Global overturning circulation: freshwater transports and down-gradient flow

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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.

(1) 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.

(2) 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

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

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

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

Down-gradient global flow

$$\frac{Du}{Dt} - fv = -\frac{1}{\rho_o}\frac{\partial p}{\partial x} - ru$$

$$\frac{Dv}{Dt} + fu = -\frac{1}{\rho_o}\frac{\partial p}{\partial y} - rv$$

Steady state, linear
Zonally integrate or simplify to no zonal flow (u = 0)
Linear and diffusive: U/Lr << 1
(or Reynolds # Re = UL/A << 1): spatial scales appropriate for this scaling are on the order of 10,000's km

$$-fv = -\frac{1}{\rho_o}\frac{\partial p}{\partial x}$$ Geostrophic (Ro = U/fL << 1)

$$0 = -\frac{1}{\rho_o}\frac{\partial p}{\partial y} - rv$$ Down-gradient

Wright and Stocker (1991); Huang, Vallis texts

Salinity, freshwater, and overturn

Dynamic height 0/3000

Dyn. Ht. due to salinity only (at T=5°C)

Dyn. Ht. due to temperature only (at S=34.9)

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

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

1. 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)
2. Interbasin FW transport pathways are largely through the upper ocean