Climate response to changes in the meridional energy transport : role of ocean dynamics

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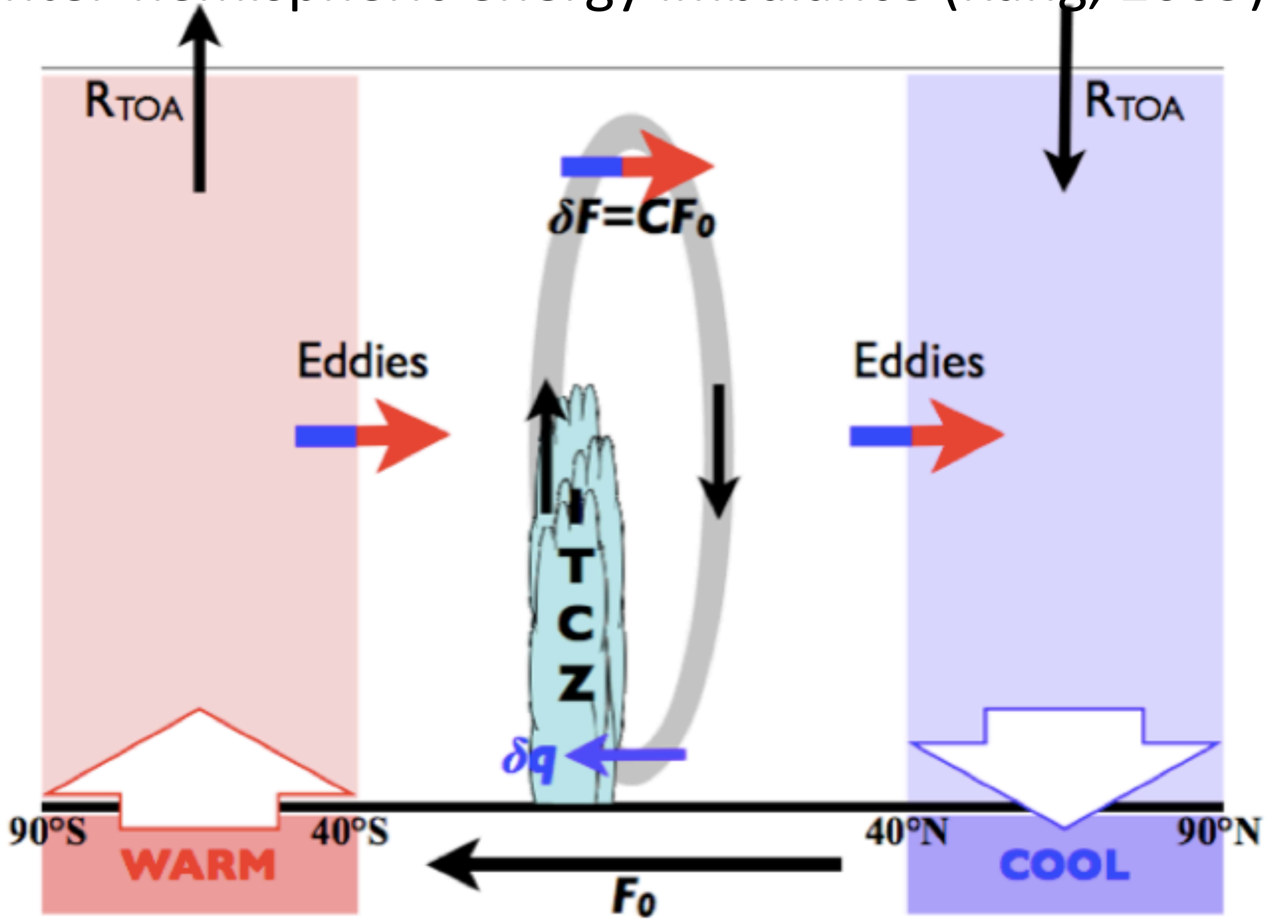
Introduction

Response of atmospheric circulation and ITCZ to inter-hemispheric energy imbalance (Kang, 2009)



Kang (2008,09), Frierson (2012,13), L'Héveder (2015), Donohue (2013,14), TRACMIP project…

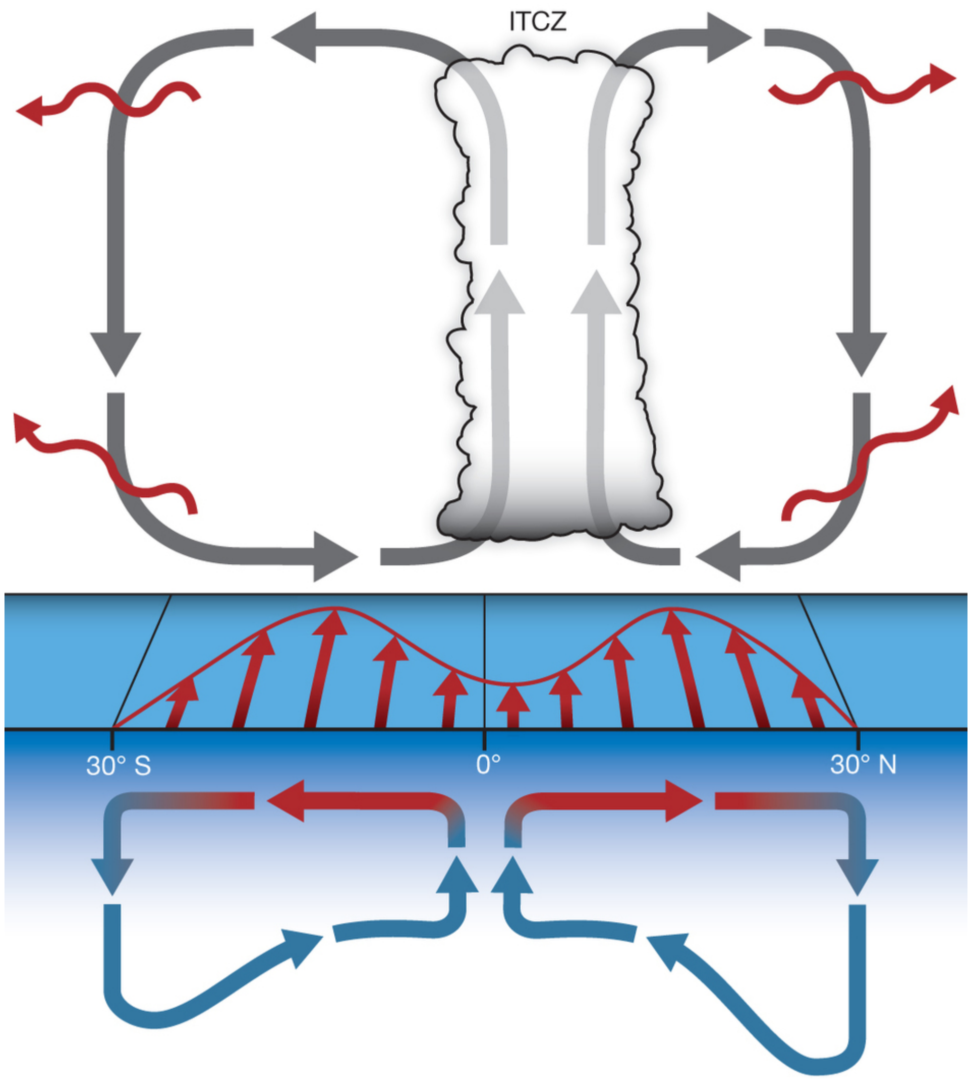
All these studies use a « slab » ocean... $\rho C H \frac{\partial T}{\partial t} = F_{\text{surf}} + Q$

