The s=0 Atmospheric Oscillations in 35-Year MERRA Zonal Wind and Temperature

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Acknowledgment

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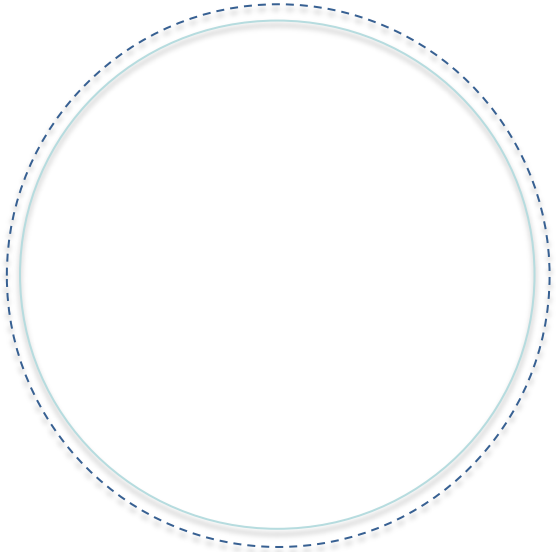
Motivations

- What are Earth's atmospheric responses to the solar forcing variations?
- How are these responses coupled between the lower and upper atmospheres (with focus on dynamical coupling)?

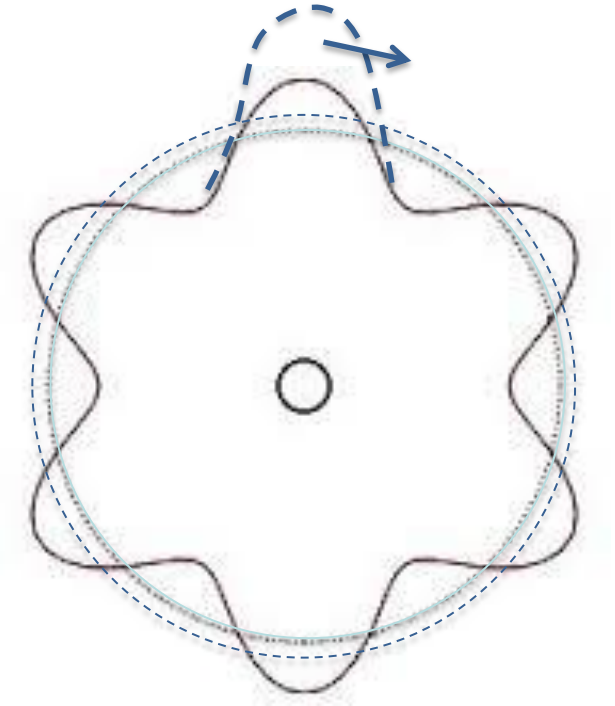
- How much is the 11-year variation in the MERRA reanalysis data?
- What are the impacts of other internal variabilities on the solar signal seen in the atmosphere?

Introduction

Changes in zonal mean state or wavenumber (s=0)

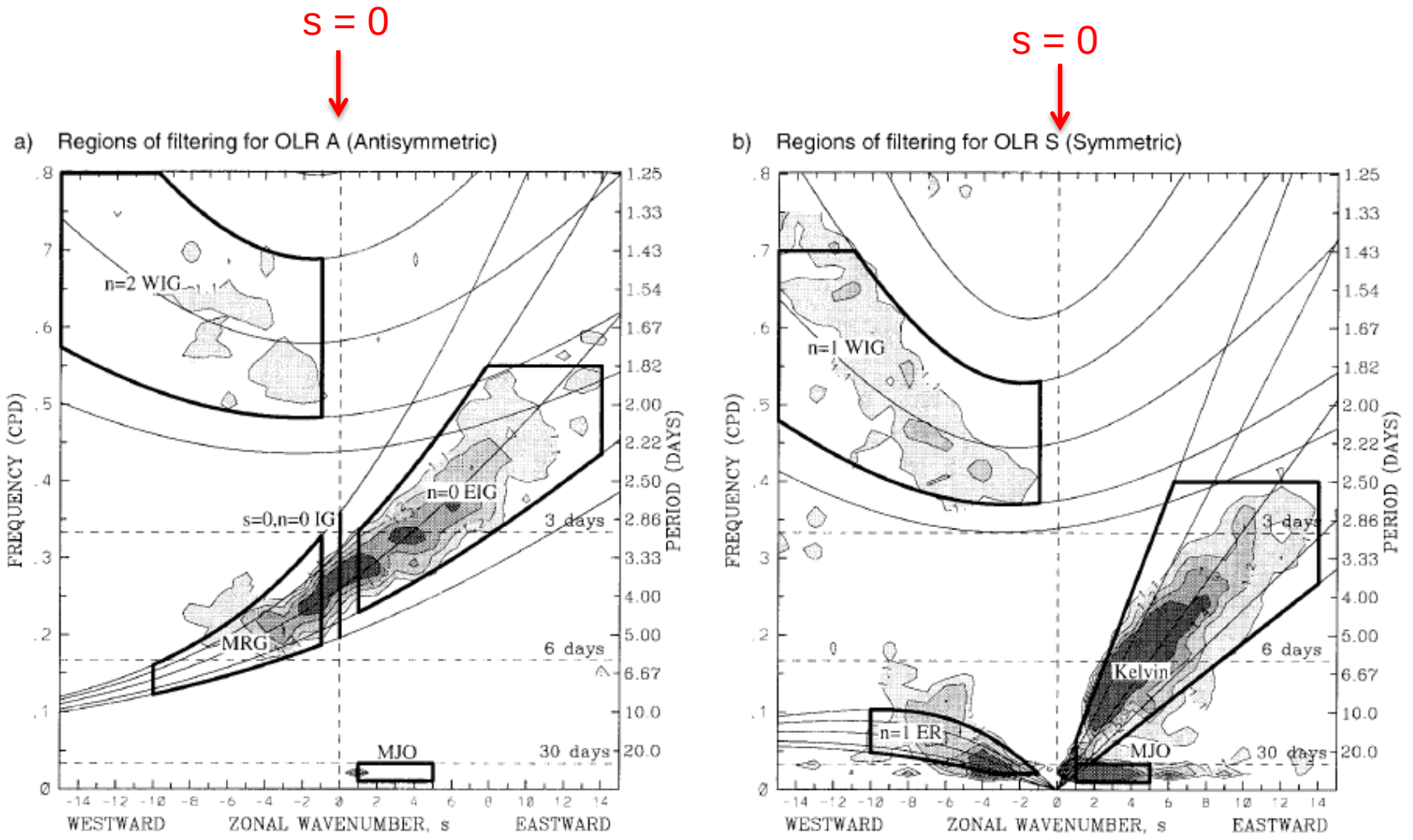


Beating in time



Wave Processes

Wavenumber-Frequency Diagram



Wheeler et al. (2000)

Oscillations Driven by Solar and Internal Forcings

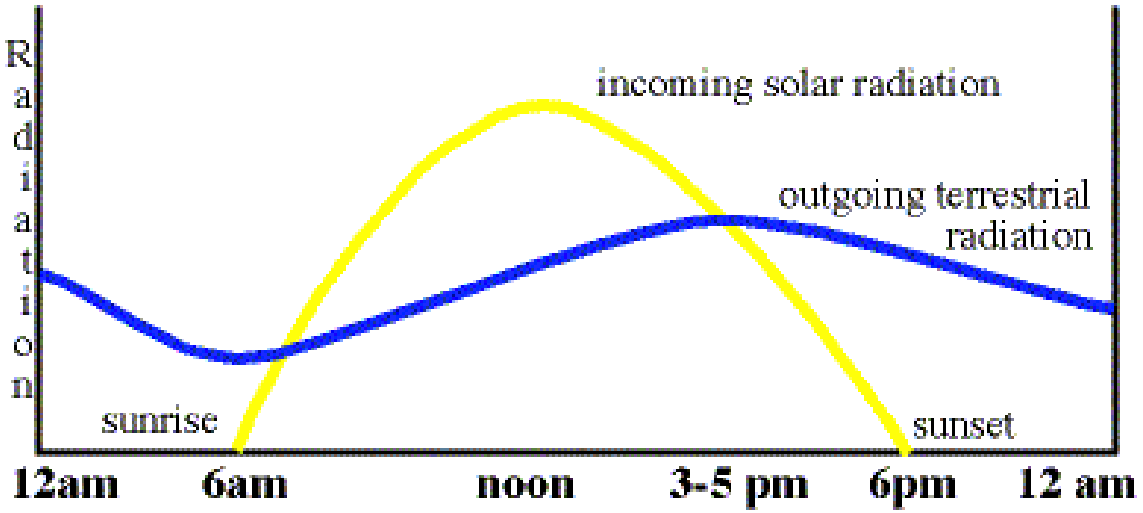
Related directly to solar forcings

- Diurnal
- Semidiurnal
- 27-day Cycle
- Annual
- Semiannual
- 11-year Cycle
- …

Related to internal variabilities

- Quasi Two-Day Wave
- Mixed Rossby Gravity Wave
- Madden-Julian Oscillation
- Quasi-Biennial Oscillation
- El Niño-southern oscillation
- …

