Earth Surface Dynamics Discussions

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Comment on esurf-2021-88

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Referee comment on "Modeling the spatially distributed nature of subglacial sediment transport and erosion" by Ian Delaney et al., Earth Surf. Dynam. Discuss., https://doi.org/10.5194/esurf-2021-88-RC1, 2022

Summary:

This paper is a modeling study of subglacial sediment transport. Subglacial sediment production and transport is important as a major landscape construction process in glacial-deglacial settings, and can greatly impact downstream rivers' water quality. Whereas physics-based glacial ice flow models are now sophisticated enough to be merged into global climate models, understanding of the role of basal erosion and subglacial sediment transport interactions is much less understood. The authors are pioneering a reduced-complexity numerical model of glacial processes and subglacial hydrology.

The study implements a two-dimensional subglacial sediment transport model using previously formulated subglacial sediment transport and bedrock erosional processes presented in Delaney et al 2019. A new, be it simple, planview flow and sediment routing scheme is added to the model to transports sediment down-glacier based upon the hydraulic potential gradient. It is in this coupled component that the novelty of this paper lies!

However, findings from some of the synthetic model case studies (most notably the ice sheet case) are hard to interpret/generalize, as process outcomes depend on the simplifications and boundary conditions. I recommend improvements to the study design and results sections. These changes involve omission and clarification, they do not change the model design perse or require entirely new simulations, so I would call them moderate revisions. I detail suggestions in the notes below.

Major comments

The study implements a two-dimensional subglacial sediment transport model using previously formulated subglacial sediment transport and bedrock erosional processes presented in Delaney et al 2019. A new, be it simple, planview flow and sediment routing scheme is added to the model to transports sediment down-glacier based upon the hydraulic potential gradient. It is in this component that the novelty of this paper lies.

Three cases are used to demonstrate model input and behavior. These synthetic cases are inspired by the Subglacial hydrology Model Intercomparison Project (SMIP), which is a sound applaudable approach! The aim is to use the synthetic test cases to show the model's ability to reproduce known processes and find new insights into the spatially distributed processes responsible for subglacial sediment dynamics. However, I think that there may be improvements to the study design and results sections needed.

For the synthetic ice sheet case, this study finds that sediment discharge in the model run decreases after the climate warms and reaches a stable regime. The decrease occurs due to sediment exhaustion from increased water discharge, and associated sediment transport, which removed till that was unable to be transported in a cooler climate with less available meltwater able to transport sediment.

I find this model behavior problematic to generalize: it would be an interesting finding, depletion of sediment flux, yet the outcome is entirely controlled by the model assumptions on initial till height and bedrock sediment production. So, it is hard to draw any conclusions on this process being of relevance?

I think the paper would be strengthened by omitting this case study, it oversimplifies the ice sheet system by too much.

Results on the effect of spatially-distributed fluxes seem of more of importance, and this effect is more pronounced in the alpine glacier case. The alpine glacier case recreates high sediment concentrations in early season, and his is explained by spatial variability in the till distribution and sediment transport access to these sediment patches. This effect has been observed in proglacial streams.

It seems that there is a large process parametrization discrepancy between the general bedrock sliding law applied (with no grainsize dependence and validated over glacial-deglacial scales) and the heavily grainsize dependent sediment transport law (Engelund-Hansen). A note of caution should probably already be added into the results section, and refer to the later discussion section on this topic.

On the structure of the paper:

Title: I recommend simplifying the title.

Suggestions: "Bedrock erosion and sediment transport variations across a glacier bed controlled by glacier behavior and hydrology" or "Modeling of the spatially distributed nature of subglacial sediment erosion and transport dynamics"?

Introduction: can be tightened. Please read carefully through and omit some of the sections that are repetitive or wander.

Model description: I do appreciate the review of the hydraulic model, even if it previously been well described in Delaney, 2019, but is needed here to have this paper be a stand-alone contribution.

