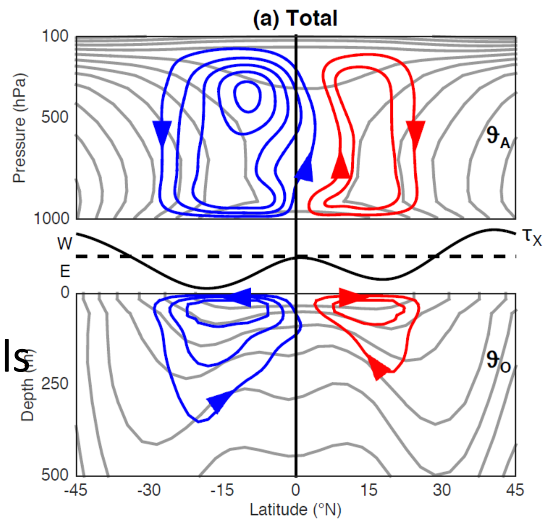
Coupling of ITCZ/Monsoons to ocean circulation

(John Marshall, MIT)

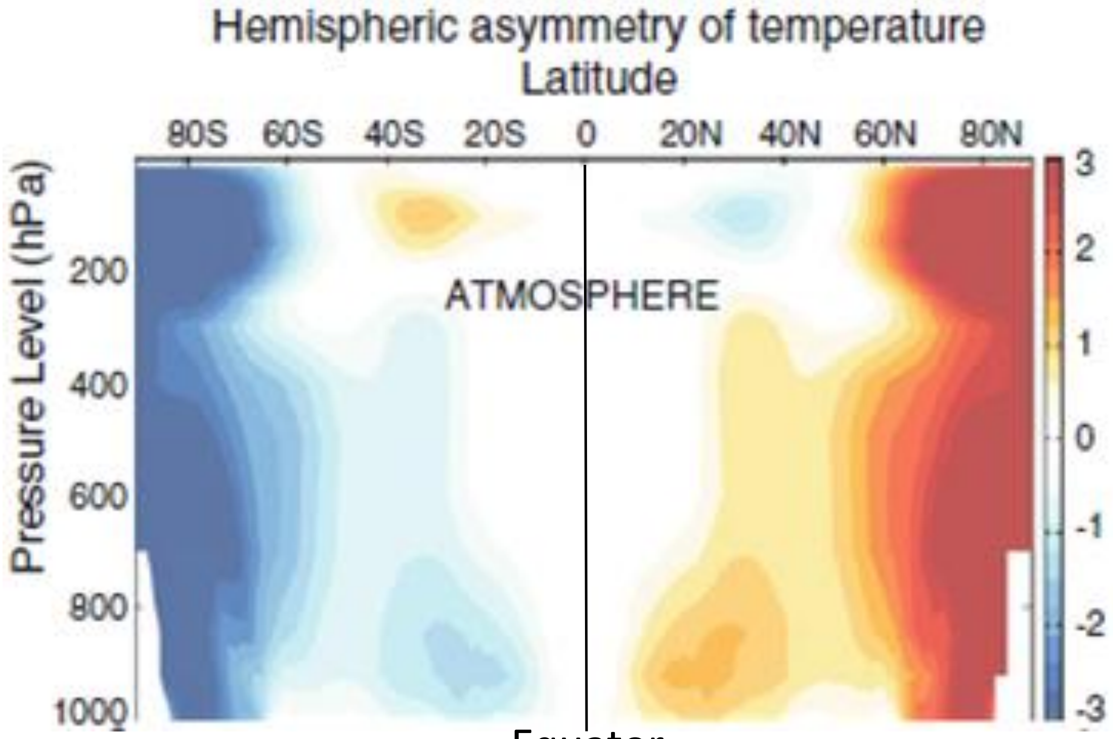
Hadley Cells



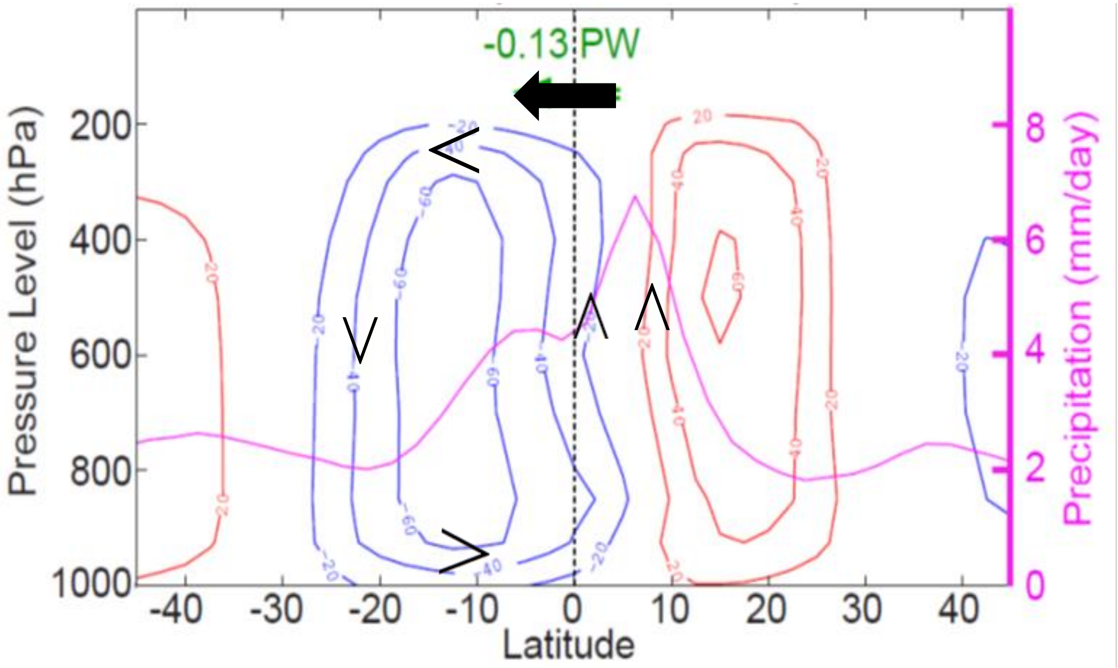
Subtropical Cells
STCs

1. Climatological position of the ITCZ is north of the equator because of cross-equatorial ocean heat transport.
2. ITCZ migrations are strongly damped by coupling of trade winds to ocean's subtropical cells. (Brian Green)
3. Explore Strong coupling of the Indian monsoon with ocean circulation. (Nick Lutzko)

ITCZ resides in the warm hemisphere



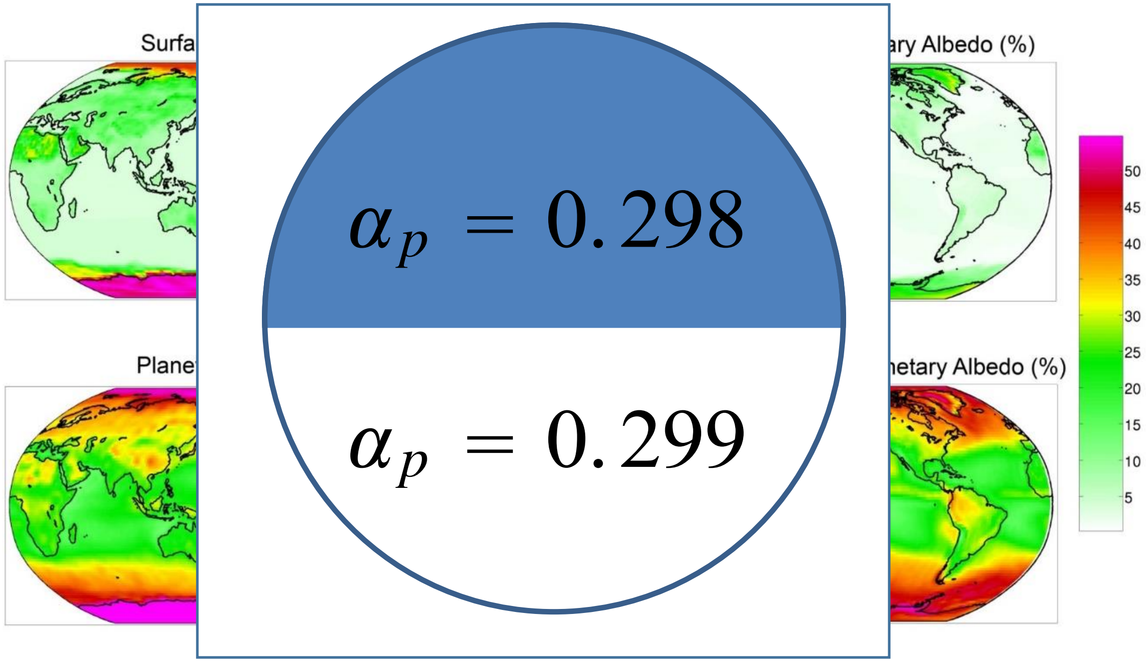
Kang et al, 2008



Obvious explanation for relative warmth of the Northern Hemisphere might be albedo differences.

However…..

Symmetry of Hemispheric planetary albedos



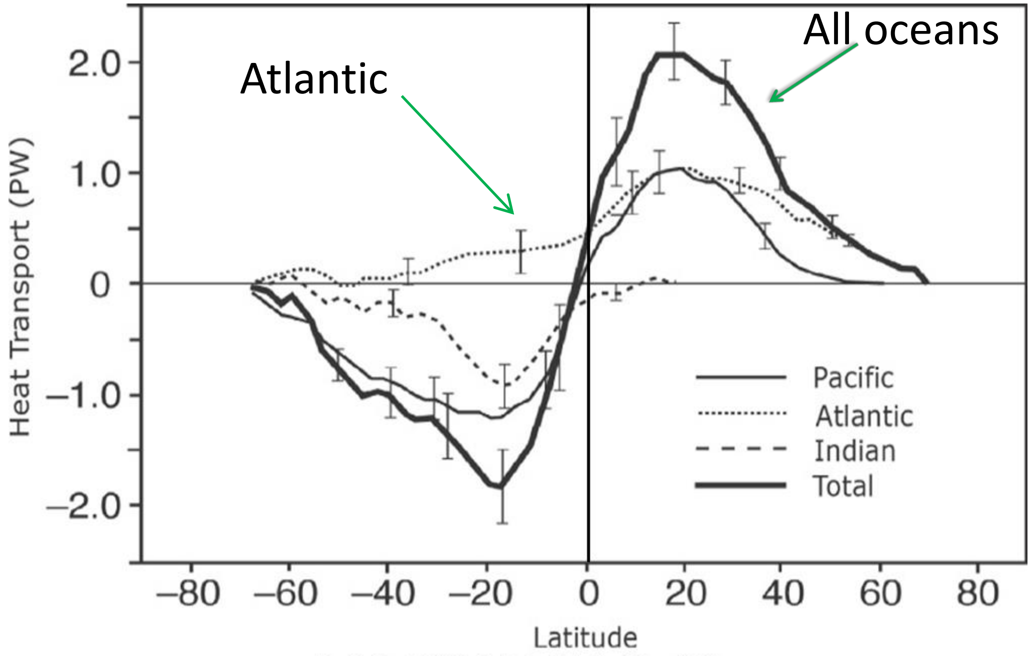
Donohoe and Battisti, 2011, J. Climate

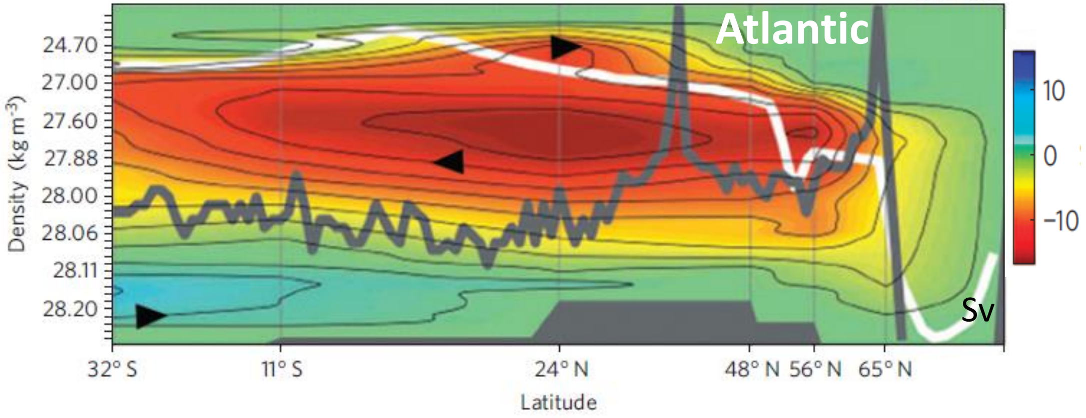
Voigt et al, 2013: J. Climate

Stevens et al, 2015, GRL

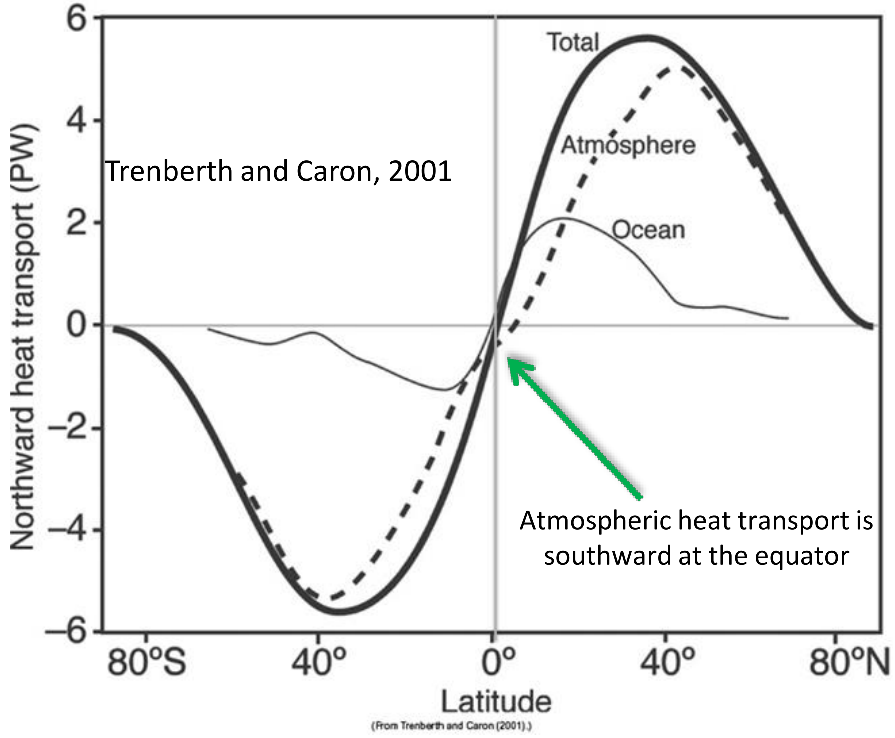
Note, a 0.01 difference in α_p implies a cross-equatorial heat transport of 0.2PW.

