Modeling the General Circulation of the Atmosphere. Topic 3: Midlatitude General Circulation

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Precip Changes with Global Warming

- Multi-model mean precip change
  - With stippling based on a weak significance criteria

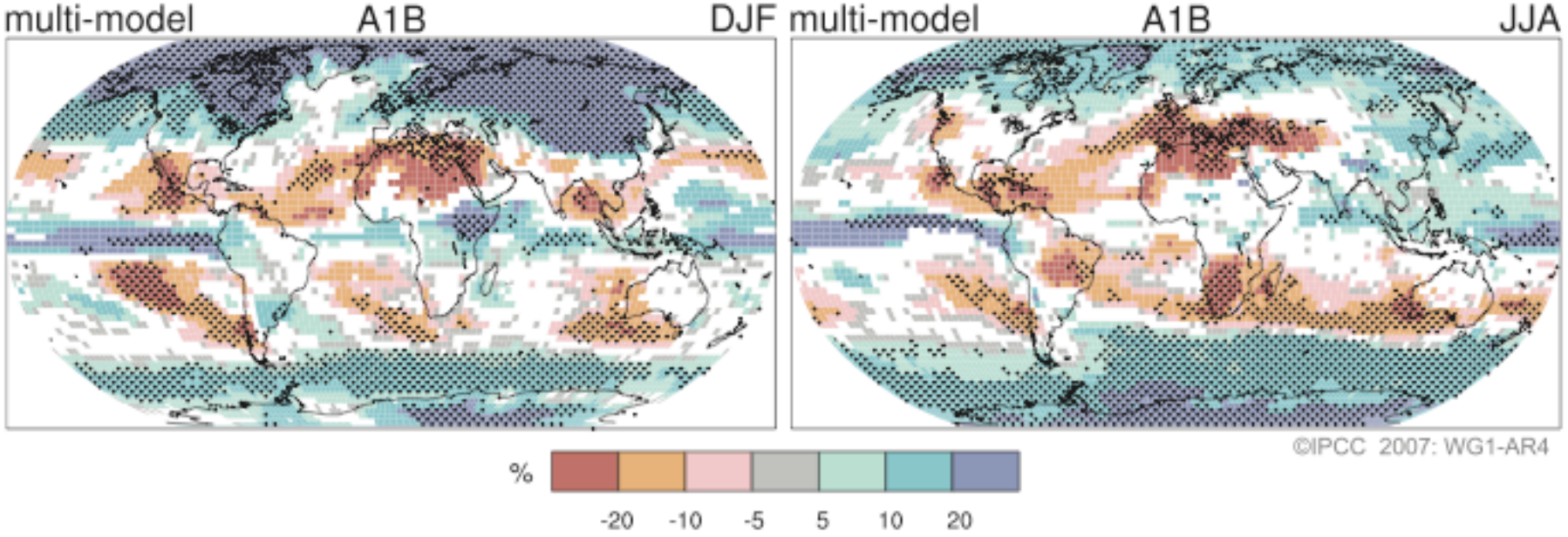


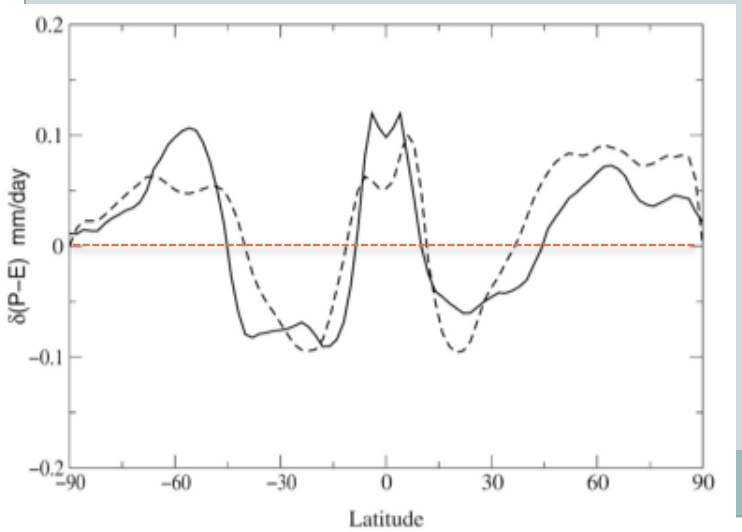
Figure SPM.7. *Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}*

Why Wet Get Wetter

- More moisture in the atmosphere
  → more moisture flux
  → wet get wetter, dry get drier

