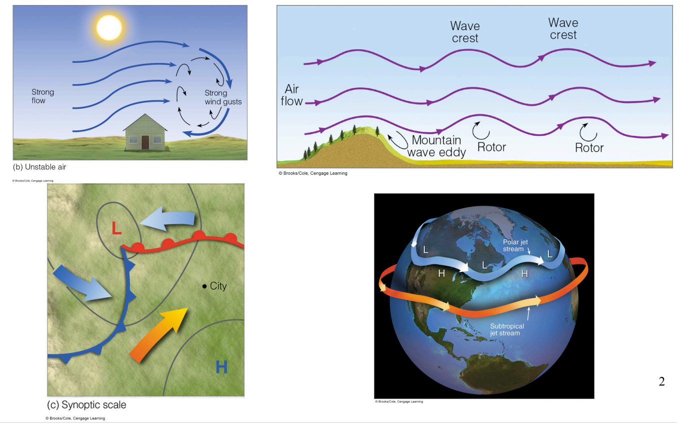
WEDNESDAY AM: General Circulation, El Nino / La Nina, Polar Vortex

General Circulation

- What makes the wind blow?
- General circulation of the atmosphere

1

Atmospheric Motion takes Place on a Variety of Scales



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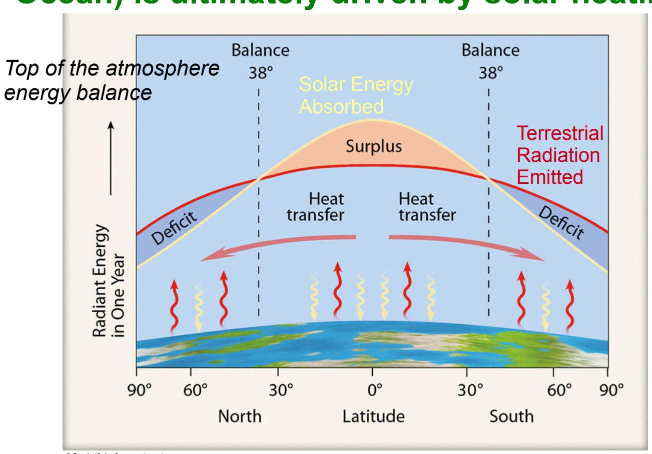
The Circulation of the Atmosphere (and the Ocean) is ultimately driven by solar heating.



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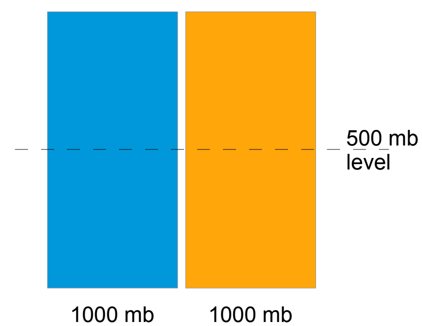
Two columns of air, same temperature, same distribution of mass:



