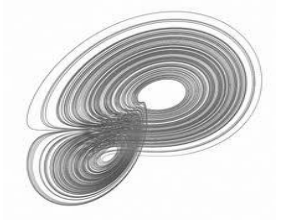
Water in the Climate System

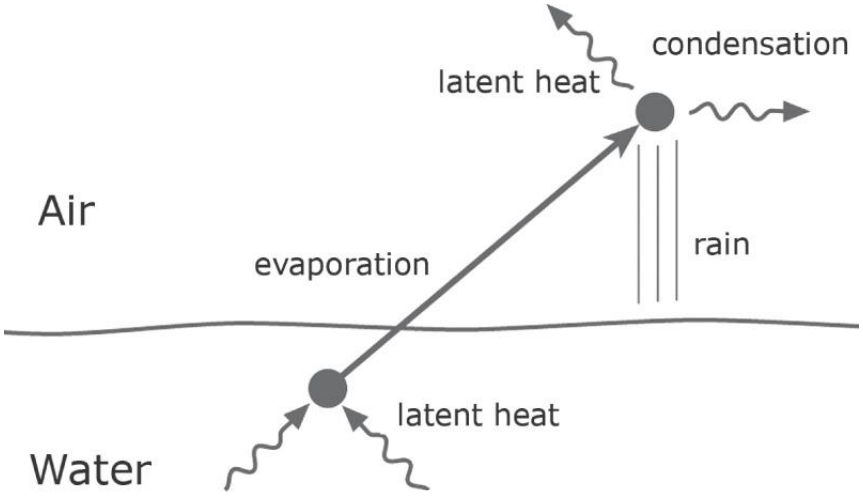
Lorenz Center Workshop
February, 2014



Role of the ocean in the coupled hydrological cycle

John Marshall
Massachusetts Institute of Technology

In steady state,
atmospheric moisture transport must be balanced by an equal and opposite freshwater transport by the oceans.



It's a coupled problem
- but to what extent is the ocean active in this coupling?

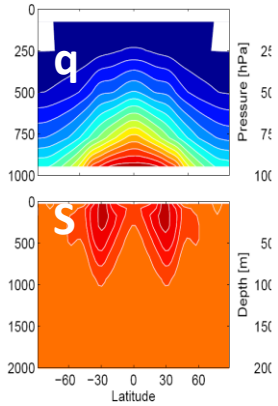
Acknowledge collaboration with David Ferreira and Aaron Donohoe at MIT

Briefly touch on three aspects of coupled hydrological cycle

1

Does oceanic freshwater transport place constraints on atmospheric water transport?

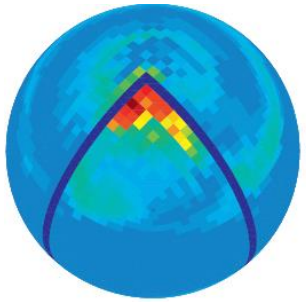
Is the ocean passive, or a true partner?



2

Zonal asymmetries in the hydrological cycle
- organization of atmospheric storm tracks.

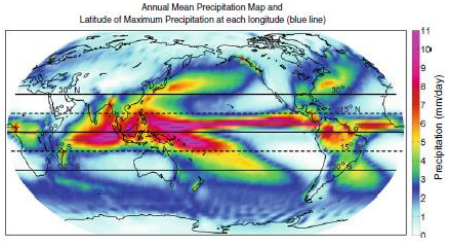
Localization of deep ocean convection in the north Atlantic



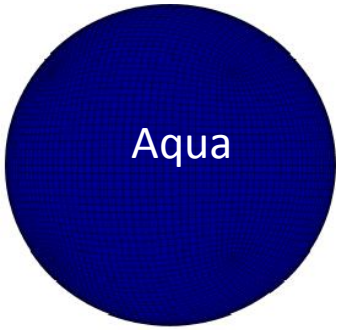
3

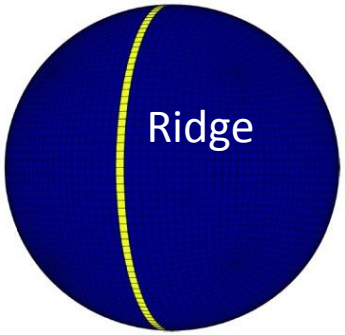
Role of ocean in inter-hemispheric asymmetries in climate
- implications for atmospheric hydrological cycle.

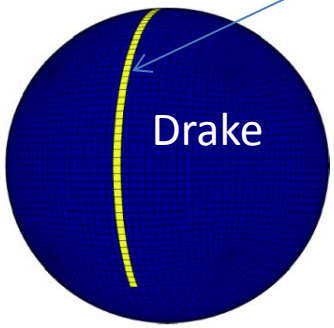
Why is the ITCZ north of the equator?

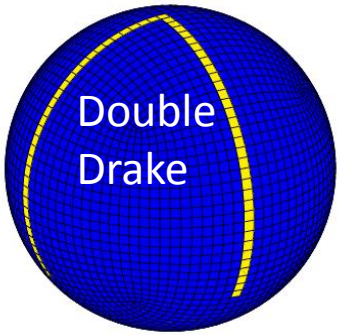


Hydrological cycle in coupled aquaplanet solutions









Barriers introduce geometrical constraints on ocean circulation

Ocean can run currents along boundary, connecting the hemispheres together

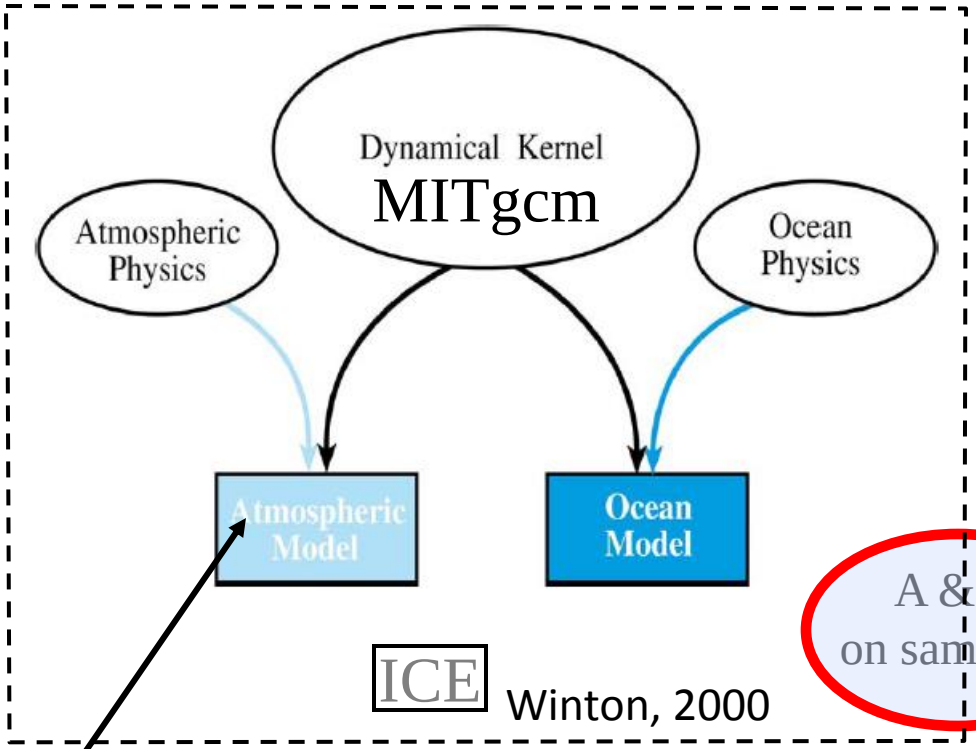
Use to explore the role of the ocean in the coupled system

