The Role of the Polar Vortex in Sun-Earth Coupling

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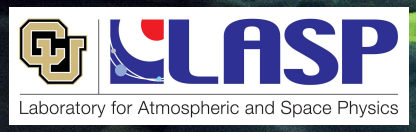

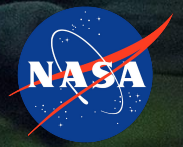

2022 Sun-Climate Symposium, 17 May 2022

Outline

- The winter Polar Vortex
- The mean meridional circulation
- Sudden Stratospheric Warmings “precondition” the IT
- Top-Down coupling – descent of EPP-NO_x in the vortex
- Bottom-Up coupling - Gravity waves and Traveling Ionospheric Disturbances (TIDs)

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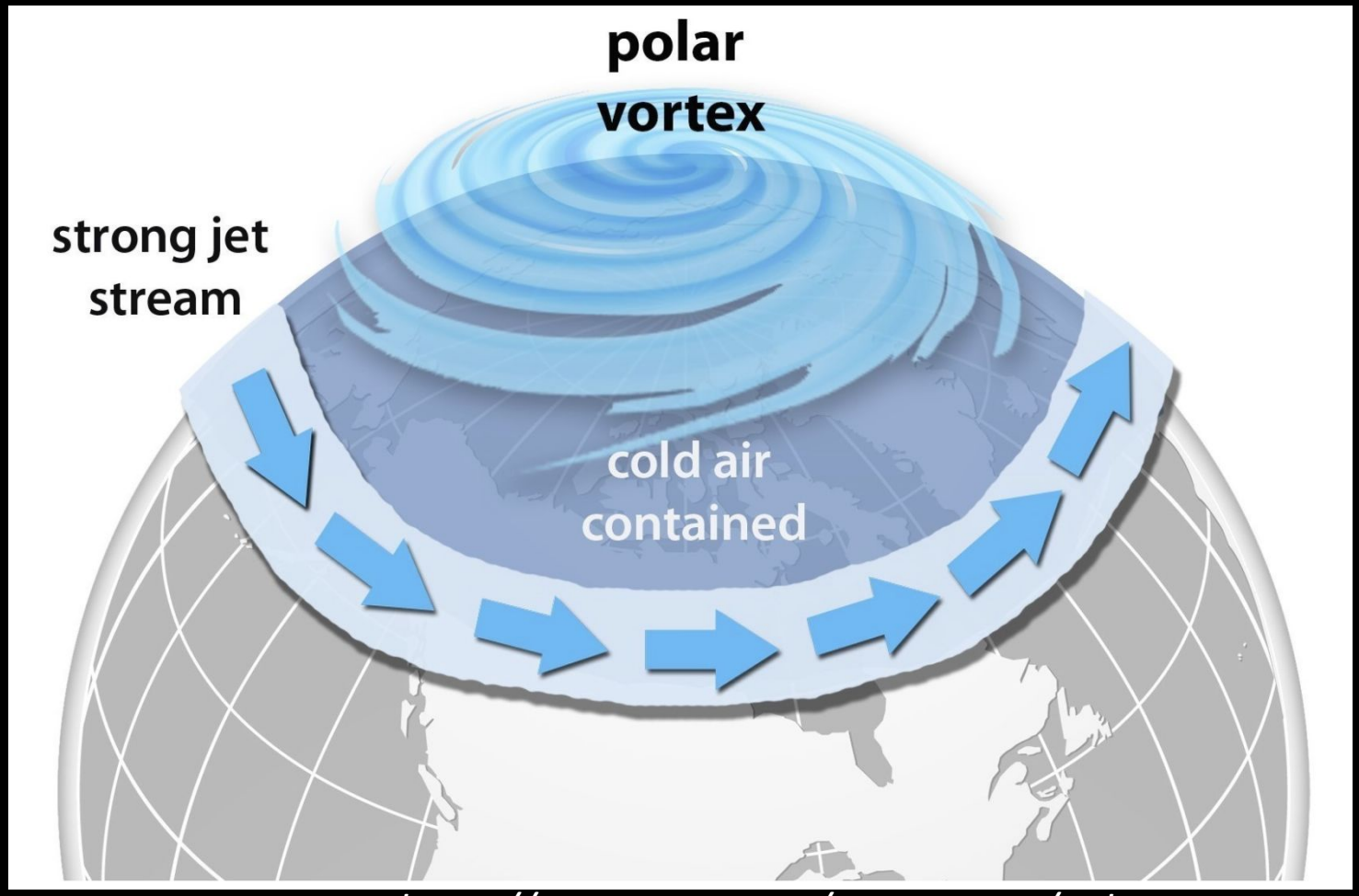
The winter polar vortex



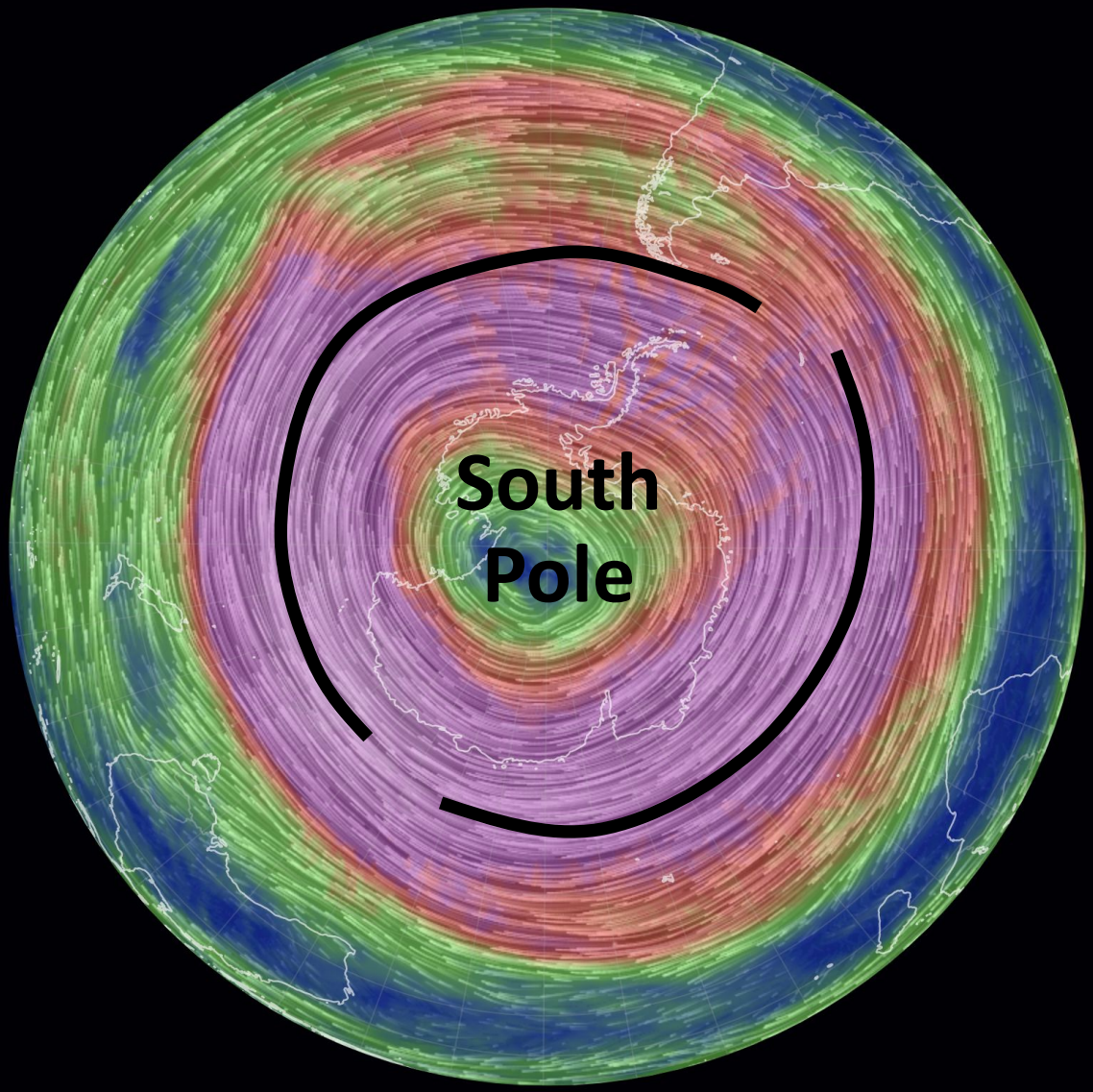
https://www.rmets.org/metmatters/polar-vortex-ssw

- During winter in the dark polar night there is UV to heat O_3
- This results in a very cold polar stratosphere
- A west-to-east jet stream encircles the cold air

The Arctic polar vortex wobbles about the pole from day to day due to weather below

What does the polar vortex look like today?

