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# *Interactive comment on* "Numerical simulations of glacier evolution performed using flow-line models of varying complexity" *by* Antonija Rimac et al.

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General comments: The authors compare results from a shallow ice approximation (SIA) model with a full-Stokes (FS) model (FSM), which uses ElmerIce. Several model experiments are performed to assess model differences in glacier evolution. The experiments all start from a steady-state that has been chosen for both models as to represent the same initial steady-state geometry. The experiments include a step-wise forcing as well as periodic fluctuations of the equilibrium line altitude. Further a change in glacier width and changes in bed slope are introduced. The force balance equation is used on the FSM to gain insights into which components of the force balance are important along glacier for the various experiments.

The paper is for the largest parts carefully written but in my view too long and it be-



comes not clear what the authors want to get out of it. While reading I got rather confused as it is not always clear if the comparisons between model results are comparable. The model set up is e.g. not the same as the one used in Leysinger Vieli and Gudmundsson (2004) (e.g. using no-slip) but the results are much compared with each other and differences mentioned but the possible reason behind it is neither analysed nor discussed. I did not understand the aim of this model comparison study and neither did I understand what can be learned from it. It is not clear if some general recommendations can be made that are valid for all SIA and FS models.

The main weakness is that the authors compare the two models that have been adjusted by some parameters to produce the same initial geometry but the effect of this adjustment on the calculations is not really tested and accounted for. A further weakness is the grid resolution. It becomes not clear in the paper if the grid resolution is correct. It does not mean that the FSM needs the same resolution as the SIA - especially at the front the resolution might be too coarse.

I am not sure what the paper is adding to the current knowledge, what is new to previous studies. If the paper could be more specific in saying for what this comparison is made and something new is learned from it, the contribution would be valuable.

Specific comments: In order to obtain the same steady state geometry for the SIA and FS model, the parameters for sliding and deformation have been tuned for the SIA model. For the three different slope three different geometries are obtained that are initially the same for both the SIA and the FS model. The models allow for sliding at the base described by a Weertman-type sliding law. The sliding parameter in the FSM is connected to the sliding parameter in the SIA model so that the sliding velocities are equal in both models. This is done by choosing the mean ice thickness and divide it by the sliding parameter used in the SIA model. Reading equation (2) I understand that for the sliding velocity the thickness varies along the glacier. But for the FSM in equation (4) using the sliding parameter C as defined in equation (5) the thickness H is the mean thickness. So H does not change along glacier. This is a problem at the front where the ice thickness becomes very small. At the front the basal velocity in FSM and the sliding velocity in SIA are not the same due to not accounting for the change in thickness in the FS model. This effect is seen in the basal shear stress as well as in the force balance components (e.g. Figures 5-8 in (c-d)), where a high peak in the FSM is obtained at the glacier front. This might also be the reason why the SIA seems more responsive than the FS model (e.g. Figure 2).

As a very first experiment and to test the two models (and not the physics) I would have expected to run the steady state using an x-dependent mass balance distribution and therefore without any altitude mass balance feedback. The steady state front positions must be equal for both models and can be determined analytically allowing to estimate the accuracy of the two numerical models and also determine the most suitable grid resolution for the two models.

For the comparisons with Leysinger Vieli and Gudmundsson (2004) it is not clear what the observed differences mean - neither has been considered that the front evolution in the FS model used by Leysinger Vieli and Gudmundsson (2004) is not bound to spatially fixed grid points as it uses and adaptive grid moving with the surface. The authors of this study mention on page 8 that a smaller grid leads to a 50% change in phase lag. This makes me wonder if the results in general have a grid dependency, especially at the front. The changes in length do seem to be contained within 1 grid size (e.g. Figures 2 (b), 3 (b) and 4 (b and d), which is a random and not a significant result. However this is not reflected in the discussion of the results. This grid difference is also important for the discussion of advance and retreat rates. Looking at Figure 2(b) the slope of the curve for an advance looks slightly different between SIA and FS model but nearly identical for the retreat. Furthermore, the statement made in the discussion (p. 13 lines 6-11) on steady state length for an advance and a retreat does not take into account that the current paper (Rimac and others) uses a linear mass balance function whereas Leysinger Vieli and Gudmundsson (2004)use a non-linear mass balance function (two different gradients above and below the ELA). A



further difference is that Leysinger Vieli and Gudmundsson (2004) used a no-slip basal condition.

For the experiments using a varying width, I am not sure what we learn from it for the three different glaciers. The width varies along flow and not relative to the glacier length. This is fine comparing the models but what does it mean for inter comparison of different sized glaciers? Why continue all experiments with the change in width instead of looking at just one added complication.

Technical corrections: P1, L8: Another paper to consider is M. P. Lüthi, 2009. Transient response of idealised glaciers to climate variations, Journal of Glaciology, Vol. 55, No. 193.

P1, L20: 'Leysinger Vieli' without hyphen.

