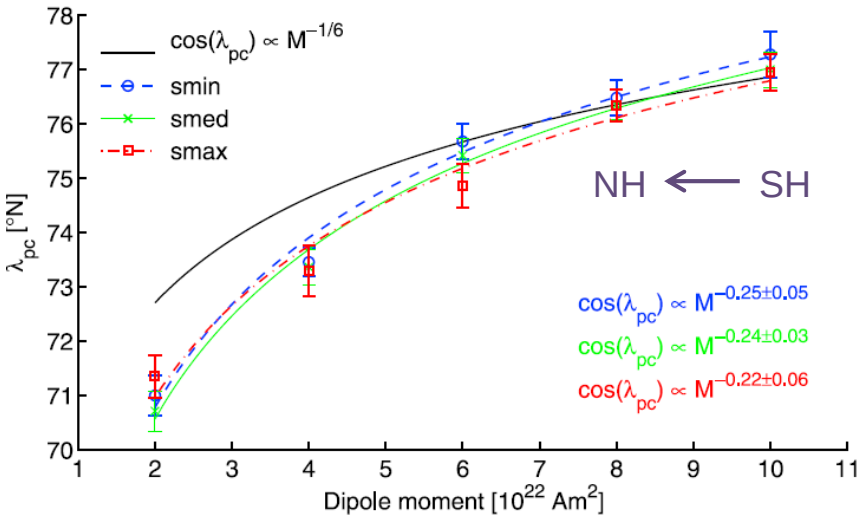
Cnossen, Richmond and Wiltberger, JGR, 2012

Influence of magnetic field strength

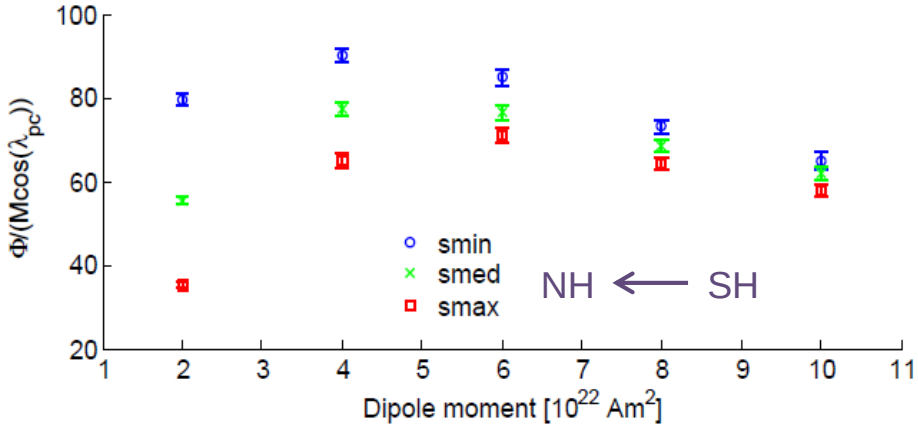
Cross-polar cap potential



Latitude of polar cap boundary



Measure of **ExB** drift magnitude (E/B)

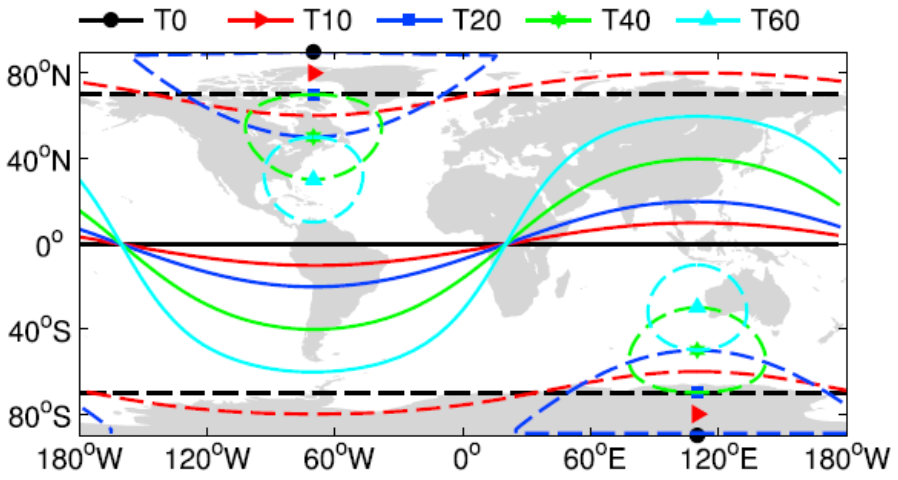


- For lower magnetic field strength
  - Cross-polar cap potential ↓
  - Polar cap size ↑
  - **ExB** drift magnitude ↑
- **ExB** drifts and high-latitude neutral winds NH>SH

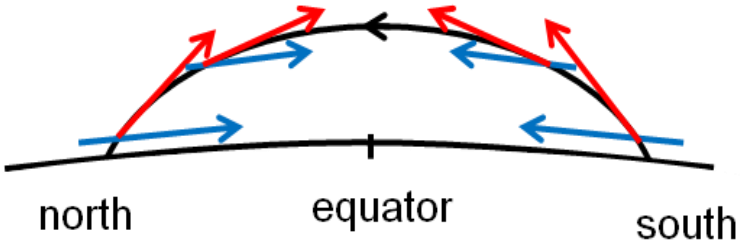
Cnossen, Richmond and Wiltberger, JGR, 2012

Why the dipole orientation matters for the ionosphere

- Geographic locations of important features, e.g., magnetic equator, magnetic poles, auroral oval
- Orientation of the magnetic poles w.r.t. the Sun and solar wind
  - Solar illumination of polar cap
  - Solar wind-magnetosphere-ionosphere coupling efficiency (see Cnossen, Wiltberger and Ouellette, JGR, 2012)
  - Strength of polar ionospheric flows and Joule heating
- Plasma transport depends on orientation of **B:**
  - **ExB** drifts
  - Plasma transport by neutral winds
  - Diffusion along the magnetic field



Cnossen and Richmond (JGR, 2012)

