Response to reviewer C. Martin

December 5, 2011

The paper presents a state-of-the-art 3D full Stokes model of the grounding line dynamics and shows the stabilizing effect of pinning points through two numerical experiments. The complexity introduced by the full Stokes system in an area where a mesh refinement of tens of meters is needed, presents a very challenging problem that it is crucial to solve in order to understand the dynamics of the area. This paper analyse the main difficulties of the problem and show the evolution of the grounding line in two controlled scenarios. I believe this papers shows a step in the right direction and I recommend its publication in The Cryosphere.

I don't have any major criticism of the paper as the authors point out the main model limitations, i.e., the mesh-dependent results and the fixed grid that only allows the use of the model in controlled experiments. I have written bellow some comments and suggestions, mainly to include a sensitivity study of the mesh dependence in the verification section, eliminate Table 2, Figures 2, 4 and 6, and rewrite Section 2.5 and the Conclusions.

English is not my first language but the paper seems to be well written. I have to admit I find it wordy and, as I have written above, repetitive in some sections.

The main modifications that have been done to the paper are the following:
- We rearranged the paper in order to clarify it. A 3rd section dedicated to numerics has been added, with details about the mesh choices, the 3D geometry spin up procedure and the model algorithm. All the numerical experiments have been gathered in a 4th section (verification experiment, pinning point experiment and mechanical reversibility experiment). The results have been discussed in the corresponding subsection, and the conclusion has been rewritten to be more concise and straightforward.
- The verification experiment has been redone with a larger migration of the

grounding line (it is related to the sensitivity study asked by the reviewer, more explanations below).
- The non relevant repetitions have been removed.
- Figure 4 and 6 have been removed.

General comments

It is my understanding that the word "validation" is used to determine the ability of the physical model to describe reality, and "verification" determine that a computational model accurately represents the underlying mathematical model. In this context I would suggest to use the word verification instead of validation in Section 3.

Following the recommendations of both reviewers, the word "validation" has been replaced by the word "verification".

My main concern about the results presented in this paper is the mesh dependency. The rational is that the sensitivity of the results to the mesh should be insignificant when compared with the typical scale of the problem. But in the model verification Section the authors show a mesh dependent offset of the grounding line 1km when the results show a divide migration of 3-5km. I believe that the paper would benefit from a discussion about this mesh dependency and I would find interesting a Figure showing grid sensitivity, in particular convergence of the solution with mesh refinement.

We agree with the remark of the reviewer, the migration of the grounding line was quite small in regards of the offset between steady positions. We therefore reran the simulation, and we now propose a run with a much larger advance before testing its retreat.
Concerning the sensitivity experiments proposed by the reviewer. We fully agree that it would have been pertinent to present a sensitivity study. It is however extremely hard to compute such a study as the associated numerical cost would be tremendous (the amount of resources that would be requested is almost 500000 hours of CPU time, equivalent to about 6 months of computations). But few elements can already provide reasonable confidence in the results:
- As shown in the paper, during the retreat, the grounding line is initially curved, then starts to become straight before retreating. Therefore, during most of the retreat the 3D problem is similar to a 2D one. In the figure we propose below (Figure 1), we made two simulations series, one in 2D, the other is the equivalent laterally extruded 3D problem. Results are extremely

similar, slight differences can be most probably imputed to the different interpolation functions (linear vs bilinear) for the 2D and 3D cases (respectively). The sensitivity experiments have been done in 2D and presented in Durand et al. (2009). We are therefore very confident with the convergence of the steady solution with decreasing mesh size.

- In his comment, the reviewer seems to be also concerned by the small difference between the offset and the length of the retreat. We here propose a new experiment where we start from different steady positions and force the grounding line to retreat (relaxation during 10000 a). This experiment is run in 2D, as computing resources limits our 3D simulations to hundreds of years. All flow parameters are the same and, as shown by Figure 2, all the runs converge towards the same steady position. As discussed before, and shown by Figure 1, we are confident that 3D results would be similar.

This discussion is very technical and switching from 2D 3D experiments is probably confusing for most of the readers. This is the reason why we choose to keep the explanation into the answers to reviewers. We hope that it will satisfy both the editor and reviewer.

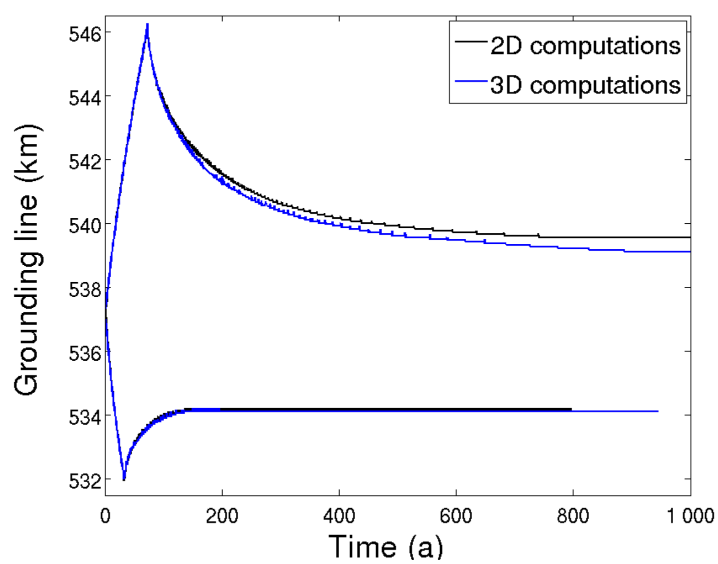

Figure 1: 2D and 3D reversibility experiments with similar parameters.

