A Partial AMOC recovery under sustained freshwater forcing

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1 Abstract

Subsurface warming of the Atlantic is expected to follow a weakening of the Atlantic Meridional Overturning Circulation (AMOC), due to less convective cooling of these layers. ***Will subsurface changes break down the surface stratification imposed by increased future climate change forcing, and thus partially reinvigorate convection and the AMOC?*** And will the meridional heat transport (MHT) recover even more because of it? We explore these questions ***using freshwater hosing experiments with both a fully coupled model and an idealized 2D forced ocean model***, and find the answer is yes in both cases. Close similarities between the two models suggest that simple 2D mechanisms are responsible for the changes on multi-decadal-timescales.

2 Motivation

Following a climate-change induced AMOC weakening, will it:

1) Continue to weaken?
2) Reach a new steady equilibrium?
3) Partially recover?

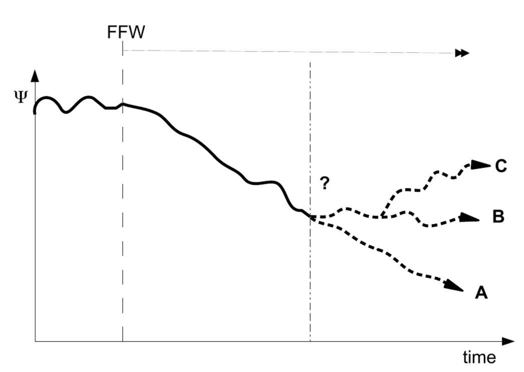


Fig 1. Possible future AMOC trajectories in response to climate forcing

We hypothesize a partial recovery: under a weaker AMOC state, the subsurface ocean often warms in climate models (Liu *et al.* 2009; Fig 2), due to weaker convective cooling of the intermediate layers. This has the potential to break down the stratification imposed by climate change-induced surface buoyancy forcing.

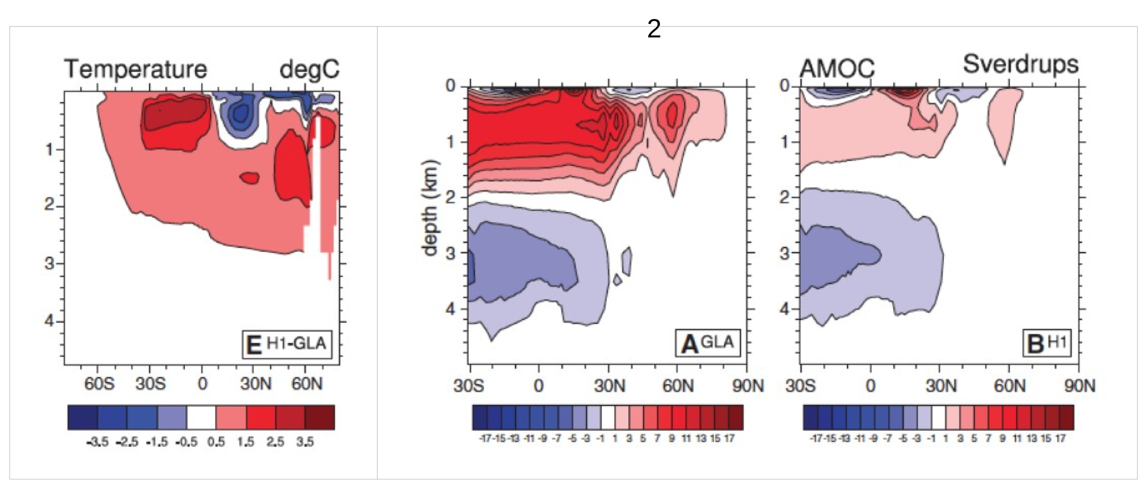


Fig 2. Atlantic zonal-mean Temp. change (left) from a strong (middle) to a weak (right) AMOC

There is evidence from AMOCMIP (Bakker et al., 2016) that recovery can occur in climate models, approximately 100 years after climate forcing is initialized (Fig 3).

