What influences the location of the ITCZ? A collection of idealized modeling studies

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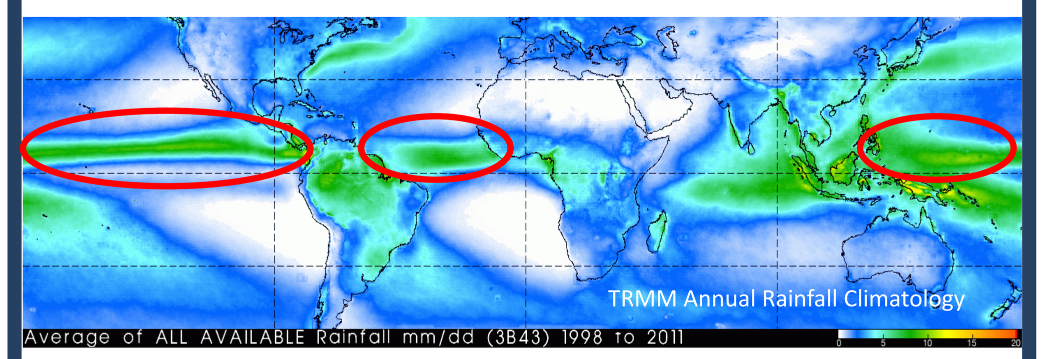
The zonally averaged annual mean intertropical convergence zone (ITCZ) is in the northern hemisphere.



Some component of the Earth System must be forcing this climate asymmetry.

- Orbital parameters (Giese and Carton, 1994)
- Land-sea contrasts (Giese and Carton, 1994, Philander et al, 1995)
- Coastline configuration (Philander et al,1996)
- Mountains (Takahashi and Battisti, 2007)
- Influence of extratropics (Kang et al, 2008)
- Role of Ocean (Fučkar et al, 2013)

Motivation: To determine the most influential forcing(s) on tropical precipitation and circulation

Models of varying complexity are used in idealized setups to test the importance of each forcing.

Simpler ↑ / ↓ More complex

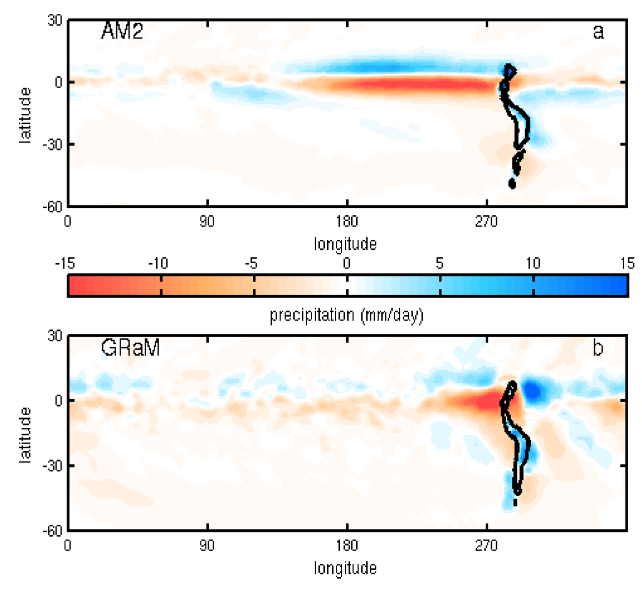
Gray radiation atmosphere (Frierson et al, 2006)
- aquaplanet slab ocean moist GCM
- spectral T85 / B-grid (2x2) dynamical core, 25 vertical levels
- ***no clouds***, no water vapor radiative feedback

