2 December 2025

Dear Riccardo Scandroglio,

Dear Editor,

We sincerely thank you for the careful, thoughtful, and constructive evaluation of our manuscript. Your detailed comments and suggestions significantly improved the clarity, structure, and robustness of the work. We appreciated the depth of your engagement, particularly given your recent contributions to high-resolution flow monitoring in permafrost-affected rock walls.

We have revised the manuscript extensively in response to your feedback. This includes improving several figures, clarifying the methodology, strengthening the distinction between results and discussion, adding missing information, reorganizing some sections for better flow, and correcting numerous minor issues you identified.

In this document, we provide a point-by-point response to all reviewer comments.

For clarity, your original comments appear in regular black text, and our responses follow in indented blue text.

A file containing all revised figures is provided separately, as requested.

All changes described in this letter are implemented in the revised manuscript.

We thank you again for the time and expertise you invested in this review, and we hope that the revised manuscript now meets the expectations of the reviewers and the editor.

The manuscript by Ben-Asher et al. presents a detailed investigation of water flow dynamics within a fractured permafrost rock wall at the Aiguille du Midi, Mont Blanc Massif. Using a multi-method approach, the authors examine the sources and timing of water flow in a high alpine permafrost environment. The methodology is innovative within the context of permafrost research, and the dataset is both rare and valuable. The study makes a meaningful contribution to our understanding of water infiltration processes in permafrost-affected bedrock.

However, several aspects of the manuscript require significant improvement before it can be considered for publication.

First, many of the results are not adequately supported by graphical representation or statistical analysis. Key claims are made without sufficient visual or quantitative evidence, leaving the reader unable to verify the conclusions (e.g., Tables 2, S1, S2, S3). Additionally, several numerical values lack precision and are often presented without measures of variability (such as standard deviation or coefficient of variation), despite the fact that the processes under study are known to exhibit high variability.

We thank the reviewer for highlighting this important issue. In the revised manuscript, we substantially strengthened the graphical and statistical support for our results. Specifically:

- ***Tables 2, S1, S2, and S3** were revised to include clearer definitions, precise numerical values, and appropriate measures of variability (e.g., quantile ranges for peak-flow timing).*
- ***Table 3** was added to summarize key flow characteristics in a more accessible format.*
- *Statistical descriptions of diurnal cycles, recession parameters, and lag correlations were clarified and expanded.*
- *Figures now visually support the corresponding analyses, including zoomed panels where needed.*

These updates improve the transparency, reproducibility, and interpretability of the results.

Second, the graphical presentation of results is limited and in need of substantial improvement. Overall, the figures do not sufficiently support the analysis and should be revised for clarity and readability. For example, Figure 5 and 7 both show water flow and air temperature, but in neither case are the values clearly legible or effectively presented.

We agree that the graphical presentation needed improvement. The following major revisions were made:

- ***Figures 5, 6, and 7** have been redesigned for clarity, with larger panels, clearer labels, thicker lines, and revised color schemes.*
- ***Figure 6** now includes a zoomed 17-day window to resolve daily cycles.*
- ***Figure 7** was rotated to landscape format, enlarged, and includes improved precipitation visualization, event markers, water temperature, and a complete caption.*
- *Updated figure sets are provided in a separate PDF as requested.*

These changes significantly improve readability and strengthen the link between the visual data and the manuscript's conclusions.

The text also requires revision. The introduction is overly general and lacks site-specific details—such as fracture characteristics or distances between loggers and snow cover—that are critical to contextualizing the study. Sections 4.1.3 and 4.1.4 are particularly difficult to follow and include figures that do not appear directly relevant. Furthermore, the separation between results and discussion is not always maintained; some interpretive content appears in the results section, while parts of the discussion are descriptive rather than analytical. The discussion would also benefit from

comparisons with similar studies to better situate the findings within the existing literature.

Thank you for this comprehensive and insightful comment. We have substantially revised the manuscript to address all of these structural and contextual issues. The introduction was rewritten to include clearer site-specific information, including fracture characteristics, distances between the terraces and the tunnel, and the spatial configuration of the sensors relative to snow cover. This provides readers with the necessary context from the outset.

Sections 4.1.3 and 4.1.4 were reorganized, rewritten and merged into section 4.1 for clarity. Figures that were not directly relevant were removed or simplified. The distinction between Results and Discussion has also been strengthened. Interpretive statements were removed from the Results section, and descriptive elements were relocated from the Discussion to earlier sections where appropriate. The Discussion now focuses more clearly on process interpretation and includes expanded comparisons with previous studies, including recent work on alpine bedrock hydrology and permafrost (e.g., Scandroglio et al., 2025), to place our findings in a broader scientific context.