NH is warmer than the SH because of ocean circulation



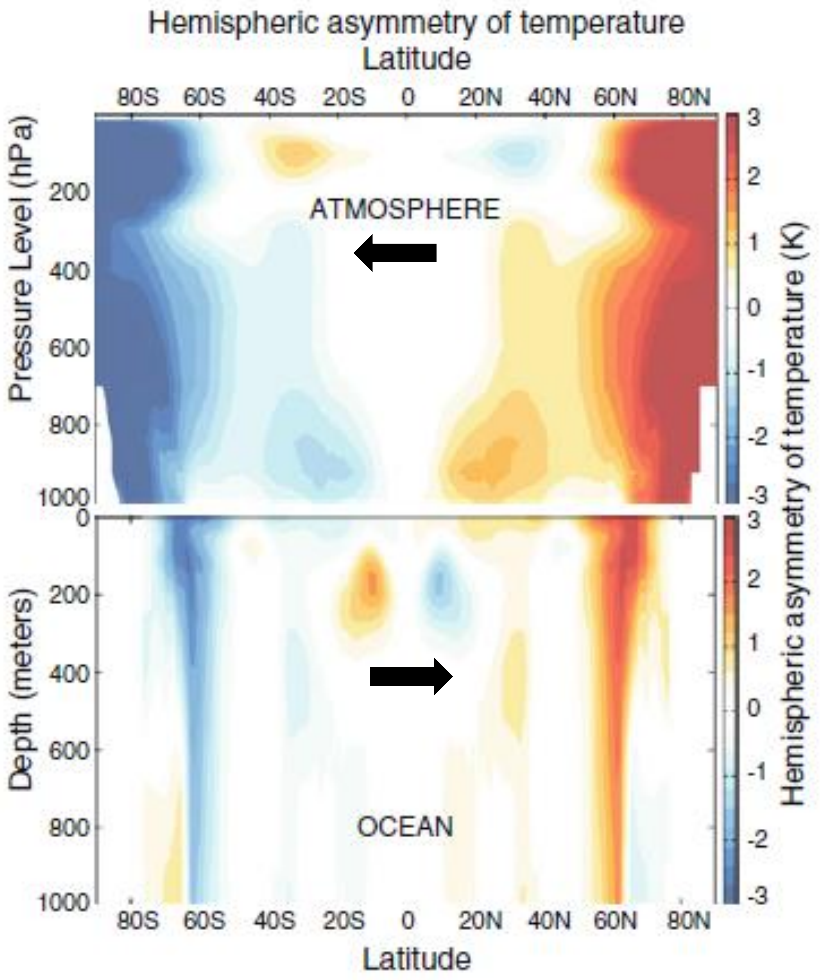


Lumpkin and Speer, 2007

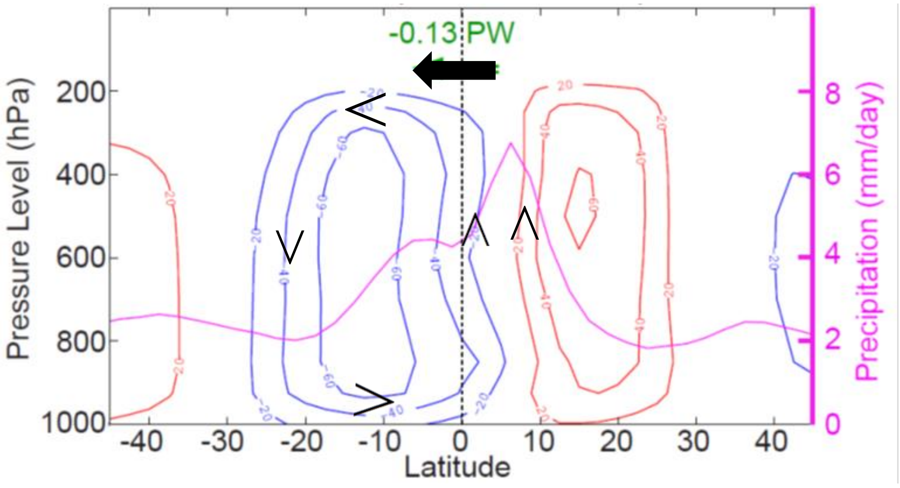


To compensate, ITCZ shifts north to ensure that atmosphere transports heat south across Equator

ITCZ is in the NH because of ocean circulation



Kang et al, 2008



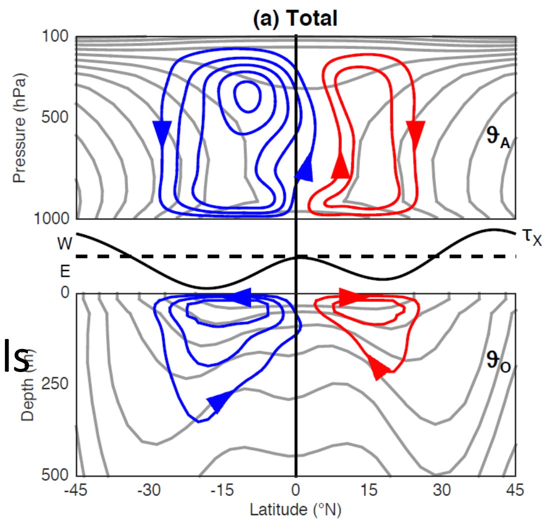
Donohoe et al, 2013; Frierson et al, 2013; Marshall et al, 2014; Schneider et al, 2014; Stevens et al, 2015

Heat transport can be up-gradient in the ocean because the ocean is mechanically forced

Coupling of ITCZ/Monsoons to ocean circulation
(John Marshall, MIT)

Hadley Cells

Subtropical Cells
STCs



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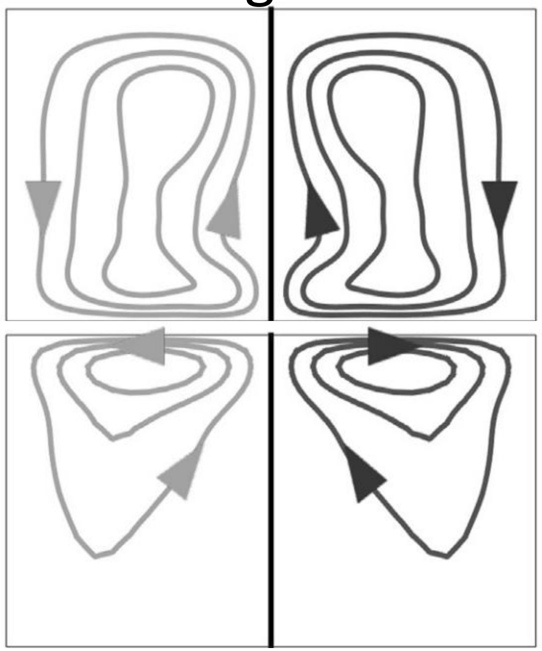
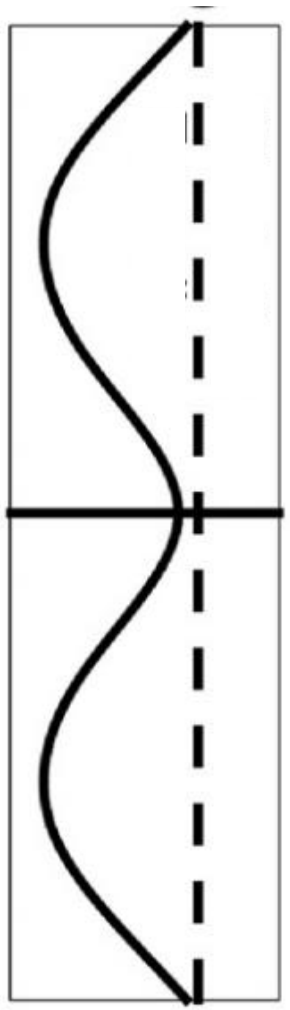
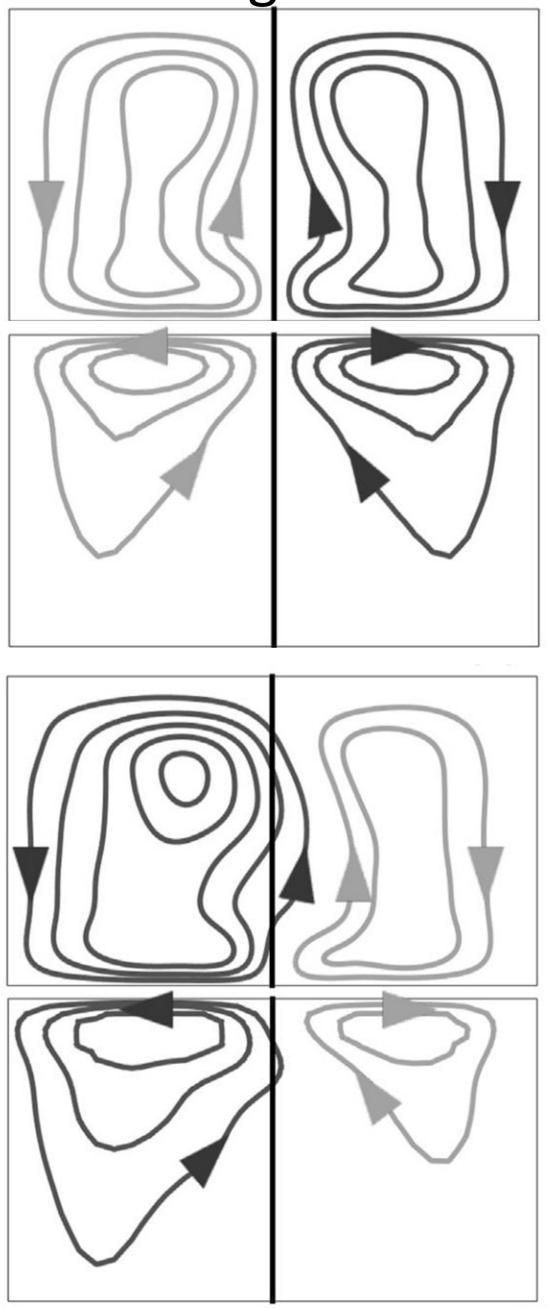
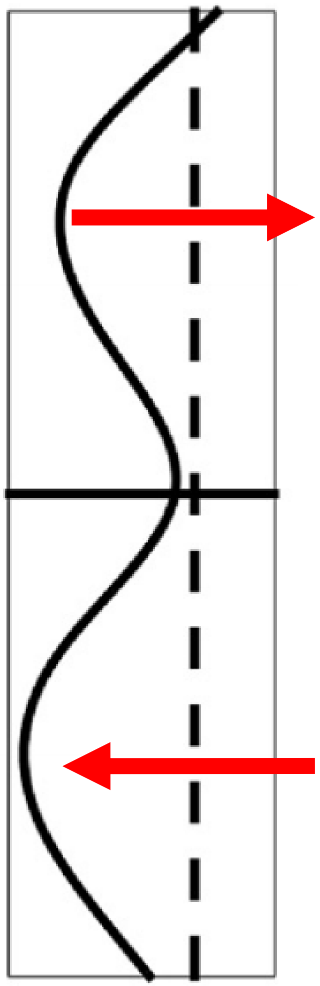




