Studies of connections between the stratosphere and thermosphere/ionosphere

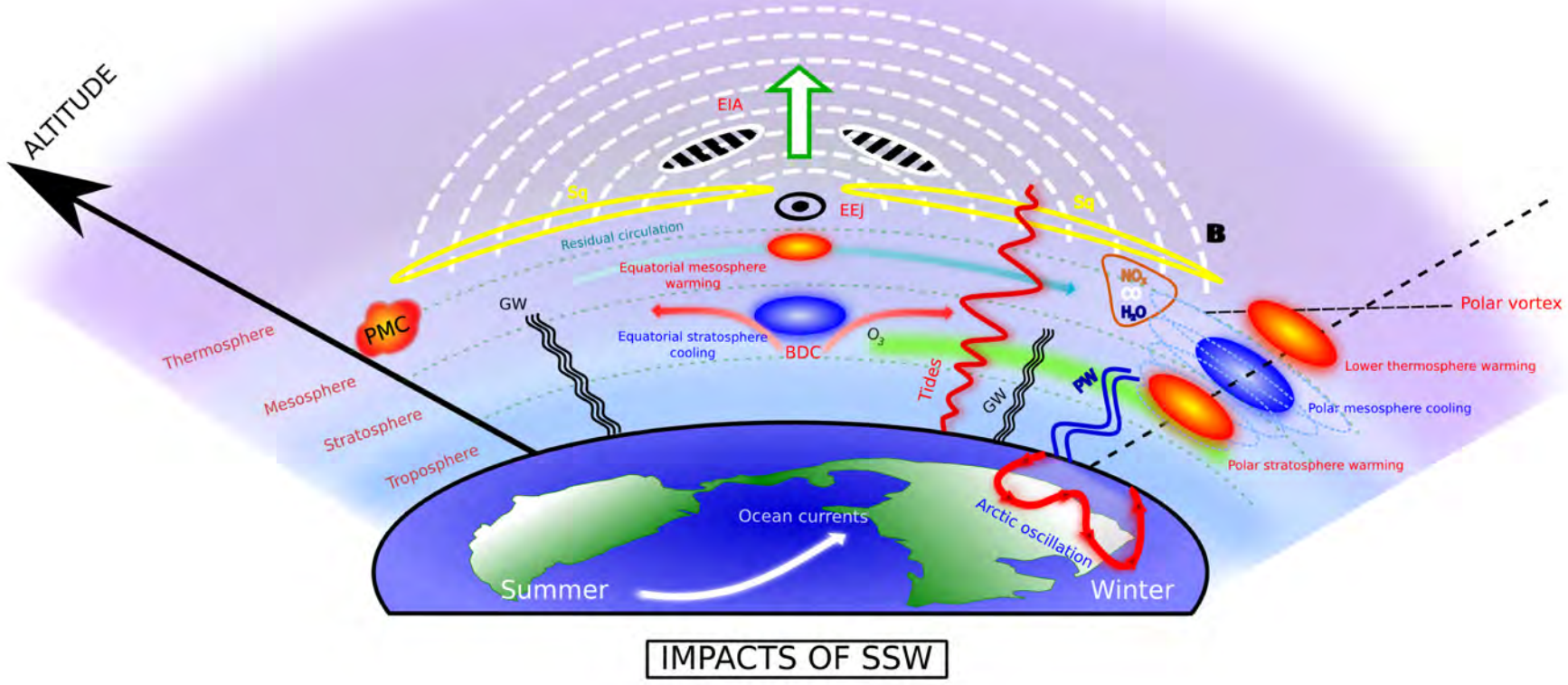
Larisa Goncharenko,

MIT Haystack Observatory

MIT HAYSTACK OBSERVATORY

NEROC symposium, Nov 16-17, 2020

Variety of effects during sudden stratospheric warming: from Arctic stratosphere to troposphere and to mesosphere and ionosphere over Antarctica



From *Pedatella et al., 2018 AGU EOS*

The polar vortices play a central role in vertically coupling the atmosphere from the ground to geospace

- Downward signal propagation: stratosphere-troposphere
  - Cold weather fronts, snowstorms, heavy rainfall
  - Can occur over Europe or over US/Canada, depending on the type of polar vortex disturbances
- Upward signal propagation: stratosphere-mesosphere-thermosphere/ionosphere
  - Over Arctic regions, NH mid-latitudes, tropics, SH midlatitudes, and even over Antarctica