Decomposition of Wave Components



- Non-sinusoidal
- Non-linear or lagged responses
- Wave-wave interference or interactions
- Red background

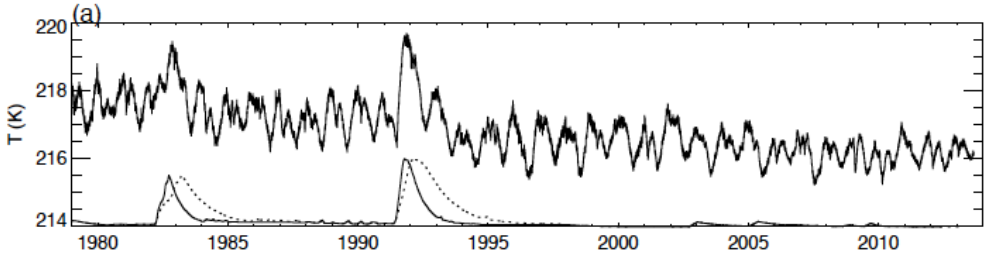
MERRA Reanalysis Data

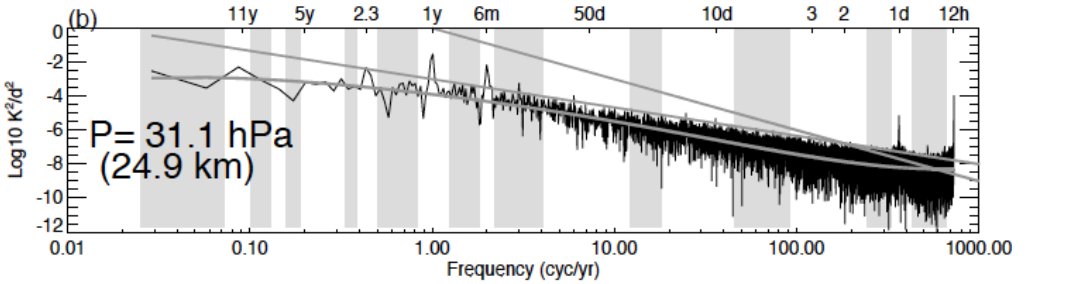
- 1979-present
- Model top = 0.01 hPa and 72 pressure levels;
- This study: 1000-0.1 hPa
- 6 hourly outputs -> resolving the semidiurnal variation
- 0.5° x 0.67° Lat-Lon resolution

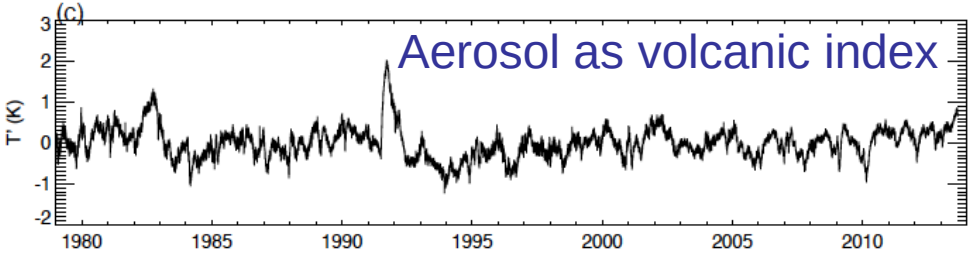
Trend and Volcanic Effects

- Linear trend
- Volcanic effects:
  memory and delay

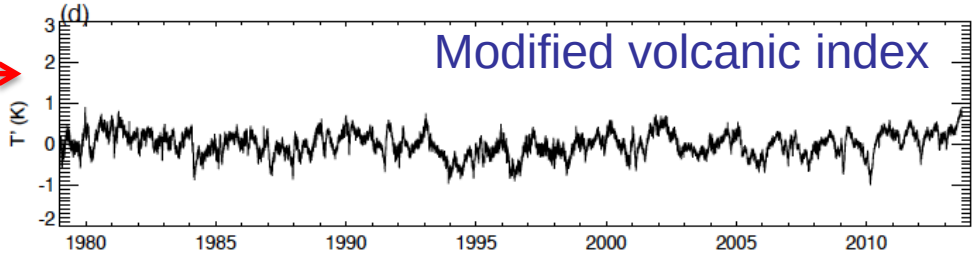
- Memory effect
  - Aerosol index not good for dynamic response
- Delay in the upper-atmos
  - Lagging in responses
  - Different memory length







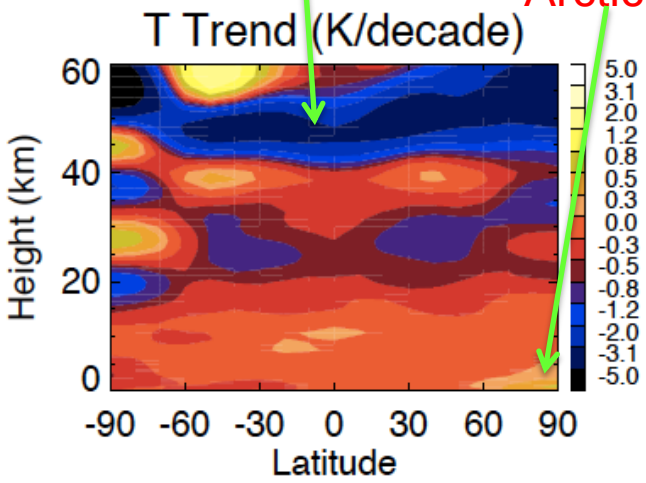
Annual cycle removed →

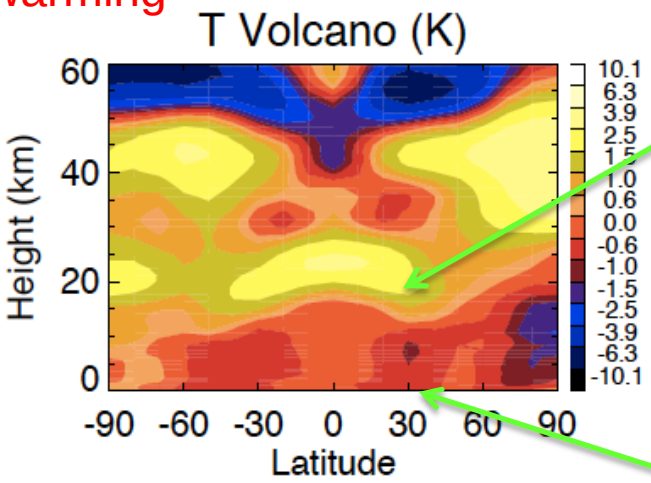


Trend and Volcanic Amplitudes

Mesospheric cooling

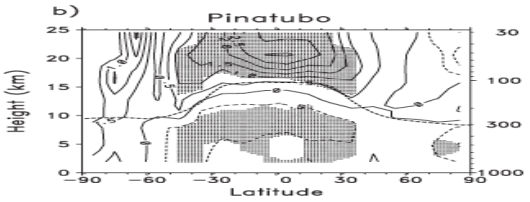
Enhanced Arctic warming



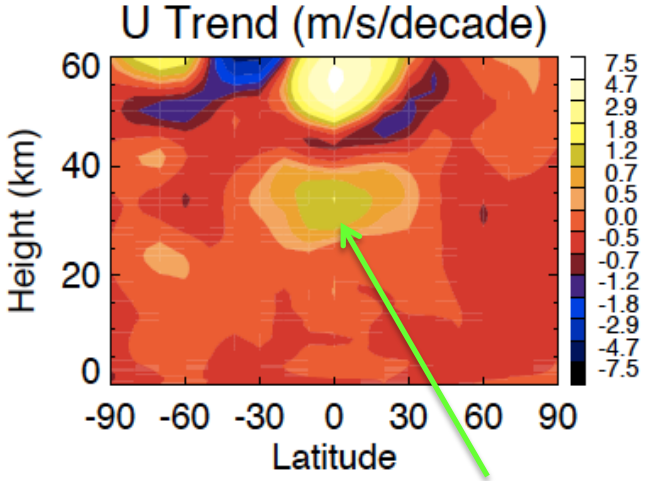


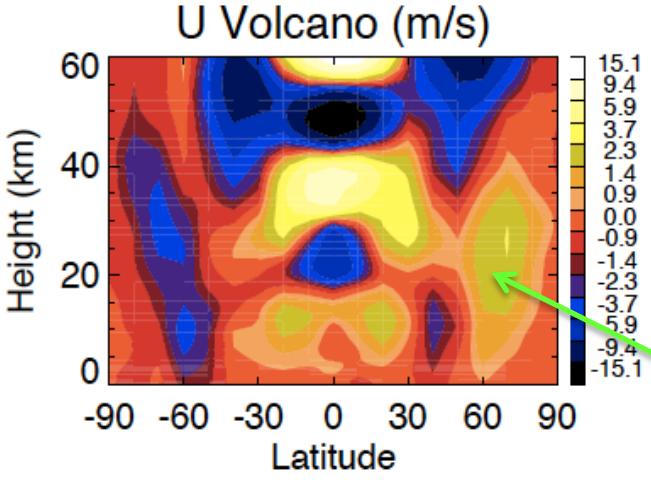
Stratosphere warming

Randel (2010)