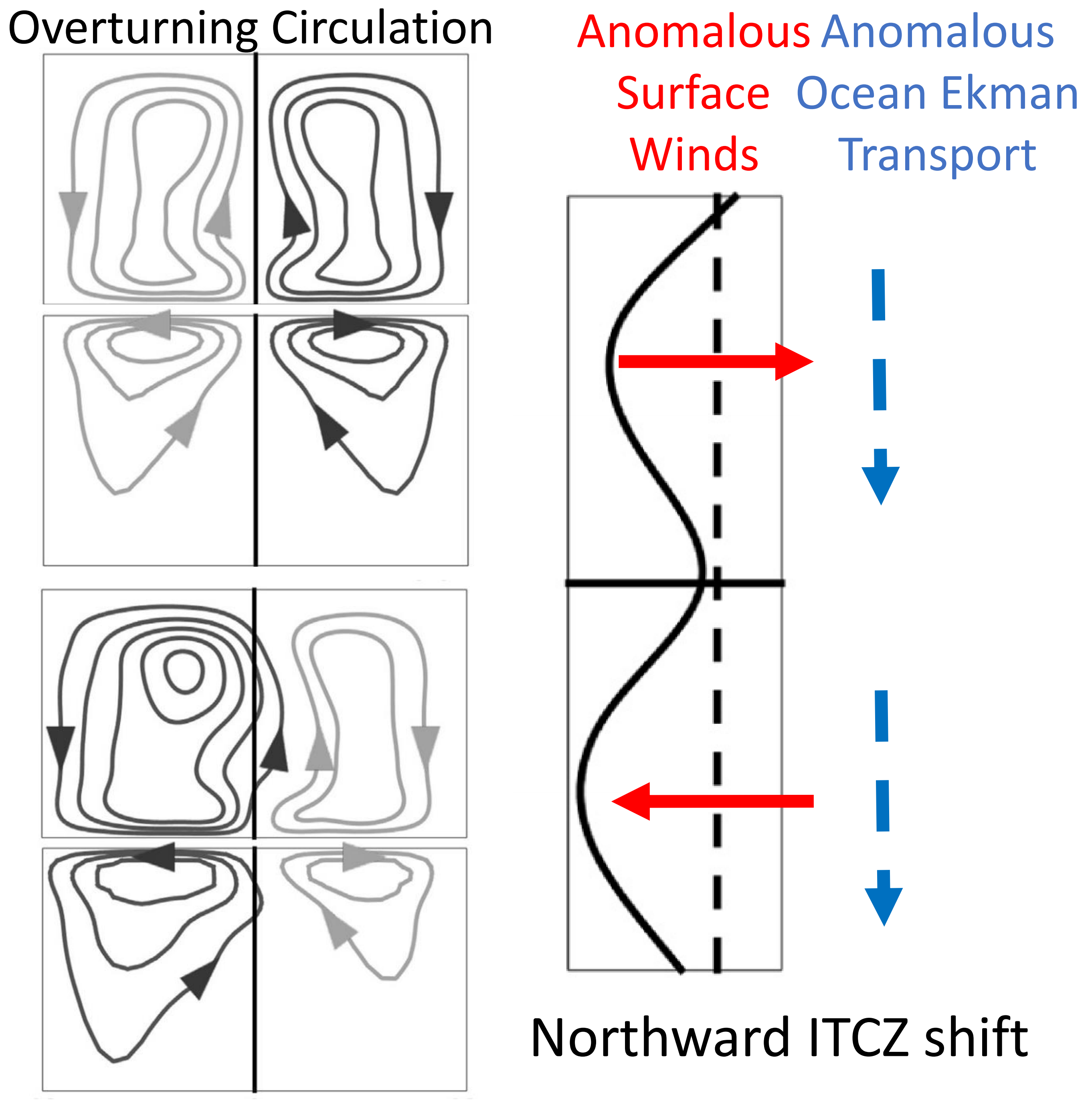
ITCZ on the Equator

Overturning Circulation

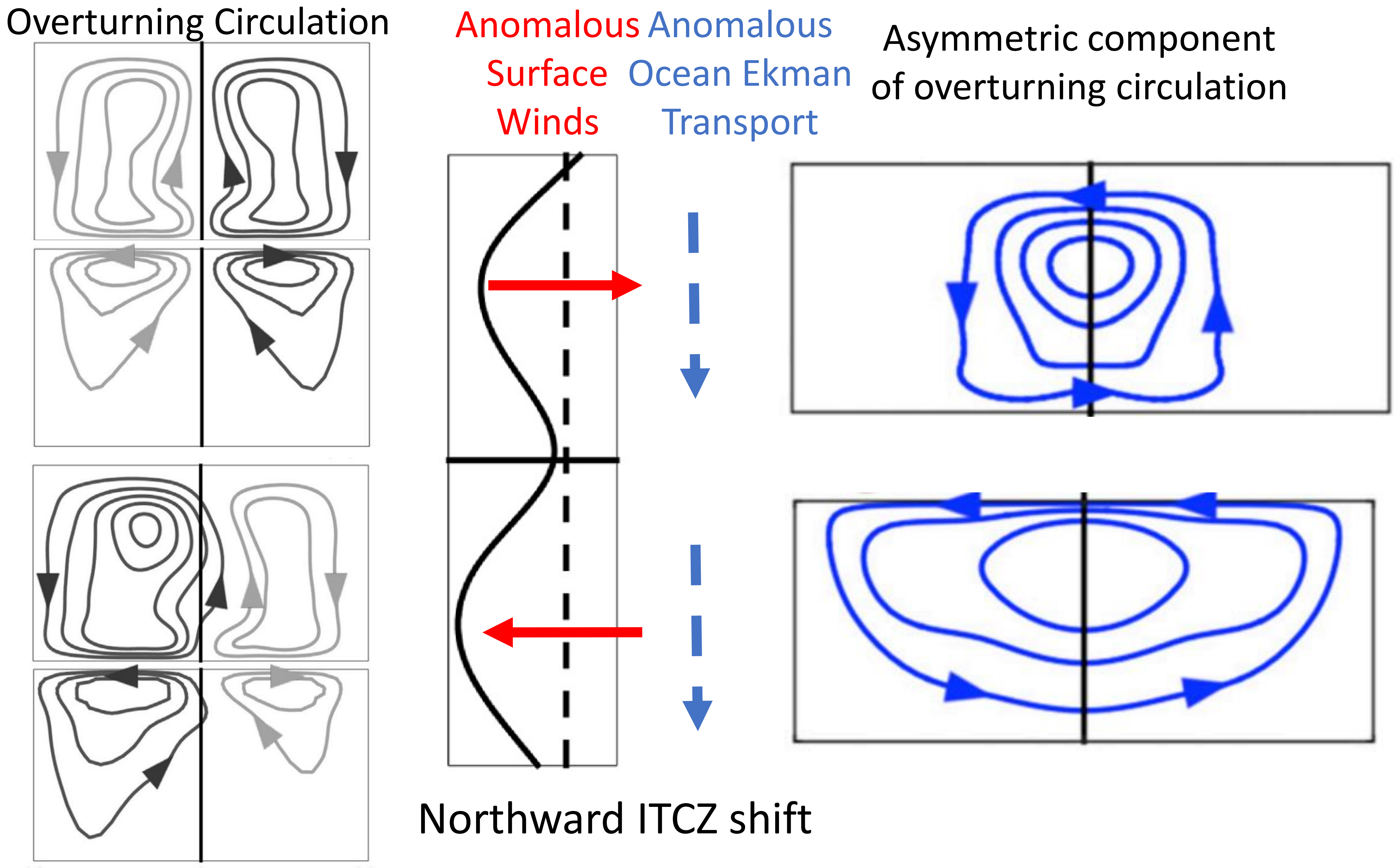


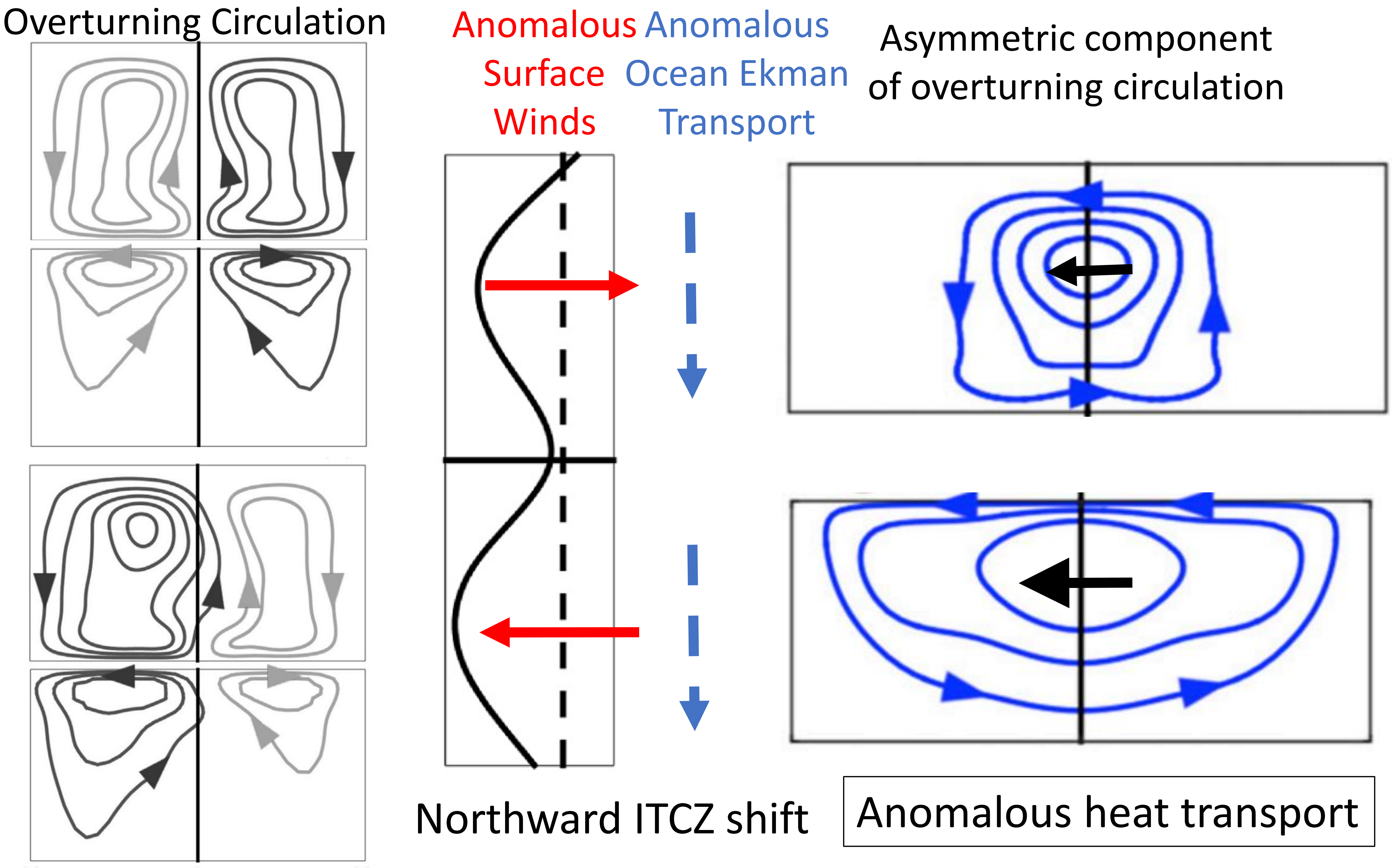


Northward ITCZ shift

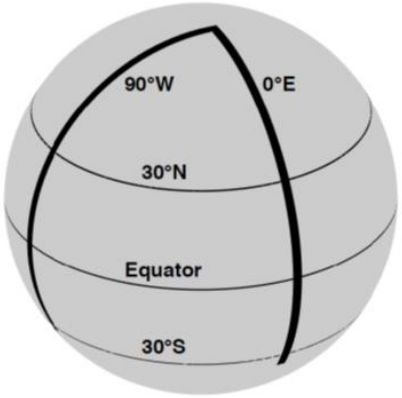


Overturning Circulation
Anomalous Surface Winds
Anomalous Ocean Ekman Transport
Northward ITCZ shift

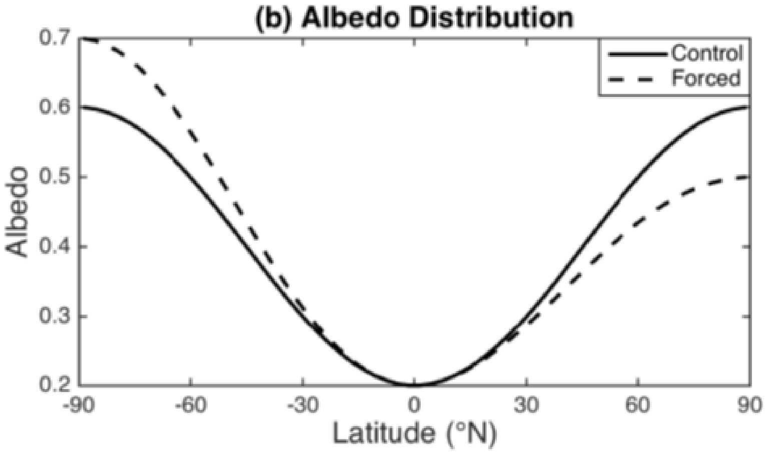

Overturning Circulation
Anomalous Surface Winds
Anomalous Ocean Ekman Transport
Asymmetric component of overturning circulation
Northward ITCZ shift


Overturning Circulation
Anomalous Surface Winds
Anomalous Ocean Ekman Transport
Asymmetric component of overturning circulation
Northward ITCZ shift
Anomalous heat transport

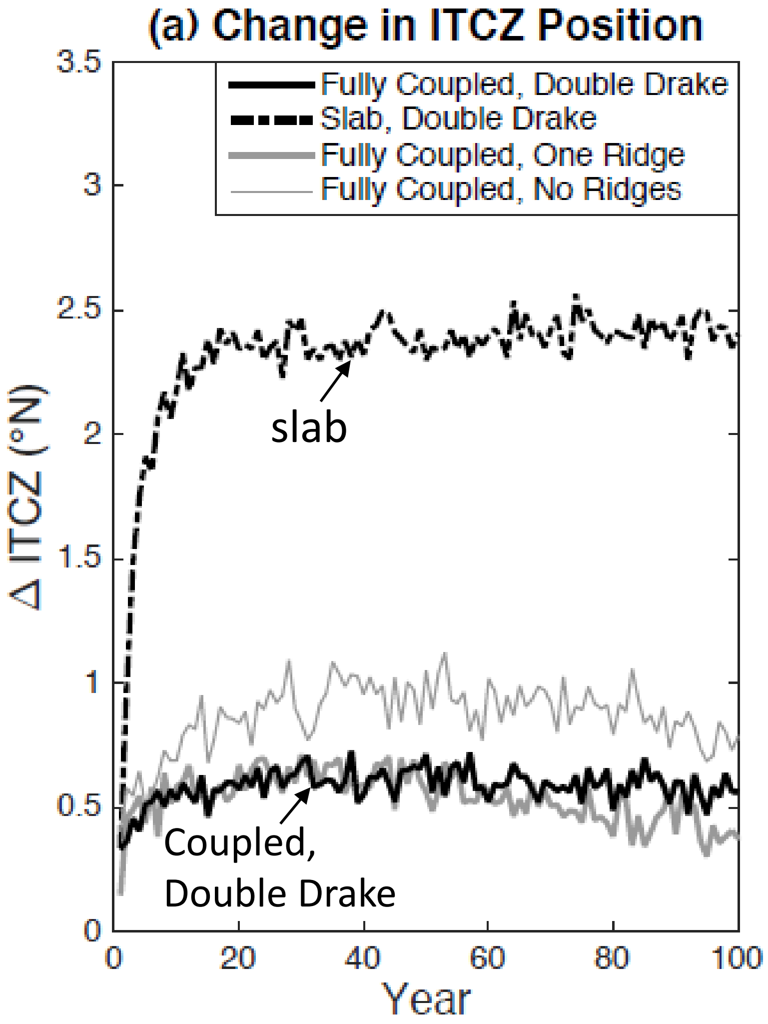
The ITCZ is 'sticky'



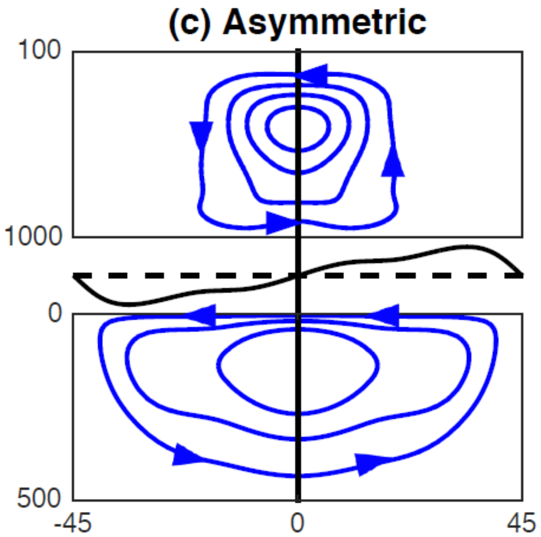
MITgcm with Frierson moist physics



Green and Marshall, J. Climate, 2017



Forced minus control



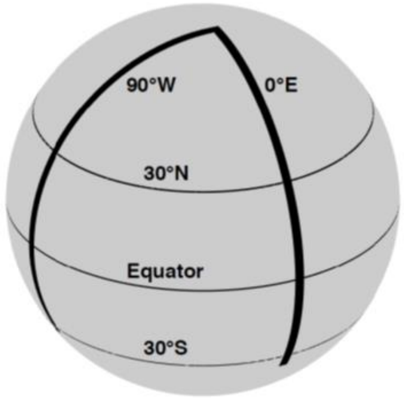
$$\Delta\phi_{ITCZ} = b \cdot SW \cdot C$$