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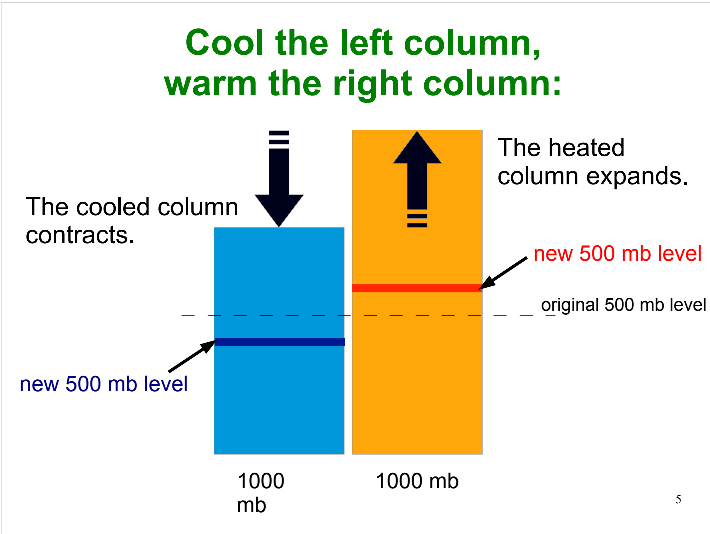
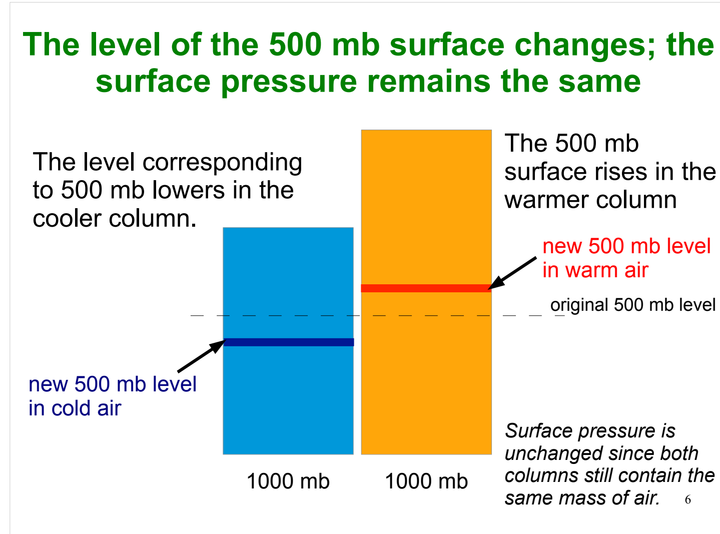
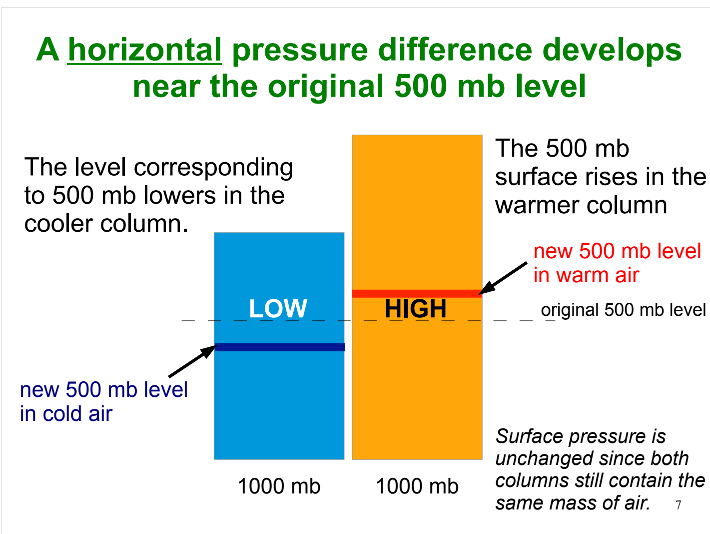
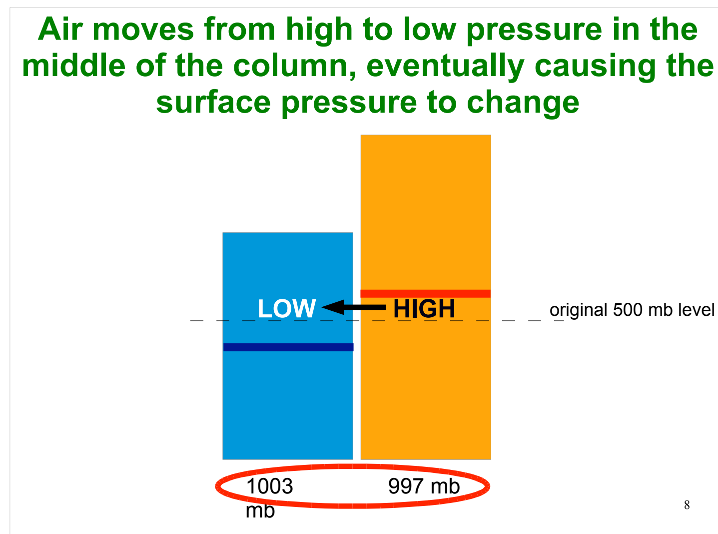
Wednesday AM, Explain: General Circulation









