Physical oceanography
Lecture 3
Meridional overturning circulations in the ocean and their energy transport

ICTP: The General Circulation of the Atmosphere and Oceans: A Modern Perspective

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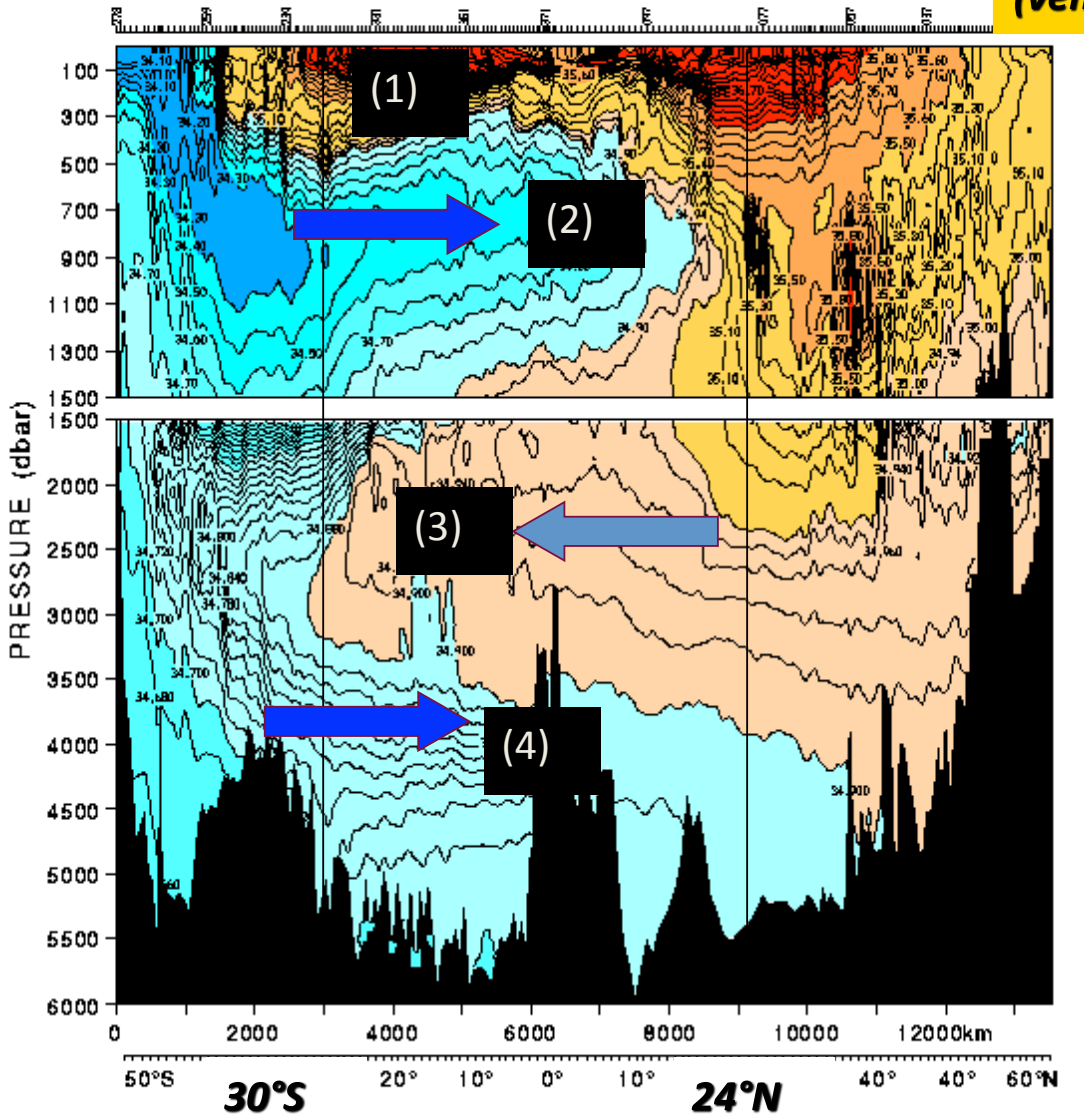
Meridional overturning circulation

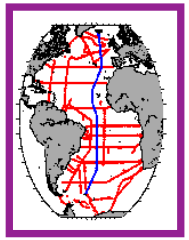
- Deep water layering and net meridional direction, deep water formation sites
- Observed deep ocean circulation, overturn and schematics
- Forcing of the large-scale overturn
- Deep water formation regions and processes
- Upwelling regions and processes
- Meridional overturning circulation diagnosis
- Ocean heat transport
  - Role of MOC
  - Relative importance of MOC and shallower overturns in the gyres and tropical cells

Atlantic overturning: traced in salinity

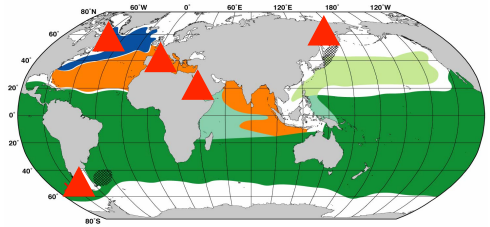
Atlantic Salinity (south-north section)



(1) surface waters (ventilated thermocline)