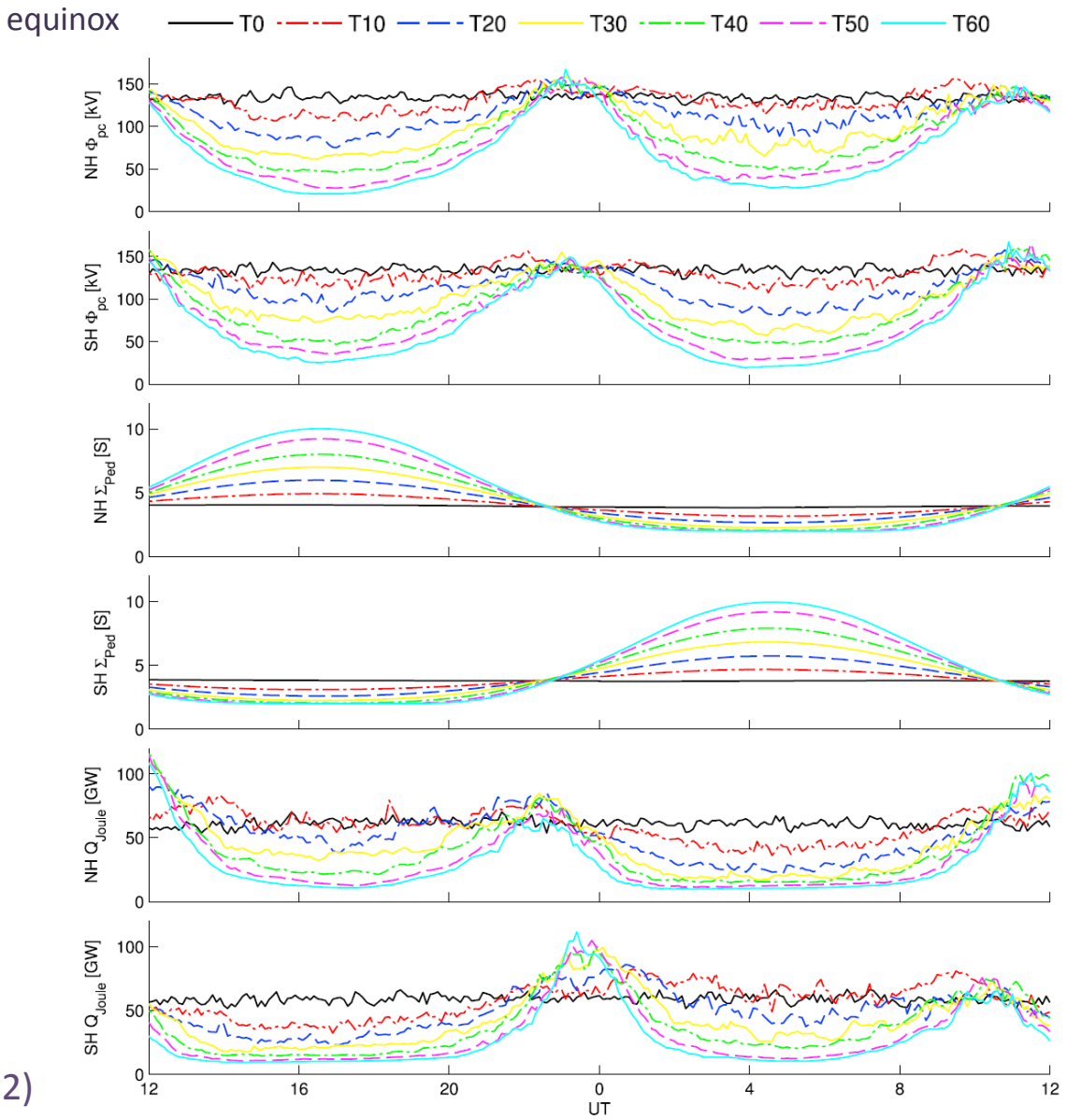


Cnossen (InTech Open, 2012)

Diurnal variation in CPCP, conductivity and Joule heating

Equinox:

- Larger diurnal variation for larger dipole tilt
- Lower mean CPCP and Joule heating for larger dipole tilt



Cnossen and Richmond (JGR, 2012)

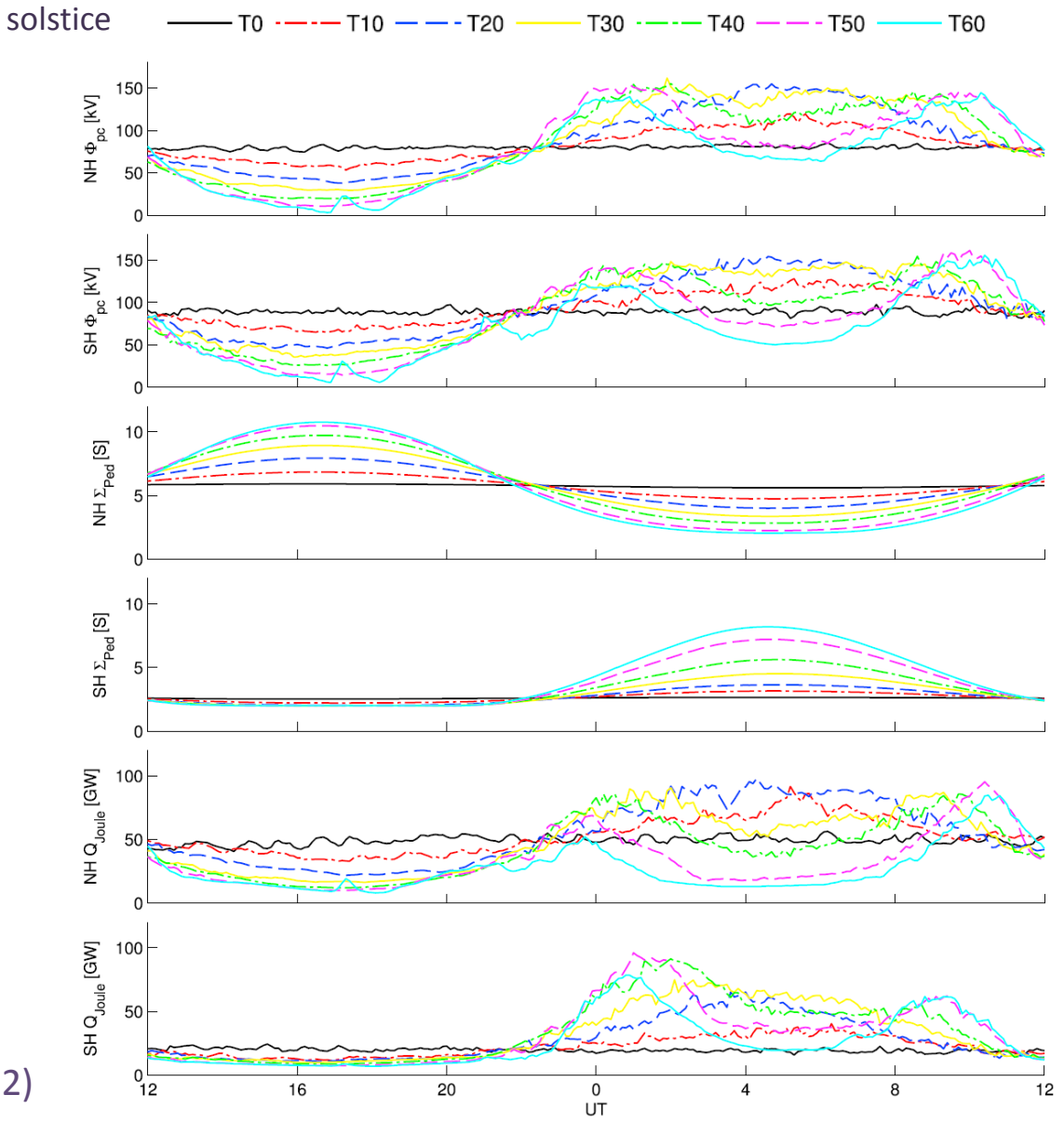
Diurnal variation in CPCP, conductivity and Joule heating

Equinox:

- Larger diurnal variation for larger dipole tilt
- Lower mean CPCP and Joule heating for larger dipole tilt

