Atmosphere-Ionosphere Coupling

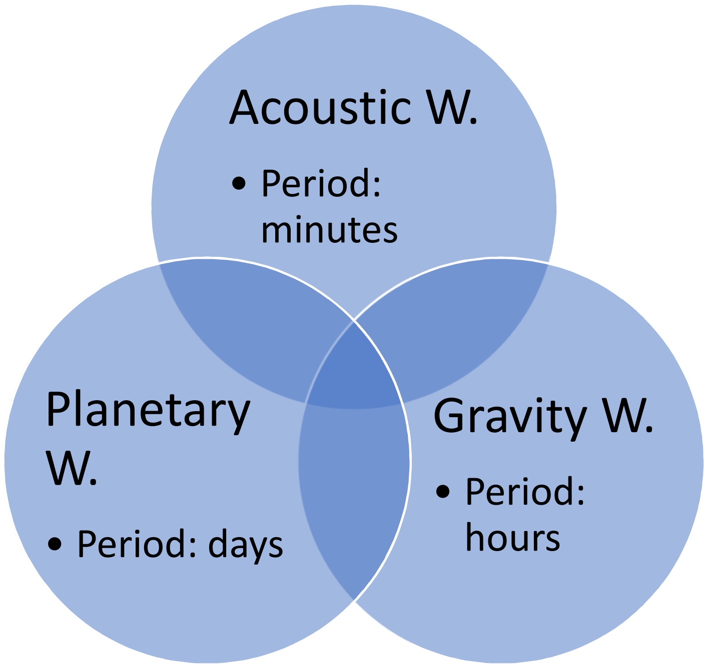
Outline

- Dynamical coupling: atmosphere waves
- Chemical/ radiative coupling

Dynamical Coupling

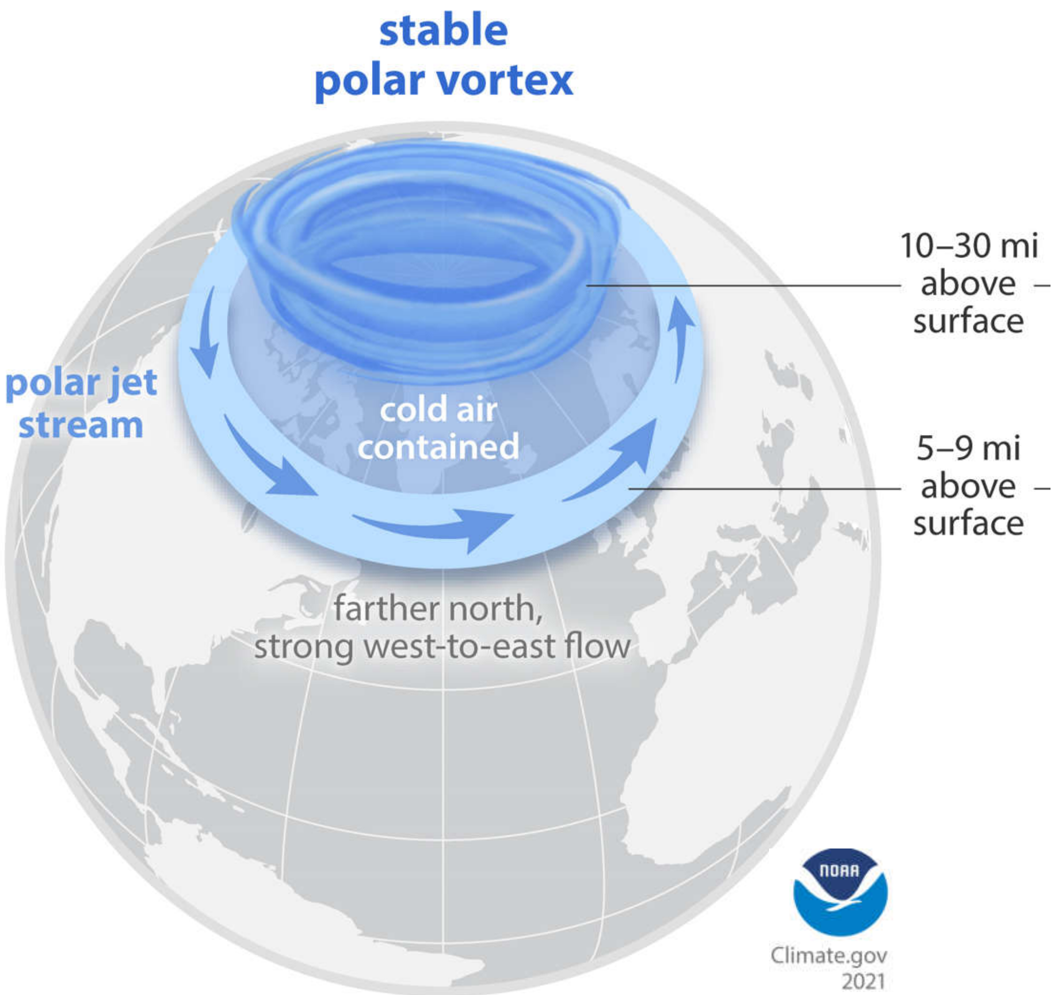
Atmospheric waves

Free



Forced

Polar vortex



- Low pressure in the stratosphere (~30 km altitude) at pole during every winter
- Strong westerly winds
- Cold air contained over the Arctic
- Tropospheric jet stream normally don't interact with stratospheric vortex
- Southern Hemisphere stratosphere polar vortex even stronger in its winter.
- Northern Annular Mode (NAM) used to describe the strength of the polar vortex in the stratosphere

Planetary Waves (Rossby Waves)

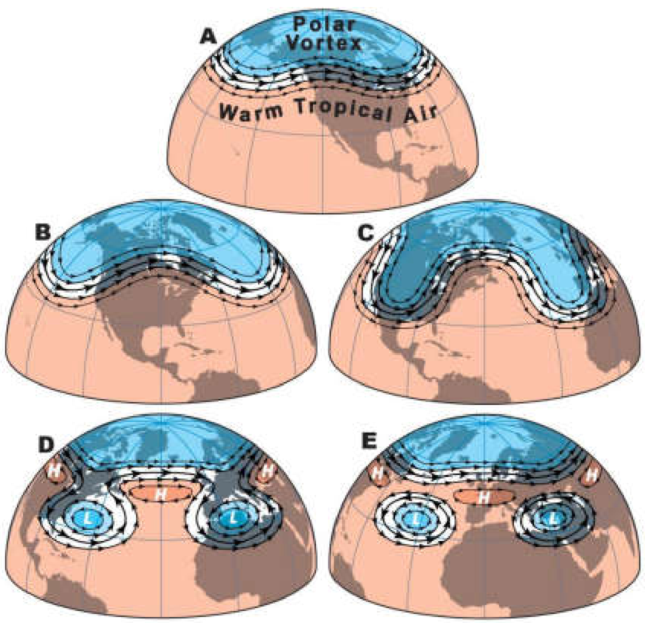


Figure 2. Evolution of the southern edge of the Rossby waves as the cold air mass (in blue) moves eastwards [9, Figure 3.8]. H represents a high air pressure cell (an anticyclone) while L represents one of low pressure (a cyclone).

(Figure from Harris, 2019, doi: [10.3934/environsci.2019.1.14](https://doi.org/10.3934/environsci.2019.1.14))

- Applies for large-scale meteorological systems
- β-Effect: Coriolis force changes with latitude

$$\beta = \frac{df}{dy} = \frac{2\Omega cos\phi}{R_E}$$

- two categories: quasi-stationary waves and transient waves
- Orography and irregular heating over the earth provide nearly stationary sources and sinks of vorticity, which force quasi-stationary planetary waves
- Weather systems introduce large-scale vertical motions and temperature gradients that develop and dissipate quickly
- Free waves largest scales move most rapidly westward

Planetary Wave Upward Propagation

- The strong zonal winds of the polar vortex provide a channel for the upward propagation of Rossby waves from the troposphere.
- Charney and Drazin (1961) first showed that only the largest scale Rossby waves can propagate upwards into the strong westerly polar vortex winds during winter,
- The synoptic scale Rossby waves (responsible for most of the tropospheric variability) are trapped in the troposphere
- An upward-propagating large-scale Rossby wave (commonly known as a planetary wave) increases in amplitude with increasing altitude as the density decreases
- As they propagate into the stratosphere, planetary waves distort the longitudinally symmetric structure of the vortex

