Hemispheric asymmetries in climate

John Marshall
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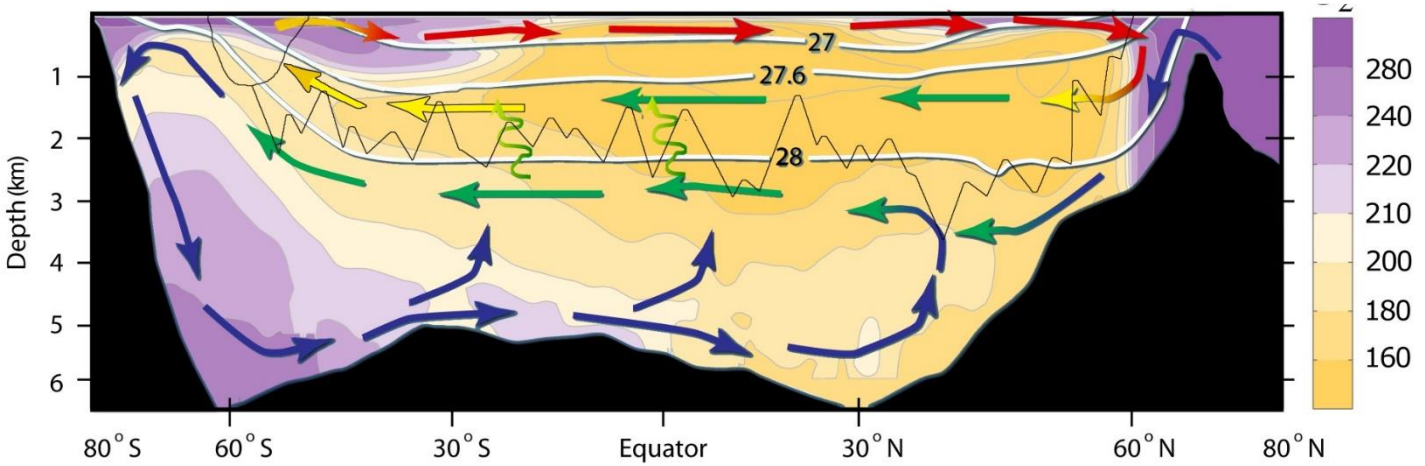
Meridional Overturning Circulation of the Ocean



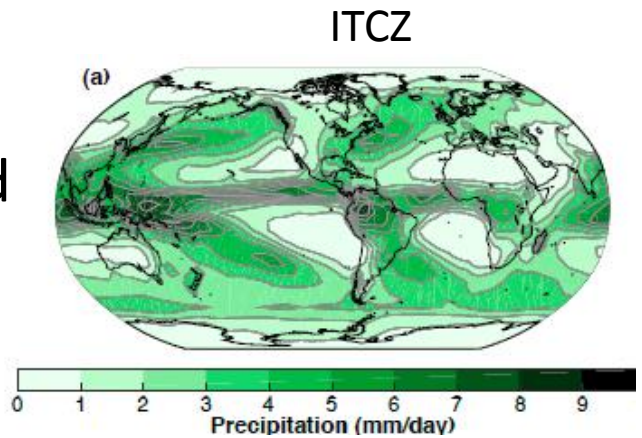
Review by Marshall and Speer, 2012

Upper Cell emanating from the north (Atlantic)
Lower Cell from the south (around Antarctica)
Complex, 3-D circulation extending from pole to pole

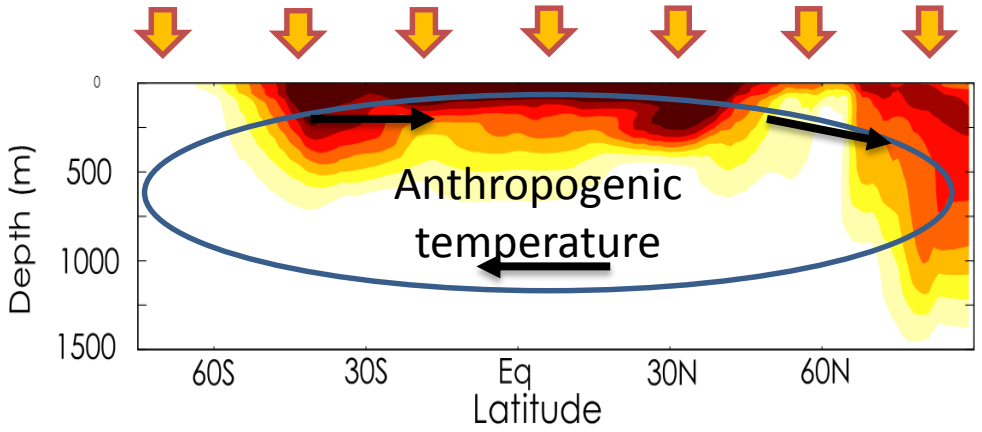
Results in hemispheric asymmetries in climate

Some Global Climate Consequences of Ocean's MOC

1. The NH is warmer than the SH, so climate's axis of symmetry is displaced away from the equator



2. In a warming world, the NH warms up faster than the SH



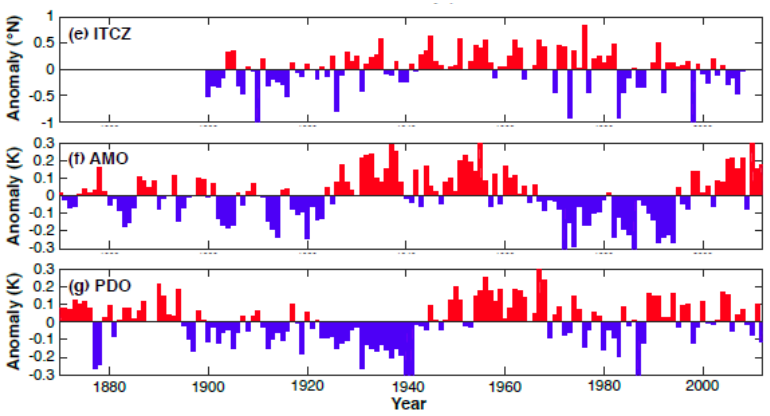
ITCZ position and migrations

1. Hemispheric asymmetries in Earth's energy budget and the position of the ITCZ

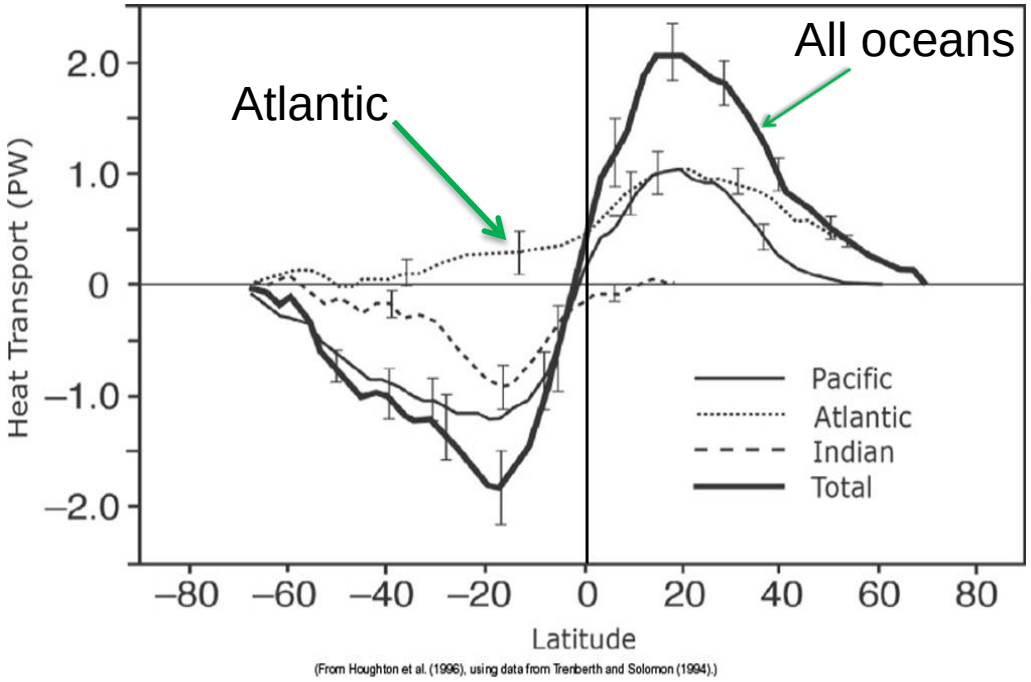
2. Study cross-equatorial heat transport and asymmetries in idealized coupled systems