Surface cooling



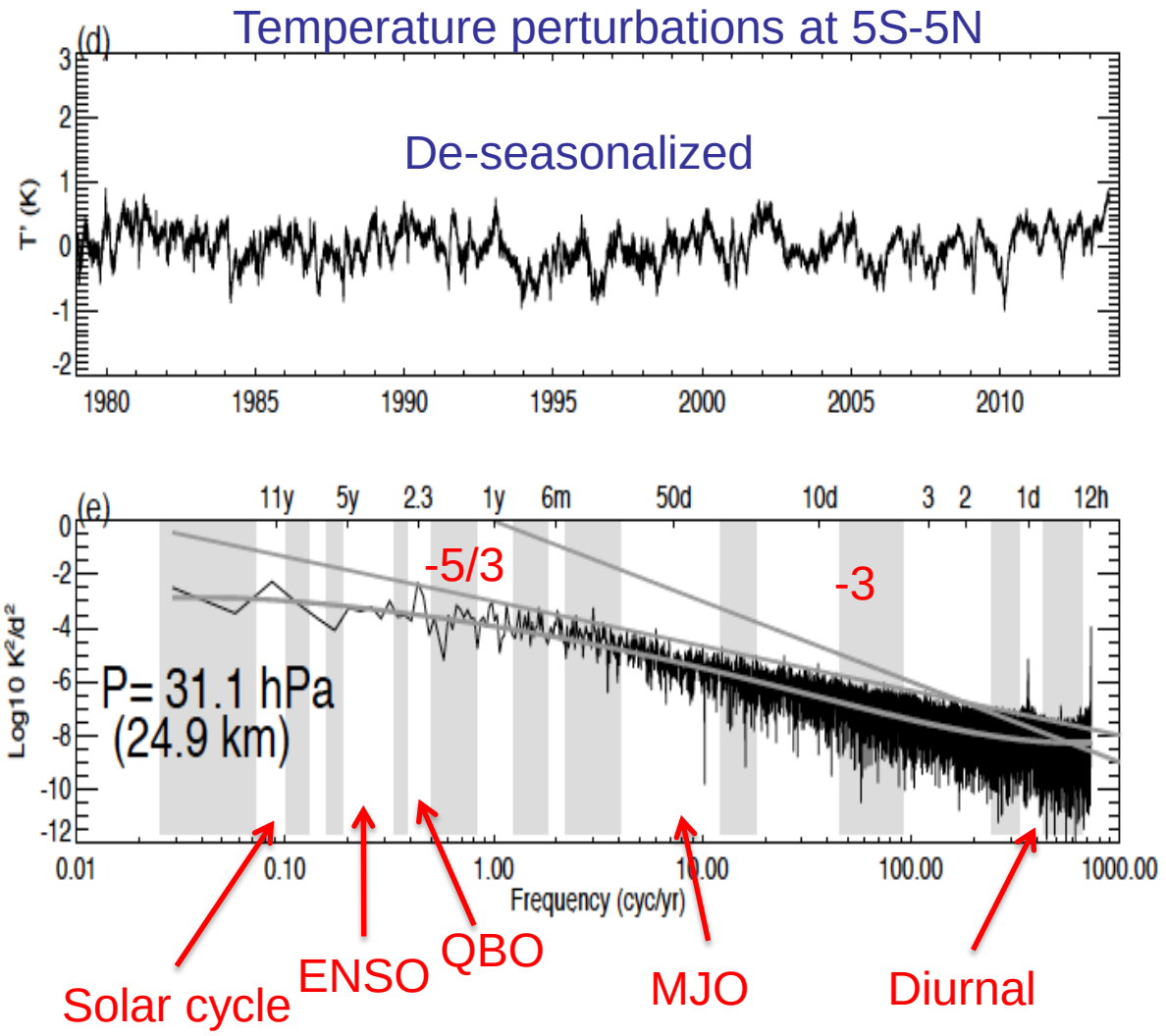


Stronger polar jet

Stronger strat jet

Red Background in Power Spectra (1/2)

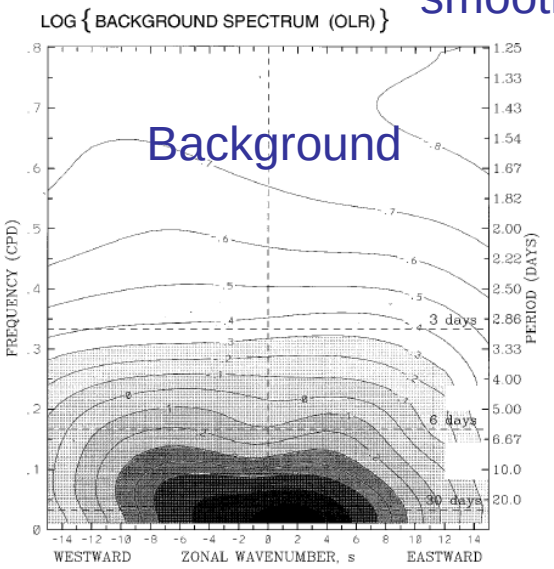
- De-seasonalizing to remove the annual and semi-annual
- Polynomial fit to obtain the red background
- Mini-bands for major atmospheric oscillations
- SNR = (band power)/bg



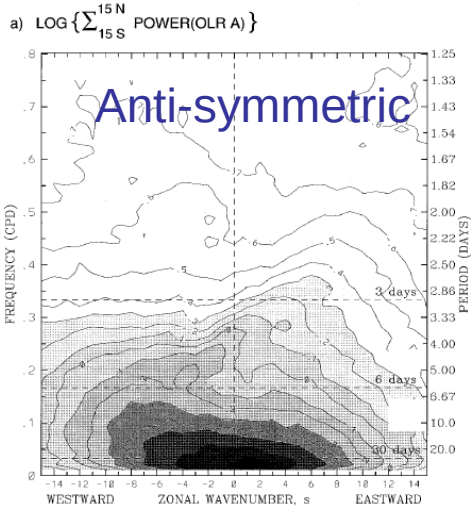
Red Background in Power Spectra (2/2)

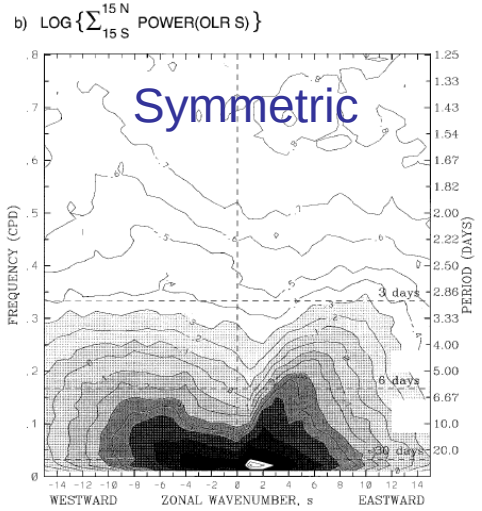
Wheeler et al. (1999)