Rich solutions which exhibit Earth-like properties

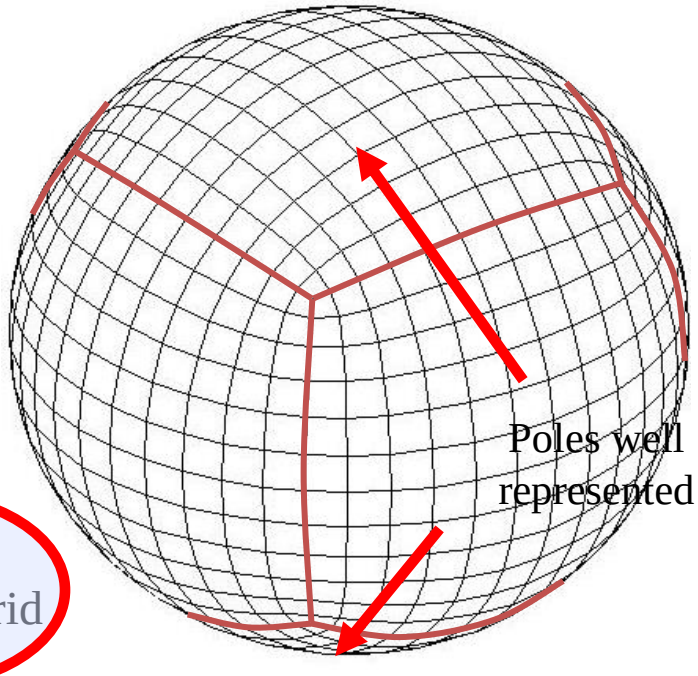
Emphasize aspects that relate to the hydrological cycle

Coupled climate model

Fully coupled:
no adjustments



A & O
on same grid



'SPEEDY' → Intermediate complexity

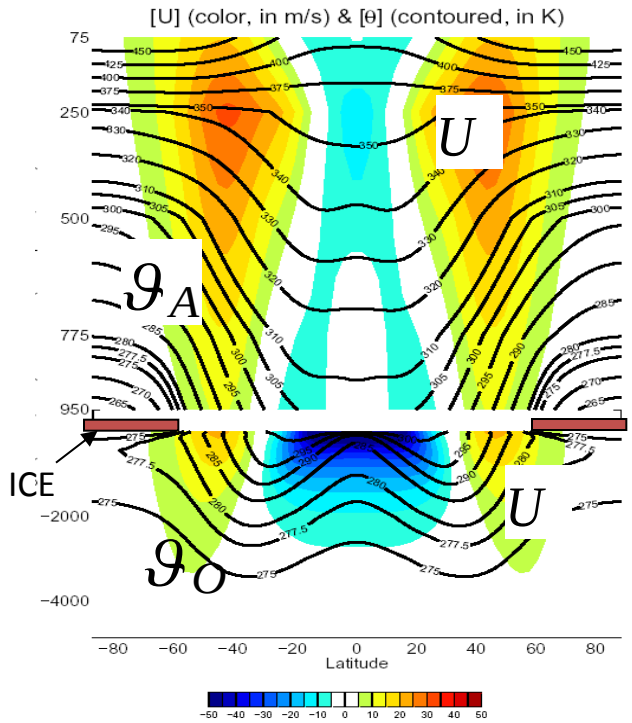
Molteni, 2003

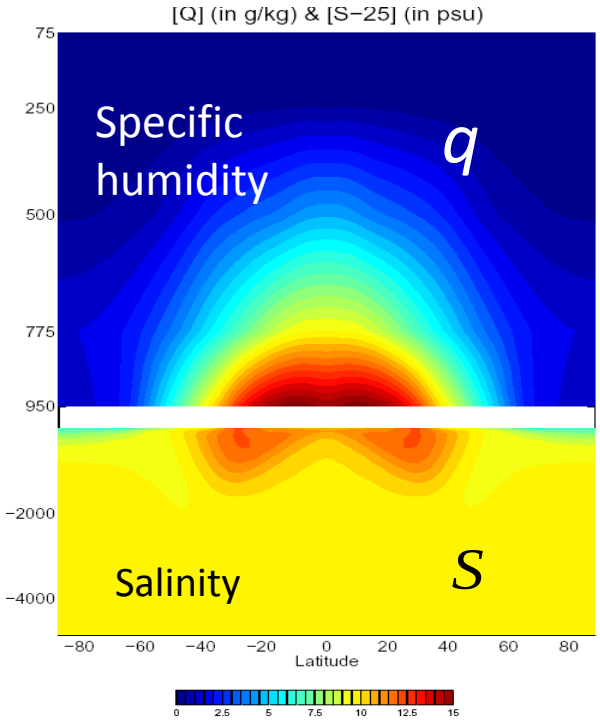
1500 years in 1 week of CPU time
(synchronous)

