Next: effect of eddies on the Hadley circulation

- We talked about ways to incorporate eddy heat fluxes into an axisymmetric model
- How about effect of eddy momentum fluxes?
  - Ferrel cell derivation
  - An eddy-driven Hadley cell model

Effect of eddy fluxes

- Compare the dry dynamical core model run axisymmetrically versus with eddies
  - Hadley cell is significantly stronger with eddies
  - Suggests eddies are a major driver in this model!
  - Heat fluxes or momentum fluxes?
- Not true in moist model!
  - Axisymmetric cell is stronger in moist GCM
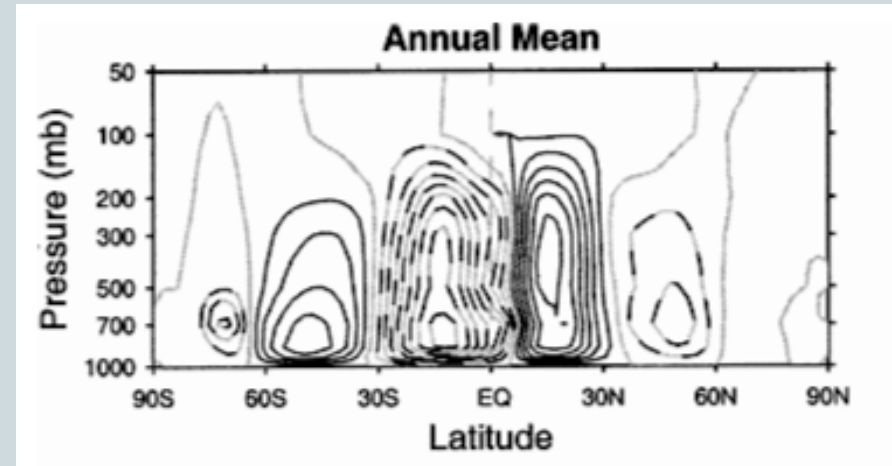 - Comparing axisymmetric and full Hadley cells in different models could be nice project
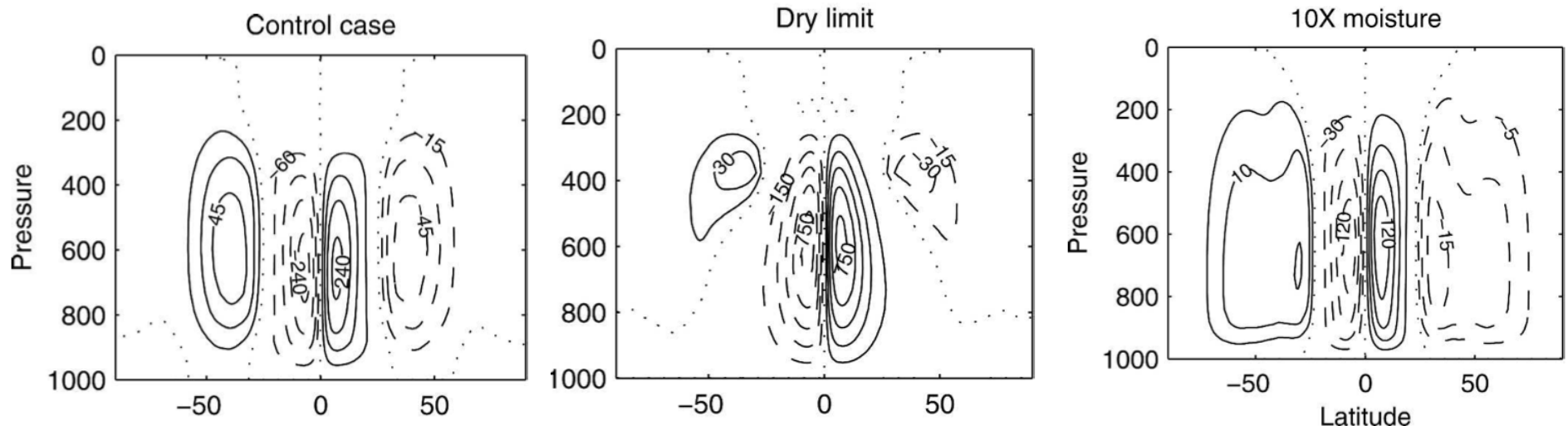
Dry GCM Results

