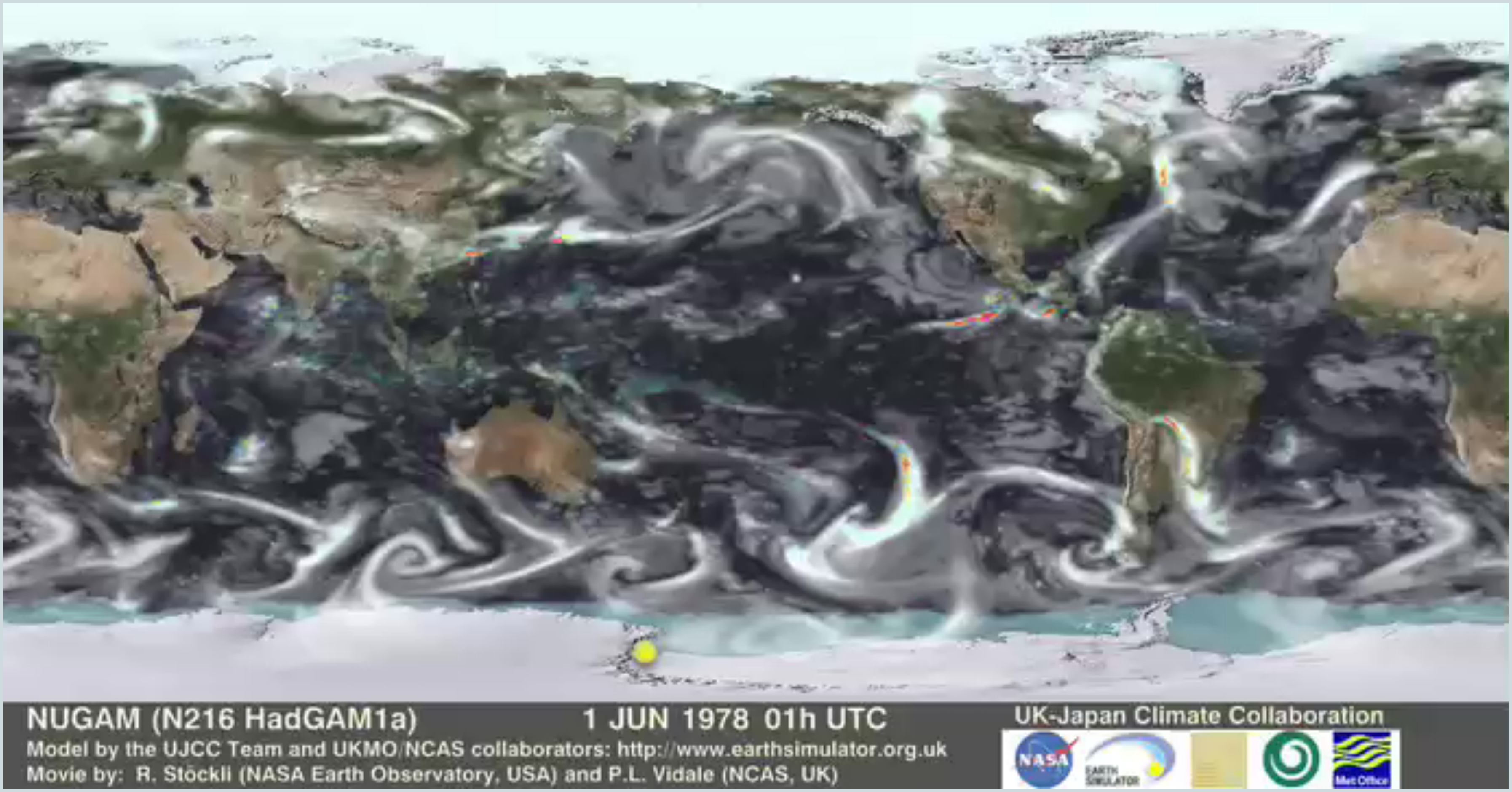
Climate Dynamics (PCC 587): Water Vapor & the Hydrologic Cycle

DARGAN M. W. FRIERSON
UNIVERSITY OF WASHINGTON, DEPARTMENT OF ATMOSPHERIC SCIENCES

DAY 4: 10-7-13

Water Vapor and the Hydrologic Cycle

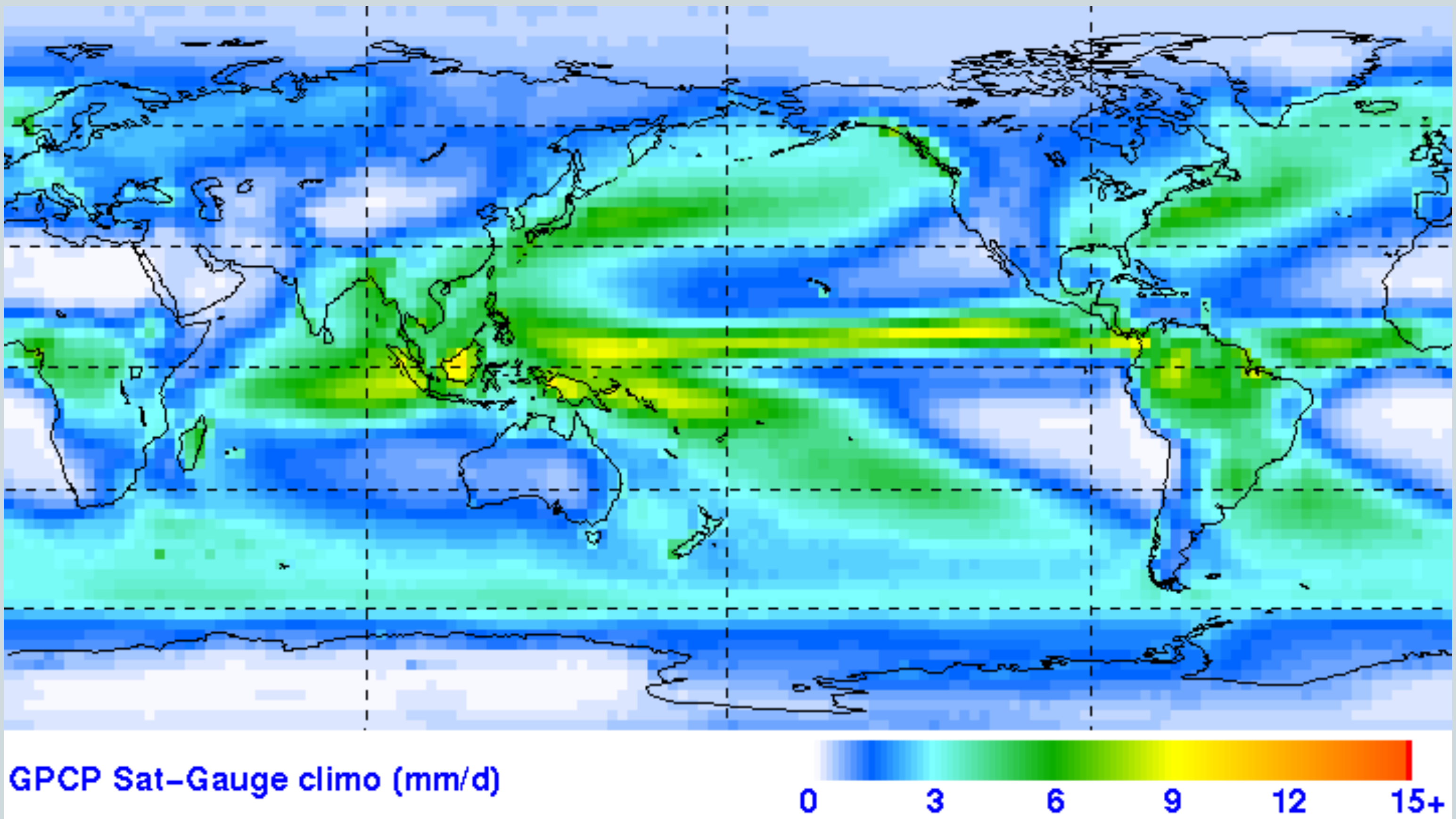


What's Required for Rain?

- To get rain, you need **water vapor** and **rising motion**
  - **Condensation** (water vapor turning to liquid water) happens when **moist air cools**
    - And this cooling almost always happens with rising motion
- Let's take a look at precipitation on a global scale…

Why does it rain where it does?

- For reference, the precip climatology from GPCP

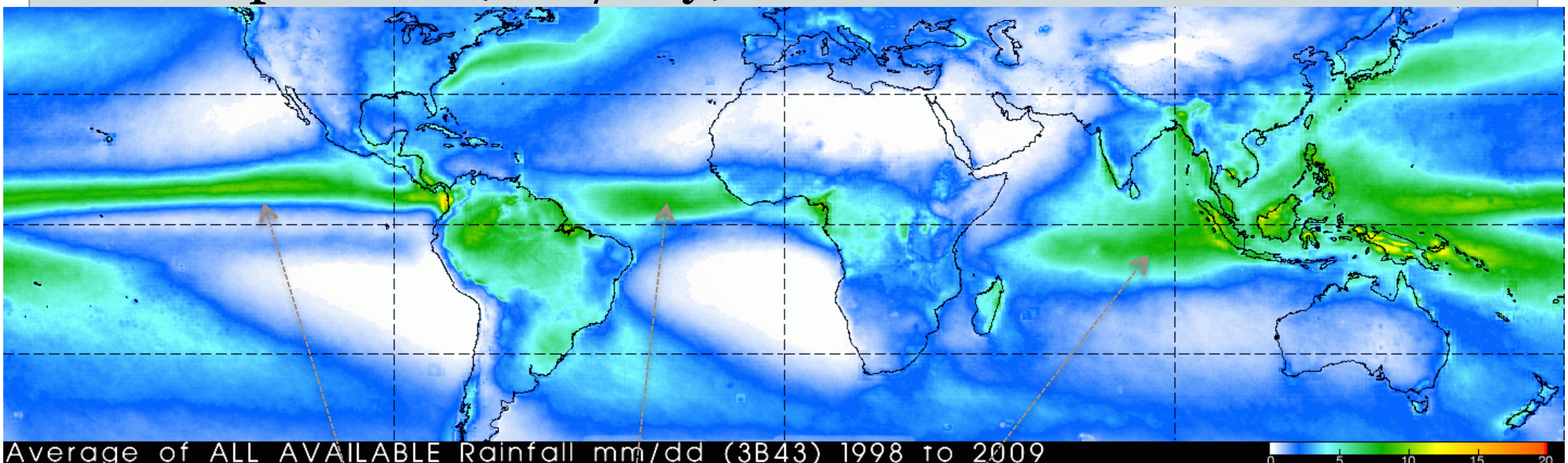


What Causes Primary Precipitation Features?

