Coupled Climate Dynamics: Energy transport by the Atmosphere and Ocean

John Marshall, MIT

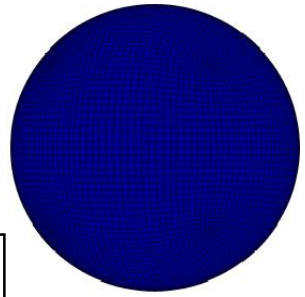
1. Energy transport by A & O

Observations

Importance of hierarchical modeling

2. Climate of an Aquaplanet

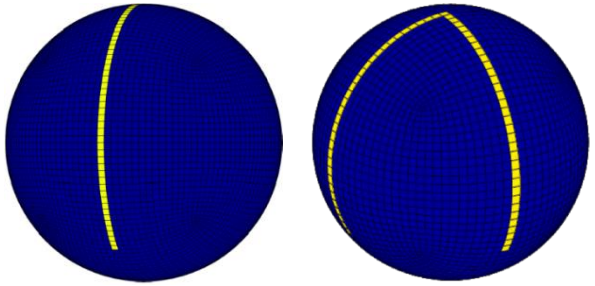
Thus far we have considered solutions that are hemispherically and zonally symmetric.



3. Oceans and Climate asymmetries

What happens if we introduce geometric asymmetries?

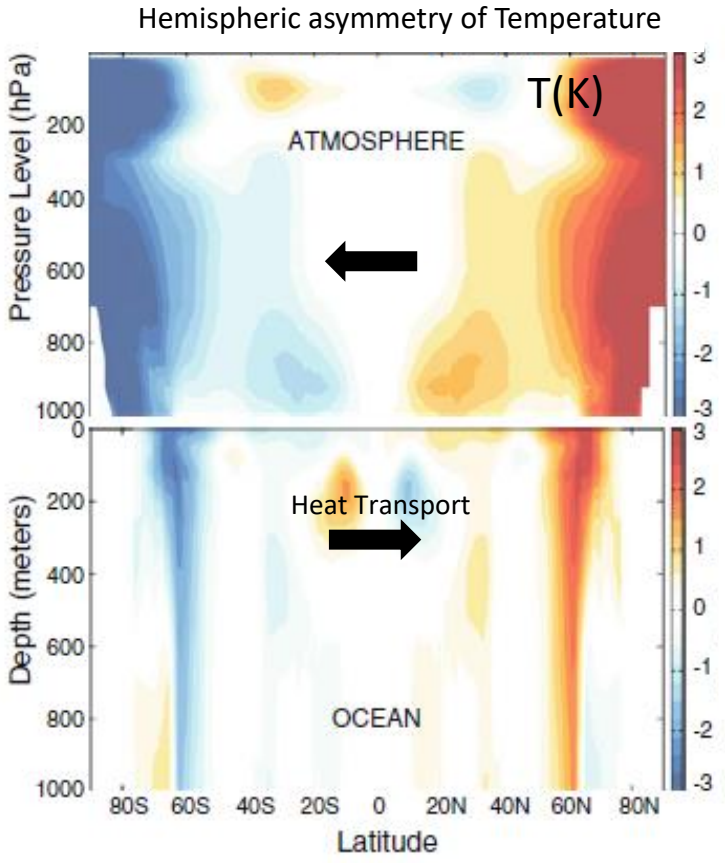
Meridional, Zonal



Oceans and Asymmetries of climate

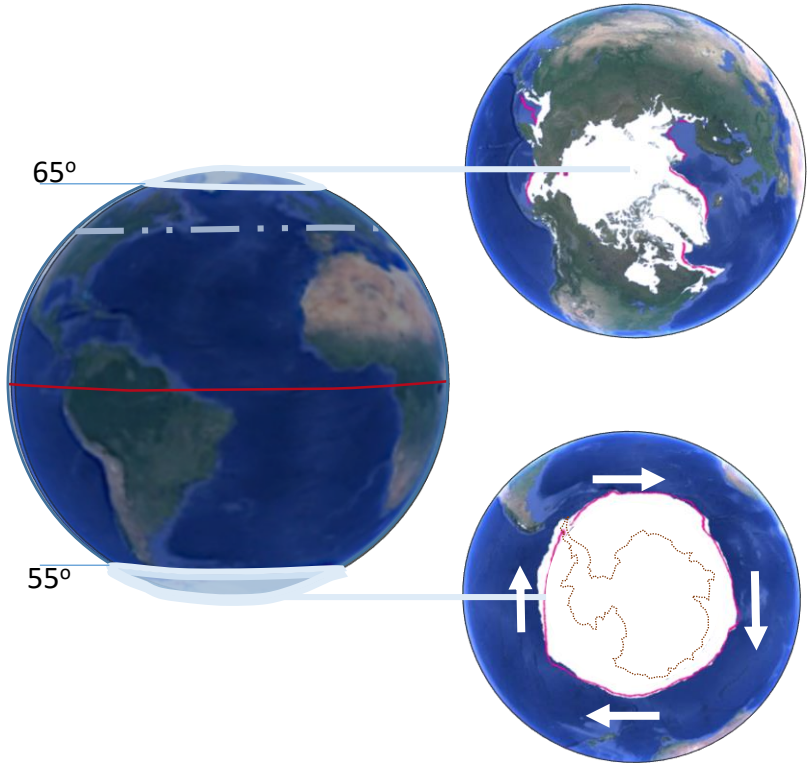
NH warmer than the SH

Observations



Ocean carries heat across the equator warming the NH

Antarctica ice extent >> Arctic

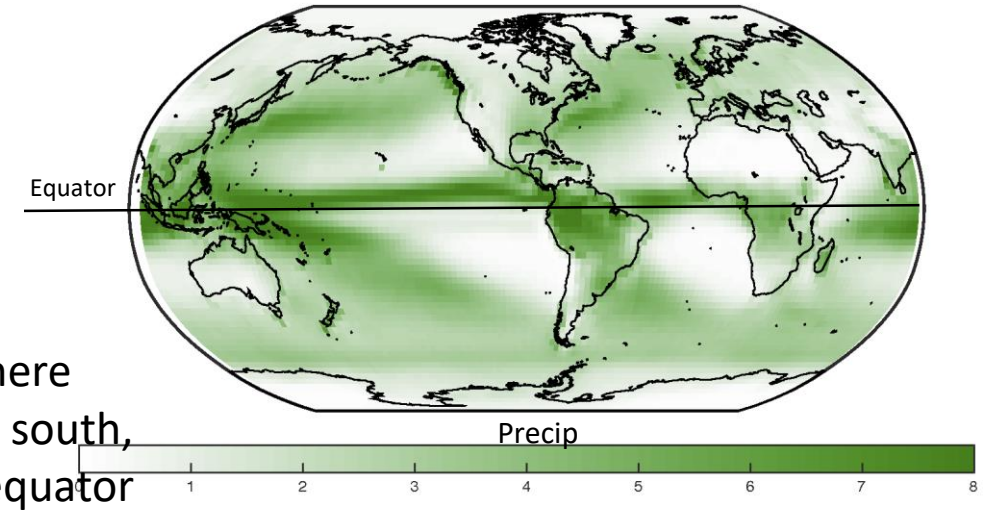


Thermal isolation of Antarctica by Ocean Circulation

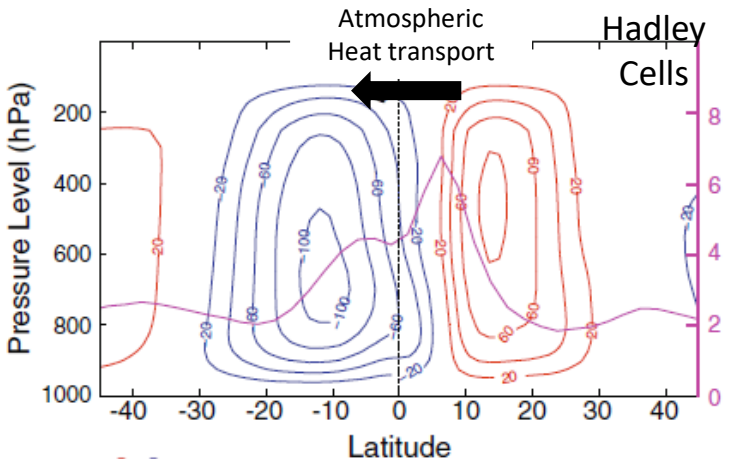
Oceans and Asymmetries of climate

ITCZ displaced north of Equator

Annual-mean precipitation (mm/day)