q ↑
vq ↑

$$P = E - \nabla \cdot (vq)$$ ↑

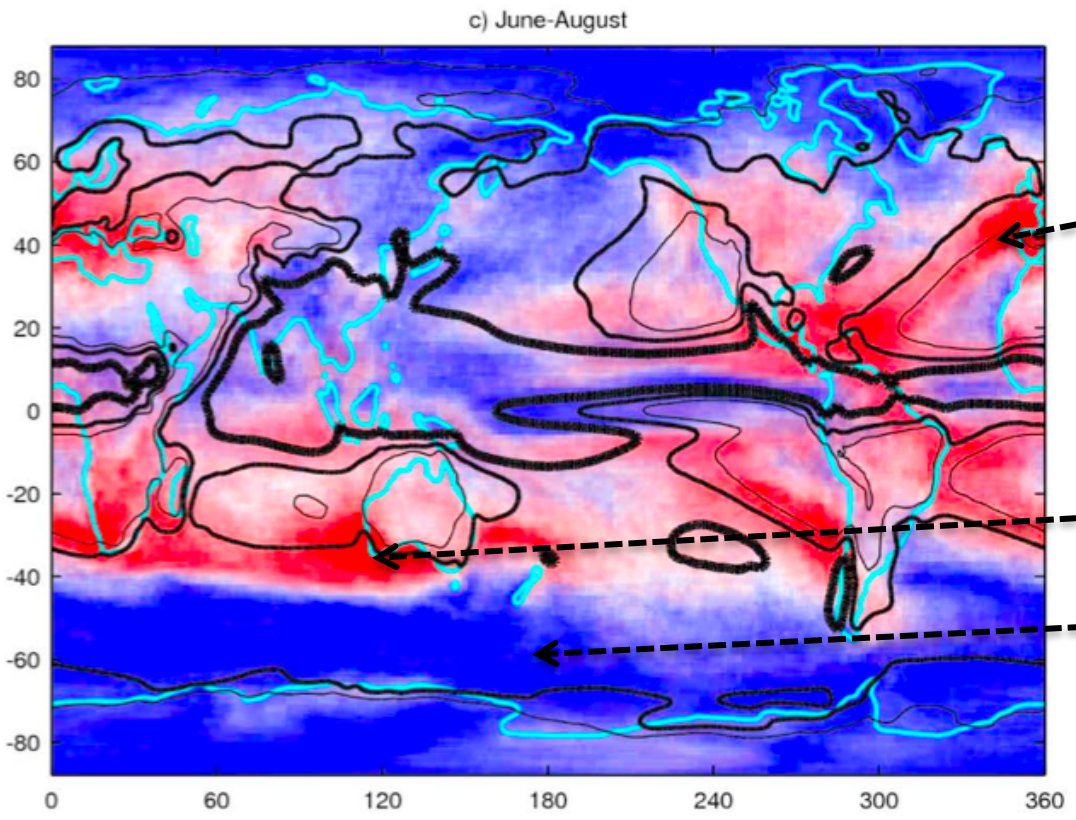


Actual (solid) and thermodynamic prediction (dashed) of P-E change with global warming

Held & Soden 2006, Allen & Ingram 2002, etc

Poleward Expansion of Deserts

- Results of Jack "The Chef" Scheff
  - Robust drying is mostly due to **poleward shift** of *midlatitude* systems



Storm track shifts are the primary cause of significant drying

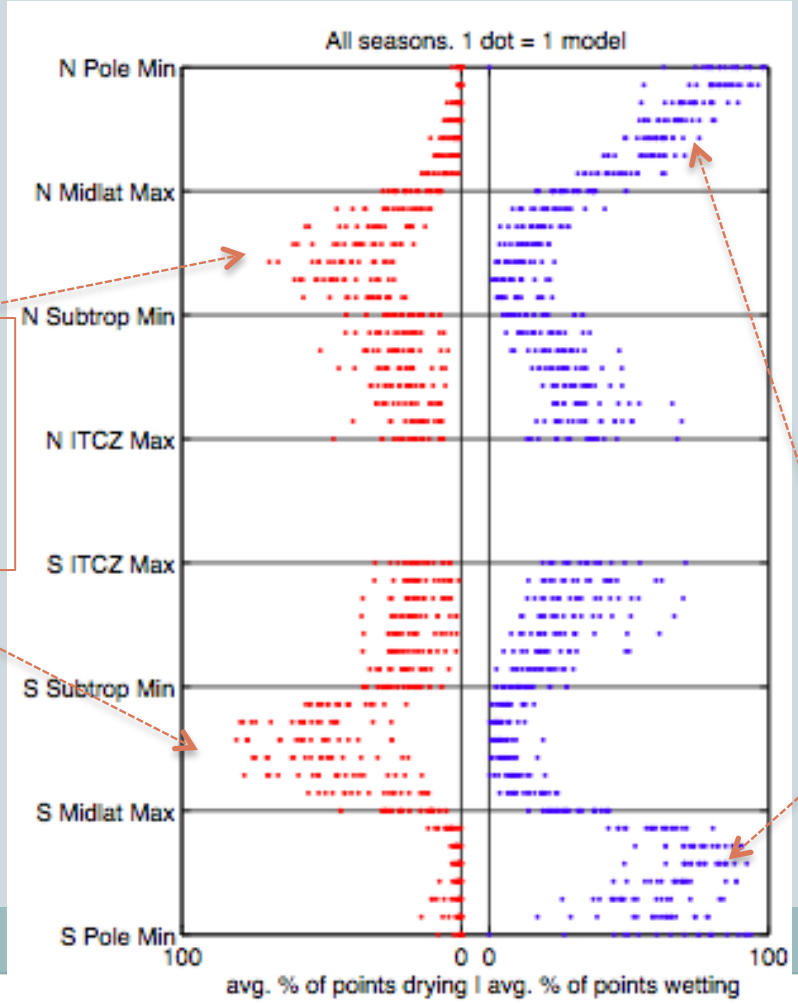
Drying on equatorward side

Moistening on poleward side

Scheff & Frierson (2012; GRL)

Poleward Shifts of Midlatitude Storm Tracks

- **Feature-relative** precipitation changes



Each dot = 1 model
Blue/Red = fraction of points w/ significant moistening/drying