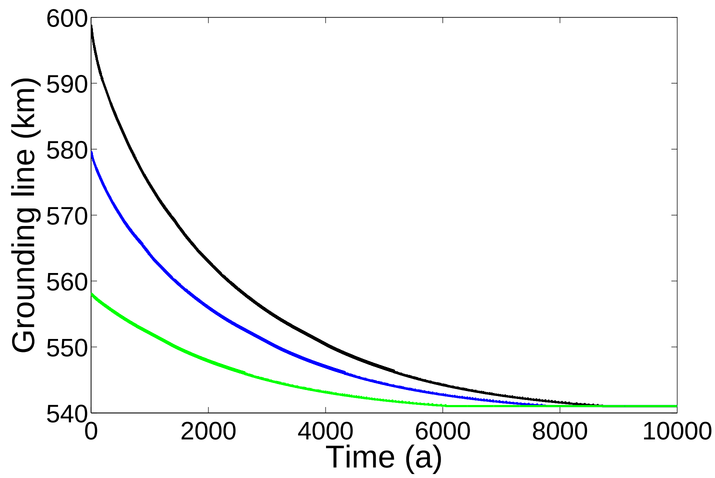

Figure 2: 2D retreat experiments.

Most of the Section Conclusions is just a repetition of Sections 3 and 4. Most of the rest should be better placed on Sections 3 and 4 in a Results and Discussion Section or in another new Discussion Section. I really think that this Section needs to be rewritten and Conclusions should be a concise Section highlighting the paper main findings.

As mentioned above, we followed these recommendations.

Specific comments

Abstract

1996 L2-L6 Excessive repetition of i.e. in the abstract.

These have been removed.

1996 L7 I would say the word “mathematical” is unnecessary.

Removed

1996 L14 The word “demonstrate” has a very strong meaning in science, why not use the word “show”.

The word “demonstrate” has been replaced by “show”

1996 L14 is it me or “multiple grounding lines” sounds confusing? What about “a curved grounding line and the effect of pinning points under the ice self”

Indeed at the grounding line the velocities are generally oriented land side to ocean side, whereas it is not the case for the pinning point boundaries with the ocean. Therefore, we rephrased the sentence as advised.

1 Introduction

1997 L7-L16 I find this few sentences awkward to read. What about talking first about the source of instability and explain at the end that recent studies point out to potential instabilities in East Antarctica as well?

These sentences have been rearranged.

1999 L13 I would use advection equation instead of local transport as it is more concrete and descriptive.

Done

2 Detailed description of the model

2000 L2 I would add that you are using a full Stokes solver.

Done

2000 L8 I wouldn’t talk about the linear mesh in this Section. In my opinion is better to separate mathematical model and numerics.
All the numerics have been gathered in an intermediate section.

2001 L9 Again I would suggest using “advection” instead of “local transport”

Done

2.5 Model algorithm

2005 L10-20 I find this Section too long and in particular this paragraph is mostly unnecessary.

This part has been moved in the new section talking about numerics, and reduced a bit.

2006 L7-11 I may be missing something but I fail to see the interest of how the authors label the nodes and I can't see the significance of Figure 4.

We fully agree. Figure 4 and related parts in the text have been removed.

3 Validation of the 3-D full Stokes model

2007 L3-6. I don't understand what plane of longitudinal symmetry the authors are referring and how only half the domain is taking in to account. Do they mean the xz-plane at y=50km?

We simulated only half of the domain in the y-direction to save CPU time. The boundary condition at y=50km is thus a symmetry condition ($\mathbf{u}.\mathbf{n}$=0). Precisions have been added in the text in Section 3.2

2008 L4 I don't see Figure 6 bringing anything interesting to the paper.

Figure 6 removed.

2008 L11 Figure 7b is not showing velocity, parenthesis should refer the reader to Figure 8

Done

2008 L13 there is a reference to Figure 9 but I can not see the volume change for the verification experiment in Figure 9.

The reference to the volume has been removed.

2010 L8-11 I find a bit weird justifying this oscillations with Schoof theory when the final state of the grounding line presented in Figure 13 is precisely in the up-slope side of the bedrock bump. I would write something as "this oscillations could be related with".

We shouldn't have asserted this, so we are now more cautious and changed the sentence using your suggestion. However, the fact that the final state is located in the up-slope side of the bedrock bump has no meaning since the ice sheet is not in steady state at that time. Obtaining the steady state would imply several weeks more of computations.

Table 2 Is this table really necessary?

This table summarizes well the three experiments so we kept and modified it.

Figure 2 This highly detailed table together with the description in Section 2.5 is very repetitive and unnecessary. A sort paragraph describing the algorithm and how to solve the contact problem would be in my opinion more effective.

About the table, we think that it is an easy and fast way to check the parameters of the model, so we kept it. About Section 2.5, we agree with you and created a new "numerics" section in which we put stuff about the mesh, the algorithm and the contact problem, and how we did the spin up.

Figure 12 dashed black line?

Wrong words changed.

Figure 13. It could be me being particularly slow but I find that Figure very difficult to understand.

We tried to clarify Figure 13 and its caption, even if the reviewer didn't tell us which specific point should have been improved. Tell us if you prefer it now.