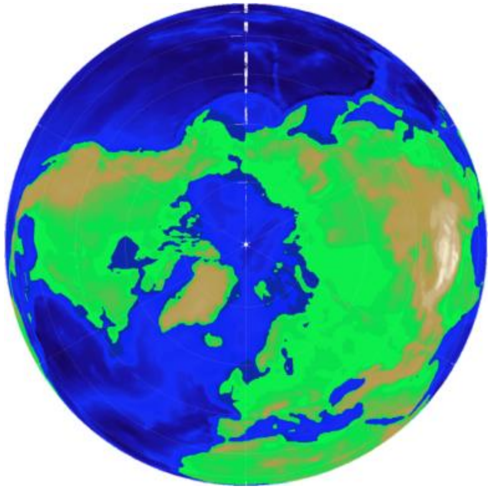
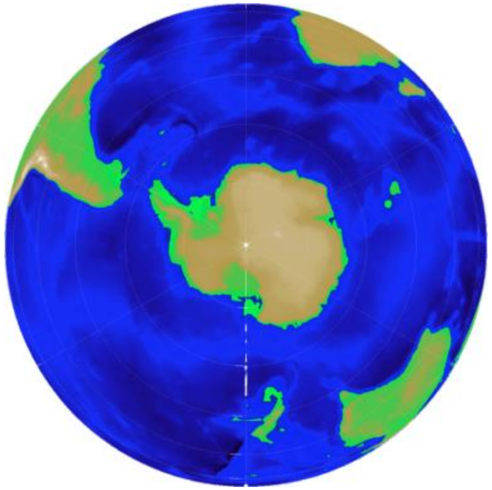
NORTH-SOUTH ASYMMETRIES AND INTER-HEMISPHERIC PROCESSES IN THE MIDDLE AND UPPER ATMOSPHERE:

Causes, Observations, and Modelling





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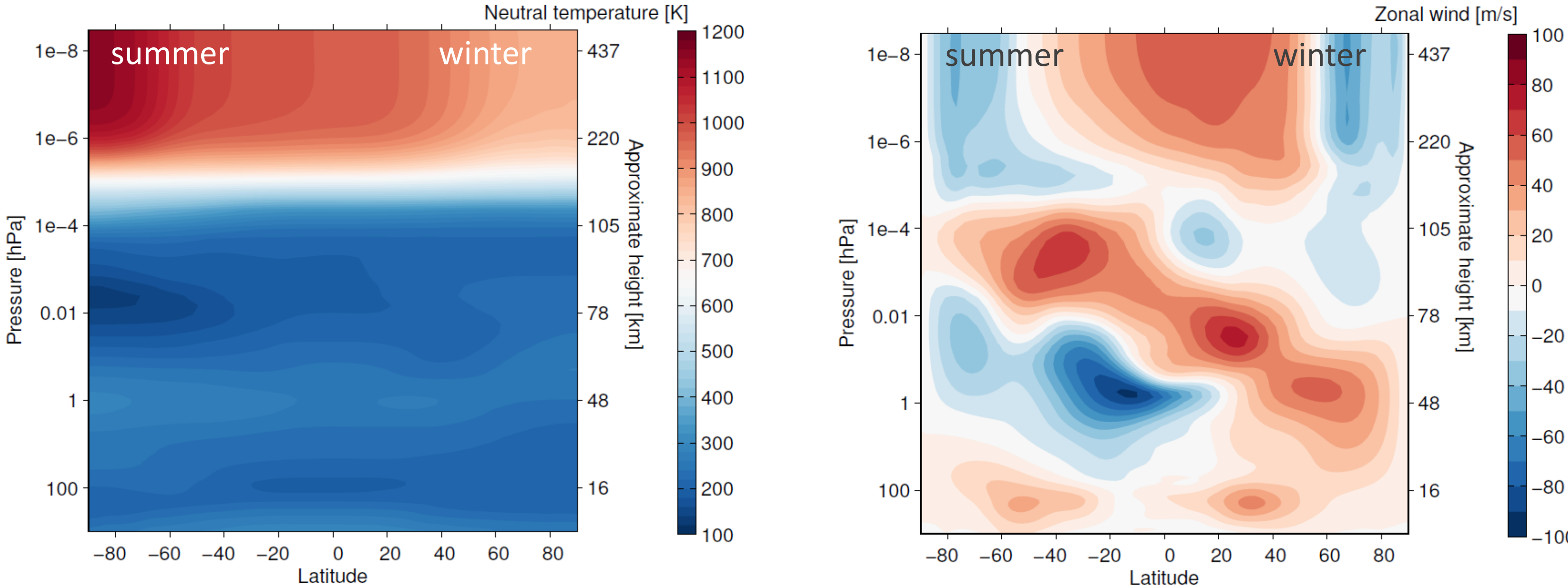
Seasonal differences/effects (summer/winter): neutral atmosphere

WACCM - January



- Difference in solar illumination causes asymmetry in neutral temperature, density, winds

Seasonal differences/effects (summer/winter): neutral atmosphere

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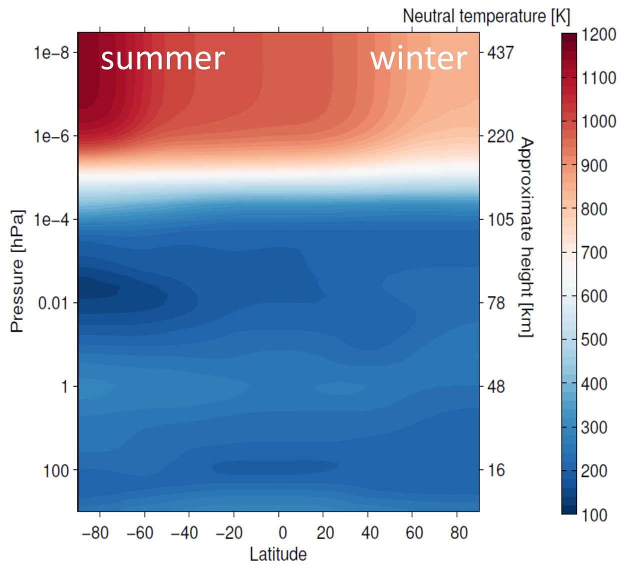
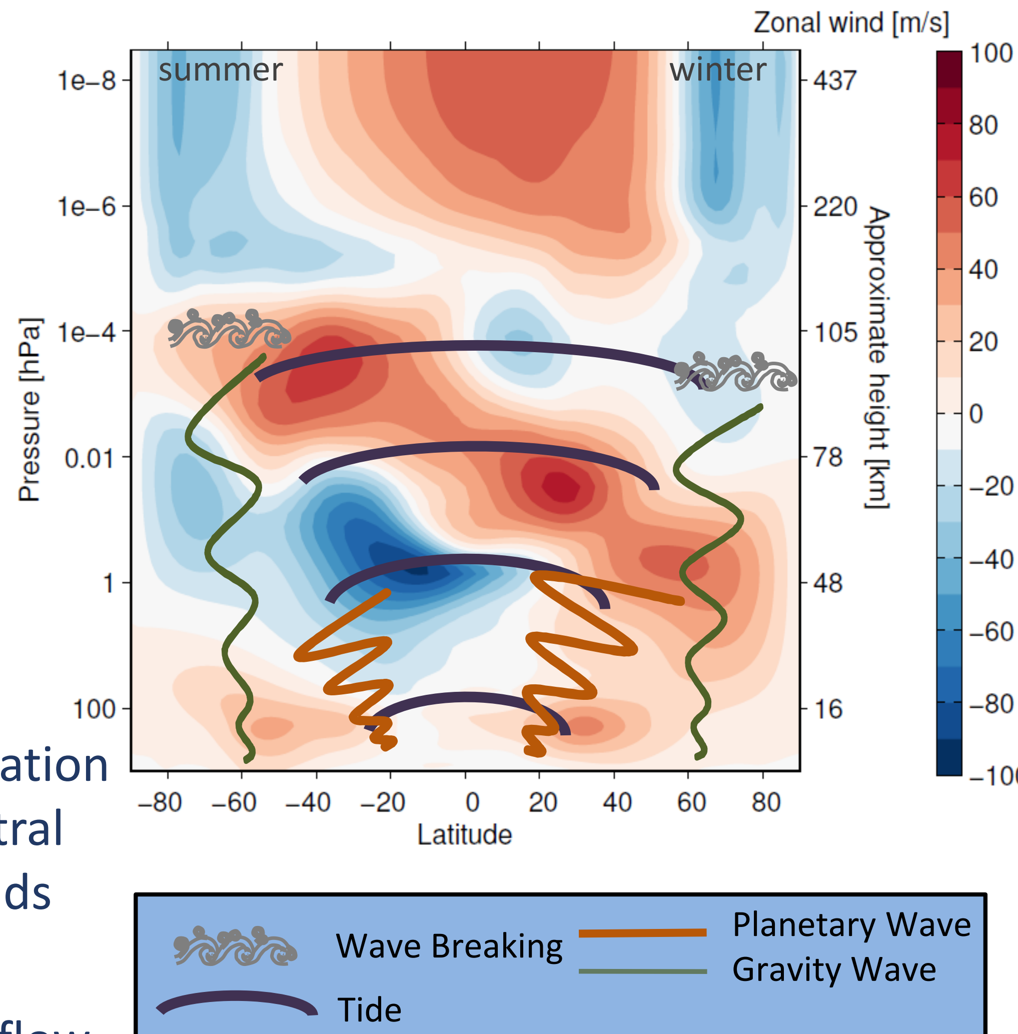
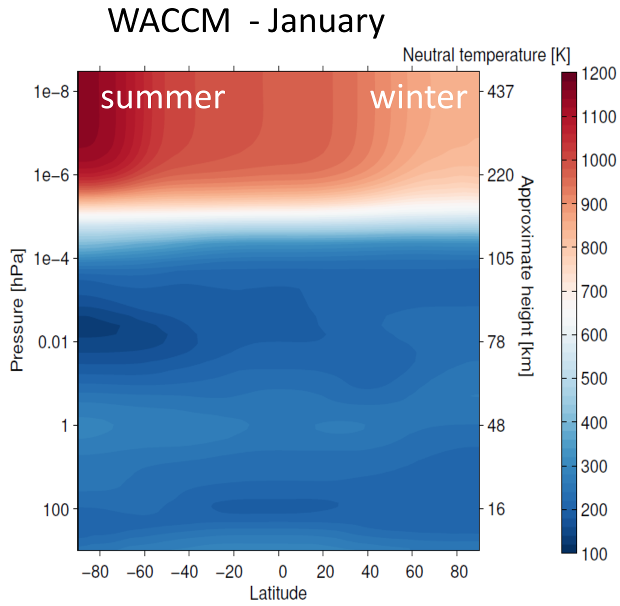
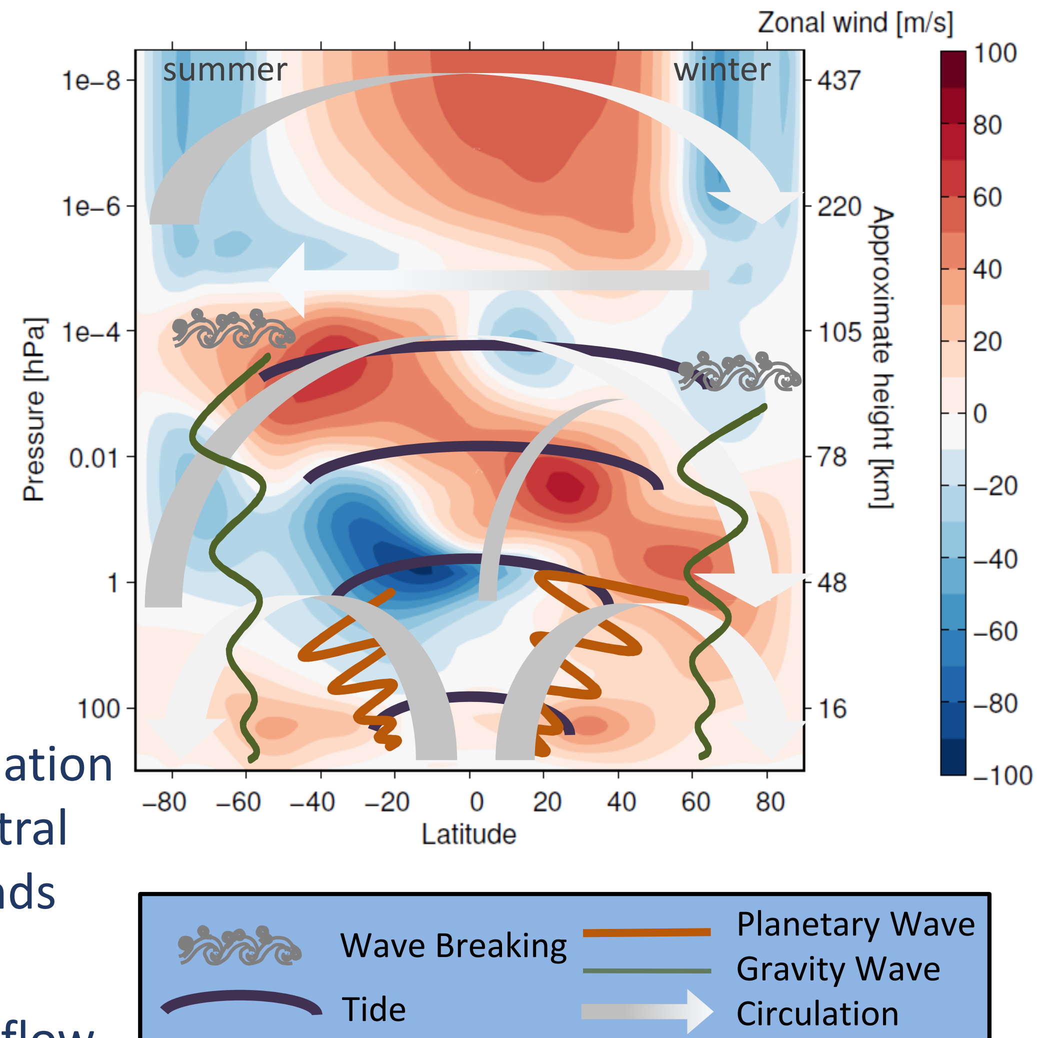




