The Atlantic Meridional Overturning Circulation and its Sensitivity to Enhanced Runoff from the Greenland Ice Sheet

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The Atlantic Meridional Overturning Circulation (AMOC) is an important component of the climate system, because it transports significant amounts of heat to high northern latitudes. The sensitivity of the AMOC to freshwater capping in the northern North Atlantic is a big concern in view of the current mass deficit of the Greenland Ice Sheet (GrIS), which is expected to accelerate in future decades. Determining the sensitivity of the AMOC to enhanced melt water from the GrIS is therefore essential for climate change projections.

In this study we address the sensitivity of the AMOC to enhanced run-off from the GrIS by comparing the AMOC response to enhanced melt-water input in a global, strongly-eddying ocean model to that in a non-eddying model typical of the current generation of climate models. We find that the AMOC response in the strongly-eddying model is greater than in the non-eddying model, suggesting that the AMOC may be more sensitive than previously thought.

The Atlantic Meridional Overturning Circulation (AMOC) is an important component of the climate system, as it transports significant amounts of heat to high northern latitudes [1]. Its deep branch consists of the southward transport of relatively cold North Atlantic Deep Water (NADW, roughly between 1000 and 2000 m), and is compensated by a northward flow of warmer waters at shallower levels. The production of NADW takes place mainly in the Labrador and Nordic Seas by a process called deep convection. Convection is induced by intense surface cooling (which tends to make the surface waters less buoyant), but is vulnerable to freshwater input (which tends to make the surface waters more buoyant). This is a serious concern considering the fact that the Greenland Ice Sheet (GrIS) is losing mass at an increasing rate due to the warming of the climate system [2]. Assessing the sensitivity of the AMOC to melt water from the GrIS is therefore an important task for climatologists.

Unfortunately, water mass transformations are notoriously hard to represent in the current generation of numerical climate models—spatial resolution is sacrificed for the requirement to integrate these models for centuries, and the ocean's turbulent eddy field is not explicitly represented but parameterized. In order to study how those turbulent processes influence the sensitivity of the AMOC to enhanced melt water input, we performed a suite of integrations with two configurations of the same ocean model [3]. The strongly eddying configuration (indicated by $R_{0.1}$) has a high spatial resolution that is fine enough to resolve important transport processes like eddies, narrow and energetic boundary currents, and small-scale convective processes. The non-eddying configuration (called x1) has a low spatial resolution that is characteristic of the current generation of climate models; the transports accomplished by eddies are necessarily represented by complex parameterizations.

In addition to simulations without any anomalous forcing we performed sensitivity experiments where we applied an anomalous freshwater flux around Greenland to mimic enhanced run-off and calving from its extensive ice sheet. We found that there is a significant difference in the response of the Meridional Overturning Circulation (MOC) strength (Fig. 1): in the non-eddying case there is a strong initial slow-down of the MOC, followed by a gradual adjustment to a new equilibrium. In the strongly eddying configuration, however, the MOC declines more gradually but for a much longer period of time, with the final decline being almost double that in the non-eddying model. Apparently the sensitivity of the MOC to a freshwater flux perturbation is enhanced when smaller-scale transport processes are explicitly resolved.

A main difference between the two model configurations is the representation of transport processes. In the strongly-eddying case, transports by turbulent eddies are explicitly accounted for, whereas they are parameterized in the non-eddying model. To monitor how this affects the dispersion of the freshwater signal, we put a dye tracer into

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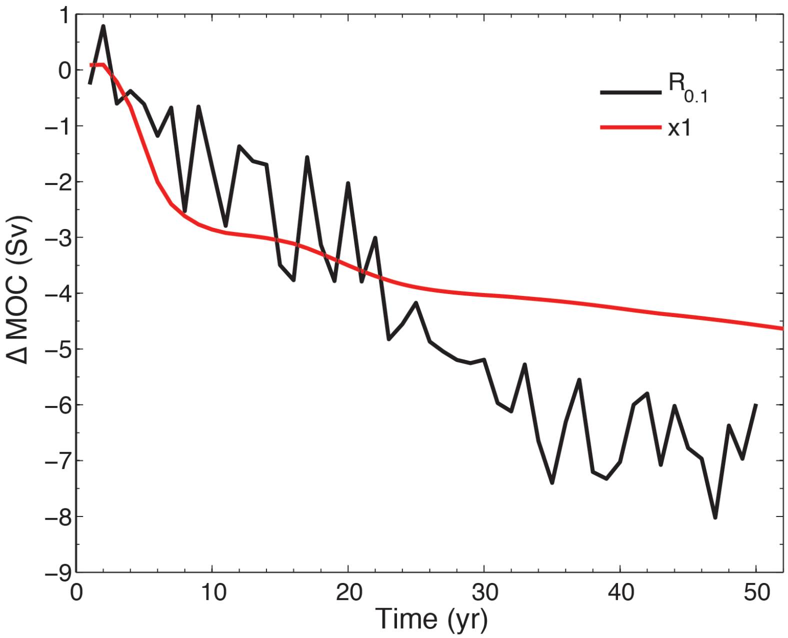

