# The abrupt seasonal transition of the Northern Hemisphere general circulation: Mechanisms and future changes

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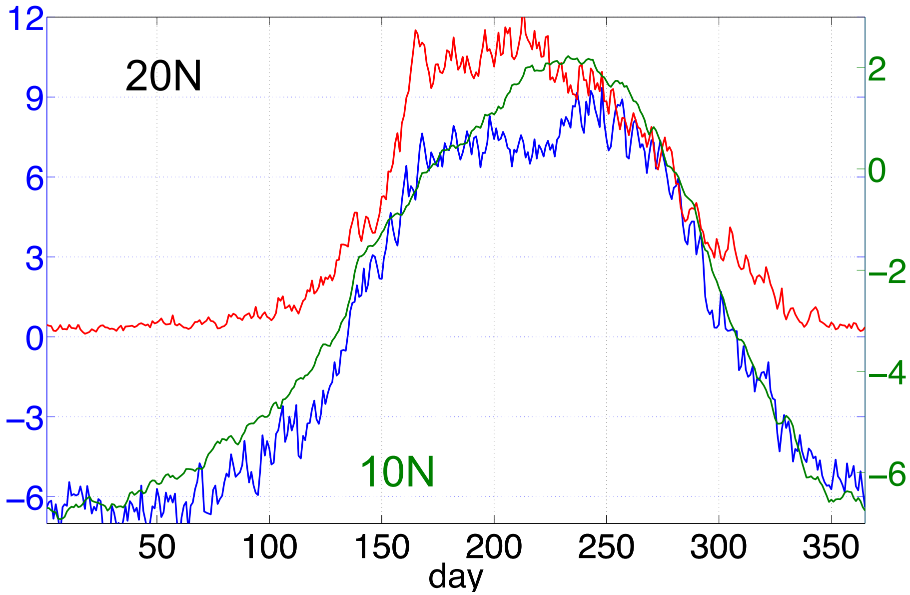
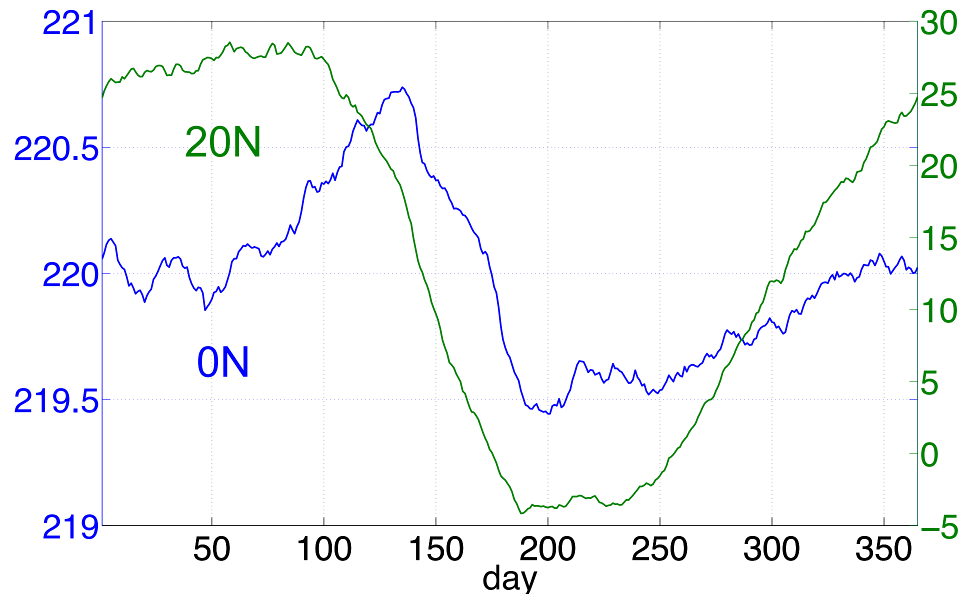
# The NH seasonal transition