- Hadley cell strengths:

Model
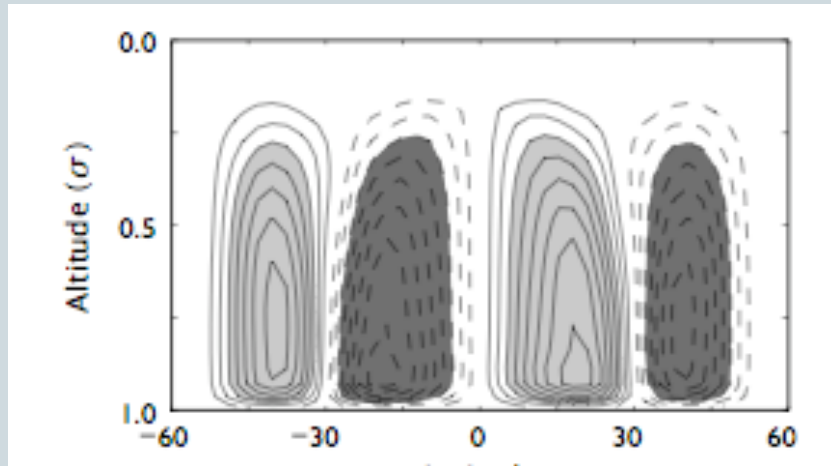
Obs

Hadley Circulation in GrAM

Remember those simulations varying moisture content? (control, dry, and 10x Clausius-Clapeyron constant)
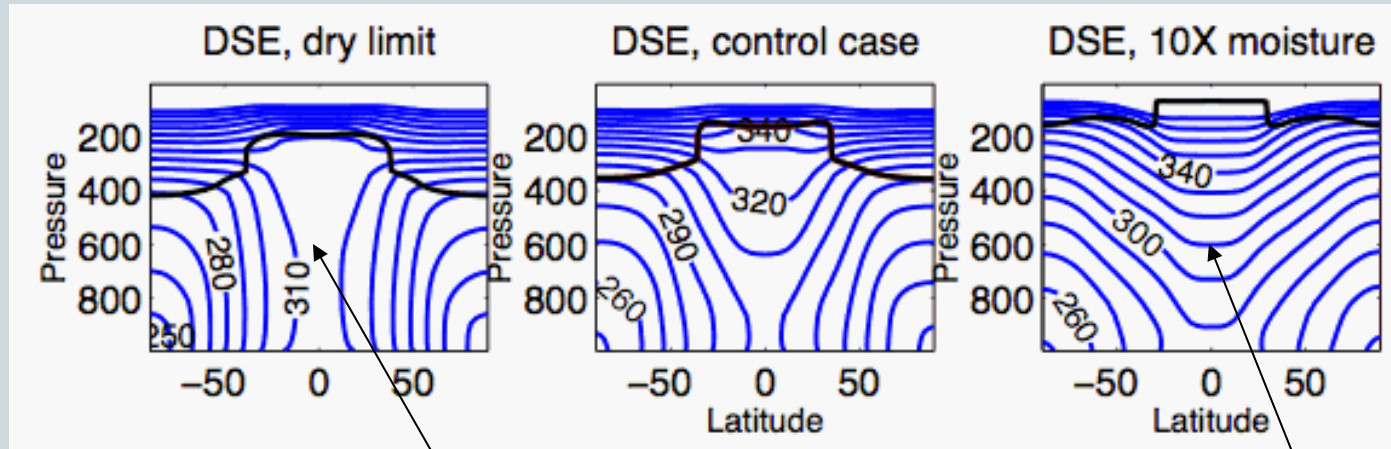

Control case — Max contour = 240 Sv

Dry limit — Max contour = **750** Sv

10X moisture — Max contour = **120** Sv

Hadley circulation is **much stronger** in **dry** case!