- Charney Drazin criterium

$$0 \leq \bar{u} - c \leq u_c$$

$$u_c = \frac{\beta}{k^2 + l^2 + f^2/(4H^2N^2)}$$

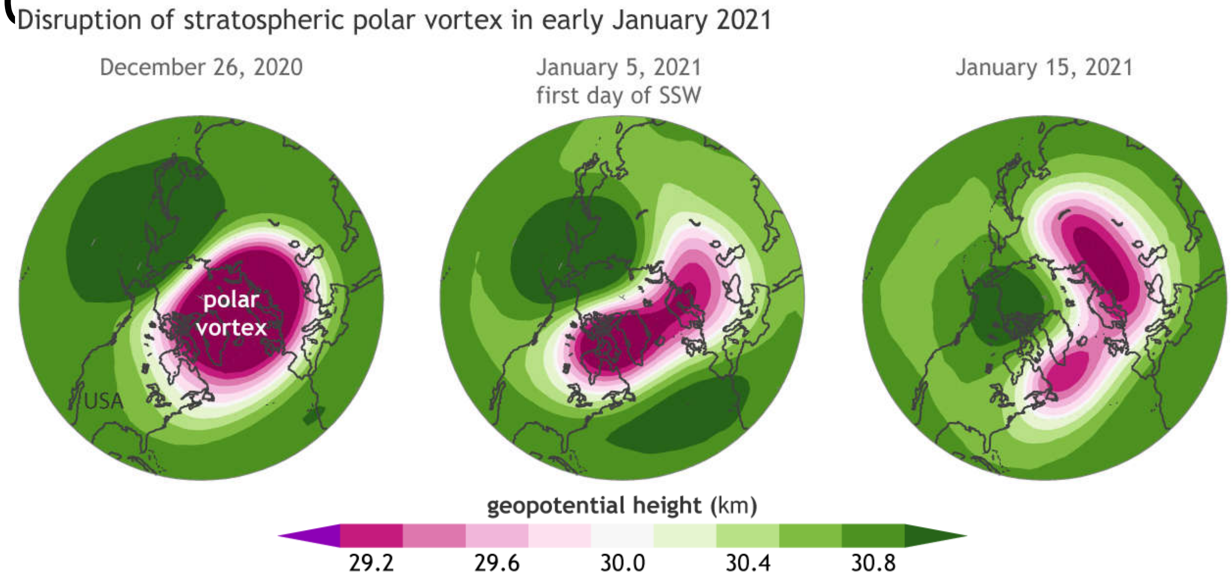
$\bar{u}$: zonal mean flow

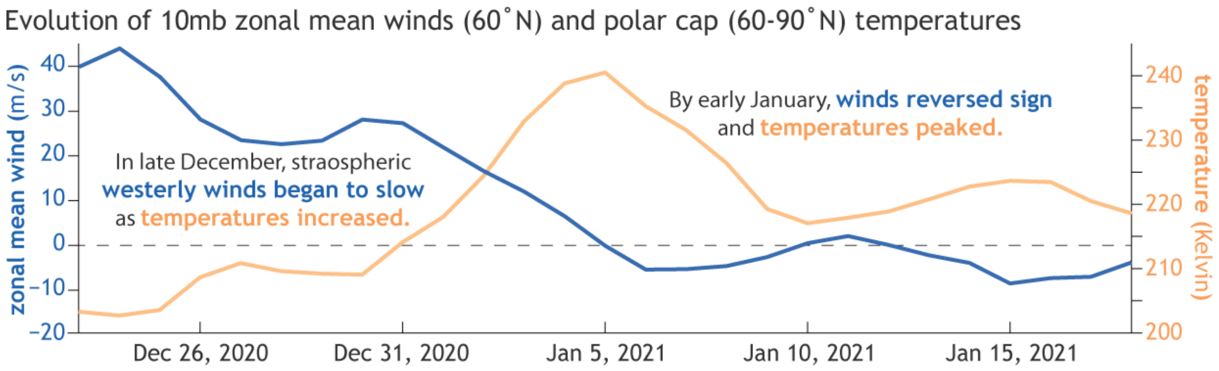
c: phase speed (c=0 for stationary waves)