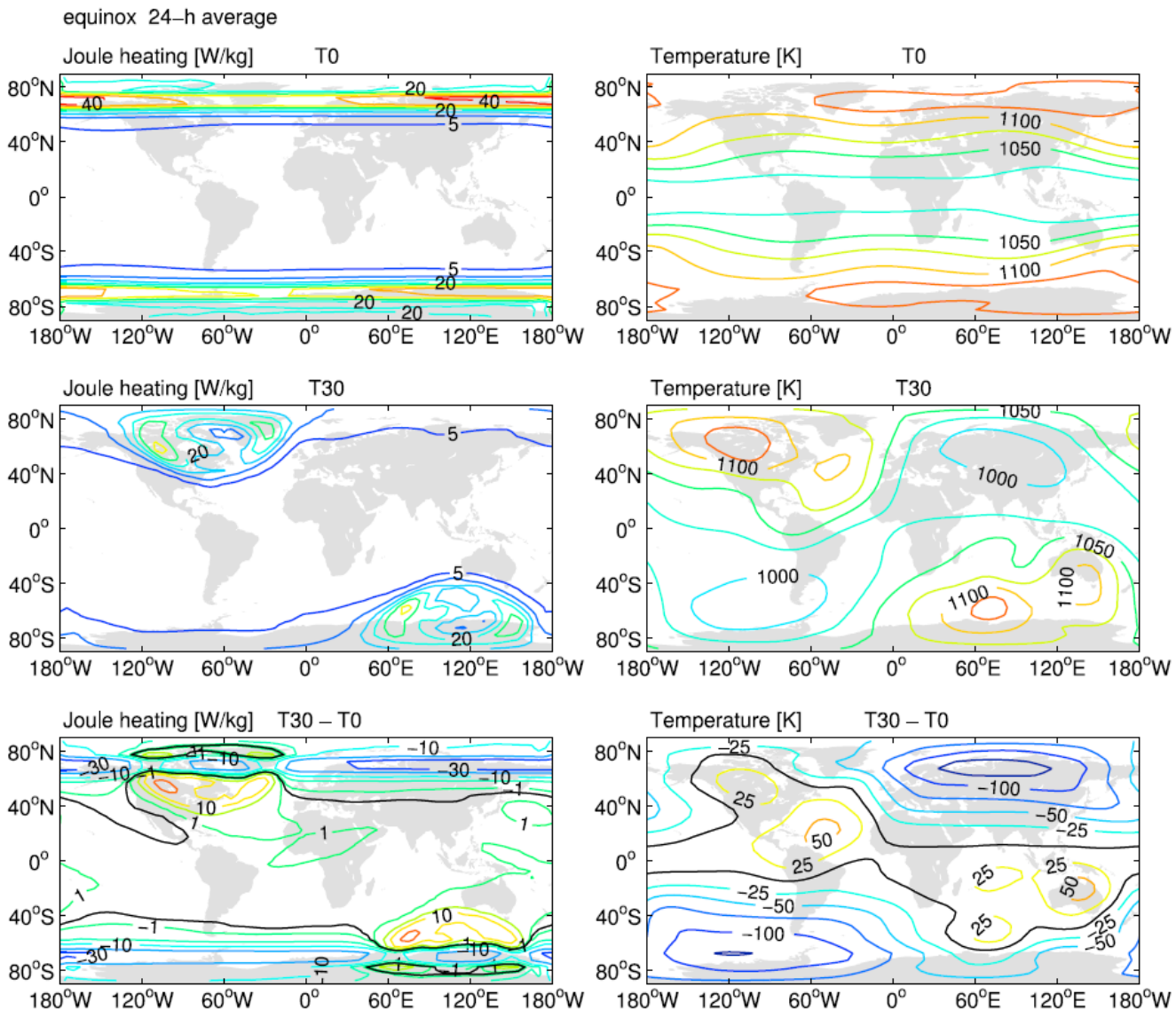
Solstice:

- More complicated diurnal variation pattern for large tilts due to multiple $\mu = 0$ crossings
- μ = angle between dipole axis and GSM z-axis



Cnossen and Richmond (JGR, 2012)

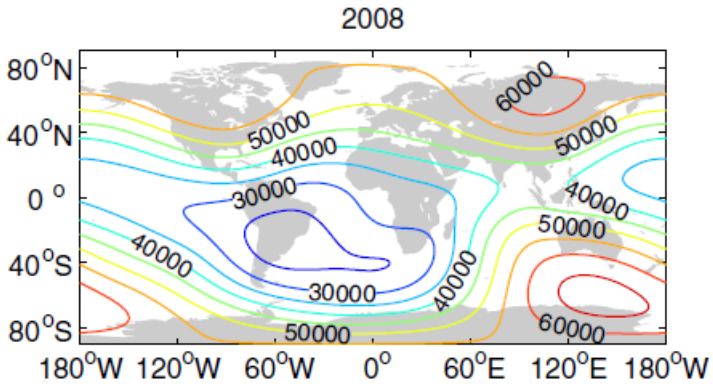
T0 vs. T30: Joule heating and temperature

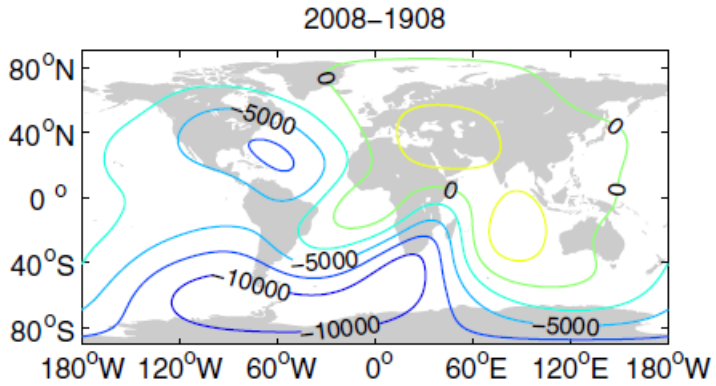


- T30 gives less Joule heating than T0
- Changes in geographic distribution of Joule heating
- Changes in temperature structure more or less follow

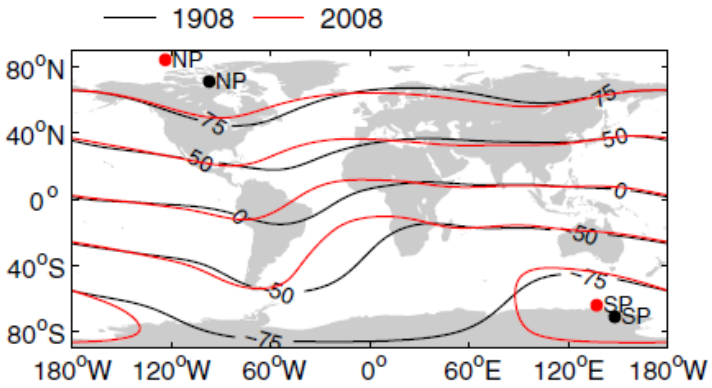
Cnossen and Richmond (JGR, 2012)

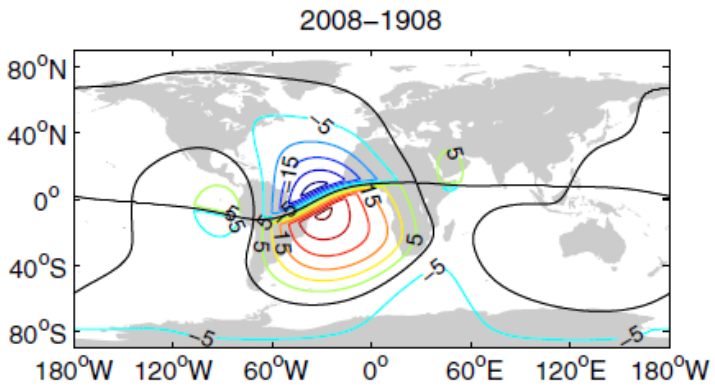
Realistic magnetic field changes 1908-2008





Magnetic field strength in 2008 and difference with 1908 (nT)