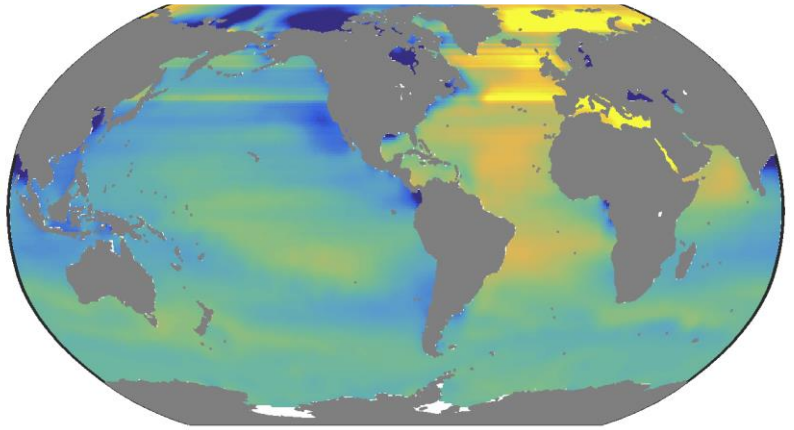


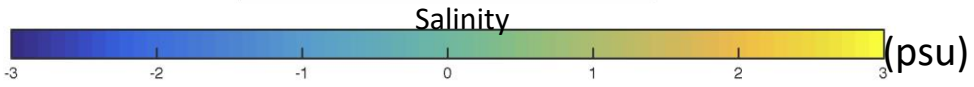
Atmosphere carries heat south, across the equator



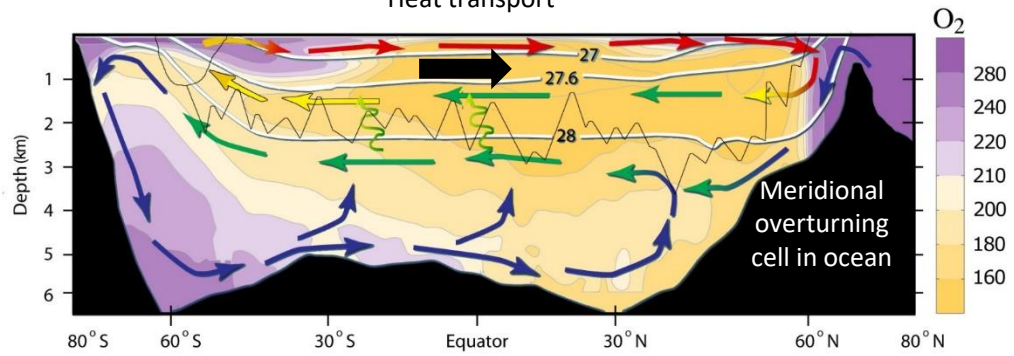
Atlantic warmer and saltier than Pacific

