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Hydrology and Earth System Sciences Discussions

Interactive comment on "Estimation of permafrost thawing rates in a sub-arctic catchment using recession flow analysis" *by* S. W. Lyon et al.

S. W. Lyon et al.

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Thank you very much for your efforts spent evaluating and handling our manuscript originally titled 'Estimation of permafrost thawing rates in a sub-arctic catchment using recession flow analysis'. Based on the comments of three reviewers and your comments, we have significantly improved the manuscript and hereby resubmit it for possible publication in the *Hydrology and Earth System Sciences*. Please find detailed responses to both reviewer comments posted online.

In the following, we provide a detailed response the comments outlined by editor. We begin each response with a paraphrase of the editor's original comment.

1. Review of [relevant] studies is absent in the paper and the references underpinned the main authors assumptions are not related to the permafrost hydrology.

This comment is similar to comments made by Review 1. This is a valid comment and we have, thus, included a more through literature review covering relevant research in the realm of permafrost hydrology (in particular, recession studies) as follows in the revised manuscript (Introduction, Paragraph 4):

’Previous process-based studies have used flow and recession characteristics to help quantify the response of and characterize the hydrologic processes of arctic and sub-arctic hydrologic systems. Dingman (1966, 1973) used hydrograph characteristics to describe the influence of permafrost position on formation of high water tables leading to surface runoff. Ice layers at the interface of the organic and mineral soils have often been cited as the main cause of lateral runoff (Kane et al., 1981; Roulet and Woo, 1988; McNamara et al., 1997), with much research emphasizing their role in water storage and restriction of transmittance properties (Santeford, 1979; Slaughter and Kane, 1979; Hinzman et al., 1993; McNamara et al., 1998). Subsurface flow can, thus, become a main mechanism for the rainfall-runoff generation on mountainous slopes (Kuchment et al., 2000). Carey and Woo (2001) used recession analysis to identify contributing areas to runoff production, which varied greatly between events. Yamazaki et al. (2005) looked at recession gradients and attributed monthly variations to seasonal changes in active layer thickness. While such studies have advanced our understanding of the hydrologic processes that occur in arctic and sub-arctic regions, they have often been limited to relatively short (typically <10 years) of observations and, thus, unable to investigate the long-term responses of arctic and sub-arctic systems to changes in climate (Woo et al., 2008).’

Note that much of this previous work focuses on the recession gradient (not intercept) term and much of the previous research focuses on a limited number of events or a short period (<10 years) of observation. Our study is novel in that it takes advantage of a long record of observation. We have highlighted this throughout the revised manuscript.

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2. I agree with the authors that small changes in maximum depth of the active layer have lead to small changes in the depth-averaged hydraulic conductivity. Thus, for me, the assumption that there are no changes in the hydraulic conductivity needs further consideration and testing.

Let us consider relaxing this assumption. This implies that the increases in recession intercept observed can be related to changes in hydraulic parameters and primarily hydraulic conductivity. Based on the analysis in this study (Figure 3), this would imply an increase in hydraulic conductivity in addition to the possible increase in depth term. For the Abiskojokken catchment where there has been observed permafrost thawing over the past 29 years based on direct measurements, this implies an increase in depth-average hydraulic conductivity under conditions of thawing permafrost. There is no physical support for such an interpretation since (has highlighted by the Editor and Reviewer 1) it has been observed in many settings that hydraulic conductivity decays with depth. Since our analysis indicates counter to this (Figure 3), the changes in depth-averaged hydraulic conductivity are likely to be relatively minimal compared to the effect of changes in depth on the storage-discharge relationship. That is, for a given increase in depth there would be a relatively small change in, for example, depth-averaged hydraulic conductivity.

We have rearranged the discussion section to highlight this in the revised manuscript (Discussion and result comparison, Paragraph 3):

'Åkerman and Johansson (2008) reported rates of permafrost thawing, ranging from 0.7 to 1.3 cm per year, based on 29 years of direct observations in the Abiskojokken region. This direct observation of thawing supports our interpretation of the recession flow analysis. Specifically, it supports the above assumption of minimal influence of change in hydrologic characteristics since there is observed thawing occurring. Based on the analysis in this study (Figure 3), the change in recession flow intercept would imply an increase in depth-average hydraulic conductivity in addition to the observed permafrost thawing. There is no real physical support for such an interpretation since hydraulic conductivity tends to decay with depth in most arctic systems (Quinton et al., 2000; 2008). Any changes in depth-averaged hydraulic conductivity in Abiskojokken are, thus, likely to be relatively minimal compared to the effect of changes in depth on the storage-discharge relationship.'

3. The recession analysis should be shown in more detail. The most important question is: what are the errors of estimates of the recession coefficient for separate years?
This is an excellent comment and echoes the comment made by Reviewer 2. We have added error bars indicating the 95% confidence intervals for the recession flow intercept values shown in Figure 3. This allows the reader to assess the significance of the linear trend using visual inspect along with the significance indicated by the p-value. In addition, we have included a new figure showing the hydrograph for one season and indicating the recession periods used in the Brutsaert-Nieber recession analysis as it is conducted in this study (Figure 1b). These two additional figures provide more detail to the recession analysis.

The minor comment: Eq. 4 is not well written. I suggest re-writing Eq. (4).
This has been done such that Eq. 4 evaluates the total amount of thaw (as a Δ D) over a period of time. From this total amount of thaw, an average annual rate can be estimated.

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