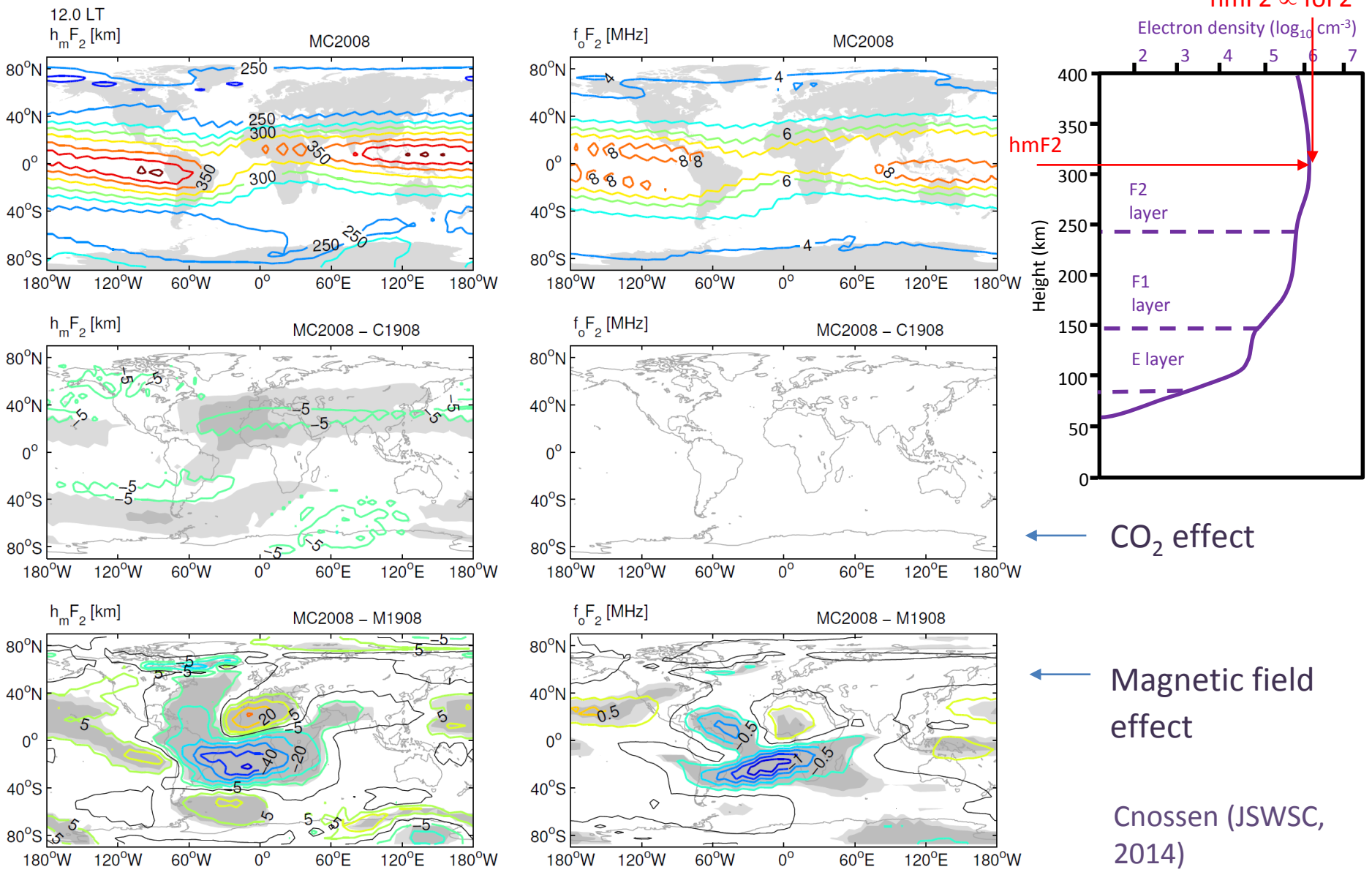
Inclination angle contours of 1908 and 2008 and differences in inclination (°)

- Expansion and intensification of the South Atlantic Anomaly region of low magnetic field strength
- Northward and westward movement of magnetic field structures
- Strongest inclination angle changes in Atlantic region (~100°W-50°E; ~40°S-40°N)

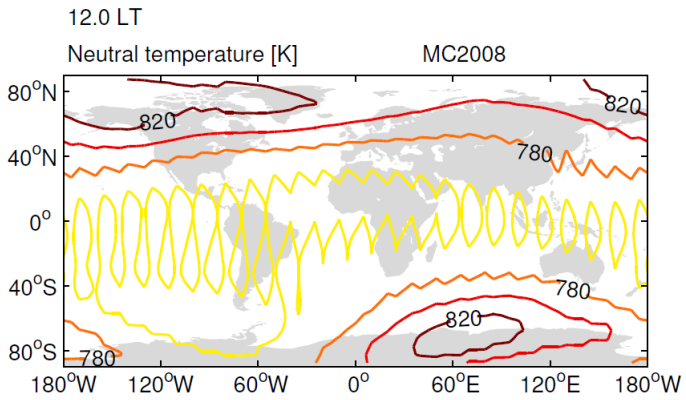
IGRF = International Geomagnetic Reference Field

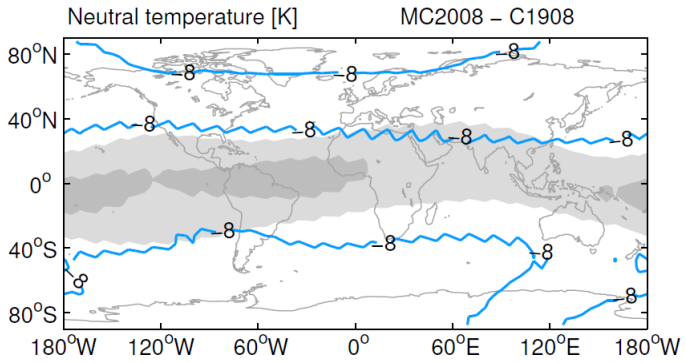
Cnossen and Richmond (JGR, 2013)

Magnetic field vs. CO_2 effects: h_mF_2 and f_oF_2

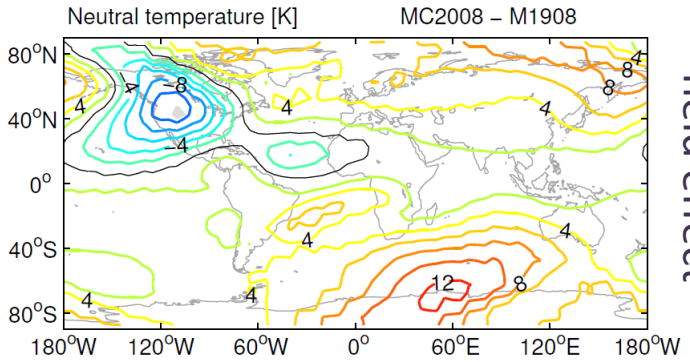


Magnetic field vs. CO_2 effects: temperature @ 300 km





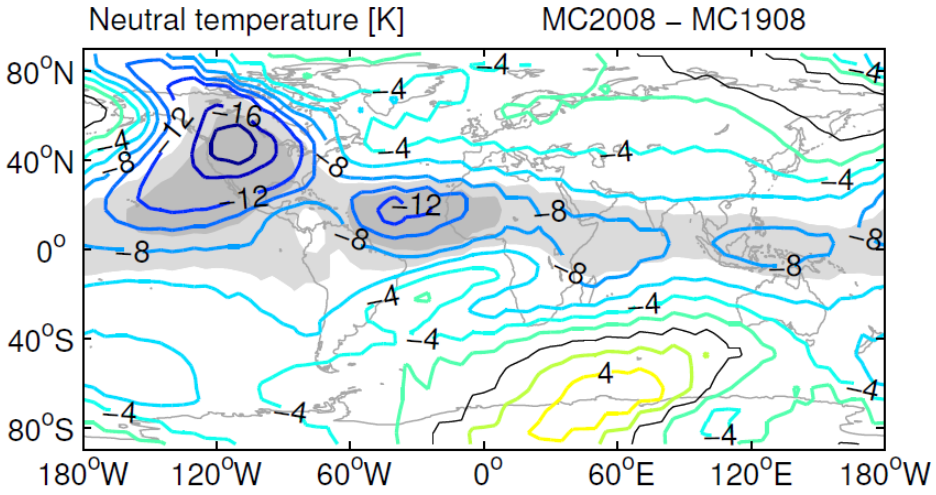
CO_2 effect



Magnetic field effect

- Increase in CO_2 concentration is more important
- But changes in the magnetic field do contribute

