Storm Tracks and Jet Streams Pt. 1

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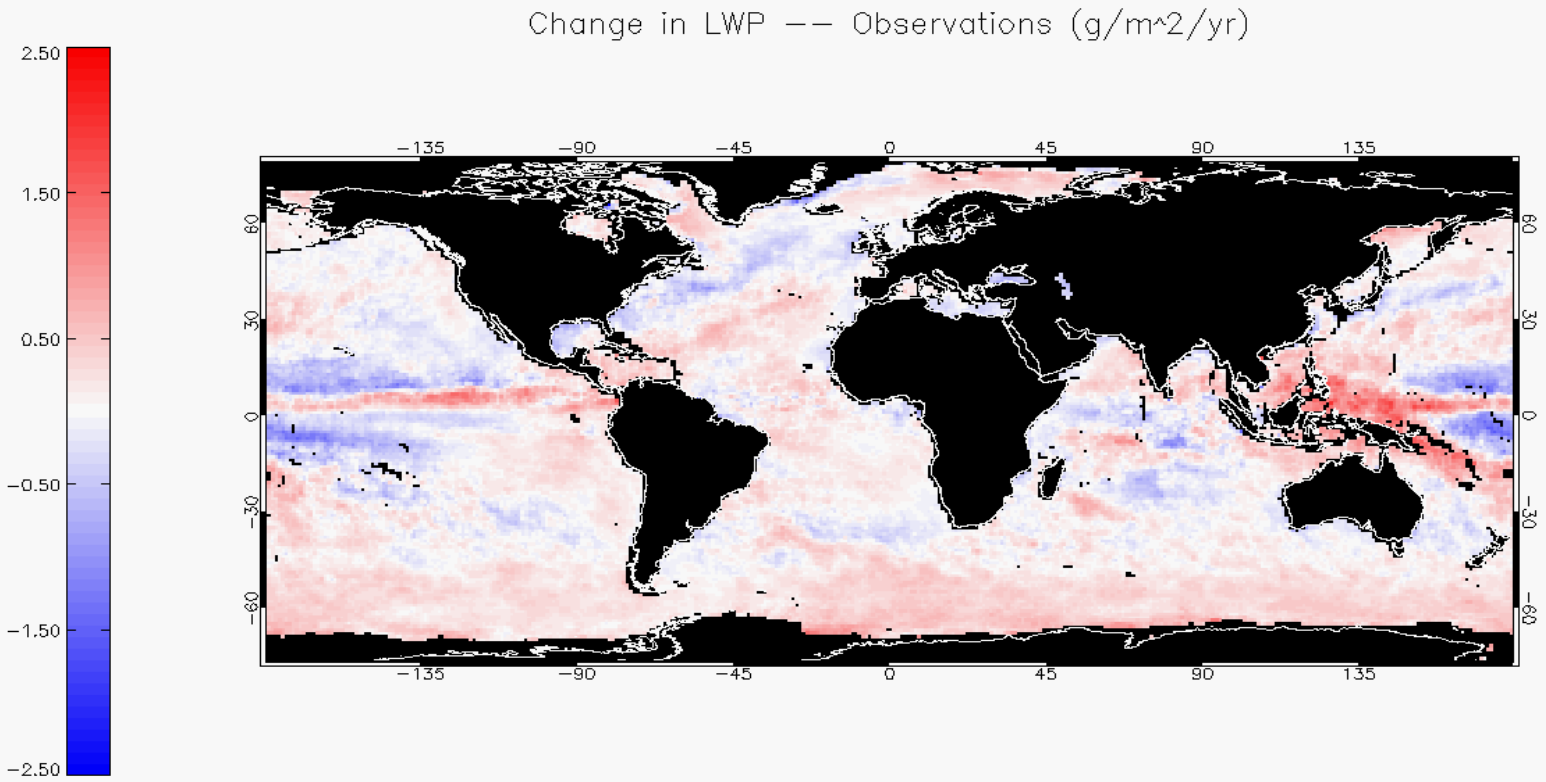
ATS 780

Shifting of Storm Tracks

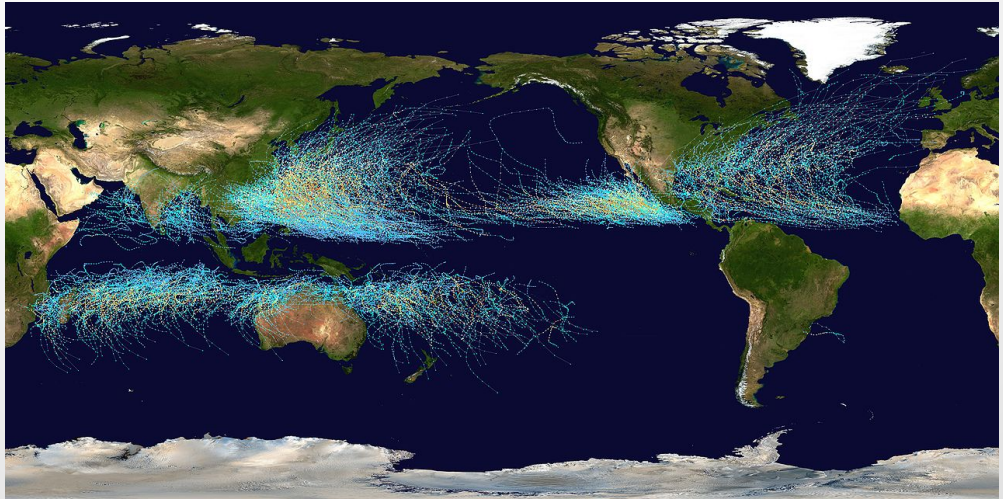
- It has been suggested that in a warming climate, extra-tropical storm tracks will shift poleward (IPCC, 2007)
- This shift can be generalized as a positive feedback on the climate system (IPCC, 2013)



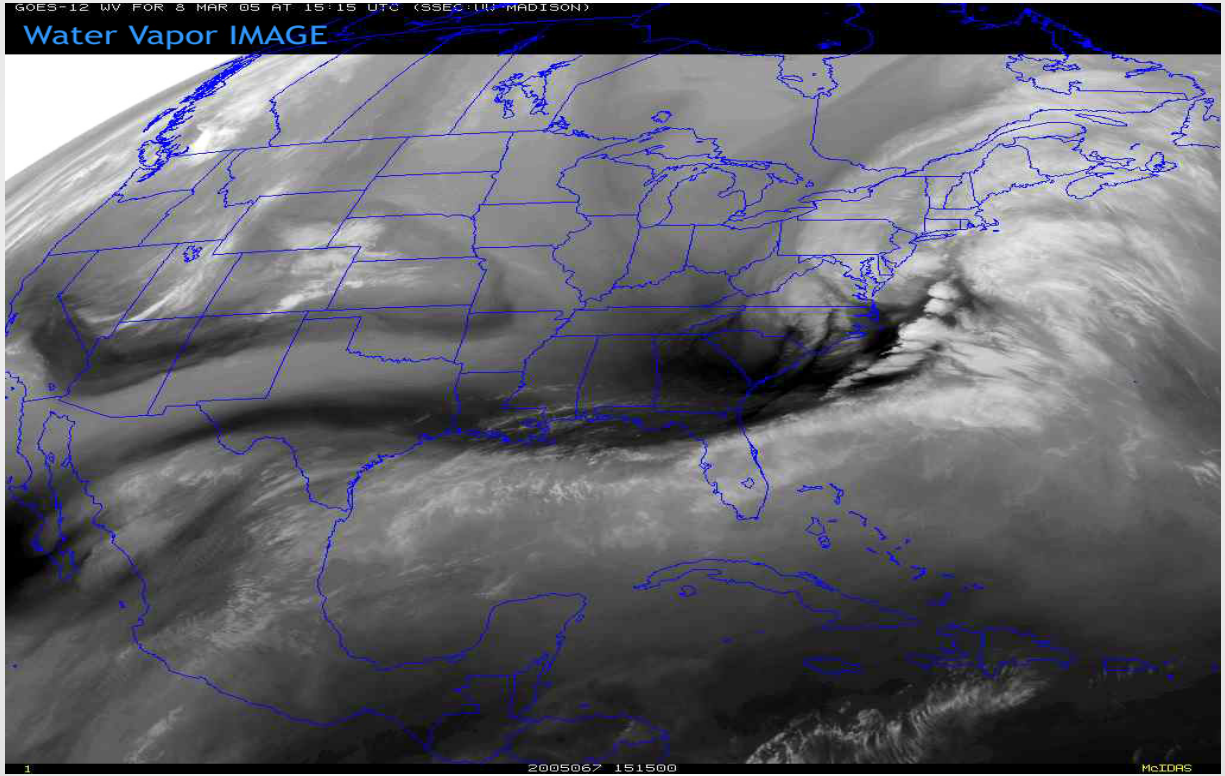
Trends in Cloud LWP from 1988-2013

What Variables Determine Storm Tracks?

- Water Vapor
- Static Stability
- Horizontal Temperature Gradients



Water Vapor



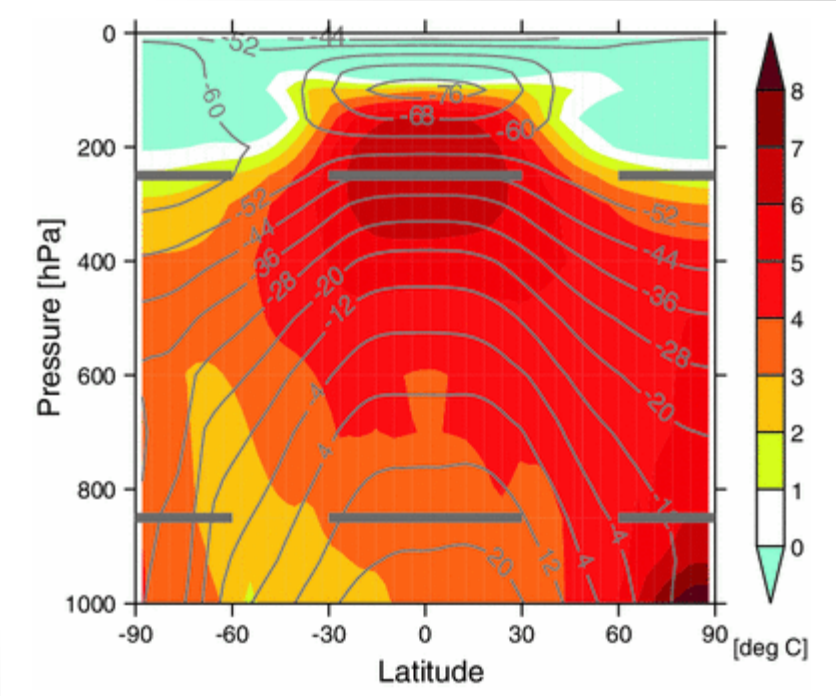
Source: http://cimss.ssec.wisc.edu/

Static Stability

- Tropical upper tropospheric warming -> increased static stability
- Greater increases on tropical flank of storm track -> suppression of baroclinic eddy generation
- Region of largest baroclinic eddy generation shifts poleward

Horizontal Temperature Gradients

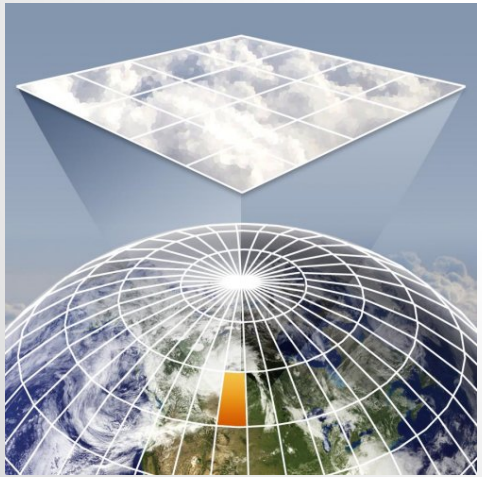
- Equator-pole T difference increases aloft, decreases near surface
- Stronger meridional temperature gradients -> more energy for storm tracks
- Focus of Harvey et al.