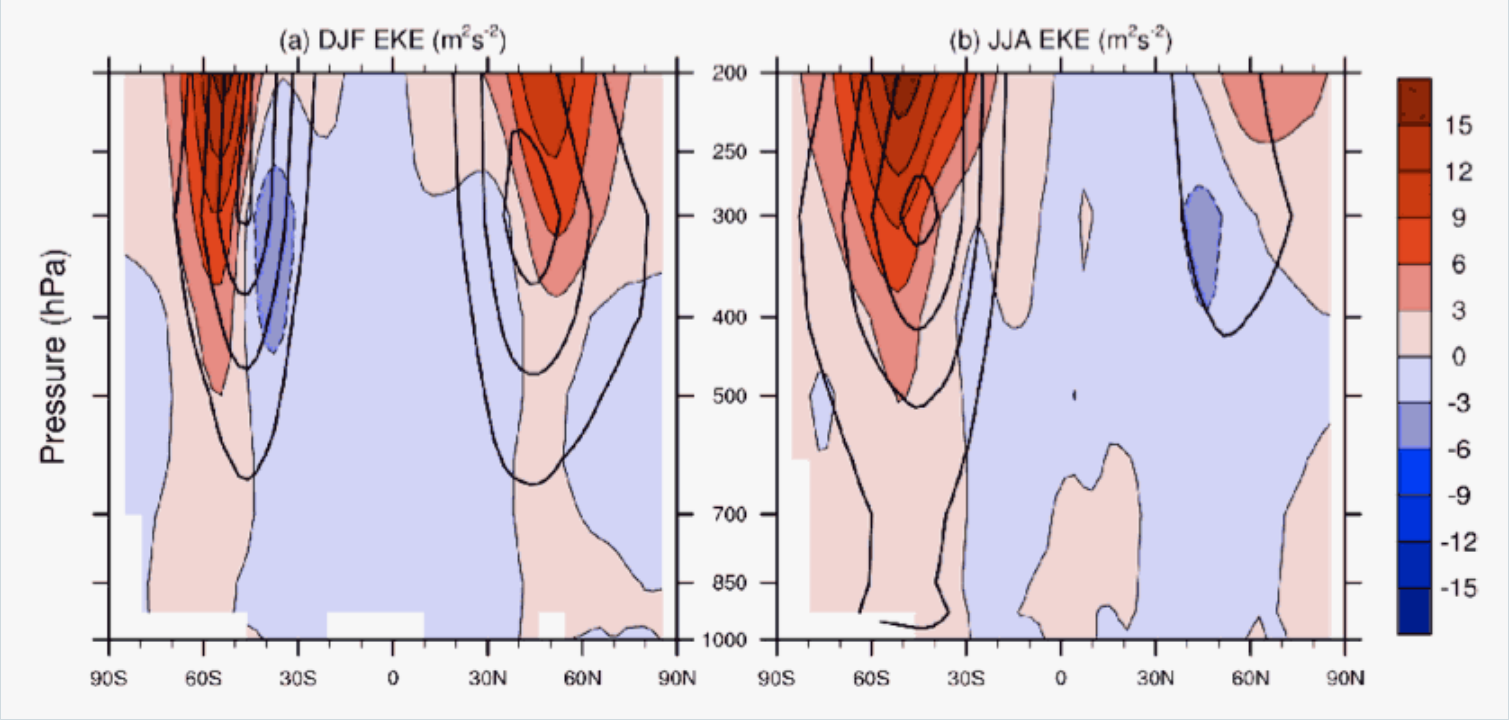
Most drying occurs b/w midlat max and subtrop min

We confidently project high latitude moistening

From Scheff and Frierson (2012, J. Climate)

Poleward Shifts of Eddies w/ Global Warming

- Eddy kinetic energy changes from Yin 2005
  - Black contours are current mean, colors are predicted change

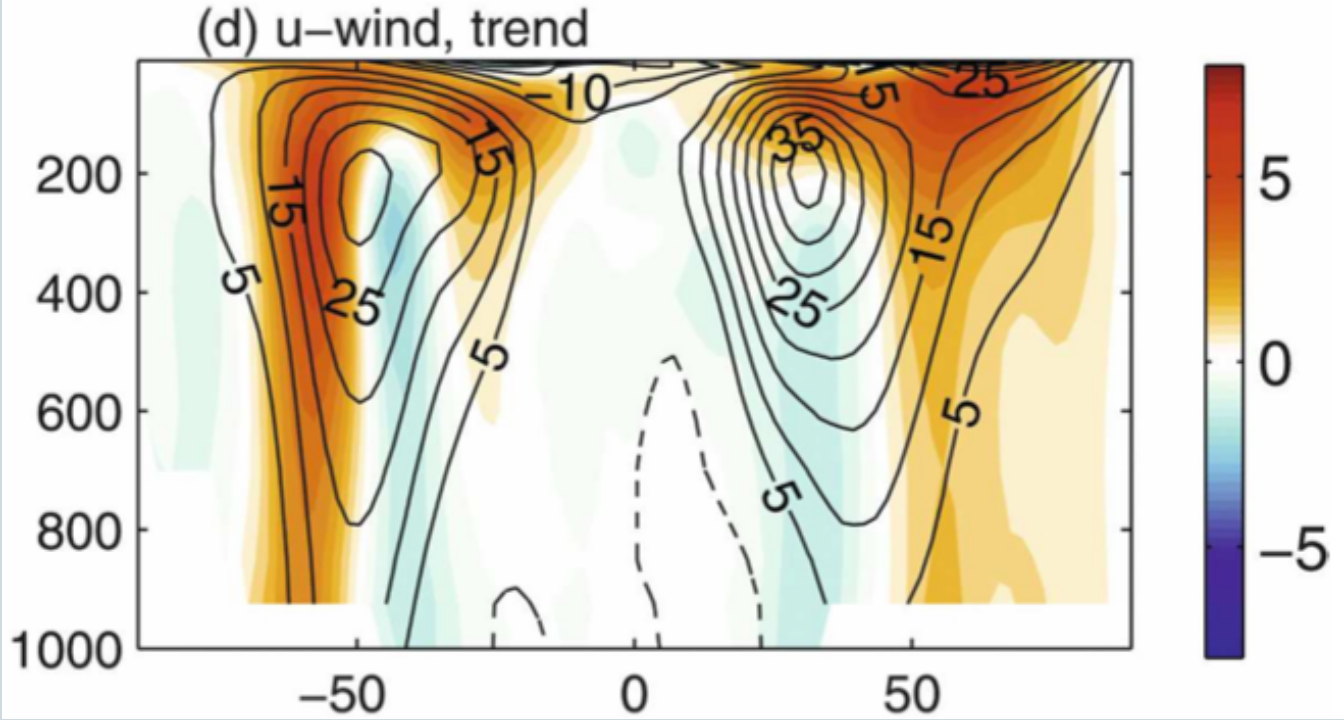


- Poleward (and upward) shift with global warming

See also Kushner et al, Miller et al, Lorenz & DeWeaver, Previdi & Liepert, etc

Poleward Shift of Eddies

- DJF zonal wind changes from Lu, Chen & Frierson 2007
  - Black contours are current mean, colors are predicted change



