Observations of pole-to-pole, stratosphere-to-ionosphere connection

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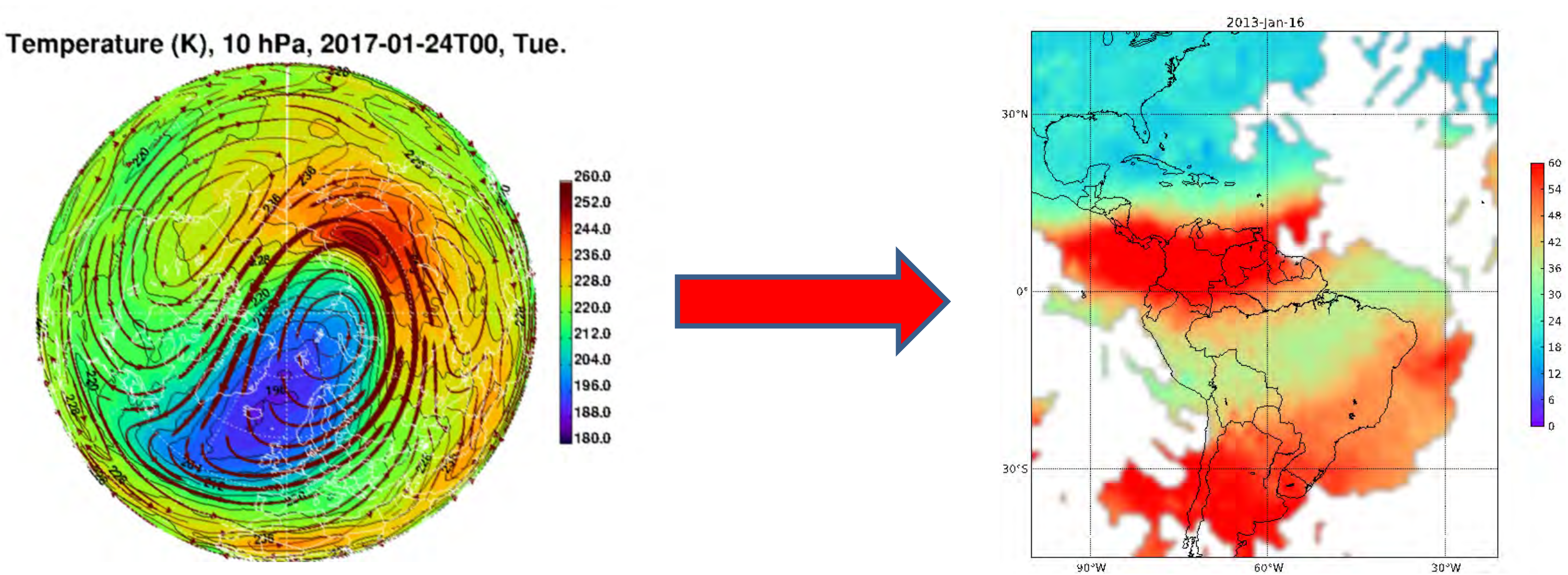


NEROC symposium, Nov 1, 2019, MIT Haystack Observatory, Westford, MA

Coupling from above:
Solar, magnetospheric and geomagnetic processes

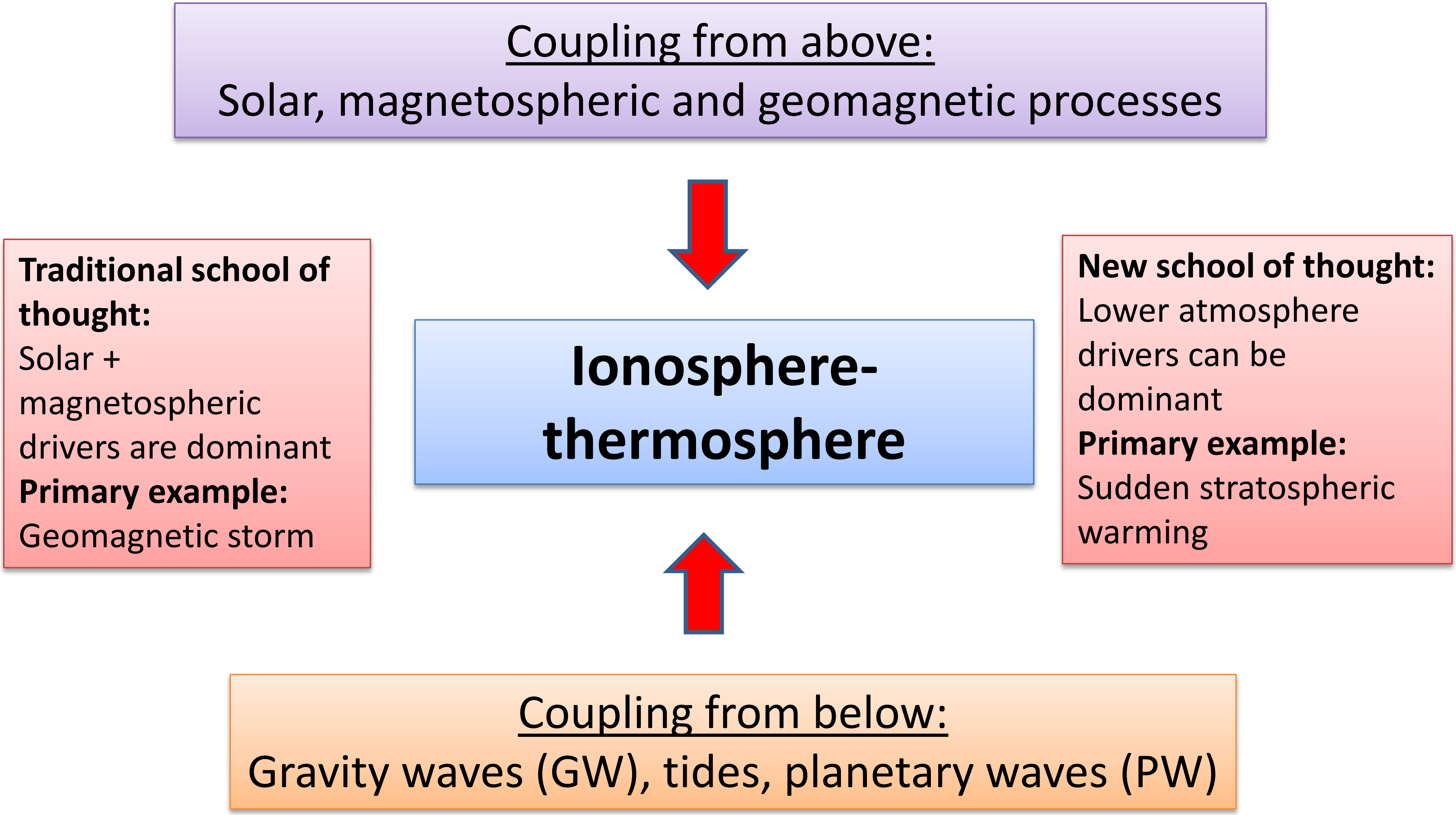
Traditional school of thought:
Solar + magnetospheric drivers are dominant
Primary example:
Geomagnetic storm

