Grand Challenge Tutorial: Interhemispheric Asymmetry (IHA) in the I-T System

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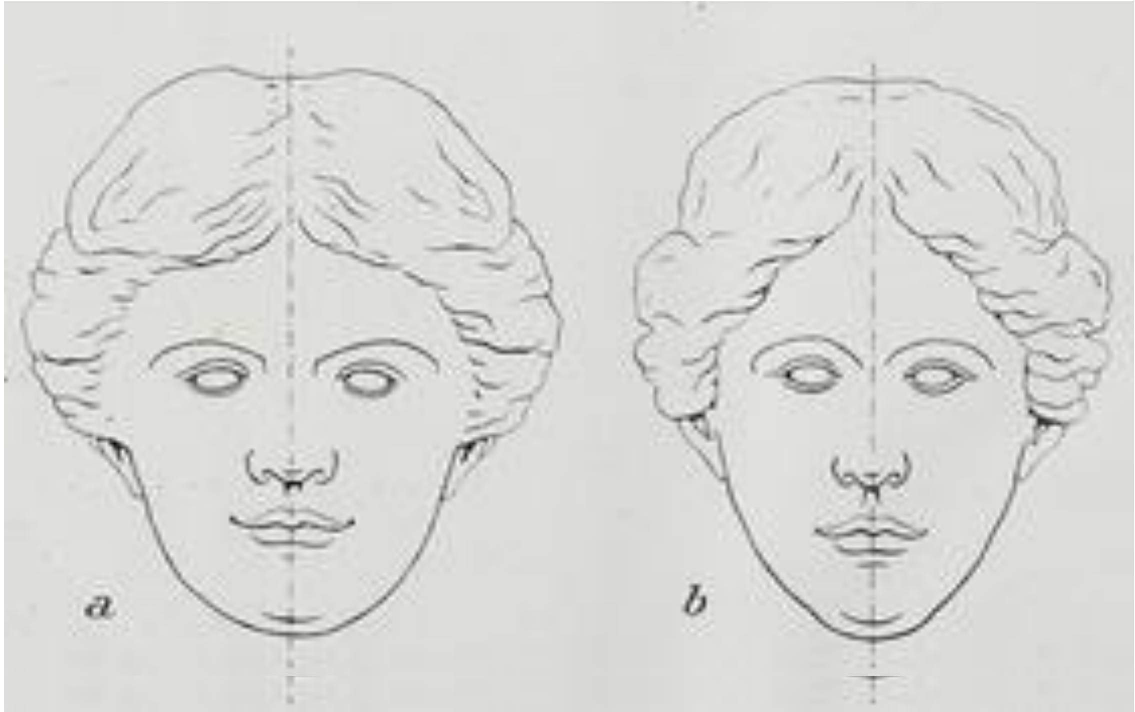
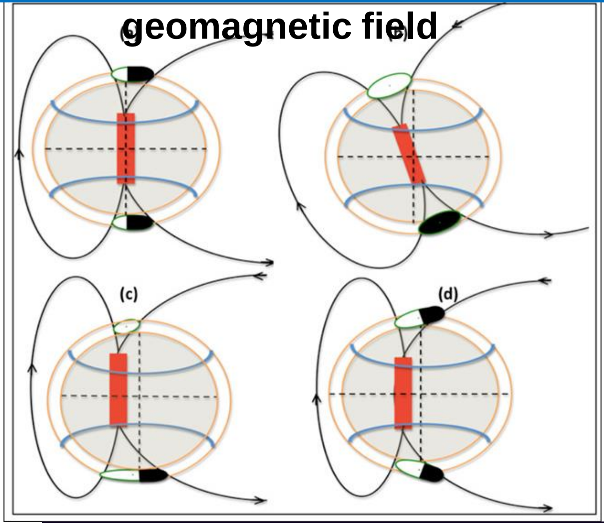
Symmetry?

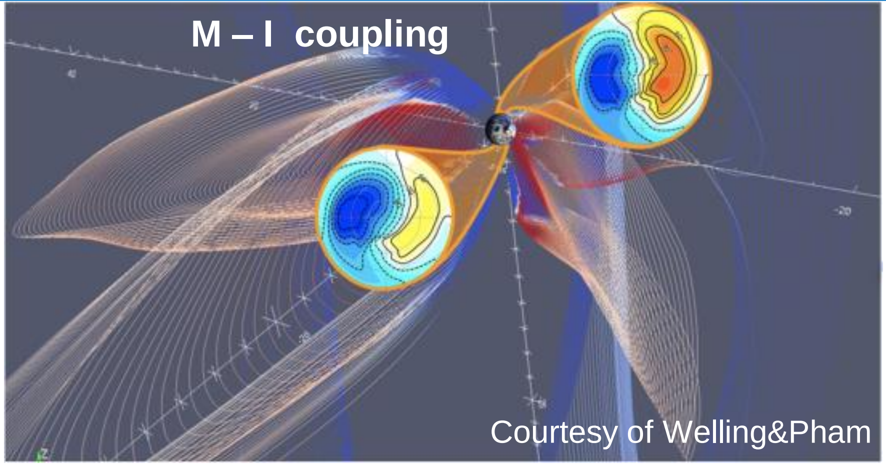
only **2% of the world's population** has true facial symmetry.

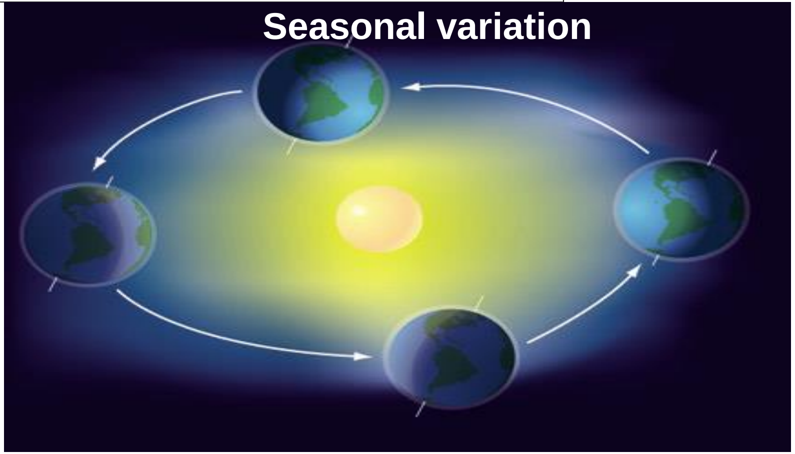


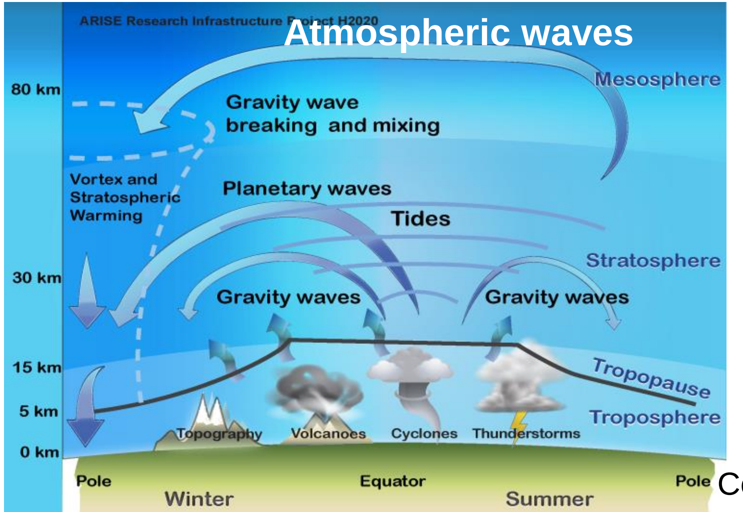
Courtesy of Wikipedia

What causes IHA?





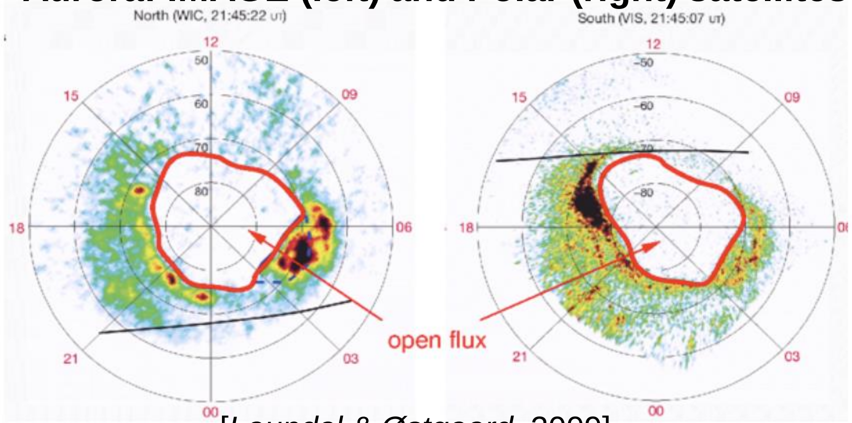




Courtesy of ARISE

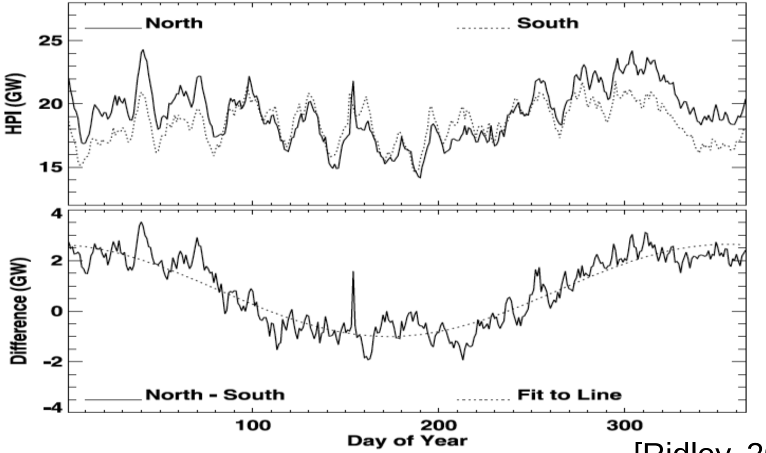
IHA in high-latitude forcing:

Aurora: IMAGE (left) and Polar (right) satellites



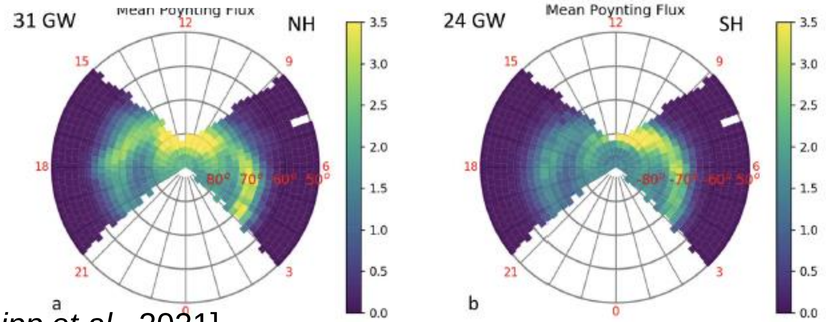
[*Laundal & Østgaard*, 2009]

NOAA satellite: HP



[Ridley, 2007]

Poynting flux: DMSP

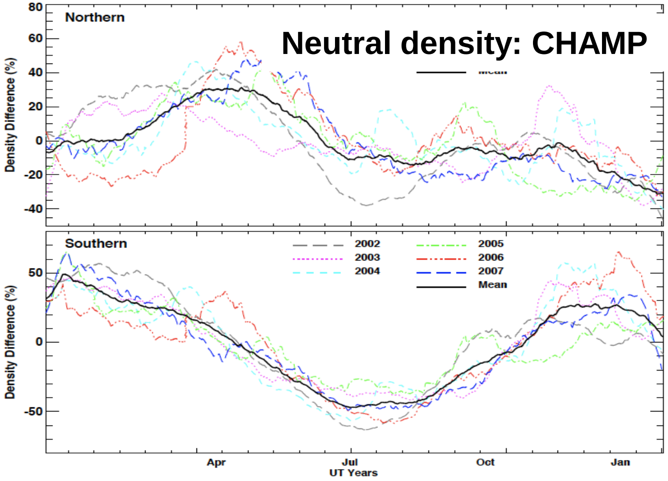


[*Knipp et al.*, 2021]

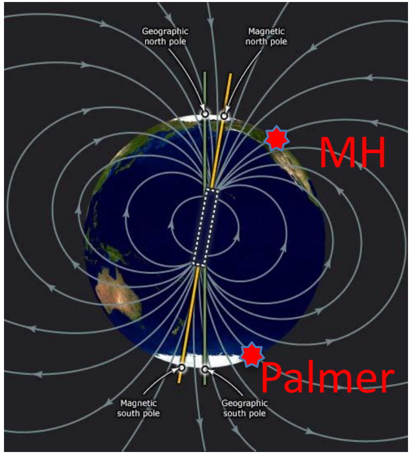
- **Aurora & polar cap** are quite asymmetric.
- **Hemispheric power (HP):** NH is 5-10% higher than that in SH.
- **Poynting flux**: NH is ~25% higher than that in SH.