where '*C*' is the compensation

$$C = \frac{1}{1 + F_O/F_A + LW/F_A}$$

2.5 0.4

Dynamics of the Ocean’s Cross-Equatorial Cell



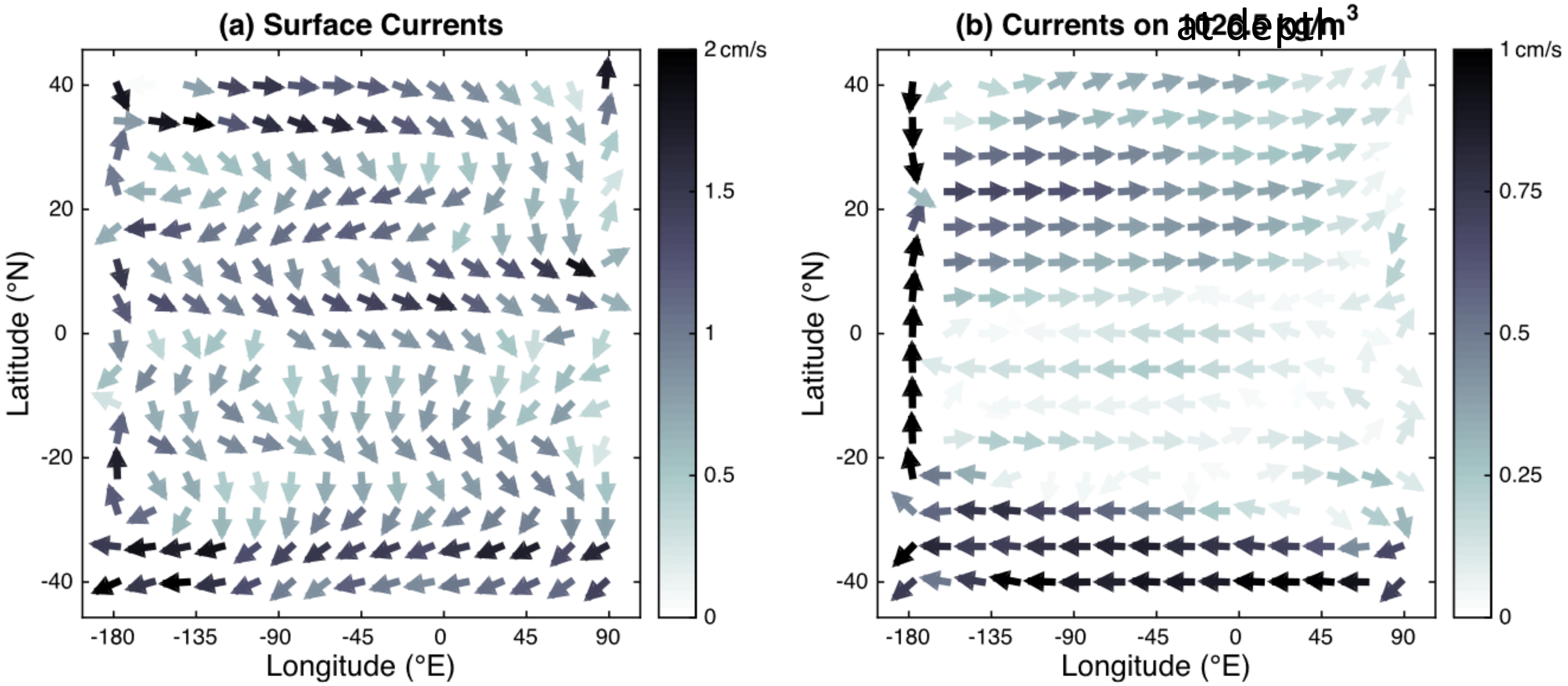
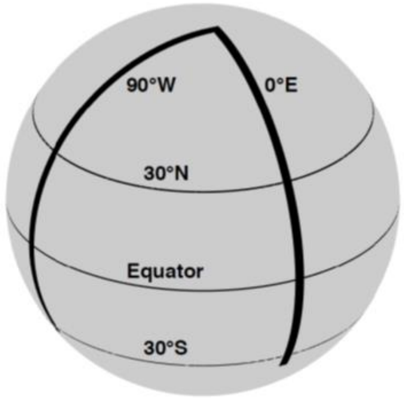


FIG. 9. Pathways of anomalous CEC currents in the large basin. (a) Surface branch. (b) Return branch. Current speed is shown by shading, and direction is shown by arrows.

Dynamics of the Ocean's Cross-Equatorial Cell



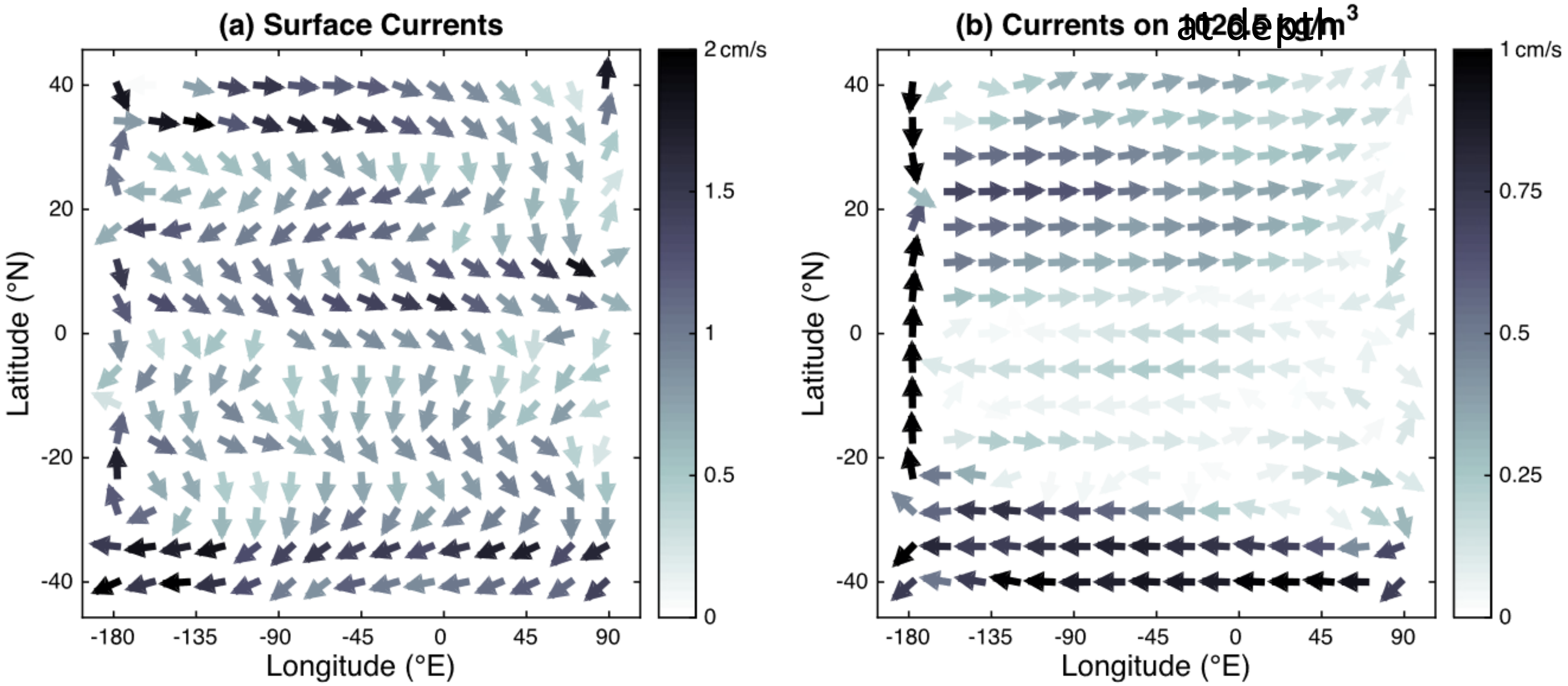


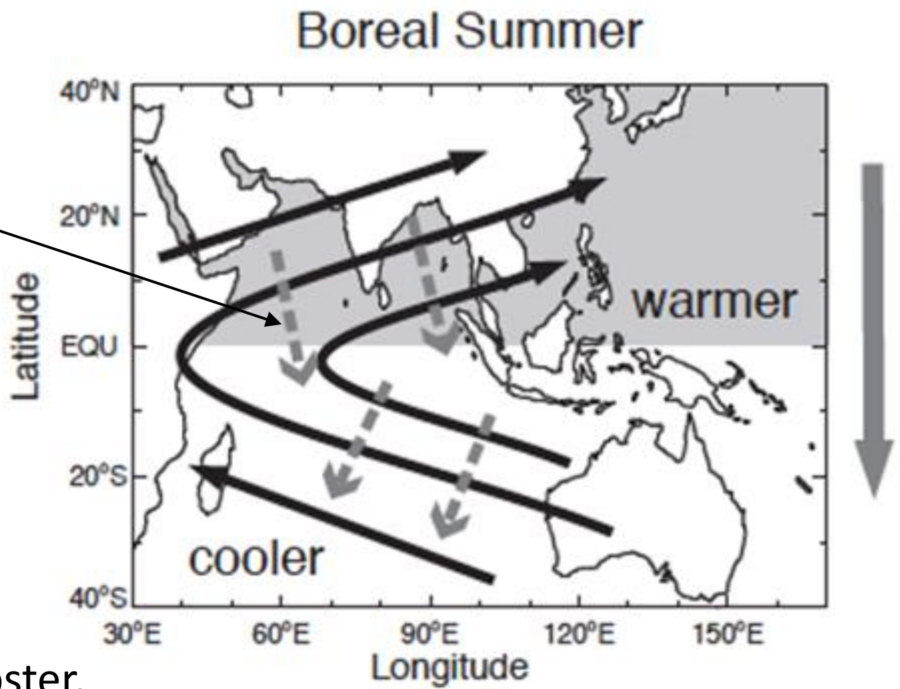
FIG. 9. Pathways of anomalous CEC currents in the large basin. (a) Surface branch. (b) Return branch. Current speed is shown by shading, and direction is shown by arrows.

Literature on the Cross-equatorial Cell of the Indian Ocean

Fritz Schott (observationally)
Jay McCreary (theoretically)
and collaborators

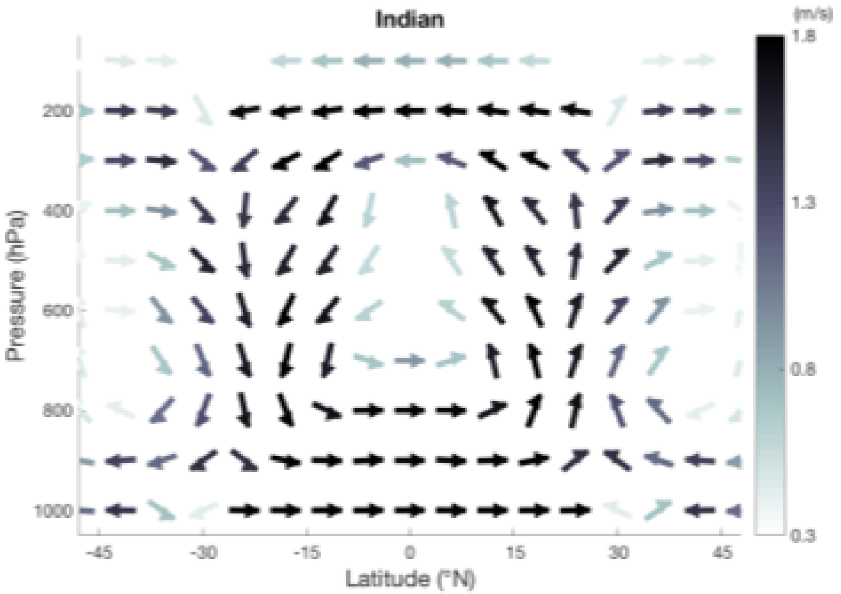
Coupling of Monsoon with Ocean Circulation

Ekman transport



Schematic from Peter Webster

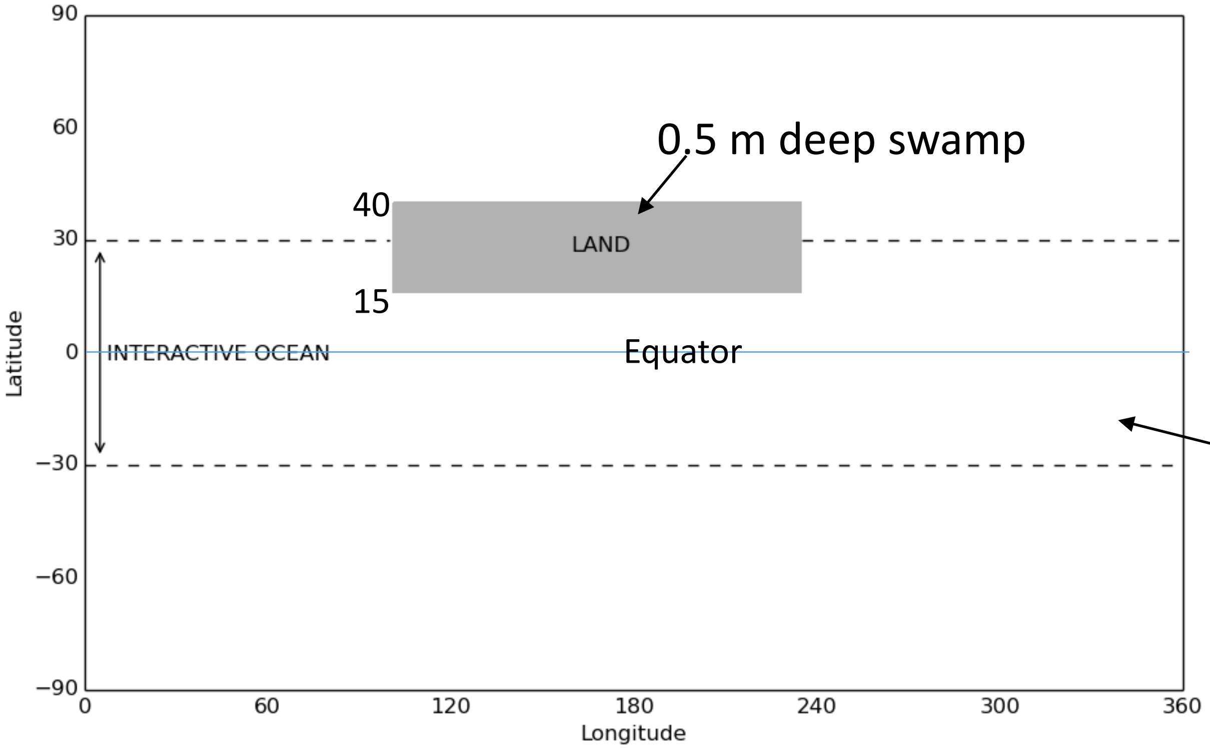
Loschnigg and Webster, J. Climate, 2000



Asymmetric component of overturning circulation in Indian Sector

1. Coupling of Hadley Cell with ocean's subtropical cells
2. Damping of ITCZ migrations (Brian Green)
3. Coupling of monsoons with ocean circulation (Nick Lutsko)

Minimalist model of coupling of Monsoon to the ocean



GFDL dynamical core, Frierson physics

Seasonal Cycle

24m mixed layer with interactive q-flux

Surface stress from atmospheric model

Ocean heat transport:

$$\boxed{F(\phi) = 2\pi a \cos\phi c_p \frac{\tau_x}{f} \Delta T}$$

Temperature difference across the thermocline.

