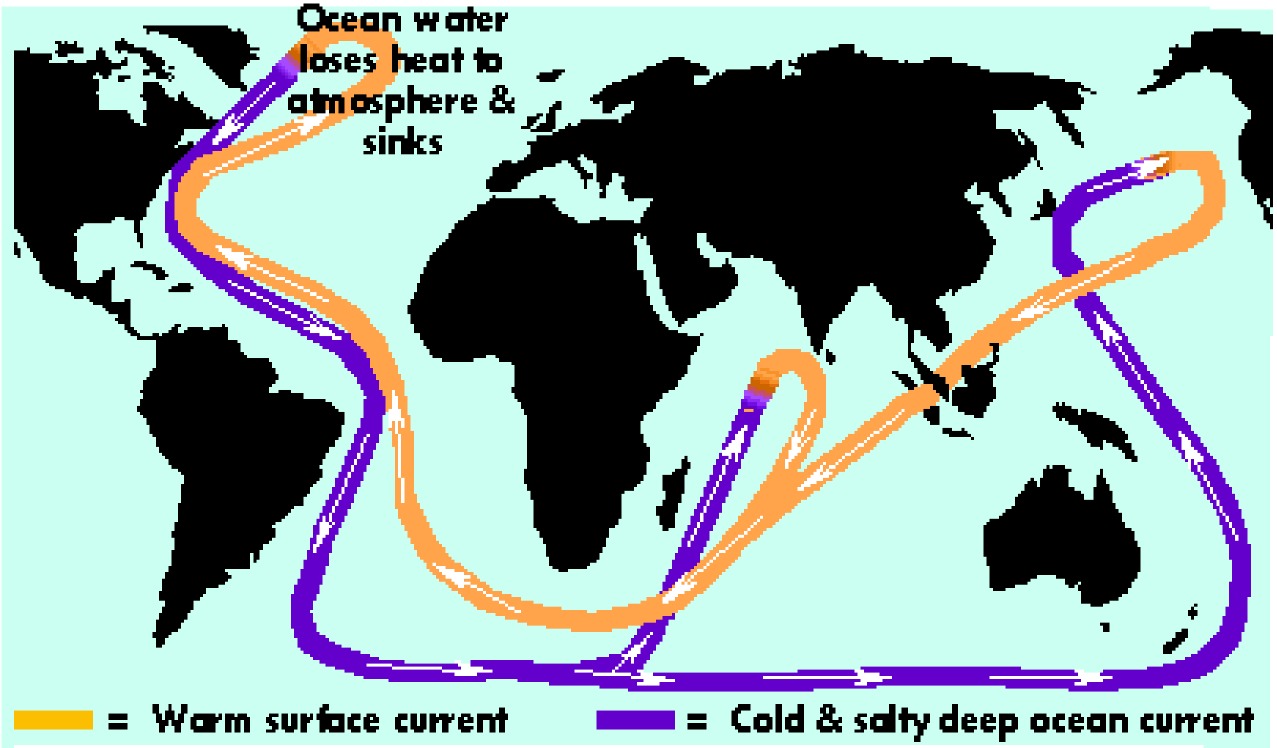
Dense Water Formation and Overturning: What is the Connection?

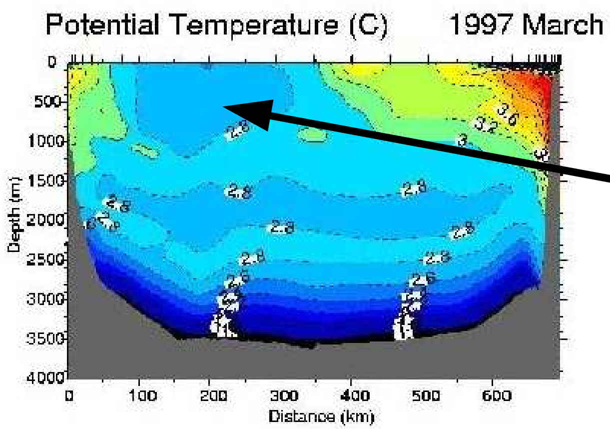
Fiamma Straneo



Variability in convection => variability in sinking => variability in MOC => climate variability

