Response letter for Model-based analysis of solute transport and potential carbon mineralization in the active layer of a hillslope underlain by permafrost with seasonal variability and climate change, by Hamm, A., Mannerfelt, E.S., Mohammed, A., Painter, S.L., Coon, E., Frampton, A.

23 May 2025

Message from Editor

Based on the last reviewer's report, it appears that the main issue, namely the clear definition of the study's focus, has been addressed adequately, leaving only minor concerns regarding the description of the methodology. If these can also be addressed, the manuscript should be in a good shape for publication.

Response: We thank the Editor for their careful assessment and positive feedback and appreciate the recognition that the main concerns have been addressed. We have revised the manuscript to clarify the remaining points raised by the Reviewer, as outlined in our responses below. We are grateful for the Reviewer's recommendation for acceptance with minor revisions and for their support in moving the manuscript toward publication.

Comments from Reviewer

The additional work done by the authors enables to better defined the scope and the limits of their study. The authors propose a modelling work somewhere in between the study of an idealized, generic case and the study of a site-specific case, which in my opinion makes difficult to draw the line between the conclusions that are generic and those that are site-specific. Nevertheless that is the explicit aim of the authors, and as such I think that it can be presented to the community. I have still some minor concerns regarding the presentation of the study site and of the simulation methodology that should be dealt with prior to publication, see my specific comments below. But overall I think that now the manuscript is in a sufficiently good shape for publication, so at this stage I recommend acceptance with minor revisions.

Response: We thank the Reviewer for their constructive feedback and positive assessment. We have carefully addressed the remaining minor concerns regarding the presentation of the study site and simulation methodology, as detailed in our responses below. We believe these revisions further clarify the objectives and methods and further strengthen the manuscript presentation.

Specific comments:

l99-111 (line numbering from the final manuscript version): in this paragraph the ecotype of the site (tundra, bare soil, ... ?) must be given.

Response: The site description has been updated with a specification of high-arctic mountain tundra, as follows (L103): “The landscape in the area is characterized by high-arctic mountain tundra with gentle slopes towards the valley bottom …”

l115-116: “a synthetic domain that is broadly representative of hillslopes in continuous permafrost regions.”
I am still not convinced that the chosen hillslope maybe considered as ‘broadly representative’ of continuous permafrost region. This is a N-W slope in (probably) high arctic tundra, most likely it is not representative of S-E slopes, or of boreal forest environments. This sentence could be rephrased as follow : “a synthetic domain that is representative of the site conditions, in a high arctic tundra environment (?) of the continuous permafrost area.”

Response: This specification has been included and the text has been rephrased, as follows (L115): “The model design aims to capture key physiographic characteristics of the site and is intended to be a synthetic domain that is broadly representative of hillslopes in a high-arctic mountain tundra environment underlain by continuous permafrost.”

l 154-156: “The variable-width mesh approach preserves flow convergence, enables a reasonable representation of the surface-energy balance, and allows hydrological processes to be well represented without the expense of a fully three-dimensional model (e.g., Fan and Bras, 1998; Troch et al., 2003; Hazenberg et al., 2015).”
Concerning the ‘reasonable representation of surface-energy balance’ and the ‘well represented hydrological processes’, this sentence presents assumptions as demonstrated facts, at least in permafrost contexts. Moreover, the cited literature does not deal with coupled water and heat transfers with freeze/thaw, nor with solute transport. The sentence could be rephrased in the following way: ”The variable-width mesh approach preserves flow convergence, and enables a reasonable representation of the hydrological processes in non-permafrost contexts without the expense of a fully three-dimensional model (e.g., Fan and Bras, 1998; Troch et al., 2003; Hazenberg et al., 2015). In this study we assume that this modelling approach is also suitable for the simulation of coupled water and heat transfers with freeze/thaw, and to waterborne solute transport in such a permafrost context.”

Response: This has been included and the text has been rephrased, as follows (L154): “The variable-width mesh approach preserves flow convergence, enables a reasonable representation of the surface-energy balance, and allows hydrological processes to be well represented without the expense of a fully three-dimensional model (e.g., Fan and Bras, 1998; Troch et al., 2003; Hazenberg et al., 2015). In this study we assume that this approach is also suitable for simulation of coupled water and heat and solute transport with active layer freeze-thaw in a permafrost environment."

l 675-676: "Simulated temperature and x-velocity using the fine and superfine meshes are nearly indistinguishable (Fig. D5 and D6)." Indistinguishable by the human eye on a figure is not a relevant criterium of comparison for a convergence study. Here a quantitative comparison must be done, for instance by giving the L1 and L2 norms of the values of the differences between the temperature fields obtained with the two meshes.

Response: A quantitative comparison between the temperature fields and velocity fields for the mesh cases further demonstrates that the differences between them are negligible. We updated the text in Appendix D showing the result of the differences, as follows (L678): "The mean absolute temperature difference between the fine and superfine meshes in the thawed part of the highly refined transport region is 6.55 10^-3 C. The mean absolute difference in x-direction Darcy velocity between the fine and superfine meshes in the thawed part of the highly refined transport region is 5.91 10^-7 m/s."