- Tropics:
  - Rising motion & rain over **warmest temperatures**
  - **Diurnal** & **seasonal** precipitation
- Midlatitudes
  - Rising associated with high/low pressure systems
  - Storm track location/intensity is key

Average Precipitation

- Precipitation (mm/day):



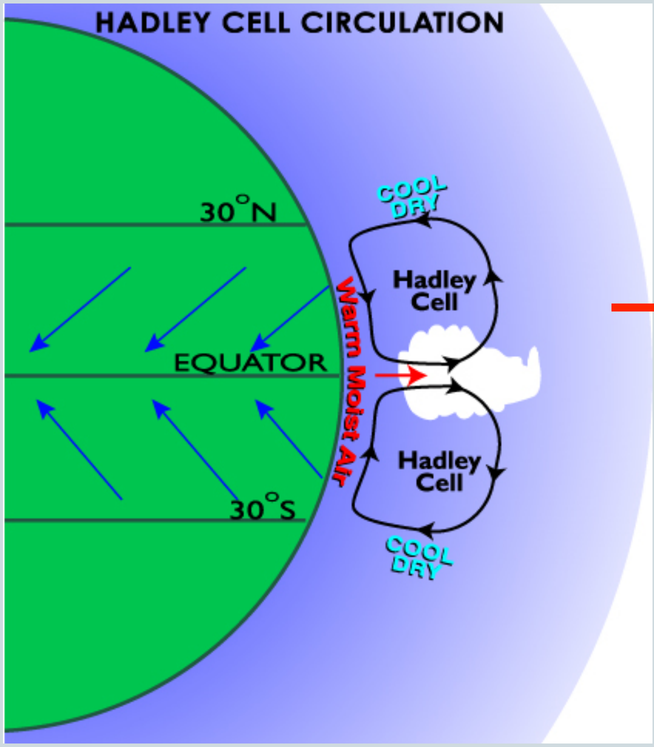
Rainiest spots on global scale are **narrow bands** near the **equator**

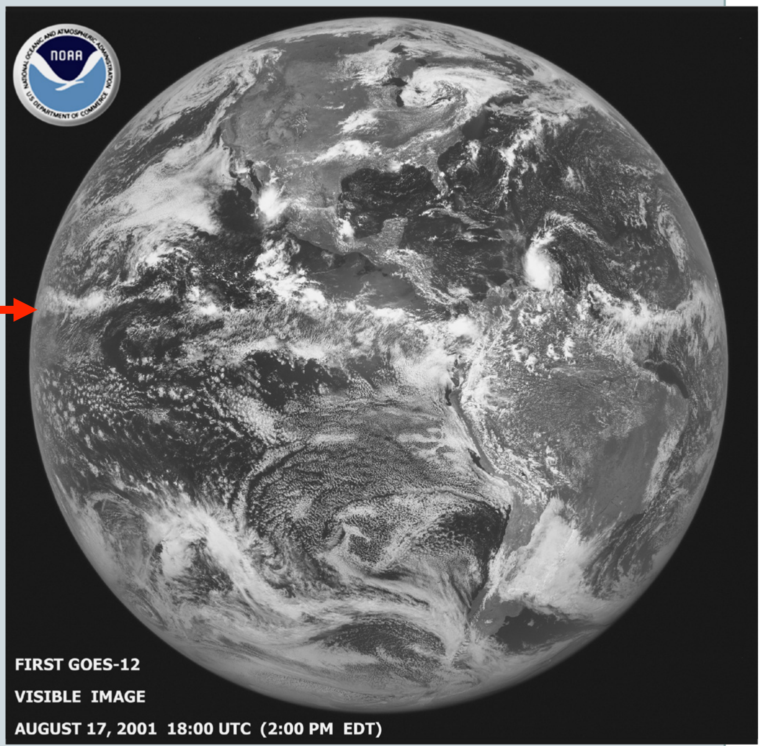
Many of the driest places on Earth are over the ocean!
Most deserts are around 30 degrees latitude

The Hadley Circulation

Air rises above the **warmest** ocean surface

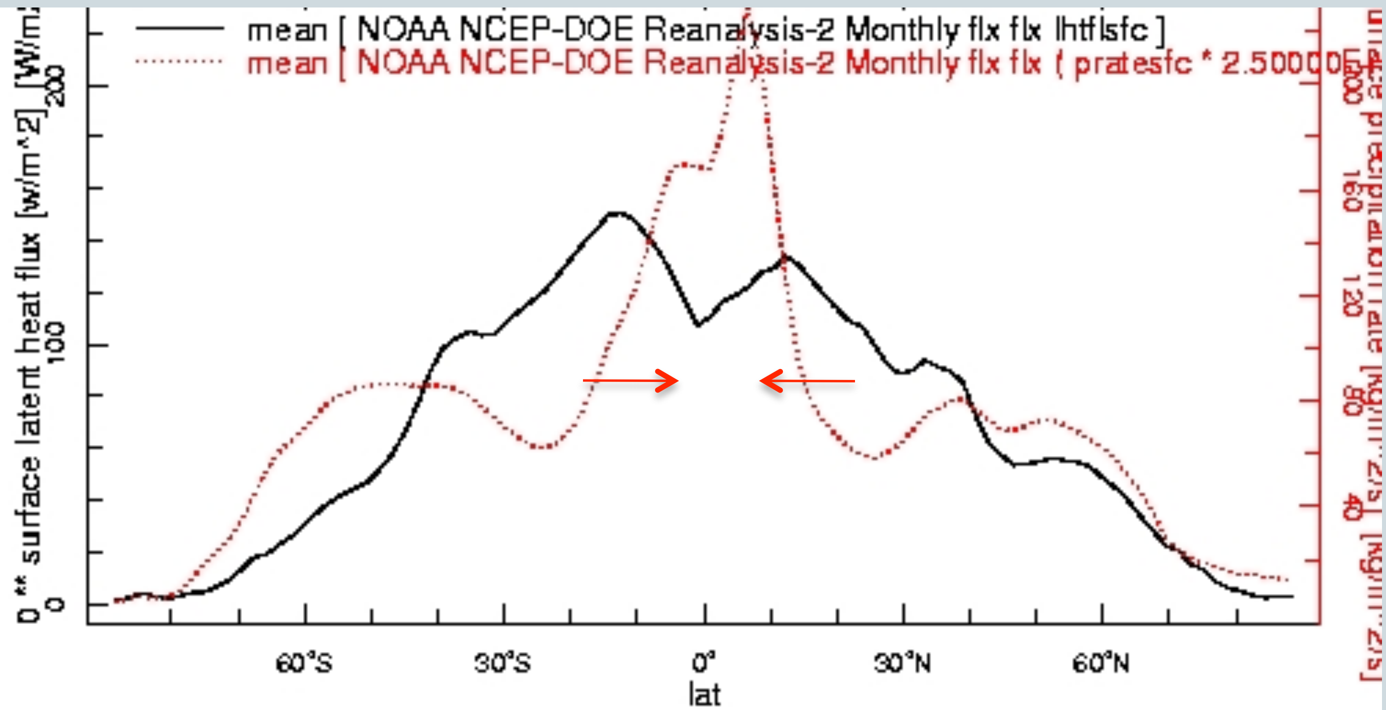
The circulation takes water vapor **away from** the **deserts** at 30 degrees and brings it **into** the tropical **rainy regions**





Zonally averaged precip and evap

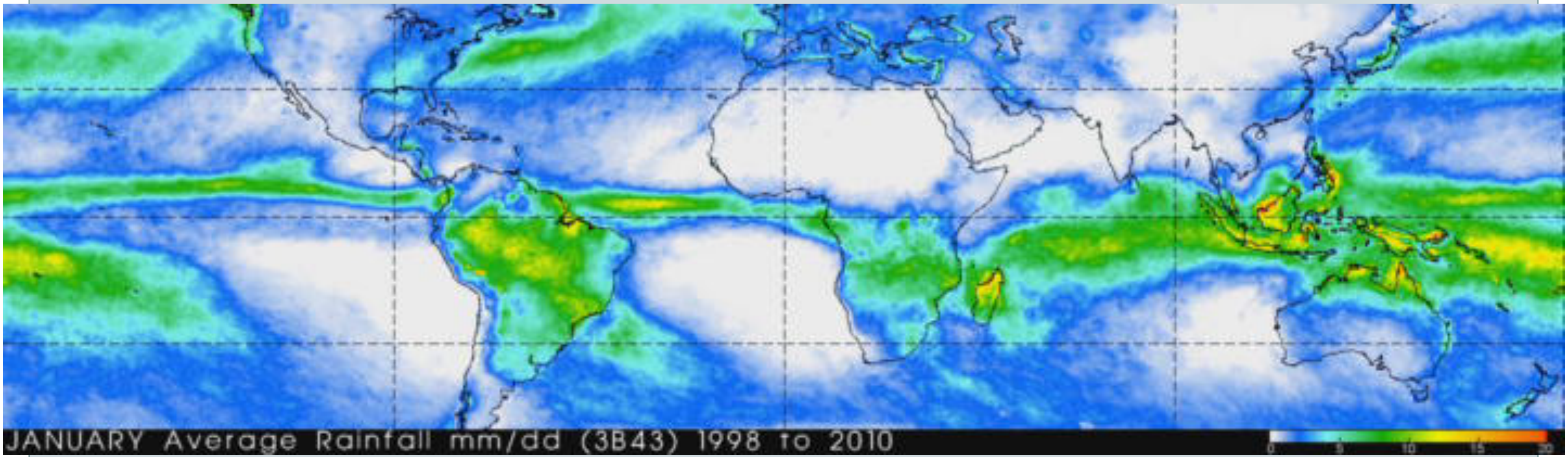
- Hadley cell is key to converging moisture towards the equator
  - From the dry subtropics into the deep tropics



Evap and precip annual means (NCEP Reanalysis 2)

Seasonal March of Tropical Rains

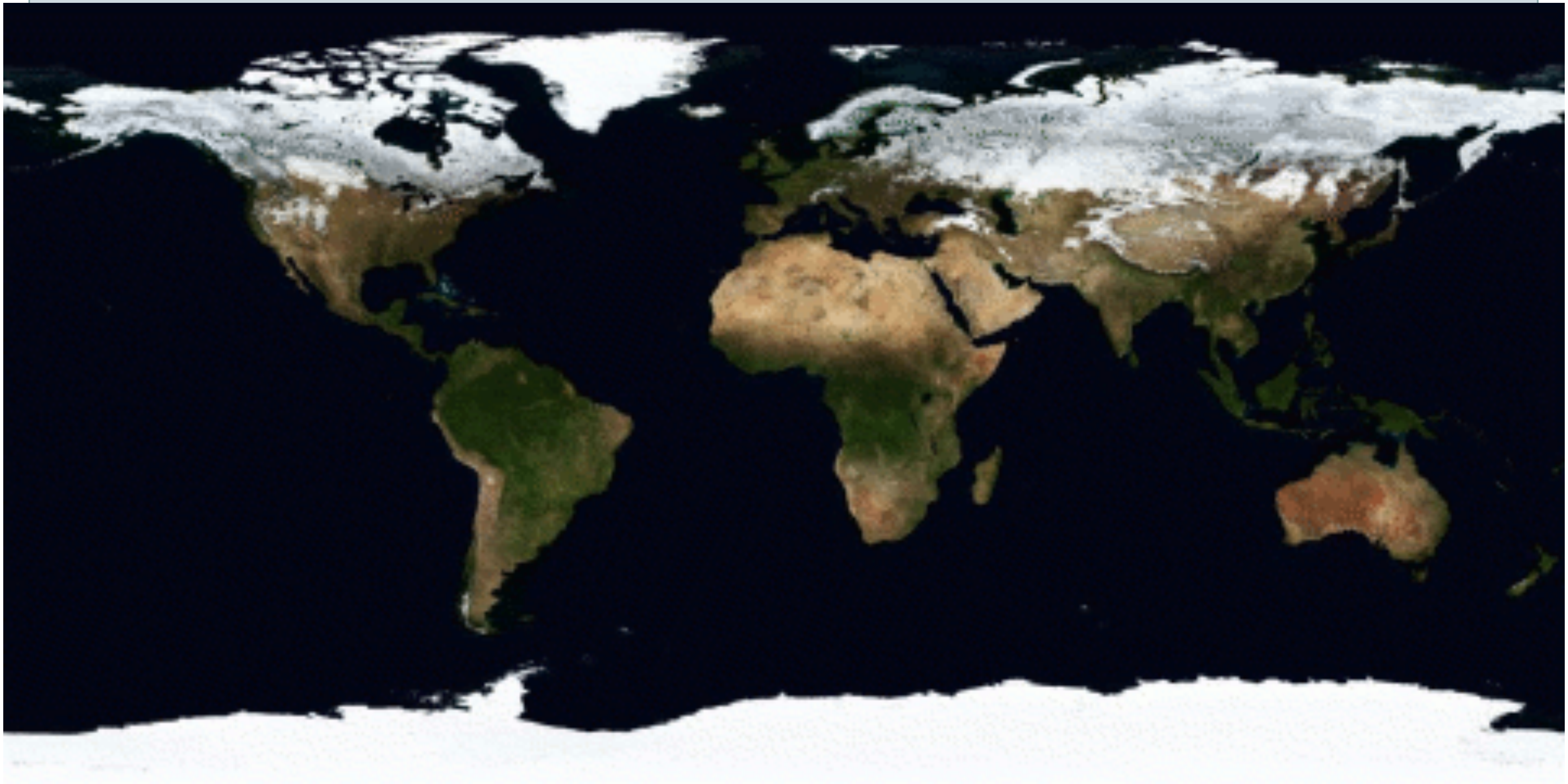
- Rain shifts northward in Northern summer (JJA), southward in Southern summer (DJF)