Ionosphere-thermosphere

New school of thought:
Lower atmosphere drivers can be dominant
Primary example:
Sudden stratospheric warming

Coupling from below:
Gravity waves (GW), tides, planetary waves (PW)

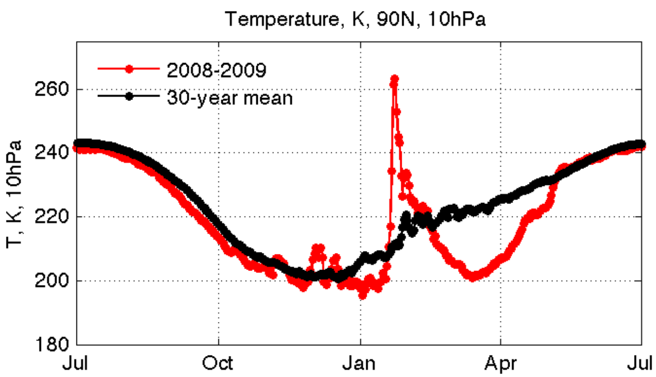
- Geomagnetic storms and sudden stratospheric warmings are two extremes



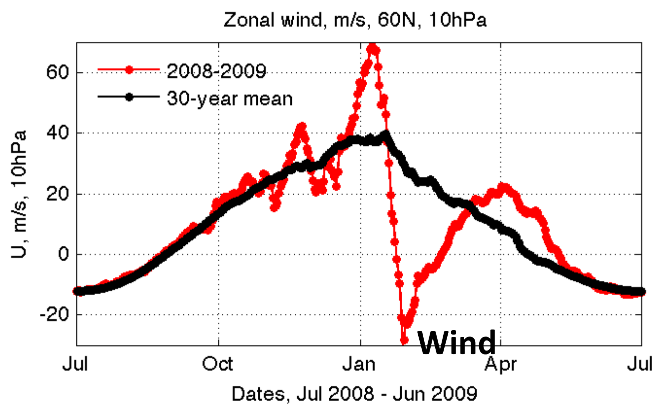
"We have reached a paradigm shift, where any self-respecting space weather model of the upper atmosphere now needs to have some representation of the lower atmosphere" – Jackson et al., Space Weather, Oct 2019

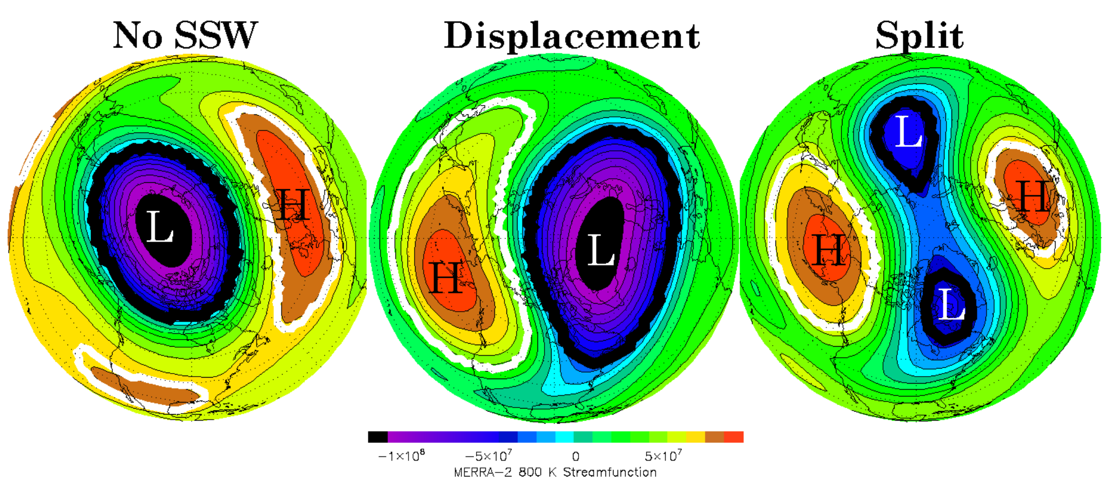
Special case: sudden stratospheric warming

- Large disruption of the polar vortex
- Largest known meteorological disturbance
- Rapid increase in temperature in the **high-latitude** stratosphere (25K+); from winter-time to summer-time
- Accompanied by a change in the zonal mean wind
- **Anomalies last for a long time in the stratosphere (2 weeks +)**
- SSW events occur 1-3 times per winter



