Southern Ocean and Antarctic ice sheet response to AMOC collapse during the penultimate deglaciation

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Motivations

According to geological records, **the sea level during the Last Interglacial (~ 129–116 ka) peaked 6 to 9 m higher** than during the pre-industrial with a major contribution from the Antarctic ice sheet (Figure 1, Dutton et al. 2015). According to Clark et al. 2020, a longer period of reduced Atlantic Meridional Overturning Circulation (AMOC) during the penultimate deglaciation compared to the last deglaciation could have led to greater subsurface warming and subsequent larger Antarctic Ice Sheet retreat (Figure 2).

We hypothesize that both the duration and timing of reduced AMOC can significantly affect the sensitivity of the Antarctic Ice Sheet. A longer period of AMOC reduction will lead to a larger subsurface warming in the Southern Ocean and subsequently a larger ice sheet retreat. On the other hand, an AMOC reduction earlier (later) in the deglaciation implies that the ice sheet that is affected by this subsurface warming is still fairly large (already small).

Objectives

- **Study the response of the Southern Ocean to transient climate forcing with a forced AMOC collapse at different timing and duration during the penultimate deglaciation (~ 138–128 ka)**
- **Build climate forcings to constrain the magnitude and timing of the minimum volume of the Antarctic ice sheet during the Last Interglacial**

Method

The transient idealized simulations are done with the Earth System Model of Intermediate Complexity iLOVECLIM (Roche et al. 2014). We run iLOVECLIM with greenhouse gases and insolation forcings. Then, we make additional experiments where we **force the AMOC to collapse by releasing a constant freshwater flux of 0.3Sv in the North Atlantic** for 2ky, 4ky or 6ky long (Figure 4 b)). The time at which those hosings are happening varies also all along the penultimate deglaciation, starting from 140ky to ending at 128ky.

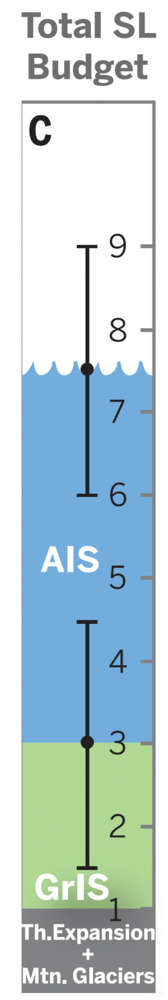

Figure 1 : Total sea-level budget of MIS 5e from the compilation by Dutton et al. 2015.

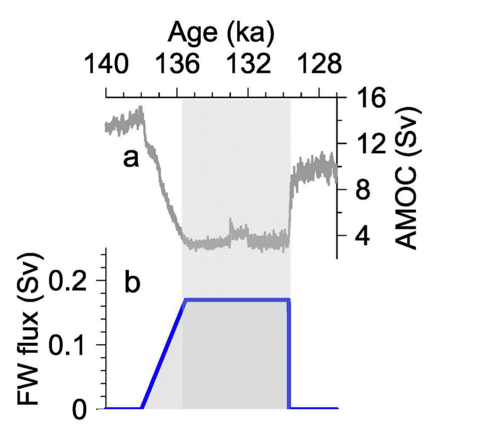

Figure 2 : Fresh water flux forcing and AMOC strength in Clark et al. 2020.

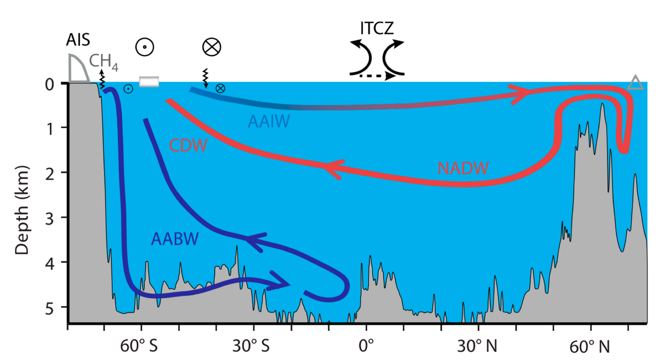

Figure 3 : Schematic of the AMOC and Antarctic Bottom Water (AABW) circulation reconstruction in the late Heinrich 11 from Turney et al. 2020.