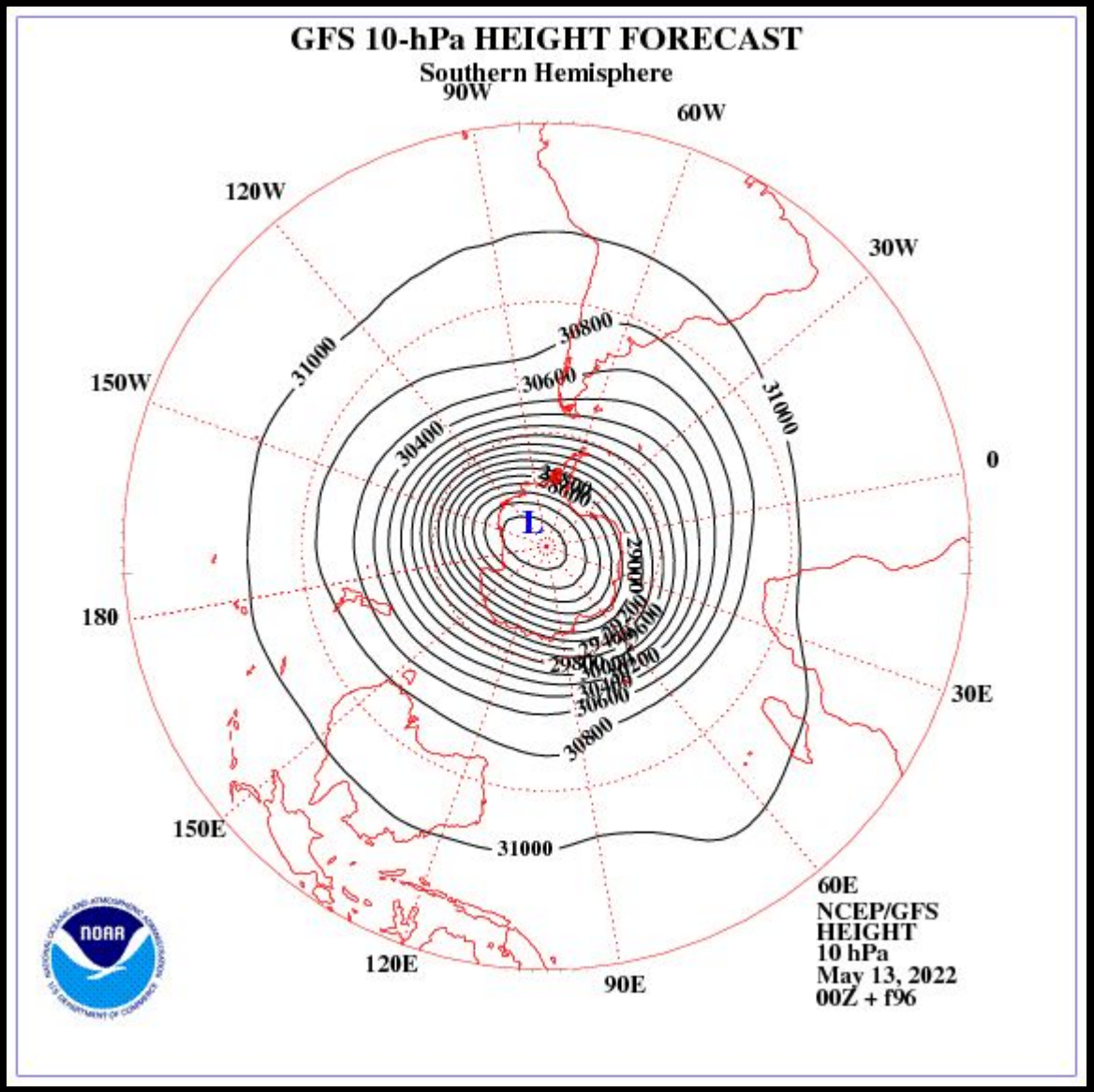
The Antarctic Polar Vortex is still strengthening



May 13
2022
~30 km

http://earth.nullschool.net

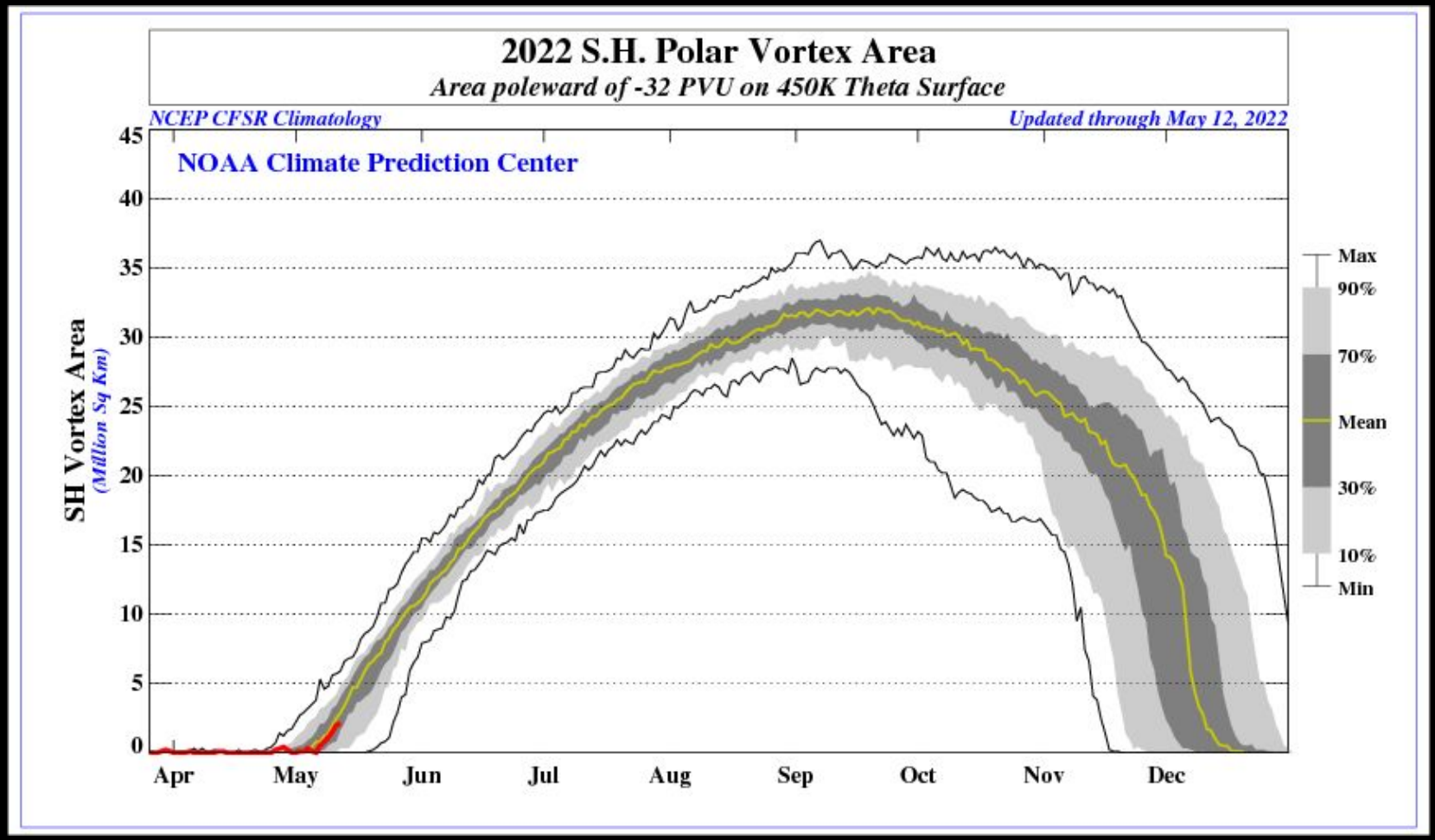
The Antarctic Polar Vortex today, and next week



May 17 2022
~30 km

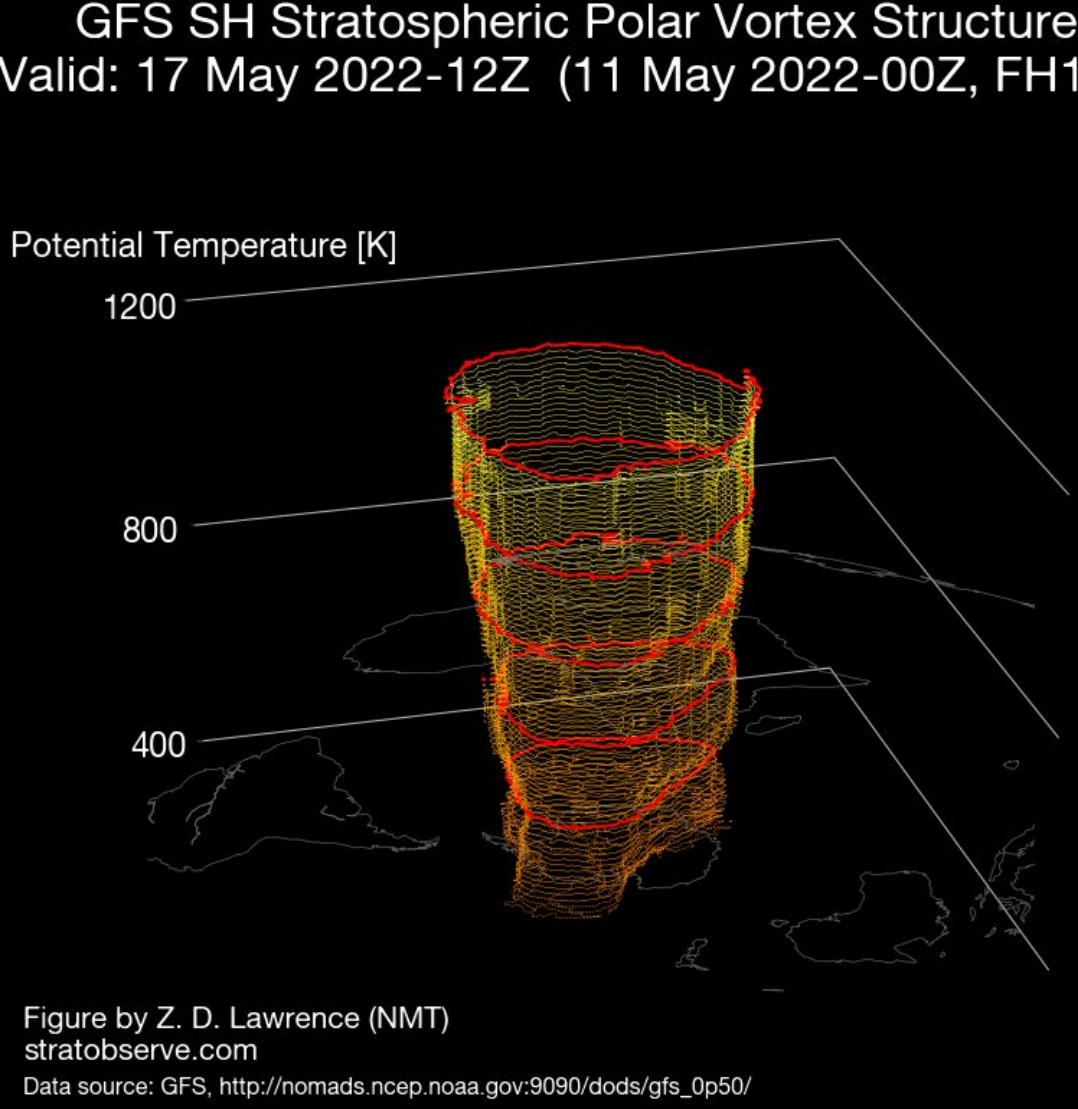
The Climate Prediction Center forecasts out to 16 days
http://www.cpc.ncep.noaa.gov/products/stratosphere/strat_a_f/