3. Observed correlations of ITCZ migrations and multi-decadal SST variability over 20th C.

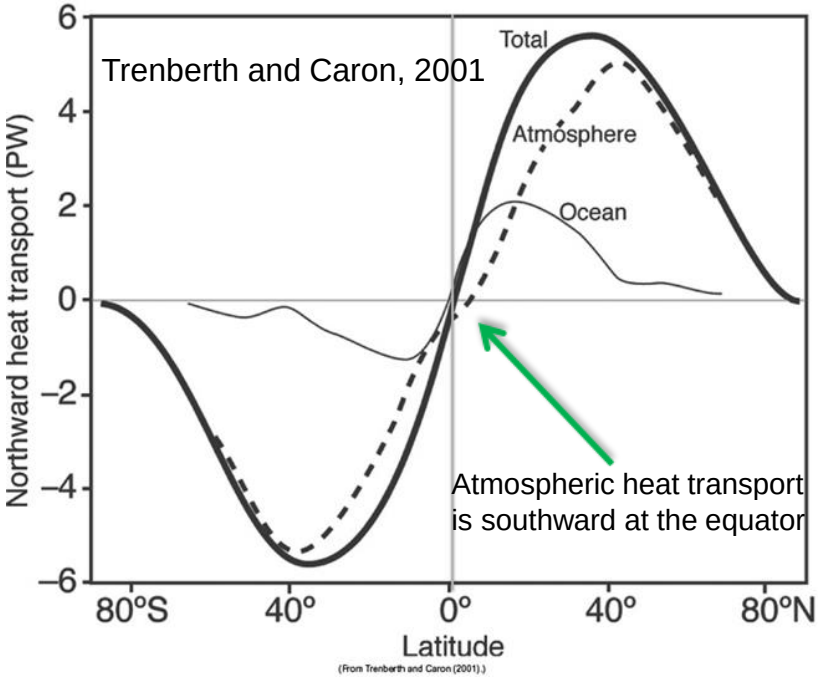
Green et al, 2016

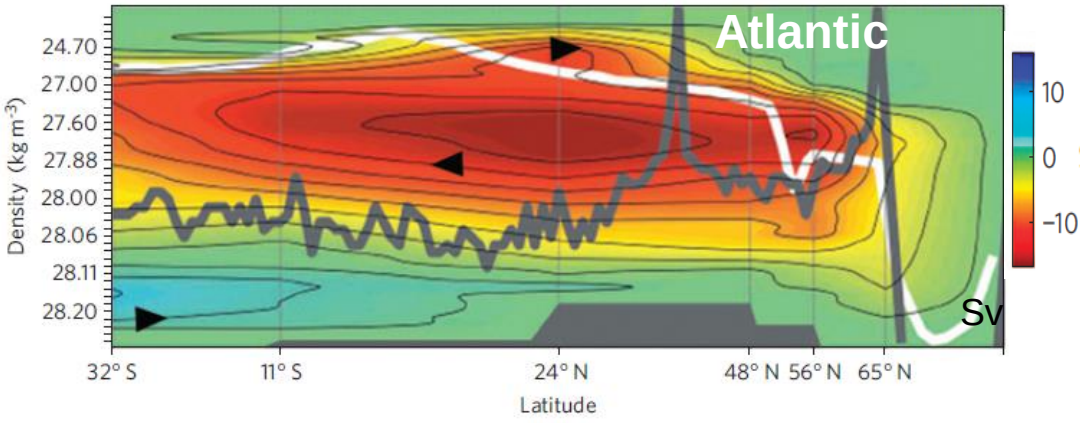


Atlantic carries roughly 1/2 PW heat northward across the equator



Largely compensated by Atmospheric heat transport

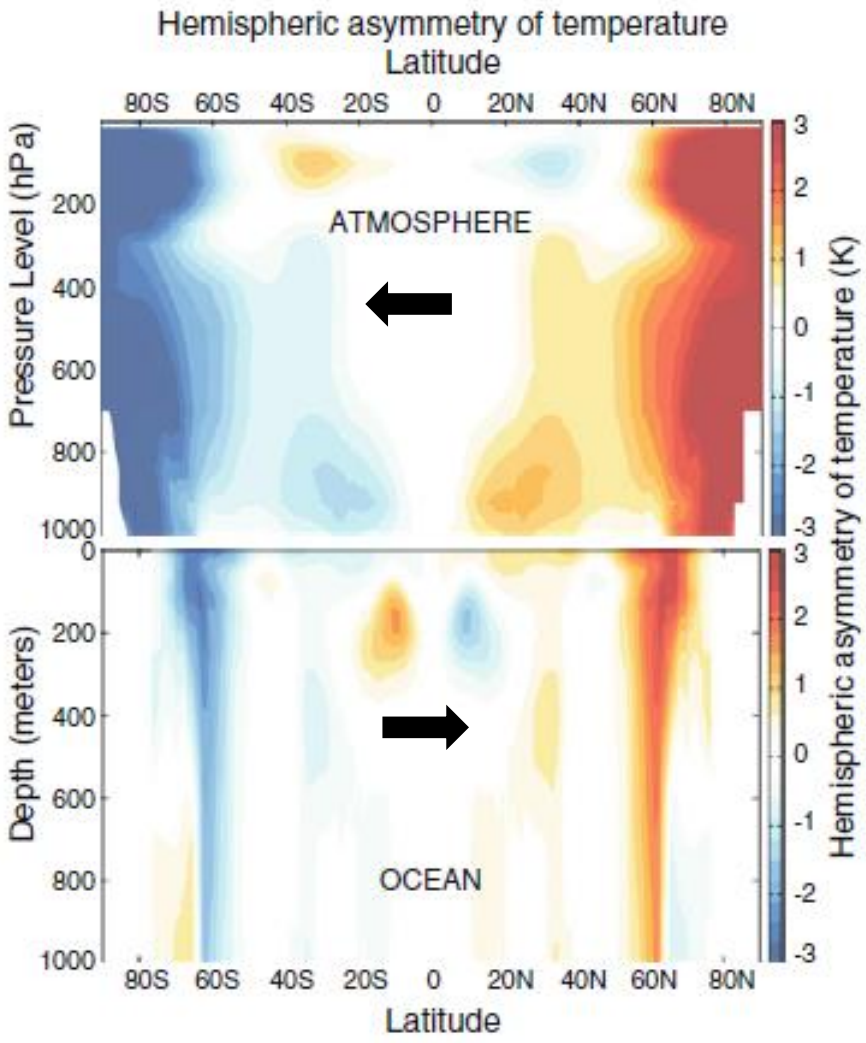


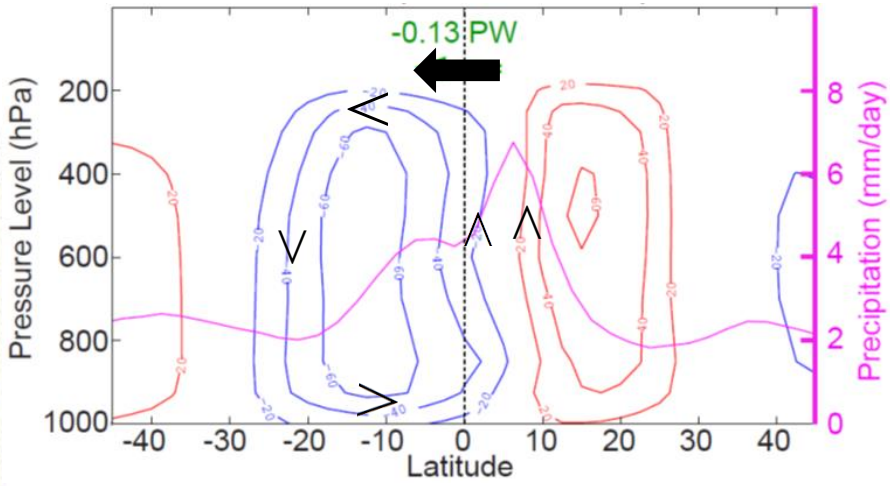


Lumpkin and Speer, 2007

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

NH is warmer than the SH because of ocean circulation

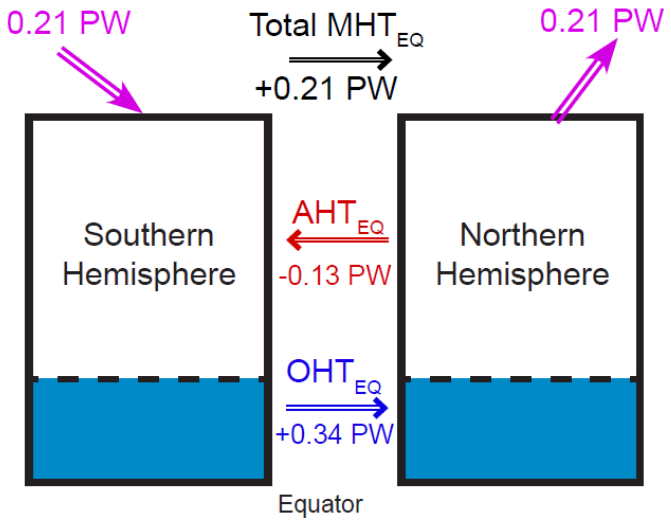




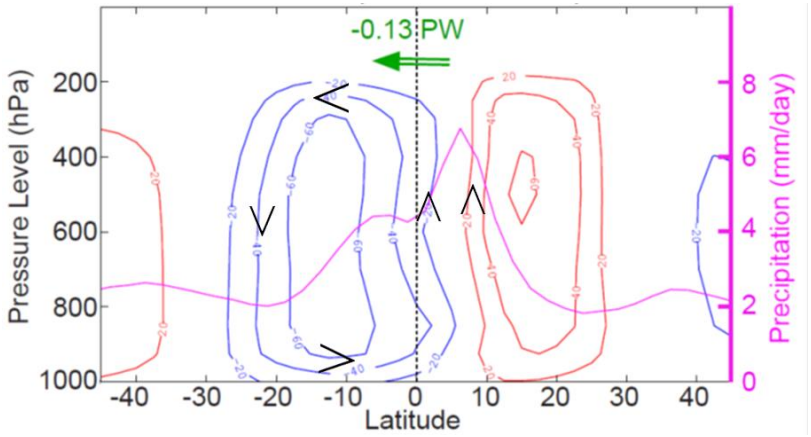
Kang et al, 2008; Donohoe et al, 2013
Frierson et al, 2013; Marshall et al, 2014
Schneider et al, 2014