Observations have revealed that IHA manifested in different forms

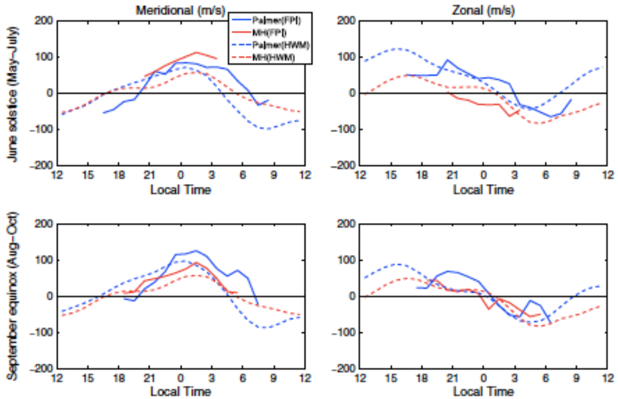
IHA in Thermosphere:



[*Ercha et al., 2012*]

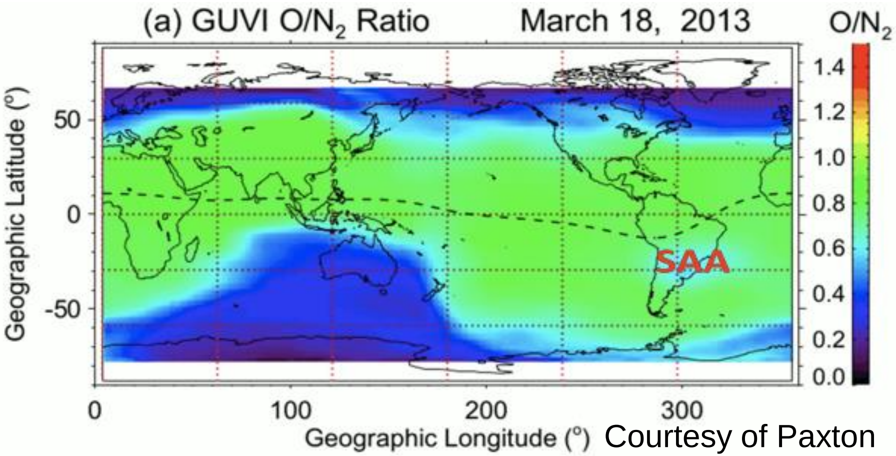


Neutral wind: FPI stations



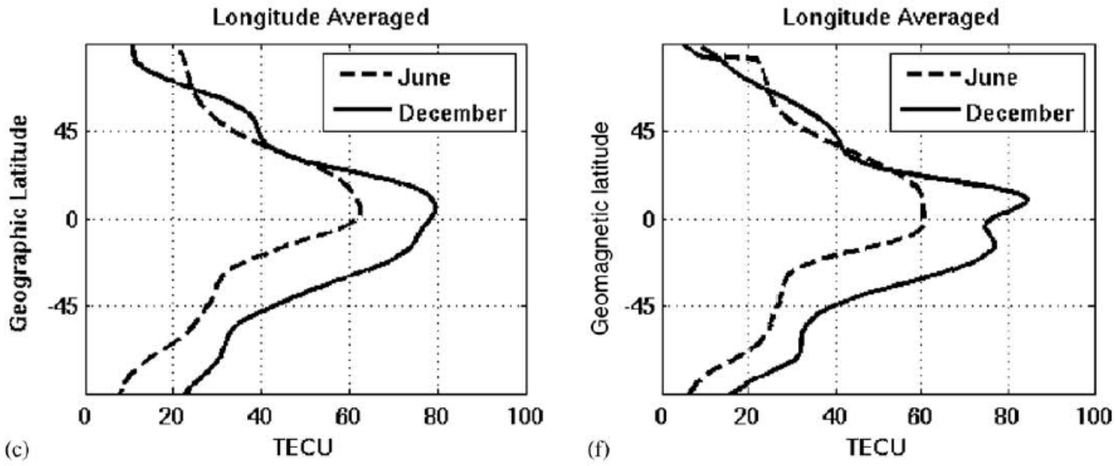
[*Deng et al., 2014*]

- **Neutral density:** SH shows a dominant annual variation while NH has a clear semi-annual variation.
- **FPI neutral wind:** asymmetry in both directions.
- **Composition (O/N2 ratio)**: Asymmetry is evident, especially during storm times.



Courtesy of Paxton

IHA in Ionosphere:



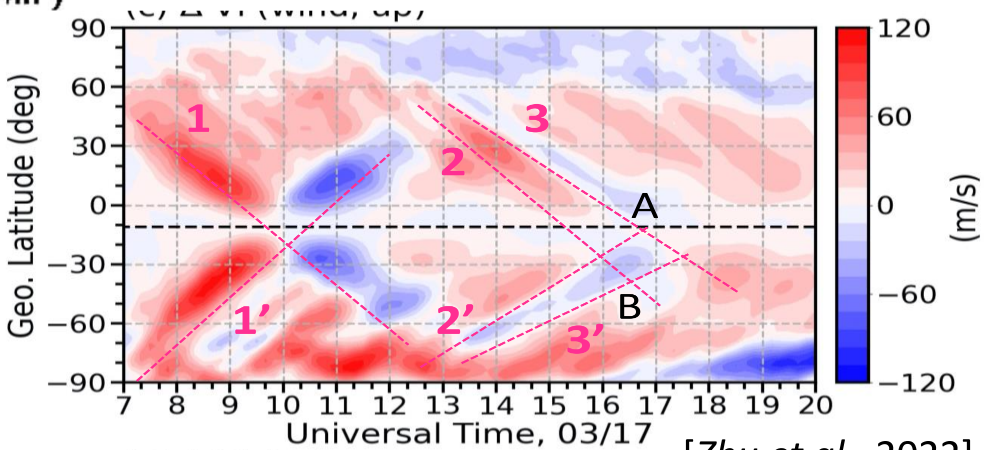
Total Electron Content at Local Noon (Unit 10^{16} e^{-}/m^2)

[*Mendillo, et al.,* 2005]

Total electron content (TEC) at noon shows a strong annual variation and IHA in both geographic and geomagnetic coordinates.

TADs/TIDs: GCMs

Traveling atmospheric disturbance (TADs) and **Traveling ionospheric disturbance (TIDs**) can be asymmetric in terms of magnitude, propagation speed and time.



[*Zhu et al.,* 2022]

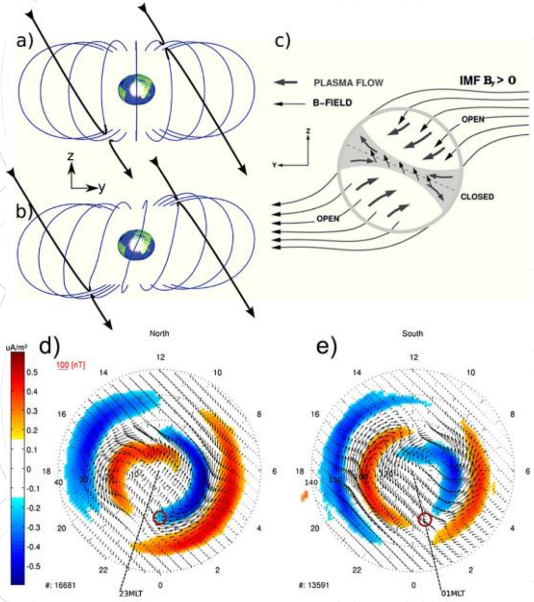
Why IHA?

- The community has insufficient understanding of the nature of interhemispheric asymmetries.
- The asymmetry has been typically ignored in the data analysis and empirical models.
- The lack of IHA input to GCM models has prevented simulations from testing their impact on the global I-T system.

- This workshop focuses on quantifying interhemispheric differences observed in the I-T system and understanding their causes and importance for the upper atmosphere.

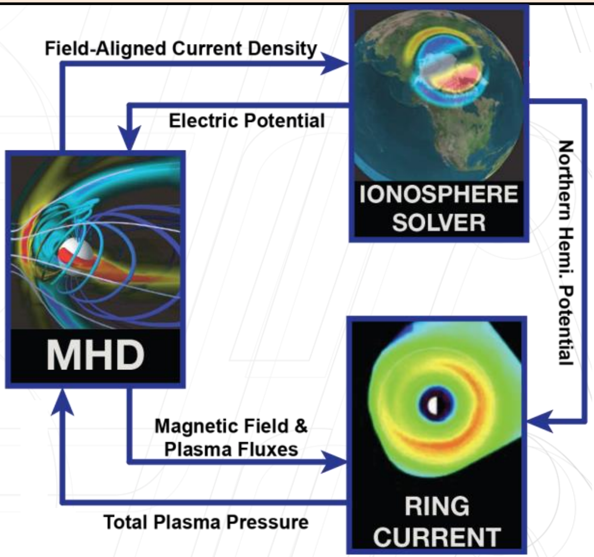
The Center for the Unified Study of Interhemispheric Asymmetries

<u>DRIVE Center Vision</u>: The **Center for the Unified Study of Interhemispheric Asymmetries** (**CUSIA**) will usher in the next generation of theory and models that account for the ever-present asymmetries imposed onto the geospace system.