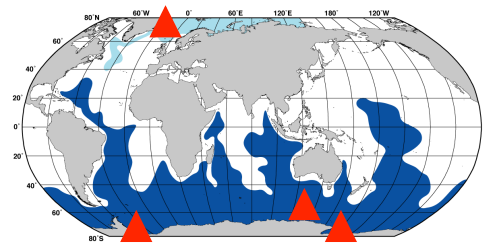


(2) Low salinity Antarctic intermediate water



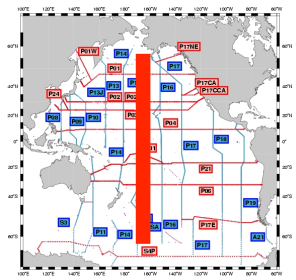
(3) High salinity

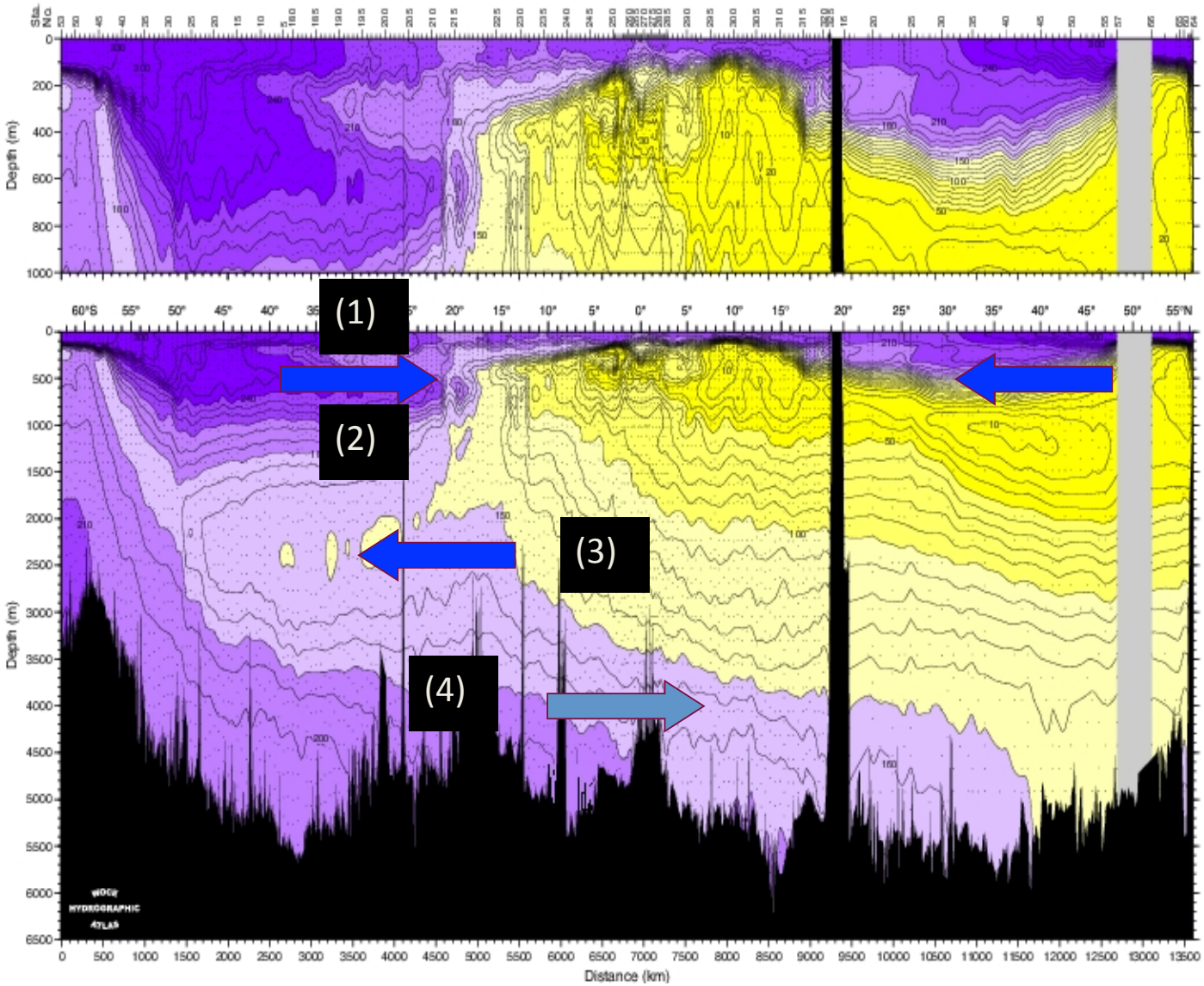
North Atlantic Deep Water



(4) Low salinity Antarctic bottom water

Meridional overturning: Pacific oxygen





Use oxygen because salinity does not provide easy tracking

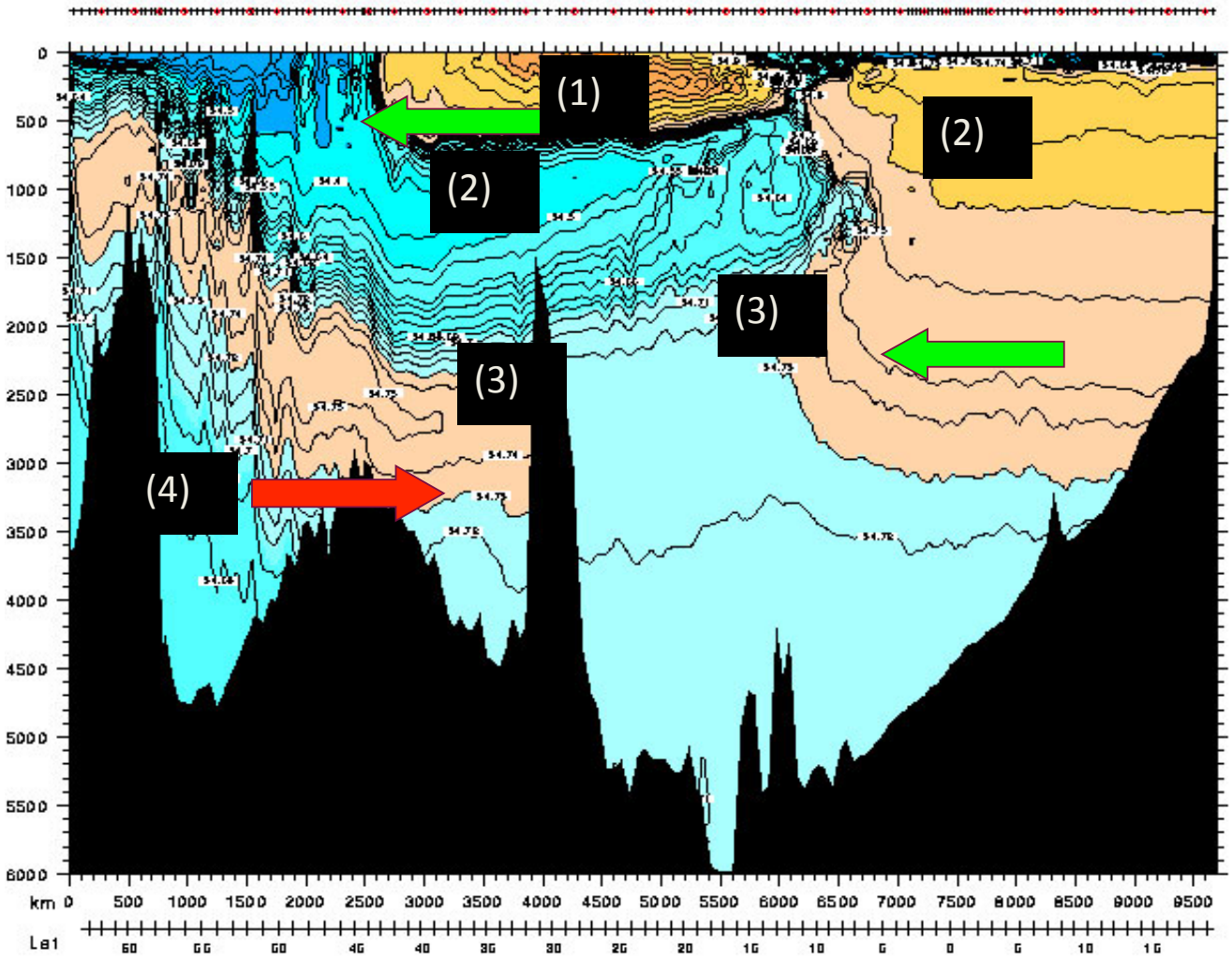
(1) Upper

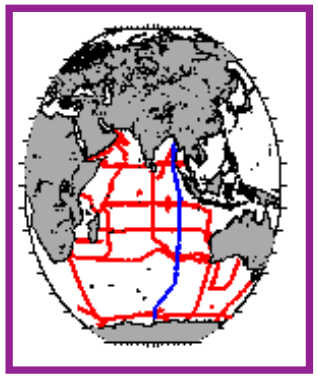
(2) AAIW and NPIW

(3) PDW

(4) LCBW (AABW)