Precip. (mm/day) U (m/s) W (mm/s) 900hPa

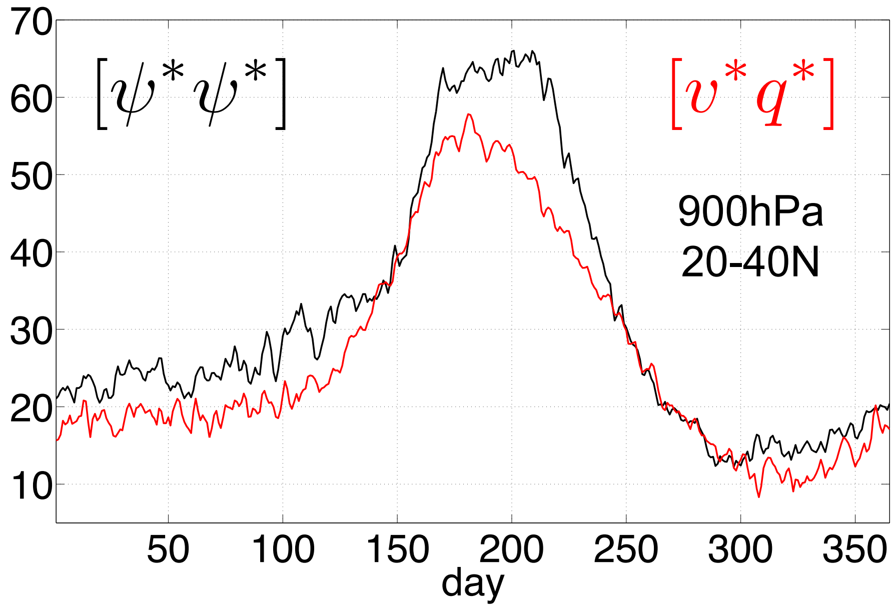


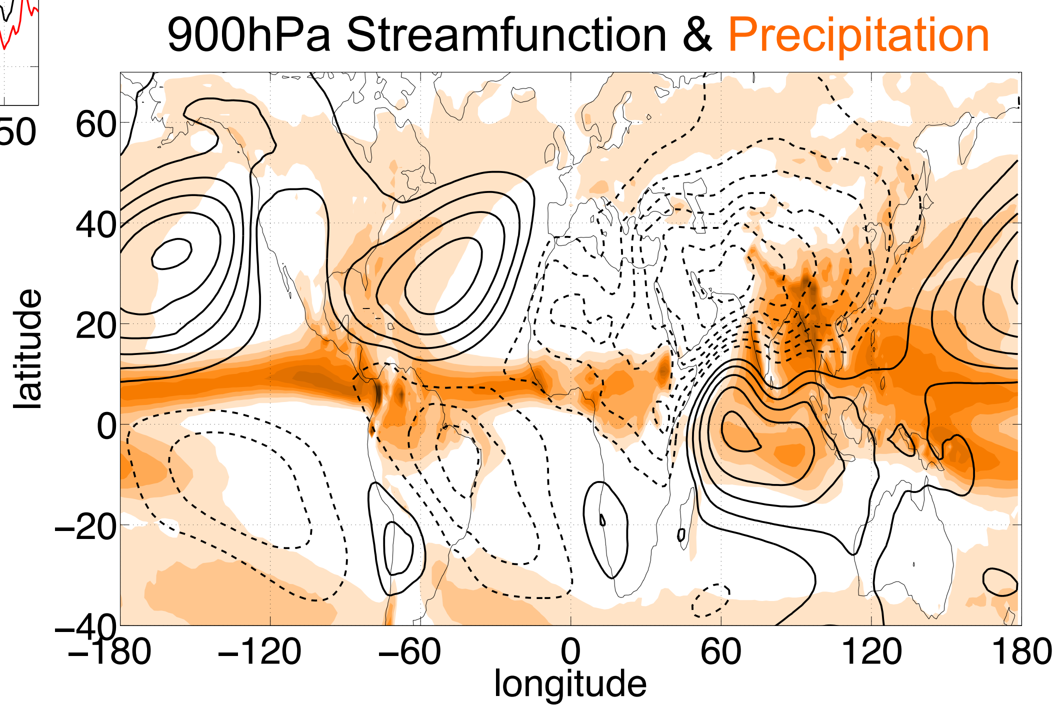

ERA-Interim data 1979-2012

U (m/s) T (K) 200hPa

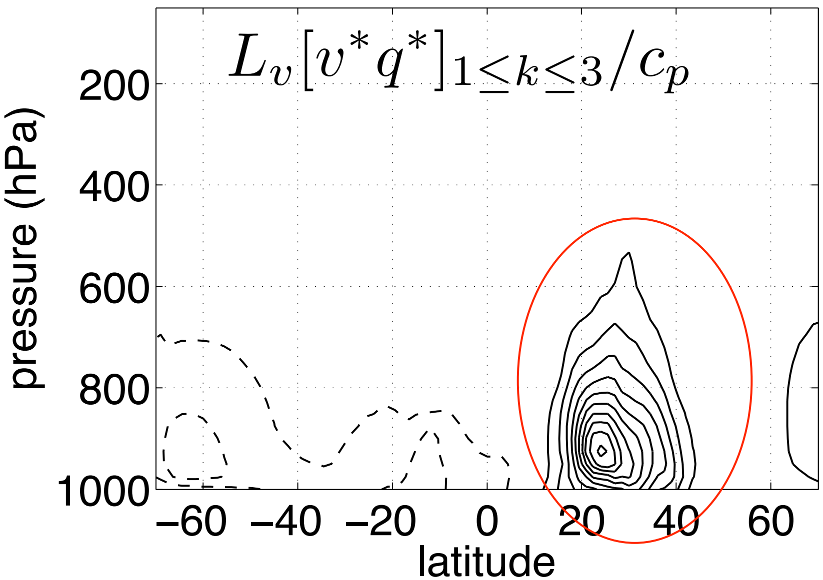


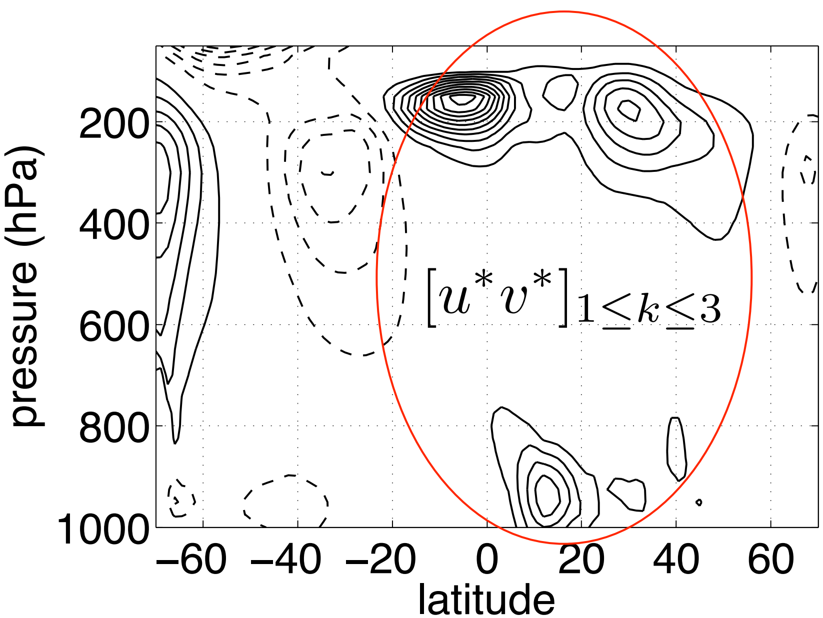
# Transition coincides with organization into land cyclones oceanic anticyclones