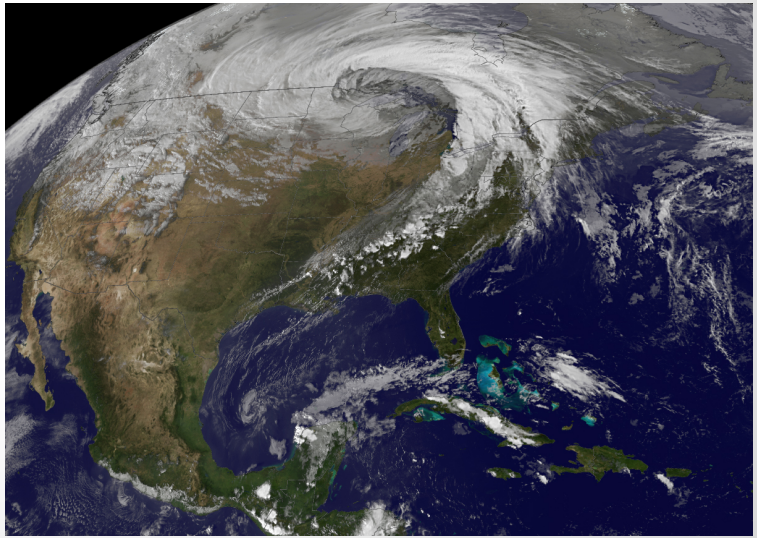


Harvey et al. Fig 1

Equator-to-pole temperature differences and the extra-tropical storm track responses of the CMIP5 climate models (Harvey et al. 2013)

- Paper's main goal is to understand physical processes that cause large spread in CMIP5 storm track projections
- Relationship between 2-6 day mean sea level pressure variance (proxy for storm track activity) and upper- and lower-tropospheric equator-to-pole temperature differences examined



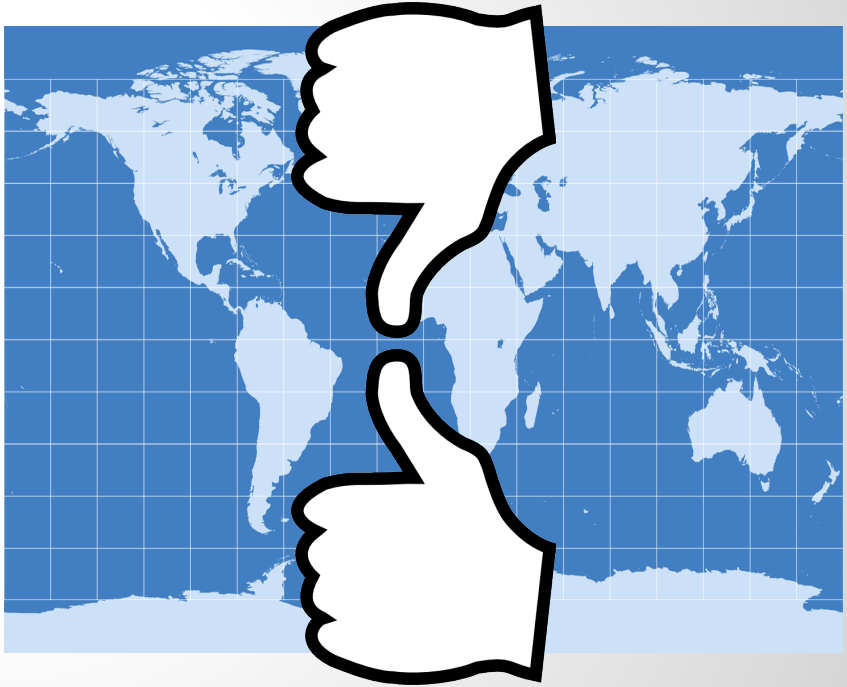


What Did They Find?

- Large regions in the Southern Hemisphere where the temperature difference responses were well correlated with storm track responses
- Linear regression model based on temperature differences explains 30-60% of inter-model variance in storm track responses

What Did They Find?

- Northern Hemisphere correlations were significantly different
- In the summer, lower-tropospheric temperature differences dominate spread of storm track responses
- In the winter, both upper- and lower-tropospheric temperature influence storm track responses
- Due to the fact that the Northern Hemisphere is much more complicated than Southern Hemisphere (more land, mountains, etc…)



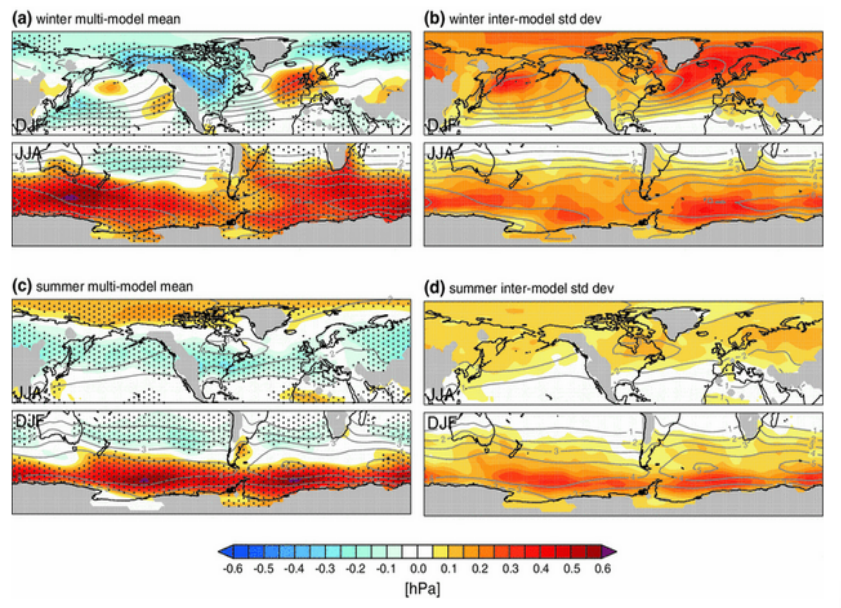
Methodology

- Harvey et al. uses 24 models from the CMIP5 dataset
- 1 ensemble run from each model
- Uses the June 1976-August 2005 historical run (HIST) and June 2070-August 2099 RCP8.5 and RCP4.5 scenarios

Methodology

- Storm track defined as the standard deviation of the 2-6 bandpass filtered MSLP
- Storm track response is defined as the difference between the seasonal storm track values between RCP and HIST runs
- Equator-to-pole temperature differences defined as the difference between the temperature in the tropics (30S-30N) and the temperature at the poles (60-90 N/S) for both the 850hPa and 250hPa pressure levels

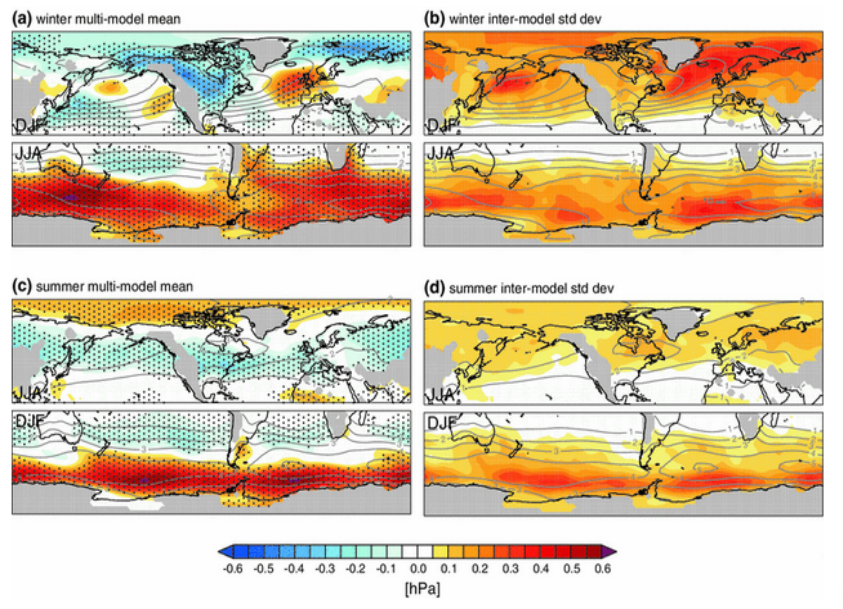
Results



Harvey et al. Fig 2

- Figure displays multi-model mean HIST storm tracks (contours) and multi-model mean storm track response in RCP 8.5 (shading) in panels (a) and (c)
- Standard deviation in panels (b) and (d)
- Areas of warmer (cooler) shading indicate areas of increased (decreased) storm track activity

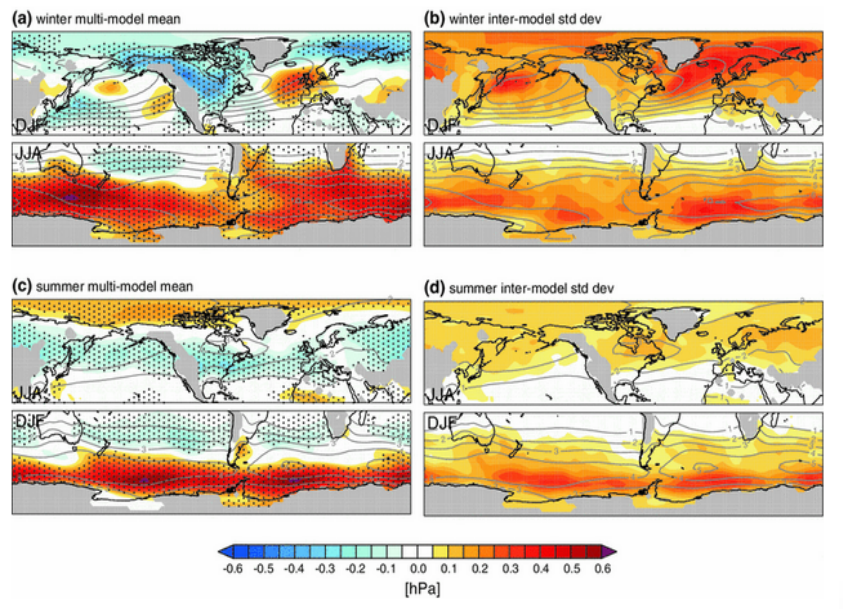
Results - Winter



Harvey et al. Fig 2

- Weakening of storm track activity in N.H. winter everywhere except North Atlantic
- Significant strengthening of storm track activity in most of S.H. in the winter

Results - Summer



Harvey et al. Fig 2

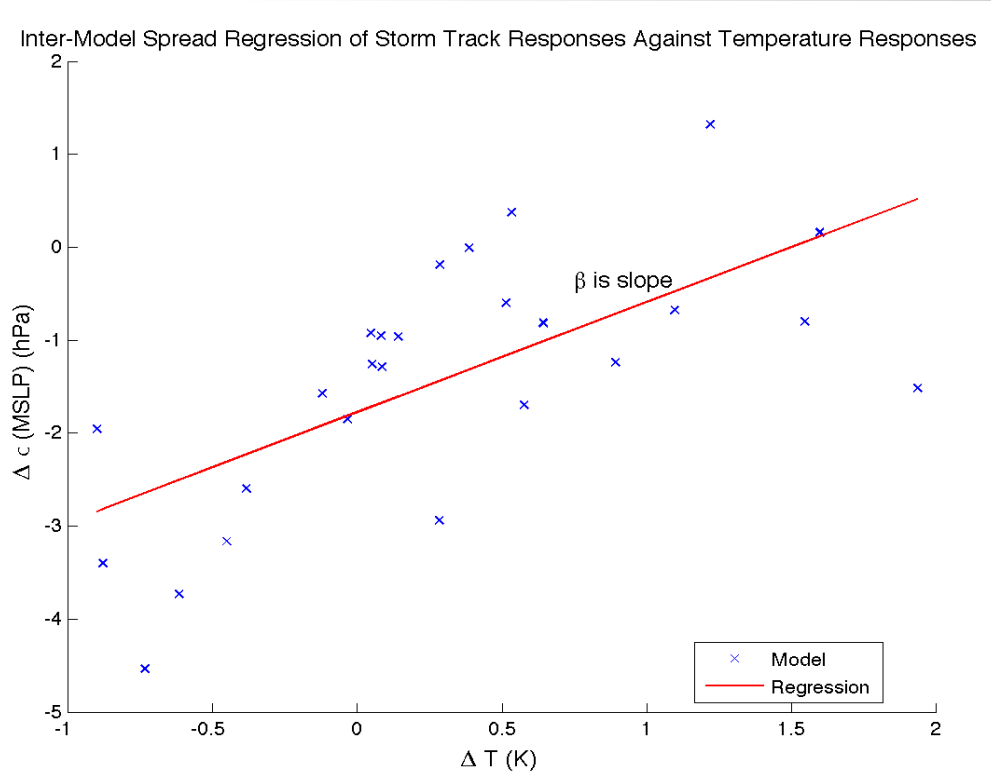
- Weakening of storm track activity in N.H. summer everywhere except Arctic
- Poleward shift of storm track appears to occur in S.H. summer (decrease in activity in subtropics, increase in high latitudes)