Temperature Structure Changes

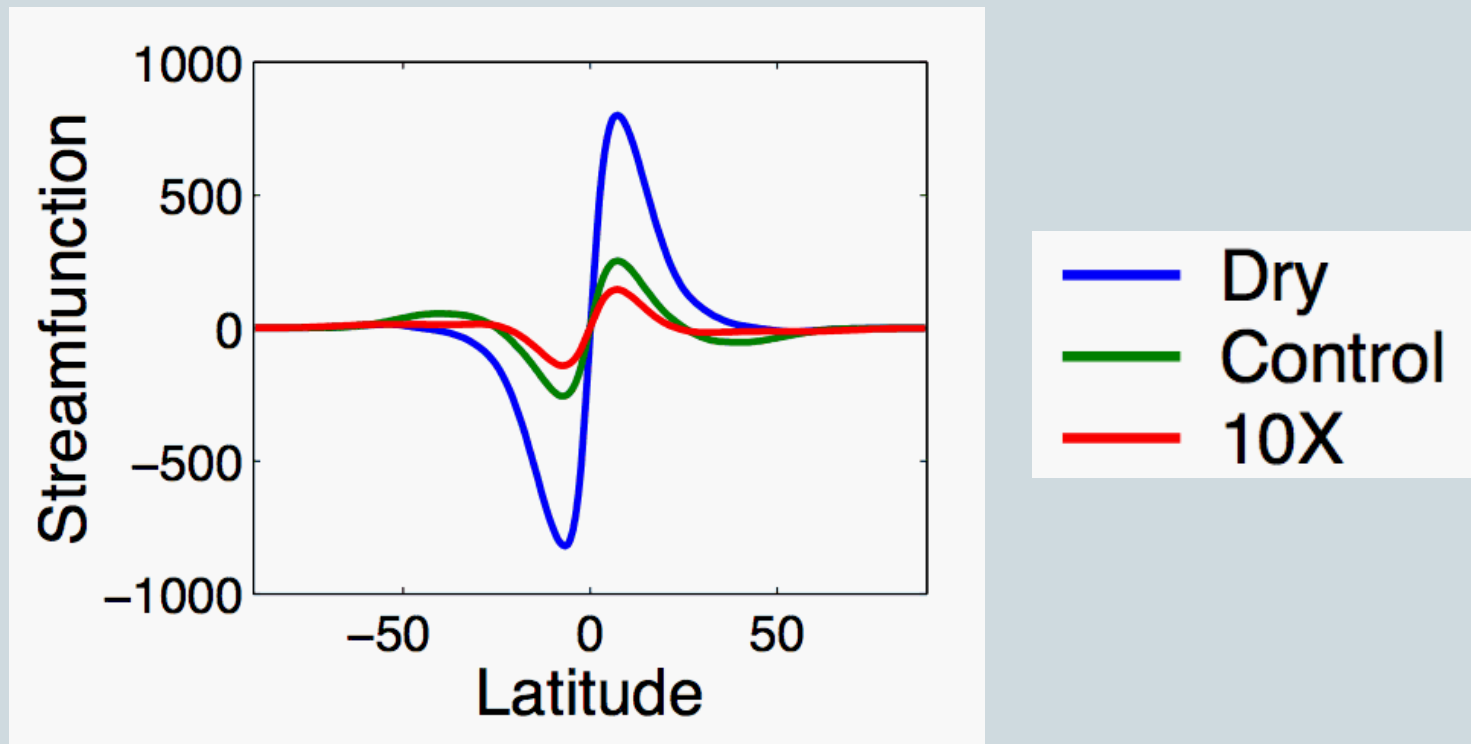- Dry static energy, idealized GCM simulations:

~Zero stability   Large stability

- Static stability ($\frac{d\theta}{dz}$) increases in tropics (as expected)