- Difference in solar illumination causes asymmetry in neutral temperature, density, winds
- Asymmetries in wave propagation, wave-mean flow interaction

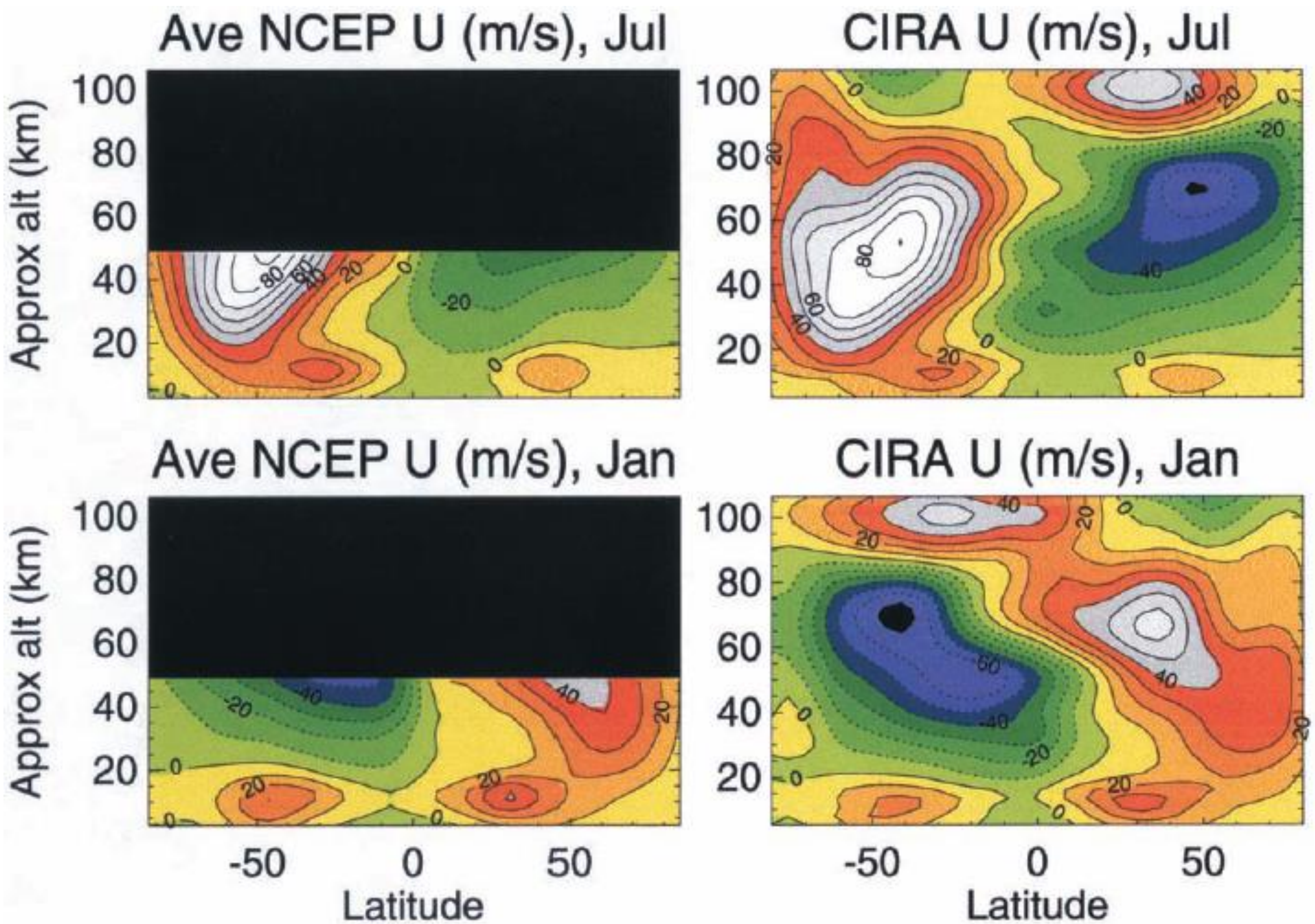
Seasonal differences/effects (summer/winter): neutral atmosphere





- Difference in solar illumination causes asymmetry in neutral temperature, density, winds
- Asymmetries in wave propagation, wave-mean flow interaction
- Interhemispheric flow

North-South asymmetry in zonal mean zonal wind

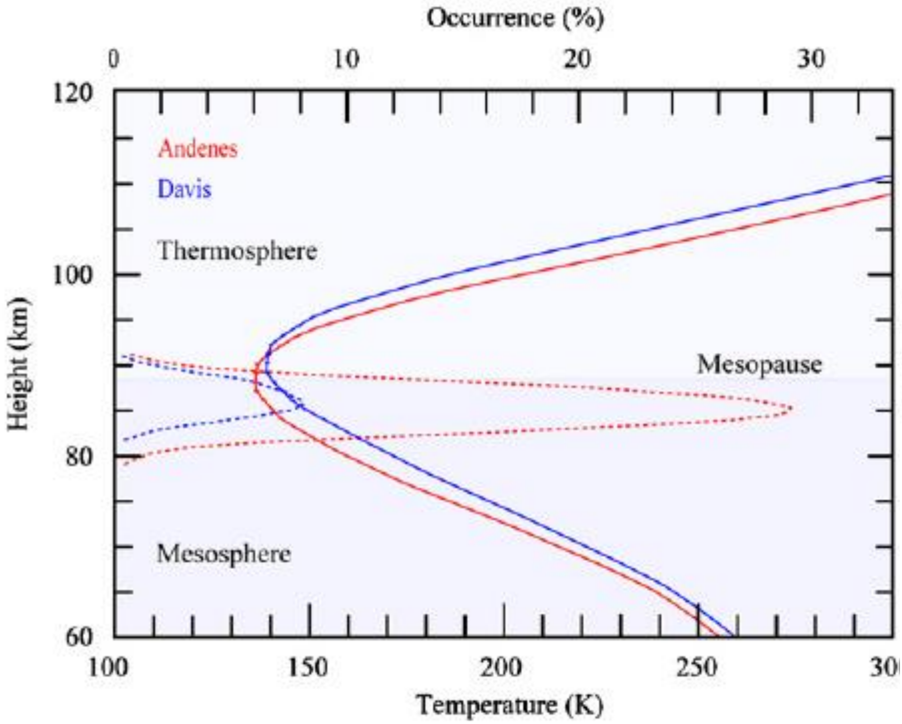


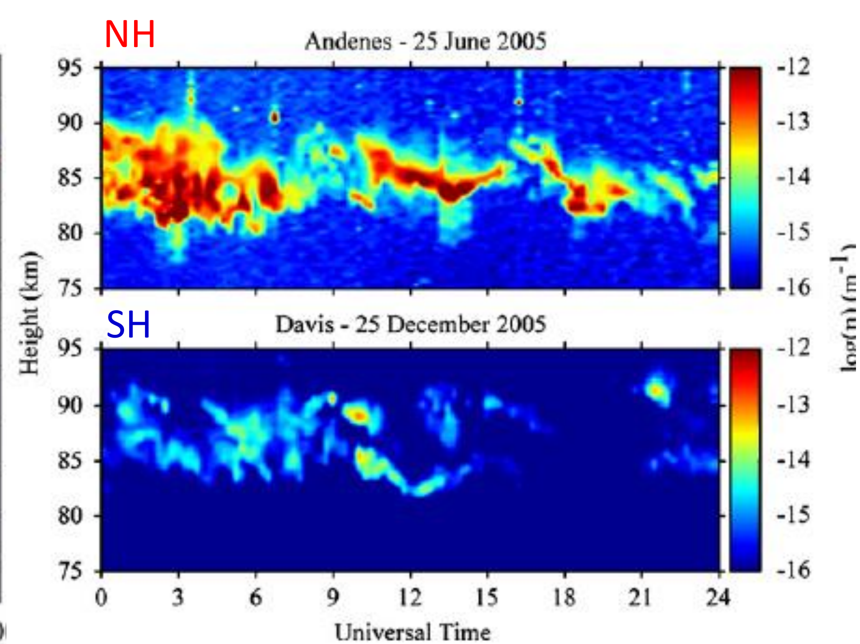
Siskind et al. (2003)

