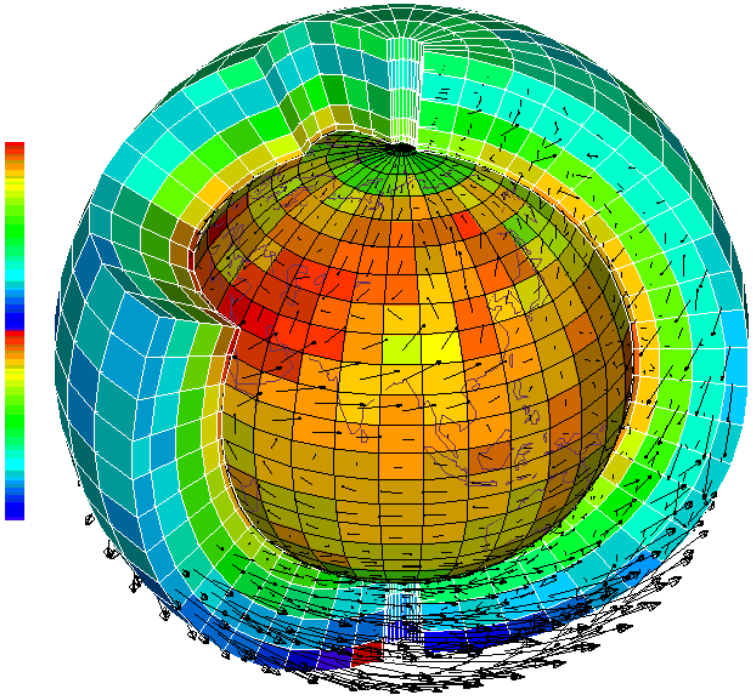
Role of ocean circulation in the climate response to meridional energy imbalances

My main button ?



Francis Codron

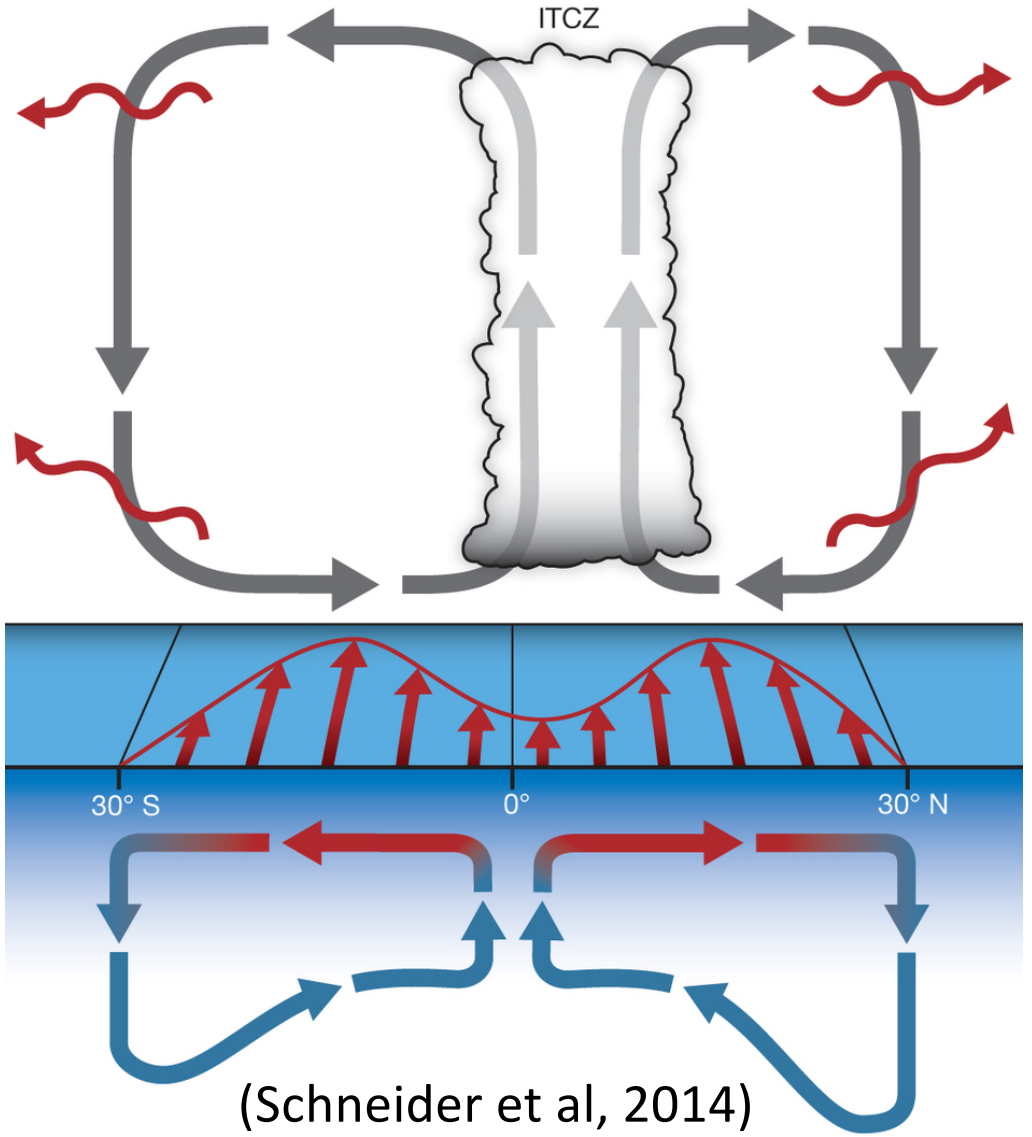
LOCEAN/IPSL, Sorbonne-Université, Paris

Motivation :
Coupling of energy transports by atmosphere and ocean in the Tropics

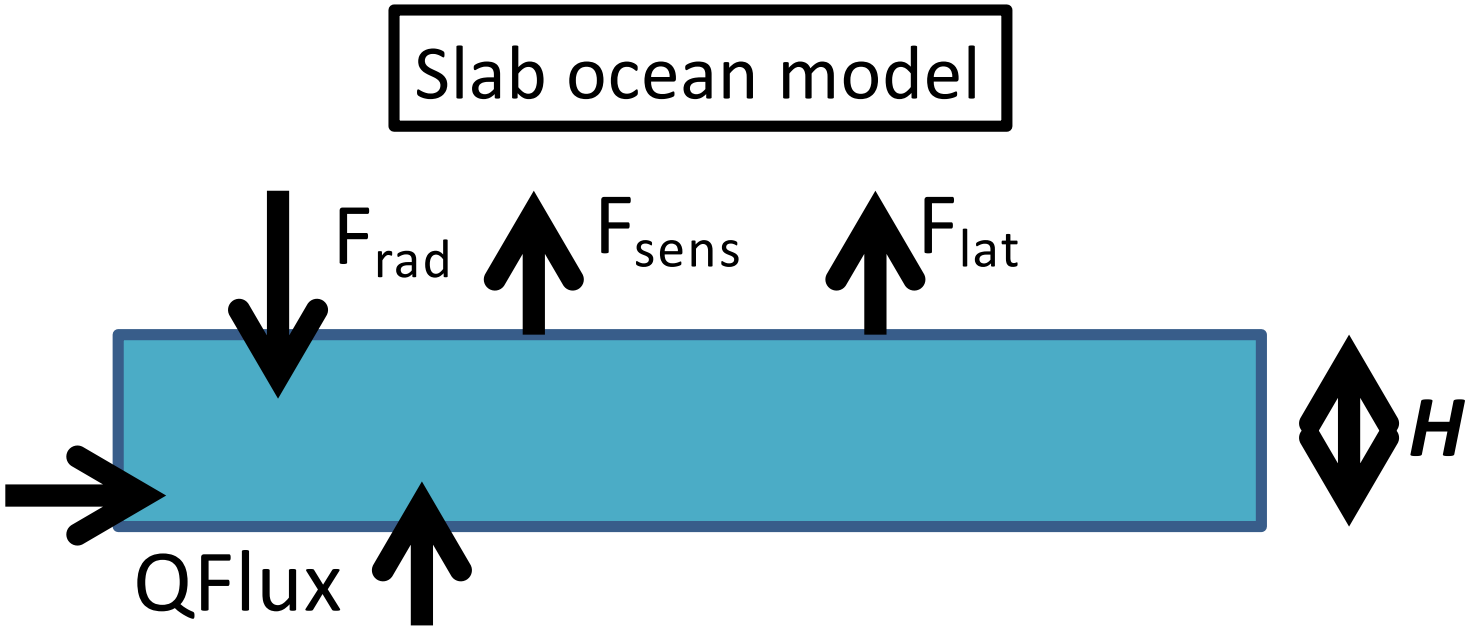
Atmosphere:
Hadley cells.