Overall, these revisions improve the clarity, coherence, and scientific framing of the manuscript.

Although the manuscript is mostly well-written, it would benefit from a thorough proofreading to address grammatical, stylistic, and consistency issues.

In summary, this paper presents a unique and promising dataset with strong potential to advance the field, but requires major revisions in terms of structure, data presentation, and clarity, as listed in the attached file. I recommend the manuscript be accepted **pending major revisions**.

Detailed comments to

“Water flow timing, quantity, and sources in a fractured high mountain permafrost rock

wall” by Matan Ben-Asher, Antoine Chabas, Jean-Yves Josnin, Josué Bock, Emmanuel Malet, Amaël Poulain, Yves Perrette, and Florence Magni

L 18: AT --> air temperature

This was corrected.

L 39: double citation of the same paper. Please correct.

Double citation was merged.

L 48: Scandroglio at al 2020 doesn’t seems to be the right citation here. Remove.

Citation was removed

L 69: … data and a snowmelt model to infer timing and quantities of water flow and constrain the hydrological pressure in the fractures.

The sentence was edited. Thank you.

L 69: You should mention here that for the first time they applied recession curves analysis to high alpine bedrock fractures, not later.

Added this: They also analyzed recession curves of the measured flow rate, a technique that was never applied to alpine rock fractures before

L 84: Weber et al 2017 is working on the Matterhorn – what about the Mont Blanc? Please explain.

Good point. Added another reference to: Guillet, G., Ravanel, L., Beutel, J., and Deline, P.: Fracture kinematics in steep bedrock permafrost, Aiguille du Midi (3842 m a.s.l., Chamonix Mont-Blanc, France), https://doi.org/10.3929/ETHZ-B-000309262, 2018.

L 88: Please clearly and precisely define here the research gaps you want to tackle. You might use bullet points or questions. (Remember that timing and quantity of water flow has been already intensively analyzed in Scandroglio et al 2025).

Scandroglio et al. (2025) were indeed the first to publish real-time, high-resolution flow-rate measurements in a permafrost-affected mountain environment, and their work addressed several of the same knowledge gaps. However, their study did not fully resolve these gaps, and many fundamental aspects of water movement in high-elevation bedrock permafrost remain unclear. Data from a single site cannot fully explain processes that are spatially variable and globally relevant. To clarify the research gaps in our study, we expanded the text to explicitly include "water source," and we now highlight that our site is located in high-elevation permafrost rock (~1000 m higher than the Zugspitze site), where hydrological drivers and thermal conditions differ substantially.

L 96 to 103: Is this description of the MBM relevant in this context? Please reduce and leave only information that is relevant in this context. No need for the whole geotectonical history of MBM. You are just a few meters under the surface, the reader wants to know what is the situation there, and not get confused.

*The section was greatly reduced to: "The Aiguille du Midi (AdM) is a peak composed of three granite pillars - Piton Nord, Piton Central, and Piton Sud, with the central pillar (Piton Central) reaching an elevation of 3842 m asl and towering approximately 3000 m above the valley of Chamonix (**Error! Reference source not found.**). The site lies on the NW flank of the Mont Blanc massif (MBM) that covers an area of about 550 km^2 and is oriented NW-SE between France, Italy, and Switzerland".*

L 118: Add country borders in the small map.

Boundary added.

L 121: I suggest the use of local data instead of average data of the whole Europe, that are not necessary very representative for a unique climatic area, like the MBM.

The first paragraph is to provide a wide regional context. Local analysis is detailed later in the *next paragraph*.

L 122: What you here call AT is MAAT by convention. Please review overall and clarify if you are talking of MAAT or AT (daily or hourly values).

AT refers to just air temperature. We changed it to MAAT here and used AT later, to avoid confusion.

L 125-138: The reader gets completely lost in this paragraph: a lot of numbers and comparisons but it's hard to follow. You don't have to explain every figure. Please rephrase with only important information.

Section was rephrased with the main information.

If you improve Figure 2 by adding the long-term comparison (1993-2022) for AT and precipitation, the comparison would be much easier for the reader.

The long-term average was added to the figure.

L 131: remove: "(continuous hourly records started in 1993 in Chamonix)" – not relevant.

Done

L 135: You talk about spring 2022 in the previous paragraph with other numbers. Why the

repetiton? Clarify

This section was rephrased

L 143: Improve Figure 2: clearly separate data from Chamonix and AdM, add temperatures form Chamonix and long-term averages for both datasets AT/Precipitation

The long-term averages were added. The AT data is from AdM and precipitation is from Chamonix (no reliable precipitation is available in AdM).

