Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2019-84-AC1, 2019

Hydrology and Earth System Sciences Discussions

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Interactive comment on "Assessing the influence of soil freeze-thaw cycles on catchment water storage – flux – age interactions using a tracer-aided ecohydrological model" *by* Aaron A. Smith et al.

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Received and published: 29 May 2019

General Comments

In this paper, the authors apply a tracer aided hydroecological model to assess the role of frozen ground on water fluxes, storage and ages in a cold regions watershed in northern Sweden. The model performed well enough to make sound conclusions about the relative magnitude of fluxes and the distribution of ages of water comprising different components of the water budget. The subject matter of this research is very relevant

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in regards to beginning to address larger questions about how climate, vegetation and hydrology interact. These are important questions as the globe warms, and tools such as the model introduced here will be important for predicting and attributing change. The paper is well written. I have some minor suggestions where improvements could be made. A bigger concern is an incomplete explanation of how the authors assessed the role of ground frost on water fluxes and ages. The authors explain that they turn frost dynamics off in the model to do so. I perhaps misunderstand, but how is it possible to not have the soil freeze if the same forcing dataset is used? This is a crucial piece in the methodology and it needs better explaining than currently exists. Without it, the paper does not achieve its goals. There are some suggestions I have that might improve the presentation. My specific comments are below.

Response to General Comments:

The authors thank Reviewer 1 (Christopher Spence) for the indispensable comments which have greatly aided in the clarity of the manuscript. The primary concern raised by Reviewer 1 relates to the dynamics of the soil frost routine. The authors recognize that the explicit nature of the modifications of the model to account for long-term freezing temperatures in water physics may not have been stated as clearly as necessary. For additional clarification, the authors will state that the model would not previously freeze water (regardless of temperature) as the model was not originally designed for cold regions. The modifications presented here allow the model to account for phase change of soil water during freezing conditions as well as limit the mobility of solid water.

Major Comments

R1C1: Page 1 Line 34: It is not clear how the limited number of monitoring sites is tied to implications of hydrological change. Maybe rephrase to "The limited number of long-term monitoring sites with high quality data is a concern because it may prove difficult to document the anticipated hydrological change in these catchments".

Response to R1C1: Thank you for the suggestions. The authors will revise the statement accordingly.

R1C2: Page 4 Line 39: How is the equation presented here related to the assumption that the ground and snowpack temperature are the same?

Response to R1C2: Within the model framework, the surface temperature (Ts) is not directly isothermal with the snowpack, but is damped to imitate thermal conduction through a snowpack. The authors recognize that the earlier definition of the isothermal properties of temperature appeared to indicate that the whole soil profile was isothermal with the snowpack. This will be adjusted within the manuscript and explicitly state (after Page 4 Line 39) that a simple estimation of conduction is considered.

R1C3: Page 5 Line 50: Here and elsewhere, the paper would benefit greatly from the inclusion of units when introducing variables.

Response to R1C3: The authors will revise the text throughout the manuscript to ensure that the units of new variables are included.

R1C4: Page 5 Line 50: These equations imply the soil moisture scheme assumes no movement of water in the column? I cannot think this is correct, and I must misunderstand. Could the authors please improve the clarity here?

Response to R1C4: The reviewer is correct that this is not how water movement is estimated. Rather, the soil water is redistributed within EcH2O and the equation in the manuscript describes how the soil moisture changes after the redistribution due to freezing. This will be clarified in the revision.

R1C5: Equation 6: It might be the version I see, but the equation seems incomplete and the description doesn't quite match with no mention of outflow.

Response to R1C5: The authors thank the reviewer for noticing this typo. There were two subscripts missing in the equation and will be added in the revision.

R1C6: Page 5 Line 62: Perhaps show the equation from Ala-aho, to show the difference to the reader.

Response to R1C6: The authors thank reviewer 1 for the suggestion. The authors will include the equation (inline) to provide a direct comparison for how the modifications are conducted and the influence of the change, as well as the physical meaning of these changes.

R1C7: Figure 1 could be better drafted and explicitly label the locations of S12 and S22.

Response to R1C7: The authors will revise Figure 1 to include the locations of both S12 and S22 as an inset plot (inclusion within Figure 1a was previously tried but was too difficult to see S12 and S22).