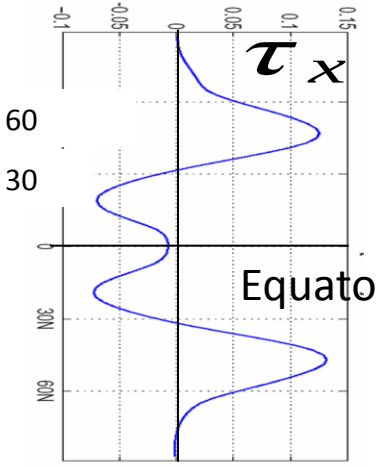
J-M Campin
David Ferreira

David Ferreira

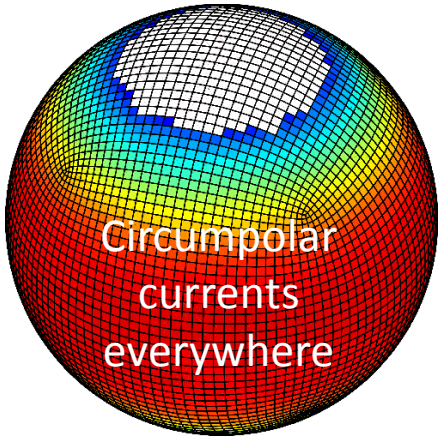
Climate of an aqua-planet







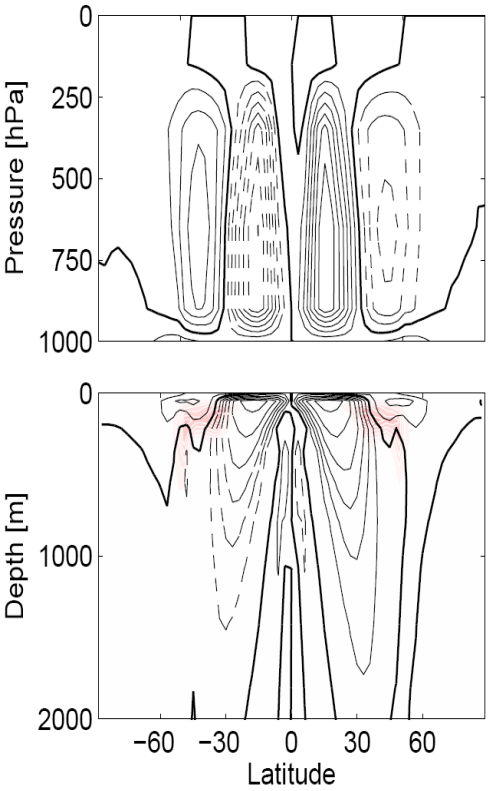
Zonal jets in ocean



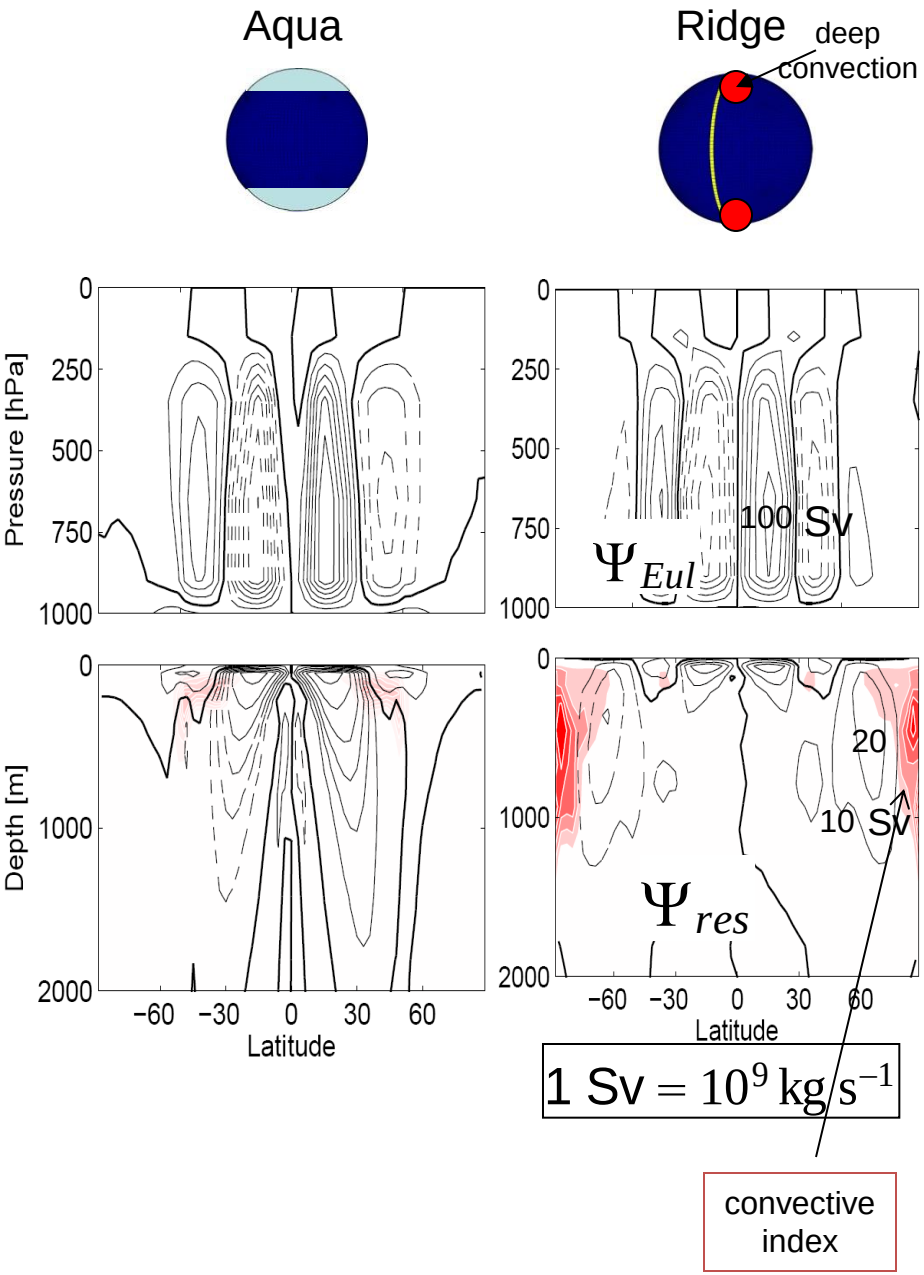
Marshall et al, JAS, 2007

Overturning circulation and convection

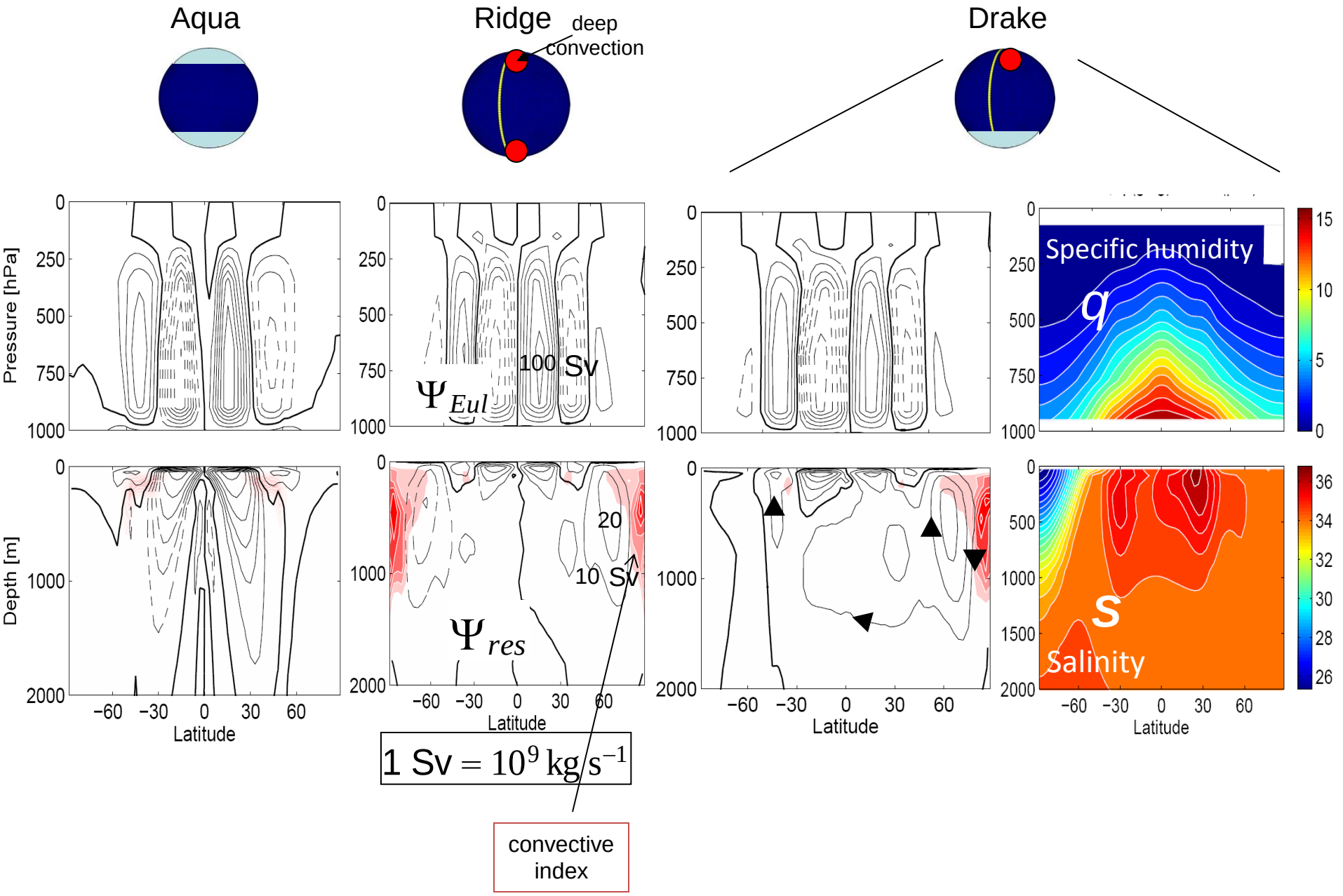
Aqua



Overturning circulation and convection



Overturning circulation and convection



1

Does oceanic freshwater transport place constraints on atmospheric latent heat transport?

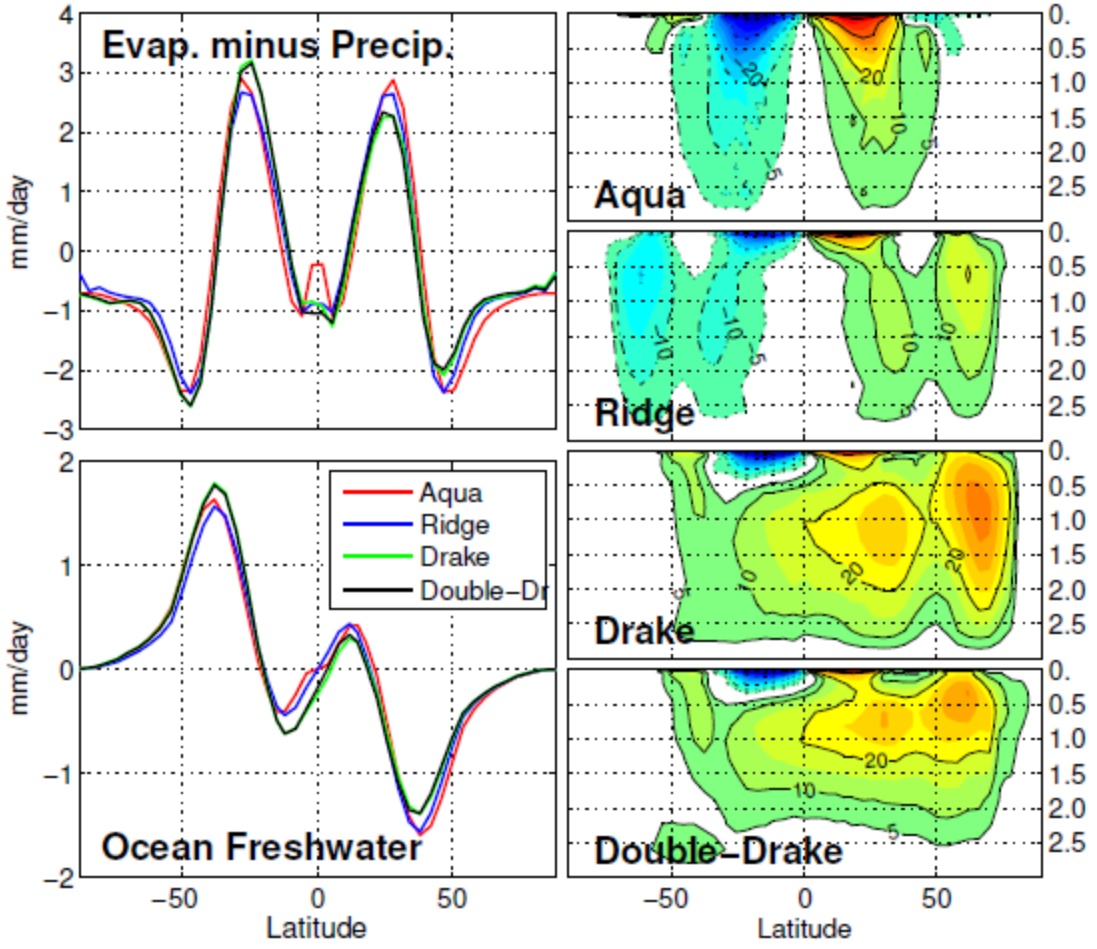
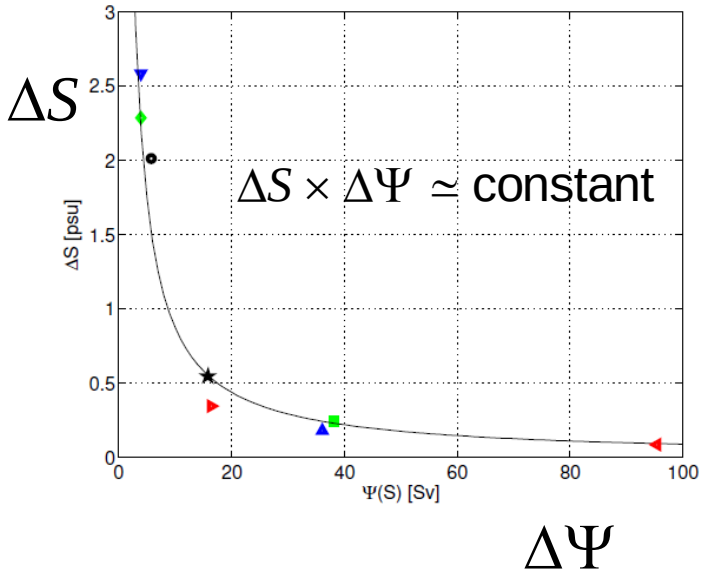


