

Dear Dr. Brovkin,

We would like to thank both referees for constructive comments. We acknowledge that detailed information on the downscaling procedure is critical to the evaluation of model performance and apologize to both referees for this flaw in our previous manuscript. Please find detailed responses to the reviewers comments below. Changes in the manuscript are highlighted in blue.

Best regards,
Andreas Born

Anonymous Referee #1

Received and published: 8 September 2010

The paper 'Warm Nordic Seas delayed glacial Inception in Scandinavia' by Born and coauthors describes results from experiments, where results from global atmosphere ocean models and stand-alone atmosphere model simulations for 115ka have been investigated with the help of an ice sheet model. The authors focus on Scandinavia. In general, the findings are sufficiently new, although not completely surprising, and the topic fits into Climate of the Past. The description of the experiments could be more clear. I did not find in the text, how long the ice sheet model has been run and how it was initialized. However, in the way the authors use the ice sheet model, this may not even matter, as they basically restrict their analysis to results from the very simple mass balance scheme of the model. The analysis of the results is not particularly advanced and could be further substantiated. However, if the prescribed temperature changes in the Norwegian Sea translate 1:1 into temperature changes in Norway (the glacier nuclei are probably on the atmosphere grid point next to the ocean, where SST has been modified or may be even on the same grid point), the analysis is probably sufficient and more would be an overkill. The paper should be published after some corrections. A second round of review is not necessary.

A- The model was initialized with preindustrial ice and bedrock topography and run into quasi-equilibrium for 50,000 years.

The results of this publication might not be completely surprising to glaciologists. However, previous work on the Scandinavian inception in the field of paleoceanography hypothesized an acceleration of ice growth due to warmer sea surface temperatures in the Nordic Seas and an enhanced moisture supply which we could now show is not a realistic scenario. After investigating the origin of these warm surface conditions observed in the proxy record and establishing a theory based on

two completely different climate models in two previous publications, we believe it is a valuable contribution to take one more step and test the effect of the simulated climate data (from one model) on land ice in a physically consistent ice sheet model.

Detailed comments:

1507-20 Give some information, how you downscaled the atmosphere data onto the finer SICOPOLIS grid. Where all grid points used for the interpolation onto the fine grid, or just land points? This becomes essential, as surface temperature is used to calculate the mass balance (or did you use surface air temperature? In the this case please be more accurate in the text).

A- *We did use surface air temperature of all atmospheric grid points, that is over land and sea. This is now described in detail in the manuscript.*

1507-21 There must have been used some height correction for the downscaling as well. Describe it.

A- *The downscaling procedure has now been detailed in Section 2. We interpolate surface air temperature of all grid points, ocean and land, bilinearly to obtain a climatology on the fine ice sheet model grid. In addition to this horizontal interpolation that is done only once before each integration, a vertical correction of temperature for height differences is carried out in each time step.*

1508-2 As resolution is an issue, especially with the steep Scandinavian orography, the resolution of the atmosphere model should be given here explicitly and the reader should not have to do a literature research to find these facts.

A- *Information on the climate model configuration has been added. We explicitly state the resolution of atmosphere, sea ice and ocean subcomponents in degrees latitude and longitude, and provide an estimate of atmospheric resolution over Scandinavia in kilometers in order to compare it directly to the ice sheet model resolution.*

1508-10 Where ends the 'North Atlantic' in the south? Where is the margin between the adjusted and unadjusted SSTs in the sensitivity experiments?

A- *The southern boundary is at 50N where the anomalous sea surface temperatures have been smoothed meridionally over three grid points so no artificial jump is created. This information is now part of the main text.*

1508-10 It may be an improvement, if the description of the atmosphere-only experiments is moved to section 4, where it is partially described again.

A- We appreciate this comment, but would like to keep the description of the models entirely in Section 2. The repetition in Section 4 is only to the extent necessary to remind the reader.

1509-10 This is probably not restricted to 115ka, but also valid today. Is the relation between Scandinavian summer temperatures and Greenland-Scotland-Ridge heat transport at 115ka different than in the control simulation? Is the ocean lead by 1 year statistically significant?

A- We calculated a cross correlation for various time lags. Only correlations around zero lag were found to be significant and the maximum correlation was found for one year lead of ocean heat transport. This has been clarified in the main text.

The same correlation is found in the preindustrial control run indeed, but with no lead (980 years, $r=0.77$).

1509-21 Mention explicitly that these runs are atmosphere-only., see comment 1508-10.

A- This has been added.

1511-17 Does this ice rafted debris in the Nordic Seas really origin from Scandinavia? Or could the longer lifetime of the icebergs from Greenland and Svalbard due to the colder temperatures (and the associated longer advection length scale) explain this fact as well? How long does it take to build up a Scandinavian ice sheet that can transport enough ice rafted debris into the Nordic Seas?