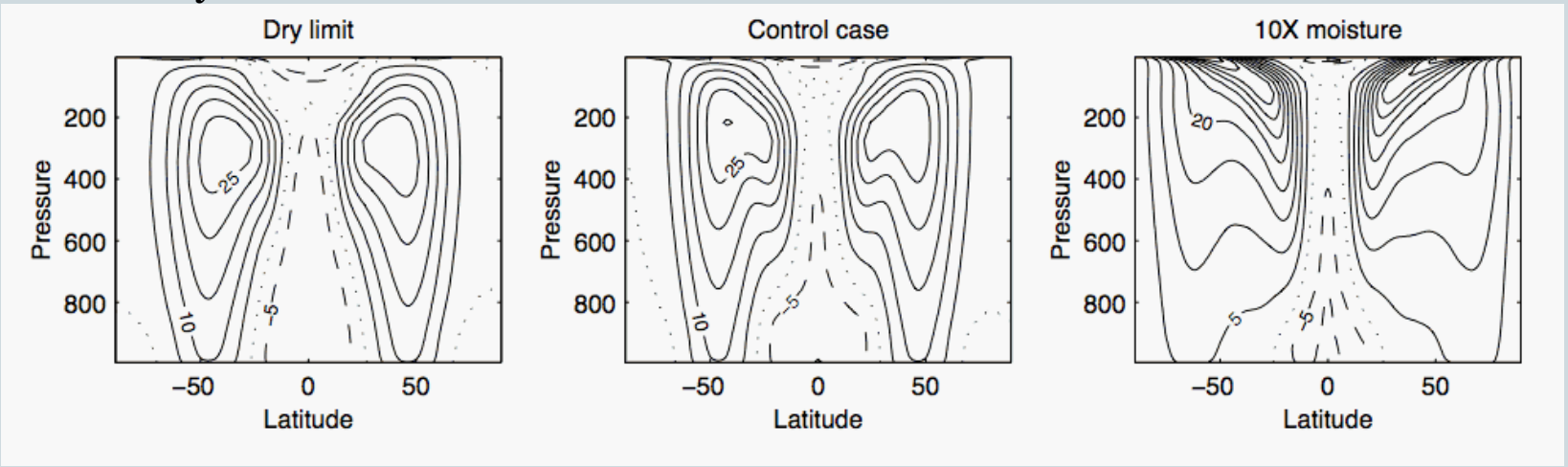
- Poleward (and upward) shift with global warming

See also Kushner et al, Miller et al, Lorenz & DeWeaver, Previdi & Liepert, etc

Idealized Model Changes with Moisture

- Zonal winds in a simplified physics aquaplanet GCM:

Dry simulation | Control | High moisture case



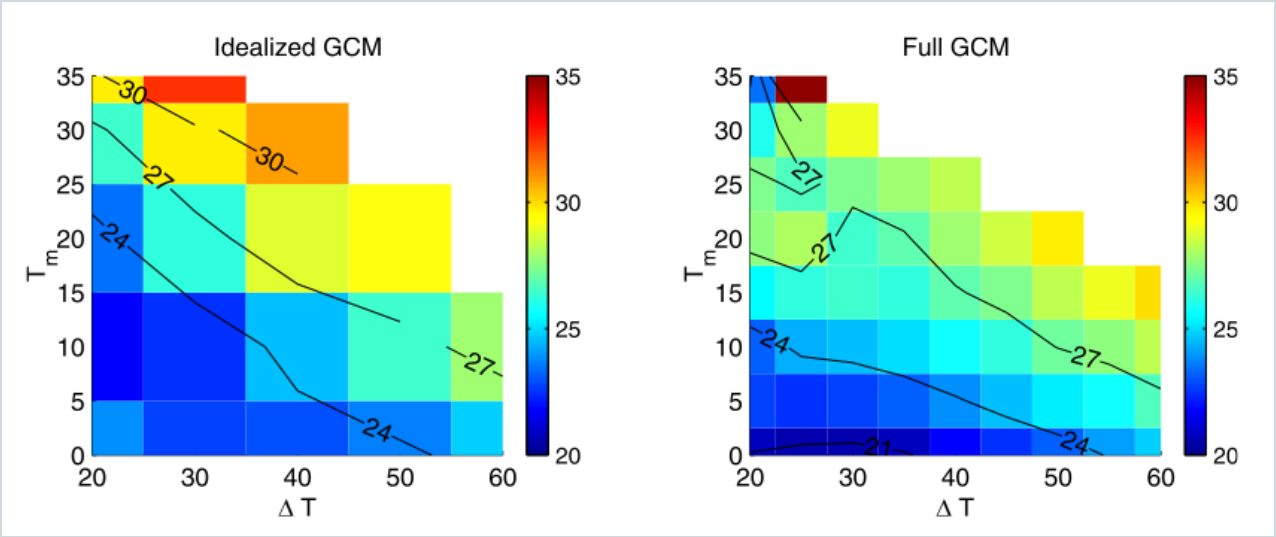
- Poleward and upward shift with increased moisture
  - Similar to global warming simulations

From Frierson, Held and Zurita-Gotor (2006)

Poleward Shifts in Aquaplanet Models

- Poleward shifts with warming (and equatorward shifts with cooling) are **very robust** in many types of models over large range of climates