Figure 1. Left: (top) Zonal- and time-average of Evaporation minus Precipitation (in mm/day) and (bottom) time-average ocean FWT (in Sv) for Aqua, Ridge, Drake and Double-Drake. Right: Residual-mean MOC (in Sv), the sum of the Eulerian and (parameterized) eddy overturnings. Clockwise and counterclockwise circulations are denoted by red and blue shadings, respectively.

$\Delta S, \Delta\Psi$ at 60N,S



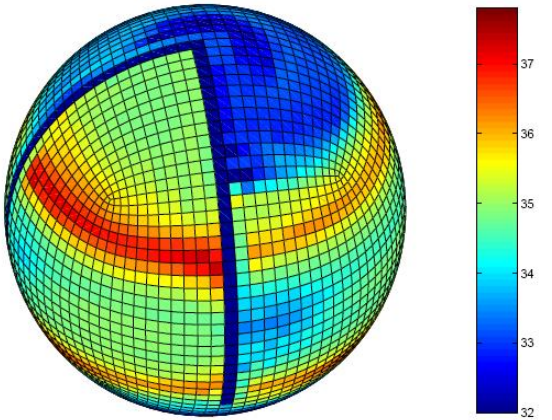
Ocean FWT is 'slaved' to the atmosphere.

Ferreira and Marshall, 2014

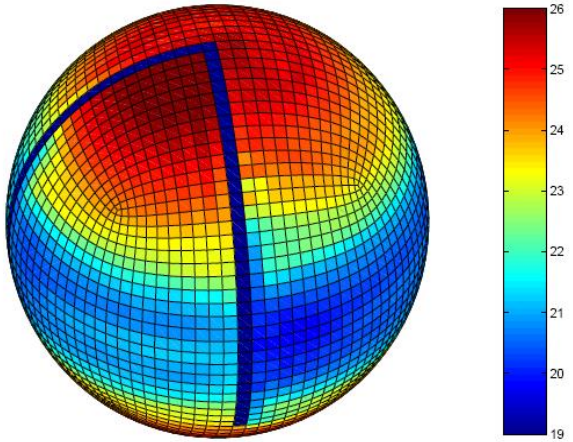
2

Zonal asymmetries in the hydrological cycle

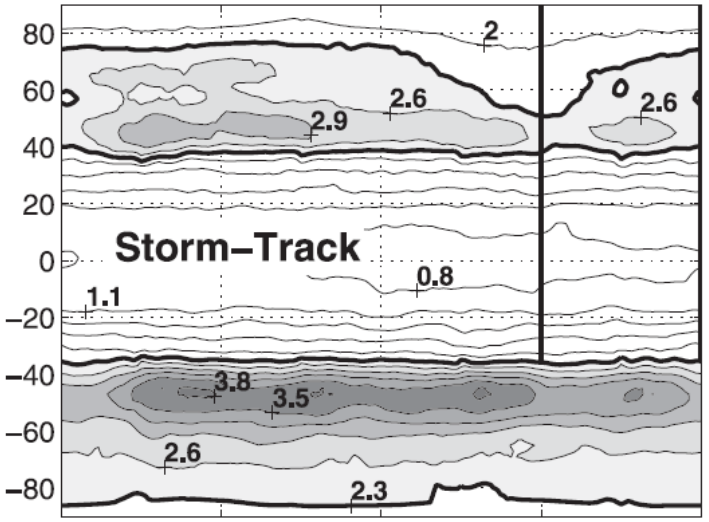
Surface Salinity



Surface Density

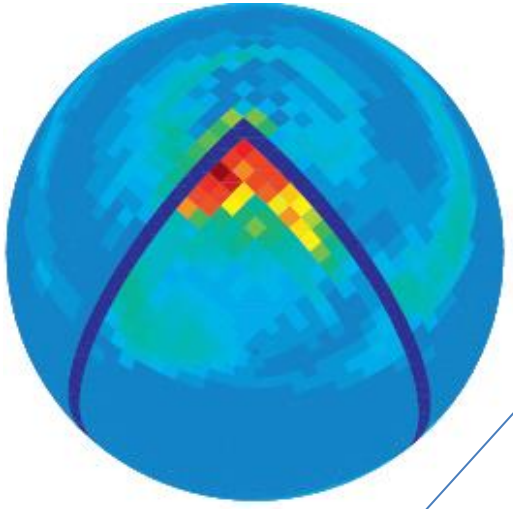


T variance
at 500mb



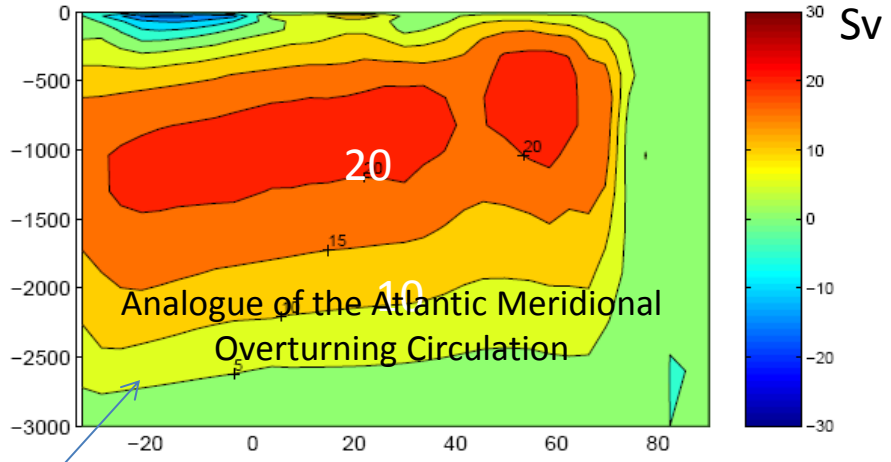
Deep Overturning circulation is confined to the small (salty) basin