"Convergence zone": where winds come together
"Inter-tropical convergence zone" (**ITCZ**): the tropical band.
The ITCZ follows the warmest ocean temperatures as they shift with the seasons

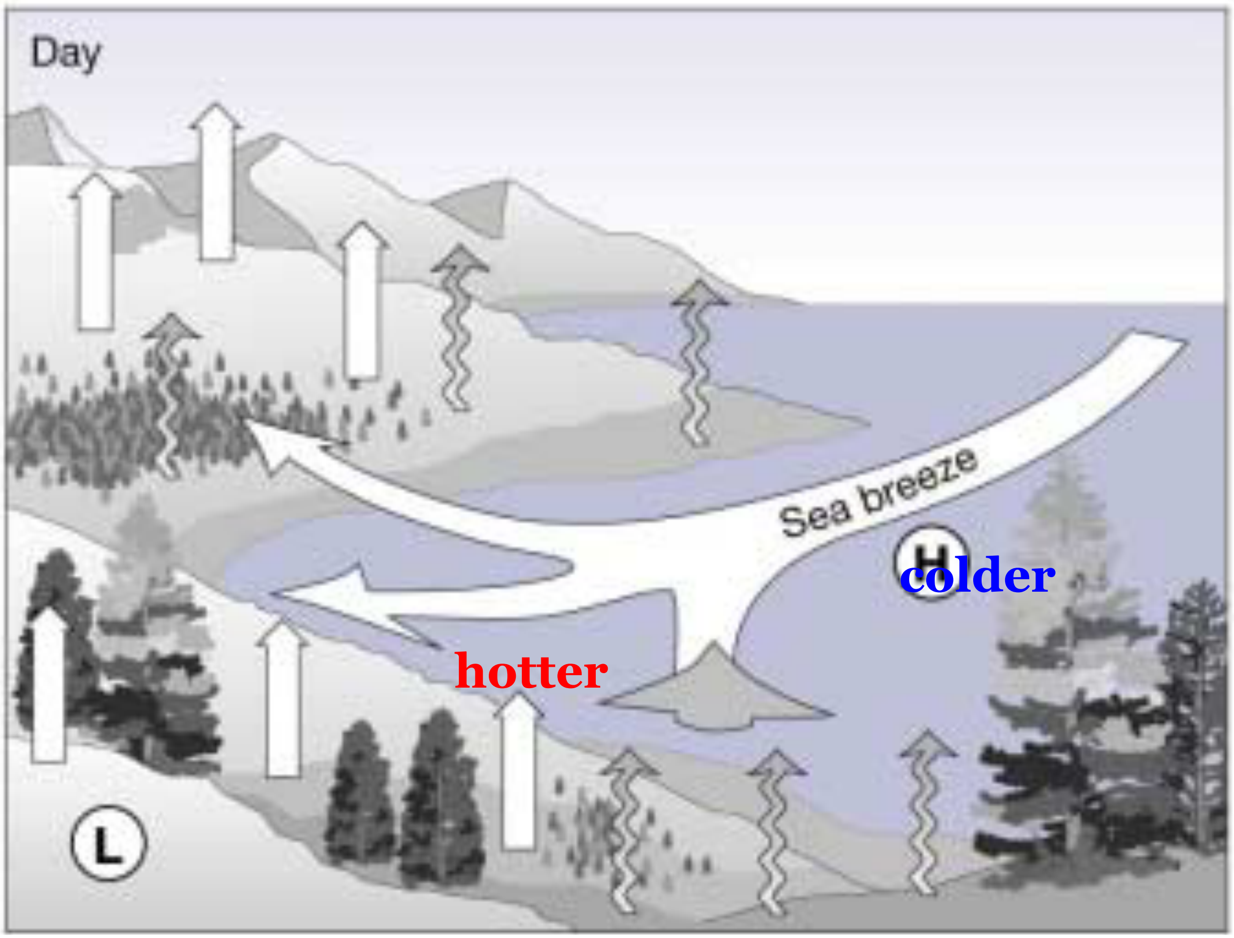
Rainfall and Vegetation

- Vegetation follows the seasonal march of rainfall



Monsoon Circulations

- Land heats up in the summer, leads to rising/rain



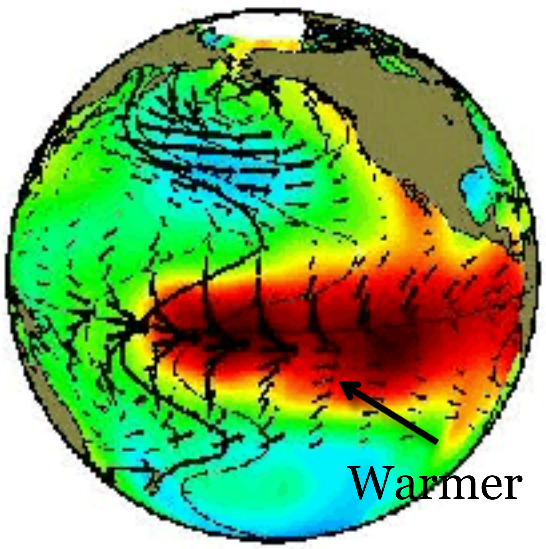
India, Africa, Australia, etc all experience strong monsoons

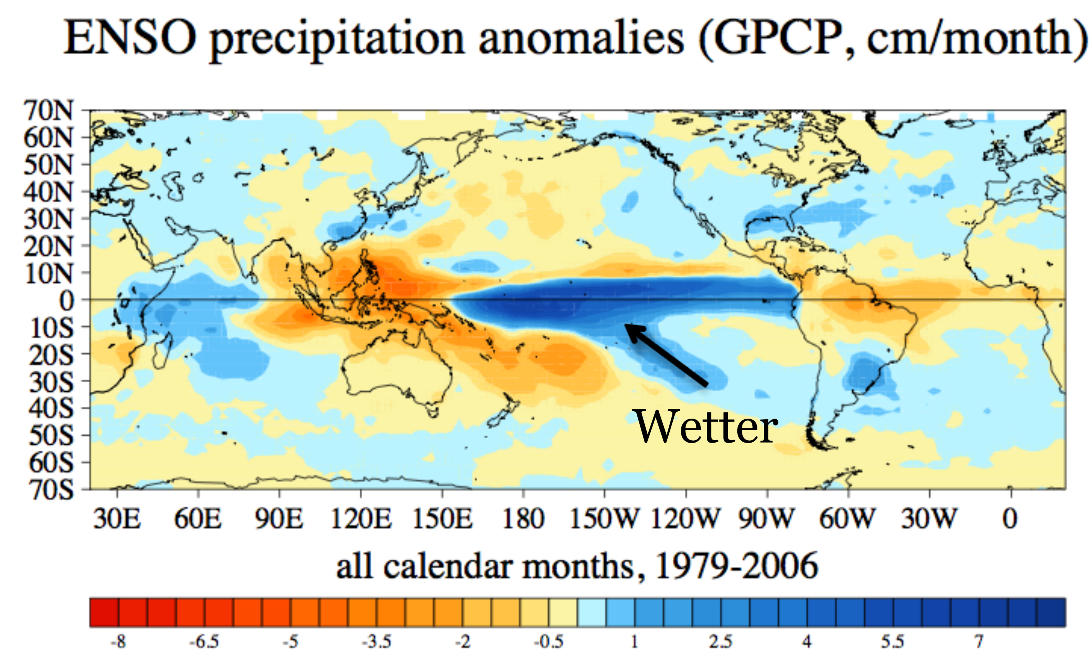
El Nino cycles greatly modify the location/intensity of monsoons in India & Australia

