

## ***Interactive comment on “Large sensitivity of a Greenland ice sheet model to atmospheric forcing fields” by A. Quiquet et al.***

**Anonymous Referee #1**

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### General comments

This paper describes experiments with the 3D thermo-mechanically coupled, hybrid (solving both SIA and SSA) ice sheet model GRISLI where a number of (8) forcing fields (temperature and precipitation) from temperature parameterization, reanalysis dataset (ERA-40), regional climate models and general circulation models (both coupled atmosphere-ocean and atmosphere only GCMs) are used to force the ice sheet model, by applying a positive-degree day method to compute the surface mass balance. The focus is on how well the resulting ice sheet compares with observed present day ice sheet and conclusions about the forcing fields drawn from the differences. A simple downscaling of the temperature field, with a single topographic lapse rate for the whole ice sheet that varies seasonally with sinusoidal cycle with a minimum in July,

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is done from the low resolution of the climate models to the resolution of the ice sheet model (15 km) and the precipitation is downscaled with empirical equation linking temperature difference with accumulation change.

The sensitivity of the model results to these parameters, topographic lapse rate and precipitation ratio parameter, is only tested by not applying these and comparing the results, but no tests of how sensitive the result is to the selected value is done. It would be interesting to perform a sensitivity study on the value of these parameters and present the results in the paper.

The experiments described in the manuscript are very important first step towards coupling the ice sheet model to climate model and the results demonstrate that not all climate models are providing realistic enough climate fields to maintain the current Greenland ice sheet and therefore not possible to couple these directly for projection runs. It is concluded that appropriate downscaling methods are necessary and in some cases the climatic fields should be used as anomalies on top of reference climate fields rather than direct forcing fields.

Before the forcing fields from climate models can reproduce present ice cap it may not be sensible to adjust the ice sheet model parameters, but the author do not explore the possibility that boundary conditions such as geothermal heat flux or the ice sheet's model parameters may be tuned for each forcing field to produce the present ice sheet, do authors think this possible?

No ice sheet or climate model developments are presented, or innovative downscaling or coupling methods developed and no suggestions for a way forward to accomplish a coupled ice sheet-climate model for projections into the future are given in this manuscript. The described experiments are important and necessary first step for the coupling of climate and ice sheet models, but the critical question: would the perfect climate model actually force this ice sheet model into a steady state similar to the present ice sheet? Is not addressed. Can we expect that once the climate models are bias free

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the coupling to this ice sheet model will be smooth? What criteria should be met? How can the results be assessed?

My recommendation is to publish the paper, this study is important, but request that the authors critically assess their results with the aim of giving a clear indication of what has been learned by doing these experiments and what the steps forwards should be to accomplish a coupled model system. The language in the paper is in many places poor and needs good editing, I have pointed out a few places, but good editing and polishing of the text is necessary before the paper can be published.

#### Specific comments

Be consistent when discussing the atmospheric model forcing fields or climate model output, I would not call the climate model output datasets as they do not have observational nature, throughout the paper it is called dataset (e.g. page 1045 line 6, line 15, Table 1 caption) or experiment (e.g. page 1059 line 10) - please go through paper and be consistent.

It is interesting the the ERA-40 reanalysis is too warm over the ice sheet, but both RACMO and MAR that use ERA-40 as lateral boundaries are not - does this indicate that the dynamical downscaling done by the regional models add something to the forcing fields that the lower resolution models cannot include?

Why not compare the steady state modeled ice sheets to the observed ice sheet? It is confusing to compare volume difference to another volume difference. The text can then be simplified if the modeled volume is simply compared to the observed volume.

Suggest to move Figure 4 to Figure 1 as it is an overview figure and it is mentioned first in the text.

The Enhancement factors are discussed in section 2.1 and their values are given in Table 2, before the discussion of the atmospheric model output, suggest to move table 2 to table 1 and refer to this table in the text in Section 2.1

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#### Technical corrections

page 1038 line 11 suggest to rewrite, replace "difficulties" with "biases in temperature and precipitation near the coast". Or discuss why biases arise, model resolution perhaps?

Line 3, change "insights on" to insights into line 25, inconsistency in reference, in reference list the year is 2011, but in text it is Robinson, 2010 check which is correct

page 1039 line 8, suggest to replace "accessible" with "feasible" line 15, add e.g. to reference, or add more, as there are many more publications discussing observations of fast processes in Greenland line 18, suggest to replace "Relevant" with "Applied" line 20 suggest "coupling to a GCM" or "coupling to GCMs" line 21 when forced the GCM output line 29 "projections of the future ice sheet state"

page 1040 line 2, suggest to replace "reacts" with "responds" lines 2-4 rewrite, this sentence is unclear, suggest something like "extent of ablation zone is often less than 100 km" GCMs have lower resolution than typical ISMs regardless of the extent of the ablation zone, this sentence does not really make sense. Lines 7-10 unclear sentence, rewrite to make the point clearer line 8 → explicitly Lines 13-16, also unclear sentence, please try make clearer what is meant with this sentence line 23 "specificities" → specifications line 26 "ths" → the