u_c: critical wind speed

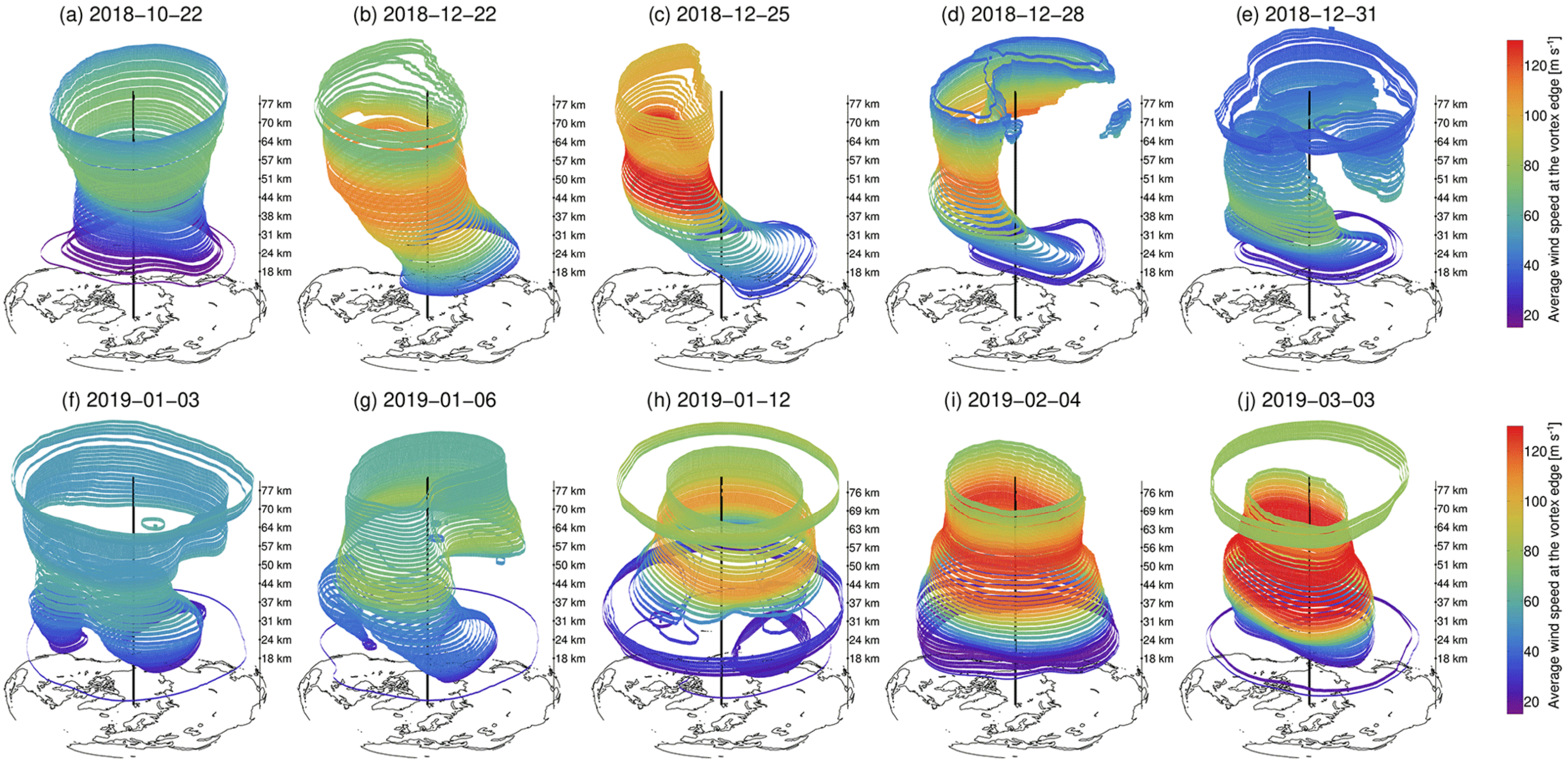
Sudden Stratospheric Warming (SSW)

