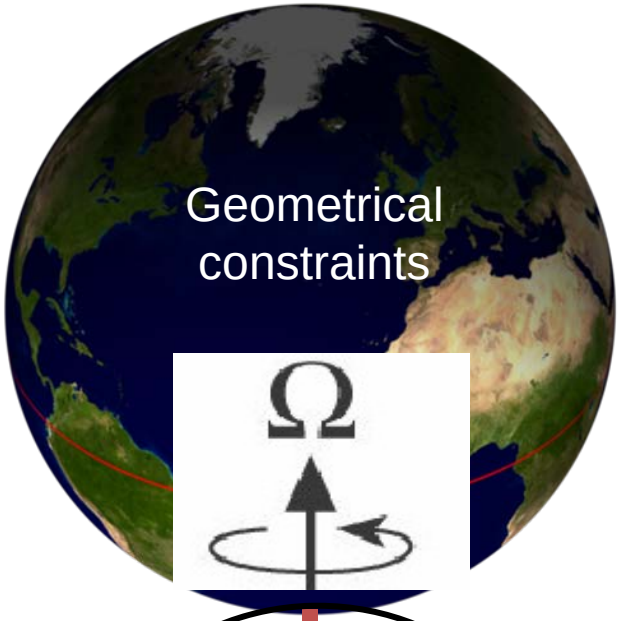
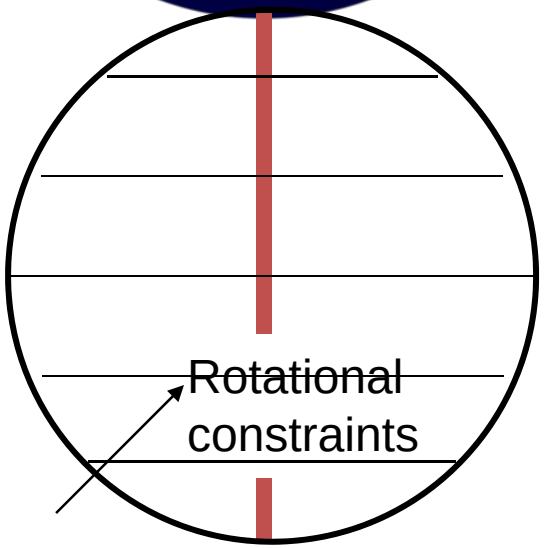
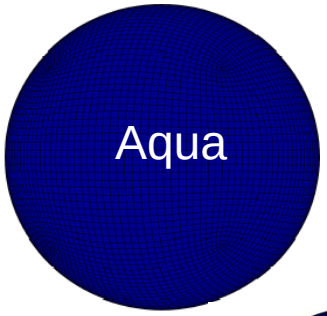
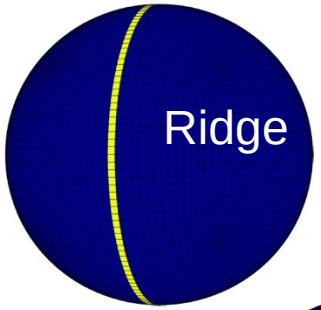
Role of the ocean in climate

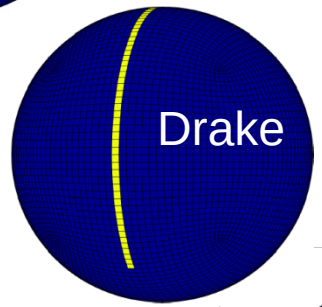




‘f’ contours



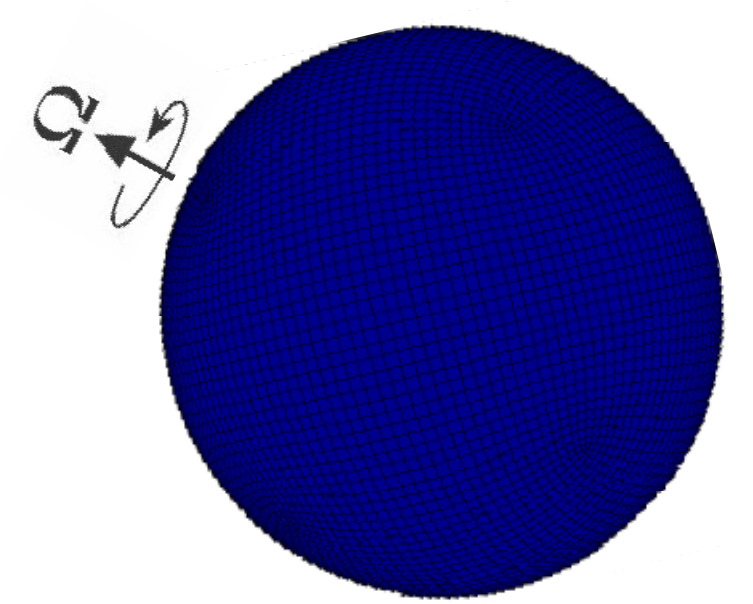




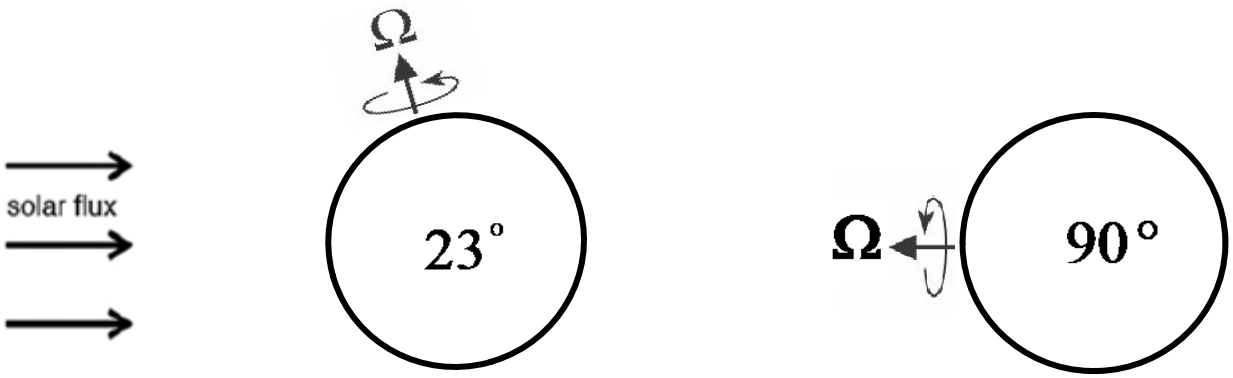
Climate of an Earth-like Aquaplanet at High Obliquity

David Ferreira, John Marshall
Paul O'Gorman, Sara Seager

Massachusetts Institute of Technology



Climate as a function of obliquity



1 Why is the problem interesting from a climate dynamics perspective?

c.f. Kristen Menou presentation

2 Climate of an aquaplanet at present day (low) obliquity

Earth-like planet with an atmosphere,
an ocean and possibility of ice,
.....but no land!

