Review of "Climatic controls on mountain glacier basal thermal regimes dictate spatial patterns of glacial erosion"

General comments

Dear Editor,

Thank you for the opportunity to review this paper. This paper discusses the role of a glacier's thermal regime on glacier erosion. To accomplished this, the authors use PISM, a well-established model for the thermo-mechanical physics of ice flow. The authors argue that in warmer climates, a greater proportion of the glacier bed can experience sliding and thus erosion is increased in a warmer climate. Additionally, greater erosion can occur in warm/wet conditions, with a high mass-balance gradient, than on a cold/dry glacier. Thus, a glacier's ELA does not greatly affect it's capacity to erosion a landscape.

I like this paper. It is well written, concise and organized. Generally, the experiments and conclusions are thoughtfully executed. In my opinion, much work remains to evaluate the interaction between climate and glacier erosion, and I applaud the authors for pursuing this topic. This is highly important given that increased knowledge of glacial erosion processes will help to interpret the sedimentary records of erosion, understand the landscape response to the forthcoming deglaciation and better evaluate the relationship between tectonic uplift and glacier erosion. Implementing a complex model that considers these processes cohesively definitely contributes to our knowledge. In its most basic sense, these results show the complexity of glacial erosion. In this paper, however, I have some questions about the conclusions drawn from these numerical experiments and the experiment design. For me, personally, to subscribe to the conclusions of this paper, they will need to be answered fully.

1. Most importantly, to what degree is basal shear stress (largely influenced by driving stress), and not basal temperature, responsible for the change in glacier sliding, and thus erosion? Lower glacier surface gradients at high elevations may cause a decrease in sliding and thus erosion there. This is discussed in the Methods of the paper where the Weertman-style sliding law is explained. Changes in driving stress are what Seguinot and Delaney (esurf-dis) suggest as the process responsible for variations in erosion. Given the experiment design, basal thermal conditions might be a factor, however, the role and effects of basal shear-stress (and other impacts on glacier sliding) should be thoroughly considered and addressed.

   Some changes in erosion might be linked to basal conditions. However, the role of increased precipitation in glacier erosion suggests to me that glacier topography and in morphology could well play a role in the increased erosion observed in those model runs. At high elevations, increased precipitation means increased ice flux down glacier and potentially high driving stresses.

   For me, these processes (basal temperature and shear stress) should be attributed clearly.

2. The time transgressive nature of the climate forcing is not addressed. I was left wondering why this forcing was applied, as opposed to a steady forcing, given the lack of discussion about temporal variations in erosion. By examining temporal patterns of glacier erosion, the authors may find that similar basal conditions produce different erosion rates due to changes in glacier morphology and driving stress. If this is the case, the authors might be able argue that basal conditions are responsible for background erosion rates, however, variations in erosion largely come from changes in climate and glacier dynamics. Nonetheless, these timescales and processes should be parsed and explained in order to present the cases where basal temperature is the primary control on glacier erosion. In this way, the findings herein and from Seguinot and Delaney (esurf-dis) might be able to complement each other.

3. Related to the last question, the response time of the glacier temperature changes is very slow and it can take a long time for the glacier to reach an equilibrium. I did not adequately understand the initial conditions prescribed to the glacier and I am uncertain the degree to which these conditions could propagate into the results. Basically, it seems that the conclusion that basal temperature drives the erosion rate might be a manifestation of the initial condition chosen and not necessarily the time transgressive response to variations in temperature. The impact of the initial condition could well be a reasonable result, however, it should be made clear and it is a limited component of how the natural system operates and responds to climate. Some commentary on the response of glacier sliding and temperature to climate, and the time scale there of, will help with some of these results.

A revised manuscript should address these comments above. More specific comments are given below.

Hopefully the authors find my comments well-guided. As stated above, I believe this to be an important topic to pursue, and I am glad to see papers being pursued to these ends. I wish the authors the best in concluding and presenting this research and look forward to seeing the final result.