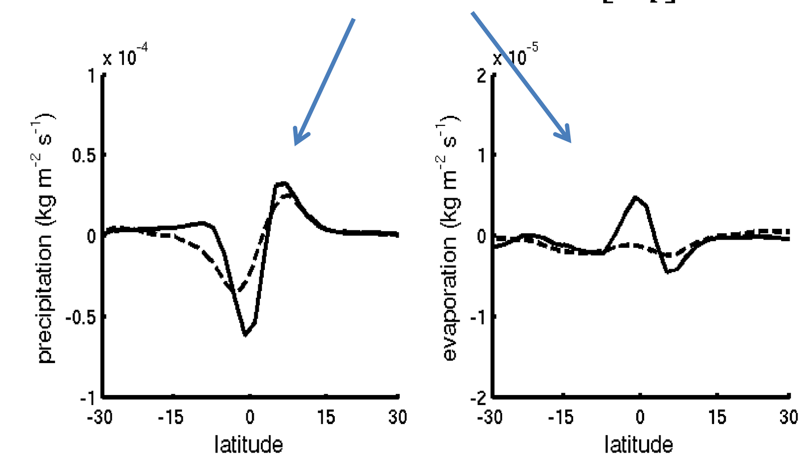
MOMMA (ICCMp1) (Farneti and Vallis, 2009)
- Sector ***coupled*** ocean-atmosphere GCM
- B-grid gray radiation atmosphere, 3.75x3, 7 vertical levels
- MOM4 ocean (Griffies et al, 2005), 2x2, 24 vertical levels
- Also includes sea ice and land models

AM2 (Anderson et al, 2003)
- Aquaplanet with slab ocean model GCM
- Finite volume core, 2.5x2, 24 vertical levels
- Complex radiation and clouds

The addition of an Andes mountain range results in a northward shift of tropical precipitation.

$$P = E - \nabla \cdot [\overline{vq}]$$

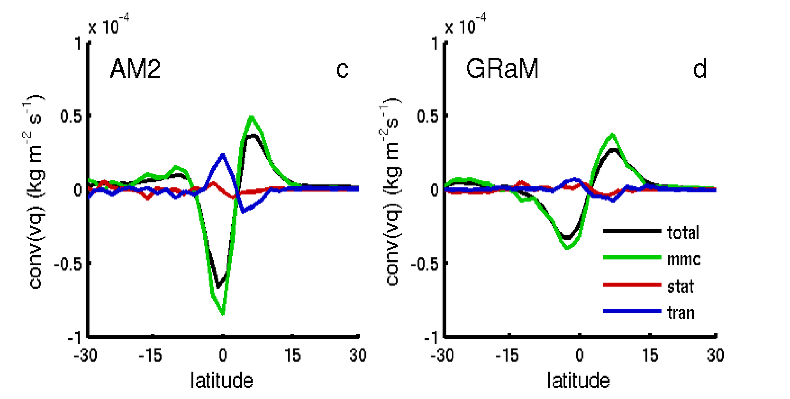




Most of the change in precip is related to changes in moisture flux convergence.

Total — Mean meridional circulation — Stationary eddies — Transients

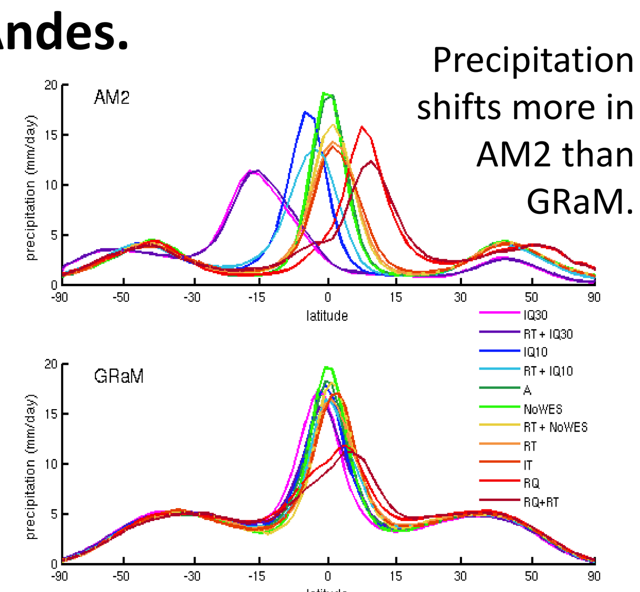
$$-\nabla \cdot [\overline{vq}] = -\nabla \cdot [\bar{v}][\bar{q}] - \nabla \cdot [\overline{v^* q^*}] - \nabla \cdot [\overline{v'q'}]$$