From Frierson, Held and Zurita-Gotor (2006)
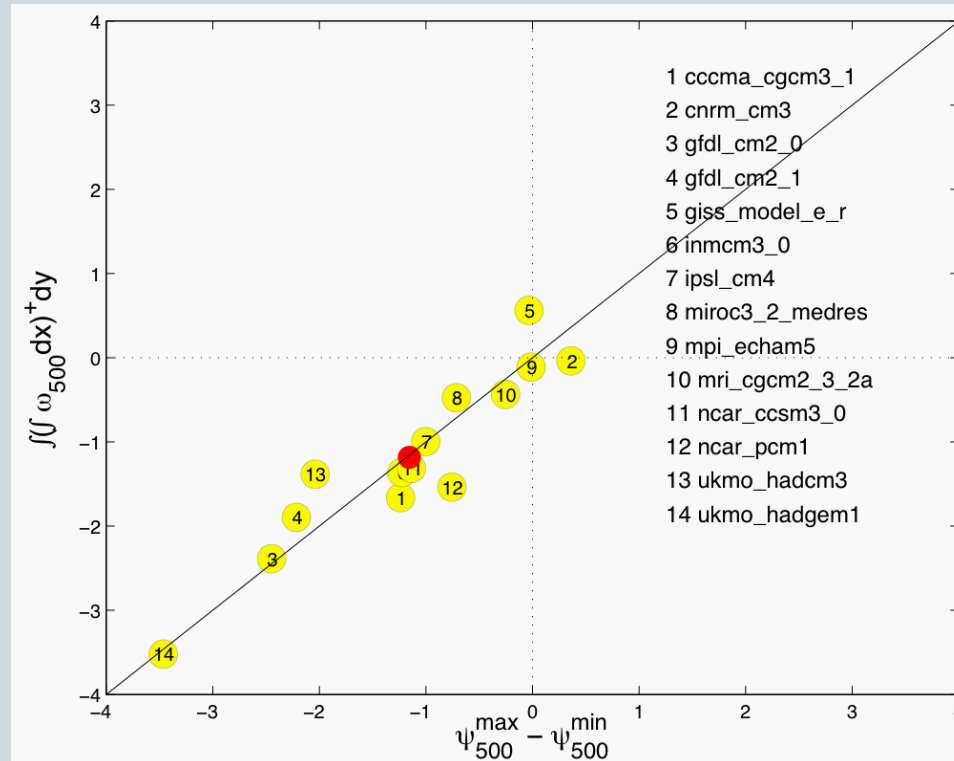
Hadley Circulation in GrAM

Hadley circulation is **much stronger** in **dry** case!

Hadley Circulation Changes

- Changes w/ global warming in CMIP3:

Decreases 0-3.5% per K warming

From Lu, Vecchi, and Reichler (2006)

Streamfunction measure

Next...

- We'll return to Hadley cell later when discussing extratropical-tropical interactions
- Next: theories with an active moisture budget and the "gross moist stability" (GMS)
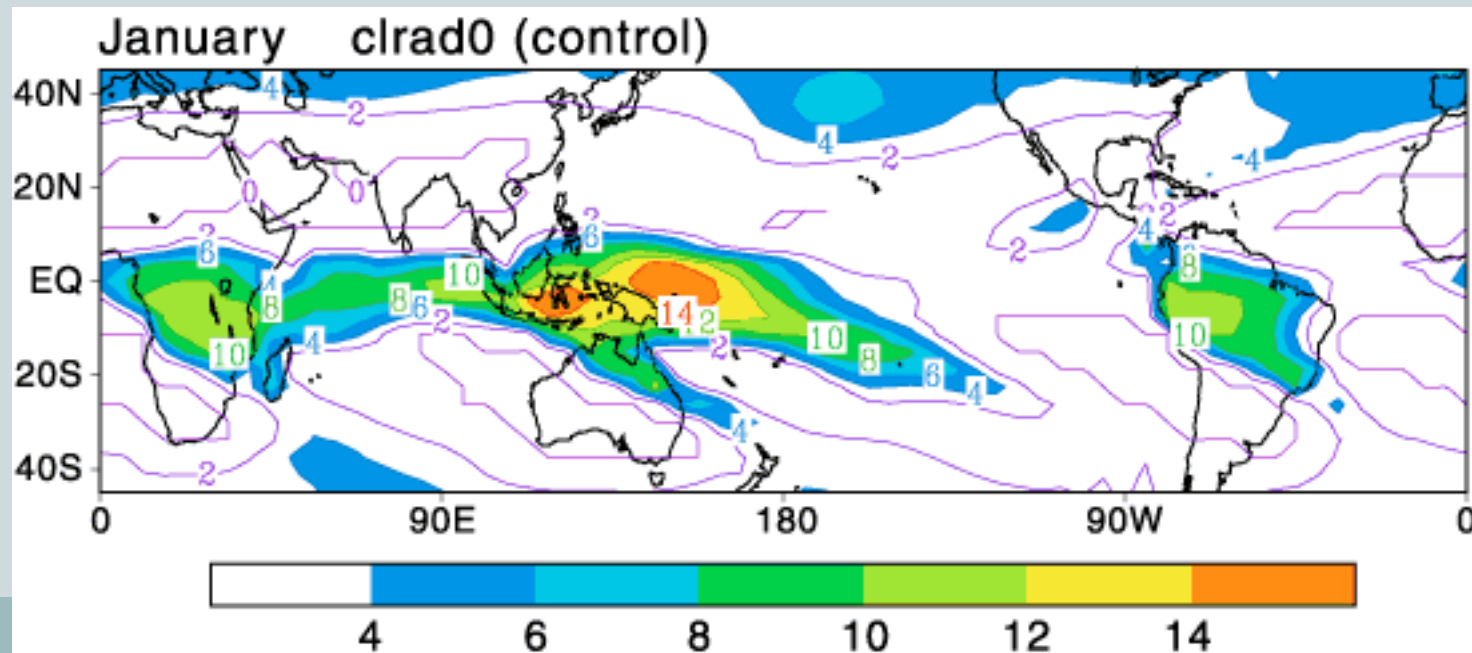
Models with a Moisture Budget