Surface salinity (psu), departure from zonal mean

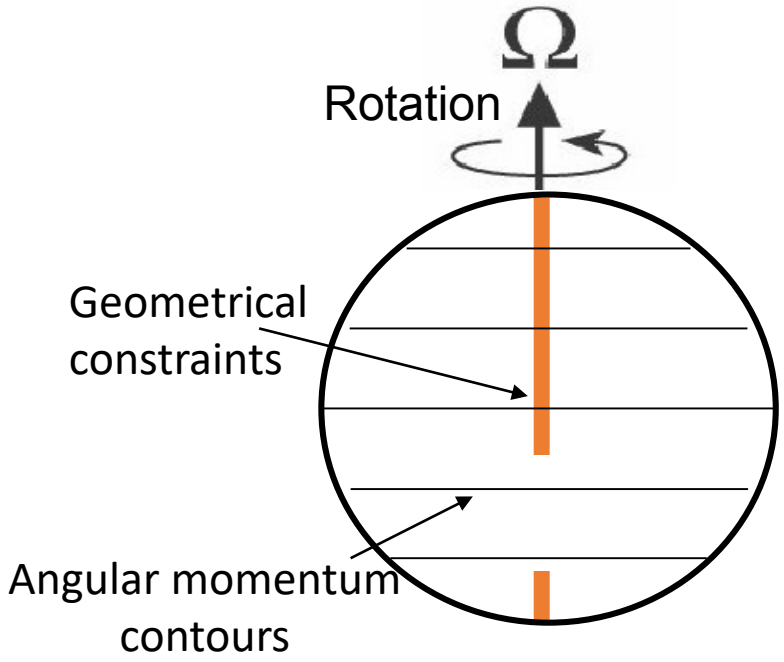




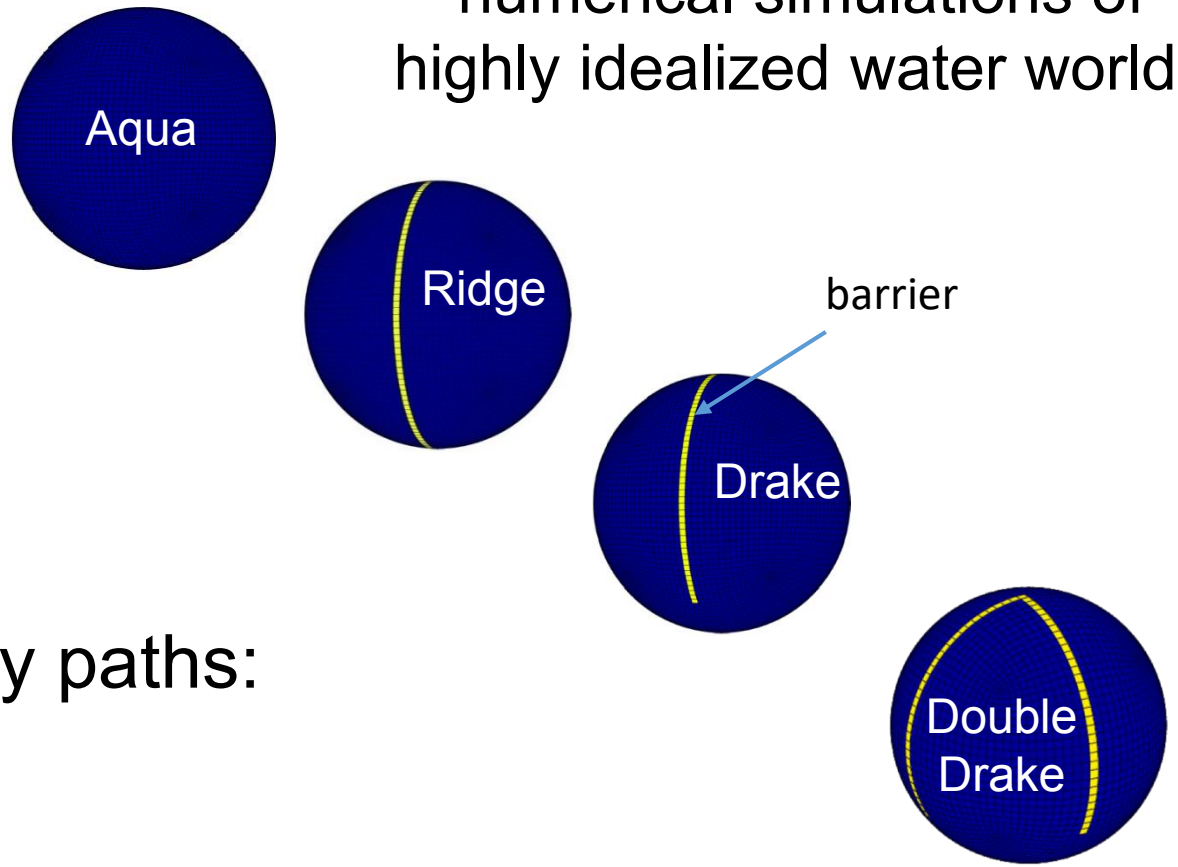
Ocean
Heat transport



Let's explore in our Water World



Explore with a series of numerical simulations of highly idealized water worlds

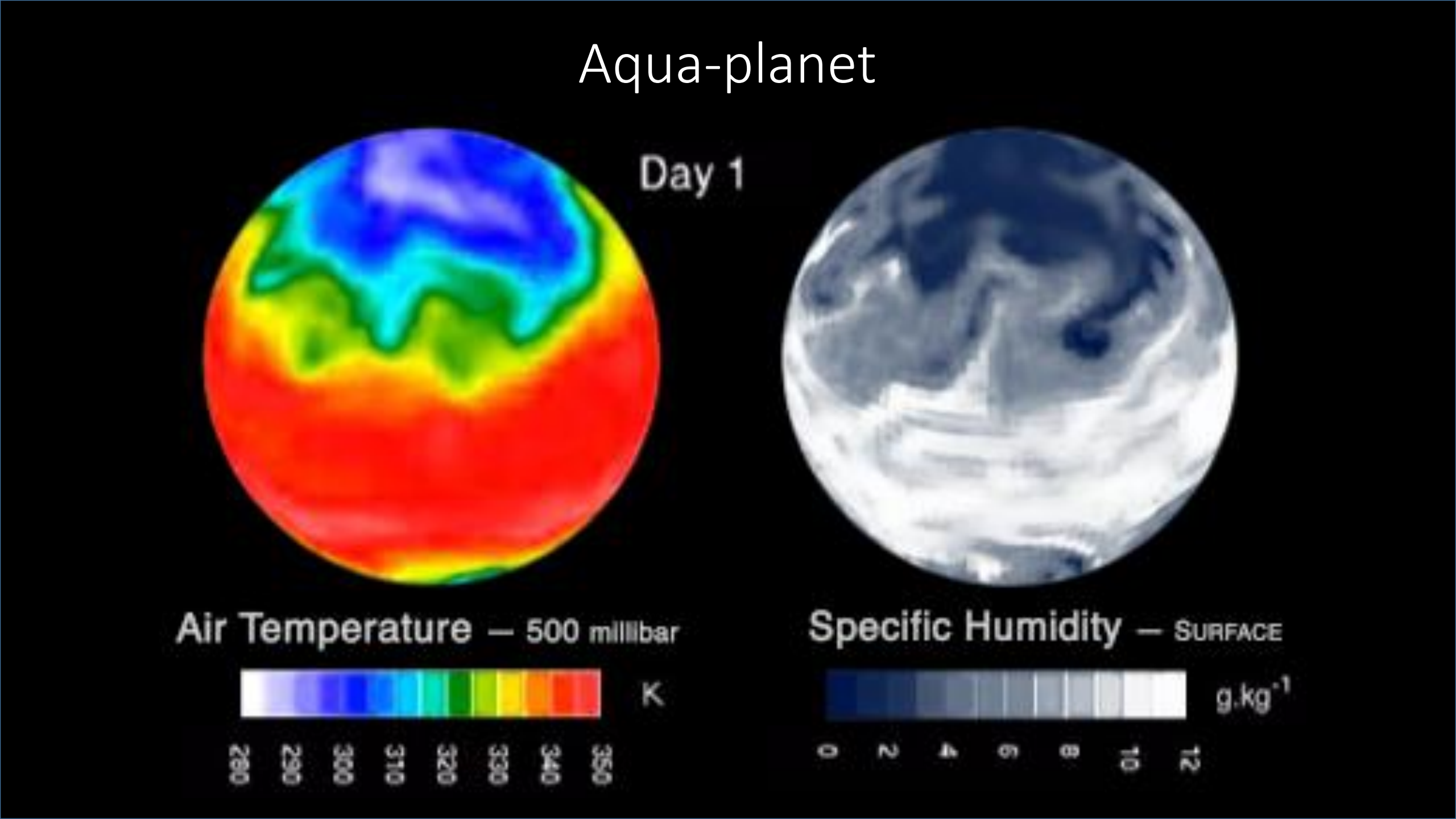


Ocean cannot move in arbitrary paths:

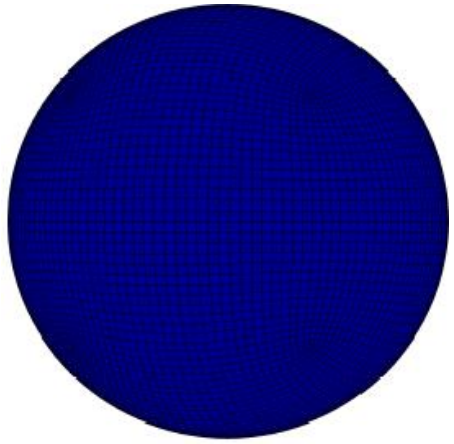
geometrical and rotational constraint

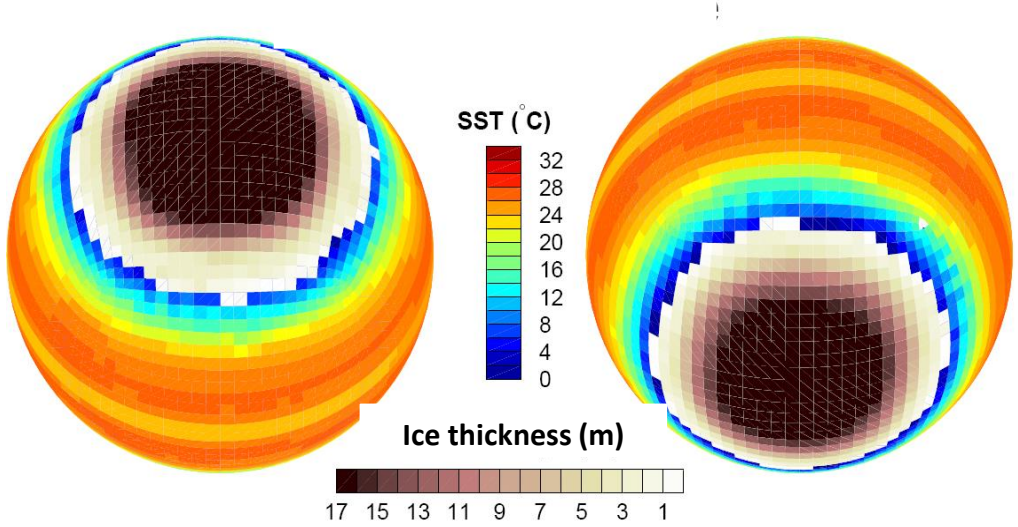