Ocean:
Shallow circulation cells, driven by trade winds / Ekman transport

- Mass transport is coupled by wind stress.
- Energy transport in the same direction



(Schneider et al, 2014)



- Oceanic surface mixed layer. 50-m depth
- Temperature equation :

$$\rho c_p H \frac{\partial T}{\partial t} = F_{surf} + QFlux$$

- F_{surf} Surface fluxes
- *Qflux* Ocean circulation. Prescribed *or* parameterized

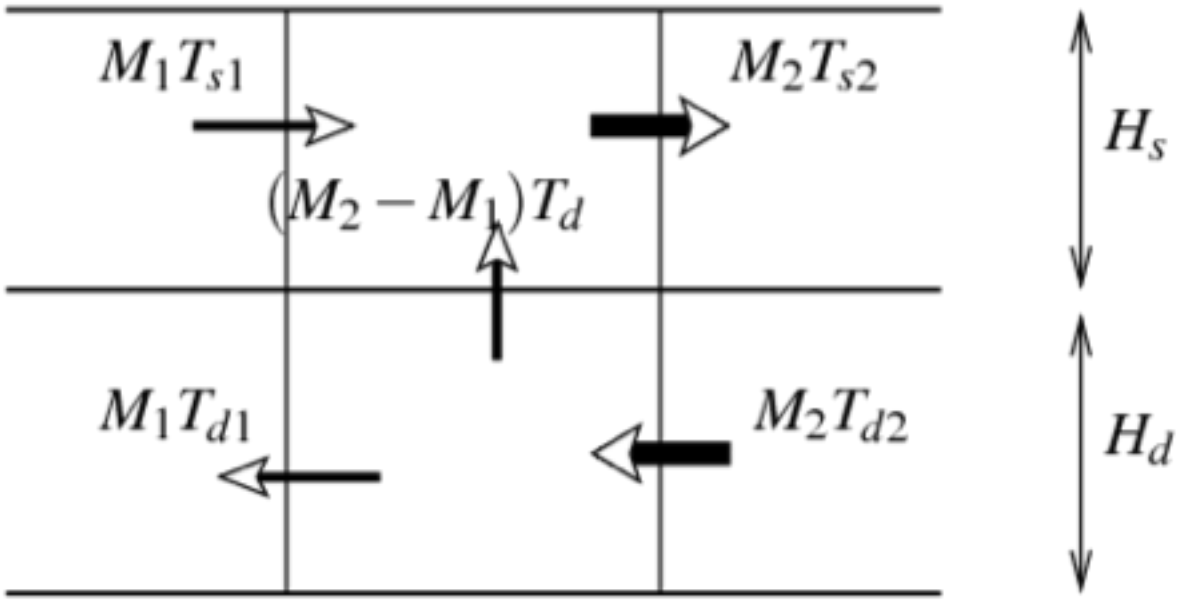
Ekman transport parameterization *(Codron 2012, Clim. Dyn)*

- 2 slab layers, prognostic temperatures T_s and T_d
- Ekman mass transport (vertical integral over surface layer) :

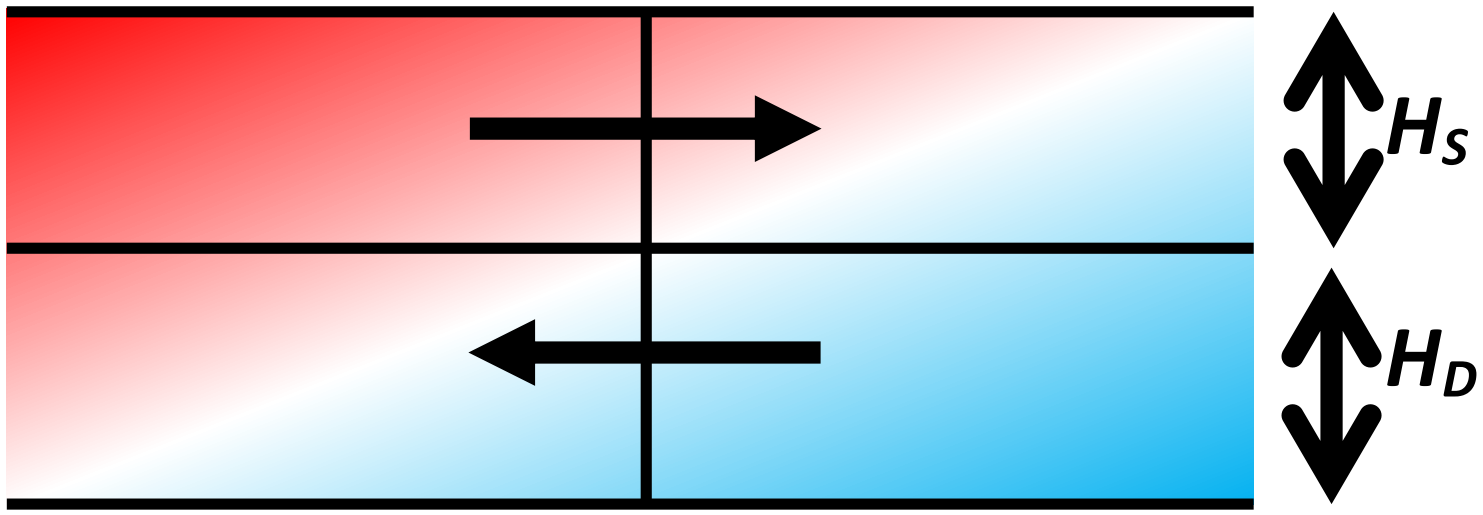
$$\overrightarrow{M_E} = \frac{1}{f}\vec{k}\times\vec{\tau}$$

(At the equator, $M_E^y = \frac{1}{\beta}\partial_y \tau_x$)

- Opposite return flow at depth



Gent-McWilliams scheme (eddy diffusivity)



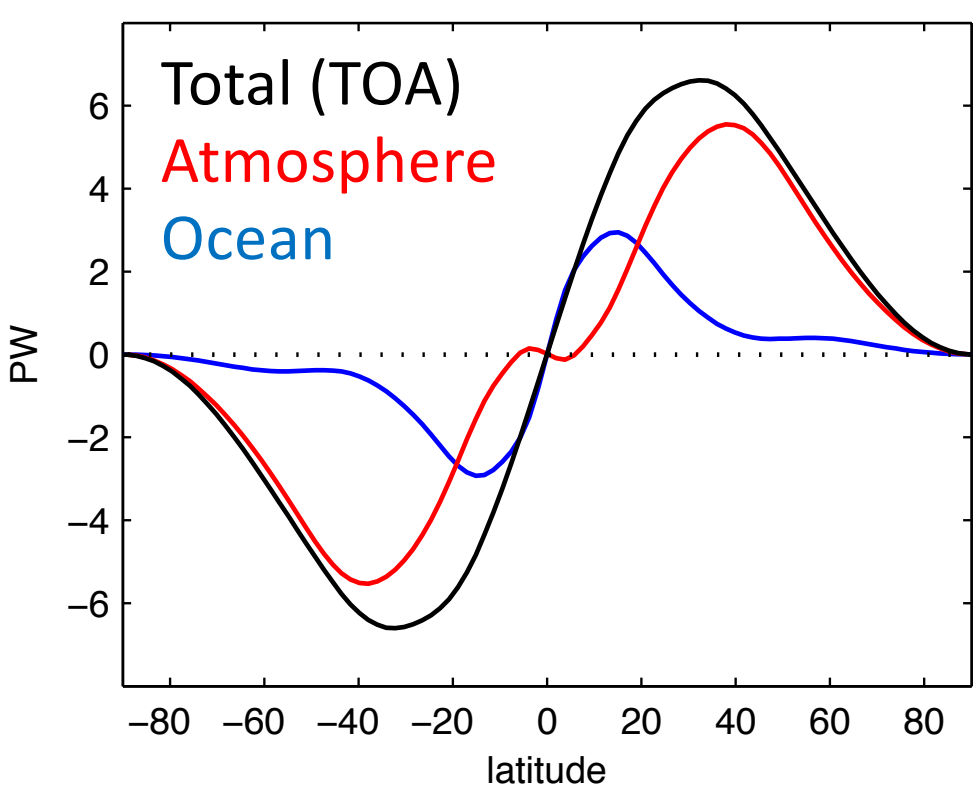
Impact of eddy fluxes is to reduce the slope of isotherms.

