



# Global overturning circulation: freshwater transports and down-gradient flow

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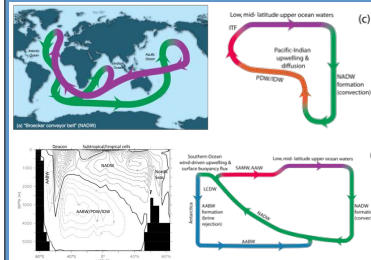
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## Abstract

The relation between the observed global overturning circulation, observed steric height distributions at all depths, and freshwater transports is examined.

- The global circulation is down-gradient in terms of the largest spatial scales of steric height distributions, at all depths from the surface to the bottom, based on observational syntheses. Diapycnal upwelling in both the Southern Ocean and the Indian/Pacific Oceans is integral to the global overturn, in addition to downwelling in the well-known deepwater source regions. The Indian/Pacific upwelling to mid-depth forms the deep waters that return to the Southern Ocean (22 Sv total), upwell to the sea surface, and feed the northward surface flows that eventually return to the northern North Atlantic (NADW overturning cell of 18-20 Sv). The remainder of the Indian/Pacific Deep Waters join the upwelled North Atlantic Deep Water to form the large (34Sv) Antarctic Bottom Water overturning cell.
- The distribution of diapycnal fluxes depends mainly on the small salinity differences between ocean basins that arise from the pattern of atmospheric water vapor transports. The equatorward freshwater transports from the high latitude southern and northern hemispheres are carried by the surface overturning cells in the south, and by North Atlantic Deep Water and North Pacific Intermediate Water formation in the north; the dynamical difference is due to the open Drake Passage in the south.

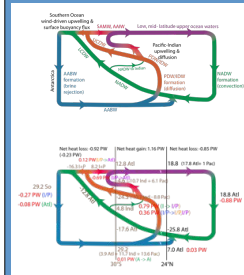
## Global Overturning Circulation



Incomplete overturning circulations

NADW-Indian upwelling-Pacific upwelling (warm water conveyor) (Missing Southern Ocean and AABW)

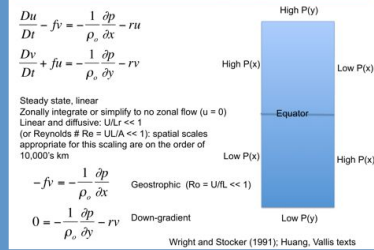
NADW-AABW overturning cells in zonally-averaged circulation (missing Indian-Pacific)



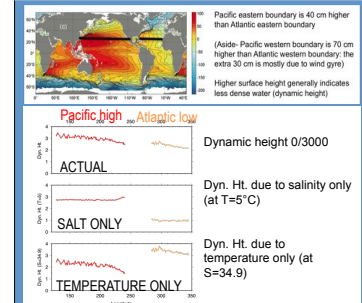
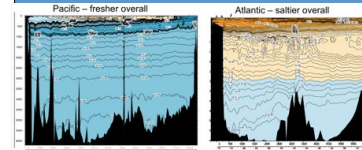
Essential elements of the global overturning circulation  
North Atlantic and Antarctic dense water formation

Upwelling in the Southern Ocean  
Upwelling in the Indian and Pacific Oceans  
Formation of AABW from upwelled NADW in the Southern Ocean  
Warm return path water from upwelled AABW in the Indian and Pacific, including S.O. and warmer return paths for upwelled water

## Down-gradient global flow

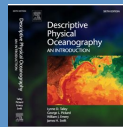


## Salinity, freshwater, and overturn



Salinity difference accounts for the gross dynamic height difference between the N. Pacific and N. Atlantic. Temperature difference partially offsets the salinity difference.

## Global Overturning Circulation



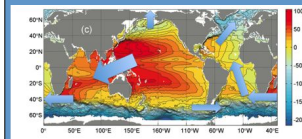
Upwelling of AABW in the Indian and Pacific, into Indian and Pacific Deep Waters

Upwelling of IDW and PDW in the Antarctic, feeding northward transport of SAMW/AAIW (with buoyancy gain) plus formation of AABW (with buoyancy loss)

Upwelling of NADW in the Antarctic, feeding formation of AABW

Southern Ocean view of the overturning circulation, in the style of Schmitz (1995) and Lumpkin and Speer (2007), from Talley et al. (2011) DPO textbook, Chapter 14

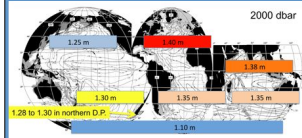
## Down-gradient global flow



Surface height

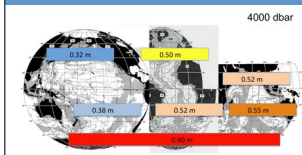
From surface drifters (Maximenko et al., 2009)

Superimposed informal arrows are the "conveyor belt" plus "cold water path" through Drake Psg. - note similarity to down gradient direction at the largest scale.



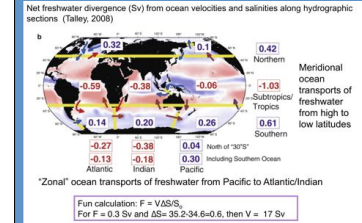
Deep Waters: 2000 dbar

Adjusted steric height (absolute geostrophic flow) (Reid, 1994, 1997, 2003).  
Down-gradient direction from North Atlantic to South Atlantic and North Pacific



Bottom Waters: 4000 dbar

Adjusted steric height (absolute geostrophic flow) (Reid, 1994, 1997, 2003).  
Down-gradient direction from Antarctic to all other regions



Freshwater divergence: Pacific gains freshwater, while Atlantic and Indian lose freshwater, accounting for the salinity difference between oceans and crudely the mass transport exchange

- Continental distribution (Drake Passage vs. Northern hemisphere land masses) creates northern-southern hemisphere asymmetry in ocean freshwater transport mechanisms:
  - Arctic freshwater is exported southwards mainly through NADW formation
  - Antarctic freshwater is exported northwards mainly through the upper ocean (subduction, subtropical gyres)
- Interbasin FW transport pathways are largely through the upper ocean