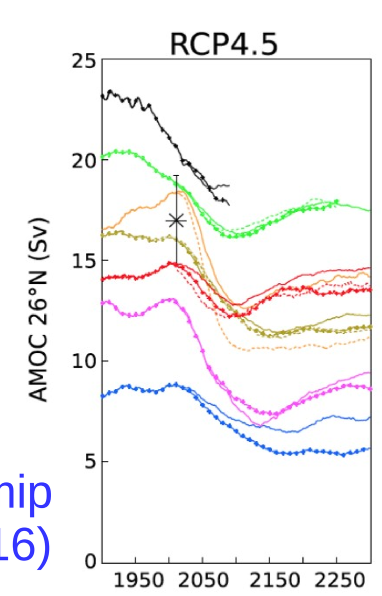


Fig 3. Comparison of AMOCs from AMOCmip models with RCP4.5 forcing (Bakker et al., 2016)

3 Freshwater hosing in 2 models

Apply a modest *but sustained* high latitude freshwater flux (FWF) distributed in 2 models as shown in Fig.4. Hosing applied to:

1) Fully coupled CESM configuration
- 1°horizontal ocean resolution
- 60 vertical levels
- CAM5 atmosphere

2) 2D zonally integrated forced ocean model (Sevellec and Fedorov, 2011; see box below)
- 1° lat-only resolution.
- 15 vertical levels
- SSS flux, SST restoring

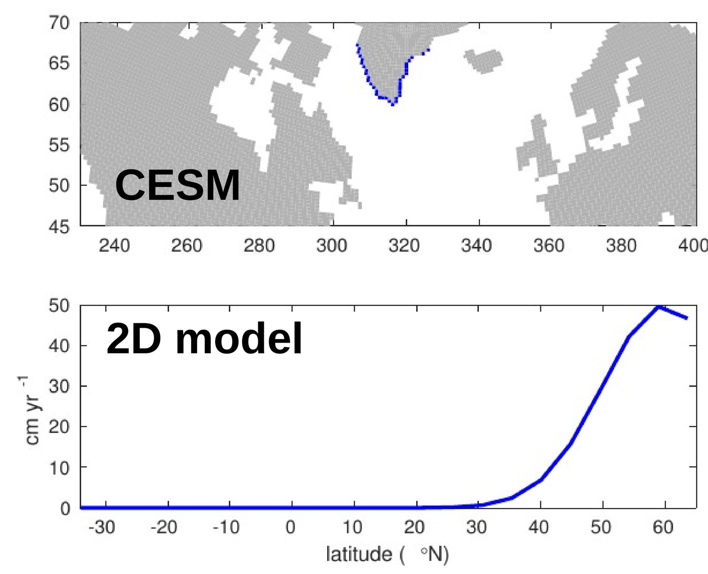
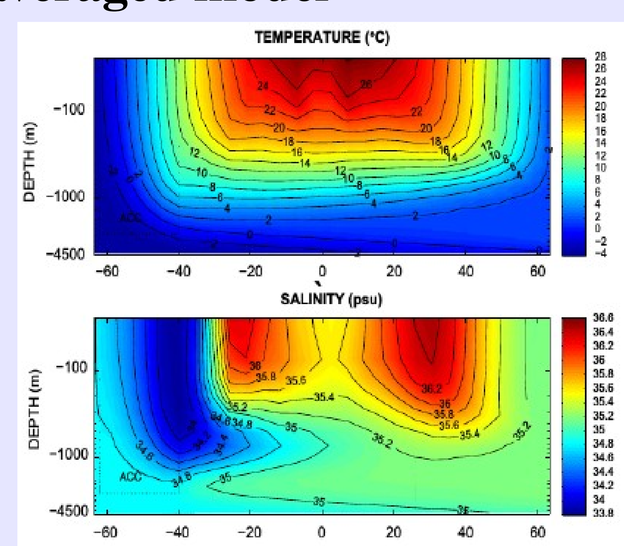


Fig 4. Freshwater flux locations in CESM (total 0.1 Sv), and in the 2D model (see box below)

Model control AMOCs in the 2 models are shown in Fig. 6(a,c).