Precipitation Changes with El Niño

- Warmer water & rainier over **central Pacific** during El Niño

El Niño sea surface temps

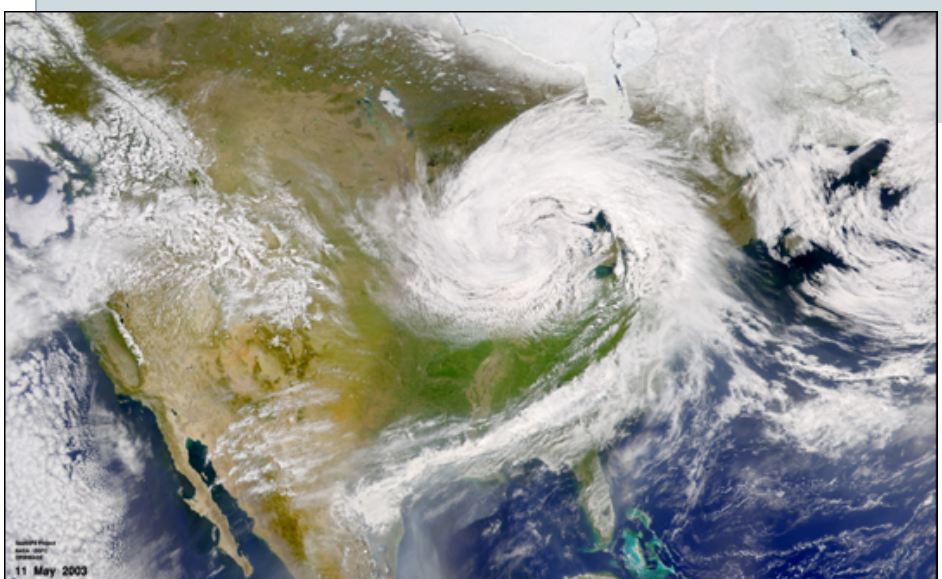


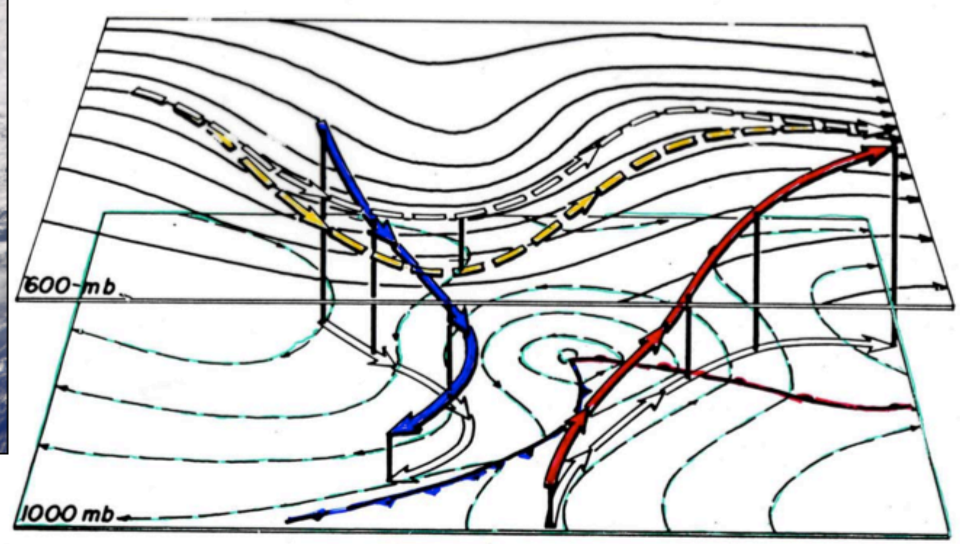


East-west sloshing of warm water/precipitation

Midlatitude Precipitation

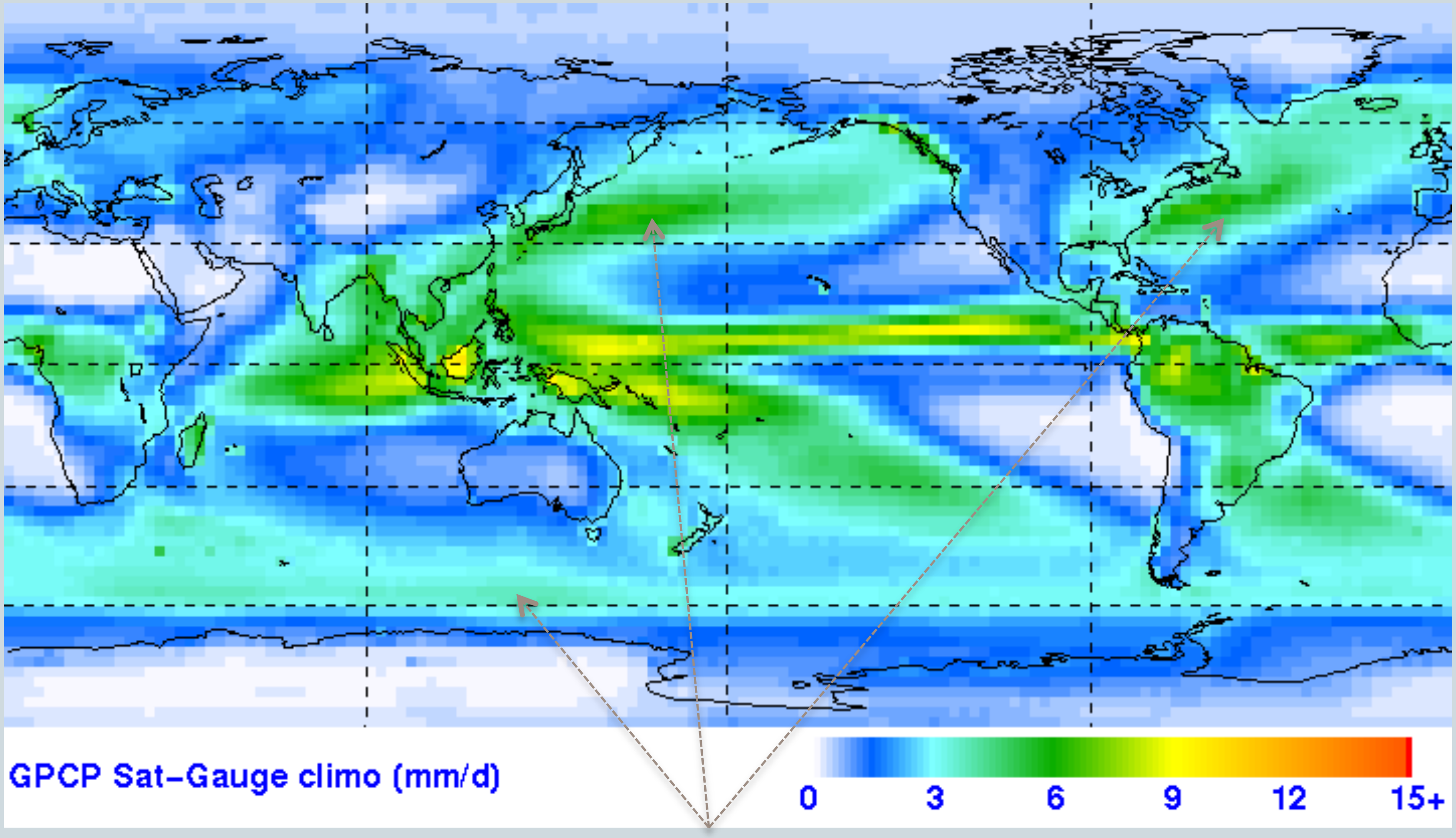
- Midlatitude precipitation is associated with "baroclinic eddies"
  - Rising motion is generated in particular regions of the weather systems





“Storm Tracks”

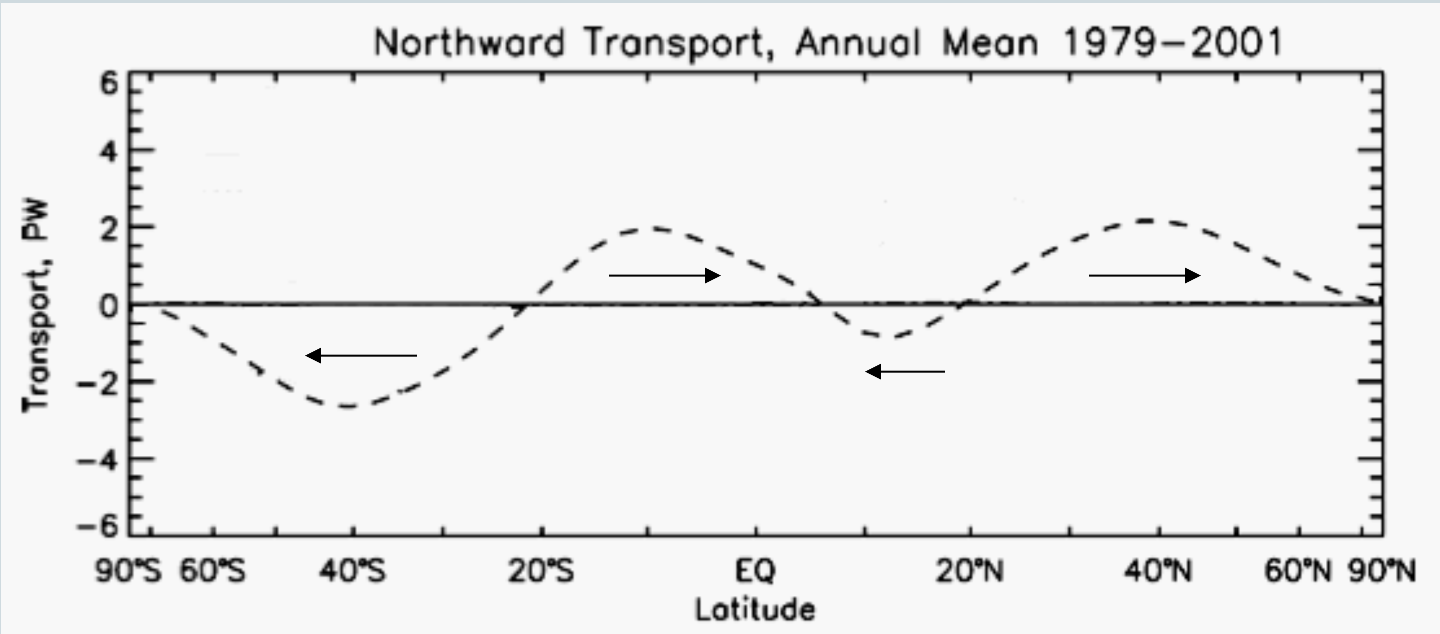
- Precipitation (mm/day):



Midlatitude precipitation is in **storm tracks**: preferred locations for storms

Northward Moisture Flux

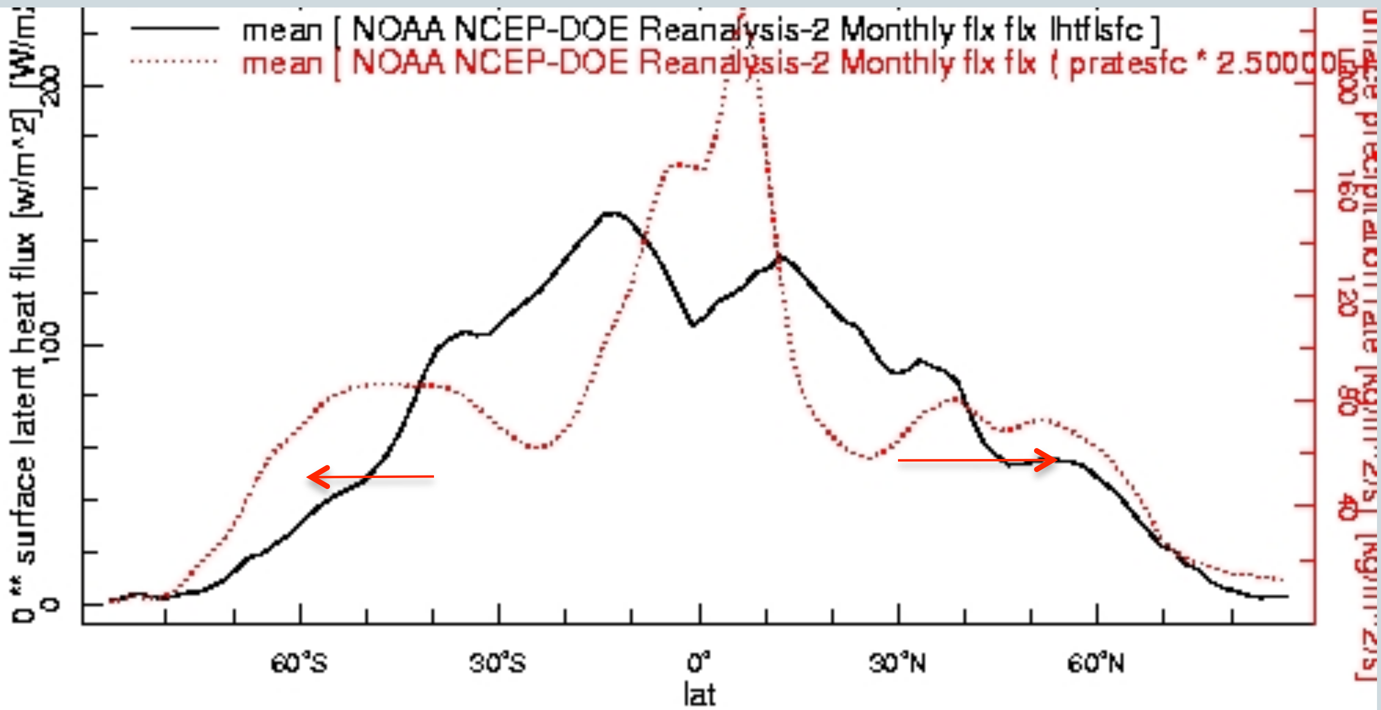
- Annual and zonal mean northward moisture flux in the atmosphere:



Equatorward moisture flux in the tropics
Poleward moisture flux in the extratropics