L 148-149-150: "(Figure 3, Figure 4). Fluorescent dyes were poured into the snowpack on the rock face above the gallery to trace the water. Ground Surface Temperature (GST) sensors were installed on the rock surface, below and around the snowpack, where fluorescent dyes were inserted." These parts are repeated afterwards. Remove here.

Done

L 154: -Figure 3: text overall too small, increase. "North camera" not readable because of the color.

The figure was edited

L 165 Missing a verb.

Rephrased sentence to: The dye powders were inserted directly into the bottles with the original mineral water.

L 173: “in the vicinity” define more precisely.

Changed to: “…at the snow-rock interface, on the terraces where the fluorescent dyes were injected”

L 179: remove “marks”

Done.

L 191: Provide precise information in the fractures: length, opening, orientation.

Added to the sentence:

Preliminary observations revealed that water was mostly dripping from two adjacent fracture ***systems with a generally subvertical dip (70°-90°) oriented toward north-west****.*

L 203: “five measurements” of what? since it's a new paragraph, it is not clear what you are talking about. Clarify or unite to previous paragraph.

Rephrased to: “Averaged values from the installed sensors were recorded every 10 minutes with a PC400 Campbell Scientific datalogger”

Figure 4: The yellow box is unclear to me: clarify what you want to show. What is the last picture on the right in the green box showing? please improve caption!

The figure was edited, labels added, and the caption was improved.

L 252: “where flow paths could extend for several hundred meters.” You make an assumption that is not included in the cited paper and not based on any scientific data you present. Why do you suppose that?

Changed to: “Their study focused on a 55 m-deep tunnel in karst limestones, where flow paths extend at least 55 m and possibly farther due to tortuosity.”

How did you compute the path length here, at the AdM? I miss clear figures on: the positioning (depth) of your gallery with respect to the surface, the orientation if the clefts in the area, and a clear explanation on how you are computing path length.

We used a new high-resolution 3D model generated from drone imagery. The sentence was corrected with the measured elevation: “…sub-vertical granite fractures with a path length range of 12 m (lower terrace) to 20 m (upper terrace)”.

From the Photo in Figure 3 it seems there are only a few meters from “Dye1” location and the galley. Add measures to Figure 3 / Text or include a 2D profile of the study area on scale.

We added the terrace elevation in section 3.1: "Sulphorhodamine-B in 2022 and Fluorescein in 2023 were injected on the "upper" terrace of the face, ***which is located 18-24 meters above the tunnel****, while amino acid G was injected on the "lower" terrace,* ***7-12 meters above the tunnel****, in 2022 and 2023". We used a new high-resolution 3D model from images taken with a drone survey.*

L 253: "widely open, sub vertical" Quantify. If possible, provide also images. It seems adequate to present here a scan line/ fracture mapping of the tunnel / of the outside.

Added to section 3.3:

Preliminary observations revealed that water was mostly dripping from two adjacent fracture ***systems with a generally subvertical dip (70°-90°) oriented toward north-west****.*

L 254: "Additionally, Scandroglio et al. (2025) used a single best-fit curve for their entire dataset, which included only 23 events over eight years. In comparison, we used 93 events for recession curve analysis (out of 144 events that were recorded, see 4.1.5 for more details) over two consecutive.» This is part of the discussion, move this sentence there. How do you define events? This can variate from author to author. Add your definition, it seems to me you define an event for each daily cycles, both for rain and snowmelt. On the contrary Scandroglio et al 2025 considered only rain events and clearly defined events: "An output flow event starts with a sudden increase in the discharge, independent of the starting value, and ends when the flow returns to a value smaller than a threshold … By convention, multiple flow events are classified as one if precipitation interruptions are shorter than 24 h and the resulting hydrograph at the gauges does not reach baseflow status between the two rain event." Please be precise and correct or remove this comment.