The Antarctic Polar Vortex Area this year ~20 km



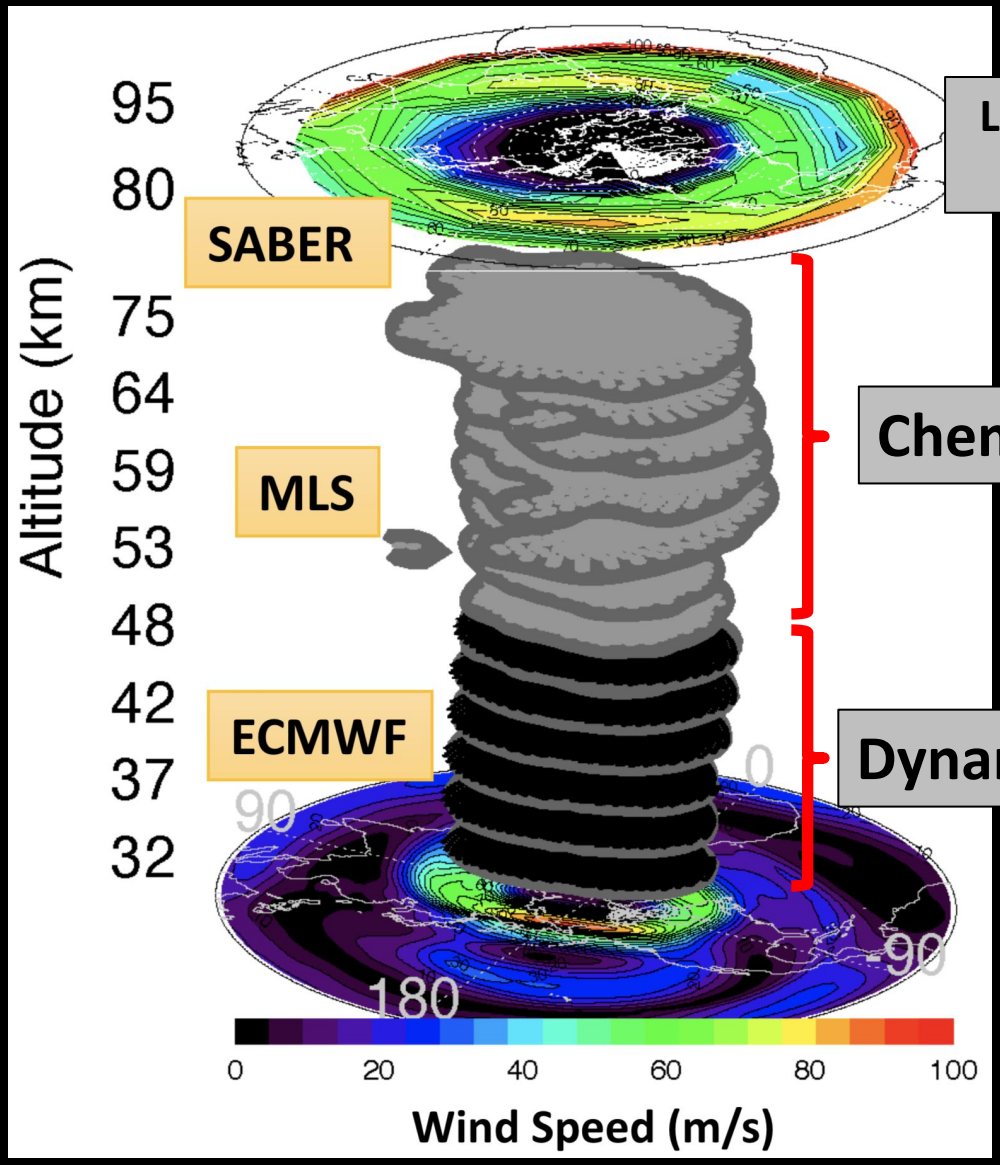
The Climate Prediction Center seasonal evolution and multi-year climatology
https://www.cpc.ncep.noaa.gov/products/stratosphere/polar/

The Antarctic Polar Vortex today, in 3-dimensions



Zak Lawrence - https://stratobserve.com/misc_vort3d

Defining the polar vortex from the tropopause to the mesopause



Lagrangian Coherent Structures

Harvey et al 2021

Chemical definition

Harvey et al 2015

Dynamical definition

Harvey et al 2002

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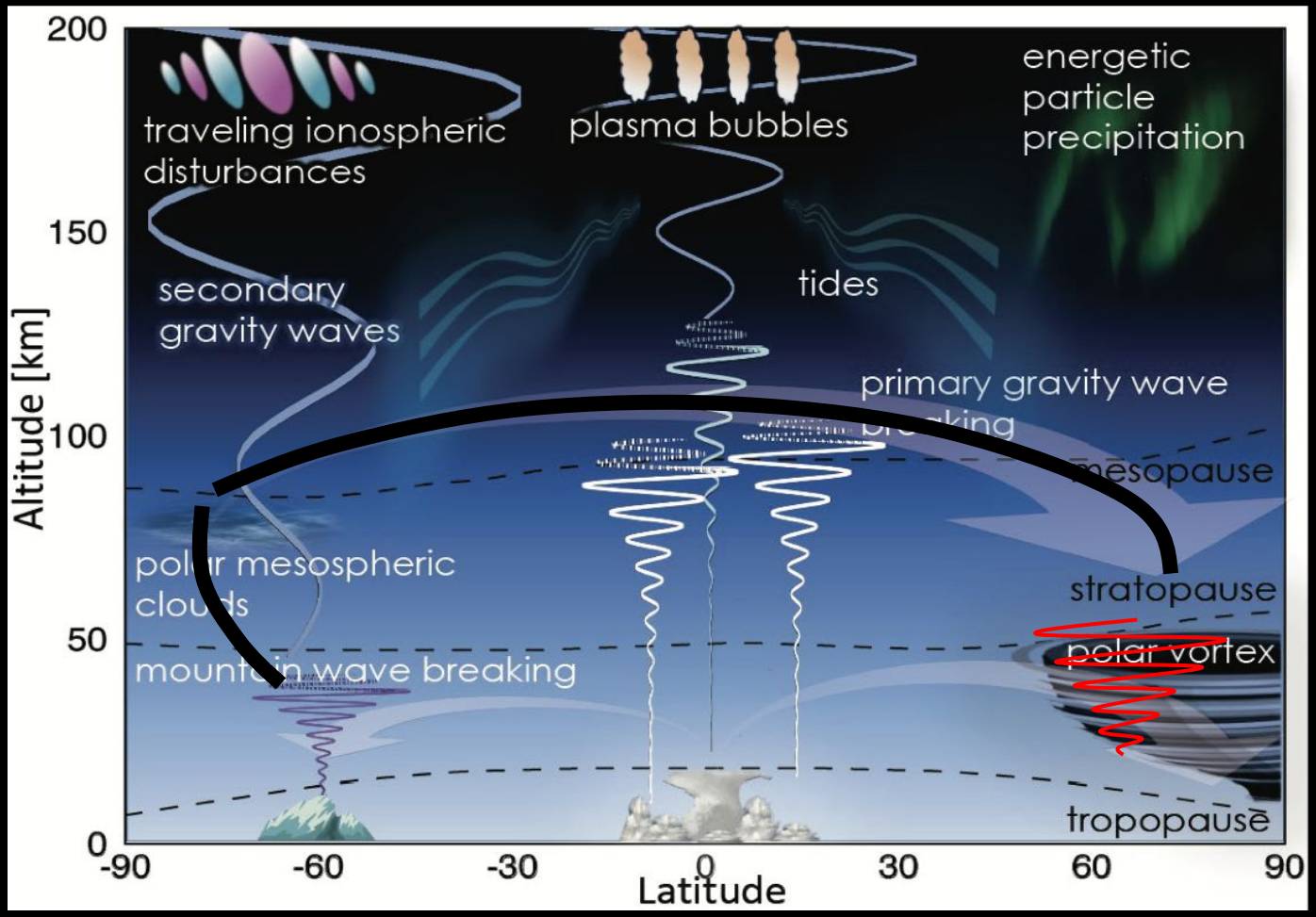
Mean meridional circulation, polar vortex, waves, and connections to the IT