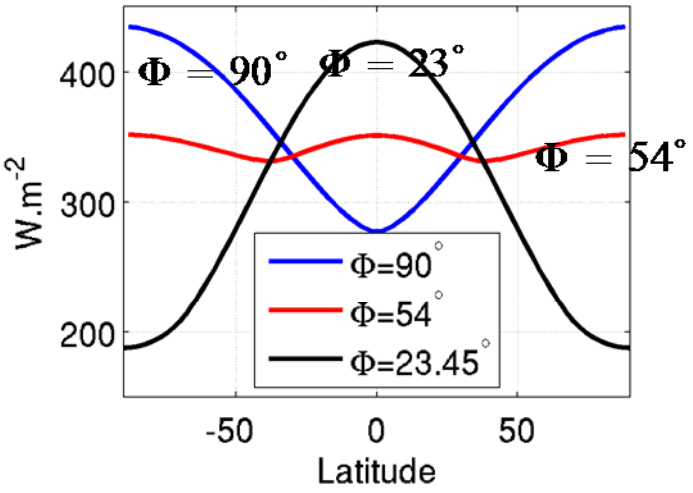
3 Describe possible climates at high obliquity

Conclusions

1 Climate dynamics

Incoming solar radiation

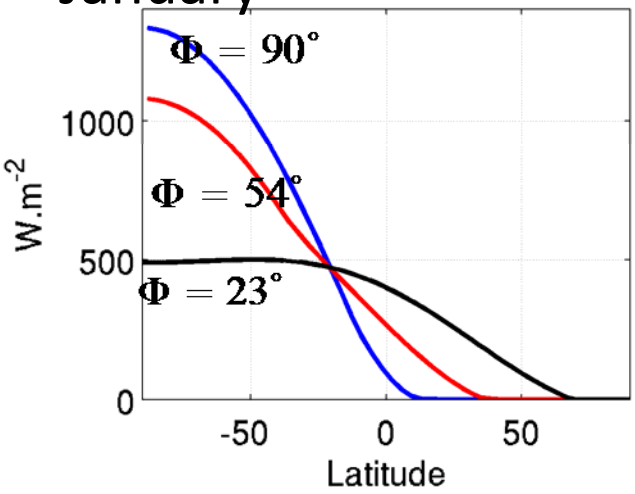
Annual mean



At high obliquity the poles are warmed more than the equator

Expect a reversal of pole-equator temperature gradient !!

January

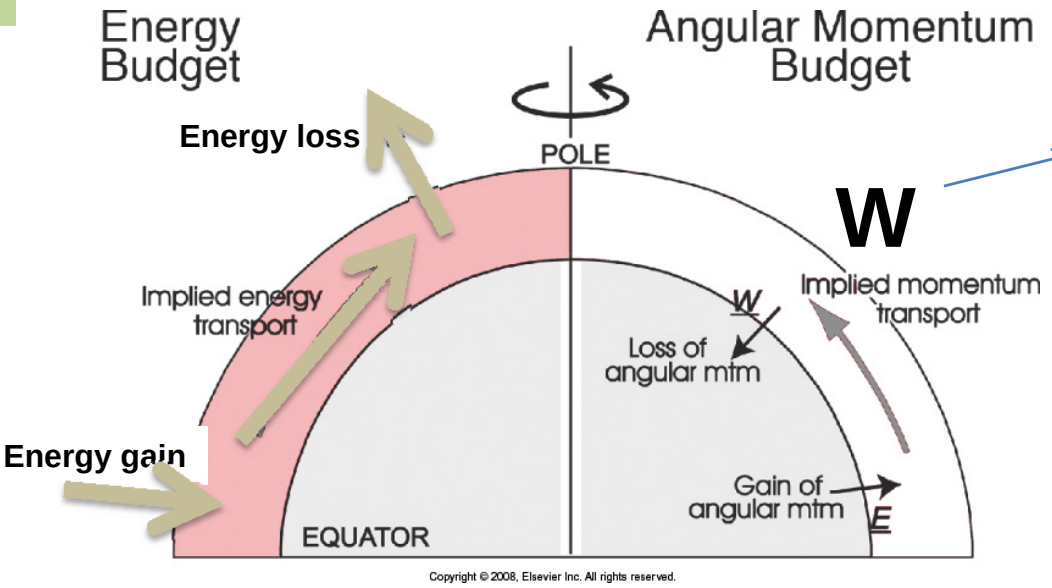


Extreme seasonal cycle

If polar temperatures are not to wildly fluctuate, heat must be stored or carried there.

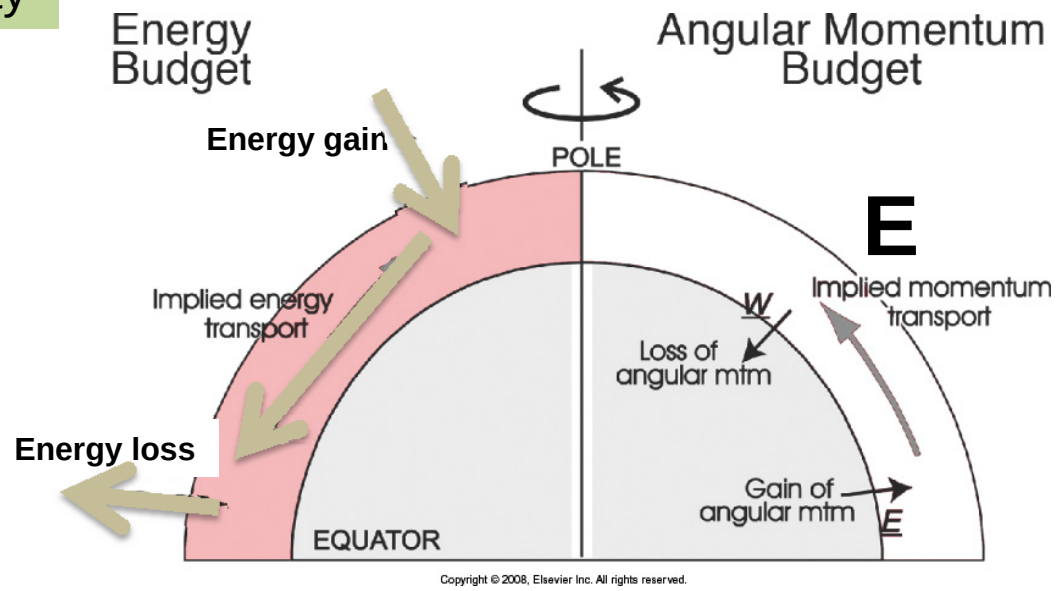
Likely key role for the ocean

Low obliquity



Westerly winds
i.e. west to east

High obliquity



?

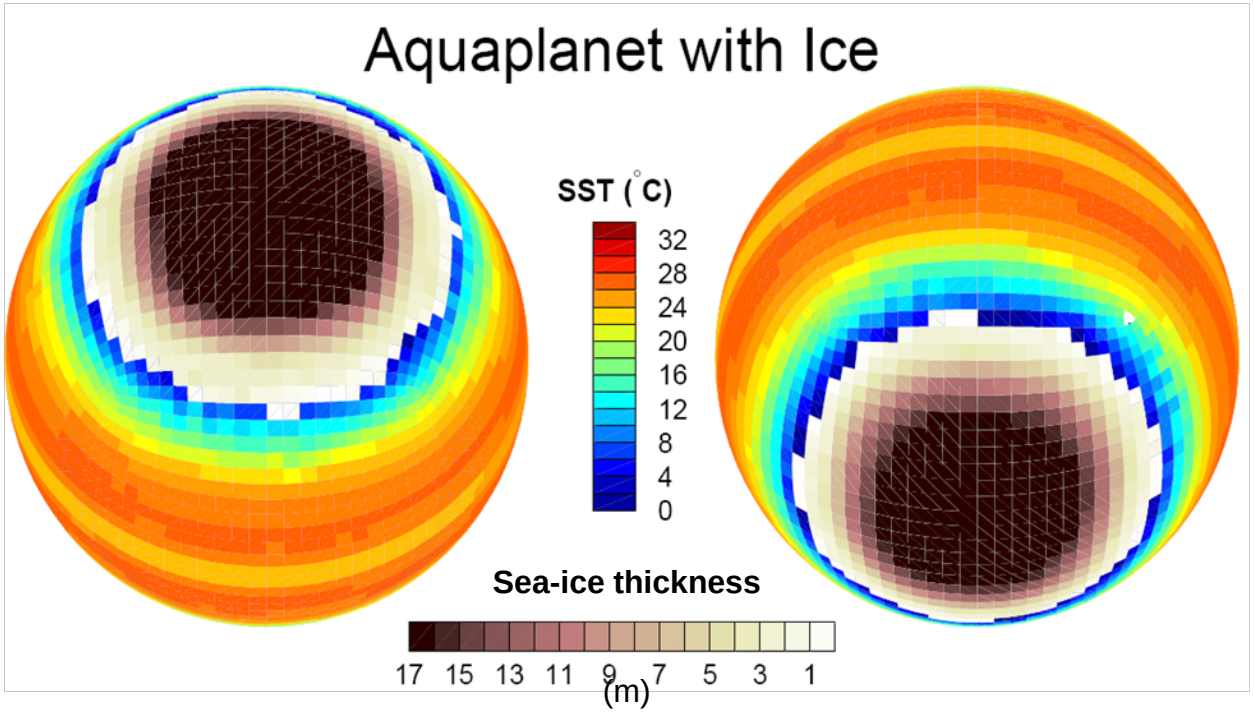
Key climate questions

- What determines the meridional energy transport and its partition between the atmosphere and ocean?
- What determines the pattern of surface winds?