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

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



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



Donohoe et al, 2013, J. Climate

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

ITCZ is 'pushed northward' by OHT

Marshall et al, 2014; Climate Dynamics

$$AHT + OHT \gtrsim 0$$

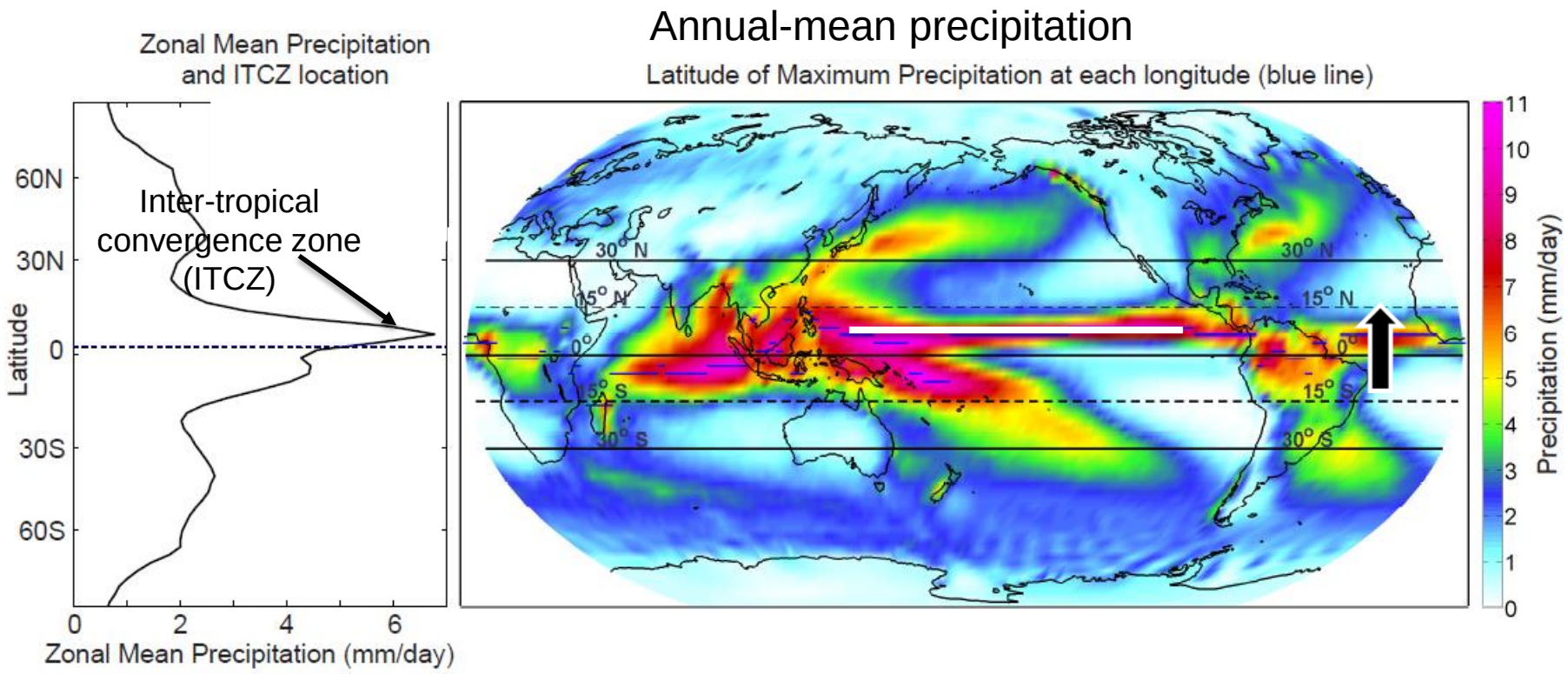
$$OHT > 0$$

and so, atmospheric heat transport must be southward

$$AHT < 0$$

See also Voigt, Stevens, Bader, and Mauritsen, 2013:
The Observed Hemispheric Symmetry in Reflected Shortwave Irradiance. *J. Climate*, **26**, 468–477.

Summary



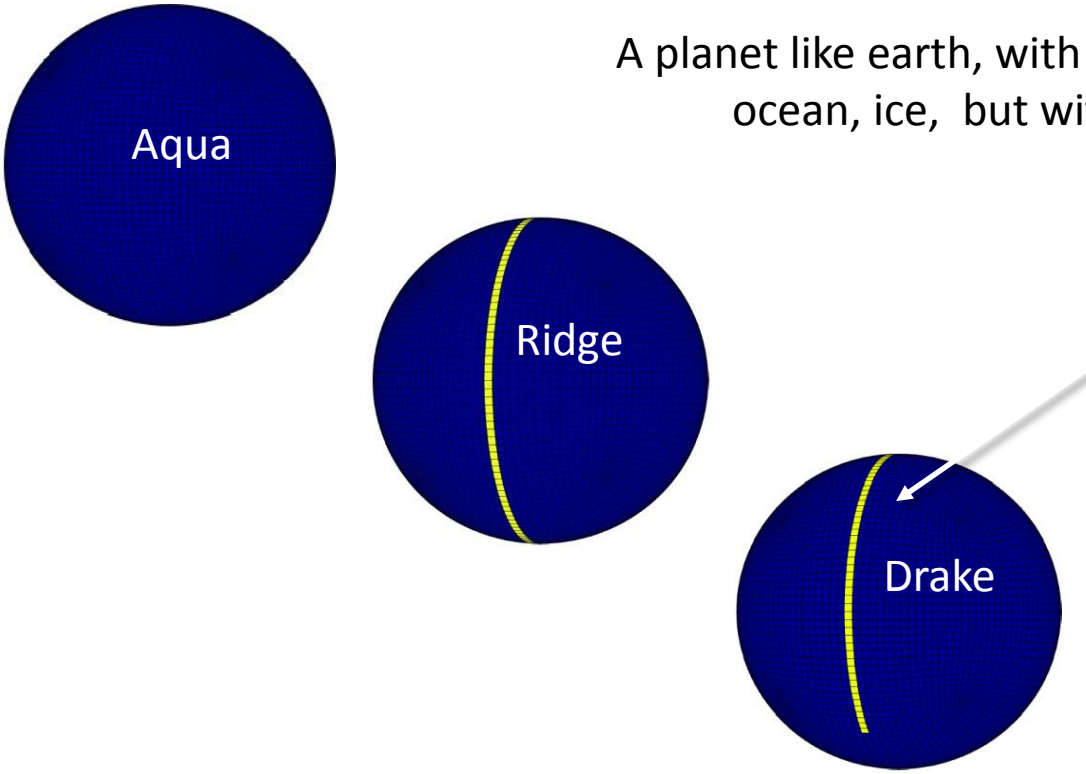
1. Atlantic ocean circulation transports heat northward across the equator

2. This results in a warming of the NH relative to the SH, and the ITCZ being displaced north of the equator

3. Variability in cross-equatorial ocean heat transport may lead to decadal ITCZ shifts

Study energy transport in idealized systems

Aqua-planet



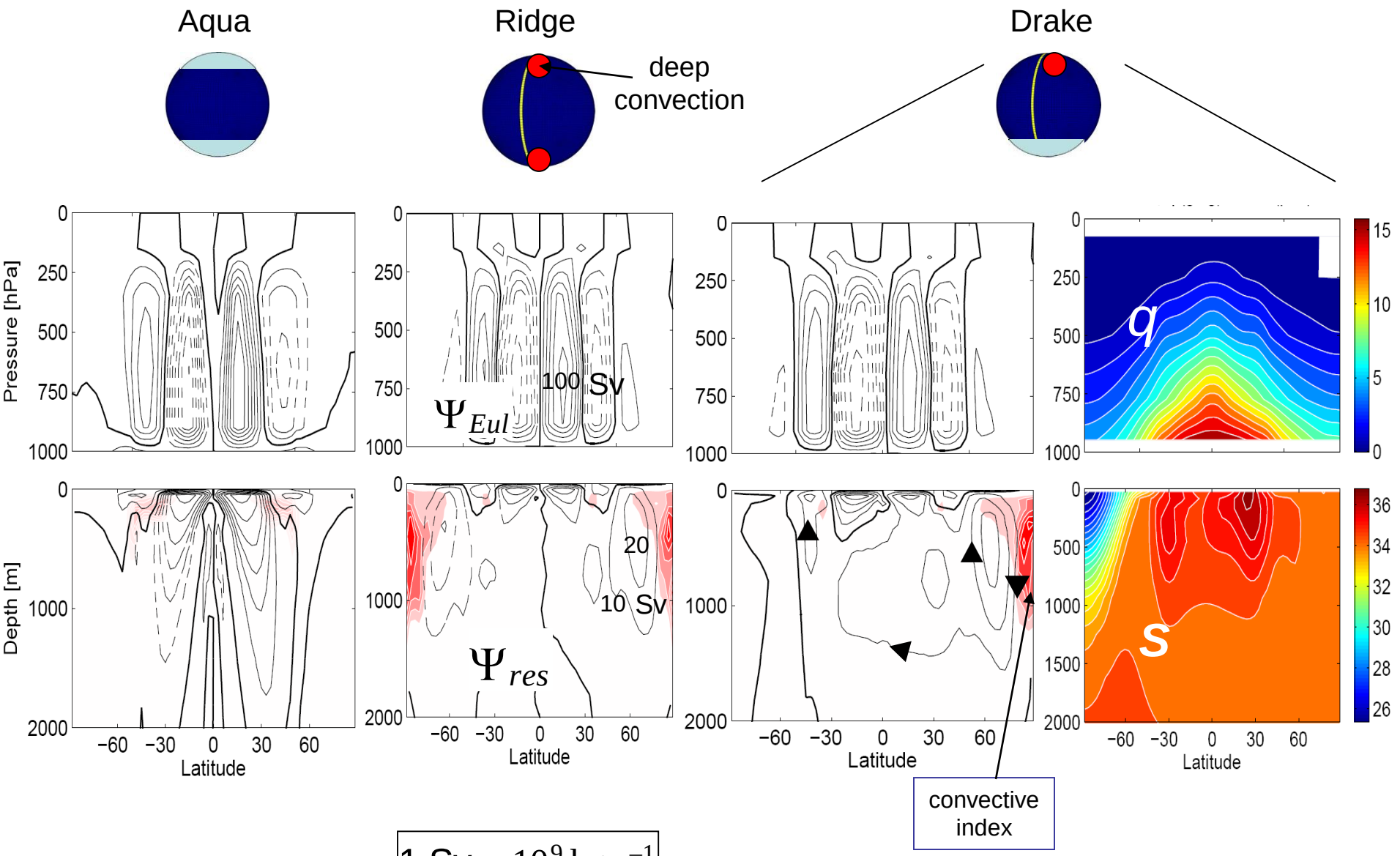
A planet like earth, with an atmosphere, ocean, ice, but with on land

Barriers introduce geometrical constraints on ocean circulation

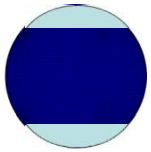
Marshall et al, 2007
Enderton and Marshall, 2009
Ferreira et al, 2010

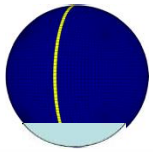
Rich solutions which exhibit Earth-like properties