- SH winter polar vortex is stronger than NH winter polar vortex, summer winds also different
- Consequences for gravity wave filtering, temperature structure

North-South asymmetry in polar mesospheric clouds

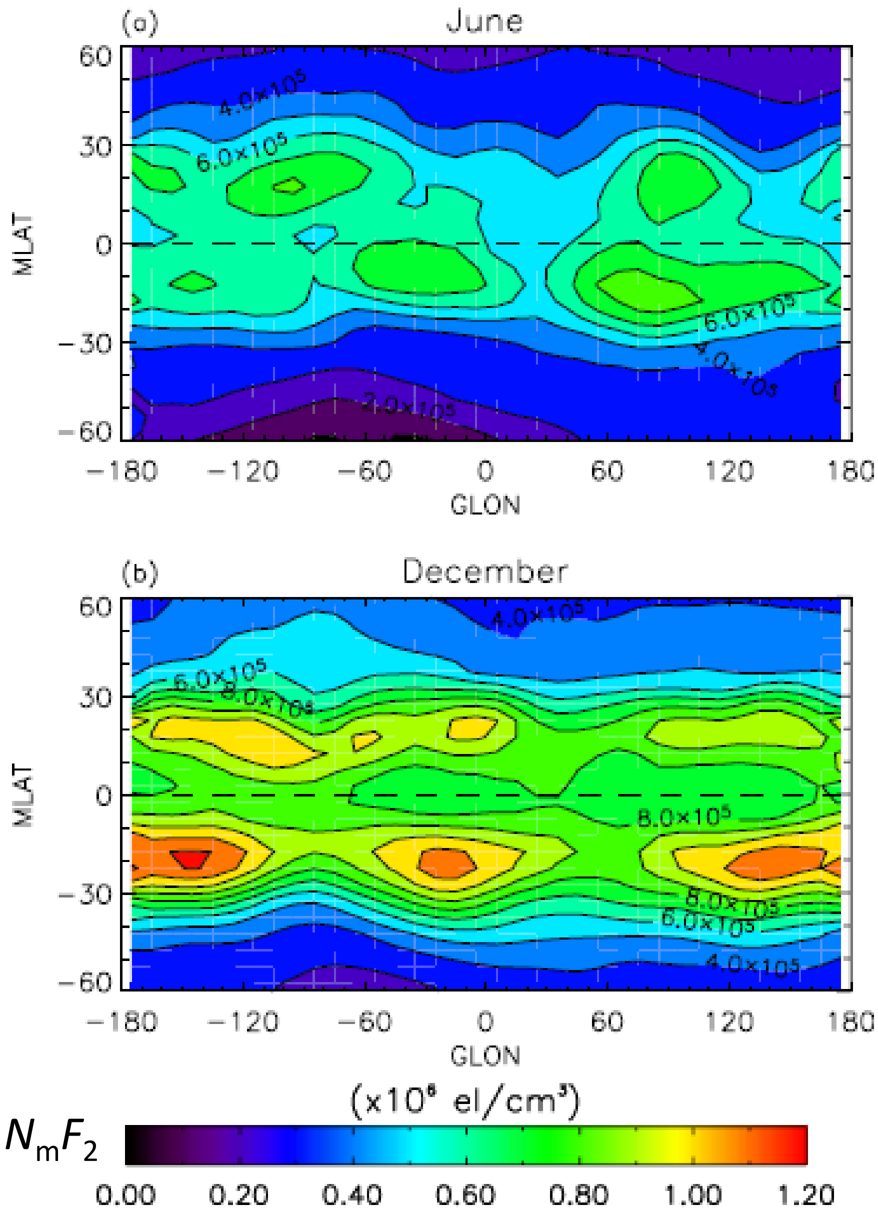
- Polar mesospheric clouds occur more frequently and are brighter in the NH than the SH due to colder NH summer mesopause





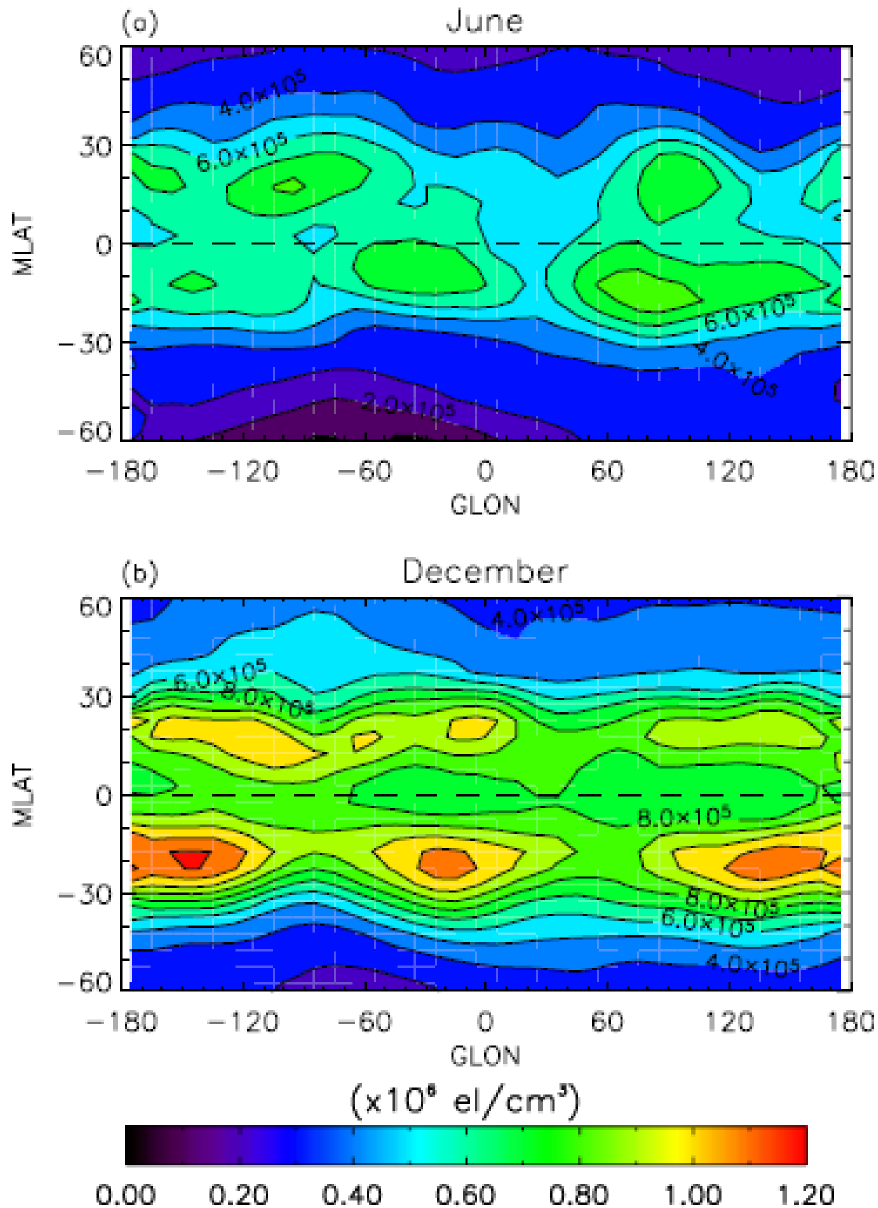
Morris et al. (2009)

Annual asymmetry in electron density

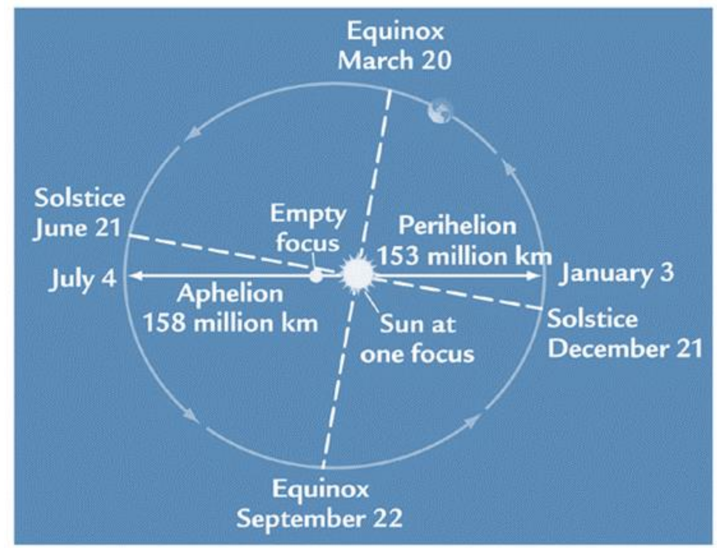


- Global electron density ~30% smaller for June solstice than for December solstice (COSMIC data; Zeng et al., 2008)

Annual asymmetry in electron density

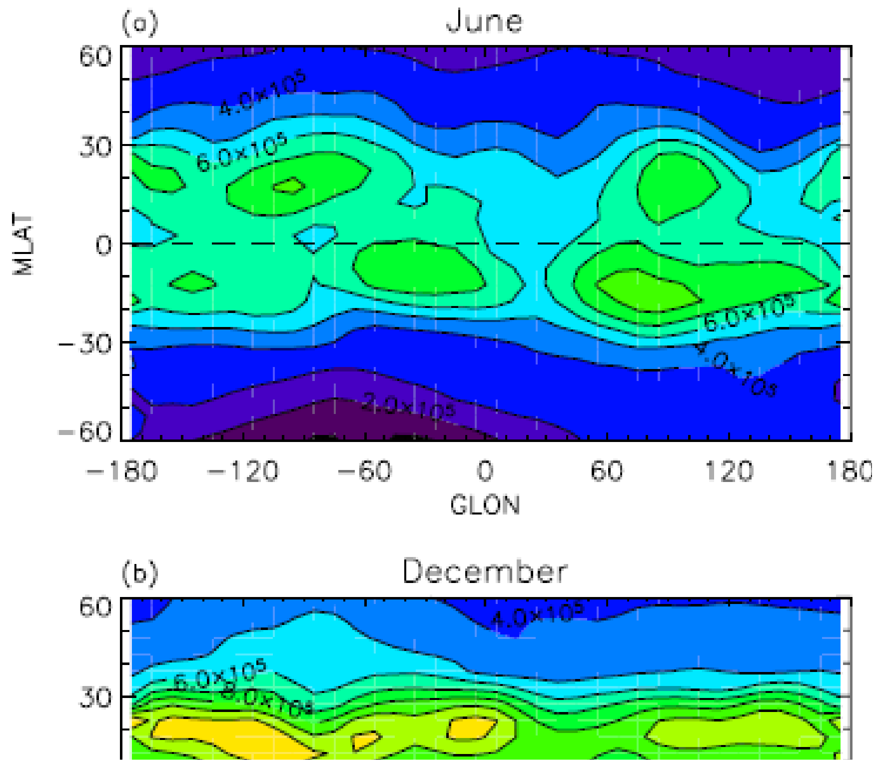


- Global electron density ~30% smaller for June solstice than for December solstice (COSMIC data; Zeng et al., 2008)
- Annual variation in Sun-Earth distance