Fig. 1. Decline in the strength of the AMOC in response to enhanced melt water input from the GrIS, measured with respect to a control simulation (1 Sv = 10⁶ m³/s). Red line is for the non-eddying model configuration, which is characteristic of the current generation of climate models, black line is for the strongly eddying configuration.

the ocean around Greenland along with the melt water. Figure 2 shows the time it takes for this dye to reach a certain location in the Atlantic Ocean, either close to the surface (upper panels) or at depth (lower panels). It is clear that the dye is transported southward much more quickly when eddies are doing the job. However, there are also shadow zones (specifically in the eastern off-equatorial Atlantic) where no dye has penetrated even after the full 50 years of integration.

The main conclusion is that explicitly resolving turbulent transport processes matters for the sensitivity of the AMOC to melt water fluxes, and that the AMOC may be more sensitive than previously thought [4].

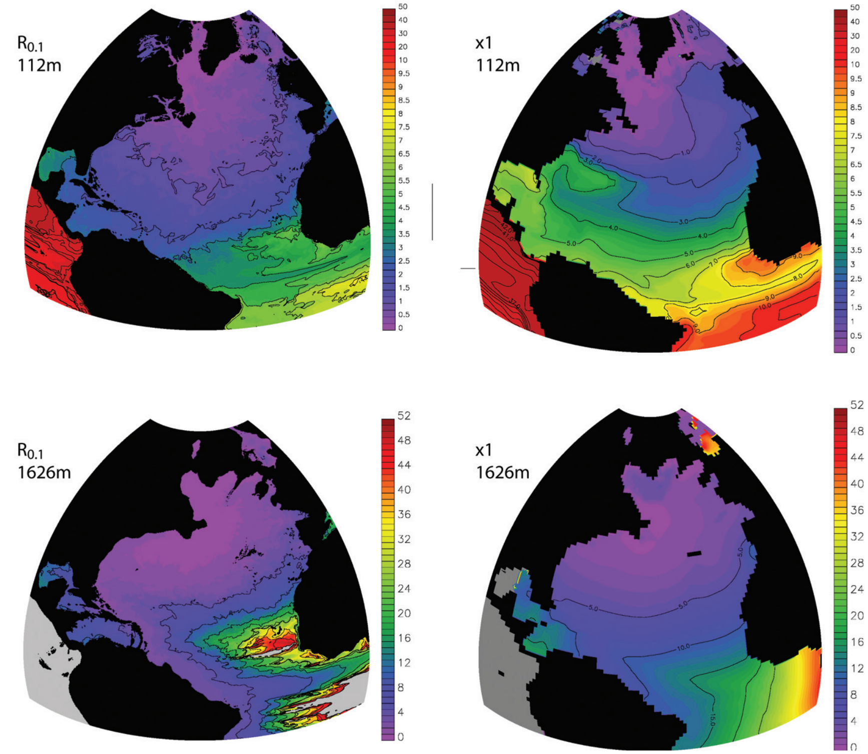

Fig. 2. Arrival time (in years) for a dye introduced along with the melt water around Greenland to reach a certain location in the Atlantic. Left column is for the strongly eddying configuration, right for the non-eddying case.

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[2] van den Broeke, M. et al., *Science* **326**, 984 (2009).
[3] Maltrud, M. et al., *Environ Fluid Mech* **10,** 275 (2010).
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Funding Acknowledgments
DOE Office of Science, Biological and Environmental Research, Regional and Global Climate Modeling Program