page 1041 line 1, suggest to add "and suggestions" for future attempts . . . line 6 "uses" for what? rewrite sentence, suggest: applies SIA and SSA to solve the Navier-Stokes equations line 11, suggest to use different word, "association" → combination, or relationship between line 17 are the velocities observed or calculated balance velocities? If balance velocities, what is the SMB used to compute the balance velocity? Line 22 rewrite, either a linear viscous sediment type, or linear viscous sediments

page 1042 line 3 specificity → specialty ? Lines 3-4 rewrite, sentence is not clear, suggest: that combines the strain rate components from the Glen's and Newtonian

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flow laws. Line 7 multiplication coefficient line 9-10 impact of the fabric – on what? Not a clear sentence, rewrite line 22, suggest to move Figure 4 to Figure 1 page 1043 line 1 would not call the model output datasets as they are not of observational nature line 2-3 not a clear sentence, rewrite, suggest: The ISM requires the climatological monthly mean near surface air temperature and precipitation as well as the climate model's topography. Line 4, suggest: "from a common 20 years reference period, 1980-1999" line 11, rewrite, as discussed in - or explained by line 18 how is the IPSL surface scheme updated? What has been updated, is there a reference? This sentence needs more explanation line 20-26 not well written sentences, please rewrite and be concise and clear line 24 "this case" → model? Line 25 "enhanced" → improved?

Page 1044 line 5-6 scaling effects on what? Explain better, how much different surface climate? In what sense? Line 8 "data" → model output line 9 either simulation from Fettweis et al. (2011) or "the model output stems from 1958-2009 simulation (Fettweis et al., 2011) line 20 data → model output line 24 data set → model output or climate fields line 27 it consists of:

page 1045 line 6 data set → forcing field line 15 different datasets → different models line 21 – is there a reference for this statement?

Page 1046 lines 1-8 rewrite, this sentence is very confusing line 8 suggest affect/impact the ice sheet model line 10 – here is the term atmospheric fields used, suggest to use this rather than datasets for the model output line 21, even though the scheme is commonly used, that is not a good reason to use it, suggest to add something like: and can be tuned to simulate observed SMB and its variability line 26 The melt capacity computed with the PDD method is first used ... line 28 please explain this better and give reference, why 60%?

page 1047 line 1 Remaining melt capacity is used .. What is the time step size in these PDD computations? Line 11, again, can you give a better justification for using a simplified scheme? Does it give realistic results? Line 12-14 how big is slight difference?

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- can you be more specific, does it mean that refreezing does not matter? Line 17 can you validate and thereby justify the use of this simple partitioning between liquid and solid precipitation? Does it give realistic results?

Page 1048 lines 5-7 rewrite, this sentence is not clear, suggest: The hypothesis that the sensitivity of the results to topographic lapse rate correction is of secondary order compared to the different forcing fields is tested in Section 3.5 line 15, add extra digit to the value, or remove the digit in line 16 line 16 remove "approximately" page 1049 line 6 suggest: still affected by the temperature increase during the last deglaciation

page 1050 line 9 here should be ESSA line 11 surface velocities? Lines 14-15 suggest to take "us" out and rewrite the sentence, it is not clear, what is a distribution of velocity amplitudes?

Page 1051 lines 2-5 here sensitivity study is briefly mentioned, more detailed explanation and information about the results would be helpful here lines 12-18 this paragraph is very unclear, please rewrite and explain better, what do you mean by this type of experiment is closer to a future projection experiment, in what sense? - because the initialized ice sheet model does not resemble the present day ice sheet?

Page 1052 line 1, what do you mean, that the climate is better presented in the southern part in all the climate models? Line 7 is that because of the low resolution of the ice sheet model? - or the physics of the model? Line 10 have you tried running the ice sheet with a higher resolution? Would it give better results? Line 16 – rewrite the English here is not good, delete "in general" and "here" line 22, can you give reference to the "nudging procedure" - can you confirm that it is due to this procedure?

Page 1053 line 12-13 suggest to rewrite: regional mean precipitation is compared in Figs. 6 and 7b. Line 19 suggest: colder than observations line 20, rewrite, not clear sentence, explain better suggest: the assumption of sinusoidal seasonal variation does not give realistic results lines 23-25, can you show that it is the higher temperature, not the higher precipitation, that causes higher velocity?

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Page 1054 line 5 do you mean thinner ice? Line 9 rewrite, what do you mean by “certainly partly” line 11 either a storm-track, or storm-tracks line 21 replace dataset with forcing field line 27 replace experiment with forcing field line 28 and line 1 on page 1055 – is this only one accumulation field? With two references? Or two accumulation fields?