- Definition at 10 hPa (~30 km altitude) at 60° latitude
- Rapid increase in polar stratospheric temperatures
- Zonal mean wind reversal
- Negative NAM
- most common in mid- to late winter
- Sudden warmings appear to descend from higher altitudes





Sudden Stratospheric Warming (SSW)



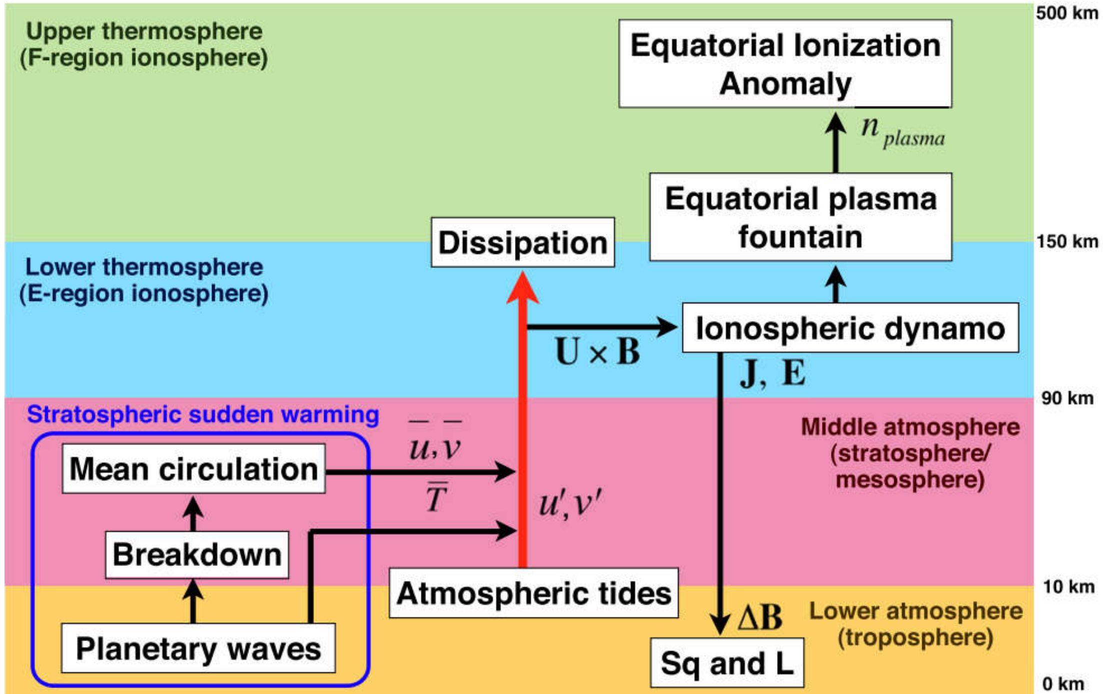
Schranz+ (2020), https://doi.org/10.5194/acp-20-10791-2020