Dual nature of polar vortex influences: polar vortex and gravity waves

TOPIC #1

1hPa, ~48km

3hPa, ~40km

5hPa, ~36km

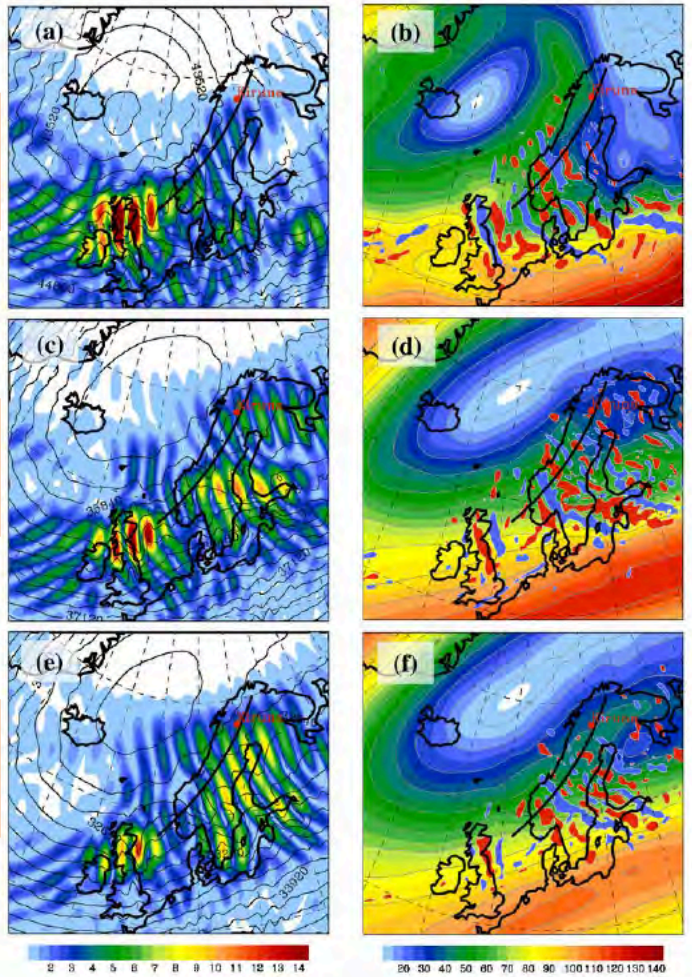


Figure 4: Left column: composite of the magnitude of V_H^{IGW} (m s^{-1}, color shaded) from the normal mode analysis and the geopotential height (m, black contour lines) from IFS operational analyses. Right column: composite of the magnitude of the balanced wind V_H^{BAL} (m s^{-1}, color shaded) from the normal mode analysis and the horizontal divergence (values larger/smaller ± $2 \cdot 10^{-4}$ s^{-1} are filled with red and and blue, respectively) from operational analyses. The plots are at 1 hPa (~ 48 km; a, b), 3 hPa (~ 40 km; c,d), and 5 hPa (~ 36 km; e, f) and they are valid at 06 UTC on 30 January 2016. The black line marks the baseline of the vertical sections shown in Fig. 6.

Dornbrack et al., 2018

1. Stratospheric polar vortex can be a source of gravity waves
   - Excited at the inner edge of polar vortex
   - Propagate upward and downward
   - Upward propagating GW increase in amplitude – GW 'hotspots'
2. Stratospheric polar vortex strongly influences upward propagation of GW generated in the troposphere – filtering effect
   - Mountain GWs propagate to stratosphere and mesosphere for strong polar vortex conditions
   - Strong stratospheric winds (associated with polar night jet) allow for growth to large vertical wavelengths and amplitudes