Thank you for this correction. There was a misunderstanding in the definition of a flow event. We have now clarified this in the revised text and moved the comparative discussion to the appropriate section. The updated paragraph reads:

> *Additionally, while we define a flow event as the period between a well-defined rise and the following recession of the hydrograph, Scandroglio et al. (2025) defined an event as a flow period beginning with a sudden increase in discharge, independent of the starting value, and ending when the flow returns below a set threshold, potentially including several peaks. They applied a single best-fit curve to their entire dataset, which comprised 23 high-flow events over eight years. Their approach is well suited to rain-controlled conditions. In contrast, our field site at 3840 m a.s.l. is dominated by snowmelt and thus strongly influenced by the diurnal solar cycle. We therefore identified 93 well-defined single-peak events for recession-curve analysis (out of 144 recorded; see Sect. 4.1 for details) over two consecutive seasons. To capture temporal variations in flow characteristics, we developed an algorithm that automatically fits a separate curve to each event, allowing us to track changes through time and compare flow behavior between Box 1 and Box 2 (Figure S2).*

L 256: Please provide a list of all your events including date, duration and start/peak/end discharge.

Thank you for this suggestion. All events will be available in the public dataset associated with this manuscript. Adding a full list of 93 events to the main text would considerably lengthen the manuscript without providing additional scientific value. As noted in our response to the previous comment, our definition of a "flow event" differs from that used by Scandroglio et al. (2025), which may have led to this request. The revised text now clarifies our event definition and the methodology used to identify and analyze these events.

L 263: 109 what?

This section was completely rewritten as follows:

> *A moving-window cross-correlation analysis was used to quantify correlations and lag times between pairs of measured time series, including flow rate, air temperature (AT), and ground surface temperature (GST). For each lag time, the Pearson correlation coefficient (PCC) was calculated between one series and a time-shifted version of the other (+1: high correlation, 0: no correlation, -1: reverse correlation). For example, at lag time = 0, flow and AT measured at the same time were compared; at lag time = +6 h, the flow series was correlated with the AT series shifted 6 h forward. Lag times were evaluated in the range of –12 to +12 h in steps of 1 h.*
>
> *The analysis was performed in a moving window of 24 hours starting from 00:00, without overlapping, which corresponds to the observed daily cycles in both flow rate hydrograph and also GST and AT. Window size is an important parameter: shorter windows highlight transient events but may be sensitive to noise, whereas longer windows yield more stable estimates at the cost of smoothing short-term variability. In this study, a window length of 24 hours was selected as a compromise between detail and stability.*
>
> *Prior to analysis, all time series were high-pass filtered with a one-hour moving average to reduce noise. Only days with a maximum flow rate above 6 L h^{-1} were included, ensuring hydrographs with clear diurnal signals. The analysis was conducted for the full flow season (mid-May to August in 2022, and June to September in 2023).*

L 268: You don't need to refer multiple time to Fig 5 in the same paragraph.

Deleted extra references to Figure 5.

L 272: "The timing and magnitude of flow diUered between Box 1 and Box 2." From my

understanding box 1 and box2 were collecting water from the same cleft - now I'm confused. Are they not installed on the same metal plate on the ceiling? Please clarify the text before and improve the figures to make it clear!

We thank the reviewer for pointing out this confusion. The two boxes indeed collect water from the same drainage plate but from different sides of a central divide in the convex metal ceiling. As shown in Figures 3 and 4, the plate was originally installed by the operating company to divert dripping water toward two drainage pipes located on opposite sides of the tunnel. The convex shape of the plate naturally separates the flow into two directions, each draining water from a different set of fractures. This is precisely why two boxes (Box 1 and Box 2) were installed in the first place—to independently monitor the water originating from each side of the divide.

We clarified this point in the revised text in Section 3.3 and referred explicitly to Figures 3 and 4 as follows:

> *We installed a real-time monitoring system in May 2022 in the west tunnel of the Central Pillar, to characterize the water flowing from fractures that cross the tunnel. We took advantage of an existing water diversion ceiling set up by the operating company (Figure 4), made of a convex metallic plate collecting water drips and flows, and diverting them to two pipes, one on each side of the tunnel (east and west) to drain water outside. Preliminary observations revealed that water was mostly dripping from two adjacent fracture systems.*

L 272: Reference missing: please next time you submit a version of your article be sure all references are working. This problem is appearing many times in this article and makes work harder for reviewer.

We sincerely apologize for the inconvenience caused by the broken references in the previous version. This issue resulted from a Word formatting error during file conversion. All internal and external references have now been carefully checked and corrected in the revised manuscript.

L 276: This image is hard to read. What is "Max" adding as information here? why not removing it? would strongly improve clarity.

I also recommend using bars instead of a line for the volume of water, since it's "per day".

Is flow rate from 1, 2 or both? Clarify.