Warmer →



Higher gradient →

Higher gradient →

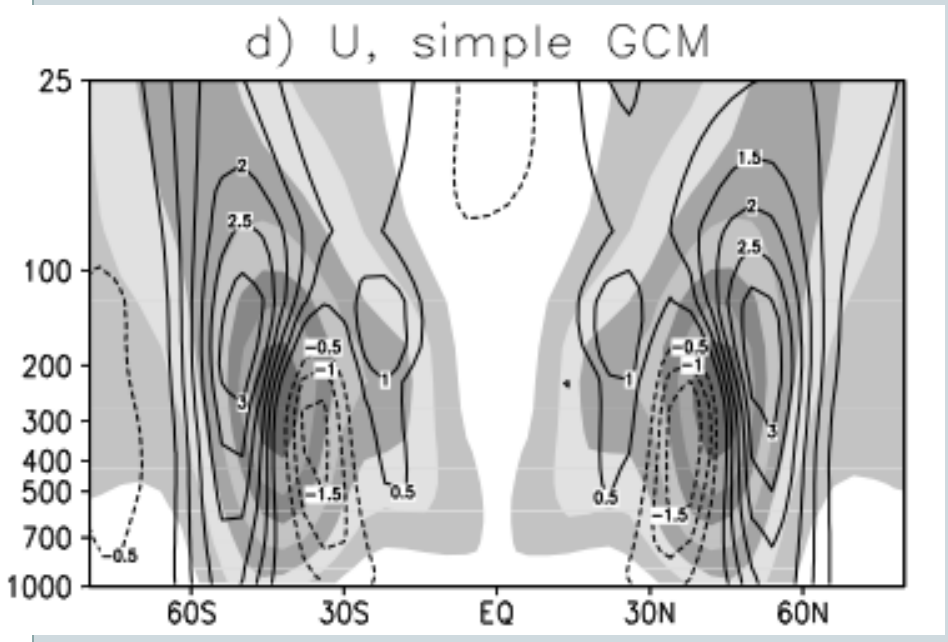
Each box is one simulation (72 sims total).

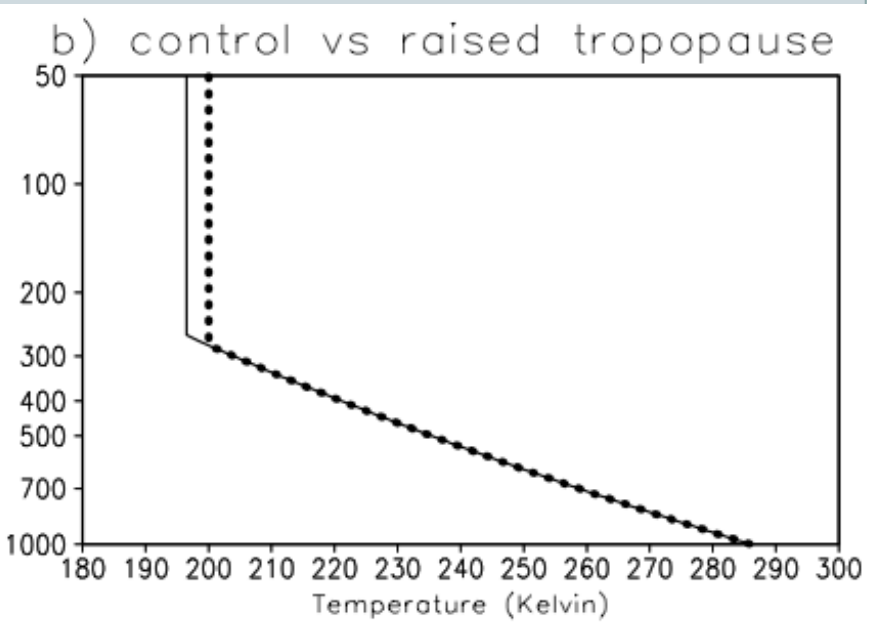
Latitude of dry zone is contoured.