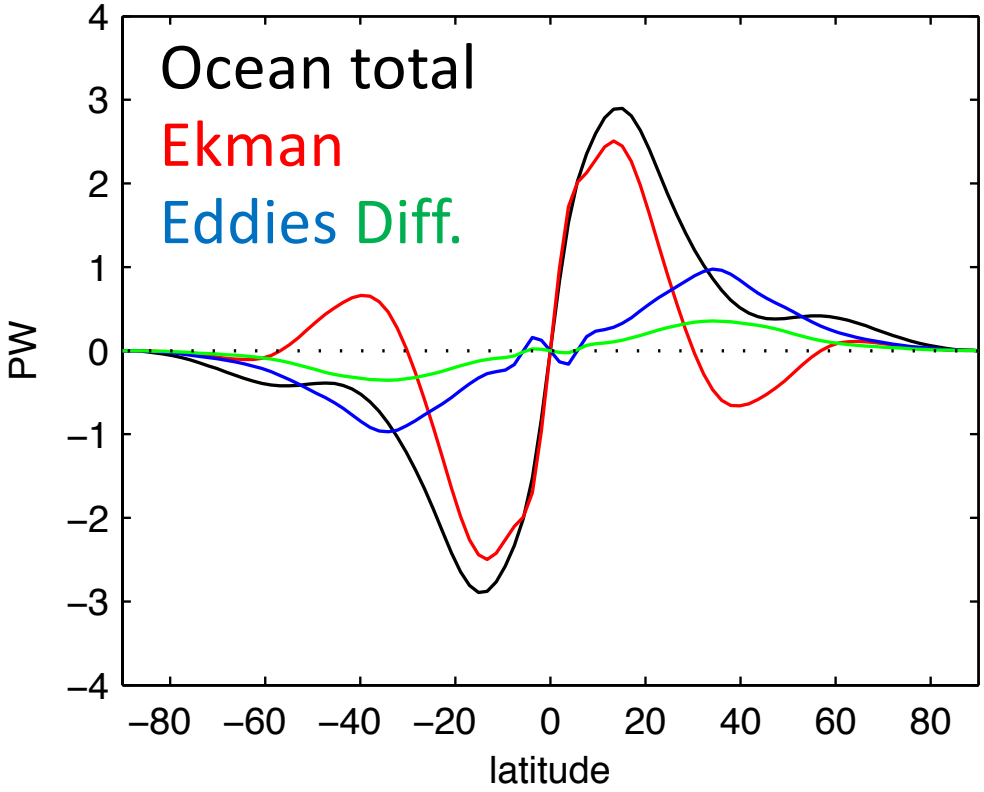
- Eddy-induced velocity, mass flux opposite in the 2 layers, proportionnal to the slope
- Downgradient heat flux
- Re-stratification

Implementation

- LMDZ AGCM, 96x96 grid points, 39 levels
- Ocean-planet geometry, no sea ice (water does not freeze)
- Obliquity (seasons), no eccentricity
- Ekman and G&M transport, plus horizontal diffusion
- No additional heat flux (Q-flux = 0)

Mean northward energy transports





- Ocean energy transport dominates in the (deep) tropics
- Ekman large, poleward in tropics
- Equatorward, weaker mid-latitudes
- Diffusive transport max in mid-latitudes

Sensitivity experiments:

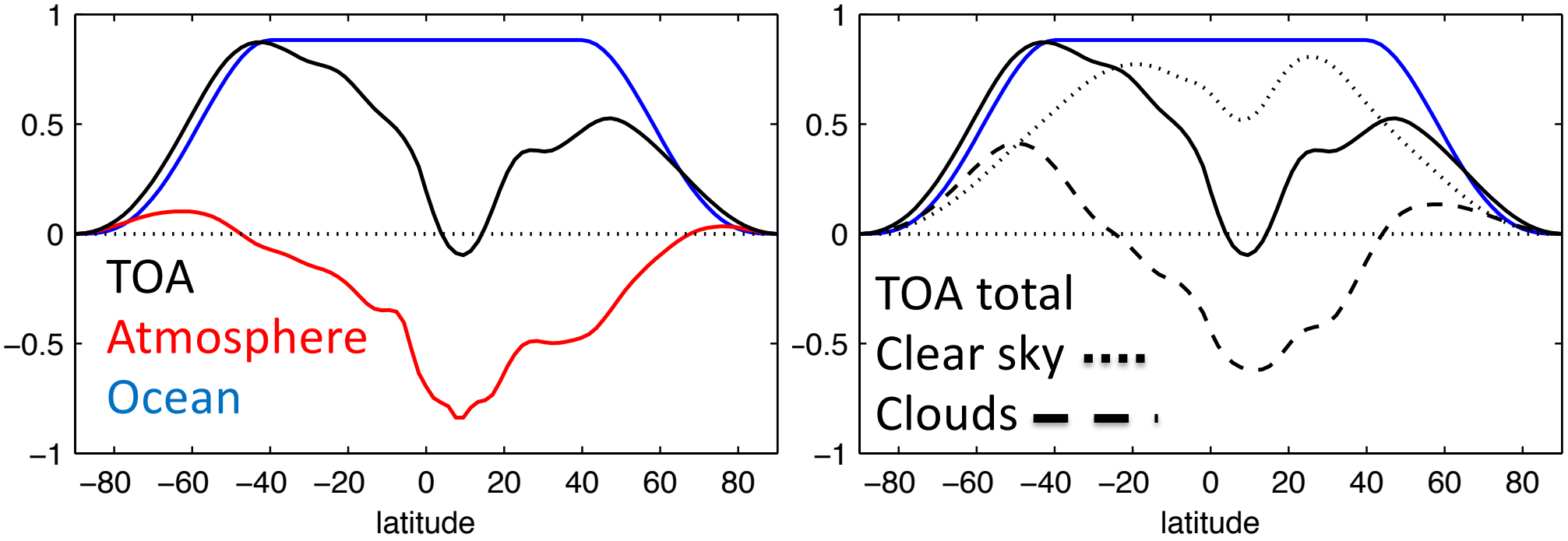
1. add 1 PW northward transport between 40°S and 40°S (as additional prescribed Q-flux in the slab)

2. CO_2 doubling

- Interactive Ekman and diffusive transports (INT)

- Ekman and diffusion prescribed (as Qflux) to the control run seasonal cycle (FIX)

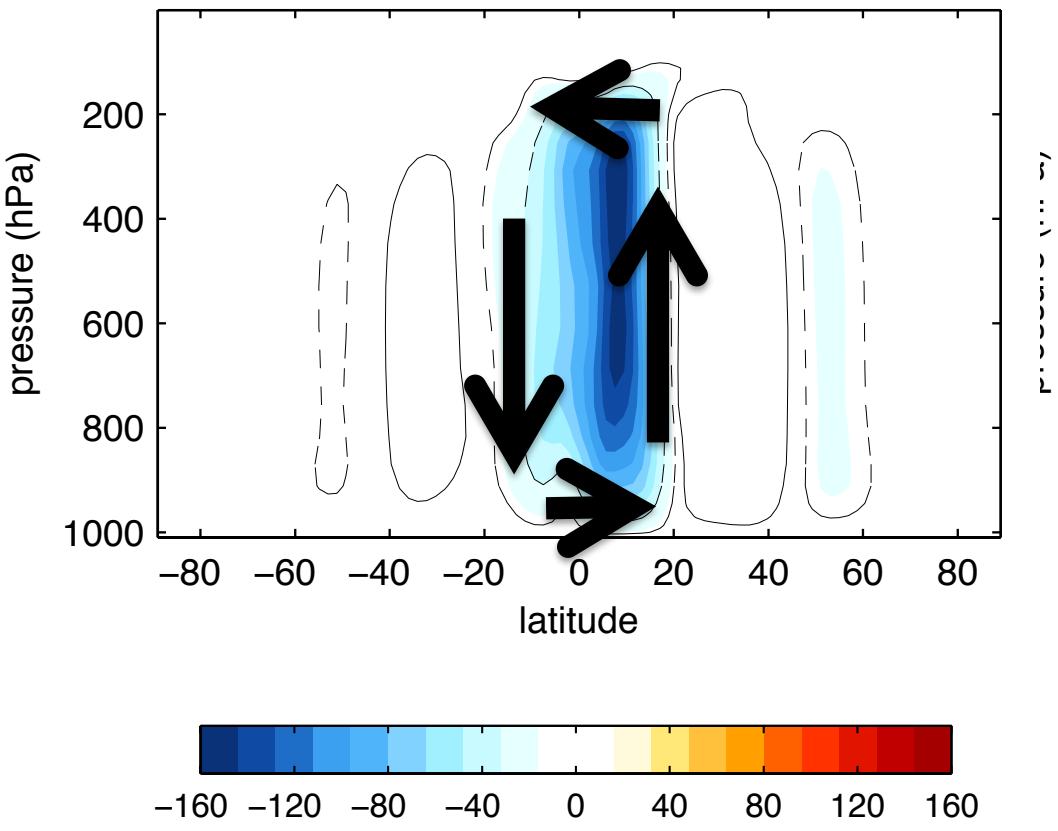
Northward energy transport difference, fixed ocean heat transport (OHT)