But energy transports by atmosphere and ocean are not independent

Tropics:

Shallow circulation cells

- Driven by trade winds / Ekman transport
- Mass transport = Hadley cells
- Transport energy poleward



(Schneider et al, 2014)

Ekman heat transport for slab ocean

(Codron 2012, Clim. Dyn)

Momentum balance, surface mixed layer:

$$\begin{cases} \varepsilon u - f v = & -1/\rho\,\partial_x P + \partial_z(\overline{u'w'}) \\ \varepsilon v + f u = & -1/\rho\,\partial_y P + \partial_z(\overline{v'w'}) \end{cases}$$

Vertical integration (ignoring pressure gradient)

$$\begin{cases} \varepsilon M_x - f M_y = & \tau_x \\ \varepsilon M_y + f M_x = & \tau_y \end{cases}$$

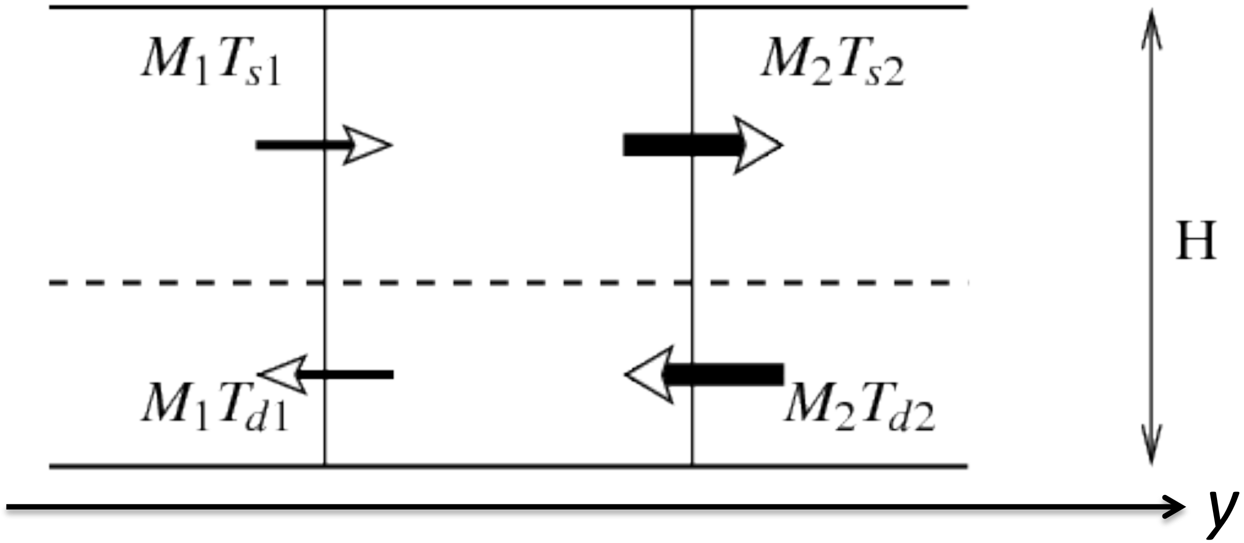
Wind-driven horizontal mass fluxes:

$$\begin{cases} M_x = & (\varepsilon \tau_x + f \tau_y)/(\varepsilon^2 + f^2) \\ M_y = & (\varepsilon \tau_y - f \tau_x)/(\varepsilon^2 + f^2) \end{cases}$$

($\varepsilon << f$ except near the equator)

1.5-Layer scheme

Slab temperature $T_{s,}$ return flow at T_d

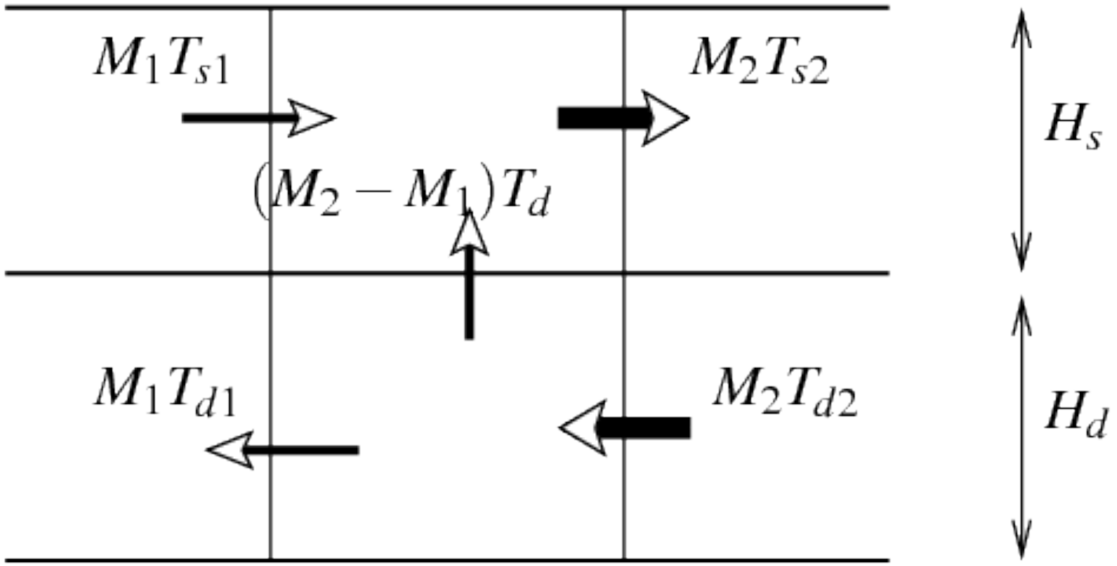


Deep temperature: $T_d = \alpha T_s + (1-\alpha) T_0$

$$\rho H S \frac{\partial T_s}{\partial t} = M_1 (T_{s1} - T_{d1}) - M_2 (T_{s2} - T_{d2})$$