Temperature



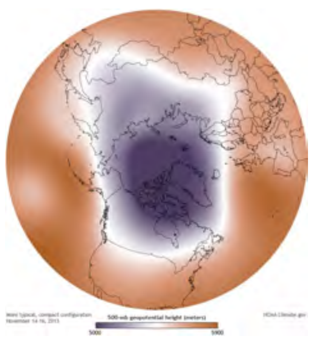


"Normal" polar vortex is small, round, centered on the North Pole

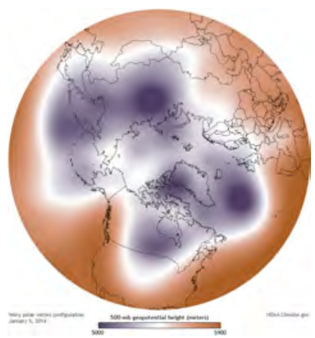
Disturbed vortex is broken into 2 cells

Disturbed vortex is broken into 4 cells

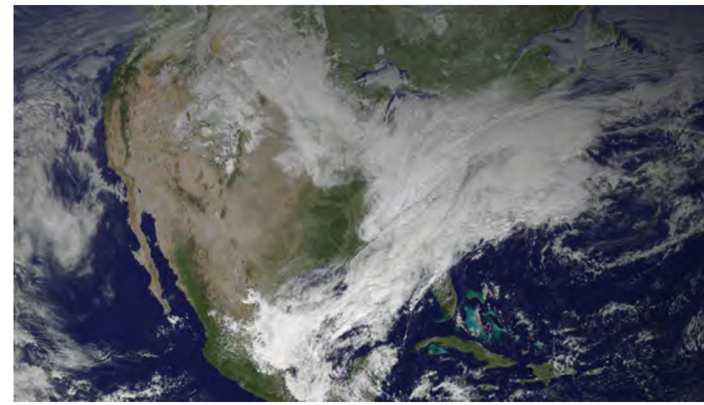
Early 2014 North American cold wave



Typical polar vortex:
Nov 15, 2013

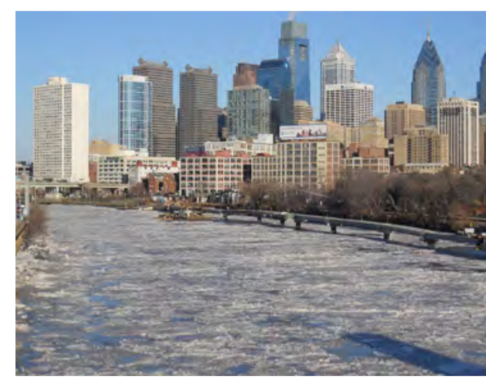


Abnormal polar vortex:
Jan 5, 2014



Ongoing blizzard across Ohio River Valley and Northeastern US as cold air from Canada moves across warm air from the Gulf of Mexico.
A GOES-13 image on January 2, 2014

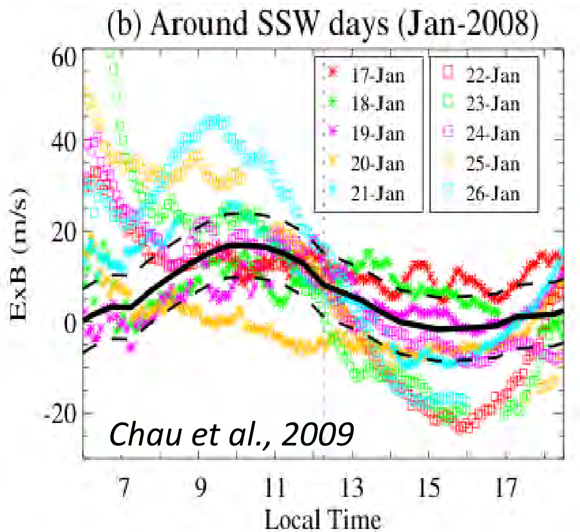
- Record (or near record) temperatures:
  - -37ºF in Babbit, Minnesota
  - -9ºF in Marstons Mills, MA
  - 21ºF in Huston, 31ºF in Tampa, FL
- 49 record lows for the day across the country on January 7
- Heavy snowfall or rainfall + strong winds
- 23.8 inches of snow in Boxford, MA
- $5 billion in damage, 21 fatalities



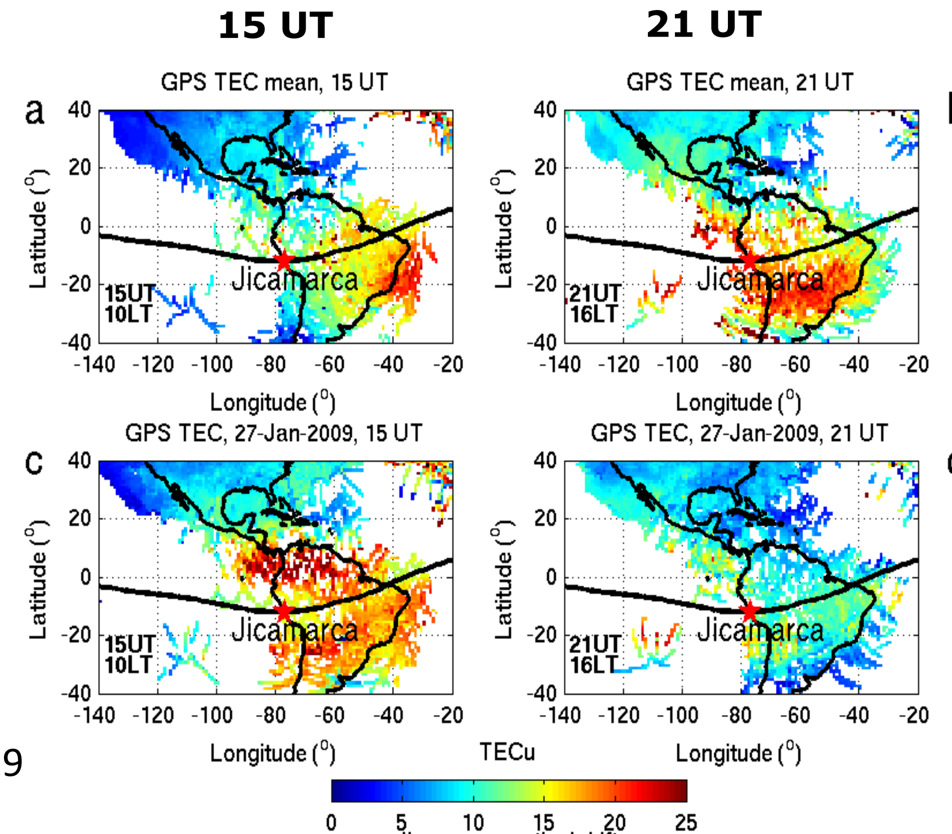
Ice formations on the Schuylkill River in Philadelphia