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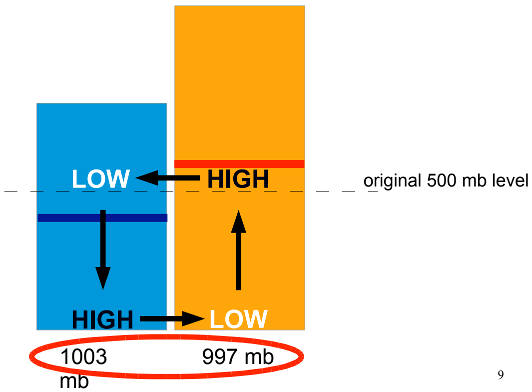
Air moves from high to low pressure in the middle of the column, eventually causing the surface pressure to change

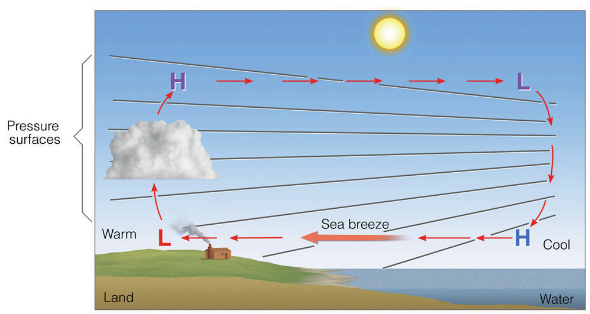


What have we just observed?

- Starting with uniform atmosphere at rest, we introduced differential heating
- The differential heating caused different rates of expansion in the fluid
- The differing rates of expansion resulted in pressure differences along a horizontal surface
- The pressure differences then induced flow in the fluid (air)
- This is a microcosm of how the atmosphere converts heating into motion (i.e. Wind!)

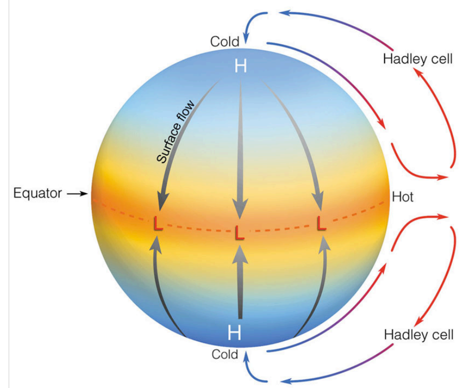
Example: Sea Breeze

- During the day, land warms up more strongly than a nearby ocean → rising motion (cloud formation possible) and outward flow at upper levels → inward flow (sea breeze) at low levels to replace ascended air over land



(a) Sea breeze

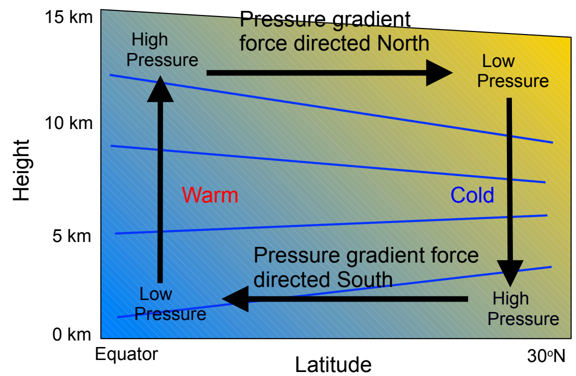
Single (Hadley) Cell: non-rotating Earth



(a)

- Differential heating of tropics vs poles
- Circulation somewhat like sea breeze, except globally
- Energy (heat) transported from equator to poles
- Air rises at the equator and sinks at the poles

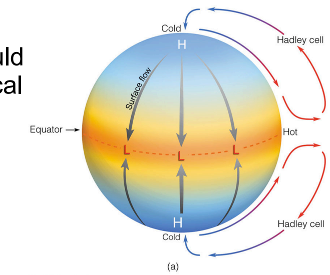
Thermally direct Hadley Cell



Differential heating between tropics and higher latitudes drives thermal circulation.

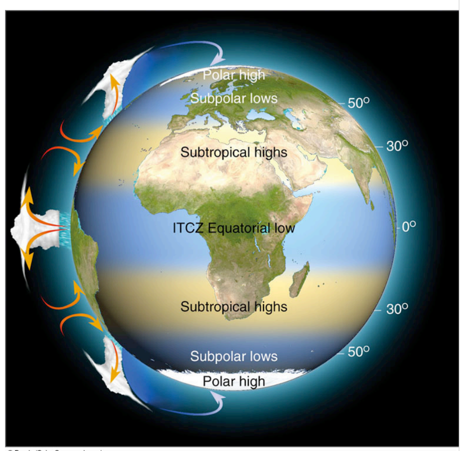
What's wrong with the single cell model of the general circulation?