2-layer scheme

2 slab layers, prognostic temperatures T_s and T_d

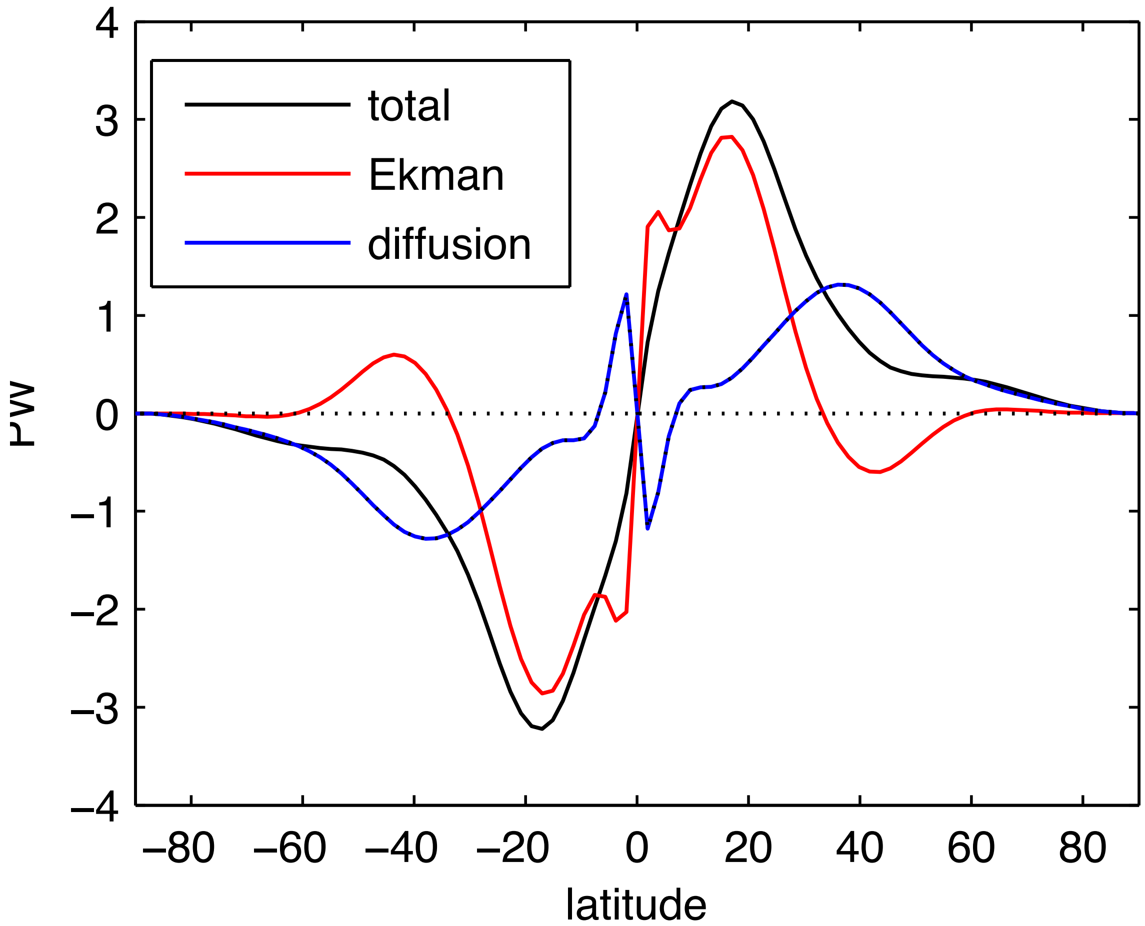


- Surface heat fluxes go in the surface layer
- Convective adjustment

Implementation

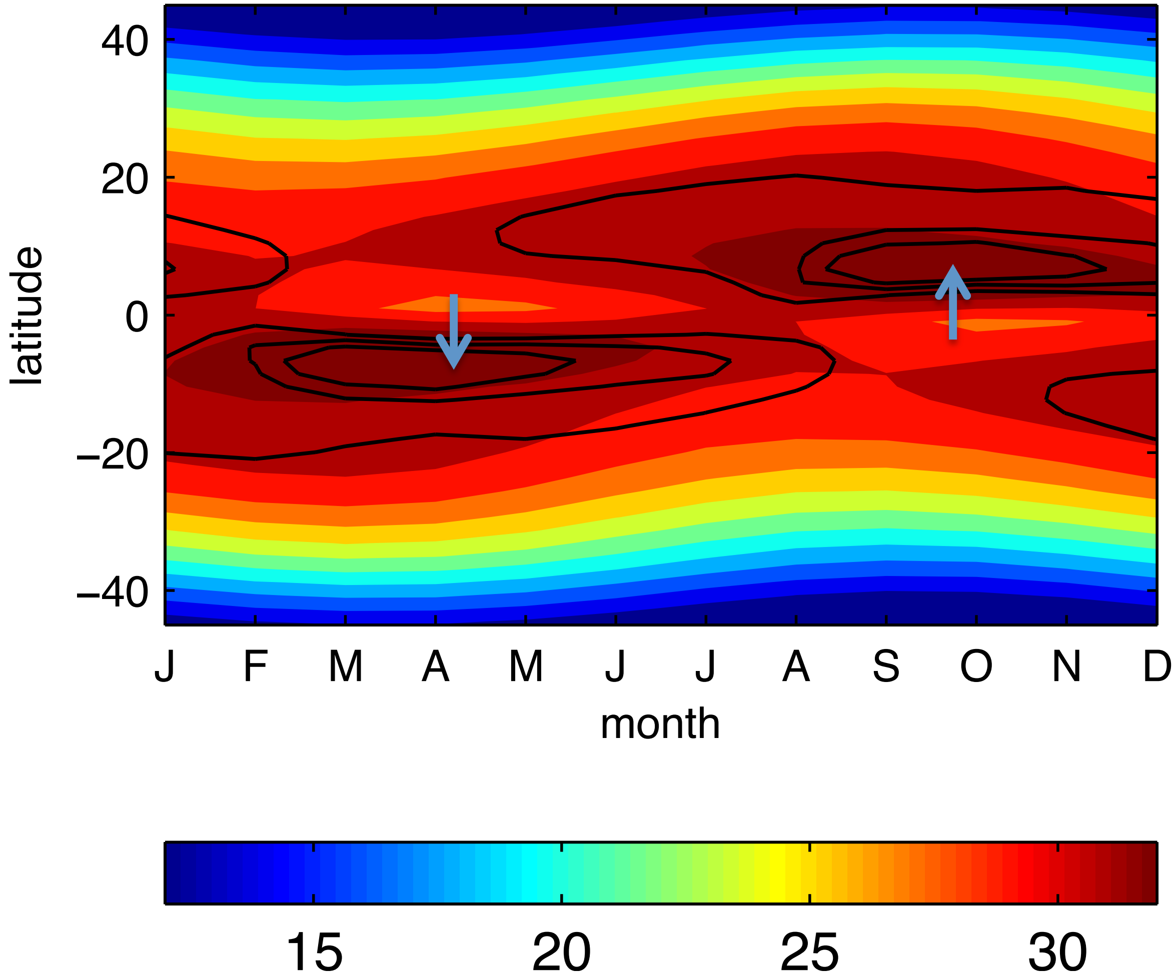
- LMDZ AGCM, 96x96 grid points, 39 levels
- Ocean-planet geometry, no sea ice
- Obliquity (seasons), no eccentricity
- Ekman transport and horizontal diffusion (constant *K*)
- No additional heat flux (Q-flux = 0)

