Dynamic sea level changes associated with a changing MOC: does vertical mixing matter?

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Most climate models predict a weakening of the meridional overturning circulation (MOC) in a warming climate and an associated sea level rise in the North Atlantic Ocean of several tens of centimeters. The implementation of new parameterizations for the vertical mixing rate κ, which reflect our increased understanding of the mixing and can replace the current (nearly) constant κ, will alter these projections for sea level rise.

1. MOC and dynamic sea level

The MOC (Fig. A) is characterized by downwelling at high latitudes and upwelling by vertical mixing in the interior, and is accompanied by a gradient in sea surface height (SSH) of ± 60 cm.

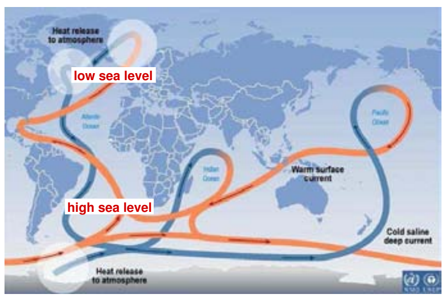

Figure A. The MOC and associated SSH gradient

New parameterizations for vertical mixing [1] may impact simulations of (changes in) the MOC and the associated SSH gradient.

2. Scaling relations

For a two-layer ocean (Fig. B) with density contrast $\Delta\rho$ and vertical mixing at a rate κ, scaling relations for MOC strength Ψ [1,2] and SSH gradient Δh [3] can be derived

$$\Psi \sim \kappa^{2/3}\Delta\rho^{1/3} \qquad \Delta h \sim \Delta\rho H \sim \kappa^{1/3}\Delta\rho^{2/3}$$

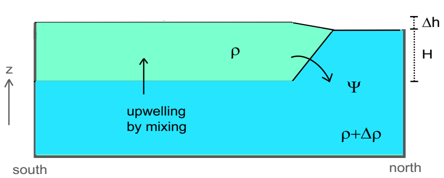

Figure B. Two-layer model used to derive scaling relations for MOC strength Ψ and SSH gradient Δh [after 2]

2.1 Constant κ

When κ is constant, Ψ and Δh scale as

$$\Psi \sim \Delta\rho^{1/3} \qquad \Delta h \sim \Delta\rho^{2/3}$$

A smaller density contrast $\Delta\rho$ thus yields
- a weaker overturning Ψ
- a smaller SSH gradient Δh

2.2 Variable κ

As an example of variable κ, consider

$$\kappa \sim \Delta\rho^{-1},$$

a parameterization of mixing by wind-generated internal waves that takes global energy constraints into account [1]. It yields

$$\Psi \sim \Delta\rho^{-1/3} \qquad \Delta h \sim \Delta\rho^{1/3}$$

A smaller density contrast $\Delta\rho$ thus yields
- a stronger overturning Ψ
- a smaller SSH gradient Δh, but the dependence is weaker than for constant κ.

Other parameterizations that allow κ to vary in space and time yield scaling relations for Ψ between $\Delta\rho^{1/3}$ and $\Delta\rho^{-1/3}$ [1] and for Δh between $\Delta\rho^{2/3}$ to $\Delta\rho^{1/3}$ [3].

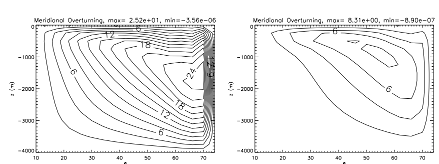

Figure C. Modelled MOC using (left) constant $\kappa_0 = 2.3 \cdot 10^{-4}$ m^2/s and (right) $\kappa = \kappa_0 \Delta T_0/\Delta T$ for $\Delta T = 30°C$ [no salinity effects, the imposed ΔT controls $\Delta\rho$]

3. Numerical verification

The mixing parameterization has a strong impact on the character of the calculated circulation in a single-hemispheric domain, forced by a north-south temperature gradient ΔT at the surface [Fig. C, 4].

3.1 Constant κ

For large ΔT, solutions for Ψ and Δh approach the 1/3 and 2/3 power laws (Figs. D and E). For small ΔT, $\Psi \sim \Delta T$ because the circulation is weak [4].

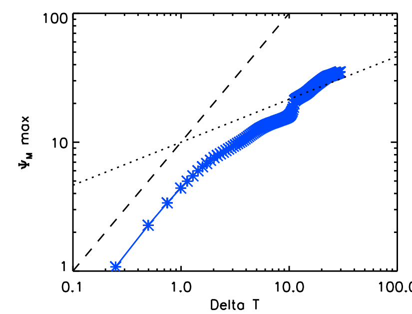

Figure D. Verification of scaling relation $\Psi \sim \Delta T^{1/3}$ (constant κ, dotted line)

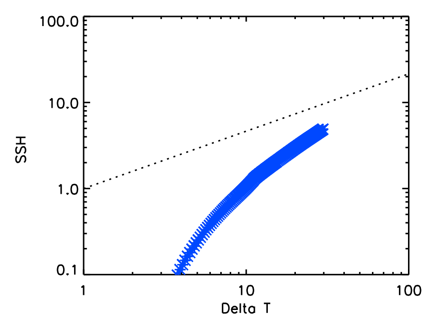

Figure E. As Fig. D, for $\Delta h \sim \Delta T^{2/3}$ (constant κ)

3.2 Variable κ

The model simulations using variable κ confirm the predicted reversal of the dependence of Ψ on ΔT and the weaker dependence of Δh on $\Delta\rho$ (Figs. F and G).

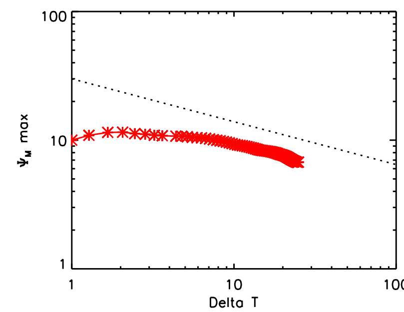

Figure F. Verification of scaling $\Psi \sim \Delta T^{-1/3}$ ($\kappa \sim \Delta T^{-1}$)

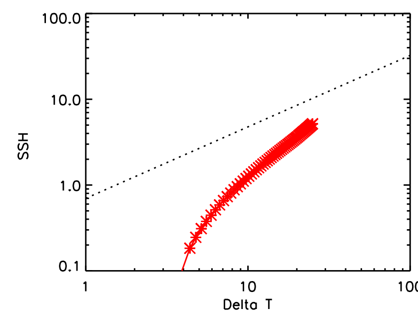

Figure G. As Fig. F, for $\Delta h \sim \Delta T^{1/3}$ ($\kappa \sim \Delta T^{-1}$)

4. Simulating a warming climate

Climate models currently use a (nearly) constant vertical mixing rate κ. They predict a local sea level rise in the North Atlantic Ocean of several tens of centimeters for the next century, due to weakening of the MOC. Different parameterizations of κ result in a different dependence of the SSH gradient Δh on the MOC strength Ψ and density contrast $\Delta\rho$. Implementation will hence affect projections for local sea level.

References

[1] e.g., Nilsson et al (2003), JPO 23, 2781-2795
[2] Gnanadesikan (1999), Science 283, 2077-2079
[3] Katsman et al (2006), document in preparation
[4] Dijkstra et al (2001), te Raa (2003)

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