Top-down

Bottom-Up

Courtesy of Laura Holt

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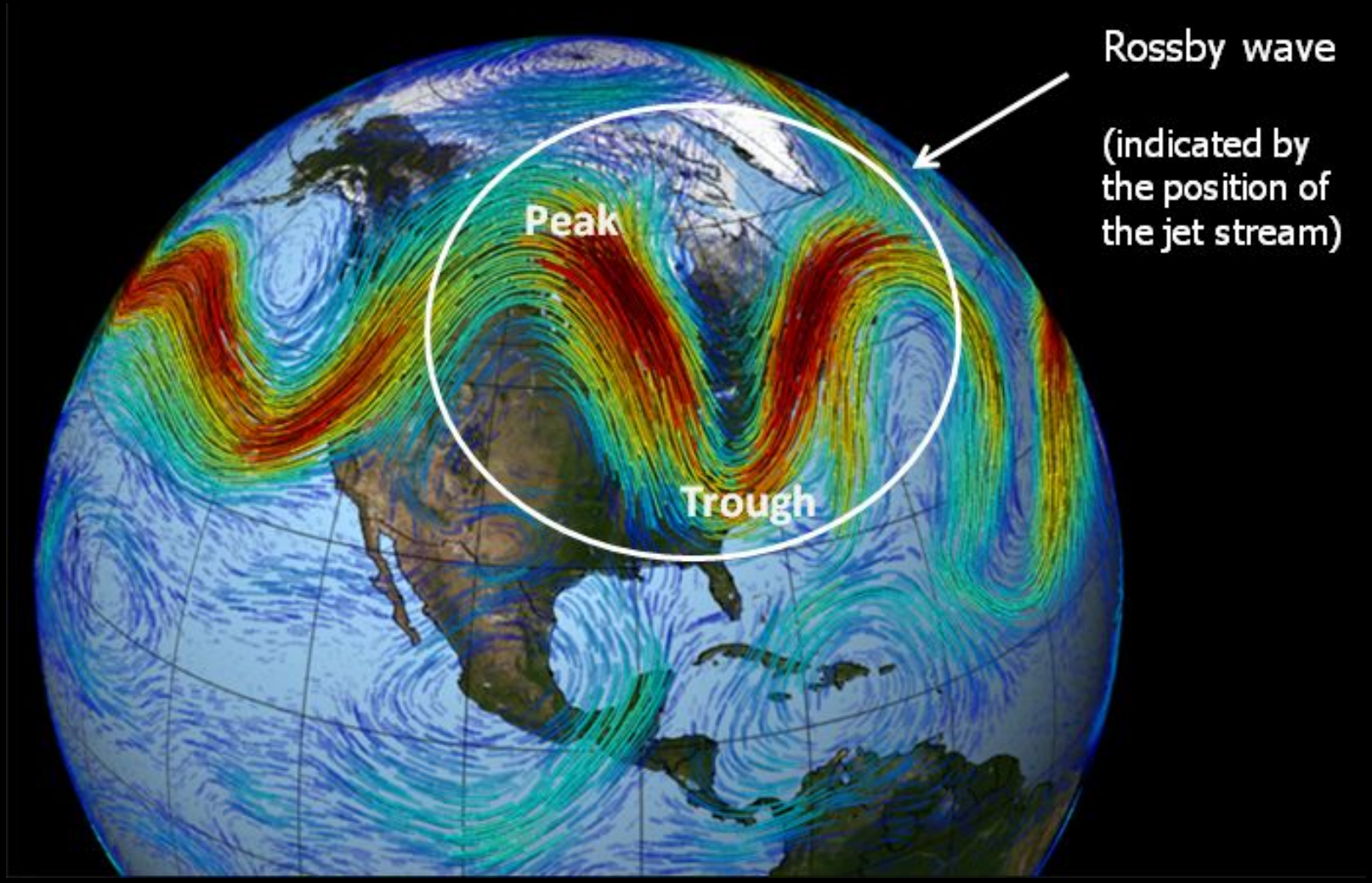
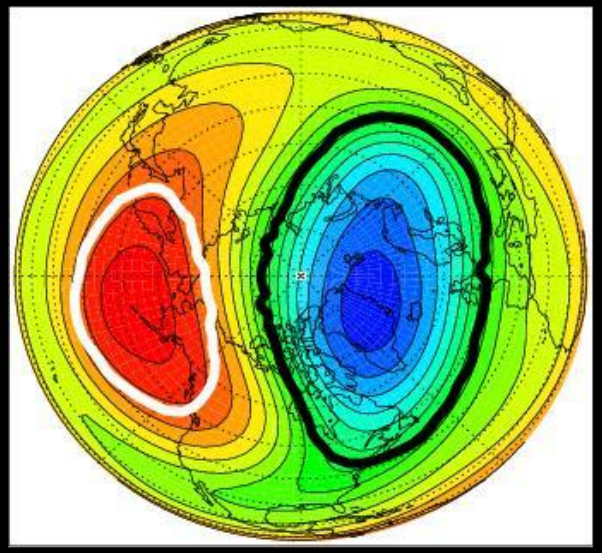
Planetary waves form in the upper tropospheric jet stream due to weather systems below



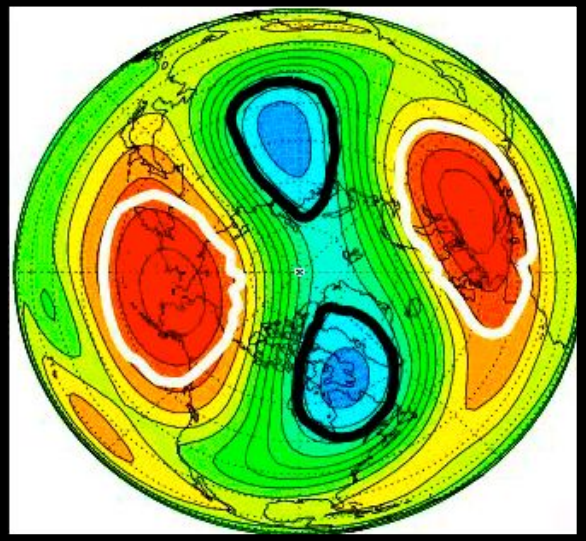
They propagate upward and amplify and "disturb" the polar vortex

Sudden Stratospheric Warmings (SSWs) are large disruptions to the polar vortex

- (1) Vortex *displaced* from pole
  - a.k.a. “Minor”, “Wave 1”
  - <u>One anticyclone</u>