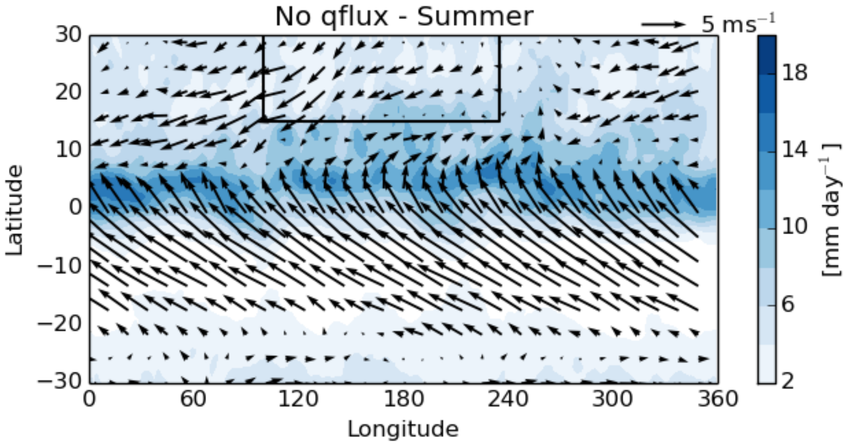
Prescribed and held constant

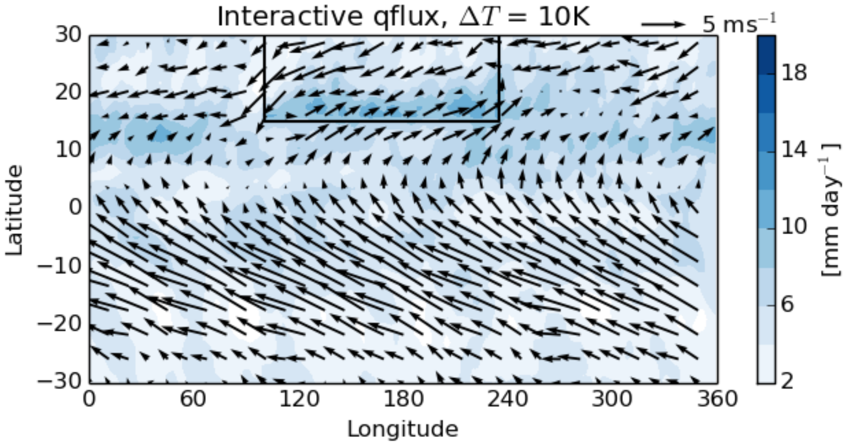
Surface winds, precipitation and Moist Static Energy