Sudden Stratospheric Warmings

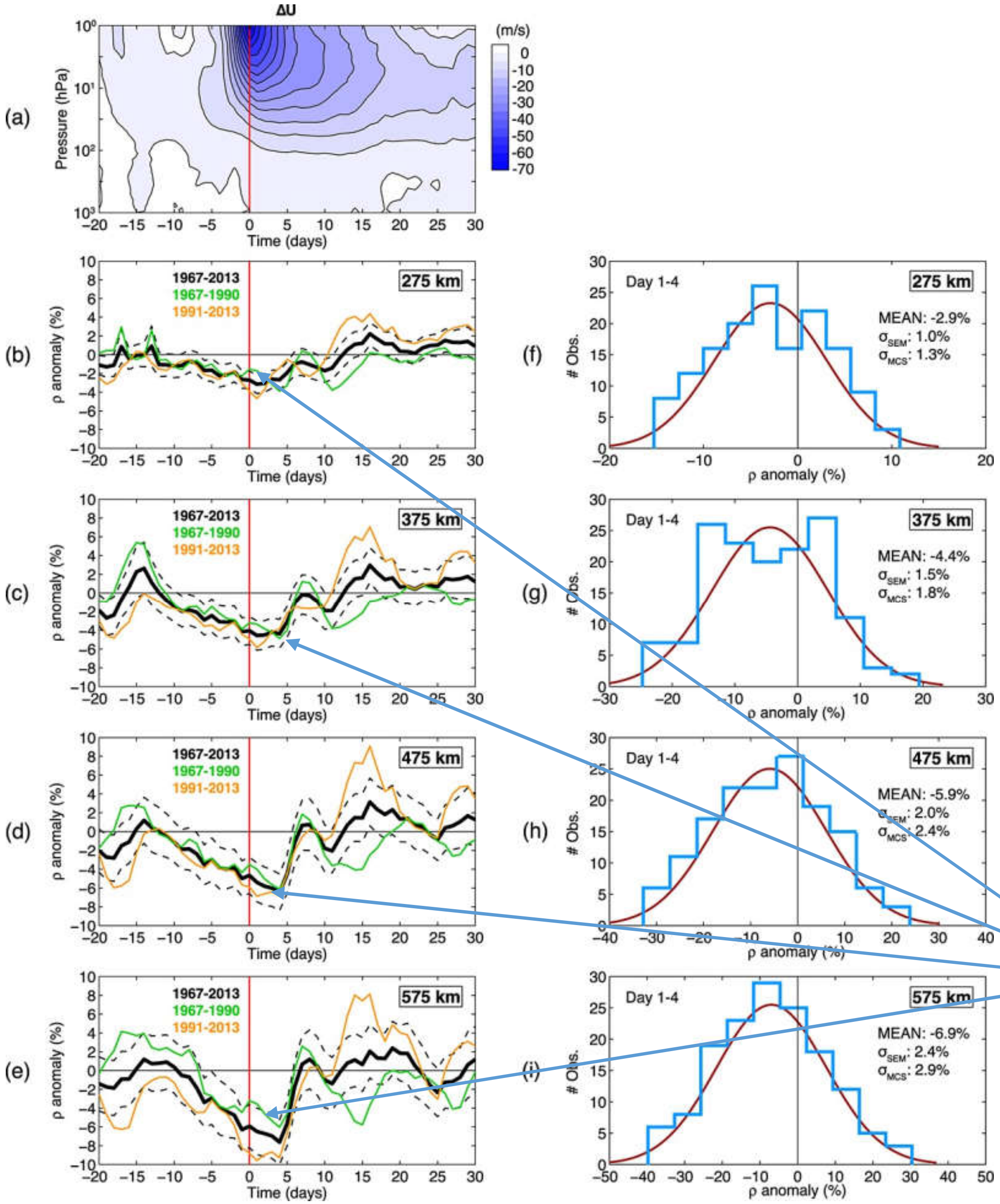
- SSWs occur primarily in the Northern Hemisphere because planetary waves that drive the formation of SSWs tend to have larger amplitudes in the Northern Hemisphere compared with the Southern Hemisphere
- strong connection between SSWs and extensive changes throughout Earth's atmosphere
- changes can affect atmospheric chemistry, temperatures, winds, neutral (nonionized particle) and electron densities, and electric fields
- changes extend from the surface to the thermosphere and across both hemispheres
- stratospheric circulation changes during SSWs modulate the spectrum of atmospheric waves that propagate upward into the mesosphere, leading to changes in the daily average wind speeds and temperatures in the upper mesosphere and lower thermosphere (80–120 kilometers above the surface)

Stratospheric Sudden Warming

- Tidal changes can result from changes in the mean flow, interaction with planetary waves, and changes in the tidal sources
- Numerical studies have shown that an amplification occurs in both solar and lunar semidiurnal tides at dynamo-region heights in response to stratospheric sudden warmings
- During SSW, dynamo-region electric fields are disturbed due to enhanced solar and lunar tidal forcing
- The tidal changes during SSWs alter the equatorial electrojet as well as the global solar quiet current system
- changes in the equatorial electrojet strength is closely related to changes in the F-region electric field and plasma density
- modulation of the equatorial plasma fountain