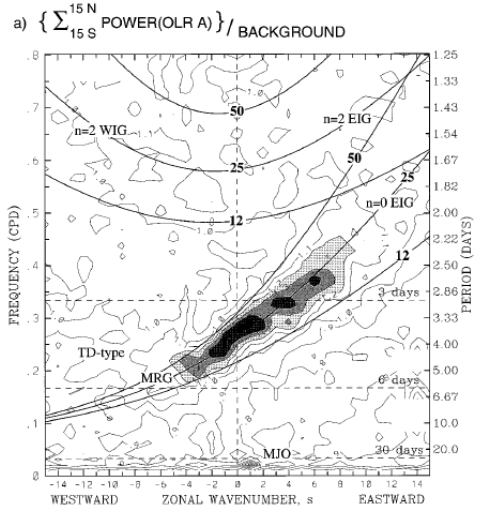
1-2-1 smoothing

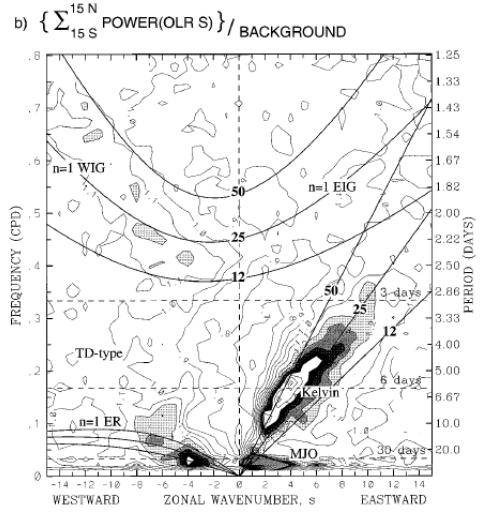


Background removal



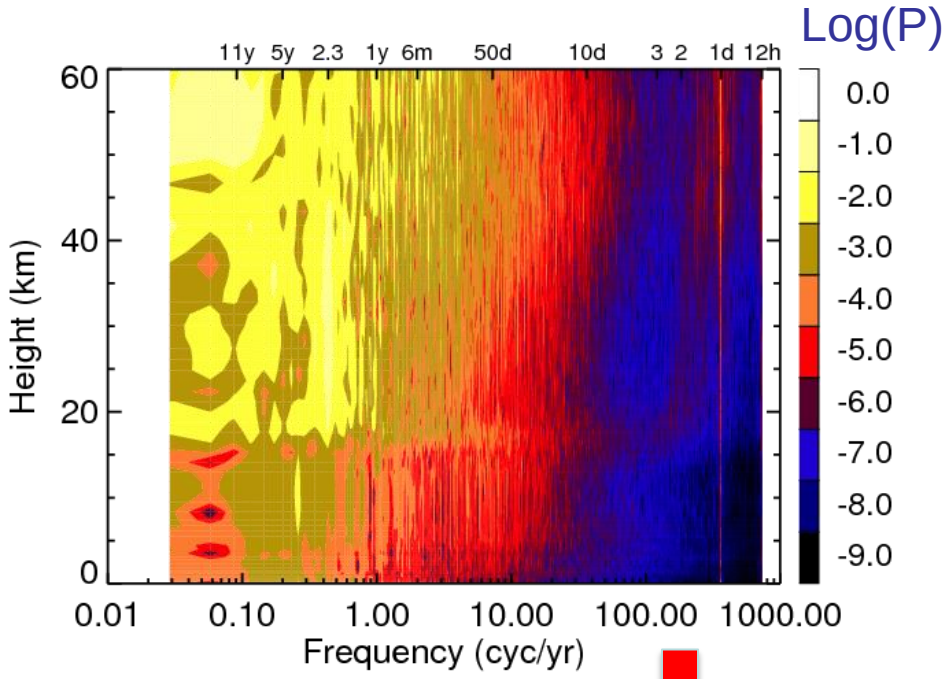


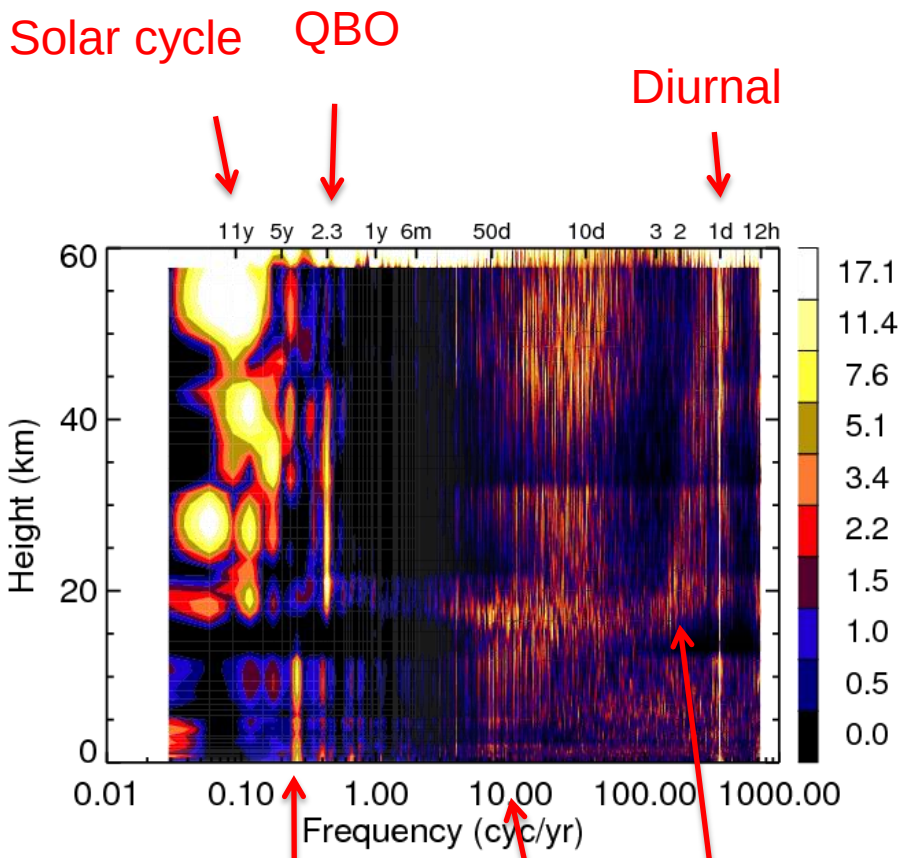




MERRA Temperature Spectra

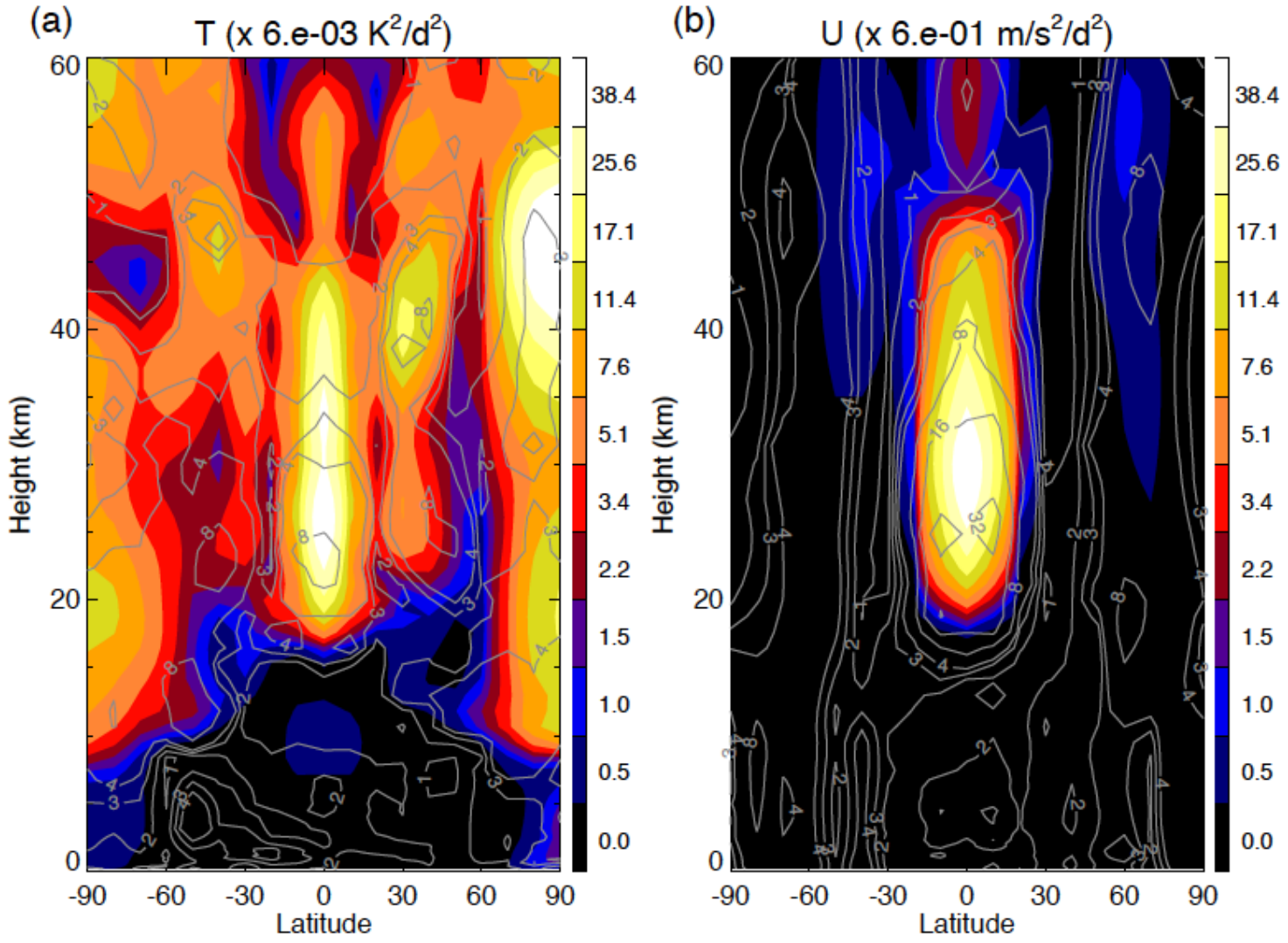