Coupled A, O, Ice model

Aqua-planet

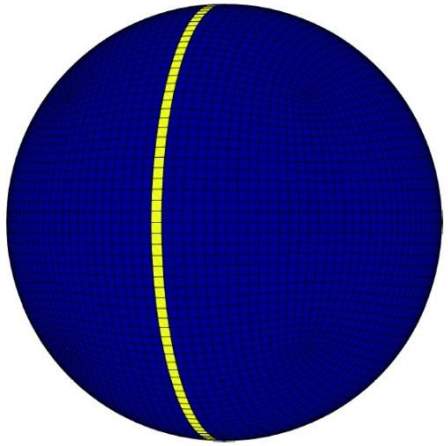

Day 1
Air Temperature — 500 millibar
K
260
280
300
310
320
330
340
350
Specific Humidity — SURFACE
g.kg-1
0
2
4
6
8
10
12

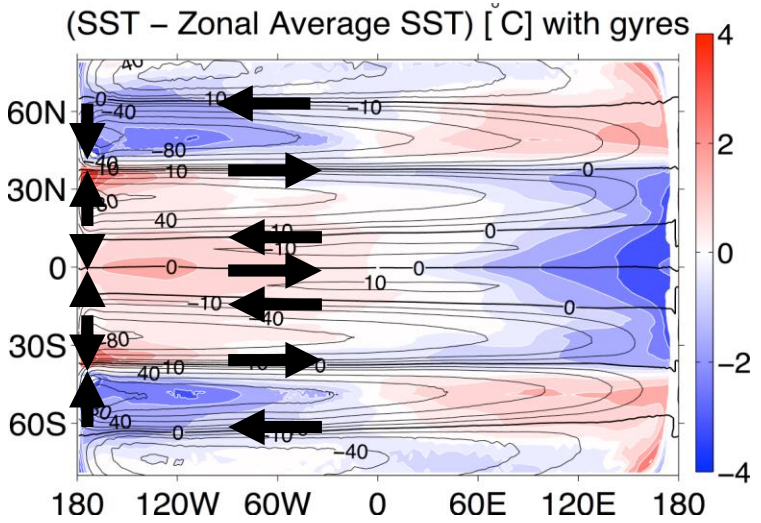
Aqua



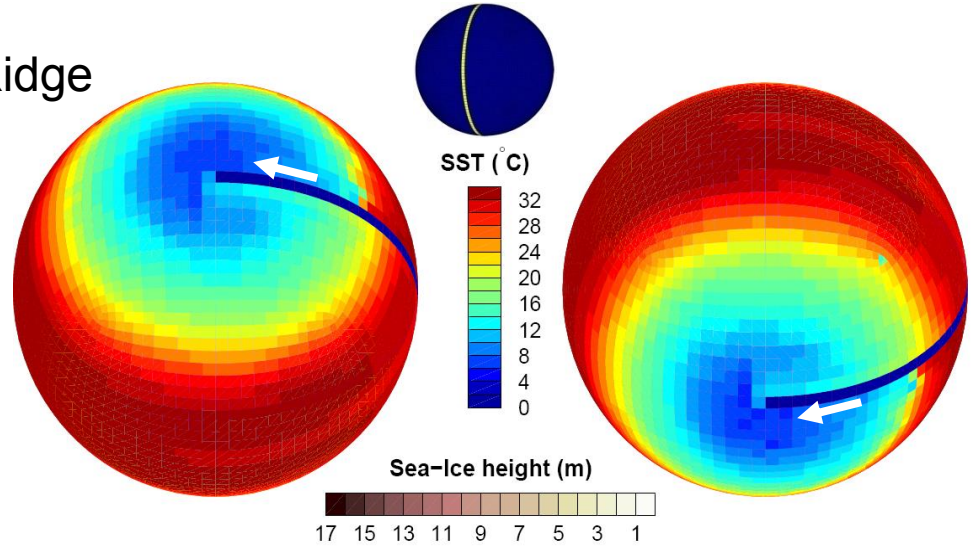


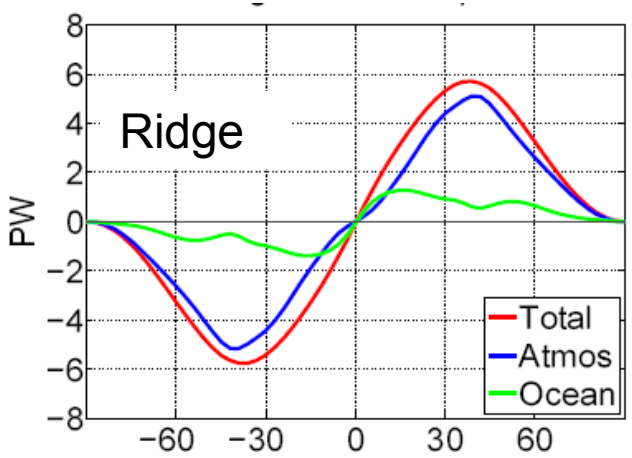
Ridge



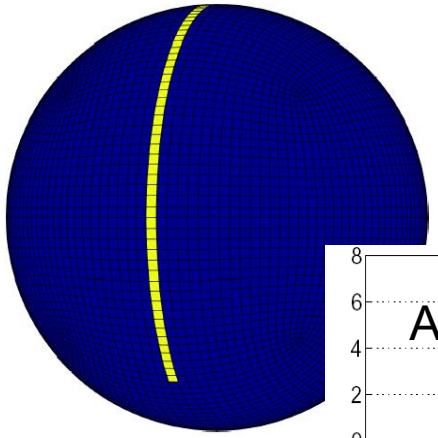

(SST – Zonal Average SST) [˚C] with gyres
60N
30N
0
30S
60S
180
120W
60W
0
60E
120E
180
4
2
0
−2
−4