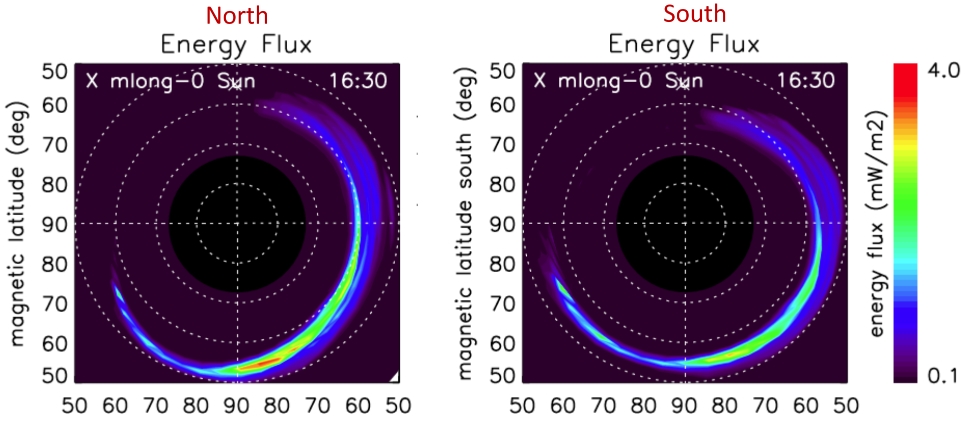


Observations uncovering model shortcomings

Improved models complete observationally-based understanding of M-I-T System

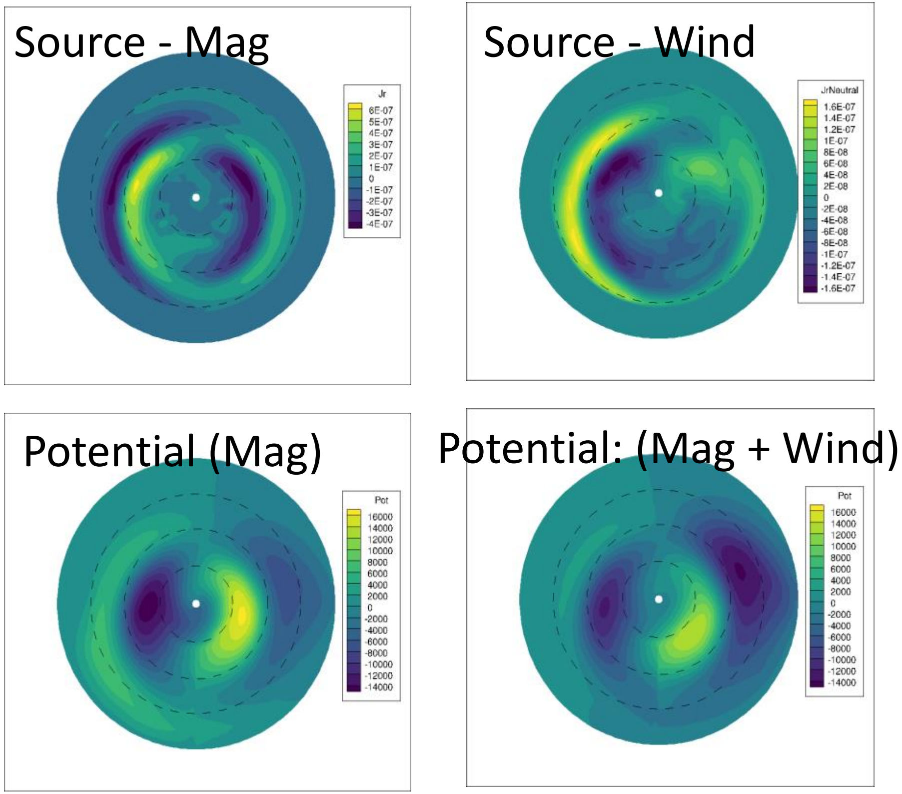


M-I coupling



Replace dipole with IGRF → particle precipitation

Neutral dynamo → PCP

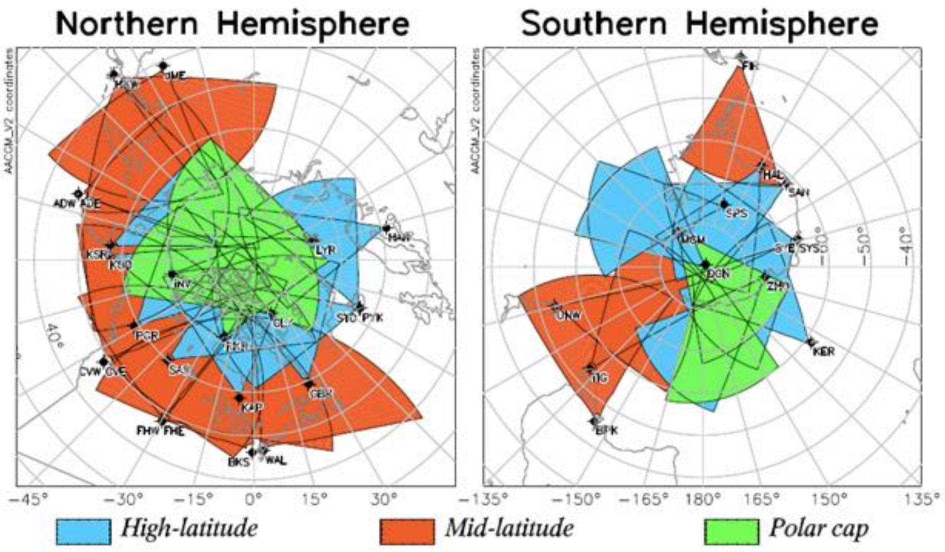


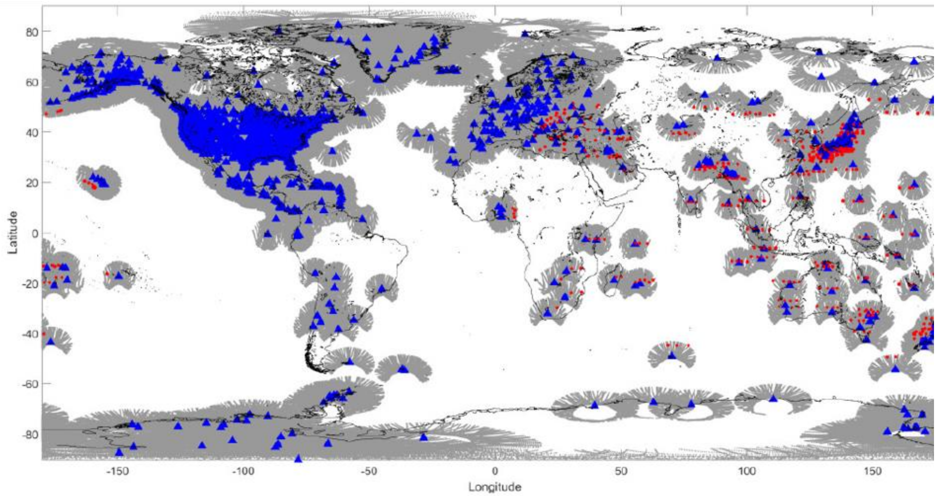
Courtesy of CUSIA team

Ground-based observations:

Super DARN radar:

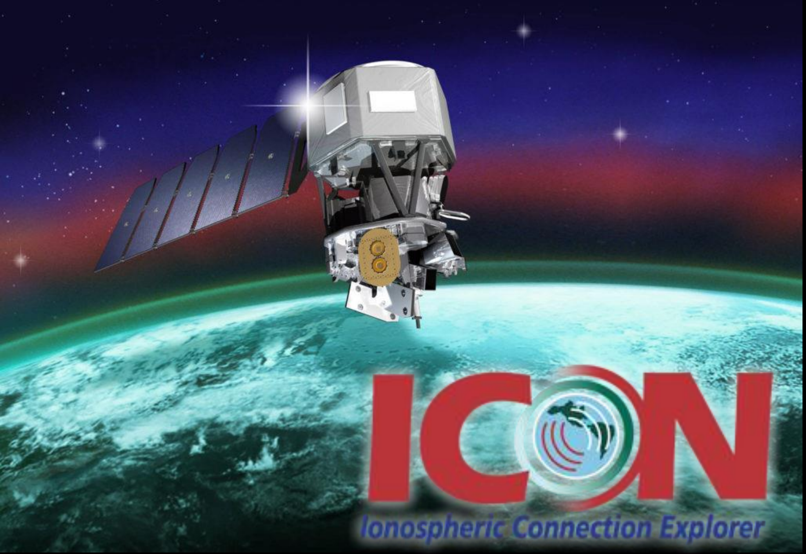
25 in NH + 14 in SH

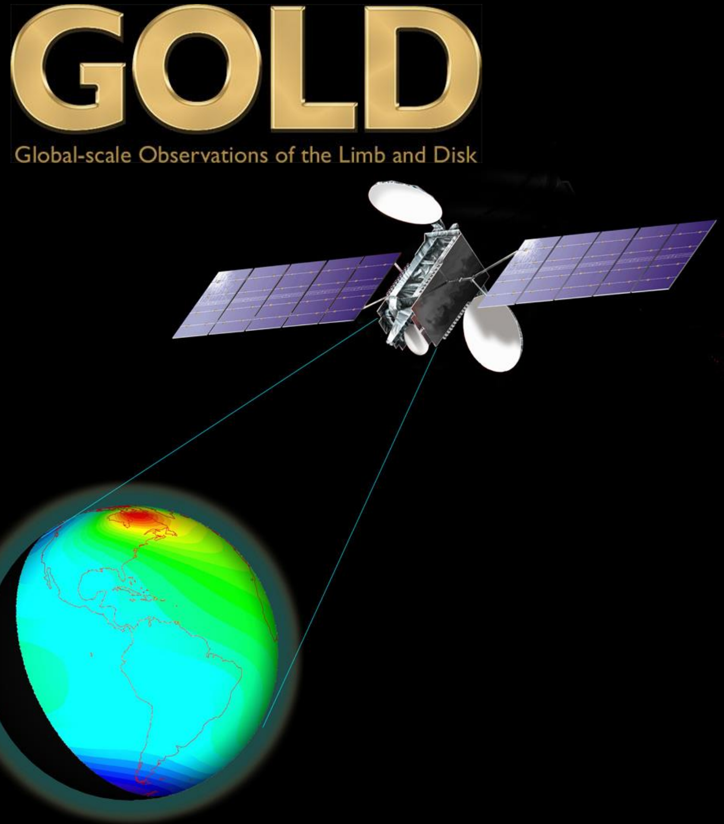


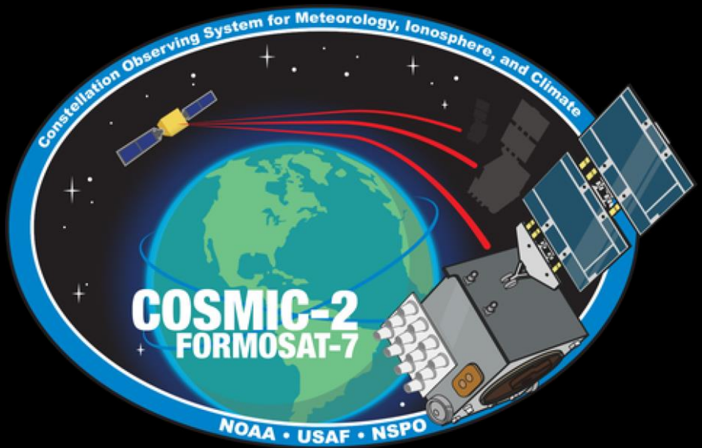


GNSS TEC :

utilizes 6000+ global receivers

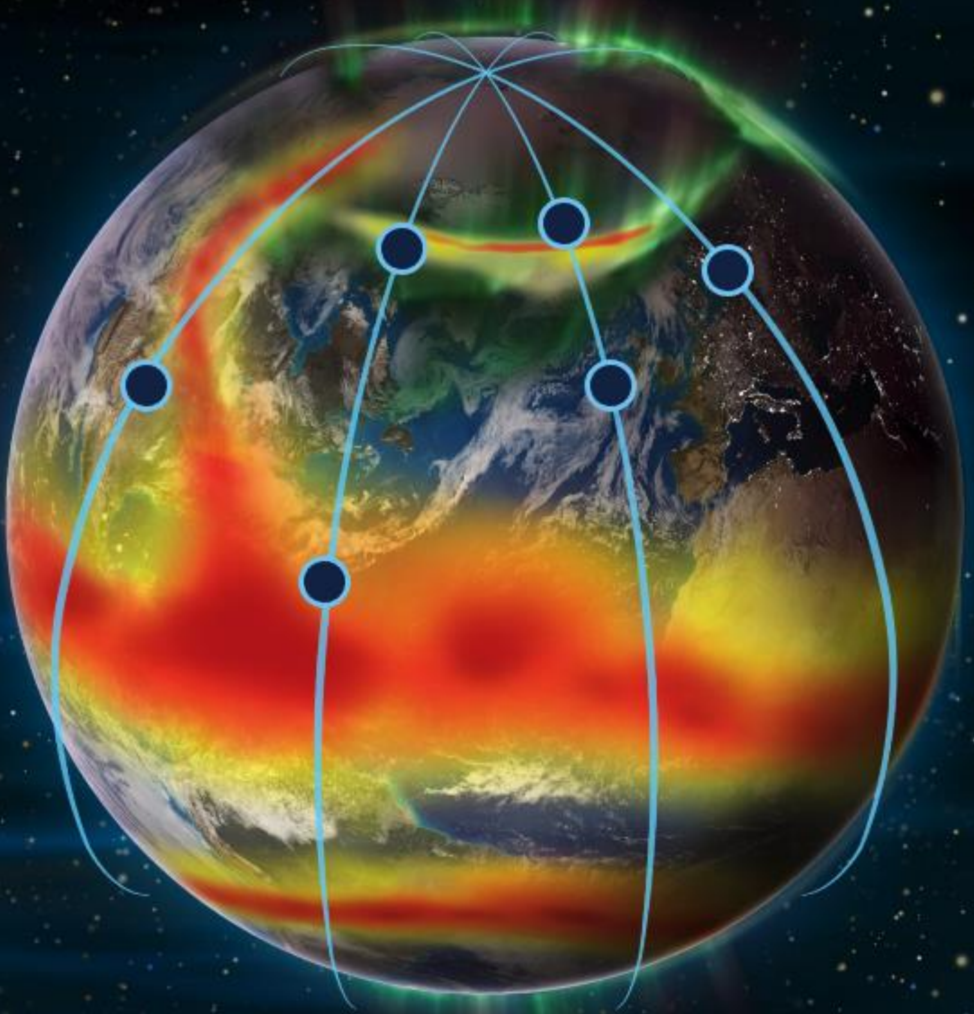

ICON
Ionospheric Connection Explorer


GOLD
Global-scale Observations of the Limb and Disk


Constellation Observing System for Meteorology, Ionosphere, and Climate
COSMIC-2
FORMOSAT-7
NOAA • USAF • NSPO

Geospace Dynamics Constellation (GDC) mission

Objective 2.6: Determine how hemispheric asymmetries in the Earth’s magnetic field, seasonal variations, and magnetospheric input affect the ionosphere-thermosphere system.



Proposed challenge questions:

Our overarching goal is to understand IHA in forcing from both above and below and to investigate their impacts on the global I-T system. Specifically, we propose to focus on the questions below:

- What are the difficulties to measure IHA and how could these gaps be closed?
- Where and under what conditions does IHA happen at different latitudes? What are the spatial and temporal characteristics of these IHA?
- How large are IHA in the MI coupled system during quiescent and disturbed conditions? How effectively do these IHAs contribute to the asymmetries in the IT system?
- How large are IHA in lower atmospheric forcing and do they generate IHA in the upper atmosphere system?
- What is the importance of IHA associated with lower atmospheric forcing during quiescent times and meteorological disturbed times?