  (angular momentum transport) - critical to ocean circulation
- What is the role of the ocean in modulating seasonal extremes of temperature (through storage and transport)?
- How do the above depend on orbital parameters?

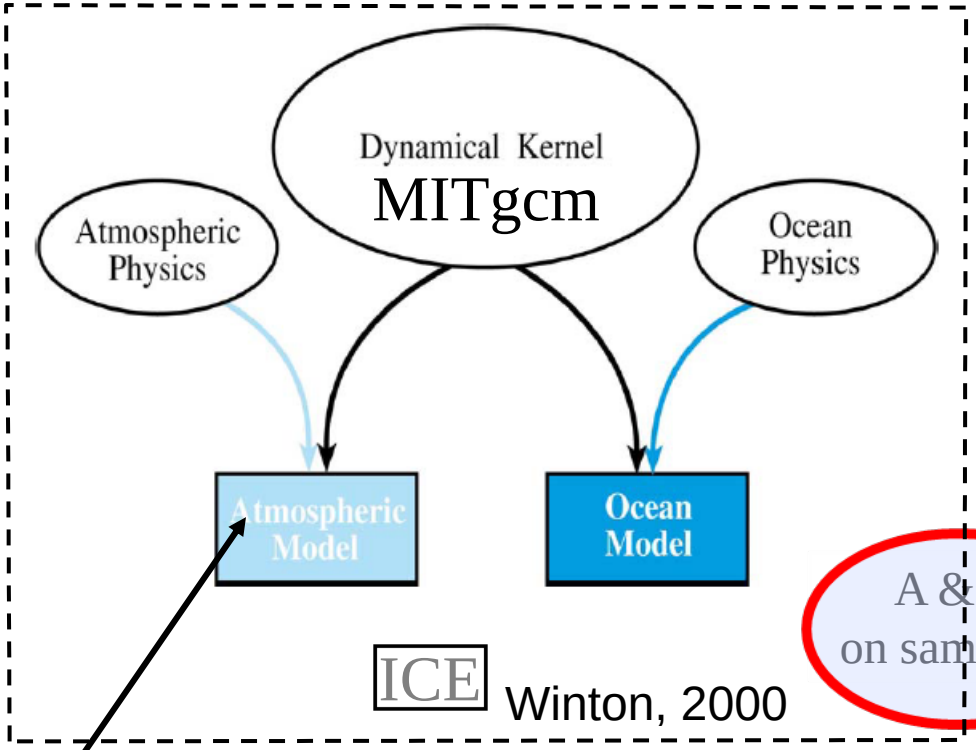
  in particular on obliquity
- Many others……

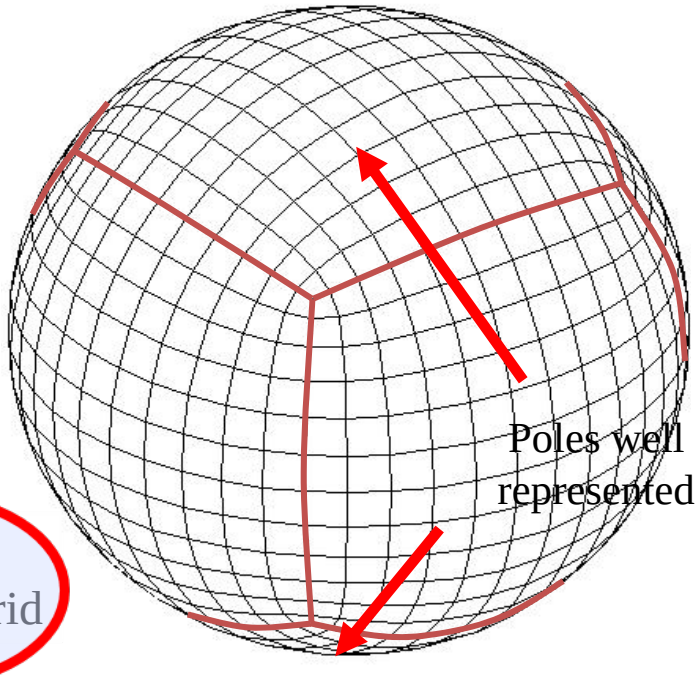
2 Climate of aqua-planet at obliquity of 23º



SST & sea ice

Coupled model





'SPEEDY' → Intermediate complexity

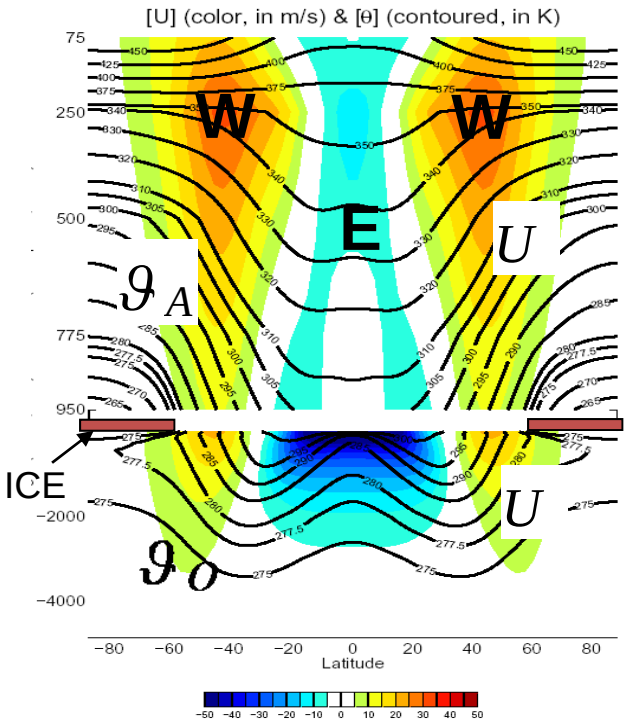
Molteni, 2003

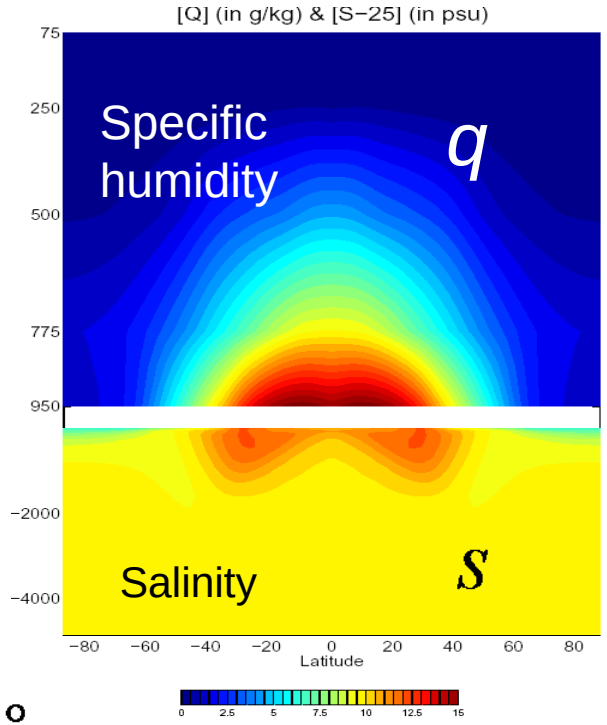
Fully coupled:
no adjustments

3000 years in 1 week of CPU time
(synchronous)