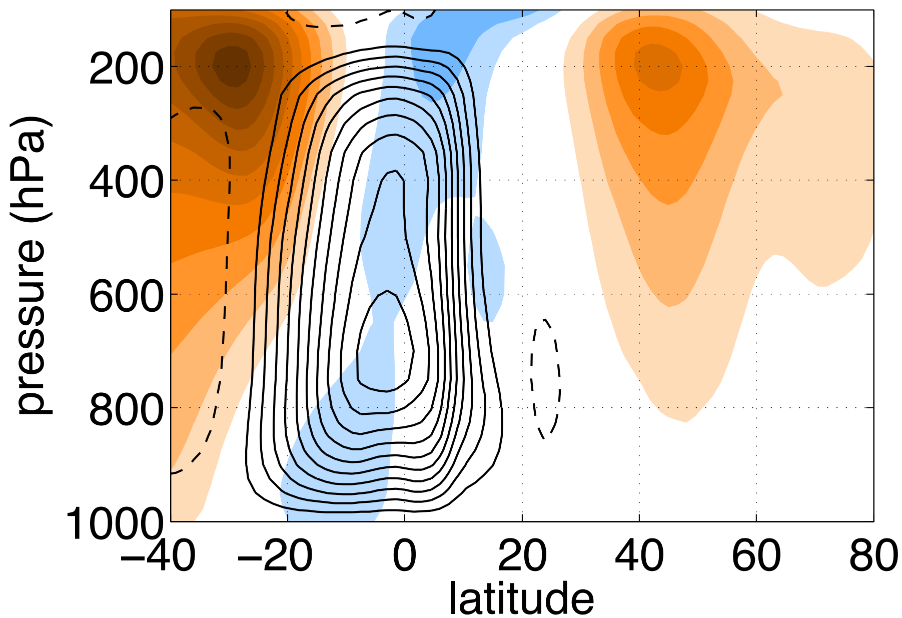


# Summer circulation



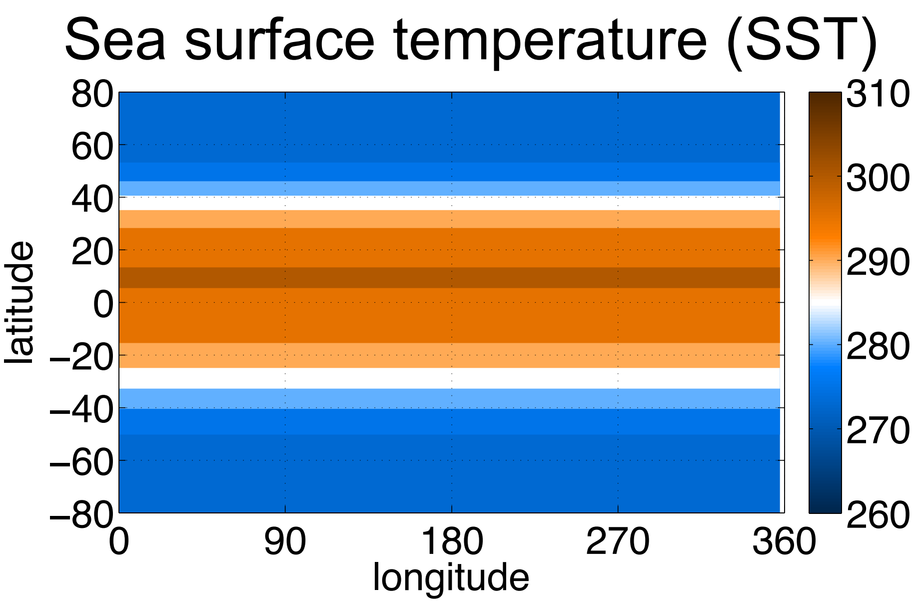



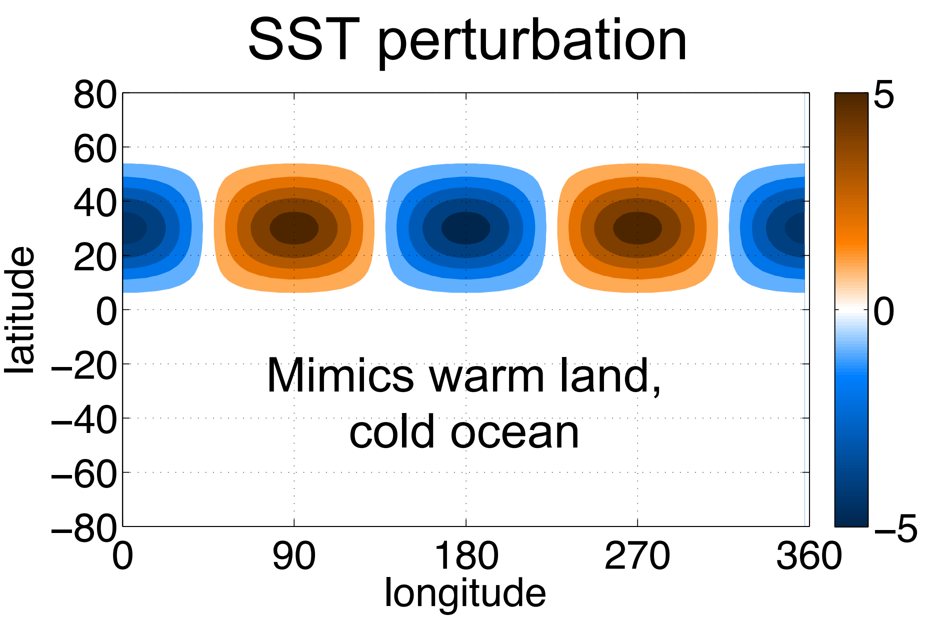
# Questions

- What dynamical mechanisms are involved in the seasonal transition?
    - How is the transition related to regimes of the large-scale flow?
        - Transition to thermally direct circulation (Schneider 1987, Plumb & Hou 1992, Emanuel 1995)
        - Angular momentum conserving vs. extratropical eddy driven (Bordoni & Schneider 2008, Schneider & Bordoni 2010)
    - What is the role of land-ocean heating asymmetries in the transition?