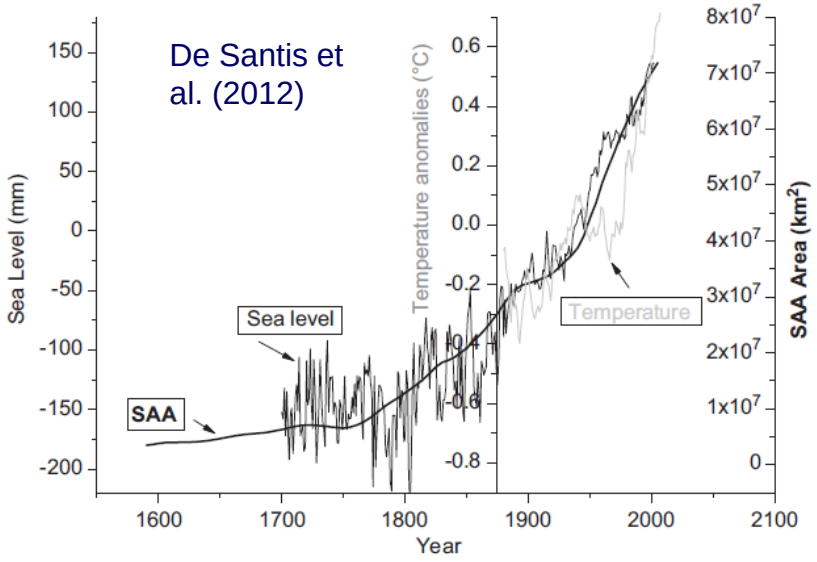
Combined CO_2 and magnetic field effect

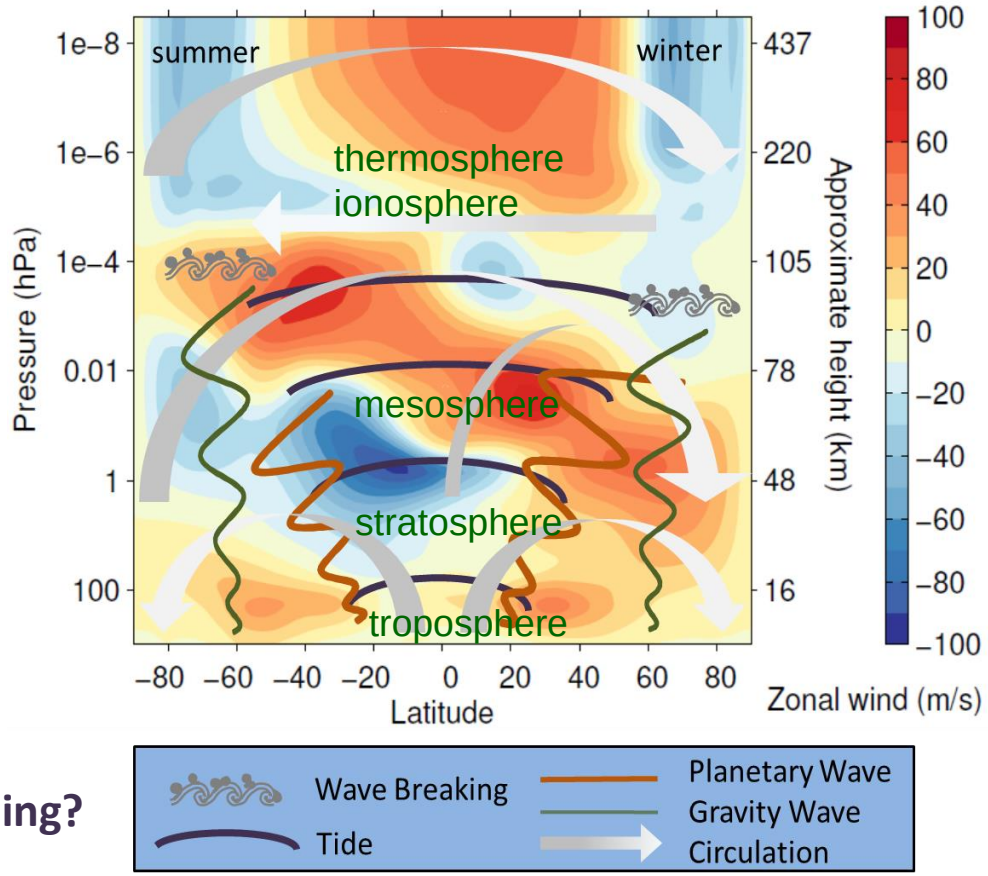


Cnossen (JSWSC, 2014)

Whole atmosphere response to magnetic field changes

- Some observational evidence for a magnetic field influence on tropospheric climate



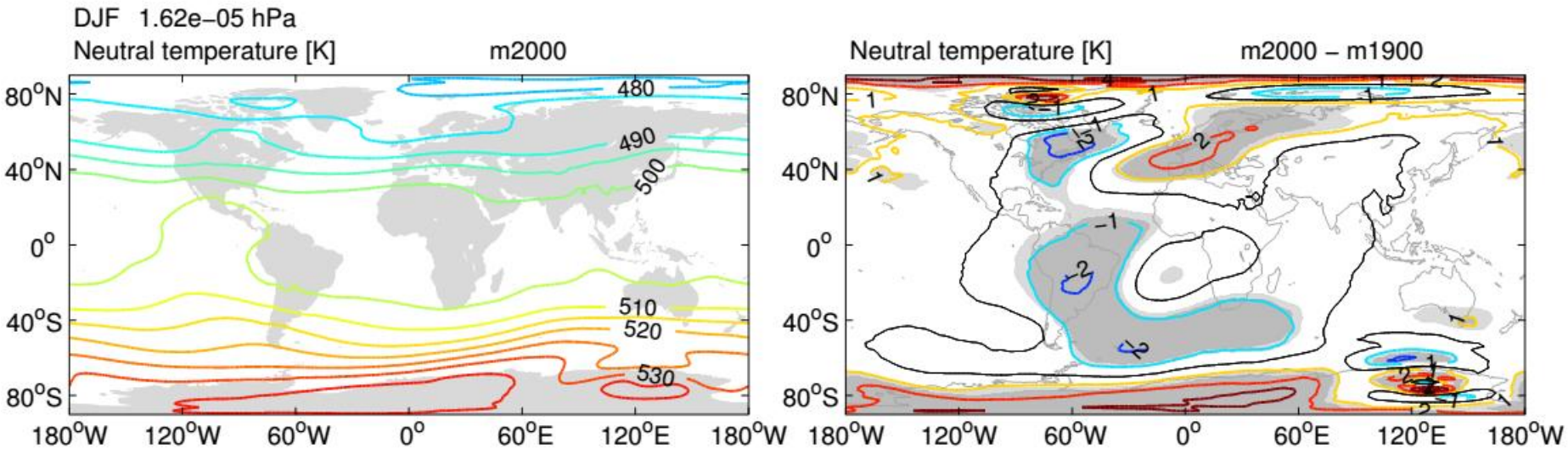


- Mechanism unclear – ***controversial***
- **Whole atmosphere dynamical coupling?**
  - Upwardly propagating atmospheric waves induce a residual circulation that extends downwards when they break

Simulations with WACCM-X

- WACCM-X = **W**hole **A**tmosphere **C**ommunity **C**limate **M**odel e**X**tension (~0-500 km)
- Simulations with magnetic field (IGRF) of **1900** and **2000**
  - 38 year duration each
  - High solar activity (F10.7=200); low geomagnetic activity (Kp=2)
- Significant changes in neutral temperature and winds down to lower thermosphere
- Does this affect the atmosphere below? How??