Zonally averaged precip and evap

- Midlatitude storms take moisture out of subtropics and transport it poleward



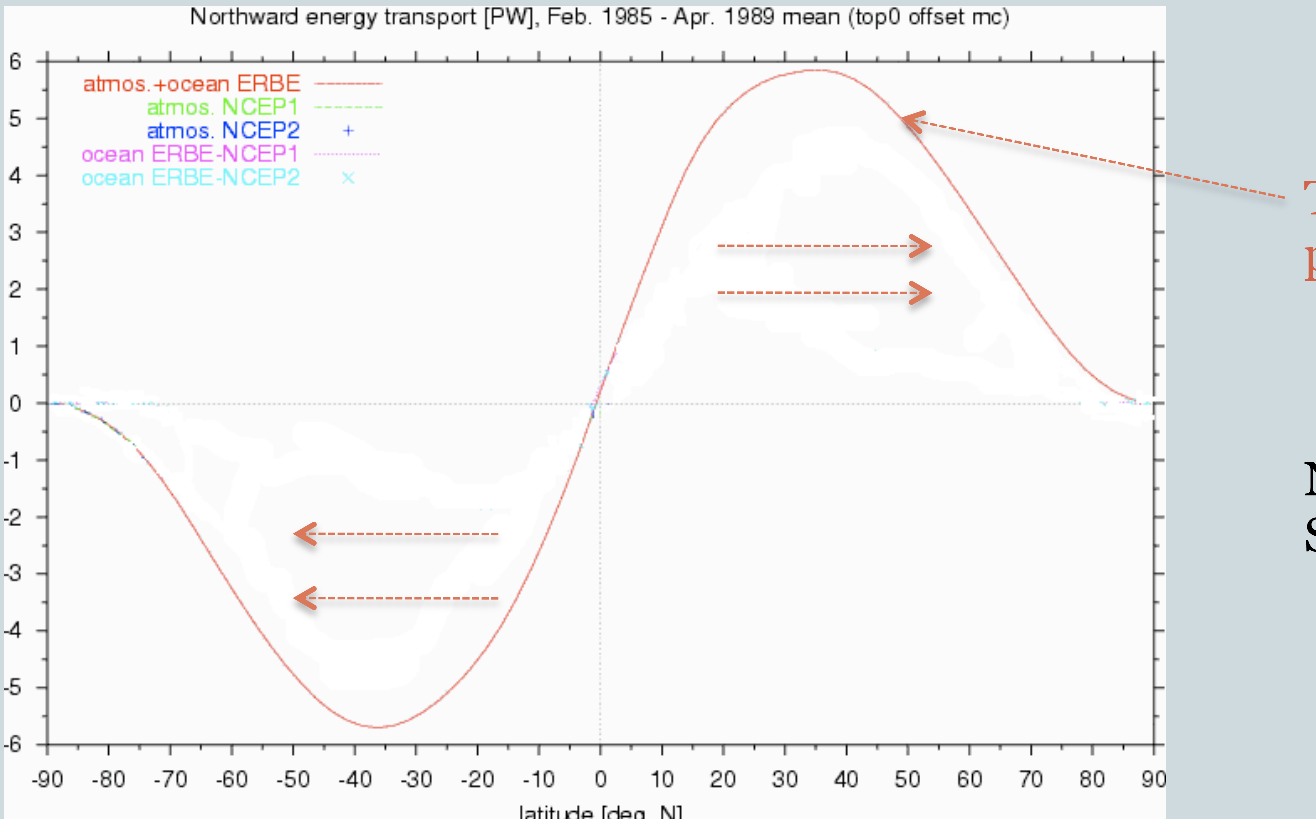
Evap and precip annual means (NCEP Reanalysis 2)

Moisture and Horizontal Temperature Gradients

- Next: moisture also strongly influences pole-to-equator temperature gradients
  - If moisture **evaporates** at low latitudes, but **condenses** at higher latitudes, this is exactly like a poleward transport of heat
- Let's examine **atmosphere and oceanic energy transports**

Energy Transports

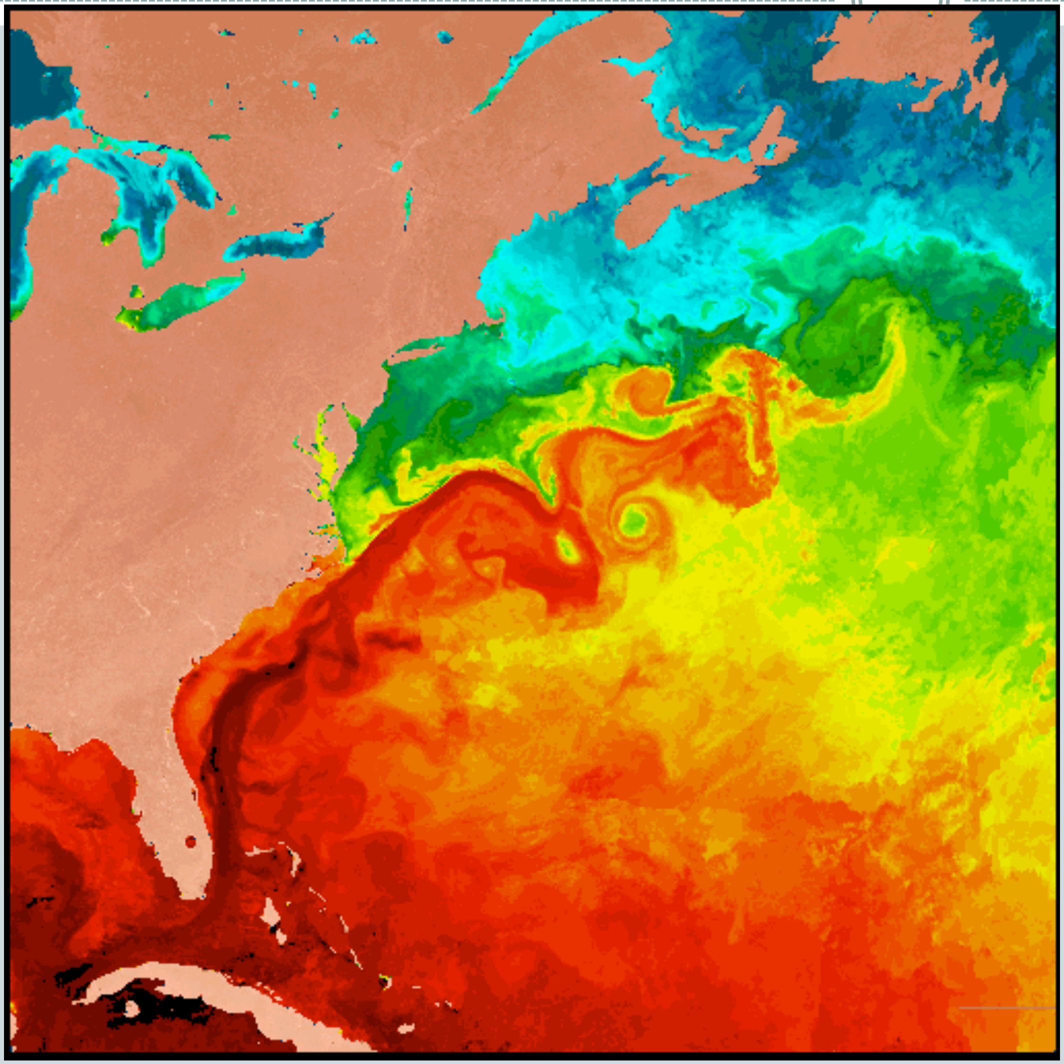
- Climate system transports energy polewards (from hot to cold)

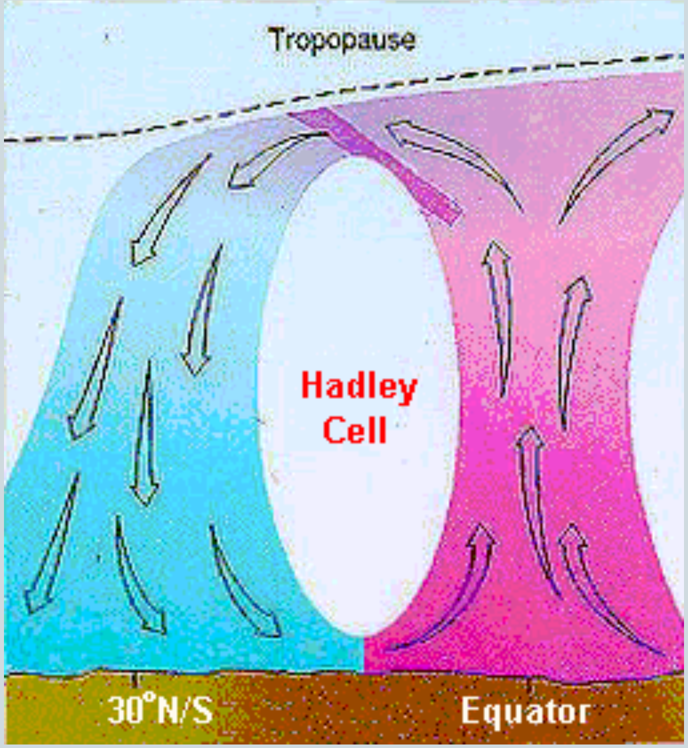


Latitude

Northward flux in NH,
Southward flux in SH

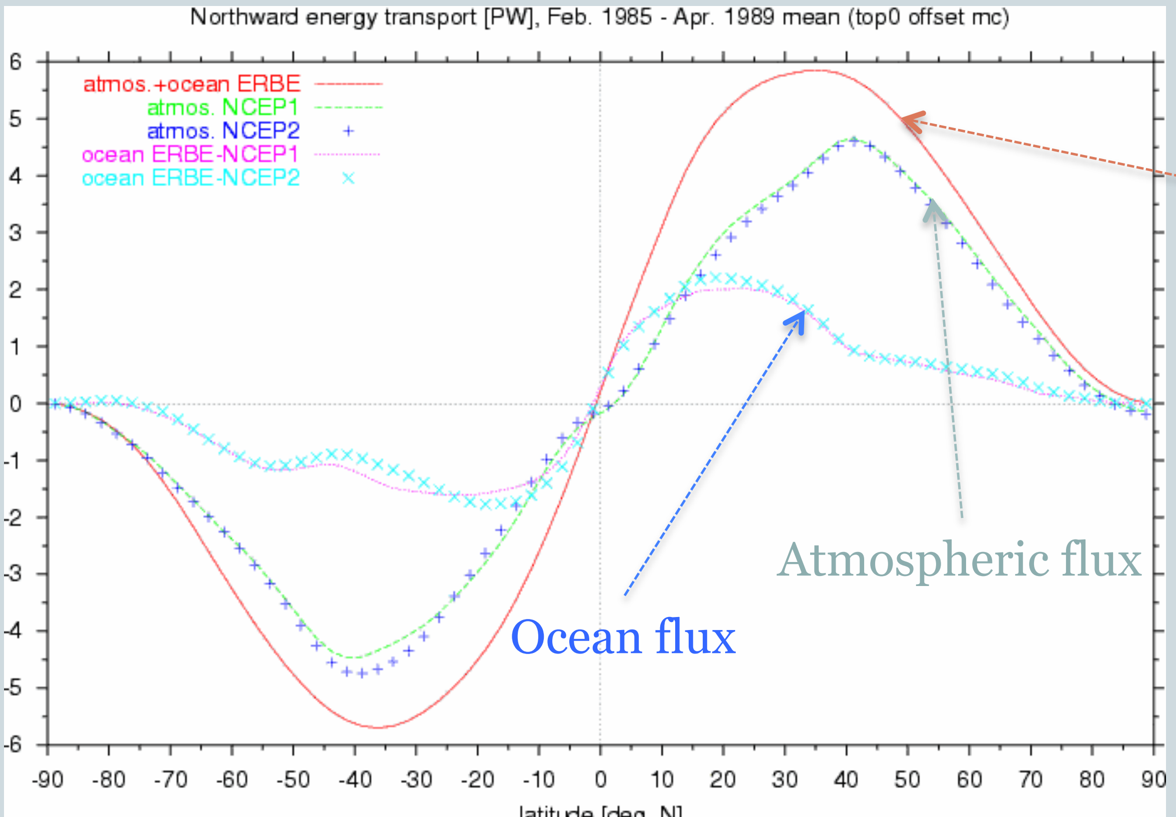
Atmospheric and Oceanic Energy Transports





Back to Observed Energy Transports

- Separated into atmospheric and oceanic components:



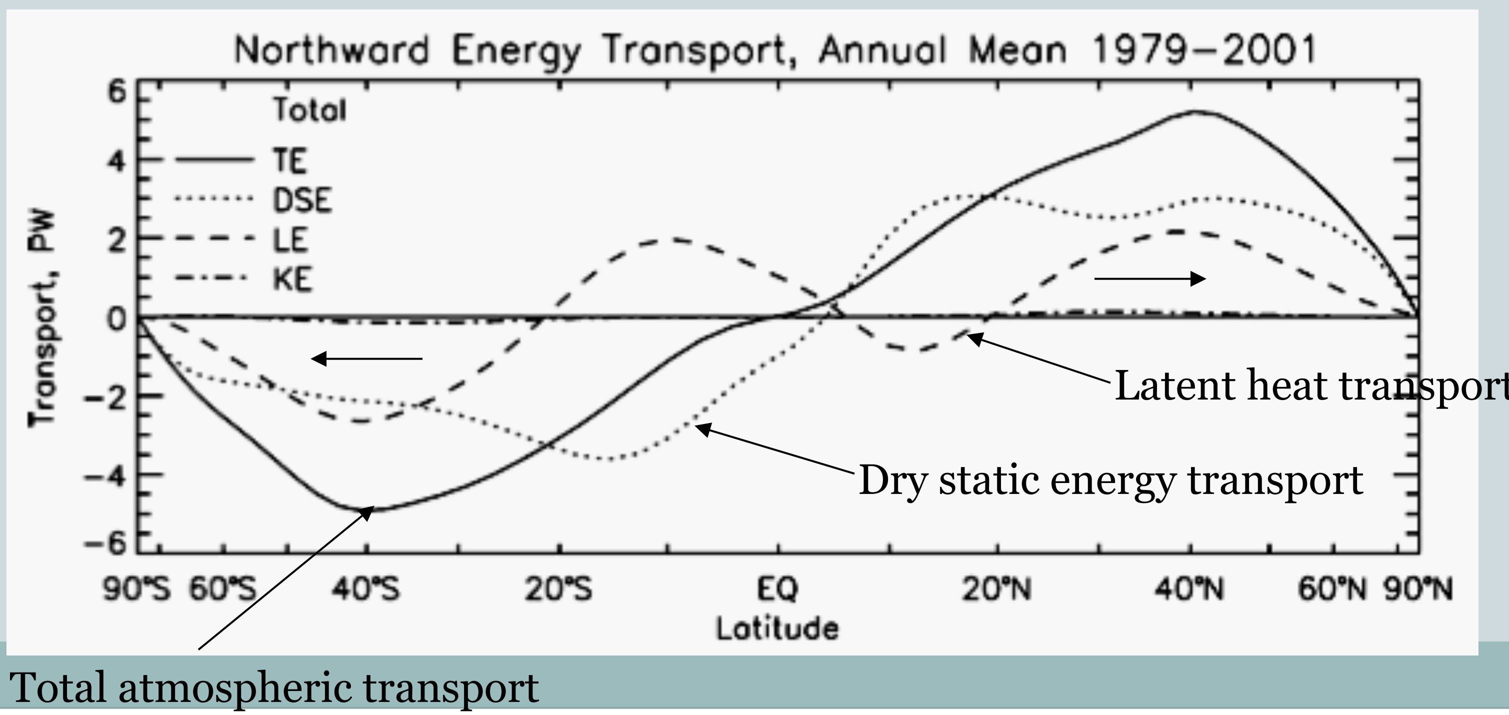
Total (atmosphere plus ocean) flux

Atmospheric flux is larger in midlatitudes, oceanic flux is larger in deep tropics

Latitude

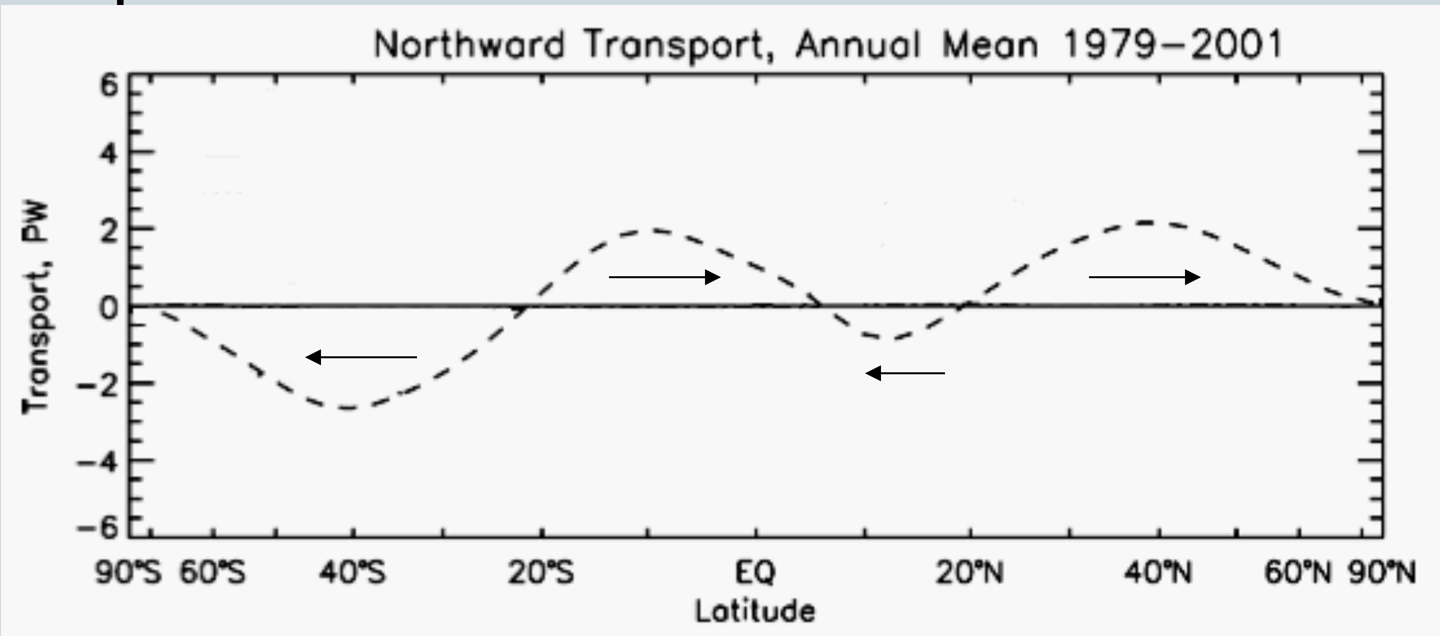
Atmospheric Energy Fluxes

- Let's take a closer look at the **atmospheric** energy fluxes
  - **Dry static energy** flux = internal + potential energy flux
  - Latent heat transport = moisture flux



Moisture flux

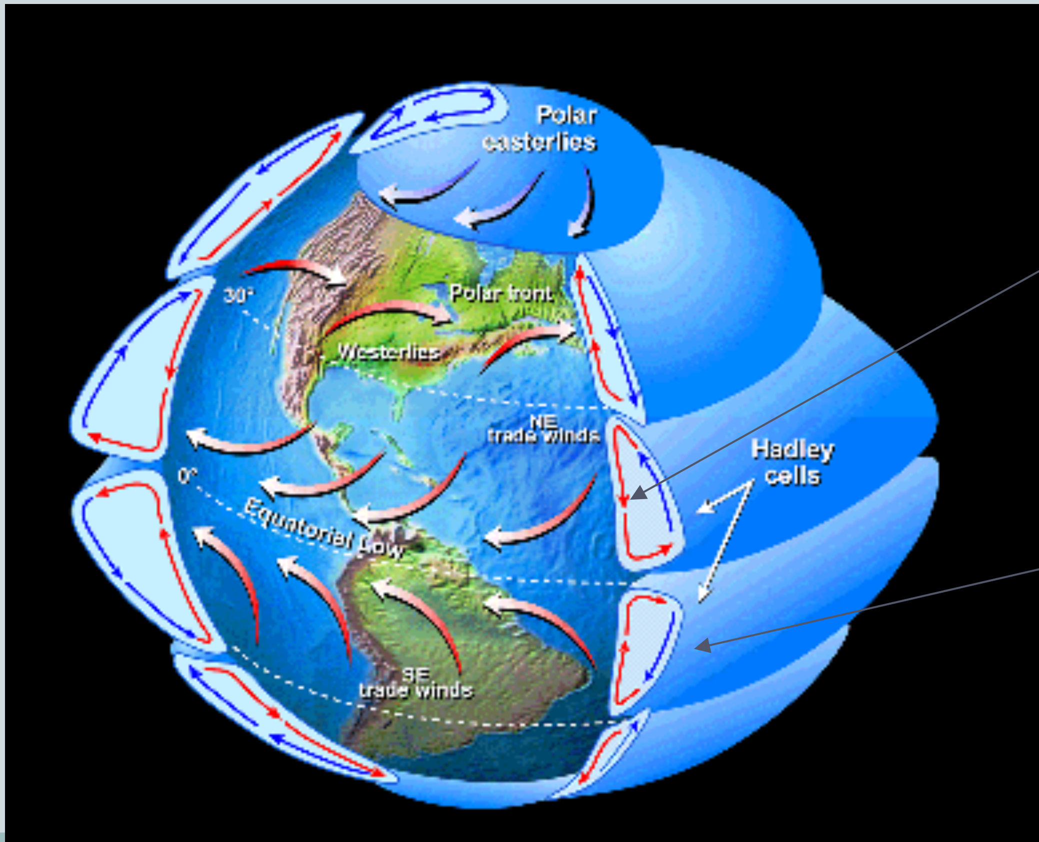
- Annual and zonal mean moisture flux in the atmosphere:



Equatorward moisture flux in the tropics
Poleward moisture flux in the extratropics

Hadley Cell Energy Fluxes

- Equatorward moisture flux & poleward dry static energy flux in the tropics are due to the Hadley cells

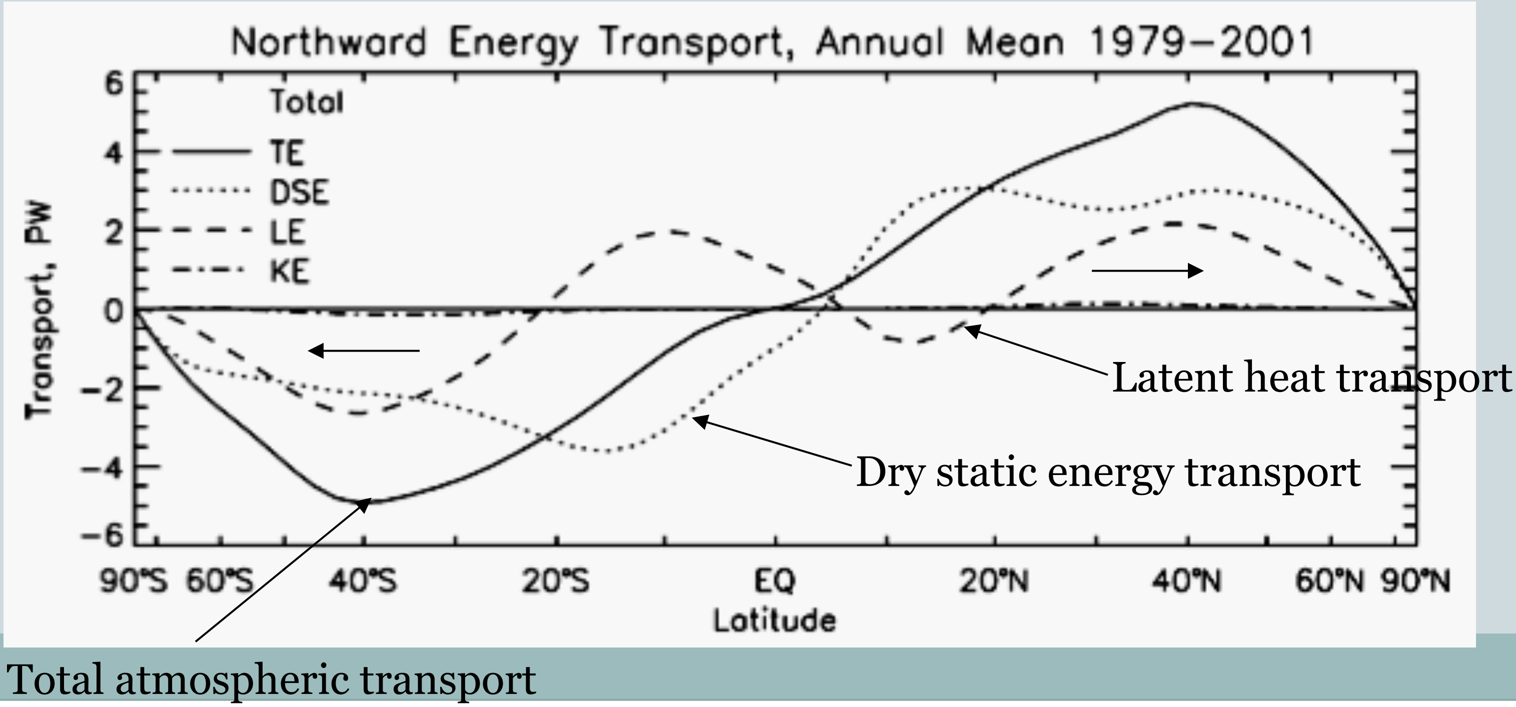


Moisture near the surface is converged equatorward by Hadley cells

High dry static energy air aloft causes total transport to be away from the equator