Methodology: Regression

-**inter-model spread** of SLP response regressed against T response

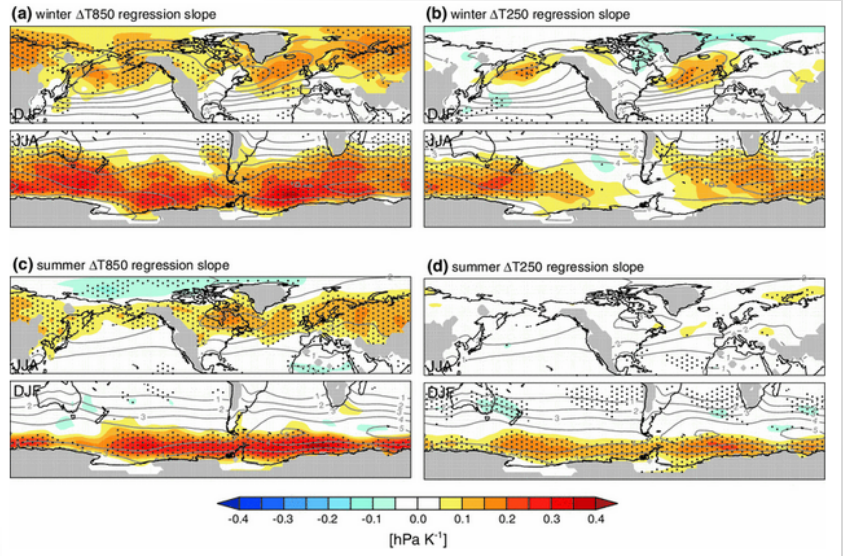
-Linear regression, β is slope

-Remember, for β >0, positive association b/w T response and ST response



Regression Results

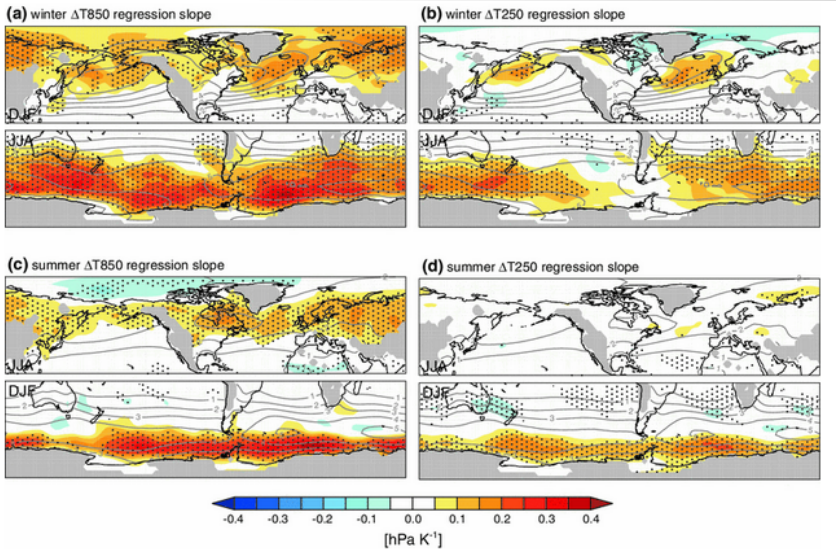
- Figure shows regression slope of storm track responses on equator-to-pole temperature difference responses
- Regions of positive values indicate storm track activity increasing with increasing equator-to-pole temperature difference responses



Harvey et al. Fig 4

Regression Results - Winter

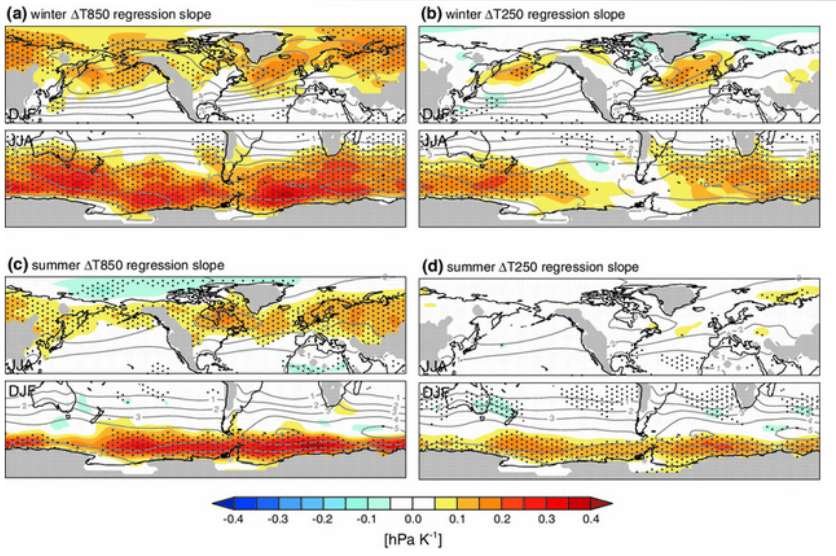
- In the winter, 850hPa regression is positive almost everywhere -- stronger in S.H.
- Wintertime S.H. 250hPa looks similar to the 850 hPa. N.H. only has positive slope in ocean basins at 250hPa



Harvey et al. Fig 4

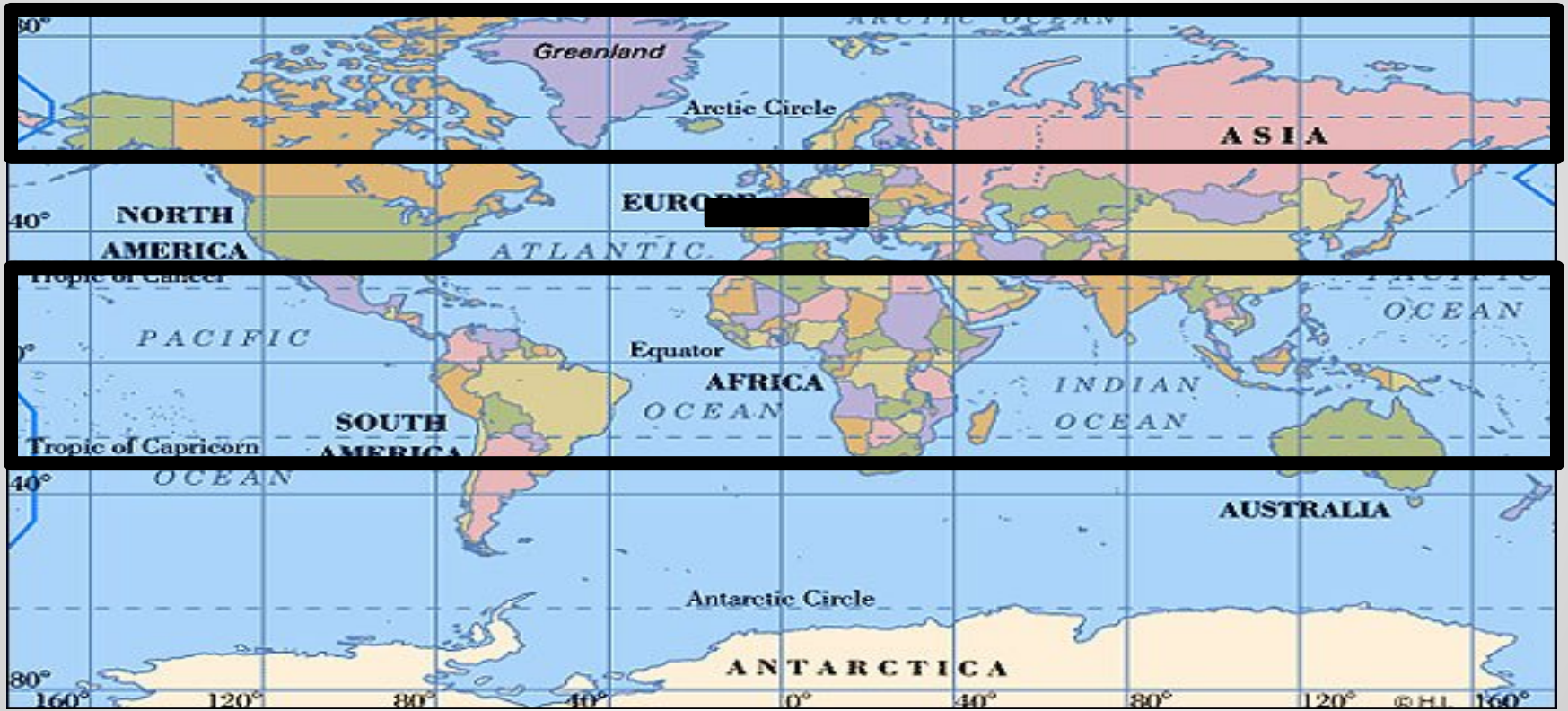
Regression Results - Summer

- Narrower band of positive regression slope in S.H. at both 850hPa and 250hPa levels
- High correlation between storm track responses and 850hPa temperature differences in N.H.
- Almost no correlation at 250hPa level in N.H.



Harvey et al. Fig 4

Differencing Method



Differencing Method

Northern Hemisphere Wintertime

- Used aforementioned, longitudinally confined, equator-to-pole temperature differences to create new regression map shown in figure
- Paper concludes that Atlantic basin equator-to-pole temperature differences are more strongly associated with storm track responses than zonal mean temperature differences

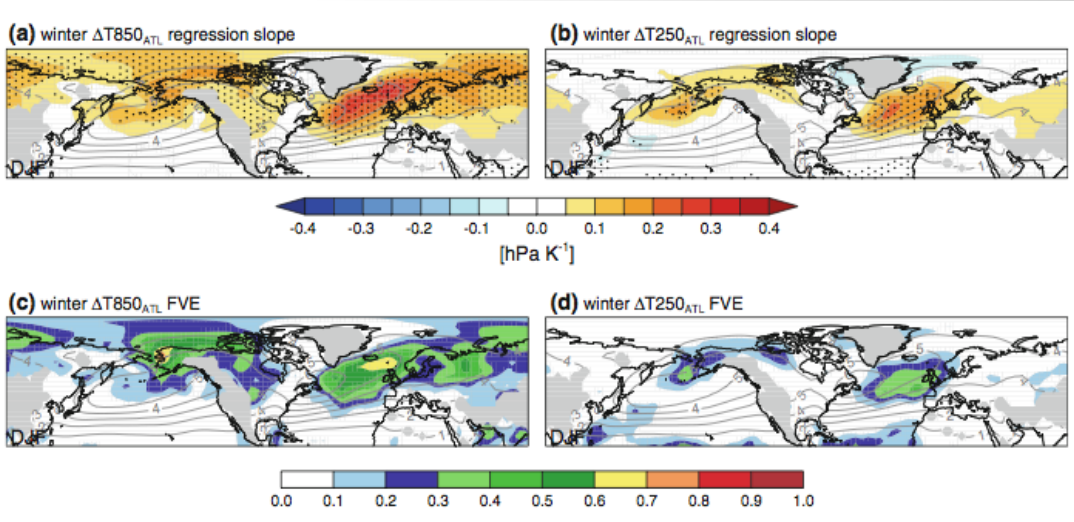


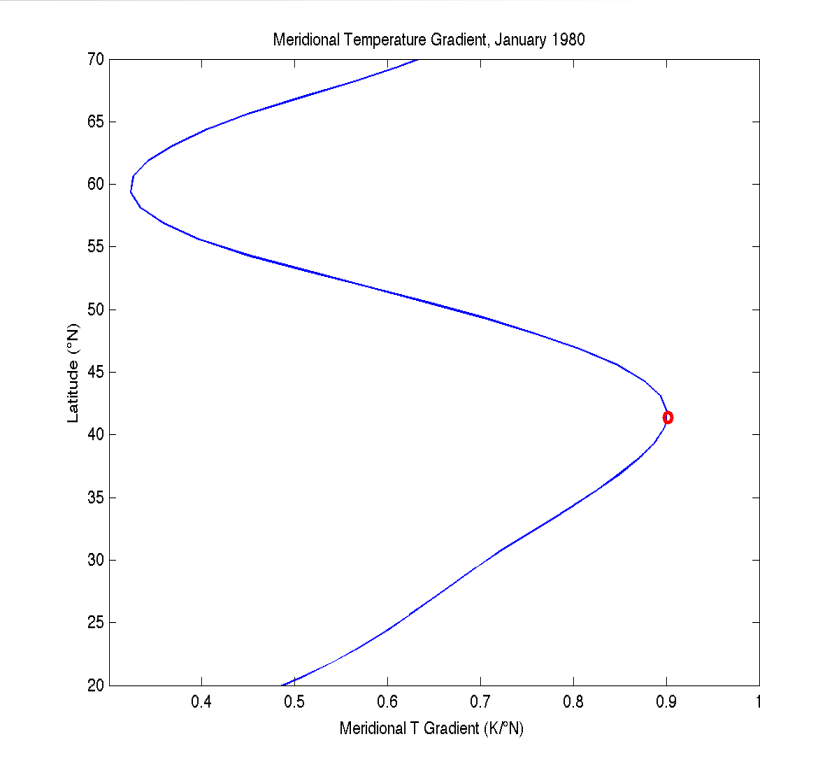
Figure 8, Harvey et al.