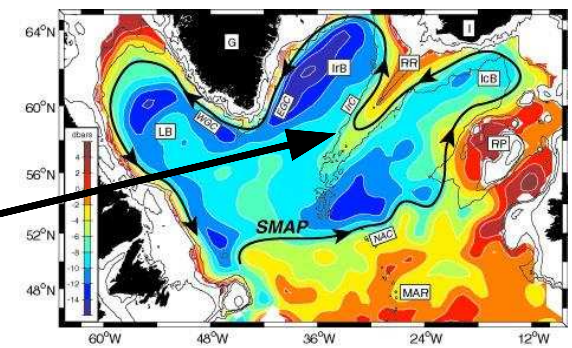
How Convection Regions are Connected to the Global Circulation

Pickart et al., 2002



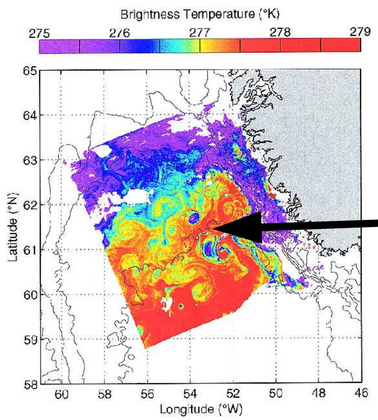
Convection occurs in mostly quiescent interior regions

Lavender et al., 2000



surrounded by a boundary current which is the principal pathway for the import of light fluid and export of dense fluid from the basin

Prater, 2002



the exchange between the two regions is regulated by boundary current instabilities - eddy fluxes

Visbeck et al. 1996, Jones and Marshall 1996, Khatiwala et al. 2002, Katsman et al. 2004, Chanut and Barnier, 2004

Lilly et al. 1999 and 2003, Lazier et al. 2002

Sinking and Convection

No net sinking (net vertical mass flux) in open-ocean convection regions

During convection (1-2 weeks)
downward mass flux within plumes is balanced by upwelling between them.

theory - Spall and Pickart, 2001; Send and Marshall, 1995
observations - e.g. Schott and Leaman, 1991
non-hydrostatic simuations – Harcourt et al. 2002

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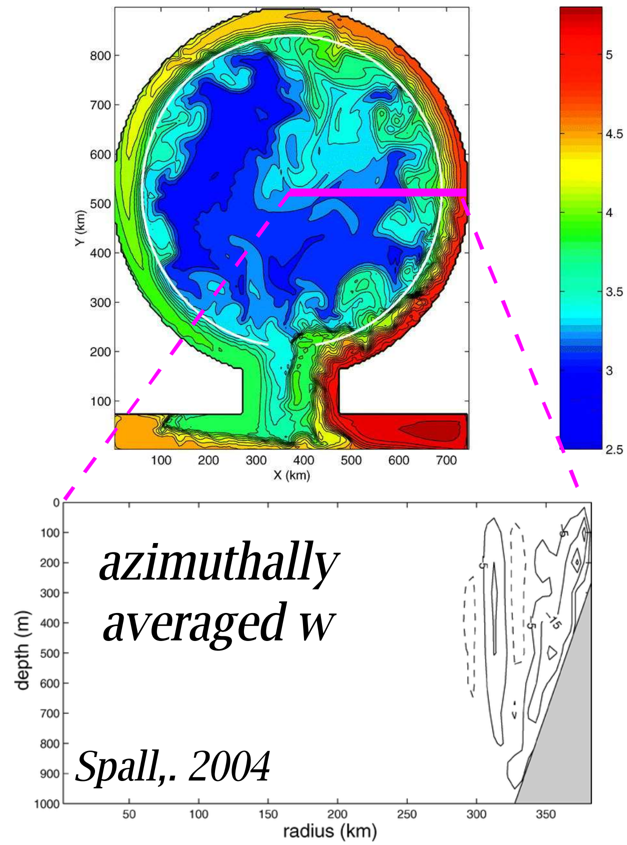
After Convection (during Restratification)
the amount of sinking due to the eddy fluxes is small