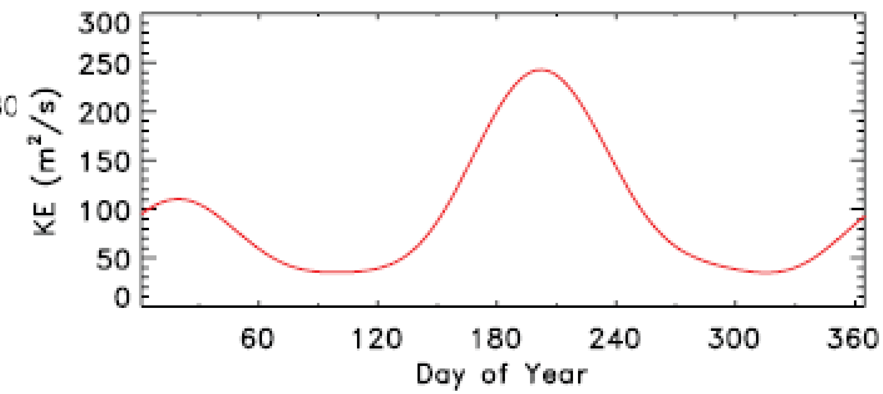
- Solar illumination 7% higher in January than in July – not enough

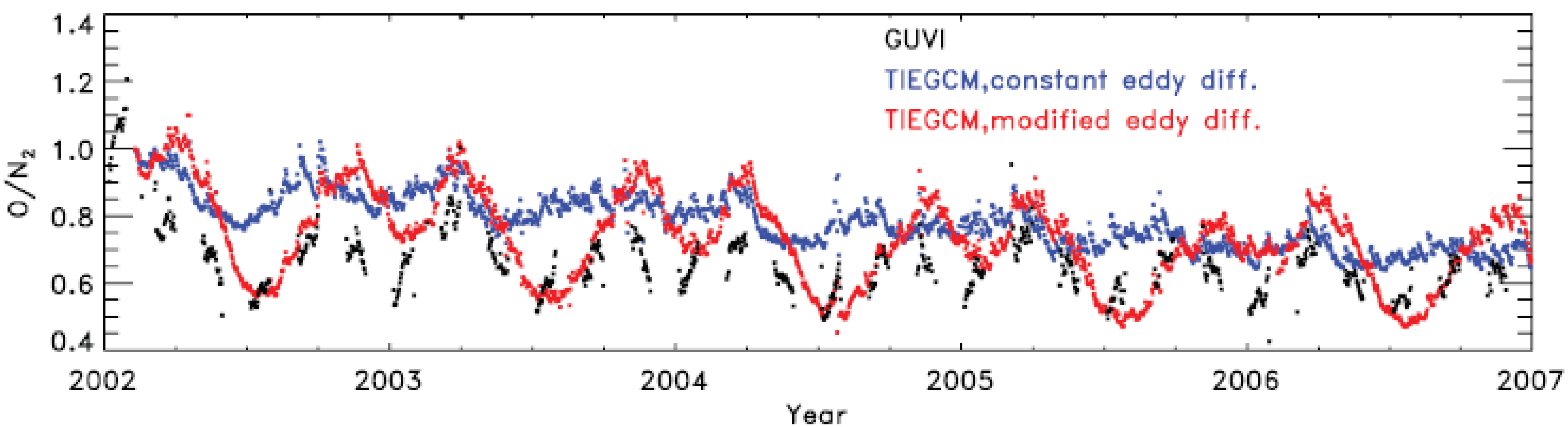
Annual asymmetry in electron density



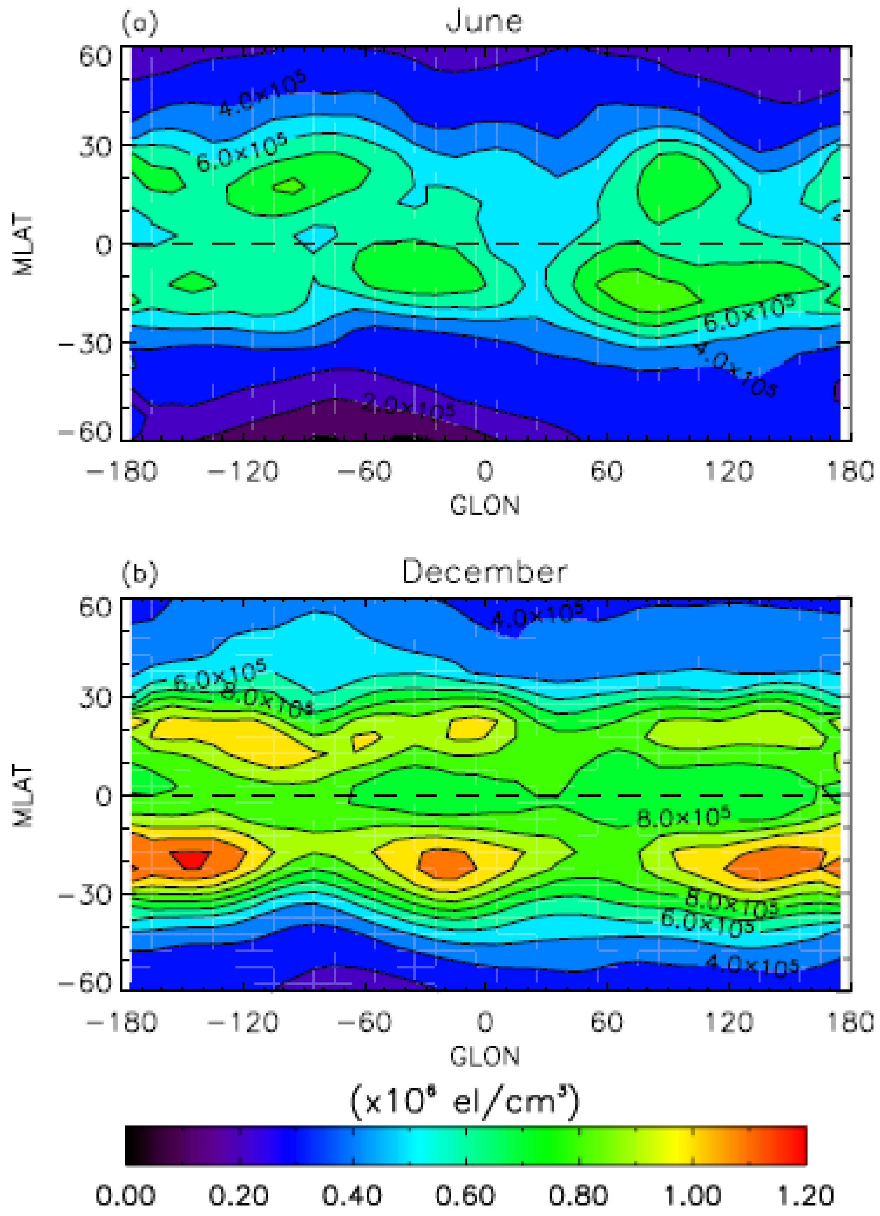
- Annual variation in Sun-Earth distance – not enough
- Influences from below? Maybe

Qian et al. (2009)



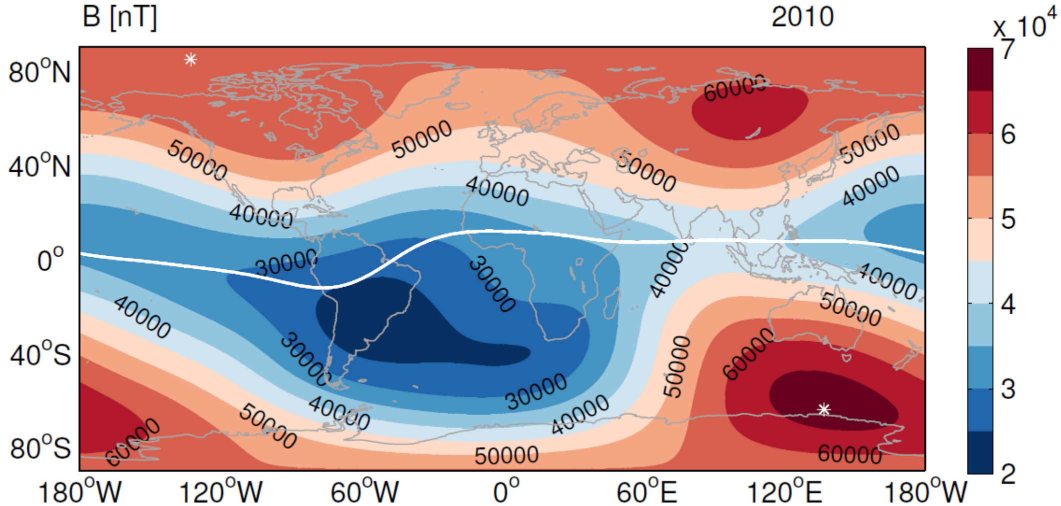


Annual asymmetry in electron density

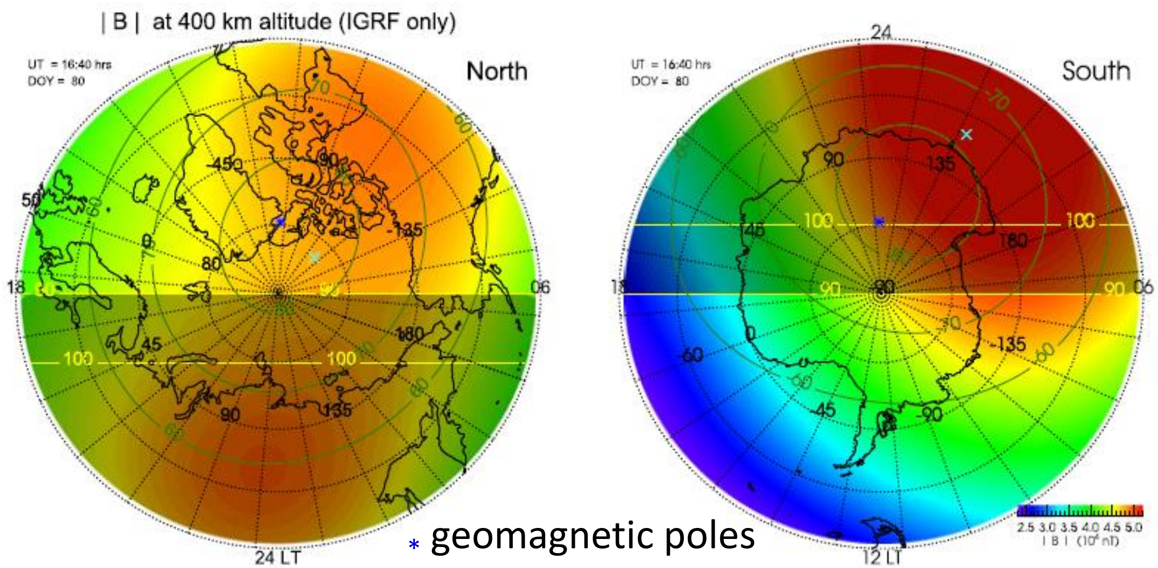


- Annual variation in Sun-Earth distance – not enough
- Influences from below? Maybe
- Earth's magnetic field? Zeng et al. [2008] found this to be the dominant cause