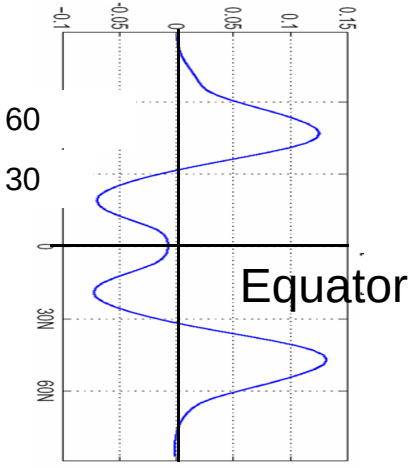
J-M Campin, David Ferreira, Chris Hill

Climate of aqua-planet at obliquity of 23^o



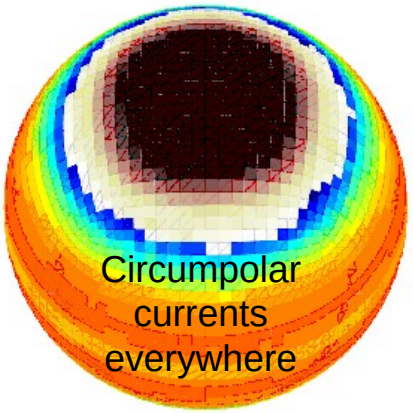


$$\Phi = 23^\circ$$



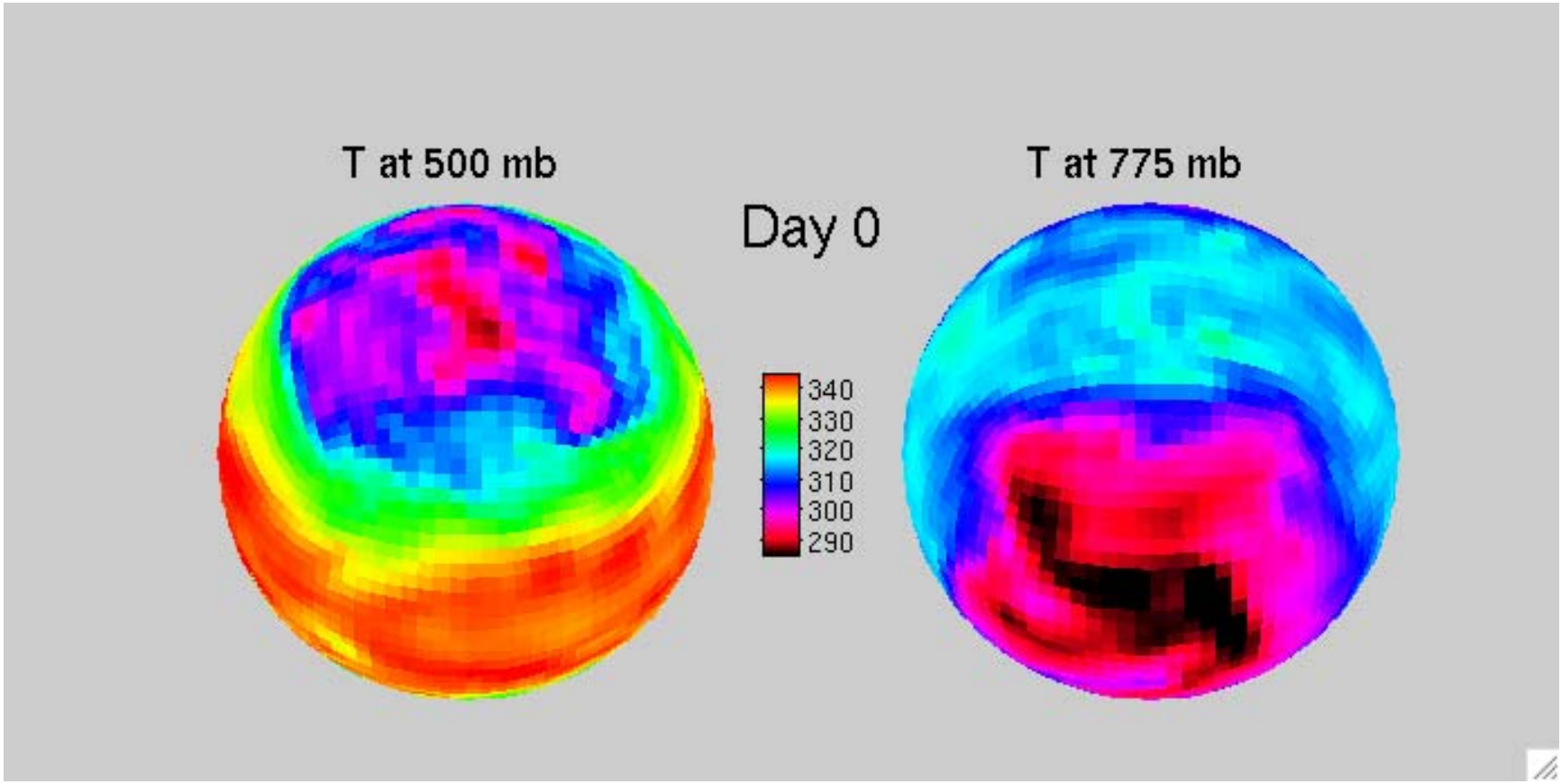
Pattern of surface winds

Zonal jets in ocean



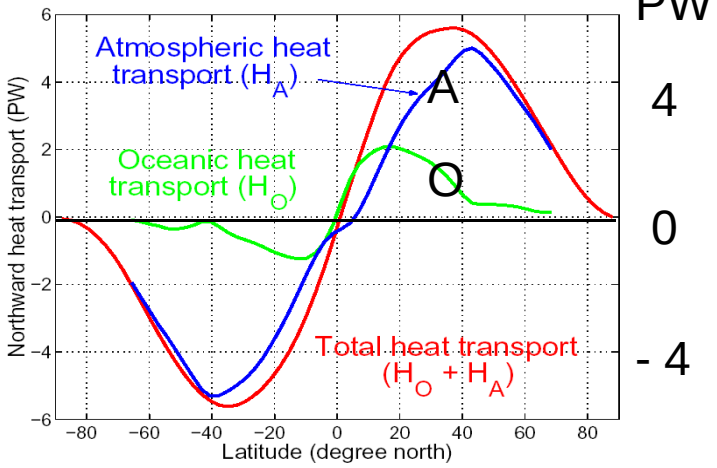
Aquaplanet solution discussed in Marshall, Ferreira et al, 2007, J.Atmos Sci

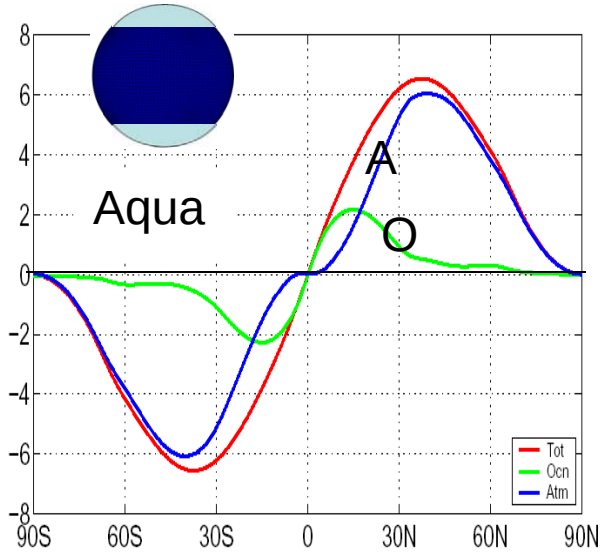
Evolution of atmospheric temperature at 500mb and 775mb