I found the order in Section 2.2 non-intuitive. Indeed, it is important to detail the Exner equation approach first, but then begin with bedrock erosion parametrization, as that is the term that produces sediment, and then describe sediment transport.

One suggestion to make each of the source terms and in-out fluxes clear is to add a diagram of a mass fluxes in the Exner equation, and label the processes. Like Fig 1 in Paola and Voller, but then made specific for this special implementation.

Line-by-line minor comments:

line 6: the concept of 'sediment connectivity' needs explanation or definition before being invoked as an important control. Either explain within the abstract, or omit.

Line 14: this sentence is unclear."We find that sediment grainsize plays an important role. Smaller sediment sizes....

Line 24: possibly add this paper by Dongfeng Li 2021, although the increasing sediment

loads are not just attributed to glacier melt but also due to permafrost thaw and rainfall change. Li, D., Lu, X, **Overeem, I.**, Walling, D., Syvitski, J., Kettner, A.J., Bookhagen B., Zhou, Y., Zhang, T., 2021). Exceptional increases in fluvial sediment fluxes in a warmer and wetter High Mountain Asia. *Science, 10.1126/science.abi9649*

Line 30: replace with: 'are limiting nutrients in the oceanic ecosystem'

Line 45: add flow after …water

Line 51: although if there is little sediment embedded there is little abrasion!

Line 90: please clarify this approach: is there a single hydraulic diameter and single associated water discharge for the entire distributed drainage system? Or dothese properties Q* and Dh get assigned/calculated for individual drainage channels?

Line 94: this selection of representative discharge seems really difficult and perhaps arbitrary? how do you decide ahead of time what quantile (or did you mean quartile?).

Line 103: please spell out R-channel at its first occurrence.

Line 124: I am not sure about the limit, H-lim, at 10 cm, this seems really arbitrary. Sediment transport in a pressurized pipe flow can probably easily scour bedforms to 4-5 times that depth almost instantaneously? I understand that perhaps there is little data to constrain this parameter, but it may be prudent to explore whether the model is sensitive to this setting.

line 165: this switch in describing code is a bit out of style, perhaps better to describe this in the code documentation as opposed to command lines in the paper.

line 177 Reference is oddly formatted, please make conform journal requirements

line 184 First explain why this would be a non-stiff problem, and then state that this solver is apprporiate for non-stiff problems.

Line 202-208 this section has several ‘disclaimers’ on your assumptions that would be better suited for the discussion of model limitations later in the paper.

Line 245: I am not intimately familiar with SHMIP, but does the rate of temperature offset originate from those setups? Do I understand it right that the total warming scenario is an added 15 degrees C to diurnal amplitude? Over 30 years? That warming rate seems really abrupt, and unprecedented even under the most catastrophic warming scenarios?

Line 255: line 255 replace till height by thickness?

Line 372. Repeat for careless readers, what are the last three time spans?

Line 374. Isn’t one of the important changes of this approach that you do have a way to access different patches of the glacier bed?

Could it be model underestimation of till thickness and erosion instead?

Figures

Figure 2: This figure is really helpful in providing a feel for the dimensions of the subglacial drainage network , flow velocity magnitude (small), and spatial distribution of discharge.

Figure 3. Recommend this figure to go to an appendix. It is not too well explained in the text and seems important for a manual of the model, not for the scientific findings.

Figure 5: Perhaps improve this figure by changing the aspect ratio of these figures, at present they are hard to read.

May help to add 2 initial panels with icesheet topography map and ice flow velocity? And then have the 'maps' of the basal conditions.

Figure 7

May help to add 2 initial panels with icesheet topography map and ice flow velocity? And then have the 'maps' of the basal conditions.

Perhaps improve this figure by changing the aspect ratio of these figures, at present they are hard to read.

Great to see this as animations.

Figure 9. Remove ‘likely ‘ from the caption.

Figure 10.Add to the figure caption what parameters are modeled vs observed.