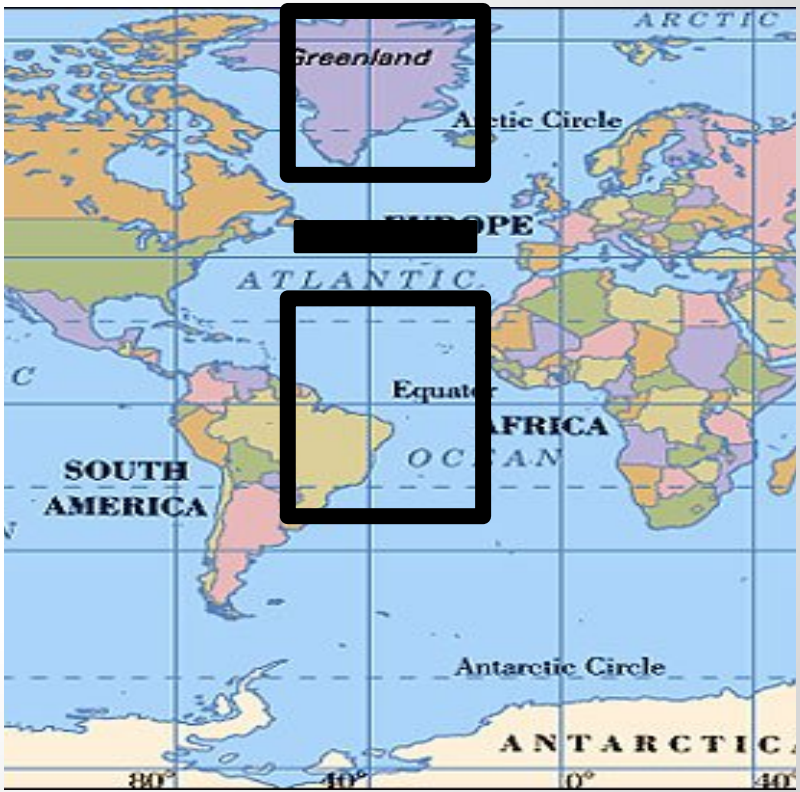
A Different Method...

- Baroclinic eddy generation depends on dT/dy
- Is that really what we are measuring here?

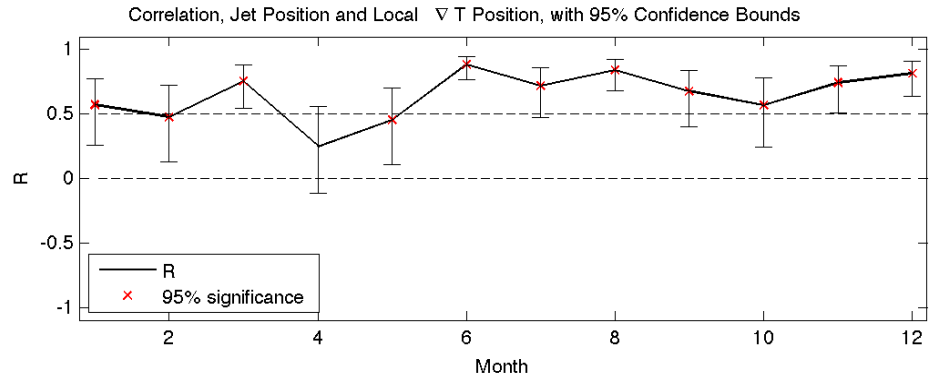
NO

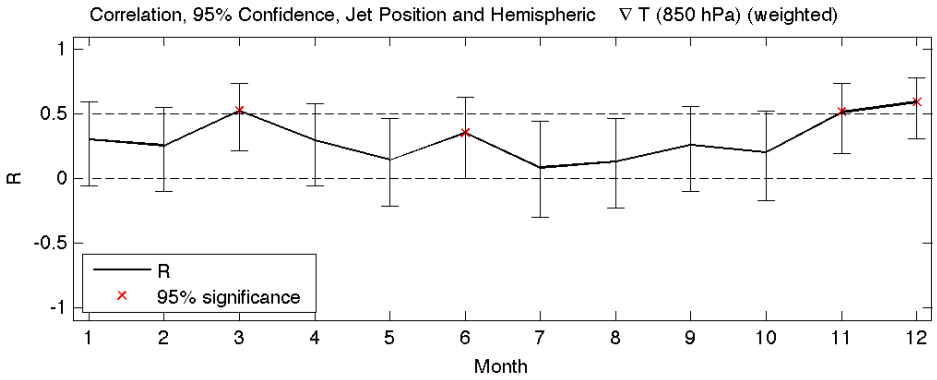
dT/dy vs. Eq-Pol T Difference

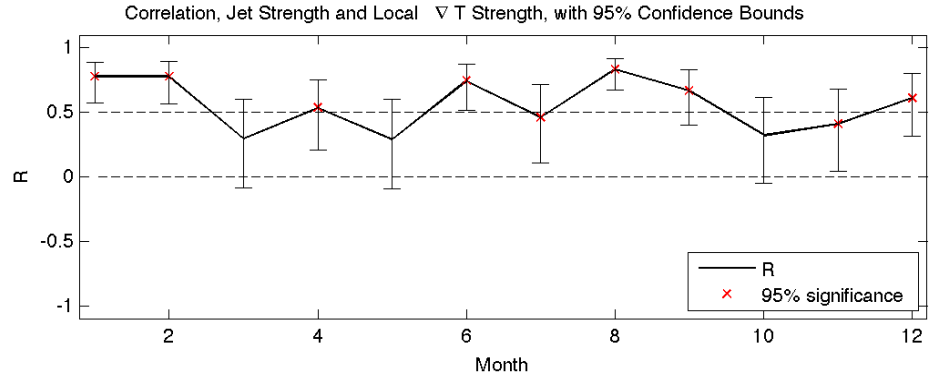


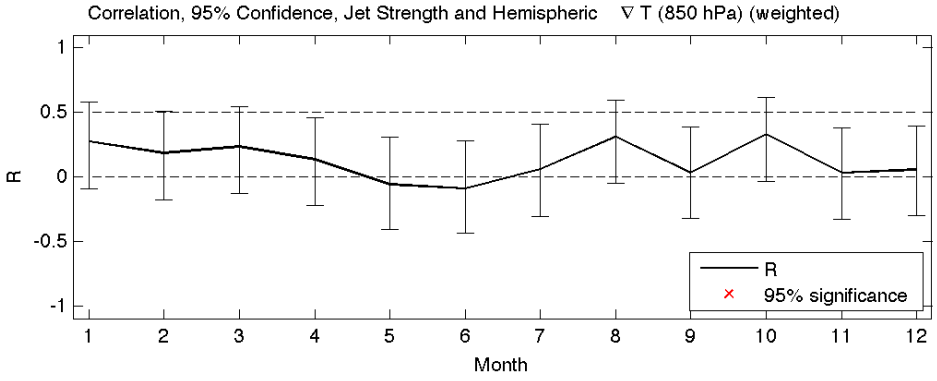


dT/dy vs. Eq-Pol T Difference









Jet correlated with dT/dy

Jet correlated with hemispheric T difference

Back to the Northern Hemisphere...

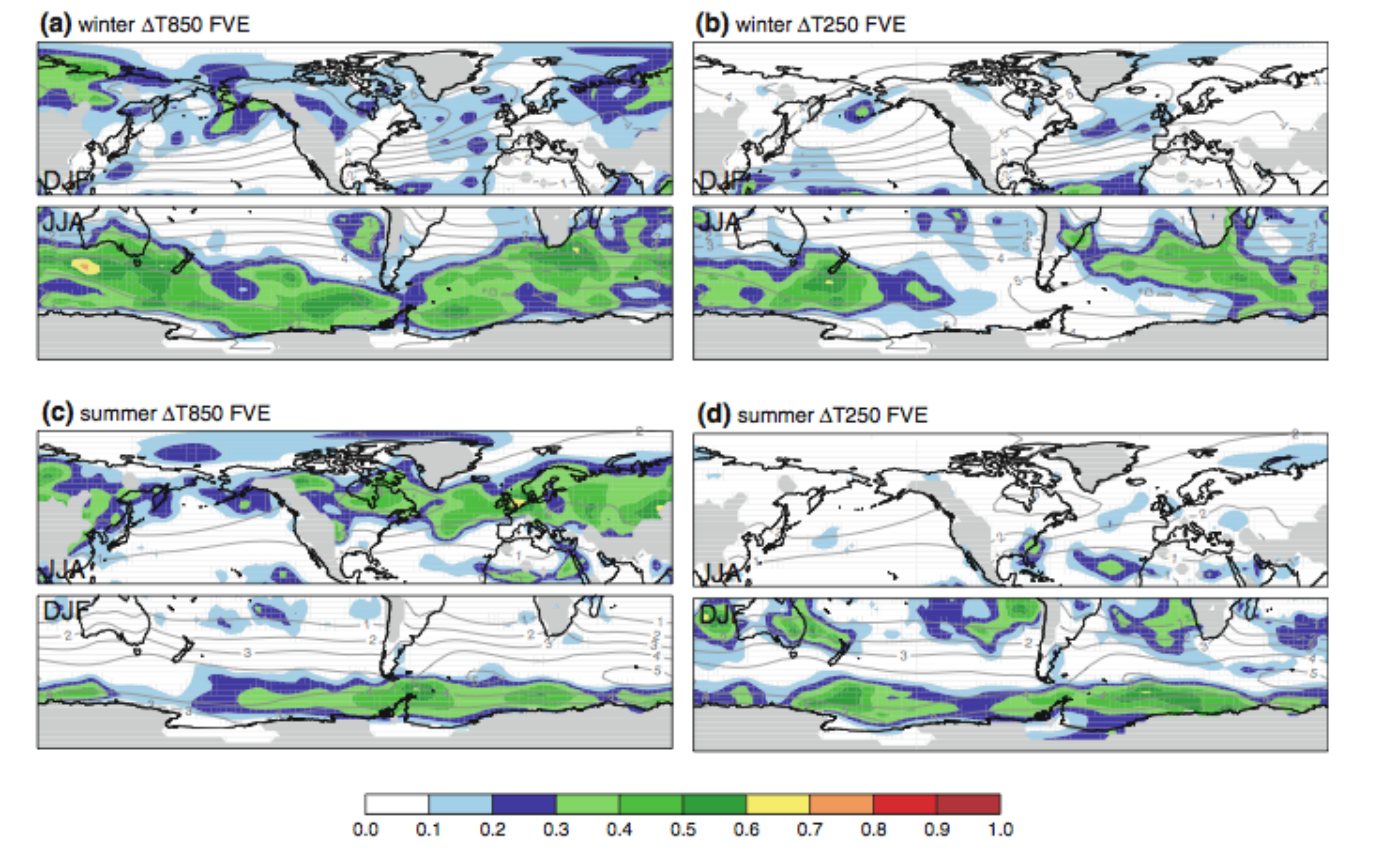


Figure 5, Harvey et al (2013)