Year 1:

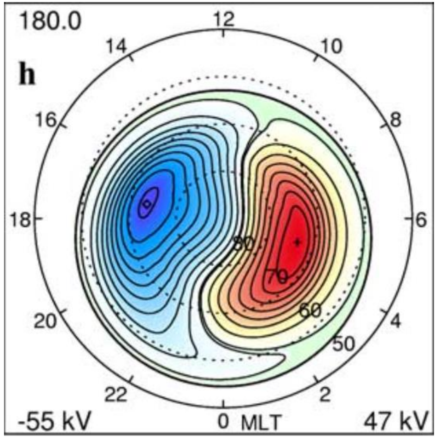
- What recent results and resources are available to address the GC questions?
- What are the hurdles for making progress?
- What problems can we realistically push forward over the next 3 years?
- Can we identify ways to characterize/parameterize IHA in forcing and I-T system?
- Can we identify collaboration opportunities to conduct research for year-2 and 3?

- **Session A**. Generated by high-latitude forcing (Wed 10:00-12:00)
  Session B. Generated by lower atmosphere (Wed 13:30-15:30)

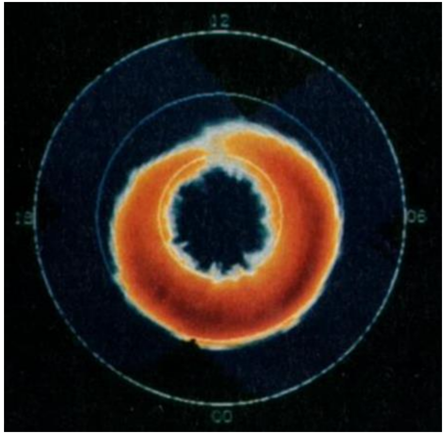
NCAR | NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

- Grand Challenge tutorial

Ion convection
[Weimer, 2005]



Electron precipitation
[Fuller-Rowell & Evans, 1987]



Session A: Interhemispheric asymmetries in the I-T system: generated by high-latitude forcings

Qingyu Zhu (NCAR)

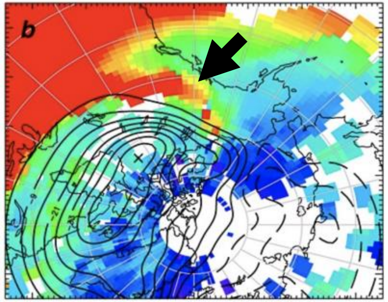
On behalf of the GC convenors: Yue Deng, Astrid Maute and rest of GC convenors

2022 CEDAR workshop, Austin

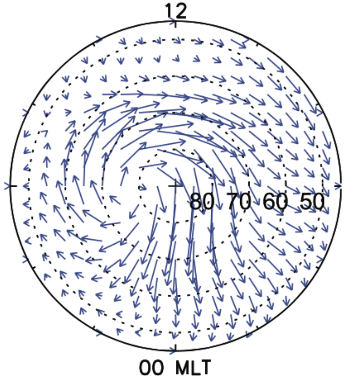
High-latitude forcings

- **Ion convection + Auroral particle precipitation**
  - Mainly associated with the magnetosphere-ionosphere (MI) coupling
  - Intense and dynamic during geomagnetic storms
  - Drivers of the I-T system, e.g.,:
    - Affect high-latitude F-region plasma density
    - Affect high-latitude neutral winds
    - Generate Joule heating at high latitudes (i.e., ion-neutral frictional heating)
      - Alter the dynamics, electrodynamics, density and composition of the global I-T system

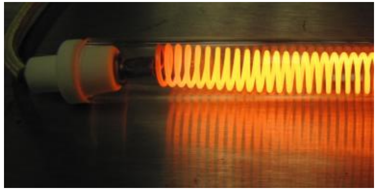
A SED plume [Thomas et al., 2013]



Neutral wind [Dhadly et al., 2019]



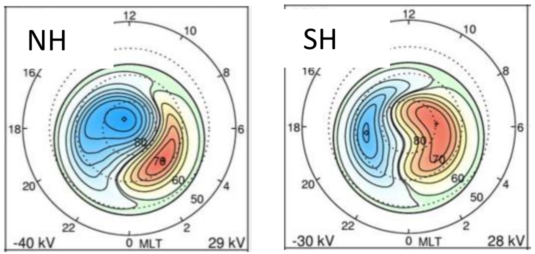
Joule heating [Wikipedia]



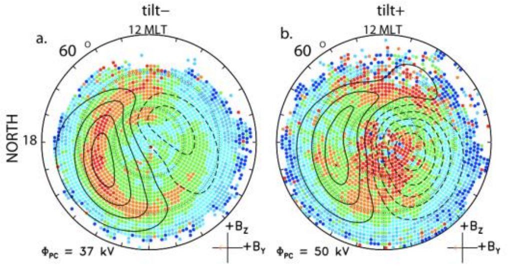
Asymmetries in the high-latitude forcings

- **IMF conditions**
- **Season**
- **Magnetic field configuration**

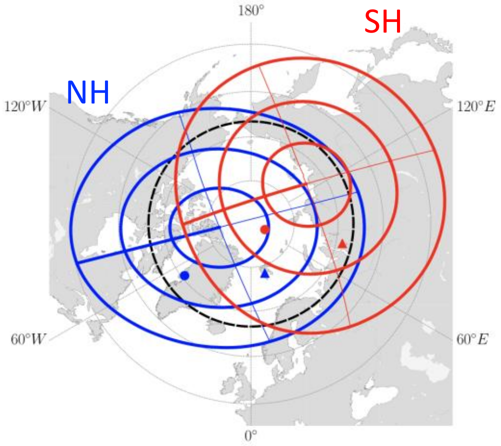
[Ion convection]



[IMF B_y+]   [Adapted from Weimer (2005)]

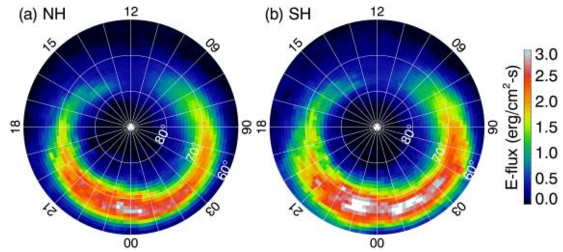


[Cousins et al. 2010]



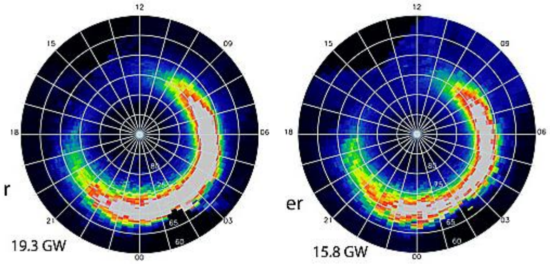
[Laundal et al., 2017]

[Electron precipitation]



[IMF B_y+]   [Liou & Mitchell, 2019]

Winter   Summer



[Newell et al. 2010]

- Cause asymmetries in the background conductance and affect the MI coupling

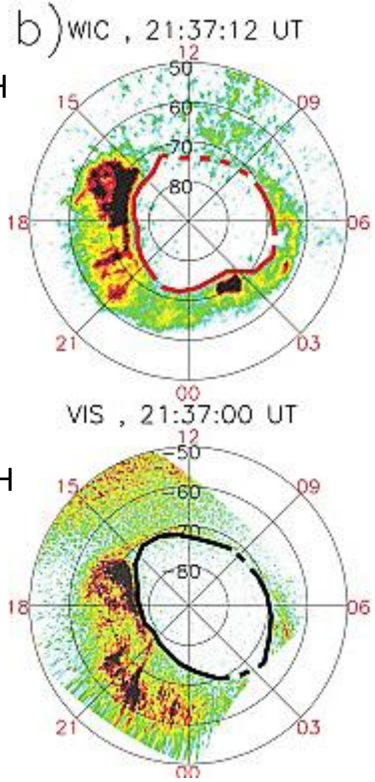
- Cause asymmetries in the background conductance and affect the MI coupling
- Asymmetric distributions of forcings in the geographic coordinates

Asymmetries in the high-latitude forcings

- **Substorms**

Electron precipitation

NH



SH

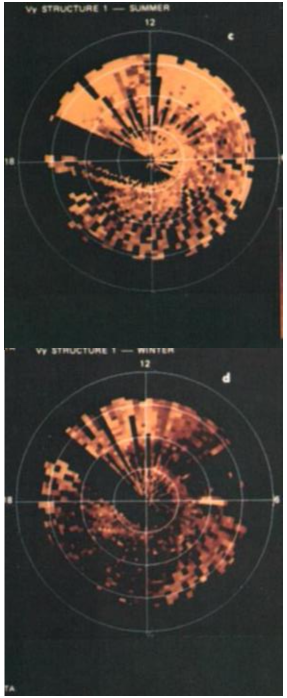
[Laundal et al., 2010]

- **Small-scale & Mesoscale (<500 km)**

Ion drift

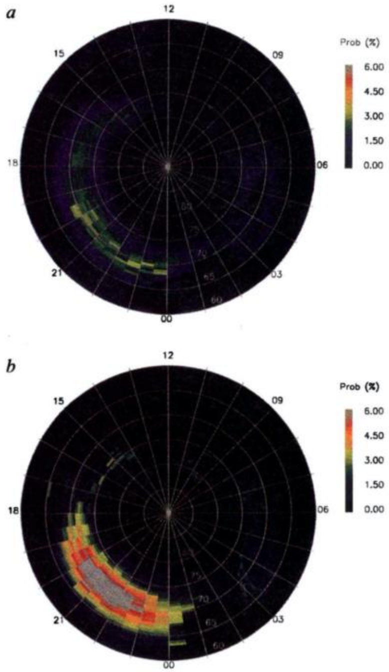
More sunlit

Less sunlit



[Vickrey et al., 1986]

Discrete electron precipitation



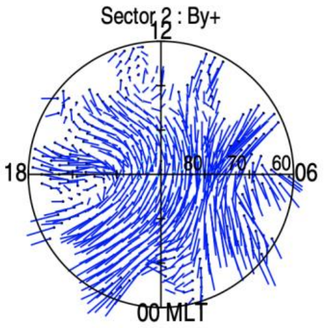
[Newell et al., 1996]

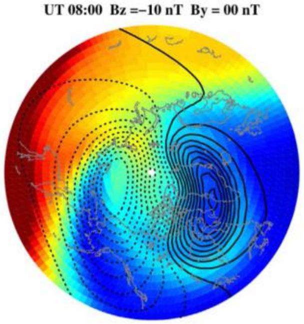
- How large IHAs can be in high-latitude forcings on different scales?
  - Statistically?
  - Single event?
- What are the major causes of those IHAs?

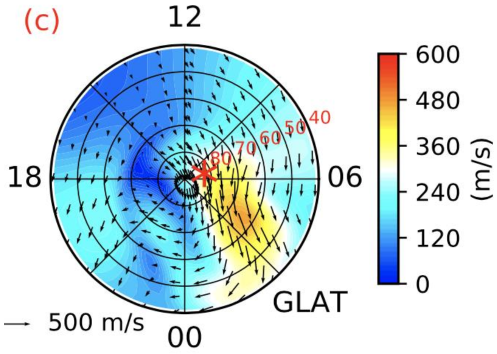
Asymmetries related to high-latitude forcings

	Neutral winds [IMF By polarity]	Electron density [Geomagnetic field configuration]	Neutral winds [Geomagnetic field configuration]

