Tipping points in Antarctic Bottom Water formation and Southern Ocean carbon sequestration

The response of ocean circulation and carbon cycling to changes in freshwater supply

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In Short

- Climate change leads to an increased freshwater discharge into the Southern Ocean due to the continuous melting of ice shelves.
- The freshwater alters the properties and distribution of water masses, affecting the formation of bottom water masses.
- These bottom waters act to sequester carbon, i.e., they lock carbon away from the atmosphere for 100 years or more, suggesting major implications of changes in freshwater supply for the global carbon cycle and climate.
- In the most extreme scenario, above a certain level of freshwater discharge, a tipping point could be reached, leading to a cessation in bottom water formation, with dramatic consequences for global ocean circulation, carbon cycling, and climate.
- Here, with a set of model experiments, we will quantify the changes and identify possible tipping points in the ability of the Southern Ocean to form bottom water and to transport carbon to the deep ocean upon an increase in freshwater discharge from ice shelves.
- To that aim, we will use a global ocean circulation model (FESOM) with an increased grid resolution in the Weddell Sea, the most important bottom water formation region. The model includes interactions of the ocean with sea ice and ice shelves and is coupled to a biogeochemical model to simulate the carbon cycle (REcoM2).

The Southern Ocean plays an essential role in oceanic carbon uptake, carbon sequestration, global ocean circulation, and hence global climate, but the ability of this ocean basin to draw down atmospheric CO_2 has varied in the past and is projected to be altered in the future due to on-going climate change [1]. In general, ocean circulation largely controls the oceanic uptake of CO_2 and the transfer of carbon to greater depths in the Southern Ocean. On the one hand, the upwelling of deep water masses brings naturally carbon-rich waters to the surface layers, where the carbon can be released to the atmosphere (Fig 1). On the other hand, large amounts of carbon are locked away from the atmosphere by the sinking of water masses to the ocean floor at high-latitudes, i.e. the formation of Antarctic Bottom Water. In this context, the Antarctic Bottom Water formation regions have been suggested to dominantly set global atmospheric pCO_2 levels [2], as these can sequester carbon on time scales of centuries to millenia. Amongst all Antarctic Bottom Water formation regions, the Weddell Sea has been suggested to be the most important one [3], making any change in Antarctic Bottom Water formation in this area especially critical for global carbon cycling and climate.

The formation of Antarctic Bottom Water is a result of an increase in the density of surface waters [3], due to air-ocean and ice-ocean interactions, i.e., due to a cooling from the overlying atmosphere and due to the increase in salinity as a result of ice formation, respectively (Fig. 1). Similarly, this suggests that any addition of freshwater to the Southern Ocean, which leads to a decrease in water density, directly impacts the formation rates of Antarctic Bottom Water and subsequently Southern Ocean carbon transfer to depth. In fact, as a consequence of the recent warming, the mass loss of Antarctic ice sheets has accelerated over the last decades [4], discharging additional freshwater into the coastal areas of the Southern Ocean. While especially the melt rates of ice shelves in West Antarctica have accelerated, those in East Antarctica, including the Weddell Sea, have done so to a much lesser extent [4]. However, modeling experiments have demonstrated the possibility of accelerating melt rates of ice shelves in the Weddell Sea in the upcoming centuries as well [5], with a possible complete shutdown of Antarctic Bottom Water formation within a few decades [6]. Yet, the possible response of Antarctic Bottom Water formation rates and Southern Ocean carbon cycling to the expected future changes in freshwater discharge remain surrounded by large uncertainties or largely unquantified altogether, as these have so far been hindered by model resolution and/or missing model complexity, e.g. by not accounting for changing freshwater discharge from ice shelves and associated feedbacks in their simulations.

Here, we propose to quantify changes in Antarctic Bottom Water formation and carbon sequestration due to increased melt rates of ice shelves by performing model perturbation experiments with FESOM-REcoM2. This model is a global ocean cir-

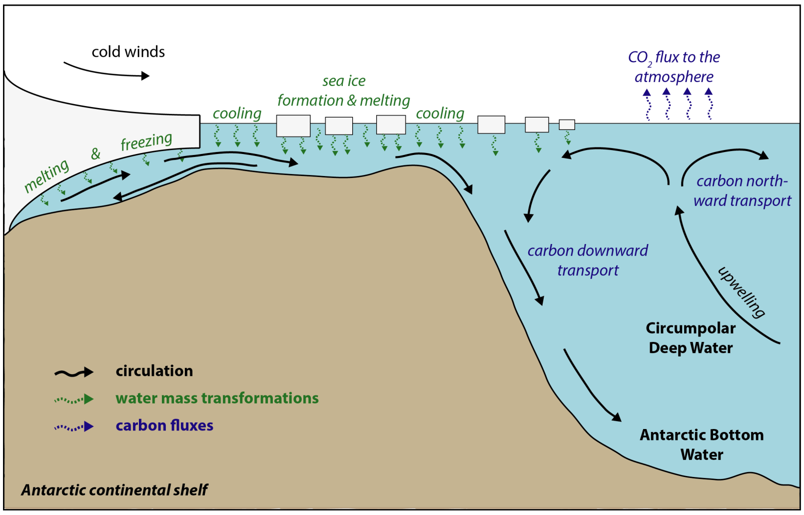

Figure 1: *Sketch illustrating the main features of high-latitude Southern Ocean circulation (black arrows), the air-ocean and ice-ocean interactions involved in changing the density of water masses (green), and the main features of Southern Ocean carbon cycling (blue).*

culation model with a description of interactions of the ocean with sea ice and ice shelves, as well a description of the marine carbon cycle. The setup used here has a higher grid resolution in the Weddell Sea, allowing for a realistic representation of processes inducing Antarctic Bottom Water formation in this area (Fig. 1). The coupling to the biogeochemical model REcoM2 then facilitates a detailed assessment of the resulting changes in oceanic carbon cycling upon the applied increases in freshwater discharge. Thereby, we will be able to quantify the imprint of freshwater perturbations on Southern Ocean carbon sequestration and air-sea CO_2 exchange, with ramifications for global carbon cycling and climate.

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More Information

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