Convective index



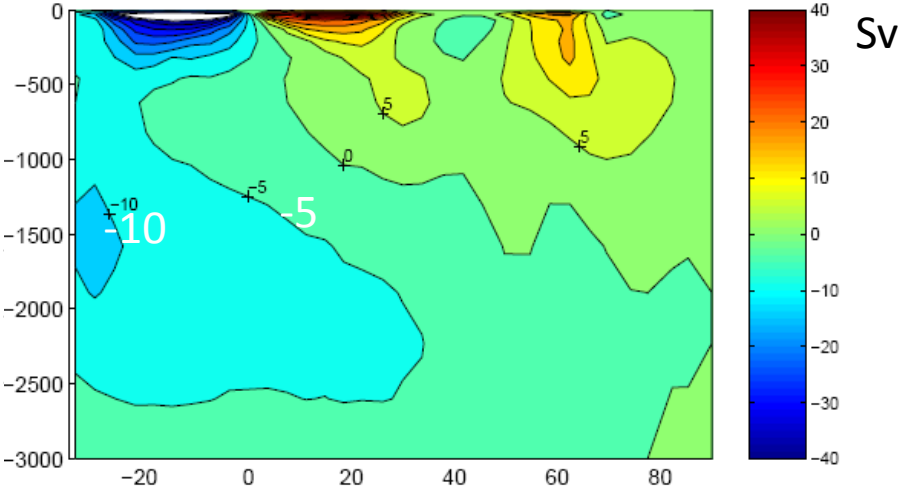
Connects the hemispheres together

Small basin



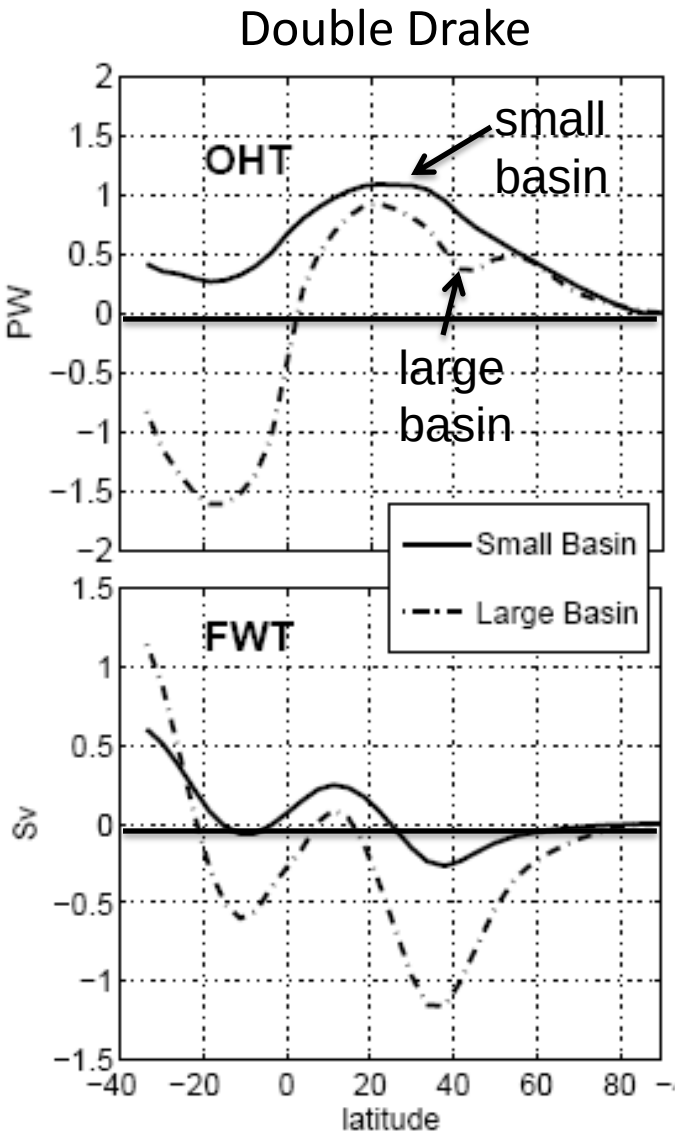
Analogue of the Atlantic Meridional Overturning Circulation

Large basin



Heat transport (PW)

Fresh water transport (SV)



Heat transport (PW)