Mean northward energy transport by the ocean



- Ekman : poleward transport in the Tropics, weaker equatorward in mid-latitudes
- Diffusion where large Temperature gradients

Annual cycle : SST and precipitation



Strong SST / surface wind / ITCZ
meridional coupling near the equator

Sensitivity experiments:

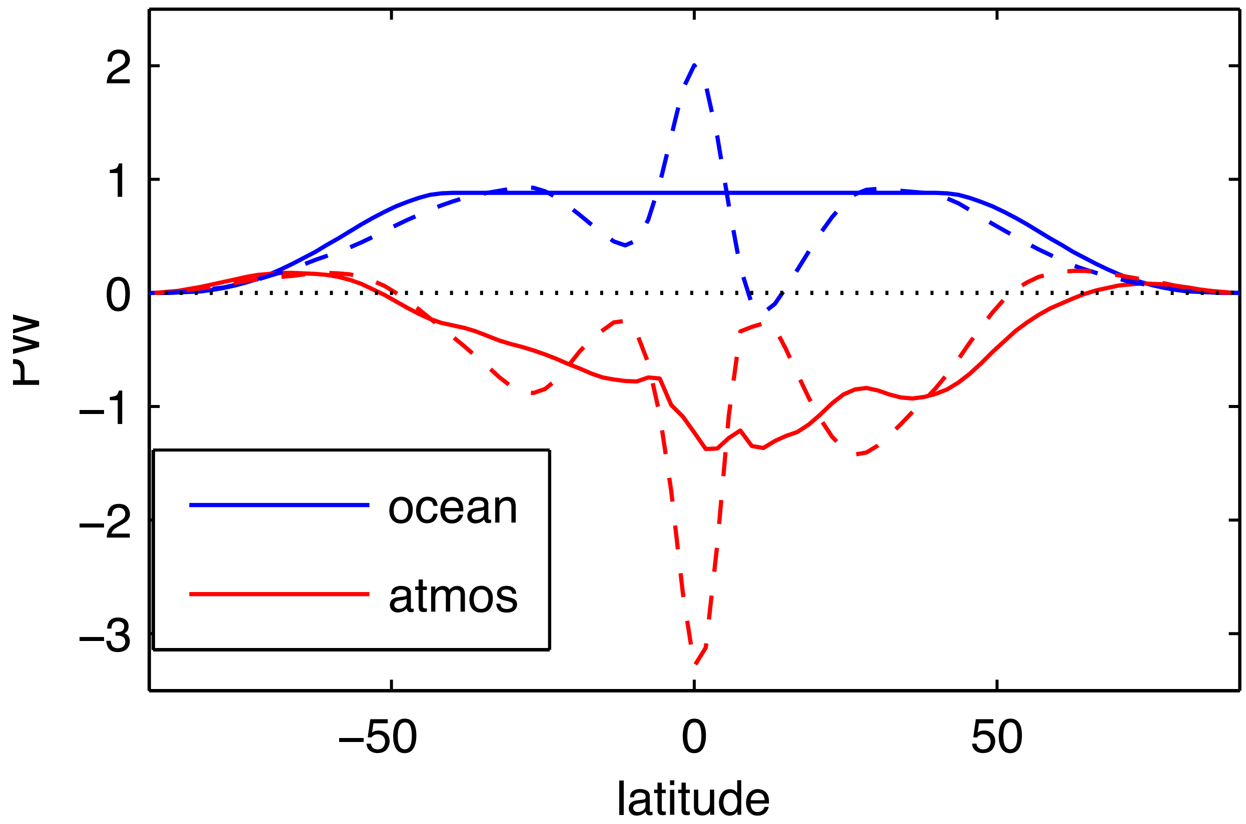
add 1 PW northward transport between 40°S and 40°S
(as additional prescribed Q-flux in the slab)