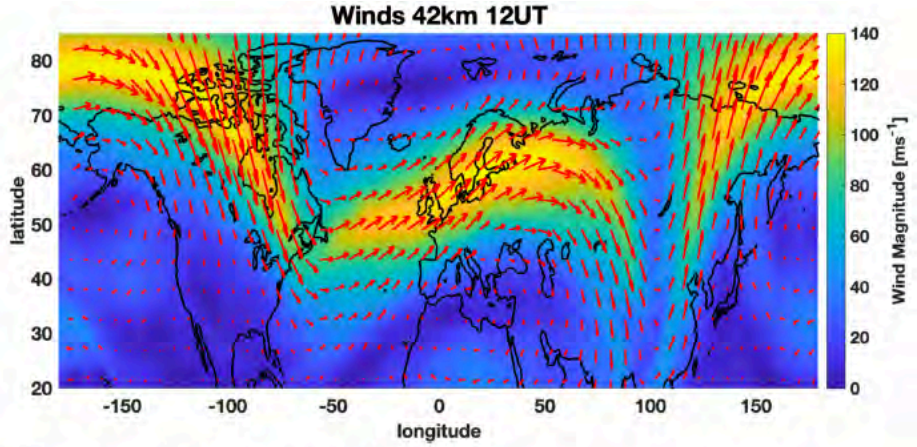


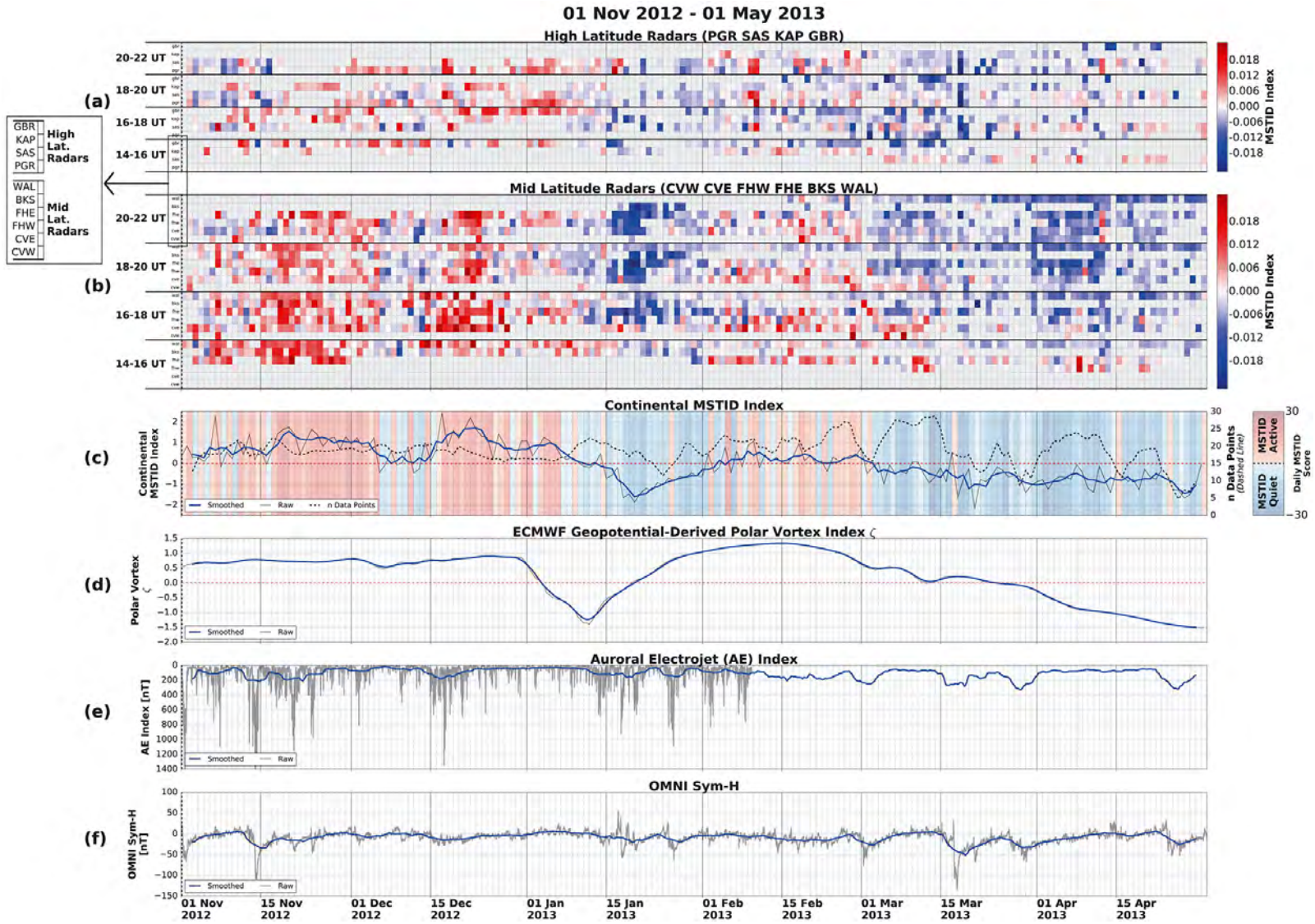
Figure 12. MERRA-2 wind magnitude and wind vectors at z = 42 km and 12UT.

