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Interactive comment on "Comparison of hybrid schemes for the combination of Shallow Approximations in numerical simulations of the Antarctic Ice Sheet" *by* Jorge Bernales et al.

Anonymous Referee #2

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The manuscript by Bernales et al uses an ice-sheet model for Antarctica to test different schemes for the calculating of the ice velocities. The main focus is on combining the shallow ice and shelfy stream approximations and use different hybrid schemes to combine the two. Four different schemes are implemented in the model and used to inversely determine the basal sliding coefficient C0 by looking at the difference between modelled and observed ice thickness. Differences between the four schemes are explained clearly, through how the spatially varying basal sliding coefficient differ for each scheme, how grounded ice volume evolves and how ice thicknesses vary relative to the observations. Model performance is also checked against observations of ice surface velocities. Methods and results are explained clearly. The two main concerns I have

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are that the manuscript does miss a real strong final conclusion and that uncertainties in the methodology should be discussed in more detail.

Main comments

1. Uncertainties in methodology
Paragraph starting on Page 2, Line 30 to Page 3, Line 8:

You should here also mention that there are more parameters and/or processes involved that are poorly constrained (or less known) such as bedrock uplift due to post-glacial rebound (GIA), response of the bed itself to current changes in ice, heat flux from the bed, properties of ice flow (flow parameter) or the bedrock height uncertainty (see Bedmap2 paper). Following on the uncertainties, an important point to make using this method is that by solving for the basal stress you actually compensate/correct for other (some of them mentioned above) uncertainties in the boundary conditions and uncertainties/errors in the model itself. This is I think a key point to keep in mind when using the methods described in the manuscript. This should be mentioned here and discussed thoroughly in the final discussion/conclusion as well!

2. Rewording of basal velocities and SIA
Starting on Page 4, Line 16:

Throughout the manuscript it is mentioned that SIA has a basal velocity. This is mostly a matter of rewording some of the text, not so much an error but rather how this is actually computed. I think the SIA itself does not have a basal velocity, but rather that the basal velocity is a basal boundary condition to calculating the SIA, which could also be set to zero if you do not include sliding at all. This is actually nicely illustrated in Fig. 1 of Bueler and Brown (JGR, 2009). I think this could be rewritten in some parts of the manuscript. In the general comments below some of these lines are mentioned.

3. Final conclusions
On page 19:

The sentence “This suggests .. Stokes equations.” seems quite obvious but good to mention. However in the final conclusions I do miss a discussion on two things particularly:

- Is a distribution of basal parameter C0 derived using present-day forcing and observations also applicable for long-term paleoclimate simulations, can it be used for other time periods and climate regimes?

- What is the best scheme to be used here? Is there a scheme that simulates the observations best, also considering the lowest over- and underestimations, i.e. the lowest absolute difference in ice thickness.

General comments

Page 1
Line 1: Replace introduced with used or implemented

L 5: What do you mean with realistic scenario? Do you mean like present day climate forcing? Please be specific.

L 8: Remove comma after Despite this

L 8: Robust agreement with what, or of which variable? Again please be specific.

L 17: Change to: However, the time scales over which an ice sheet builds up and disintegrates

Page 2
L 9: Remove commas before membrane and after important

L 7-14: You could first introduce the SSA (L10-14) and then discuss the ice streams (L7-10).

L 15: Instead of mentioning highly dynamic regions, actually state here something like: The limitations of SIA models for calculating the highly dynamics ice streams have ..

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L30: Rephrase realistic scenarios, same as in the abstract, present-day climate forcing?

Page 3
L 17: No new paragraph, start sentence as: First, the ice-sheet model

Page 4
L 16: Please rewrite, the SIA itself does not have a basal velocity, but rather U-b is here the basal boundary condition to calculating the SIA.

L 18: Eexplain here how the effective basal pressure Nb is calculated.

L 22: Is Tm an actual temperature or a temperature difference. Explain this in the text.

Page 5
L 19: Rewrite to something like: where ub is the Weertman sliding velocity (Eq. (2)) and us the surface SIA velocity, respectively.