        - Lorenz (1969, 1984) referred to the problem of including east-west asymmetries as the "modified Hadley circulation" (the "ideal Hadley circulation" is zonally symmetric)
    - What are the relevant dynamical indicators of the transition?
- How is the transition projected to change in the future?

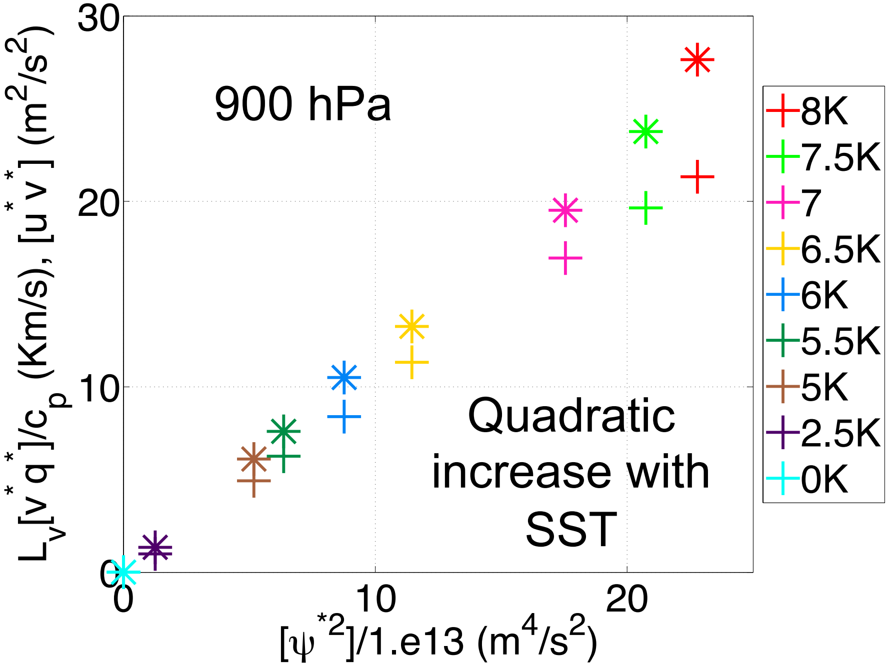
# Idealized modeling

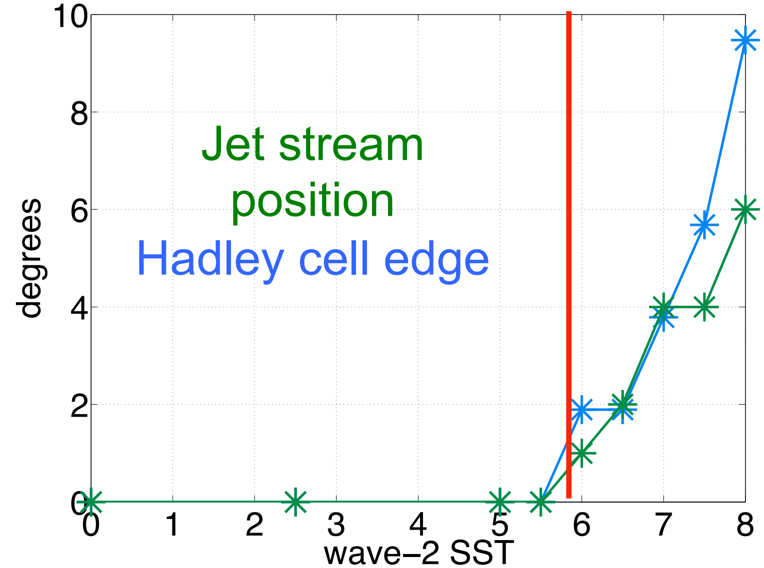
- Use CAM5 aquaplanet model to test hypothesis that subtropical waviness driven by subtropical land-ocean heating asymmetries can produce regime transition