Steady-State Circulation Response to Climate Change-Like Thermal Forcings (Butler et al 2010a)

What does the time-mean, zonal-mean circulation in an idealized GCM look like when perturbed by:

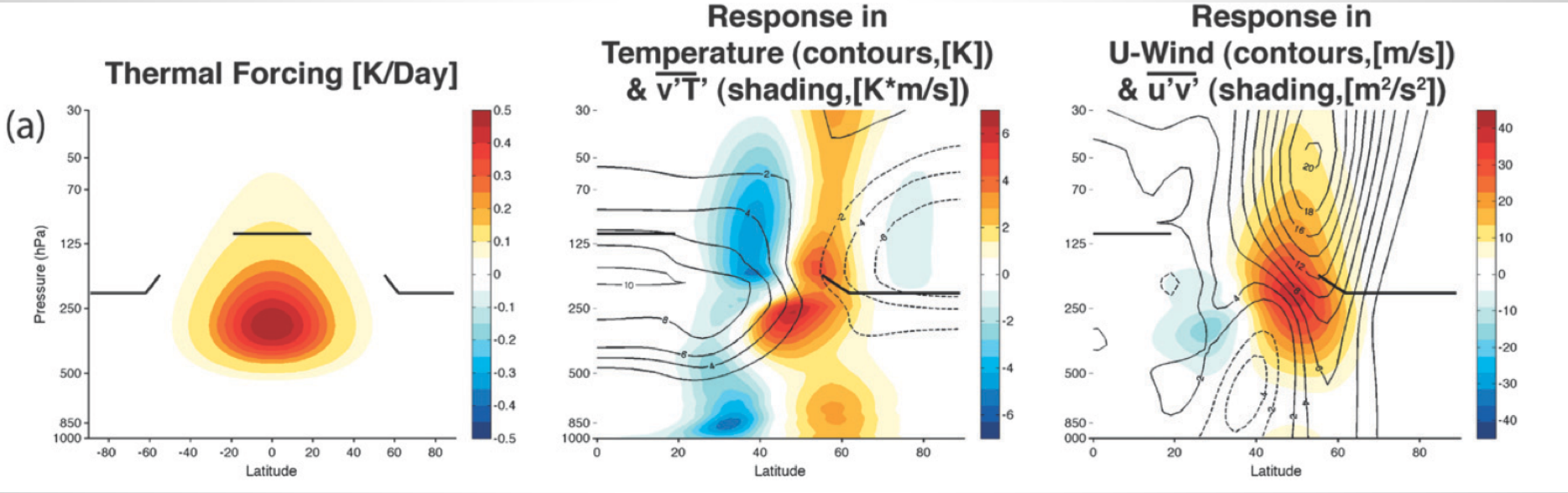
-upper tropospheric tropical warming (greenhouse gas forcing)?

-polar stratospheric cooling (ozone loss)?

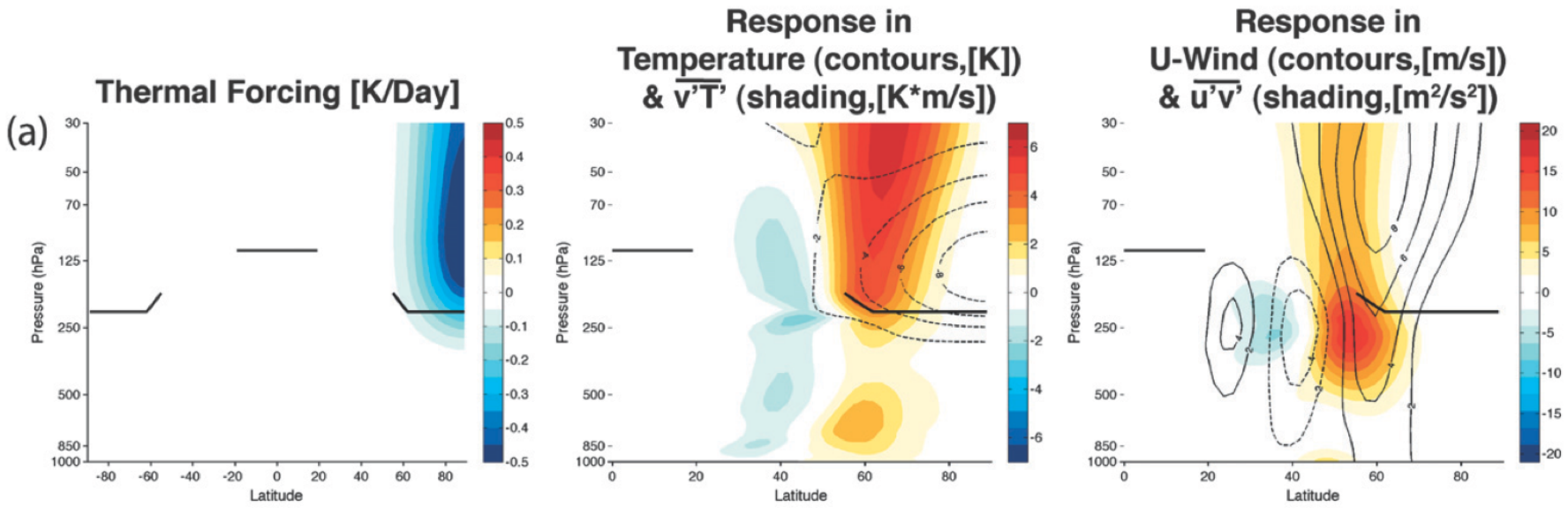
-polar surface warming (Arctic amplification)?