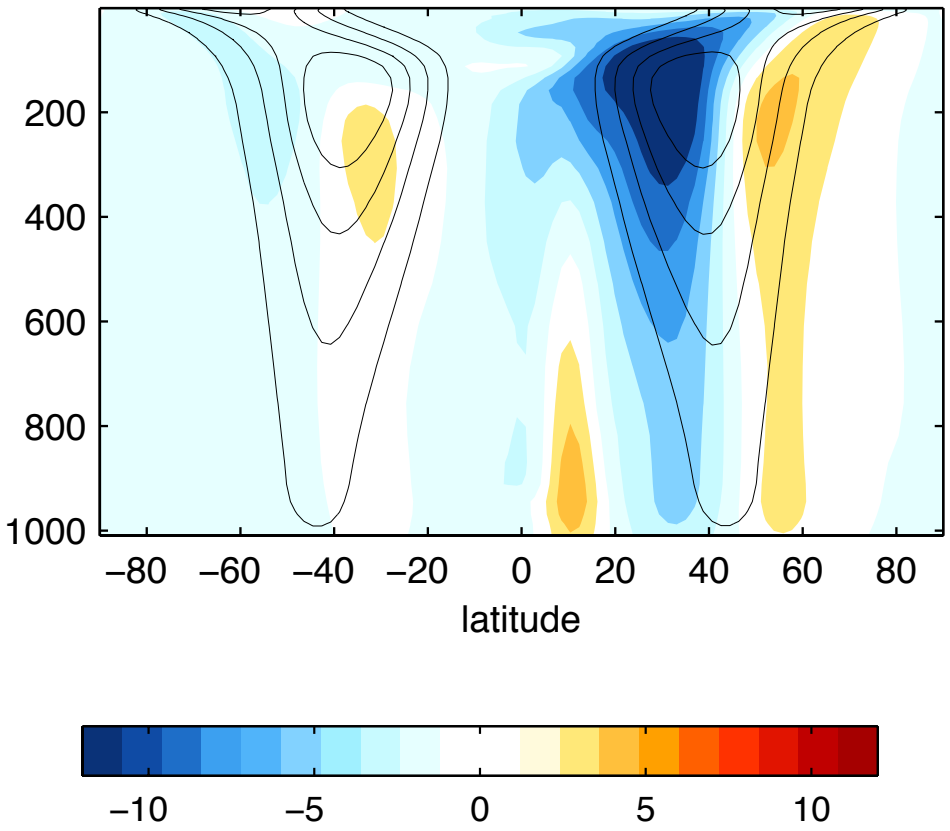
- Large compensation by radiative fluxes in mid-latitudes
- Compensation by atmospheric transport in the Tropics (Clear-sky and cloud forcing responses cancel out)
- North-South asymmetry

Atmospheric circulation response, fixed OHT case

Meridional Streamfunction (10^9 kg/s)



Zonal wind



- Northward jet shifts
- Cross-equatorial Hadley cell & opposite trade wind changes

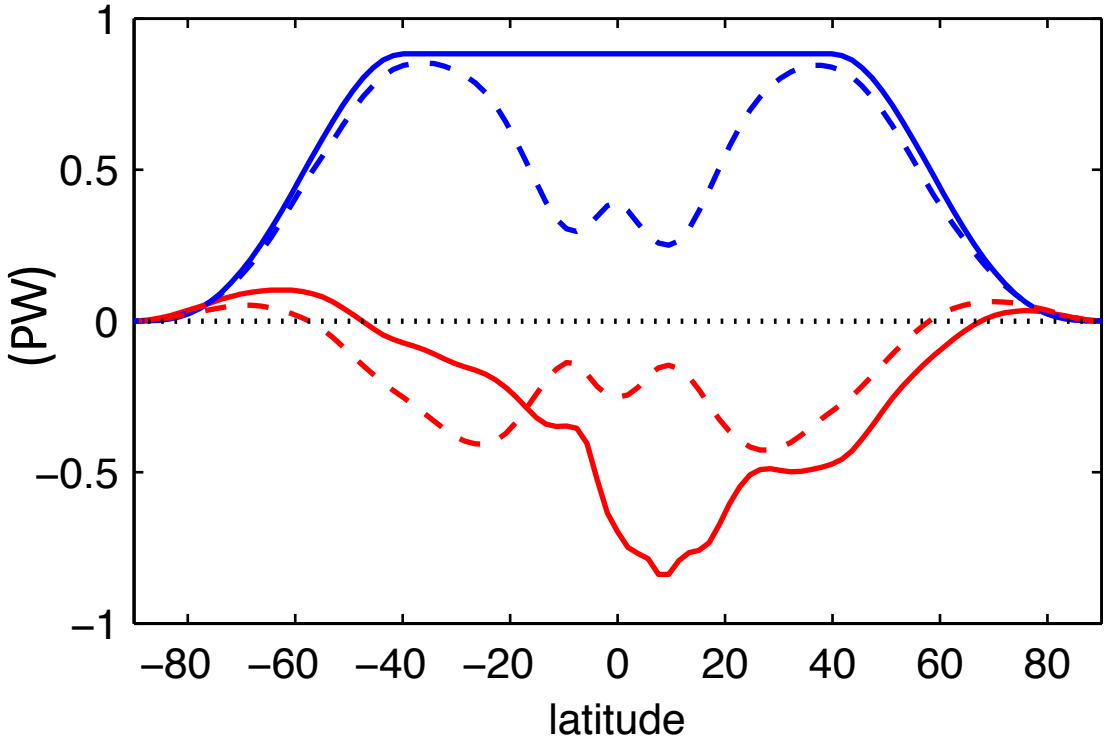
Northward energy transport difference, interactive ocean

