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Interactive comment on "A full Stokes subgrid model for simulation of grounding line migration in ice sheets using Elmer/ICE(v8.3)" *by* Gong Cheng et al.

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Response to Anonymous Referee #3

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This paper presents a subgrid interpolation across the grounding line for the Stokes equation. This interpolation is based on the stress balance at the base of the ice, $\chi = p_w + \sigma_{nn}$ with σ_{nn} the normal deviatoric stress at the ice base, and p_w the water pressure. If the last grounded element is at node i, and the first floating element is at $i+1$, then the position x_{GL} of the grounding line is determined as the first point where χ goes to zero. This position is then used in the evaluation of the weak form of the basal boundary condition.

Unfortunately, the incorrect citation style and at times awkward writing of the paper (in particular the introduction) distract from its contents. These need to be corrected before publication can be considered.
Response: We apologize for the citation style. They have been corrected.

Scientifically, the approach is a logical first step for interpolation of the basal boundary condition across the grounding line, and the same approach has been used in Seroussi et al. (2004), though not for a Full Stokes model. That said, I think that the analysis of the results could be improved significantly by

1. comparison with other interpolation schemes in 1 horizontal dimension, and

2. extension to 2 horizontal dimensions. The latter case is briefly discussed in lines 229-333, but I think an implementation would show whether this approach in indeed able to deal with complex grounding line geometries.

These kinds of comparisons are standard for the study of numerical grounding line schemes (see e.g., Seroussi et al., 2004, Feldmann et al., 2014).

For point 1 above, I am specifically interested in seeing a comparison to an interpolation of the basal shear stress constant β between the last grounded and the first floating point, i.e., if one would multiply β with $(x_{GL} - x_i)/(x_{i+1} - x_i)$, how would the results differ? This is the interpolation scheme traditionally used in depth-integrated models (e.g., Feldmann et al., 2014, Pattyn et al., 2006) and also introduced as SEP1 in Seroussi et al. (2014). I am wondering whether such an interpolation alone would already provide the observed improvement in the numerical performance, as suggested from my reading of Seroussi et al. (2014). I am also sceptical about the effect of setting β to $\beta/2$ in the interpolated cell, as suggested in lines 282-283? This introduces an additional interpolation which is similar to the interpolations used in models with a structured grid, and has no physical basis in the presented scheme as the interpolation is already done by splitting up the integral for the boundary condition.
Response: Actually, the subgrid model we developed is equivalent to multiplying β by $(x_{GL} - x_i)/(x_{i+1} - x_i)$. This explanation is added in the revised version according to the comments from referee #1. However, the difficulty in this formulation is not only about how to treat β, but how to determine x_{GL} in an accurate way in the FS equations. Also, as the boundary conditions in FS involve $\mathbf{u} \cdot \mathbf{n} = 0$, we introduced the Nitsche's method to weakly impose this, such that it can also be imposed partially on the GL element. The details of the implementation are rephrased in Section 4 with Fig. 2 and 3, and Algorithm 3.

Moreover, it wasn't completely clear to me which parts of the FEM implementation in Elmer/Ice were actually altered. For example, my impression of the time-stepping

scheme is that it is basically the same as in Durand et al. (2009a), in which case section 3.3. is unnecessary.
Response: Section 3.3 is included to: 1. explain the whole algorithm in which the GL treatment is embedded, 2. interpret the damping introduced in (Durand 2009a) as an implicit time integration of the position of the floating ice base, 3. show in a simple calculation how short the timesteps would be with an explicit method.

Other comments (kept short as I think the entire paper needs to be rewritten):

1. Better use $\dot{\epsilon}$ for the strain rate, τ is usually used for a stress tensor
   Response: The correction has been made.

2. Equations (7) and (8) are the kinematic boundary conditions, and should be referred to as such
   Response: We agree that they are the kinematic boundary conditions. However, these names follow the convention as in (;).

References

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