Bossert et al., JGR-Atm, Oct 2020

Observational evidence in the ionosphere: MSTIDs are weaker after polar vortex weakening

TOPIC #1

- Medium-scale traveling ionospheric disturbances from SuperDARN data have a strong correlation with polar vortex dynamics, but no correlation with space weather activity
- Possible explanation: Filtering of gravity waves by stratospheric wind system

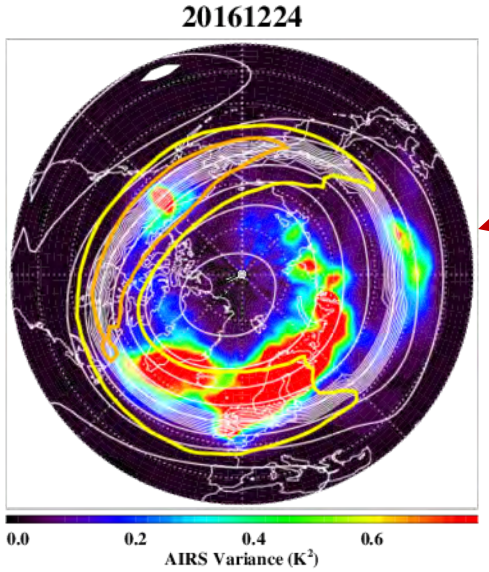


Frissel et al., 2016

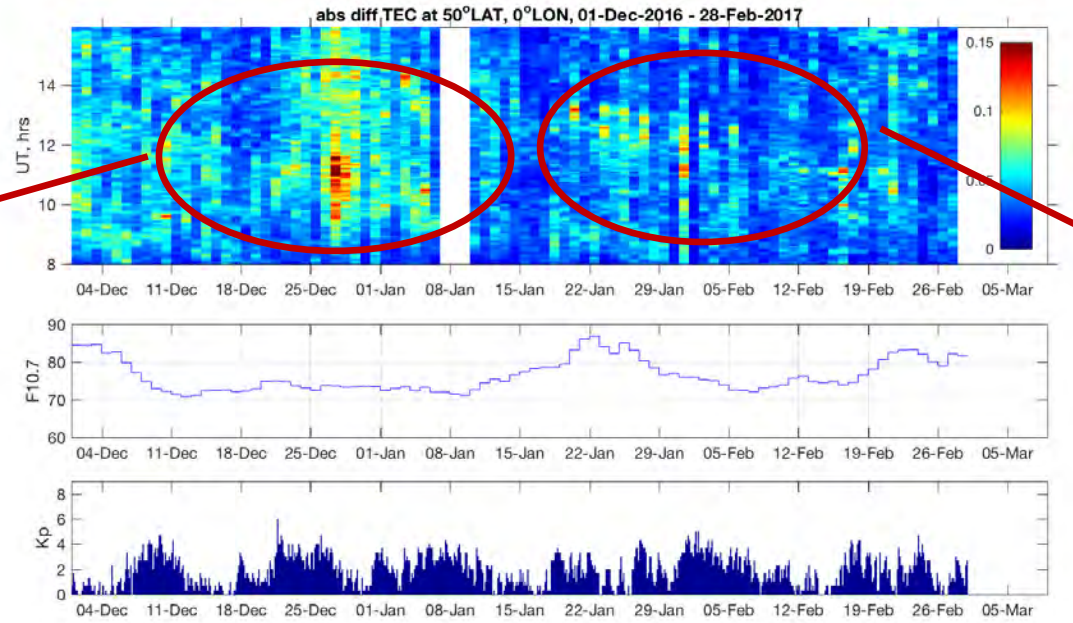
Regional TID activity and polar vortex

TOPIC #1

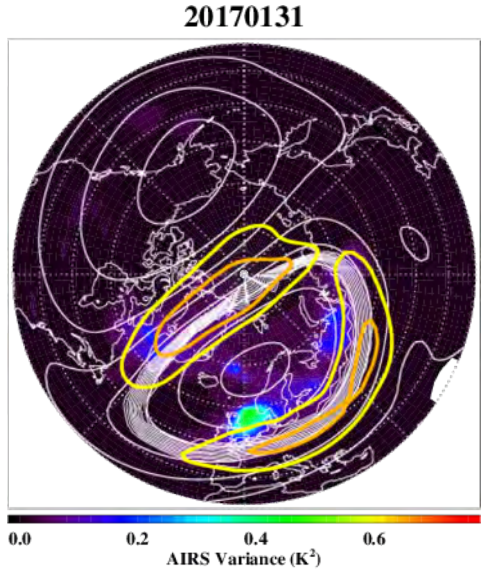
Stratospheric GW: high



Ionospheric TIDs



Stratospheric GW: low



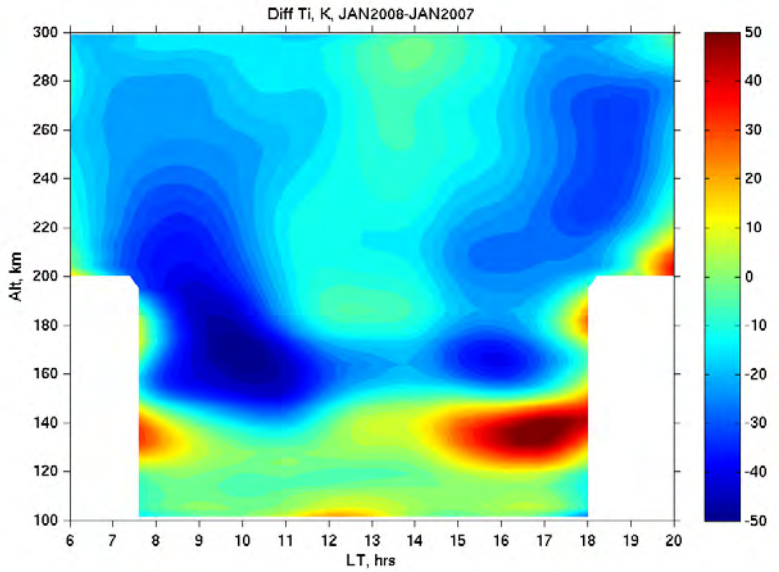
Goncharenko et al., in prep

- Case study of winter 2016-2017 (work in progress)
- Dec 2016 – Jan 15, 2017: strong polar vortex and high stratospheric GW activity in AIRS data
- After Jan 15, 2017: weakening and break-up of polar vortex, low stratospheric GW activity