Atmosphere

Ocean

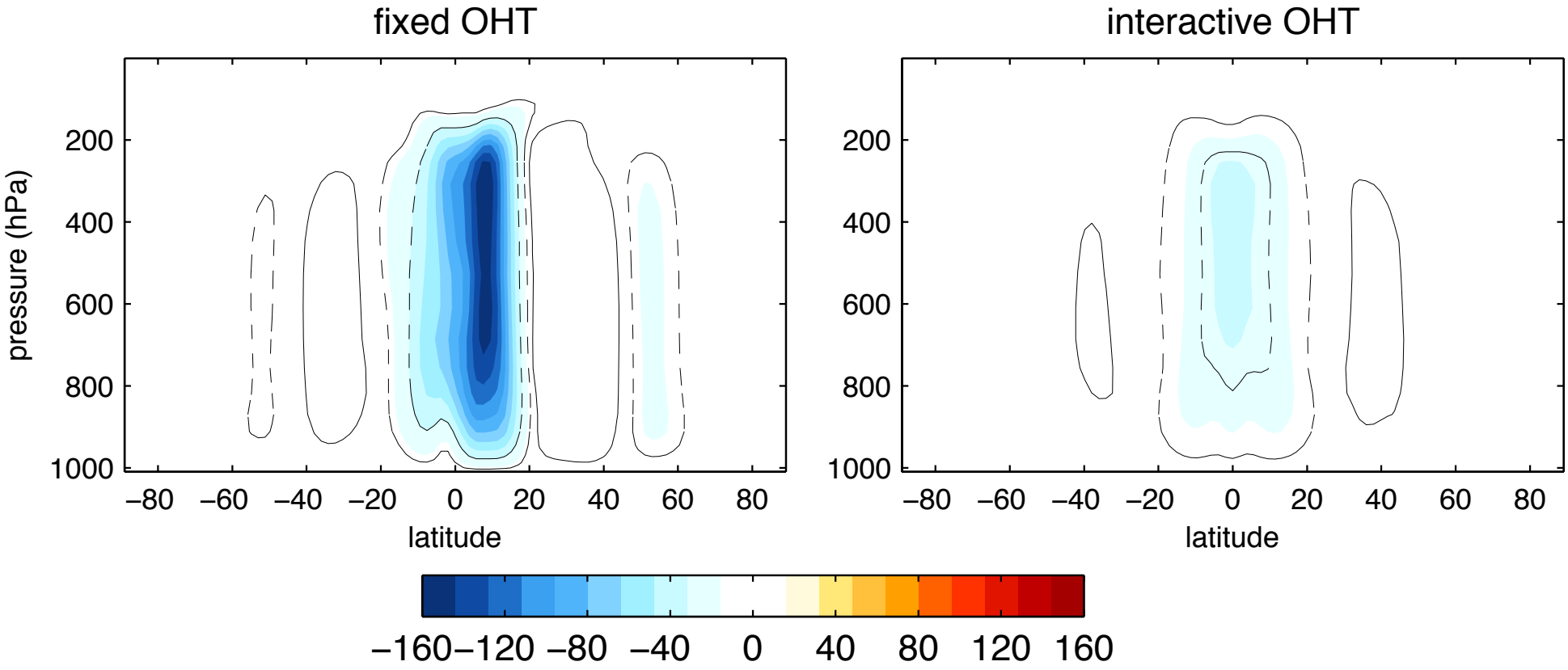
Fixed OHT

Inter. OHT



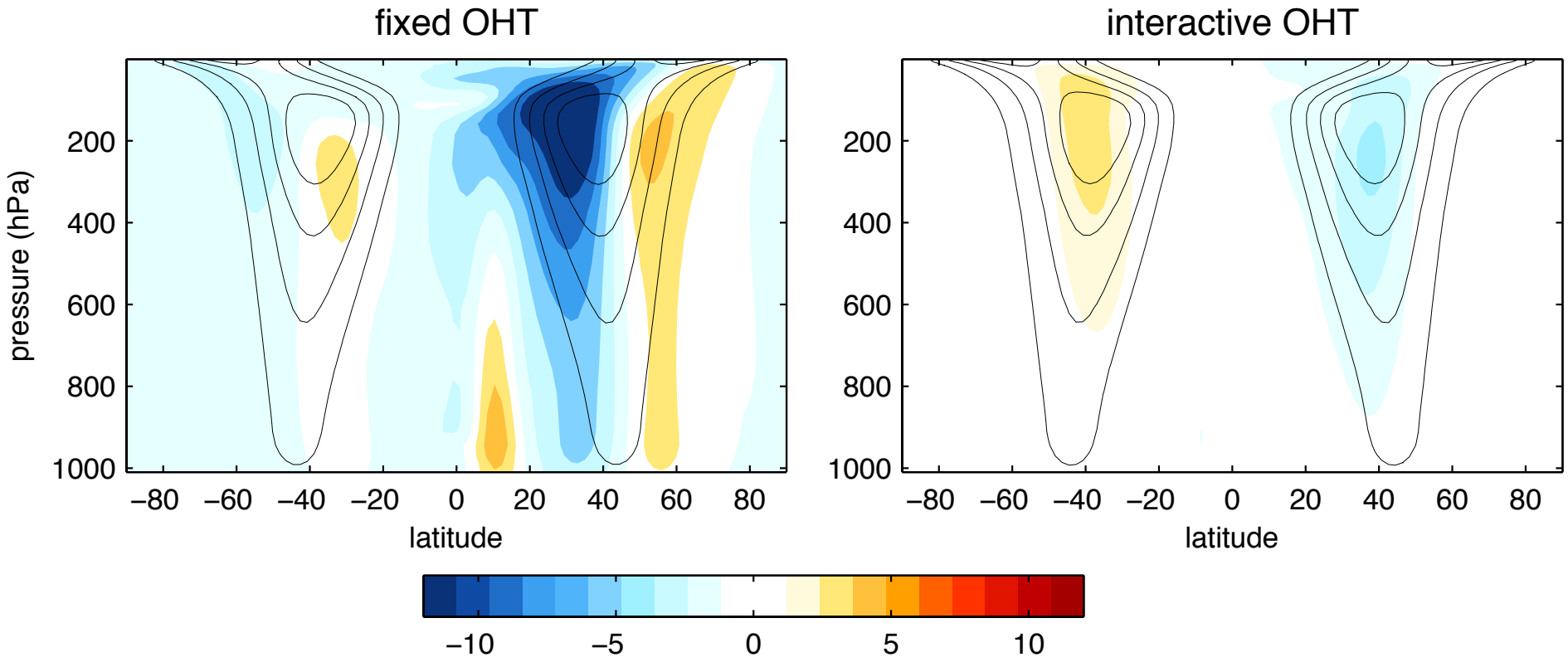
- In the tropics, large compensation by ocean (Ekman cells)
- Weaker atmospheric transport
- More symmetric structure

Response of Hadley cells (mean meridional streamfunction)



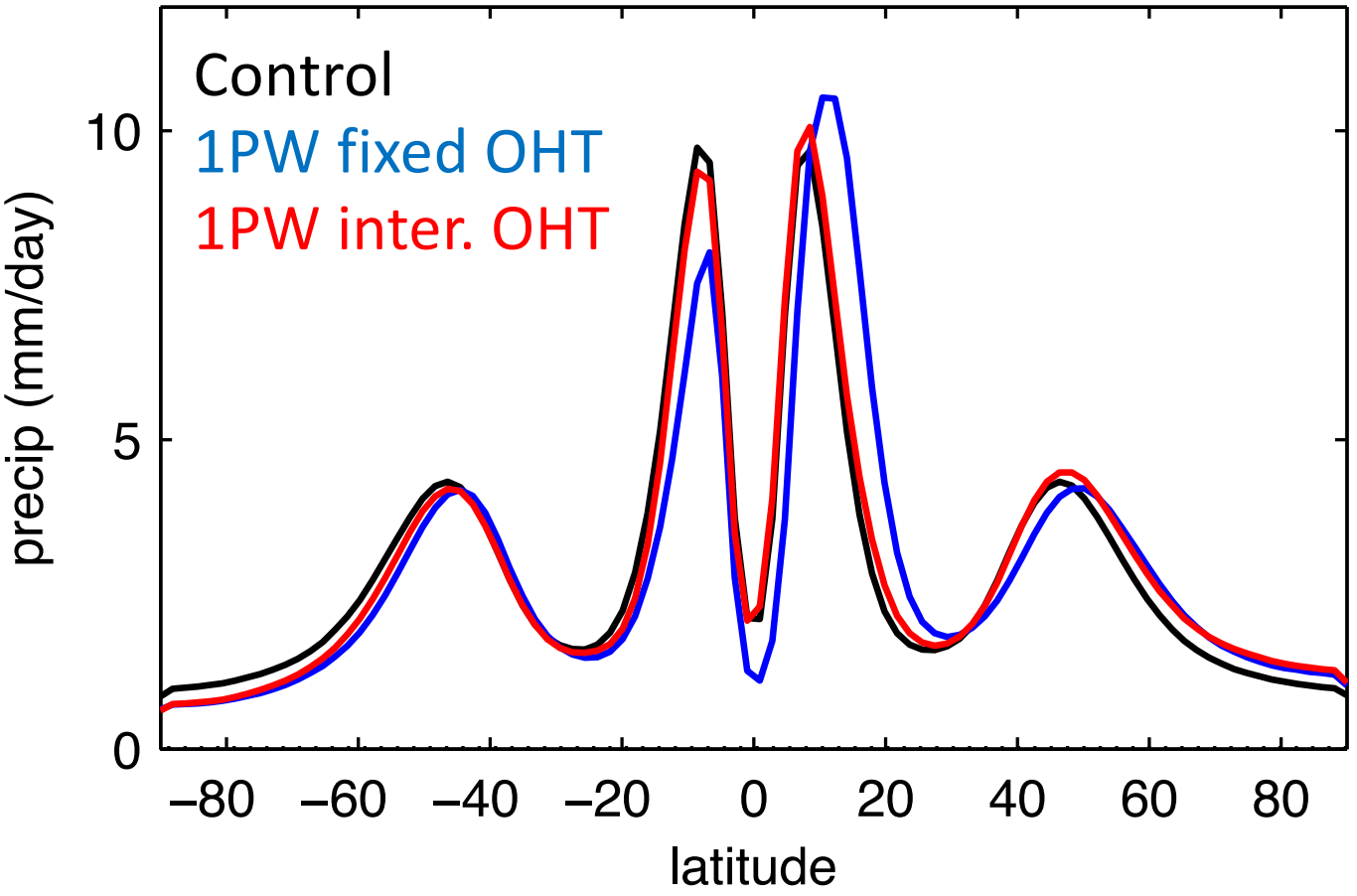
Response of zonal winds

(m/s) colors = differences, contours = control run



- Weak Hadley cell-related changes
- Northern hemisphere : jet weakening northward shift
- Southern jet strengthening & northward shift