1. Interactive Ekman and diffusive transports

2. Ekman and diffusion prescribed as control seasonal cycle

Difference of northward energy transport by Ocean and Atmosphere

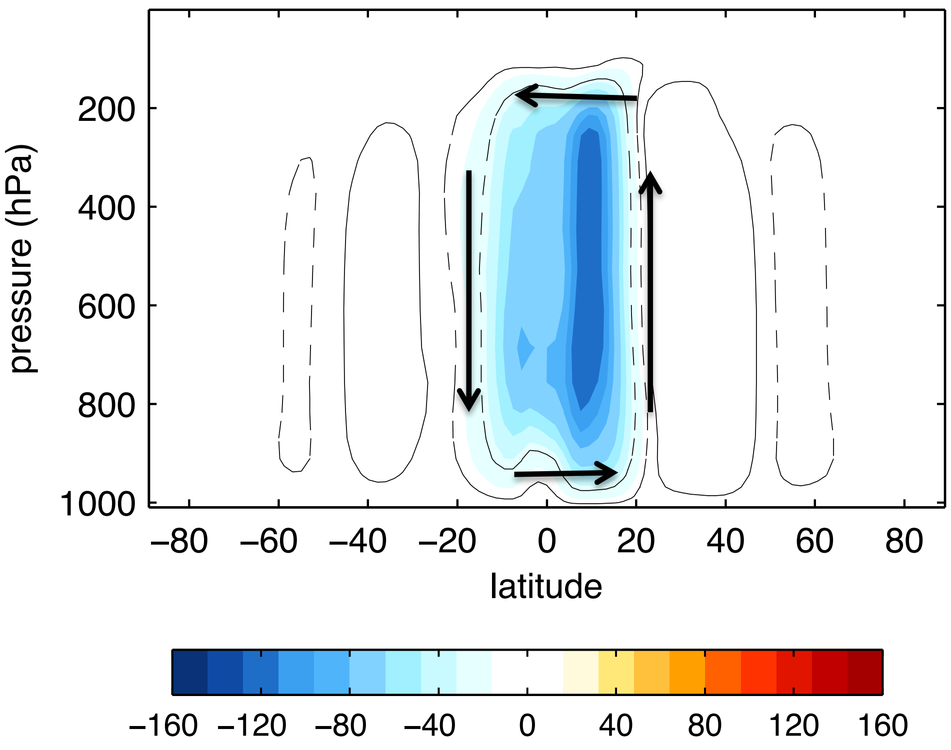
- Fixed Ekman / diffusion (solid line)
- Interactive Ekman / diffusion (dashed line)



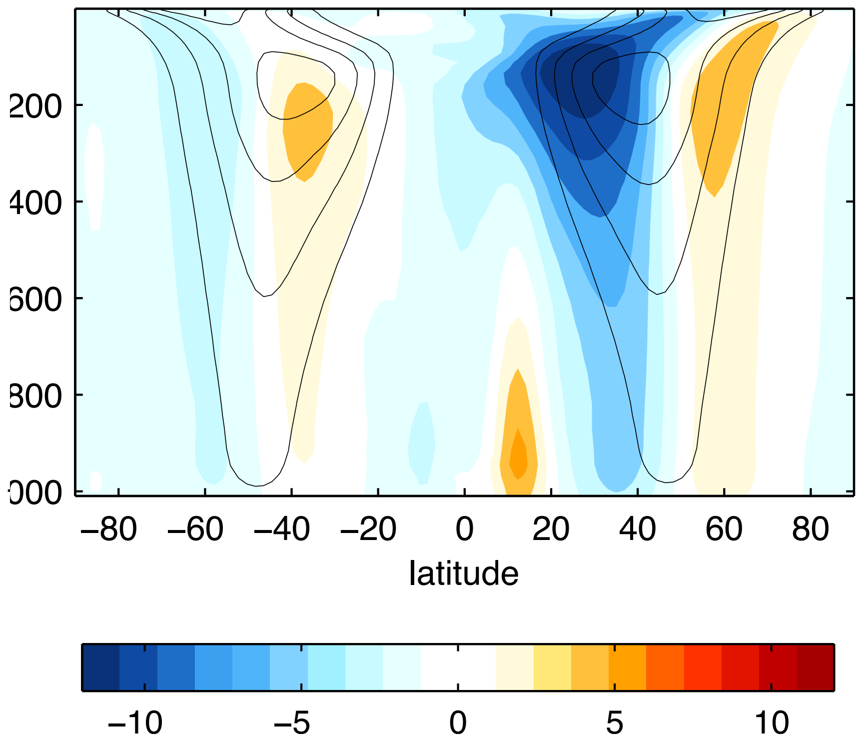
- ➢ Large differences between fixed / inter cases (esp. Tropics)
- ➢ Good compensation between ocean and atmosphere

Atmospheric circulation response, fixed OHT case

Meridional Streamfunction (10^9 kg/s)