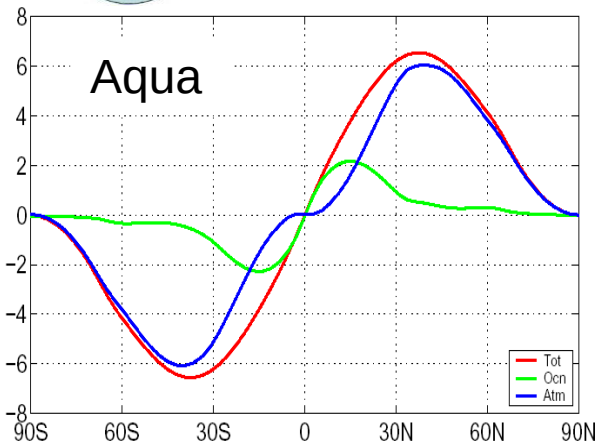
Overturning circulation and convection

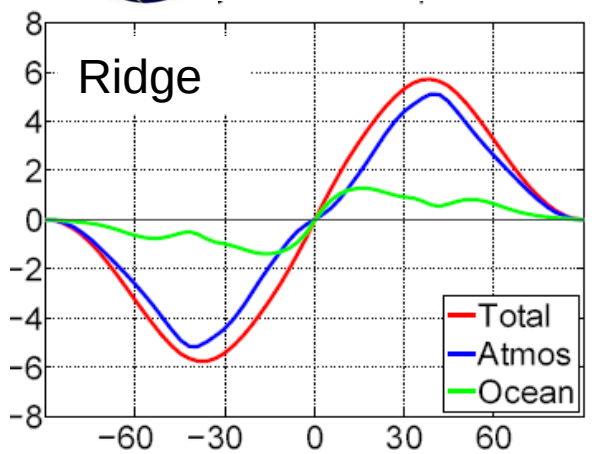


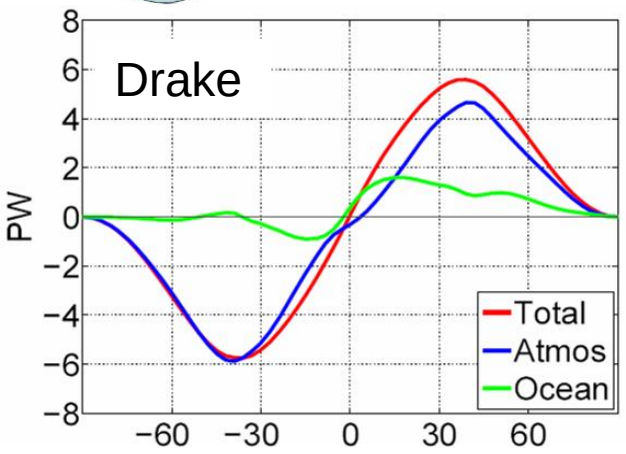
$$1\ \mathrm{Sv} = 10^9\ \mathrm{kg\ s^{-1}}$$