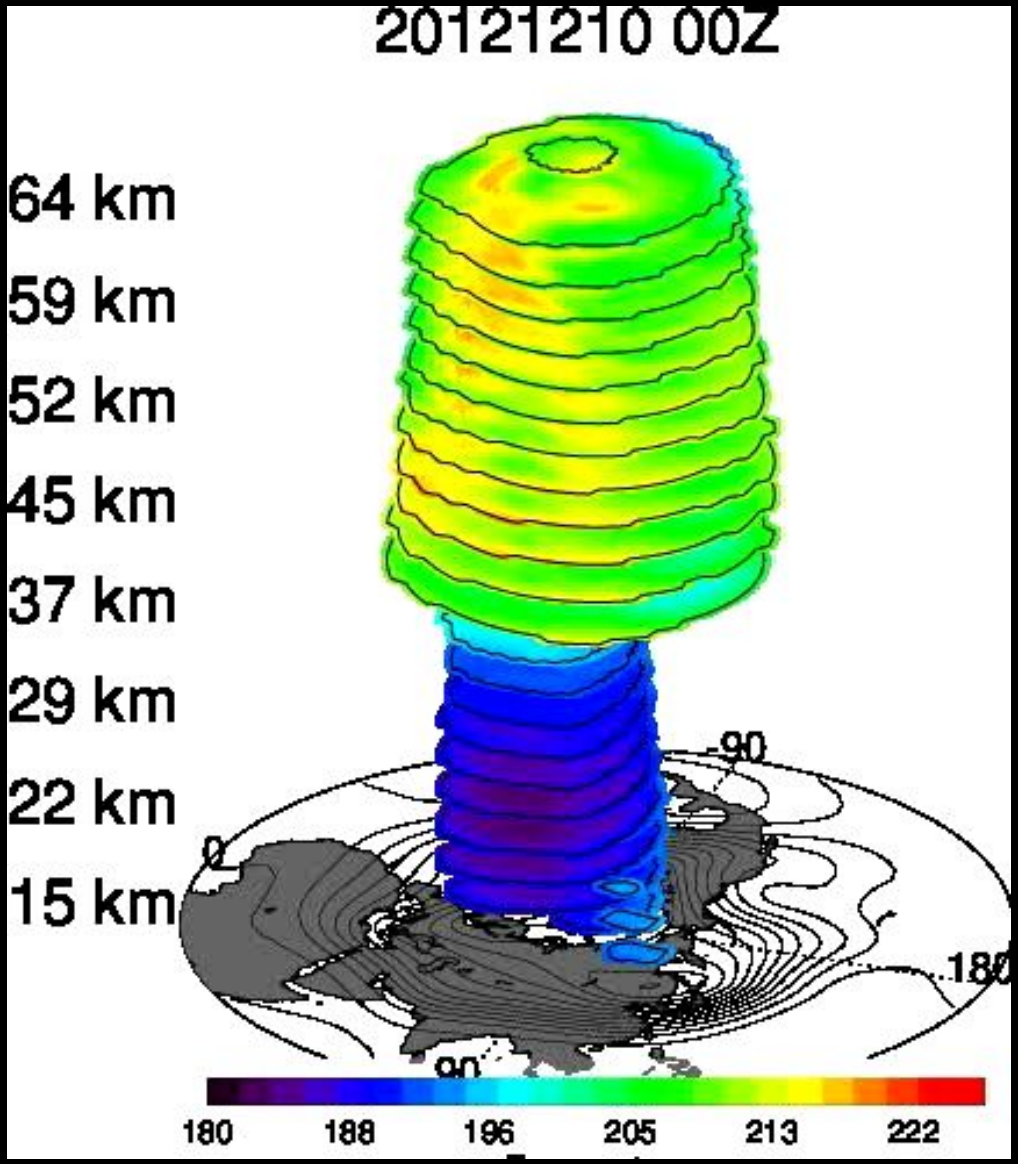


- (2) Vortex *split*
  - a.k.a. “Major”, “Wave 2”
  - <u>Two anticyclones</u>

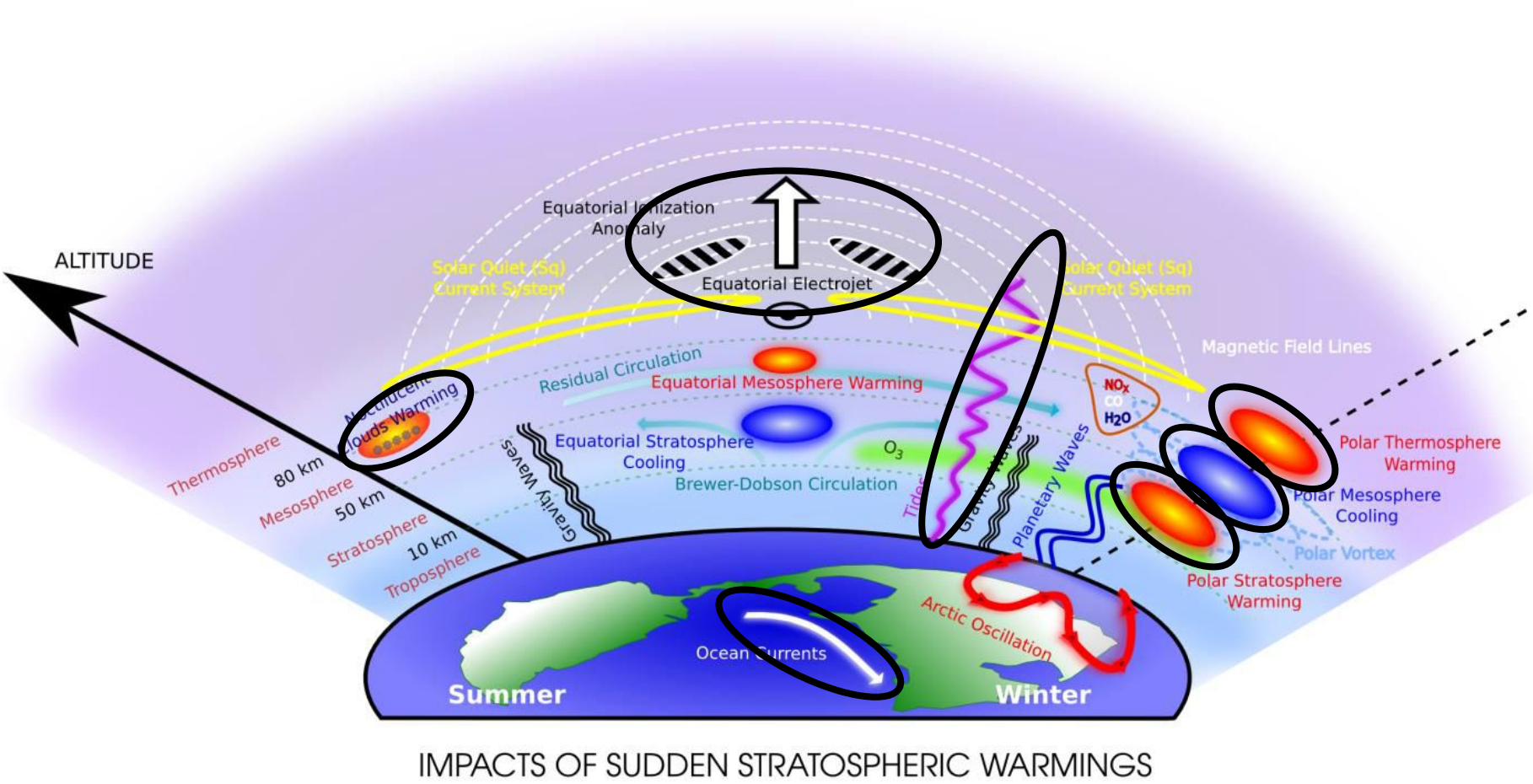


The **Arctic vortex is weaker** and more variable than in the Antarctic due to land-ocean contrasts.

Polar vortex split in January 2013



Effects of SSWs are observed throughout the ocean-atmosphere-ionosphere system



Pedatella et al. (2018) EoS

SSWs precondition the IT system to respond differently to subsequent solar and geomagnetic disturbances

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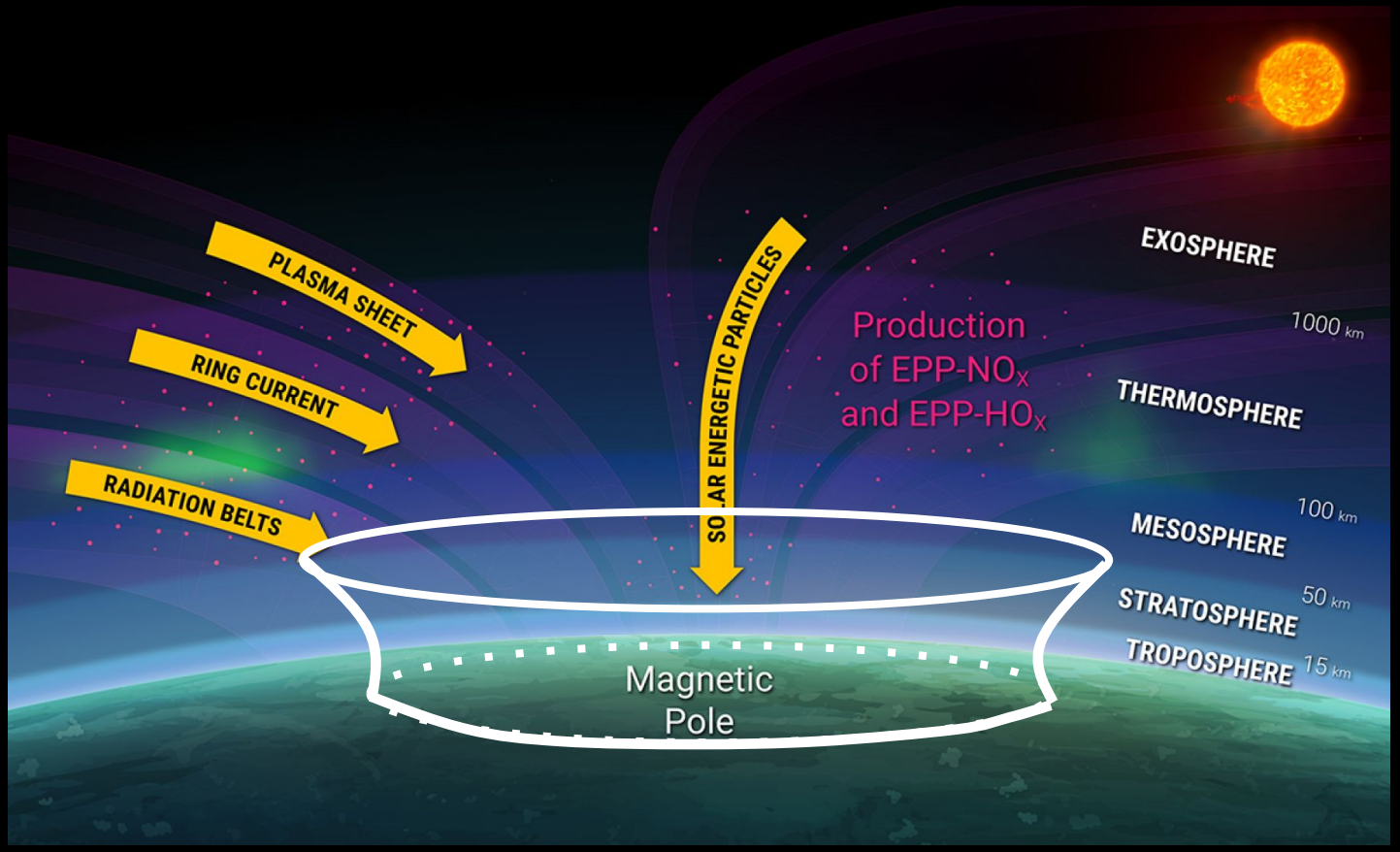
Precipitating energetic electrons and solar protons produce HO_x and NO_x, which destroy ozone catalytically



Courtesy of Dan Baker & Allison Jaynes, CU Boulder/LASP

- **Descent in the vortex transports the EPP-NOx downward**

EPP INDIRECT EFFECT (EPP-IE)

Randall et al. (2006)

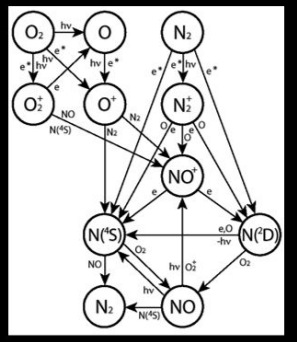
· NO_x formed in MLT via EPP

↓↓↓

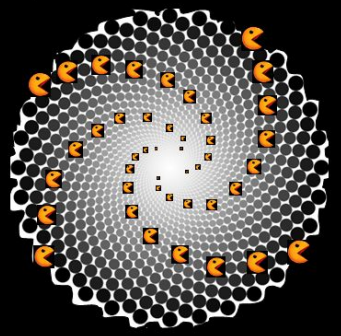
· Descends in polar vortex during winter

↓↓↓

· Ozone destroyed (~22-40 km)