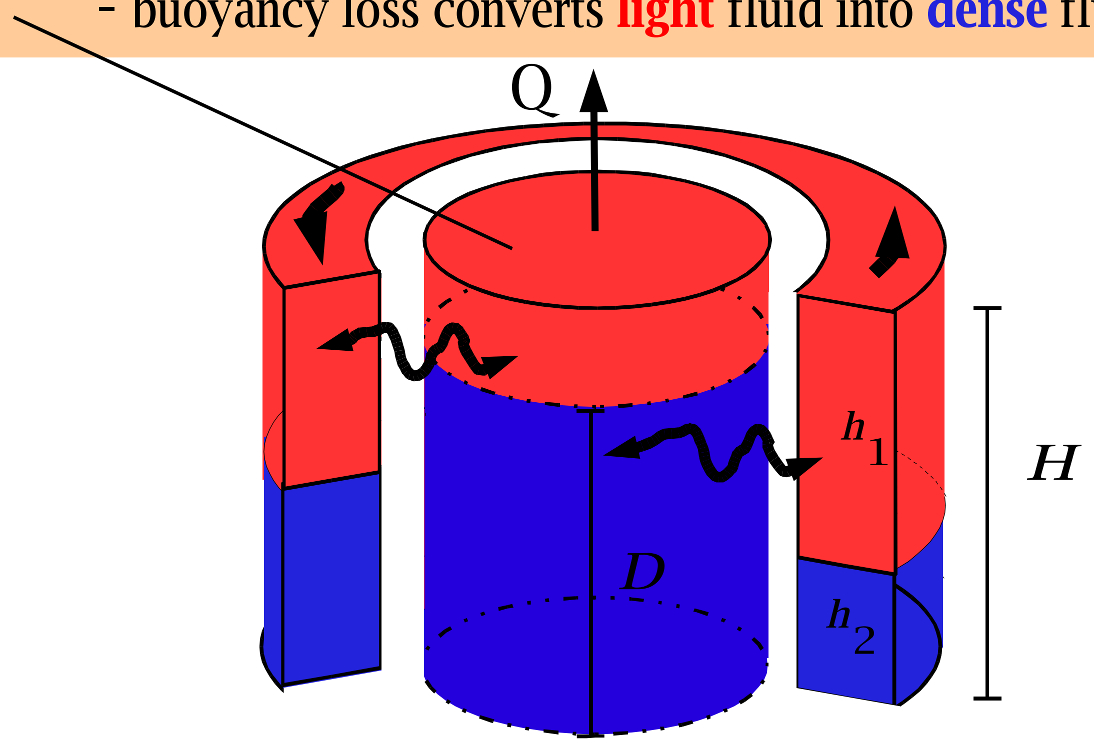
theory – Spall and Pickart (2001)
non-hydrostatic simulations – Spall (2004)

But significant sinking can occur at the topographic boundaries.



A Two Layer Model for the Labrador Sea

Interior
- no mean flow, no sinking
- buoyancy loss converts **light** fluid into **dense** fluid



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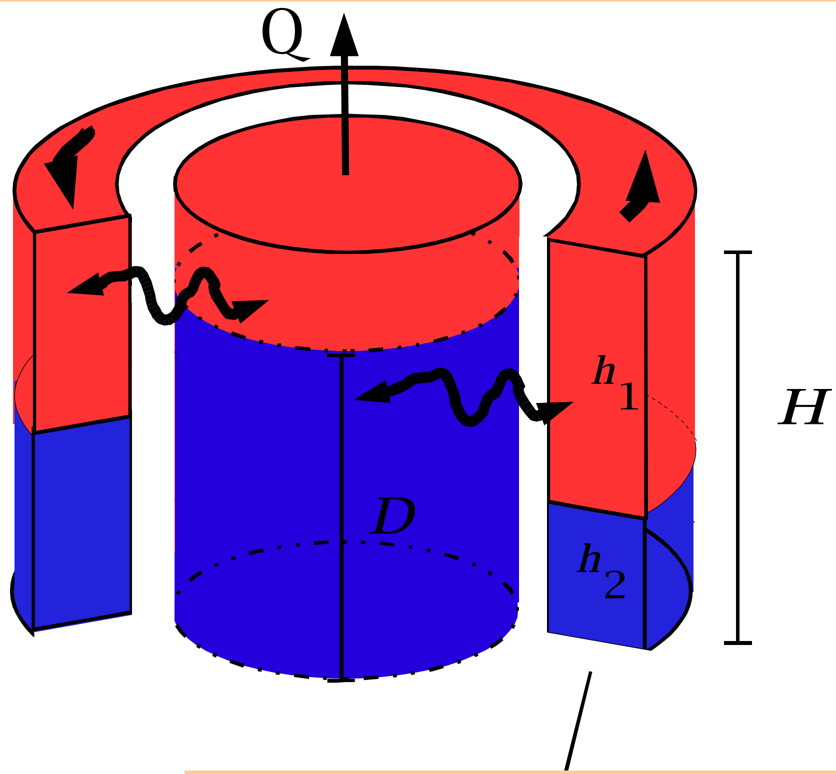