Latitude = 5° S – 5° N





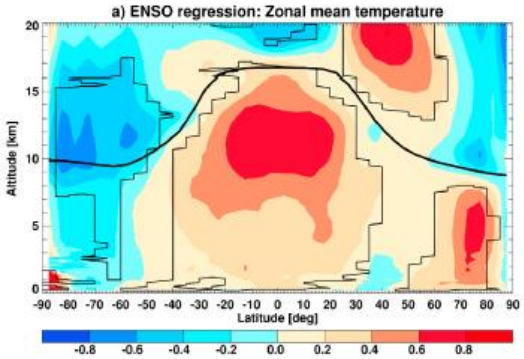
Red background removed

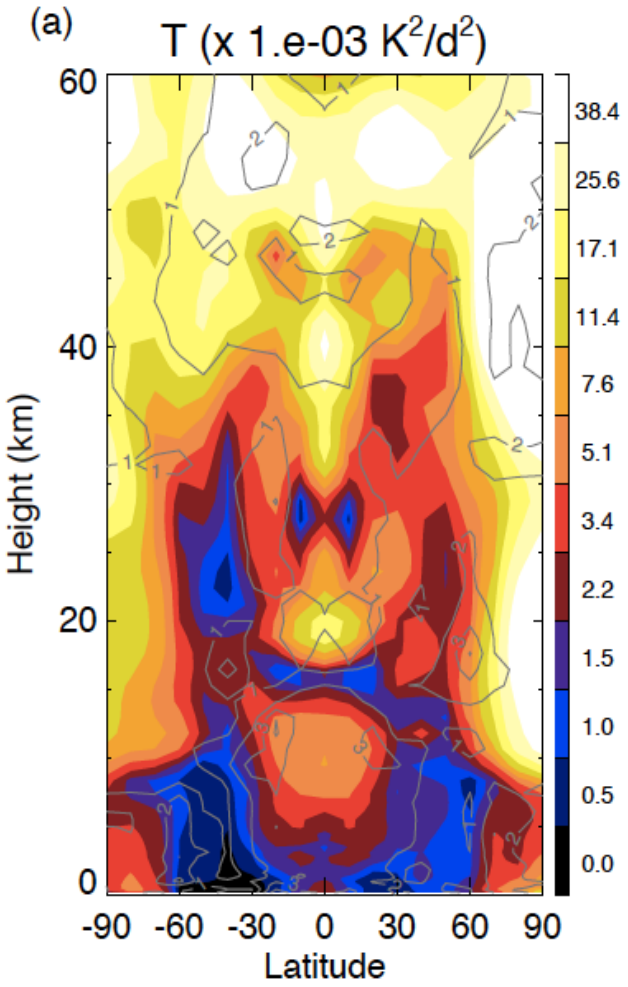
QBO (2.0y-2.6y) Amplitude

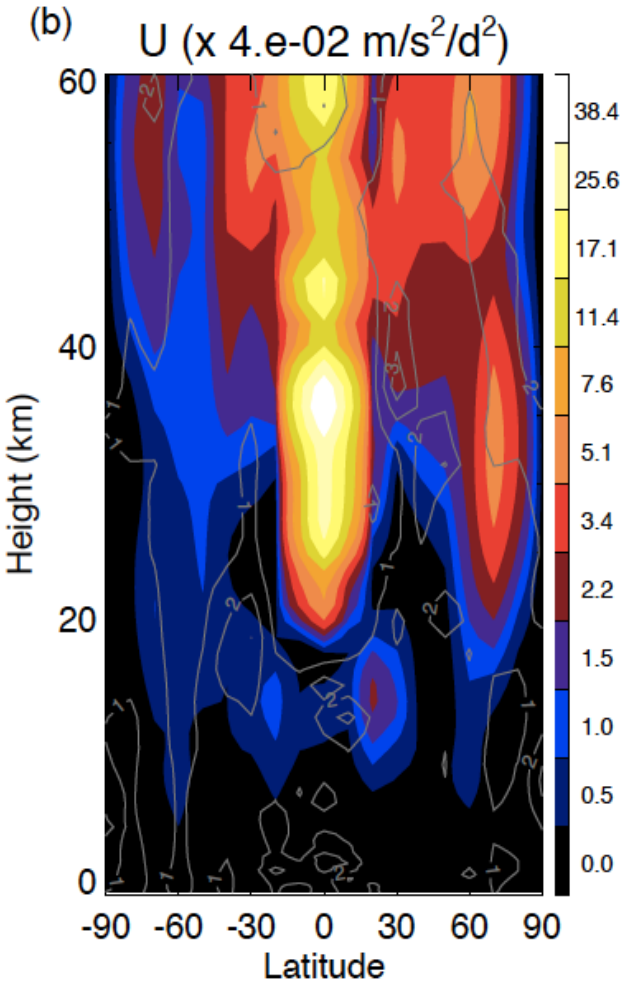


ENSO and Quasi-Quadrennial Oscillations (3.0y-5.3y)

GPS-RO data
Scherllin-Pirscher et al. (2012)