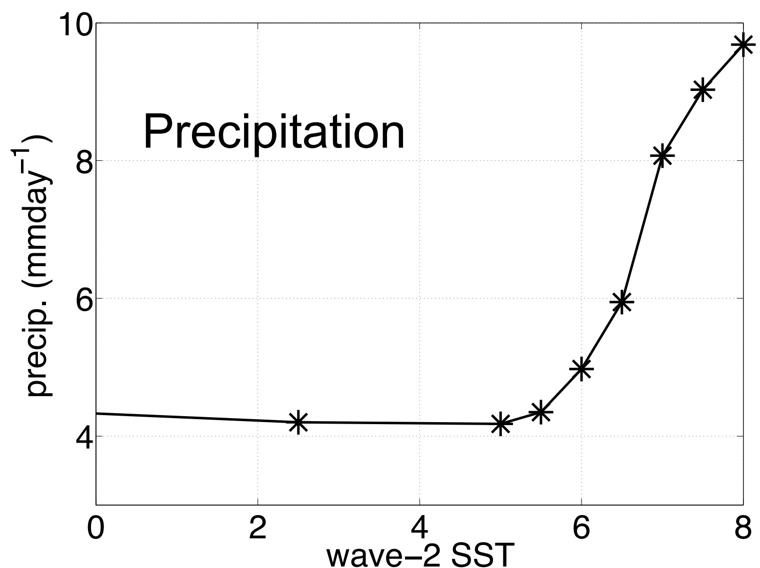


# Idealized forcing captures circulation transition



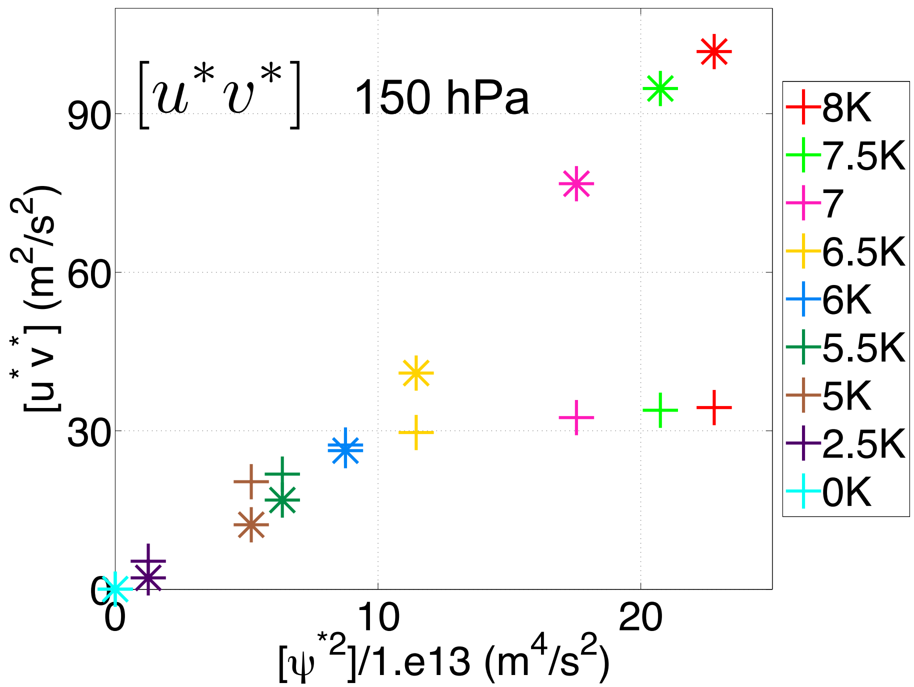



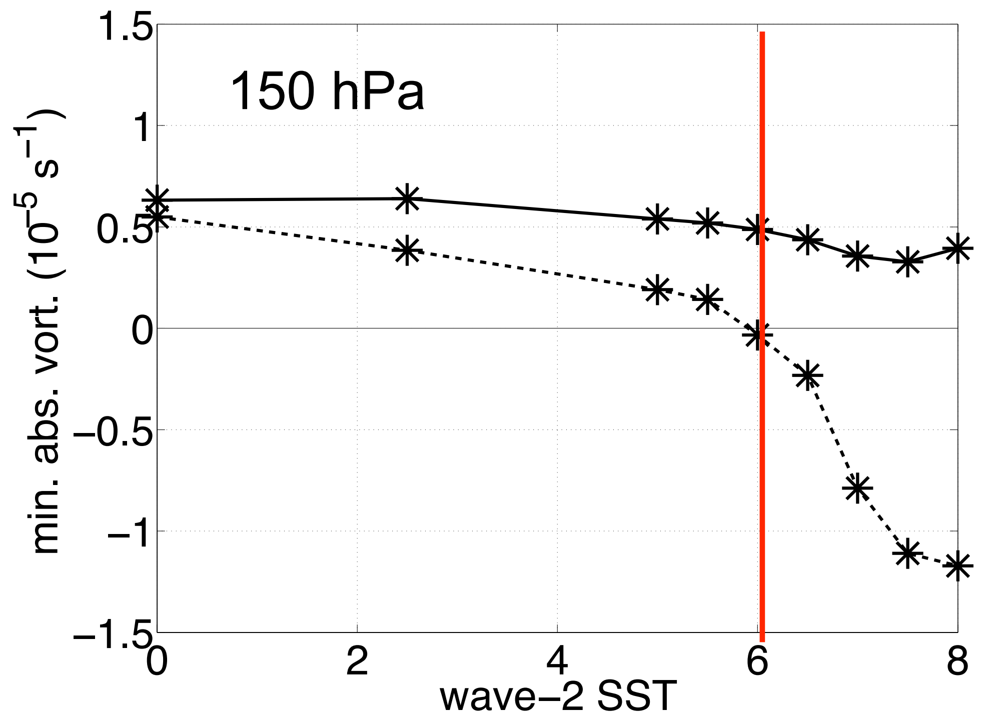




$$[u^* v^*] = k\ell[\psi^* \psi^*]$$

$$[v^* q^*] = \gamma k m[\psi^* \psi^*]$$

# Upper level response



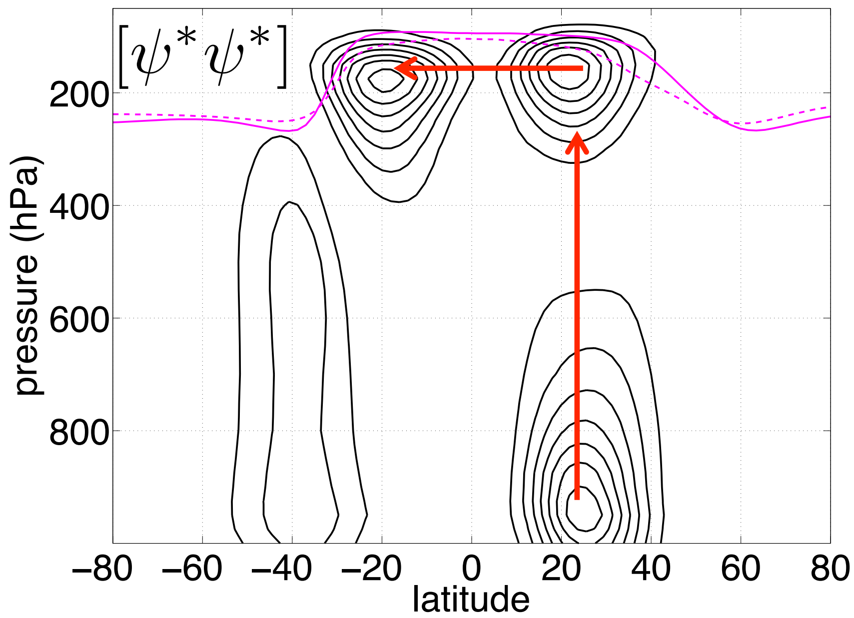




Relates to circulation constraint