-note: all of these results are for equinoctal conditions

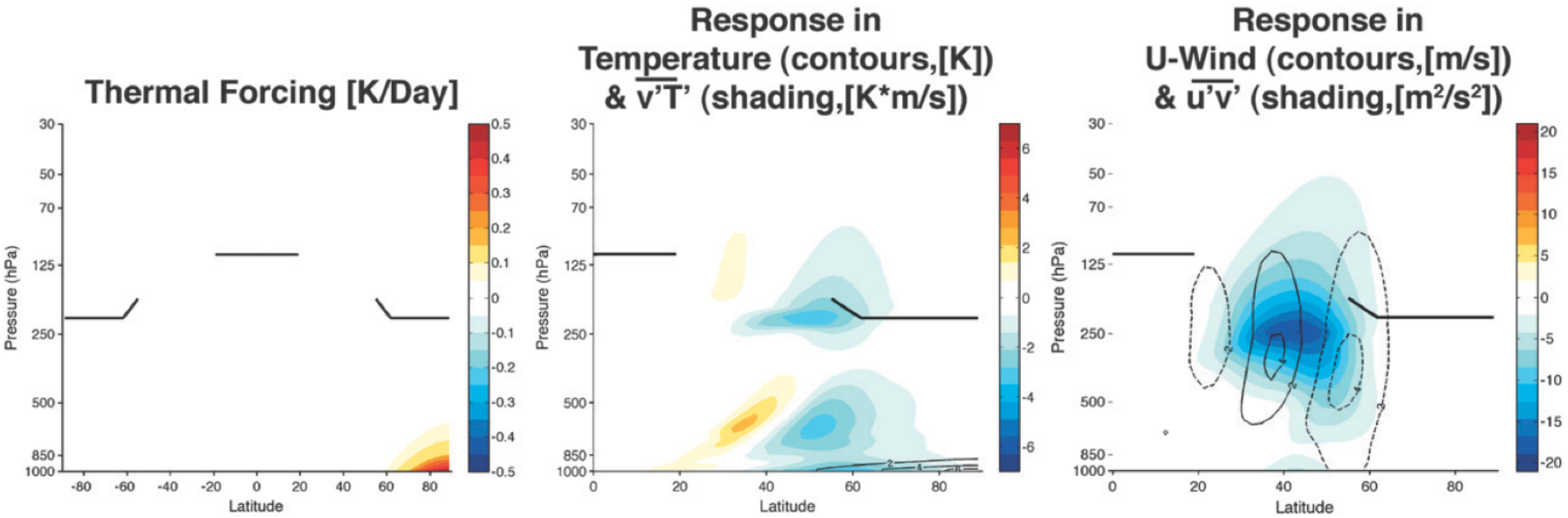
Response: Tropical Heating



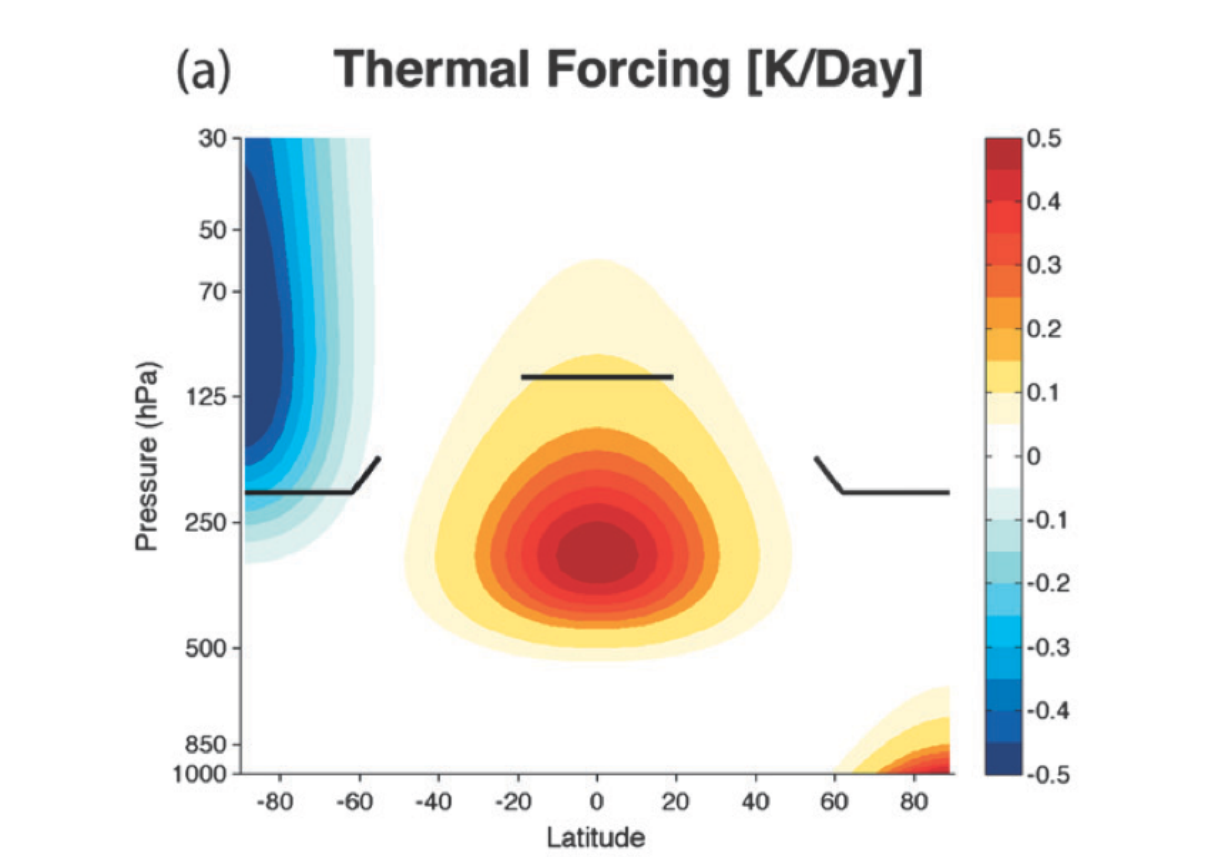
Response: Polar Stratospheric Cooling



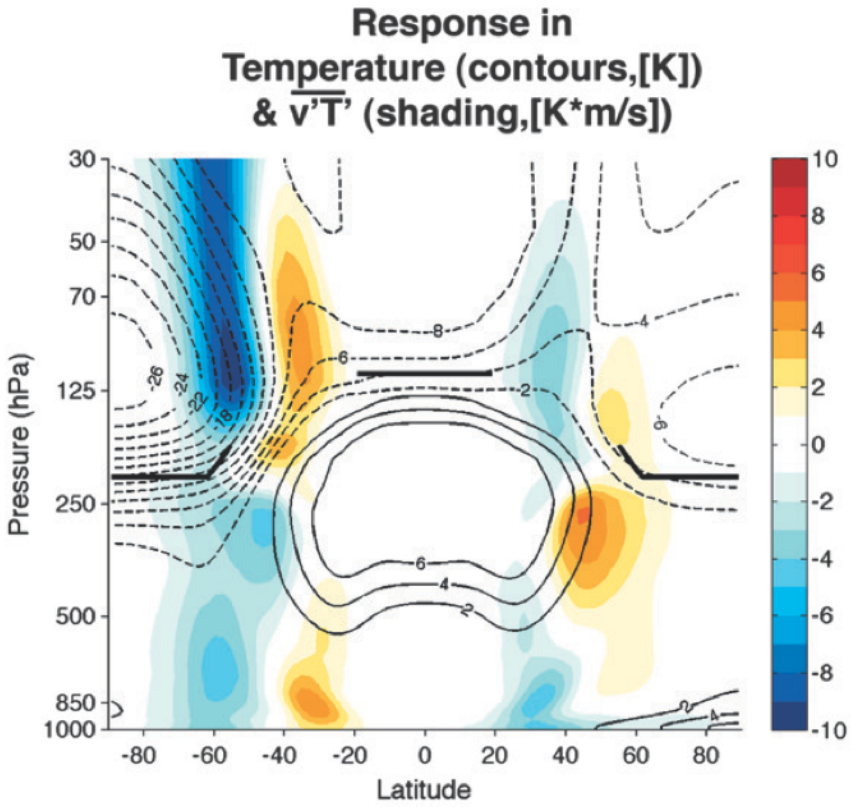
Response: Polar Surface Warming

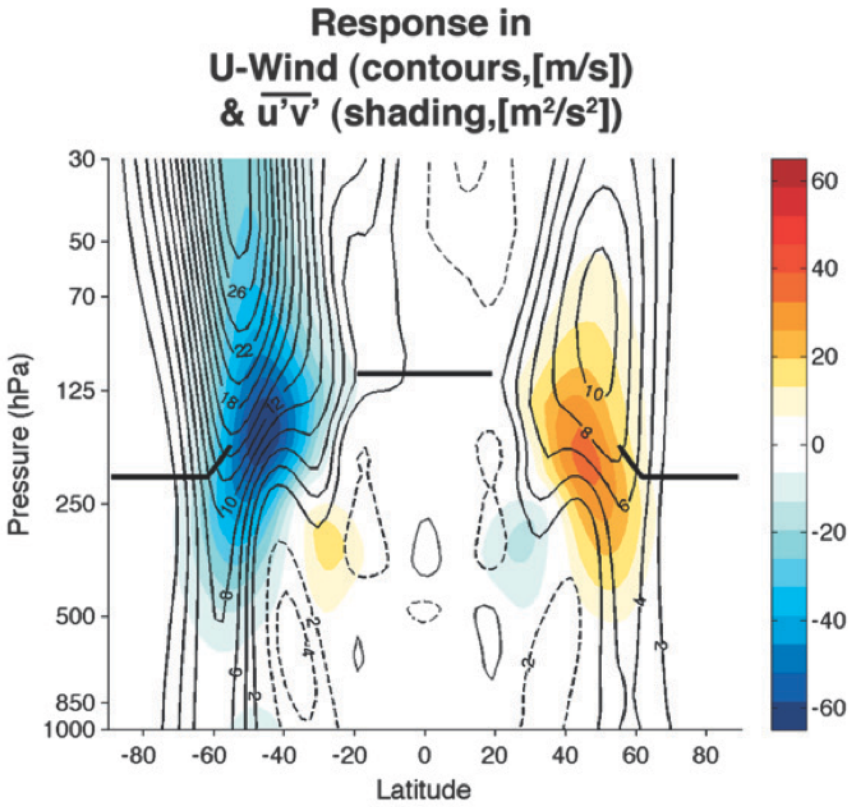


Response: Multiple Forcings



Response: Multiple Forcings





Jet Shifts in CMIP5

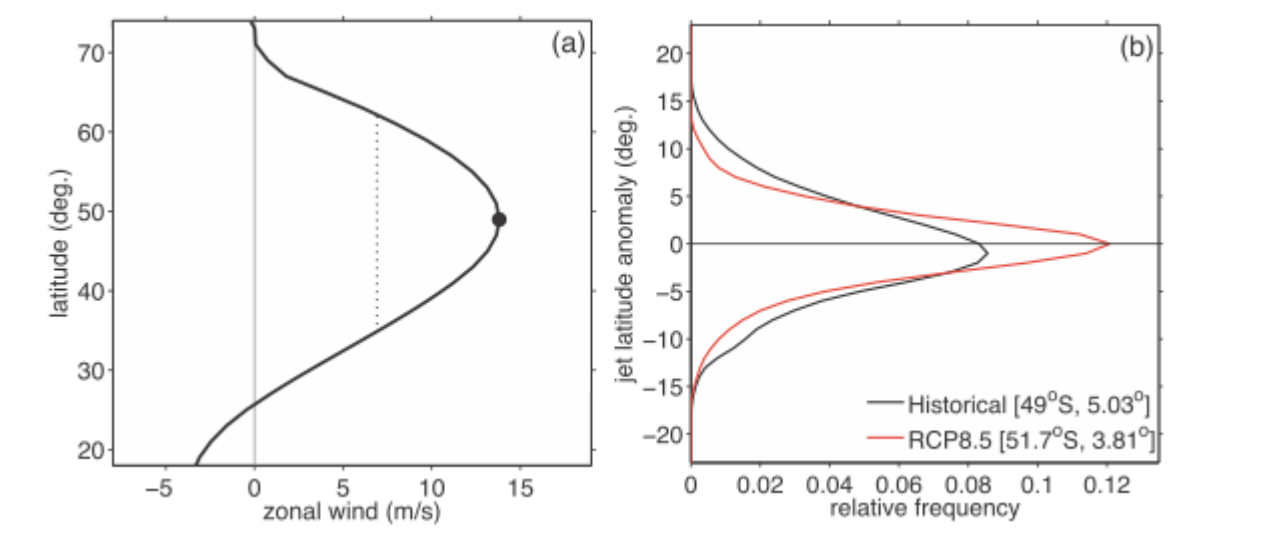
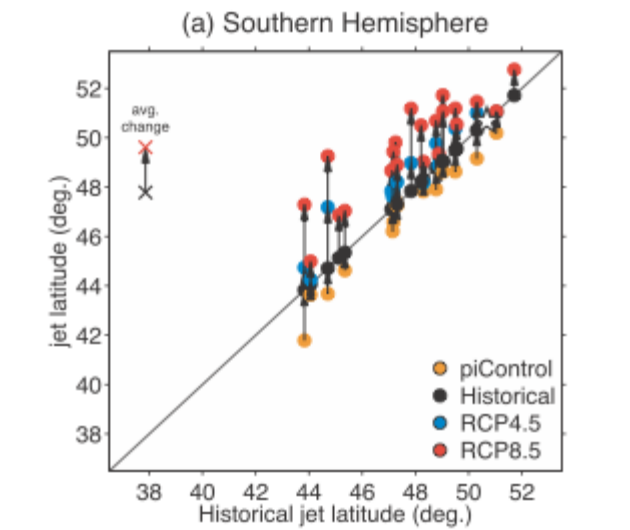


Figure 1, Barnes and Polvani (2013)

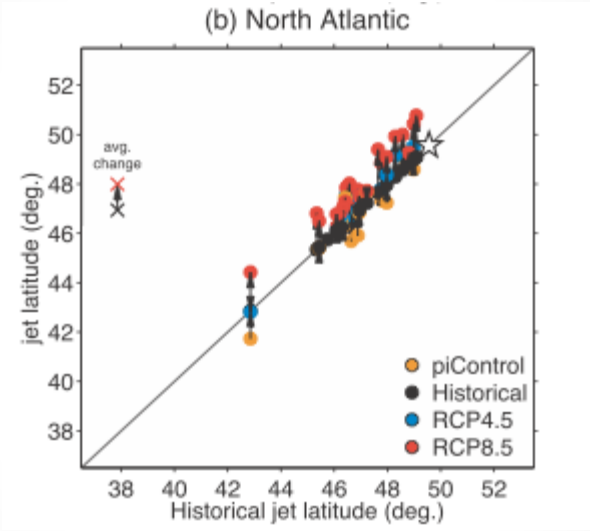
- RCP8.5 also shows a poleward shift
- Narrowing of the histogram -> contraction of storm track

Jet Shifts in CMIP5

Southern Hemisphere



North Atlantic



North Pacific

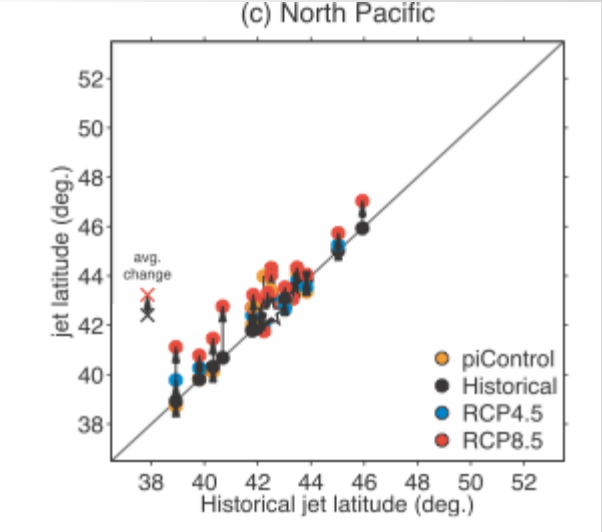


Figure 2, Barnes and Polvani (2013). Mean jet position vs. historical jet position; arrows connect different experiments in same model.

Possible Physical Mechanisms for Jet Shifts

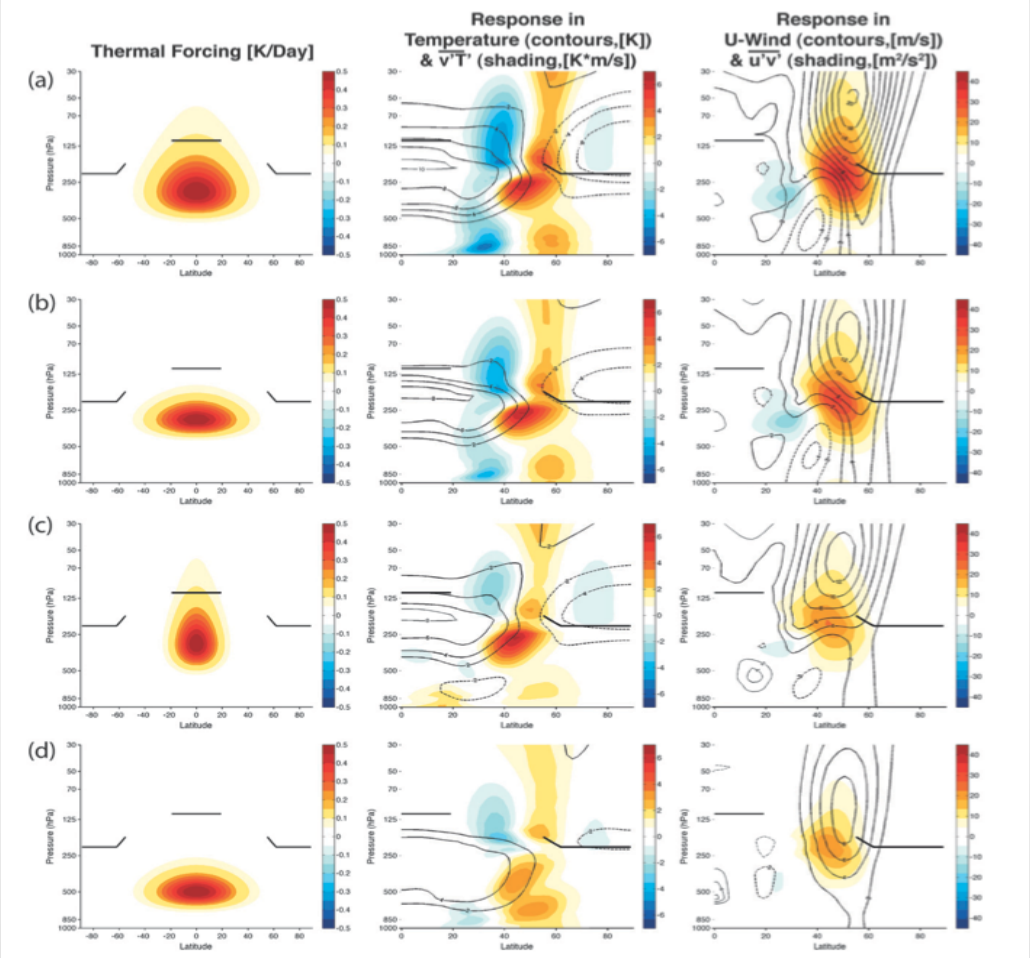
- Two we discussed:
  - Increases in static stability in tropics
  - Changes in horizontal T gradients (dT/dy)
- Changes in Rossby wave phase speeds and Rossby wave breaking
  - Complicated, but cool!
- ???