… and in Massachusetts …

Ionospheric response to sudden stratospheric warming: plasma motion and dramatic TEC changes



- Upward drift in the morning, downward in the afternoon – enhanced 12-hr tide
- Related increase and decrease in electron density
- Reviews Chau et al., 2012; Goncharenko et al., 2019

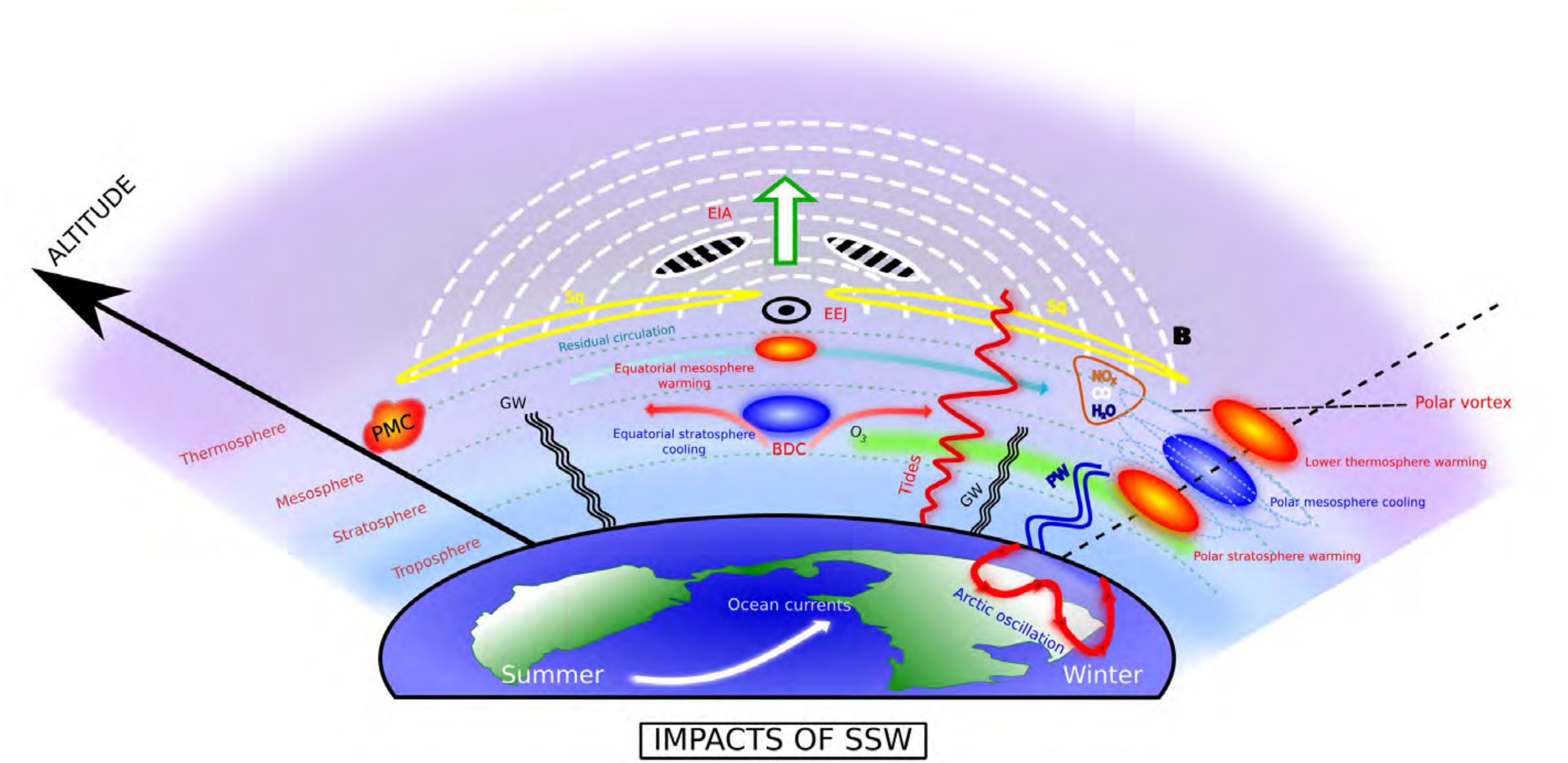


Goncharenko et al., 2010

Entire daytime low to mid-latitude ionosphere is affected during stratwarming; Total Electron Content change 50-150%