We thank the reviewer for these helpful suggestions. Following this and similar comments from the other reviewers, we revised the figure accordingly. The panels were labeled, the air temperature line was made thicker for better visibility, and the caption was expanded to clearly describe the data sources and variables plotted. We also clarified that the flow rate represents the combined signal from Box 1 and Box 2. The revised caption now reads:

> *Figure 5: A) Photos showing the evolution of the snow cover on the NE face during the snow melt season in 2022. Note the change in snow cover. B) 2022 season AT, GST measured on the NE face, above the tunnel entrance, directly above the*

monitoring system, and flow rate measured at the output from rock fractures in the tunnel wall (Box 1+Box 2). Solid lines represent the daily mean. C) 2023 season AT, GST measured on the NE face, above the tunnel entrance, directly above the monitoring system, and flow rate measured at the output from rock fractures in the tunnel wall (Box 1+Box 2). Solid lines represent the daily mean. Note the zero-curtain period, which marks the melting of the snowpack and the exposure of the rock surface to atmospheric heating. D) Photos showing the evolution of the snow cover on the NE face during the snow melt season in 2023.

L 288: (2581 L): Interesting why so much water so late in summer. Is this summer snow melting?

Yes, most likely. Figure 7 shows significant amounts of precipitation at the end of August 2023 and below 0 °C temperatures, followed by a period of above 0 °C temperatures, which correlate with the late flow events.

L 289 Figure 6: You squeeze your most valuable data in these small graphs where it is not possible to properly diU erenciate the lines and read values. Use the whole page width for B and C, A can go alone or be moved to supplementary

- Showing only the period from mid-May to end of September.

- Maybe even rotate and put full page size.

We thank the reviewer for this valuable suggestion. Following the recommendation, Figure 6 was substantially revised to improve readability and focus on the key results. Panel A was removed, and a new zoomed panel (C) showing a representative 17-day period was added to highlight daily variations. The x-axis time range in A-B was narrowed to display data from mid-May to the end of September, making the seasonal patterns clearer and making the figure overall much easier to interpret.

L 291 – Figure 7: Same problem: This is your central Figure but it's very hard to read.

- consider increasing size and turning it 90°

- hourly flow rates are impossible to read at this scale - consider using daily values and make a zoom for hourly - (see Scandroglio et al 2025 fig. 2)

- add here information on the presence of snow, form the camera

- highlight important events with numbers/letters

- diU erentiate liquid and solid precipitation (using temperature)

- where is the caption????

- Flow rate = 1+2?

Quite some improvements can be achieved here…

We thank the reviewer for these detailed and constructive suggestions. Figure 7 was revised accordingly. The figure was enlarged and rotated to landscape orientation to

improve readability. The caption was completed and now clearly explains each panel and dataset. Flow rate values represent the combined signal from Box 1 and Box 2, which is now explicitly stated.

Important events are now marked on the time axis, labeled, and described in the captio.

Regarding the time resolution, we chose to retain the hourly data because the diurnal oscillations in flow are a key observation in our study and would not be visible at daily resolution. A zoomed view of a representative period is already included in the previous figure (Figure 6), which allows detailed inspection without redundancy.

Snow-cover information from the automatic camera was available only for the 2023 season (1 March–22 August 2023). Because snow cover changed gradually and was not binary, we did not attempt quantitative classification, which would require advanced image analysis beyond the scope of this study. However, snow presence can still be inferred:

- *visually from the overlaid precipitation and temperature data, and*
- *from the GST sensors, where GST values remaining at or below 0 °C indicate snow cover, and GST rising above 0 °C indicates snow-free conditions.*

These signals make it possible to interpret snow conditions directly within Figure 7 without adding additional layers.

L 293: It's impossible to evaluate the numbers you are suggesting from Fig 7. - provide a zoom (example period) and a statistical analysis.

This line now refers to figure 6 which now includes a zoom window.

L 294 - Figure S1: missing the y-axis

I find the analysis presented in S1 not scientifically based and the approach questionable. What is your thesis here, what do you want to prove? You are putting together periods with different length and making an average "curve". How did you decide the length of each period? It would be much better to provide a statistical analysis. Alternatively, you could plot all cycles together and produce a density graph.

Thank you for this insightful comment. We agree that the previous version of Figure S1 and its caption were confusing. The figure presents the normalized monthly average daily flow-rate cycle, but the caption mistakenly referred to shorter time periods, which created ambiguity. The selected periods were chosen to include days with continuous flow during each month and to exclude days without flow, which would otherwise distort the hourly average. Because the curves are normalized, the y-axis is dimensionless. However, we acknowledge that the underlying approach was not clearly explained. To improve clarity, we revised the caption to specify exactly what is plotted and why the averaging periods differ across months. The y-axis label and the normalization procedure are now explicitly described.