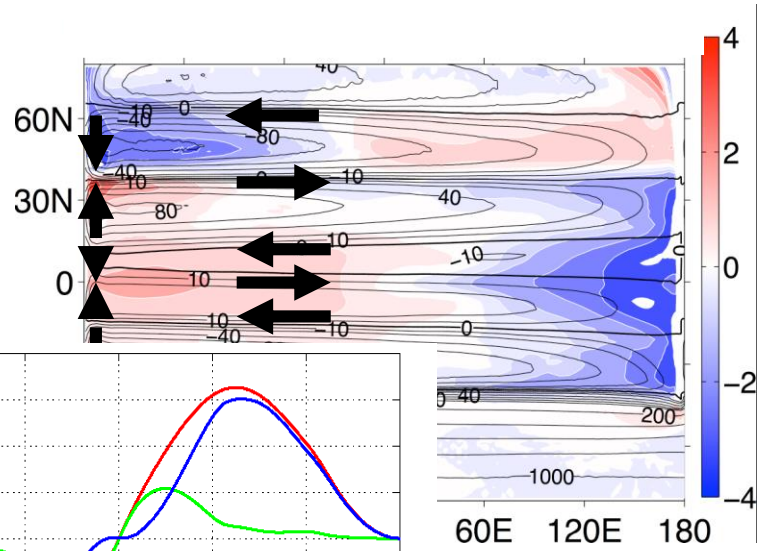
Ridge


SST (˚C)
32
28
24
20
16
12
8
4
0
Sea−Ice height (m)
17 15 13 11 9 7 5 3 1

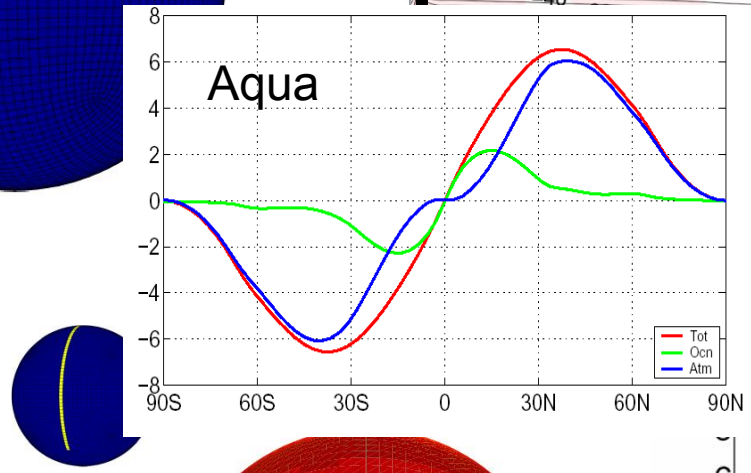

Ridge
PW
8
6
4
2
0
−2
−4
−6
−8
−60
−30
0
30
60
Total
Atmos
Ocean

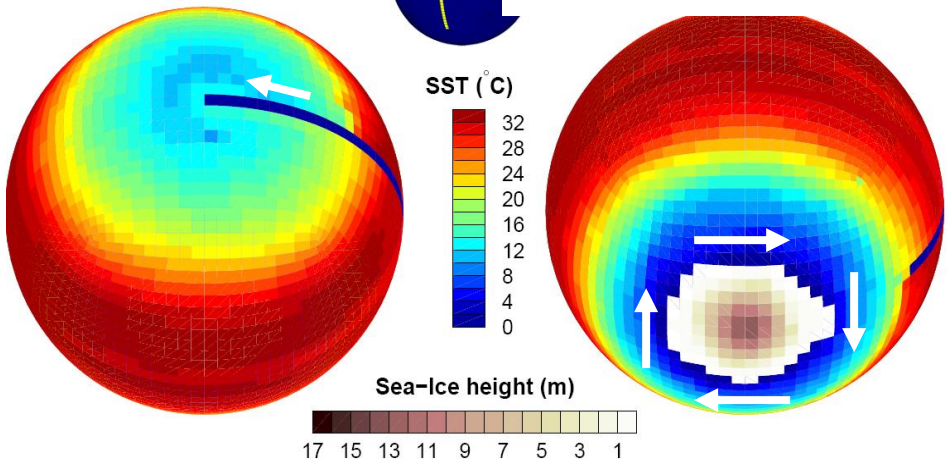
Drake

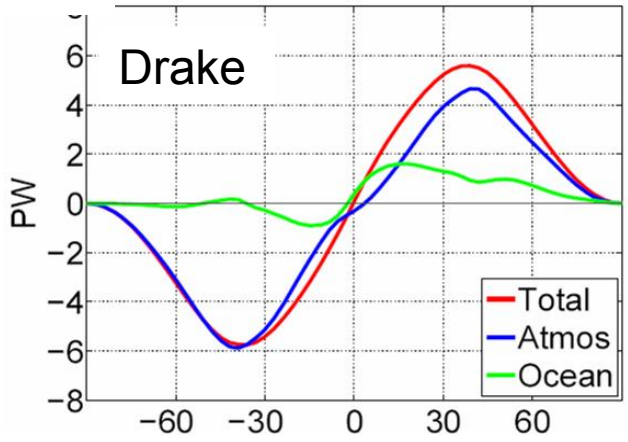




ar Current

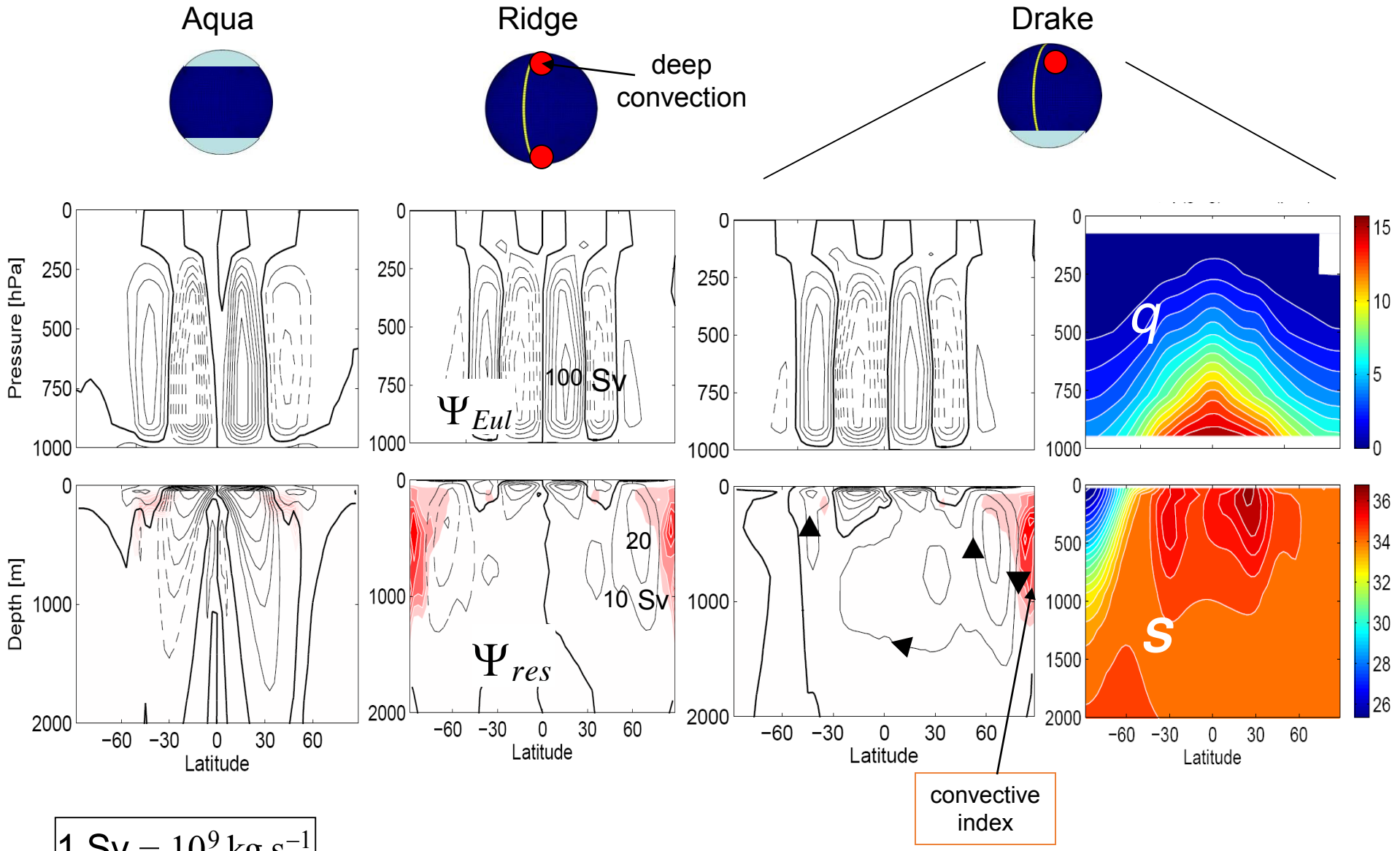




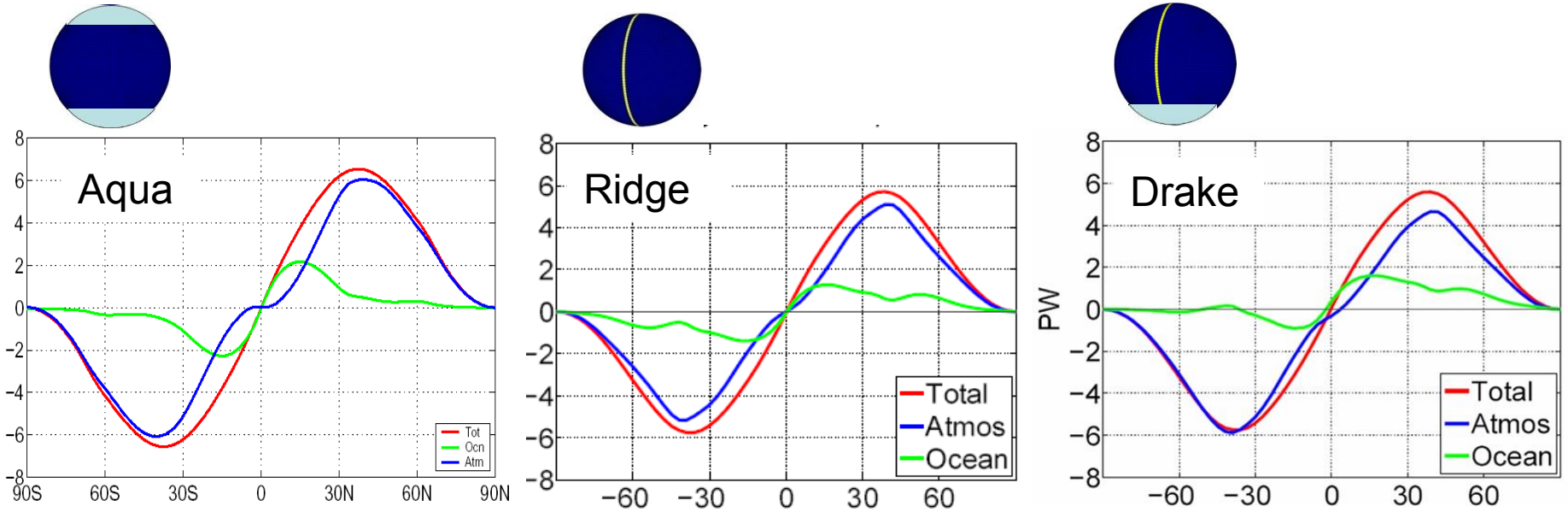


[Note: opening up a gap at equator warms both poles, not shown]

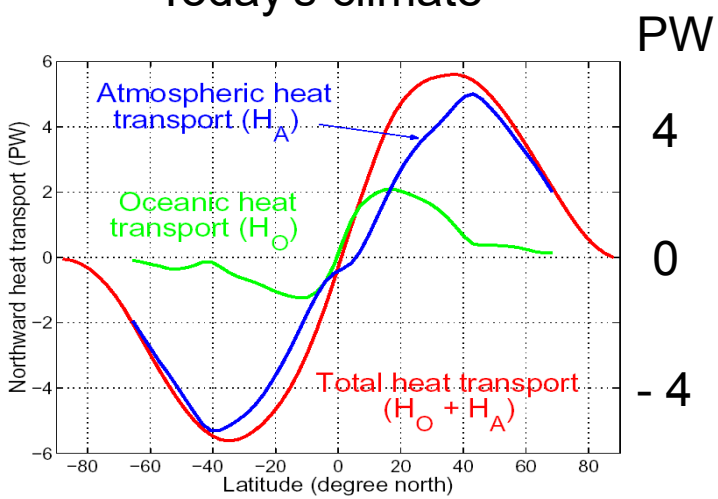
Overturning circulation and convection



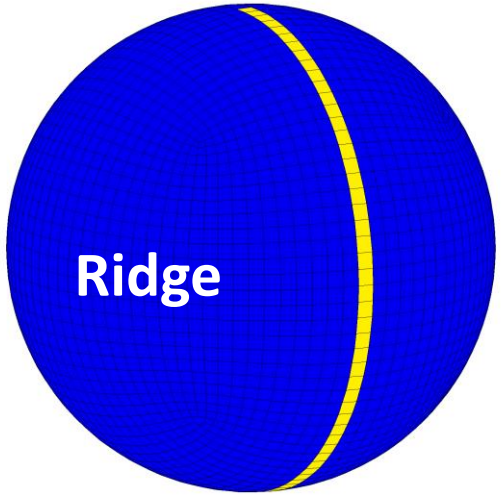
$1\ \mathrm{Sv} = 10^9\ \mathrm{kg\ s^{-1}}$

