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Geoscientific Model Development Discussions
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Interactive comment on "Extended enthalpy formulations in the ice flow model ISSM version 4.17: discontinuous conductivity and anisotropic SUPG" *by* Martin Rückamp et al.

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1 General comments

This paper introduces two improvements to the thermodynamics represented in the ISSM (Ice Sheet System Model). ISSM is one of most widely used and advanced large scale ice sheet models in the world, and correct treatment of the thermodynamics is needed for many applications. The improvements are related to the discretization scheme rather than physics, but are analyzed in the context of the ice sheet physics. They are well enough described for other developers to see how to implement them,

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Discussion paper

and examples are given that show their benefits. Given that, I think this is a suitable paper for inclusion in GMD.

I do think that some minor attention to the manuscript is in order.

2 Specific comments

1. L17-20 - perhaps include some examples, e.g the thermomechanical instability discussed by e.g Hindmarsh 2009.
2. L35 'Numerical instabilities inherent to the advection component of this equation tend to occur without stabilizing the standard Galerkin finite element method.' and indeed, any other method.
3. L82 'The temperate ice conductivity'. Expand on this a bit: say what it means physically (e.g transport of latent heat down a moisture gradient and often against a temperature gradient), and indicate typical literature value for K_0/K_c (including zero)
4. L130. Are S_1 and S_2 introduced just fit the equations on the page? That is the impression I get. But I wondered if the sources cited also split S this way and take some specific interest in each term.
5. L140 (and after) How is θ found? And is θ a volume?
6. 149 'The applicability of the three models is controversial in the literature and depends strongly on the problem' - citation/examples would help here.
7. 'Since heat conduction through porous media is likely a combination of both structures, a geometric mean can be interpreted as accounting for both processes as

it always results in a value in between an arithmetic and harmonic mean' - but so would a number of combinations, and you might imagine trying to weight them.

8. Figure 1. It is hard to make out the order of the symbols especially for the geometric mean (because they are close together) One solution could be to plot |CTS($\Delta z, K_0$) - CTS($K_0 = 0, \Delta z = 0$)| (|numerical solution - analytic solution|) on a log scale, though that might only help with the smaller K_0 cases. A sharp eye might then tell what the rate of convergence was, both as $K_0 \to 0$ and $\Delta z \to 0$.

9. Figure 3. log scales for both $x-$ and $y-$ axes would help to make this figure clear, perhaps with indicative rates $(\Delta z)^n$ for suitable n I would also plot $1/\Delta z$ on the $x-$axis rather than Δz (so left -> right has increasing number of DoF but that really is a minor detail)

10. Figure 7 the caption does state that ASUPG and SUPG minK overlay one another, but if one line was dashed (or thicker) that could be apparent in the figure.

3 Technical corrections / very minor copy editing suggestions

1. Abstract, first line: 'ice sheets' should be 'ice sheet'?

2. L30 An increasing number of ice flow models is adopting $\to$ ...are adopting, or ...have adopted

3. L38 convection-dominated. You used 'advection' in a previous line so I would stick with it.

4. 'The aspect ratio of anisotropic grid-cells in the FEM is particularly problematic' $\to$ 'Low aspect ratio mesh elements in the FEM are particularly problematic'?

5. ISMs are dealing with very thin geometries - maybe say 'low aspect ratio' here to be clear.
6. 'For instance, a . . . ' → 'A . . . '
7. 'Our work is indeed inspired by the' → 'Our work addresses'
8. L83 'At the upper surface, Dirichlet boundary conditions are imposed'. In this case - but potentially a heat flux might be imposed if coupled with a snow pack model.
9. L100 'bilinear elements' → Piecewise linear?
10. L111 'Once the elements become anisotropic or distorted'. Is the 'distorted' helpful here?
11. L159 'We run' or 'We ran' - not so important I guess but 'methods in the past, results in the present'
12. L165 'The setup poses a *reasonable* situation in glacier modelling' typical? representative?
13. L167 'The horizontal velocity...' (and does not vary horizontally)
14. 174 In this set-up, no stabilization is applied, i.e. the term $S(E, w)$ in Eq. 4 is ignored. (Because Pe is small I suppose? but is that the case below the CTS?)
15. L214 'without *the* necessarily reaching a steady state' (remove the)
16. L221 (and onward) 'CTS position'. CTS elevation?
17. L245 'Due to symmetry reason, only' → 'Due to symmetry, only'
18. 'too much diffusion' → 'far more diffusion than the other choices?'

19. L265 'the oscillations could cause the temperature to diverge'. From what? In one sense they do already (from the solution, as h_K grows), but I think you mean numerical error so severe that it becomes grossly unphysical (e.g $E < 0$, or E very large) and/or numerical error so severe it causes an iterative solver to produce successively worse approximations (blow up).

20. L277 'Treating the discontinuous conductivity as a geometric mean'. A bit of rephrasing is needed: the conductivity is not treated as any kind of mean, rather, a particular formula is used when estimating K_{eff} at various points.

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