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The Cryosphere
Discussions

Interactive comment on "Parameterization for subgrid-scale motion of ice-shelf calving-fronts" *by* T. Albrecht et al.

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Response to Referee: Xylar Asay-Davis (xylarstorm@gmail.com)
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I am not a fan or anonymous review, and I therefore have chosen not to review this paper anonymously.
General comments:
The paper describes and validates a method for parameterizing the sub-grid scale motion of ice-shelf calving fronts. The method is novel and of broad interest to ice sheet modelers. Furthermore, this paper is a nice companion to the two other papers

from the same group on the PISM-PIK model that are also currently under review. The validating experiments are appropriate and provide a convincing case that the sub-grid scale parametrization is both useful and necessary in order to capture the correct ice shelf dynamics. The length of the paper and the number of figures are entirely appropriate for the material being presented. It is my feeling that the manuscript is ready for publication with some minor revisions. My suggested revisions are described in the specific comments below, and are focused largely on clarifying the description of the method and the experiments used to validate it.
I do not think that any additional experiments or figures are required in order for the manuscript to be ready for publication.

Specific comments: *p1501 although the definitions will be obvious to most (perhaps all) readers, it doesn't hurt to define all variables and parameters in your equations. In particular, please define v_c, H_c, Δx (this can be especially ambiguous when dealing with fractions of a cell – is Δx the size of a cell or the size of the fraction of the cell containing ice? My understanding is the latter), $\bar{\nu}$, ρ, ρ_w, i and j.*

We agree and added some variables with the used values in the Table 1 and adjoined explanations in the manuscript. In fact, Δx is the length of a single grid cell in our regular grid (and Δy analogous in y-direction). We do not define any sub-grid increment, but we account for this by the scalar R, which can be associated with the fraction of the total grid-cell area $a = \Delta x \times \Delta y$, which is covered by ice of the thickness H_r.

p1503 l10-12: Presumably advance doesn't happen in such a way that $R = 1$ exactly at the end of a time step, so that in reality $i + 2$ will begin to fill up in the same time step as when $i + 1$ is full.

This is right, R is set to 1 and we account for the residual volumes (variant 2) in p1504 l15ff

p1503 l15: "This effect is not desirable..." It's a minor point, but I'm not quite clear on why this is a problem. It just seems like you are extending most of the properties of cell i (ice thickness, etc.) into cell $i + 1$ by a fraction R but thinning in cell $i + 1$ is the same as i. This seems physically reasonable.

It does not seem to be a problem and we will just cancel this sentence in the manuscript to not confuse the reader.. We just wanted to point out, that such cases can occur. The described variation within the partially filled cell is not physical with regard to the local flow physics even though it can be understood as an extension of properties.

p1504 l5: Could you explain a bit more about the residual volume that is lost? This is because the cell is full and you can't change the thickness, since this is determined by the neighboring cell?

Exactly. We calculate the mass flux through the boundary into the partially filled grid cell, which gives the new volume $V(i + 1)$. The ratio R is determined according to the old terminal ice thickness H_c of all direct neighbors (which gives the reference H_r as average). Hence there may be some extra volume V_{res} that needs to be redistributed at the same time step (variant 2).

p1505 l4: Maybe mention that Q_0 will be defined in Sec. 4.
In the sentence before we refer already to the analytical solution in the next following section and we hope this is sufficient.

1505 l8-9: I do not completely understand what is meant by the assertion that

guessing at the reference thickness neither jeopardizes mass conservation nor the parameterization. Could you explain a bit more why this is true?

We make a linear guess for $H_{r,red}$ derived from the analytical solution of an unconfined ice shelf in steady state for a special set of parameter. The calculated $H_{r,red}$ is only a reference value to determine the ratio R for an independently calculated new volume $V(i + 1)$ in the partially filled grid cell. The volume flux and the new volume itself is not affected by H_r or $H_{r,red}$ and the total ice mass is conserved. This procedure can be understood as an additional tuning of the parameterization to yield a better transient behavior.

p1505 l24: What precisely is meant by "The bottom of the ocean does not influence ice-shelf propagation"? Does this refer to the bathymetry? Or to the ocean dynamics at the bottom of the ocean under the ice shelf?

We made this clear in the revised manuscript by reformulating: "The bathymetry can be chosen to any arbitrary value deep enough to fulfill the floatation condition." Since the ice shelf is floating the topography of the ocean ground underneath the shelf can be chosen to any value insofar the floating condition is fulfilled. In other words: The depth of the water column has no influence on ice dynamics in our model.

p1506 Eqs. (9)-(12): Again, a minor point. Can these be generalized to n not equal 3? If so, this might be useful as Richard Hindmarsh has stated in one of his talks (and I think in his publications) that there is good evidence for n=4.5 or 5 in certain circumstances.