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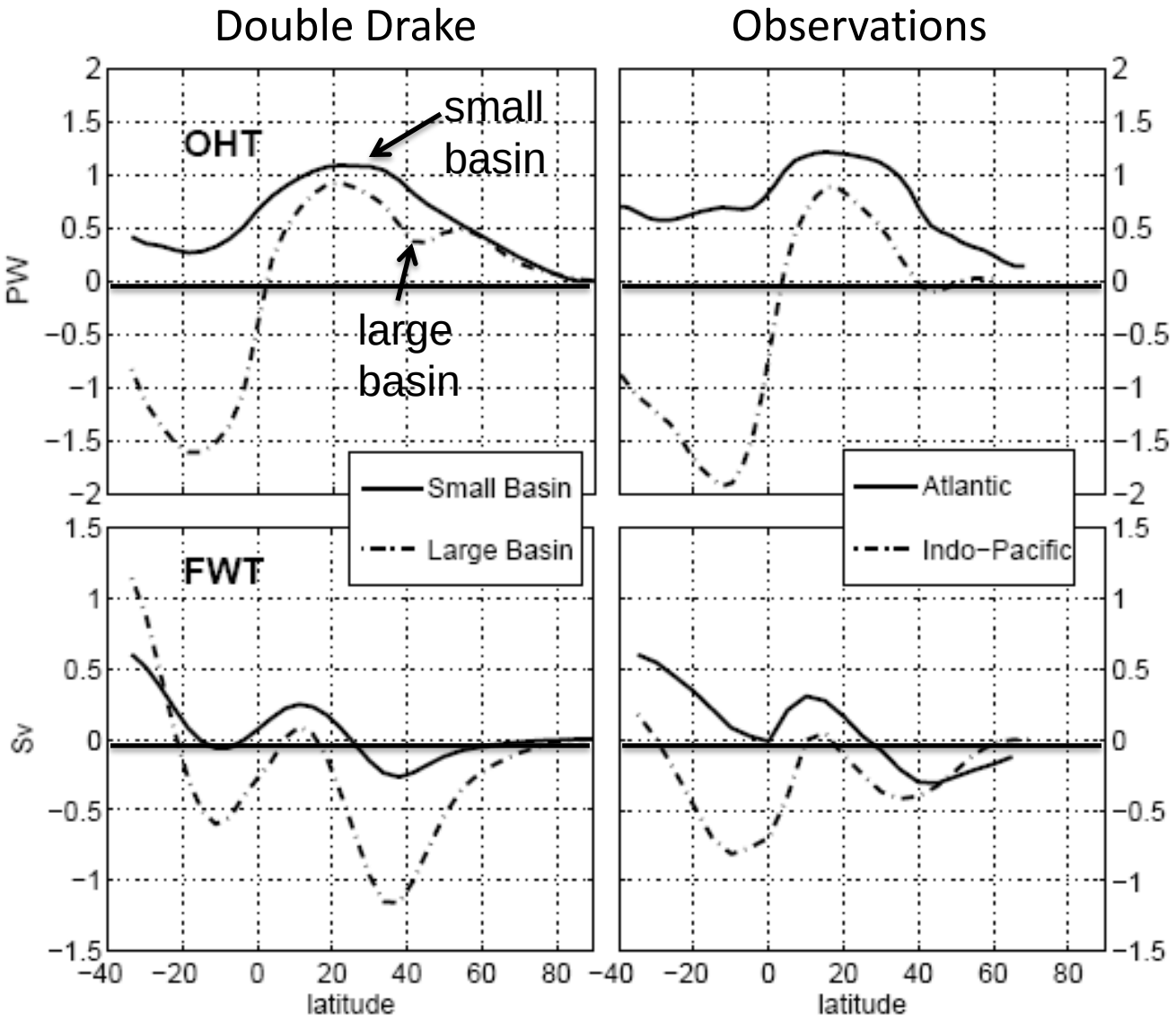
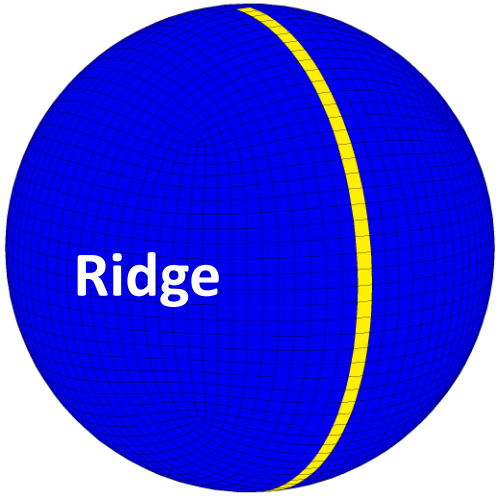
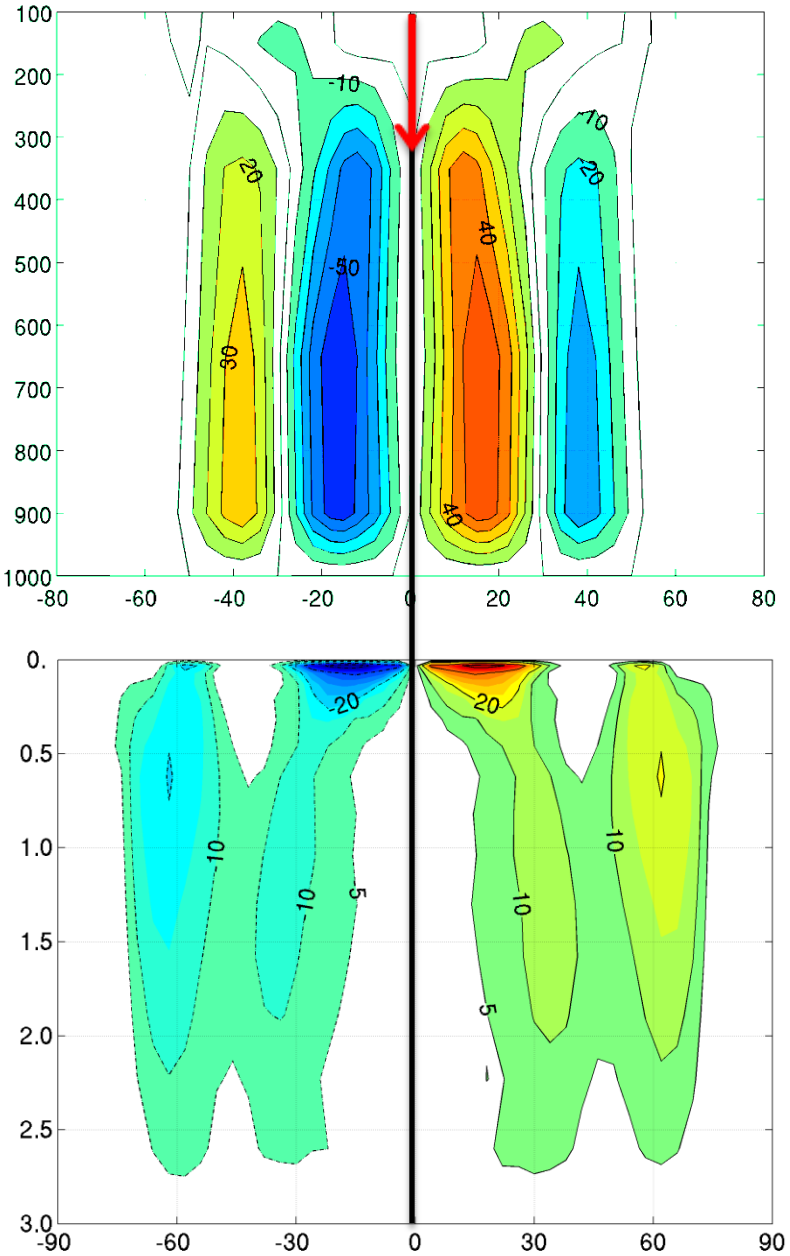
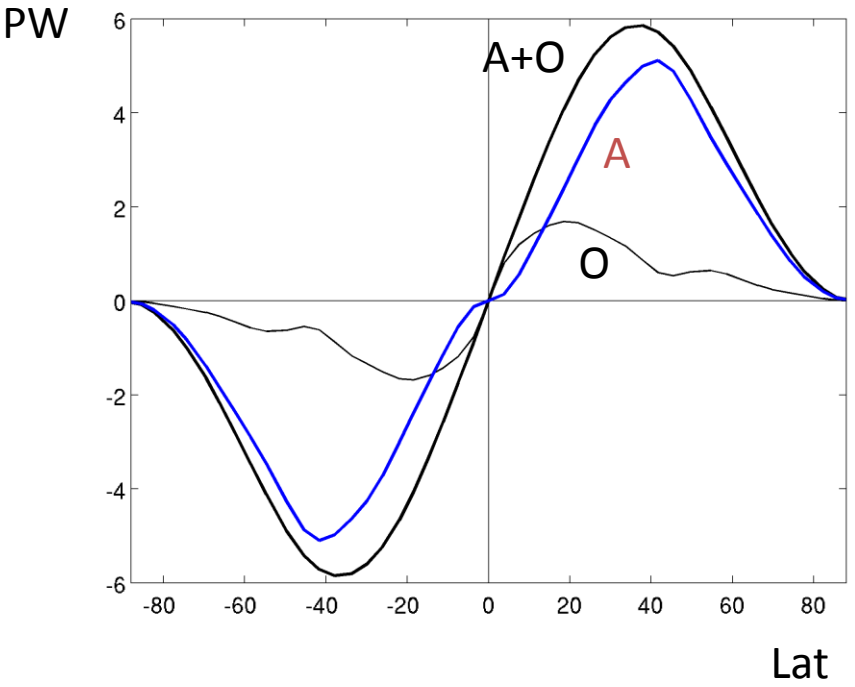


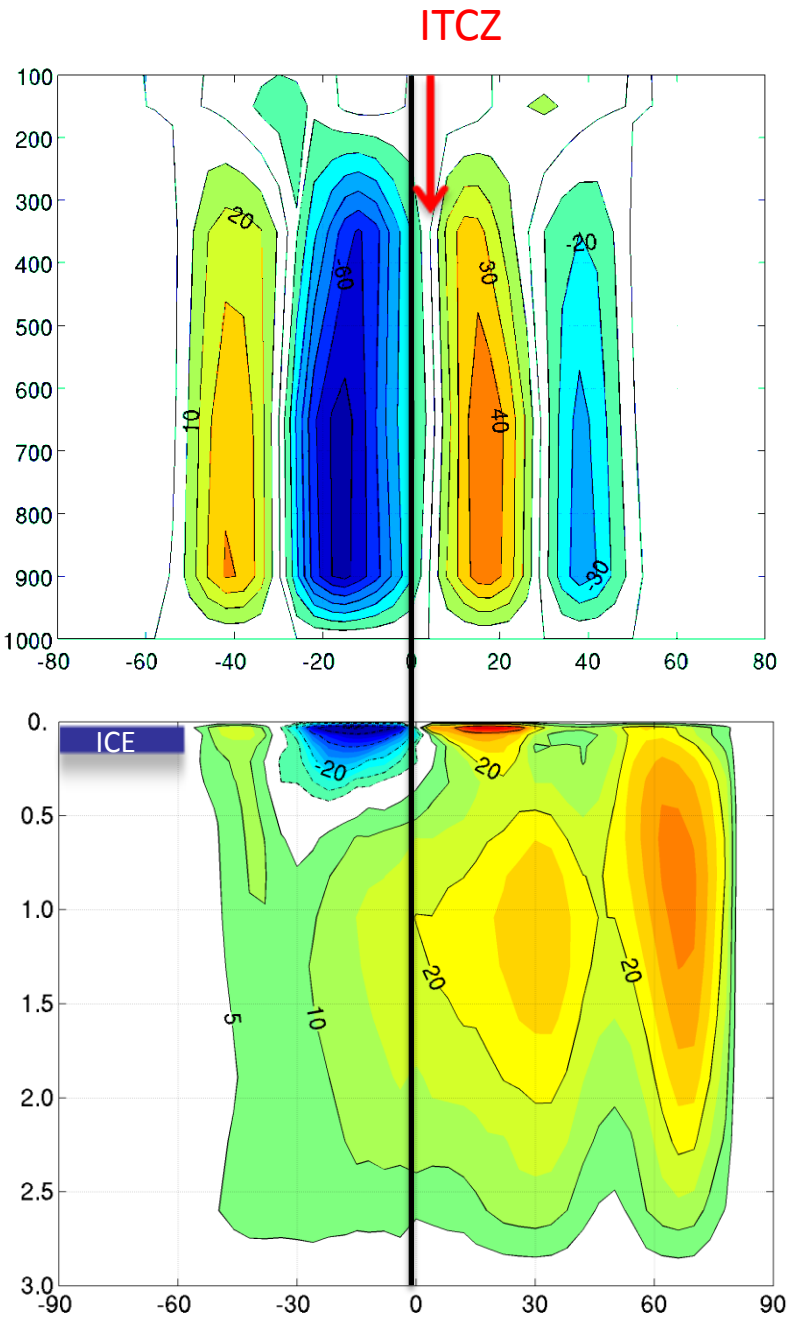
3 Role of ocean in inter-hemispheric asymmetries in climate