(Schneider 1987, Hsu & Plumb 2000)
Also connected to low-level moist
entropy (Emanuel 1995)

$$[v] \cdot \nabla [M] = 0$$

$$\zeta_a \int_A \nabla \cdot \mathbf{u} \; dA = 0$$

# Mechanisms

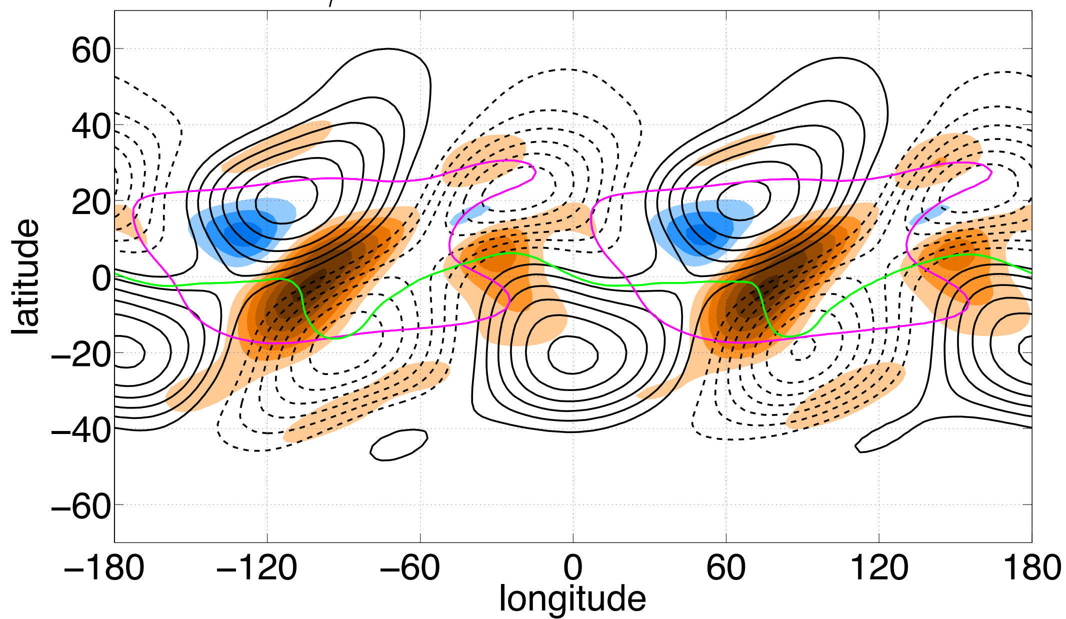



- Growth of subtropical stationary wave
- Upper level cross-equatorial propagation through region of westward flow since $[v]^2 < [u]^2/3$