- Regional diff TEC (and TID) activity correlates well with geomagnetic activity at 60N
- **Regional diff TEC is amplified during high stratospheric GW activity and decreased during low GW activity**

Ionospheric response to SSW at middle to high latitudes: temperature "sandwich"

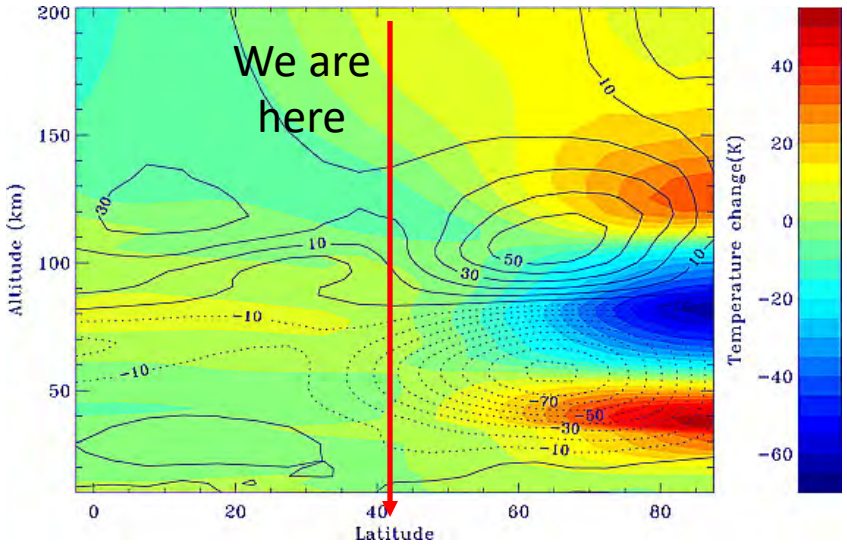
TOPIC #2

Data: Millstone Hill ISR, 42°N



Goncharenko and Zhang, 2008

Model: TIMEGCM



Liu and Roble, 2002

- Data: warming at 120-140km; cooling above ~150 km; 12-hour wave;
- First experimental evidence of alternating warming and cooling of upper atmosphere
- Model: mesospheric cooling and secondary lower thermospheric warming
- **Large-scale disturbances in thermospheric/ionospheric parameters (temperature, wind, electron density, TEC) due to meteorological causes at middle to high latitudes remain an unsolved issue; low latitudes are better understood**
- **Sustained effort is needed to separate meteorological and solar/magnetospheric forcing**

Polar vortex – extension to mesosphere and I/T?

