25 September 2025

We sincerely thank Marcia Phillips for the thorough and constructive review. The comments have helped us to improve the clarity, presentation, and scientific depth of our manuscript. Below, we provide a point-by-point response. Reviewer comments are reproduced in *black, followed by our responses in italic blue text. All line numbers refer to the original version*. *All the* revised figures and captions are available at the bottom of this document.

Paper 'Water flow timing, quantity and sources in a fractured high mountain permafrost rock wall' submitted by Ben-Asher et al. (EGUsphere).

Reviewer: Marcia Phillips

General comments:

The paper entitled 'Water flow timing, quantity, and sources in a fractured high mountain permafrost rock wall' by Ben-Asher et al. presents the results of a two-year campaign monitoring fracture water in high elevation permafrost at the Aiguille du Midi, France. The subject is currently of great interest, as rock slope failures in high mountain areas appear to be linked to the loss of sealing permafrost ice plugs in rock fractures and to deep-seated infiltration of water into the newly accessible fracture systems. The extent of the fracture systems and their hydrology is poorly known. This study uses a combination of methods to identify the sources of water flowing through rock fractures, the rates and timing of flow, preferential flow paths, and the thermal regimes of the rock and water. Most of the relevant literature is cited (see my suggestions in the detailed comments (attached) for further literature), but in some cases the references do not appear (error message). Most of the figures need enlarging and labelling to improve their legibility. The figure captions do not adequately describe the figures. The language is mostly clear but with some grammatical or consistency issues (see detailed comments). Some small changes to the paper structure should be considered, particularly in sections 4.3.1 and 4.4, where the explanations/hypotheses should be moved to the Discussion. The paper is highly relevant and I suggest it be accepted for publication, with major modifications.

The missing literature was added to the manuscript. Erroneous references were corrected.

All figures, excluding two, were edited and are now clearer with more informative and detailed captions:

Figure 1: Panels were labeled, and the caption refers to each panel specifically.

Figure 3: Unnecessary details were omitted. Text size was enlarged. Caption was edited.

Figure 4: Panels were labeled, text in the figure was refined. Caption was elaborated with an improved description of the experiment setup.

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Figure 5: Panels were labeled, and the transparency of the water volume and air temperature colors were reduced to improve visibility.
Figure 6: Column bars of the monthly flow volume were widened to improve the distinction between 2022 and 2023 data.
Figure 7: Caption was edited and is now much more detailed. Missing y-axis labels were inserted. Panels were labeled.
Figure 8: A new figure that was in the supplementary materials. Added with labeled panels and detailed caption.
Figure 9: Panels were labeled, and the caption refers to each panel specifically.
Figure 10: No changes
Figure 11: Caption was edited. Text size increased. A new distribution was added – tunnel air temperature.

Detailed comments:

l. 18: air temperatures (ATs). *Corrected.*

l. 18: rock temperatures (not *ground*). *Corrected.*

l. 22: flow rates. *Corrected.*

Key words: water infiltration. *Keyword added..*

Introduction: perhaps you could mention somewhere that water infiltration due to loss of ice plugs is a problem for tourist infrastructures like the AdM, Jungfraujoch or Klein Matterhorn and that the owners have had to install protective roofing in the past decades in the tunnels so the tourists don't get wet (as you use this roofing for your experiment). *We appreciate the reviewer's suggestion to highlight the implications of water infiltration for tourist infrastructure. However, in the context of this paper, our focus is on the hydrological and permafrost-related processes and their relevance for landscape evolution and slope stability. While tourist comfort (e.g., avoiding water dripping inside tunnels) is a practical concern, it is not scientifically relevant in the framework of Hydrology and Earth System Sciences. For this reason, we chose not to include such details and instead emphasized the broader geomorphological and hydrothermal implications of our observations.*

l. 34: for an example of water driving a catastrophic failure (Pizzo Cengalo) see Walter et al. 2020 https://doi.org/10.1016/j.geomorph.2019.106933 The references you use here are more process related and not necessarily linked to rock slope failure events. *Reference was added.*

l. 37: ... and leads to rock fall... . *Added to text.*

l. 38: ... may also trigger large rock slope failures by reducing... *Corrected.*

l. 39: ... the presence of sealing ice in pores and fractures favors... *Corrected.*

l. 42: for another example of thermal perturbations (warming and cooling), see https://doi.org/10.1016/j.coldregions.2016.02.010 (Phillips et al. 2016). *Reference was added.*