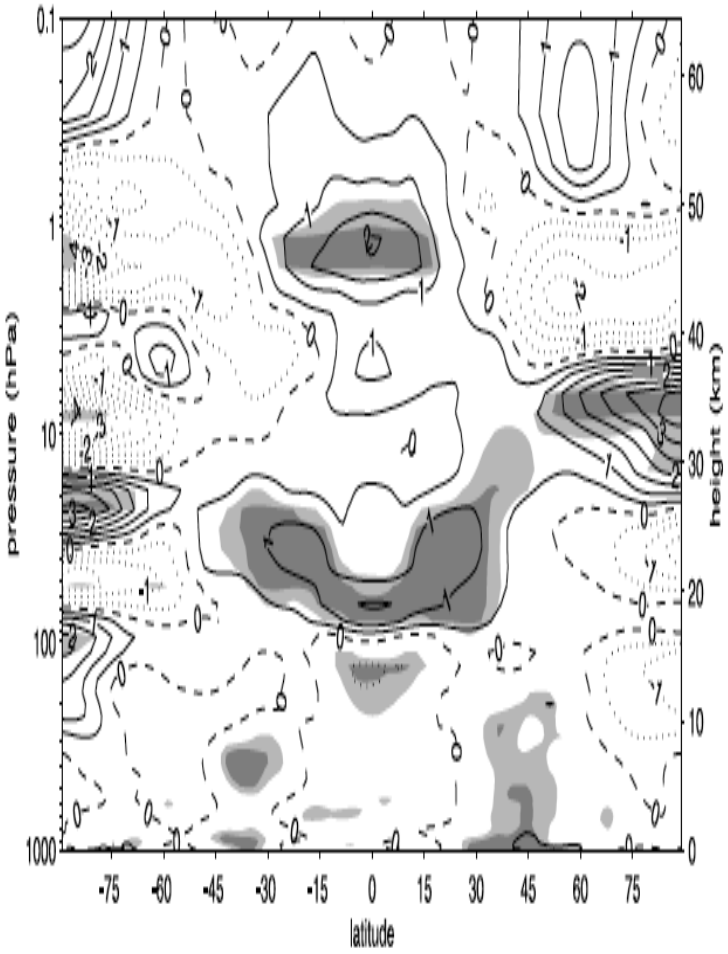




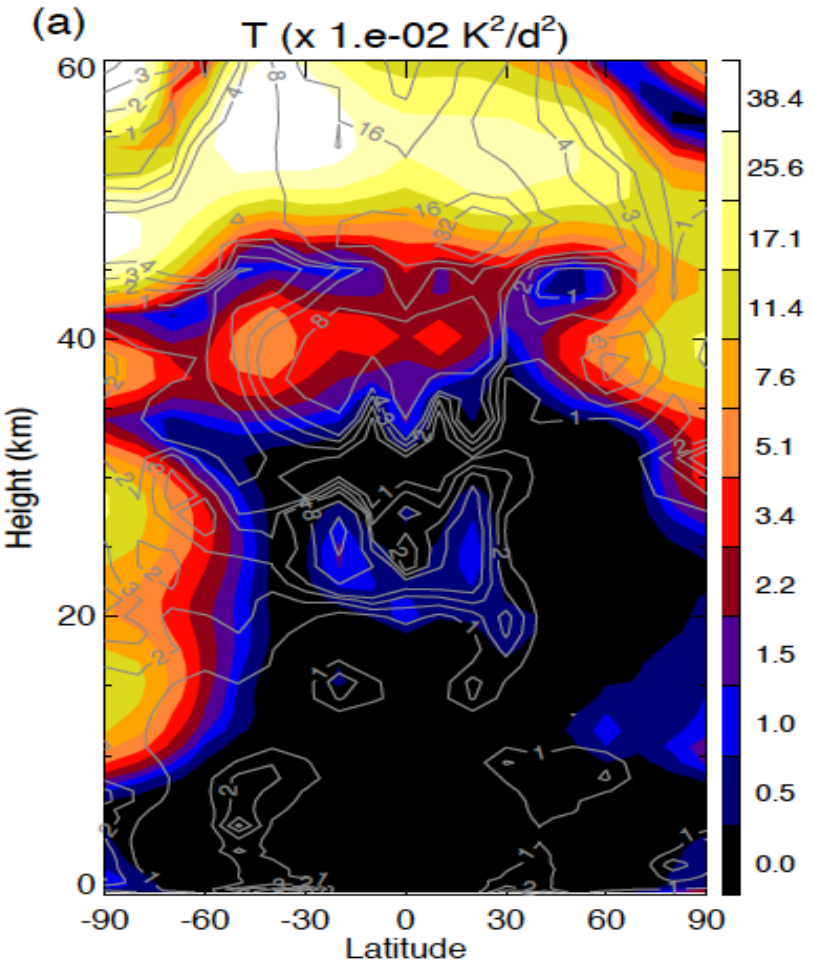


11-yr Solar Cycle (10y-14y) Temperature

ERA40
Frame and Gray (2010)

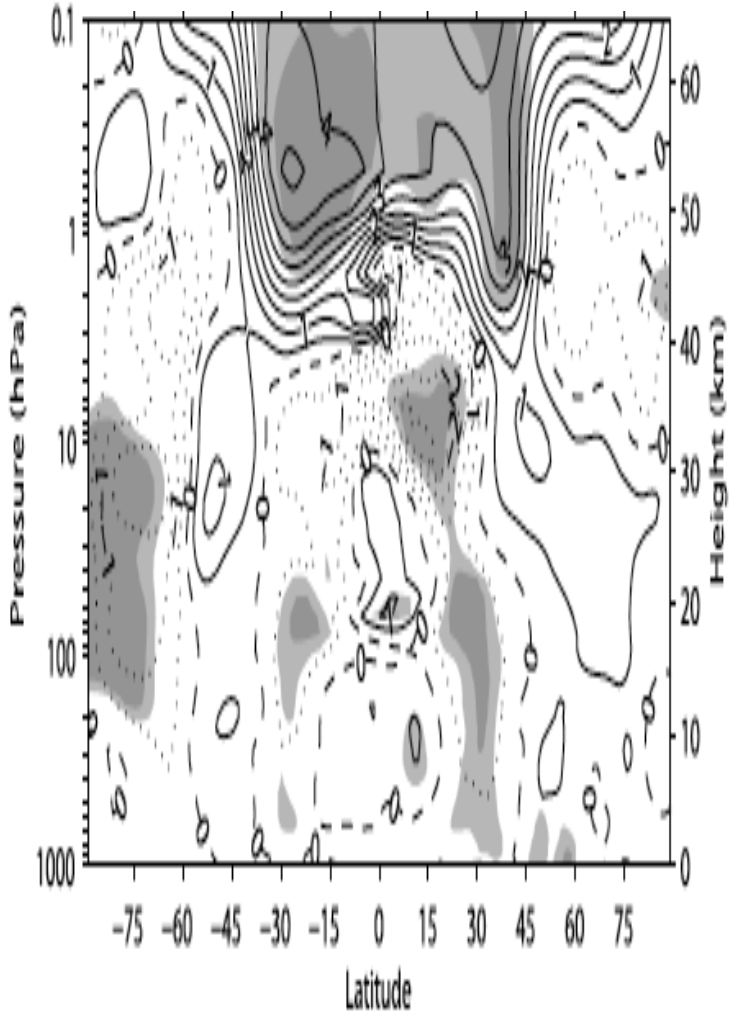


MERRA (1979-2013)

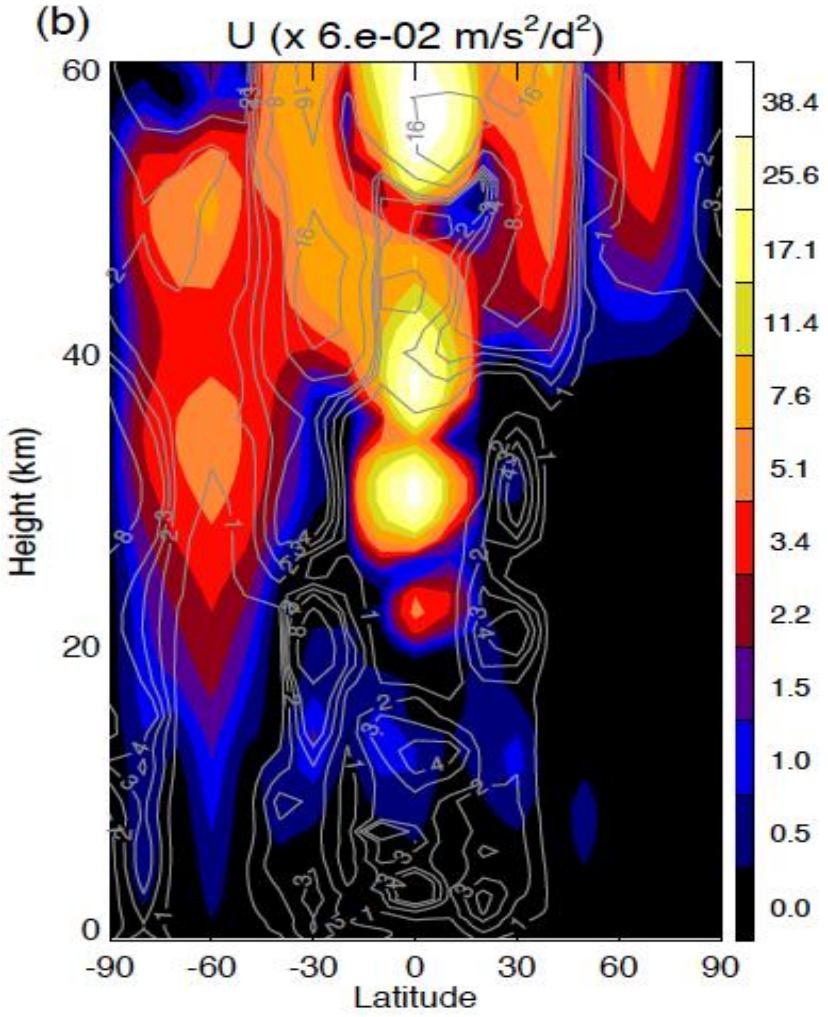


11-yr Solar Cycle (10y-14y) Zonal Wind

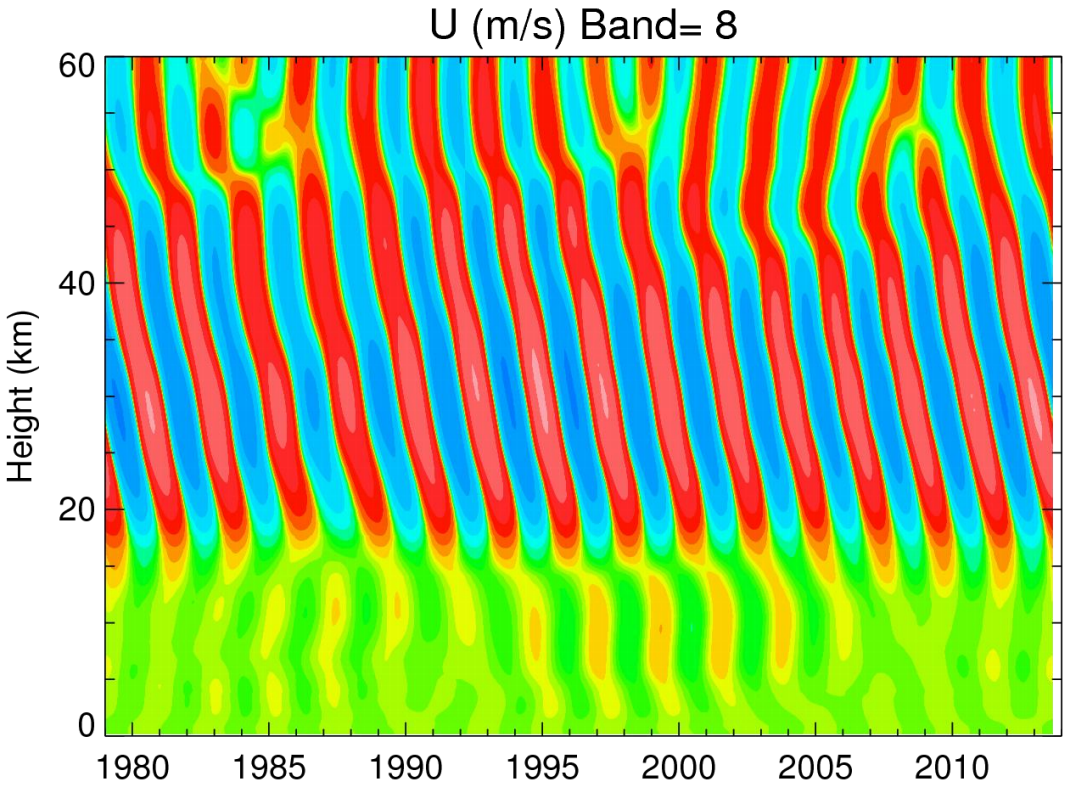
ERA40
Frame and Gray (2010)