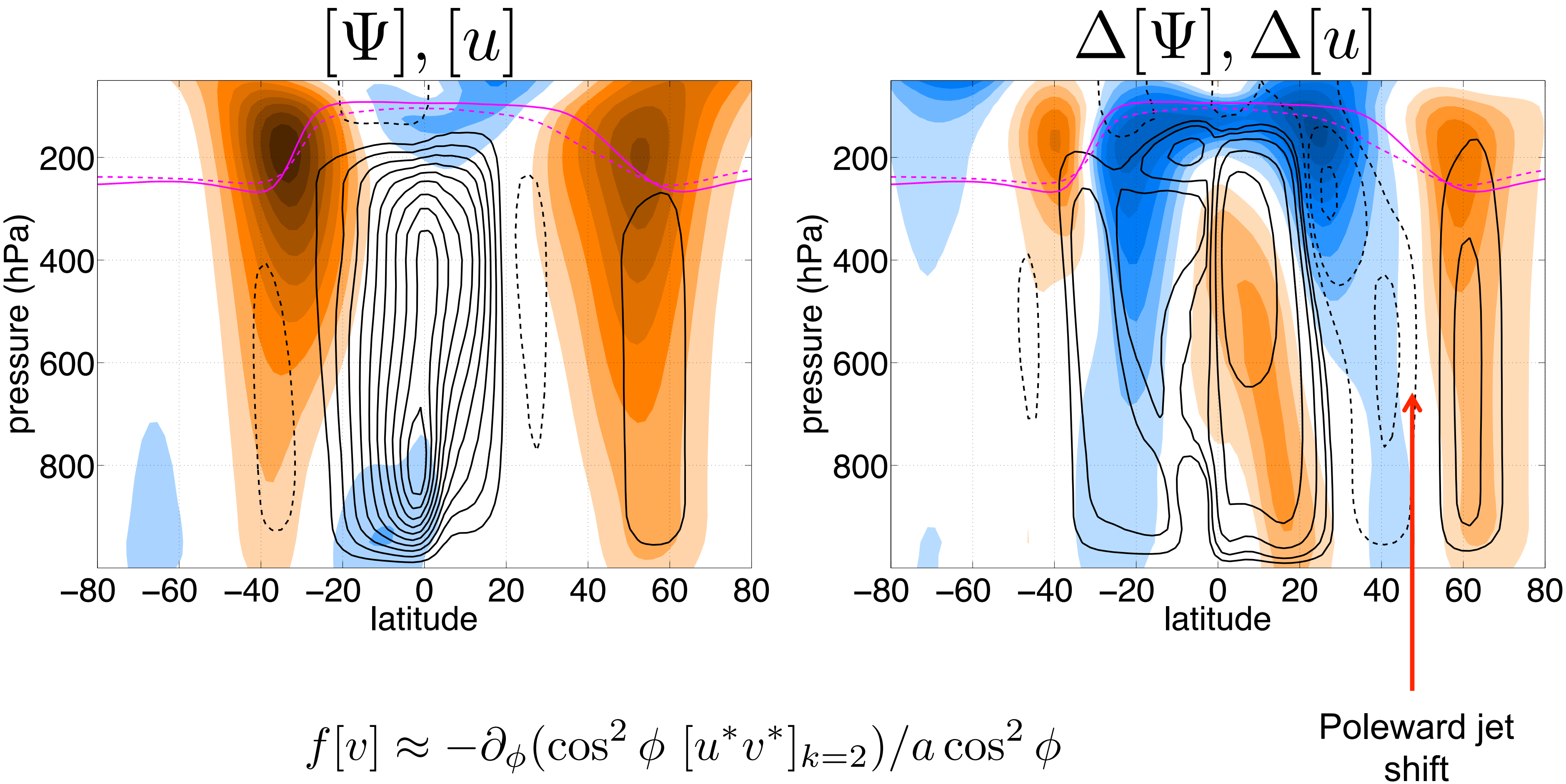
$$c_{gy} = [v] + \frac{2\beta^* k\ell}{(k^2+\ell^2)^2}$$

Schneider & Watterson (1984)

$\psi^*$ & $u^*v^*$ 150hPa



# Circulation response




$$f[v] \approx -\partial_\phi(\cos^2\phi\ [u^* v^*]_{k=2})/a\cos^2\phi$$

$$[\omega]\partial_p[\theta] \approx -\partial_\phi(\cos\phi L_v [v^* q^*]/c_p)/a\cos\phi$$

# Dynamical indicators of the transition

- Previous research shows that a zonally-symmetric forcing can produce a regime transition of the circulation (e.g. Bordoni & Schneider 2008, Schneider & Bordoni 2010)

- The features unique to a zonally-asymmetric forcing transition are
  - Reversal of absolute vorticity in the upper troposphere connected to an angular momentum maximum in the NH
  - Edge of the circulation coincides with maximum subtropical streamfunction variance (not the maximum zonal-mean sub cloud moist entropy)
  - Poleward eddy moisture transport that flattens meridional gradients
  - Circulation response does not conserve angular momentum

