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Interactive
Comment

Interactive comment on "Basal shear stress under alpine glaciers: Insights from experiments using the iSOSIA and Elmer/ICE models" *by* C. F. Brædstrup et al.

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Reviewer 2

In this reply we comment on all remarks given by the reviewer and present the associated changes to the manuscript. The comments from each review have been copied into this document in grey and are marked with C for comment and a sequential number. The corresponding response is marked with R.

We thank the reviewer for positive and constructive comments. We have largely followed the reviewer's advice throughout.

C-1.1: This is a useful and straightforward study that aims primarily to compare simulated fields of basal shear stress and sliding speed between two different models, for the purpose of informing landscape evolution models that employ glacial erosion. The 2-D depth-integrated high-order model iSOSIA (the 'home team' in this case) is compared to the 3-D Stokes model Elmer/Ice in two steady-state experiments, while sliding laws and erosion rules are compared in a third transient experiment that is restricted, for computational reasons, to iSOSIA.
The study is worthwhile, the results useful and the paper itself clear. The only scientific objection I have is in the design of the experiments themselves, or perhaps in the justification of the experimental design: (1) I understand the rationale for using only iSOSIA in Experiment 3, but I don't under- stand why at least 2 sliding laws (Weertman/Budd-style and Coulomb friction) were not used with both models in Experiments 1 and 2. Using only the Weertman-style law for these experiments might limit the discrepancy between model results. Was the choice to exclude the Coulomb-friction law from Experiments 1 and 2 made for scientific or technical reasons?

R-1.1: The comparison study between iSOSIA and Elmer/Ice was limited to the Weertman sliding law for technical reasons. In short, we were not able to make Elmer/Ice work in our setup with sliding laws that depend on effective pressure. We tried hard for a long period to make it work, but we were not able to make the solver converge, in spite of assistance from the Elmer team. We speculate that the challenge for Elmer/Ice arises when ice margins exist inside the FEM grid. We did not want to discuss these technical issues too much in the manuscript, partly because we do not think that our problems with Elmer/Ice should keep others from trying. However, we understand that this info is important for motivating our experiments. We have therefore added sentences about this to section 2.3.

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We will for the abovementioned reason not be able to supply additional Elmer/Ice experiments. However, we believe that 1) the comparison study based on Weertman sliding shows that the two solvers predict the same regional patterns of basal shear stress, and 2) the iSOSIA experiments using three different sliding laws demonstrate that patterns of basal shear stress are robust and not overly sensitive to the choice of sliding law (Fig. 8).

C-1.2: (2) I also wonder why two of three sliding laws tested were essentially the same, rather than choosing one in which sliding is linearly related to basal shear stress for example. Given the assumption of a uniform flotation fraction of 80% in order to compute N in (7), the Weertman law and the Budd law differ only by a factor that depends more or less on ice thickness (unless I have misunderstood something about the implementation here). One could argue that testing m=1 versus m=2 in the erosion law takes care of this, but only for the computed erosion rate rather than for the computed basal shear stress and sliding fields. Another means of differentiating the first two sliding laws would be to adopt a different flotation fraction to compute N. Does it make a difference?

R-1.2: We agree that varying the stress exponent in the sliding laws more would increase the difference between experiments. We have thus increased the stress exponent in the empirical sliding law from 2 to 3 (See also response to comment C9 by reviewer 1) and repeated the experiments shown in Figs. 8 and 9). The details of the initial shear stress now vary a bit more, but the overall conclusions about regional patterns and the feedback from erosion remain the same.
We also agree that comparing models with different flotation fractions would complement the existing experiments nicely. We have therefore repeated the experiment using the Coulomb friction sliding law for two additional flotation fractions of 70% and 90%. We compare these to the model using 80% in a new figure (Fig. 10).

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C-1.3: (3) Finally, I wonder what difference it would make if the glacier geometry for Experiments 1 and 2 were created with Elmer/Ice rather than iSOSIA. Could the current methodology (creating topography with iSOSIA and then computing steady-state/diagnostic fields with both models for comparison) be responsible for some of the short-wavelength heterogeneity in the Elmer/Ice results (e.g. Fig. 2b and 2c)? The explanation given for the heterogeneity was that iSOSIA, due to its depth-averaging, would be expected to produce smoother results. It wasn't clear to me whether this was just a plausible explanation or one that had been demonstrated by the authors as the leading explanation. I imagine that the authors may have done some of the tests suggested above already, and that there may be reasons not obvious to the reader (or this one at least) that the results were not mentioned or included. I think the paper would make a stronger case for the robustness of iSOSIA if it were put to what would seem more rigorous (though not more difficult or complicated) tests, as outlined above. At the very least, a better justification for the present experimental design would be appreciated.