A- It is very unlikely that icebergs travel so far from either the Greenland or the young Laurentide ice sheets. Thus, while we cannot rule out this option, we believe that the nearby source is the most likely. This is supported by terrestrial data.

Glaciers in western Norway almost reach sea level today and the fjords provide an efficient way of transporting ice from far inland to the open ocean. Given that the inception was probably quite rapid in Scandinavia (Mangerud et al., 1981), it probably doesn't take long to accumulate enough ice to record an IRD signal. However, this is speculation and thus not included in the manuscript.

Fig. 2 Units are missing.

A- *Have been added.*

Fig. 5 The small ice caps are hard to see, you have to know that they are there to see them on the plot.

A- *We are aware of this issue and have been experimenting with different solutions. The (preliminary) decision was to keep this format in order to be consistent with the other figures and to show the entire Arctic domain. A final decision depends on how the figures will be formatted in the final paper, which will be discussed with the publisher's production division.*

Anonymous Referee #2

Received and published: 1 October 2010

I also concur with the first reviewer that the submission by Born et al needs more detail (comments below were written before reading the first review) in the model setup description. Until more details are provided about the climate model, its biases and such, no significance can be gleaned from the stated magnitude of extra cooling required to get inception. Such a study also needs some analysis of the climate dynamically processes involved. What is happening to sea ice, storm tracks,... during the inception interval? Until I see more details on the model setup, I'm unable to judge whether this paper is worth publishing.

A- *It appears that the original manuscript failed to make clear that the climate forcing is time-independent and thus caused a misunderstanding. Dynamic climate changes of the glacial inception in IPSL CM4 are discussed in depth in previous publications and corroborated in a completely different model (Born et al. 2010a, 2010b). These results have also been discussed with respect to the available proxy reconstructions. The aim here is to analyze the impact of these changes on land ice. Therefore, the ice sheet model has been forced with time slice simulations of a critical period during the last glacial inception (115 ka) and its sensitivity to sea surface temperatures has been evaluated.*

We hope that this aim is clearer in the revised version. In addition, we discuss surface air temperature and winter precipitation changes due to the reduction in sea surface temperatures in section 4 and in one additional figure (Fig. 7). Additional information on climate model biases and the downscaling method has been added to the manuscript.

references:

- A. Born, K. H. Nisancioglu and P. Braconnot (2010): Sea ice induced changes in ocean circulation during the Eemian. *Climate Dynamics*, (online)
- A. Born, K. H. Nisancioglu and B. Risebrobakken (2010): Late Eemian warming in the Nordic Seas as seen in proxy data and climate models. *Paleoceanography*, (in revision)

#specific comments

by 74 m (Peltier, 2004). Eurasia was covered with a ice volume equal to 2.5 times the Greenland ice sheet, or 17 m sea level equivalent. Additional 25-30 m of sea level equivalent accumulated on the Antarctic ice sheet (Lambeck and Chappell, 2001) for a total sea level decrease of 120 to 130 m relative to present (Waelbroeck et al., 2002).

Peltier's ICE-5G is about 80 m eustatic equivalent for North America. No reasonable glaciological model that I know of has generated even 20 m of sea-level for Antarctica at LGM perature decrease of about 3 C as inferred from planktic foraminiferal data.

A- Peltier's ICE 5G reconstruction states a sea level equivalent of 74 m for the Laurentide ice sheet (Fig. 10b in Peltier 2004). We agree that an ice volume increase above 20 m sea level equivalent on Antarctica is inconsistent with data and model reconstructions. The text now states more precisely that the remaining 25 to 30 meters include additional ice on Antarctica and small ice caps (e.g. Patagonia, Tibet, European Alps, etc.).

reference: Peltier, W.R. (2004), GLOBAL GLACIAL ISOSTASY AND THE SURFACE OF THE ICE-AGE EARTH: The ICE-5G (VM2) Model and GRACE, *Annual Review of Earth and Planetary Sciences* 32(1), 111-149.

Ice-rafted detritus indicates that ice growth over Scandinavia started at about the same time.

IRD only indicates the presence of marine ice, ice growth could have started much earlier and remained terrestrial

A- Present day glaciers in Scandinavia as well as nucleation sites for glacial inception are very close to fjords. Ice growth in this region would rapidly lead to calving and thus the production of ice-rafted detritus. This is also suggested by the rapid onset of ice growth found by Mangerud et al. (1981). This additional information has been added to the manuscript.

reference: Jan Mangerud, Eivind Sonstegaard, Hans-Petter Sejrup and Sylvi Haldorsen (1981), A continuous Eemian-Early Weichelian sequence containing pollen and marine fossils at Fjosanger, western Norway Boreas 10, 138-205.

stereographic projection centered on the North Pole (Fig. 1). The horizontal resolution 15 is set to 40 km and there are 90 vertical layers: 80 equidistant layers in cold ice and 10

This is a relatively course resolution. Shallow ice models can easily be run at 20 km resolution for such a region, given the time interval covered. monthly surface temperature and total precipitation.