- Neglect of rotation, but the Earth does rotate:
  - with rotation comes Coriolis force
  - Surface winds in single cell model would tend to spin down the Earth
  - Upper level winds would accelerate to unphysical speeds near the poles



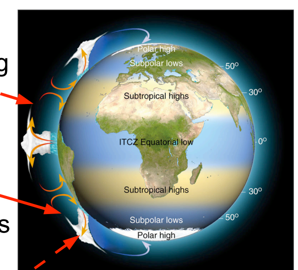
Three Cell Model: rotating Earth

- Rising motion (deep convection, lots of rain) in tropics
- Sinking motion (adiabatic warming & drying) in subtropics
- Atmospheric storm formation in midlatitudes along polar front

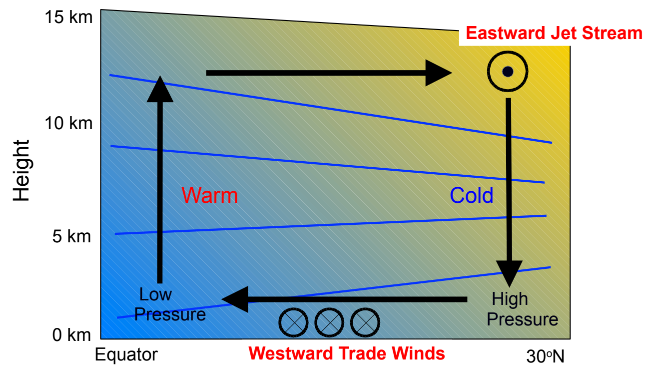


Key Features of the Three Cell Model

- **Hadley Cell** (thermally direct)
  - driven by N–S gradient in heating
  - air rises near equator and sinks near 30 degrees
  - → deserts, trade winds, ITCZ
- **Ferrel Cell** (thermally indirect)
  - driven by heat transport of eddies
  - air rises near 60 degrees and sinks near 30 degrees
  - Explains midlatitude surface westerlies (30–60 degrees)
- Weak winds found near the equator and 30 degrees
- Boundary between cold polar air and midlatitude warmer air is the polar front



Thermally direct Hadley Cell



The Coriolis force deflects flow to the right (N.H.) setting up the Jet Stream and Trade Winds. Strength depends on pressure gradient, i.e. on temperature contrast between tropics and higher latitudes.

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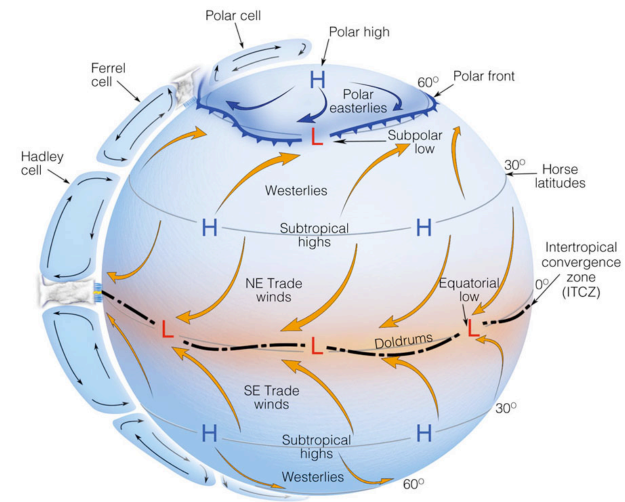

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The Role of Midlatitude Storms (Eddies)

- (Angular/rotational) momentum is transferred from the Earth to the atmosphere in the trade wind belt.
- (Angular/rotational) momentum is transferred from the atmosphere to the Earth in midlatitudes.
- Midlatitude Storms (Eddies) transfer eastward (westerly) momentum (and heat) poleward in the upper troposphere and to the surface.
- This helps drive the Ferrel cell but also weakens slightly the Hadley cell.
- Comparing the overall overturning strength, the Ferrel cell is much weaker than the Hadley cell.

