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Interactive comment on "A moving point approach to model shallow ice sheets: a study case with radially-symmetrical ice sheets" *by* B. Bonan et al.

Anonymous Referee #1

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This paper presents a particular velocity-based moving point approach, which is based in conservation of local masses, to track explicitly ice sheet margins in ice sheet modelling. To my knowledge, this is the first time this method is applied to the dynamics of ice sheets. The authors deal with very simple ice sheet problems to be able to verify their model with analytical and/or accurate solutions. The ice sheet is fully grounded (no grounding line), isothermal, the surface mass balance is constant in time and no loss of ice is considered through the downstream margin (no calving). The authors implement their moving approach within a Shallow Ice Approximation framework and deal with a radially symmetric ice sheet.

The authors propose four verification experiments to evaluate the accuracy of their model. The steady states obtained with the moving point approach are verified for

both an advancing and a retreating ice sheet, for both uniform and non uniform initial distribution of grid points, for flat and non flat bedrocks, and for different grid resolutions. They also verify their moving point approach for transient states for which analytical solution is available.

The results looks good and the moving point scheme accurate. The moving point approach and the way it is implemented in the SIA scheme is well detailed and understandable, even though the mathematical formalism needs a bit of concentration. I think this was a good choice to develop the equations of the moving point approach in the text, and put all the more technical aspects of the finite difference algorithm in Appendix. I clearly find the approach interesting and I would like the method to be published. However, the paper needs substantial revisions to deserve a publication. My main concerns are detailed below:

1.You lack a lot of references, especially in the introduction. Even though all the model with moving and adaptive grid are not using the Shallow Ice Approximation, you should mention them. For example, you say that significant efforts have been made by the ice sheet modelling community to improve models, but you seem to forget about the MISMIP's intercomparison exercises. About the moving grid and adaptive approach you can find a lot in these intercomparisons that you don't even mention: what about authors like Goldberg, Gladstone, Durand...

2.Some of the experiments are not clearly detailed and this is not straightforward to understand what you actually do in some places, such as in section 4.1.

3.You only comment your results, but you don't discuss them at all. I think you have the possibility to put your method in a larger context in a dedicated discussion section. You can discuss the gain of computation time for example. You mention it in the text but you don't really show that you have a substantial gain of time computation. You could perhaps run a basic SIA model and compare the CPU time to the moving point approach. Also, you mention it in the conclusion, but you could also discuss the possible extension of your approach to more complex cases before entering the conclusion.

4. English is not my first language. However, I have to say that I find the text too verbose and repetitive. For example, I think you could summarize the various experiments that you performed in a table. Your text would gain in comprehensiveness.

I have other specific comments:

p4238 l5: "and the waiting ... efficiently". Even though I understand what you want to say, I find this sentence odd. You don't model the waiting time behaviour but the ice sheet. Could you rewrite the sentence.

p4238 l9: "The scheme ... states". There are two issues here. (i) I don't think this sentence really summarizes all the verifications you made, for you also have transient solutions involved, and (ii) you talk about exact solutions, but what does it mean ? If you mean analytical solution, this is not true for every verification since you used the composite trapezoidal rule and, even though its solution is really accurate, this is still not an exact solution... Could you clarify this sentence ?

p4238 l11: Is it precision or accuracy here ?

p4238 l13: "large" is too vague here, could you quantify ?

p4238 l14: "this ice loss ... grounding lines". This sentence should be rephrased. Could you explain the process by which the ice loss contributes to acceleration of the ice sheet and retreat of the grounding line, in a less vague way.

p4238 l16: Even though I know what you are talking about, this is really not straightforward to identify "both" as being the two kind of margins and "their" as being the ice sheet of Greenland and Antarctica. Could you rephrase ?

p4238 l22: "At ... nonlinear". What do you want to say here ? Could you rephrase ?

p4239 l1: "Other ... approximation". I don't understand this sentence.

p4239 l4 to l8: I would have like to see the flaws of the SIA written down. Here it looks like this is as fast and efficient as accurate, which is not the case...

p4239 l9 to l12: with these two sentences, we don't really have the feeling that "significant efforts have been invested", you seem to forget about all the other intercomparisons exercises, namely MISMIP2D and MISMIP3D. Even though these two exercises compare not only SIA models, I think you should mention them. It would also help you to be more complete with your description of adaptive and moving mesh methods (see below).

p4239 l15 to l17: I have a problem with this sentence that I think misleading. The grid resolution has a significant effect on the position of the grounding line in a marine ice sheet. However, you applied the moving point approach to an ice sheet with no marine part. In that case, the influence of the grid resolution on the margin (here the most downstream point of the ice sheet) and on the ice volume is much lower. What happens if you run a fixed grid model in SIA and compare it to your moving point approach in terms of CPU time computation ?

p4239 l18 to p4240 l2: Here you miss a lot of references about adaptive and moving mesh methods. You will find those in the two MISMIP's exercises. I think they should be mentioned even though they were not all implemented in the frame of the SIA.

p4240 l2: "pure transformed grid...". What does "pure" mean here ?

p4240 l21: Some of your exact solutions are approximated solution, such as when you approximate a steady state thickness profile with the composite trapezoidal rule in section 4.1, which is not an exact solution.

p4241 l21: Here, this is not necessary to recall the fact that you apply a moving point approach.

p4242 l14: Again, is it necessary to recall the moving point approach here ?

p4243 l5: Replace "instant of time" by "timestep" p4243 l15: Replace validation by verification (see above)

p4243 l20: I don't understand why the constant of proportionality cancels out. The volume can not be equal to the mass if the ice density is about 1000 kg/m3. Could you reformulate ?

p4246: Could you explain why you can use this Frobenius expansion to write h close to the margin ?

p4247 l12: Again, I would use verification instead of validation

p4248 l6: "simple enough". What does it mean ? Could you be more specific ?

Equation 23: Why do you use this type of profile for the initial state, is there a particular reason ?

p4249 l5: I don't understand why you chose three

Section 4.1: In this section it is difficult to clearly see the differences between the first series of experiments and the moving margin experiment from the EISMINT exercise. Could you summarize what you do in a Table for example, or detail it in a more clear way in the text ?

p4249 l24: Do you compare your results to the 2-D fixed grid models of EISMINT or to your exact solution from equation (19). This is not straightforward to understand the way you write it.

p4250 l1 to l6: You did not define the way you calculate the error, this is relative error right ? If it is the case, it should be mentioned.

p4250 l4 to l5: Am I wrong to think that O($n^{1.95}$) should be O($n^{-1.95}$) ? (same for the other O())

p4252: I think your theoretical and technical work is great. You verified that you can apply successfully the moving point approach to grounded ice sheet with a good accuracy

in both the ice thickness and position of the margin. However, here you should discuss your work in a larger scale. For example you claim that you can gain time computation with this method. Thus could you try to compare them to a basic SIA model ? Also you applied the moving point approach to a simple case. Would it be possible to discuss about the possibilities of extending the method to more complex situations, such as with a grounding line or considering a calving flux through the downstream boundary. You mention this in the conclusions but I think it should be discussed more deeply.

p4252 l25: I don't think you demonstrated that your scheme is "rapid".

p4253 l5 to l17: Those two paragraphs should be also part of a discussion before the conclusion.

Table 1: A is the creep parameter according to Cuffey and Paterson 2010.

Figure 2: Please use the same scale for the plots, otherwise this is not easy to compare.

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