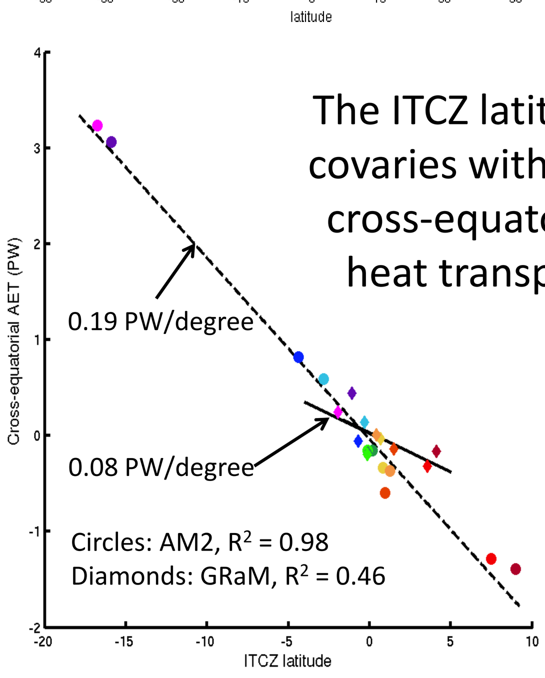
Decomposing moisture flux convergence shows that most of its changes due to the addition of the Andes stems from changes in the MMC, not in the stationary component.

Ocean heat fluxes result in a stronger shift of precipitation than the addition of the Andes.

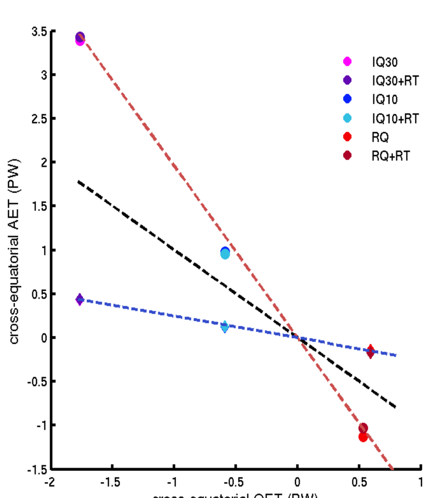
Precipitation shifts more in AM2 than GRaM.



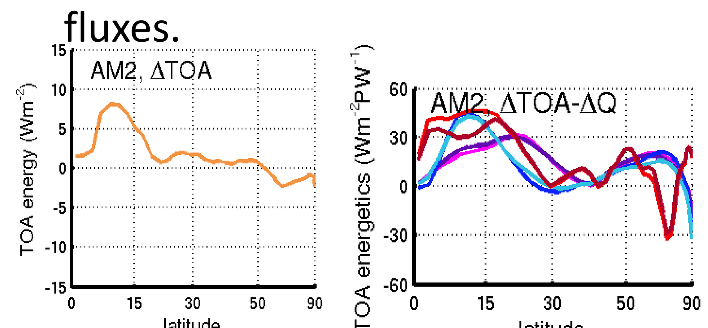
The ITCZ latitude covaries with the cross-equatorial heat transport.



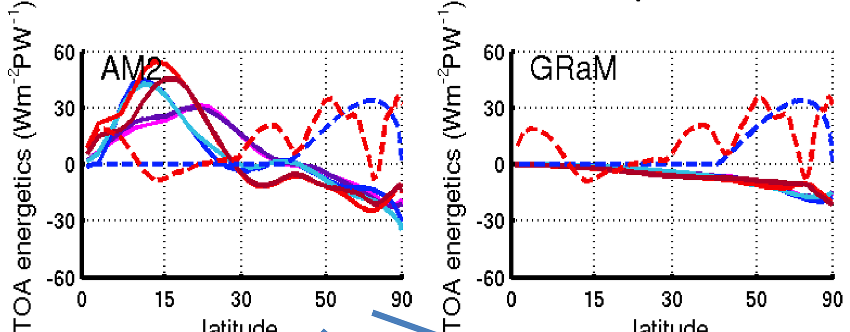
AM2 over-responds to a given ocean heat forcing, while GRaM under-responds.