TOPIC #2

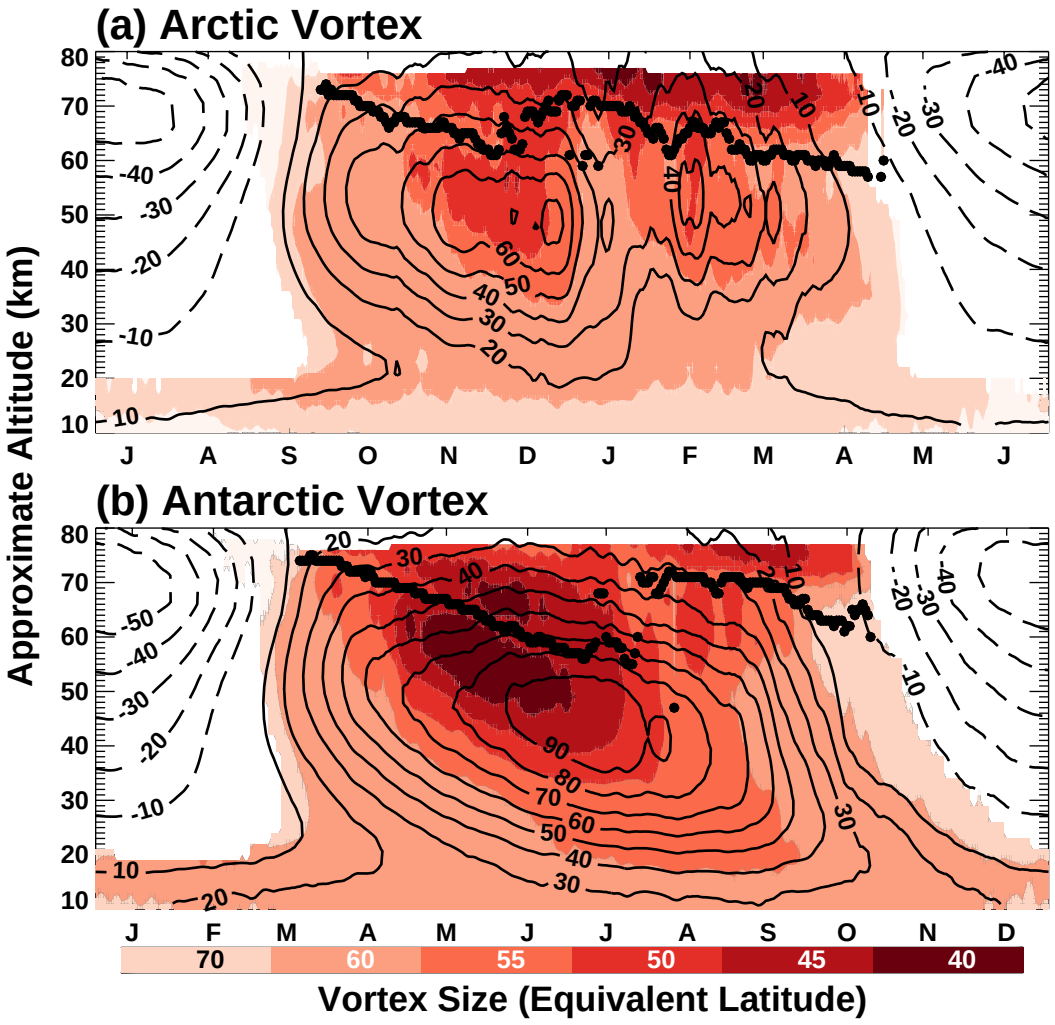
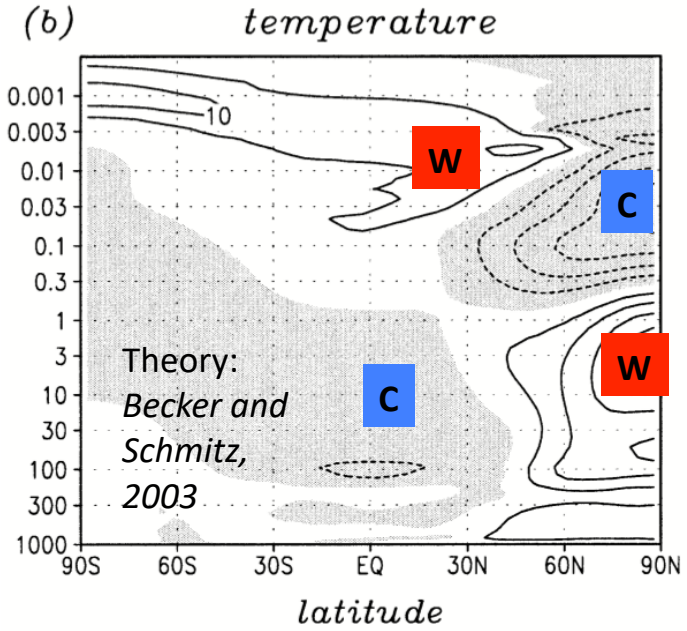


Figure 8. Altitude-annual cycles of multi-year (2005-2017) mean polar vortex edge equivalent latitude in (a) the NH and (b) the SH. The winter season is in the center of each panel. From *Harvey et al., 2018*

- **Does the state of the polar vortex affect the mid to high-latitude ionosphere and thermosphere on daily and seasonal scales?**
- Polar vortex definition extended to mesosphere (Harvey et al., 2018)
- Polar vortices are funnel-shaped – wide top, narrow bottom
- How does it connect to the I/T system?
- Experimental evidence:
  - MIPAS on ENVISAT – Tn increase at 120-140 km (*Funke et al.*, 2010)
  - Ti increase at 120-142 km in EISCAT data (*Kurihara et al, 2010*)
  - Tn and Ti decrease in the F-region at Poker Flat – FPI and ISR data (*Conde and Nicolls*, 2010)
  - Ti variations in Millstone Hill data (*Goncharenko et al.*, 2013)
  - Ne/TEC – *Shpynev 2015; Chernigovskaya 2017; Yasukevich 2018*
  - What about wind, composition, neutral density, electron density?
- Complicated – need to separate from auroral forcing, seasonal variation, etc.