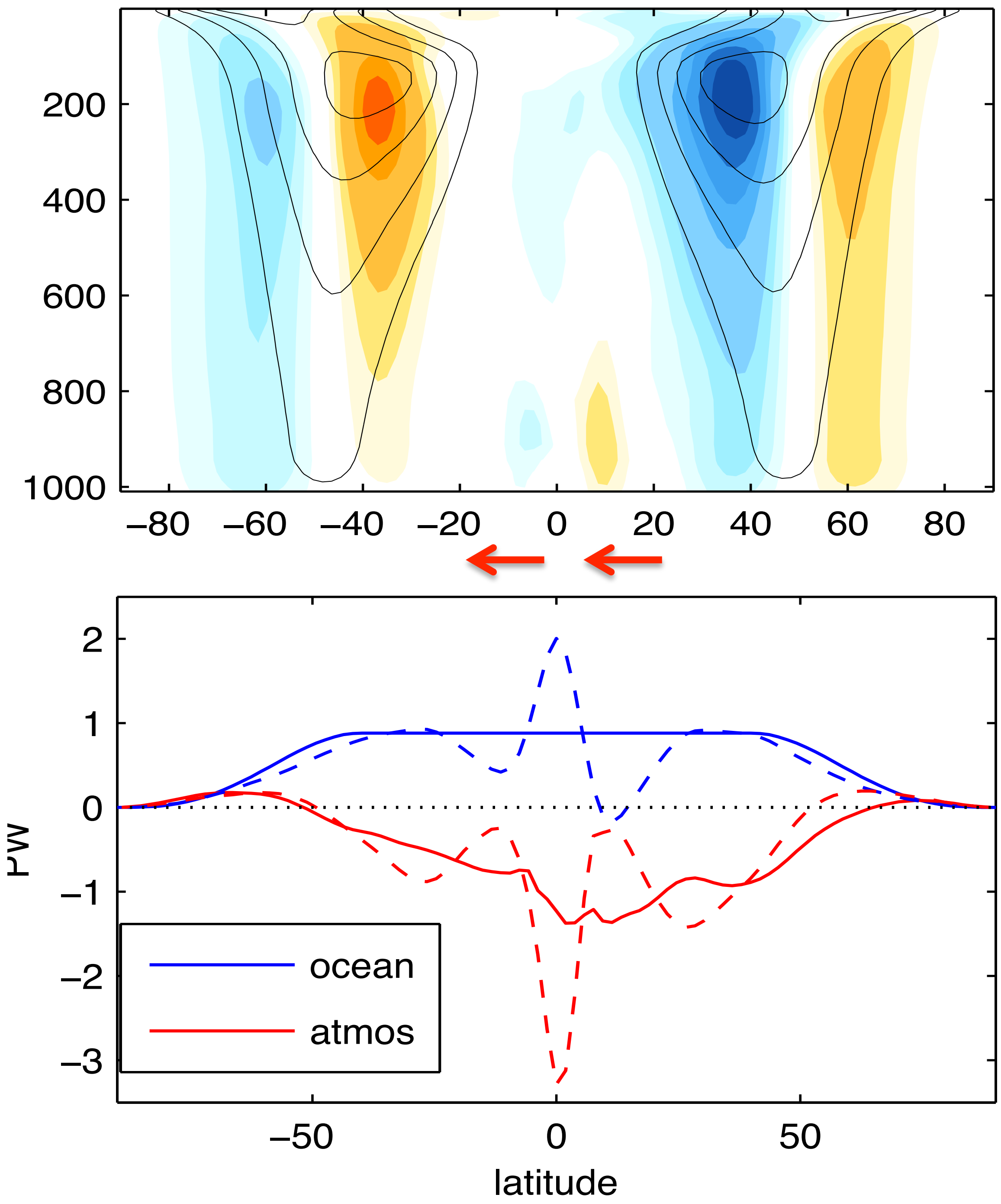


Zonal wind



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

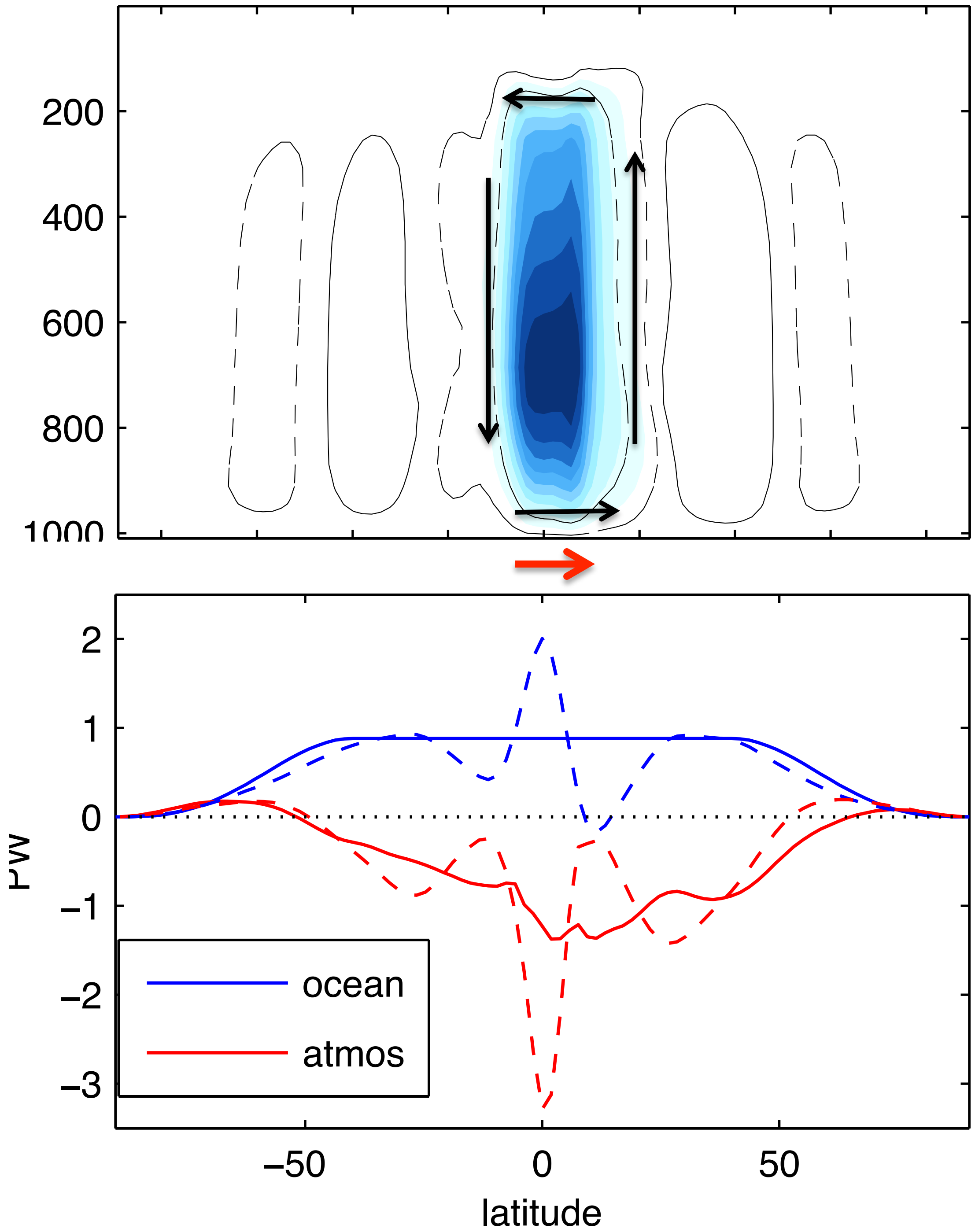
Ocean heat transport: Tropics (off-equator)