Boundary Current
- wind and buoyancy driven
- geostrophic
- no convection
- mass conservation
- buoyancy conservation

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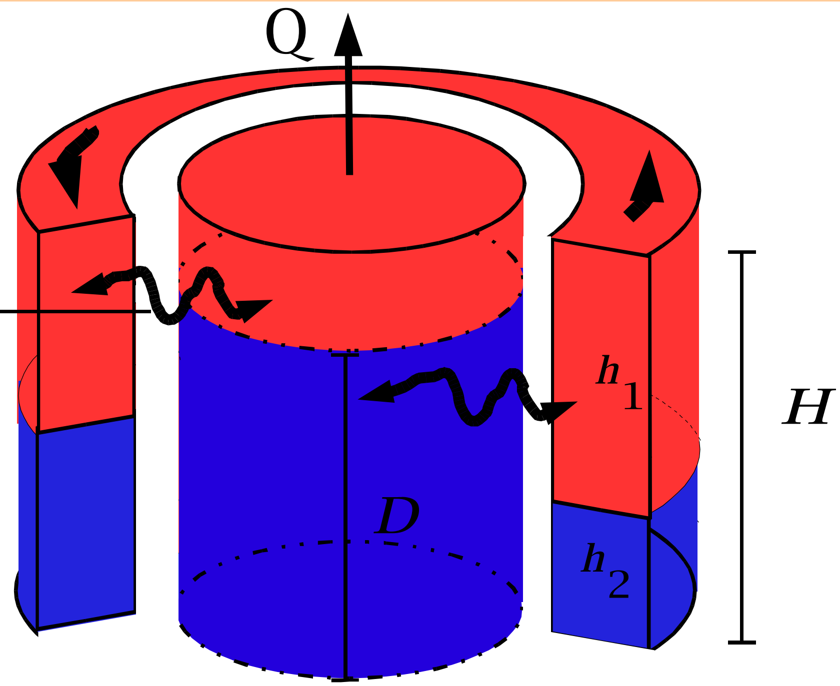
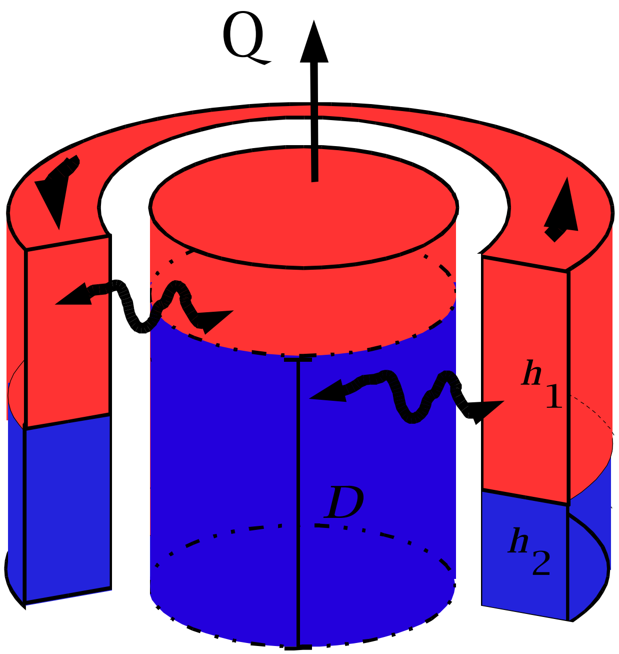


Eddy fluxes
- proportional to the isopycnal gradient between interior and boundary current

Boundary Current
- wind and buoyancy driven
- geostrophic
- no convection
- mass conservation
- buoyancy conservation