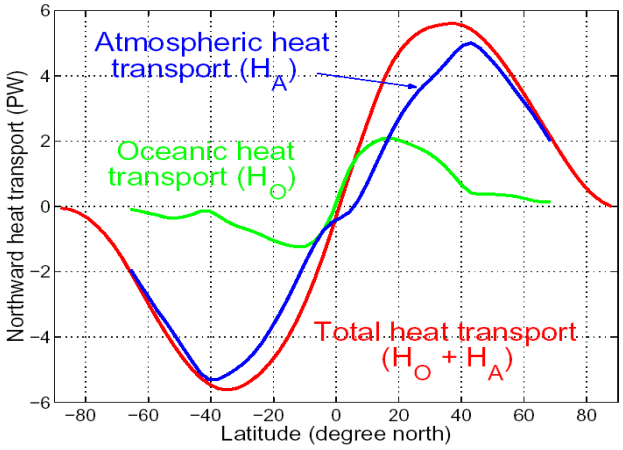








Today's climate



PW

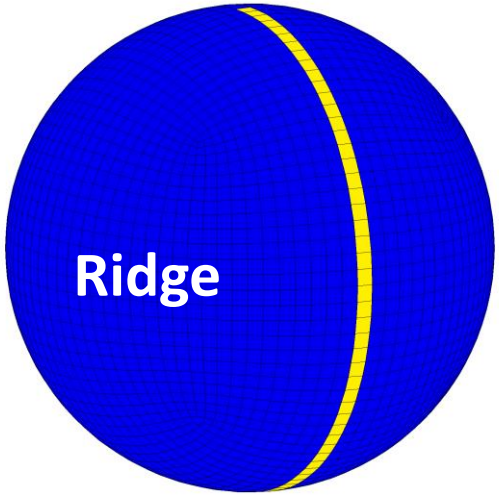
4

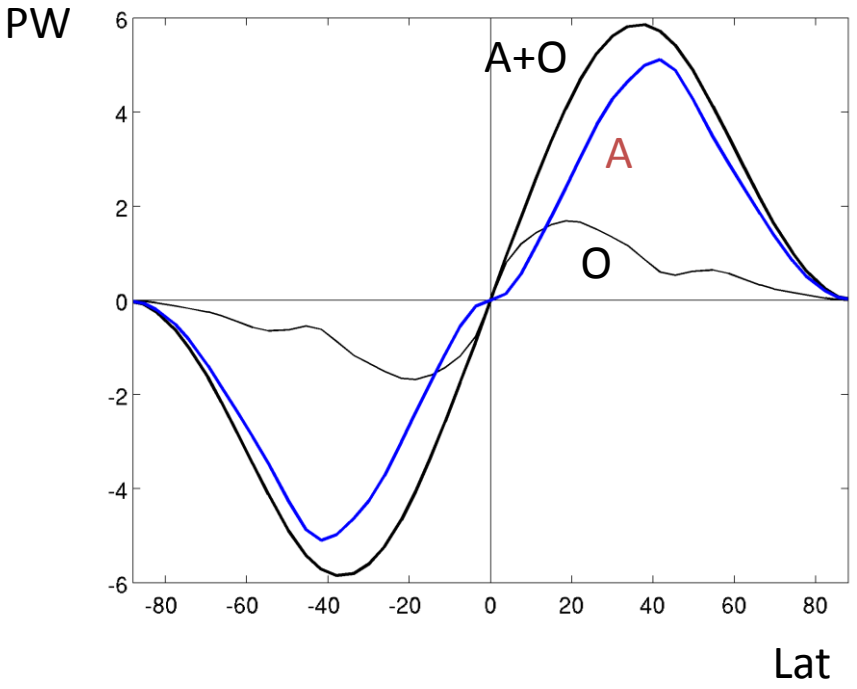
0

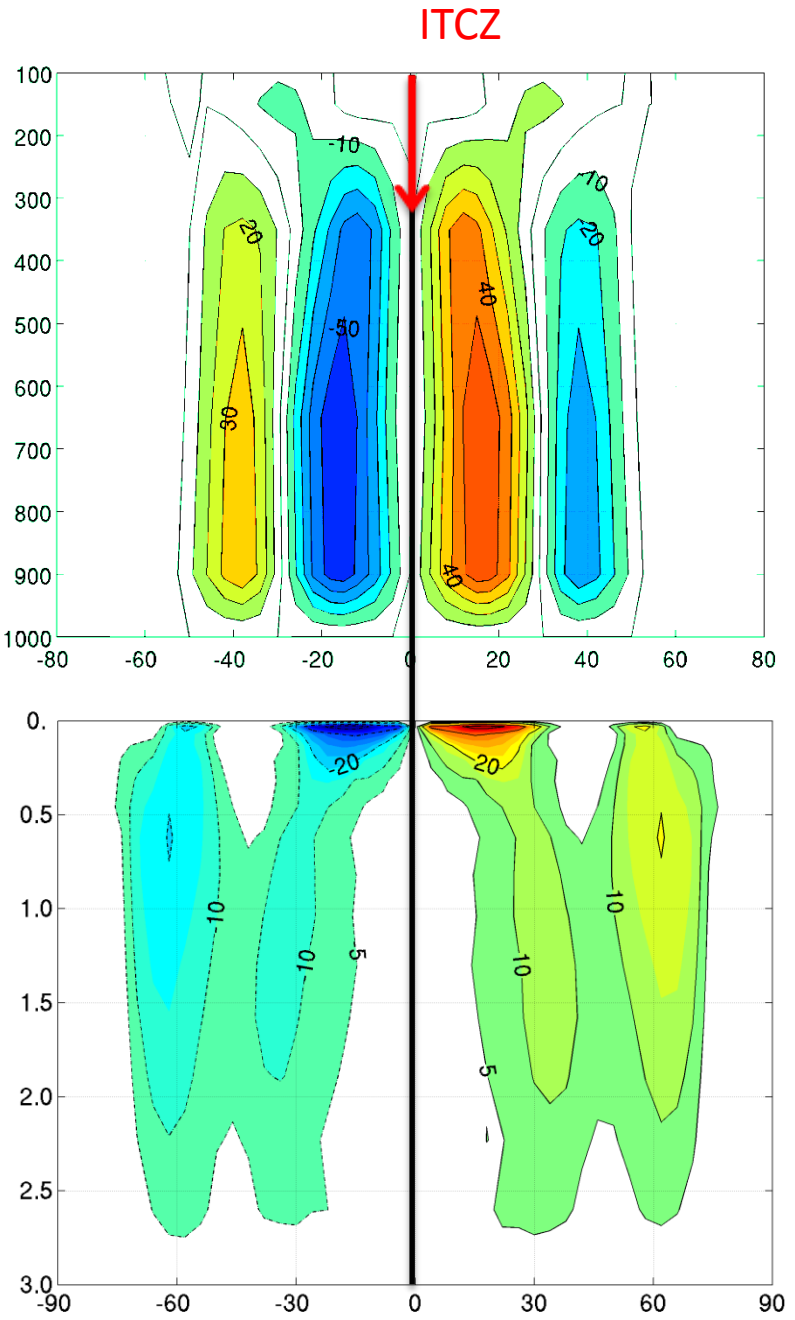
- 4

Enderton and Marshall, JAS, 2009

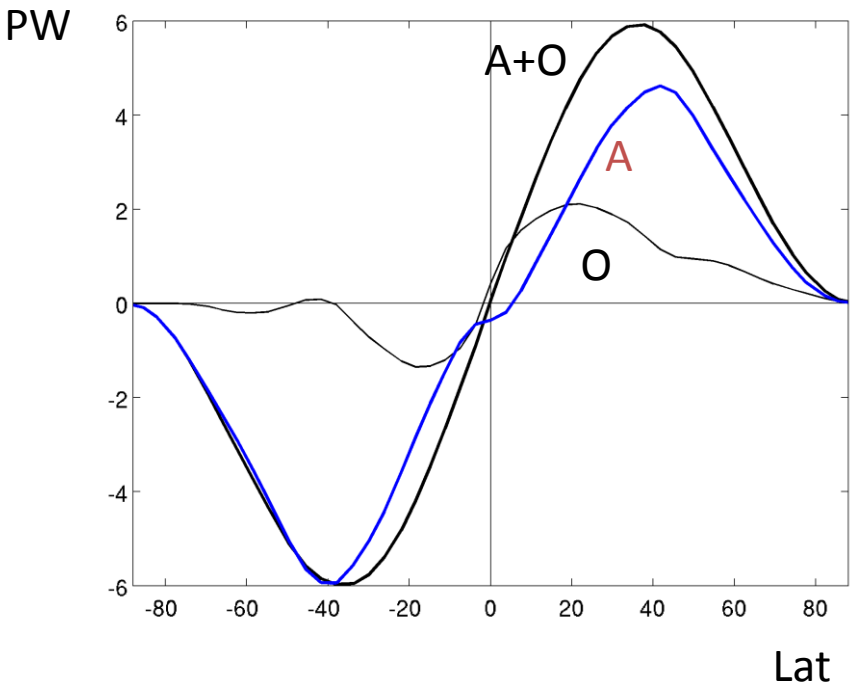
Position of the ITCZ

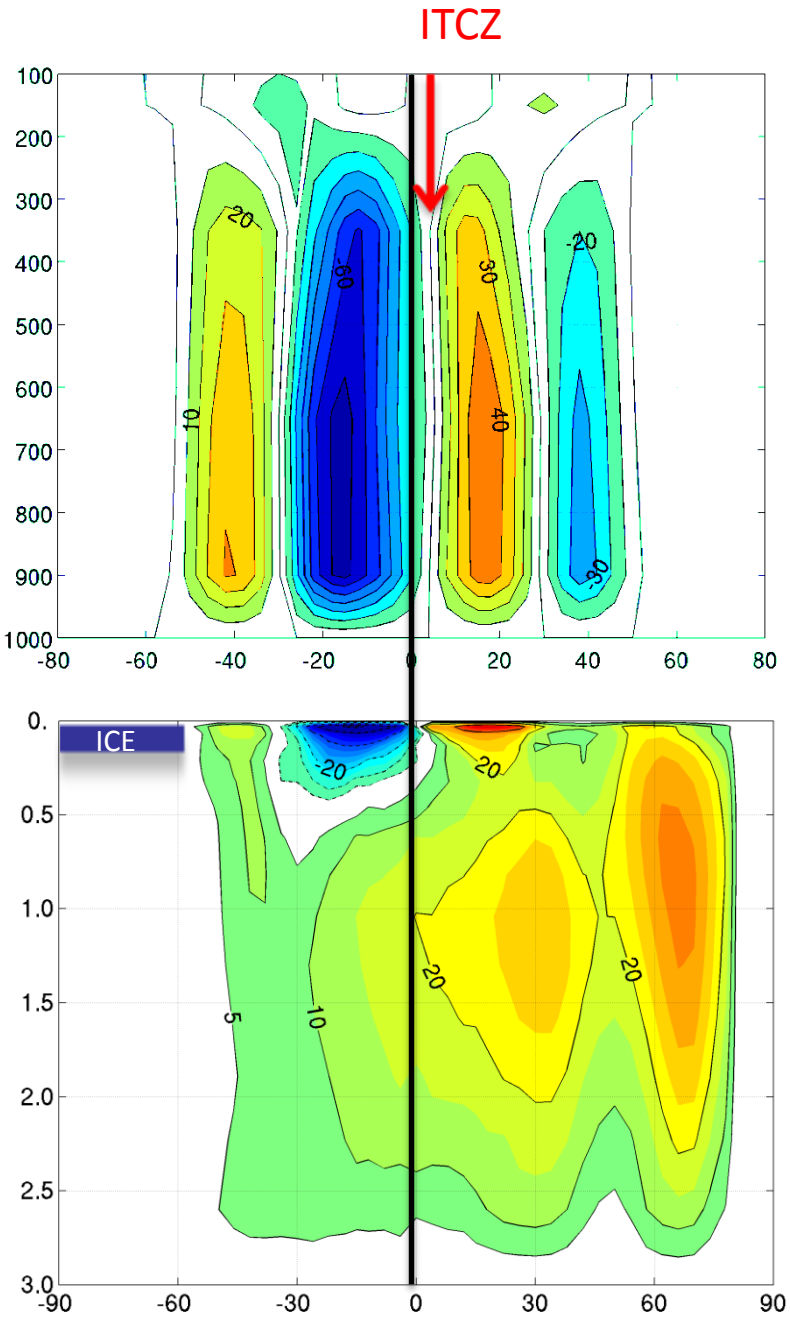






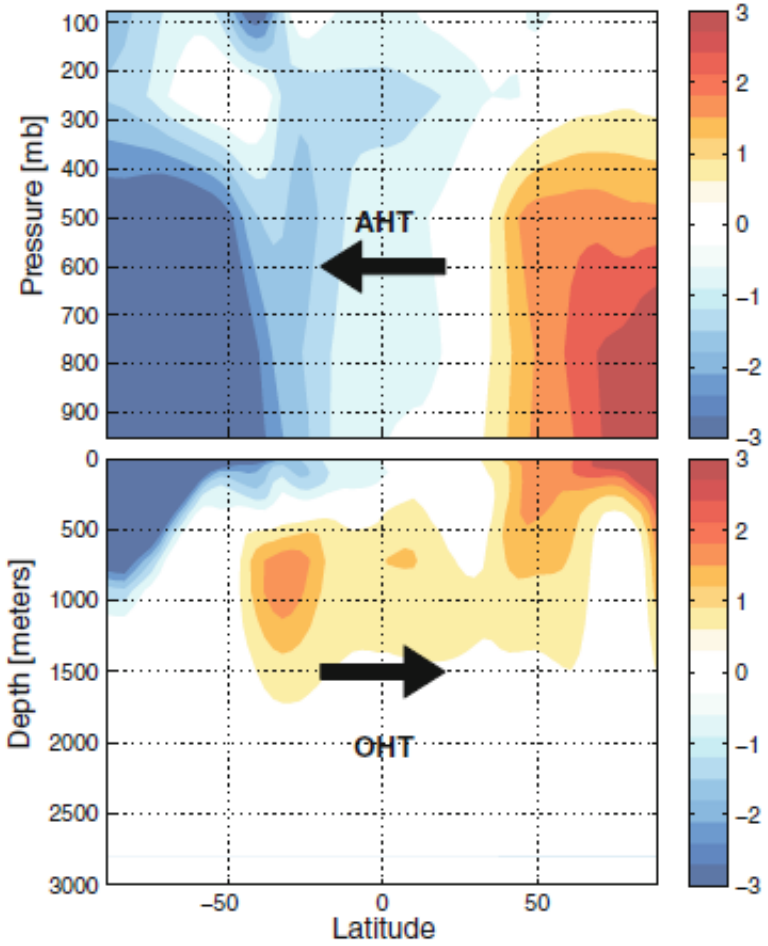
Position of the ITCZ

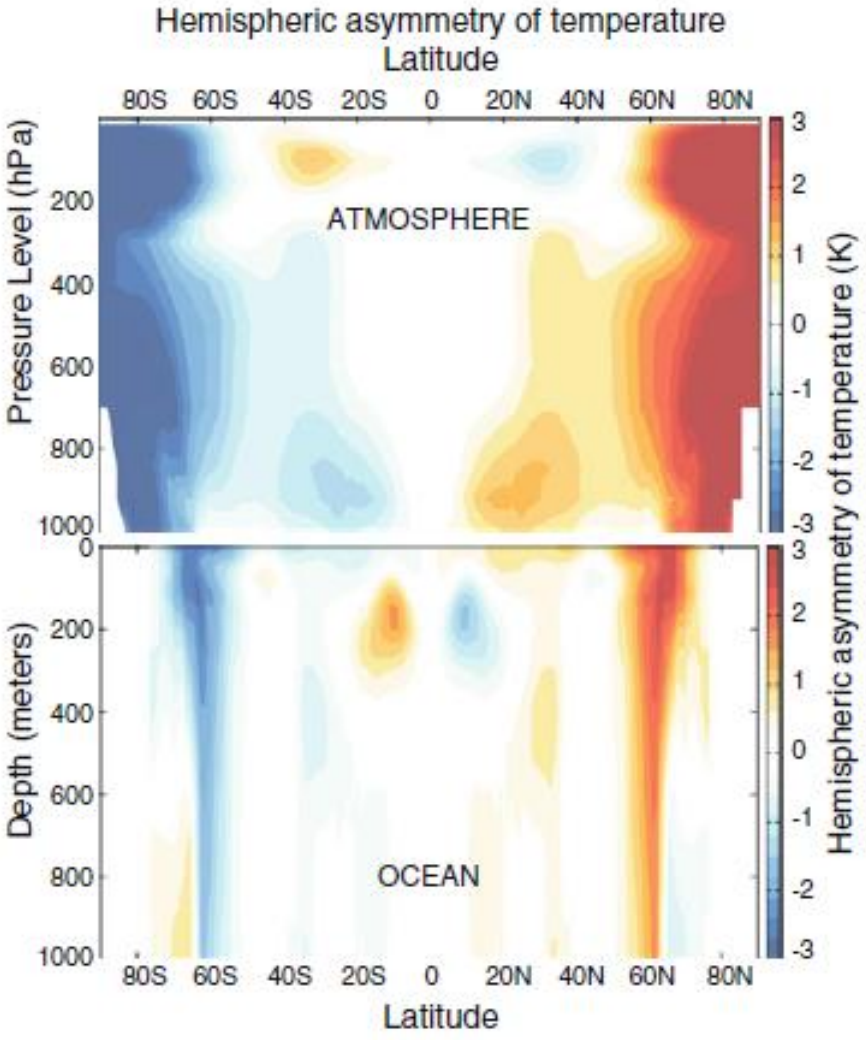




NH is warmer than the SH because of ocean circulation

Drake minus Ridge
zonal-average temperature

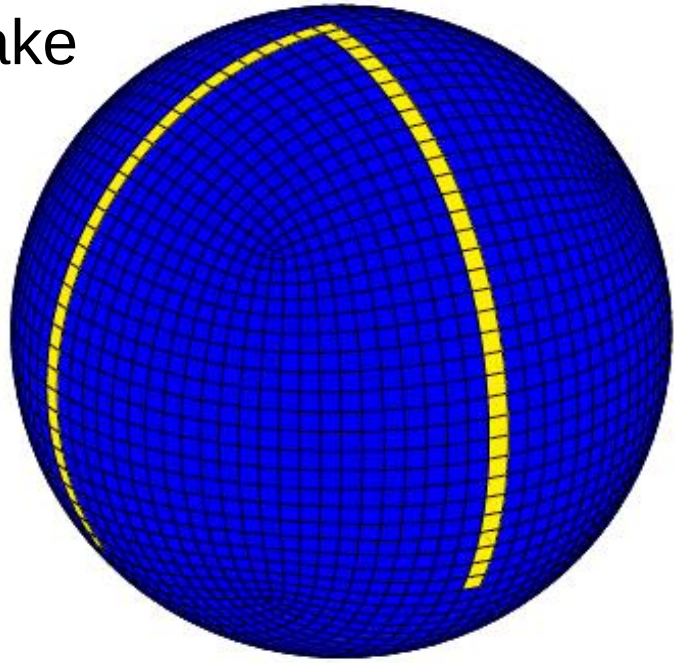




Heat transport can be up-gradient in the ocean because the ocean is mechanically forced

Why is the ocean's MOC confined to the Atlantic basin?