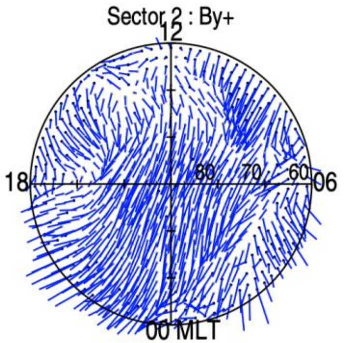
NH

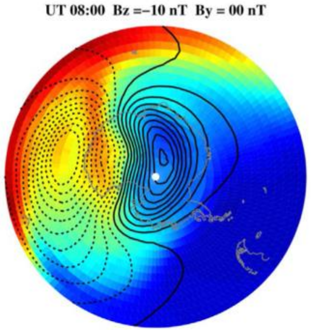


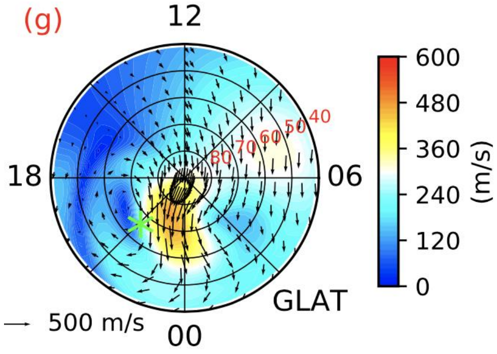




SH







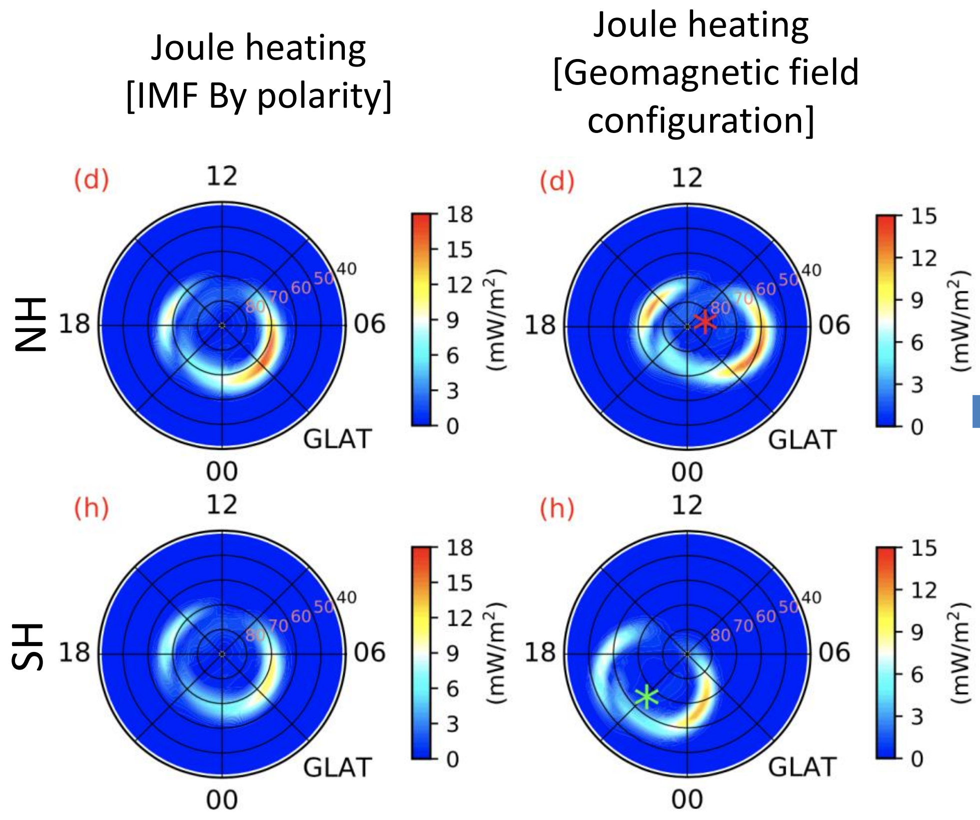
[Förster et al., 2008]

[Liu et al., 2017]

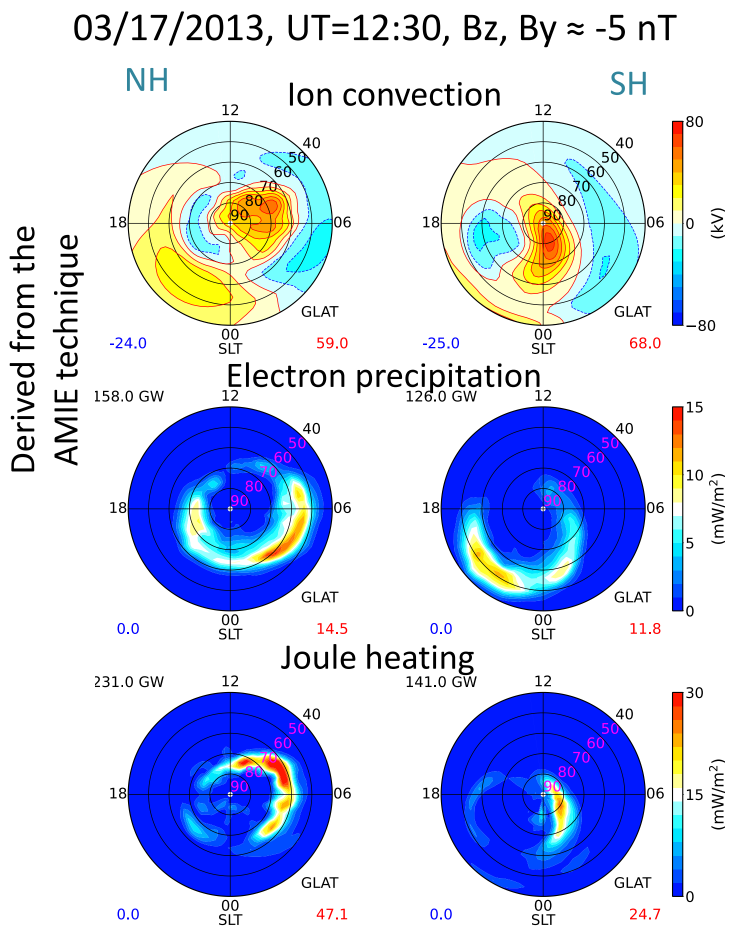
[Hong et al., 2021]

- How does IHAs in the high-latitude forcing contribute to the IHAs in the high-latitude I-T system?

Asymmetries related to high-latitude forcings

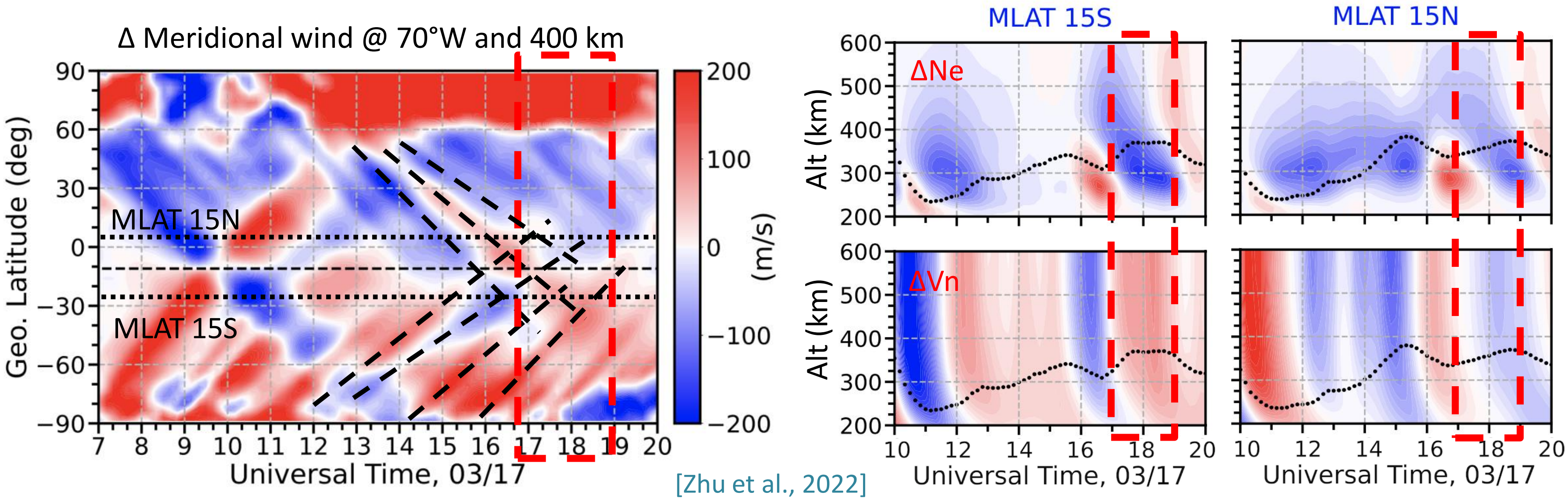


[Hong et al., 2021]



[Zhu et al., 2022]

Asymmetries related to Joule heating dissipation

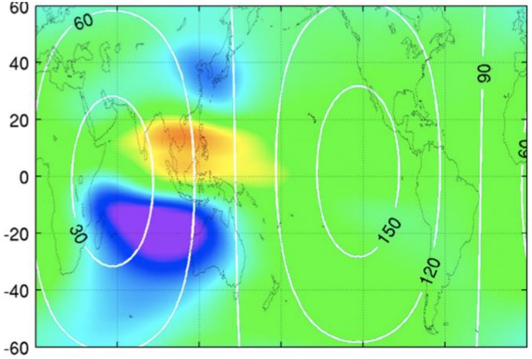


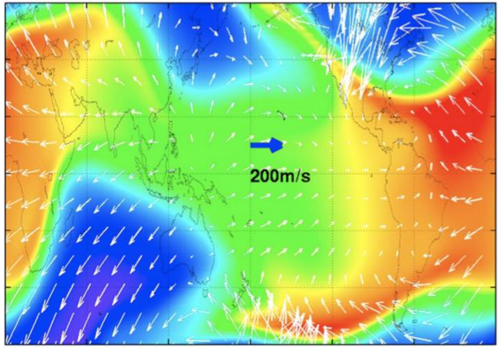
[Zhu et al., 2022]

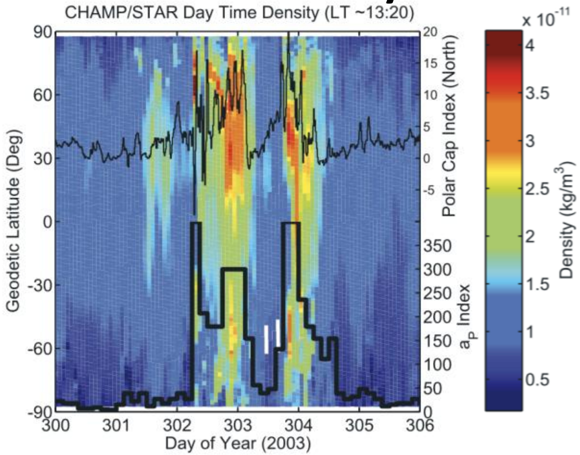
- Joule heating can induce traveling atmospheric disturbances (TADs)
- Due to asymmetries in the Joule heating, the generation, propagation and interaction of TADs can be different in the different hemispheres
- TADs can cause asymmetric negative storm effects at the typical EIA peak regions [GC-A @10 am]

Asymmetries related to Joule heating dissipation

- ΔNe
- O/N2
- Neutral density







[Yue et al., 2016]

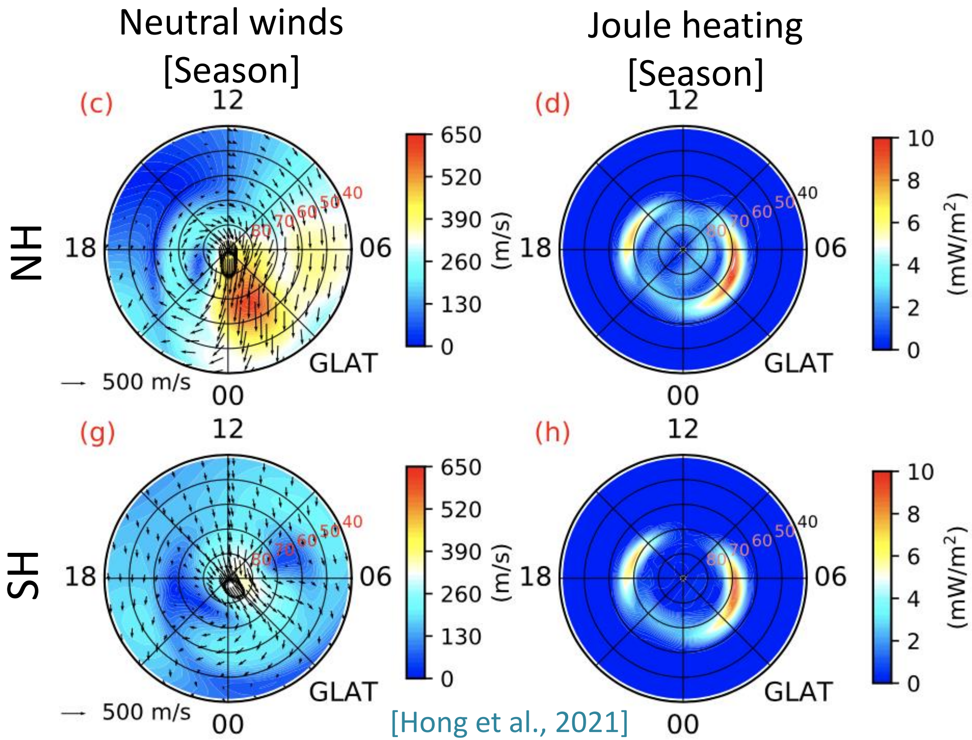
[Sutton et al., 2005]

- Joule heating cause changes in the thermospheric composition, which can further change the ionospheric electron density.
- The Earth's magnetic field configuration can also leads to IHAs in the neutral wind, thus the composition and electron density.
- Joule heating cause asymmetries in the neutral mass density.