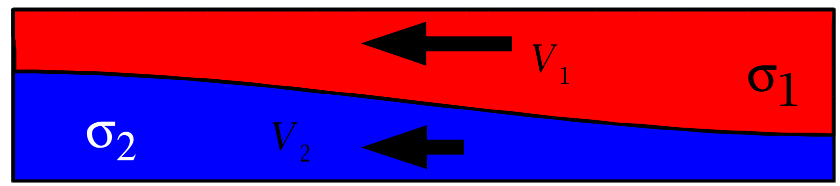
Steady State



Interior

convection increases dense water reservoir
eddy fluxes remove dense water

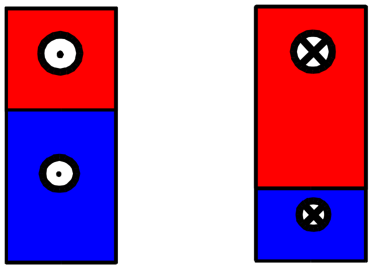
Boundary Current



dense water is `picked up' around the basin at the expense of light water

Steady State - Poleward Buoyancy Transport

Poleward Buoyancy (Heat) Transport



$$PBT = g' L \left[V_2 h_2 \right]_{inflow}^{outflow} = g' w_F$$

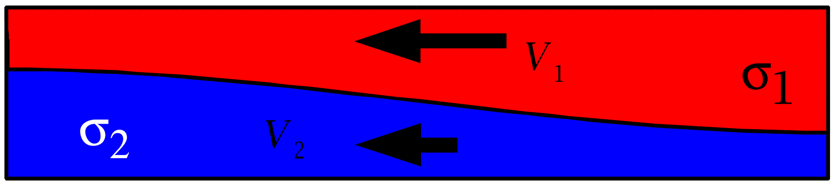
$$= g' w_H + g' w_D$$

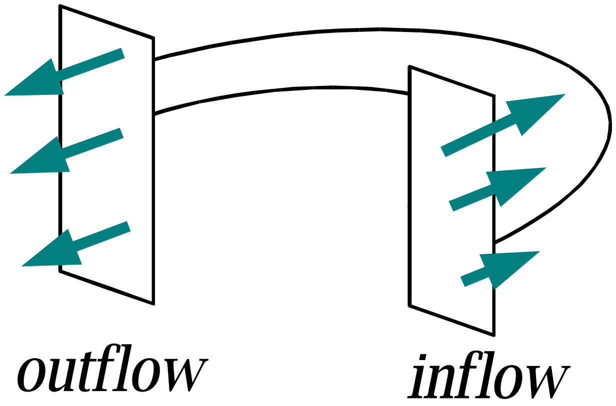
$$w_H = L V_2^{outflow} \Delta h$$

$$w_D = L\, h_2^{inflow} \Delta V_2$$

horizontal transport

sinking (depth) overturning





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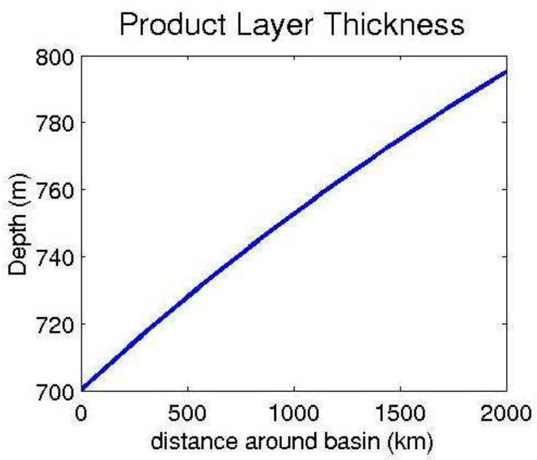
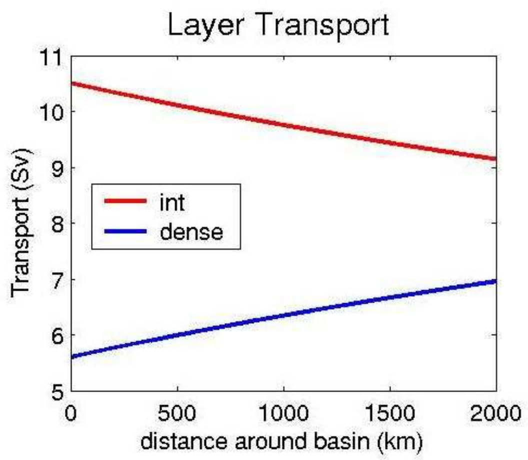
Steady State Solution --- Labrador Sea Case