Magnetic field asymmetry



- Magnetic field strength is non-uniform
- Offset between geographic and magnetic apex pole greater in SH (~16°) than in NH (~8°)

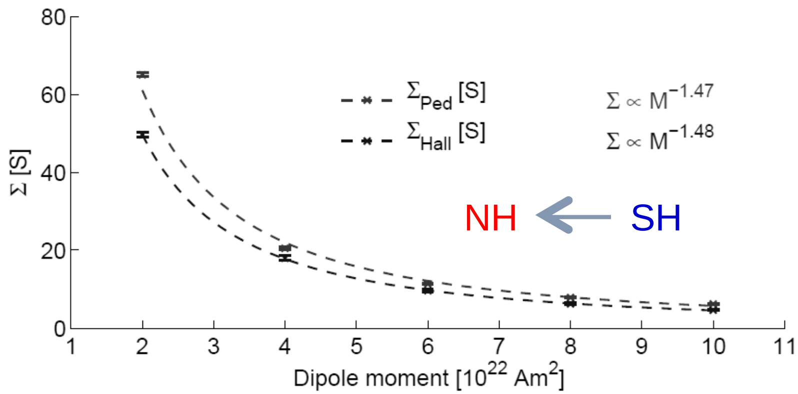


* geomagnetic poles
x dip poles
— AACGM coordinates

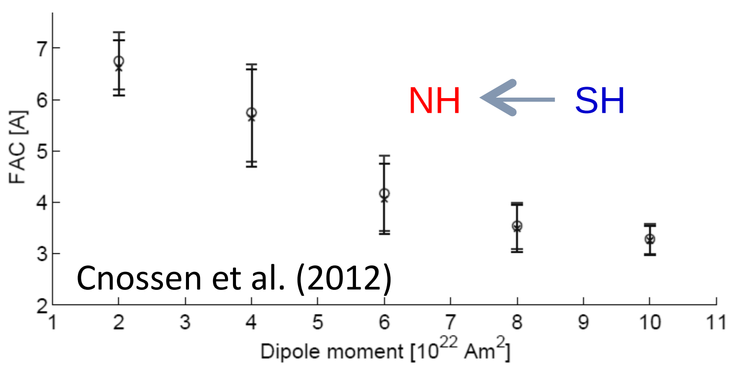
Förster and Cnossen (2013)

Effects of magnetic field strength

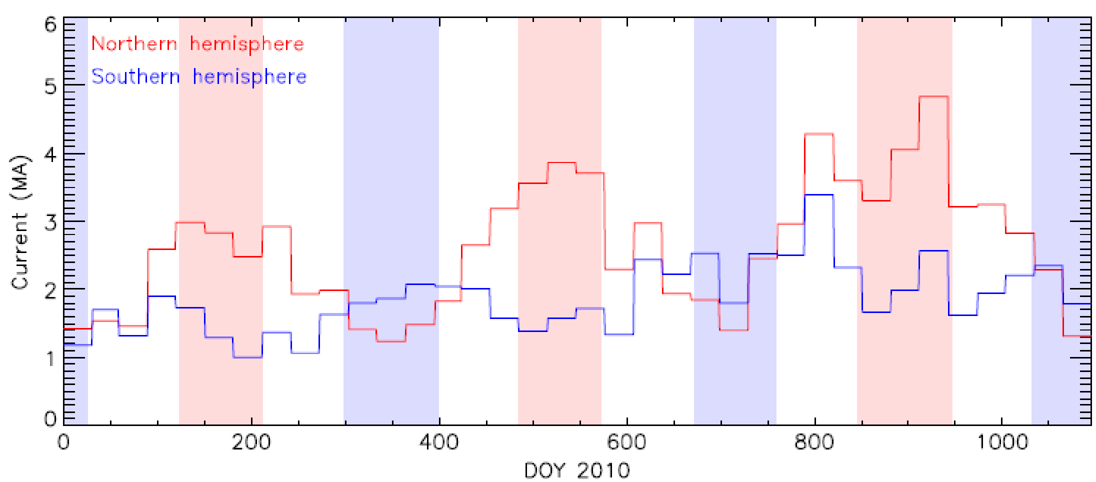
Conductance



FAC

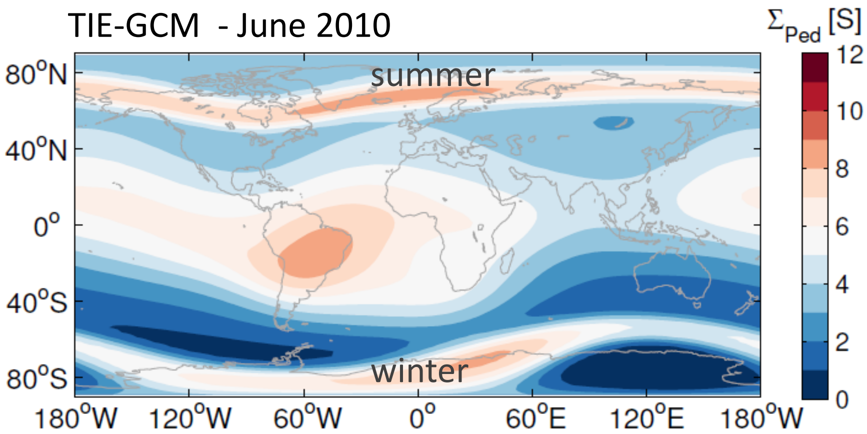


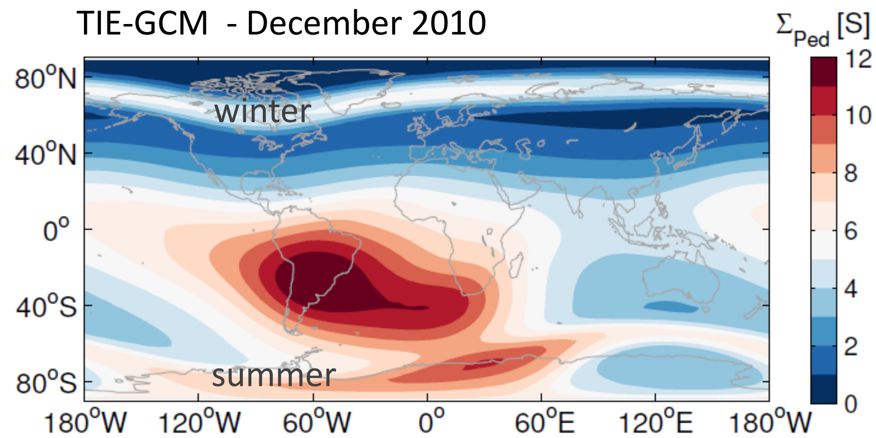
- Lower magnetic field strength (as in NH at high latitude) gives
  - higher conductivity
  - larger field-aligned currents (FACs)
- AMPERE data show larger FACs in NH (Coxon et al., 2016)
- But observed NH-SH difference larger than expected



Laundal et al. (2017), modified from Coxon et al. (2016)

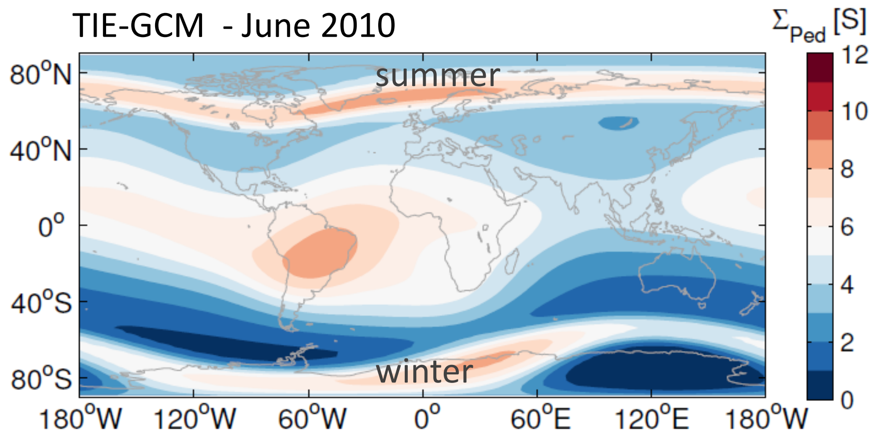
Seasonal differences, North-South asymmetry and inter-hemispheric coupling in the ionosphere



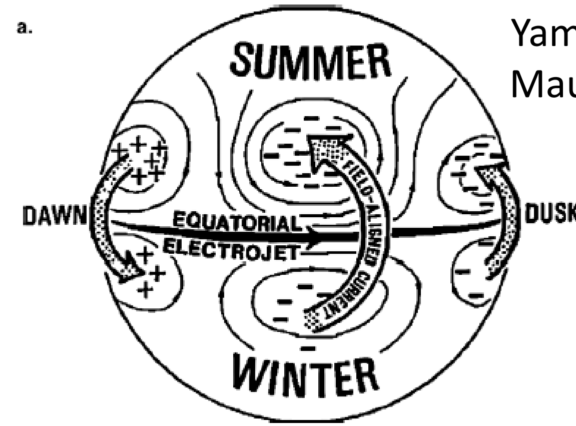


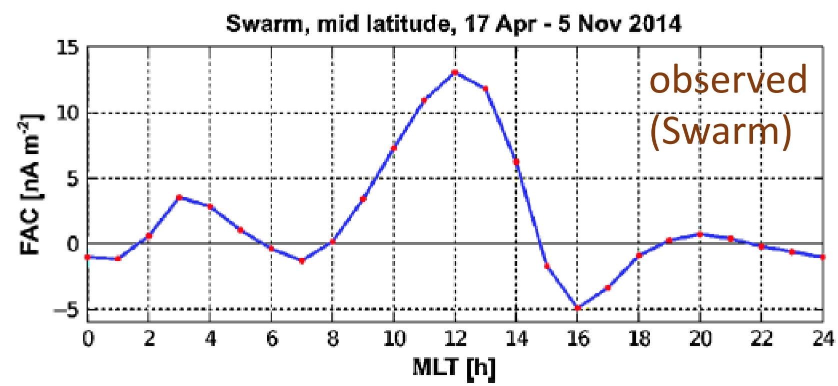
- Difference in solar illumination causes seasonal variation in conductance
- Earth's magnetic field causes further asymmetry

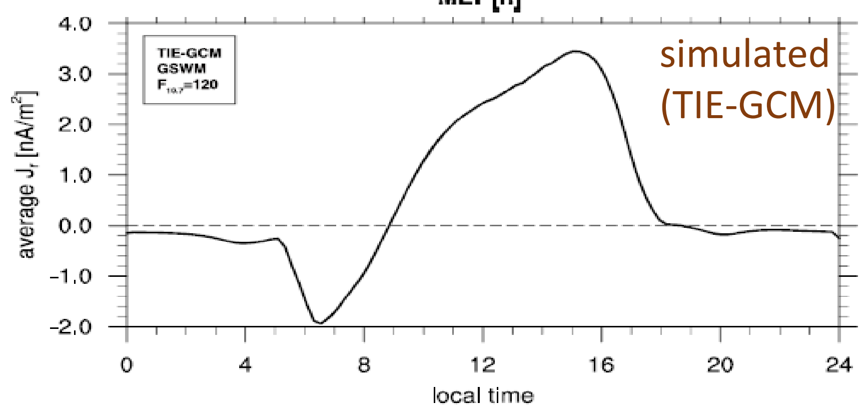
Seasonal differences and inter-hemispheric coupling in the ionosphere