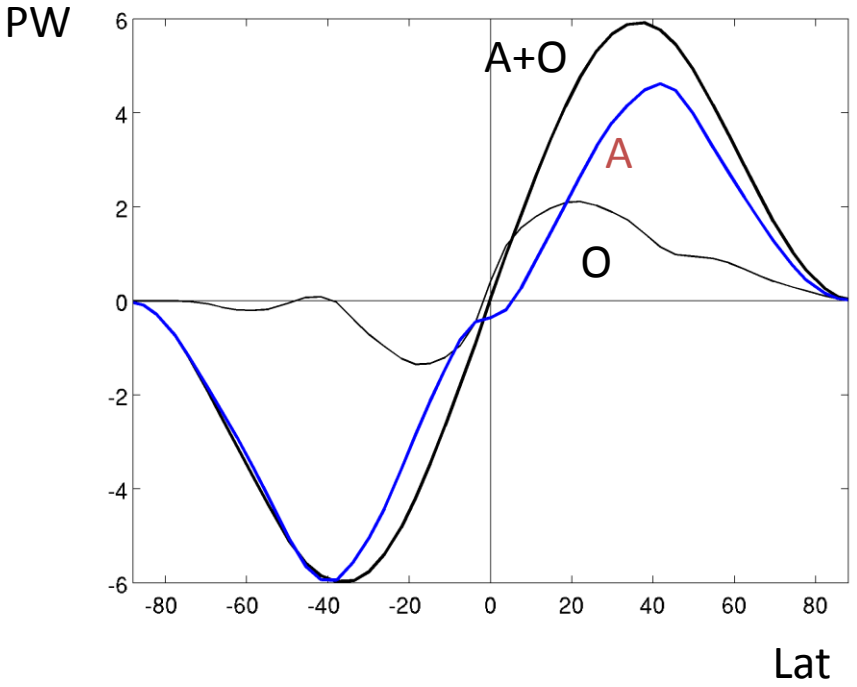






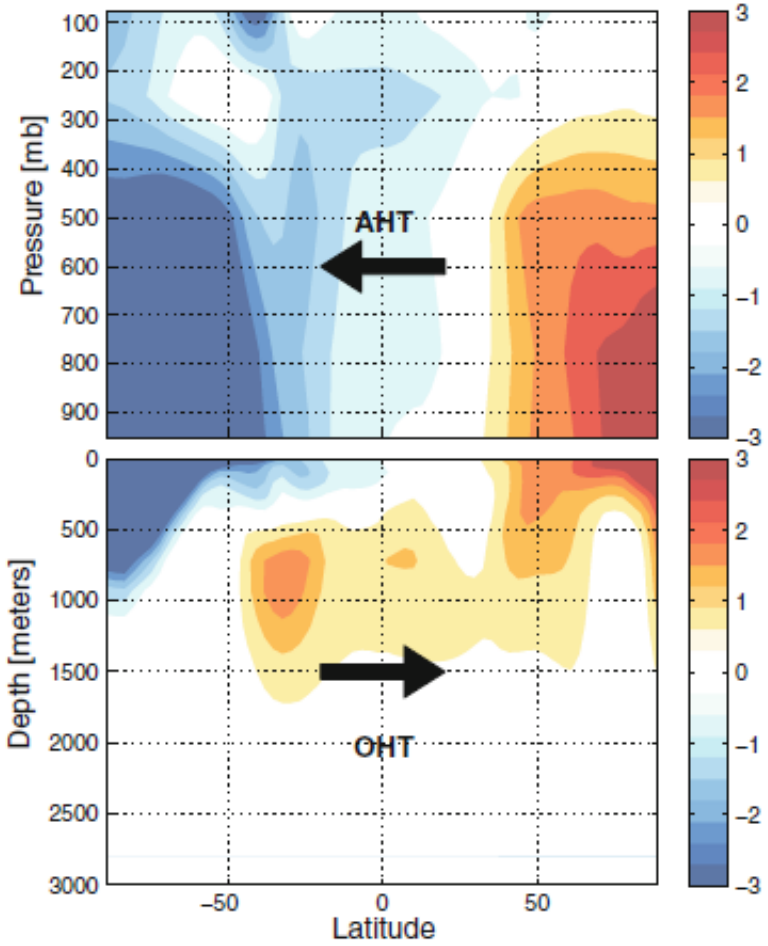

Drake

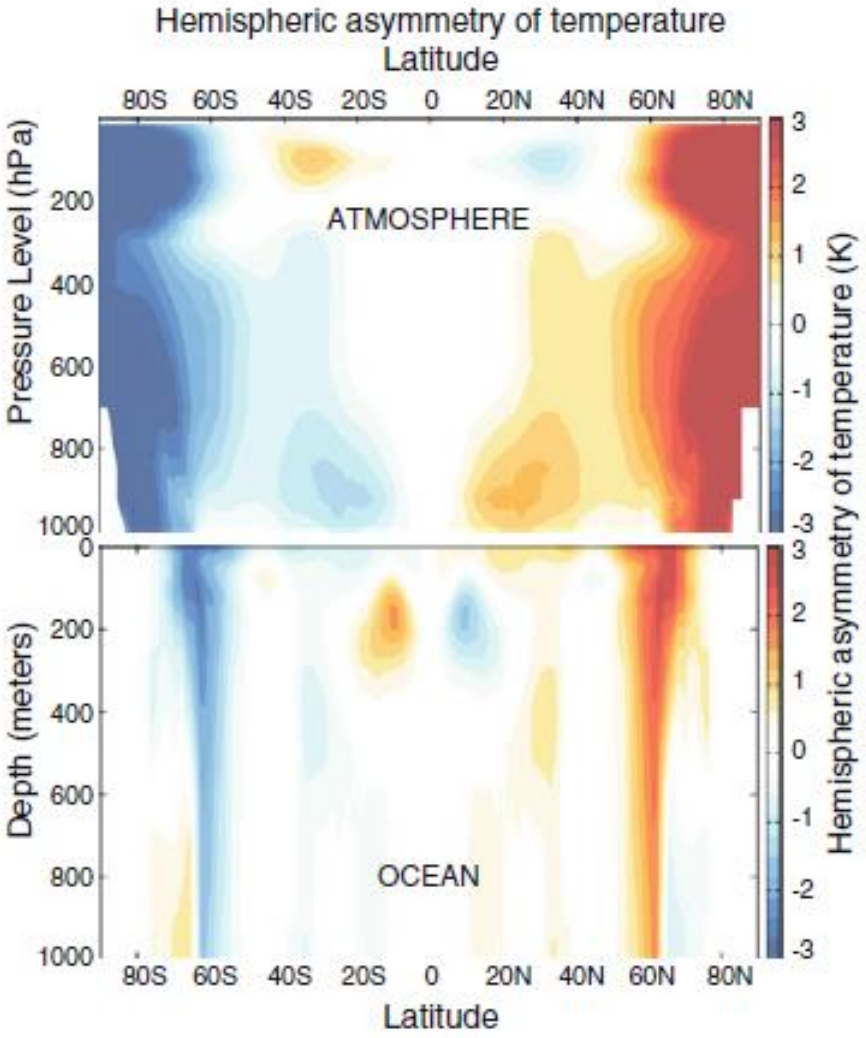

ITCZ
ICE


PW
A+O
A
O
Lat

NH is warmer than the NH 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

Tentative support from observations of Earth's radiation budget

Aaron Donohoe

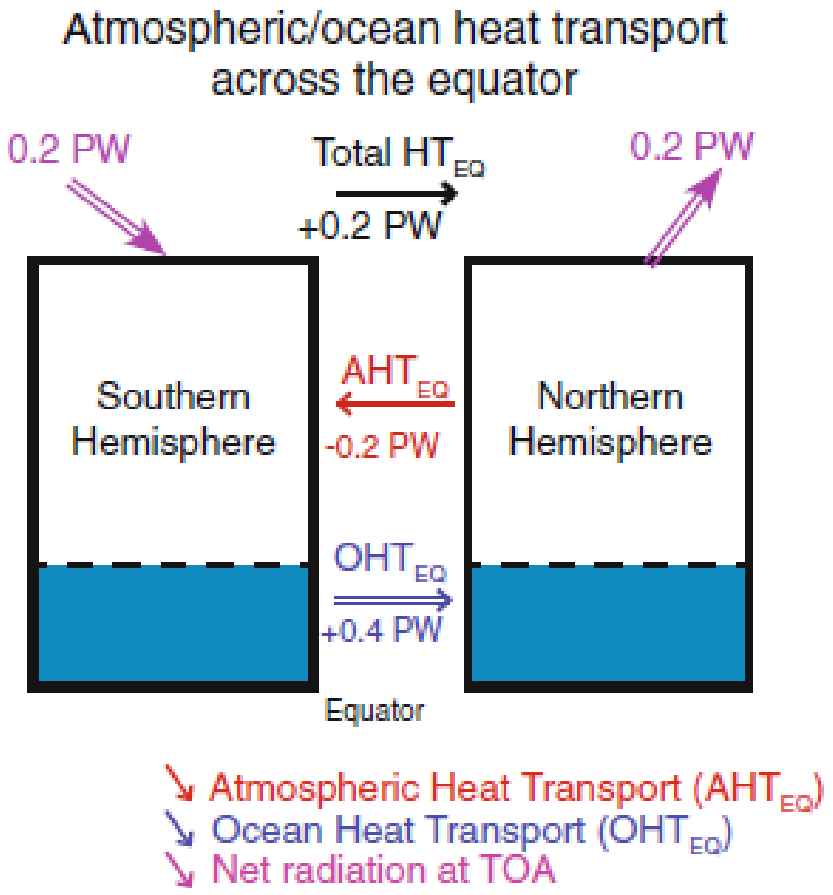
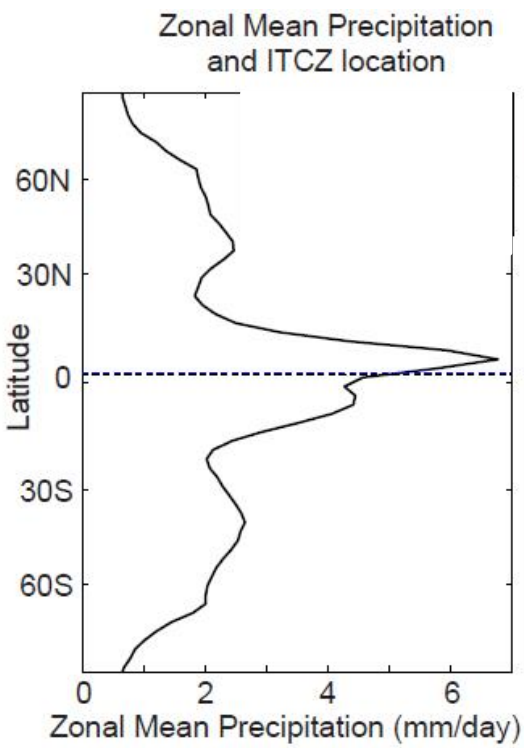
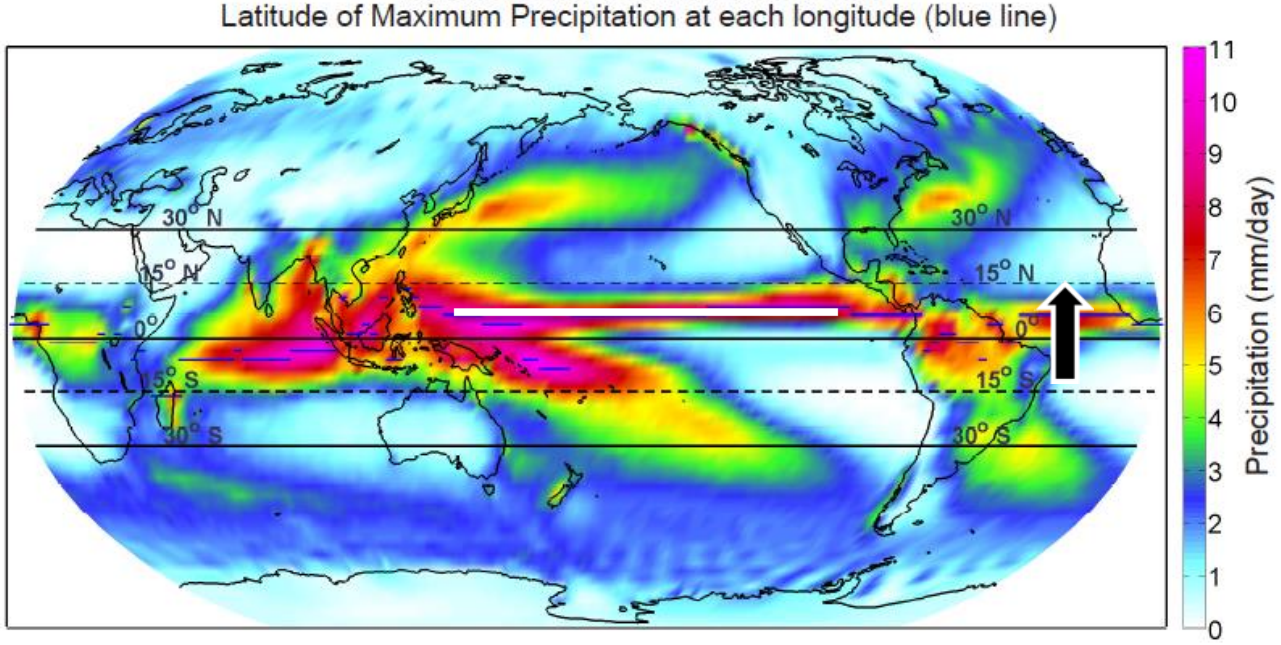


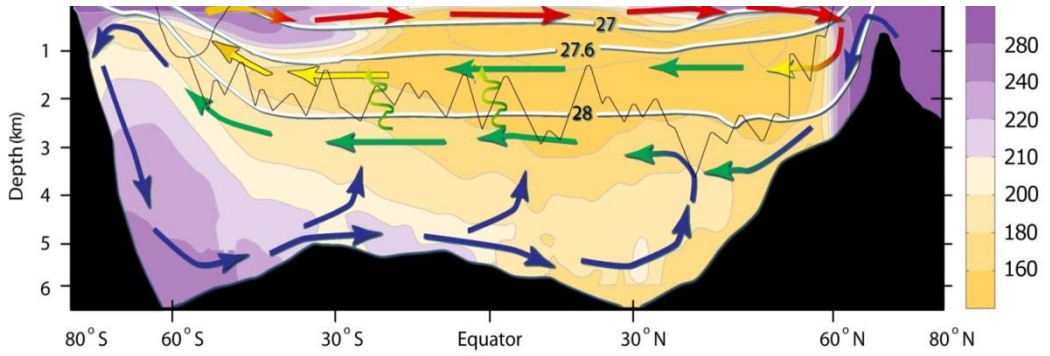
Fig. 2 Energy input at the TOA and its relationship to energy flux across the equator. AHT_{EQ} and OHT_{EQ} are the atmospheric and oceanic heat transport across the equator respectively. The *numbers* are estimates obtained in this study using observational reanalysis and satellite data. The *error bars* in all fluxes are order ±0.1 PW. OHT transport is estimated as a residual