Results included in the space physics textbook in 2015

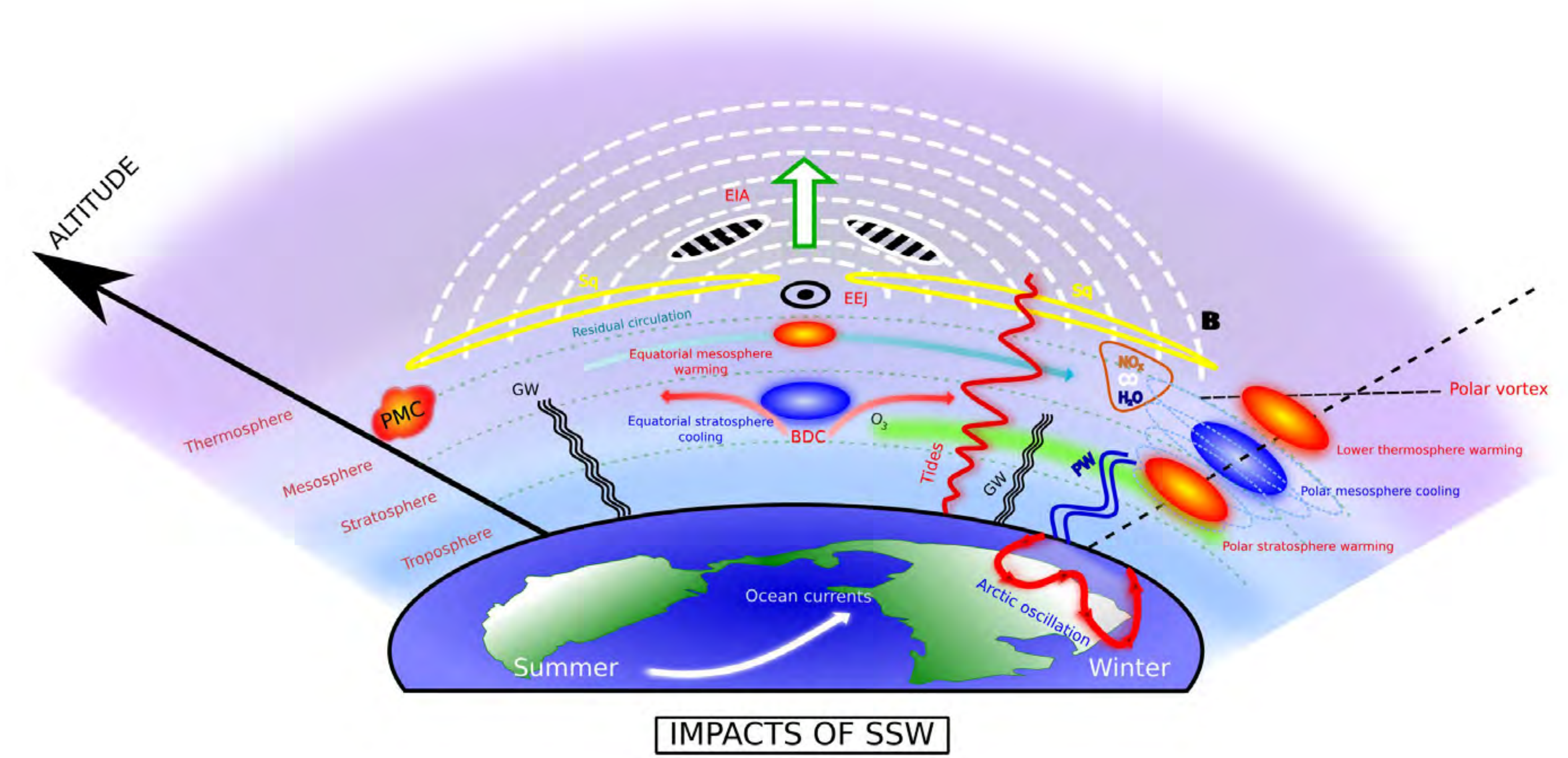
Variety of effects during SSW: from Arctic stratosphere to mesosphere over Antarctica



From *Pedatella et al., 2018*
AGU EOS

Variety of effects during SSW: from Arctic stratosphere to mesosphere over Antarctica

