Response to Referee #2 (Neelarun Mukherjee)

This manuscript integrates multi-decadal InSAR observations with streamflow recession analysis to investigate permafrost degradation in a mining-disturbed alpine basin. The topic is timely and the combination of surface deformation monitoring with a hydrological signal is novel. The long-term deformation dataset spanning five SAR sensors is a genuine contribution.

Response: We thank the reviewer for the positive assessment and constructive comments. In response, we have: (1) quantified the uncertainty in the climate-versus-mining attribution of Ks by calculating the climate-unexplained residual and its 95% uncertainty bounds; (2) examined the temporal variability of the recession parameter b, performed a fixed-b sensitivity analysis; (3) discussed the unobserved temporal gap in the SAR record. Detailed responses are provided below.

I have some comments: 1. Attribution of Ks changes to mining versus climate: The paper fits a multiple linear regression (MLR) using pre-mining data (1973–2002) and applies it to 2003–2022 to estimate climate-driven Ks changes. The authors do acknowledge uncertainty in attribution generally, but they do not quantify it.

Response: Thank you for the comment. To quantify the attribution uncertainty, we calculated the climate-unexplained residual and its 95% uncertainty interval by propagating the uncertainty bounds of both the in situ-derived and climate-predicted Ks estimates. This allows us to assess whether the post-mining Ks anomaly remains distinguishable from the climate-driven expectation after accounting for the uncertainties in both estimates. The result shows that the climate-unexplained residual remained significantly above zero from 2009 to 2016, coinciding with intensified mining activity and indicating an additional mining-related influence on streamflow recession dynamics. The results have been added to Section 4.2 and presented in Fig. R1 (revised Fig. S14).

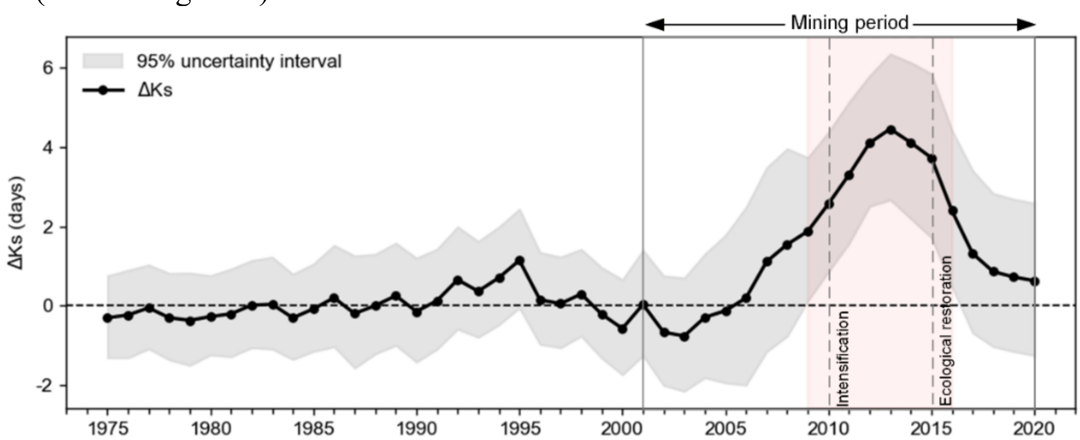

Fig. R1 (Revised Figure S14) Climate-unexplained residual of the streamflow recession time constant (ΔKs) and its 95% uncertainty interval. ΔKs was calculated as the difference between the in situ-derived and climate-predicted recession time constants. The 95% uncertainty interval was conservatively propagated from the uncertainty bounds of both estimates. The red shading highlights periods when ΔKs and the lower bound of its 95% uncertainty interval both exceed zero.

Line 499-: *"Model predictions during the mining period failed to capture the sharp increase in Ks, and the climate-unexplained residual remained positive from 2009 to 2016, with its 95% uncertainty interval entirely above zero, coinciding with intensified mining activity (Fig. S14). These results indicate that the observed Ks anomaly during this period cannot be fully explained by climate variability alone and imply an additional mining-related influence on streamflow recession dynamics."*

2.The recession parameter b and the interpretation of Ks: The paper defines Ks = 1/a, where a is the coefficient of the power-law recession −dQ/dt = aQ^b (Kirchner, 2009). In this framework, a and b are estimated jointly: the magnitude of a depends on the value of b, and both parameters change when the shape of the recession curve changes. If b shifts systematically with permafrost degradation, which is physically plausible, since deeper active-layer drainage may alter the storage–discharge nonlinearity, then a time trend in Ks reflects a combination of changes in recession timescale and recession shape, not timescale alone. The analysis focuses exclusively on a/Ks and does not report b or its temporal variability. The authors should examine whether b shows a trend over the study period and discuss how any such trend affects the interpretation of Ks as a proxy for active-layer water storage.