R-1.3: This is a good suggestion. We were not completely satisfied with our discussion of the high-frequency fluctuations in Elmer/Ice, because depth-averaging in iSOSIA should not make a big difference close to the bed. That Elmer/Ice was forced to use the iSOSIA ice configuration makes a better explanation for the high-frequency variations, and we have now incorporated this in the text.

C-1.4: 1144.1: Suggest 'partially controls basal sliding' or 'exerts a significant control on basal sliding', since basal hydrology also plays a major (arguably dominant) role in some environments. Nice introduction.

R-1.4: We agree. We now use "exerts a significant control on basal sliding".

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C-1.5: 1149 (Section 2.3). The experimental set-up is generally described in this section and some differences between Expts 1-3 are mentioned (e.g. steady-state vs. transient). It would help to know exactly what the three experiments are in this section (e.g. purpose, which models), rather than having to wait until the beginning of each subsection of the results to find out.

R-1.5: We have modified the text in the beginning of section 2.3 to motivate all three experiments upfront.

C-1.6: 1150.5: Figure 1b shows ice thickness, so might be better to say 'ice thickness distribution' than 'ice surface configuration'.

R-1.6: Done

C-1.7: 1150.6-8: Given that the mass balance is specified as a function of bed topography (through the dependence of temperature on bed topography), it is unclear why there would be any mass-balance elevation feedback in the model unless the bed topography changes through time with isostasy.

R-1.7: The feedbacks between bed topography and mass-balance are due to lowering of topography through erosion. We have now added this info to the relevant sentence.

C-1.8: 1151. Given that most of the paper focuses on modeled basal shear stress and sliding, it seems different exponents for (6) or (7) would be as or more important than different exponents for (9).

R-1.8: We have changed the stress exponents of the empirical sliding model from 2 to 3 (see also R22 and R9)

C-1.9: 1154.3: Would be good to have this basic information on purpose and set-up of the Expt. before Results (i.e. in section 2.3).

R-1.9: This is a good suggestion, and we have therefore moved much of this info to the beginning of section 2.3 (see also R25).

C-1.10: 1155.13-14 'reflects the influence of pressure. . .as well as vertical shear stress com- ponents' I'm not sure what this explains. The basal shear stress dominates the force balance, as expected for a valley glacier, but...?

R-1.10: We can see the problem with this sentence. We have changed it to "The basal shear stress along the profile is 2 to 4 times greater in magnitude than the horizontal stress components, which highlights how basal shear stress dominates the force balance of valley glaciers".

C-1.11: 1156.19: 'rather uniform'. Here and elsewhere there is room for quantification of re- sults. Reporting the mean and standard deviation, for example, would be a better way of establishing this. See also paragraph below: 'regional misfit remains small'.

R-1.11: We have increased the level of quantification in this and other sentences. We now refer both to the mean and the standard deviation and several sentences that refer to Figs. 3 and 5.

C-1.12: 1157. Figure 6 could use an additional panel showing the difference between the two, or some field that would better convey the features mentioned in the text.

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Even annotating the existing figure would make it more instructive.

R-1.12: We have added a third panel showing the total erosion. We have also annotated panel b) highlighting the trough, the hanging valleys, and truncated spurs.

C-1.13: 1158.8-10: The increased uniformity of basal shear stress only appears visibly obvious for the Weertman case. Perhaps some quantification of this effect would support the text that this effect is strongest for both Weertman and Coulomb-friction cases.

R-1.13: It is true that the trend of decreasing shear stress with erosion is most obvious for the Weertman sliding law. However, the other two sliding laws follow the same trend. We now refer specifically to the quantified decrease in max shear stress for all sliding laws.

C-1.14: Technical details (page.line):
1144.13: suble => subtle
1148.18: Stoke => Stokes
Eqn 1: divergence, not curl, of the flux
1149.17: 'Ablation and accumulation are'
1152.2: 'sliding-based erosion laws'
1155.2: correlate with => have
1155.18: remarkable => remarkably
1155.26: 'driving stress . . . shows'
1156.7: Seems like both Figure 4b and 4c should be referenced here for 'drainage patterns', not just the sliding component (4b).
1156.14: 'magnitude . . . increases'
1157.3: 'in the order' => 'on the order'

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1157.11: ‘costs . . . prevent’
1157.25: ‘development . . . causes’
1160.7-8: ‘bends ... that form’ ? [note sure to what ‘interlocking spurs’ refers]
1160.9-10: ‘erosion . . . removes’
1160.21: ‘features that resemble’
1160.22: reasonably => reasonable
1161.8: smoothened => smoothed
1162.3: suggest omitting ‘three-dimensional’. Not relevant to sentence, especially since some variables were depth-averaged for comparison with iSOSIA.
1162.11: ‘reduction in’ 1169.Table1: Coulomb mis-spelled 1174.Fig5 caption: Forth => Fourth

R-1.14: We have followed the reviewers advice here and corrected all the above.

Interactive comment on Earth Surf. Dynam. Discuss., 3, 1143, 2015.