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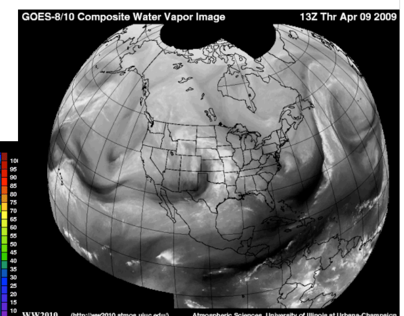
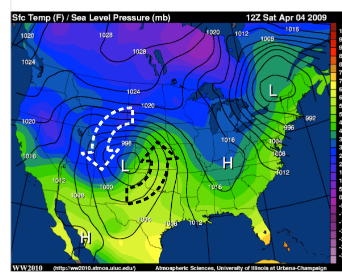
Midlatitude Storms

- Transport heat and momentum poleward: e.g. compare surface temperature distribution around intense low in below graphic
- Also transport moisture and with it latent heat (graphic to the right)





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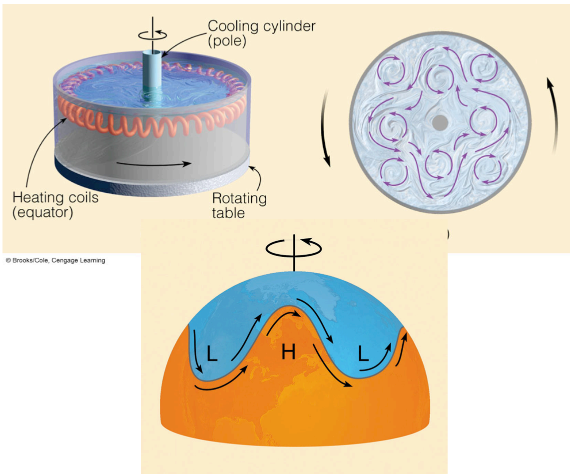
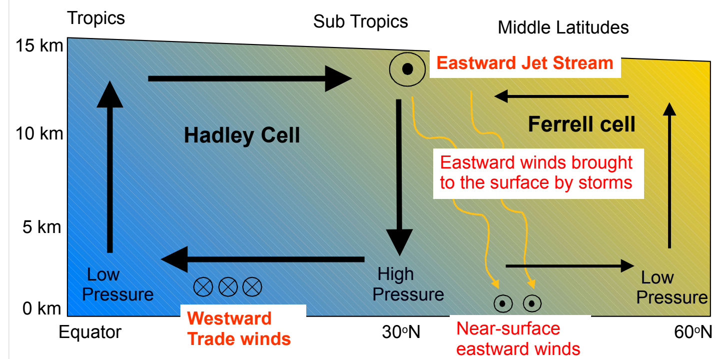
The "Dishpan" Experiment



The Atmosphere's Average Circulation

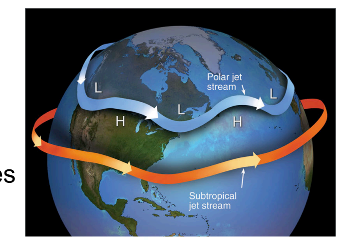


Surface winds are generally from the west in mid latitudes, because storm systems transport eastward winds to the surface. There can be one jet stream or two jet streams in each hemisphere, depending on the large-scale conditions.

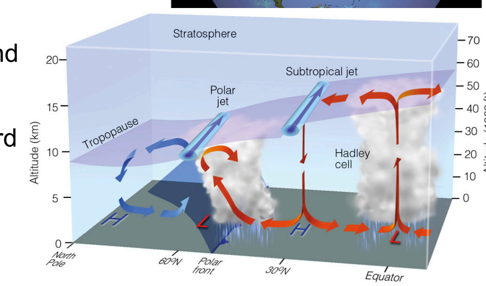
The Atmosphere's Average Circulation

- Ultimately driven by solar heating contrast between the equator and the poles. General Circulation acts towards compensating this differential heating, that is it transports heat poleward.
- In Hadley cell, warm air rises and moves poleward. Equator to pole Hadley cell is impossible to achieve (unstable) in the presence of rotation.
- Coriolis force deflects fluid to the right in the N.H. and to the left in the S.H. and thereby produces:
  - Trade winds, surface westerlies in midlatitudes, upper-level jet streams
- Ferrell cell is the zonal mean response to the poleward heat and momentum fluxes by eddies.

