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Interactive comment on "Towards direct coupling of regional climate models and ice sheet models by mass balance gradients: application to the Greenland Ice Sheet" *by* M. M. Helsen et al.

Anonymous Referee #1

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General comments

This paper describes a method to take into account the elevation-surface mass balance (SMB) feedback , when using the output from a regional climate model (RCM) that has a constant ice sheet geometry to force an ice sheet model that has evolving geometry. The authors use the output SMB of a regional climate model, in this case the RCM RACMO/GR, and for each ice sheet model grid point an elevation-surface mass balance relationship is found, separate linear regressions for the accumulation and ablation areas, by considering elevation and SMB of RCM points within a certain radius of it. A rather arbitrary criteria of including 100 points around each ice model grid point

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is used and the radius of considered area is increased until that number is reached, rather than determining what is a reasonable distance to expect correlation of the SMB values. For points in the centre of the accumulation area there is a long distance to ablation points to include in the regression analysis, as seen in Fig. 3c. Additional constraints for the minimum and maximum SMB values are added to avoid getting too high or too low SMB values. The perpendicular distance between points and the regression line is minimized, rather than the distance of the SMB value to the regression. A similar elevation dependence of the refreezing output from the RCM is found to take into account temperature adjustment due to refreezing. The spatially varying Hs-SMB relationships are then used to compute the elevation-SMB feedback as predicted by the RCM, which is necessary since the elevation in the RCM is not changing. This method is then used to force a standard SIA ice sheet model for constant climate forcing and standard glacial cycle model experiments.

The method developed in this paper is useful while direct coupling between climate and ice sheet models is not yet practical due to the different time scales of the models, but the authors could, in my opinion, make more use of the large amount of model output from the climate model. For example, they only use the average Ts for the period 1958-2007 rather than the time series from the model or (multi-)decadal averages to see how variable their results are over the period of the RCM run, and in their PDD calculation they assume a simple seasonal variation, rather than using the monthly or daily means that should be available from the RCM model. They also do not use the now available surface elevation and/or mass change observations from the Greenland Ice Sheet to validate their model results, but use only the total volume and simulated shape as has been done in ice sheet modeling studies for the last decades, so not much use of new observations or forcing is made in this paper, but rather standard model setup and validation is done. For this paper to present advancement in coupling regional climate and ice sheet models more use of the available RCM output should be made and hopefully it can be shown that using the SMB and SMB gradients from the RCM an improved present day ice sheet configuration can be achieved. The presentation

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of the results in the manuscript as it is now is not convincing the reader that improved present day ice sheet is simulated with this method.

There are a number of issues the authors should address before the paper becomes publishable so my suggestion is to make major revisions to the paper, some suggestions for improvements are outlined below.

The abstract claims that a new parameterization of SMB is presented, which is not right, the authors are developing an elevation-SMB relationship based on the SMB output computed by a RCM. Also, on page 2125, line 17 the text indicates that a new method of SMB forcing is developed, again the paper describes method to compute elevation-SMB relationship from the SMB computed by the RCM. This is stated in the conclusion, the abstract and the beginning of section 2.4 should be rewritten to clearly state what is done in the paper.

Throughout the paper the SMB simulated by the RCM is stated to be data, which is not right, it is an output of a model that is used as input to another model, please rewrite on page 2119 line 25, page 2120 line 4, line 13, line 17, page 2121 line 7, line 10, line 16, page 2124 line 14 and maybe other places (please look carefully through the paper)

The assumptions made are not clearly stated, please formulate the description of your model setup such that the assumptions that are made are clear. For example the assumption that the simulated SMB from the RCM is assumed to be realistic (this is related to the comment above, the simulated SMB is NOT data). Would the results be similar if the output of another RCM would be used? how general are the results? Also, I would suggest to make a sensitivity study of for example the very critical parameter γatm which controls the response of the ice sheet in the glacial cycle experiment, the constant 26.6 in equation (5) and the value 0.25 in equation (4) that seems to be somewhat arbitrarily chosen.