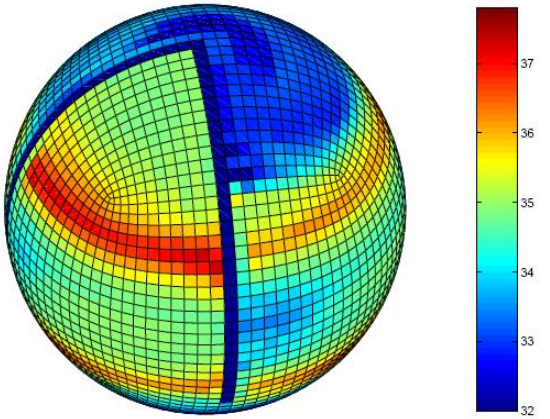
Double Drake



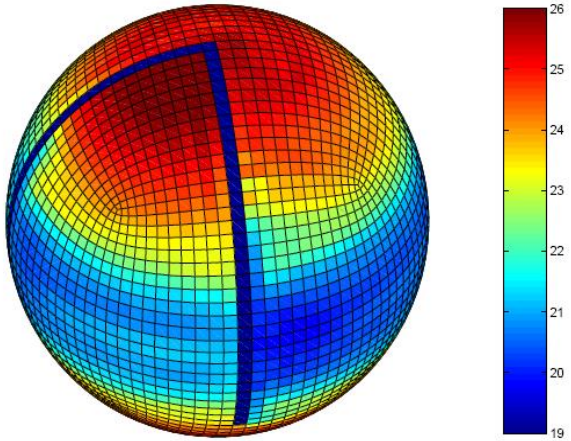
Ferreira et al, J. Climate, 2009

Zonal asymmetries in the hydrological cycle

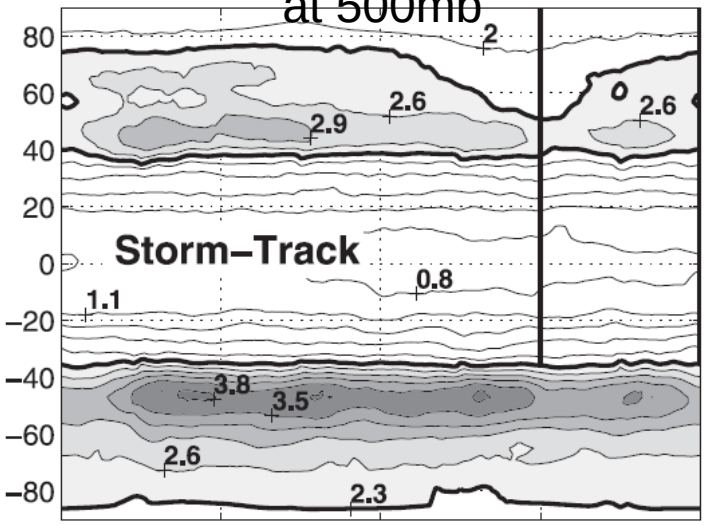
Surface Salinity



Surface Density

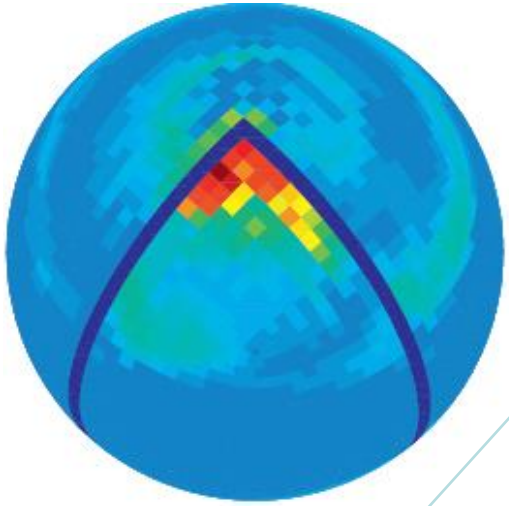


T variance at 500mb



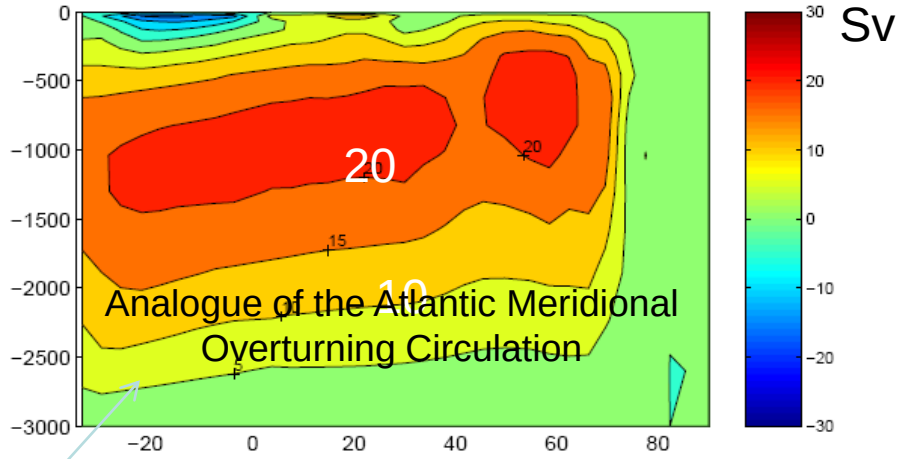
Deep Overturning circulation is confined to the small (salty) basin

