Clim. Past Discuss.,
https://doi.org/10.5194/cp-2017-143-RC2, 2018

Interactive comment on "Oceanic forcing of the Eurasian Ice Sheet on millennial time scales during the Last Glacial Period" *by* Jorge Alvarez-Solas et al.

Anonymous Referee #2

Received and published: 2 February 2018

Alvarez-Solas et al. investigate the respective role of atmospheric forcing and oceanic induced sub-shelf basal melting (and refreezing?) rates in the variability of the Eurasian ice sheet during the last glacial period. The paper is scientifically very exciting as whilst a fair amount of climate records exist only little is known about glacial ice sheet variability and in particular the role of the ocean in this variability. However, I have serious doubt on the experimental setup and in particular concerning the basal melting perturbation chosen. If the authors really use an oceanic perturbation allowing for refreezing (and at a greater rate than snow accumulation!) the validity of the paper findings can be largely questioned. I suggest that the authors clarify their methodology as I will not support publication of this paper with the OCN experiment as presented.

I would recommend the authors to perform again their OCN and ALL experiment with an alternative basal melting rate perturbation (e.g. based on a ratio as for precipitation or at least with a positive threshold).

General comments

- I am worry about your experimental setup: as it is written in the manuscript, the sub-shelf basal melting rate perturbation allows for refreezing under your ice shelves, and in huge amount! In the Nordic seas you have a temperature difference interstadial minus stadial which is about +1 to +6°C. Your kappa is set to 5m/yr/°C in your standard OCN experiment which means that for negative beta you can easily end up with refreezing rate greater than 5 m/yr which seems completely off-scale (largely greater than snow accumulation). If refreezing is observed locally under ice shelves (due to recirculation of ice melt induced fresher waters along the ice), I think that a 40x40km shelf with more than 5 m/yr refreezing is completely unrealistic. I hope that I misinterpreted your equations, but if I am correct this is a serious flaw in your study. I may be wrong but I think that what we see in Fig 2d is due to your very large basal melting perturbation (with an amplitude st/is of more than 40 m/yr!): in the OCN experiment, your artificial refreezing allows for a rapid growth of ice shelves followed by a rapid disintegration. A side note: this is somehow rather peculiar to see that your ice sheet re-growth is actually faster than ice sheet collapse! Maybe you could show a figure showing the evolution of the spatially integrated value of the basal melt and how does this number compare with snow accumulation, ablation and calving rate. I strongly suggest the authors to use an oceanic perturbation written in a similar way to precipitation, based on a ratio of basal melting rate instead, preventing negative values.

- More generally, this is not clear to me if you distinguish correctly calving flux from melt. The two perturbation you applied (ATM and OCN) in the experiments impact the melt. Because you don't mention how your calving rate is calculated nor you give the extent of the ice shelves, it is difficult to quantify the respective role of melt vs. calving. Please provide the two fluxes separately in Fig. 2 and with the same units so that we can clearly measure the impact of the oceanic perturbation on your calving flux. This addition would be very useful as basal melt cannot explain the IRD concentration in marine sediment cores. Also, as mentioned in my previous comment you should show the evolution in time of your basal melting rate along with the other components that explain the ice sheet volume evolution (surface ablation, accumulation and calving).

- I guess that in the model it does not matter if it comes from below or from above: melt is melt. It seems to me that if you get a larger response from the oceanic perturbation it is because your perturbation is also larger, am I right? I tried to get my answer from Fig. 4 but the color scale makes difficult to read the value of the basal melt along the coastlines: about 30 m/yr for the Scandinavian ice sheet and about 4 m/yr in the Bjørnøyrenna region (where you have no surface ablation at all)? If you impose a much larger oceanic perturbation than the atmospheric perturbation it is somehow expected to get a larger response? Please discuss. More or less related to this, how you maintain unconfined ice shelves with such high values of basal melting rates?

- Sub-shelf basal melting rate is not the only control exerted by the ocean on ice dynamics. What about sea level variability (and/or glacio-isostasy)? Some authors present the marine based Kara-Barents complex as an analogue for present-day West Antarctic ice sheet for which bedrock topography is a major control for stability. Of course marine ice sheet instability is generally triggered by a sub-shelf basal melt perturbation but is largely amplified by local bedrock depth with respect to sea level. In addition to provide more information on how your model deals with grounding line dynamics and glacio-isostasy, I think you should add a discussion about marine ice sheet instability of the Kara-Barents complex.

- Please provide more model information. SMB: what is the parameters used in the PDD model? Do you have a fixed daily variability (sigma)? Do you take into account refreezing? What is the value of your vertical lapse rate? GRISLI-UCM: how do you define the calving rate in the model? Maybe more importantly for ice sheet dynamics: how is computed the grounding line position? How do you combine SIA and SSA

approximations? You should also provide more information on your experimental setup: how is the ice sheet spun-up? Do you include glacio-isostasy? Do you have any kind of sea level forcing?

- You should assess the sensitivity of your results to the calving parametrisation / parameters.