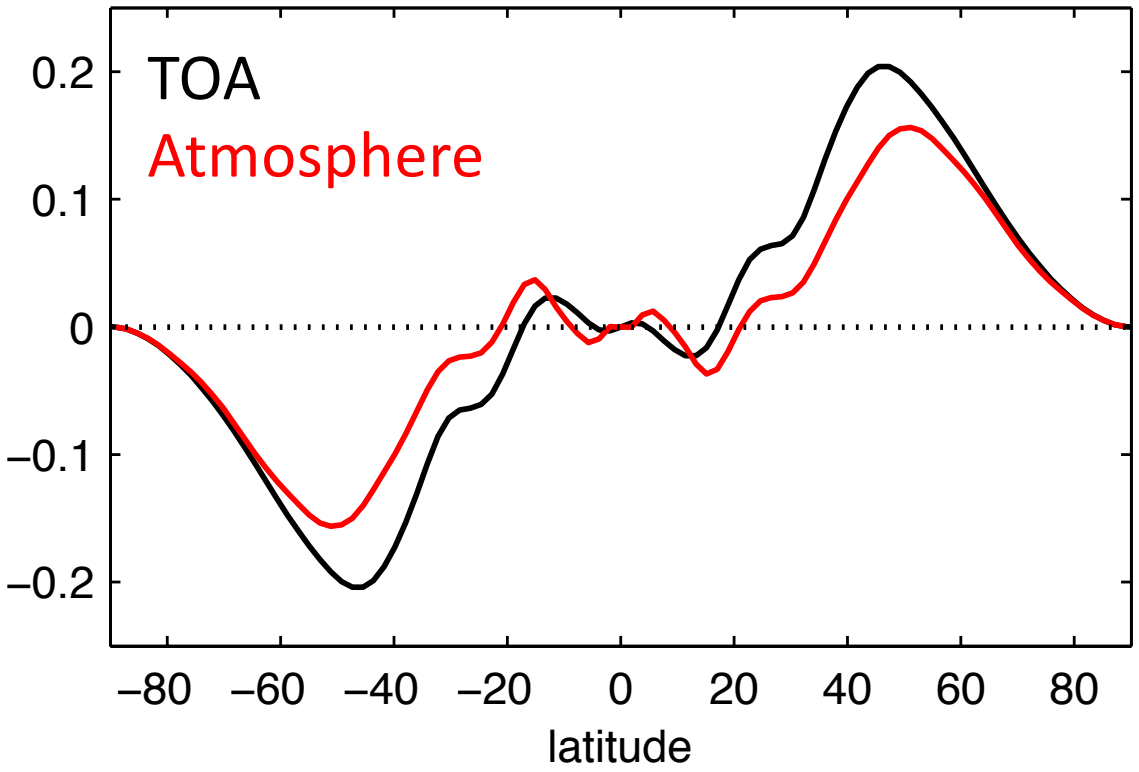
Precipitation response



- Fixed OHT : more precip in warmer hemisphere + shift of the peak.
- Interactive ocean : very small changes

Response to CO_2 doubling, fixed ocean transport

Change in northward energy transport (PW)

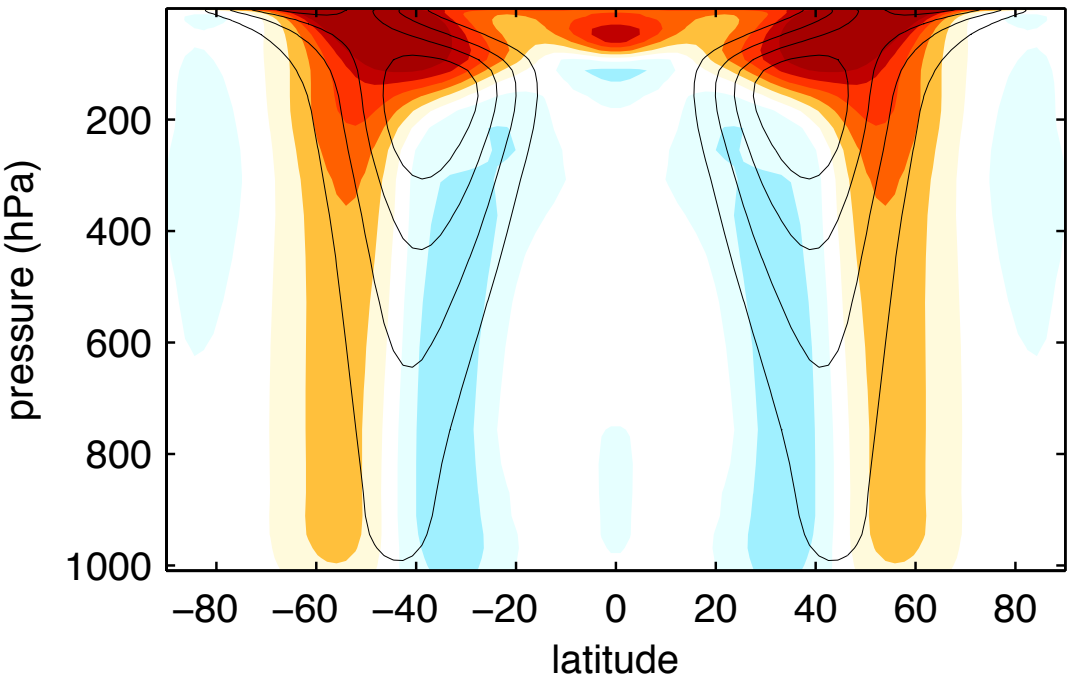


- Small changes overall (0.2 / 6 PW)
- *Very* small changes in the Tropics

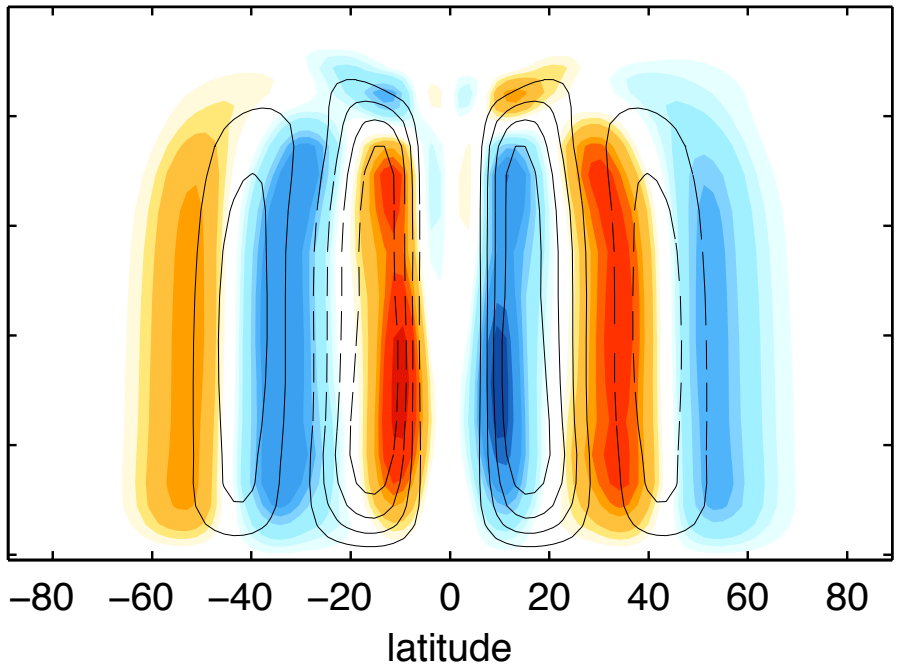
Circulation response, fixed ocean transport

Control (contours), response to CO_2 (colors)