Jet Streams and Temperature Fronts



- Polar front jet stream forms near the tropopause where strong thermal gradient causes a strong pressure gradient
- Strong pressure gradient force and Coriolis force produce strong westerly/eastward wind parallel to contour lines



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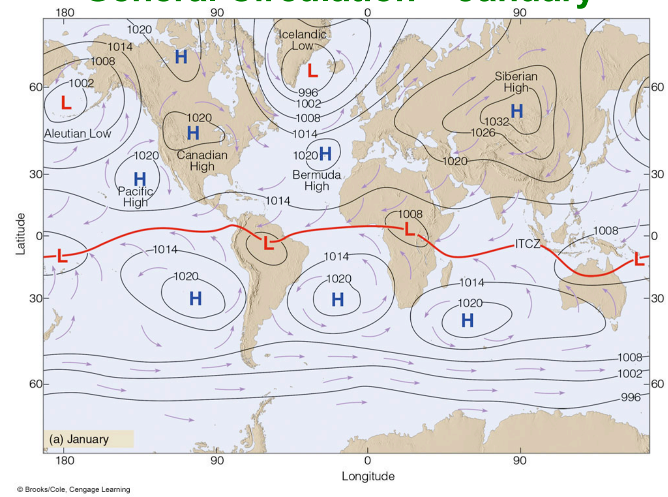
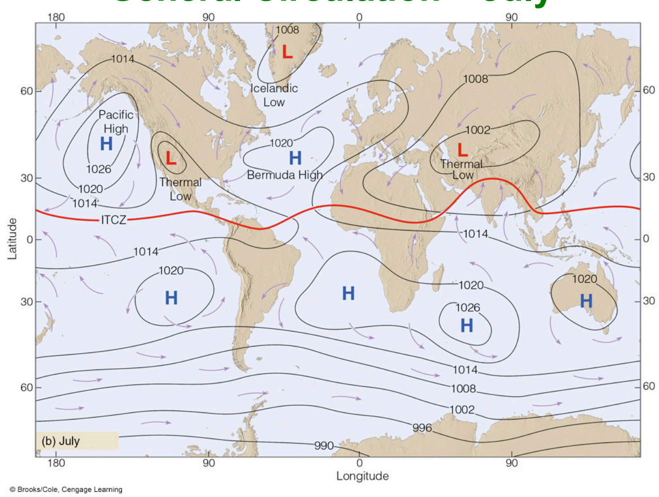
Variations in East-West Direction make the Circulation more complex

- Land masses, mountain ranges, and variations in temperature along latitude circles make the Earth's circulation more complex
- If averaged over all longitudes the major patterns do become similar to the previous plots/graphics
- Variations with season also occur
- Semipermanent high and low pressure systems persist throughout large periods of the year
  - During winter, highs form over land, lows over oceans. Vice versa during summer. Consistent with differences in surface temperature.
- The intertropical convergence zone (ITCZ) shifts towards south in January and towards north in July!

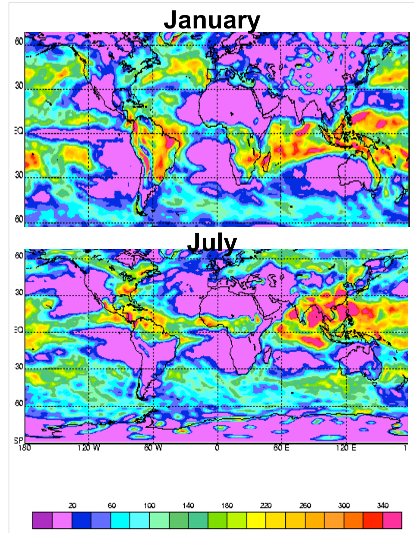
General Circulation – January



General Circulation – July



Precipitation (mm/month)



- Very wet over tropics
- Seasonal shifts (N/S)
- Monsoon regions
- Extremely dry suptropical highs
- Midlatitudes get more summer rain
- July rainfall looks like a map of forest cover