References

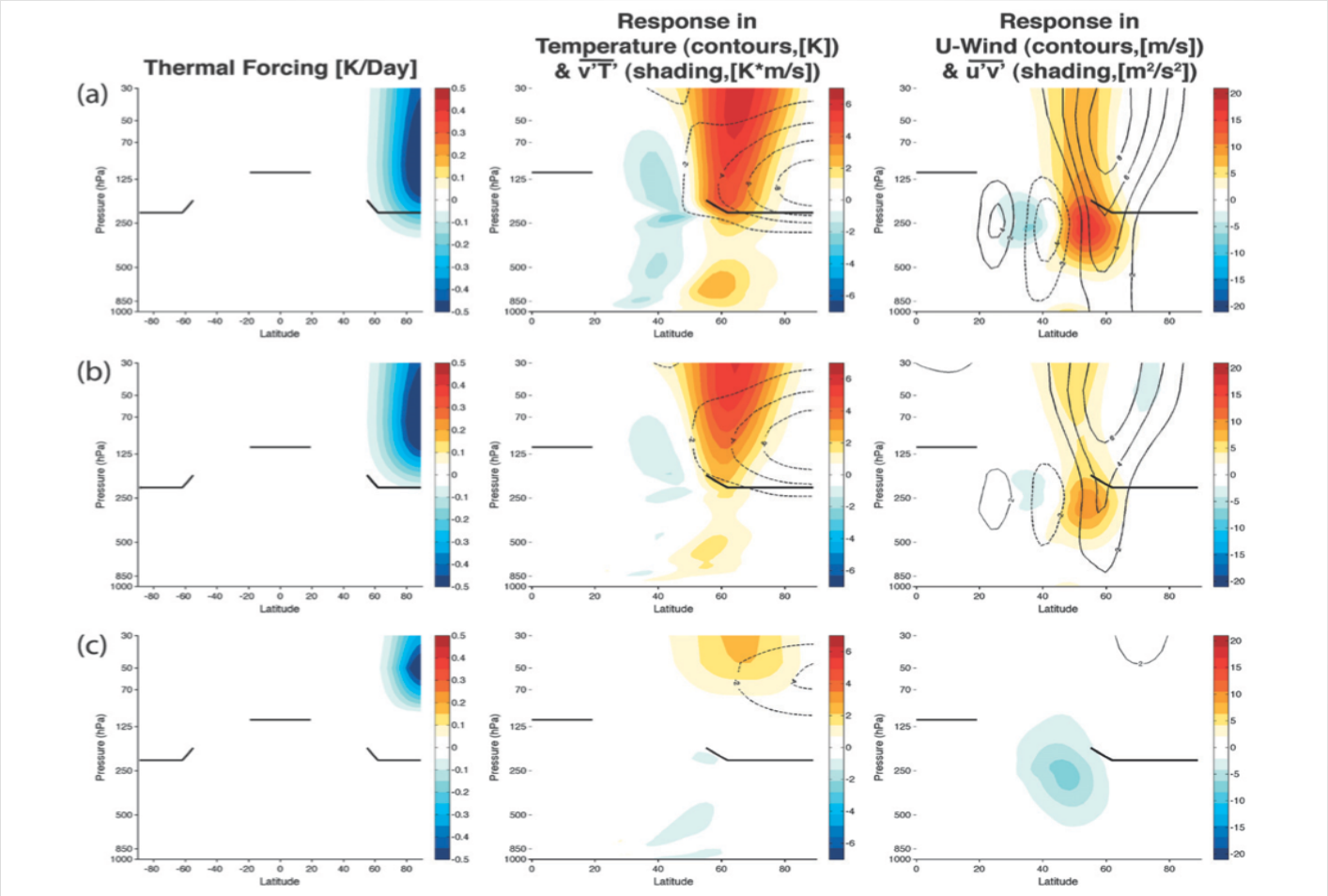
- Barnes, E.A., and L. Polvani, 2013: Response of the midlatitude jets, and of their variability, to increased greenhouse gases in the CMIP5 models. *J. Climate,* **26,** 7117-7135.
- Butler, A.H., D.W.J. Thompson, and R. Heikes, 2010: The steady-state atmospheric circulation response to climate change-like thermal forcings in a simple general circulation model. *J. Climate,* **23,** 3474-3496.
- Chen, G., and I. Held, 2007: Phase speed spectra and the recent poleward shift of Southern Hemisphere surface westerlies. *Geophys. Res. Lett.,* **34,** L21805.
- Harvey, B.J., L.C. Shaffrey, and T.J. Woollings, 2013: Equator-to-pole temperature differences and the extra-tropical storm track responses of the CMIP5 climate models. *J Clim. Dyn.,* **43,** 1171-1182.

