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Interactive Comment

Interactive comment on "Modeling debris-covered glaciers: extension due to steady debris input" *by* L. S. Anderson and R. S. Anderson

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The authors present a 1-D ice flow model that incorporates the feedbacks between glacier mass balance and glacier length, and imposes the effect of rock debris deposition onto and transport through the glacier. The model is used to explore the phenomenon that debris-covered glaciers can advance indefinitely in the absence of climatic change due to the insulating effect of supraglacial debris that reduces surface mass balance. The model is suggested to be representative of glaciers in the Himalaya, relying on data presented by Scherler et al. 2011, but only weakly represents these glaciers using a few measured parameters from this region. The model design is not sufficient to represent the behaviour of specific glaciers in a region with highly negative mass balance and instead would be more convincing as a theoretical case. In particular, the model only operates with steady state simulations, whereas the mass balance of present-day glaciers in the Himalaya is clearly far from equilibrium. The strength of this study lies in the study of the internal processes that cause debris-covered glaciers to change in the absence of climatic change. However, the comparison with data from glaciers in a sustained state of mass loss is misleading. The manuscript could be revised to focus on exploring the behaviour of debris-covered glaciers in the absence of climatic change and the conditions that govern their transition into rock glaciers and the geological record. The manuscript is mostly well written, but would benefit from greater clarity and enhancing accessibility to a broader audience (I have given some minor comments below).

Major points Relevance of the study to present-day glaciers. The introduction section almost exclusively considers glaciers with negative mass balances where mass loss has been ongoing for several centuries. However, the work presented here does not address glaciers in this condition, but rather those that are slowly advancing without a climatic driver. The comment on P6425 at line 15 is misleading; whilst a minority of Himalayan debris-covered glaciers are advancing (which may be due to distinctive surge-type behaviour, although it is not clear here which glaciers the authors refer to), the majority lose mass by surface lowering rather than terminus recession (e.g. Bolch et al. 2011, TC), so comparison of their terminus positions over time is a poor metric by which to explore glacier change.

Implications/impact of the modelling. The authors could revise the manuscript to instead consider hypothetical glacier change rather than by attempting to match observational data, still by using mass balance/flow parameters that are representative of real glaciers. The interest in this study for me is in exploring how debris-covered glaciers can advance in the absence of climatic change, transform into rock glaciers, and how these processes are observed in the geological record. Under what conditions will an advancing glacier retain sufficient supraglacial debris to significantly affect its mass balance? The authors state that these results have important implications for palaeoclimate reconstructions from glacial geology, which would be a valuable outcome from this study.

Assumption of steady state. The main model output is change in glacier length, which is not a suitable variable for observation of debris-covered glacier mass loss when considering present-day glaciers with a generally negative mass balance, such as those in the Himalaya. Moreover, the authors should emphasise the usefulness of their steady-state simulations to this study; for example P6426 line 24, clarify if/why one would expect debris-covered glaciers to ever reach equilibrium. The dataset presented by Scherler et al. 2011 captures glaciers where surface lowering is sustained and is therefore difficult to relate directly to the model results. The impact of climatic change on debris-covered glaciers could be discussed by reference to transient simulations by Rowan et al. 2015, EPSL.

Relevance to Himalayan glaciers. The simulations presented here cannot be considered to represent 'real' glaciers as the model design is too simplistic to capture the key factors controlling the behavior of these glaciers, such as high relief, variable bed topography, highly variable flow velocities, and highly negative mass balances. While the model parameterisation may be more representative of Himalayan glaciers at some point in the geological past, the assumption of steady state undermines the relevance of the study to a complex set of glaciers in a variable climatic regime. The comparison to glaciers in the Himalaya or indeed elsewhere, does not add value to the paper as there is no clear indication that mountain glaciers ever approach steady state over decadal–centennial timescales. This could be addressed by considering longer-term change over glacial cycles where small climatic fluctuations could be "averaged out" by much larger glaciers.

Manuscript style. The manuscript is mostly well written, but would benefit from being more accessible to a glaciological and geological audience. The introduction does not really describe the specific problem considered in the study. Even with similar interests to the topic of this manuscript, I found the detail of text and figures somewhat dense and difficult to follow in places. In particular, the relevance of different parameters noted to impact on and be affected by glacier behaviour (debris cover, AAR, glacier velocities, etc.) should be discussed quantitatively in light of the outcomes from the modelling experiments.

Minor points Title: would better describe the study and read more readily without the colon. Suggest: “Modelling the extension of debris-covered glaciers due to steady debris input” or similar, as the model presented in this manuscript simulates this rather than all aspects of glacier change.

Abstract: should include more clearly quantitative results, for example, the conditions of the experiment described by “Our model and parameter selections produce two-fold increases in glacier length.” is not clear.

P6425, line 2: Scherler et al. 2011b is cited before 2011a.

P6425, l 5: “ablation” rather than “melt”

P6425, l 14: what is meant by “almost coherently”?

P6427, l 4–5: please phrase the problem more precisely, e.g. “how does the location/timing/frequency/magnitude of debris delivery and the description of the relationship between debris thickness and ablation affect change in glacier length/rate of advance/mass balance, relative to glacier morphology (e.g. size, shape, etc.)”.

P6428, l4: are these simulations run over thousands of years?

P6436, l23: for Khumbu Glacier debris-covered ice mass balance, see also Benn and Lehmkuhl, 2000, Quaternary International, and references therein.

P6443, l24–26: this is not a helpful conclusion for those investigating palaeoclimate indicators in high mountain environments! Could your model results be used to reduce these uncertainties?

P6446: The “Future Work” section would be more usefully presented as “Limitation of

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the current study" or similar, to help the reader evaluate the strengths and weaknesses of the approach and results presented. The authors are then free to investigate these in future without asking the reader to wait to discover the value of the present study.

P6447, l7: what is meant by "memory in the system"?

P6447: Some of the points presented in the conclusions could be drawn from previous work rather than the current study and can be removed to the introduction. Quantitative outcomes of the present study are needed in the conclusions (and the abstract) to demonstrate where the most important sensitivities of debris-covered glaciers are. Finally, the conclusions would preferably be written as continuous prose rather than bullet points.

Interactive comment on The Cryosphere Discuss., 9, 6423, 2015.