Yamazaki and Maute (2017)



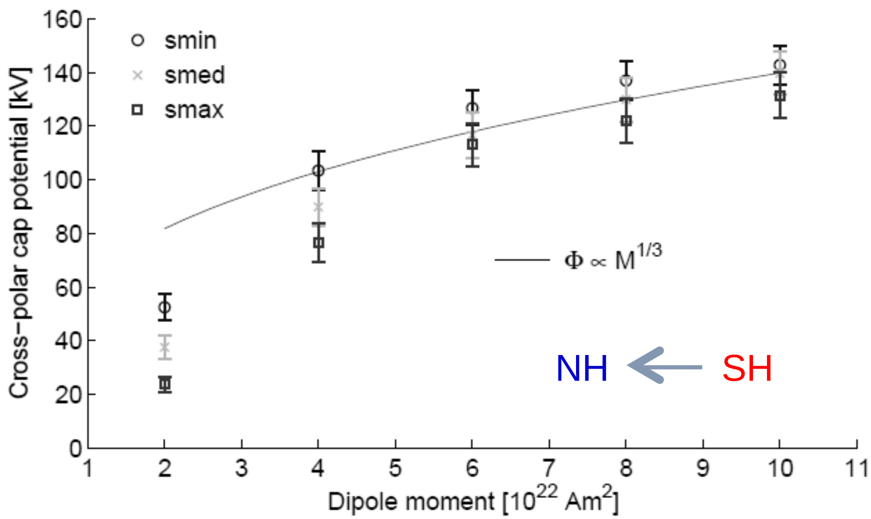




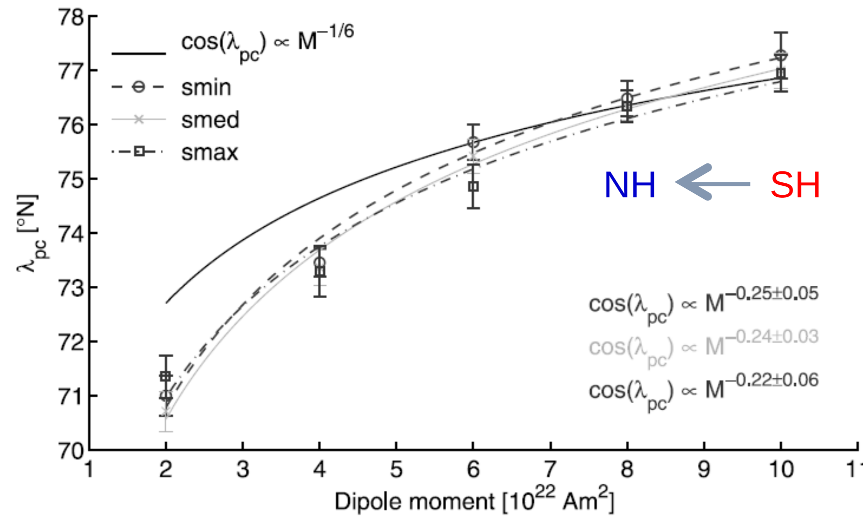
- Difference in solar illumination causes seasonal variation in conductance
- Earth's magnetic field causes further asymmetry
- Also seasonal differences in ion/electron production, electric potential
- Interhemispheric currents

Effects of magnetic field strength

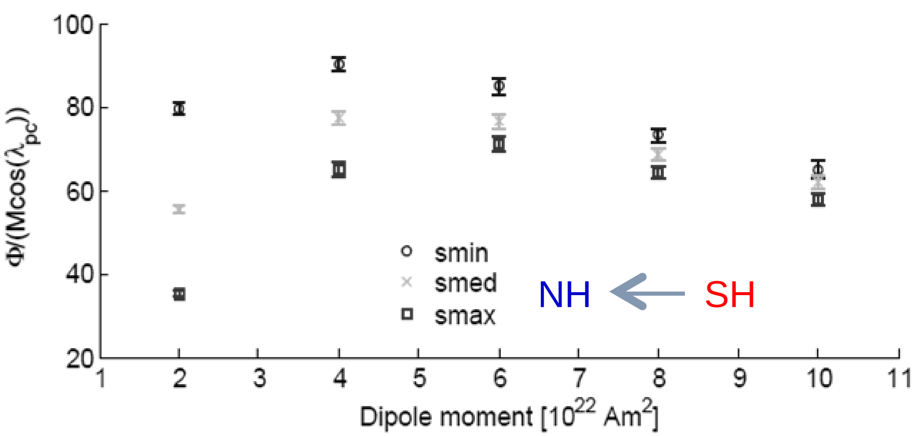
Cross-polar cap potential



Latitude of polar cap boundary



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

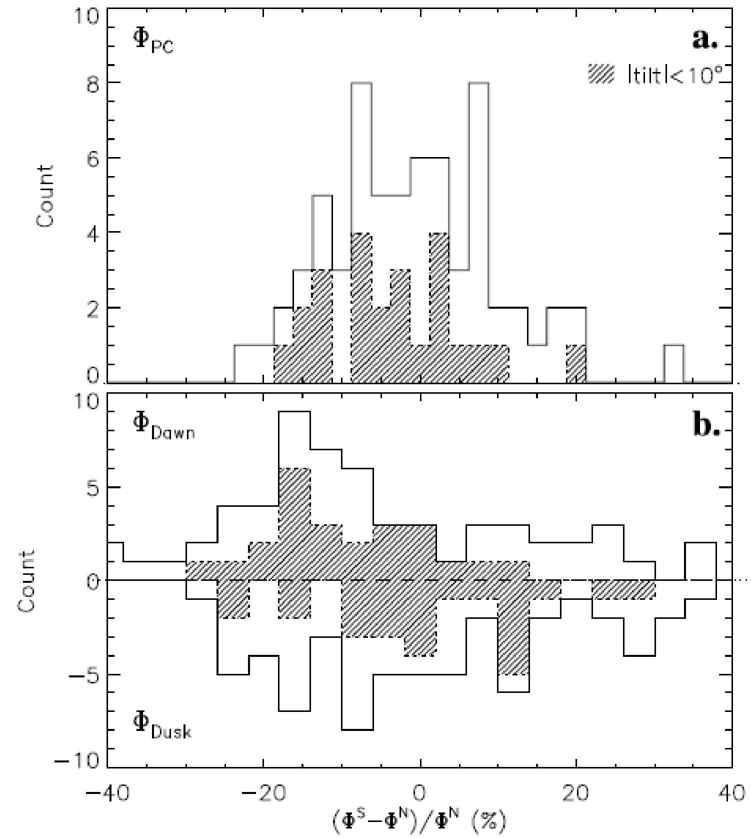


- For lower magnetic field strength (as in NH)
  - Cross-polar cap potential ↓
  - Polar cap size ↑
  - **ExB** drift magnitude ↑
- Expect CPCP, **ExB** drifts NH > SH
- Expect neutral winds NH > SH (via ion drag)

Cnossen, Richmond and Wiltberger, JGR, 2012

Observed cross-polar cap potential

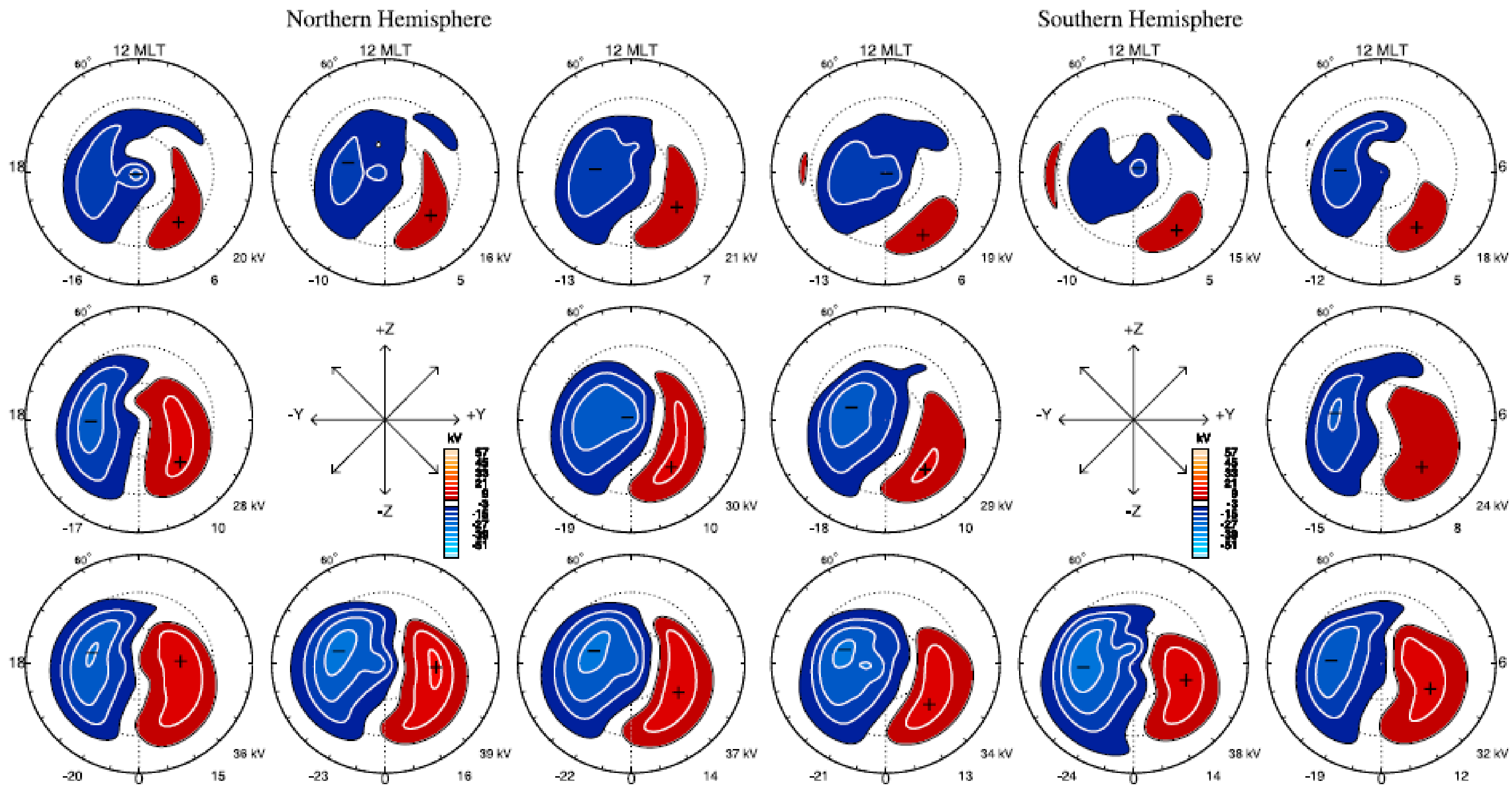
- No clear observed asymmetry in general
- Two special cases:
  - For IMF B_z^- CPCP NH < SH (8% difference)
  - For IMF B_y^- in NH compared to IMF B_y^+ in SH, CPCP NH > SH (12% difference)