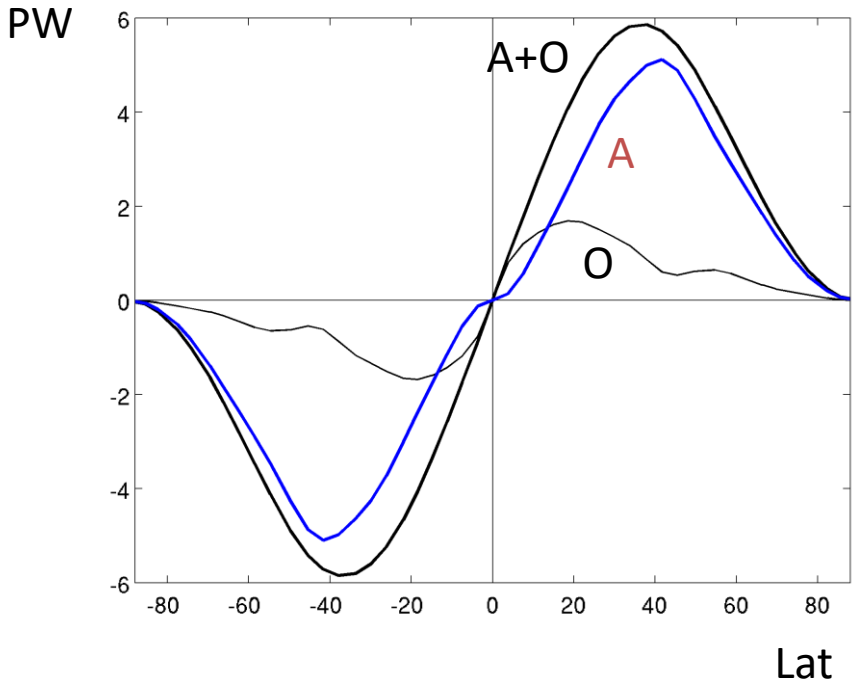


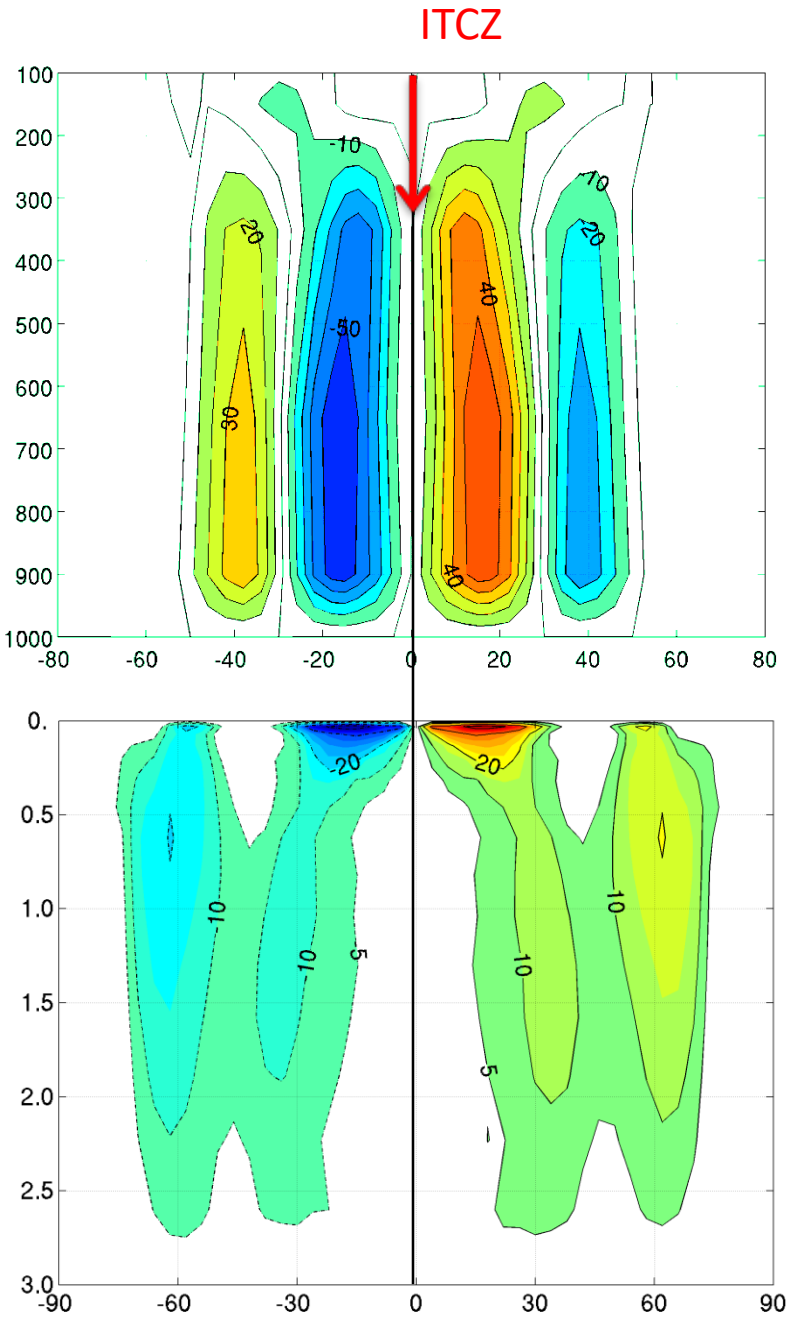
Today's climate



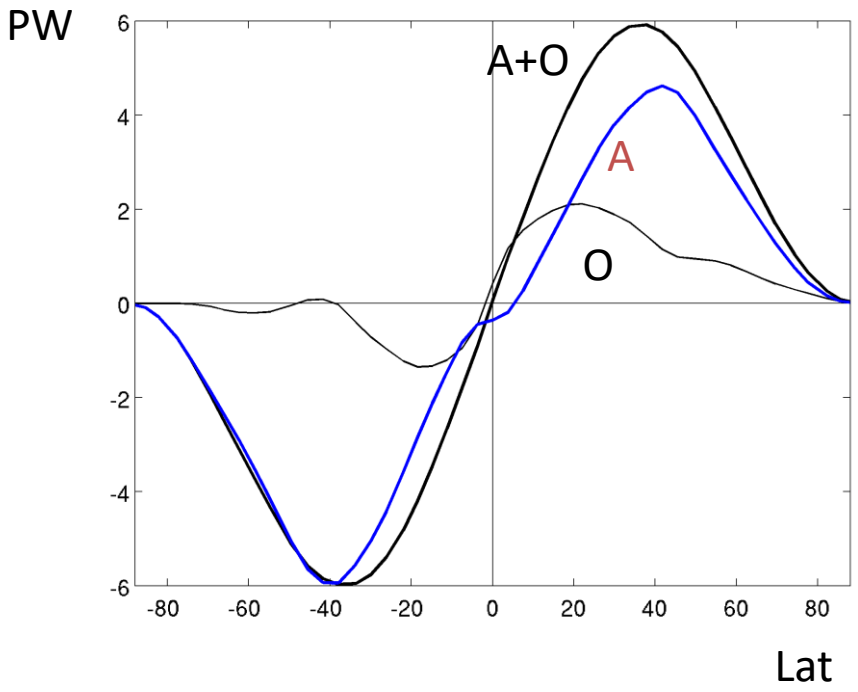
Position of the ITCZ

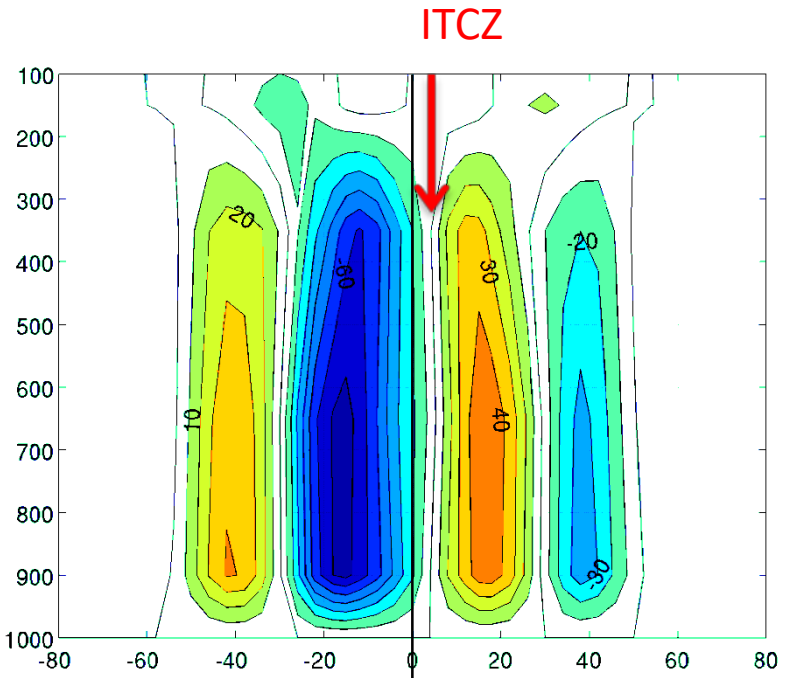


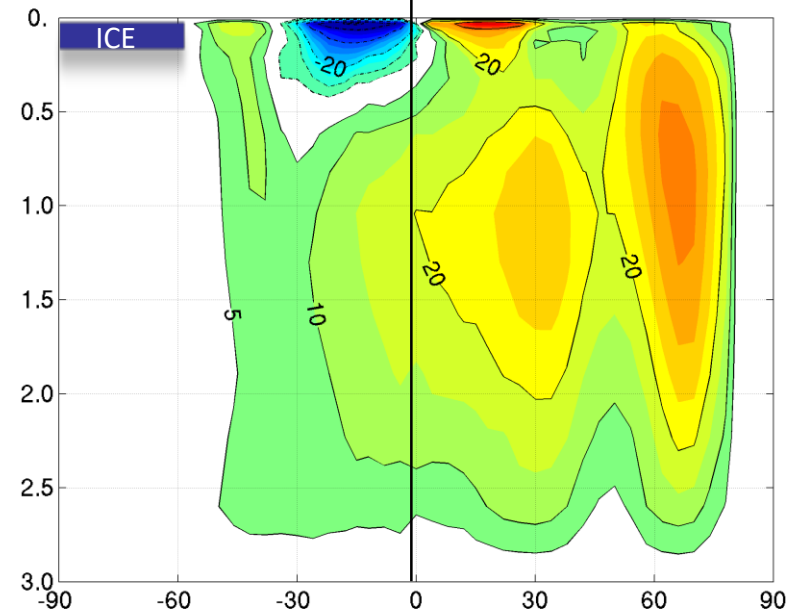




Position of the ITCZ

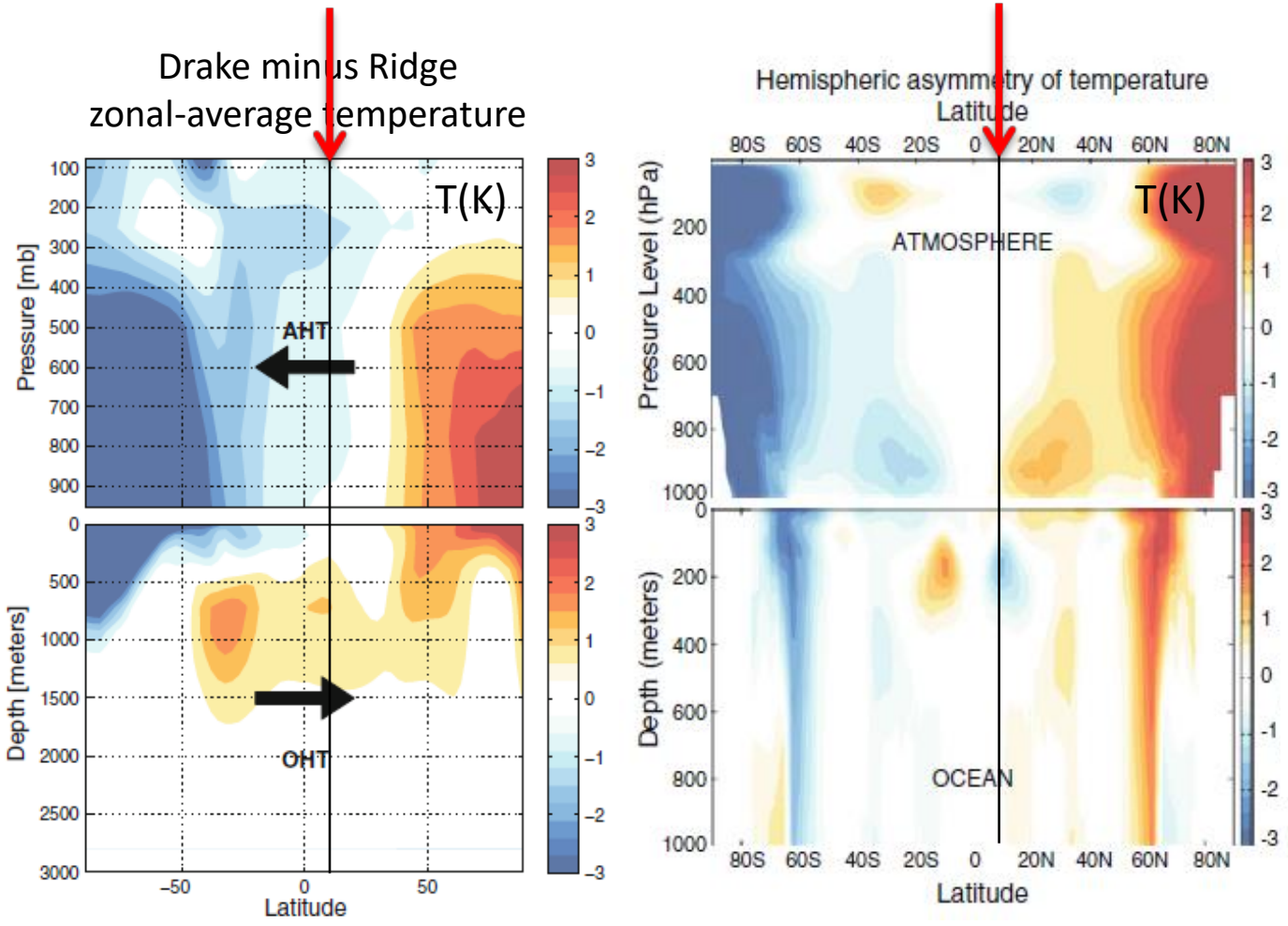






