The Cryosphere Discussions

The Cryosphere Discuss., referee comment RC2
https://doi.org/10.5194/tc-2021-60-RC2, 2021

Comment on tc-2021-60

Anonymous Referee #2

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-RC2, 2021

This paper uses idealized thermal hydrology models to investigate the influence of sloped topography on active layer thermal dynamics. Essentially a sensitivity study is performed with varying sloped domains. The sloped model domains caused subsurface water flow, drainage from uphill and increased saturation on the bottom of the slope. These are very complex processes and it is very difficult to untangle everything that is going on. To the authors credit they provide a thorough explanation of many of the possible mechanisms controlling the thermal state of the domain, which is inherently complex. Untangling these processes to understand thermal hydrology on sloped domains is important and of interest to the readers of Cryosphere. Unfortunately, as complex as the processes discussed in this paper are, the message becomes lost and confusing due to the complexity of the problem. Be that as it may, this means that the authors must work hard to simplify the message as much as possible and work to focus the manuscript so that the reader can understand what mechanisms are important. I therefore recommend substantial revisions to focus the text on the main processes driving the thermal state of the simulated domains. This is not to say that the work is not good. In fact, I am impressed by the modeling and all the analysis done. However, I strongly encourage the authors to edit and trim for the sake of clarifying the message of the paper.

- Based on what I read, the main message is because of variable saturation, hillslopes experience different thermal regimes with warmer upslope areas and cooler down slope areas. The paper seems to focus on how increased moisture in the down slope area causes increased evaporative cooling. However, the overall thermal state of the domain is slightly warmer. I'm left wondering why are sloped simulations overall warmer? Only at the end of the manuscript when the authors do an additional sensitivity study by adding more precipitation do we see a general cooling effect of the entire domain. This then suggests that it is a water balance mechanism caused by slope, i.e the system tips the evapotranspiration into an energy limited system rather than water limited and as more water is added. And that area of the domain with more evaporative cooling outweighs the domain that is water limited. However, the water balance verses degree slope, which appears to control the overall thermal state of the entire domain is not discussed.

- Similarly – and at a much smaller scale, Abolt et al., (2020) found (using the same ATS model) that rims in polygonal ground warm more in the summer due to drier conditions and associated weakened evaporative cooling, which then provides energy laterally to the cooler saturated troughs in the summer (see section 5.2 of Abolt et al., 2020). However, what determines if a saturated area is cooler or not also depends on the mass of water present. If enough water is present, especially on the surface, then a Talik will begin to form, as demonstrated in a 1D column by Atchley et al., (2016-section 4.2) and by Abolt et al., (2020) for wide troughs. This is because the timing of phase change during freeze up when snow is building can cause wet areas to stay warm throughout the winter, especially as the amount of water increases because it then requires a lot more energy loss to cross the freeze curtain. The difference with the study presented here is: 1) vary little surface inundation occurs due the surface runoff boundary condition and the assumed energy equilibrium at the downhill domain boundary condition. This assumption may not capture the thermal influence of the saturated condition beyond the boundary of the domain. And 2) very little snow accumulation occurs, which would otherwise insulate the more saturated areas during freeze up. Given that the simulations with added precipitation showed an overall decrease in ALT, this work might suggest that increased evaporative cooling affect may outweigh the increased energy loss necessary to cross the freeze curtain. However, given the larger thermal hydrology work in literature, it would be beneficial discuss these tradeoffs as well as discuss how influential an appreciable snowpack may change the results. i.e there could be a combined warming in the dry areas (little evaporative cooling) and persistent warm winter conditions in wet areas from insulative snowpacks.

Abolt, C.J., Young, M.H., Atchley, A.L., Harp, D.R. and Coon, E.T., 2020. Feedbacks between surface deformation and permafrost degradation in ice wedge polygons, Arctic Coastal Plain, Alaska. *Journal of Geophysical Research: Earth Surface*, *125*(3), p.e2019JF005349.