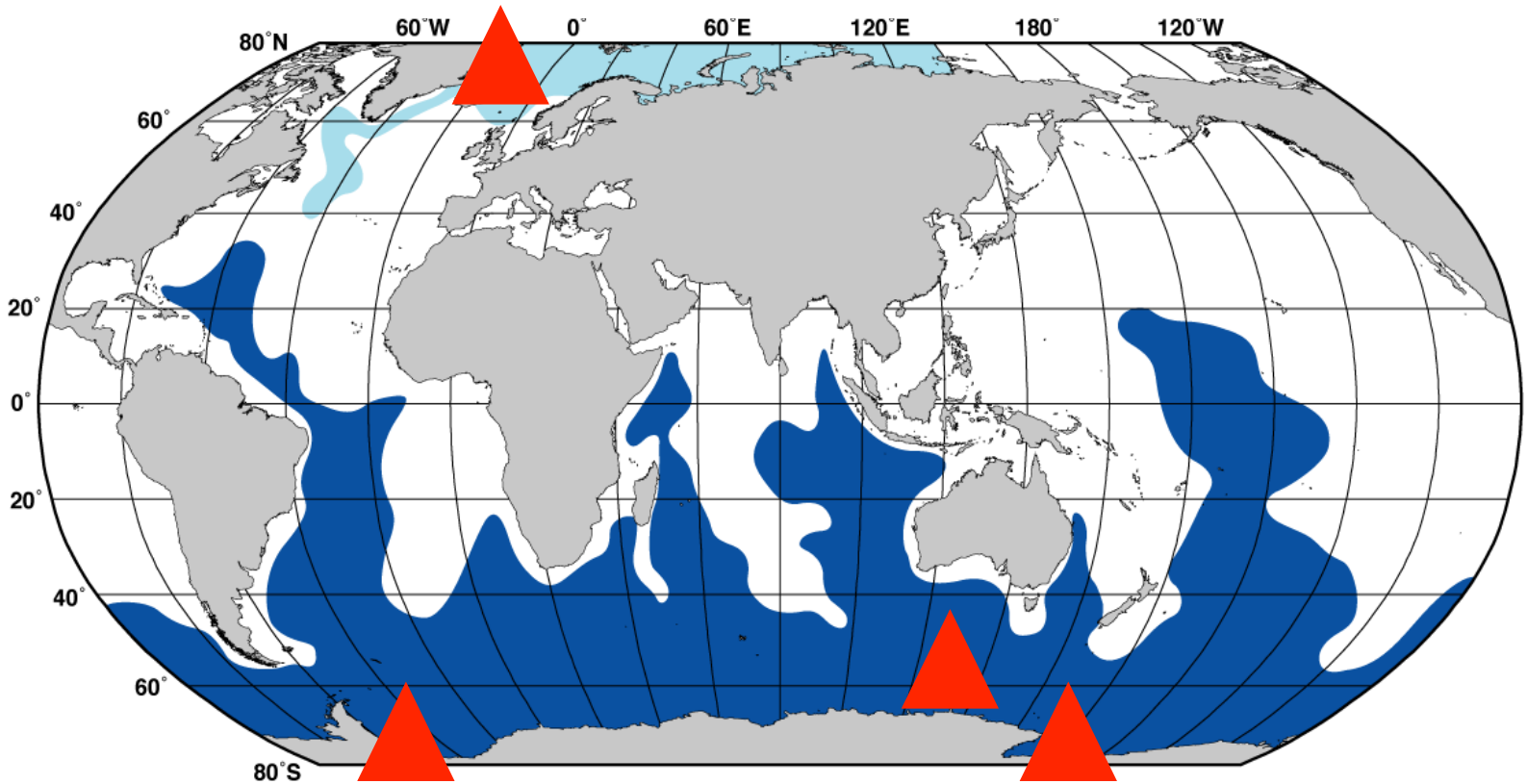
Indian overturning





(1) Upper
(2) AAIW and RSW
(3) NADW and IDW
(4) AABW

Meridional overturning circulation: deep water formation sites

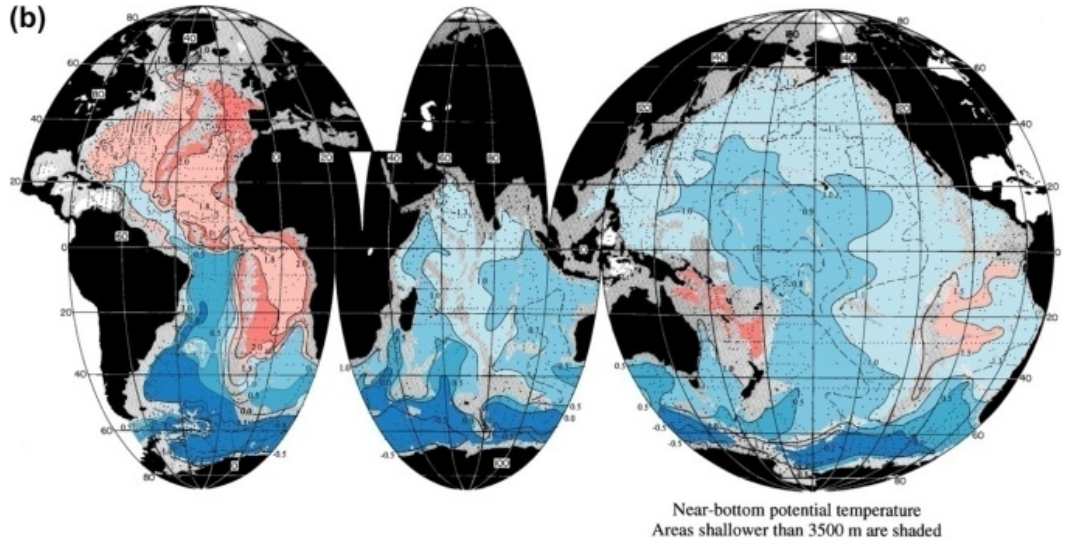


(3) Nordic Seas Overflow waters, contributing to NADW

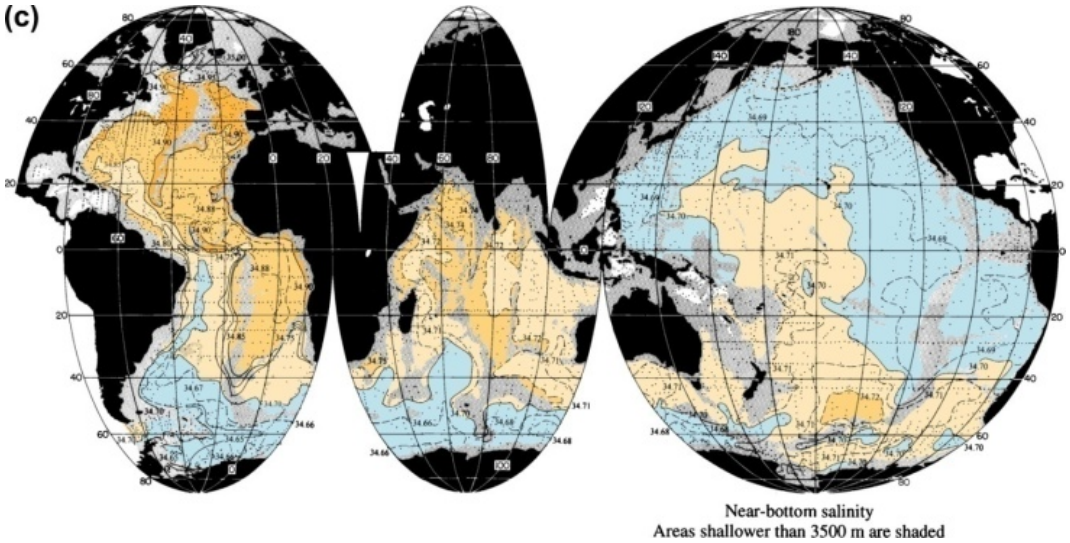
(4) Antarctic Bottom Water in Weddell, Ross Seas and Adelie Coast

Talley (1997)

Meridional overturning: deep properties



Bottom potential temperature



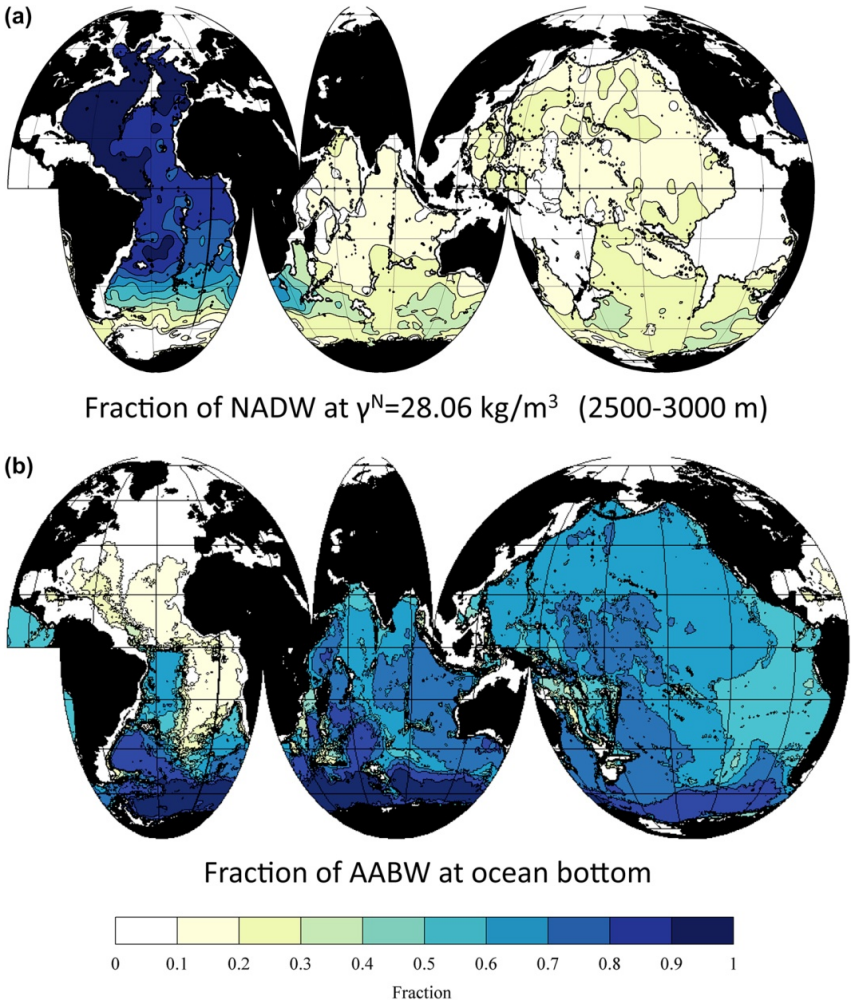
Bottom salinity

Warmest, saltiest bottom water from the North Atlantic
Coldest, freshest bottom water from the Antarctic