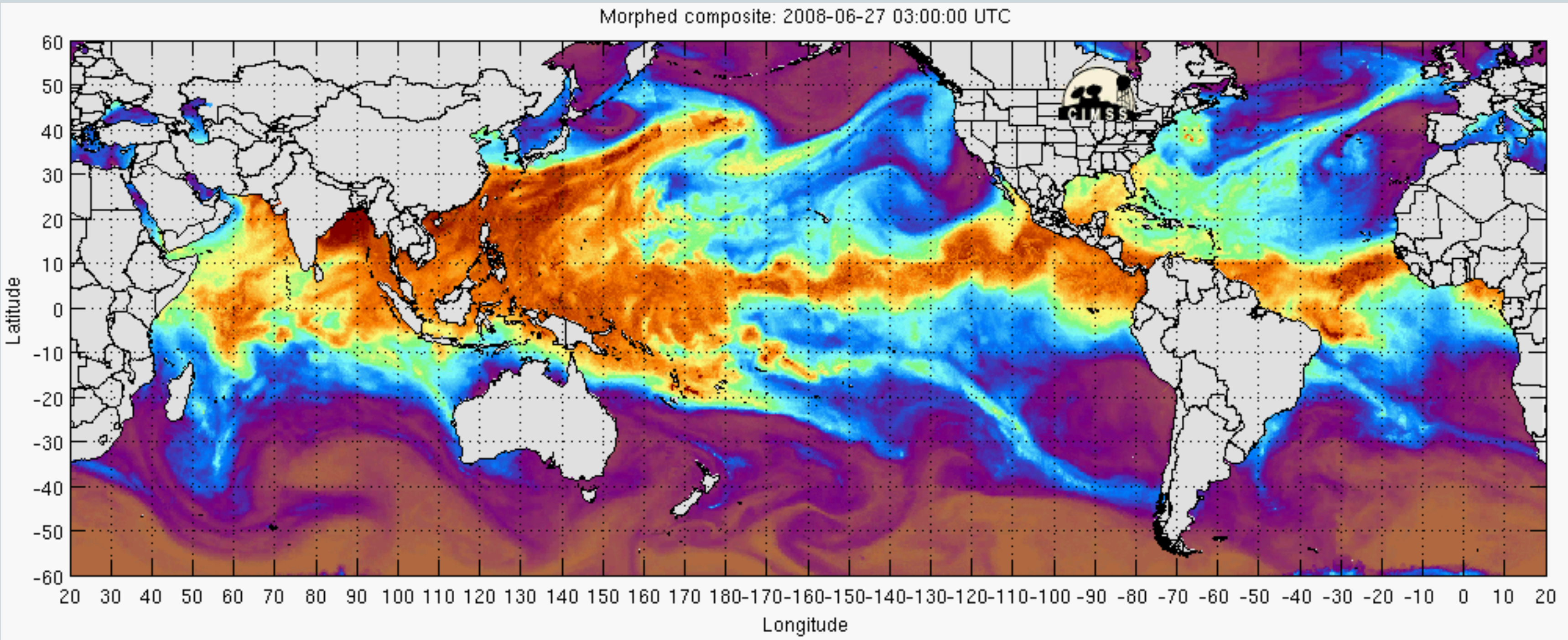
Hadley Cell Energy Transports

- Large dry static energy fluxes within Hadley cell ensure that total transport is poleward
  - High potential energy air being moved poleward



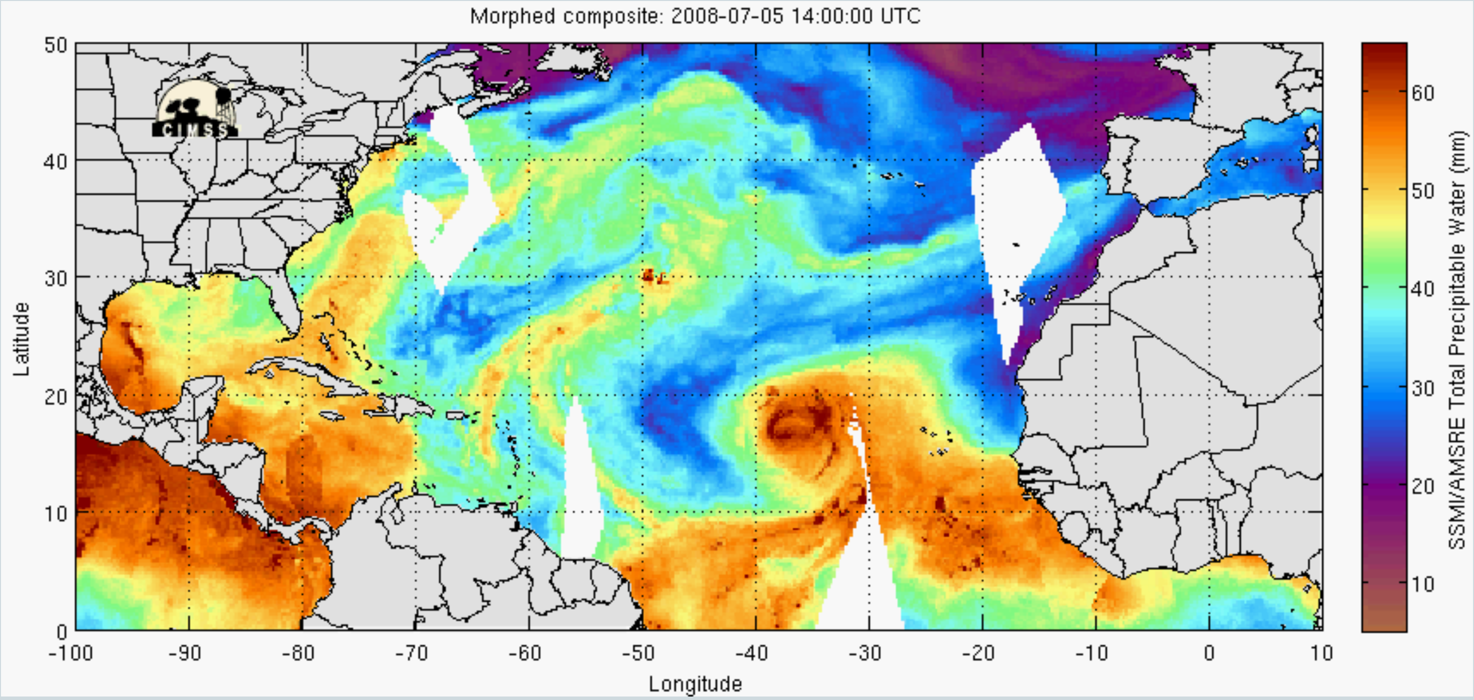
Midlatitude Moisture Flux

- Poleward moisture flux occurs in midlatitudes
  - Primarily accomplished by eddies



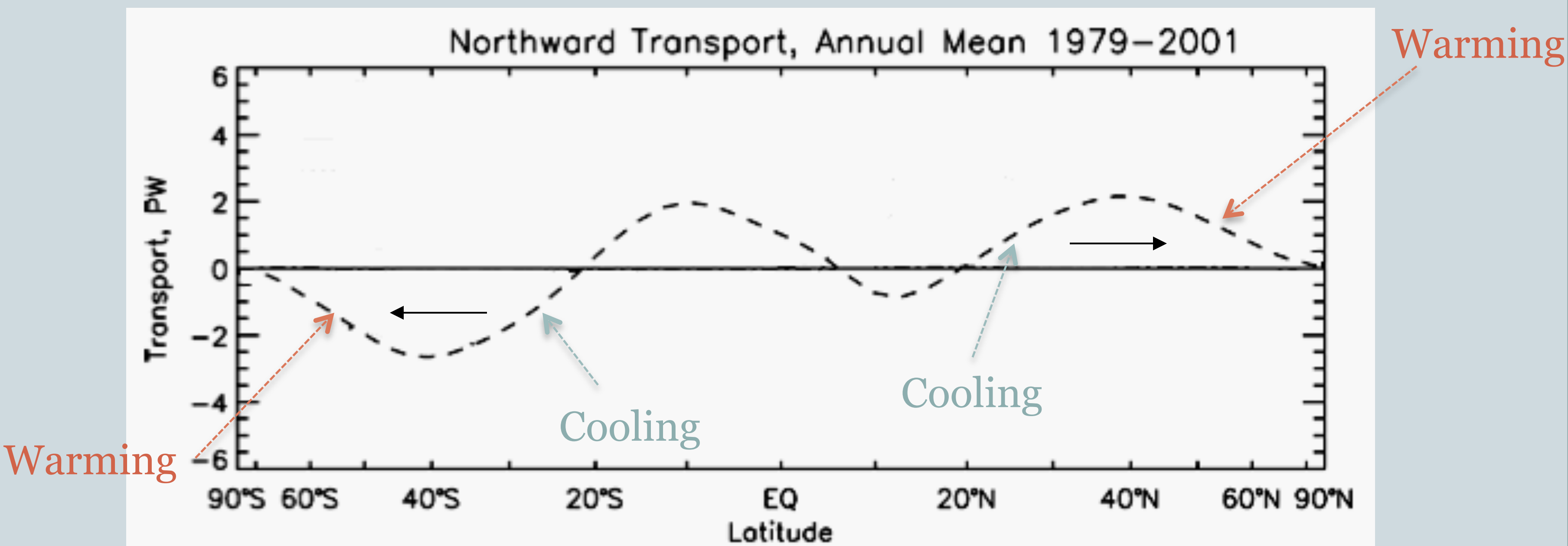
Moisture Flux in Midlatitudes

- Poleward moisture flux occurs in midlatitudes
  - Primarily accomplished by eddies



