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Geoscientific Model Development Discussions

Interactive comment on "Implementation of higher-order vertical finite elements in ISSM v4.13. for improved ice sheet flow modeling over paleoclimate timescales" *by* Joshua K. Cuzzone et al.

Anonymous Referee #2

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General comments:

Projections of future ice-sheet contributions to sea level rise require models that include the best possible physics and capture the effects of prior ice-sheet evolution. To this end, "spin-ups" over glacial cycles constrained by paleoclimate data are very useful. However, computational demands have limited these long simulations to models with simplified physics and parameterization. Some of these models have produced excellent results (e.g., several studies of Antarctica by Pollard and DeConto) but it is still highly desirable to incorporate higher-order physics into simulations over paleoclimate

timescales.

This study presents highly promising results by applying quadratic and cubic finite elements to discretize the vertical dimension of the Ice Sheet System Model (ISSM). Resolution of thermal gradients with linear vertical elements requires many layers, which can cause unnecessary computational expense when the momentum balance is solved on the same grid. The authors show that the use of higher degree vertical elements requires many fewer levels and results in roughly an order of magnitude improvement in computational speed for an idealized experiment.

Specific comments:

Introduction) It would be helpful to expand on the descriptions of the types of physics in order to more strongly make the case that Blatter-Pattyn is both desirable and expensive. I don't think you need any equations, but the hierarchy could be more explicit in terms of physical assumptions and their mathematical/numerical consequences. For a modeling journal like GMD, more detail than for a "regular" journal seems appropriate.

Line 96) "stress balance computation does not require a high vertical resolution" could use a reference.

Section 2) This could use a reference to your favorite finite element method book for the definitions of the elements.

201) Totally OK to only run one of the EISMINT2 experiments, but explain very briefly why you picked A. Presumably because it's the initial spin-up?

Section 3.1) Although you do say you're comparing to an experiment for SIA models, it should be more clear in the text that you're using SIA.

Section 3.2, first paragraph) It should be more clear what your thermal steady-state computation is, i.e. a simultaneous solution of heat transport and momentum equations coupled by viscosity. Also, the description of the effective viscosity can probably just say it's a function of strain rates/velocity gradients and a temperature dependent hardness. The variable name B isn't necessary when the equation isn't shown.

Section 4.1) It's worth pointing out that Experiment A is a comparison of models without a known analytic solution, some of which produced more plausible (to me, anyway) solutions than others (e.g., W, X and Y). Comparison to the EISMINT2 results that don't show stability problems may be more reasonable. Also, it seems possible that your 25-layer results are better than the EISMINT2 models.

Section 4.2) Given that a major selling point of the new method is making BP affordable, I'd like to see some direct description of the dynamical results at some point. How do your calculated velocities compare for different numbers of layers and vertical elements? Is vertical shearing captured well? You only discuss experiments for which SIA is reasonable. I have some concern about whether the reduction in the number of levels will work for transient runs with more realistic geometry than the ice dome that include areas in which BP is necessary.

347) "we began by using the relaxed model simulations that have thus far only used the shallow ice approximation…" Please be a little more clear that you mean the single-dome calculations from 3.1/4.1.

Technical corrections:

76) cut "a"

77) cut "for"

80) "to" instead of "towards"

109) add "more" for comparison – "to more precisely capture"

129) This formula could use a space or a multiplication sign so that the factors don't run together, which is hard to read.

143) Space on either side of the =

177) "While" instead of "As"

192) "were" instead of "was", "thermomechanical"

256) "with respect to both"

263) cut either "at least" or "and above"

357) "criterion"

Table 2) The % values should be unitless.

Figure 3) I can easily figure out what you mean, but probably good to define the labels.

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