Pettigrew et al., 2010

- Expect CPCP, **ExB** drifts NH > SH
- Expect neutral winds NH > SH (via ion drag)

Observed electric potential patterns

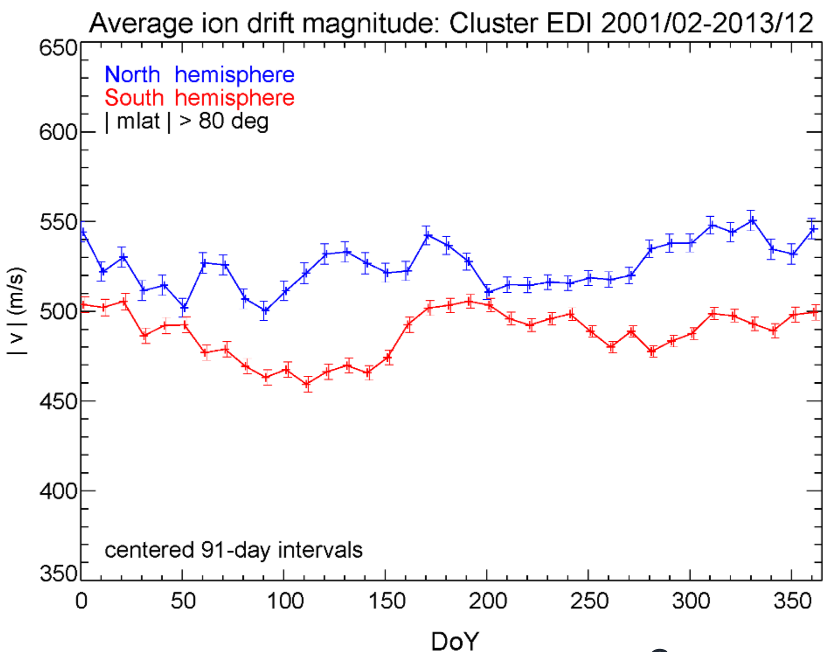


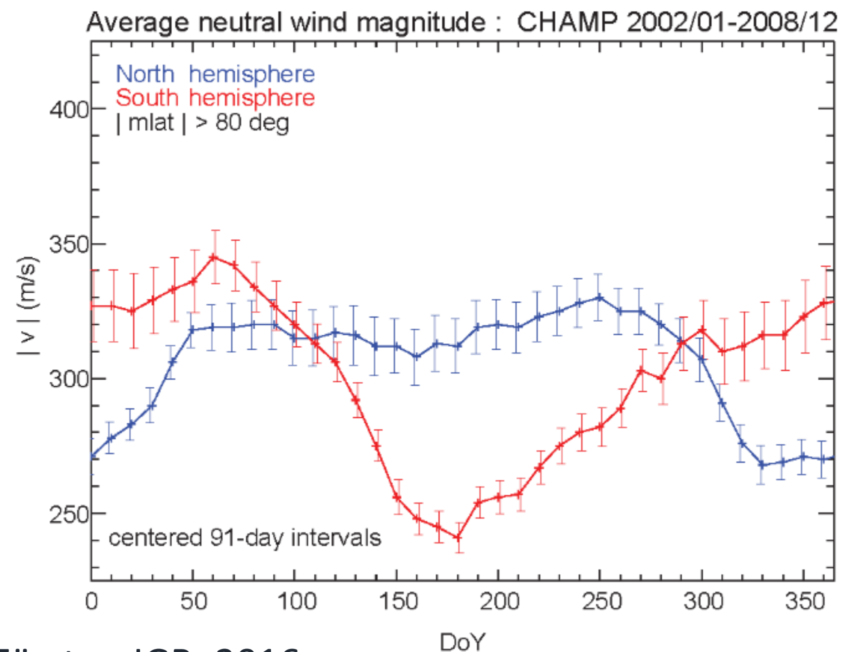
Pettigrew et al., 2010

- CPCP – no clear observed asymmetry
- There is asymmetry in convection patterns associated with IMF B_y

- Expect CPCP, **ExB** drifts NH > SH
- Expect neutral winds NH > SH (via ion drag)

Observed North-South asymmetries in high-latitude ion drift and neutral wind



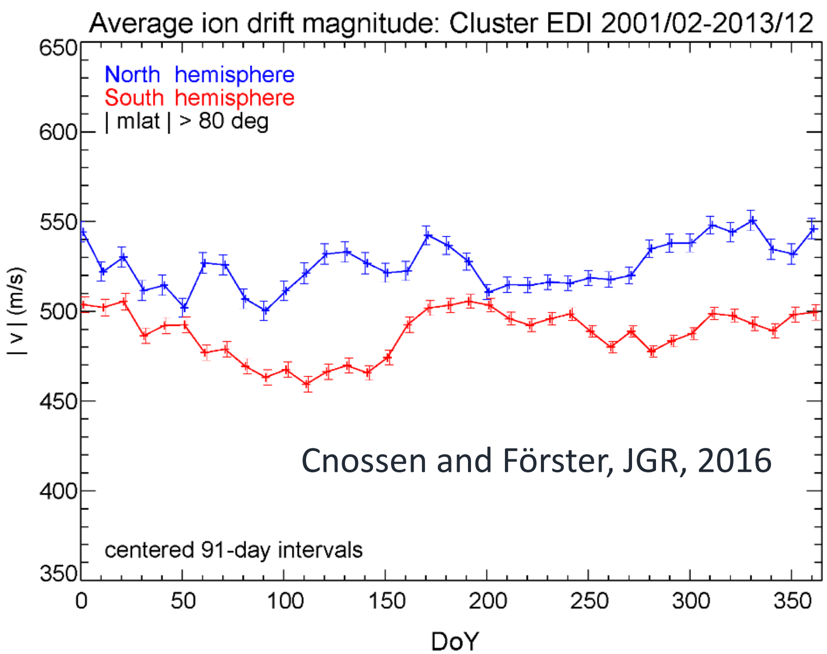


Cnossen and Förster, JGR, 2016

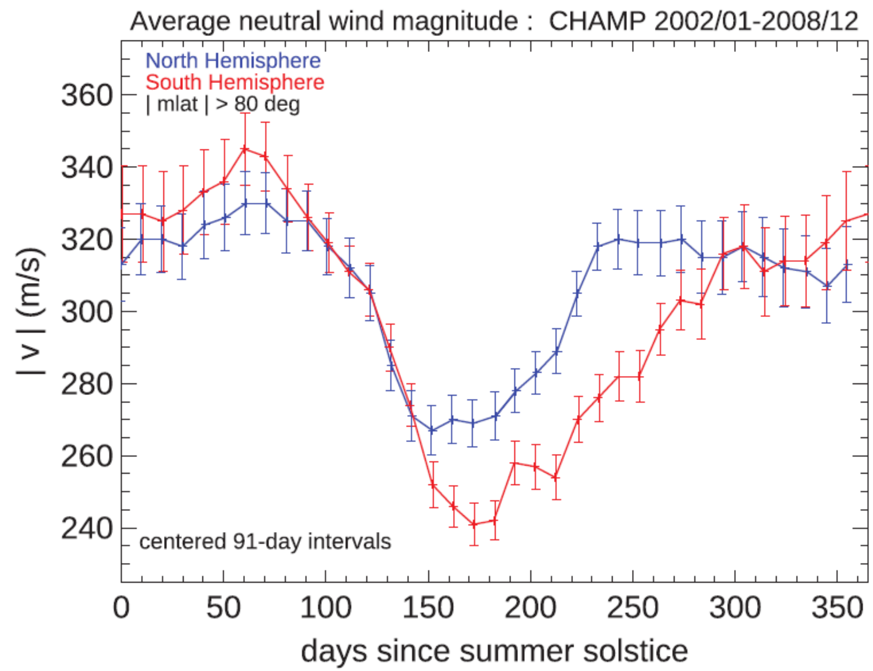
- CPCP – no clear observed asymmetry
- **ExB** drifts NH > SH
- Neutral winds strongest in local summer

- Expect CPCP, **ExB** drifts NH > SH
- Expect neutral winds NH > SH (via ion drag)

Observed North-South asymmetries in high-latitude ion drift and neutral wind



Cnossen and Förster, JGR, 2016



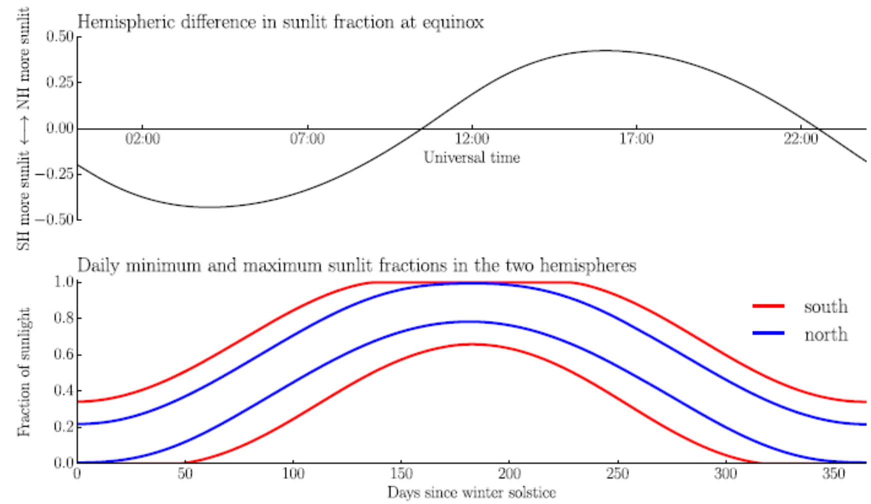
Laundal et al., Space Sci. Rev., 2017

- CPCP – no clear observed asymmetry
- **ExB** drifts NH > SH
- Neutral winds strongest in local summer
- Neutral winds NH > SH in for local winter

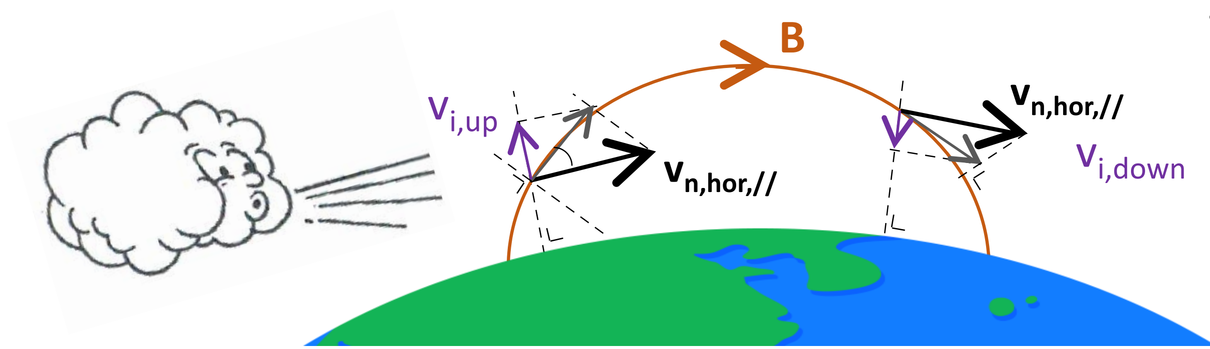
- Expect CPCP, **ExB** drifts NH > SH
- Expect neutral winds NH > SH (via ion drag)