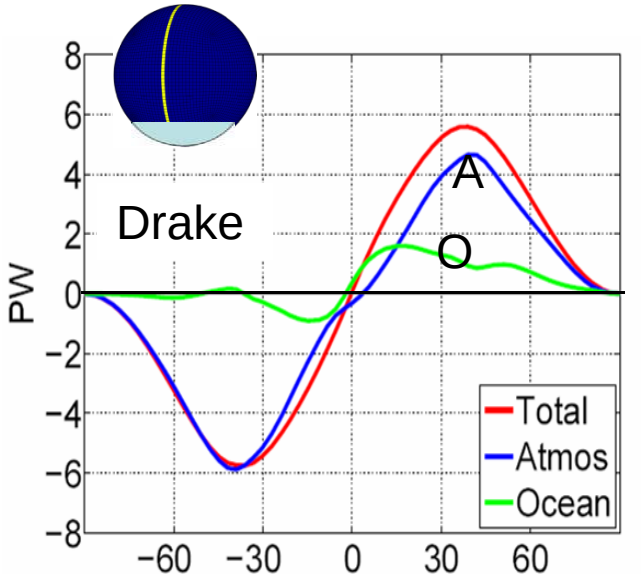


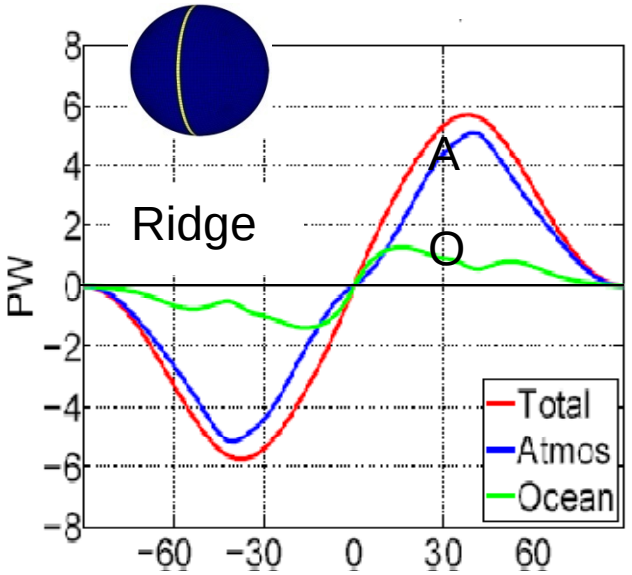
Energy transport $\Phi = 23^{\circ}$

Today's climate



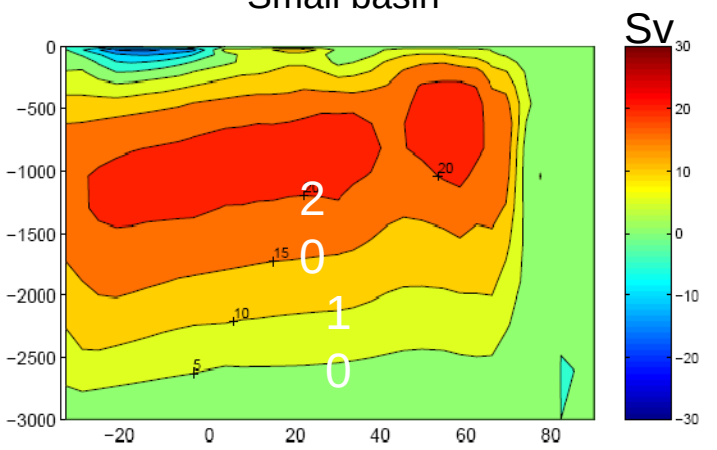




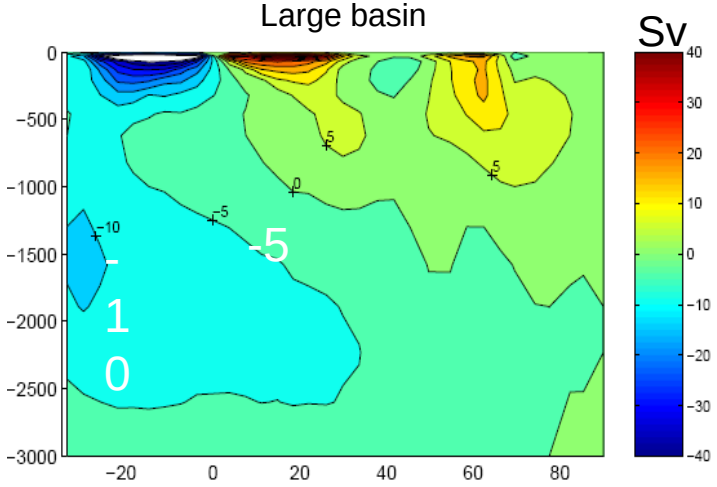


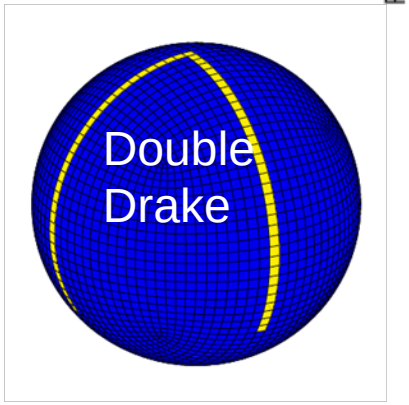
Overturning circulation in ocean

Small basin

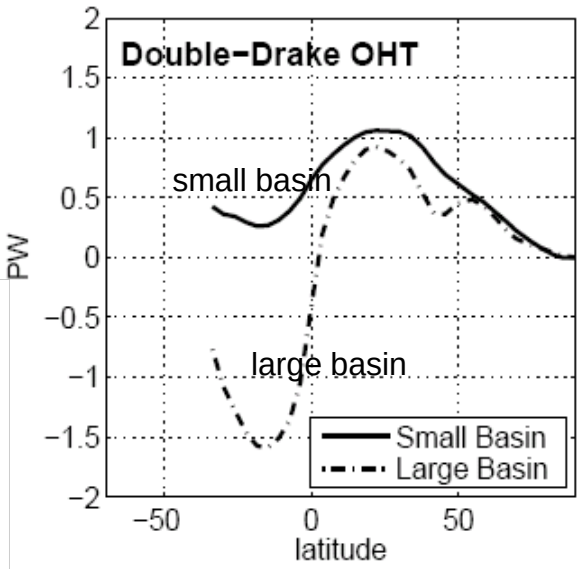


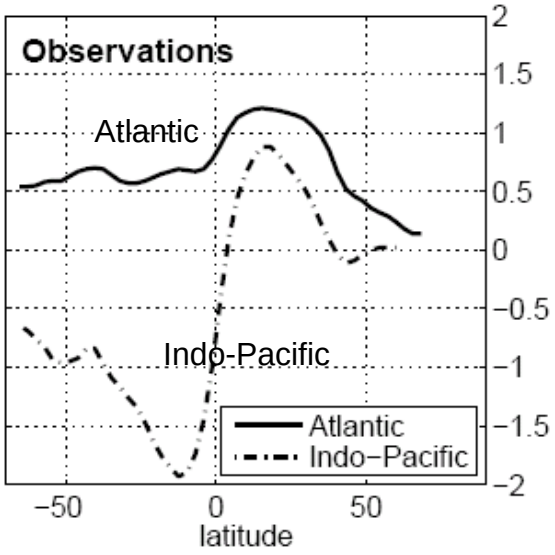
Large basin





Ocean Heat transport





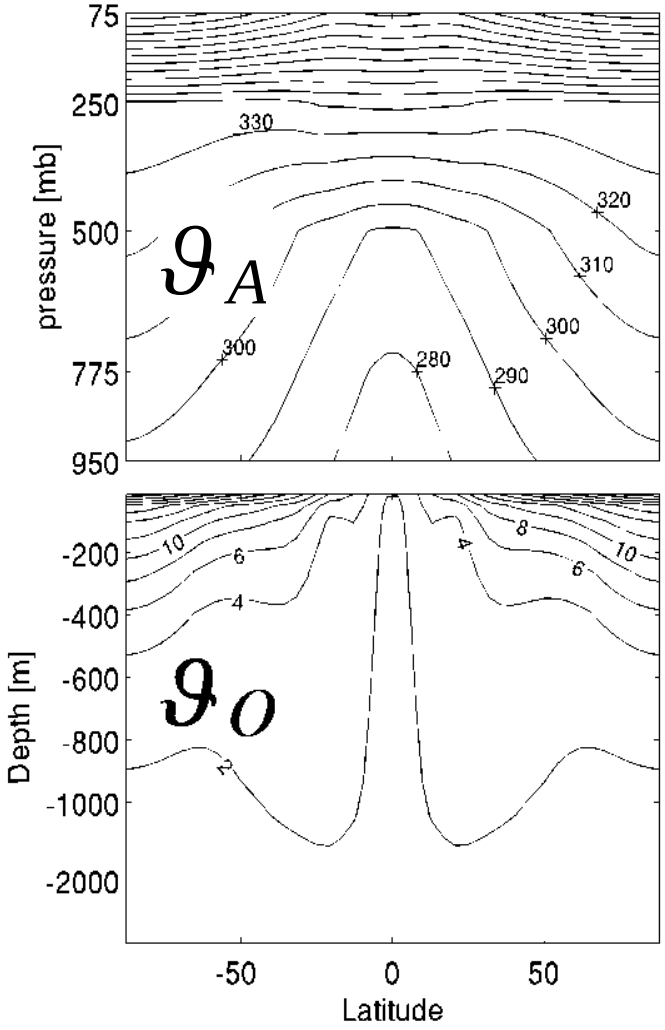
Ferreira, Marshall and Campin, 2010,
J. of Climate