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l. 51: terrain. *Corrected.*

l. 51 a reference for hydrological studies in rock glaciers (Bast et al. 2024) https://doi.org/10.5194/tc-18-3141-2024 and in scree slopes (Pellet & Hauck 2017) https://doi.org/10.5194/hess-21-3199-2017. *References were added.*

l. 62 infiltration of water. *Corrected.*

l. 72 elevation (not altitude, which is used when flying). *corrected here and in the conclusion chapter.*

l. 74 showed. *Corrected.*

l. 79: fracture network. *Corrected.*

l. 84: describe the seasonal evolution. *Description added: " ...with reversible opening in winter, superimposed on a long-term irreversible opening trend".*

l. 85 ... the extent of ice filling or plugging and develop... T*ext added.*

l. 96: ... the uplift of which... (not whose). *Corrected.*

l. 113 and throughout the paper (and in the figures): replace galleries with tunnels. *Replaced all.*

Figure 1: label the different panels of the figure (a,b,c) and refer to the labels in the caption. Maps provided by the Swiss Federal Office of Topography swisstopo. *Panels were labeled, and the caption refers to each panel specifically.*

l. 121: second warmest years on record. *Corrected.*

l. 122 (MAAT). *No need to use MAAT initials since it is only mentioned once in the text.*

l. 146 Methods. *Corrected.*

Figure 3: the top right panel is illegible. What does Location Inf. Elevation refer to and is it needed? What is the pink structure on top (antenna? Building?). Add more information in the figure caption. *Unnecessary details were omitted. Text size was enlarged. Caption was edited.*
l. 157: ... to trace the water source and rate of infiltration... (?). *Added text.*
l. 164: four 4L bottles and six 1.5L bottles .... to prepare the tracer solutions... *Added.*

l. 165 ... were inserted... *Updated the text.*

l. 168-169 label the upper and lower terraces in Figure 1. *Figure 1 does not show the terraces. Labels were added in Figure 3 instead.*

l. 174 ... to protect them (or insulate them) from direct solar radiation... *Sentence updated.*

Table 1: You are not describing the sensor characteristics but their locations (adapt caption). *Updated the caption.*

l. 178: I suggest you use the method described by Staub & Delaloye 2016 https://doi.org/10.1002/ppp.1890 rather than Hansen & Hoelzle 2004. *The citation of Hansen & Hoelzle 2004 is meant to support the assumption that stagnant GST ~0°C represents a melting period. The same assumption is made by Staub & Delaloye 2016. Reference added.*

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l. 179 snow has melted / is absent (it is not actively removed). *Text updated.*

l. 194 submerged/suspended (not plunged). *Replaced word.*

l. 203 five measurement values were… *Corrected.*

l. 206: … where sediments sometimes accumulated. (Interesting - did you measure the grain sizes of the sediments?). *Sentence updated. Unfortunately, the sediments were not collected during the experiment period.*

l. 209 thunderstorm? Was the problem caused by lightning? *Cable car was not operating because of the storm, for safety reasons.*

Figure 4: label the different panels and remove 'and issues' from Box 2. Complete the caption and refer to the yellow frame too. The purple frame looks pink. *We labeled the panels, corrected the text boxes, and edited the caption.*

Figure 5: Please label the panels. The shading for water volume is not legible. Consider placing the photographs in a separate figure. *Labeled the panels, edited the caption. did not put the photos in a separate figure but separated them into defined panels.*

l. 280: this is an example of a reference not appearing (Error! Reference source not found). *This error was fixed here and the rest of the text.*

Figure 6: I can't distinguish between 2022 and 2023 in the flow volume part. *Bars were made wider to improve the difference between the two filling textures of 2022 and 2023.*