- How does IHAs in the Joule heating dissipation contribute to the IHAs in the global I-T system?

Asymmetries related to high-latitude forcings and season

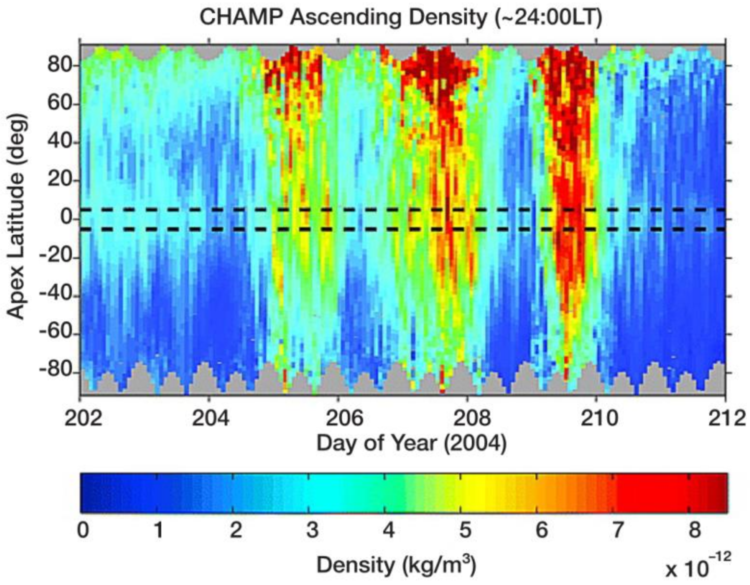
- The combination of the asymmetric high-latitude forcing and seasonal effect leads to remarkable interhemispheric asymmetry in the I-T system.
  - Different ionospheric conductivities → Different ion-neutral coupling



[Hong et al., 2021]

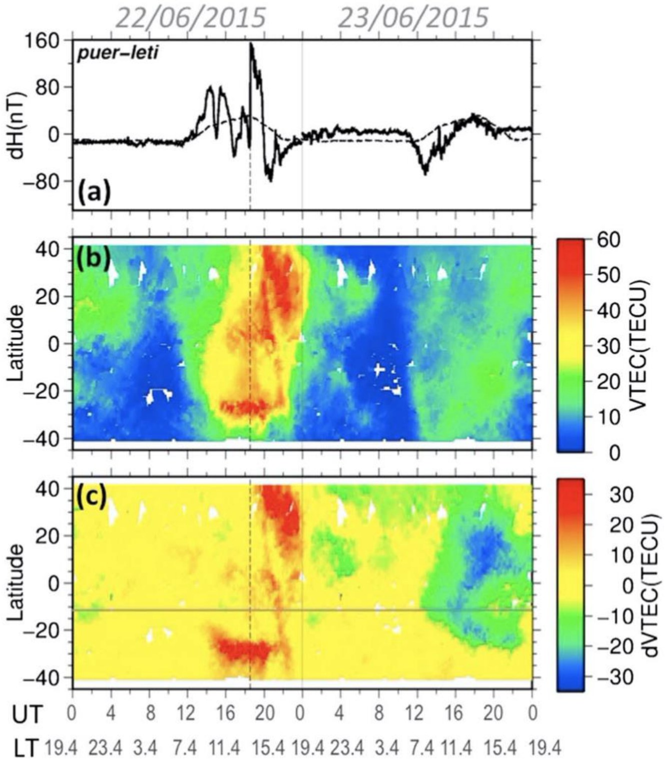
Asymmetries related to high-latitude forcings and season

Asymmetric neutral density response



[Sutton et al., 2009]

Asymmetric TEC response



[Astafyeva et al., 2018]

- Which one is more important, IHAs in high-latitude forcing or Season?

Goals

- Identifying and understanding the interhemispheric asymmetries (IHAs) in the high-latitude forcings.
  - What are IHAs in the high-latitude forcings and energy inputs?
  - What are the causes of these IHAs?
  - How do we capture the IHAs of high-latitude forcings in first-principle models?
- Identifying and understanding the interhemispheric asymmetries (IHAs) in the global I-T system.
  - What are IHAs in the global I-T system? Can they be captured in first-principle models?
  - How do these IHAs connect to the IHAs in high-latitude forcings and energy inputs?
- Identifying challenges in understanding the IHAs related to high-latitude forcings and potential pathways to address those challenges.
  - Science? Observations? Model development?

Approaches

Observations

High-latitude forcings:
AMPERE, DMSP, Swarm, SuperDARN, GUVI, ISR, SuperMAG, ASI …

Global I-T impacts:
GNSS TEC, ISR, ionosonde, SuperMAG, Swarm (CHAMP, GRACE, GOCE), FPI, GUVI, ICON, GOLD, COSMIC2 …

Simulations

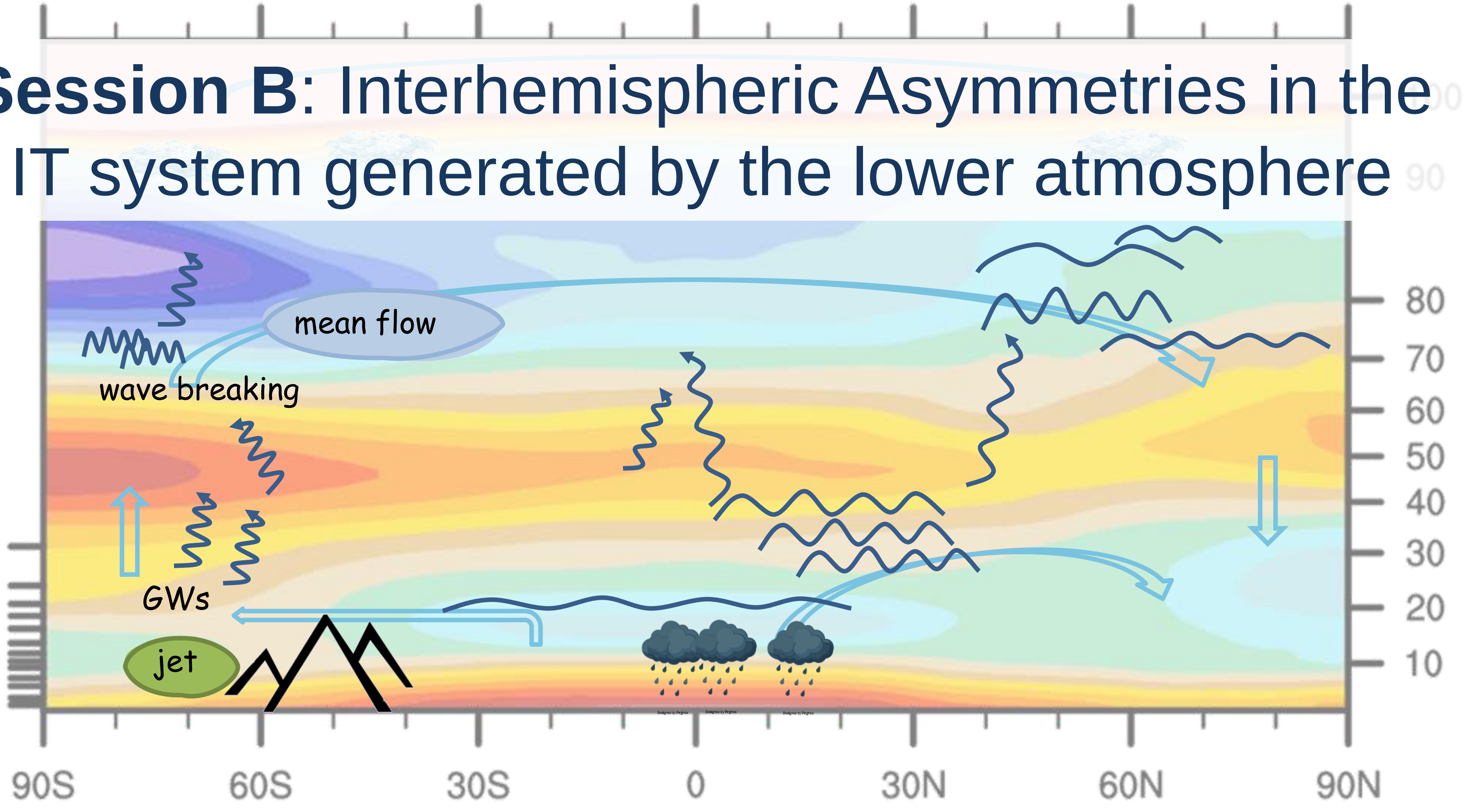
High-latitude forcings:
Realistic forcings (e.g., data assimilation);
Empirical models;
Geospace models …

Global I-T impacts:
General circulation models;
Geospace models

GC-A Session @10 am (Onyx Ballroom)

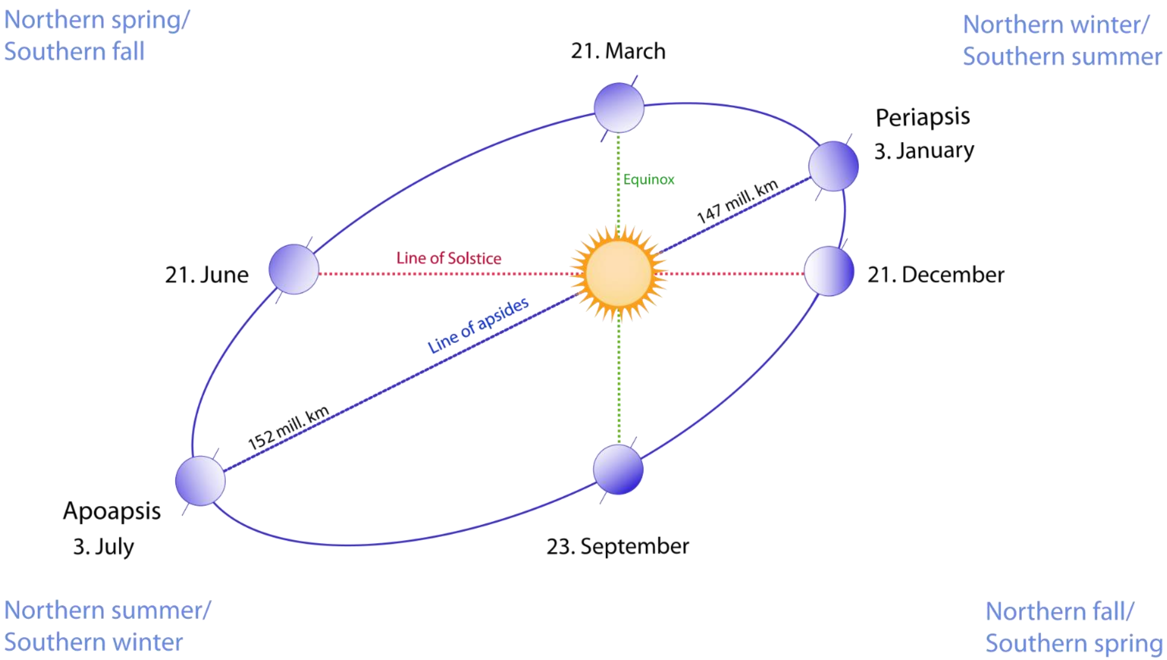
Gang Lu	Interhemispheric Asymmetries in the IT System: A multifaceted process
Marc Hairston	Preliminary results of penetration electric field asymmetry on the duskside during the 2015 St Patrick’s Day storm
Sheng Tian	Simultaneous observation of auroral streamers in conjugate hemispheres and the associated in-situ observations
Aaron Ridley	The Magnetospheric Auroral Asymmetry eXplorer
Naomi Maruyama	Impact of the hemispheric asymmetry of Superthermal Electrons on the coupled Magnetosphere-Ionosphere-Thermosphere (M-I-T) system
Qingyu Zhu	Interhemispheric asymmetries in the ionospheric response during the 2013 St Patrick’s Day geomagnetic storm
Yu Hong	Inter-hemispheric Asymmetry of Ion Convection and its Impacts on the Ionosphere-Thermosphere System During the 08-10 October 2012 Geomagnetic Storm
Delores Knipp	Inter-hemispheric asymmetries in Poynting flux: A perspective from different space-based platforms
Yongliang Zhang	Sources for Hemispheric Asymmetry in Storm-time O/N2 Depletion
All attendees	Discussion

Session B: Interhemispheric Asymmetries in the IT system generated by the lower atmosphere