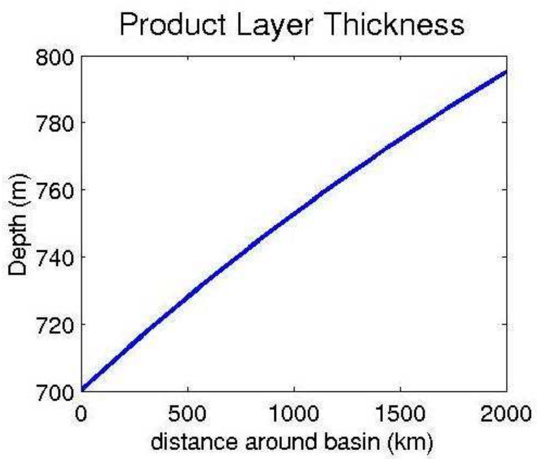


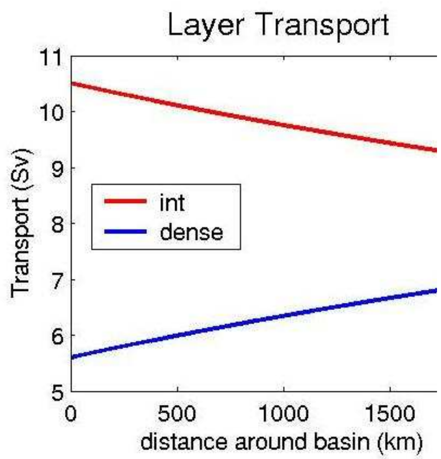
Labrador Sea Values:
R=250 km, L=100 km
H=1500m, h_2(in) = 700m,
V^W = 0.1 cm/s, c = 0.03,
Q = 30 W/m^2, $\Delta\rho$ = 0.05 kg/m^3

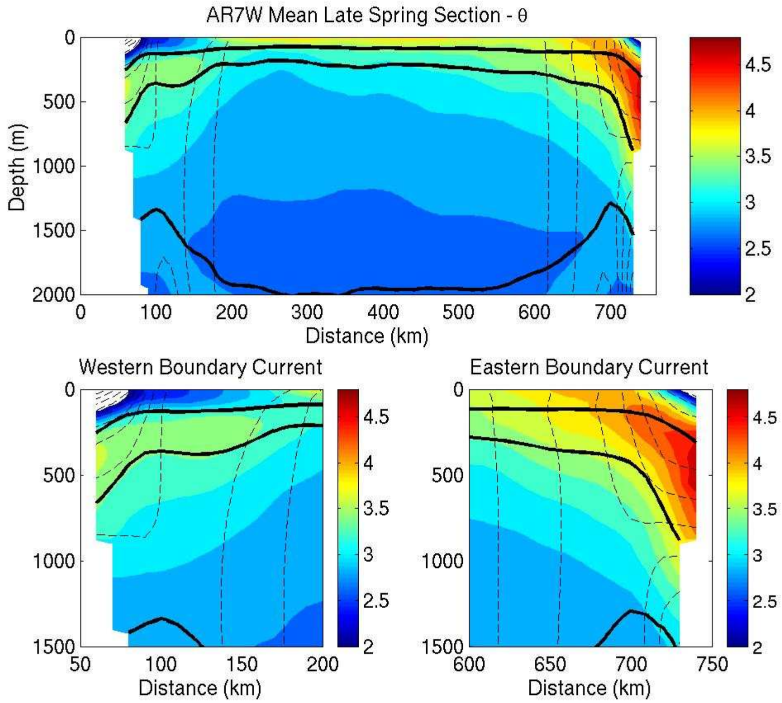
Model Predictions:
i. Mean LSW thickness 1250
ii. BC thickness change = 100m
iii. dense water formed W_F = 2 Sv
iv. Overturning = W_D = 0.8 Sv

Overturning circulation carries only 40% of the poleward heat transport.