Figure 7: this figure is very important and interesting and quite illegible (much too small)! Label panels, add description to caption. *We increased the figure size, added panel labels, and the description in the caption text.*

l. 304: melt of the winter snowpack and. *Replaced word.*

l. 318 and 321: you say daily oscillations but refer to hourly values. *In oscillations, we refer to the period that a waveform completes a cycle, i.e. peak-to-peak.*

l. 319: from 20 July to 10 August… (not the). Please use one form of date consistently. Sometimes you use 3rd and 19th (e.g. l. 332). *Sentence corrected. All dates in the text were edited to a unified format.*

l. 344 0.8 here and 0.75 in Figure 8. Which is correct? *0.8 is the correct value. Updated in the text.*

l. 379-383 this should be moved to the discussion. *Moved to section 5.3 in the discussion chapter.*

l. 390 … suggesting that much of the winter and spring snow was gone by… *Updated the text.*

Section 4.4 Some of this should be moved to the discussion. *We agree. Moved the section 5.3.*

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l. 430: is this brick wall shown anywhere in a figure? Where/what is the Hellbronner terrace? *We changed the description to: "at another location in a tunnel under the north-east face of the central peak, near the exit of the cable car going to Pointe Helbronner (Italy)."*

l. 435: Values measured (not measurements taken). *Corrected.*

Figure 10: the figure caption does not mention probability (y axis). Could you show the tunnel air temperature too? *Updated the caption and added the tunnel air temperature distribution.*

l. 445: strong weather signals (not climate!) ... at both seasonal and... *Corrected*

l.452-453: what about the role of long wave radiation (in the presence of cloud cover*)? This sentence describes an observation in the measurements. Long wavelength radiation could have increased the air temperature and increase the surface heat flux directly, but there is no data to support it.*

l. 472: did you measure the air temperature in the tunnel? Is there an influence from the infrastructure, from the body heat of the tourists or air fluxes from outside/heated buildings? *We did measure air T in the tunnel. The temperature distribution was added to Figure 11. The following sentence was added: In addition, the touristic infrastructure and human presence can contribute internal heat sources, including heating systems, the elevator motor, and body heat from visitors.*

l. 476: weather (not climate). *Corrected.*

l. 483: 'reference source not found', ditto on l. 506, 513. *This error was solved.*

l. 490: could this also be due to the fact that there was very little snow in winter 2021-2022? *Yes, absolutely. It is actually seen in Figure 5 when comparing snow cover in mid-June in both years. Added to the text in section 5.1.1.*

l. 499: remove 'from a geomorphological perspective'. It is rather from a geotechnical or cryospheric perspective. *Deleted the sentence.*

l. 503 remove well-identifying, just use identifying. *Removed.*

l. 520: (approx. 3 m apart). *Corrected.*

Section 5.3: perhaps you would like to consider the characteristics of the snowpack and the fact that a layer of ice often forms in spring between the snow and the frozen bedrock (see Phillips et al. 2017 https://doi.org/10.1016/j.coldregions.2017.05.010), which may affect the timing of water infiltration into the fracture system. *We are familiar with the work of Phillips et al. (2017), and we acknowledge that ice layers at the snow–ground interface can influence infiltration in some settings. However, our results show no evidence of such an effect in this study. The first flow events occurred in direct correlation with surface warming above the* *melting point and already contained tracer dye applied at the snow surface, indicating rapid infiltration and high connectivity between the snowpack and the fracture system.*

l. 527: remove direct. *Removed.*

l. 546: the melting of fossilized ice (not the thawing of fossilized water). Have you considered dating the water? *Thank you for this comment. We agree that the melting of fossil ice is a more accurate term. We used stable isotopes to attempt to differentiate modern from older water, but the results were not conclusive. Absolute dating of meteoric water is not straightforward, yet it is certainly worth considering in future work, especially in light of our findings..*

l. 569: 1950s. *Updated the text.*

l. 592: melting of older ice (ice melts, ground thaws). *Updated the text.*

l. 594: melting of fossil ice (not water). *Updated the text.*

l. 601: suggests. *Corrected.*

I suggest you add an Outlook section with further possible investigations and open questions.*This is an excellent idea. We added a new section 5.5. Outlook and Future Directions: Future investigations could build upon this study by applying more detailed chemical analyses of dissolved elements, which would help constrain water–rock interaction processes and potential solute sources. Characterizing the mineralogy and size distribution of sediments flushed from fractures could provide complementary evidence on transport pathways and mechanical erosion. Further stable isotope analyses, combined with absolute dating techniques (e.g., tritium–helium, radiocarbon, or noble gas methods), may allow a clearer distinction between modern meltwater, rain inputs, and contributions from older subsurface ice. Together, these approaches would refine our understanding of fracture-scale hydrology in steep permafrost rock walls and its sensitivity to climate forcing.*