2D zonally averaged model



$$\partial_t T = -J(\psi, T) + \partial_s(K_I \partial_s T) + \partial_n(K_D \partial_n T) + C_T + \mathcal{F}_T,$$

$$\partial_t S = -J(\psi, S) + \partial_s(K_I \partial_s S) + \partial_n(K_D \partial_n S) + C_S + \mathcal{F}_S,$$

$$v = -\frac{1}{\varepsilon \rho_0} \partial_y P + v_{\mathrm{Wind}} + v_{\mathrm{G\&M}},$$

$$\partial_z P = -\rho g,$$

$$\partial_y v + \partial_z w = 0,$$

$$v_{\mathrm{G\&M}} = -\partial_z (K_{\mathrm{G\&M}} s),$$

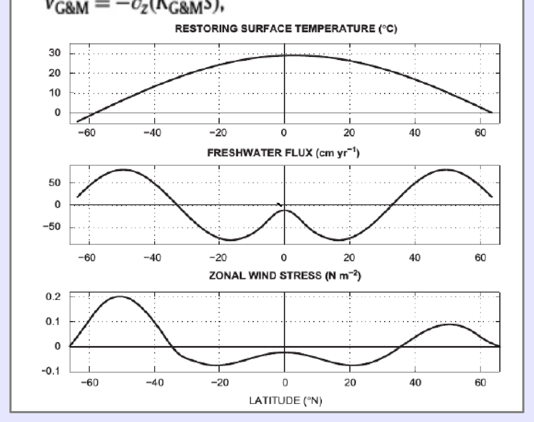


Fig 5. (top right) model equations, (left) T and S fields, and (bottom right) surface forcing (from Sevellec and Fedorov, 2011)

4 AMOC response to freshwater flux

AMOC responses to FWF:

- After 50 year of weakening, starts to recover (Fig 6a,c).
- The AMOC streamfunction is reduced throughout the Atlantic, centred at high latitudes (Fig 7b,d)
- The Meridional Heat Transport (MHT) reduction is less strong (Fig 6b,c).
- The similarity of the two models indicates that simple 2D dynamics can explain the responses.
- The response of the 2D model is robust across the parameter space

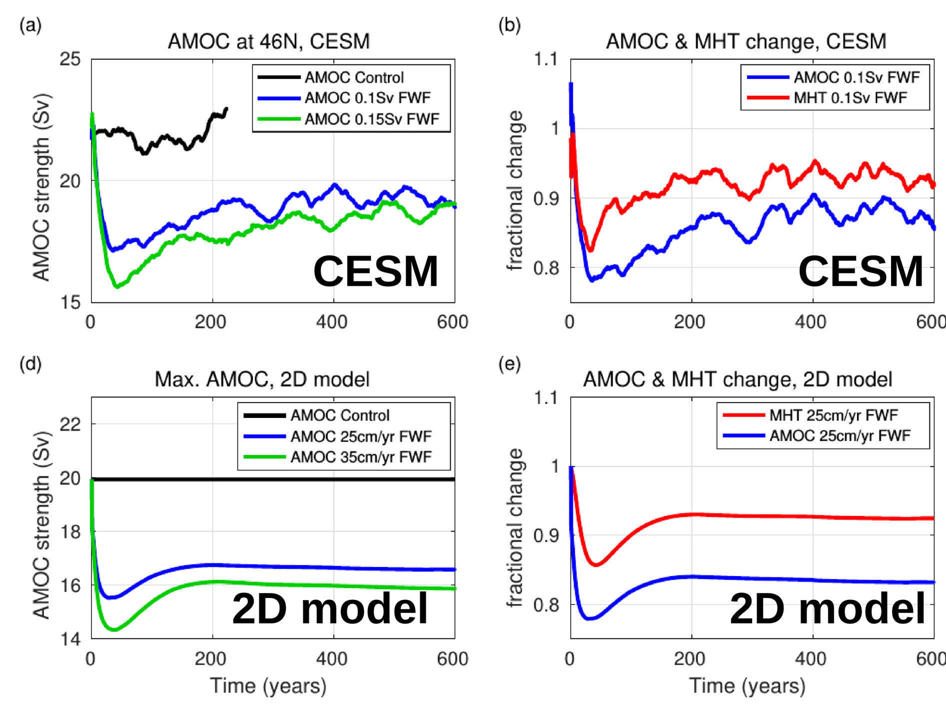


Fig 6. (Left) AMOC responses and (right) normalized AMOC and MHT fractional changes