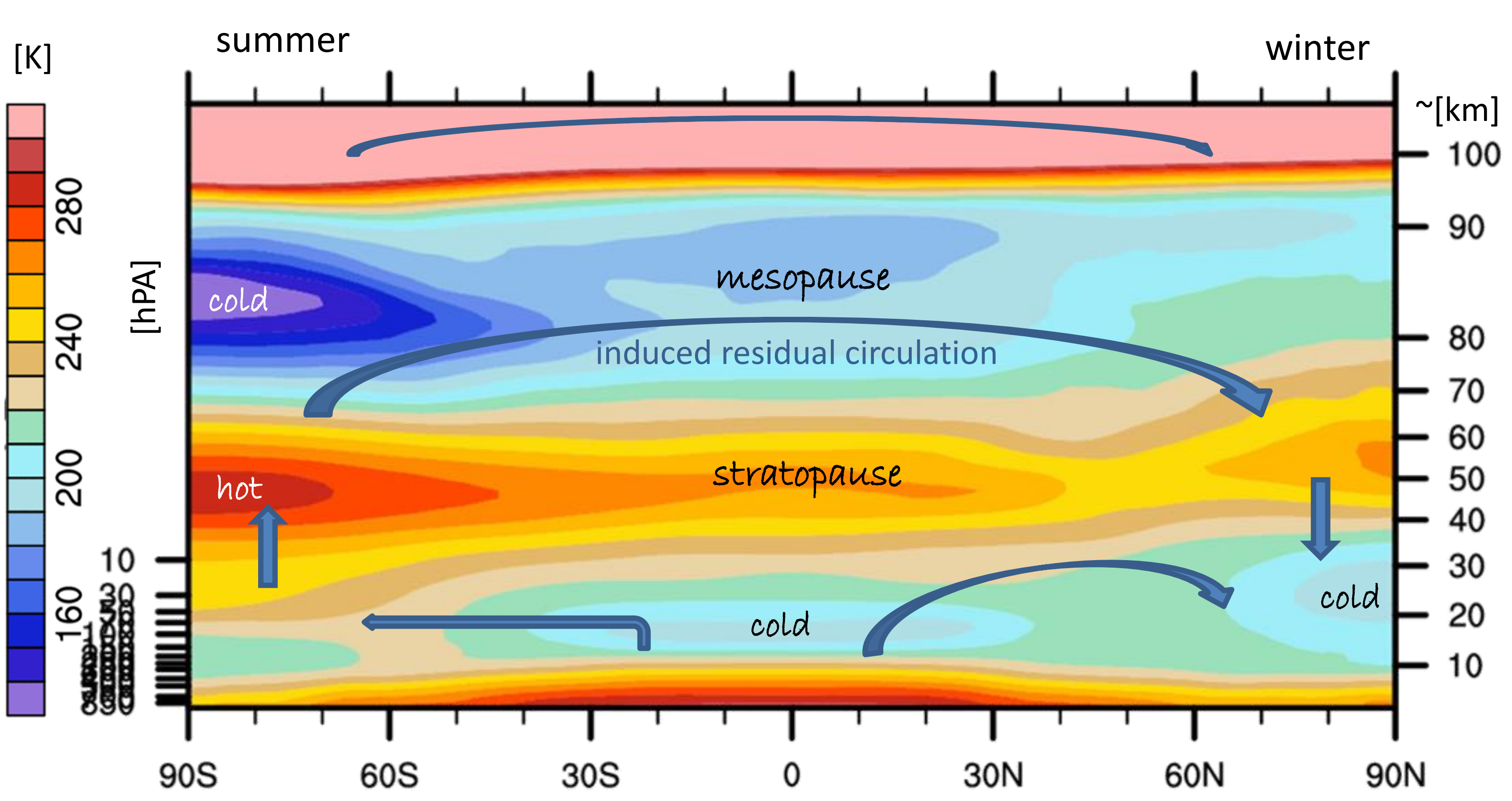
Earth's tilt and orbit influences solar illumination

- Difference in solar flux causes seasonal asymmetries in the background atmosphere and in wave excitation.
- Earth closer to the Sun in January than July (3.5%) which equals to ~7% difference in solar flux.



[http://www.thesuntoday.org/tag/perihelion/]

Zonal and diurnal mean temperature



Solar absorption by

N_2 & O_2

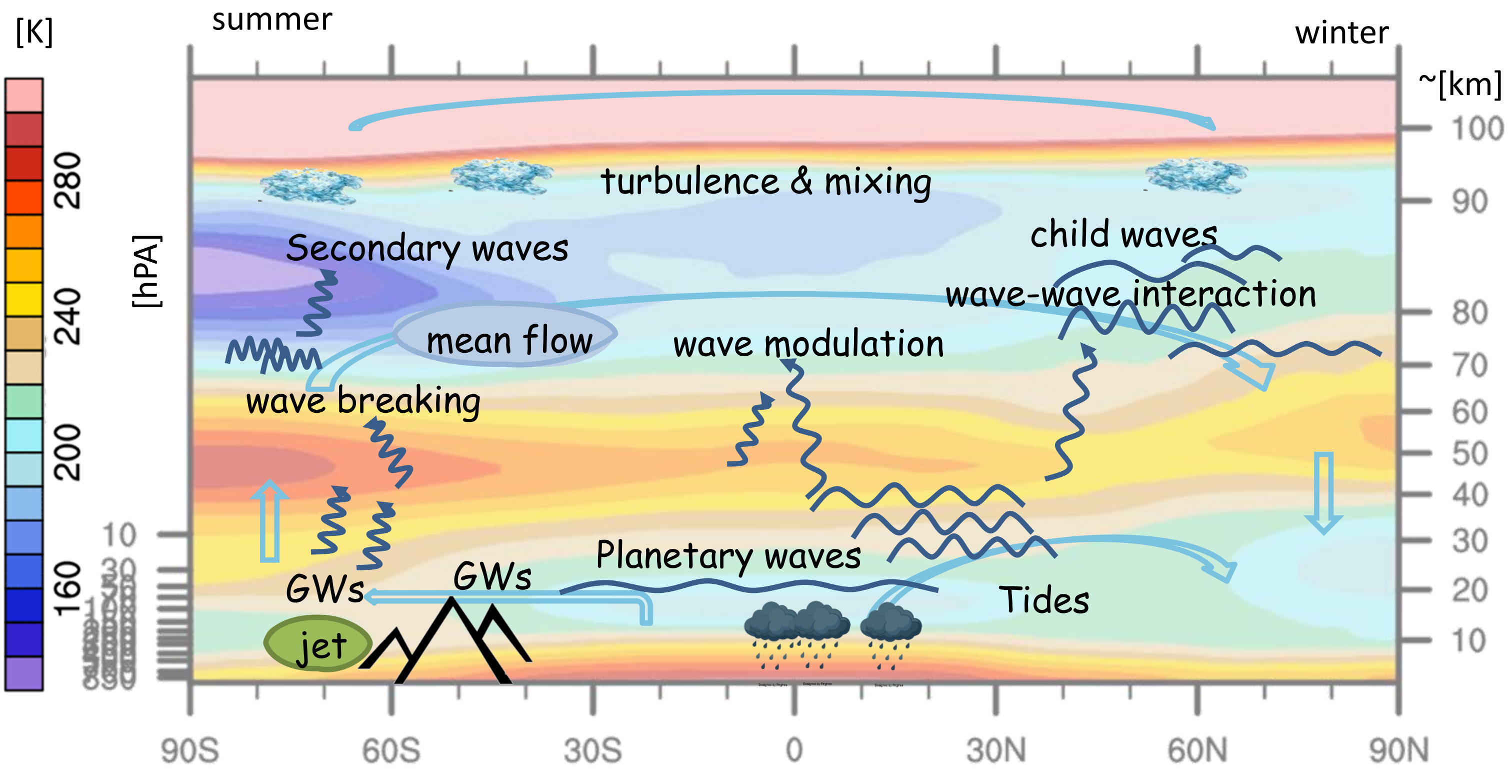
O_3

H_2O

Induced circulation is not symmetric.

WACCM-X/GEOS-5 simulation for 2020

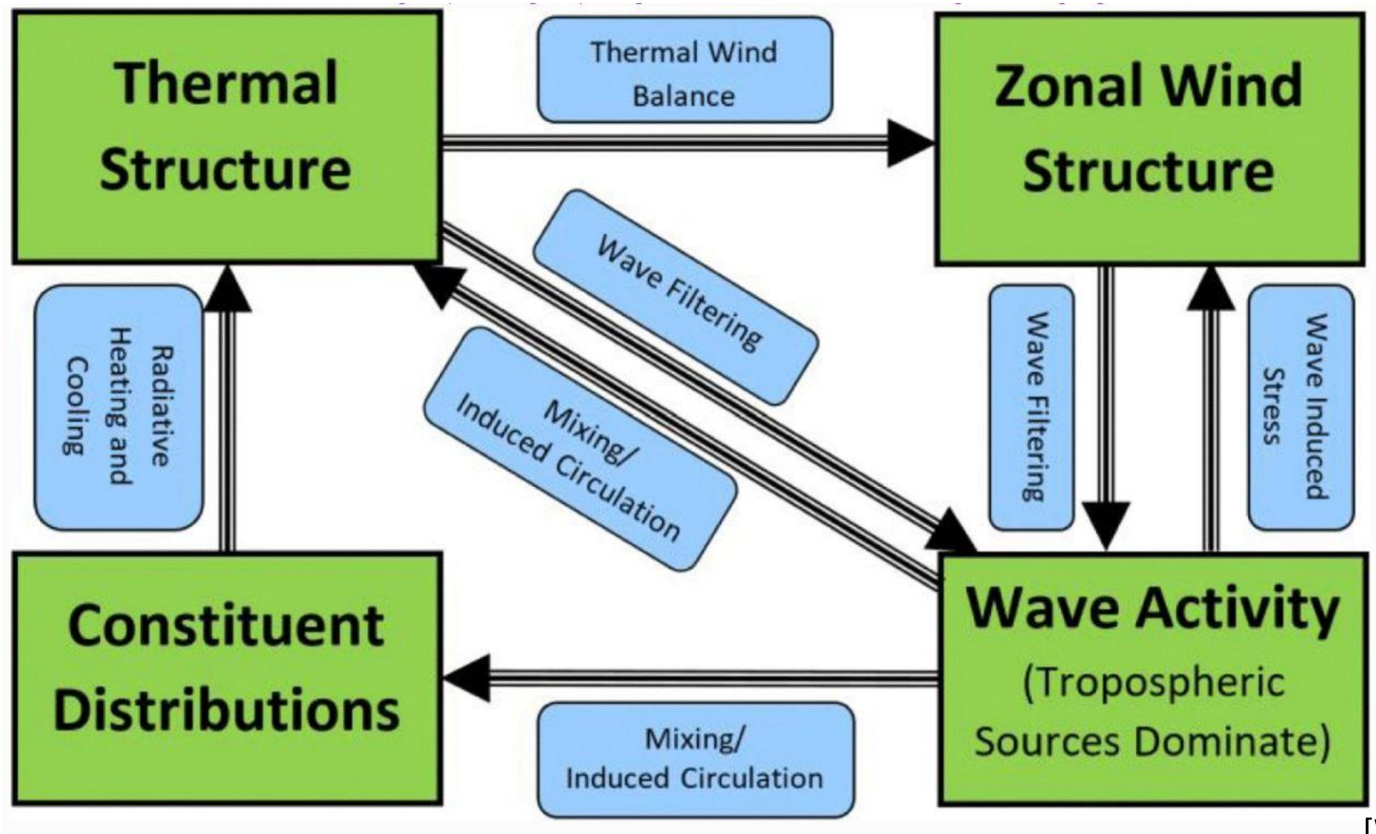
Schematic of wave variability



Solar radiation & absorption differences can cause asymmetries.

Differences in mean atmospheric state can modify the wave propagation and wave dissipation.