From Frierson, Lu, & Chen 2007

Poleward Shifts in Dry Models

- Happens in dry models due to rises in the tropopause height

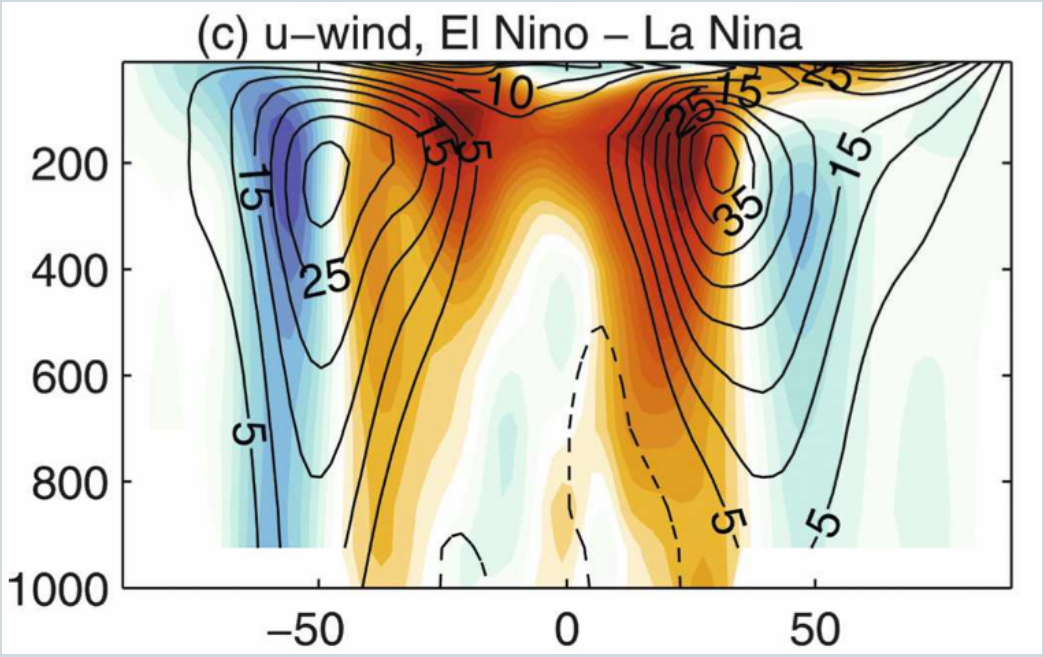




Lorenz & DeWeaver 2007

Not due to El Niño…

- People often talk about "El Niño-like" responses to global warming…



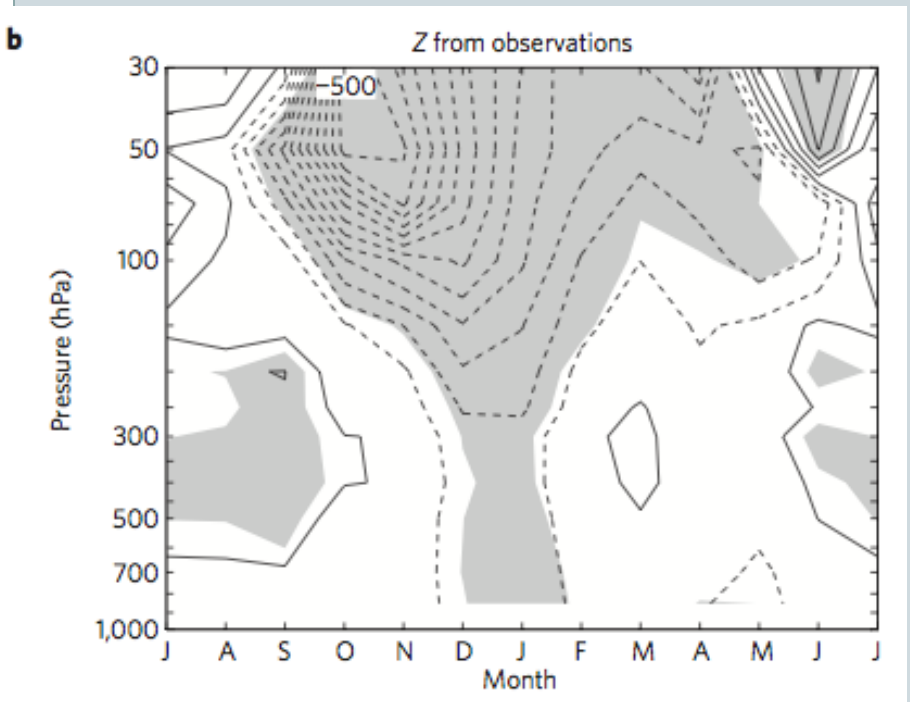
- But El Niño causes an **equatorward contraction**
  - Although zonal asymmetries are clearly important in ENSO…

Lu, Chen & Frierson 2008

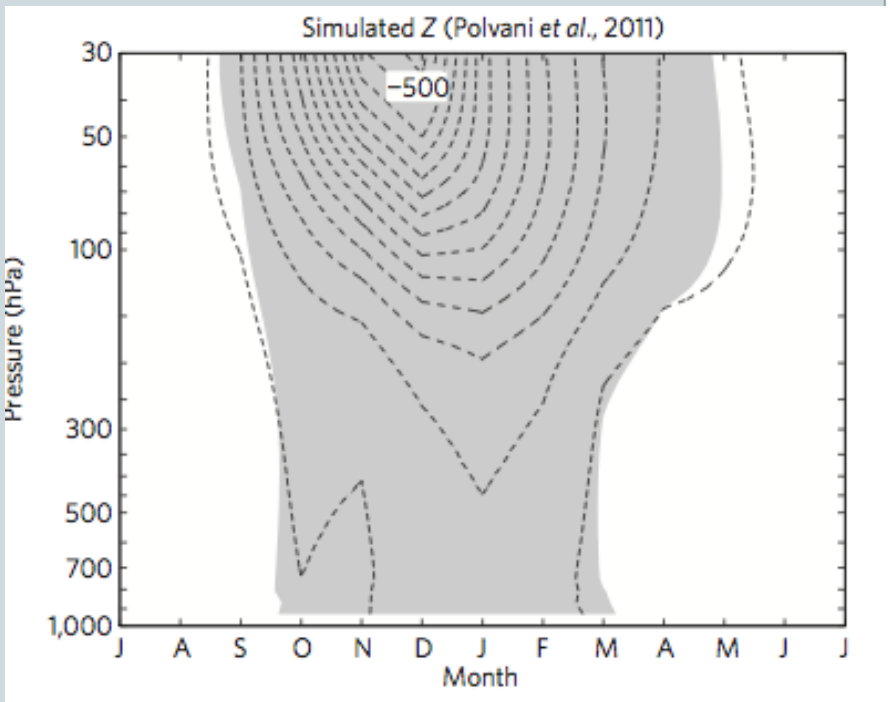
SH Poleward Shift due to Ozone Depletion

- The **ozone hole** has clearly induced changes in winds as well – only in DJF though