TALLEY

FIGURE 14.14

Meridional overturning: deep properties



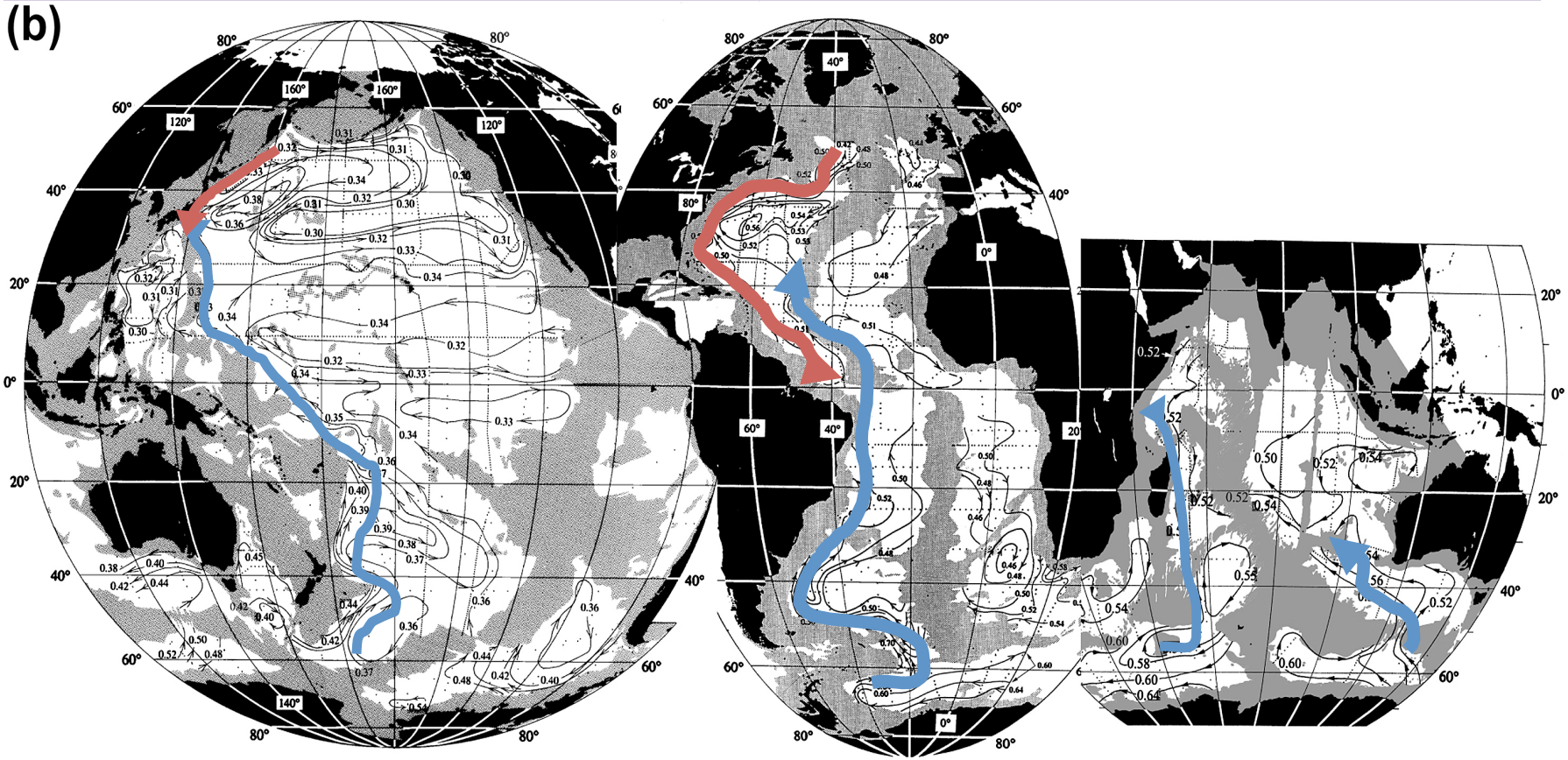
Fraction of water at 2500-3000 m from the North Atlantic (North Atlantic Deep Water) and

And at the bottom from the Antarctic (Antarctic Bottom Water)

Result: NADW strongly affects the Atlantic, weakly present in rest of oceans. AABW present over much of world ocean except North Atlantic

FIGURE 14.15

Meridional overturning circulation: Deep Western Boundary Currents



Circulation at 4000 dbar (adjusted steric height)

DPO Fig. 14.4b

Below depth of NADW in S. Atlantic

Dominated by topography. Deep Western Boundary Currents, deep cyclonic flows in some isolated basins

(Reid, 1994, 1997, 2003)

Meridional overturning: theory of Deep Western Boundary Currents

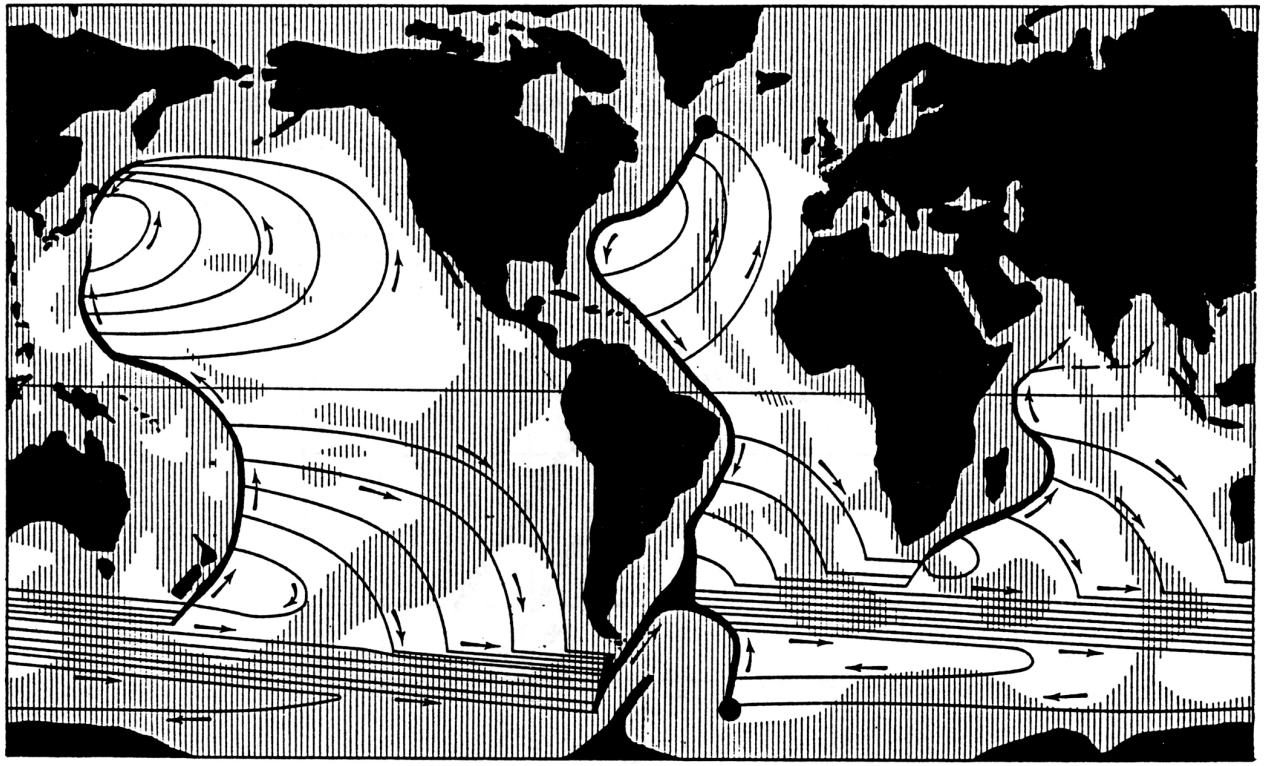


Figure S7.42

Very idealized model of global DWBCs (Stommel, 1958)

Potential vorticity dynamics: stretching due to upwelling, interior poleward flow, DWBC to close circulation

No topography

2 sources:NADW and AABW (very idealized versions!!!)

Meridional overturning circulation

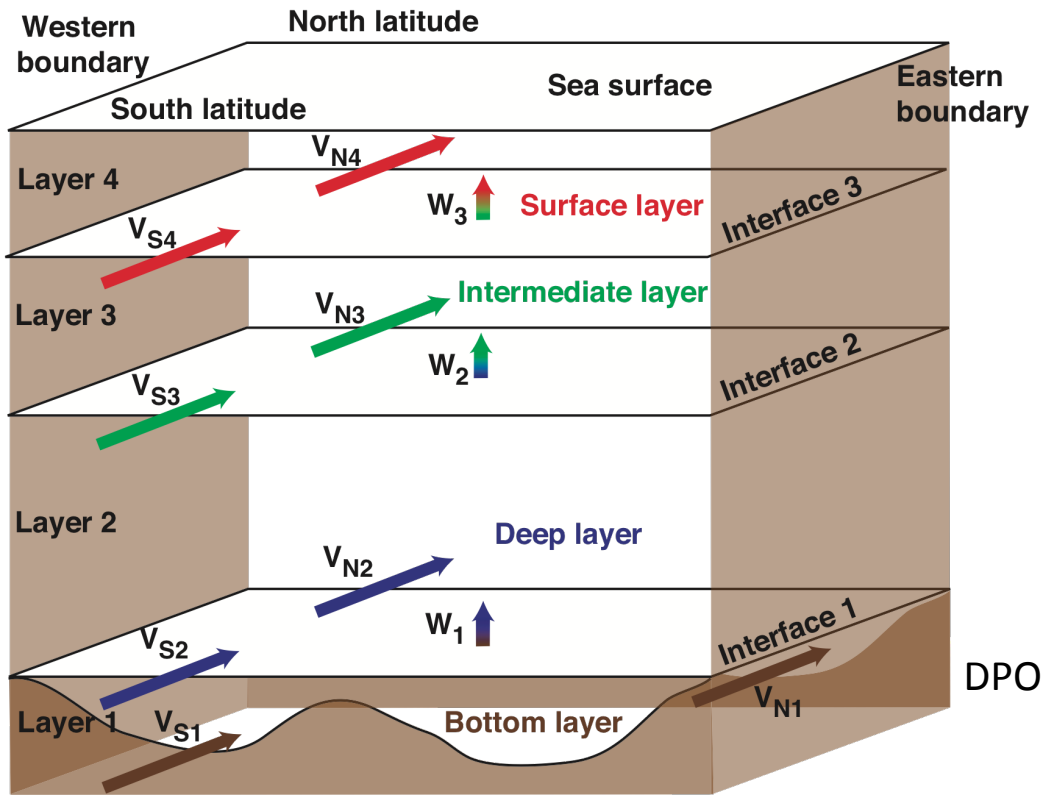
- Because sources of densest waters are in the northern N. Atlantic/ Nordic Seas (NADW) and in the Antarctic (AABW), interesting to see how these fill the global ocean, upwell and return in upper ocean back to source regions

- Common to look at NET MERIDIONAL TRANSPORT across latitudes. Most useful to look at this in isopycnal layers (not depth layers), since flow is mostly along isopycnals.