The text is in many places unclear, the English could be improved considerably by proof reading the paper carefully before submission. A few places where the text could be

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improved are indicated below, but I am not native English speaker so my suggestion is good proof reading to polish the English before resubmission.

Page 2118, lines 22-23 rewrite sentence, it is not clear what this sentence means

page 2128, lines 5-8, rewrite sentence to make it clearer

page 2129 Lines 9-10 rewrite, the English is strange here, do you mean that the sensitivity of the integrated SMB to changes in temperature is assessed?

page 2131 lines 4-5 rewrite, this sentence is not clear

page 2131 lines 12-13 rewrite, last glacier period. How can you be sure it occurred in reality?

Page 2131 lines 23-25 rewrite, not well structured sentence

page 2132 lines 5-9 rewrite, what is meant by "different fields of ice sheet elevation and extent" - changing geometry?

page 2132 line 10 rewrite, suggest "to assess the sensitivity of the ice sheet reconstruction to the SMB forcing

page 2133 line 13-16 not clear sentences here (reconstruction of what?)

page 2133 line 17-19 rewrite, English is poor here

page 2133 line 19-22 what do you mean by correct estimation? Do you know that frequent coupling will improve the results? How can you validate the results?

Page 2133 line 22-23 "in between these couplings" what is meant here? Please make this sentence clearer

The naming of the method developed in this paper is not consistent throughout the paper, on page 2135 line 4 and Table 2 it is called SMB gradient method, in figure caption 9 and 10 it is called Hs-SMB gradient method, please be consistent throughout the paper.

The last part of the the conclusion is a direct repetition of the last part of the abstract, which I find a poor style, if nothing new is presented in the conclusion this section could be omitted, or the abstract could be rewritten as not to give away the conclusions of the paper.

Specific comments

page 2116 line 7 replace "in" with "with" (or rewrite sentence to be clearer)

line 12 what does "dynamic SMB forcing" mean here? rewrite

line 13 this method also uses a temperature lapse rate (equation (5)) to compute the elevation response, so that is not circumvented here either

line 15 "more realistic" - how do you know it is more realistic?

Page 2117 line 8 add well after "reasonably"

page 2118 line 2 with assumption of (or rewrite, sentence is not very clear, suggest: Run-off is calculated by including an assumption of the amount of superimposed ice formation)

line 4 replace "non-stationarity" with spatial variability

page 2119 line 1 suggest: by using the same spatial SMB gradients

line 21-22 here the assumption is that the RCM is producing realistic gradients, is that well validated?

Line 26-27 same as above, the assumption is the the RCM is providing the "right" values

page 2120 line 1, what model results indicate that the gradients given by the RCM can be extrapolated outside the ice sheet mask?

Line 9, how accurate is the refreezing in the RCM? How well is it actually validated?

Line 10 how realistic is the RCM output? Some indication could be given here.

Page 2121 line 3, how much is the intercept adjusted? How sensitive is the result to the selected intercept value?

Line 6, what do you mean here, if the fit becomes worse, why do you use that rather than the first?

Line 13-14 how much too high? Please be concise in describing your choices and assumptions

line 18 take "again" out

line 19 replace predicted with parameterised

line 22 "works well" what do you mean here? Does it give good ice sheet shape?

Line 25 "vulnerable" what do you mean, sensitive? How sensitive, can you give us indication by doing a sensitivity test? What do you mean by large changes?

Page 2122 line 5 "most suitable" what do you mean? What criteria do you use to select the "most suitable values?

Equations (3) and (4) explain the overlined values

line 9 relationship

lines 10-18 how can you validate these results? Some kind of estimate of the robustness of these results should be given

line 19 the standard way of writing ice equivalent is m ice equiv. (see also page 2123 line 4, page 2125 lines 12 and 13)

line 21 how can you know that the established relationships are valid outside the glacier mask?

Page 2123 line 5, why 1m?

Lines 5-7, please explain better, what has been tested and how sensitive is the results to your choices/assumptions?

Line 14 rewrite, sentence is not clear "1-several km wide" what does that mean?

Line 27, what do you mean by on-line?

Page 2124 line 3 model setup

line 7 relationship

line 15 relationship

line 19 "asynchronously" what do you mean, explain better, rewrite this sentence.