Swamp

Summer

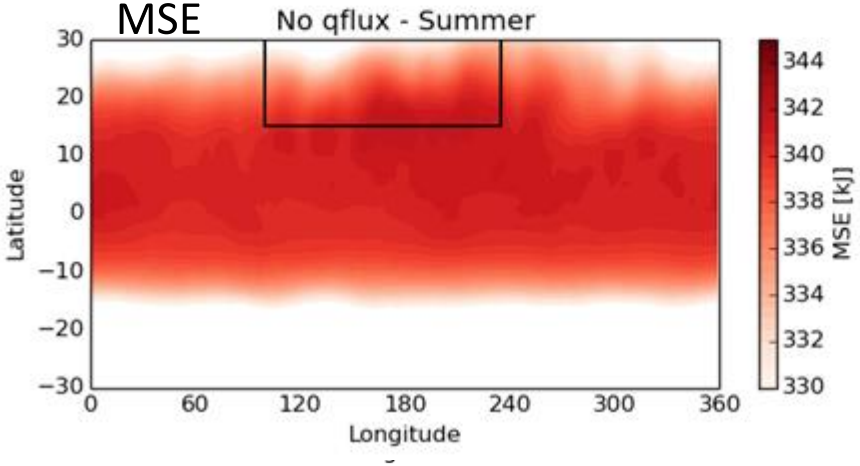
Interactive ocean



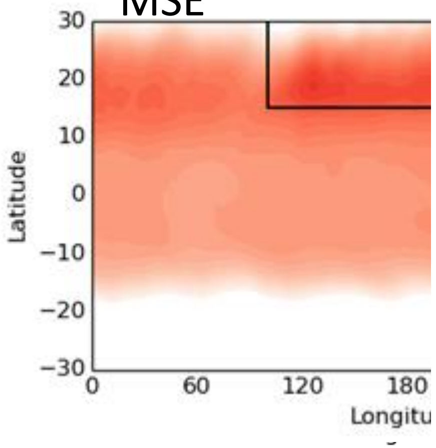


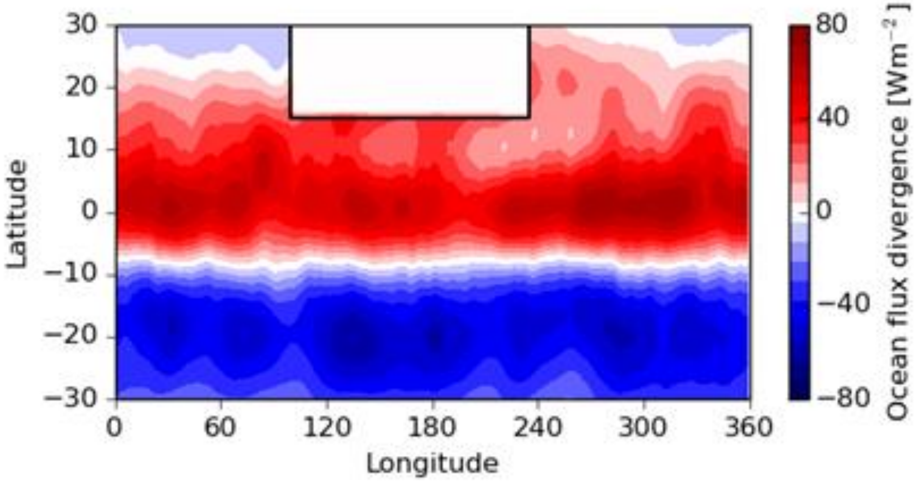
$$\Delta T = 10K$$

MSE



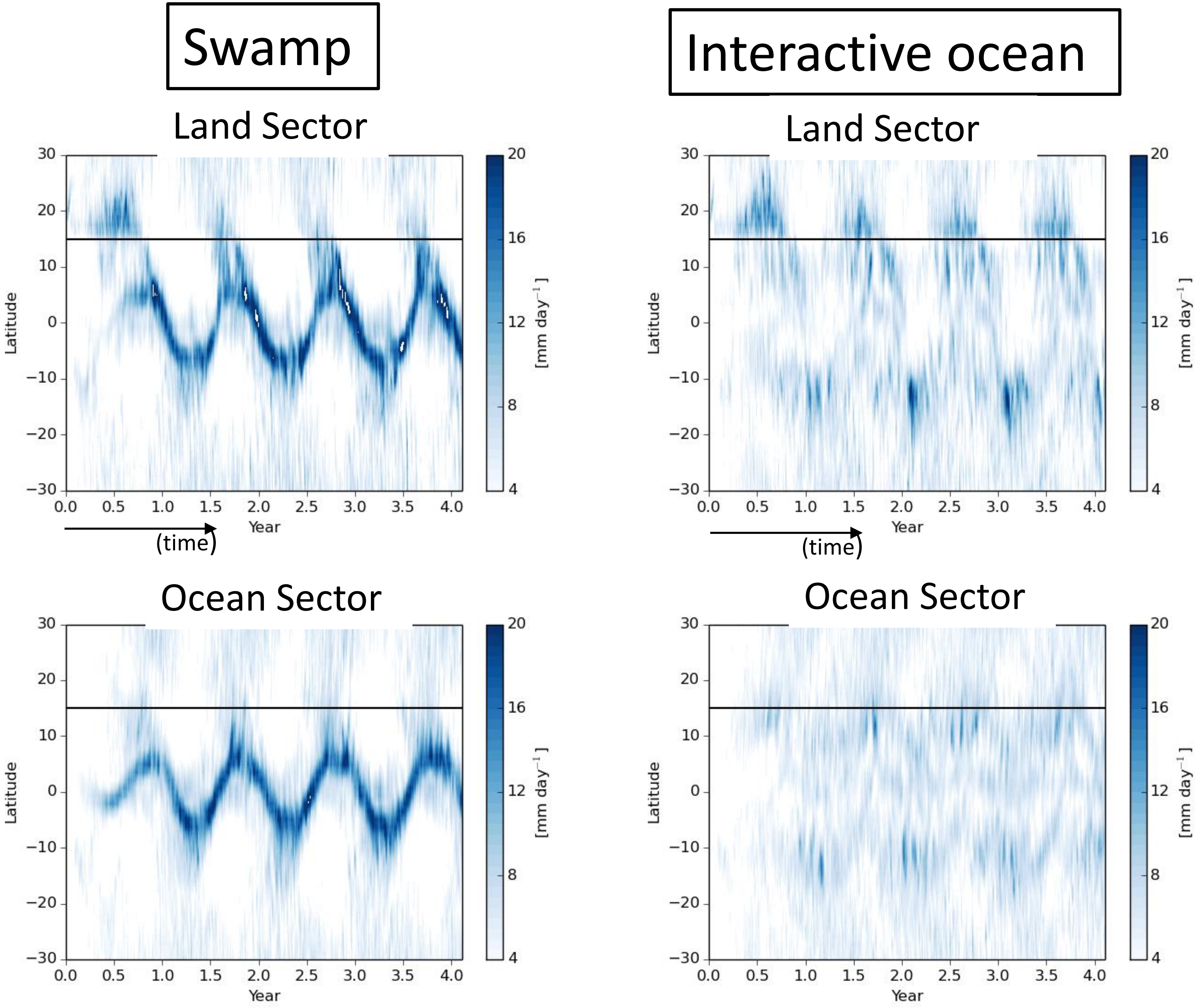
MSE

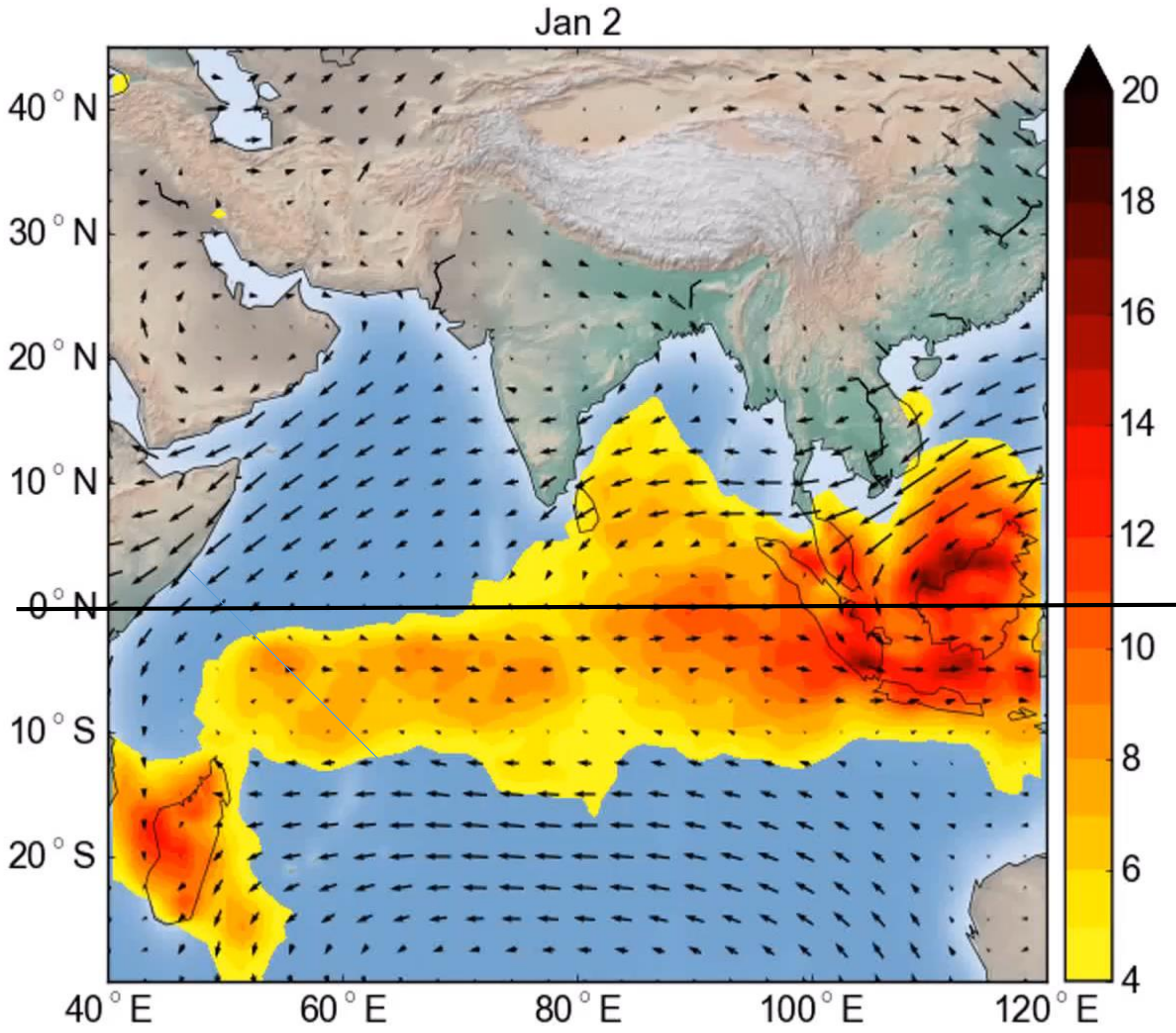




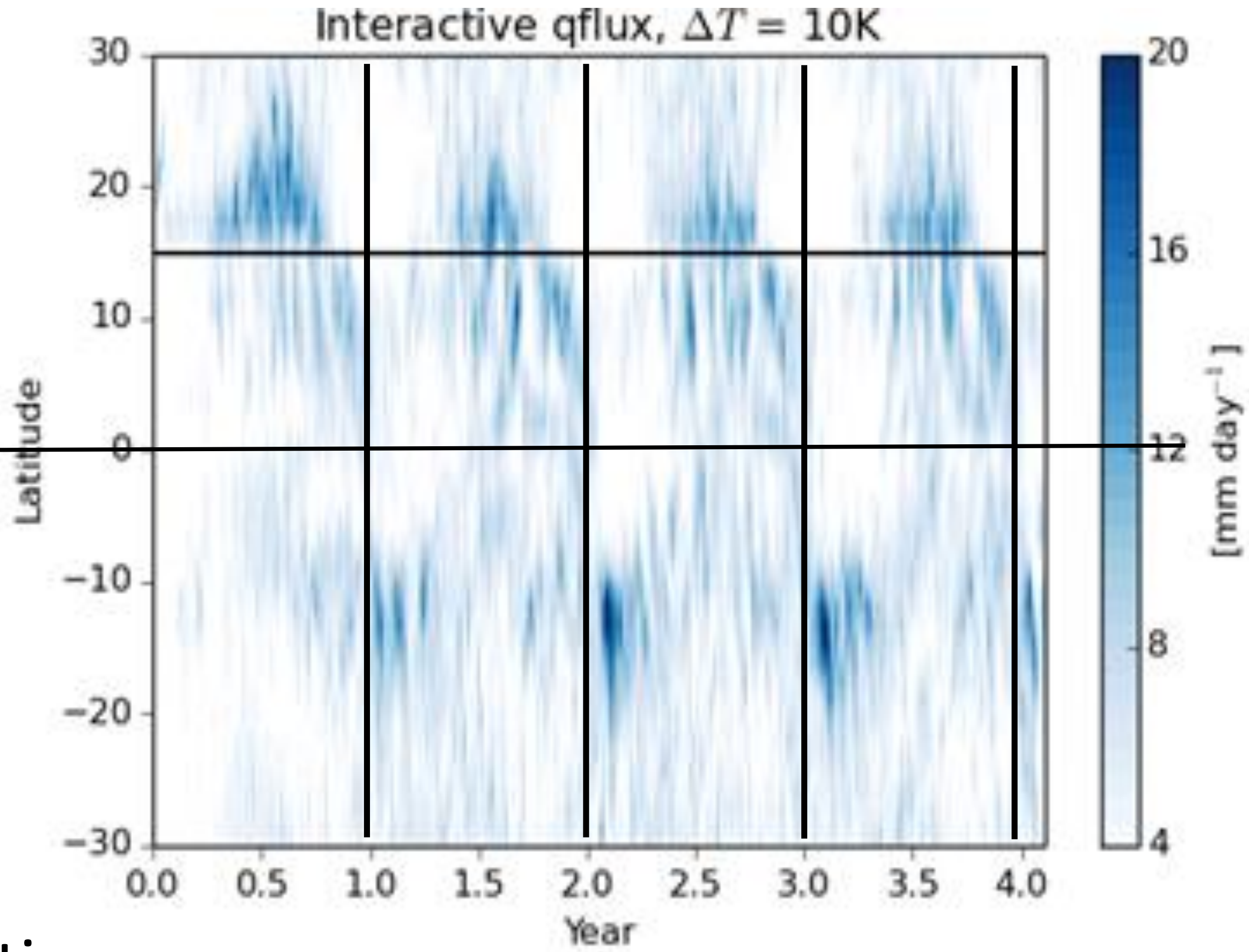
Precipitation

$\Delta T = 10K$





Precipitation



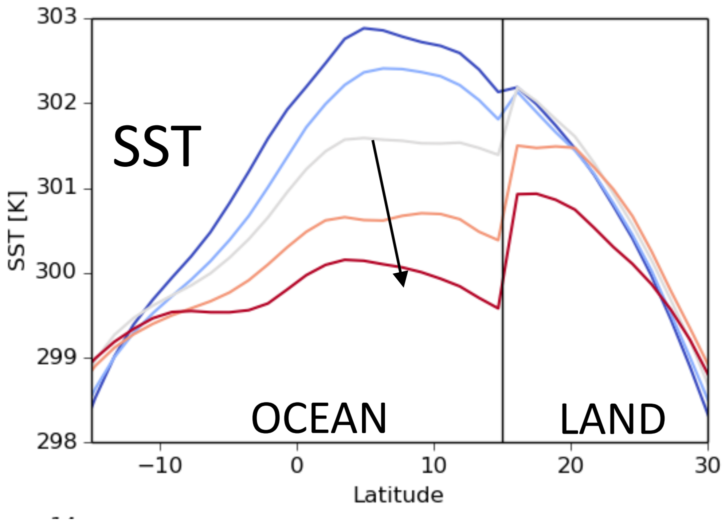
Observed Surface wind and precipitation

Animation courtesy of Simona Bordoni

Enhancing role of ocean circulation

Increasing ΔT

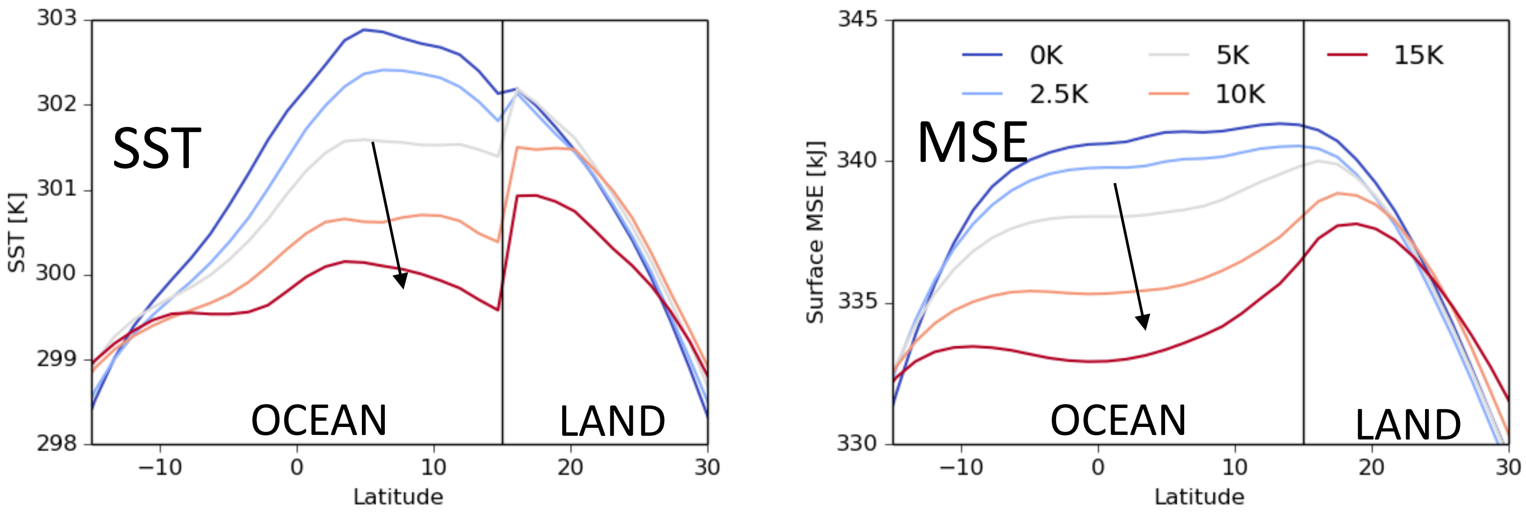
Summer



Enhancing role of ocean circulation

Increasing ΔT

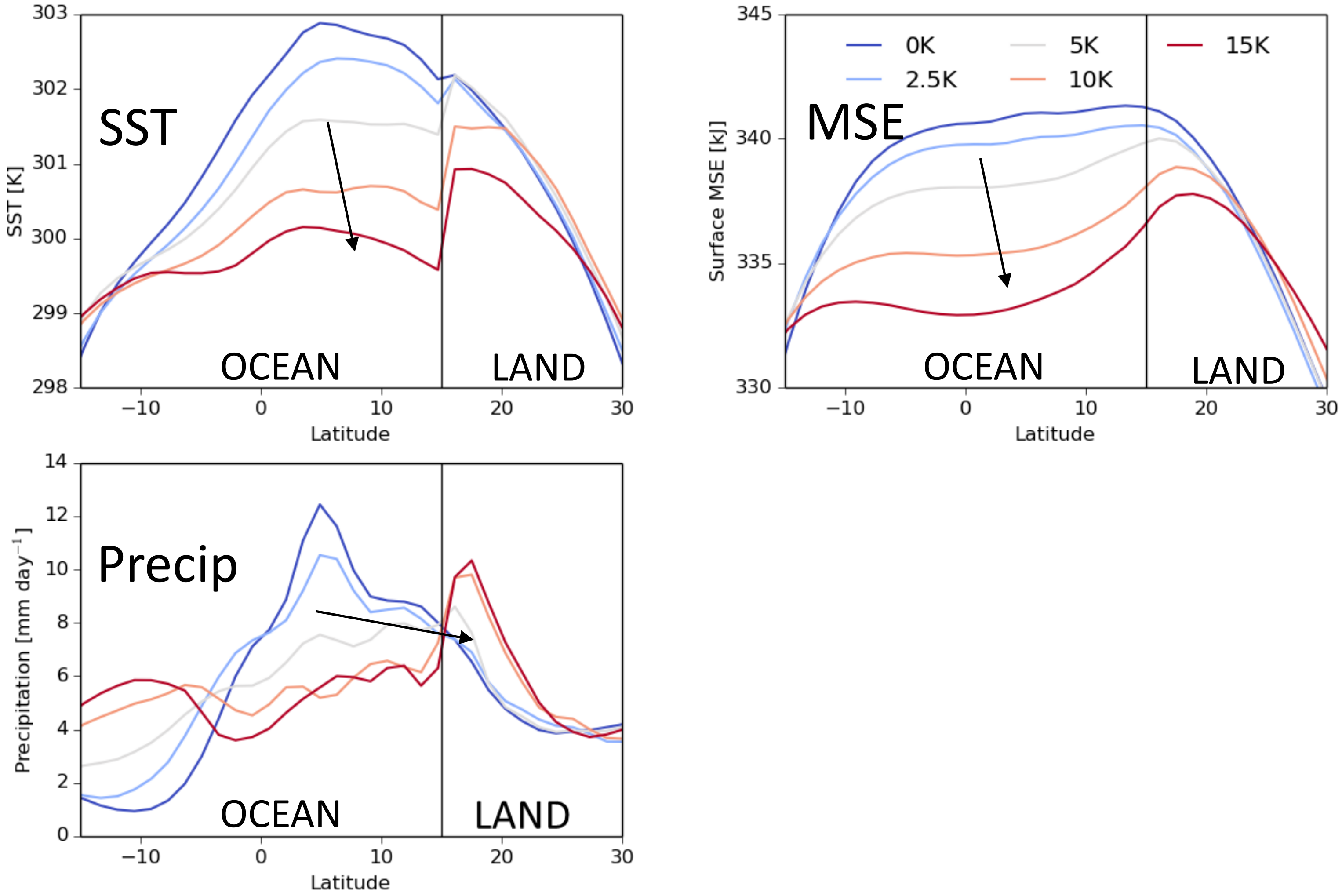
Summer



Enhancing role of ocean circulation

Increasing ΔT

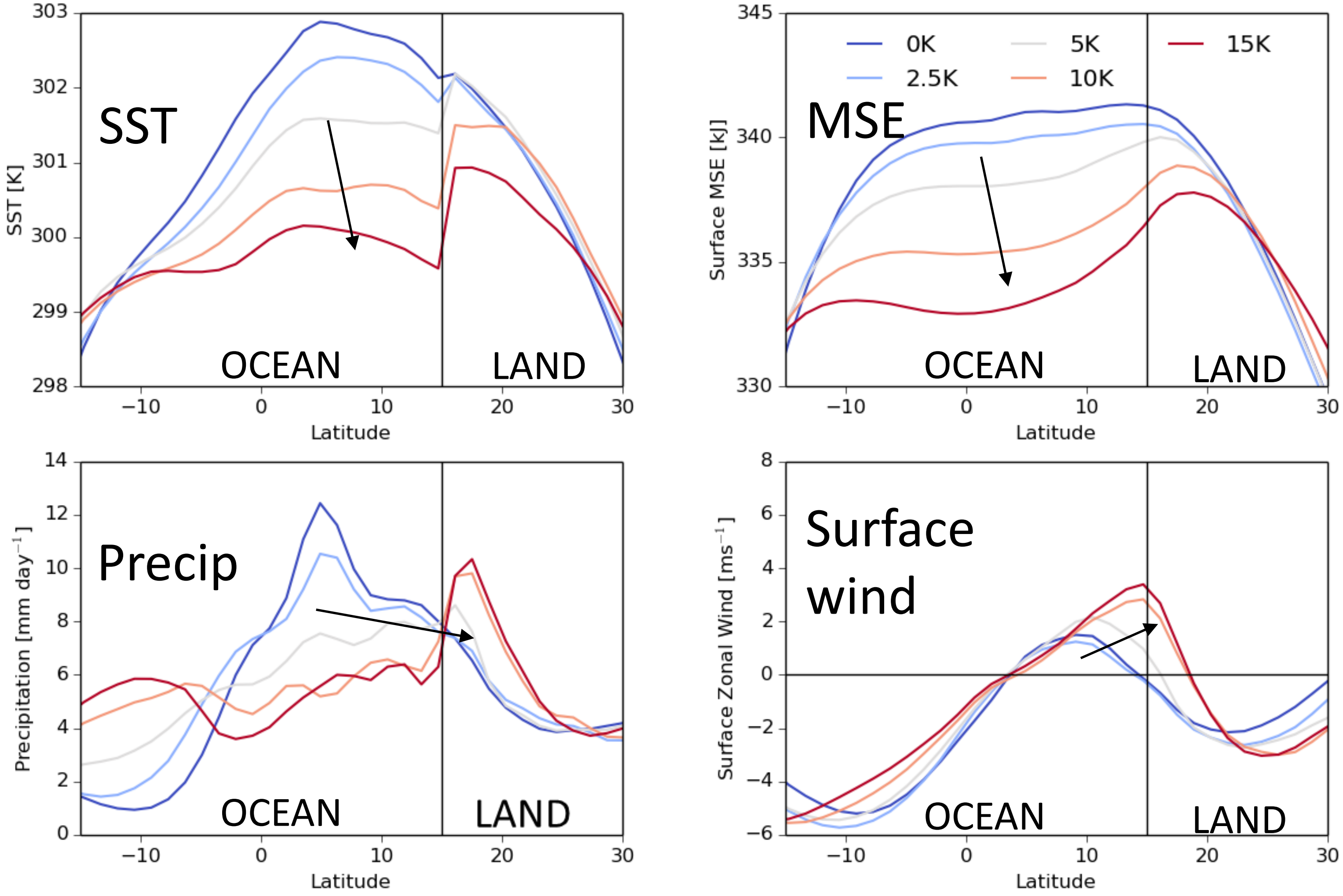
Summer

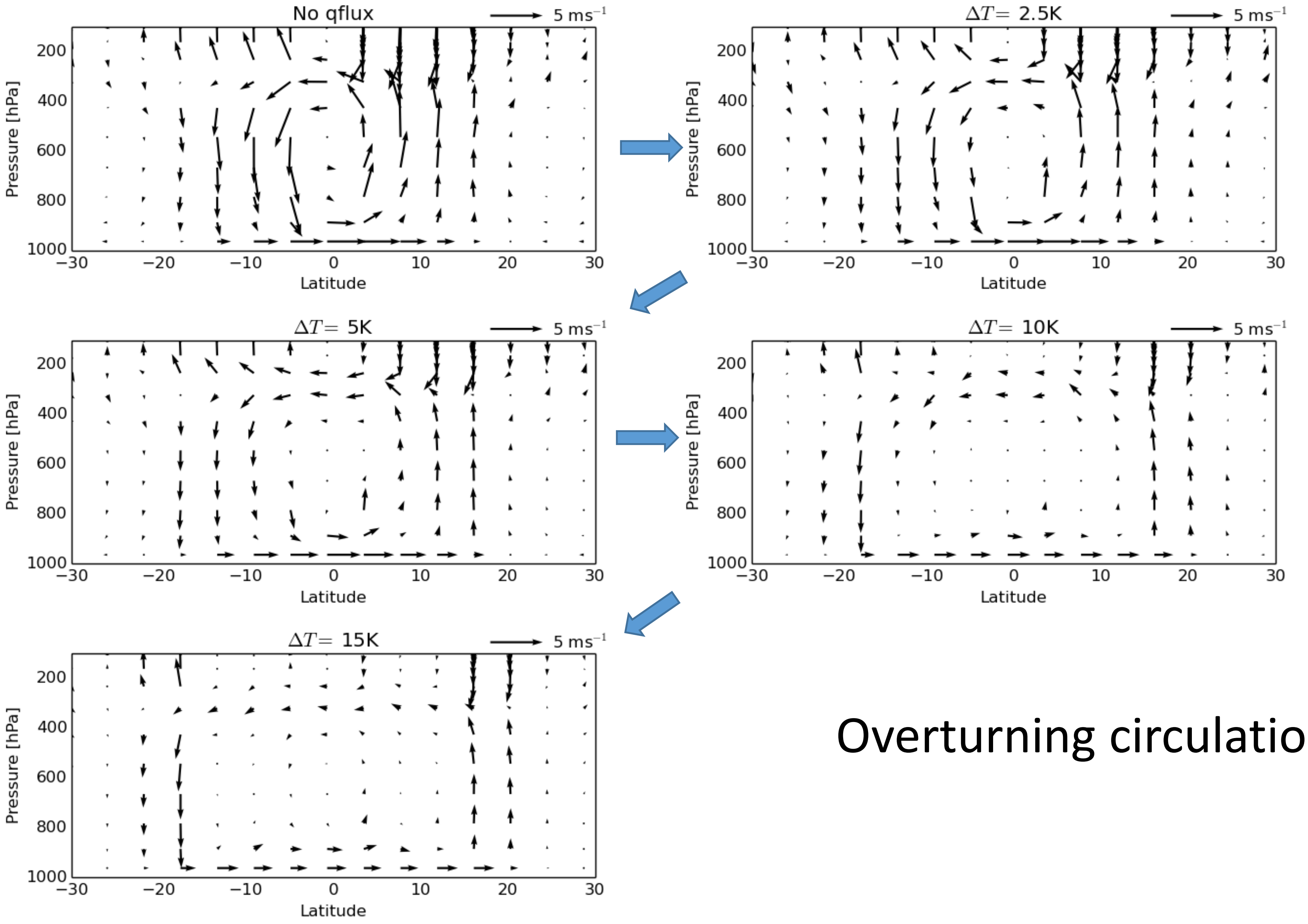


Enhancing role of ocean circulation

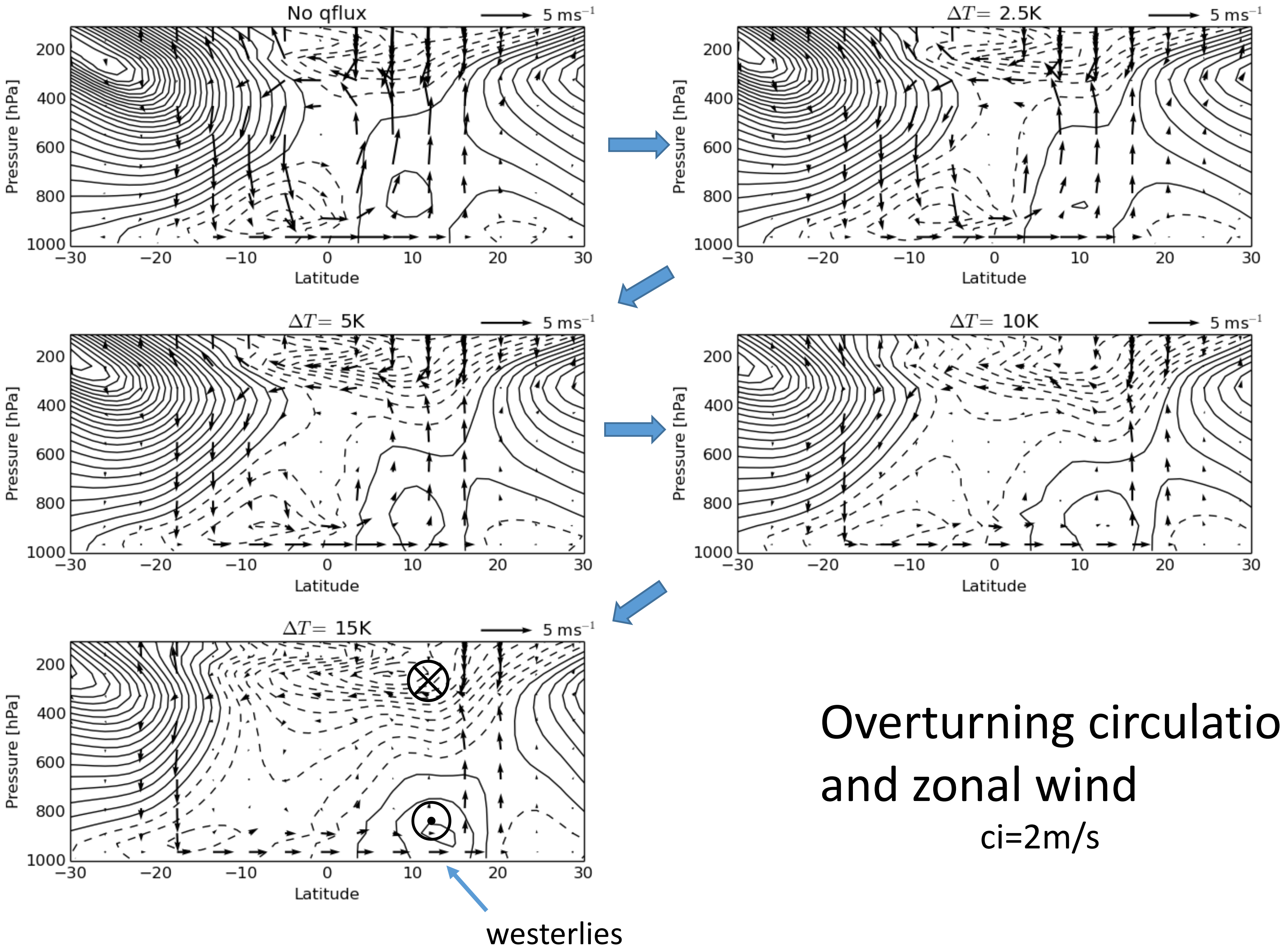
Increasing ΔT

Summer





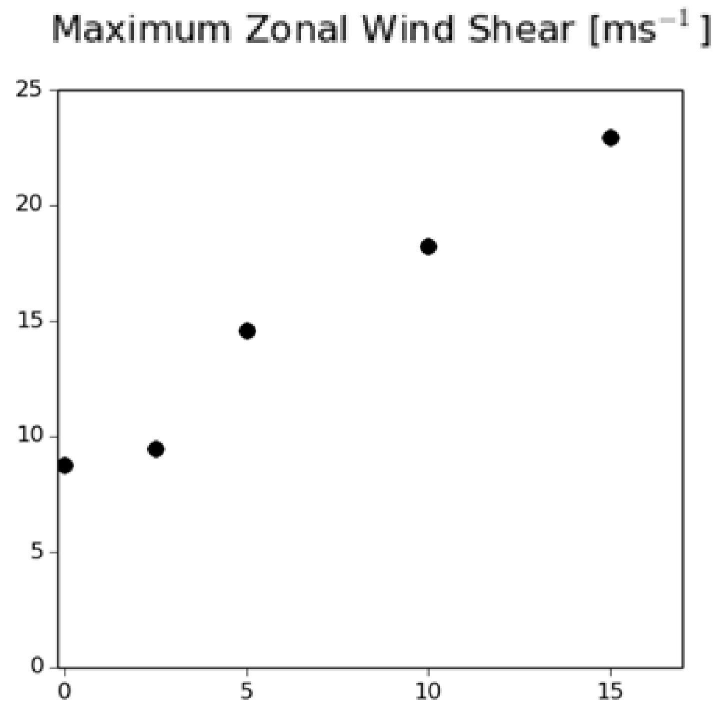