- Also look at heat transport and freshwater transport this way.

- Choice of isopycnal layers is related to water masses. We can see signature of meridional overturn by looking at the intermediate, deep and abyssal water masses.

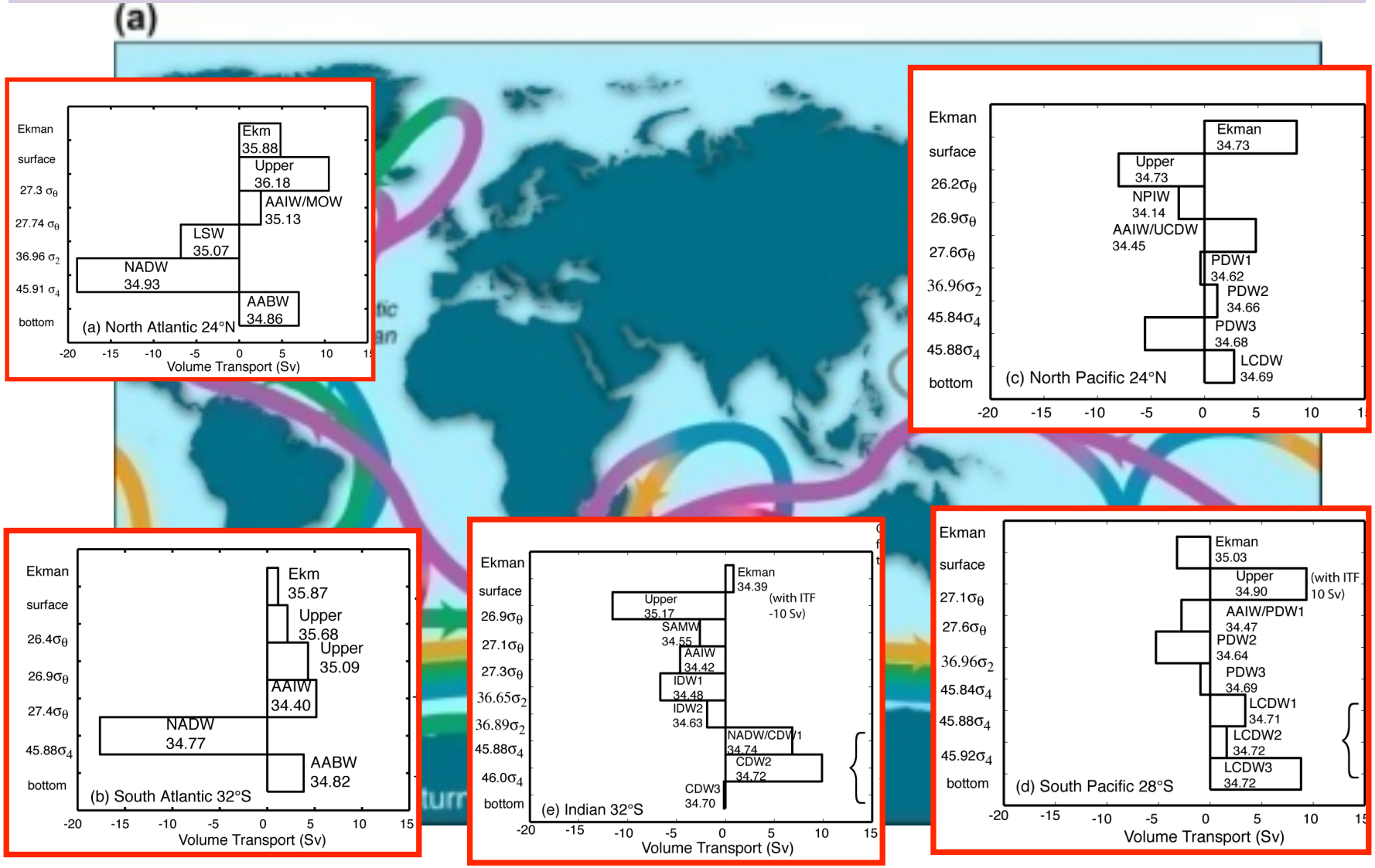
Calculation of meridional overturning



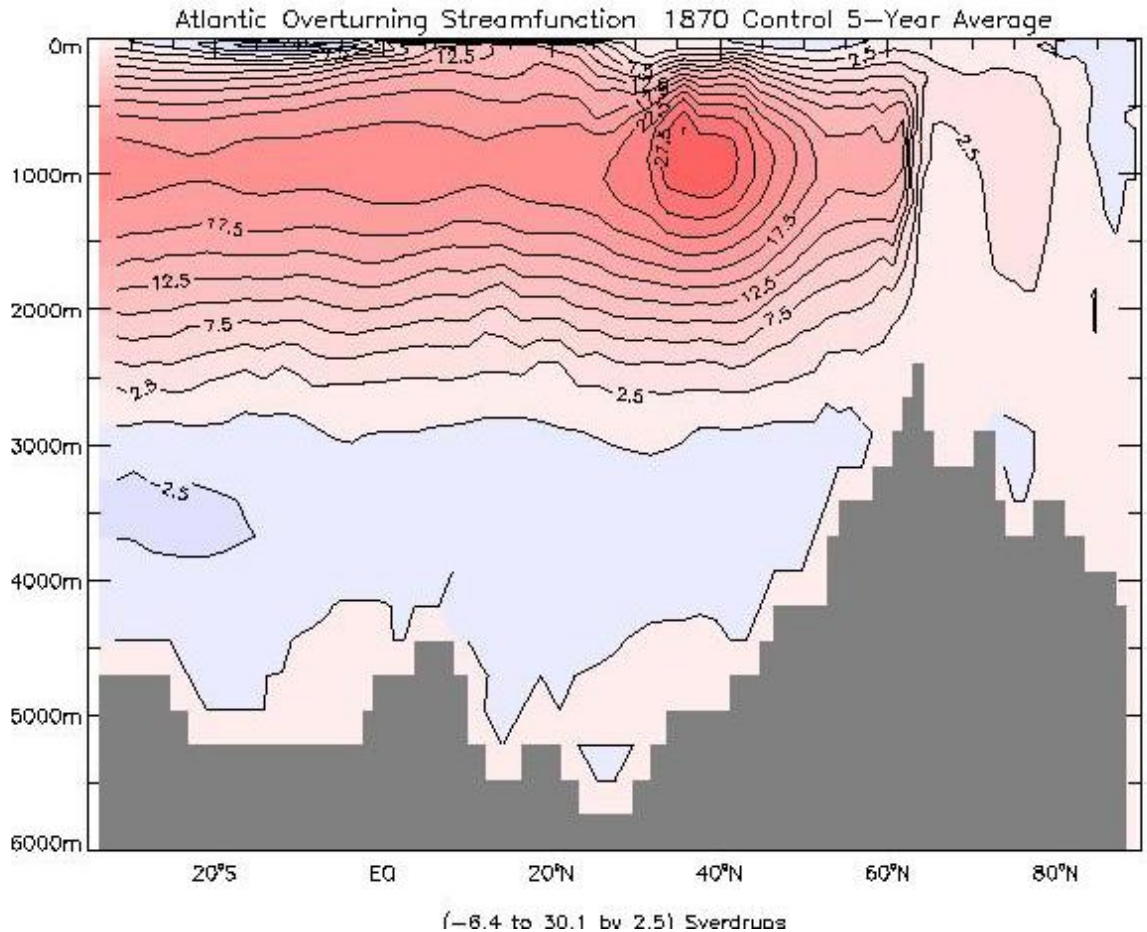
DPO Fig. 14.5

Calculated net transport of water in layers (isopycnals as interfaces between the layers).
Upwelling and downwelling between layers diagnosed from convergences and divergences.
Overturning streamfunction can then be computed from the transports.