- ## Complications with adding moisture:
  - It's an active tracer
    - Advected by the flow and influences the flow (through latent heat release)
  - Evaporation
    - Everything that precipitates has to evaporate from somewhere (where and how much evap?)
  - Convective closure
   - When does it precipitate and how much, as a function of the atmospheric state

Models with a Moisture Budget

- Common approximation for toy models of the tropics is *simplified vertical structure*
- We'll introduce the GMS in a 2-mode model with moisture
  - The Quasi-equilibrium Tropical Circulation Model (QTCM) of David Neelin and Ning Zeng is one example of this
  - Other users/contributors to QTCM include Chris Bretherton, Adam Sobel, Bjorn Stevens, Daehyun Kim, etc
- The derivation here will be slightly more based on Frierson, Majda and Pauluis (2004)
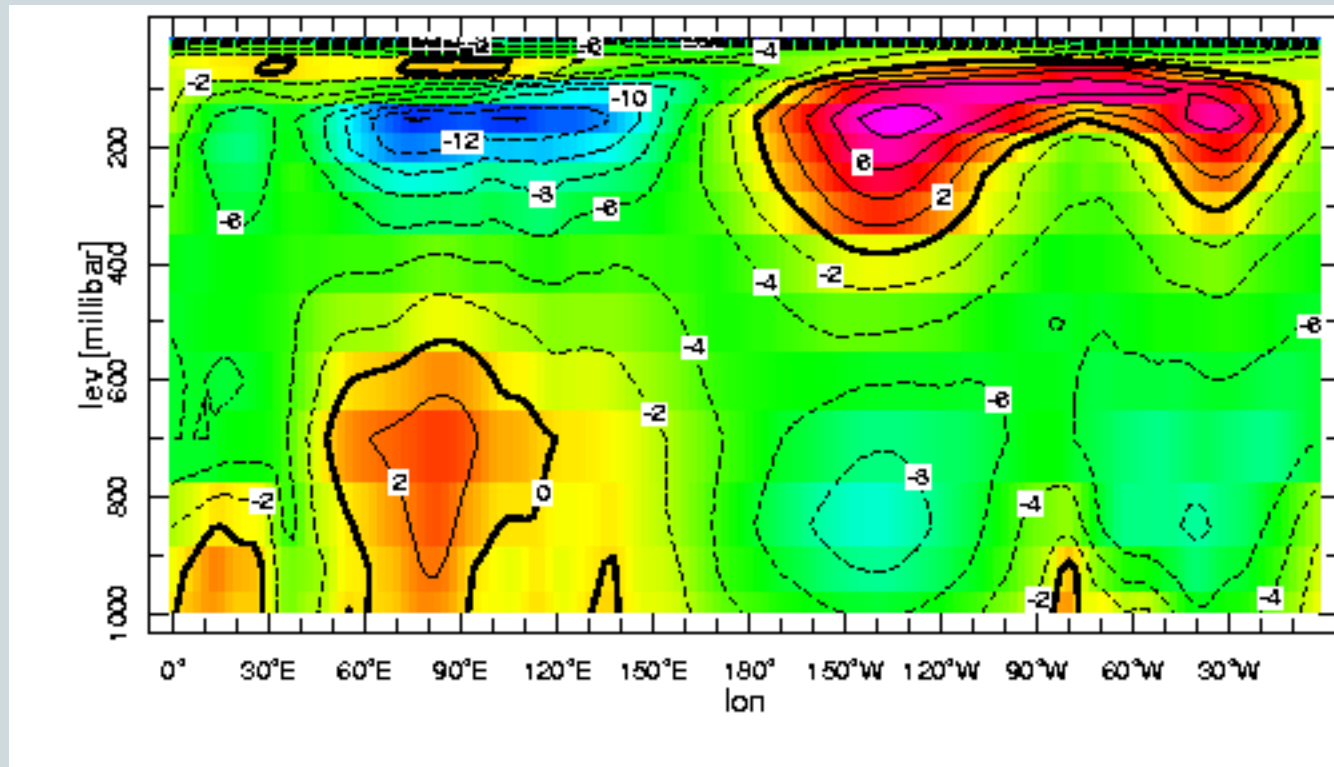
Justification for Two-Layer Approach