Figures in general: please use the same font in all figures, improve their legibility, label the panels, describe the figure in the caption. *The figures were edited and are now clearer and informative.*

Please have the English checked before you resubmit. *Done*

We believe that the revised manuscript fully addresses the reviewer's comments. In particular, we have restructured some sections, improved all figures and captions, standardized terminology, corrected errors in references, and revised the English throughout. We also added a new section on Outlook and Future Directions to highlight open questions and potential avenues for future work. We thank Marcia Phillips again for the valuable feedback, which has significantly strengthened our manuscript.

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Figures

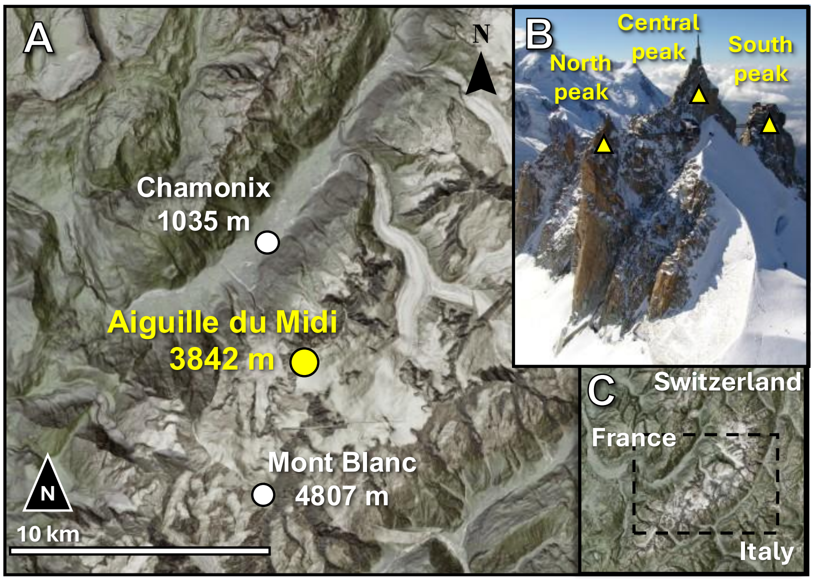

Figure 1: A) Location of the Aiguille du Midi in the Mont Blanc massif. B) view of the three peaks at Aiguille du Midi. (Picture: S. Gruber). C) Location of the Mont Blanc massif on the border of France, Italy and Switzerland. Maps provided by the Swiss Federal Office of Topography swisstopo.