New caption text:

Figure S1: Normalized hourly flow-rate cycles for each month in 2022 (left column) and 2023 (right column). For each month, only days with continuous flow were included to avoid averaging periods with no discharge. The flow-rate values were normalized by their monthly maximum, making the y-axis unitless. The averaging windows used for each month were for 2022: May (26–29), June (10–23), July (1–15), August (28 July–8 August), September (1–15), and for 2023: June (23–30), July (8–15), August (10–20), September (3–15). These periods capture the representative diurnal flow variations during days with active discharge.

L 294: "two orders of magnitude lower during the morning time" where do I see that? please show.

The range of flow rates can be seen in figures 6 and 7. We also added to the text:

> *The observed flow rate presents daily cycles (**Error! Reference source not found.**) with peak flow rates, reaching an order of 10^{1} L/h, generally occurring between 17:00 to 20:00 (**Error! Reference source not found.**, Figure S1), and minimum flow rates two orders of magnitude lower (order of 10^{-1} L/h) during the morning time.*

L 295: This table is uncomplete. Provide a proof for these values and further statistical information, like standard deviation? Is there a change with time (May to July to September) ?

The values were updated with statistically based values showing time ranges that represent the 25–75% quantile of daily peak timing.

L 298: S3 should be S2. How did you compute the values (3-9 and 0-3)? Demonstrate how you obtained these values. In the graph for GST the green shape covers the range 0-6.

Figure S3 was moved to the main manuscript text, following a suggestion from another reviewer. The range of lags was corrected to 3-9 and 0-6. These values were obtained from the visualization. The results are supported by the observed values of the peak values in Table 2.

L 305: "Most likely fell as rain since the AT was positive«. Temperature at the end of July 2022 is under zero for quite some time (2-3 days… it's impossible to decipher form the picture). Please rephrase correctly.

Figures 5 and 7 were edited and now show the information more clearly.

L 328: "This event was unusual because it lasted for 3 days" It is worth to provide a detailed Figure on this event and other special events you talk about, at least in the supporting material. Please add.

The main flow events that are discussed in the manuscript are now marked in figure 7. The specific event that is addressed here was not marked in the figure, but it can clearly be seen in Figure 7.

L 336 same here

Same answer

L 338: I suggest moving this information to a table, together with the numbers from 2022, for clarity and comparison.

Table 3 was added with the flow rate information.

Table 1: Flow rates peaks

	Peak flow rate (L/h)		Daily max volume (L)
	Box 1	Box 2	
2022	45.4	30.46	445.9
2023	39.83	21.2	1032.99

L 340: 1033 L/day --> similar to Scandroglio et al 2025, comment in the discussion.

We are not certain that a direct comparison of absolute flow values is meaningful considering the significant differences between the field sites.

L 343: Refer here to fig S2. You extracted the flow recession and then fitted it. Why is just applied on some days and not on others? How do you select which day to fit and which not? Is this based on how well your recession is fitting? ("...values below 0.8..."). Sorry but if you reject the low values, it's not a surprise that you get high R2 values.

Thank you for this important comment and the one that follows. We address both comments here. We clarified the methodology in the revised manuscript to explain how recession segments are objectively and consistently identified. The starting point of each recession is not chosen manually but is detected automatically as the last local maximum prior to the decline toward baseflow. The algorithm then isolates the concave part of the recession limb (curvature > 0), which corresponds to the exponential decay described in Eqs. 1–3. Only this section is used for fitting. Events with poorly defined or noisy recession limbs cannot be reliably fitted with an exponential function. To avoid introducing artefacts, we applied an R^2 threshold of 0.8, which resulted in retaining 93 out of 144 events (64%). These excluded events are not treated as outliers but as cases where the physical recession behaviour is not sufficiently constrained for regression analysis (e.g., multi-peak events, sensor noise, or incomplete recession). The revised text now explains this more clearly (Sect. 3.5.1):

> *To capture temporal variations in flow characteristics, we developed an automated algorithm that fits a separate recession curve to each event, enabling us to track changes through time and compare flow behaviour between Box 1 and Box 2 (Fig. S2). For each event, the algorithm identifies the recession limb as*

the interval between the last local maximum and the subsequent return to baseflow. It then isolates the concave segment of this limb (curvature > 0), corresponding to the exponential decay, and fits the appropriate form of Eq. 1 or Eq. 2. To ensure that only well-defined exponential recessions are included, events with regression fits yielding $R^2 < 0.8$ are discarded. This threshold retains 64% of all detected events (93 out of 144) while excluding cases where noisy or multi-peak recession behaviour prevents reliable fitting.