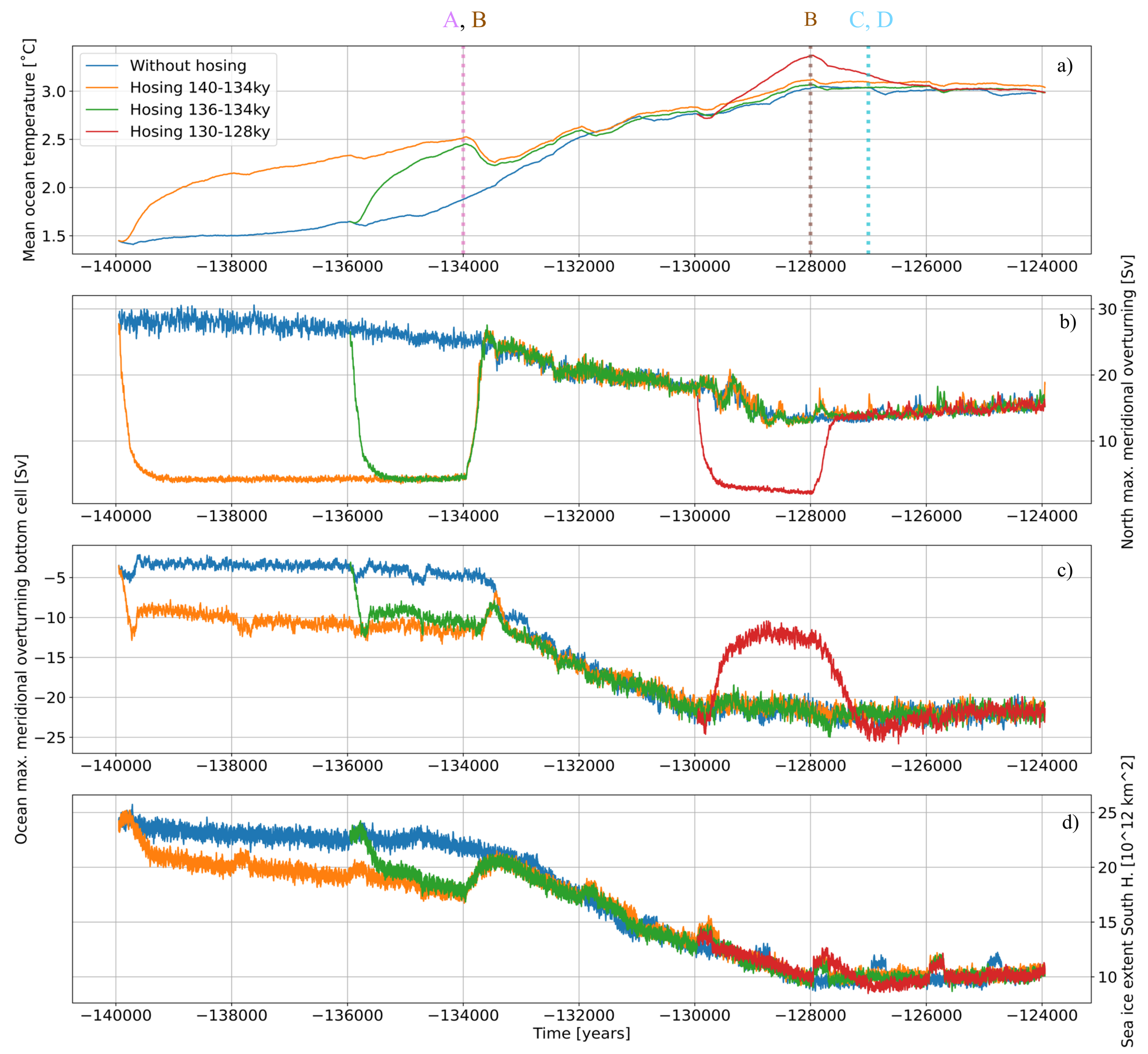

Figure 4 : Main variable outputs of the Earth System Model iLOVECLIM idealized simulations without and with hosing at different timing and duration during the penultimate deglaciation.