P2, L16/17: Where is the velocity so different? Front? And when? In steady-state?

P2, L19: What do you mean by 'crudely studied'? Explain!

P2, L20: Complexity is used in both sentences but I believe sth. else is meant. Elaborate - be more precise.

P2, L31: e.g. Lüthi, 2009 applied a sinusoidal variations of the ELA to investigate the response in glacier length and volume.

P3, L8: 'and the ice thickness' instead of 'a'.

P3, L14/15: I find this an odd argument. You can still get the numerics wrong even when others had correct results (e.g. grid size etc.). You need to test your specific case.

P3, L19: 'At the lower boundary' instead of 'he lower'. Because of Weertman type friction law I know you mean the base - but you might want to make this clearer which lower boundary (downstream end or base?) you mean.

P3, L32: I believe that 100m might be to coarse at front for the FSM. Did you check for the Courant-Friedrichs-Lewy stability condition? abs((u*delta_t)/delta_x))<= 1 using the largest velocity u in the system.

P4, L4: instead of 'tau to the power of 3' would not '1/m' instead of 3 be more correct?

P4, L4: f_d and f_s introduce a different rheology to the glaciers. Does this make sense?

P4, L6-8: Sentence is confusing as it is not clear if the difference is between SIA and FSM (which would be correct) or between the small, medium and large glaciers.

P4, L23: This condition makes that H is constant but the same is not true in Equation (3) where H varies along the glacier. This leads to large differences where thickness changes (e.g. at the front)!

P4, L28: Give the slopes also in degrees (angle).

P5, L8: You use 'Second' - where is 'First'?

P6, L4: Does it make sense to vary the slope by the same amount in slope? This means that the steeper part is relatively steeper for the low slope than for a higher slope. Why not the same slope for the steeper part? Or the same relative increase?

P6, L17: Not clear in Figure 1 what the length is. Where are these +- 1km?

P6, L19: SIA is faster due to sliding factor f_s/H (C) - see main comments.

P6, L21/22: What is the measure for steady-state?

P6, L26/25: Not sure your aim is possible with f_s and f_d parameters that are different in the models.

P7, L5/6: It differs for advance and retreat - but does it really differ between the models? At least for the retreat it does not look so. See main comment on grid size.

P7, L18: In Figure 2 a 'slight' change is seen for advance and 'none' for retreat. Front



might be the reason - grid resolution as well as f_s and f_d.

P7, L28: 'glacier length in SIA reacts faster' this again might depend on fron and chosen f_s.

P8, L18-22: This interpretation is an over interpretation of data within 1 grid cell. It's a resolution problem. Within one grid cell no statement can be made.

P9, L25-33: This paragraph is not clear to me. The problem here is C in the FSM. But are you not comparing apples with pears as all three sized glaciers have different f_s?

P10, L15/16: Does it make sense to compare the velocities for the different glaciers? The smallest glacier is sitting nearly entirely in the widest part but for the large glacier this is only a small region compared to its total volume. Should the width be chosen the same for all or relatively varying in width at the same position for all (e.g. wide in the first third)?

P10, L23: 'non-uniform glacier width' I did not understand what the change is to the previous 'exponential change' is. Equation is the same? I believe it's the same change in width?

P11, L1: add 'end' to make it clearer - 'at the bump's downstream end'.

P11, L3-9: Paragraph not very clear - not always clear if you are speaking of SIA or FSM!

P12, L19: How much does your statement depend on the chosen width?

P12, L30-33: Velocity depends on thickness and slope - is your glacier comparable to Nigardsbreen? What do you want to say by this statement?

P13, L4: 200 meters is only 2 times the grid size - this is not 'large'.

P13, L8: 'shorter than 5 km' - only one small glacier was studied with the definition of small ranging between 1<= length <= 5km. But one can not make a general statement of smaller than 5km from the Leysinger Vieli and Gudmundsson (2004) study - rather on aspect ratio.

P13, L8: ‘a SIA model’ instead of ‘an’.

P13, L9: it’s not so much ‘length’ but more importantly it depends on the aspect ratio of the glacier - so a small aspect ratio might not be well represented by SIA

P13, L10: How different in length is ‘different’ here?

P13, L14: Statement not very clear here (grammatically wrong?).

P15, L36: ‘Gagliardini’ and not ‘Gqgli..’

P17, Table2: Not clear if for an advance or retreat!

P18, Figure 1b: Not clear how long the glacier is. Here they seem shifted by 2 km.

P19, Figure 2: Why do they not start from the steady-state position? Show the start and explain what it is.

P20, Figure 3b: the length change in the minimum seems to be rather due to the grid resolution - this has then also an effect for the Maximum (two grid cells there (added to the first difference).

P21, Figure 4: Again grid size differences!

P22, Figure 5c,d: peak in FSM due to C (or rather matching it to f_s with a constant ice thickness H).

P22-25, Figures: Caption to (b) and (c) are swapped in the text.

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