2000 Temperature, ~130 km, DJF 2000-1900



Cnossen , Liu, and Lu (2016, in review)

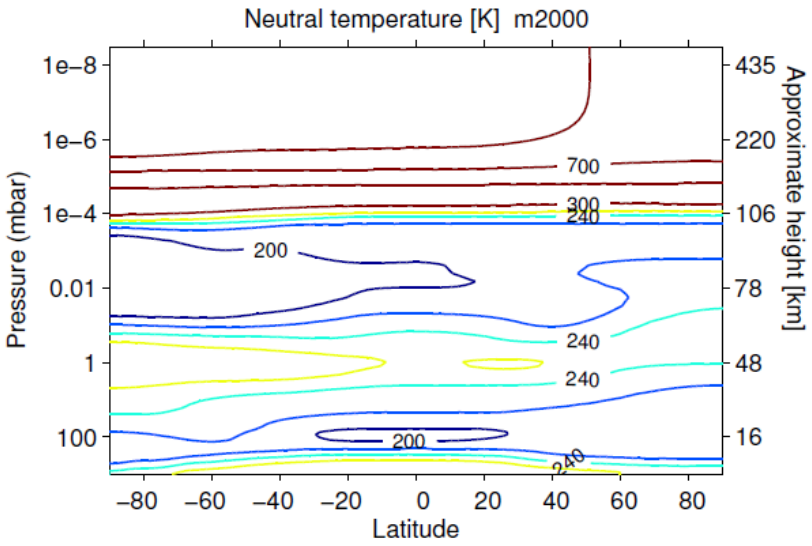
Lower/middle atmosphere response (DJF)

DJF

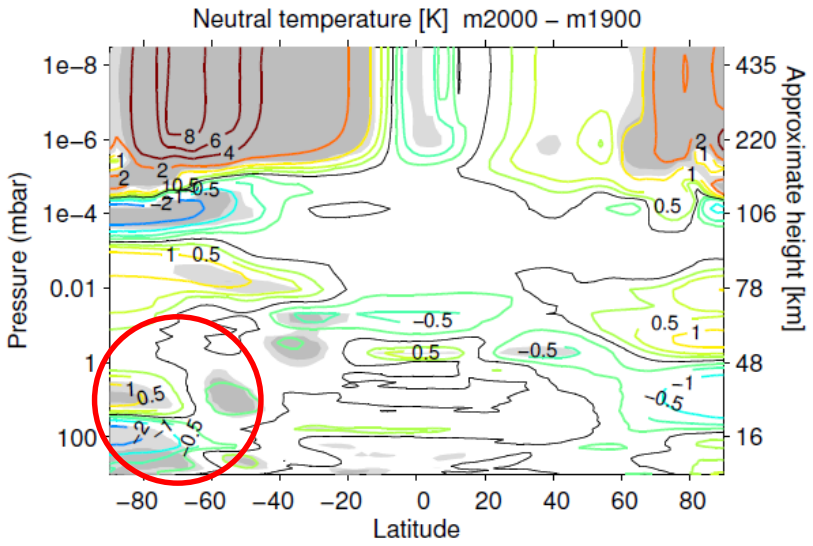
Zonal mean

Temp.