Overturning circulation



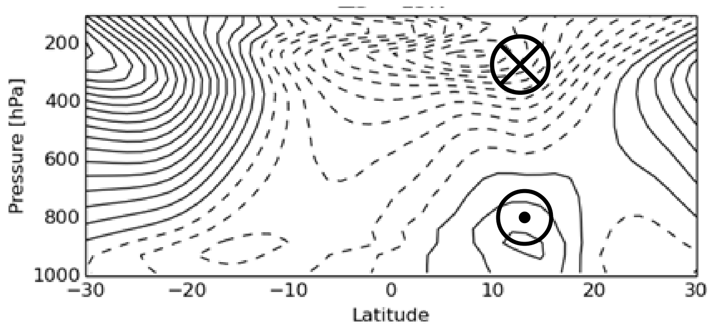
Overturning circulation and zonal wind

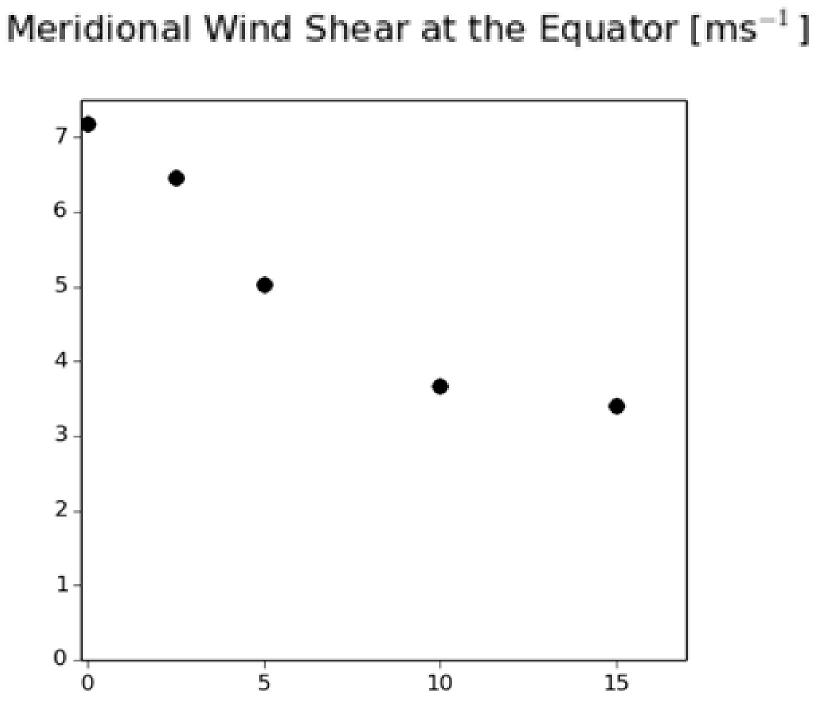
ci=2m/s

Monsoon Indices

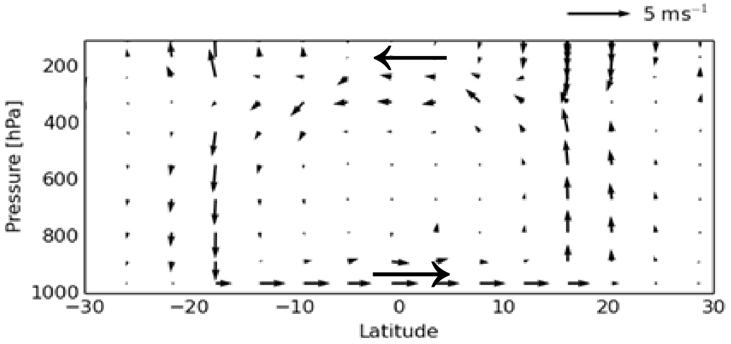


Increasing ΔT →

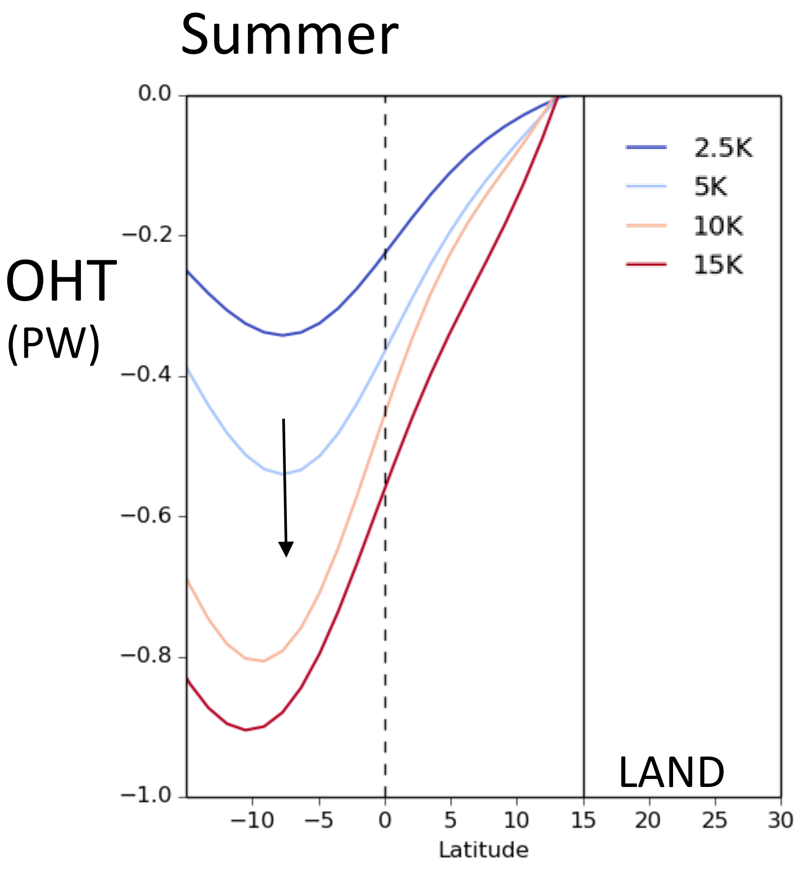


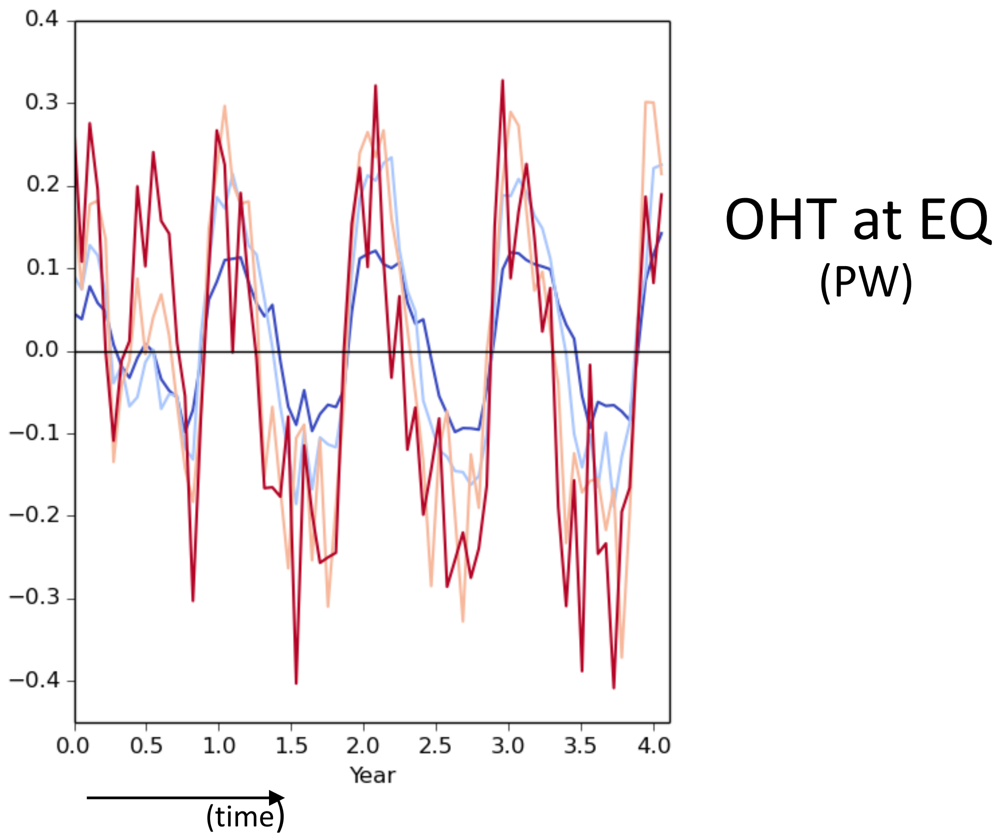


Increasing ΔT →



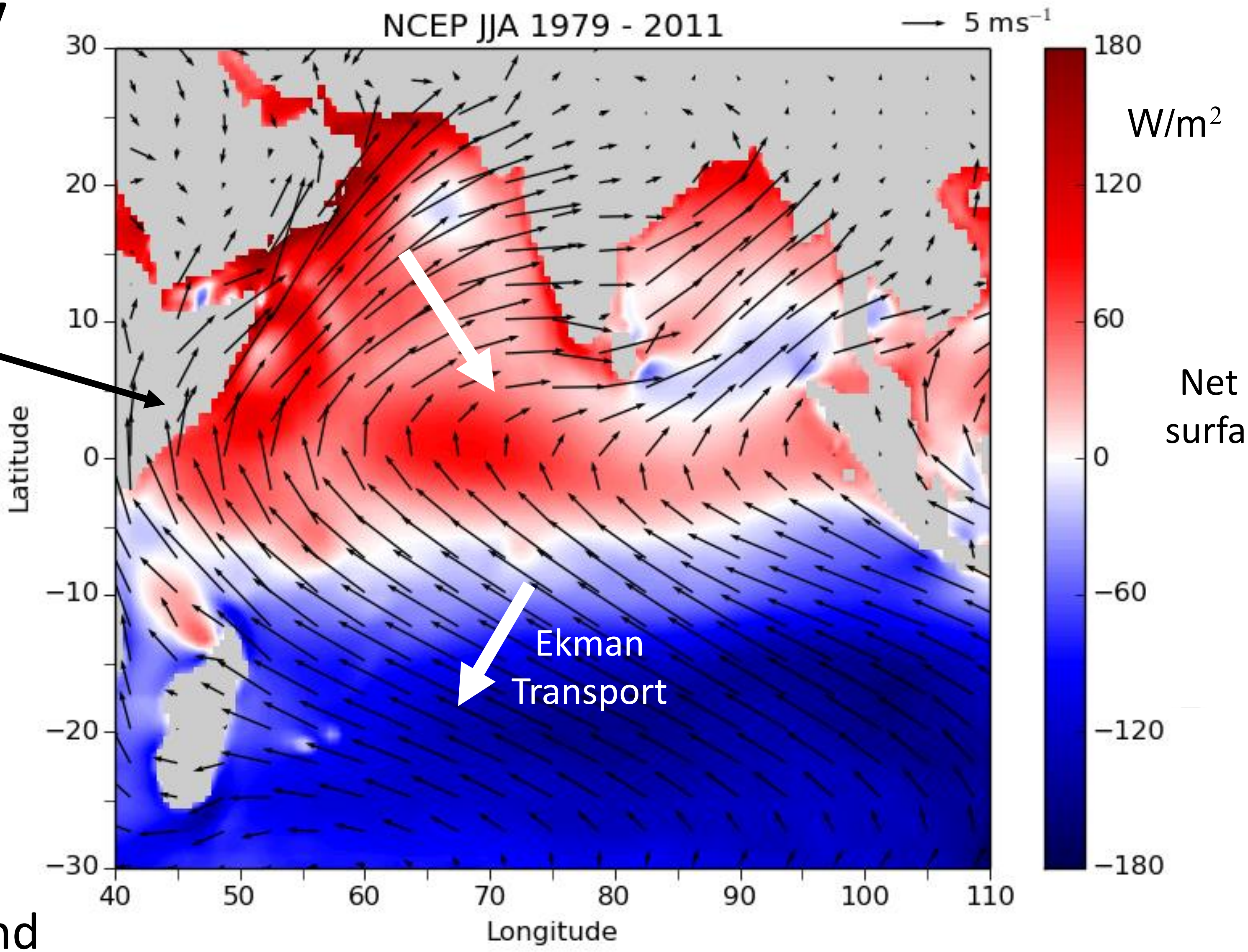
Ocean Heat Transport





Summary

Western boundary currents in the Atmosphere and Ocean



Net downward surface heat flux

Peter Webster and collaborators

Conclusions

Coupling of the trade winds with ocean's subtropical cells in the deep tropics has a profound effect on rainfall patterns:

Strongly damps ITCZ migrations

Fundamental to the dynamics of the Indian Monsoon

Many discussions with

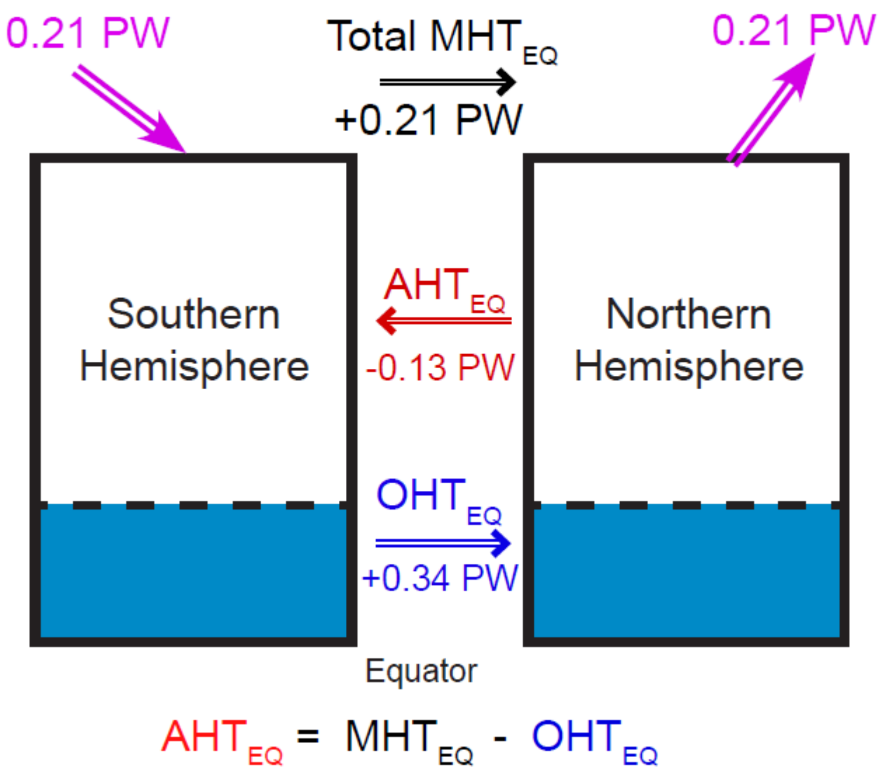
Brian Green, David McGee, Alan Plumb, Nick Lutsko, MIT

Aaron Donohoe, Dargan Frierson, UW

Simona Bordoni, Tapio Schneider, Caltech