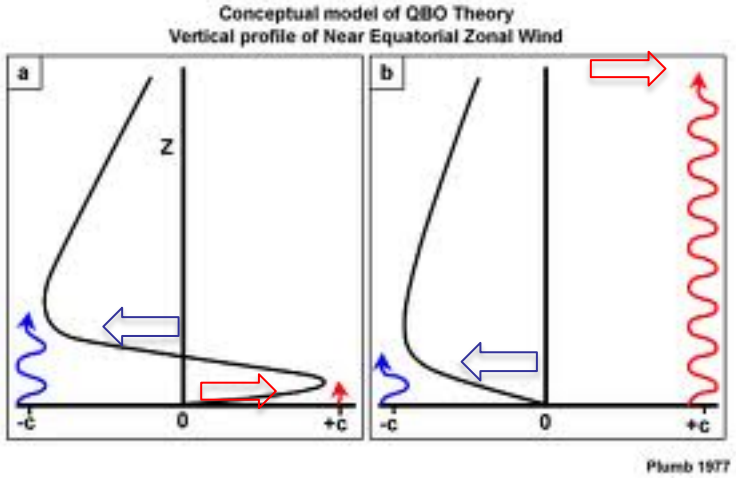


MERRA (1979-2013)



Equatorial QBO

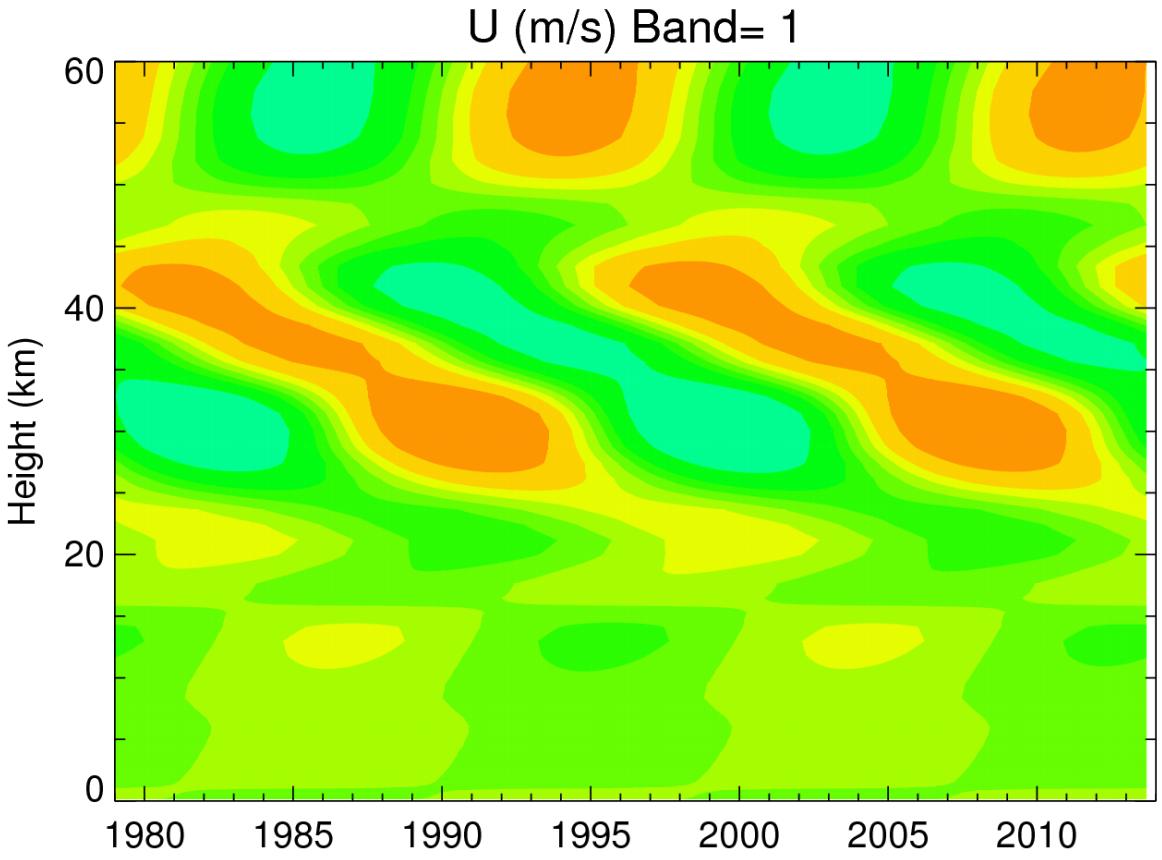




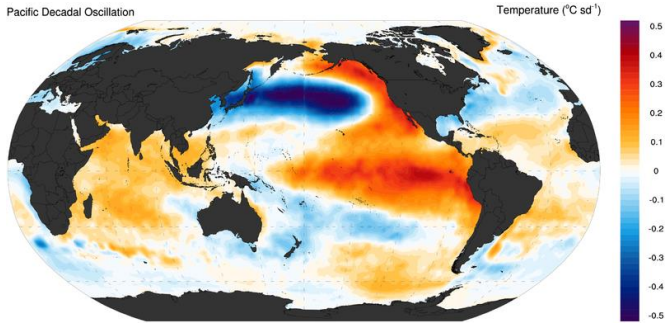
Lindzen and Holton (1968)

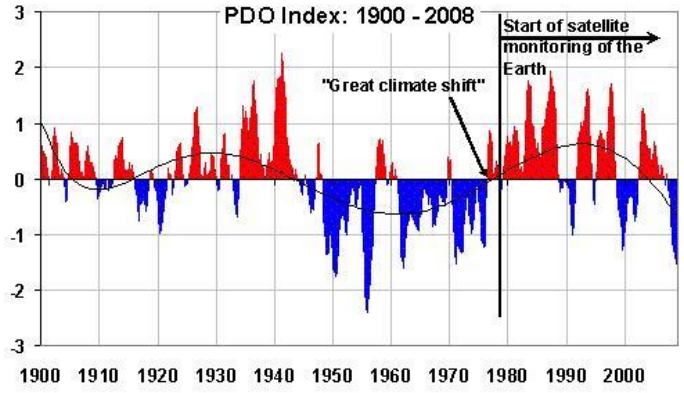
- Wave-mean flow interaction
- Two competing wave forcings in opposite directions
- Eastward: Kelvin waves
- Westward: MRG and ???

Equatorial Bi-Decadal Oscillation (BDO) (14+ Years)