Effects of magnetic field orientation

- Solar illumination in geomagnetic reference frame depends on geographic position of (apex) magnetic poles
- Neutral wind pushes plasma up/down magnetic field lines – depends on declination and inclination of magnetic field

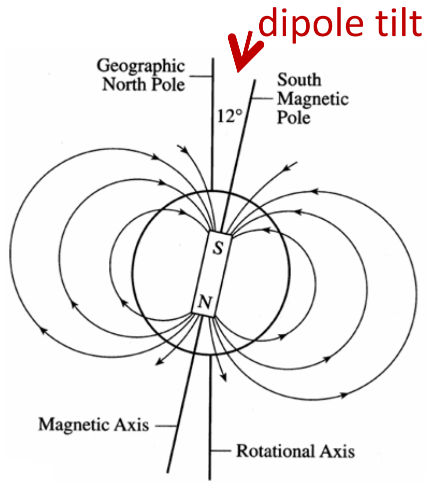


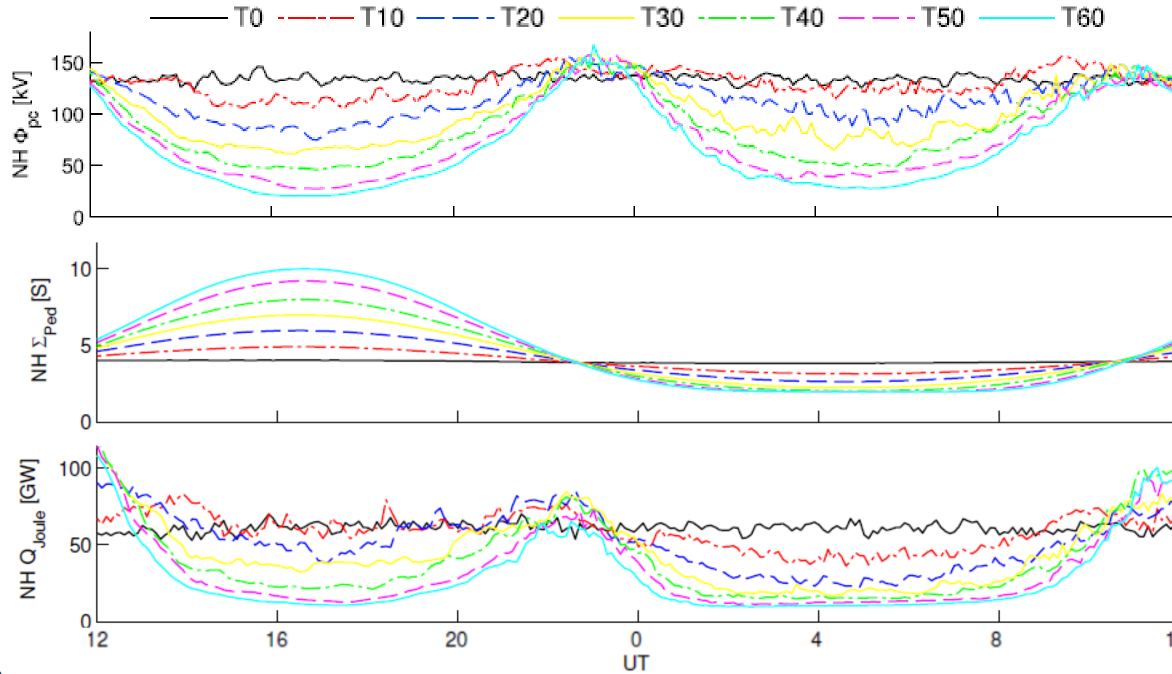
Laundal et al., Space Sci. Rev., 2017



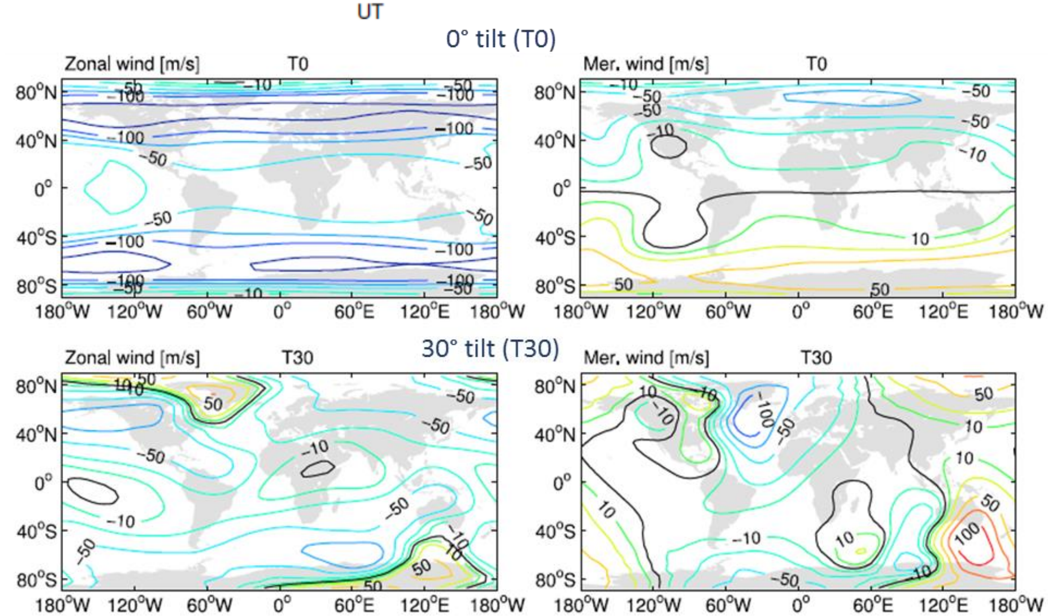
- **ExB** drifts depend on magnetic field vector
- Plasma diffusion mainly along magnetic field

Effects of magnetic field tilt (equinox)



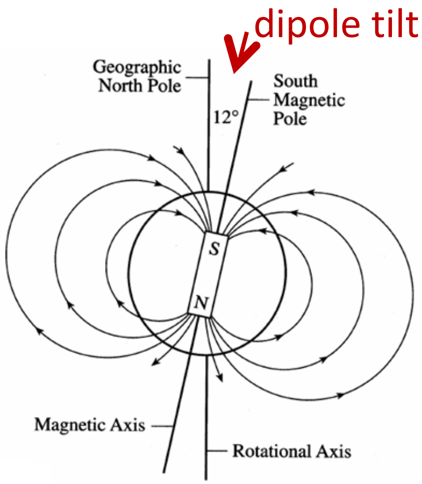


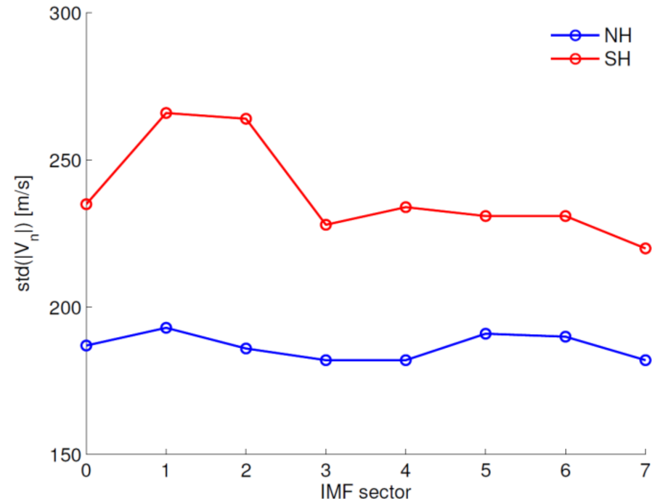
Cnossen and Richmond, JGR, 2012



- Expected tilt effects (equinox):
  - CPCP, **E**x**B** drift magnitude, Joule heating NH > SH
  - Ionospheric conductance NH < SH
  - Temporal and spatial variance NH < SH

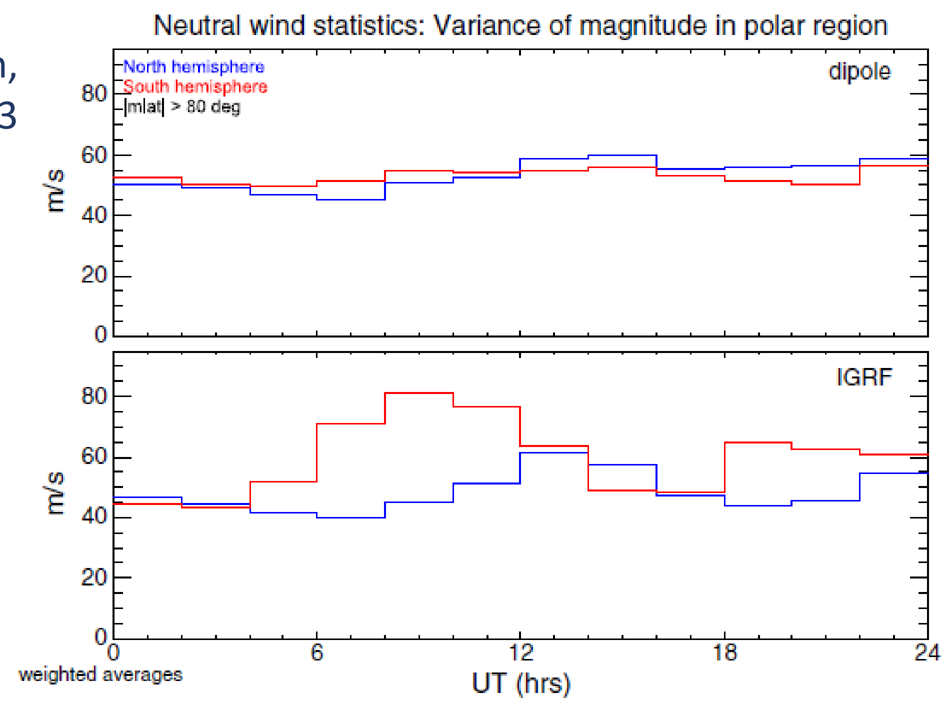
Effects of magnetic field tilt: high-latitude neutral wind variance





CHAMP data;
plot based on
Förster et al. [2008]

Förster and Cnossen,
JGR, 2013



- Expected tilt effects (equinox):
  - CPCP, **ExB** drift magnitude, Joule heating NH > SH
  - Ionospheric conductance NH < SH
  - Temporal and spatial variance NH < SH

Summary

- North-South asymmetries are present throughout the entire atmosphere-ionosphere system
- Inter-hemispheric processes couple the two hemispheres; especially asymmetric at solstice
- Causes of North-South asymmetries and interhemispheric processes:
  - *Seasonal differences in solar illumination*
  - *Annual variation in Sun-Earth distance*
  - *Difference in land/sea distribution and topography, causing differences in wave forcing, wave-mean flow interaction*
  - *Asymmetry in Earth's magnetic field*
  - *IMF B_y component*
- Complex interplay between different sources of asymmetry