Zhang et al. 2025 “Numerical modeling of the tipping processes of ice detachment: a case study of Sedongpu Glacier in the Southeastern Tibetan Plateau”
Reviewer comments

General comments

The authors present a study of glacier detachment at Sedongpu Glacier from a numerical modeling perspective that attempts to recreate conditions of glacier attachment by simulating changes in glacier viscosity and feedbacks with basal sliding. The topic and motivation is really important, as glacier detachments deserve more scientific attention and can be destructive to downstream communities and infrastructure (as the authors note as well). I think the topic of the manuscript in itself has a lot of merit, and it’s cool that the authors have been able to reproduce catastrophic collapse of the glacier. Because of this, I think that this paper is a good candidate for publication. However, I have serious concerns about the approach the authors take as well as the structure and presentation of the manuscript. These can be categorized in the following areas.

(1) I am somewhat unconvinced about the authors’ choice to model glacier detachment from the perspective of a rate-weakening basal slip and variable ice viscosity. The authors claim that the feedback between ice stiffness and basal slip plays a major role in the instability that causes the glacier to detach within minutes in their simulations. However, there is very little discussion of how this feedback mechanism or its numerical implementation works. Neither have the authors cited any works that discuss this feedback. I remain unconvinced as to why this mechanism is responsible for the detachment both from a conceptual perspective and from their model results. The authors need to strengthen their explanation of this feedback and how/why they are modeling it. This could include adding a literature review section about damage mechanics and more explanation about why they decided to structure their coupled model the way they did.

(2) I am somewhat skeptical that the instability modeled in this manuscript (the viscosity-basal slip coupling) is truly a physical instability and not a numerical instability caused by the choice of model parameters. For example, when the coupling mechanism is activated, the viscosity of the ice goes from 60 to 0 Pa yr, which then triggers the rest of the glacier collapse. A more rigorous stability analysis is needed to ensure that this is a real physical phenomenon.

(3) The authors should provide some sort of validation or provide insights into the plausibility of their results. They repeatedly claim that the viscosity-basal slip feedback is more important than subglacial hydrology or till failure, but they do not provide any evidence to support this, either in the form of citing previous works or providing any sort of validation for their model. In addition, the authors do not show the misfit for their basal friction inversion, so we don’t know whether or not their sliding parametrization is able to reproduce realistic glacier velocities.I think the authors should either include this

evidence or scale back their claim that this feedback is more important than other mechanisms which have been more extensively proven to play a role in detachments and surges (e.g., subglacial hydrology and geothermal heat).

(4) The authors don't include any sort of hydrology (subglacial or surface) in their modeling even though surface meltwater-driven hydrofracture and subglacial hydrology play a strong role in bulk ice toughness and basal slip. I get that this would be difficult to include in a model like this, but it would add a lot to the manuscript if the authors could at least address this in the text. They also talk about effective stress but have not defined it any of their model equations, and claim that high effective stress corresponds to ice acceleration which goes against the traditional glaciology definition of effective stress.

(5) I would like a lot more information on the implementation of the model or finite element scheme. What mesh resolution is used, what meshing software was used, and how the spatial and temporal resolution was determined. In addition, there should be more discussion of the implicit assumptions that go into the model and what effects these have on the results.

(6) The manuscript doesn't follow as much of a logical flow as I would prefer. There is insufficient explanation of the model and its assumptions at the beginning of the manuscript before the equations are presented. I go more in detail about this in the specific comments below.

(7) I also believe it could be helpful for a native English speaker to read through the next iteration of the manuscript as the language is often imprecise and not entirely scientific.

<u>Specific comments</u>

L5: "Yield strength of the glacier" is very general. As the authors mentioned later in the manuscript, the yield strength of the glacier is extremely heterogeneous. I would recommend changing this to something like "initial yield strength of glacier ice".

L8: "just several model time steps" is pretty vague

L9-10: How would these results be used for early warnings? Maybe you can talk about this later in the discussion.

L16: Merge this with the previous paragraph

L22: The "largest ever recorded event" of what? Of surges, of a glacier detachment? The language could be a bit more precise.

L24: The authors mention that remote sensing advances allow us to detect changes in surface features like crevasses and fractures but the authors did not use any of these data to validate the model results

L38: This is the first time the authors mention the ice stiffness-basal slip positive feedback. It would be great to have an additional few paragraphs explaining this feedback and motivating why the authors choose to model it. It would also be great to see some previous examples where this mechanism was suggested or modeled successfully before.

L41: Specify the glacier name again

L44: What is Medog? Is it a village, a weather station?

L48: Some information about the quality/texture of the Quaternary deposits would be useful here. Is it soft sediment or more coarse till? Also, how thick is the debris cover on the glacier?

Figure 1: (a) It would be great to highlight the glacier that is being modeled. (b) and (c ) the text is a little blurry - would be better to have higher resolution. Please also show the outline of the glacier in (b) and (c ) so we can get a better idea of where the glacier is inside the valley. Plotting the difference between the two DEMs would also probably be more useful (i.e., 2018 DEM minus 2015 DEM).

L56: I think this whole section (ice flow model) should go after Figure 2.

L57: What is the dimensionality of this model? It would be good to specify.

L57: PoLIM is a thermomechanical model. What are the thermal parameters specified here? What assumptions are made about heat flow? Is there any geothermal heat flux?

L70: Reference to Table 1 would be useful here.

L71: Justify why you are using a Weertman-type sliding law here, and why effective pressure (N) isn't important.

L83: There is also another model initialization section in the "results and discussion" (Section 5.1). Consider merging these two?

Table 1: What is the geothermal heat flux? Also, consider converting the rate factor A to Pa^-n s^-1 for easier comparison with other papers. It would also be good to include citations for the choices of critical strain and intact strength of the ice.