3 Climate at high obliquity

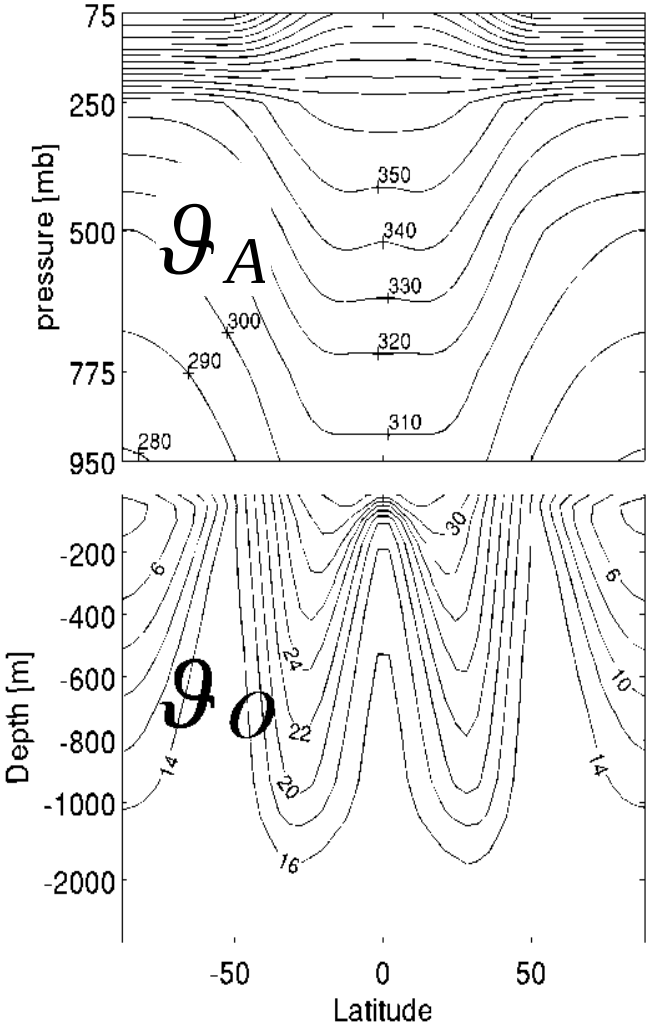
Annual means

Temperature

$\Phi = 90^\circ$

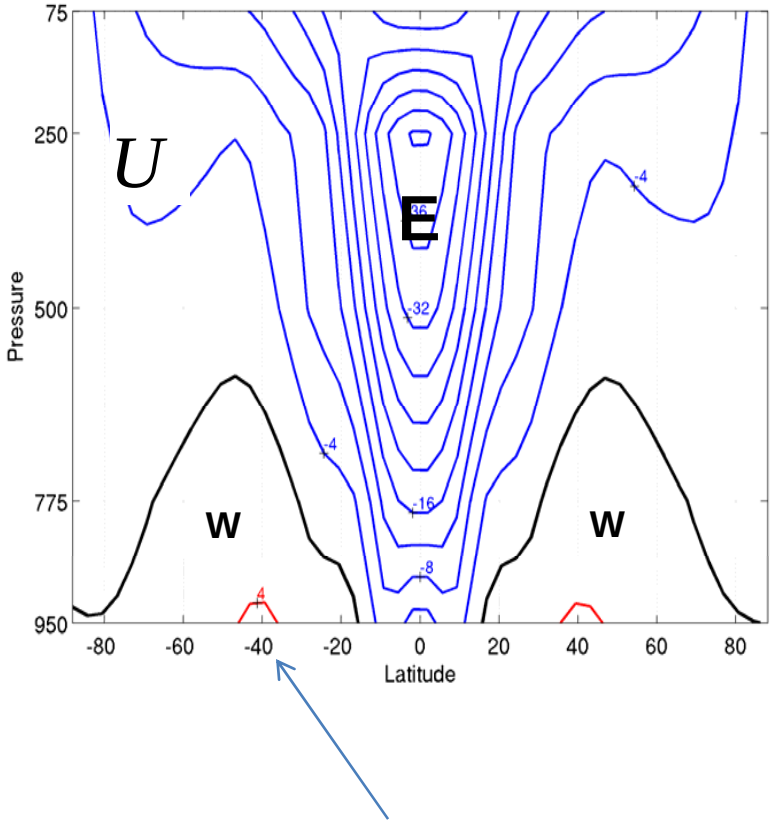


$\Phi = 23^\circ$

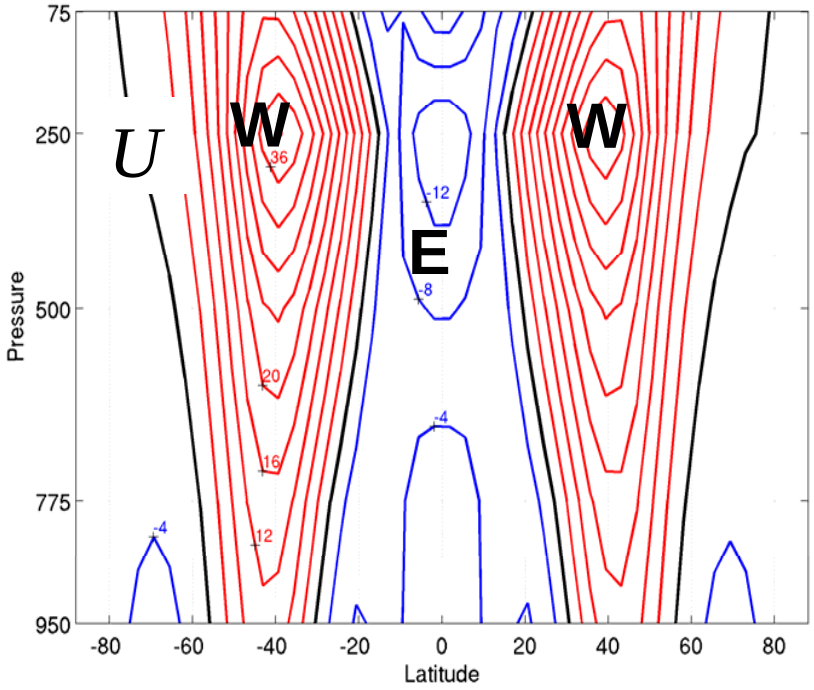


Winds

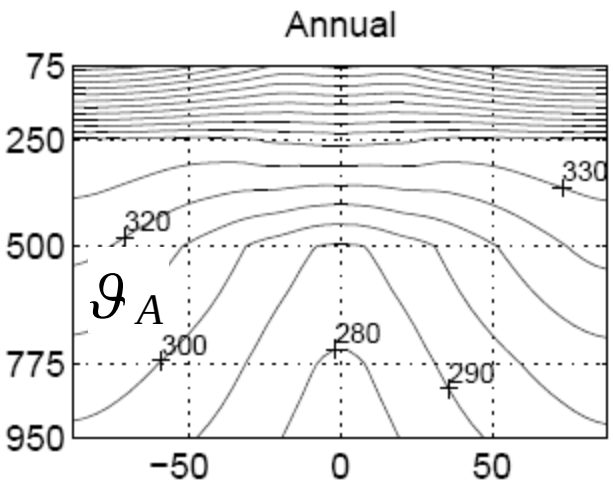
$\Phi = 90^\circ$

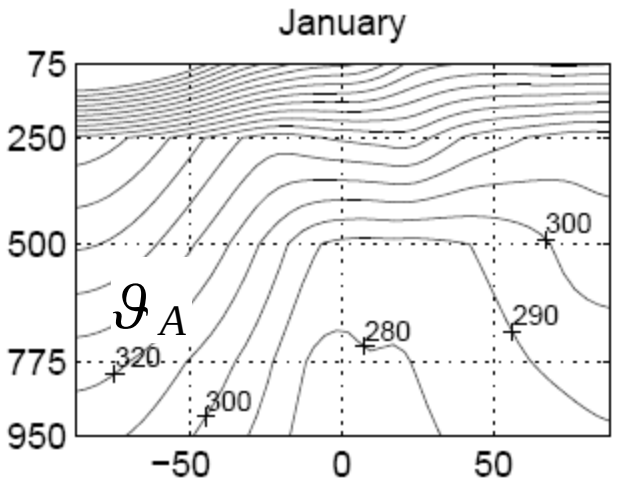


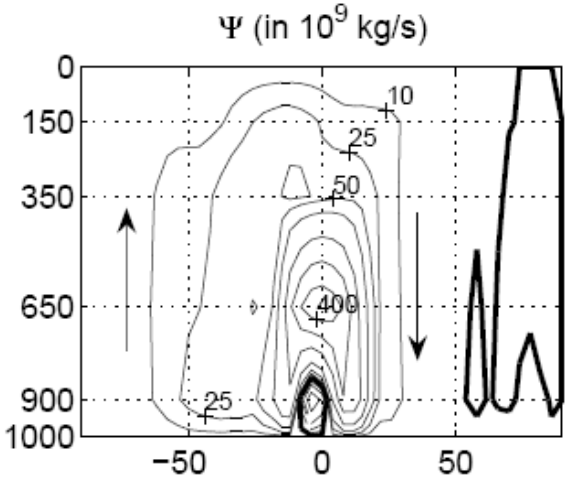
$\Phi = 23^\circ$



Surface westerlies in middle latitudes
easterlies in tropics

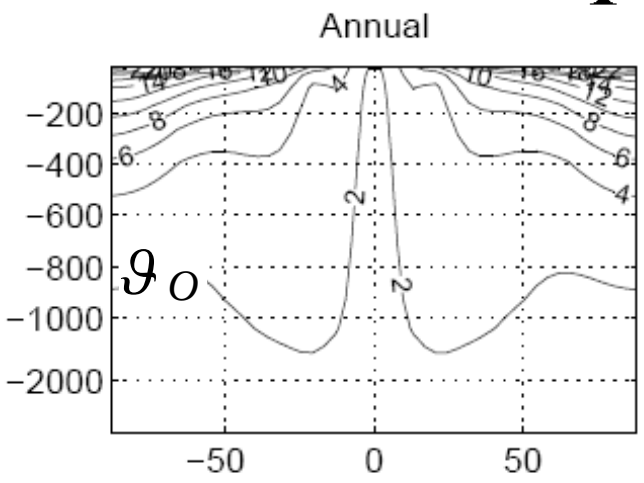


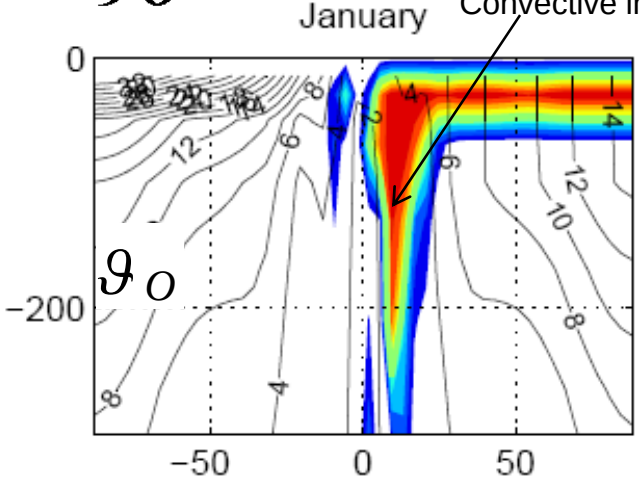


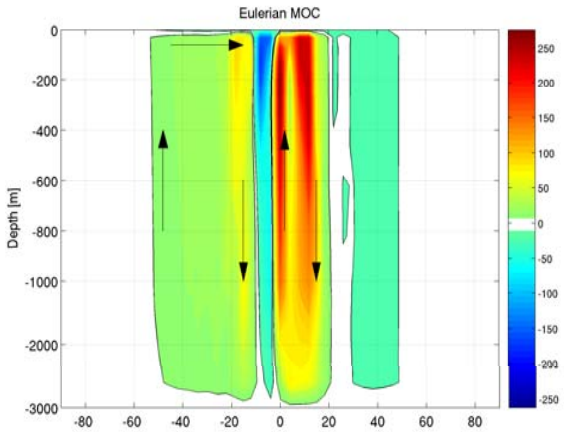


$$\Phi = 90^\circ$$

Overturning circulation



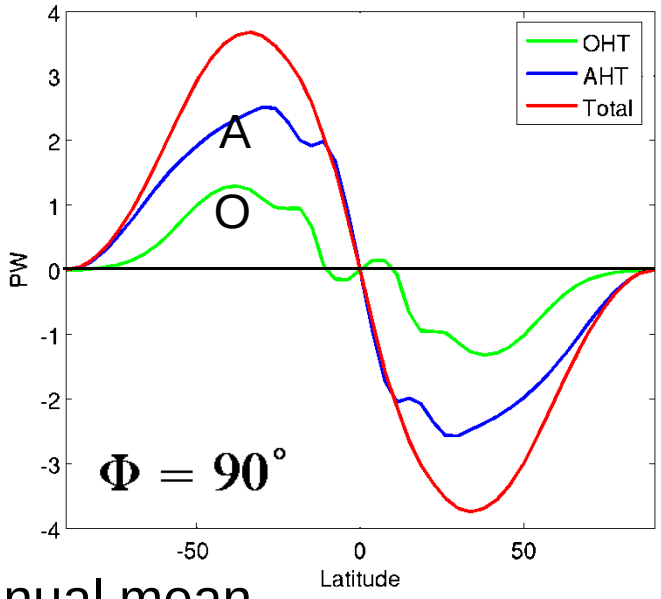




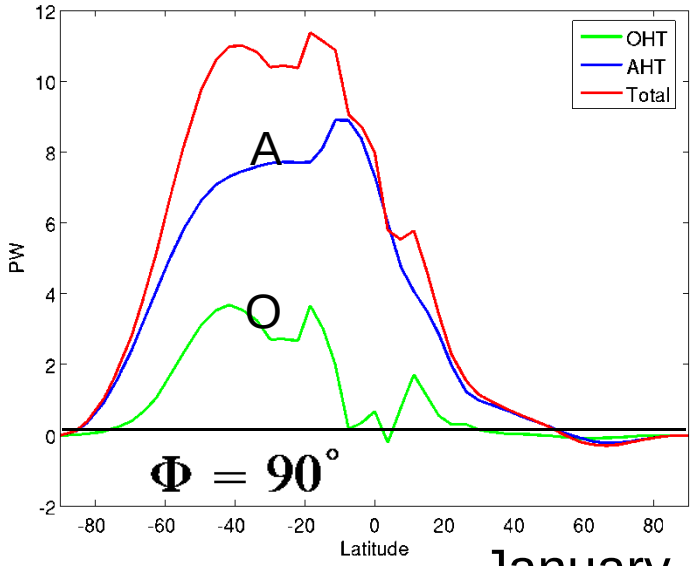
Atmosphere | Strong surface temperature gradient in summer hemisphere (~40K) and weak gradient in winter hemisphere (~10K)

Ocean | Seasonal variations restricted to top 200m