Observations



Model



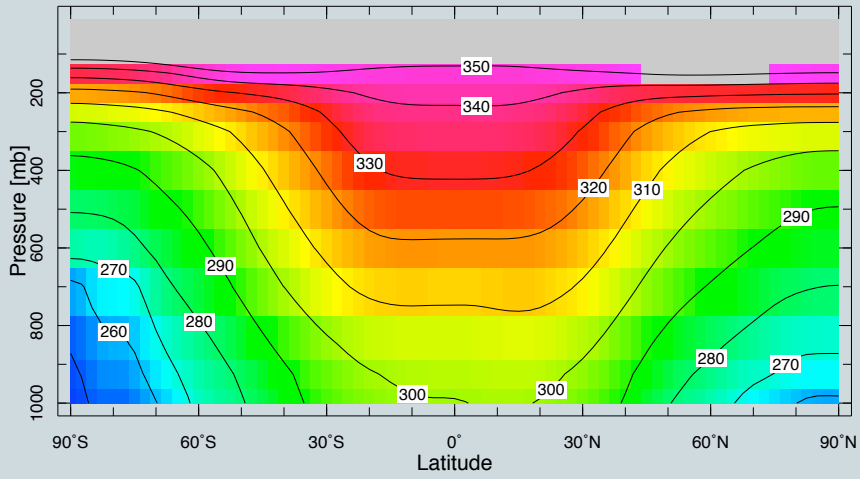
Thompson et al 2012

Width of Hadley Cell Predictions

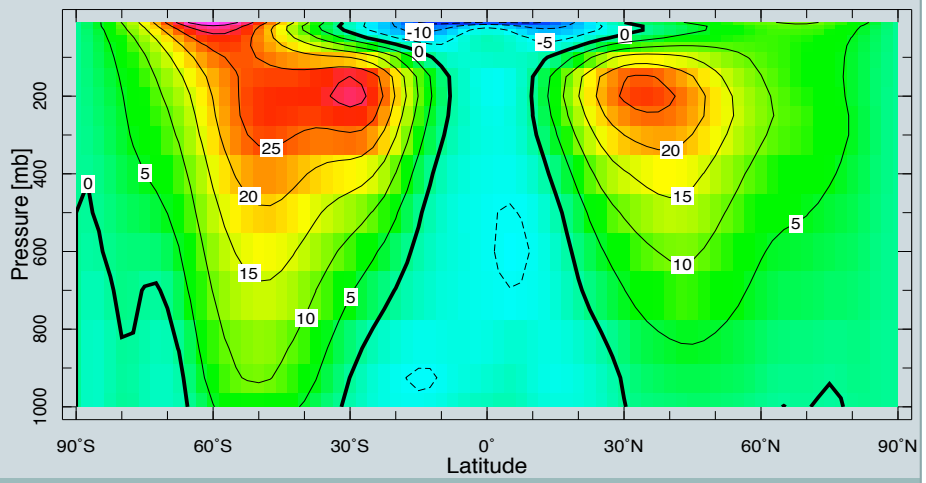
- Can we use our tropical intuition to understand the shift?
  - Predictions from Held-Hou theory
  - Alternative theory for widening: Held (2000) derivation
    - Using Phillips' criterion
    - Using Eady growth rate

Where do eddies grow?

- Eddies grow due to **baroclinic instability**
- Faster eddy growth where there's…
  - Large **temperature gradient,** or equivalently, large **wind shear**
  - Also **small stratification** helps and **higher latitudes** are better due to Coriolis



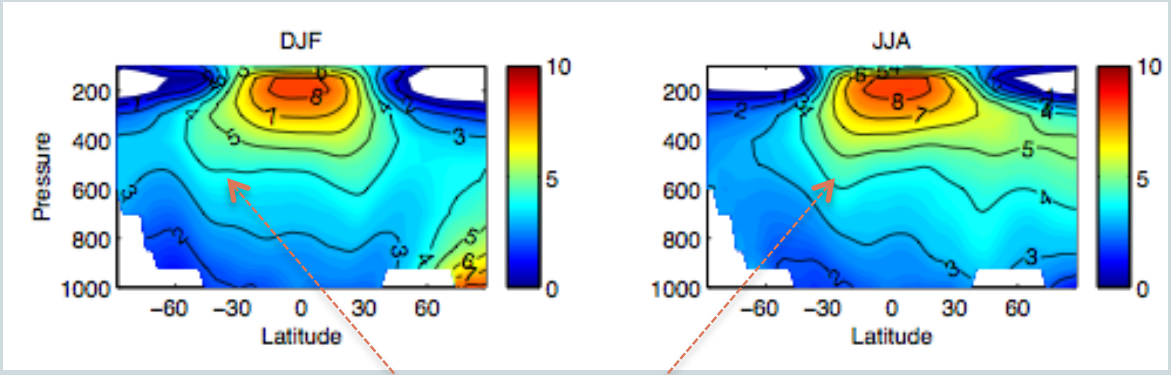
Potential temperature



Zonal wind

A Baroclinic Mechanism

- These theories focus on the **generation** of baroclinic instability
- Related argument: stratification increases preferentially on **equatorward side** of storm tracks
  - Causes shift of baroclinic instability away from stabilization?