- Simple structure of winds in Hadley cell:
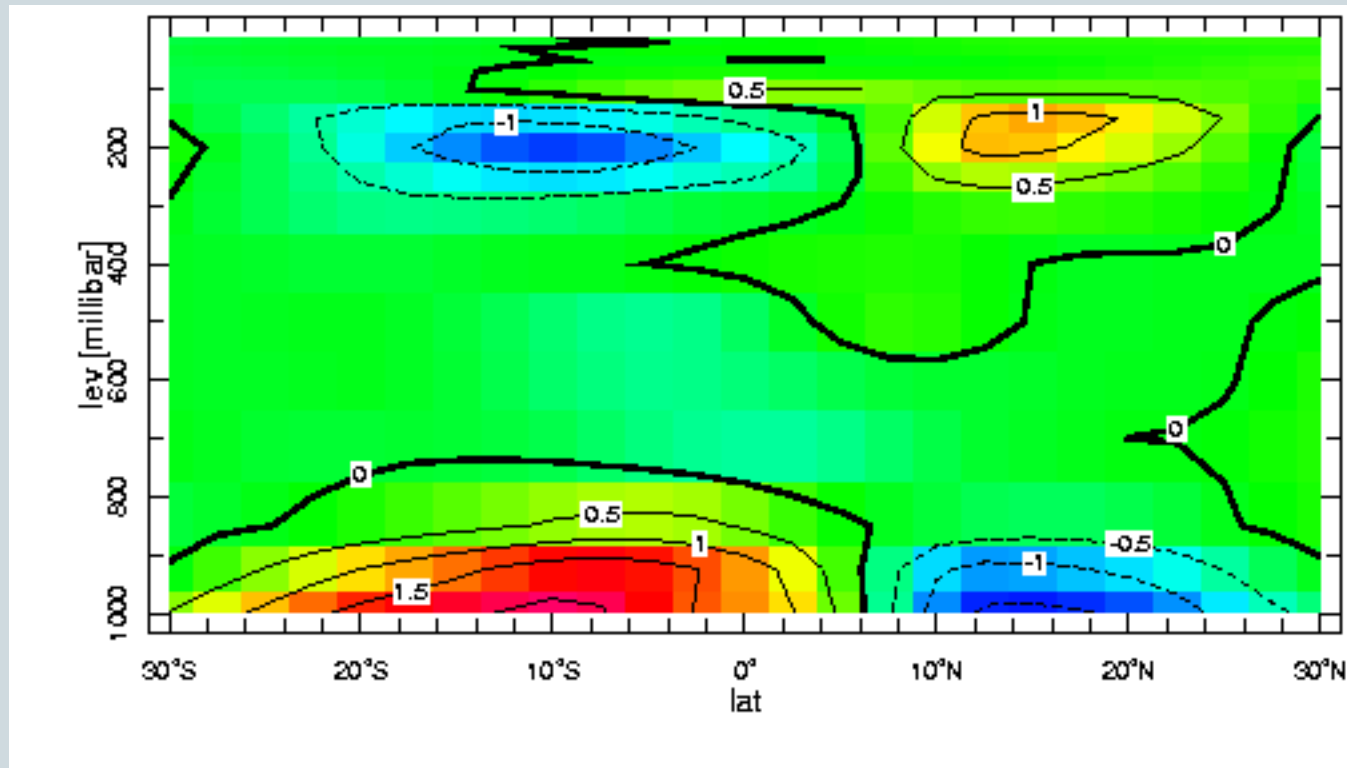
Zonal mean meridional velocity, NCEP Reanalysis 2