Net meridional transports in isopycnal layers

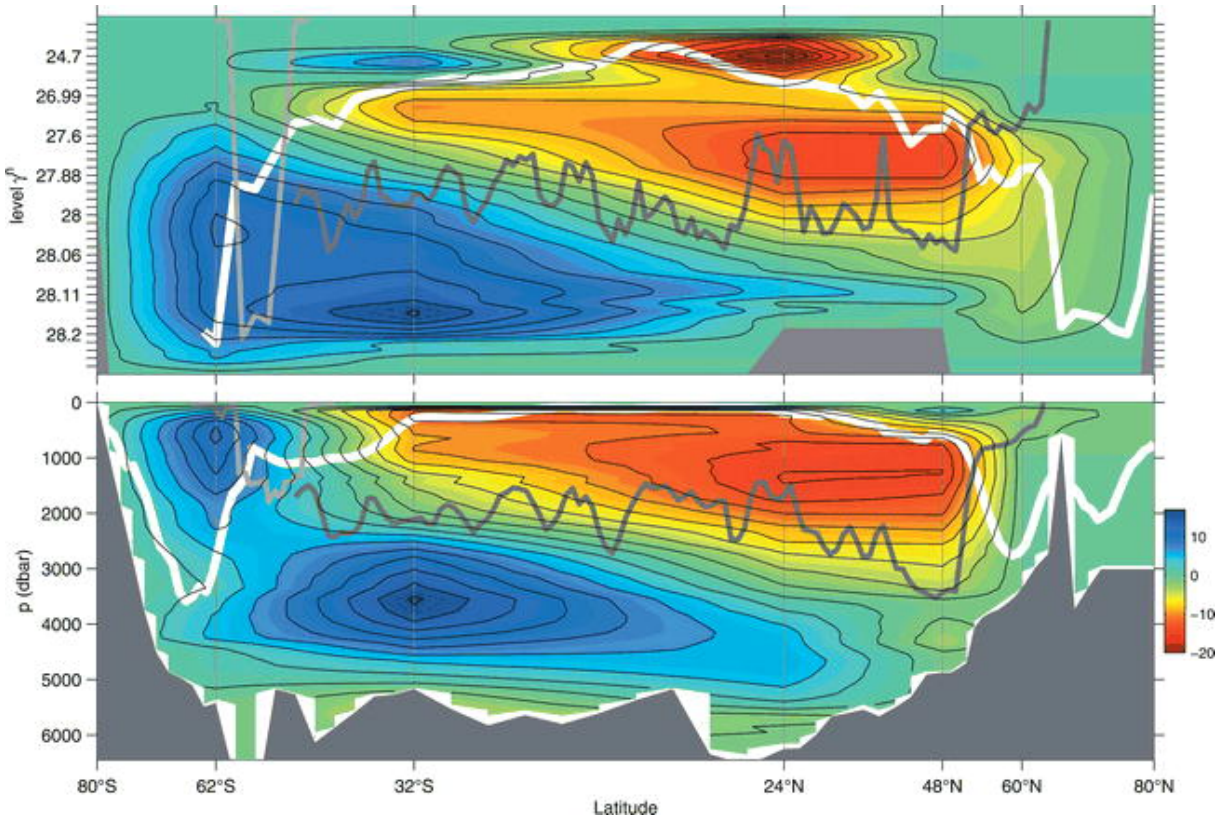


Meridional Overturning Streamfunction (model)



Example of an Atlantic overturning streamfunction (from an ocean circulation model). Numbers are transport in Sverdrups. From Gent (2000).

Meridional Overturning Streamfunction (observed)



Density coordinates (note absence of Deacon cell in south, and clear demarcation of shallow overturns)

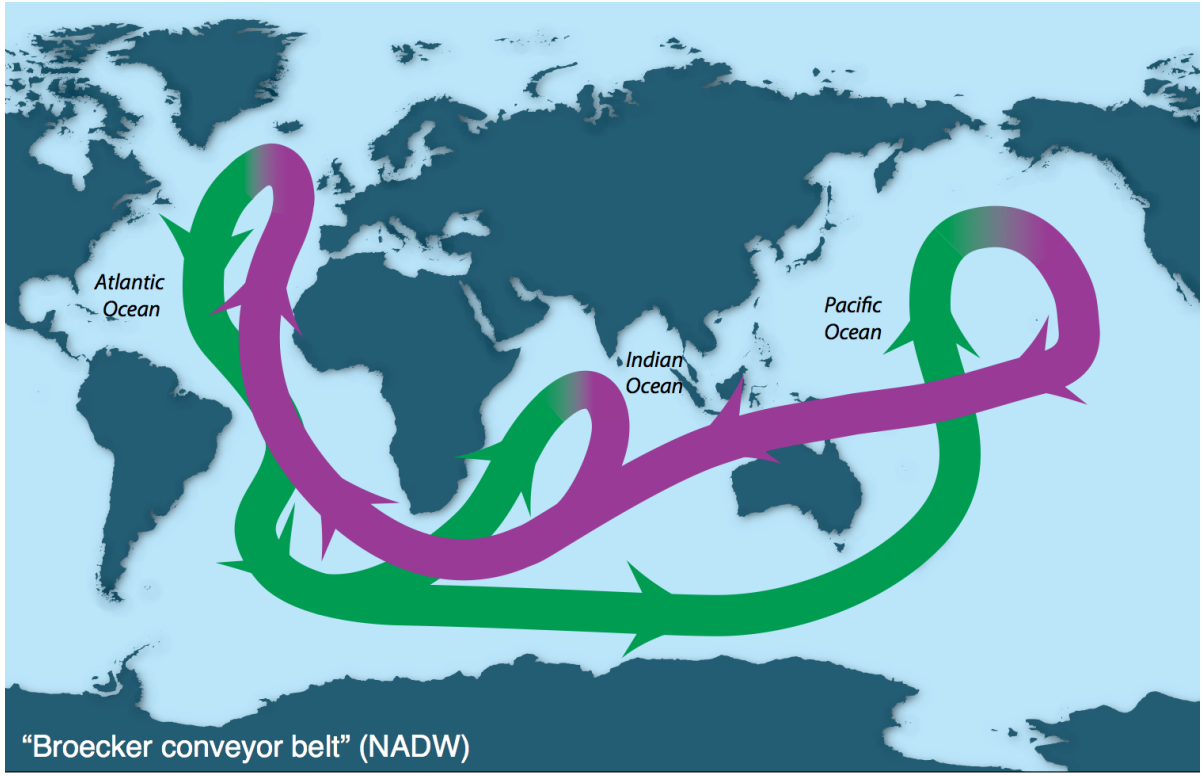
Pressure coordinates (note Deacon cell in south)

Lumpkin and Speer (2007)

Zonally-averaged global overturning.

Meridional overturning circulation: old schematic

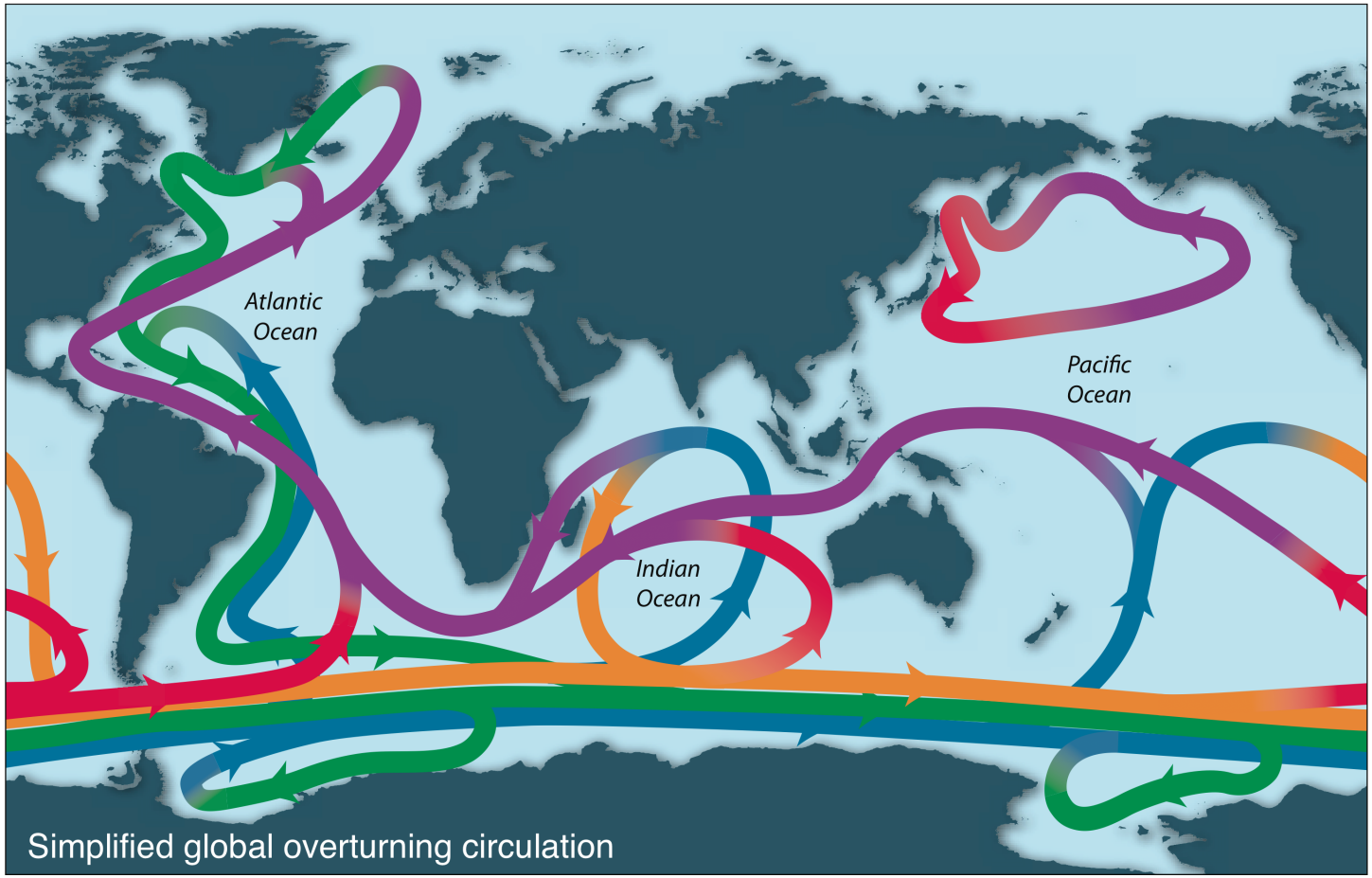
Broecker “conveyor belt”