and ionosphere



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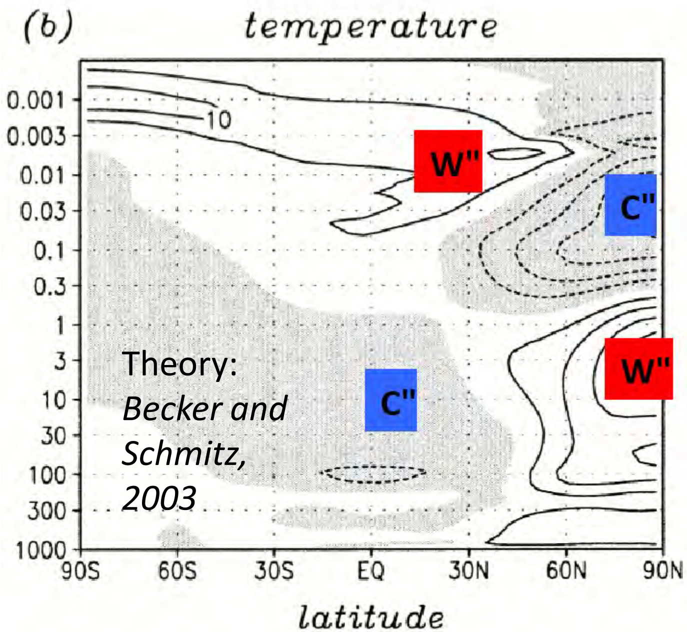
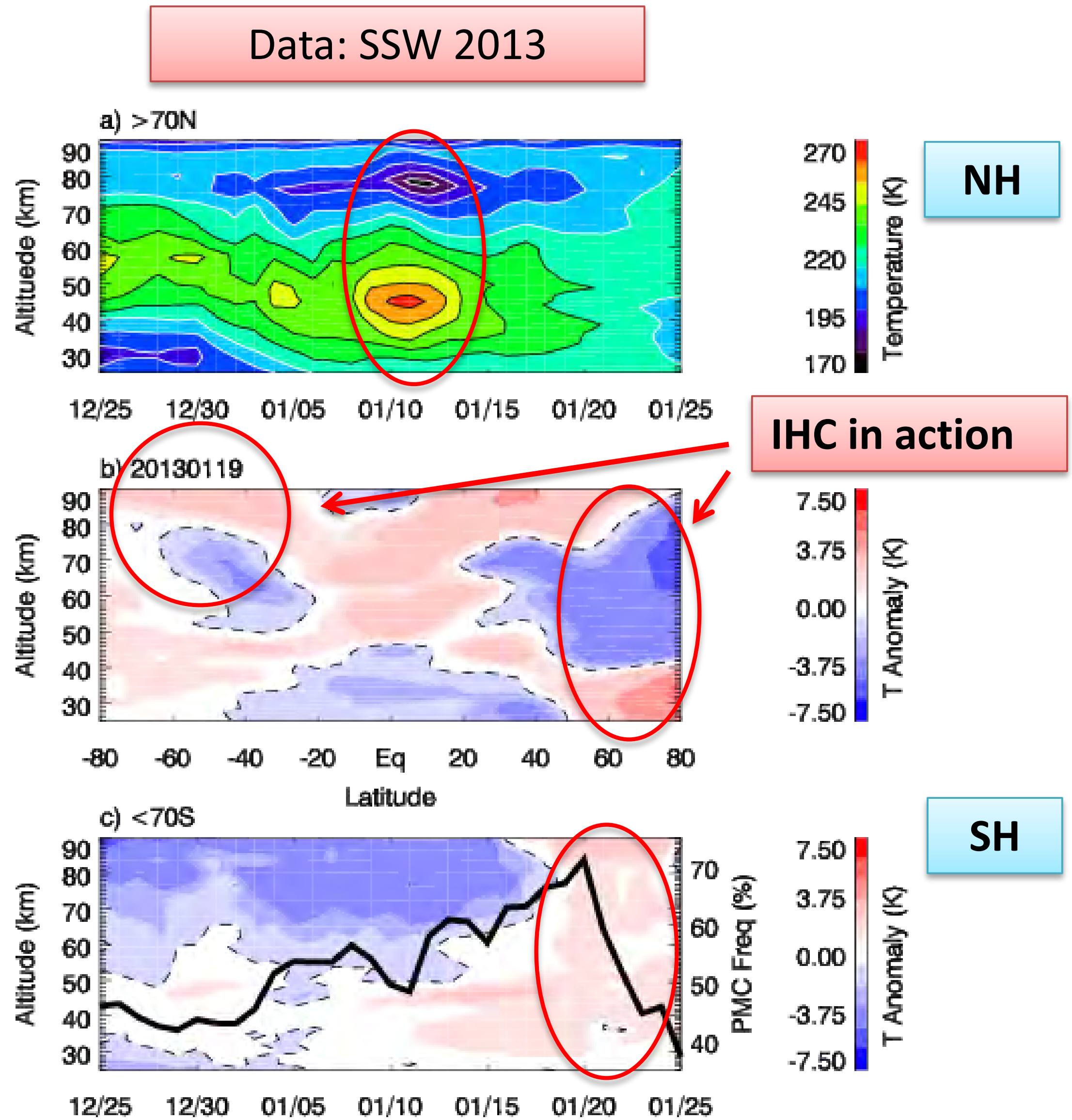
Interhemispheric coupling



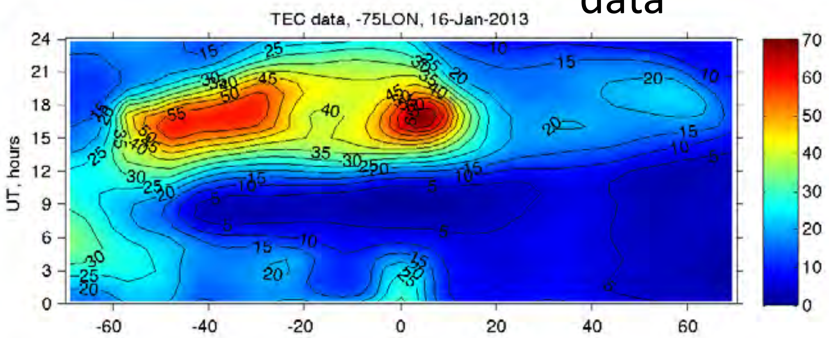
- Interhemispheric coupling (IHC) between winter stratosphere and summer mesosphere is an established phenomenon (*Becker and Schmitz*, 2003; *Becker and Fritts*, 2006; *Tan et al.*, 2012)
- **Aura MLS temperature increase and CIPS PMC frequency drop shows SH mesospheric warming during SSW 2013**