- You justified the use of SST instead of sub-surface temperature because the Eurasian ice shelves are shallow. This is not really convincing. SST might be more correlated to surface processes (e.g. SMB) than to sub-shelf basal melting rates. Please provide a plot of sub-surface temperatures anomalies (Fig. 1) and a more robust justification for the use of the SST.

- Please improve on your figure quality. The plots are generally blurry (Fig. 3 and 4) and the color scales are not necessarily suited for the interpretation of the results (Fig. 4). The projection chosen is somehow unorthodox and you should draw the meridians and parallels.

Specific comments

- P1L14-16 please moderate: the larger response is expected as you impose a much larger oceanic perturbation compared to the atmospheric perturbation

- P3L24-26 these sentences are misleading: as you do not assess the impact of sea level variations and its impact on grounding line migration, you do not explicitly test “dynamic processes related to ice-ocean interactions”. You quantify the effect of ice melt (and refreezing) scenarios on the dynamics of the ice sheet. Please rephrase.

- P4L8 What is the value of the proportionality factor?

- P4L9 How do you know where the sediment layer is saturated?

- P4L9-10 “explicitly calculates grounding line migration”: how?

- P4L10 how calving is computed?

- P4L18 Please list the PDD model parameter values. Do you use an atmospheric lapse rate?

- P4L18-19 Please provide a reference or show the equation for the inland basal melting computation

- P4L19-20 A study from 2004 is not "recent"

- P6L6-8 I understand that the present day basal melting rate in the Arctic is difficult to quantify. However, you should present a map of B0 and B40k computed from your expression in order to quantify the role of kappa. This figure could also help to choose the right kappa value: being close to 0.1 at 40k and not too strong for present day (as we have sea-ice and you use SSTs).

- P6L25-26 You should show a map of ice thickness in the CTRL experiment clearly showing the extent of the grounded part of the ice sheet.

- P6L26 What is the depth of CLIMBER first oceanic level? Please justify better the use of SSTs.

- P7L4-7 Please show a map of the anomaly in surface ablation and in basal melt rate for beta=1 and beta=-1. This is important to quantify the imposed perturbation in your ATM and OCN experiment. Unlike Fig. 4, use for this the same topography (for example your spun-up initial topography).

- P7L13 Is this total ice volume? What is the volume of your spunup topography.

- P8L23-24 It is generally assumed that the melt anomaly is not linear with the temperature perturbation (e.g. Holland and Jenkins, J. of Climate, 2008). You should put more references in here and try to quantify your chosen sensitivity with respect to other melt models available in the literature. I agree that the basal melting rate is potentially highly variable but the fact that you use SST instead of sub-surface temperature added to the fact that you choose a high kappa value might lead to an overestimation of the oceanic induced melt sensitivity?

- P8L28-29 Apart from sub-shelf refreezing, what is the mechanism for ice-sheet regrowth? Please discuss in light of your ice volume gain of about 0.7 mSLE / 1000 years deduced from Fig 2d.

- P10L6 Be more specific: atmospheric and oceanic induced melt (you did not test the impact of sea level variations).

- P10L13-14 Show that this is still the case when you don't have refreezing under ice shelves.

- Fig 1 Annual means? Do you really have +12°C In Scandinavia at 40k?

- Fig 1 In this figure or in a new one: annual mean SMB anomaly (interstadial minus stadial) along with annual mean basal melting rate anomaly.

- Fig 2 Basal melting and surface ablation here as well, integrated over the whole ice sheet.

- Fig 2 Maybe in a separated plot: grounded and floating ice extent evolution for the different experiment

- Fig 2 2d Dashed lines?

- Fig 2 2d is this grounded or total ice volume ? Please show the floating ice.

- Fig 3 Which "stadials" and "interstadials" is represented here?

- Fig 3 Please clearly show the grounding line and the ice extent everywhere.

- Fig 3 Why the selected velocity point is not in the middle of the ice stream? Is it vertically integrated velocity?

- Fig 3 We see an increase in velocity in the ATM experiment but we cannot see anything in Fig 2. Why?

- Fig 3 Your ice shelf in stadials seem to have a very limited extent. Do you have certain specific boundary conditions, such as a depth criteria? If yes, this can be an other problem as you will only have ice shelves if you start to retreat inland (which seems to be the case looking at your OCN (Is) snapshot). Conceptually, do you expect a larger ice shelf extent in interstadials relative to stadials?

- Fig 3 I am surprised to see that the British ice sheet presents generally very low velocities. I am guessing that it has a frozen bed, which is unexpected due to the warm climate in this area. Can you comment on this?

- Fig 3 In a separated plot: please show a map of ice thickness (with limit of grounded part) for the same selected glacial and respective interglacial as in Fig 2.

- Fig 4b I do not understand why there is a band of high basal melting rate (near the coastlines?). Also, why there is a wide area in the Nordic Seas with a relatively high basal melting rate: this area is not supposed to be grounded? Perhaps you have two different topographies here? This has to be clarified but I strongly suggest to plot the anomalies computed on the same ice sheet geometry (ideally the spun-up one). Please change the color scale.

- Fig 5 “region of Bjørnøyrenna”: be more specific (maybe show this region on a map).

Technical corrections

- P7L26 SATs

- P9L22 amount

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