Steady State Solution --- Model/Data Comparison







Model Predictions:

i. Mean LSW thickness 1250

ii. BC thickness change = 100m

iii. DWF --- $W_B = W_F = 2$ Sv

iv. Overturning = W_D = 0.8 Sv

Data:

i. Mean LSW thickness = 1200m

ii. BC thickness change 80m.

iii. 1.2 Sv to 7 Sv *(Rhein et al. 2002)*

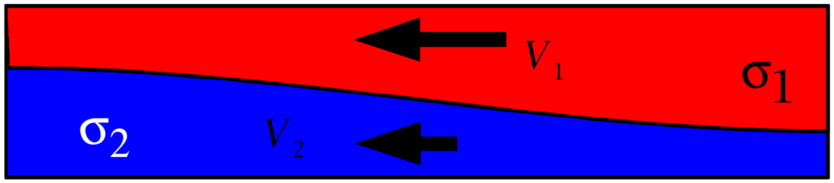
iv. 0.9 Sv from data

(Pickart & Spall, 2004)

Overturning circulation carries only 40% of the poleward heat transport.

Sinking versus Dense Water Formation

Eddy fluxes decrease the interior/boundary current gradient

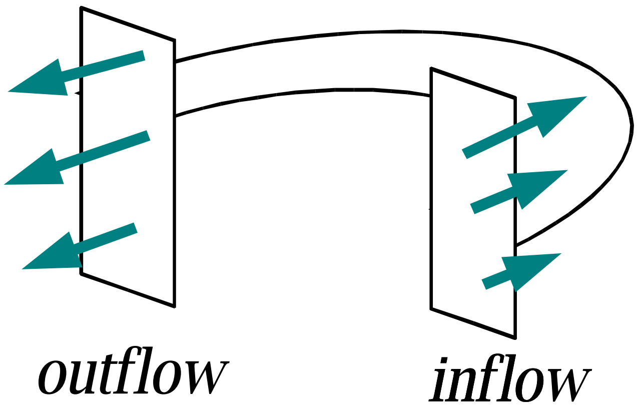


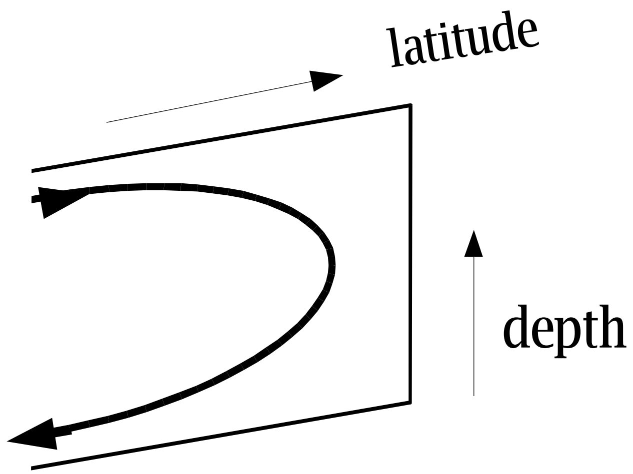
=> $V_{bcl} = V_1 - V_2$ decreases (geostrophy)

=> V_2 increases (mass conservation)

If the dense fluid speeds up => overturning

$$\Psi(z) = \int dx \int_z^0 V(x, z')\,dz'$$





Sinking, in the boundary current, occurs as a consequence of the exchange with the interior, geostrophy and mass conservation.

Model Analysis

How much overturning (sinking) occurs in relation to DWF?

Key Parameter:

$$\gamma = \frac{fluid \quad exchanged \quad by\ eddies}{fluid \quad advected \quad around}$$