See Graeme Stephens – later this afternoon

Annual-mean precipitation







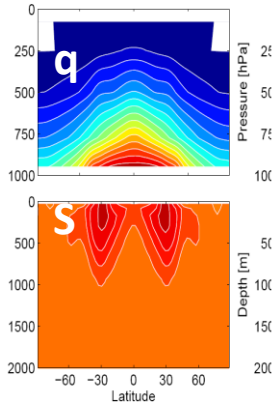
O_2

Frierson et al, 2013
Marshall et al, 2013
Kang et al, 2014

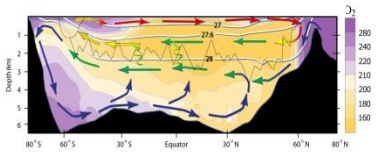
Review by Marshall and Speer, 2012, Nature Geosciences

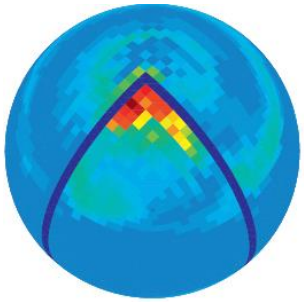
Conclusions

1 Oceanic freshwater transport is slaved to atmosphere



2 Salinization leads to localization of deep convection in the small basin and an inter-hemispheric overturning cell.





3 Inter-hemispheric energy transport due to ocean circulation warms the NH and leads to a northward shift in the position of the ITCZ.