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Climate of the Past
Discussions

Interactive comment on "The sensitivity of the Greenland ice sheet to glacial-interglacial oceanic forcing" *by* Ilaria Tabone et al.

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Review:

The study titled "The sensitivity of the Greenland ice sheet to glacial-interglacial oceanic forcing" aims the evaluate the impact of oceanic forcing over the last two glacial cycles. Tabone et al. apply a linear oceanic forcing parameterization to assess the relative impact of oceanic forcing relative to atmospheric forcing when simulating the Greenland ice sheet. An index scheme is applied to temporally evolve the atmospheric and oceanic forcing. The index is derived from a multi-proxy temperature reconstruction which spans the last two glacial cycles. Assuming a single climate forcing scenario, a sensitivity analysis is conducted on an idealized ocean forcing parameterization.

The study targets pertinent scientific questions with respect to Greenland ice sheet evolution which are within the scope of CP. The study is the first to evaluate the impact of millennial-scale oceanic forcing across Greenland. However, given a number of issues listed below with the experimental design, the results and claims of the study are not substantiated and require additional developments and experiments.

The title reflects the content of the paper and the abstract summarizes the analysis conducted. The paper is nicely structured; however, some parts are poorly written with superfluous statements and the results section reads like a string of figure captions. There is an insufficiently description of the model set-up and little discussion is placed on pertinent model weaknesses which directly impact their results (see Main Remarks). For these reasons, I suggest that the study is resubmitted upon addressing the outstanding issues discussed below. A pdf has been attached with minor technical comments of the manuscript.

Main Remarks:

1. Sea-level change

The simulations do not prescribe a eustatic sea-level history (e.g. benthic stack from Lisiecki and Raymo, 2005) which results in sea-level variations on the order of ∼120 meters over a glacial cycle. This could explain the model's inability to expand beyond the present-day coast line. A lowered sea level exposes parts of the continental shelf which can allow for the ice sheet to expand outward and show much greater sensitivity to atmospheric forcing than presented in this work.

Furthermore, the glacial isostatic adjustment component applied is based on an elastic lithosphere relaxed asthenosphere model which uses a single decay time and only considers local ice load changes. It has been shown that the North American ice sheets such as the Laurentide and Innuitian ice sheet impose a non-negligible glacial isostatic response across Greenland through the formation and collapse of a peripheral forebulge. These processes which are left out in this work were first incorporated in

Greenland ice sheet studies in Simpson et al. (2009) and this further contributes to sea-level variability.

2. LGM geometry

A number of previous modelling studies have shown the ability of the Greenland ice sheet to expand onto the continental shelf (Huybrechts et al., 2002; Simpson et al., 2009; Lecavalier et al., 2014). These previous studies lacked an explicit ocean forcing scheme based on past ocean temperatures and demonstrate a much greater sensitivity to atmospheric climate forcing. This highlights a key weakness in the current work since their simulations do not exhibit nowhere near this range of sensitivity (Bref=0,k=0), which directly impacts the main results of this work.

This is visually illustrated in Figure 11 of Tabone et al. which shows the deglacial evolution from their work compared to previous studies. Even in the case with no present-day oceanic forcing Bref=0, with the sensitivity parameter k=0, the ice sheet remain near its present-day geometry even during the glacial periods. This demonstrate that their model is unable to grow the ice sheet without the oceanic forcing scheme used as an unphysical method of ice accretion at the margin to advance the grounding line (upward to 20 m/a of accretion).

3. Oceanic forcing scheme

The basal melt scheme is a linear scheme which is attempting to capture a non-linear process, that of grounding line melt and migration, buoyancy transport and mixing, sub-ice-shelf melt and accretion. This idealized parameterization consists of two parameters, one tuned to achieve present day geometries (spatially constant) and the other is a sensitivity parameter which scales the LGM-present ocean temperature anomaly (spatially constant). This temperature anomaly is scaled by a climatic index, specifically a multi-proxy atmospheric temperature reconstruction. Firstly, the index scheme that scales the ocean temperature anomaly should not be derived from atmospheric temperatures, a proxy of past ocean temperatures is more appropriate (e.g. benthic

record).

As previously mentioned, the sensitivity parameter k, is used as an accretion scaling parameter at the grounding line in the current framework. The sensitivity experiment tests the model's ability to respond to basal accumulation during glacial periods since the ice sheet cannot expand to the continental shelf without significant grounding line accretion (several meters of ice-equivalent sea-level). A plot illustrating the volume difference for a given Bref model run and sensitivity parameter (e.g. vol(Bref=0,k=20)-vol(Bref=0,k=0)) would clearly show the volumetric impact of the oceanic melt and accretion implementation. This would emphasize the unreasonable accretion of several meters of ice-equivalent sea-level during the glaciation for grounding line advance.

Secondly, the LGM-present ocean temperature anomaly is chosen to be a spatially constant value of -3K. This assumes no spatial gradients in ocean temperature change over time which is quite simplistic when there are snapshot and transient LGM ocean temperature anomaly model results available (e.g. TraCE experiments from Liu et al., 2009).

Finally, the present-day melt rate Bref used to achieve present day grounding line extent is constant across the ice sheet, although at present the melt rates at the grounding line varies across the ice sheet since this depends on the temperature of the water column that is advected to the ice-ocean interface, among other processes. Ultimately, using a spatially constant reference melt rate and LGM anomaly is overly idealized since it does not factor for any of the spatially variability at present and through time. It would be more appropriate to implement spatially variable present and past ocean temperatures within a physically based temperature-dependent basal melt scheme.

4. Model limitations

The model uses a horizontal resolution of 20 km by 20 km which inadequately resolves high frequency topographical features such as fjords. In this current state, this study evaluates the sensitivity of the glacial Greenland ice sheet to oceanic forcing since there lacks a subgrid fjord representation which corrects for the unresolved ice-ocean interface once the ice sheet predominantly reaches the present-day coast line during an interglacial climate. Therefore, it is not appropriate to discuss or emphasise Holocene and Last Interglaciation model results since the results depend primarily on the single atmospheric forcing applied in this study, as illustrated by the model result convergence during interglacial periods in Figure 5.

This study is interested in ice sheet mass balance, somehow the study does not include a description of the calving scheme. This is a key process in ice sheet mass balance and it warrants a mention.

The paper aims to explore the relative impact of atmospheric and oceanic forcing on ice sheet evolution. The study claims that oceanic forcing is the dominant driver of Greenland ice sheet evolution. However, the claim lacks robustness since parametric uncertainties in the atmospheric forcing have not been equally explored for a true relative comparison. Additionally, a broad exploration of the boundary conditions should be considered using a variety of ocean temperatures and atmospheric precipitation and temperatures at the Last Glacial Maximum since this would yield a much broader range of viable climate forcing scenarios.

Other comments are attached in the pdf.

Please also note the supplement to this comment:
https://www.clim-past-discuss.net/cp-2017-127/cp-2017-127-RC2-supplement.pdf

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