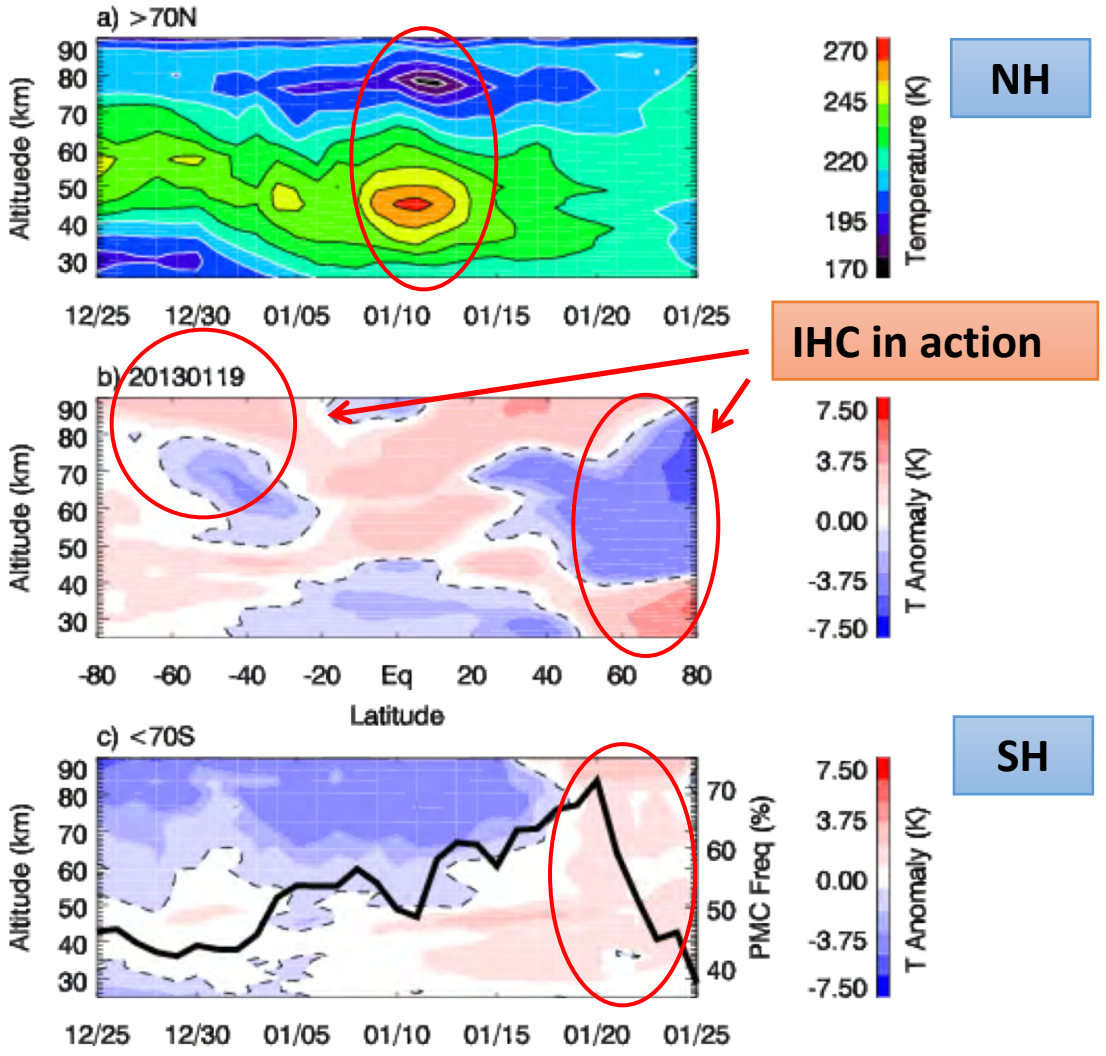
Interhemispheric coupling

TOPIC #3



- Interhemispheric coupling (IHC) between winter stratosphere and summer mesosphere is an established phenomenon (*Becker and Schmitz*, 2003; *Becker and Fritts*, 2006; *Tan et al.*, 2012)
- **Aura MLS temperature increase and CIPS PMC frequency drop shows SH mesospheric warming during SSW 2013**