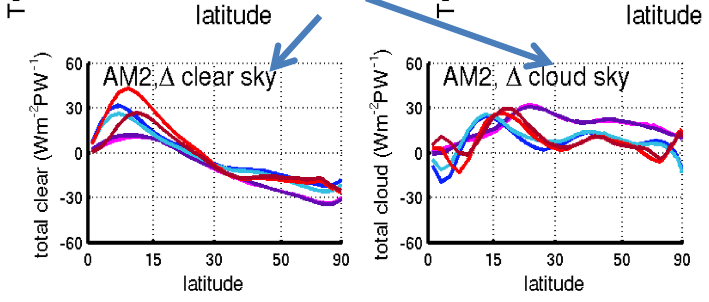
The energetic response in the tropics of AM2 is similar when adding either Andes or surface heat fluxes.



The heat transport over-responds in AM2 due to changes in the absorbed TOA radiation in the tropics.



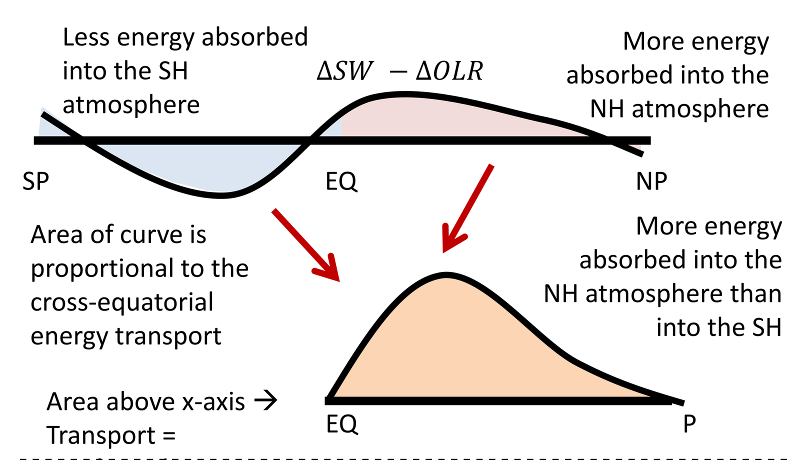
The response in the extratropics is similar in the two models.

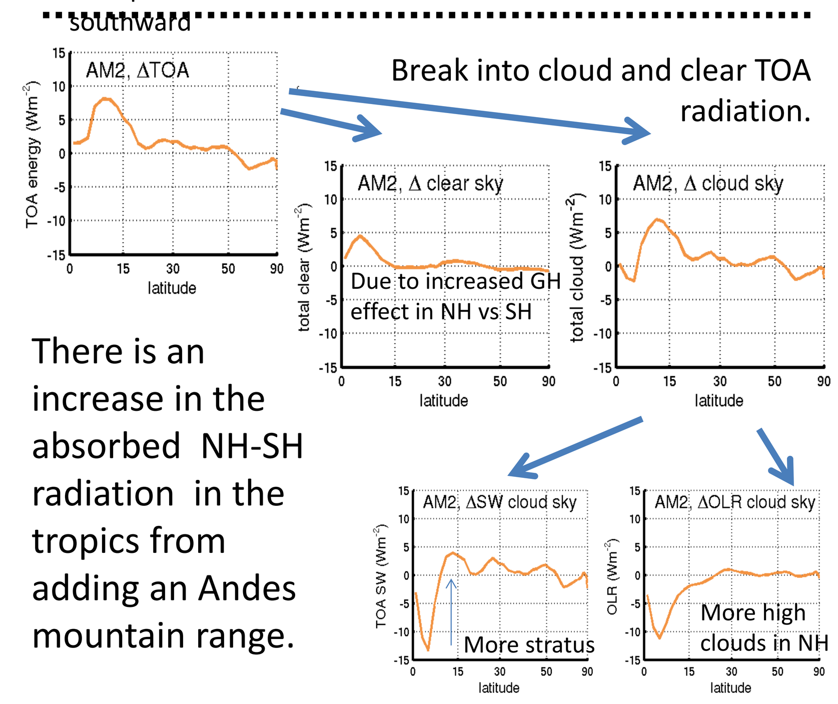


Both clear and cloud sky radiative changes contribute to the change in the tropical absorbed radiation. Both are mostly due to OLR changes.