Page 6
L 11-16: Do not mention sliding-SIA but rather SIA including (Weertman) sliding. Here it could also be discussed the carefulness of using Weertman sliding, as discussed by Bueler and Brow (JGR, 2009; see also their Appendix B) it leads to a discontinuities in the velocity field.

L 16: change to: where ub is the basal sliding velocity as in ..

L 28: At the end of section 2.2 a table could be added that summarises the 4 schemes with the column show something like : 1) name, 2) sliding 3) reference to equations, 4) reference to studies

Page 7
L 23-24: Can you explain here and perhaps clarify in the text why you stop the adjustment when the difference between modelled and observed ice thickness is reduced?? A reduction of this difference is actually what you want right?

L 22-29: This paragraph could be replaced to Section 3.

Page 8
L 13: On spin up procedures for ice-sheet models see also this paper, you might want to refer to this.

Fyke, J. G. and Sacks, W. J. and Lipscomb, W. H., A technique for generating consistent ice sheet initial conditions for coupled ice sheet/climate models. Geoscientific Model Development, 7, 1183 - 1195, 2014.

Page 9
L 15-16: Reword: a simulation time of 100.000 years (100 kyr)

L 21-22: Spanning 100 kyr (mention exact length of your experiments)

Page 10
L 1: Remove -and get insight into-

L 4: Be specific: observed ice-sheet thickness and surface velocities as a measure ..

L 19: .. the variations of the total grounded ..

L 26: Numerically more or equally stable, and also a similar computational time compared to the SoS?

Page 11
L 1: Change to: that include basal sliding with the SIA solution

L 4: Remove -high frequency-

L 7: The inset of Figure 1

L 13: Change to: that include basal sliding with the SIA.

L 20-21: The large overestimation of ice thickness between Shakleton Range and the Pensacola Mountains as you state is seen in all panels of Fig. 2. Could you give a more clear explanation why this particular area is overestimated. Also note that this is

a region of large uncertainties in ice thickness (see Bedmap2 paper).

L 28, 32: I suggest not to refer to Fig. 1a but to: the inset of Fig. 1.

Page 12
L 2: Change to: over the areas where there is no sliding and C0 is not inverted.

L 32: Change to: .. that are unresolved by the model due to its..

L 34: Remove comma after divides.

Page 13
L 7: Remove commas before and after for example

L 26: Change to: .. projection onto the course horizontal grid we use here.

L 29: Remove comma after simulation

L 33: Change to: Equation (10) uses the basal velocities from equation (2) to compute ..

L 34-35: Where sliding velocities from equation (2) are high.

Page 14
L 1: Here also perhaps mention how H-2a compares to H-2b?

L 5: are implemented

L 5: Change to: .. hybrid schemes, Fig. 4 illustrates the

L 22: Remove comma after general

L 23-24: At a first glance it may

L 25: Change to full stop: the case.

Page 16
L 2: Change to: The misfit for Hs-1 increases ..

L 4: The Hs-3 experiment shows an ..

L 19: Change to: the basal velocity in the Hs-2b experiments

Page 17
L 24: Remove commas before and after continental-scale.

L 25: Remove entire

Page 18
L 1: Also mention the range of the ice thickness errors not only the means.

L 17: Change to: which adds up SIA (without sliding) and SstA.

L 29: Also mention the uncertainties in ice thickness and surface velocities (see their respective references).

Tables and Figures

Table 2:
Should the sum of the last two columns not be 100%? Please clarify and explain.

Fig. 1:
- Label a and b can be removed, rather refer to fig. 1 and inset of fig. 1.

- Instead of a coloured bar for the pre-initialization the names of the periods could also be placed above (pre-initialization period and automatic calibration).

- In the legend of the inset the difference between solid and dashed should be clearer.

Fig. 4:
It is not really clear which scheme represents the surface velocities the best. Could you also add a correlation/R-square value to the scatter plots? Also use the correlation in the discussion.

Fig 8:

Hs-2a always seems to be have a misfit, whereas the other scheme should have a possible solution which closely fits the observations, for a particular (probably not the same) set of parameters. Please explain and discuss this in the conclusions.

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