Page 2125 line 2 scales

line 11, why do you use this value for γatm, how sensitive is your results to this parameter?

Line 25-26, rewrite, suggest "to take into account"

page 2127 line 12 a constant, take out "so no additional climate change forcing"

line 14 and 15 "quickly" and 10ka does not fit well together here, suggest to rewrite

line 18, how about glaciers and ice caps outside main ice sheet, on Greenland, do you include those in your summation?

Line 23 larger steady-state volume

line 24 after 100 ky simulation

line 25, the ice sheet advances, is it possible that the SMB is not negative enough? Can you give an indication for what the reason is, below there is discussion of the resolution, it can be also discussed here

page 2128 line 2, suggest to change SMBpos and SMBneg to SMBacc and SMBabl,

also on Figure 8

line 7 by the expansion

line 20-22, can you give an indication of what the resolution of the model should be to include this effect properly? What is the difference between the results of 10 and 20km resolution simulations?

Line 24, what do you mean by typical phenomena, is there too little ablation in all the models, or is the resolution too low?

Line 27-28 is it possible that the accumulation in the interior is too low? Can you validate the SMB in the RCM with observations?

Page 2129 lines 1-7 can this indicate that the SMB field of the RCM is wrong? Is it possible that the ablation at the margins is too small?

Line 10, it is obvious because eq (6) is setting this relationship. It must be very dependent on the value of γatm ? This experiment does not say anything about how the RCM responds to increased temperatures, is it possible that the accumulation increases more than the ablation increases?

Line 19 rewrite (take out (obviously), the sensitivity to changed T is set by equation (6), can you test the sensitivity of the results to this value

line 21-22 How realistic is this? Do you think that negative bacc are realistic?

Line 24 relationship

page 2130 line 3 "Huge difference" how large? You can add percentage change to give indication of how large the difference is.

Line 6, how can you validate this statement? What does "likely realistic" mean here?

Page 2131 line 3 response to

line 5 on the initial conditions

line 20 take out "anymore" add "compared to observations"

line 23 with simulated SMB values lower than at present

line 24, what do you mean by wide ablation area? Along the margin, or to high elevation?

Page 2132 line 2 the SMB gradient method (as in Table 2)

line 6, what do you mean by temporal gradients, doesn't the time series of the RCM run provide this? Can you do this test?

Line 12 parameters

line 13 do you mean observations, or the RCM model output?

Line 15 show SMB – elevation relationship

line 16, what different values of T, explain (do you use the T from the RCM?) and rewrite to make sentence clearer

line 18, again here a sensitivity to the chosen value of γatm should be given

line 21 "currently found" do you mean modelled by the RCM?

Line 25 "width of the ablation area" see above, do you mean width along the margin? (N-S extent or elevation extent?)

page 2133 line 2, if that is the case you would expect to see blue areas (negative difference) along the whole margin, which is not the case in figure 15b

line 11 is that decrease in SMB realistic?

Line 23-25 How can you conclude which is a "better predictor"? There is no model validation in the paper that supports this statement.

Line 24 than

page 2134 line 4 large amounts

line 4-6 the resolution of the model should be discussed here as one reason for the

line 6 direction to the coast Conclusion is a direct repetition of the Abstract, please edit this section to avoid that

page 2135 line 9 rewrite, suggestion: a number of parameters have to be chosen

line 15 the time step for the numerical integral is one month

line 15, why do you not use the monthly output from the RCM, which should be more realistic than a sinusoidal curve?

Line 20 in the forcing, we also use the... mean annual Ts (add this information to the main text)

line 26 mean annual fields? Why not mean monthly fields from RACMO?

Figure caption Figure 3, line 4: to go through

line 5 and maximum

Figure 4 why is not the same colour scale used for these figures? (a and b, c and d)

rewrite figure captions for figs 5, 6, 9, 10, 13, 14 and 15, should be consistent with the others (starting with (a) then text)

Figure 7 what are the blue points along the coast in the south? (both SE and SW)

Figure 8, change SMBneg and SMBpos to SMBabl and SMBacc

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