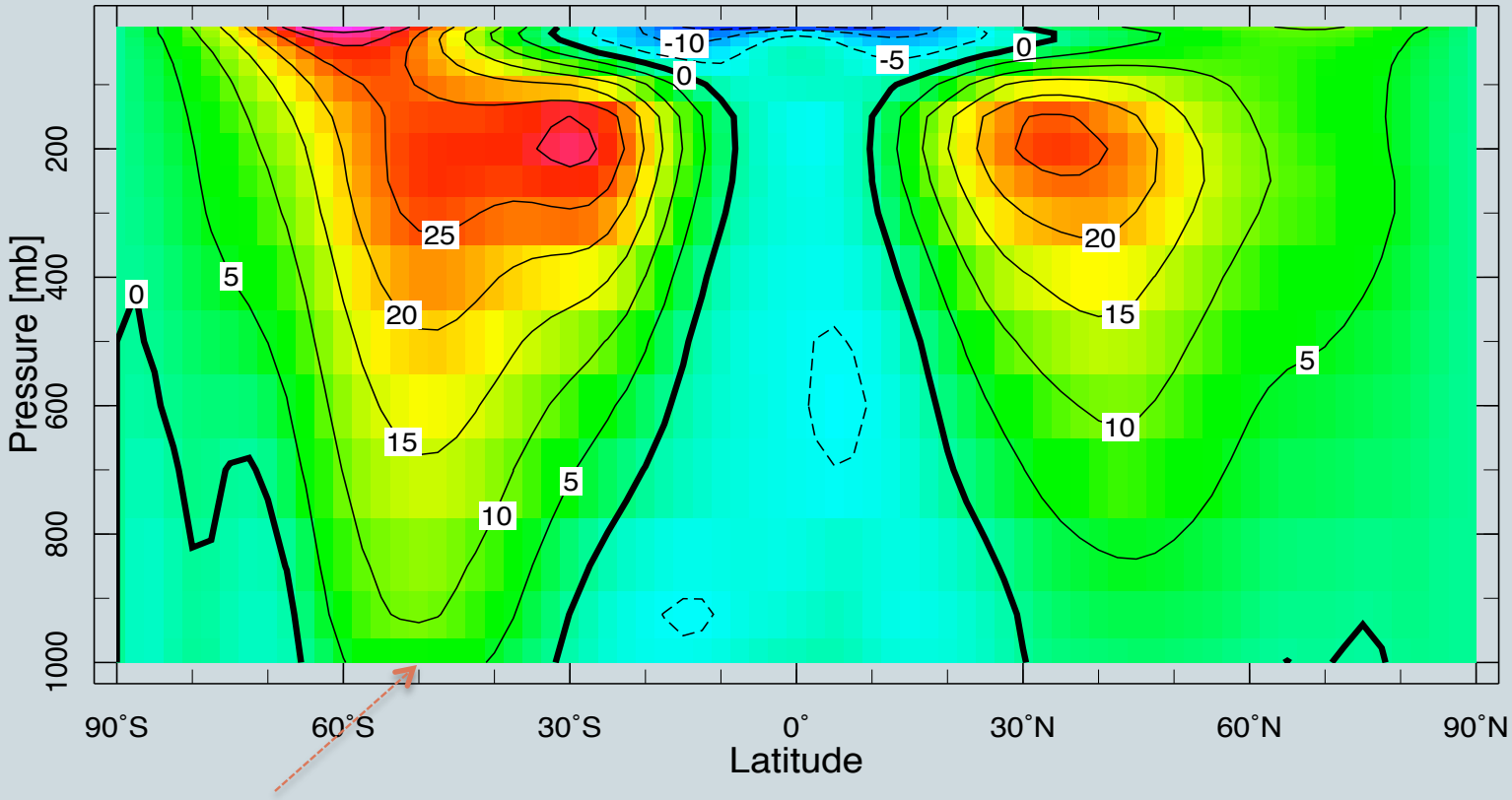


More stabilization

Frierson 2006

Midlatitude Dynamics

- Zonal winds:



Surface winds are frictionally damped: require momentum flux to support

Zonally averaged zonal winds from NCEP reanalysis

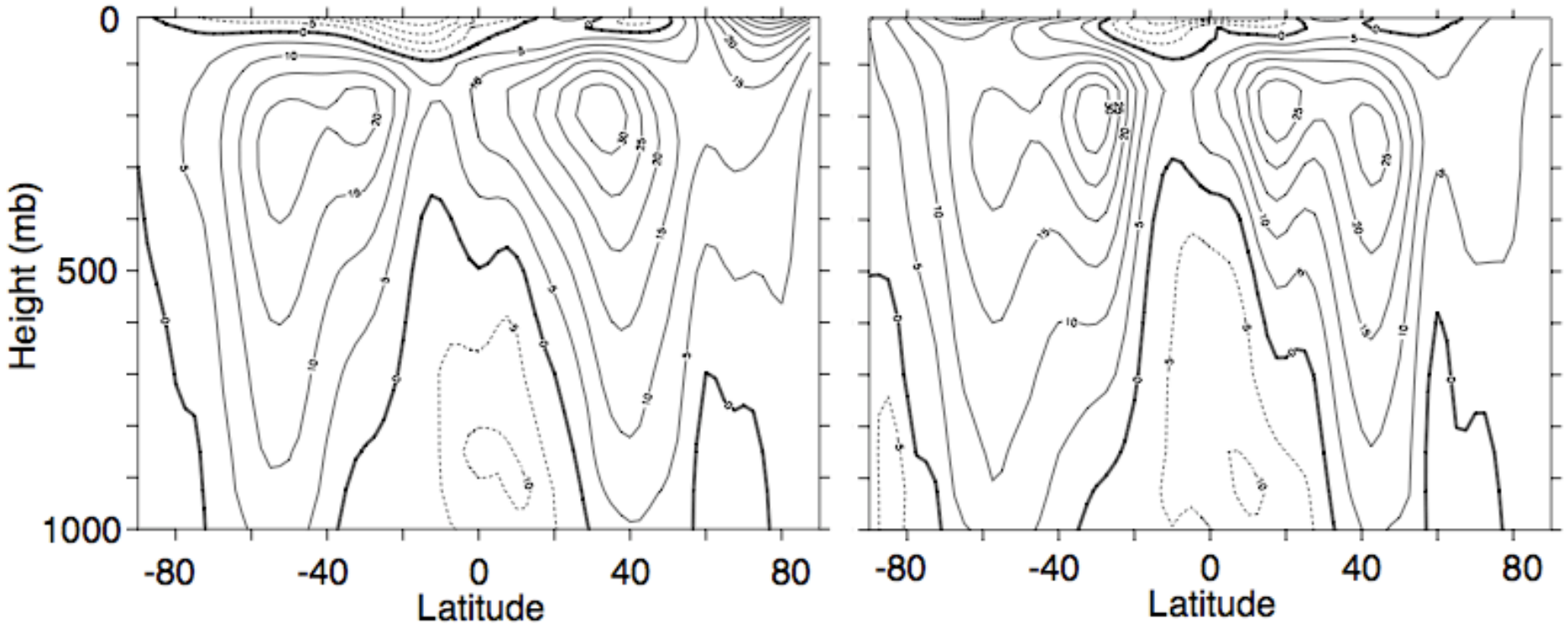
Midlatitude Dynamics: Big Picture

- Horizontal momentum fluxes => surface winds
  - (Barotropic component of winds)
  - Remember can also get Ferrel cell transport from this too
- Thermal wind balance: shear ⇔ temperature gradients
  - Energy fluxes => vertical shear
  - Or, vertical momentum flux => meridional temperature gradient!

Zonal winds in central Pacific

- Zonal winds at 150 W (central Pacific) from Vallis:

DJF MAM



Big Picture Part 2

- Subtropical jet = Hadley cell jet
  - Baroclinic but no surface westerlies underneath
- Midlatitude jet = subpolar jet = eddy-driven jet
  - Large barotropic component
  - Requires momentum transport into the jet
  - Baroclinic eddies do the driving
  - However can understand with a barotropic model!

Barotropic Vorticity Equation

- Two-dimensional, non-divergent flow
- Everything can be written in terms of 1 variable (streamfunction)
- Balanced model
- Simplest model w/ Rossby waves
- Used for first sucessful NWP experiment
- Rossby wave momentum transport derivation