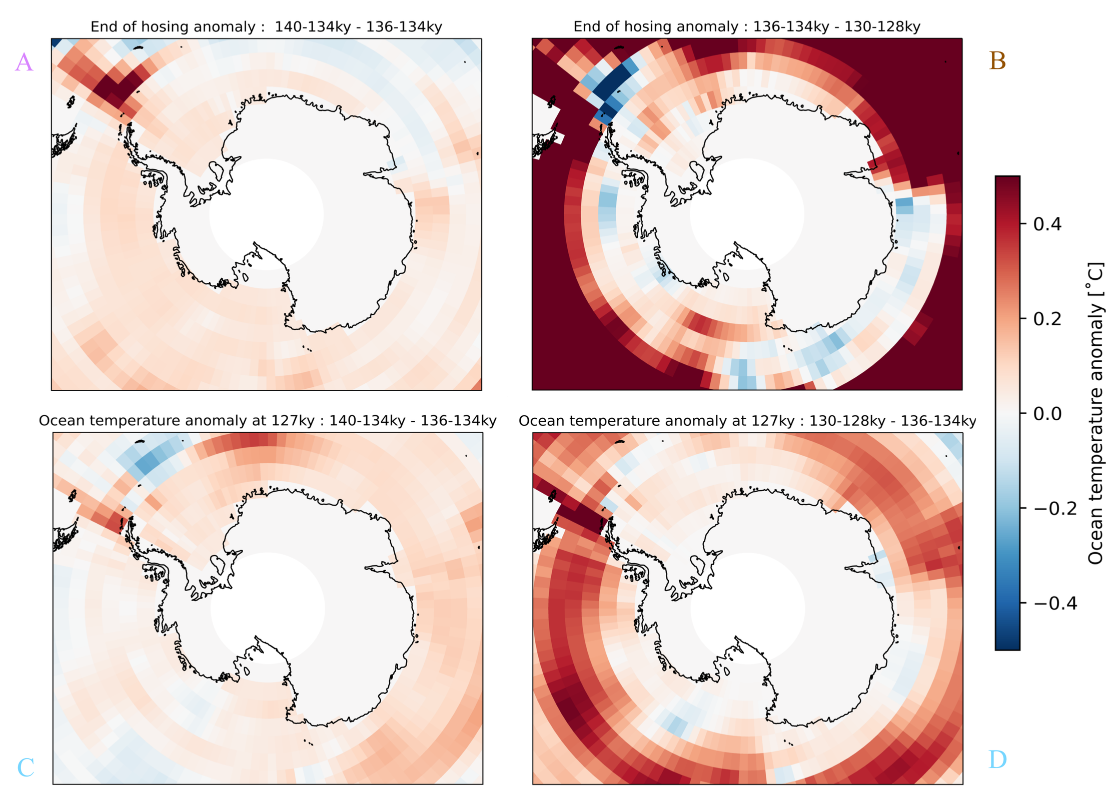

Figure 5 : Ocean temperature anomalies between experiments. A and B are anomalies between two experiments directly at the end of the hosing. C and D are anomalies between two experiments at the year 127ky. The time of the anomalies A, B, C and D are shown on Figure 1.a) with the dashed lines.

Results

The results from 4 simulations are shown here, their names explicit the starting and ending time of the constant hosing of 0.3Sv in the North Atlantic.

The **Figure 4** shows the main variables related to the oceanic circulation and the southern hemisphere. (a) shows the global mean ocean temperature with the blue curve that follows the deglaciation without hosing. **We see that the 3 simulations with hosing have higher mean ocean temperature during the hosing and up to 2000 years after the end of the hosing.** (b) explicit the forced AMOC shut down, (c) gives information on the bottom oceanic circulation and (d) shows the evolution of the sea ice in the southern hemisphere.

The bottom oceanic circulation strength has opposite responses to hosing experiments of the same length and at different timings (green and red curves).

The **Figure 5** focuses on the Southern Ocean temperature. The maps A and B show temperature anomaly between two experiments at their respective end of hosing time. Therefore, A shows a relatively small difference of between a 6ky long or a 2ky long hosing. However, B shows that **shutting down the AMOC in a glacial climate leads to higher oceanic temperature than in the early interglacial climate**. The maps C and D aim to compare duration and timing impact at the same time in the Last Interglacial : at 127ky. Here, we see that a **late AMOC shut down would lead to higher oceanic temperatures at 127ky** and potentially higher absolute maximum oceanic temperature.

Conclusion and future work

These results suggest that the timing of the AMOC collapse has a bigger role in the oceanic circulation and temperature than the duration. These results would need to be compared and validated with observations from marine sediment cores (Waelbroeck et al. 2002). **However, it remains unknown whether having a higher relative temperature during the deglaciation or a higher absolute maximum temperature during the Last Interglacial would lead to a more extensive Antarctic ice sheet retreat.**

To answer this question, we implemented the basal melting parametrization PICO (Reese et al. 2018) in the ice sheet model GRISLI (Quiquet et al. 2018) in order to have a more physical sensitivity to oceanic forcings. Preliminary results are shown on **Figure 6** with coherent patterns of high melt rate values for the Amundsen sea sector and refreezing on the bigger ice shelves. **GRISLI-PICO will then be first forced by the iLOVECLIM experiments and later fully coupled to also take into account fresh water release into the Southern Ocean from Antarctic ice sheet melt down.**

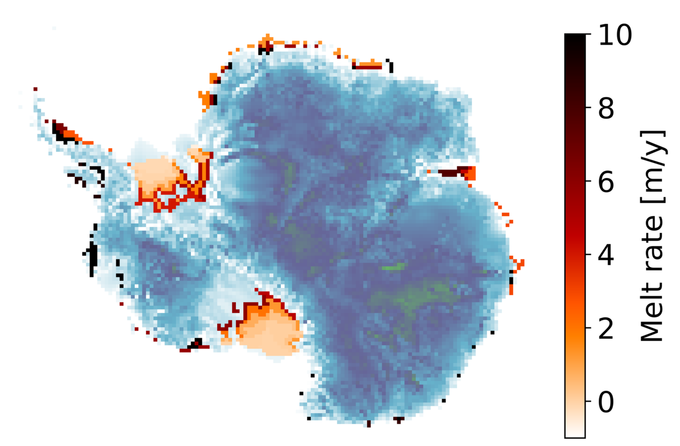

Figure 6 : Basal melt rate of the Antarctic ice shelves computed with the basal melt parametrization PICO (Reese et al. 2018) implemented in the ice sheet model GRISLI (Quiquet et al. 2018) under present day climate forcing.

References

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