The Andes induce radiation anomalies that change the energy transport at the equator.

Schematic of radiation influence using TOA NH-SH absorbed radiation:



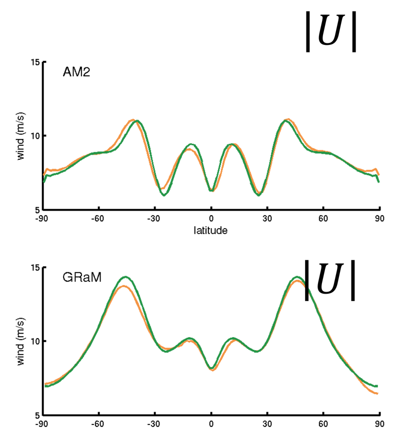


There is an increase in the absorbed NH-SH radiation in the tropics from adding an Andes mountain range.

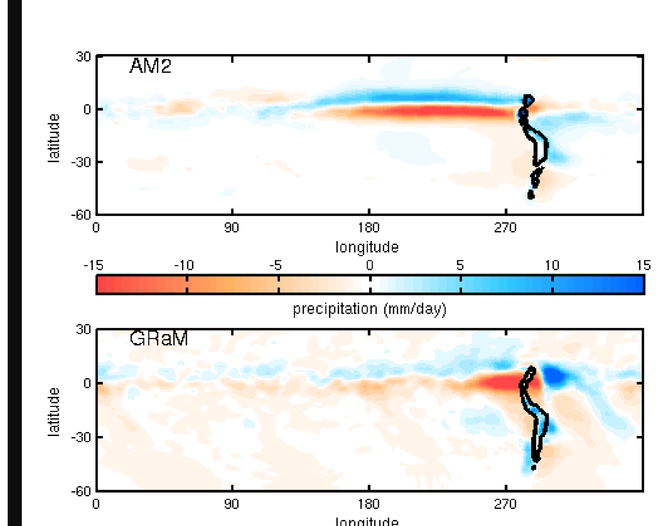
In simulations that add an Andes mountain range, precipitation still shifts northward even when wind-evaporation feedback is removed.

$$E = C_q|U|(q_s - q_a)$$

$$|U|$$



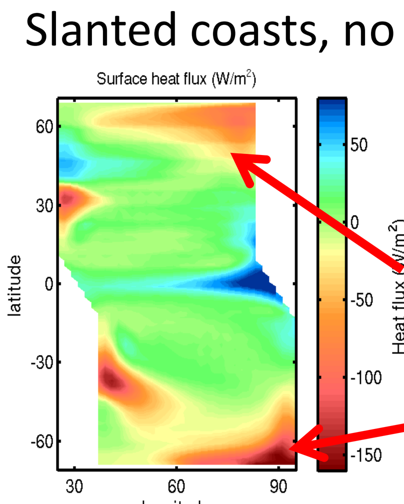
We replaced the wind strength in a simulation with Andes (orange) with the wind strength from a flat simulation (green).



Compare with the same plot in above right panel. The change in precipitation without wind-evaporation feedback looks nearly identical.

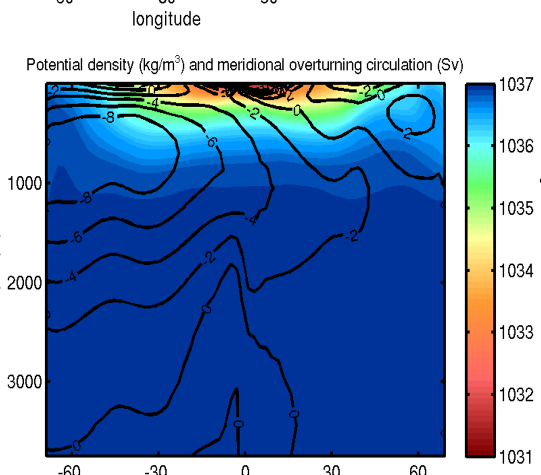
Coupled ocean – grey radiation atmosphere simulations with slanted coastlines and Drake Passage

Slanted coasts, no Drake Passage



Blue = heat into ocean
Red = heat out of ocean

More heat flux into atmosphere from ocean in **southern** hemisphere (SH).



