

The Cryosphere Discuss., referee comment RC1
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Comment on tc-2021-60

Anonymous Referee #1

Referee comment on "Impact of lateral groundwater flow on hydrothermal conditions of the active layer in a high-Arctic hillslope setting" by Alexandra Hamm and Andrew Frampton, The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-60-RC1>, 2021

General Comments

Hamm and Frampton employ a hydrology-thermal model to analyze the role of slope on active layer thicknesses for idealized Svalbard hillslopes. The authors suggest that subsurface temperatures are warmer on the uphill side of hillslopes and as a result, these regions have deeper active layers. While the work presented is likely of interest to the hydrologic and cryospheric communities, there are several specific problems involving the downslope model boundary conditions, lack of model calibration, upscaling of findings, and disclosure of modeling assumptions/limitations that need to be addressed before this manuscript should be considered for publication. I have included additional information that details specific major areas for improvement below.

- As stated on L135-136, the “downhill end of the transect represents the valley bottom and allows for water accumulation and potential ponding on the surface”. According to Figure 2, this downhill boundary is a no-flow and no-heat flux boundary but there is little justification for this no-flow condition. It looks like in Figure 1c that these hills ultimately flow into a river so are instead, flow boundaries. It may make more sense to represent these as flux or constant pressure boundaries. As no-flow boundaries, I worry that they are artificially blocking heat transport and accumulating water, which is why the rightmost column in Figure 4 does not make sense with the rest of the modeled cross-section. If these no-flow boundaries are not affecting the model outputs, it would be helpful to see a comparison of model outputs with and without the no-flow downstream boundary in the supplements. If this downslope no-flow boundary does change results, please revisit much of the results text, including your third conclusion.
- The presented models are referred to as idealized but are based on field data from Adventdalen, Svalbard which makes me wonder why a calibration was not performed? I think that uncalibrated models can be useful thought experiments, and I understand that calibrating and validating a model can be taxing. However, I question the validity of using conclusions from a model that is not calibrated to existing field measurements, especially using a model that is in the middle ground between an uncalibrated generalized model and a model that is calibrated. At a minimum, the authors need to

suggest how the model results may compare to field observations of similar sites.

- It is unclear how relevant these findings are to permafrost landscapes throughout the Arctic. How often are there hillslopes of a constant slope without valleys and lateral (cross hillslope) water flow? Even more basic, what percent of the Arctic is sloped terrain? Any additional information that could be provided to aid in the upscaling of these results outside of Svalbard would be beneficial.
- The assumptions of the study, especially the modeling assumptions, should be specifically stated in a separate section. For instance, this simulation doesn't include an organic layer, but organic layers exist in many permafrost landscapes and have very different thermal properties from mineral soil (this goes back to if these results can be upscaled or not). Is it reasonable to model hillslopes in only two-dimension? I think it can be but the reason for doing so needs to be stated and supported with other peer-reviewed papers.
- The main text needs to be revised for clarity. The figures are attractive and easy to see, which is appreciated, but many of the figures need additional annotations or subfigures to help with comprehension. It is also unusual to have the results and discussion sections combined. I would highly recommend separating these sections so you can have a more thorough discussion section where you interpret your results and compare them to other peer-reviewed studies. As is, this combined section is quite long and hard to digest. I have pointed out some specific examples below where the text and figures need to be revised for clarity.

Specific Comments

L6, How representative are these hillslopes of Arctic landscapes as a whole?

L15, Since this study only considers one slope versus a 'hilly' landscape, I would hesitate to draw this conclusion about hilly terrain.

L29, Rather, permafrost degradation has been found to increase groundwater discharge into surface waters, not decrease the seasonal variability.

L41, How much topography is 'more topography'? Is there are slope cutoff? Be specific.

Section 2.1, What are typical active layer depths at the study site?

L107, How far is this from the weather station in km?

L118, What is the hillslope length?

Figure 2, It would be helpful to show node locations.

L136, What is the depth of the mineral soil?

Table 1, Thermal conductivity values are low for a mineral soil, I would expect closer to 2.7 W/mK.

L140, What makes the no flow lateral (right and left) boundaries? Are they a watershed divide? Seems unlikely given the flat lateral topography.

Figure 3, I'm confused about what these plots are showing. It would help with clarity to first plot the temperature time series for the steep, medium, and flat simulations for both uphill and downhill and then plot these differenced values. Would also be helpful to annotate this figure, for example, you could write 'uphill warmer' above the x-axis in (a).

L192, What about the large November peak at 0.75 m in Figure 3a?

Figure 4, Label color bar with units. Which is the uphill side? Horizontal distance=0 m? Label this on the figure. Why is the far-right column in each subfigure so different than the other columns? It looks like a potential modeling error due to the no-flow boundary conditions that do not physically make sense. This difference was pointed out in section 3.2 but is concerning. Also, are the two dotted lines in the October subfigures showing the presence of a horizontal talik?

L279-280, This is likely due to the no-flow boundary on the downslope side, and is not realistic if there was a river or otherwise at this boundary.

L284-286, What about the role of specific heat, where specific heat is higher for saturated soil than unsaturated soil? This may explain your results on L390-391.

L326, Vertical diffusion of what? Heat diffusion? Be explicit even though you go on to reference heat.

L430-440, Why are these processes more relevant for a high-Arctic hillslope setting if they are for sites with no topography?

Technical Comments

L2, What is 'its'? Permafrost?

L4, Delete 'want to'.

L6, Indicate that these are the 'steep' and 'medium' cases.

L50-54, These sentences seem out of place and are too short to form a paragraph. Add more studies, incorporate them into the previous paragraph, or remove them.

L55, What is the length of the hillslopes? I imagine hillslope length will alter results.

L55, Add 'two-dimensional'.

L54-73, Condense into one paragraph, move study site details to study site section.

L68-69, Delete, repetitive.

L71, To 'what' extent.

L71, I think replacing 'inclination' with 'slope' would make this easier to understand as it uses the more common term.

L72, Typo, 'to'.

L89 and L93, Citation typo.

L112, This is the mean snow and rain for 2013-2019, correct? It's unclear as written.

L118-119, Change to 'slope'.

L149, What does 'field values' mean here?

L162, Typo 'initialization'.

L186, Delete 'significant' are these trends statically significant?

L187-188, Highlight these times (thaw and freeze up) in Figure 3 with shading or otherwise.

Table 2 and 3, Can move to supplementary material.

L199-203, Redundant, can be removed.

L205-206, I don't think you can draw this conclusion from the presented data, save this for the discussion.

L207, What do you mean by 'inversion of temperature differences'? Please reword.

L207, Again, I don't think this necessarily indicates this conclusion, remove.

Figure 5, Delete panel (b), panel (a) is clearer and shows a very similar result.

L279, I'm not sure what lateral gravitational water flow means exactly since water flows vertically due to gravitational attraction.

Throughout, Refer to as 'heat' diffusion.

L337, This is an important point to make.

Section 3.7, Add a more descriptive header.

L435-436, Also see McKenzie and Voss, 2013.

McKenzie, J. M., & Voss, C. I. (2013). Permafrost thaw in a nested groundwater flow system. *Hydrogeology Journal*, 21(1), 299–316.
<https://doi.org/10.1007/s10040-012-0942-3>