--- amplitude of ~12K at pole
--- almost steady and ~2K at equator

Atmos and Ocean energy transport at high obliquity



Annual mean

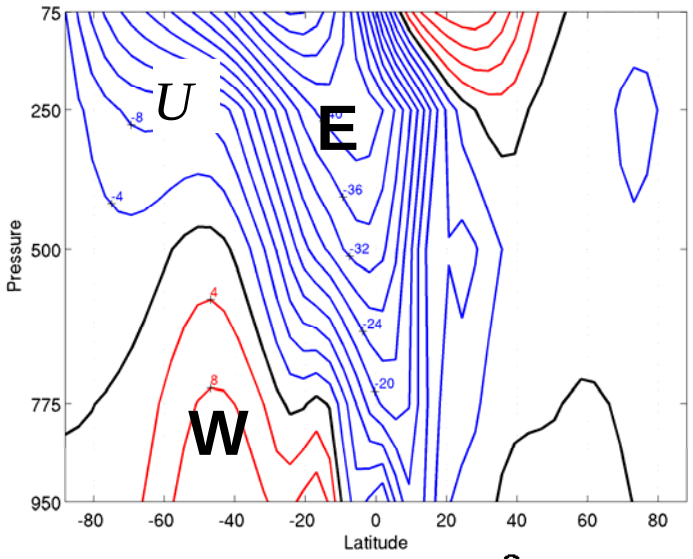


January

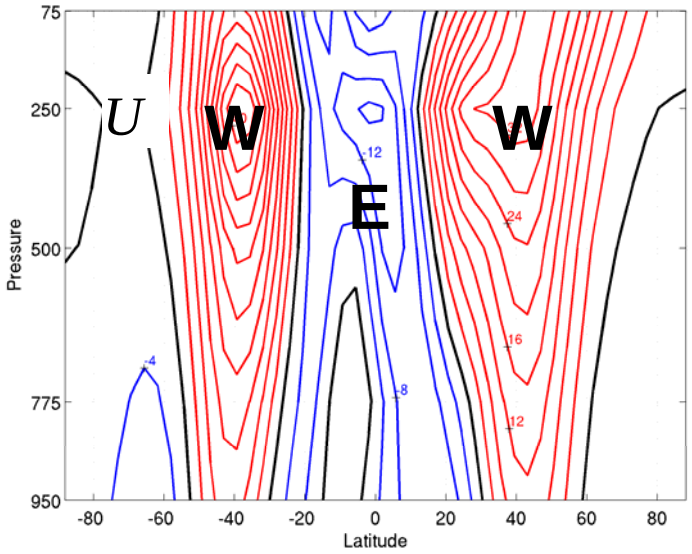
Atmosphere and Ocean heat transports are achieved seasonally
----- large in the summer hemisphere
----- nearly vanish in the winter hemisphere

Equatorward transport everywhere
----- down large-scale temperature gradient

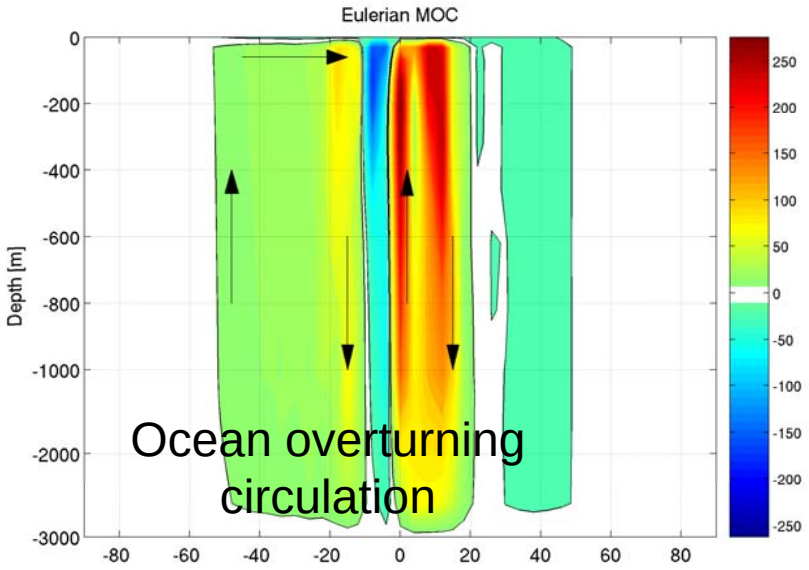
January winds



$\Phi = 90^\circ$



$\Phi = 23^\circ$



Ocean overturning circulation

c.f. Adam Showman's presentation

Conclusions

At high obliquity:

- Surface climates are rather mild despite extreme summer insolation and long polar nights – seasonal cycle between 10 and 35K.
- Atmospheric jet stream exists only in the summer hemisphere
- Baroclinic eddies are the primary heat transport mechanism – Hadley cell plays lesser role
- Surface westerlies exist in middle latitudes and trades at the equator, despite easterly winds aloft

---

- Ocean plays an important role in heat transport, carrying about 1/3 of the total
- Wind-driven middle-latitude Ekman cells are the primary mechanism – subtropical/equatorial cells play a lesser role
- Heat is stored in the ocean in the summer and delivered to the atmosphere in the winter, keeping it warm.

Future work

- Observability – what could we detect from a telescope?
  rotation rate, heat capacity,?..... Katie French
- Role of the ocean in mediating snowballs
- Multiple equilibria ……. Brian Rose

c.f. presentations by Franck Selsis and Nick Cowan

Multiple Equilibria

We have recently discovered that the coupled aqua-planet models possess multiple equilibria!

Ridge

Aqua