From chapter 3.6.1 I understand that you rejected about 1/3 of your events. This is an elevated number, and they cannot be considered just as "outliers". I suggest reviewing the methodology used in this analysis, since these results are very important in your discussion and conclusions.

See previous comment response.

L 344: Interesting analysis. I see the trends you describe the ranges you provide are not representing what it is shown in the picture.

a = 7-10 to 8.5-5

b = 1-1.08 to 1.04-1.15

Updated the text

L 349: 0.75 … I read in the text 0.8. Use the same number.

Corrected to 0.8

L 362: The link with snow melting is clear, not only a hind. Rephrase.

Replaced "hinting at a…" with "demonstrating a…"

L 364: "Summer precipitation episodes are suggested when …" Why don't you detect precipitation periods by using AT? it seems more obvious and direct for me

Rephrased to: "Summer precipitation episodes are suggested when water flow events follow periods *with limited water flow and positive GST and AT, such as in late July 2022.* "

L 385 Repetition, check and remove.

We carefully checked this line but did not identify a repetition.

L 403-404: Move to discussion

Moved to discussion.

L 410 How do you explain the "extended residence time"?

We explain in the discussion that the extended residence time is not a likely explanation

L 415-416: move to discussion

Moved to discussion

L 438 – Figure 10: I very appreciate this analysis. Could you also provide the changes of water temperature in time? Why is there a peak at -8°C for AT?

Thank you for this positive feedback and for the helpful suggestions. Water temperature measurements have now been added to Figure 7 for the 2023 season.

The peak at –8 °C is in the GST distribution and not AT. The analysis in Figure 10 is restricted to the "thawing period" (mid-May to mid-September) for both 2022 and 2023. During the early part of this period, particularly from mid-May to mid-June 2023, the ground surface at the GST sensors was still covered by winter snow, which remained cold because it had not yet received significant solar radiation. This explains the occurrence of GST values around –8 °C. In contrast, the same period in 2022 was warmer due to an early heatwave and earlier snowmelt, resulting in ground temperatures between –5 and 0 °C.

L 455: "direct precipitation": what is direct precipitation? When is it indirect?

Changed to "directly from precipitation".

L 458: "we conclude that water flow processes in high mountain rock faces are therefore seasonal,» This is quite an obvious conclusion, not really a novelty. Your results are applicable "close to the surface" but not to bigger depth.

We appreciate the reviewer's remark. While the conclusion that flow processes exhibit seasonality may appear intuitive, our observations provide direct evidence of a clear seasonal signal at depths of approximately 10 m, and at an elevation and setting where such measurements are extremely rare. In this context, "close to the surface" is relative, as very few studies have documented subsurface hydrological dynamics at this depth in steep high-mountain permafrost (>3000 m asl) . If a seasonal signal had diminished at the depth where we measure flow, it would indeed imply that little or no signal would persist at greater depths. Instead, our measurements show that the seasonal pattern remains pronounced, which has important implications for understanding water penetration into deep fracture networks at high elevation.

L 461: "Show that snowmelt is the main source of water in the fractures during the early and main stages of flow, and contributes most of the water." Similar result to Scandroglio et al 2025.

Added ref to Scandroglio et al 2025

L 463 to 468: These are results, please move this paragraph to a more adequate position.

Deleted the redundant results description.

L 475: Definition of heat wave: "a prolonged period of unusually hot weather." Please clearly define which periods are "heat waves" for you, also with figures.

This is addressed in section 2.2 in the introduction:

> *A late-spring heat wave produced record warmth in May 2022, while May 2023 was near average. Summer conditions were similar in both years, but September 2023 experienced an exceptional late-season heat wave—the warmest on record in Chamonix—whereas September 2022 was near normal.*

L 484: "Assuming that water…" Why assuming when you have measurements of water temperature! Show them in the supplementary material.

The assumption is that the water is warmer than the rock. We edited the text:

> *Assuming that water that infiltrates later in the season is warmer that the rock mass and the infiltration paths contain less ice, it can potentially accelerate permafrost degradation and deepening of the active layer.*

L 488: remove "likely"

done

L 494: What do you mean with "transfer rate" explain.

The sentence was rephrased:

> *The early detection of fluorescent dye in the first flow events suggests a relatively rapid transfer from the surface to the fractures*

L 459 "flow is unsaturated" If the flow stops, there is no water moving, neither saturated nor unsaturated. Please rephrase.