Peter Webster, Georgia Tech

In present climate there is a small 0.2 PW net (A+O) northward transport of heat across the equator



If this transport was achieved by atmosphere, ITCZ would be south of equator!

Donohoe et al, 2013, J. Climate

Marshall et al, 2014; Climate Dynamics

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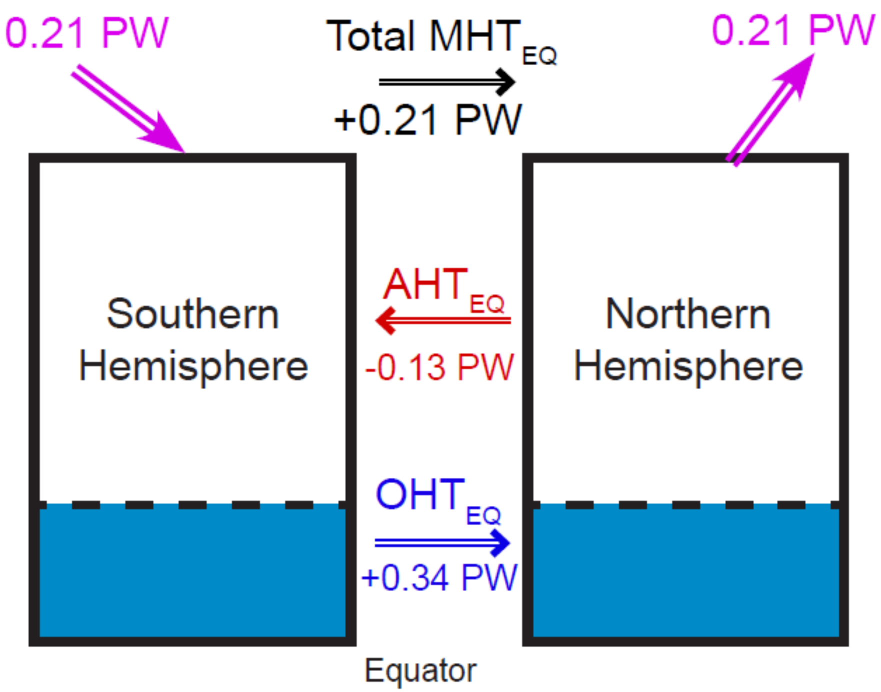


$$AHT_{EQ} = MHT_{EQ} - OHT_{EQ}$$

If this transport was achieved by atmosphere, ITCZ would be south of equator!

Donohoe et al, 2013, J. Climate

Marshall et al, 2014; Climate Dynamics

$$AHT + OHT \gtrsim 0$$

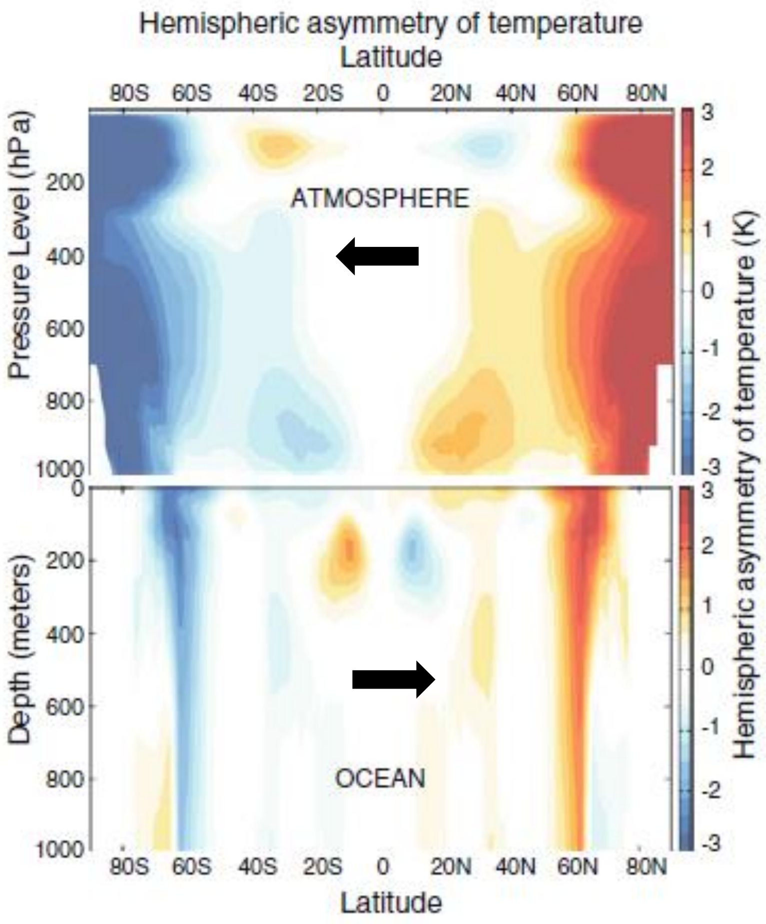
$$OHT > 0$$

and so, atmospheric heat transport must be southward

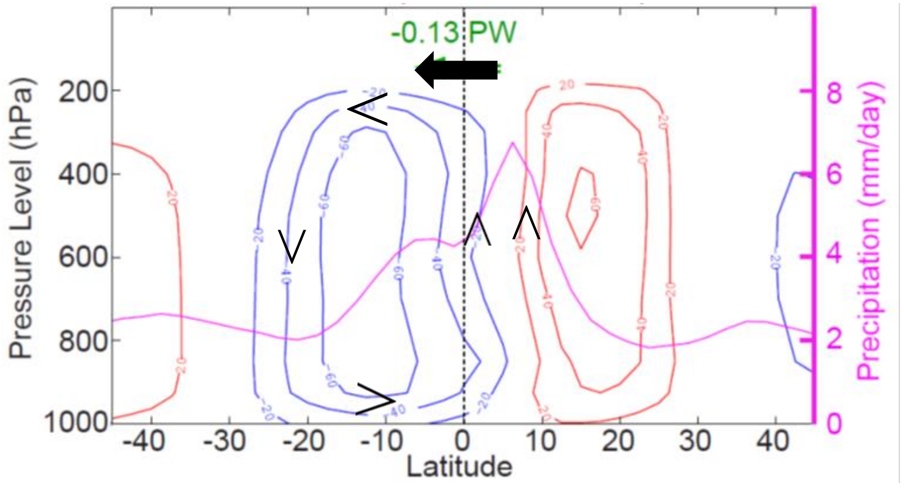
$$AHT < 0$$

ITCZ is ‘pushed northward’ by OHT

ITCZ is in the NH because of ocean circulation



Kang et al, 2008



Donohoe et al, 2013; Frierson et al, 2013; Marshall et al, 2014; Schneider et al, 2014; Stevens et al, 2015