Zonal wind

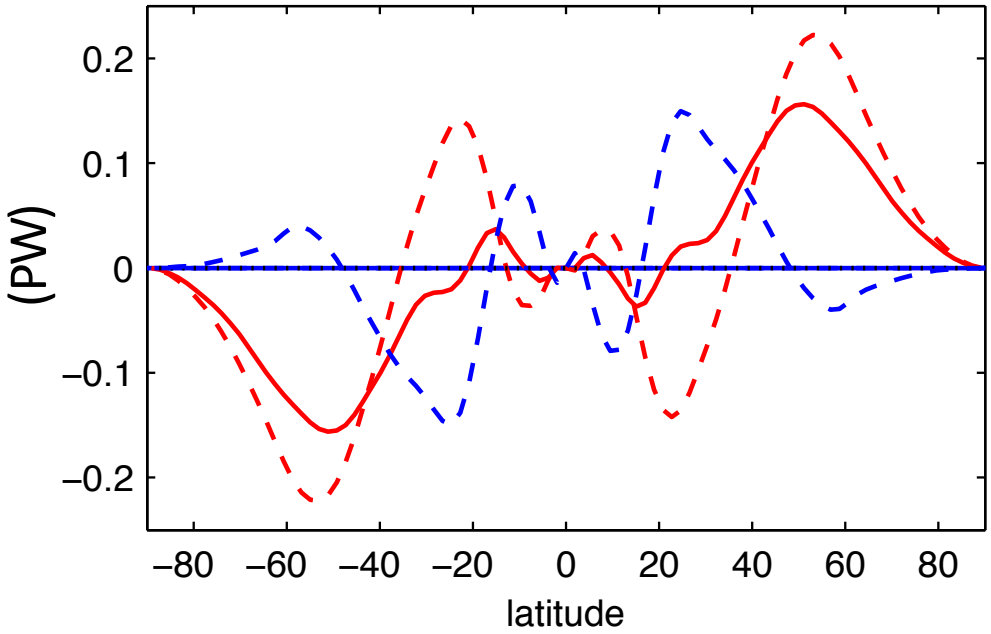


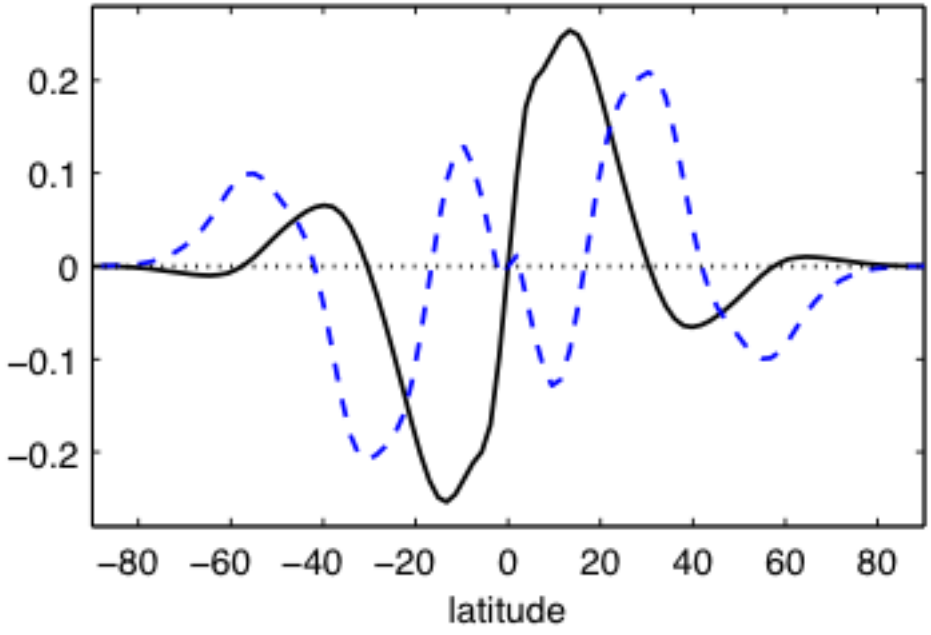
Meridional streamfuction



- Upward and poleward expansion / jet shift
- Hadley cell weakening (tropics)

Response to CO_2 doubling : energy transport





Atmosphere, fixed OHT

Atmosphere, inter. OHT

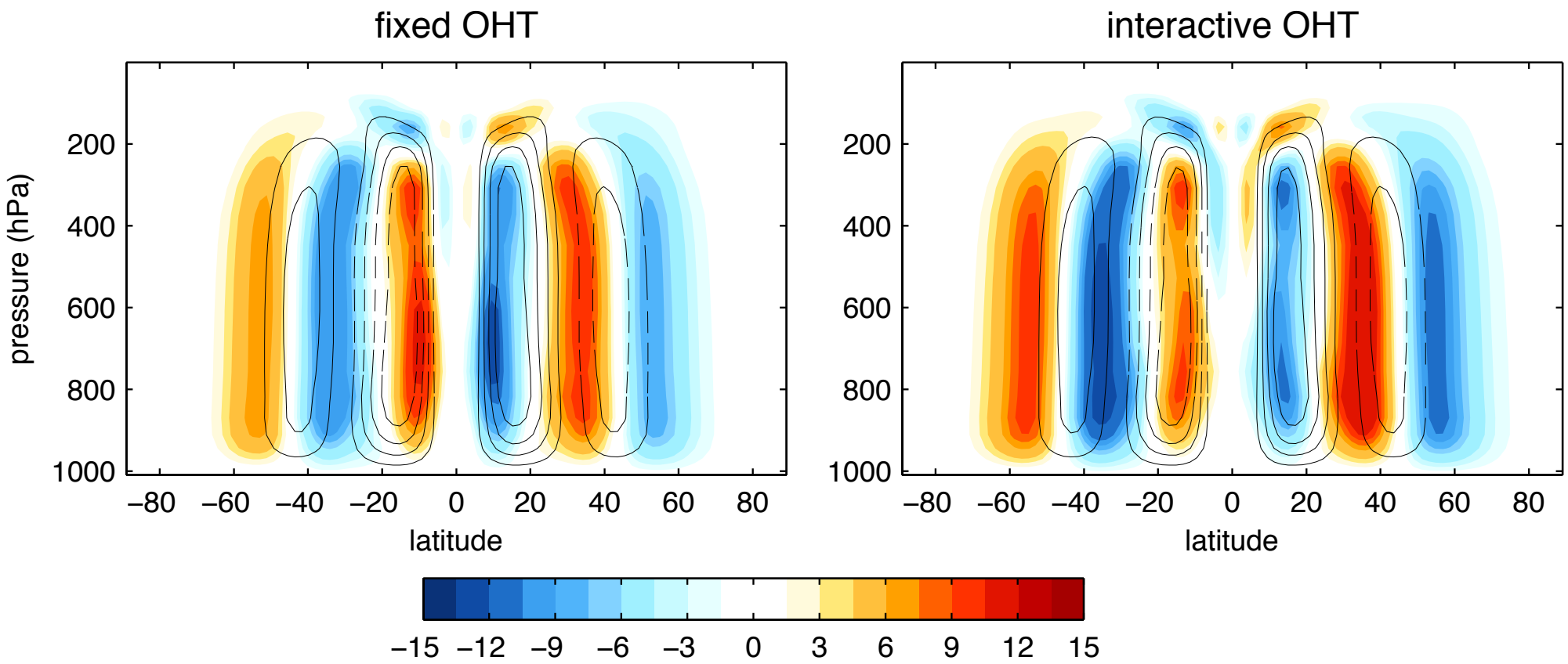
Ocean

Ekman, control / 10

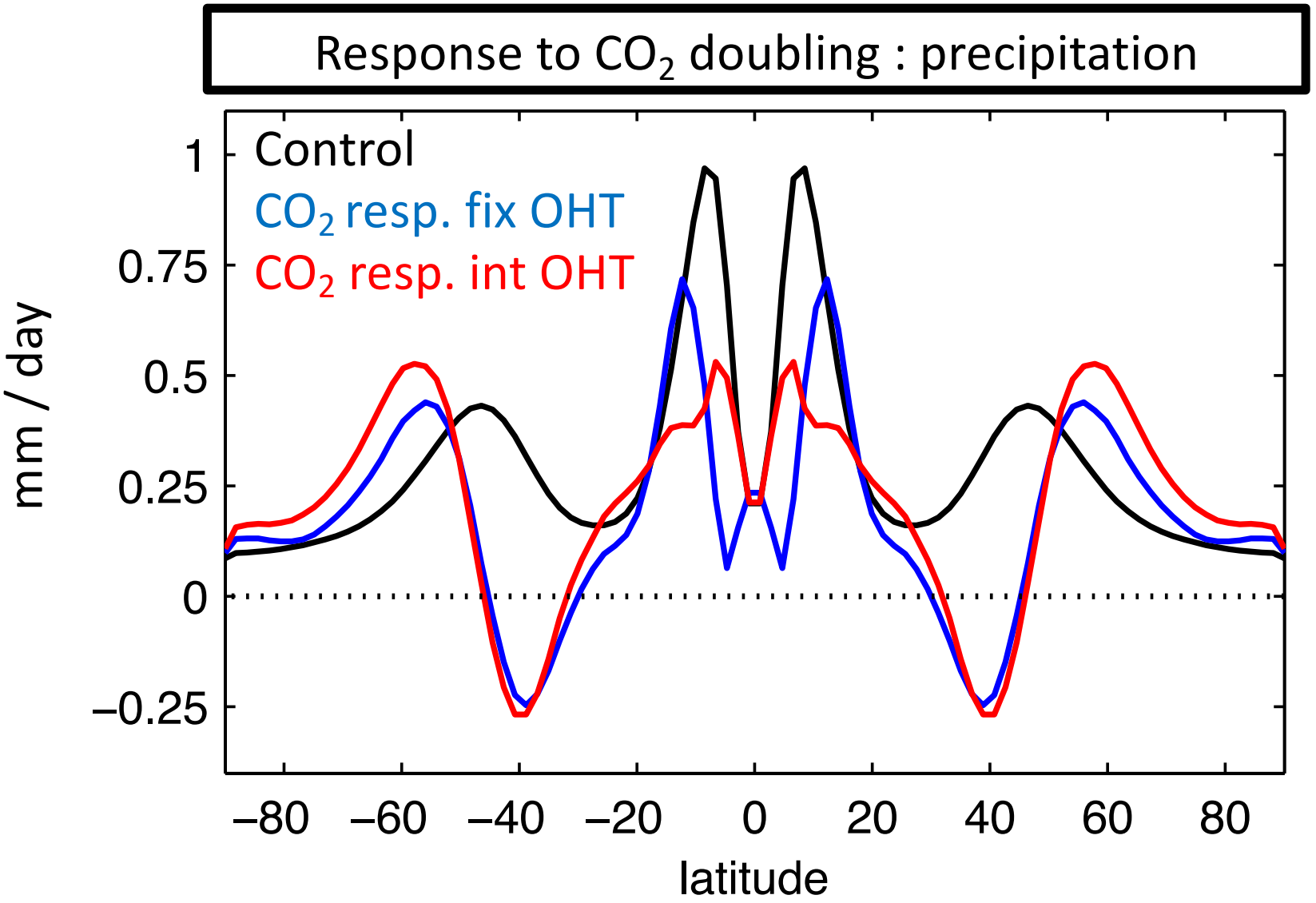
Ekman, response to CO_2

- Tropics : opposite changes in atmosphere and ocean
- Weaker Hadley cell : less poleward ocean transport
- Poleward expansion : more poleward ocean transport