Response: Thank you for this important comment. We agree that b is a key parameter in the power-law recession model and that Ks $(1/a)$ should not be interpreted independently of changes in b. We have examined the temporal variability of b and performed a sensitivity analysis by refitting the recession model with b fixed at unity, as shown in Fig. R2 (revised Fig. S13). The fitted b increased over the study period, particularly during the intensified mining period, indicating that the recession process became more nonlinear. Fixing ($b = 1$) reduced the variability of a, but the pronounced decrease in a and corresponding increase in Ks during the intensified mining period remained evident. The results indicate that the observed recession slowdown reflects a genuine hydrological change rather than being solely an artifact of parameter coupling. We have updated the methods, results, and discussion as follows:

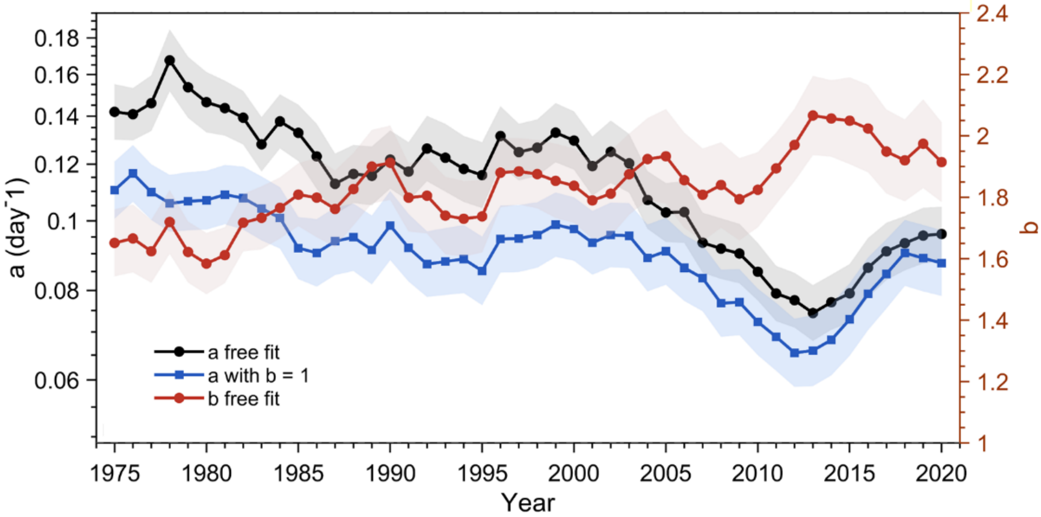

Fig. R2 (Revised Figure S13) Time series of recession rate (a) fitted from the free-b recession model, a fitted from the constrained model with b fixed to 1, and the time series of recession parameter b. Shaded areas indicate the 95% confidence intervals.

Line 299-: *"where* a *(units: days^{-1}) is the recession rate coefficient associated with the streamflow recession time constant, for which we assume* $Ks = 1/a$. b *(dimensionless) is the recession shape index that reflects the shape and nonlinearity of the recession curve."*

Line 320-: *"Since parameters* a *and* b *are jointly estimated in the power-law recession model in Eq. (7), a systematic shift in* b *can alter the magnitude of* a *and thus influence the interpretation of* Ks *as a recession timescale proxy. Therefore, the parameter* b *was also obtained from each regression window to examine its temporal variability and assess its potential impacts on* Ks. *We further performed a control analysis by refitting the recession model with* b *fixed at unity* $(b = 1)$*, corresponding to the linear reservoir assumption, to distinguish genuine changes in recession timescale from parameter-coupling effects."*

Line 478-: *"The parameter* b *exhibited an overall increasing trend from 1975 to 2020, with the most pronounced increase occurring during 2009–2013 (Fig. S13), coinciding with the period of intensified mining disturbance. This suggests that the recession process likely became more nonlinear (Hinzman et al., 2022). When* b *was fixed at unity, the temporal variability of* a *was reduced, suggesting that part of the apparent trend in* Ks *was affected by the variability in* b. *Nevertheless, it still shows a similar trend as the original fitting, with a strong decrease in* a *(i.e., increase in* Ks*) during the intensified mining period. This confirms that the recession slowdown during this period reflects a substantive change rather than being entirely a mathematical artifact of shifting* b*."*

Line 553-: *"The increase in b during the mining period indicates that the recession process became more nonlinear, further supporting a change in subsurface flow pathways. Permafrost thaw-induced increases in subsurface hydraulic connectivity and drainage heterogeneity may alter the contribution of supra- and sub-permafrost groundwater to baseflow (Hinzman et al., 2022). The interaction of these flow components with different drainage timescales results in a more nonlinear storage–discharge relationship."*

3. Temporal constraint on the deformation onset (~2005): Section 4.1.2 states that significant permafrost degradation "likely initiated around 2005." The available SAR data between 2003 and 2007 consists of a single Envisat interferogram spanning 2003–2005, which shows minimal change. The next constraining observation is ALOS-1 from 2007 onward. The 2003–2007 gap means the onset could be anywhere from 2005 to 2007: a 2-year window, and the "~2005" date is effectively the midpoint of an unconstrained interval. The authors should frame this more carefully, acknowledging the unobserved gap and presenting the onset estimate as a range rather than a point date.

Response: Thank you for pointing this out. We agree that the available SAR observations do not support the derivation of a precise permafrost degradation onset date. We have revised the text to describe the onset as occurring between 2005 and 2007 rather than at a specific year and have discussed the uncertainty introduced by the temporal gap in Section 5.2.

Line 429-: *"These results suggest that significant permafrost degradation likely began between 2005 and 2007 and accelerated afterwards."*

Line 628-: *"The ERS-2, Envisat, and ALOS-1/2 results were derived from sparse interferograms and therefore represent interval-averaged deformation rates. These observations remain suitable for identifying broad stage-scale deformation differences but provide less information on short-term or nonlinear variations and the precise identification of abrupt deformation changes. In addition, temporal gaps between SAR observation periods leave deformation during these intervals unobserved. The combined results are regarded as a sequence of period-specific estimates rather than a fully continuous deformation record referenced to a common epoch."*