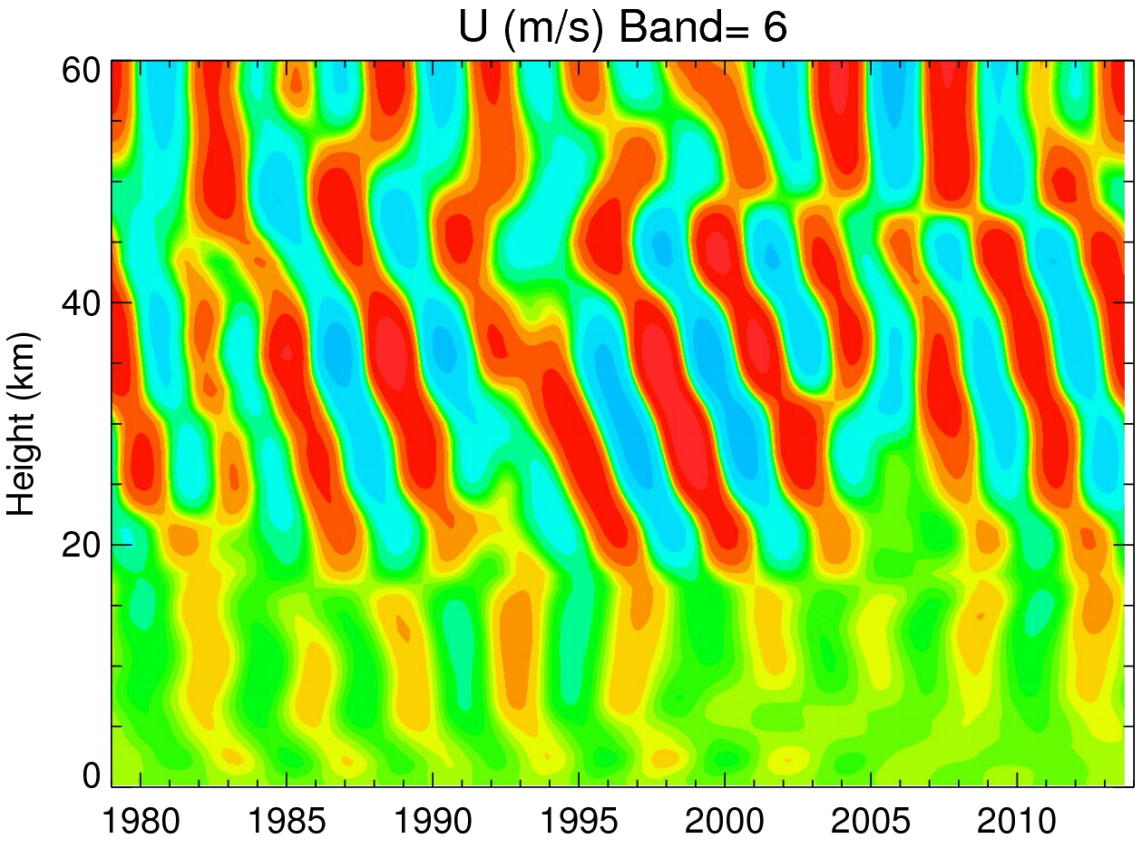


- 19-yr lunar-solar tide [Royer, 1989]
- 22-yr Hare solar cycle [Cook et al., 1997]
- Ocean variability [Ghil and Vautard, 1991]



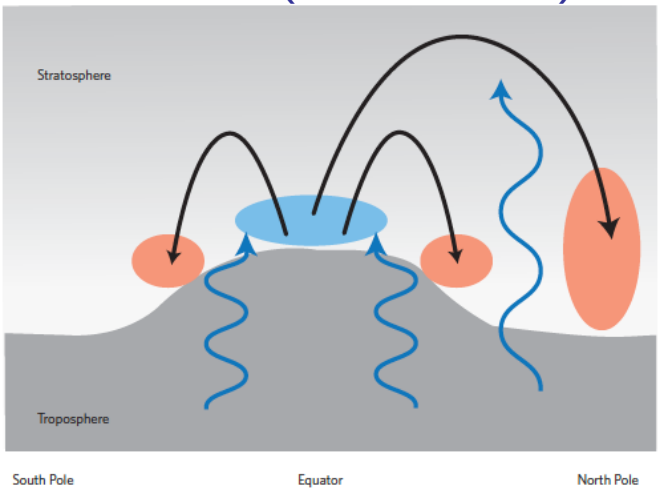


Equatorial 3y-5.3y Variations: ENSO and Quasi-Quadrennial Oscillation (QQO)

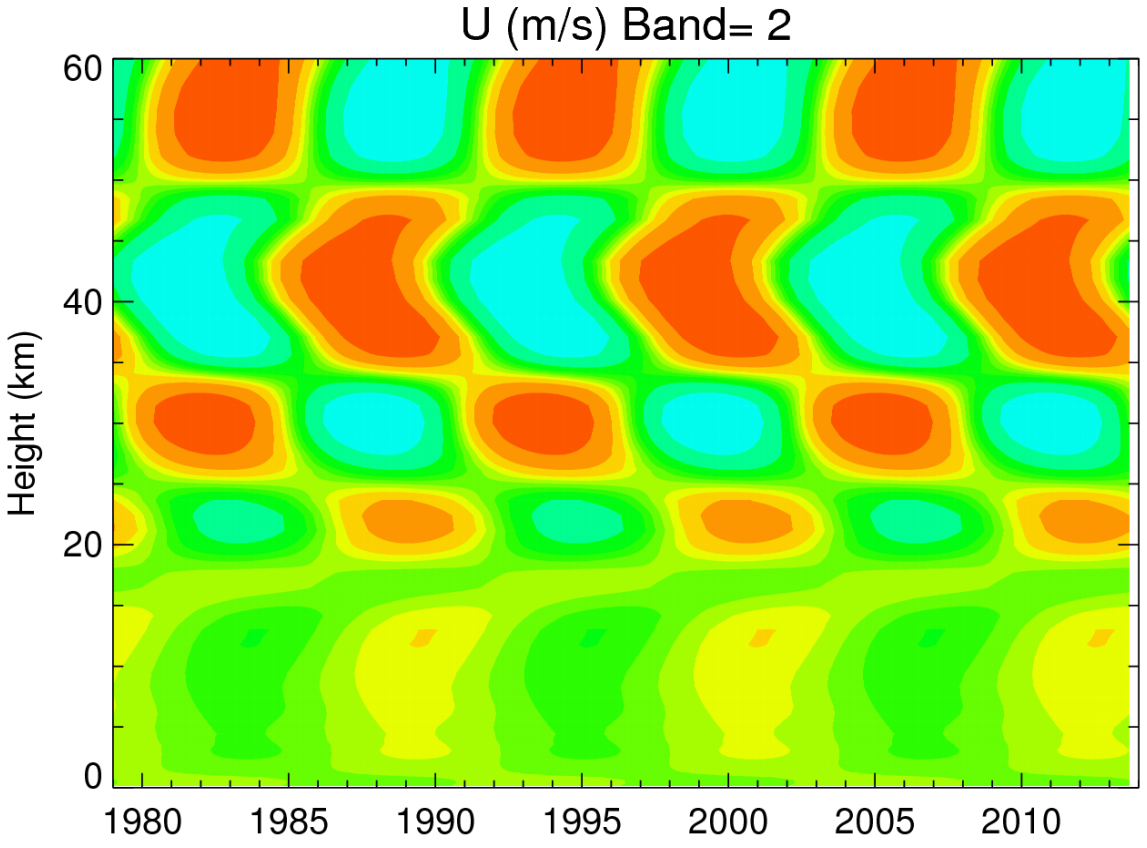


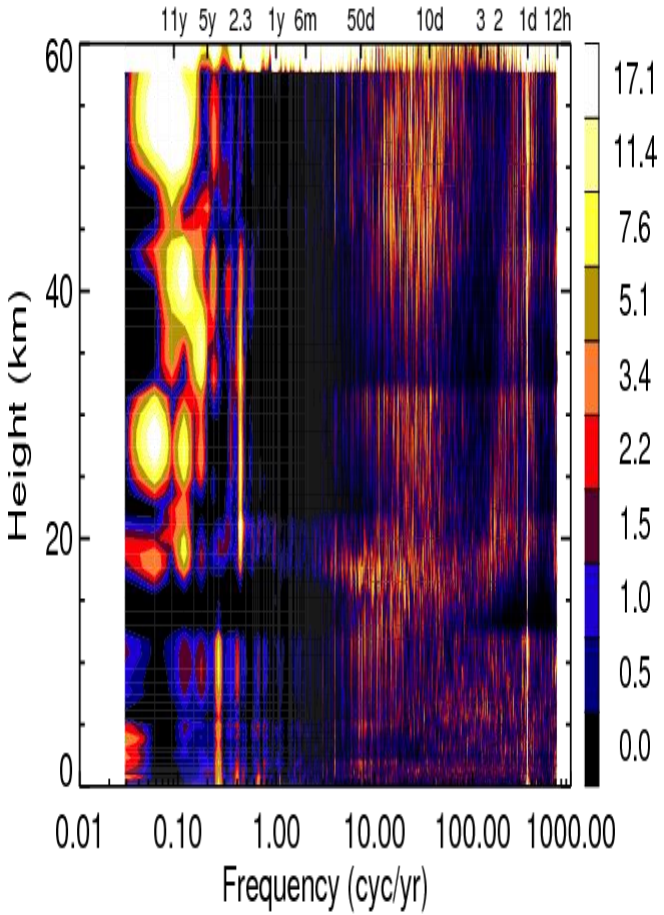
- Strengthened Walker circulation at Smax [Meehl et al. 2008]
- Impact on stratosphere via Rossby waves [Calvo et al., 2008; Li and Lau, 2013]

Manzini (Nature 2009)



Equatorial 11y-14y Variations
Quasi-Decadal Oscillation (QDO)





- Modeling QDO with the 11y solar forcing [White et al., 1997]
- Observational study [van Loon and Labitzke, 1988]

Summary

- The 11-year variations in MERRA data: more prominent in T than in U
- Artificial layering or jumps in wave amplitudes in the reanalysis data associated with model levels
- Blue shifting in equatorial wave frequency spectra (e.g., 50d ->10d, 2d->1d)
- Downward progression of equatorial oscillations (incl. QDO): suggesting the wave-mean flow interaction theory (Lindzen and Holton, 1982) for a broad range of wave spectra.
  - Wave sources in the troposphere
  - Wave-mean flow interactions in the strato/meso