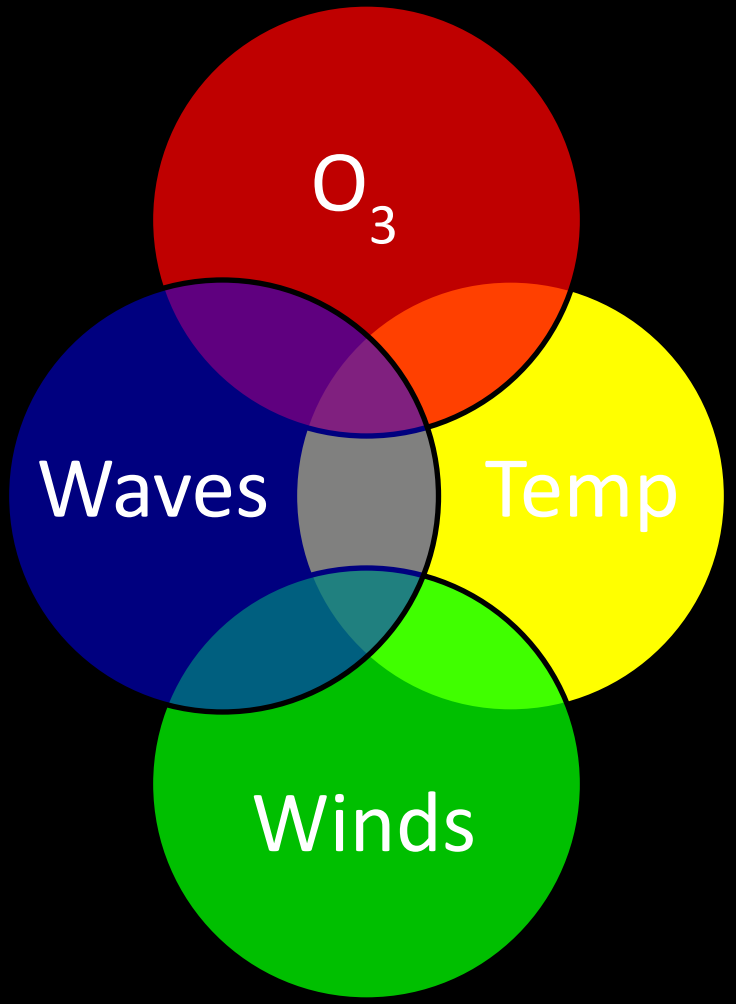


Courtesy of Charles Barth



Courtesy of Cora Randall

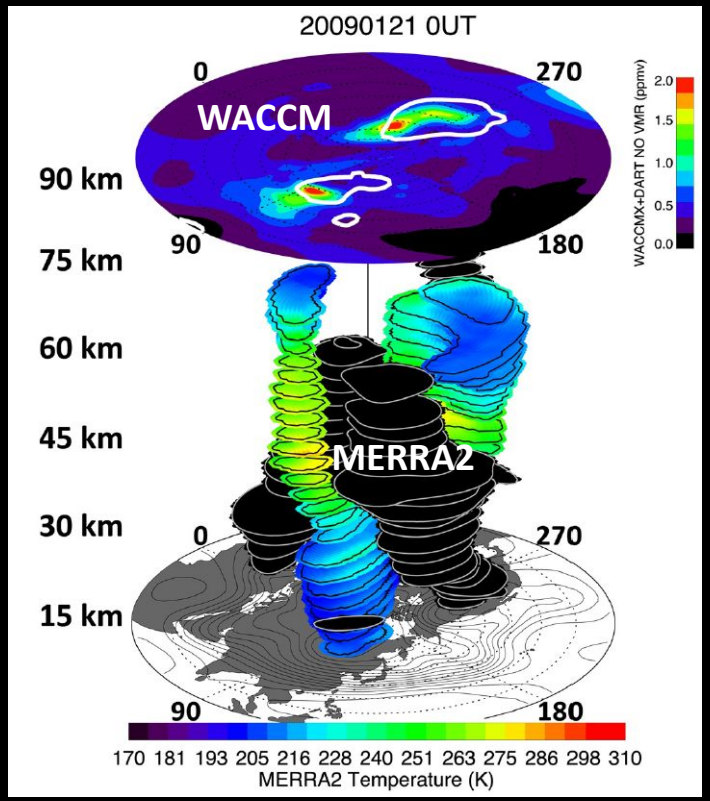
Changes in polar ozone can trigger a redistribution of solar and magnetospheric energy at Earth, coupling the upper and lower atmosphere



The EPP-IE needs to be studied in 3D

Harvey et al., JGR 2021: EPP-NOx exhibits zonally asymmetric descent into the top of the polar vortex following the 2009 SSW

- WACCMX + DART
- Lagrangian coherent structures (transport barriers) near 90 km confined EPP-NOx to the polar region
- 5x stronger descent at planetary wave trough longitudes, mostly driven by large-scale vertical advection
- EPP effects must be studied in 3D