Response to CO_2 doubling : meridional streamfunction



- Interactive ocean :
- Less weakening near equator, more in subtropics
- Stronger poleward shift



- Precipitation increase in warmer climate
- ITCZ moves poleward / equatorward with fixed / interactive ocean

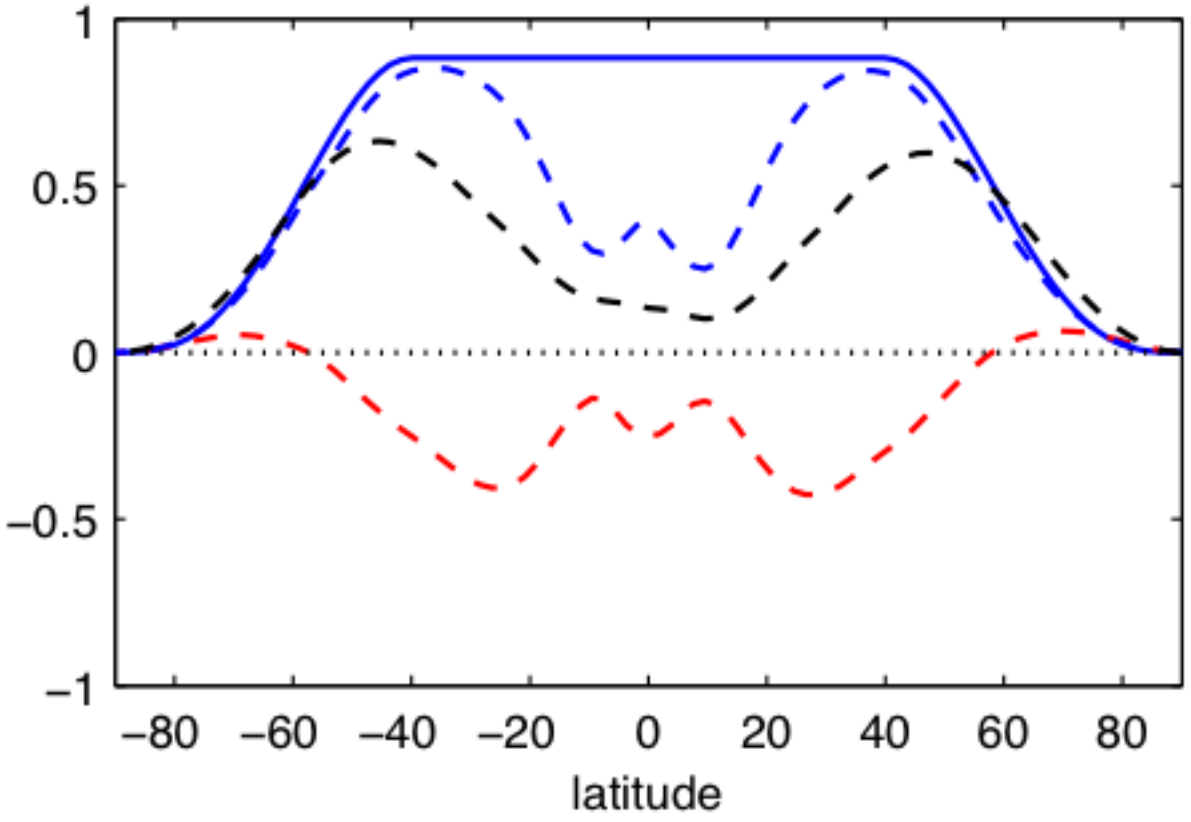
Summary - Conclusion

Adding Ekman heat transport significantly modifies the response (circulation, ITCZ) to changes in energy budget

- Inter-hemispheric transport : weaker Hadley cell & ITCZ response (compensation by ocean energy transport)

- CO_2 increase : total transport does not change (much), but compensating changes in atmosphere and ocean, due to Hadley cell weakening & poleward expansion.

- Perturbations in the meridional energy transport = coupled problem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−60
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40
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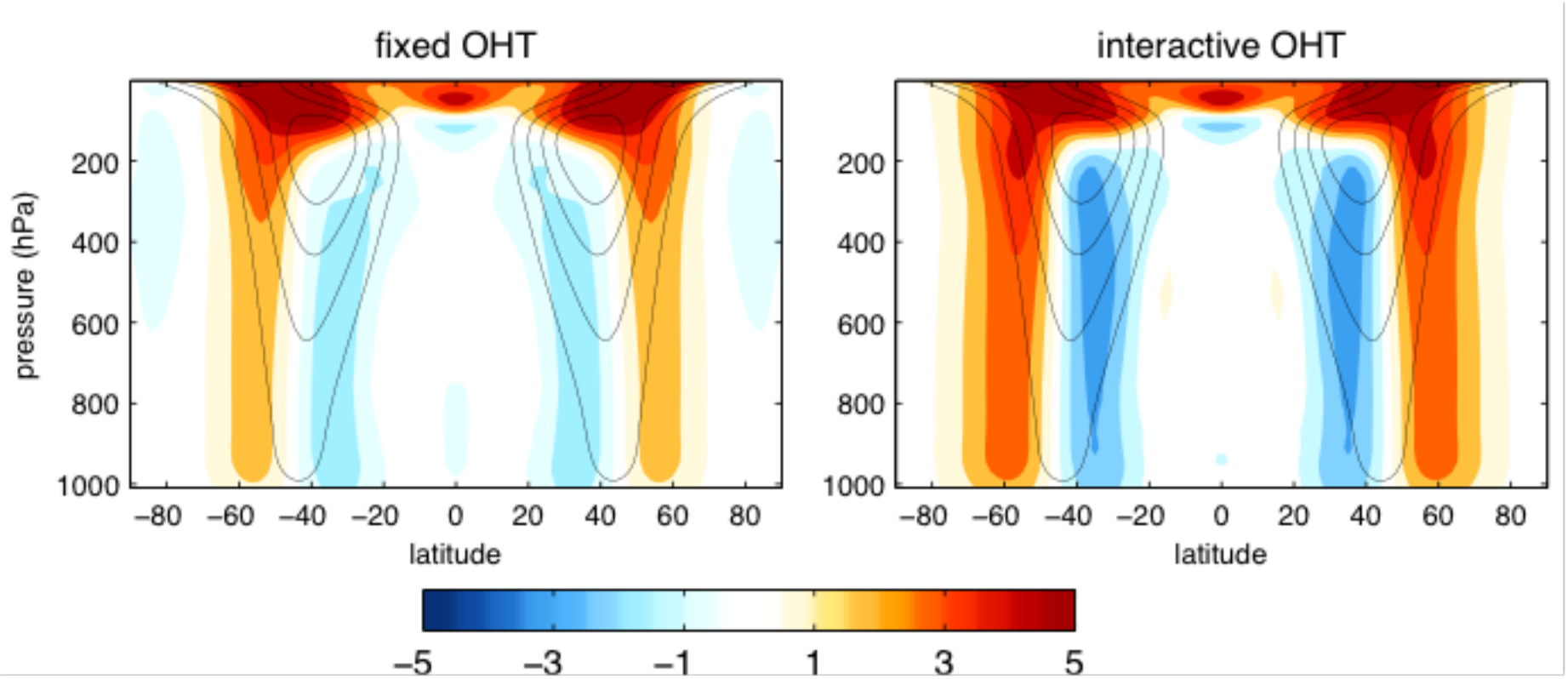
latitude


fixed OHT
interactive OHT
pressure (hPa)
200
400
600
800
1000
−80 −60 −40 −20 0 20 40 60 80
latitude
−5 −3 −1 1 3 5