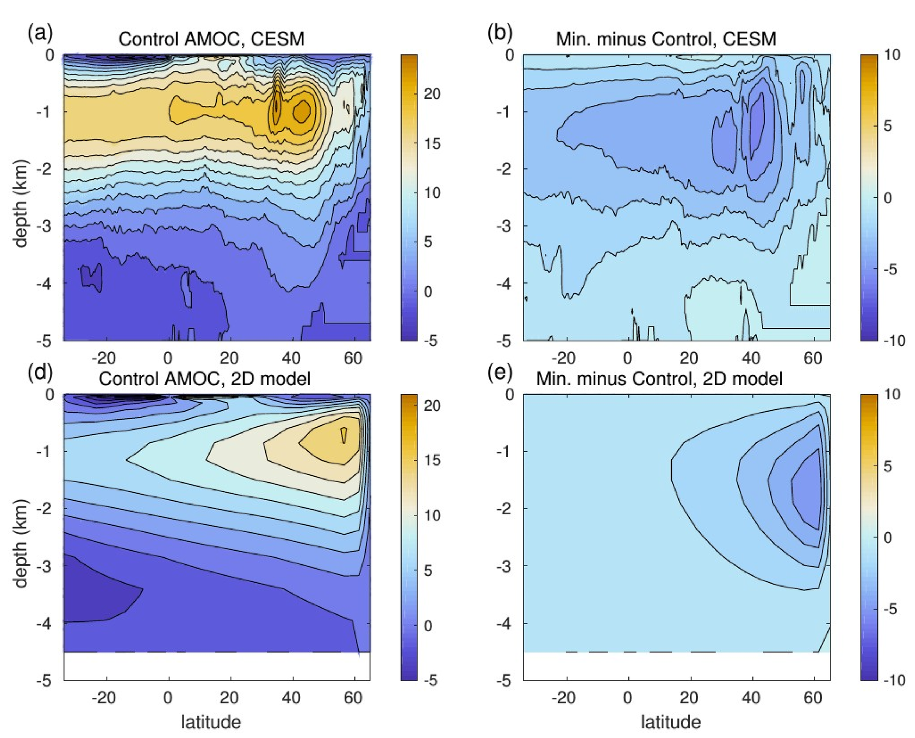


Fig 7. AMOC (Left) Control and (right) its change compared to the minimum (at year 50)

5 Mechanisms of Recovery

Why does the AMOC recover? Both subsurface warming and freshening combine to slowly weaken the stratification at all latitudes, with freshening dominating at high latitudes (Fig 8). Leads to a partial reinvigoration of convection and deep mixed layers (Fig. 9). Again, agreement between the 2 models is striking.