L90: Where do you get the Dirichlet and Neumann velocities from? What does it mean for velocity fields to be Neumann/Dirichlet? Also, what is the misfit from this inversion, and is the model able to reproduce realistic velocities?

L101: There needs to be an explanation of how you obtain eta_1 and eta_2 and what each of the three viscosities mean. Also, how is eta_min determined and what is the model's sensitivity to choice of eta_min?

L106: When and how does the viscosity transition to plastic viscosity?

L108: It would be helpful to cite previous works that have demonstrated good results with a model like this

L113: Are you using the linear Weertman-type or this rate limited one?

L117: Include a reference to Figure 2 before presenting the model equations. It would also be great to expand more on Figure 2 in the text.

Equation 13: Why is the ice yield strength in the expression for basal shear stress? In Bassis et al.'s supplement, the second term inside the brackets has tau_c (the intact strength) in the denominator, but here you have tau_y (yield strength).

L126: The "Datasets" section should be before the model equations.

L138: Need more information on what the "glaciological modeling results" are. Are they using a flow approximation? If so, what is being used? Some more details on how the glacier geometry was determined would be helpful here.

L139: What are some limitations to using a flowline model as you are doing, compared to a 2D model? How would this change the results?

L144: Why were higher velocities filtered out? It seems like a threshold of 400 cm/day could exclude important data if the glacier was moving faster.

Figure 3: Move the panel labels (a and b) to above the figures so they are more visible. Including a hillshade contour around the glacier domain would also be useful. In Panel A, you should use a diverging colormap so it's easier to see where the glacier thickness increased and decreased. Also, why is there data missing in the upper tributary in panel B?

L148: There was already a model initialization section. This should be merged with that. It doesn't make sense to have a model initialization in the Results/Discussion section.

L153: Why did you use the mean velocity from 2015-2018 instead of the velocities just prior to the detachment? Does Sedongpu exhibit seasonal variations, and how would that affect your calculation of the friction coefficient at the moment of detachment?

Figure 4: What is the resolution of this flow line model? How do these velocities compare to observations?

L159: The authors claim that external environmental forcings could be responsible for the detachment, but these forcings are not included in the model.

L164: Why is the coupling mechanism activated at t=5 minutes? What physical event does this represent? Does the model reach any sort of equilibrium prior to t_0? And why does the glacier instantaneously collapse when you activate the coupling mechanism - can you be sure that it isn't a numerical instability?

L167: 90,000 m/hour seems unrealistic. Can you comment on why it's so high, and what this could be representing?

L170: This is the first mention of effective stress in the entire paper. There is no mathematical or conceptual definition of effective pressure anywhere prior to this, and effective stress was not a parameter in any of the model equations shown. How is effective stress being calculated?

L171: An increase in effective stress should not result in ice acceleration, unless you are defining effective stress differently from the traditional glaciological definition. Higher effective stresses are associated with higher frictional contact between the ice and bed, and so a higher effective stress should correspond with the glacier slowing down. Effective stress needs to be defined explicitly in the ice flow model section and maybe again here.

L173: Is the 6.3 minutes from the beginning of the simulation or 6.3 minutes after t_0 the activation of the coupling mechanism?

Figure 5: It would be great if the authors could comment on the sudden change in viscosity from 60 to 0 Pa yr. It seems unrealistic to me that the viscosity would go to 0 within less than a minute.

L177: Nice relating with previous work

L184: If yield strength varies from 100-1000 kPa, why did you only test between 300-500 kPa?

L190: What is the sensitivity of the model to A and to the temperature of the ice?

L199: It would be great to include a conceptual explanation or discussion of why the coupling feedback mechanism almost instantaneously results in failure and rapid acceleration of the ice. This is the crux of the manuscript and should be explained in more detail.

L200: Earlier the authors suggested that hydrology doesn't play as much of a role as the viscosity-slip feedback mechanism. It is unclear to me then why rainfall events should be monitored as opposed to crevassing or softening of the glacier ice.

Figure 6: What is the normalized value? I don't think the normalization was defined clearly in the text or in the caption for the figures. Is it a spatial average? Maybe I missed it, but I don't understand the y-axis for these plots.

L206: What does ice becoming "yielded" mean?

L218-220: This sentence would make more sense if it were in the introduction. Or, if the authors wish to claim that the elastic-plastic transition is important, it would be helpful to include a scatter plot of stress vs. strain rate or something like that to show the glacier viscosity transitioning from elastic to plastic.

L224-225: "This has remarkable scientific and engineering applications for large infrastructures in the local regions" - I think it would be good to be more specific about which aspects of your results would be helpful for science/engineering applications. Otherwise, this sentence may make more sense if it were in the introduction or conclusion.

Figure 7: The panel labels are hard to see - maybe put them on top of each plot instead of at the bottom. Also the colorbars need units.

L226: This section should go closer to the beginning when you are introducing the model - it would be helpful to understand more of the model limitations from the outset.

L228: The assumption of constant ice density wasn't included in the model description at the beginning. It would be helpful to mention this in the "ice flow model" section.

L237: Could you write briefly about how including some of these mechanisms could affect the results? E.g., if you used Schoof's sliding law or Iken's bound, how would that change the results?

L248-249: What are the early warning signals of glacier detachment? These weren't discussed at all in the manuscript.

<u>Technical corrections and typos</u>
L38: "novel" -> "novel", "postive" -> "positive"
L101: "Glen's pow law" -> "Glen's power law"
L89: change "According" to "Following"
L163: "simulated" -> "simulate"
L183: "destablizing" -> "destabilizing"
L230: "descrete" -> "discrete"
L234: "hydrolodry" -> "hydrology"