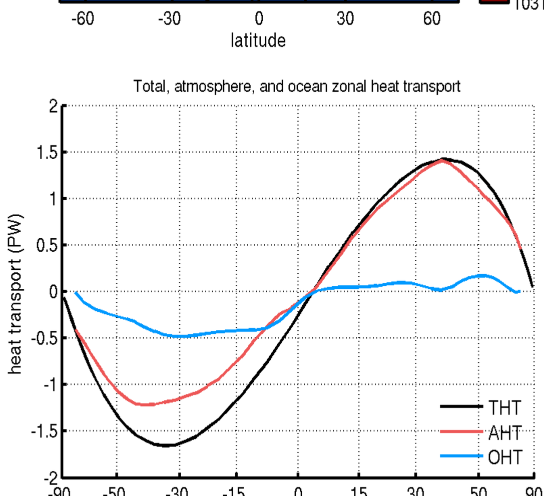
MOC = Meridional Overturning Circulation

Stronger MOC in SH than NH → more SH heat release

↓

Slanted coastlines prefer SH deep water production

↓

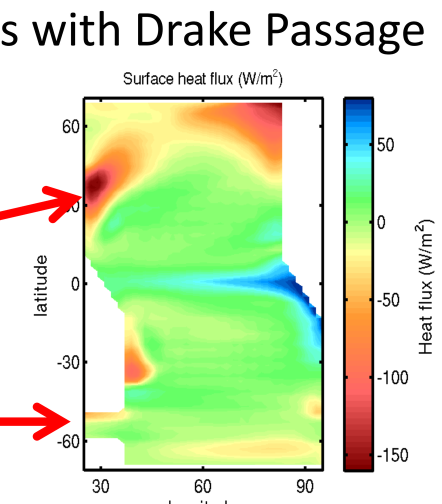


More ocean heat transport to the SH

Slanted coasts with Drake Passage

More heat flux into atmosphere from ocean in **northern** hemisphere (NH).

Drake Passage

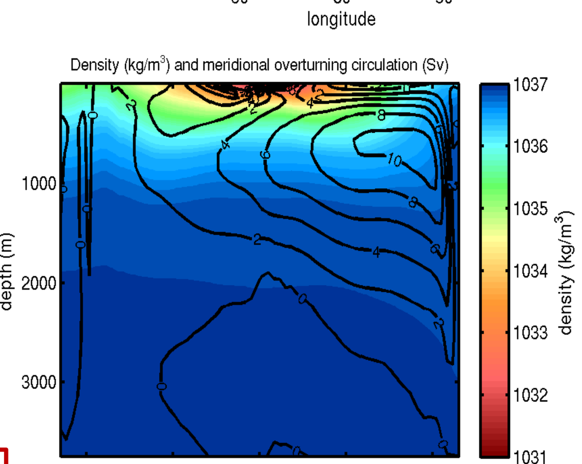


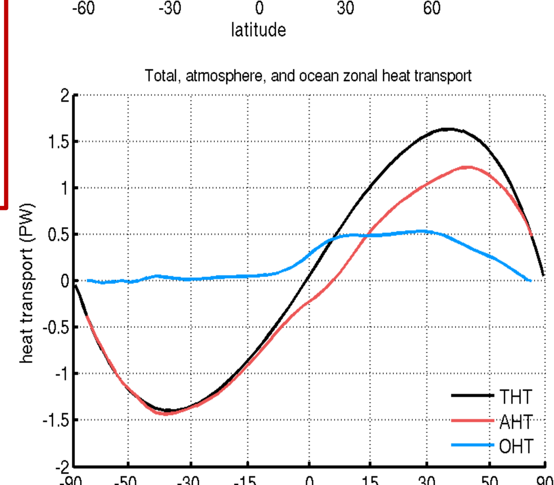
Stronger MOC in NH → more heat release in NH

↓

DP has a stronger preference for NH deep water production.