Trade wind changes drive southward transport

- ➢ Strong compensation

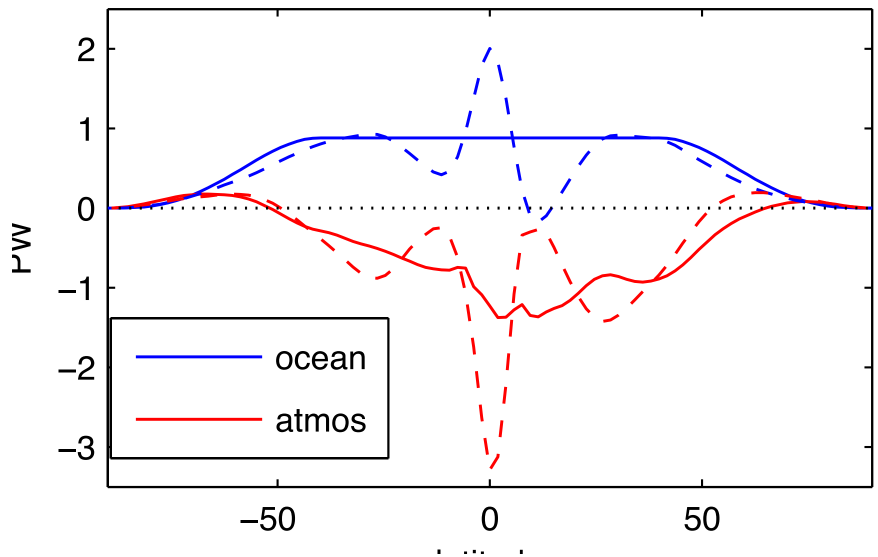
Ocean heat transport: Equator

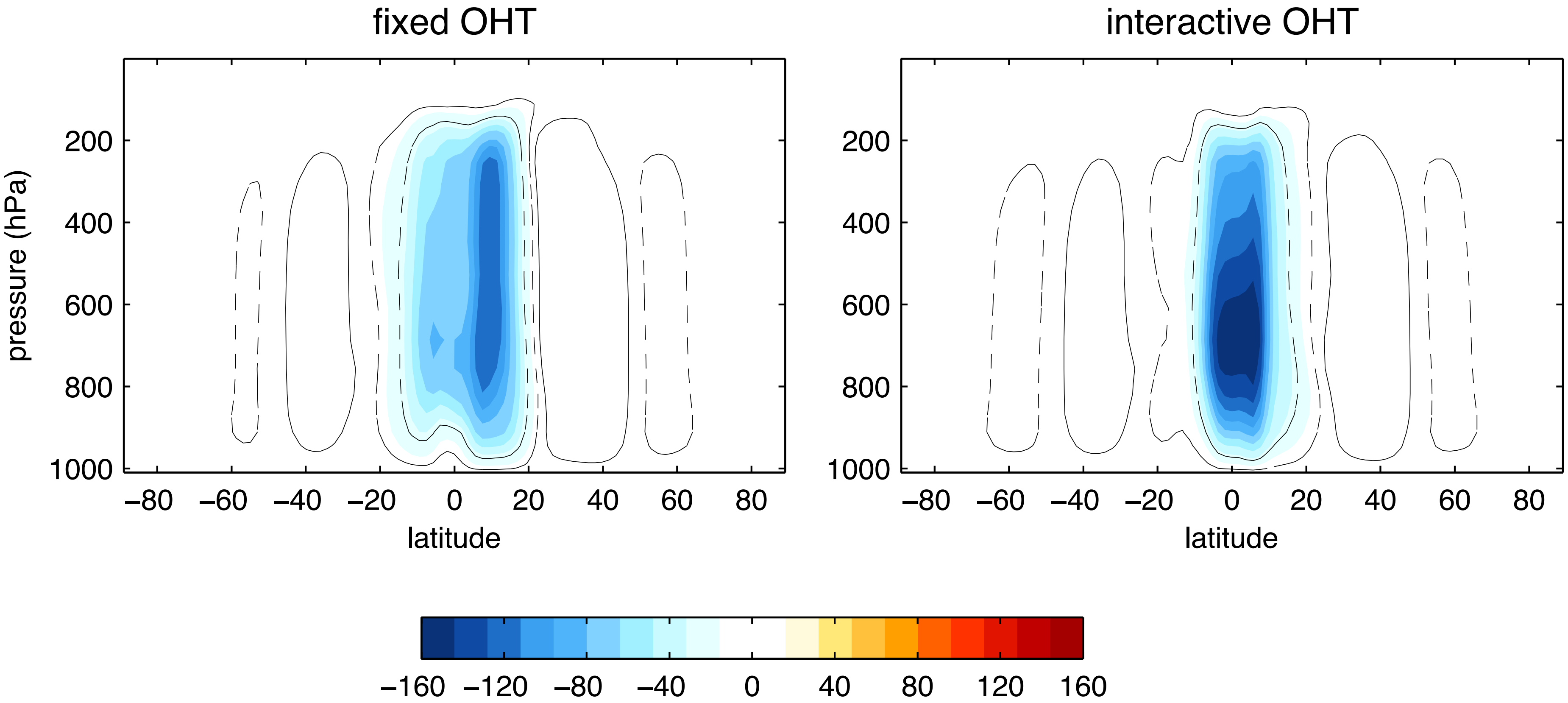


Cross-equatorial cell:
Northward transport
➢ Positive feedback

Hadley cell response with interactive OHT:

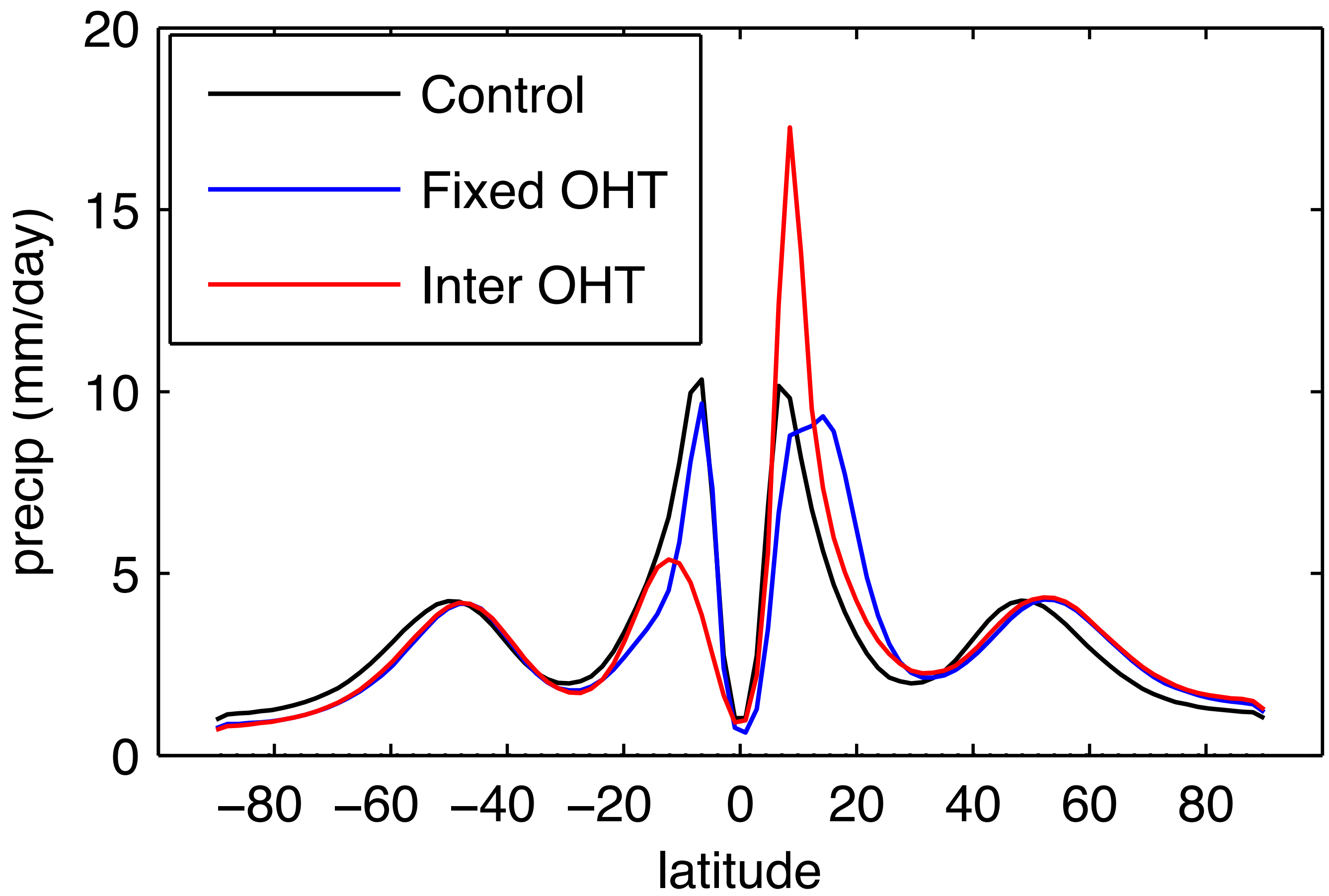
- Confined to equator
- More intense





Precipitation response:

- Median shifts to 7.5° in both cases..
- But very different structures
- Storm tracks shift northward

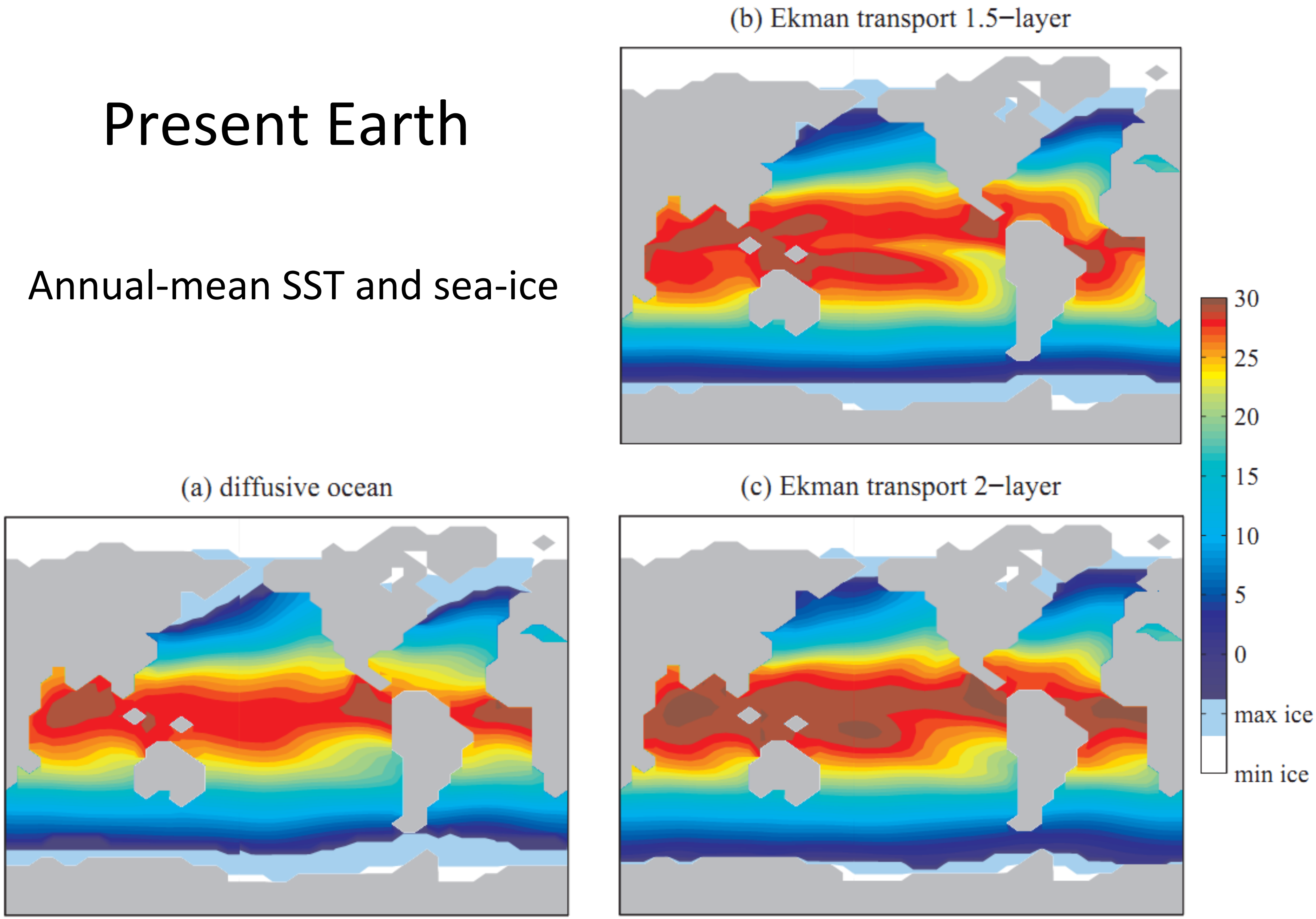


Summary - Conclusion

- Adding Ekman heat transport significantly changes the response to a prescribed energy imbalance
- Atmospheric circulation much weaker in the Tropics (except at the equator ?)
- Energy transports by the atmosphere and ocean : solution to a coupled problem ?

Present Earth

Annual-mean SST and sea-ice



Mean seasonal cycle:

Precipitation and northward energy transport by the atmosphere

Energy flux equator
In red