Simplification of NADW global overturning circulation ALONE
Missing: AABW global overturning circulation, actual ocean connectivities

Broecker (1981) (DPO Fig. 14.10)

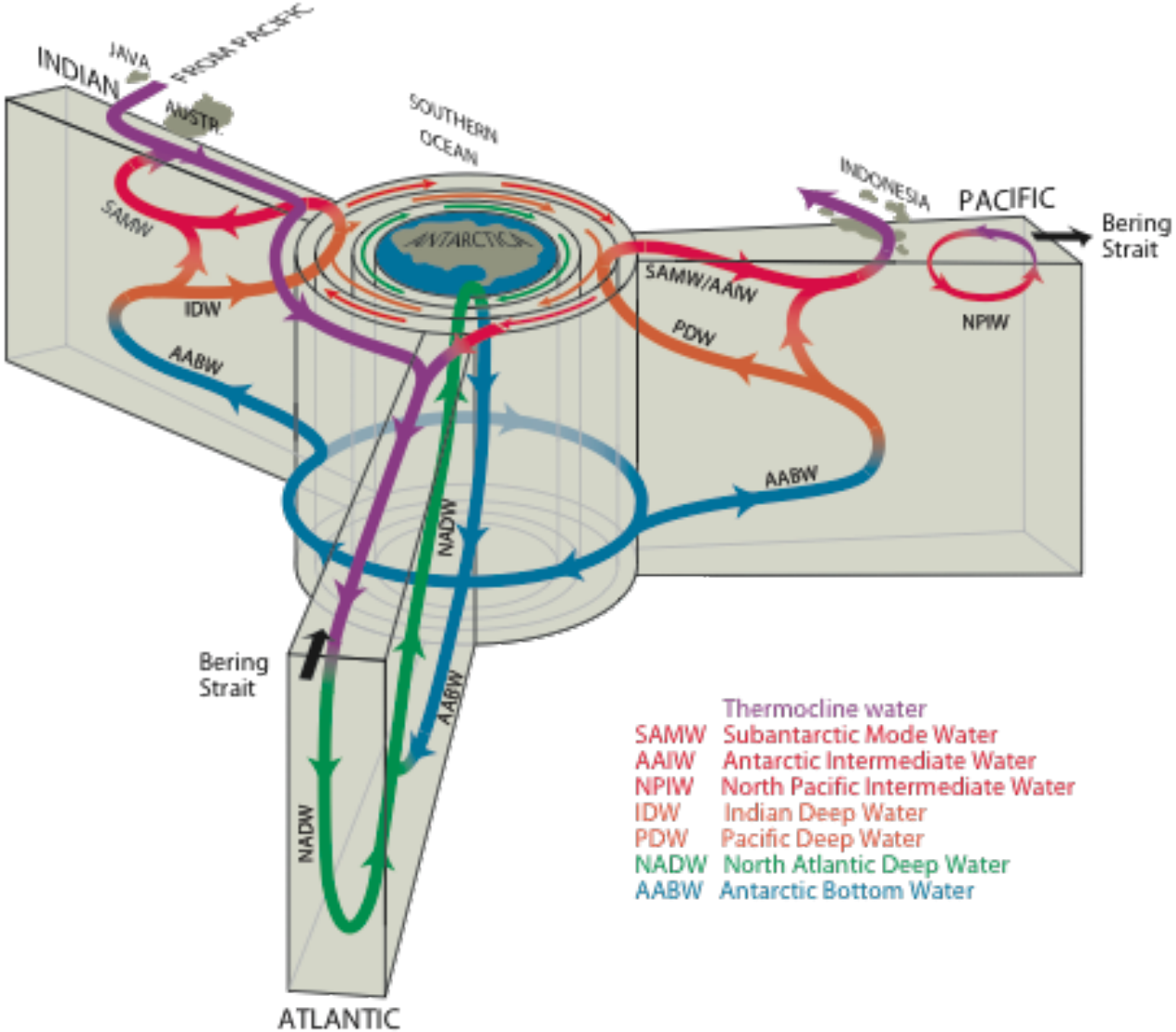
Global overturning schematic



More complete view based on major water mass transformations and quantitative overturning transports

DPO Fig. 14.11a

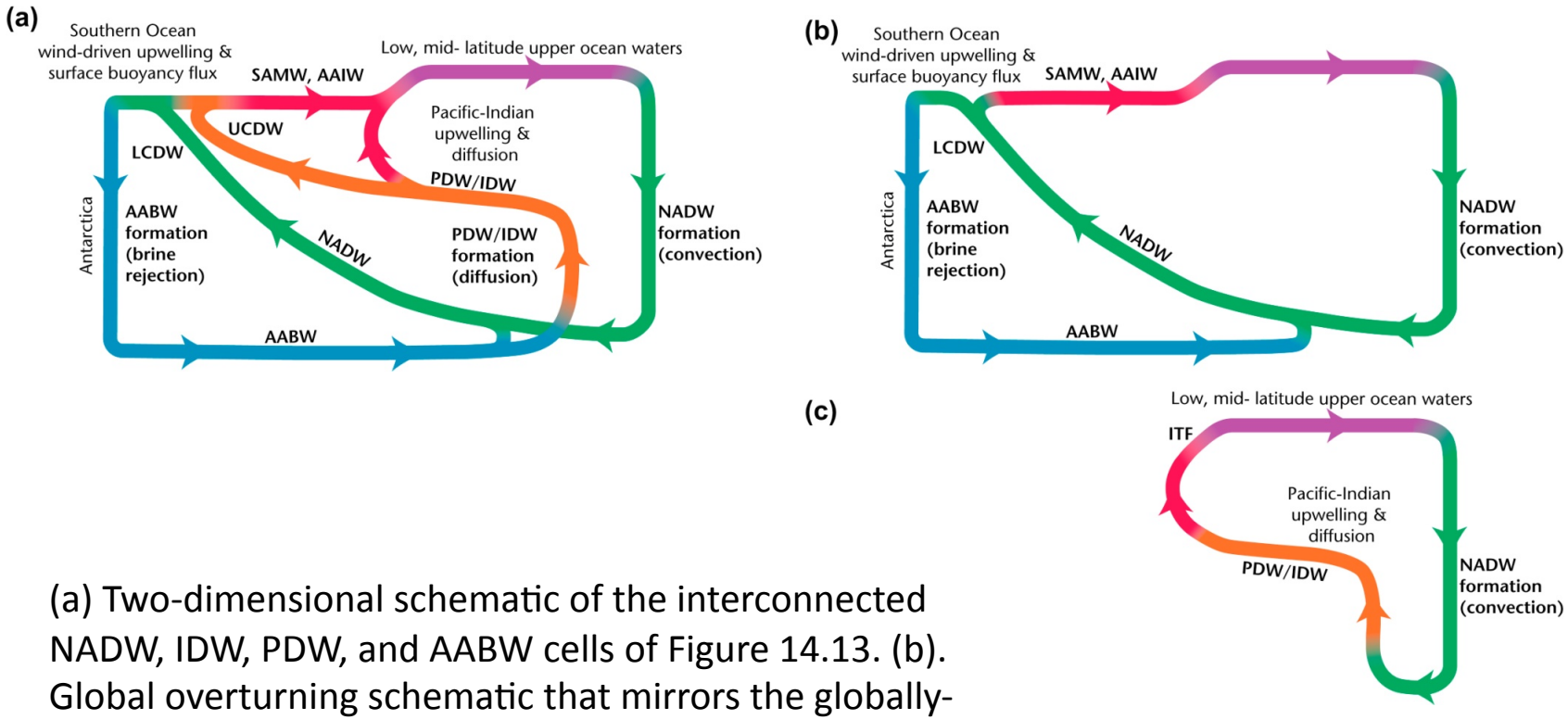
Global overturning with Southern Ocean perspective



After Schmitz (1995)