Right, the analytical expressions for the flow line case can be generally derived for any scalar n. In the simulation of Antarctica with PISM-PIK (Martin et al., 2010) the value $n = 3$ has been used in combination with enhancement factors for the shallow approximations.

Also, it might be helpful for someone trying to reproduce your results if you included a table of variables and the values you used of each. You do this with some variables in the text (e.g. B_0, H_c, n, etc.). Maybe these could be added to Table 1, where appropriate.
We added some values in the Table 1.

p1506 l18: It would be helpful (at least to me) to describe briefly here what the numerical experiments are that produces the transient profiles.

To make that clearer we added "For the transient part of the simulations in the flow-line case, when the calving front propagates downstream initiated at the boundary...". The initial condition of the experiment is a fixed ice thickness H_0 and a fixed ice velocity v_0 as boundary conditions at position x_0. From there the ice shelf front advances in positive x-direction (transient) until its terminal ice thickness falls below a critical value (as calving condition) or until it reaches zero ice thickness (at infinity). When the calving front position does not change any more and if the flux within the ice shelf is balanced everywhere we call it state steady. We actually run one flow line experiment, but we compare the transient and steady state results with each other.
p1507 l22: I don't follow what is meant by the phrase "even without applied calving rule".

Right, this is redundant. It is the sub-grid parameterization that keeps the steep shape at the front.

p1508 l8-9: I don't understand the sentence "Respective velocities for the different tested resolution increase up to 730 m/year at the terminus". Maybe you can reword this to make it clearer?

We suggest following reformulation: "The resulting velocity distribution increase monotonically in downstream direction with largest values at the terminus. For the coarse-resolution case this value reaches 730 m/yr, while for the fine-resolution case the terminal velocity equals the analytical value of 720 m/yr (Fig. 5b)."

p1508 l14: I don't understand the phrase "higher order terms in approximation". Can you clarify?

Meant is the numerical truncation error in the Taylor Approximation of the differential equations, which increases with Δx. Changed to ("truncation error in Taylor approximation").

p1508 l18-19: I am confused about why ice from whole grid cells is calved off. Isn't the point of the sub-grid scale scheme that it doesn't calve off whole grid cells?

This is true. The sub-grid method enables for an easy application of calving rates in terms of horizontal velocities. However, for the comparison with the analytical solution it is much easier to use the unphysical calving condition, which depends on a critical ice thickness (not a calving rate). And this is done here quite ad hoc: only full terminal ice shelf boxes which have thinner ice than the critical value are completely drained and the front retreats in steps of a grid length. The advance is still treated on a sub-grid scale. We added "In order to test the general idea of calving-front advance and to find steady state front positions using our parameterization we apply a simple calving condition..."

p1511 l8: "with less than 0.025% of error variance": How is this number defined? It seems extremely low to me (though that depends on how it is defined).

There are several statistical definitions and we changed to r^2-value in the revised manuscript as it is more commonly used. In the old manuscript we actually calculated the relative error variance as square of the ratio of residuals and analytical value. For example: For the 101 x 5 km resolution case I got a standard deviation (root mean square error) for the ice thickness profile of 4.44 m and thus an error variance of 19.77 m^2. But this is not a good measure for the goodness of the model. We can either take relative values by dividing by the analytical values, i.e. a relative error variance of 0.0135%, or we can calculate the r^2, which is the ratio of the difference between total variance (6156 m^2) and error variance and the total variance, i.e. 0.9968 in this case, which is pretty close to 1.

p1511 l15-16: You may want to say, "We show in transient simulations that variant 1..."
Correct! We will change that in the manuscript.

Technical corrections:

Please consider these to be suggestions. It is not my intent to be pedantic, just to be helpful.

Title: Calving fronts should not be hyphenated.

Eq. (1): I suggest changing the d's to partial's
Was changed in the manuscript!

p.1505 l8: "does neither jeopardize..." → "jeopardizes neither"

p1507 l12 and 16 (perhaps elsewhere): "below" should be changed to "less than".

Was changed in the manuscript!

p1507 l26: the word "whole" is not needed
Was changed in the manuscript!

p1508 l10-11: I would delete the sentence "Also the calving front position..." because this is stated already three sentences earlier.
This is true! Was changed in the manuscript!

p1508 l14: "gets" → "becomes"
Was changed in the manuscript!

p1508 l21: "velocities equal accurately the analytical value." → "velocities are very close to the analytic value." (You would probably do better to replace "very close" or "accurately" with something more numerical and concrete.) Reformulate with "with good accuracy".

p1509 l8: "externsion" → "extension"
oops! Was changed in the manuscript!

p1509 l27: "too low velocity profiles" → "velocity profiles that are slightly less than the analytic solution" or similar. (Again, you would do well to give numerical values rather than expressions lie "too low".)
We added some more statistical information like the r^2-formulation!

p1511 l6: "can be set to zero"→"can be ignored"
Was changed in the manuscript!

p1511 l20 "Note, that"→"Note that"

Was changed in the manuscript!