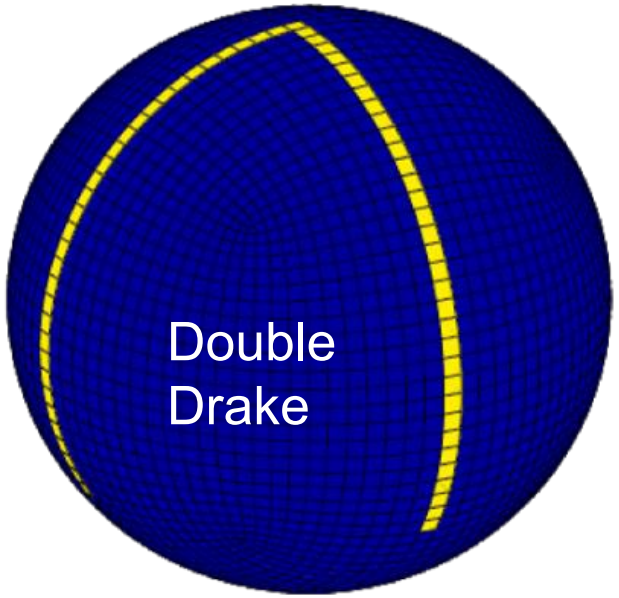
NH is warmer than the SH because of ocean circulation

(and, consequently, the ITCZ is north of the Equator)



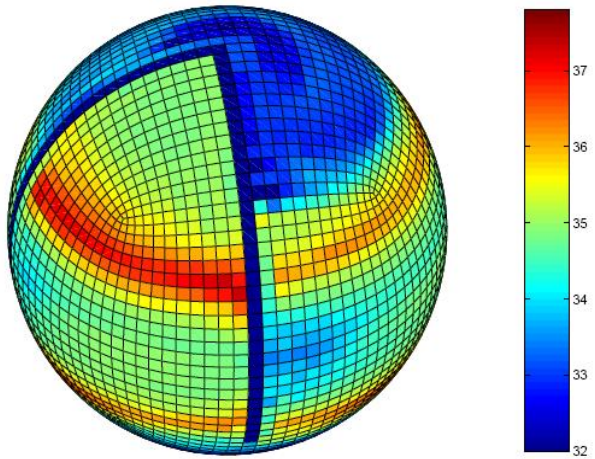
NOTE: Heat transport can be up-gradient in the ocean because the ocean is mechanically forced by the wind