Convective index

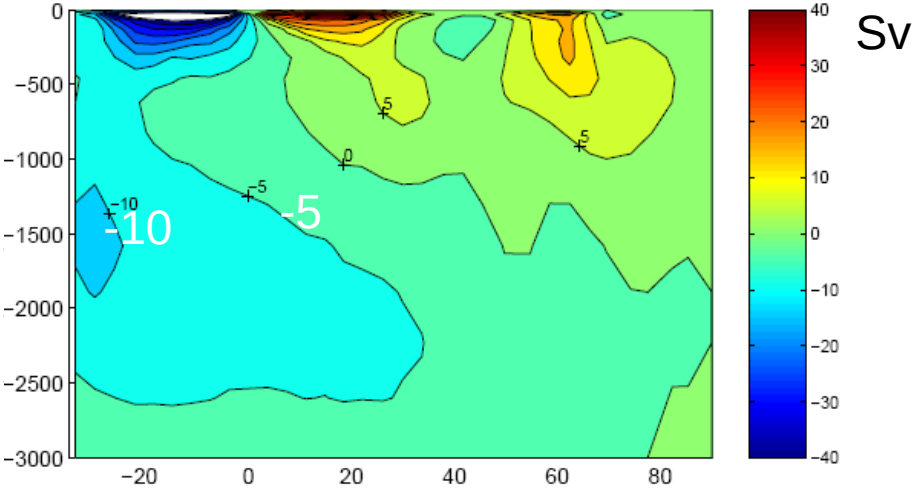


Connects the hemispheres together

Small basin

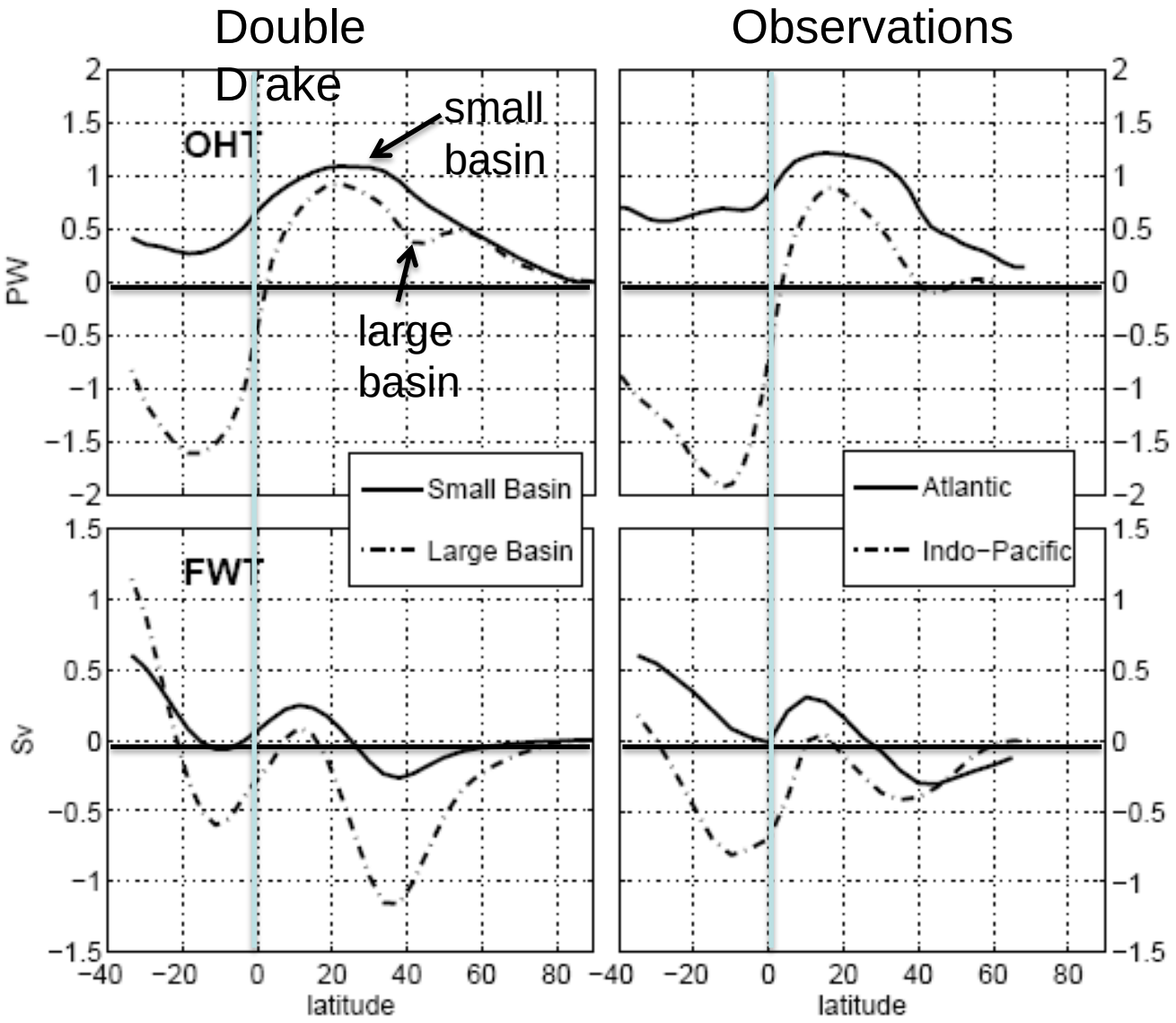


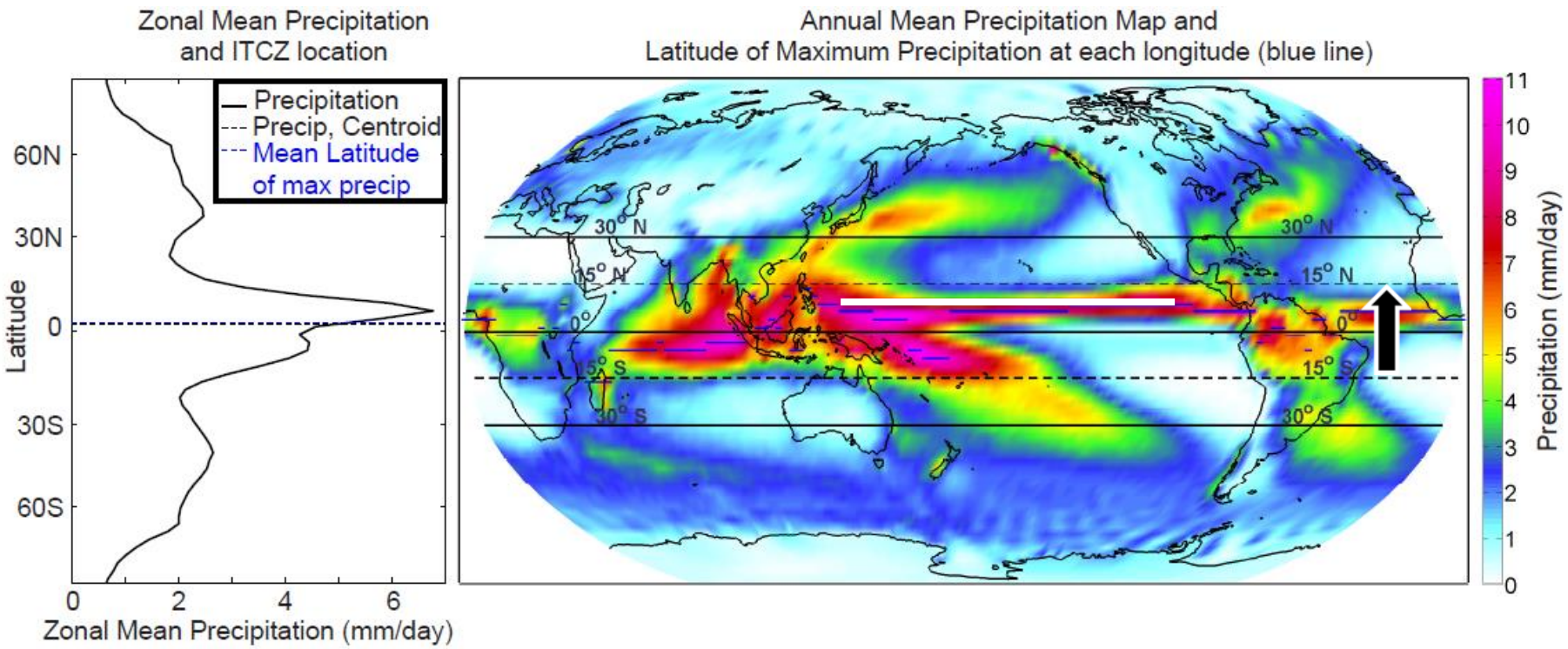
Large basin



Heat transport (PW)

Fresh water transport (SV)





I've argued that

ITCZ is displaced north of the equator

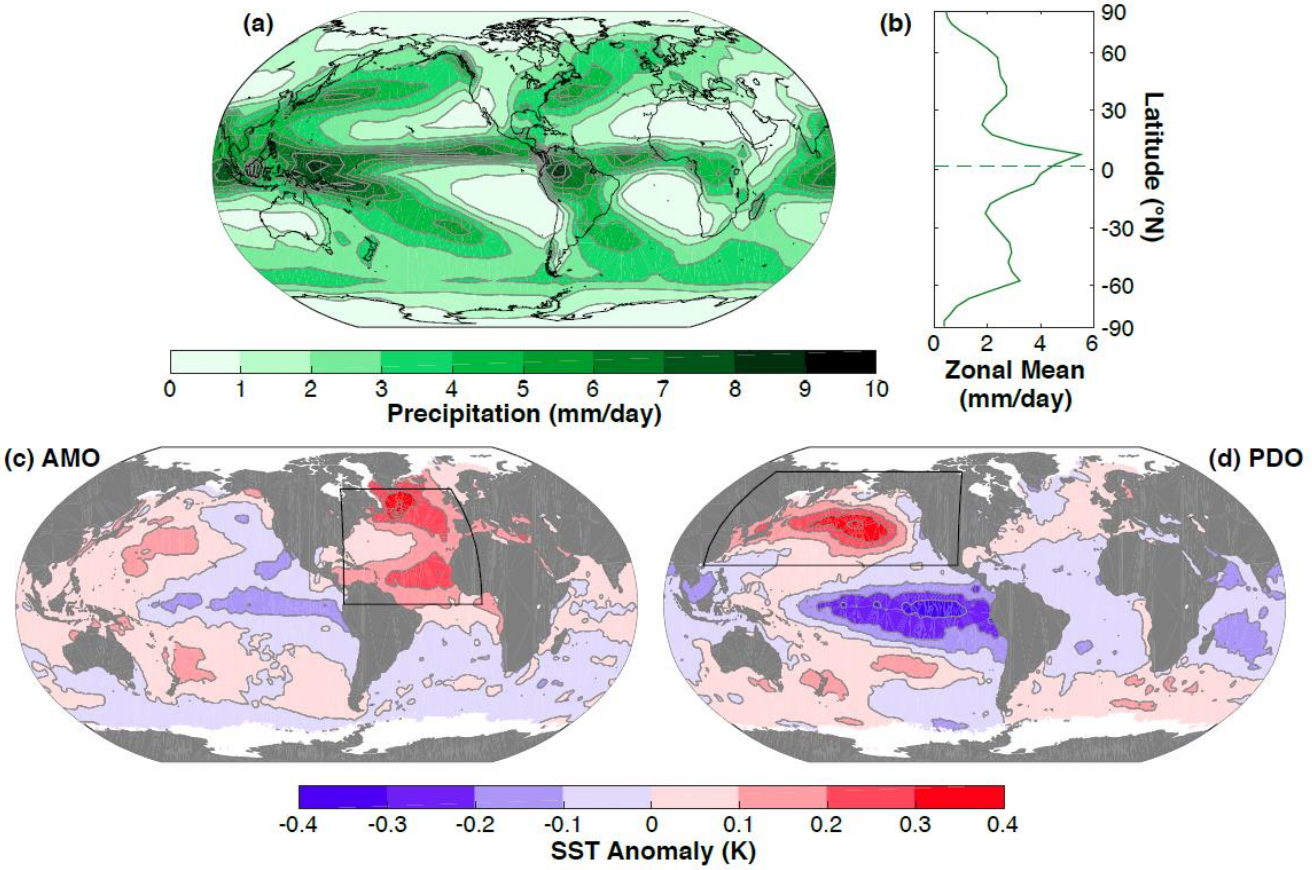
<u>because</u>

Atlantic MOC carries heat northward across the equator

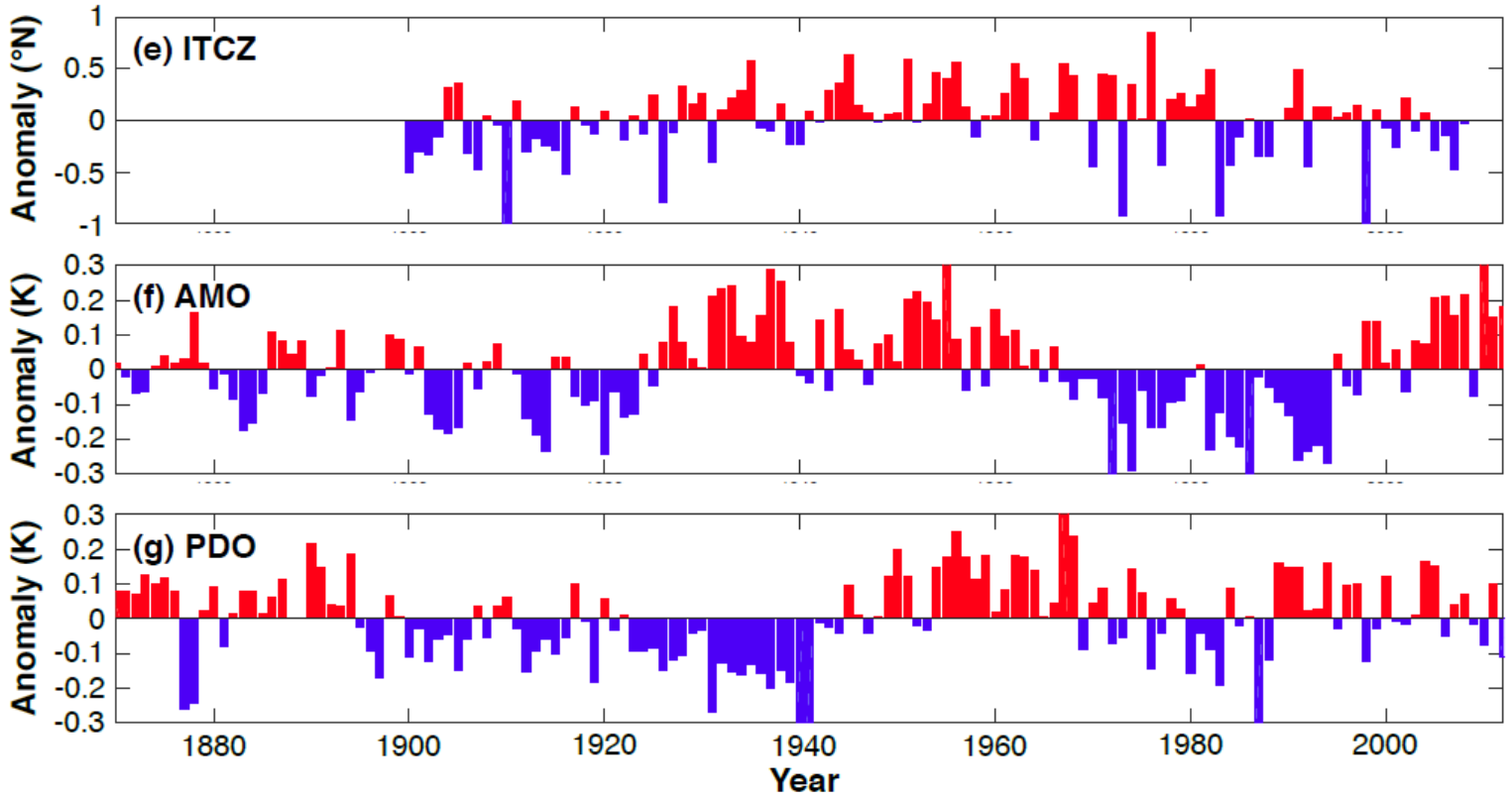
So, can decadal variability in the Atlantic MOC induce decadal shifts in the position of the ITCZ?