Best regards

Ian Delaney

Specific Comments

- **Introduction** I found the introduction well written. A couple of notes though. 1) I would recommend discussing glacier sliding more and the contributing factors. The effective manifestation of erosion here is sliding, so sliding is of interest. Also 2) consider discussing the role of understanding the glacier dynamics in the context of interpreting the sedimentary record (papers by Koppes, Fernandez and Ganti). Also, I found many unattributed statements in the introduction. Find citations for these or omit.

- **Ln 66–79** The findings of Anderson et al. (2012) may well fit well in to this paragraph.

- **Methods** In addition to the comments in the letter, some issues arose in this section. What are the initial conditions of the glacier model? Is a spin up established? Is the fluvial topography in a steady state? If not, how long was the model run for prior to the initialization of the model run? Are the fluvial and glacier models running concurrently over the same parts of the domain during the model runs?

- **Section 2.2.1** A linear erosion rule is used, which should be attributed to Humphrey and Raymond (1994). However, Herman et al., (2015), Koppes et al. (2015), and Cook et al. (2020) all empirically explain why a non-linear law likely fits better. Furthermore, the theory in Hallet (1979) suggests that an exponent of 2 should be used. Herman et al. (2021) discusses this in detail. I am not saying this erosion rule is wrong, but it should be justified. Also, work by Humphrey and Raymond (1994), Herman et al., (2015), Koppes et al. (2015), and Cook et al. (2020) all implement data to validate the rule, so citing them not only provides proper attribution, but strengthens the method.

- **Ln 134** "Fluvial landscape in Landlab"... what is the relationship between this and the Braun and Willet 2013 paper discussed above. Also Deal and Prasicek (2020) might be able to provide some good insight in to fluvial glacial relationships, depending on the relationship between fluvial and glacial erosion.

- **Section 2.4/2.5** I found some of these aspects of the design complicated. Would a cartoon or timeline with climate forcing and model interaction in addition to the map in Fig. 1 help clarify?

- **Ln 165** "PISM over an unchanging topography." I am a bit confused by this statement as I though topography was evolving (line 100).

- **Results** As stated in the letter, basal conditions are not the only driver of glacier sliding, so basal shear-stress should be implemented into this results and findings.

- **Ln 214** I was expecting a section titled "Temporal patters of glacier erosion" here.

- **Section 3.3** As mentioned the letter, the amount of time needed for the englacial temperature to adjust to the climate can be very large (10's of thousands of years). It seems that some comments on the basal temporal variations and the response time of the glacier bed to atmospheric forcing would help this section.

- **Section 3.4** Coupled with sensitivity to temperature, precipitation can affect glacier morphology and thus the stress balance. Generally, glaciers with a steeper mass balance gradient will slide faster and thus may increase in erosion.

- **Section 3.5** Nice commentary. I am glad this is discussed.

- **Ln 294–305** The findings of Anderson et al. (2012) could fit well here. Also, it may be appropriate to find an alternate explanation (average glacier conditions), but do findings here support that?

- **Ln 303–305** Here some temporal evolution topics are discussed, more would be appreciated.

- **Ln 294–312** A recent paper by Mariotti et al. (2021) high-lights the impact of climate on glacial erosion in the sediment record. I believe this paper could help the authors and give context to some findings.

- **Ln 315** “role of precipitation. . . .” Cook et al. 2020 speaks to this.
- **Ln 317** What process is responsible for precipitation changing the thermal regime? This needs some explanation, and does the relevant process fit the timescale of the erosion in the model run?
- **Ln 329–333** This is true and precipitation is not always represented well. However, it can be represented by having a large (steep) mass balance gradient in a linear mass-balance forcing relationship. Some caution should used here.
- **Ln 334–339** Comparison with Koppes et al. (2015) is very difficult. Some of the differences are discussed (i.e. land vs marine terminating). However, such a comments also requires considering the evolution of glaciers as they respond to climate.

Figures

- **Figs 1–3** There is a black box around the figs in the print version. Not a big deal but worth a thought.
- **Figs 4** Would it wise to plot ”Warm basal ice” vs ”Glacial erosion”?