Moisture Flux as an Energy Flux

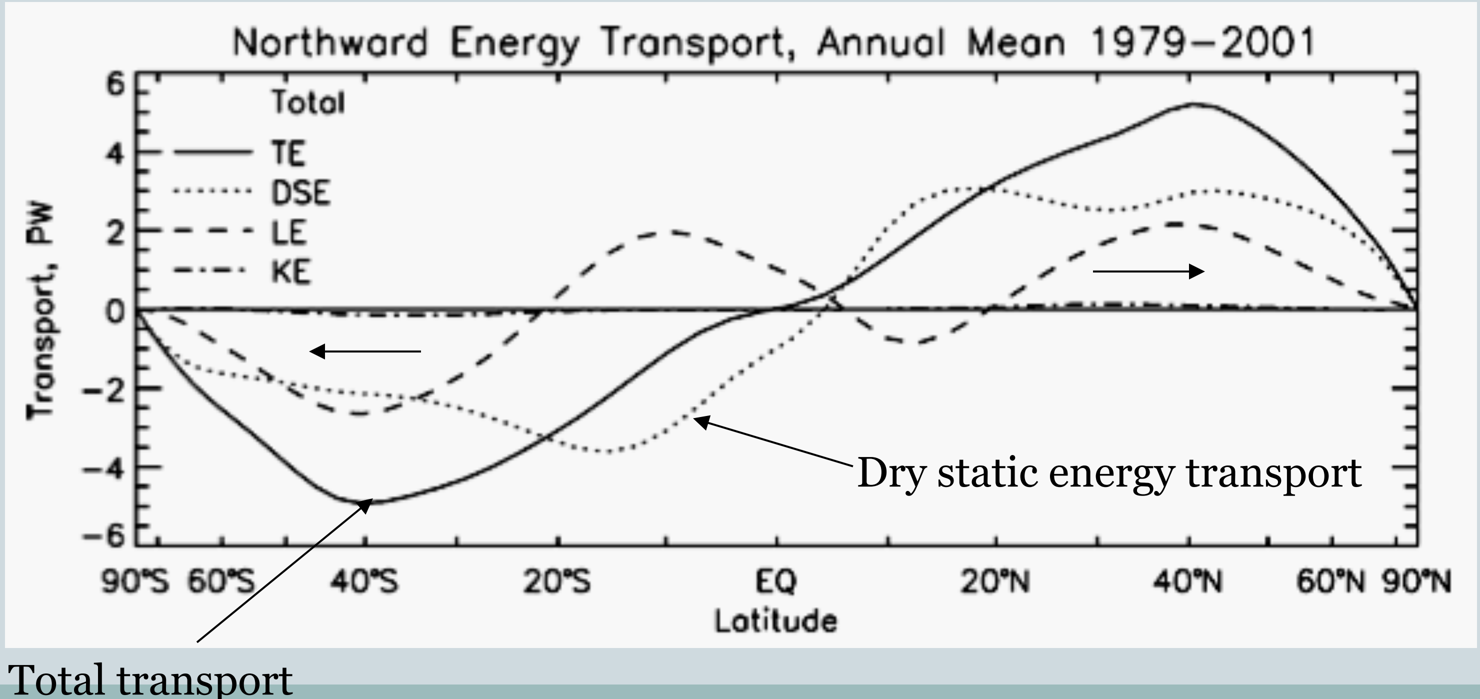
- Poleward moisture flux acts to flatten temperature gradients just like heat fluxes:
  - When the moisture condenses at higher latitudes, it warms those latitudes



Extratropical Energy Fluxes

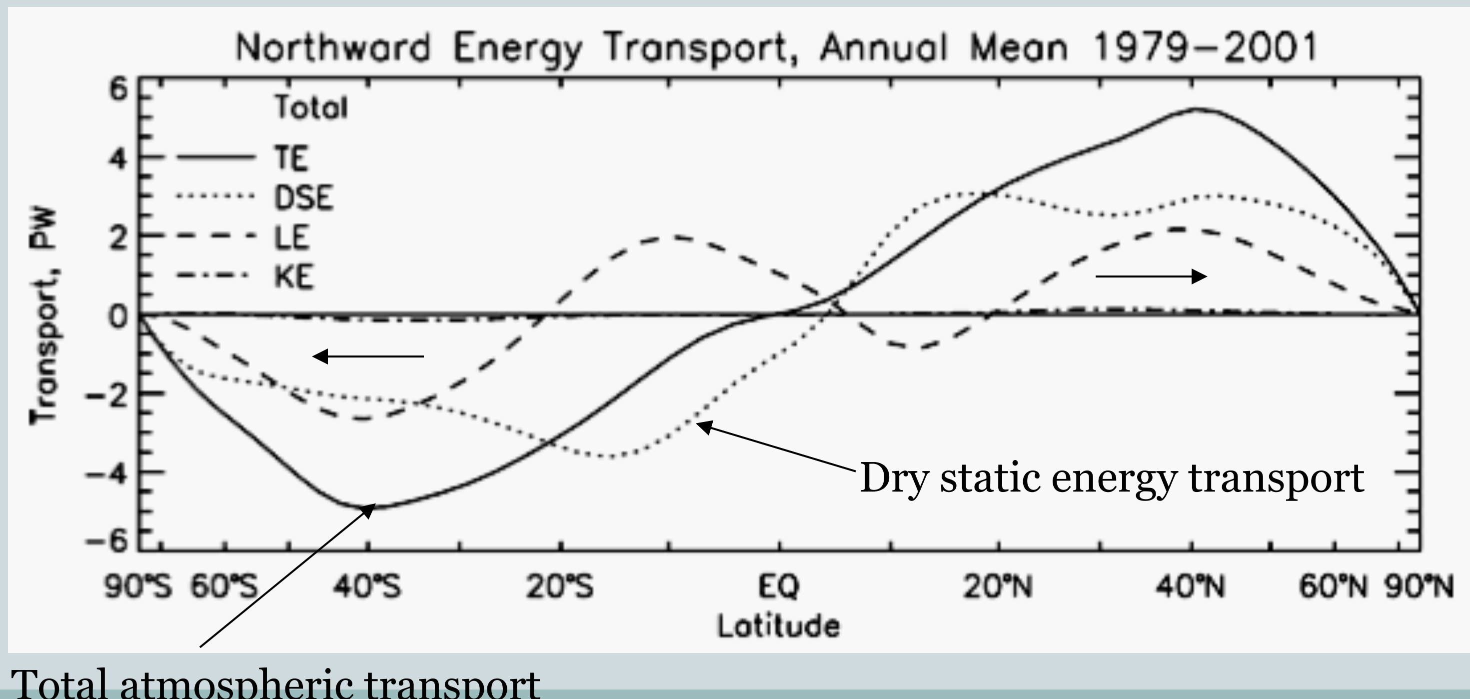
- Comparison with dry and total flux:
  - Dry static energy flux = $v(c_p T + gz)$

    = flux of internal energy + potential energy



Extratropical Energy Fluxes

- Comparison with dry and total flux:
  - Moisture flux is roughly 50% of the total transport in midlatitudes

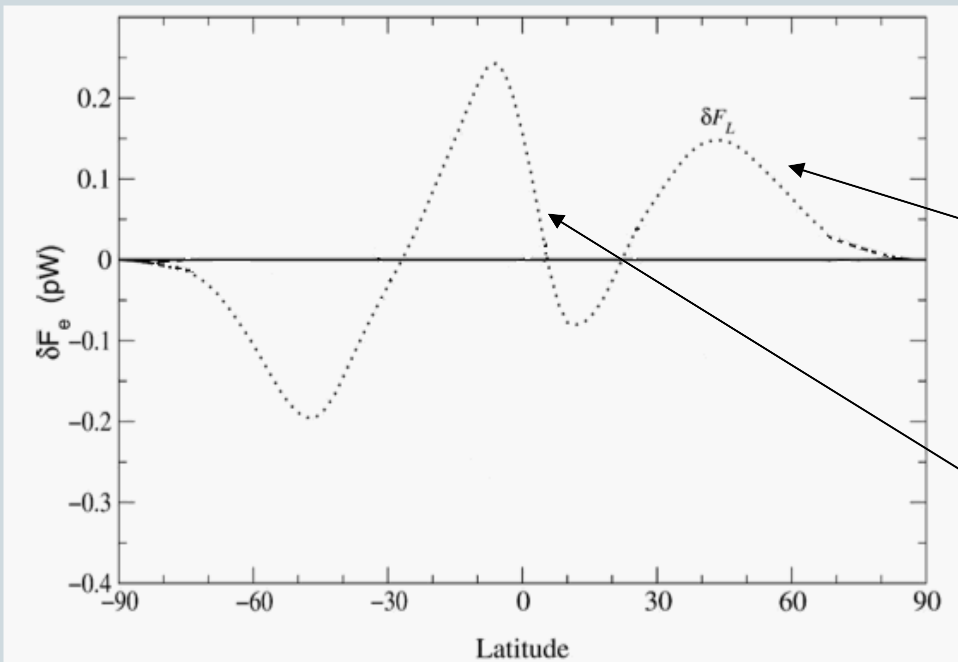


Water Vapor and Global Warming

- With global warming, atmospheric moisture content will increase
  - 20% increase with 3 K global temperature increase
- What effects will the increased moisture content have on the Earth's climate?
  - More moisture flux => flatter temperature gradients in midlatitudes
  - This should weaken dry static energy transports

Energy Fluxes in IPCC Simulations

- Change in moisture flux in slab ocean global warming simulations:

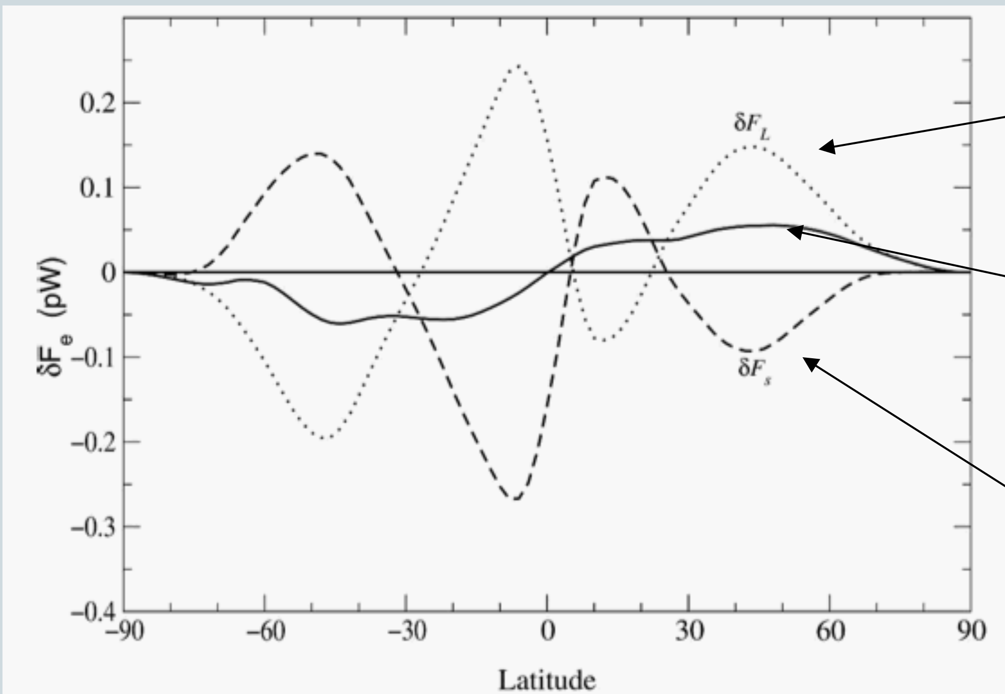


- Increase in poleward flux in extratropics
- Increase in equatorward flux in tropics

From Held and Soden (2006)

Energy Fluxes in IPCC Simulations

- Energy fluxes in slab ocean global warming simulations:



Change in moisture flux

Change in total flux

Change in dry static energy flux

~70% compensation

From Held and Soden (2006)

Moisture and Horizontal Temperature Gradients

- Moisture plays major role in determining midlatitude temperature gradients
  - Roughly 50% of flattening of temperatures is by moisture
- Moisture fluxes are expected to increase with global warming
  - Due to increased moisture content
  - Will lead to decreased temperature gradients