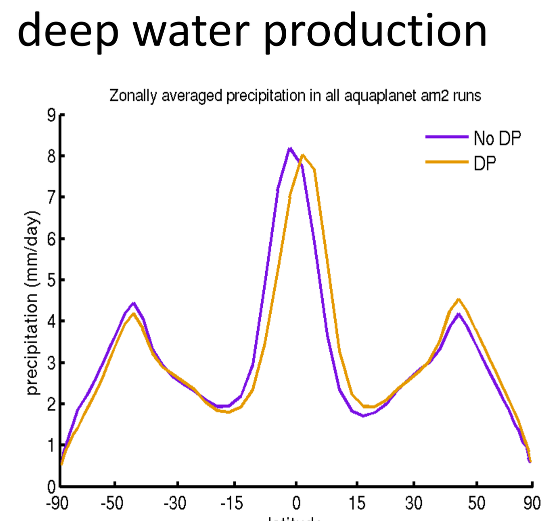
↓





More ocean heat transport to the NH

ITCZ moves to the hemisphere with greater deep water production



Drake Passage disrupts salinity flux to SH, resulting in NH ocean sinking.

↓

Greater northward OHT by MOC

↓

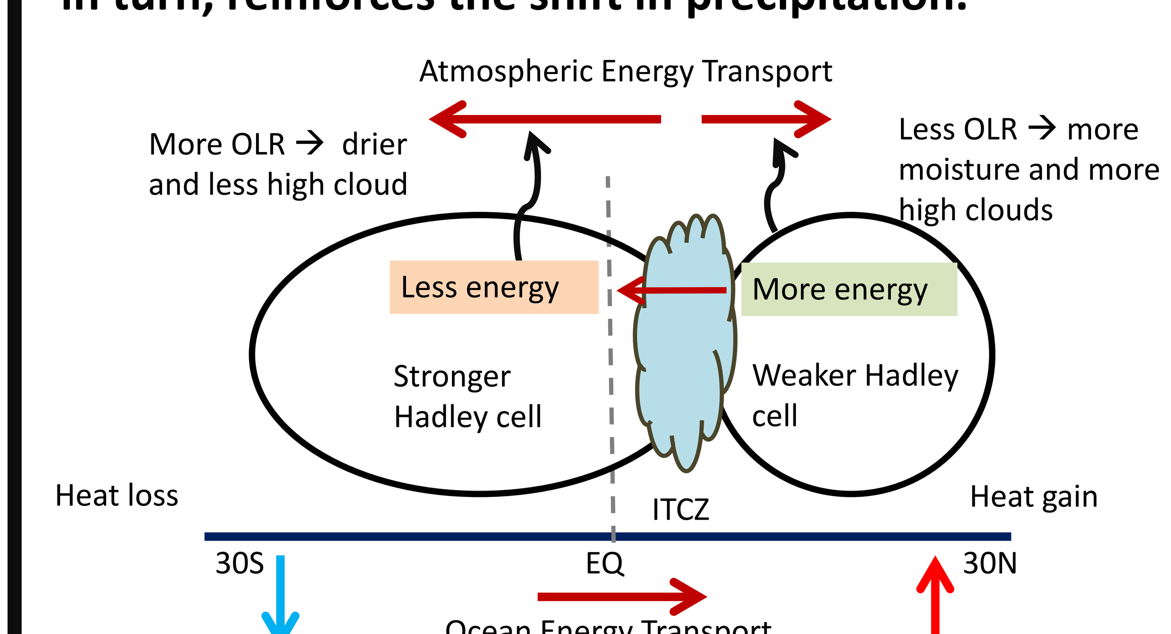
Greater southward AHT by eddies and Hadley cell

↓

Greater northward Hadley cell moisture flux

Similar experiments with similar results and mechanisms have been explored with rectangular basins in this same model. See Fučkar et all, 2013).

In AM2, cloud and clear sky feedbacks reinforce the change in energy transport across the equator. This, in turn, reinforces the shift in precipitation.



Conclusions

- The addition of an Andes mountain range moves tropical precipitation northward.
- Adding ocean heating effects the location of the ITCZ more than adding the Andes.
- AM2 over-responds due to cloud changes and moisture changes (mostly LW) in the tropics that reinforce the locations of the Hadley cells.
- Coupled ocean-atmosphere processes may influence

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