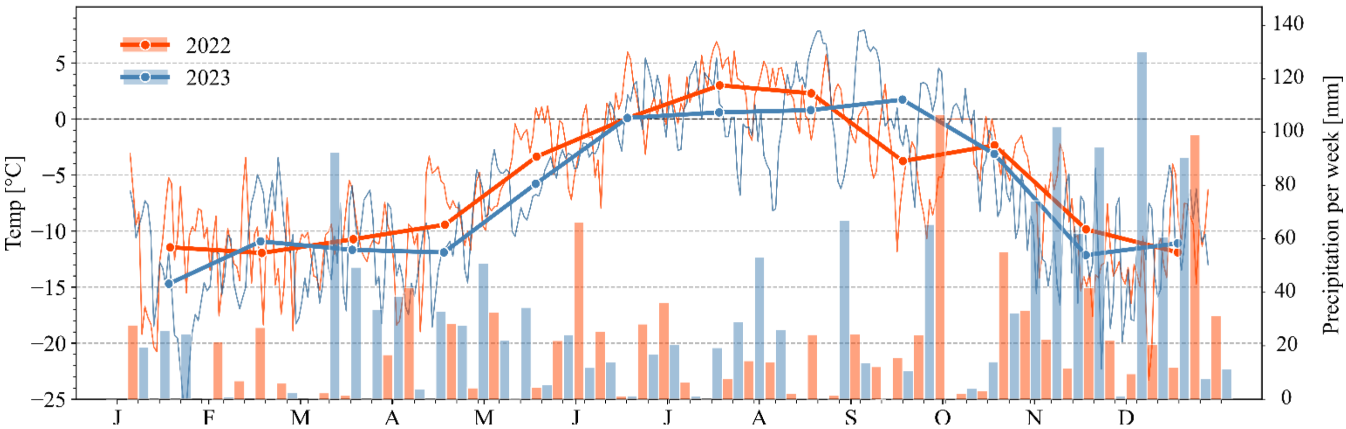

Figure 2: Daily (thin lines) and monthly (thick lines) air temperature and weekly precipitation in 2022 and 2023 (bars). Air temperature was measured at the top of the Aiguille du Midi and precipitation was measured in Chamonix (1042 m asl). Data provided by Météo France.

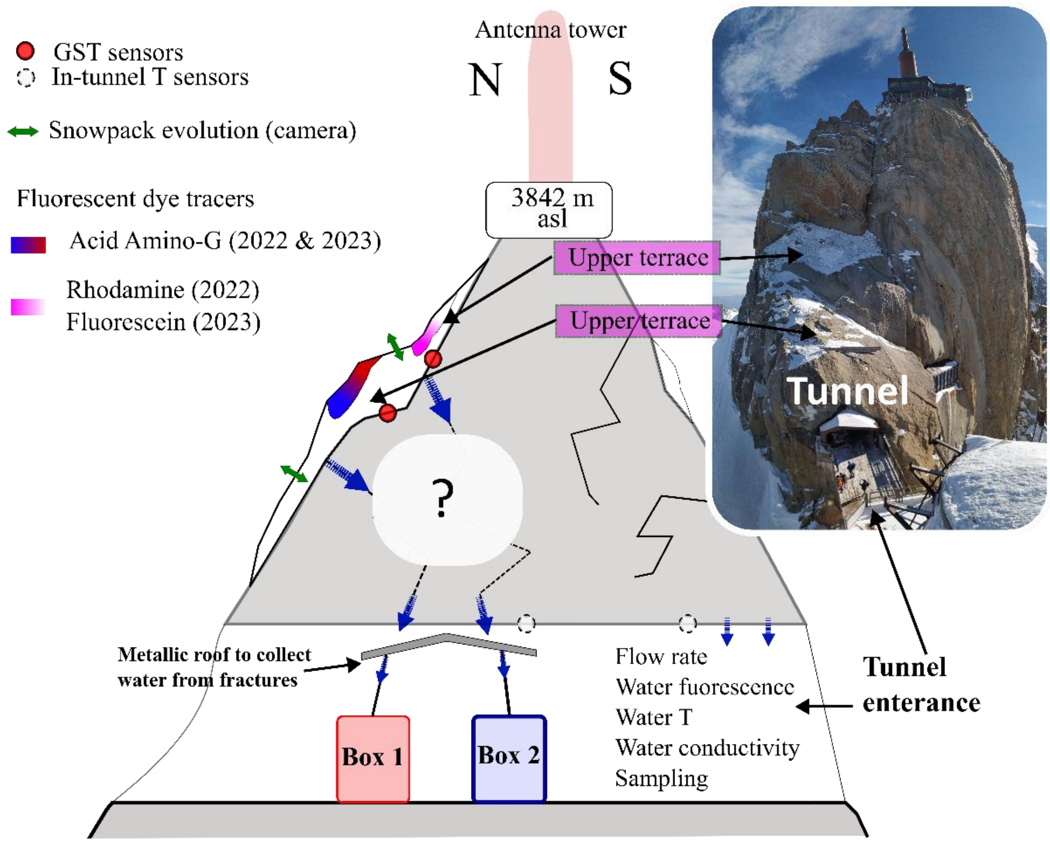

Figure 3: Sketch of the methodological approach to track and monitor water flows in the Aiguille du Midi central pillar. Note the location of the insertion locations of the dye tracers in the snowpacks on the terraces above the water monitoring boxes.