Yamazaki & Maute (2017)

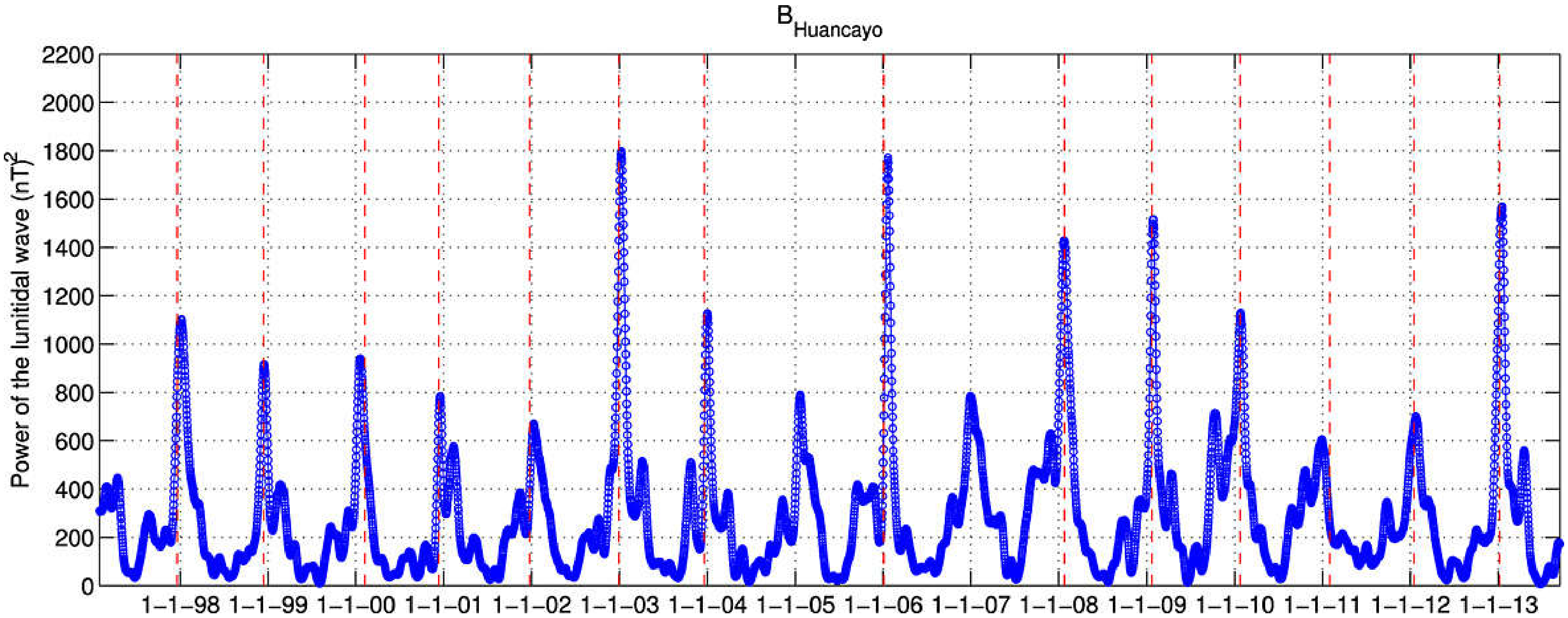


SSW impact on the ionosphere

- SSWs also drive variations in the composition, density, temperature, and winds of the upper thermosphere
- The electron density variability during SSWs is of a magnitude similar to that of a moderate geomagnetic storm [*Goncharenko et al.,* 2010]
- Reduction in the thermosphere density and temperature during SSWs [*Yamazaki et al.,* 2015]

Yamazaki et al., 2015, https://doi.org/10.1002/2015GL065395

SSW impact on the magnetic field



The power of the lunar tidal wave in HH at Huancayo (12.0° S, 75.3° W) during 1997–2013. The *vertical red lines* denote the days for the peak polar vortex weakening. From Siddiqui et al. (2015, doi:10.1002/2015JA021683)