R1C8: Page 6 Line 90: Not all of this section includes model data, and some is observational data. You could perhaps retitle the section "Observations".

Response to R1C8: The title of the section will be revised during revision

R1C9: Page 7 Line 20: Perhaps put the simulation period right at the beginning of the section.

Response to R1C9: The authors will move the simulation periods to the beginning of the section.

R1C10: Figure 2: Could the authors add a sentence or two explaining why the water ages bottom out every now and then? Perhaps I have missed it.

Response to R1C10: The water ages in the stream drop suddenly due to rain on snow events which result in rapid runoff of young water rapidly mixing with the older stream water. The relatively low streamflow volume during the winter months results in a large influence in the stream water ages. This will be added to the text.

R1C11: Page 10 Line 89: Are the words dynamic and damped mixed up?

Response to R1C11: The authors will revise this.

R1C12: Figure 3: Please explain what ‘normalized’ means.

Response to R1C12: The authors will add the description of normalizing to the manuscript figure to help make the figure stand-alone.

R1C13: Figure 3: Also, why does the soil water age get younger as the summer progress? The paper would benefit from a few sentences explaining this behaviour.

Response to R1C13: The soil water age decreased during the summer due to the flushing of older snowmelt and pre-winter water, replaced by younger growing season precipitation. Unlike many other studies, snowmelt age is accumulated throughout the winter months, therefore snowmelt is an aggregated age of the precipitation throughout the winter. The authors will add a statement explaining why the summer soil water ages decrease.

R1C14: Figure 5: Just so apples are compared to apples, perhaps total modelled evaporation and transpiration so that it can be more easily compared to the ICOS data.

Response to R1C14: The authors will add the ET to Figure 5d to help with the direct comparison of the measured evaporation and transpiration.

R1C15: Page 13 Line 41: A citation might be useful here because the data from this paper do not support such a statement.

Response to R1C15: The statement was conjecture and the authors will remove it from the manuscript.

R1C16: Page 15 Line 88: The authors have access to soil temperature data that could show if this is underestimated. A figure might help address this gap. Also, please explain how the assumption of no temperature gradient through the snowpack influence these results

Response to R1C16: The authors will clarify this statement. The modelled soil temperatures are not available throughout the soil domain but at two locations

R1C17: Page 15 Line 93 – 99: There are some typos through this section that could be fixed.

Response to R1C17: The authors will revise this section to improve the grammar to typos currently present.

R1C18: Page 16 Line 27: I missed where the ages of the soil frost are provided. It would be valuable to show them.

Response to R1C18: The authors will provide the ages of the soil frost in Figure 3 to aid the reviewer in understanding how the water ages are influenced by the soil frost estimations.

R1C19: Page 16 Line 30: It would be helpful to provide data on the relative values of these fluxes and storages in the text here to let the reader know how important each is to determine the age of water.

Response to R1C19: The authors thank the reviewer for the suggestion. Providing numerical values will aid the reader in understanding how the mixing and timing of different water sources will influence the water ages.

R1C20: Page 16 Line 32: Maybe rephrase to "...of older soil frost with younger soil water and snowmelt reduces....."

Response to R1C20: The authors will revise the statement using the reviewer's suggestion.

R1C21: Page 16 Line 35: Was it limited or just hard to detect within the uncertainties of the model? This is an important point of discussion that is missing.

Response to R1C21: Within the study site there is a combination effect. On some of the smaller streams, the influence of the soil-frost on the stream water age is more apparent, with younger snowmelt reaching the stream faster due to overland runoff as

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with rain on snow (limited infiltration). With some model parameterization, the differences are more apparent; however, on average, these differences are minor and are not significant when compared to the model uncertainties of water ages. The authors will add this to the discussion section.

R1C22: Page 16 Line 43: I am not convinced the results of the research support these statements. Please clarify. If more water is pulled from soil subject to warming would not that speed up the pattern observed in Figure 3? And in turn reduce age?

Response to R1C22: The authors will revise this statement to clarify that the increase in water availability (regardless of vegetation) will result in higher water use of the younger water in the soils. Higher use of younger water for vegetation results in less young water feeding the groundwater and stream, thereby increasing the water ages.

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