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Interactive comment on “Modelling steady states and the transient response of debris-covered glaciers” *by* James Ferguson and Andreas Vieli

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In this study, the authors apply a debris cover parameterisation to a flowline model in order to study some aspects of the transient response of debris covered glaciers to climate change. This paper helps to better understand the dynamics of debris covered glaciers, and I very much enjoyed reading it (I may be biased because I like idealized numerical studies).

Parts of my review originate from a discussion with colleagues Lilian Schuster and Lindsey Nicholson, and I would like to acknowledge their contribution here. Finally, I would like to apologize for my late review which doesn't serve well this nice paper.

1 General comments

- At the end of the introduction, you write: “*to date no study has used a coupled ice flow-debris transport model to study in detail the transient response and characteristic response times of a debris-covered glacier. This study aims to fill this gap...*”. “It has never been done before” is not a good motivation for a study, and I think that the paper would gain from clearly stated research questions. In particular, it would help to understand what motivated the model design and the design of the idealized experiments (why this bed profile, why this model design, etc.). Research questions will also help to place the study in the context of previous literature, and prepare the reader to understand what you are trying to achieve with this paper.

- The word "idealized" does not show up in the title, abstract, or introduction. I think it should be clearly stated much earlier (maybe not in the title, but at least in the abstract). “Numerical modeling” could be understood as “applied to real glaciers”.

- This may be subjective, but I don't find any of the comparisons with Jóhannesson's response times informative or useful. Even without debris cover, you can find numerical response times of glaciers which are widely different than the analytical ones, since the e-folding times are highly dependent on parameters such as bed depressions, mass-balance (MB) gradients, etc. (see e.g. Zekollari et al. 2015 or Schuster, 2020 - unpublished thesis work).

- Your code availability statement (“available upon request”) is against this journal's data and open science policies: https://www.the-cryosphere.net/policies/data_policy.html. I strongly recommend to make your code available (under a clear license), which will increase the visibility and re-usability of your work.

2 Specific comments

Abstract I'm not very familiar with the debris-covered glacier literature, but I had to search for "cryokarst" online

Abstract add "idealized numerical simulations"

eq. (1) consider using b instead of a for mass-balance (more common I believe)

L72 "for a given a bed elevation" - remove "a"

L96 having read section 2.1.4 and the appendix, it's still not clear to me how you compute H^* (and I don't want to check up on Anderson et al 2016). I notice later that H^* is a constant and a model parameter: mention this earlier in the text.

L100 specify which appendix.

Appendix A despite of your valid attempts to show that this boundary condition may be found in the real-world, I still believ that the ice-free terminus condition is more a model necessity (trick) than a real-world feature. You don't have to change anything in the text here, I just wanted to comment on that.

Sect. 3.1 (steady states) I really had to think twice about how you can reach steady state with such a model. I think that it would help to write more about it. E.g. by saying again that (i) steady state can be reached only because the MB doesn't go too close to 0 and (ii) that this is only possible by removing debris at the terminus and effectively capping the debris thickness to a reasonable value. You can refer to Fig. S1 in this section (or mention typical values of MB at the terminus in the model) to help understanding.

L155 to our knowledge, Jóhannesson et al, (1989) wrote:"The volume time-scale tau can be computed from the volume differences between two steady-state profiles

scaled to the causal mass- balance change", but did not mention the e-folding volume response time (yet). Maybe refer to another paper as well: e.g. Oerlemans (1997) or Jóhannesson (1997)

L185 volume-area scaling: since it might be unclear to some of your readers, add here that (in your model) area is directly proportional to length

L190 is "stagnant" the correct term here? I was confused several times in the manuscript about this, because you seem to use "stagnant" for when the glacier length does not change. Personally, I understand "stagnant" as "ice that is not moving" ($u = 0$). You cannot have "stagnant" ice with your numerical model setup. I would argue for using "stable terminus" in place of "stagnant", or clearly state in the text what you mean with "stagnant". At the very end of the paper there is a sentence going in this direction ("*stagnation or more specifically the cessation in local dynamic replacement of ice.*").

L277 "stagnated": same here. Is it the correct way to say that? Non-divergence is still happening with u constant and non-zero, i.e. moving ice.

Section 3.3 "white noise" traditionally, white noise climate should be applied on a year to year basis and the periods of cold and warm climates would occur "naturally", as a result of random sampling. I wonder how this would affect your results. Additionally, I wonder if an annually varying MB would still work with your debris cover formulation, since you don't deal with temporary ice/snow cover on debris as for now.

Fig. 5 while this figure carries well your main message, I think that it can be misinterpreted. In particular, the blue line in Fig. 5b gives the impression that the glacier will always grow, i.e. never reach a "steady state" (i.e. an average length around which it oscillates - albeit in a strange, debris covered way). What you could do here is continue the simulation for an additional 5k years (at least) and see what happens. It might have an interesting consequence: the “average length” of a debris covered glacier under a *random* climate might be longer than the length of the same glacier under *constant* forcing. I expect the average length to be somewhere between the steady state lengths with the two ELAs (although it might even be longer than that, which would be very interesting to discuss further).

Figure S1 : write that "SS" stands for “steady state” in the legend.

3 References

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