Zonal asymmetries in Climate

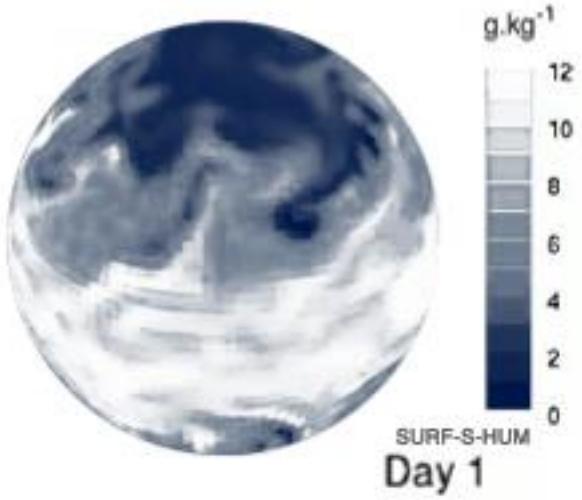


Zonal asymmetries in the hydrological cycle

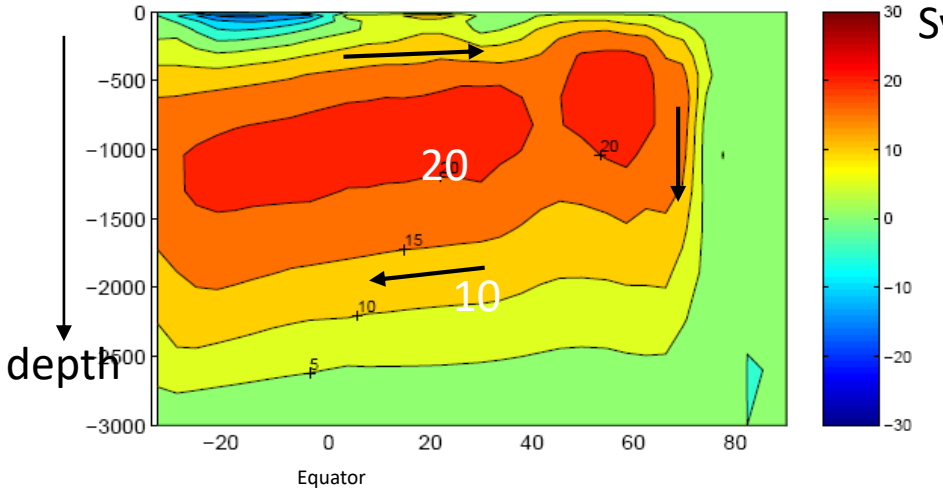
Surface Salinity



Atmospheric Moisture



Small basin

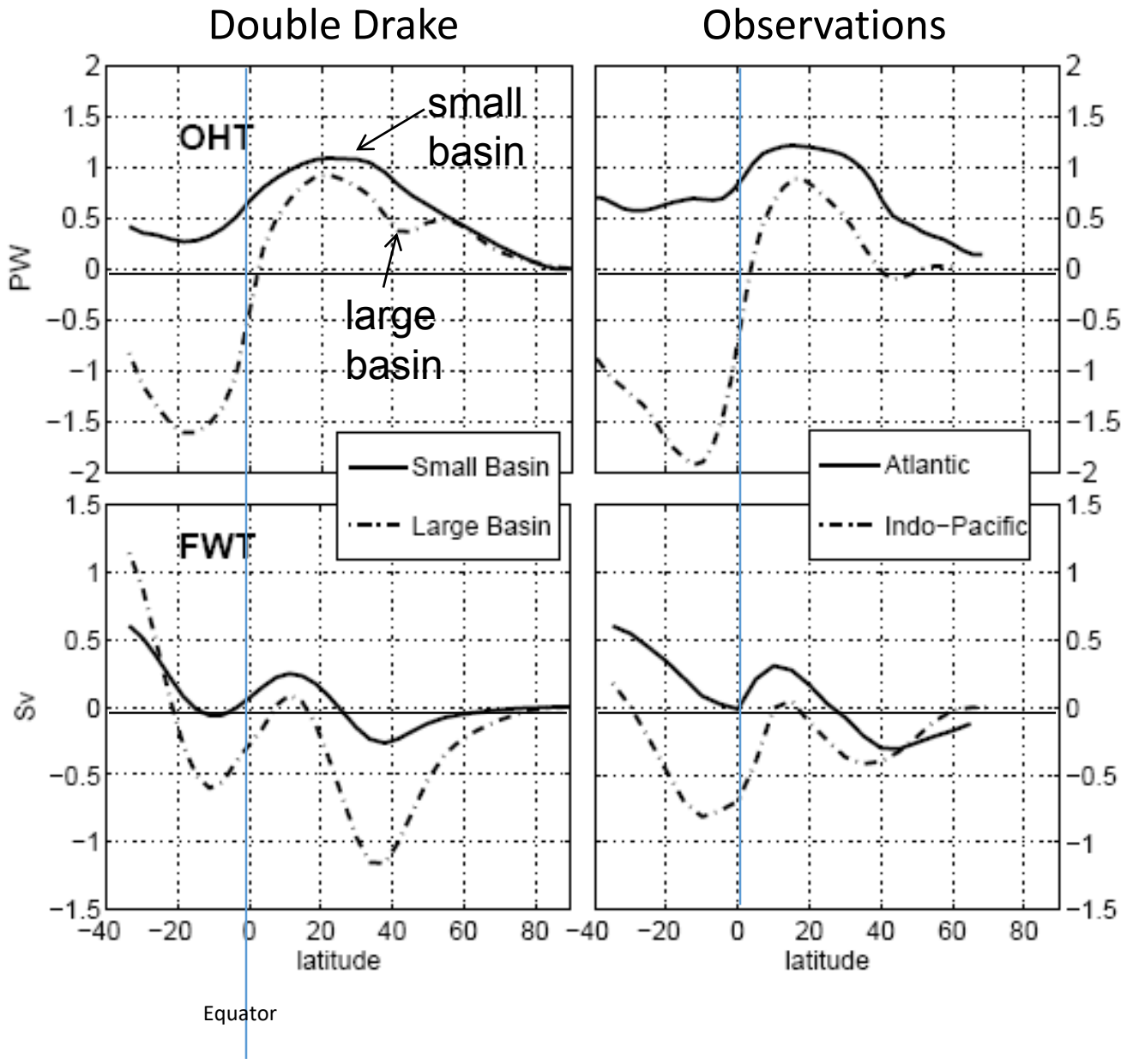


Meridional Overturning cell in the ocean connects the hemispheres together

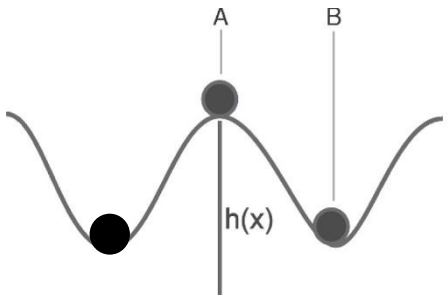
Heat and freshwater transport

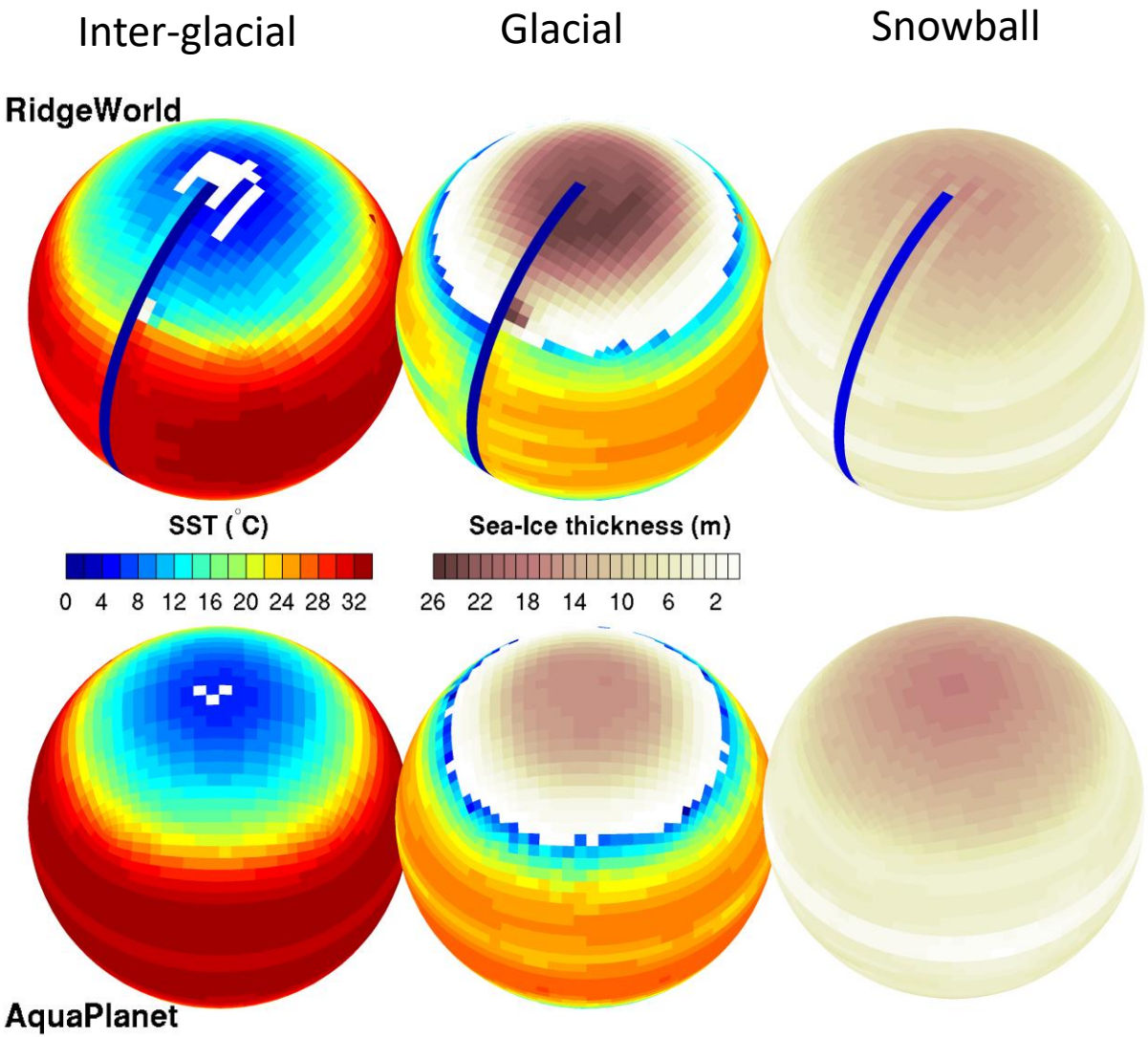
Heat transport (PW)

Fresh water transport (SV)



Aqua-planet exhibits multiple equilibria

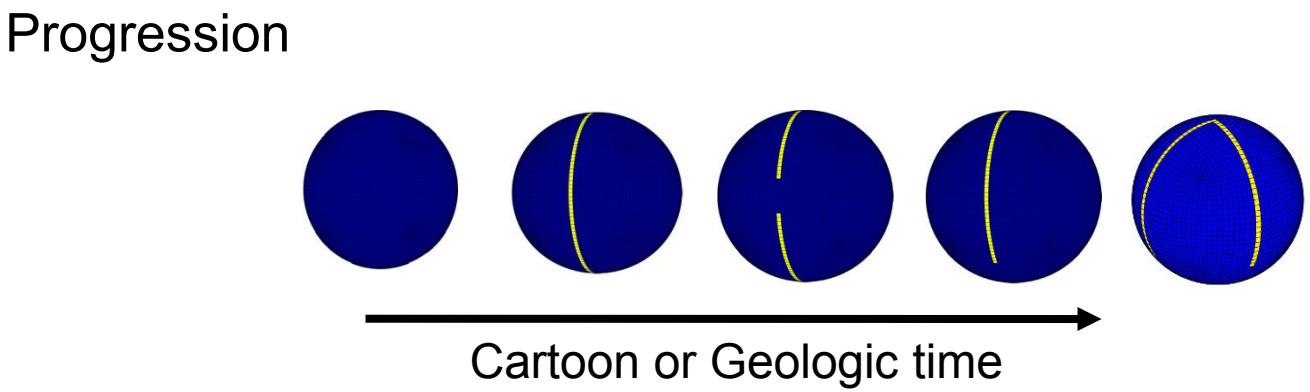




Ferreira, Marshall and Rose, J. Climate, 2011

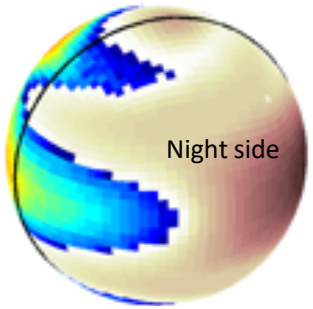
Conclusions

- Studying the climate of aqua-planets is fun
- Informs us about the elemental role of the ocean in climate



- Many unanswered questions:

  e.g. do multiple equilibria of Earth's climate exist?
  if so, how stable are they?



SST & Sea Ice

Tidally-locked exoplanet

- Aqua-planets provide a context for thinking about the dynamics of paleo climate and exoplanets

Eddying Double Drake

Vorticity at ocean's surface

Aqua-planet Project

Thanks to:

Martha Buckley
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Daniel Enderton
David Ferreira
Brian Green
Mukund Gupta
Chris Hill
David McGee
Paul O'Gorman
Brian Rose
Sara Seager