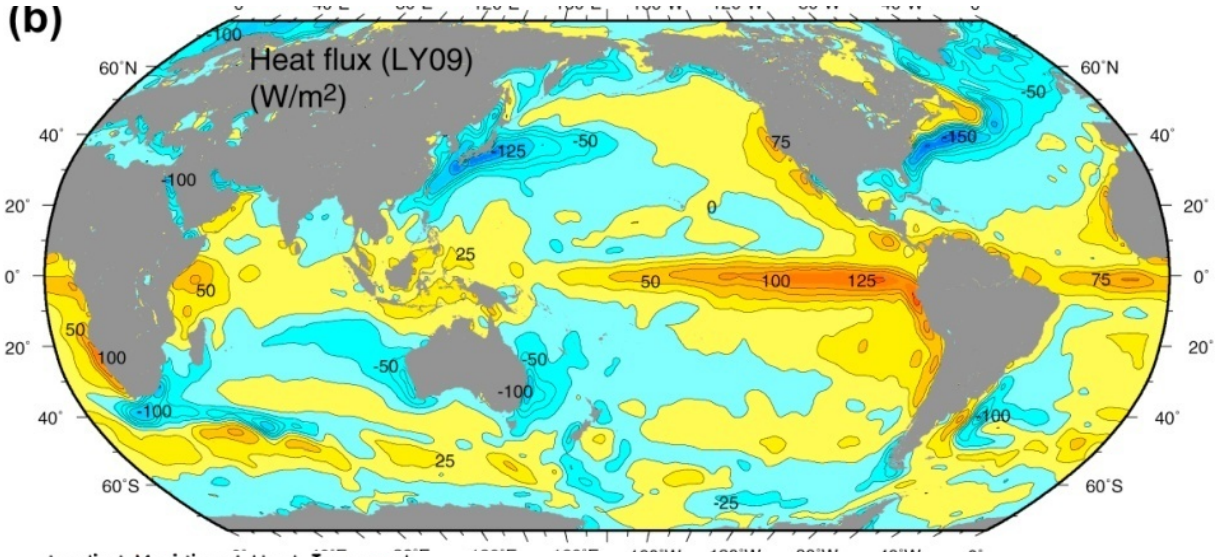
DPO Fig. 14.11b

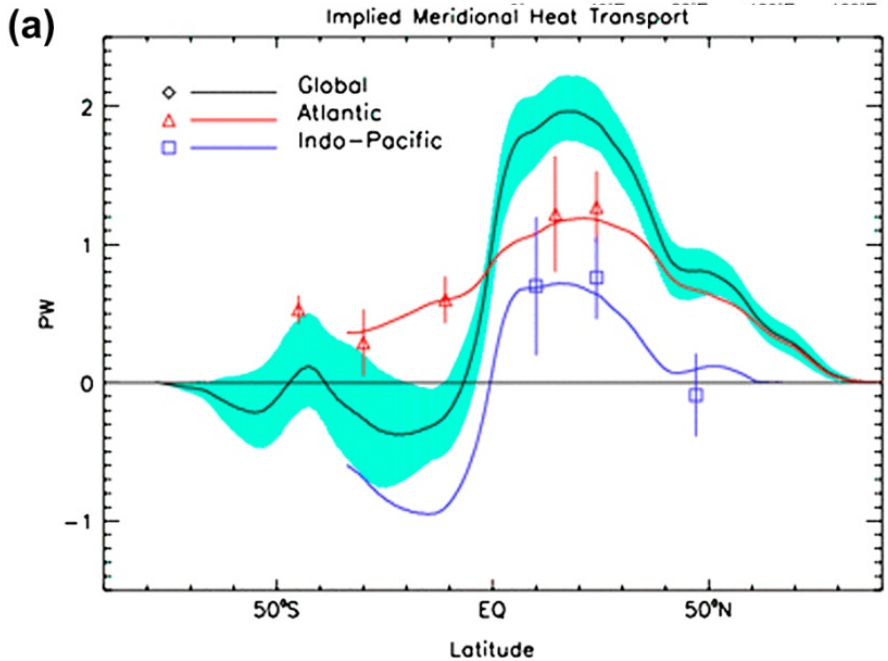
Meridional overturning schematics



(a) Two-dimensional schematic of the interconnected NADW, IDW, PDW, and AABW cells of Figure 14.13. (b). Global overturning schematic that mirrors the globally-averaged overturning streamfunction, hence concealing deep upwelling in the Indian and Pacific Oceans. (c) Implied global overturning in the Broecker schematic of Figure 14.12, which ignores the Southern Ocean upwelling and AABW formation.

Meridional overturning circulation: heat transport



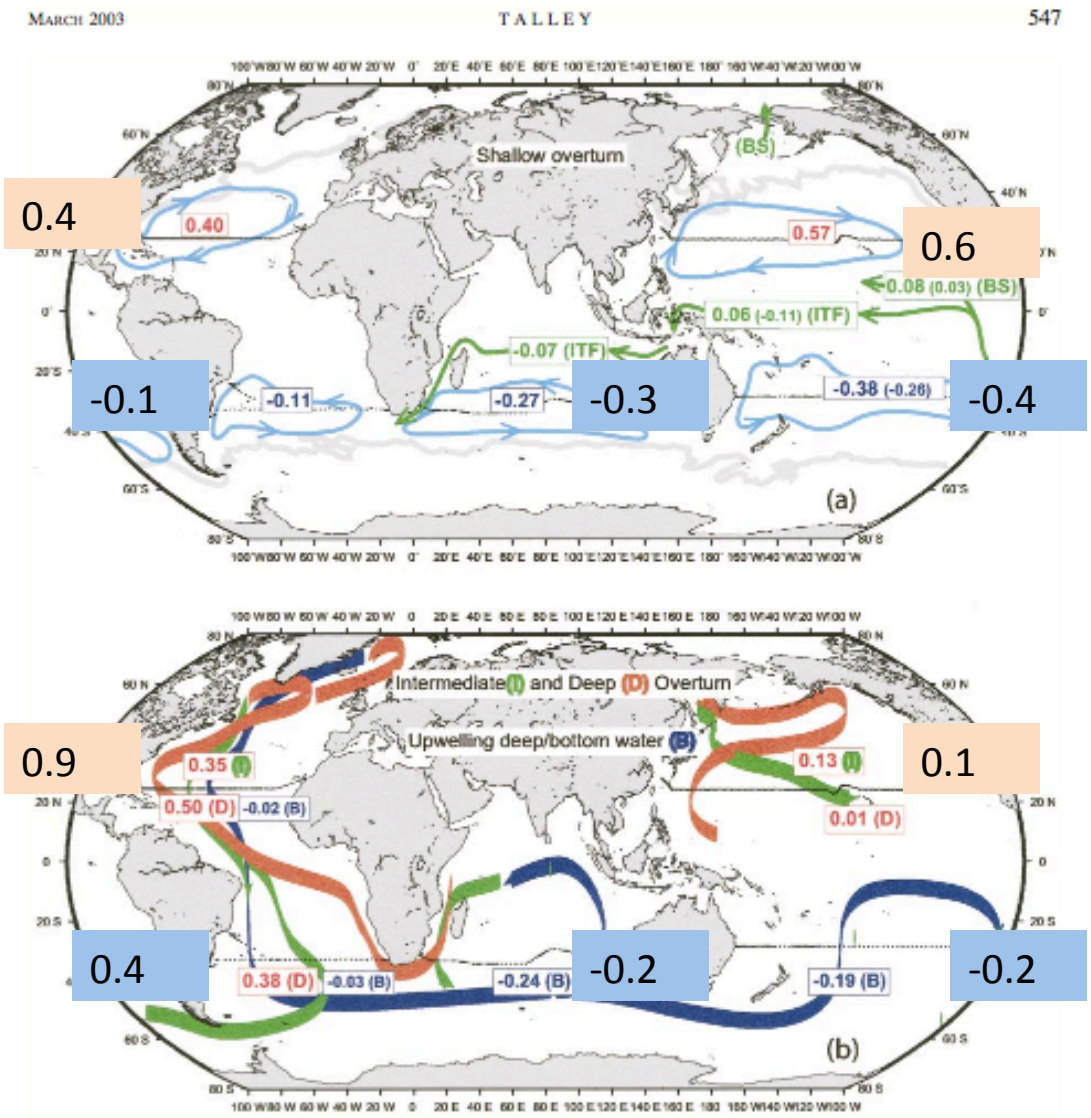


Meridional heat transport (in PetaWatts, where 1 PW = 10^{15} W).

Calculated by Large and Yeager (2009) from their air-sea heat flux analysis (map above).

Red is Atlantic (note that it is northward at all latitude).
Blue is the sum of Indian-Pacific.

Meridional overturning circulation: heat transport



Relative heat transport by the meridional overturning circulation compared with wind-driven upper ocean circulation:

Atlantic Ocean dominated by MOC, which causes northward heat transport in S. Atlantic

Pacific Ocean dominated by wind-driven circulation

Indian Ocean half and half

(Talley, 2003)