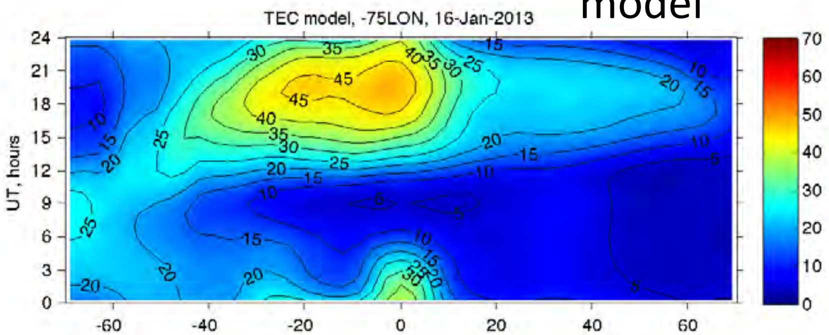
See also *de Wit, 2015*

Southern Hemisphere anomalies in TEC

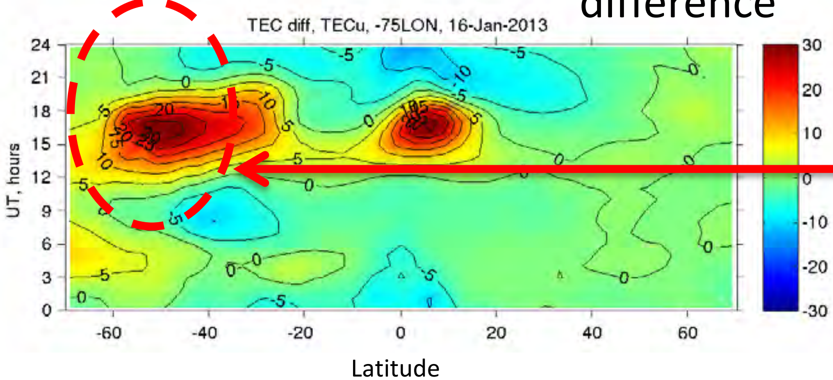
data

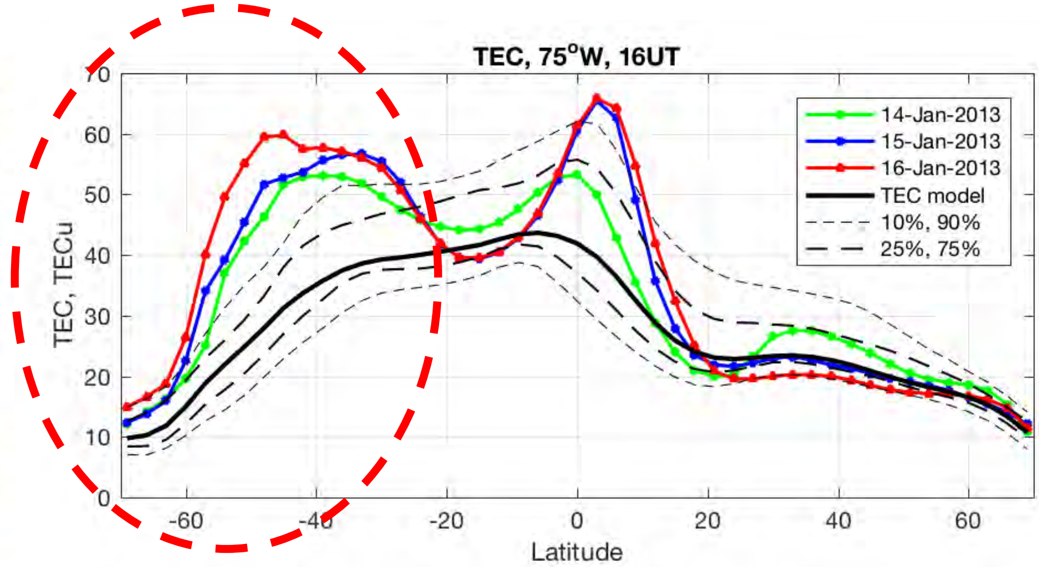


model



difference



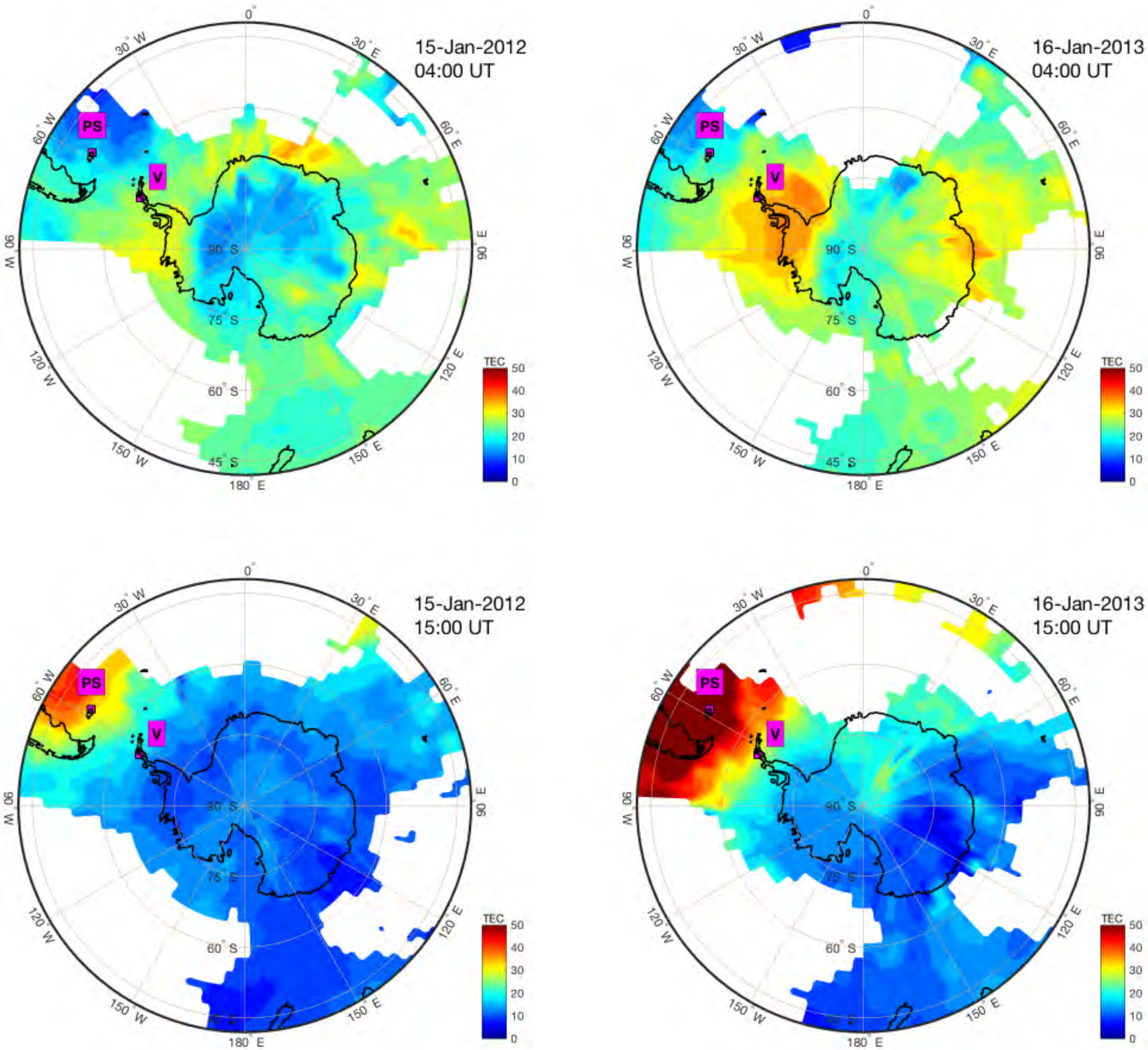


- Large positive TEC anomaly appears in the 40-70°S
- Extends to high latitudes in the Southern Hemisphere and modifies Weddell Sea anomaly
- TEC model for 75°W is developed from 15+ years of TEC data (*Goncharenko et al.*, 2018)

TEC over Antarctica

4 UT

15 UT

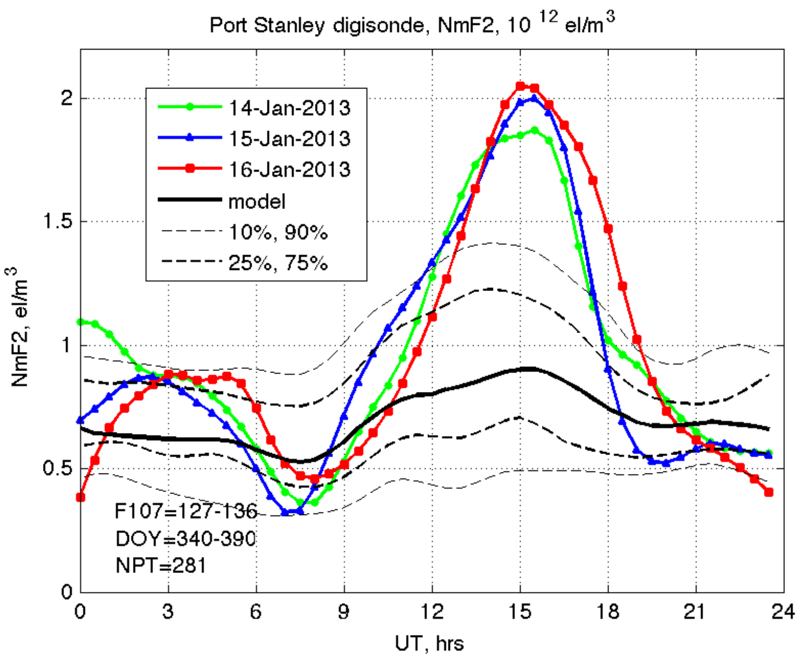


Increase in TEC during SSW in the morning to afternoon sector and around local midnight

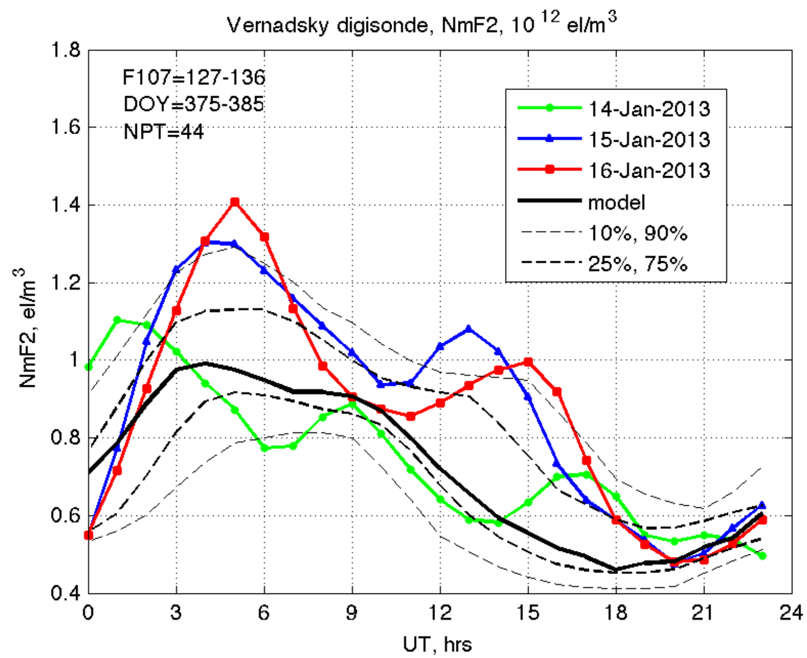
TEC control day
Jan 15, 2012
F10.7=133, Ap=4

TEC During SSW
Jan 16, 2013
F10.7=137, Ap=5

NmF2 during SSW 2013



Port Stanley, 51ºS



Vernadsky, 65ºS

- Anomalous variations in NmF2 observed at both locations
- Increase in daytime NmF2 by a factor of ~2 at 51ºS, Port Stanley and 65ºS, Vernadsky

Summary

- Persistent mesospheric anomalies over Antarctica in January 2013 are an example of interhemispheric coupling
- Mesospheric anomalies are observed with two independent datasets, Aura MLS and CSIPS on AIM
- Ionospheric anomalies are observed with two independent techniques, GNSS TEC and ionosondes
- Increase in TEC/NmF2 by a factor of ~2
- **The results provide strong observational evidence that Arctic SSW events generate truly global disturbances that reach high latitudes and altitudes of the opposite hemisphere**
- **These observations show for the first time that interhemispheric coupling extends all the way to the thermosphere and ionosphere**