Data: SSW 2013



See also *de Wit, 2015*

Arctic SSW generate disturbances in the ionosphere over Antarctica

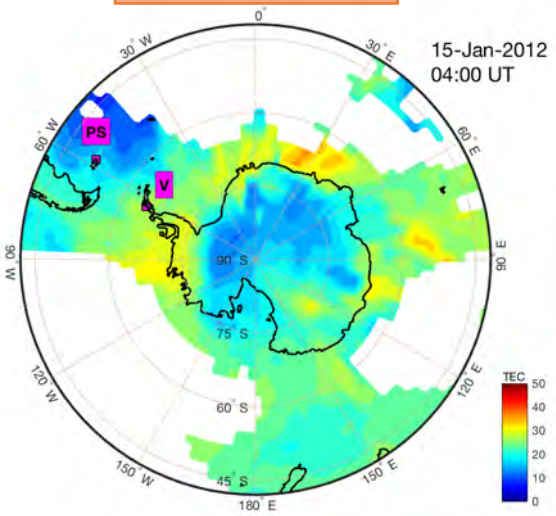
TOPIC #3

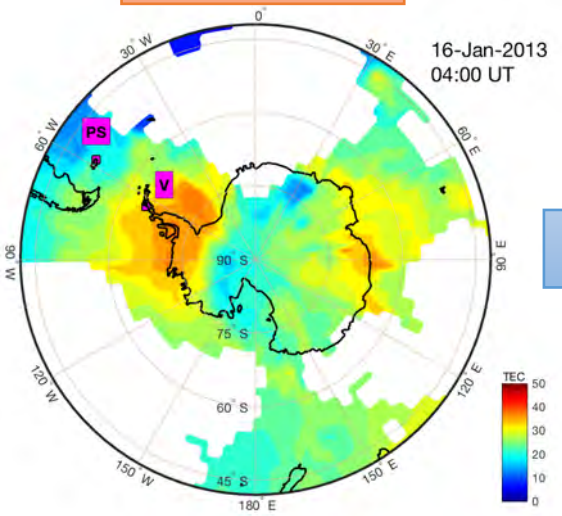
- **Extension of the IHC concept to higher altitudes, into ionosphere/thermosphere system**
- Variations in total electron content follow familiar semidiurnal pattern; TEC variations ~ factor of 2
- Independent observations from ionosondes (magenda points) confirm the level of disturbances

SSW disturbances are truly global, from Arctic stratosphere to ionosphere over Antarctica…

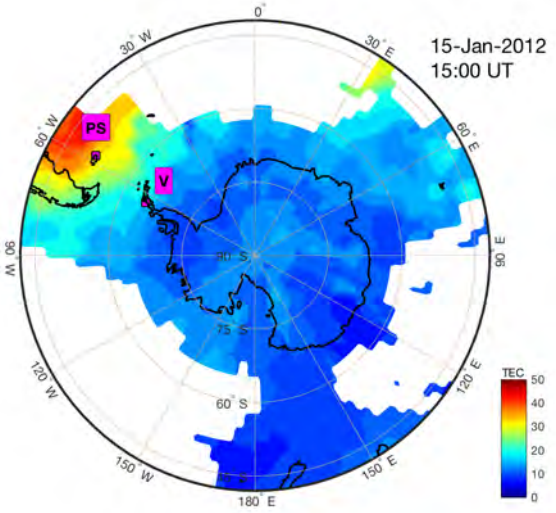
Before SSW

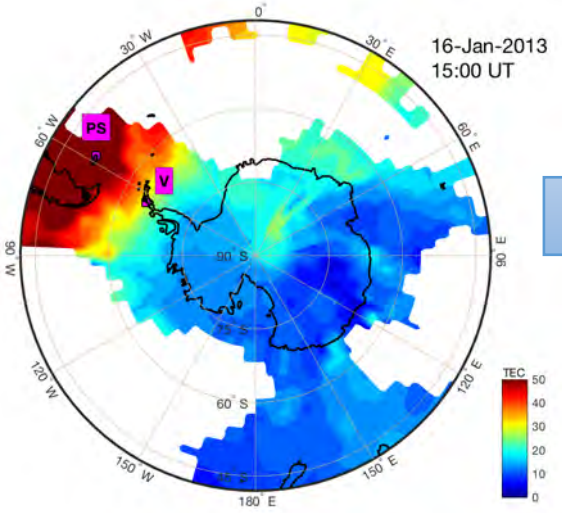
During SSW





4 UT





15 UT