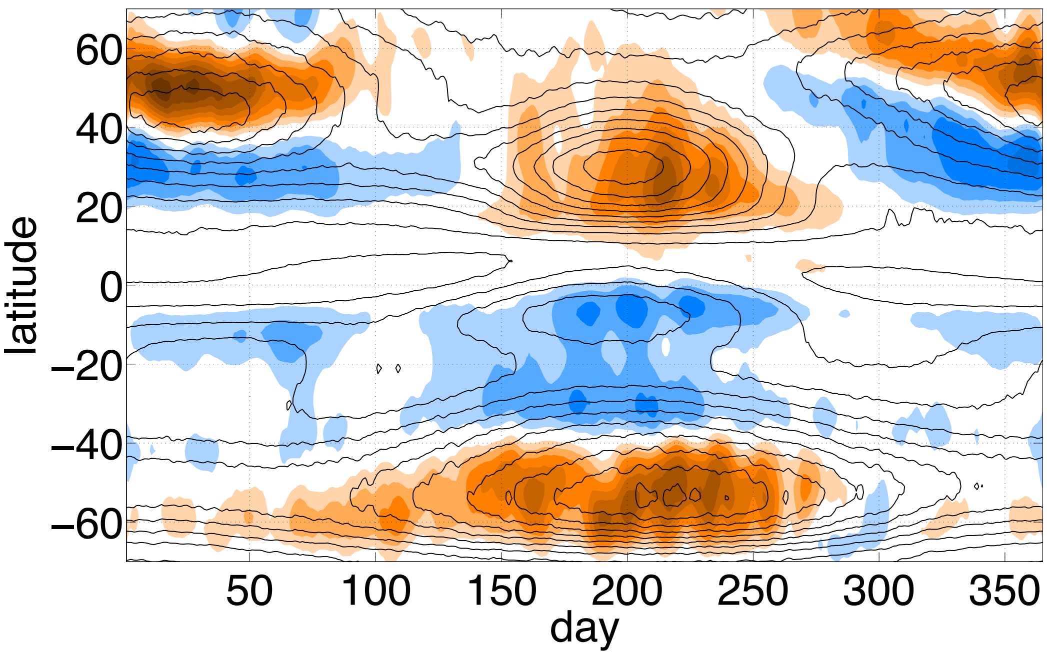
- Differences useful for defining dynamical indicators of transition
  - Clear reversal of absolute vorticity in ERA-Interim data

# Analogy with stratospheric warming events

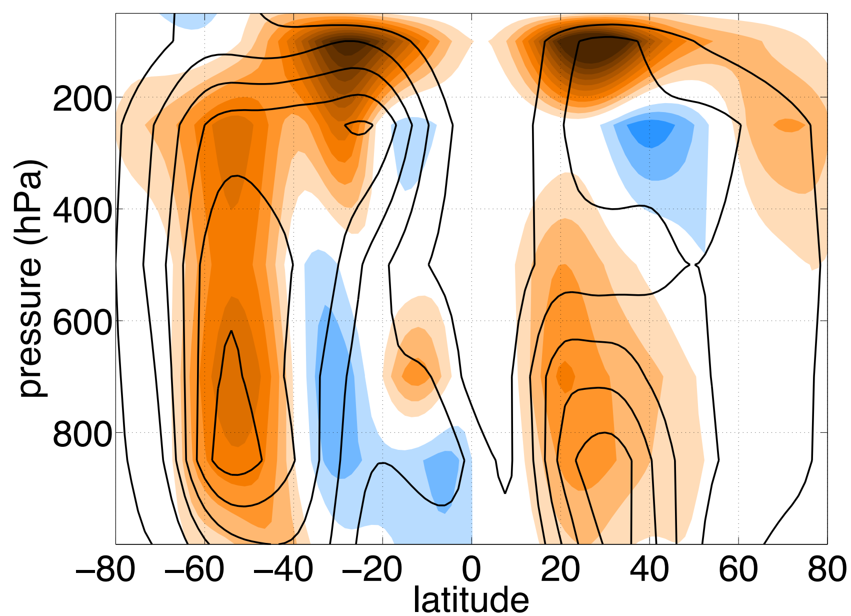
- Abrupt stratospheric sudden warming events linked to planetary wave forcing (Matsuno 1971, Polvani & Waugh 2004)
    - Abrupt increase in temperature, deceleration of zonal wind
- Final warming (seasonal transition from eastward to westward flow) highly variable due to wave forcing (Black et al. 2006)
    - Standard deviation of final warming date at 50 hPa is ~ 2 weeks
- Seasonal transition from eastward to westward flow in the upper troposphere has a standard deviation of ~ 1.5 weeks at 200 hPa

# Projected amplification of waviness due to anthropogenic climate change

$[\psi^*\psi^*]$ 850 hPa




RCP 85 (2070 to 2099) -
Historical (1979 to 2005)




Connection to poleward
jet shift

# Summary

- The NH seasonal transition involves the organization of the flow into land cyclones (Monsoons) and oceanic anticyclones
- Aquaplanet model with wavy SST perturbation captures large-scale features of the observed circulation transition
  - Wave amplitude depends quadratically on surface forcing
  - Regime transition toward planetary wave-dominated circulation dependent on reversal of absolute vorticity
  - Produces poleward shift of edge of Hadley circulation and jet stream
- Results highlight new metrics to measure seasonal transition: timing of zonal-mean zonal wind reversal, absolute vorticity reversal
- CMIP5 models suggest summer stationary wave pattern will amplify in the future, which is connected to poleward jet shift