Observed correlations between multi-decadal SST variability and ITCZ migrations

With Brian Green and Aaron Donohoe

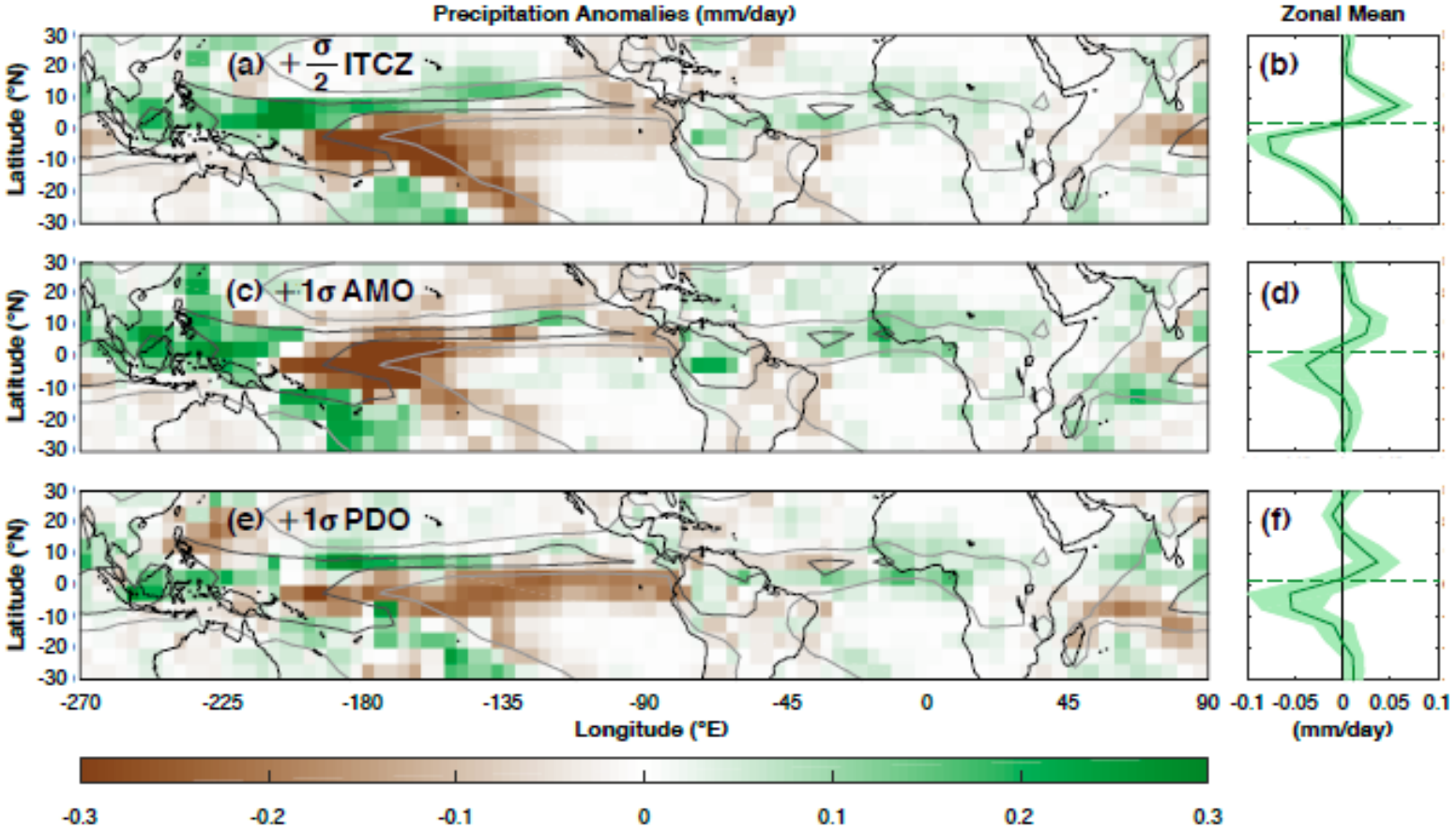


Precipitation data from 1990 due to Smith et al, 2012
SST data from Rayner et al, 2003

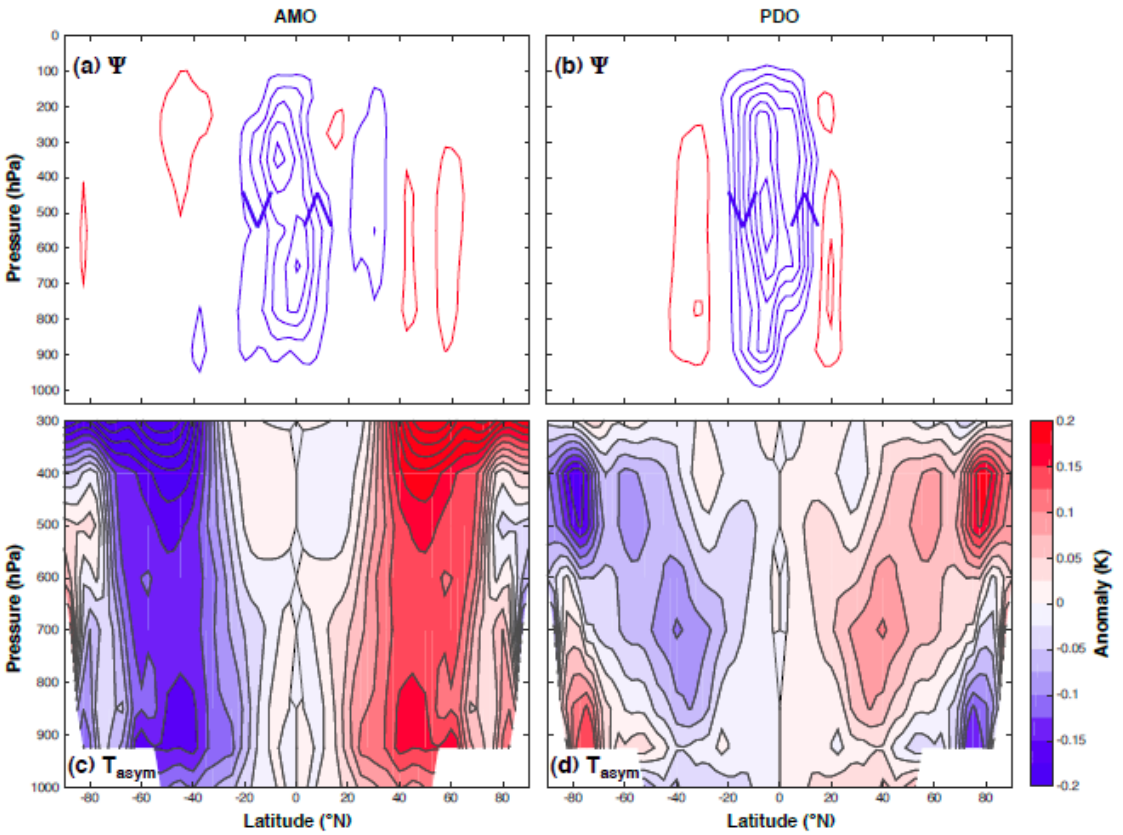


		ITCZ
AMO:	**R^2**	0.11
	Anomaly	0.07 ± 0.05 (°N)
PDO:	**R^2**	0.14
	Anomaly	0.10 ± 0.06 (°N)

Precipitation anomalies regressed against ITCZ shifts, the AMO and PDO



Overturning circulation and hemispherically asymmetric T regressed on to the AMO and PDO



		ITCZ	Ψ_{eq}	$T_{interhem}$
AMO:	**R^2**	0.11	0.41	0.74
	Anomaly	0.07 ± 0.05 (°N)	-2.9 ± 1.1 (Sv)	0.17 ± 0.05 (K)
PDO:	**R^2**	0.14	0.17	0.02
	Anomaly	0.10 ± 0.06 (°N)	-3.3 ± 1.7 (Sv)	0.04 ± 0.07 (K)

Summary

1. Distinctive feature of ocean's MOC is that it carries significant amounts of heat across the equator

2. Association between ITCZ and AHT at equator is established

e.g. papers by Kang, Frierson, Chiang, Held, Donohoe……., and others

Here, we have gone one step further to argue that, at the equator:

$$AHT + OHT \simeq 0$$

$$OHT > 0 \quad \text{and so} \quad AHT < 0$$

i.e. ocean's MOC 'pushes' the ITCZ north of the equator

Frierson et al, 2013; Marshall et al, 2014
Schneider et al, 2014

Offers an alternative perspective to that of, e.g., Philander et el, 1996

3. Decadal variability in AMO and PDO can induce decadal variability in position of the ITCZ.

Many discussions with

David McGee, Alan Plumb, Brian Green
MIT

Dargan Frierson,
Aaron Donohoe
UW