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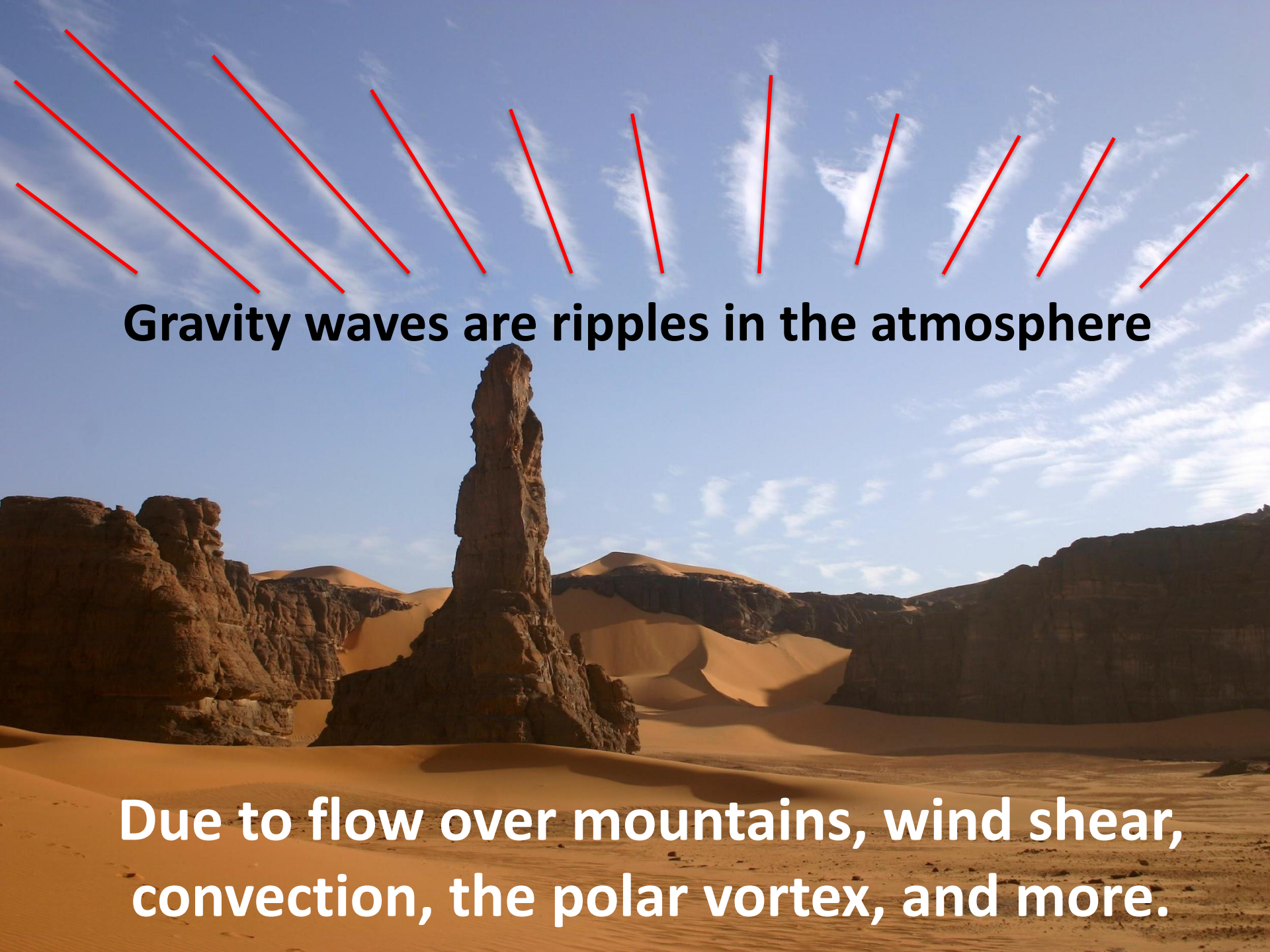
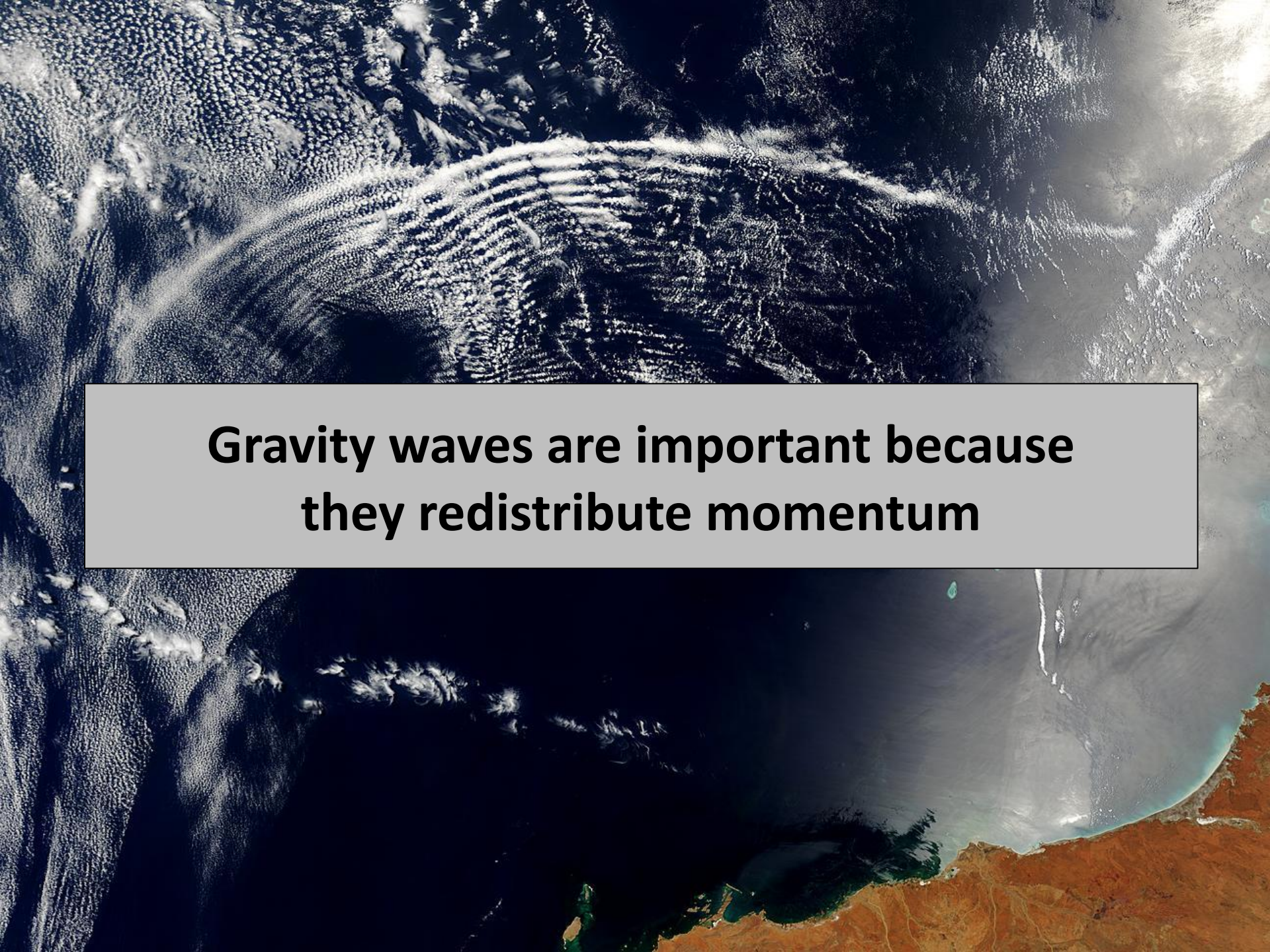
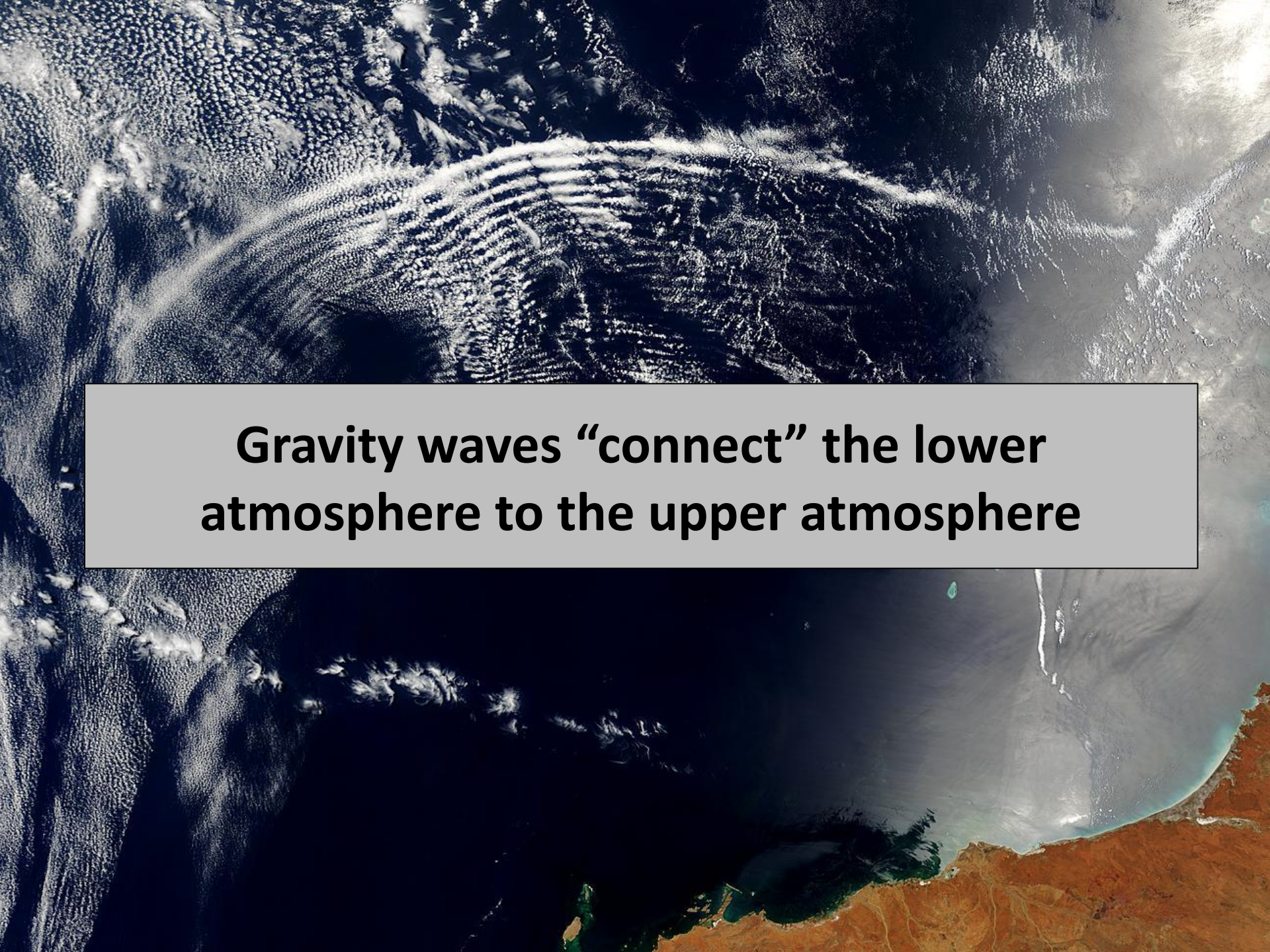
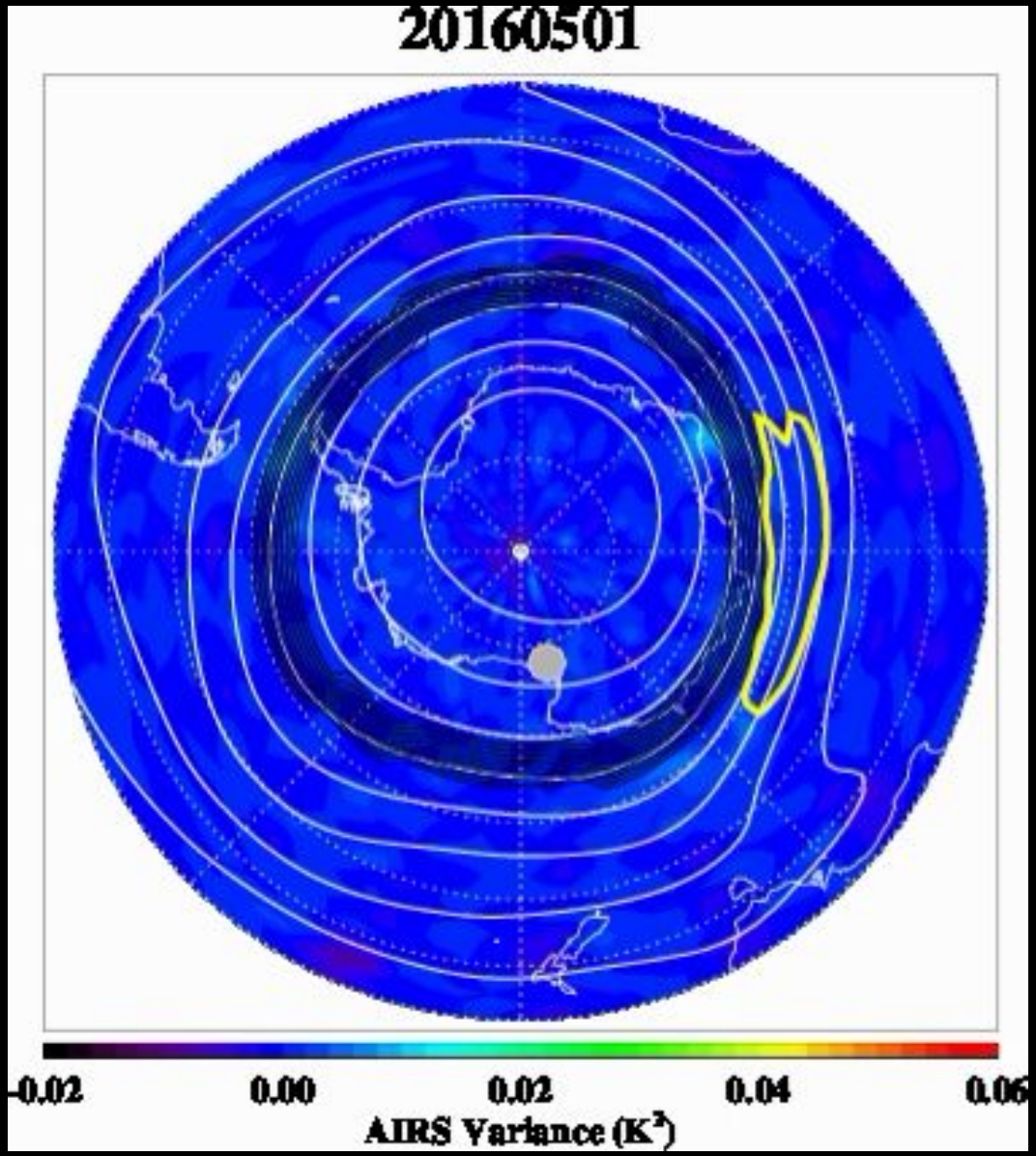

Gravity waves are ripples in the atmosphere
Due to flow over mountains, wind shear, convection, the polar vortex, and more.