Backup Slides

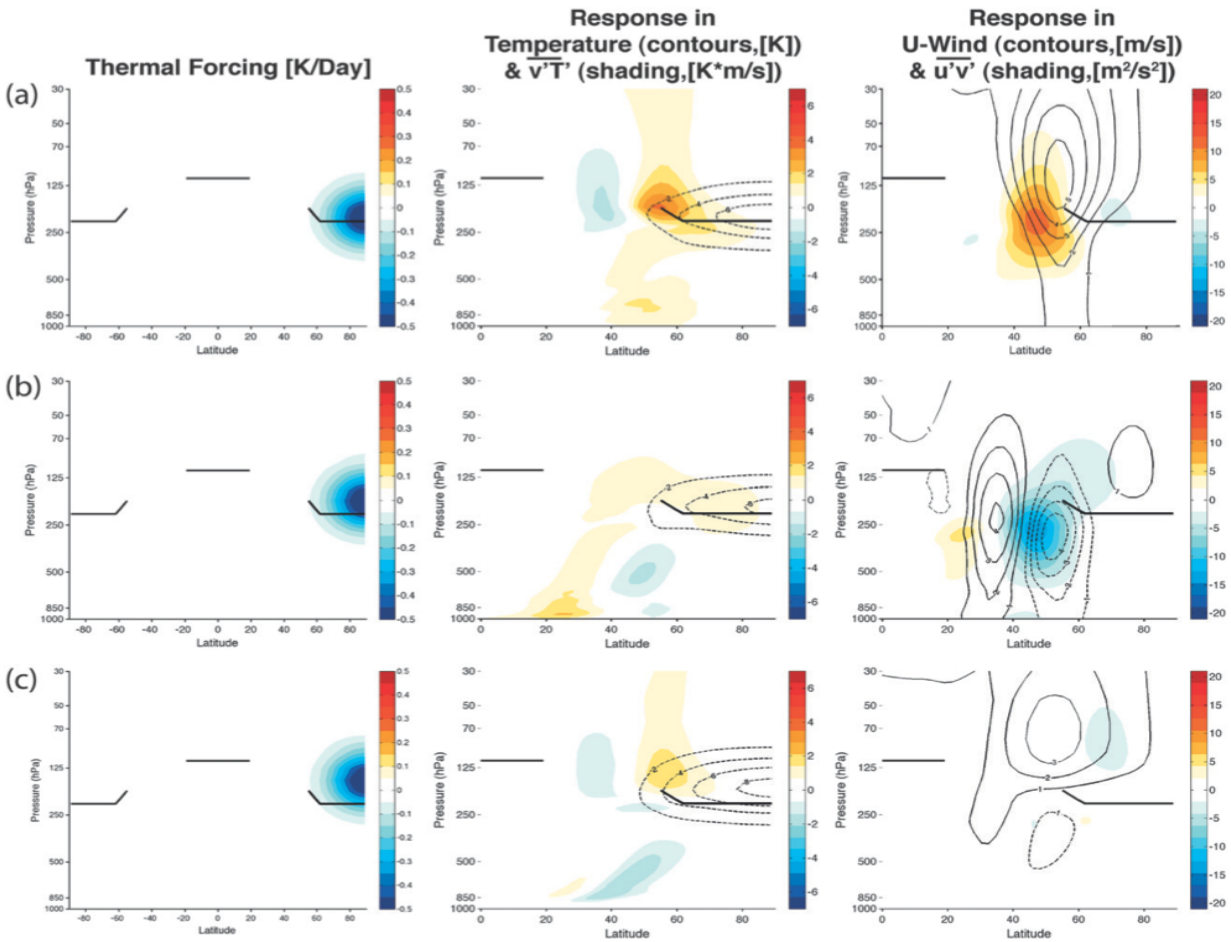
Response: Tropical Heating



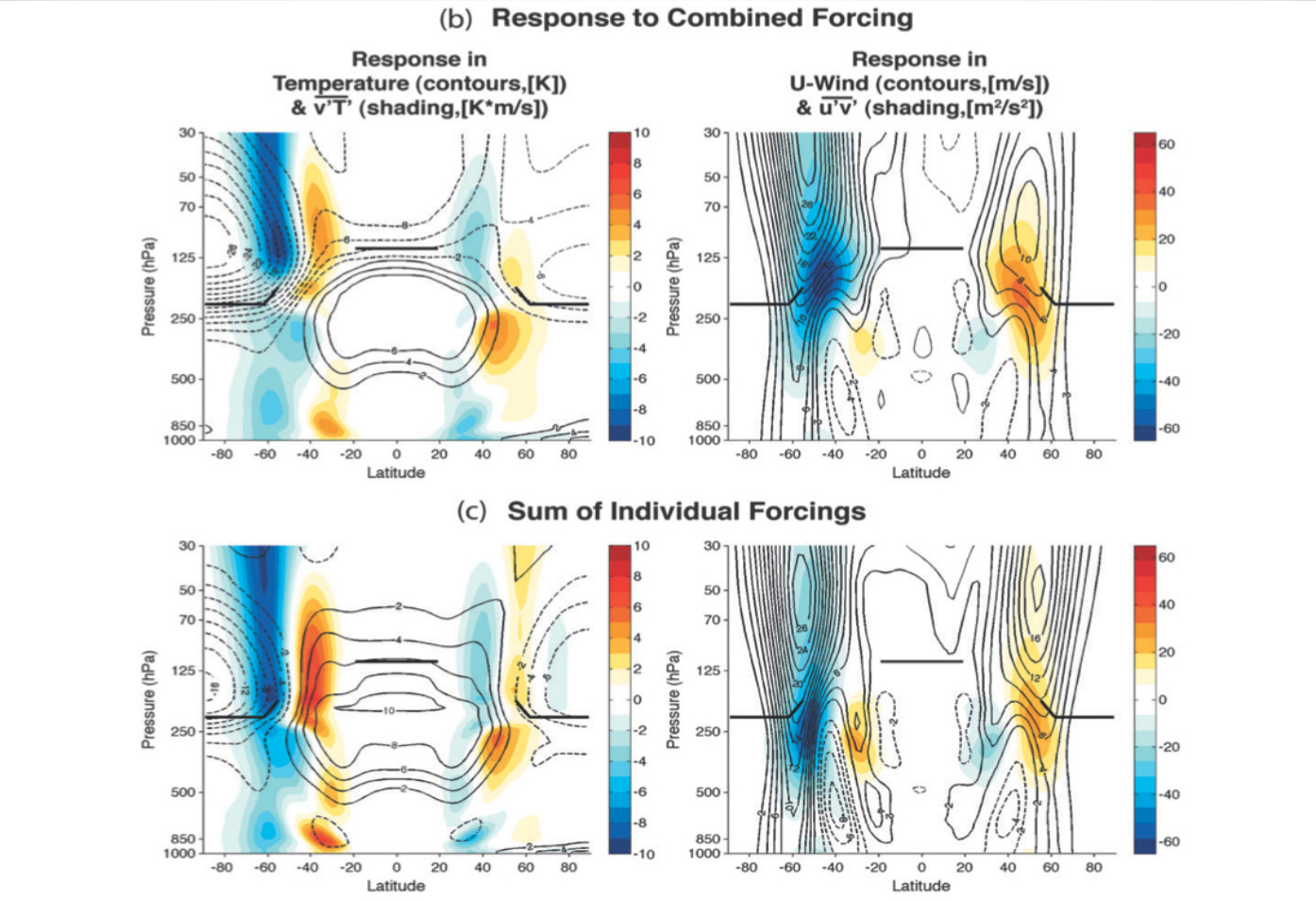
Response: Polar Stratospheric Cooling



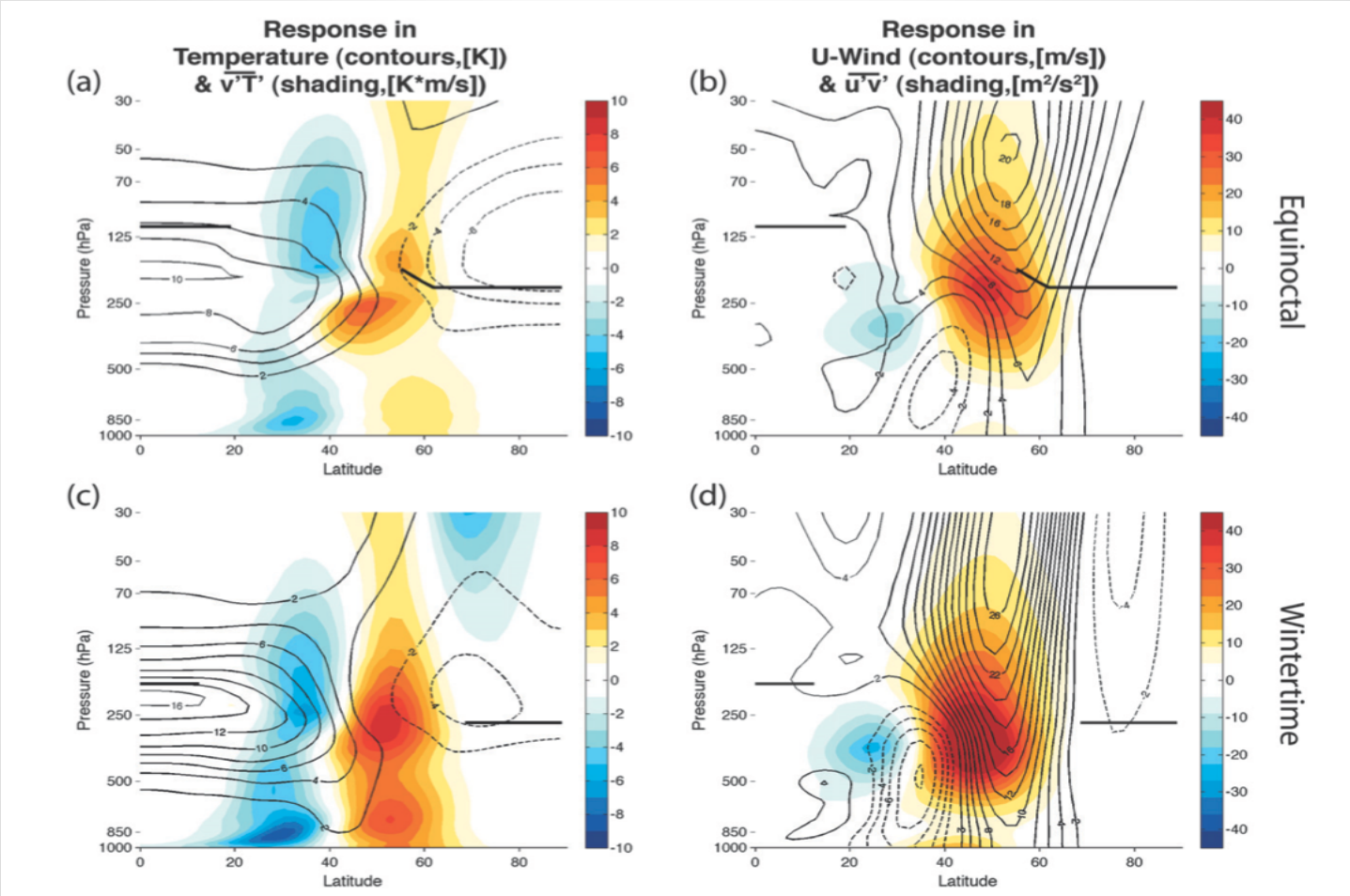
Cooling


Thermal Forcing [K/Day]
Response in Temperature (contours,[K]) & v'T' (shading,[K*m/s])
Response in U-Wind (contours,[m/s]) & u'v' (shading,[m²/s²])
(a)
(b)
(c)
Pressure (hPa)
Latitude

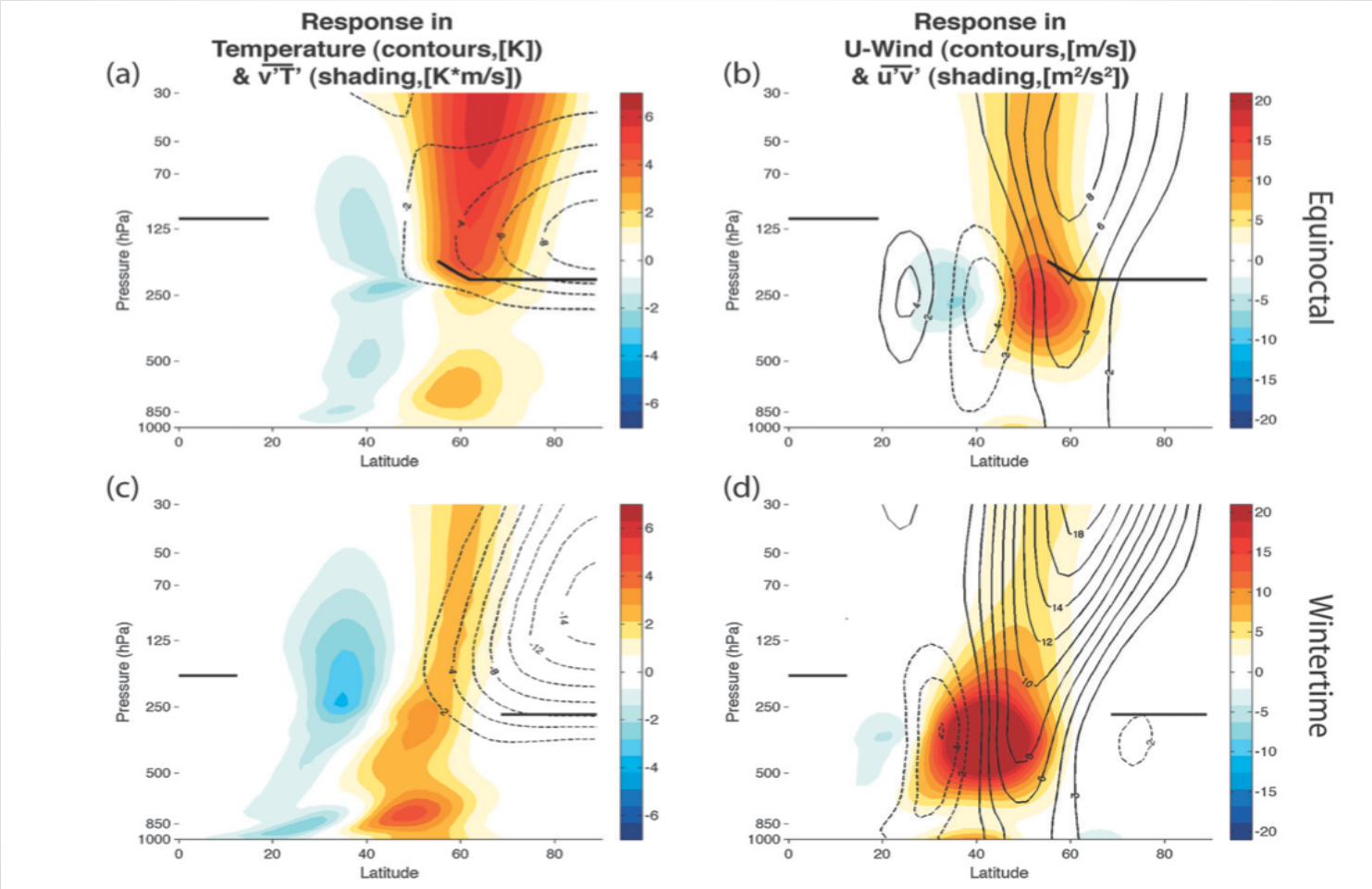
Forcing


(b) Response to Combined Forcing
Response in
Temperature (contours,[K])
& v'T' (shading,[K*m/s])
Response in
U-Wind (contours,[m/s])
& u'v' (shading,[m²/s²])
Pressure (hPa)
Latitude
(c) Sum of Individual Forcings
Pressure (hPa)
Latitude

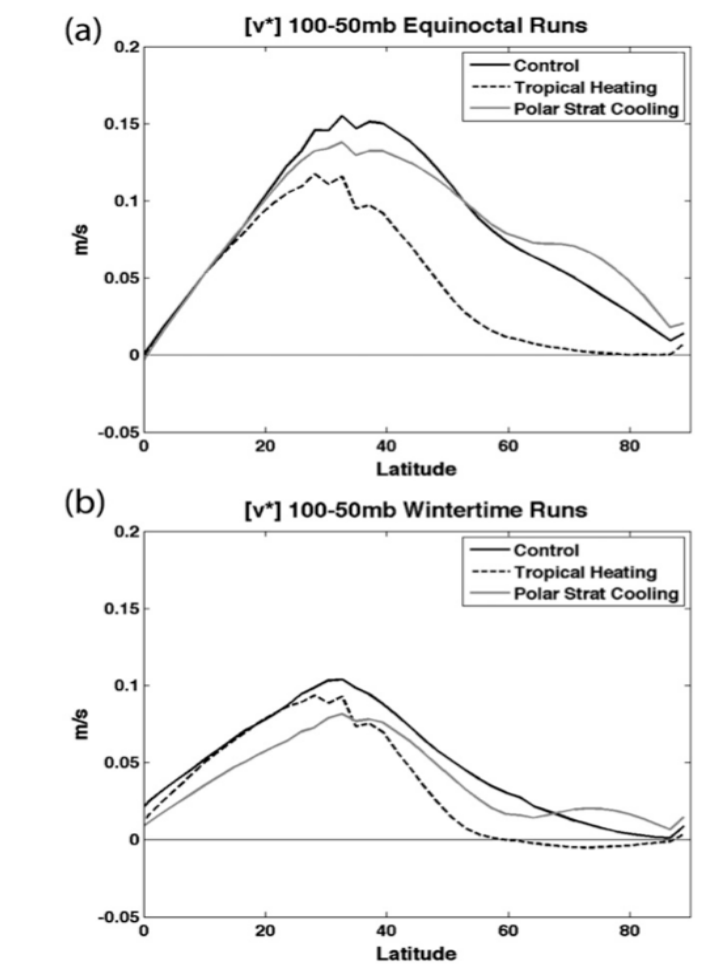
Response: Winter vs. Spring, Tropical Heating



Response: Winter vs. Spring, Polar Cooling



(v*)



Equinoctal

Wintertime

Physical Mechanisms for Jet Shifts

Rossby wave phase speed:

$$c = U - \beta/(k^2 + l^2)$$

If U increases, c will increase

Assuming k is constant, as c -> U, l ->∞ (wave breaks)

$$(k^2 + l^2) = \beta/(U - c)$$

So, if U, and thus c, are increasing, waves break anomalously poleward, shifting u'v' divergence (and conv.)