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

\[ P = E - \nabla \cdot (vq) \]

Held & Soden 2006, Allen & Ingram 2002, etc

Actual (solid) and thermodynamic prediction (dashed) of P-E change with global warming
Results of Jack “The Chef” Scheff
- Robust drying is mostly due to **poleward shift** of midlatitude systems

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

From Frierson, Held and Zurita-Gotor (2006)
Poleward shifts with warming (and equatorward shifts with cooling) are very robust in many types of models over large range of climates.

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

Thompson et al 2012
Width of Hadley Cell Predictions

- Can we use our tropical intuition to understand the shift?
  - Predictions from Held-Hou theory
    - 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
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?

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 $\Rightarrow$ surface winds
  - (Barotropic component of winds)
  - Remember can also get Ferrel cell transport from this too

- Thermal wind balance: shear $\leftrightarrow$ temperature gradients
  - Energy fluxes $\Rightarrow$ vertical shear
  - Or, vertical momentum flux $\Rightarrow$ 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 successful NWP experiment
- Rossby wave momentum transport derivation