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

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

WACCM - January
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
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

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

Siskind et al. (2003)
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.
Annual asymmetry in electron density

- Global electron density $\sim 30\%$ 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 ($\sim$16°) than in NH ($\sim$8°)

Förster and Cnossen (2013)
Effects of magnetic field strength

- 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

- 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

Yamazaki and Maute (2017) observed (Swarm) simulated (TIE-GCM)
Effects of magnetic field strength

- 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)

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

Pettigrew et al., 2010
Observed electric potential patterns

- CPCP – no clear observed asymmetry
- There is asymmetry in convection patterns associated with IMF $B_y$
- Expect CPCP, $\text{ExB}$ drifts $\text{NH} > \text{SH}$
- Expect neutral winds $\text{NH} > \text{SH}$ (via ion drag)

Pettigrew et al., 2010
Observed North-South asymmetries in high-latitude ion drift and neutral wind

- 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

- 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
- $\mathbf{E} \times \mathbf{B}$ 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, ExB 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

- Expected tilt effects (equinox):
  - CPCP, $\mathbf{E} \times \mathbf{B}$ drift magnitude, Joule heating $\text{NH} > \text{SH}$
  - Ionospheric conductance $\text{NH} < \text{SH}$
  - Temporal and spatial variance $\text{NH} < \text{SH}$

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

Förster and Cnossen, JGR, 2013
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