For small γ, ratio of Overturning to Horizontal Transport

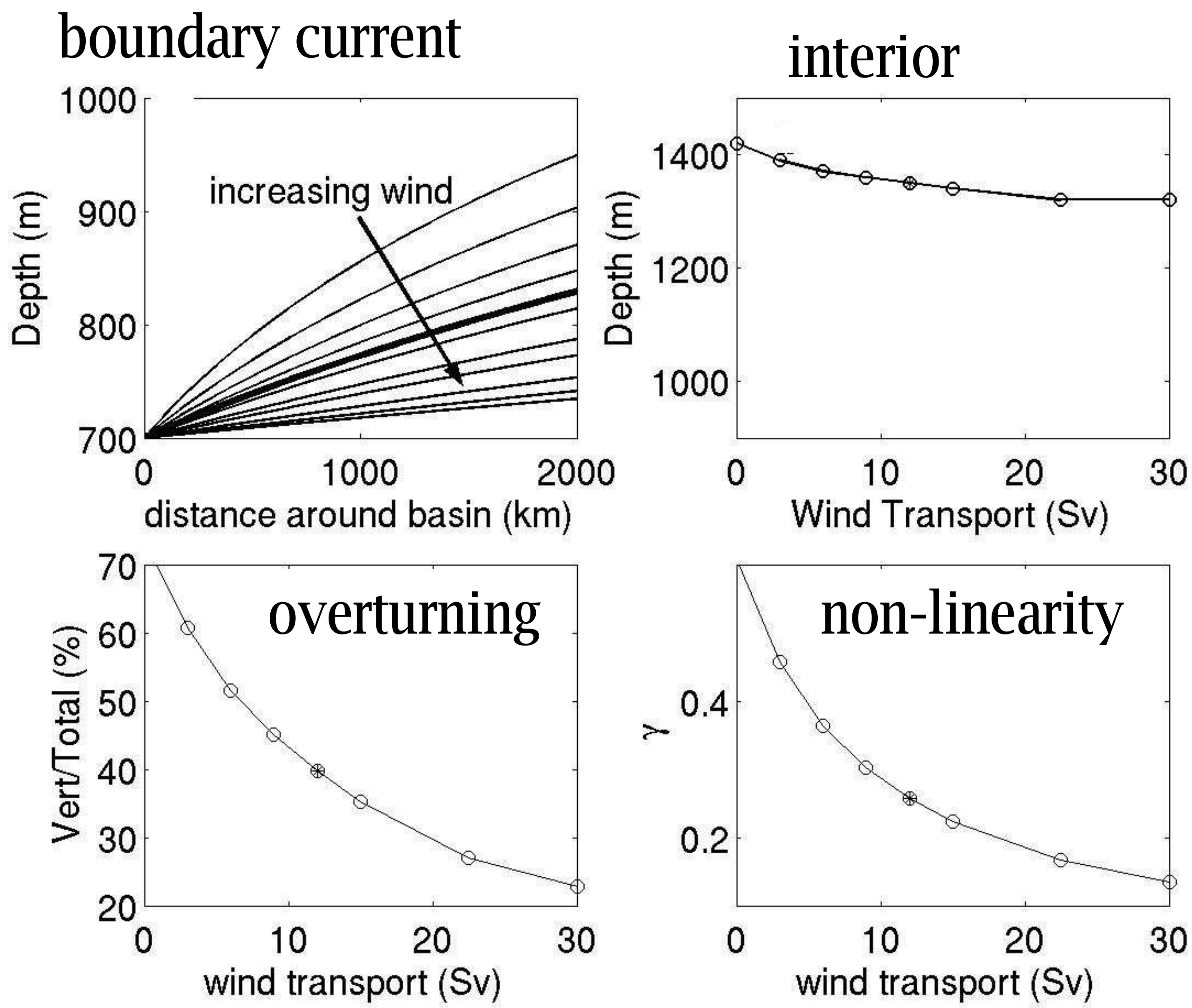
$$\frac{W_D}{W_H} \approx \frac{V_{bcl}}{V_W}$$

=> increases with:
- decreasing wind-driven circulation
- increasing eddy exchange

The amount of sinking can change EVEN if the amount of dense water formed is unchanged.

Steady State Solution --- Different Wind-Driven Transports

Q and DWF constant



Fraction of PBT due to overturning decreases if the remotely driven circulation increases.

Summary: Overturning and Convection

1. Dense water formation $\neq$ sinking
not co-located => not necessarily co-varying

2. Net poleward buoyancy (heat) transport due to convection is due to both a horizontal and an overturning circulation.

3. Overturning is tied to the change in the baroclinic structure of the flow around the basin:
the greater the change => the larger the overturning.
(only 40% in the Labrador Sea)

4. Overturning can change due to changes in circulation even if amount of dense water formed remains the same:
variability in MOC and DWF are not equal.

What is Missing?

MANY THINGS..............

1. A surface layer in the model - e.g. to reproduce freshwater anomalies, that can prevent the convection at times

2. Watermass transformation within the boundary current

3. The feedback from the subpolar gyre and beyond for long timescales

4. A more sophisticated eddy parameterization, for example dependent on wind or velocity.