Changed to: "The presence of fluorescent dye in the first water flow shows that the water transfer rate from the surface to the fractures is high"

L 496: "This unsaturated flow shows that there are preferential flow paths into the fractures, leading to open paths available for the melting water of the snowpack in the following spring." This is an assumption, prove it.

Edited the first sentences to: "Our results also indicate that an effective pathway exists within the fracture network for the infiltration of water from snowpack melt at the end of spring. The early detection of fluorescent dye in the first flow events suggests a relatively rapid transfer from the surface to the fractures. Furthermore, when flow ceases at the end of autumn and icicles form at the fracture outlet, the observed flow appears to be unsaturated. In such cases, the unsaturated flow is likely routed through preferential pathways within the fracture system, which in turn suggests that at least part of the network remains open and able to convey meltwater during the following spring"

L 506: "One reason for the delayed flow in Box 2 could be linked to the location of the draining area closer to the colder north face, while the draining area of Box 1 is closer to the west face, which is exposed to more solar radiation." You can easily prove this by reporting the orientation of the fractures where you measure water flow.

Added to section 3.3:

Preliminary observations revealed that water was mostly dripping from two adjacent fracture ***systems with a generally subvertical dip (70°-90°) oriented toward north-west****.*

L 519: Similar to Scandroglio et al 2025

We were unable to understand which part of the line is similar to Scandroglio et al 2025.

L 529: Please add some references.

We removed the words "as observed in aquifers."

L 537: "his change in recession form, from aquifer-type (Equation 1) to channel-type (Equation 3) can be explained by the thawing of ice in wide sub-vertical fractures that are likely to react more individually (rather than as a network) and enable rapid flow in the fractured granite". This is a great finding, very interesting! To prove this hypothesis, It would be very important to see this change directly … e.g. by comparing some of the recession curves. I suggest adding a figure, here in the discussion.

Added a figure to the supplementary figures:

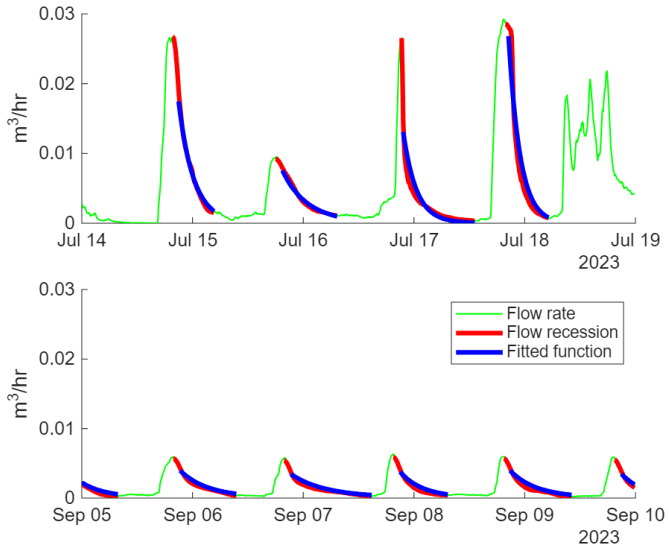

Figure S3: Comparison of flow recession and fitted function to flow rate in the beginning of the thawing season (top) and at the end of the season (bottom) in 2023.

L 555: Leinauer et al 2021 is actually using the model of Lehning et al 1999 : SNOWPACK

Added Lehning et al 1999

L 556: Meteorological forcing is driving the software SNOWPACK, therefore simulations are sensitive to it. Rephrase this sentence. It seems to me that that hydrogeological parameters are highly uncertain also here. Rephrase.

Rephrased to:

However, the outputs of such models depend strongly on the meteorological forcing used to drive them, and on hydrogeological parameters that are typically poorly constrained. The results of this study provide direct observations that can help reduce these uncertainties and improve our understanding of water availability for infiltration and its environmental controls.

L 560: which flow rate are you suggesting as a parameter for models? quantify it

The role of water flow in the heat balance of mountain permafrost is indeed an active area of research, and advective heat transport remains one of the least quantified components. This topic is central to our broader research, but the present contribution is not aimed at quantifying heat fluxes or providing model parameters related to thermal advection. Therefore, we do not propose a specific flow-rate parameter for thermal modelling within the scope of this paper.

L 567: "..the highest numbers in July"... any connection with your flow peaks 400 L/d and 1000 L/d ???

This is a plausible hypothesis and appears consistent with our observations.

L 590: Why is this time indication unsaturated path? Where are you discussing this in the text?

This is discussed in the first paragraph of Section 5.2

L 615: What about data availability?

All relevant time-series datasets used in this study will be uploaded to a publicly accessible Zenodo repository upon final submission.