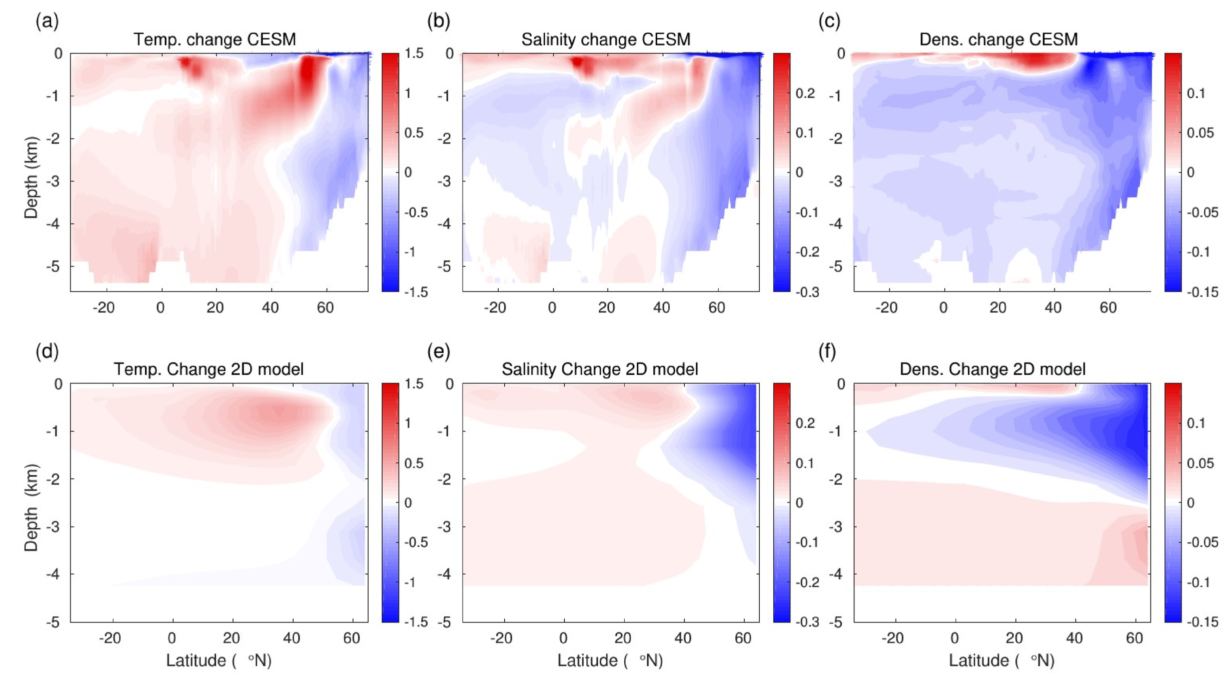


Fig 8. Property changes (FWF minus control) in (top) CESM and (bottom) the 2D model

Why does the heat transport recover more? The AMOC, although now weaker, moves warmer water northwards. Warming is first located at high latitudes before gradually moving southwards.

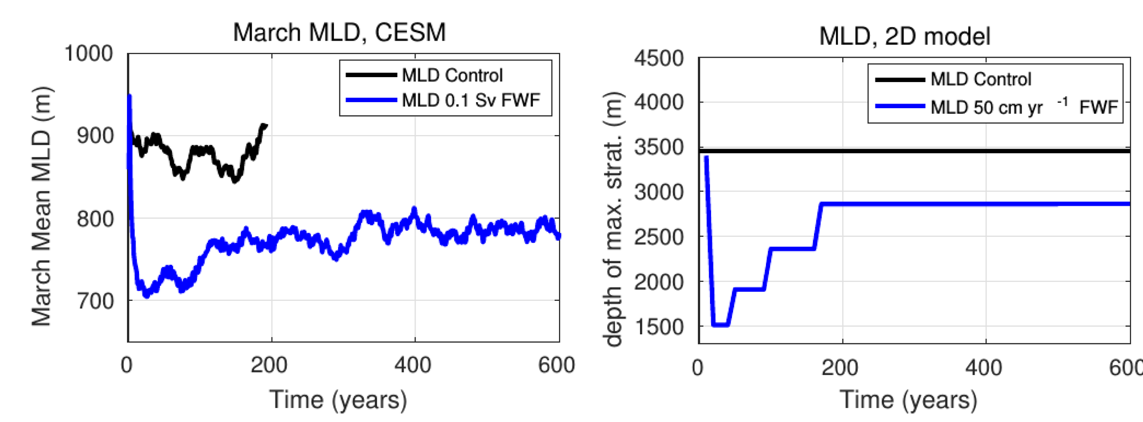


Fig 9. Mixed layer depth responses in both models (depth of maximum stratification in 2D model)

6 Conclusions

How do the model AMOCs and MHTs respond to a *sustained* increase in freshwater forcing?

- The AMOC weakens 3 Sv over 50 years, then recovers almost 1.5 Sv over 250 years (Sec 4).
- The recovery is because gradual subsurface warming *and freshening* combine to weaken stratification and reinvigorate convection and the AMOC (Sec 5).
- Subsurface warming also means that the heat transport recovers even more than the AMOC.
- Strong agreement with a 2D model reveals simple 2D dynamics to control this multi-decadal response, The results are robust across parameter space.

References and Aknowledgements

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