A- We perfomed tests with a 20 km resolution version. While the computational load was still reasonable, the large arrays exceeded the memory available on typical work stations and cluster computers (approx. 8 GB). Note that we ran our experiments into quasi-equilibrium for 50,000 years. While a shorter integration time is probably enough to simulate the relatively small ice fields of a glacial inception, the computational cost of such experiments is comparable or higher than in transient simulations from the last glacial maximum to present day or of the last glacial cycle. Similar simulations in recent years have been carried out with the following resolutions:

Charbit et al. (2007): 45 km horizontal

Peyaud et al. (2007): 40 km horizontal

Vizcaino et al. (2010): 80 km horizontal (both hemispheres), 21 vertical

Zweck and Huybrechts (2005): 50 km horizontal, 17 vertical

present study: 40 km horizontal, 90 vertical

The snow fraction of monthly precipitation is estimated as a linear function between -10 and 7 C, with all precipitation

This is an outdated approach. It would be better to at least impose a normal distribution of hourly temperatures around the monthly mean and use a 2 degree C cutoff for snow. Better yet, extract an accurate distribution from using hourly output from say 5 or 10 years of the GCM output.

A- Unfortunately, the GCM simulations were not run with forcing an ice sheet model in mind and only monthly output was kept. While it is true that the parametrization to calculate snow fraction is relatively simple, it is still used frequently in ice sheet models. Preliminary tests in which the ice sheet model was forced with snow fraction as given by the GCM yielded practically identical results. However, this approach has been rejected because it does not allow for accumulation changes on a growing ice sheet.

$s = 12 \text{ mm K}^{-1}$ for ice. A constant geothermal heat flux of 55 mW/m² is assumed at
For future work, I would recommend temperature dependent degree day melt
coefficients which can be made to fit closer to Energy Balance models. Also, Pollack et
al (1993) provides a more physically based map of geothermal heatflux. The choice of
55 mW/m² is a weak choice, though for inception studies this is not a major issue.

A- *We agree that inception does not depend on the ground heat flux because ice fields
are too thin to allow heat to accumulate sufficiently. A clarifying sentence has been
added to the manuscript.*

What land ice boundary conditions were used in the IPSL CM4 climate model?

A- *All climate model experiments assume an invariant preindustrial ice topography and
albedo. This information has been added to the manuscript.*

What temporal resolution of the GCM output did you apply to the ice-sheet model?
And how did you compute Positive Degree Days if you did not use hourly time
resolution?

A- *The climate model output is invariant to the ice sheet model besides the lapse rate
correction for changing ice elevation. We hope that this is now clear from the extended
description of the experiment design.*

*Positive degree days were calculated from monthly average data using a statistical
approach. The information and an additional reference have now been added to the
main text.*

A description of the inherent limitations and biases of the climate model wrt
capturing the physical dynamics of the atmosphere/ocean/sea-ice is in order. What key
relevant features of the ocean/atmosphere circulation are not well captured by the
model? How biased are model fields (seasonal precip, temperature, sea-ice extent) for
PD conditions?

A- *Section 2 has been extended to include a comparison of an IPSL CM4 preindustrial
control experiment with the ERA-40 climatology. As suggested, we compare annual
average surface air temperature, sea ice area and seasonal precipitation in two
additional (sub-)figures. The model has been found to simulate these critical
parameters with sufficient realism and that the temperature offset would rather favor an
early inception than delay it. Hence, our principal conclusion is robust to this technical*

shortcoming.

5 to simulate the last glacial inception and was validated against the available proxy data to simulate the transient warmth in the Nordic Seas at 115 ka (Braconnot et al., 2008;

Be more concrete/specific. What does "was validated" really mean quantitatively how were the climate fields down-scaled to the ice-sheet grid resolution?

A- The model validation has been extended with a discussion of the simulated preindustrial climate in Section 2. The validation for 115 ka climate is the result of two previous publications. The conclusion important to the present manuscript is that a transient warming seen in sediment core data is reproduced in IPSL CM4. Since this model is computationally too expensive to simulate the last glacial inception transiently, and because sediment proxy data has large error bounds, we cannot say if the model agrees quantitatively with the proxy record. We thus include the word "qualitatively" in the phrase mentioned.

Details of the downscaling procedure have been added to Section 2 (see response to Reviewer 1).

much lower temporal resolution. Sea surface temperatures of the Nordic Seas need to cool by at least 3 C from the 115 ka average for inception over southern Scandinavia. A 4 C cooling induces ice growth over northern Scandinavia. Cooling also has a positive

I can't evaluate the significance of the results without knowing the present-day region biases of the climate model.

A- Please refer to our answer above. It is unlikely that the delay of inception at 115 ka is due to a model bias because the simulated climate over Scandinavia is rather too cold than too warm.