Gravity waves are important because they redistribute momentum

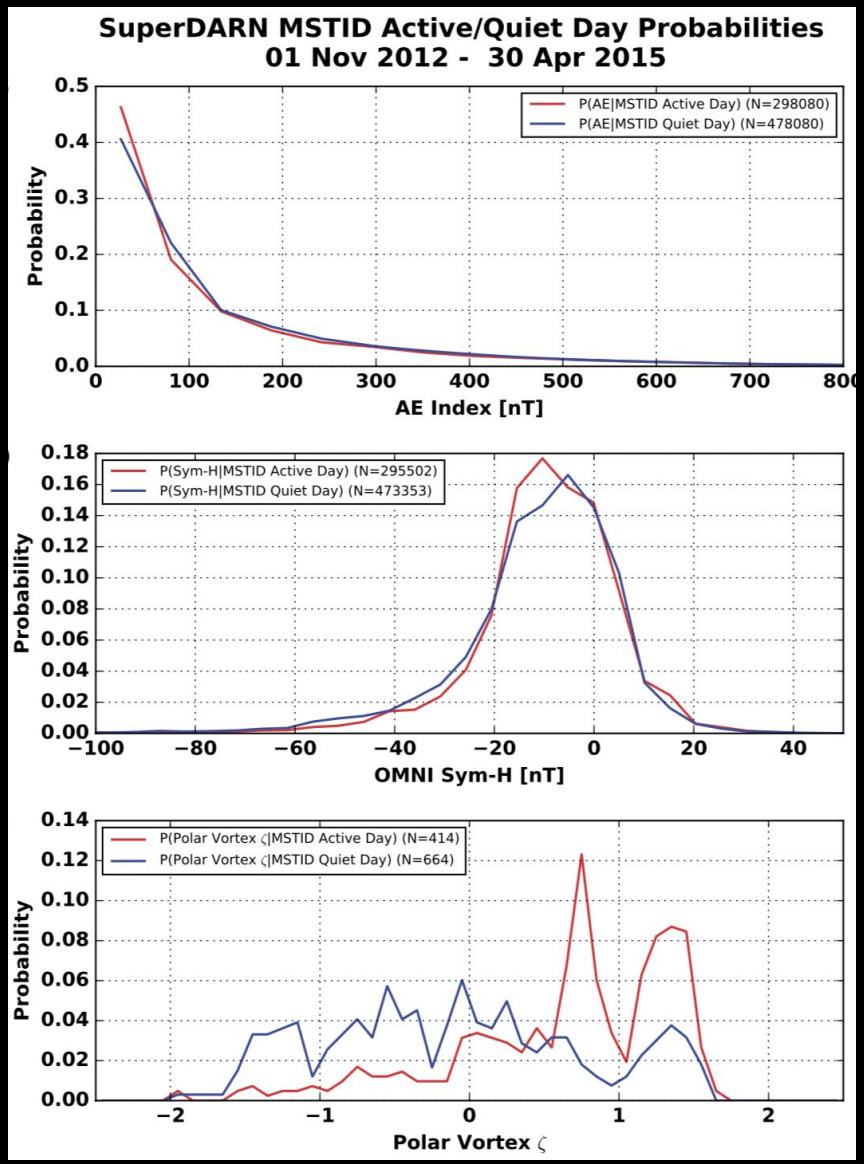

Gravity waves “connect” the lower atmosphere to the upper atmosphere

The polar vortex modulates GW distributions



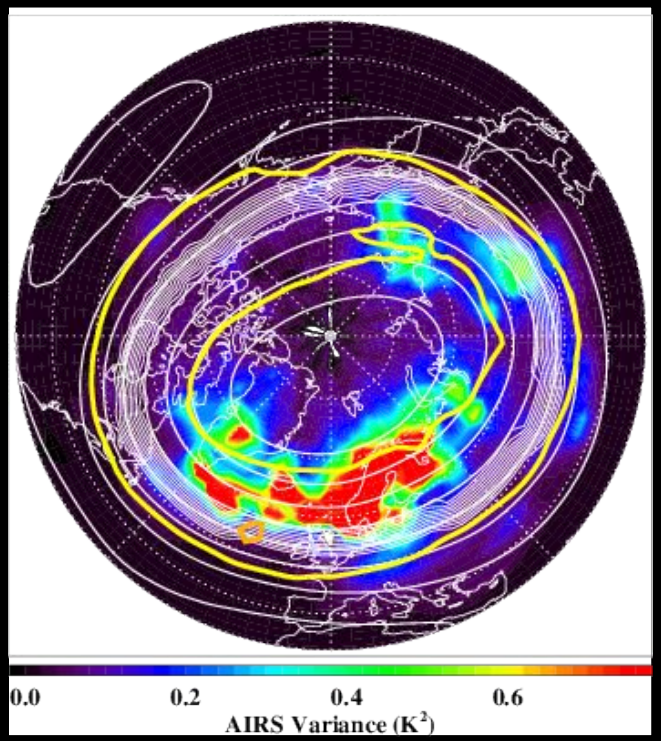
- Orographic hot spots over the Antarctic peninsula and S. Andes
- GW vertical wavelength increases in the PNJ making them visible to AIRS (“atmospheric filter”).
- GWs with long vertical wavelengths propagate to higher altitudes.
- The vortex is a GW source
- Overall, the vortex modulates GWs entering the IT

Frissell et al., JGR 2016: Daytime winter MSTIDs tend to occur when the polar vortex is strong



- A climatology of MSTIDs over North America using SuperDARN observations
- GW-MSTIDs are not correlated with space weather
- GW-MSTIDs more frequent when polar vortex is strong
- Improved predictability

When the vortex is strong, TID activity increases at a wide range of latitudes and longitudes



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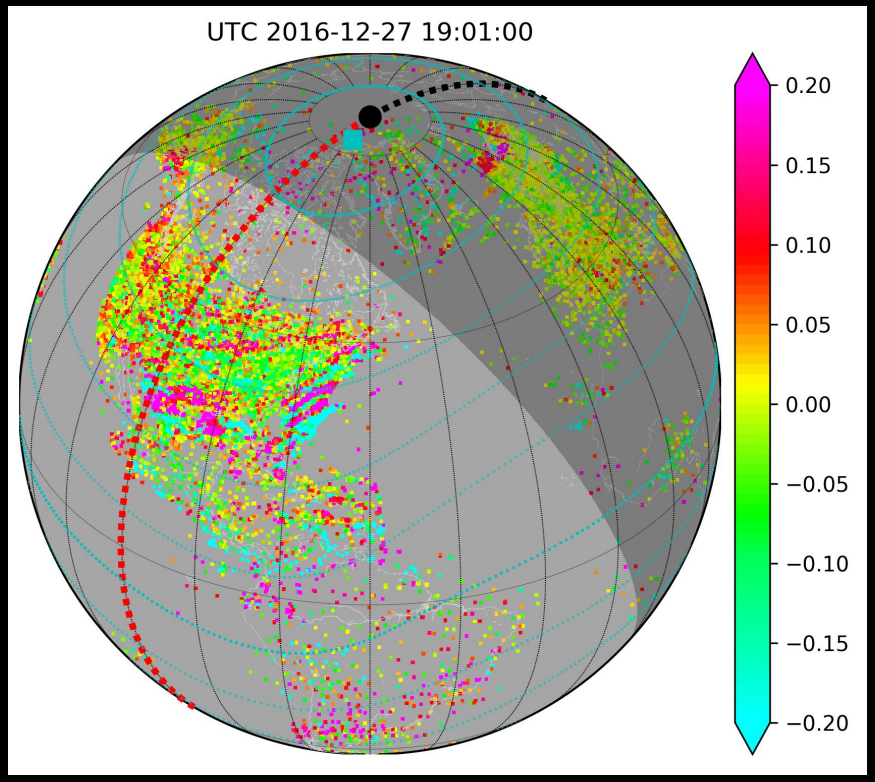

Courtesy of Larisa Goncharenko

- AIRS GWs, GNSS TEC
- Stratospheric GW hotspots imprint on the ionosphere in a wide range of latitudes and longitudes
- Like SSWs, GWs modulated by the vortex alter the state of the IT

Summary

- **The winter polar vortex is a fast jet stream in the stratosphere and mesosphere encircling a region with confined descent.**
- **Planetary wave disturbances to the vortex drive variability in the whole atmosphere-ionosphere system.**
- **Top-down coupling – Descent in the vortex connects auroral altitudes to the stratosphere via the transport of EPP-NOx.**
- **Bottom-up coupling – The vortex modulates GWs and is a GW source. More TIDs when the vortex is strong.**


Thank You!
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