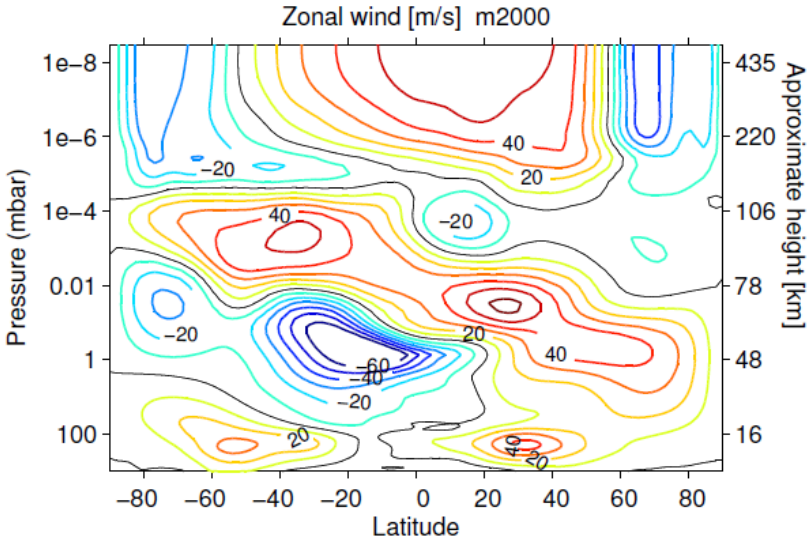
2000

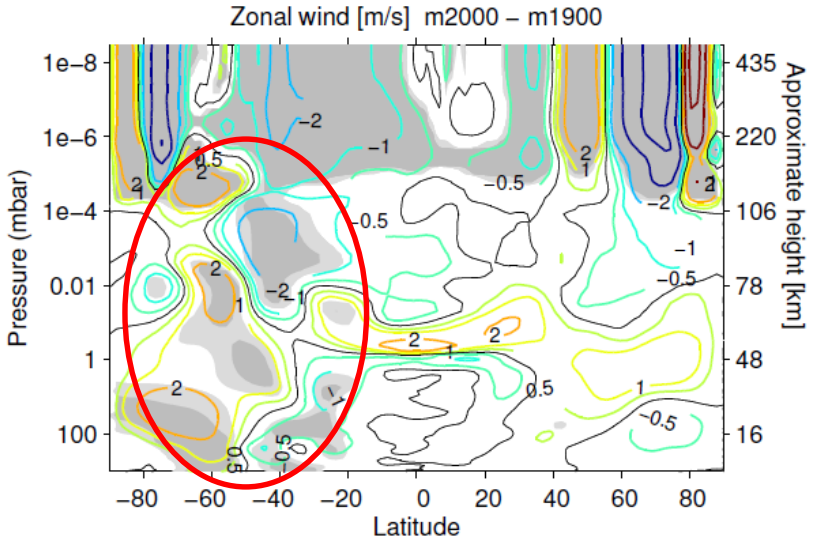


2000-1900

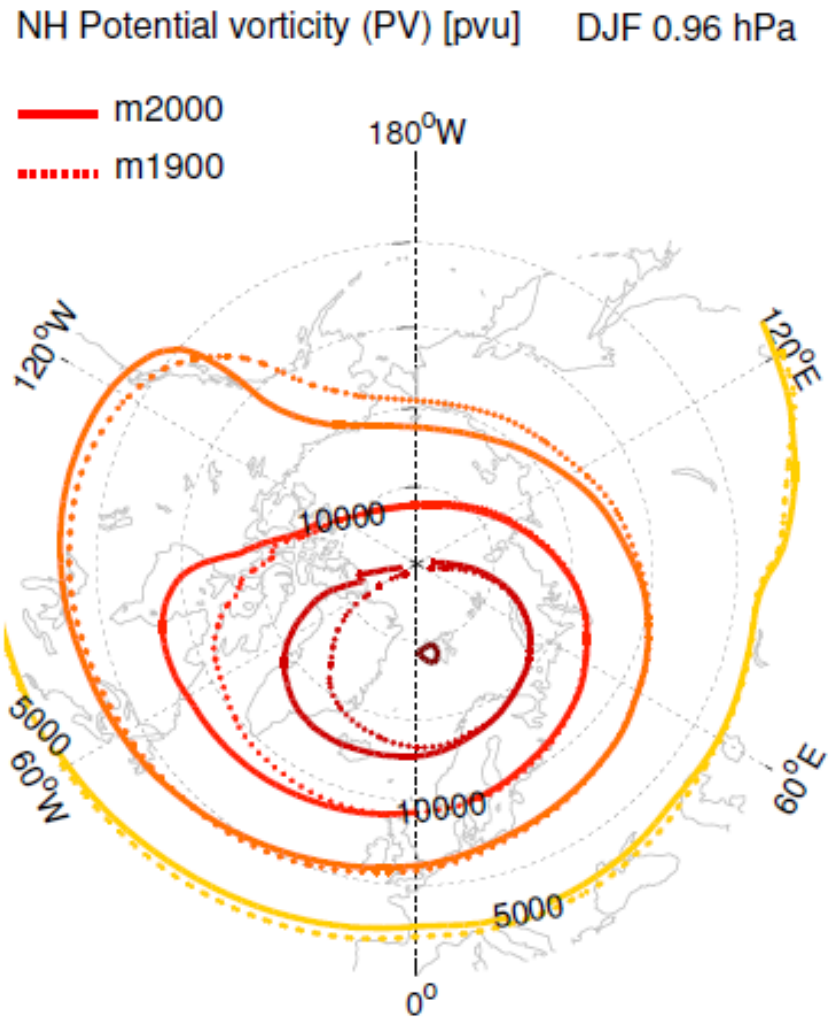


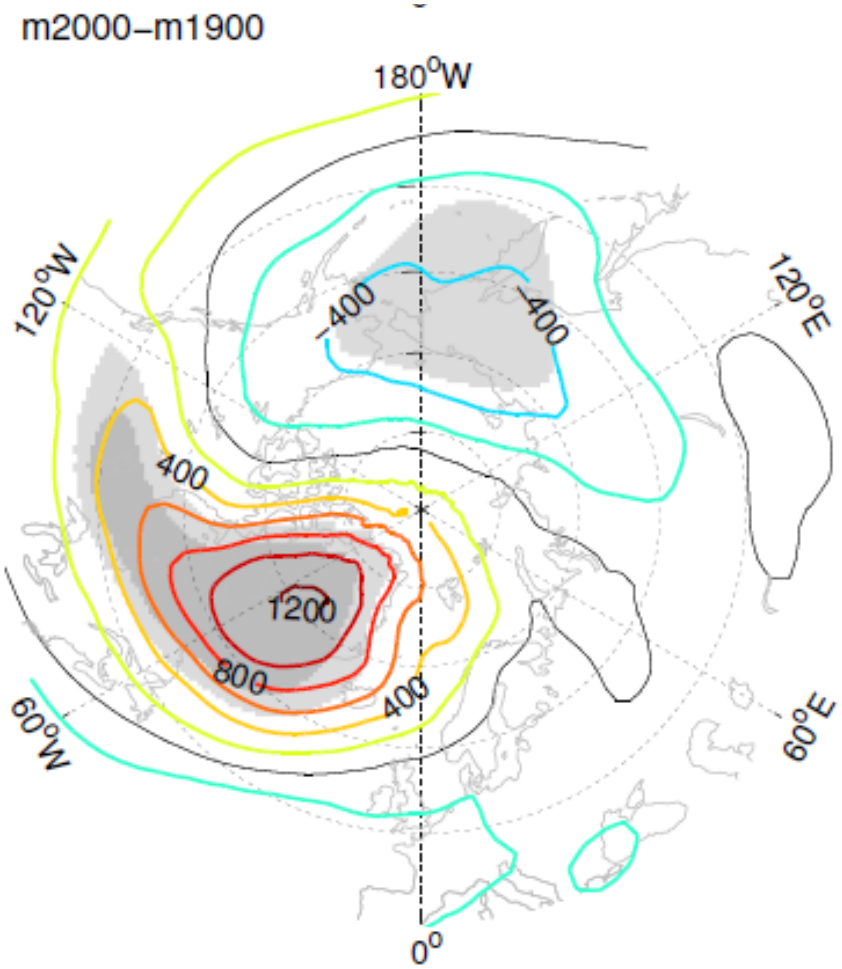
Zonal wind





Movement/distortion of NH polar vortex





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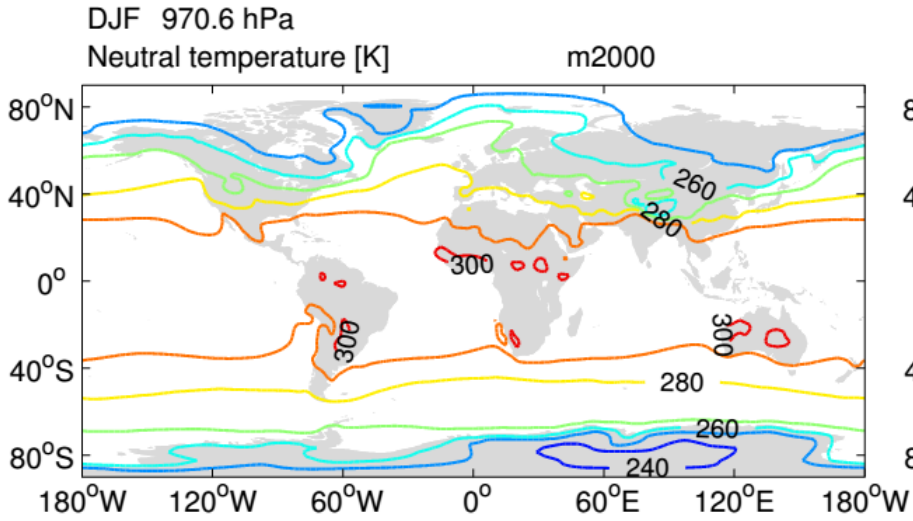
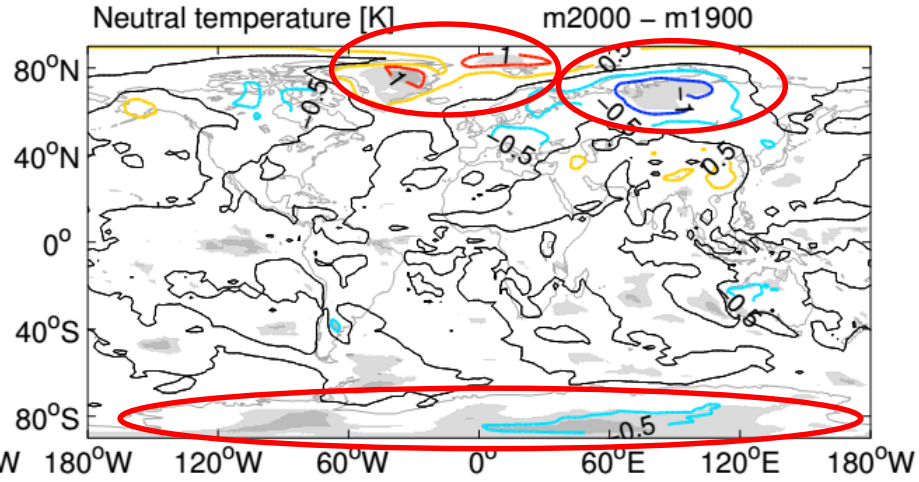
Surface temperature

2000



2000-1900



- NH: significant warming over Greenland and cooling over Siberia (±1 K)
  - Resembles negative phase of NAO
  - Inconsistent with changes in stratospheric vortex
- SH: significant high-latitude cooling (-0.5 K)

Cnossen , Liu, and Lu (2016, in review)

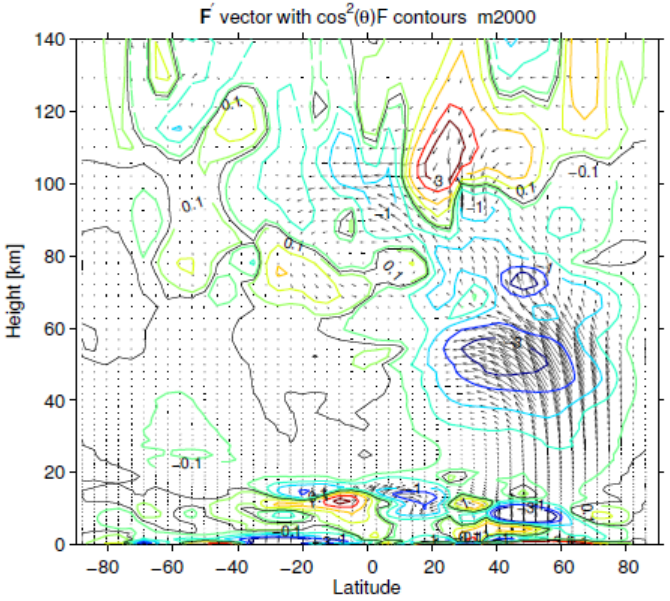
Summary and conclusions

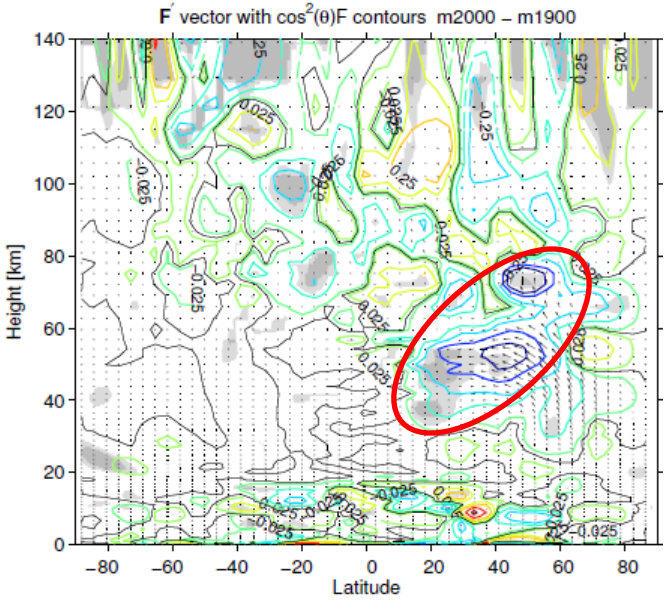
- Changes in the Earth's main magnetic field cause significant long-term change in the upper atmosphere
- Both field strength and orientation are important
- Mechanisms mostly understood
- Magnetic field changes are as important for upper atmosphere climate as the increase in CO_2 concentration!
- Upper atmosphere changes can affect the atmosphere below via changes in wave forcing, which exert a downward influence
  - Dependent on season (strongest for DJF)
  - Dependent on longitude (in NH)
- Vertical coupling mechanism is sensitive to (inaccuracies in) simulated background climatology – model improvements needed