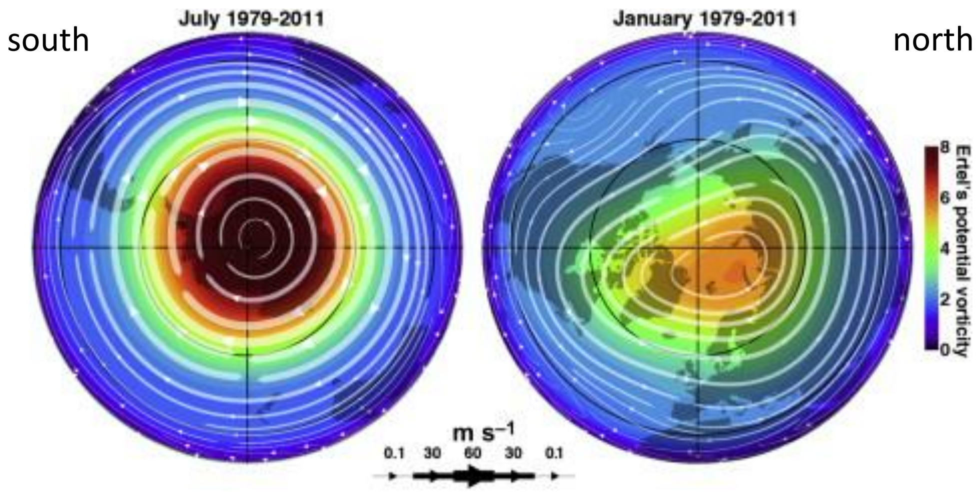
Complex connections in the middle atmosphere



[Ward et al., 2021]

Polar vortex

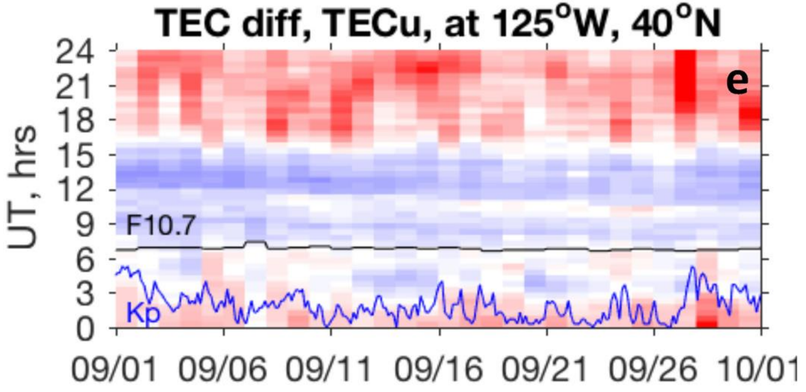
Monthly mean flow and vorticity ~20km from 33 years of MERRA



[Schoerbel & Newman, 2015]l

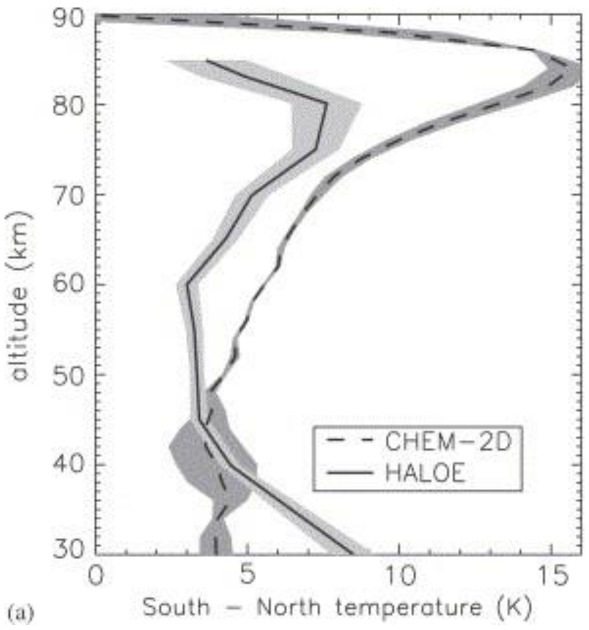
- Southern hemisphere polar vortex is stronger, larger and more stable.
- Attributed to the lack of planetary wave activity in the southern hemisphere.

- Although rare, SH SSW events provide opportunity to examine differences between hemispheric response.
- SSW of September 2019 80-100% TEC anomalies in NH reported with strong longitudinal variation.



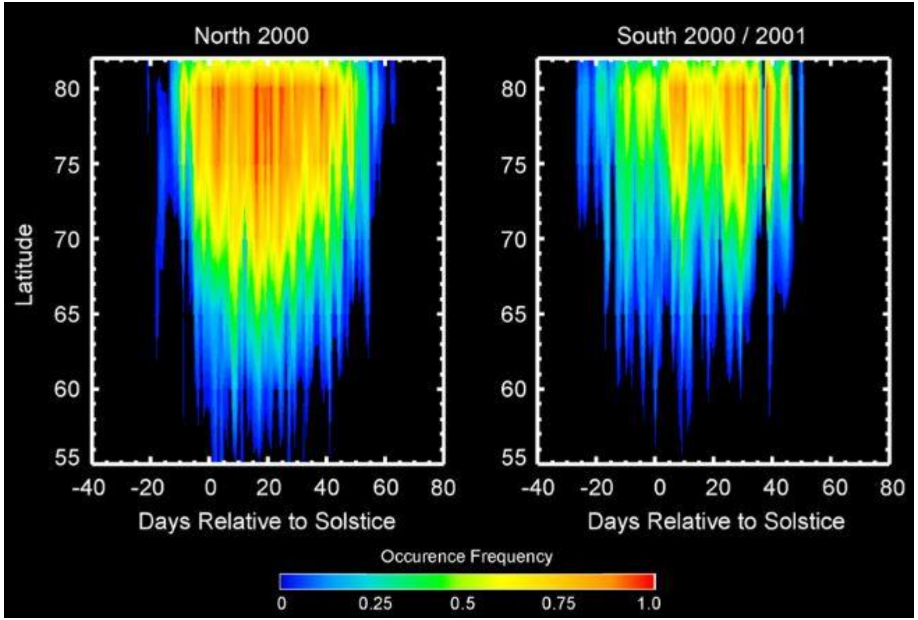
[Goncharenko et al., 2021]l

Hemispheric differences at polar region



[Hervig & Siskind, 2006]

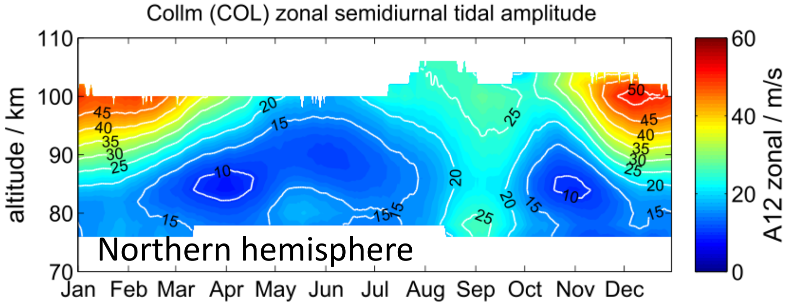
- Southern summer mesopause is warmer than northern summer mesopause attributed to gravity wave filtering.
- Polar noctilucent clouds are brighter in the northern hemisphere & extend more equatorward.

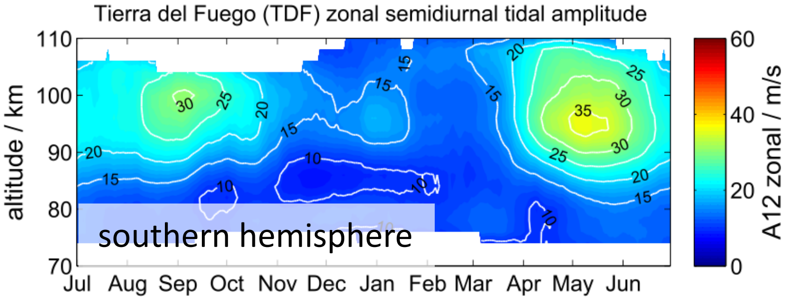


[Bailey et al., 2007]

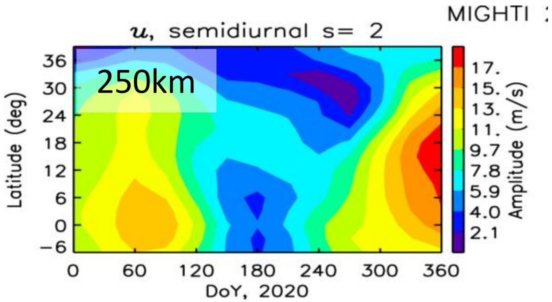
Hemispheric differences in tides

Semidiurnal zonal wind amplitude around $|\lambda_g|$=50^o

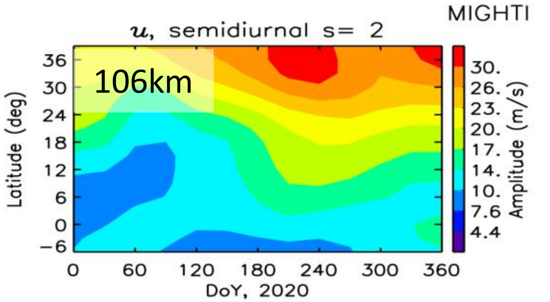




[Strobel et al., 2021]



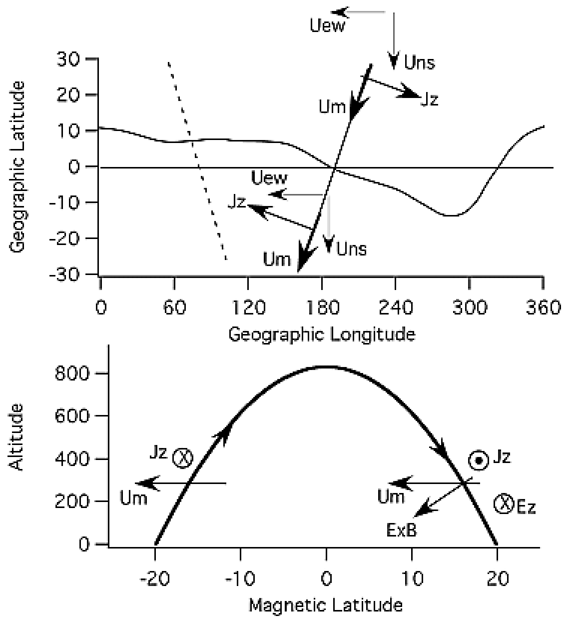
- In MLT, seasonal difference in the semidiurnal tidal amplitudes with higher amplitude in northern than southern hemispheres.
- A summer to winter transition, like in NH with an amplitude peak, is not found in the SH.
- The latitude-doy variation of the zonal wind migrating semidiurnal tide at 106km and 250km is significantly different indicating the importance of in-situ forcing, tidal nonlinear interaction, and ion-neutral coupling.



[Forbes et al., 2022]

Strength and distortion of Earth's magnetic field

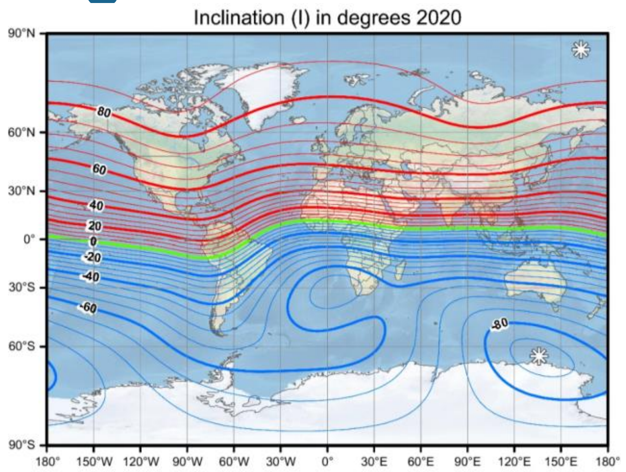
- The Earth magnetic field is distorted and varies in strength.
- The Earth magnetic field change in time is non-uniform.

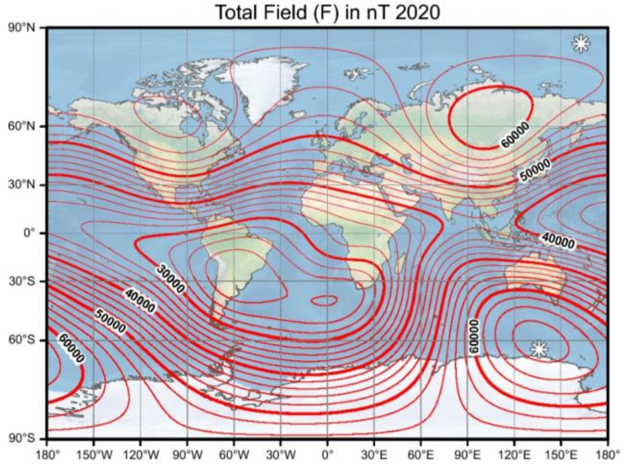


[Hartman & Heelis, 2007]

- Conjugate points at low- and mid- latitudes have the same electric field but not ExB drift.
- The atmosphere along fieldline can be illuminated differently in the two hemispheres.
- Conductivity differences due to season & magnetic field.

[Alken et al, 2021]





Agenda of Session B. Generated by high-latitude (Wed 13:30-15:30)

- Xian Lu (Clemson U.) – Modeling

- Koki Chau (IAP, Germany) - Meteor radars

- Koushik Neelakantan (Clemson) Tropical stratopause precursor of SSW

- Rich Collins (UA Fairbanks) GW forcing and "Eddy Diffusion" in WACCM variations for SSW and non-SSW

- Larisa Goncharenko (MIT) - SSWs in NH & SH

- Xing Meng (JPL) - North-South asymmetry in the ionosphere due to Earthquake

- Joanne Wu (UC Berkeley) - Correlation study of the variation in the topside ionosphere and F-region along the magnetic field line

Thanks!