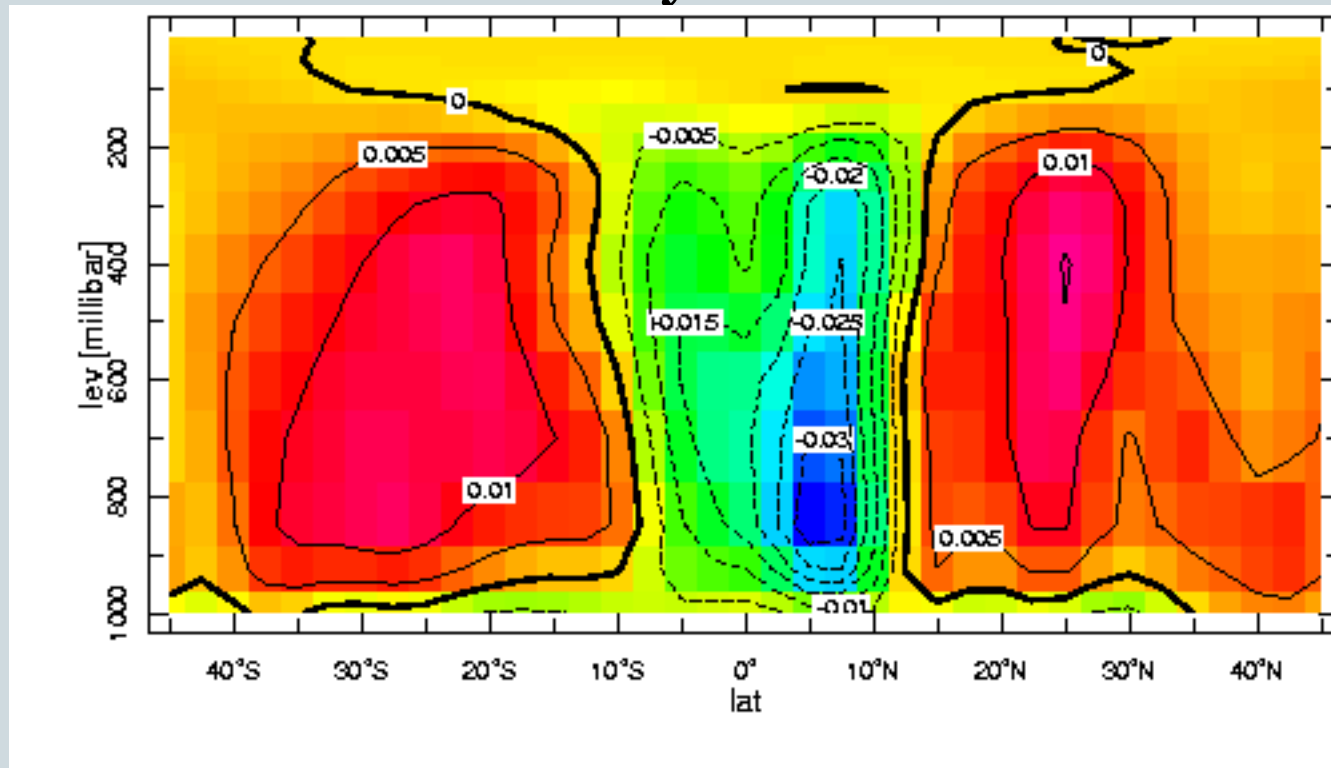# Justification for Two-Layer Approach

- ## Simple structure of winds in Walker cell:

Zonal winds averaged b/w 5N and 5S, NCEP Reanalysis 2
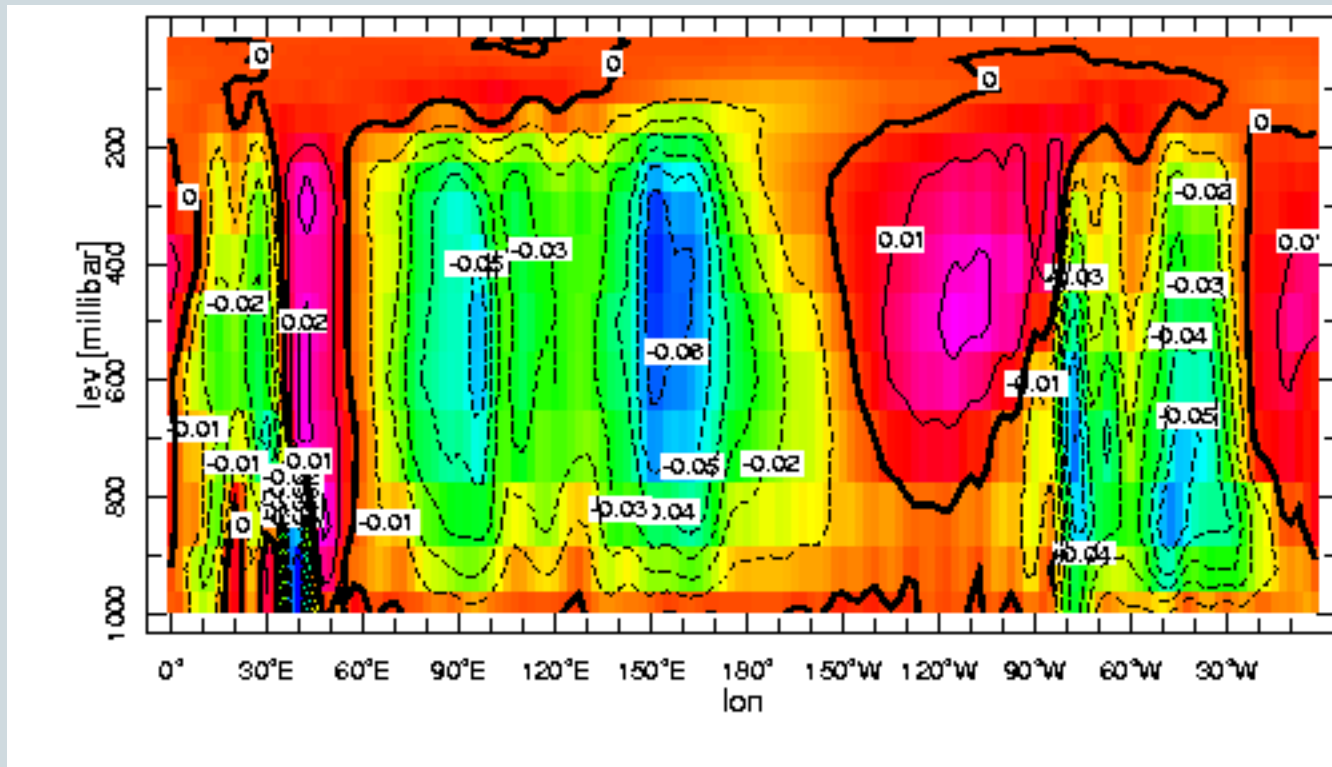
Justification for 2-Layer Approach

- Vertical motion in Hadley cell:

Zonal mean pressure velocity, NCEP Reanalysis 2

Justification for 2-Layer Approach

- Vertical motion in Walker cell:

Pressure velocity avg'd b/w 5N and 5S, NCEP Reanalysis 2