Changes in resolved wave forcing (EP flux)

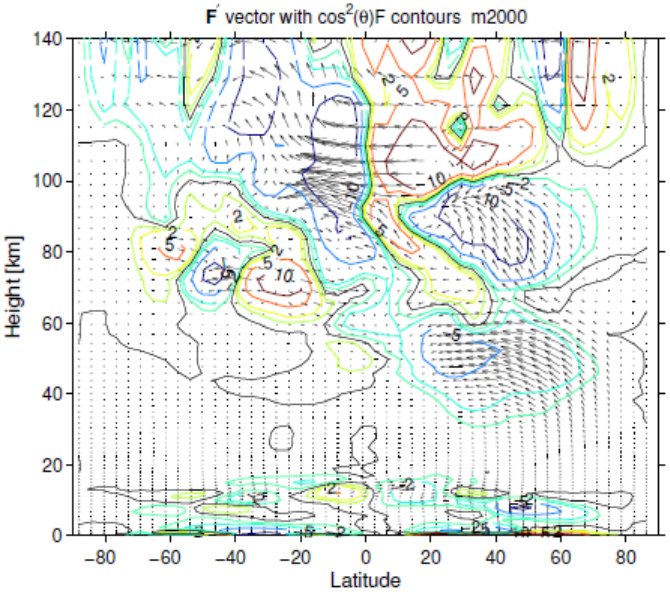
DJF

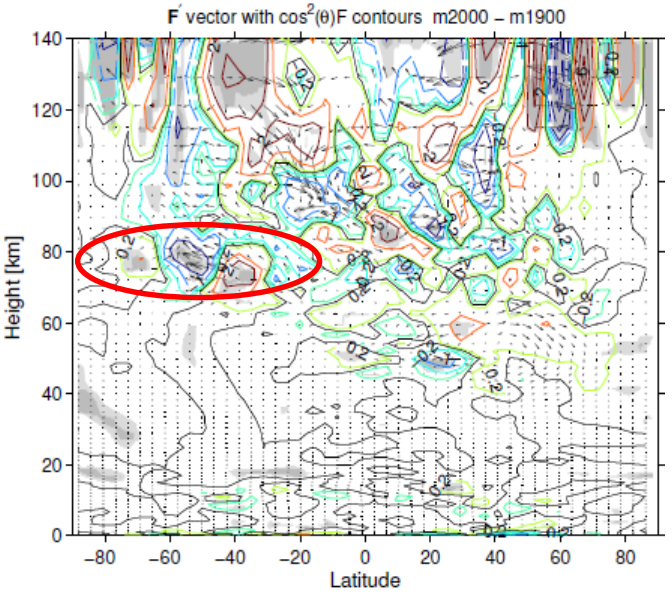
from DJF average data (stationary waves)





from 5-daily data (transient waves)





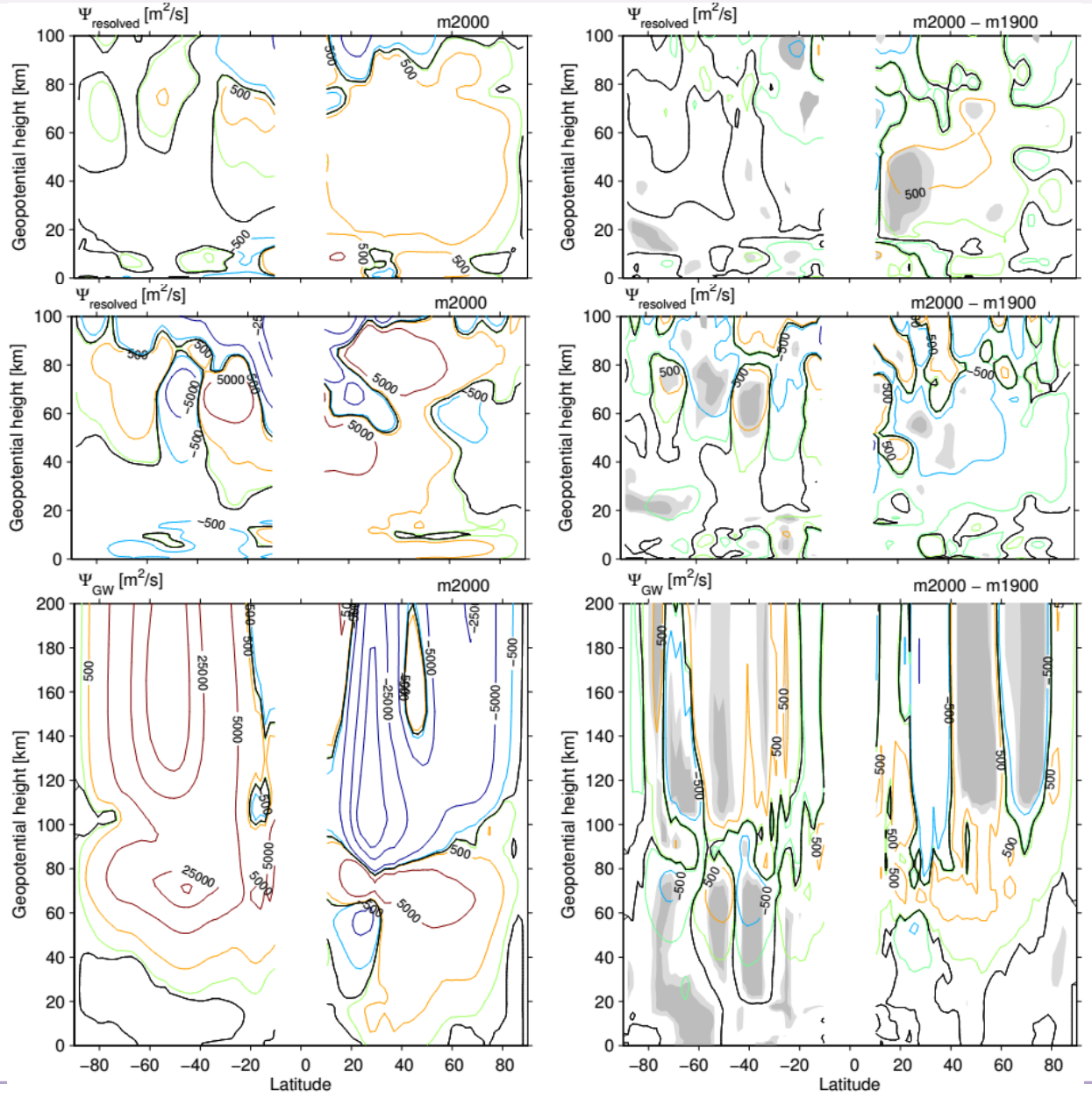
Probably influence of quasi-two-day wave (QTDW)

Changes in wave-induced residual circulations

Resolved stationary waves

Resolved transient waves

Parameterized gravity waves



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