Atchley, A.L., Coon, E.T., Painter, S.L., Harp, D.R. and Wilson, C.J., 2016. Influences and interactions of inundation, peat, and snow on active layer thickness. *Geophysical Research*

Letters, *43*(10), pp.5116-5123.

Minor comments:

L58-59: In this case the benefit of numerical modeling probably has less to do with the remoteness of the study area, and more to do with a characterized sensitivity study as well as being able to dissect the energy fluxes across the full domain, something that would take tons of sensors to do in the field.

L72: Change 'Tho' to 'To'

L89: (Painter, 2011) is outside of either sentence, I think it goes with the previous one.

L118: Omit one of the 'a steep case'.

L147-148: Why would you want to maintain a constant (same) snow accumulation across the hillslope domain, and is that realistic? This is likely to have a strong effect of simulations results.

L153-161: Note that these CV locations are right at the domain boundary, and therefore subject to any edge effects of the model domain. The assumptions and implications of being on these domain boundaries needs to be discussed in more detail. This might be especially problematic with the downhill CV, given that the no flow (energy) boundary condition assumes equilibrium with a larger body of water or saturated area.

L207-208: This sentence needs to be more specific. What do you mean by inversion of temperature differences? Differences between uphill and downhill observations? Or differences between sloped and flat? Also, what are the different processes responsible here?

Figure 3 needs more explanation in the caption. Hard to interpret it at a glance.

L215: "The upper three panels in each figure…". I assume you are talking about Figure 4 here, but it is not clear. I suggest phrasing this as, "The upper three plots in each panel…" as 'figure' refers to figure 1 through 9 in the paper, 'panel can refer to a and b, and plot is the sub plot of each panel.

Figure 7: I like this figure, or at least what it is attempting to convey. However, I think it could be improved, or perhaps simplified. Is the story in the time series of the flux? Is it necessary to show the whole time series? If not, I would suggest just showing the cumulative flux, or maybe the difference of the fluxes between the cases. That may help with the scale issue. Additionally, the location of the representative volumes in relation to

the fluxes going in and out is confusing, i.e, the lateral energy flux going in the downhill volume (positioned right in the domain) is found left in the figure. This means the reader (me) has to mentally flip the image.

Figure 8: These are pretty small fluxes. Is this figure necessary? I think this paper as a whole makes a decent argument that groundwater dynamics are important in determining the thermal state of the hillslope, even if advective fluxes only play a small role. In other words, the influence of groundwater dynamics happens in other processes. I would suggest focusing as much as possible on those processes rather than advection.

L462: "as compared to the flat case (0.75cm)." is confusing. Does the flat case change in the simulations? I thought the flat case provided a reference datum and therefore should be 0.

Figure 9: "The sign convention adopted is positive values represent heat entering the CV and negative values

leaving the CV." This would mean that I should see the evaporative cooling affect? Correct? Heat and mass leaving the downslope CV during summer?

Section 3.6: This section tests the effect of overall precipitation and demonstrates the overall effect of increased evaporative cooling – at least I think that is the purpose. However, as written it seems to play only a minor role in the manuscript (the text devoted to this seems like an after thought), and there is no figure associated with this text that actually illustrates the point other than those in the supplementary information. It would be better to have a figure in this text.

L424-L432: This paragraph provides a good summery of what was found. It seems like it would fit better in the conclusion section.

L458-46: “This downhill cooling effect is up to about 1.2 C for steep (22_) and 0.6 C for medium (11_) inclinations across a lateral distance of 50m representative for valleys in Adventdalen, Svalbard.” Seems to me that the bigger story here is not the increased downhill cooling caused by the evaporative flux, but the increased uphill warming presumably caused by the lack of an evaporative flux because overall the entire domain is warmer than the flat case.

The conclusion section is not very impactful. The paragraph in L424-432 seems to be a much better conclusion paragraph. Also, after reading the paper several times, I am confused as to why the entire sloped domains are over all warmer than flat domains? The focus appears to be more on the evaporative cooling effect, yet the domains are overall warmer unless precipitation is increased.