Page 1055 line 1 why is the accumulation field not suitable to force the ice sheet model? Explain better line 12-13 rewrite, this sentence is not clear line 16-17 why is this true? Can you explain better line 18, suggest to replace “measuring” with “assessing” line 22-through to page 1057 – why do you compute anomalies with respect to one of the models, why not simply compare the modeled volume with the observed volume? It would make this whole section simpler and easier to read. Line 22, 24 and 25 suggest to replace “variation” with “difference” lines 24 and 28 what do you mean by “standard” line 28 volume difference smaller than ?

Page 1056 line 12-13 much warmer than what? Rewrite this sentence to make it clearer line 15 simulated volume difference, or anomaly line 16, replace negative with positive line 22 larger than line 24 rewrite, take out “however”, what is reference level? Reference volume anomaly?

Page 1057 line 5-9 this paragraph is very confusing and needs rewriting line 7, could it mean that the temperature is well simulated in the climate model then? Very realistic? And in second case (line 8) the temperature bias is large? Line 14 precipitation anomaly line 17 It appears – or even, can you say that you can confirm that . . . ? lines 20-23 – this paragraph is confusing, please rewrite to make it clearer

page 1058 line 1 each point lines 6-8 again this paragraph is confusing and should be written to become clearer. Volume gain indicates positive rate of change, if the volume gain is decreasing I would think it is still increasing, but at slower rate, but if I read the sentence right author means that the volume is decreasing, is this right? Please rewrite line 11, threshold for line 17 rewrite, suggest: The ice sheet model is forced

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with the 8 climate fields again, but without lapse rate correction. Why do you now make a sensitivity study for the value of the lapse rate? How sensitive are the results to the choice of lapse rate correction parameter? Line 24 replace “models” with “runs” or model experiments – result in . . . replace “lower value of the volume anomaly” with volume closer to observations line 28 “not adapted” - do you mean the resolution is not high enough?

Page 1059 line 5 this is a very important point and should be emphasized better, maybe even write into the conclusion? Line 8 replace “global” with “general” line 9 replace “feedback” with “lapse rate correction” line 10 Two model runs . . . How big is huge? Line 11 replace “two models” with “two simulations” or model runs lines 11-14, unclear, please rewrite. This area is very dry, does that affect this conclusion? Line 15 replace datasets with forcing fields line 17 – rewrite, suggest: advance of ice over area which normally is a tundra zone line 19 rewrite, suggest to replace “important driver” with “results are sensitive to the lapse rate correction” - how sensitive are they to the value of the correction parameter? Line 19 replace dataset with forcing field Line 22-23 – unclear to me what this sentence means

page 1060 line 1 you have not only proposed this study, but also done it, rewrite line 1 add “forcing” in front of fields line 3-9 poorly written sentence, please rewrite to make the points clearer line 13 replace “major driver” with “important for the” line 17 does it mean that there are small biases in July temperature in the climate models? Line 19-20 and 21-23 rewrite, poor English here, it is not clear to me what the main point of these sentences is line 27 role in long simulations for several thousand years line 27 of secondary order

page 1061 line 1, rewrite to make sentence clearer

Figure 1 caption: add information about the time period for the averaging as well as the area, is it average over the ice only or all land points?

Figure 2 remove the title (above the figures) as the information is in the caption (same

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for Fig. 3)

Figure 5 caption suggest: Simulated ice sheet topography at the end of the 20 ky constant climate forcing model run.

Figures 6 and 7, Rewrite the figure caption to make it clearer: suggest to put (a), (b) at the front of sentence for clarity. Suggest to change “for each individual atmospheric model” to “for the steady state model runs shown in Figure 5” (b) add information about how the values are computed, as average over ice mask, or land mask above 75degN? (c) and (d) are the model values the closest grid point to the station? Or average of nearest grid points? What are the vertical bars? Variation in the observation? For how long time period are observations available? Is the initial regional volume the observed one or something else?

Figure 8 suggest to rewrite figure caption: Difference in annual accumulation between observation based map (Burgess et al 2010; van der Veen et al.,2001) and downscaled accumulation from each atmospheric model. (what is ISM evaluation here?).

Figure 9 is initial volume observed volume? Make that clearer. “for each model” add “run” or “experiment”. Rewrite the caption suggest: change “volume variation” to volume difference, “hatched bars correspond to volume difference (dVi)” computed with the precipitation in each model replaced by the Ettema et al. (2009) precipitation map. The first solid bar is the reference volume difference (see comment above, why not compare directly with observed ice sheet volume?)

Figure 11 rewrite figure caption

Figure 1 in Supplementary material. Suggest to rewrite figure caption: “ Difference between observed and simulated topography at the end of the 20 ky constant climate forcing model run applying the 8 atmospheric forcing fields”

Figure 2 and 3 in Supplementary material. Rewrite both figure captions, suggest: Difference in annual precipitation rate (mean July near surface temperature) (for wich

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period? - same for all models?) between the RACMO model (Ettema et al. 2009) and the other models used in the study (in meter of ice equivalent)

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Interactive comment on The Cryosphere Discuss., 6, 1037, 2012.

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