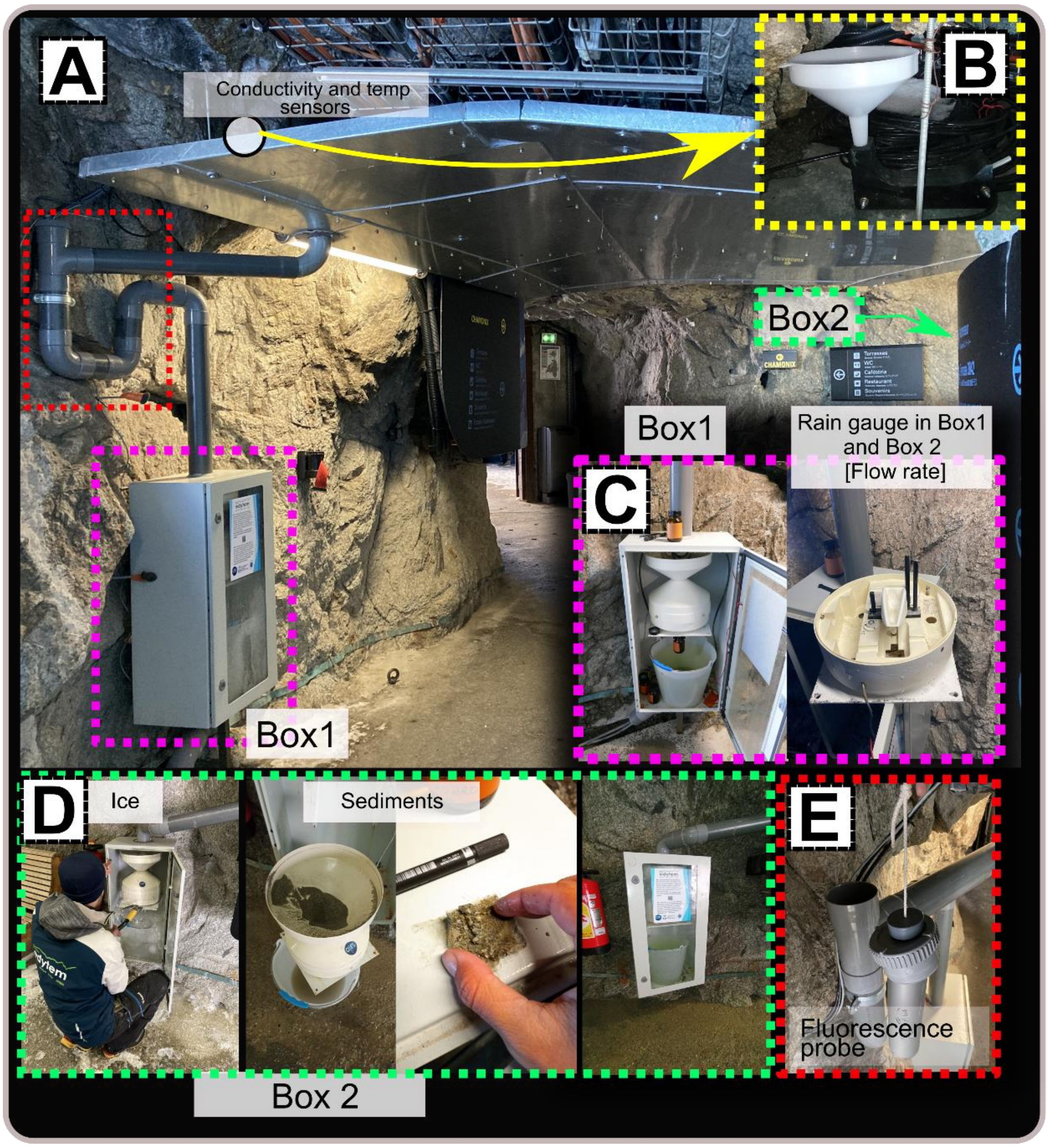

Figure 4: Real-time monitoring system in the tunnel. A) Metal roof draining to Box 1 (pink dashed frame). B) A 3D printed siphon that was placed directly under the water output from the fracture, quipped with T and conductivity sensors (yellow dashed frame). C) Box 1 interior with rain gauge to monitor flow rate, and a sampling bottle and bucket. D) Box 2 with sediments (green dashed frame). E) Fluorescence probe by TRAQUA located in the a specially designed siphon for continuous real time monitoring of the dye tracers.

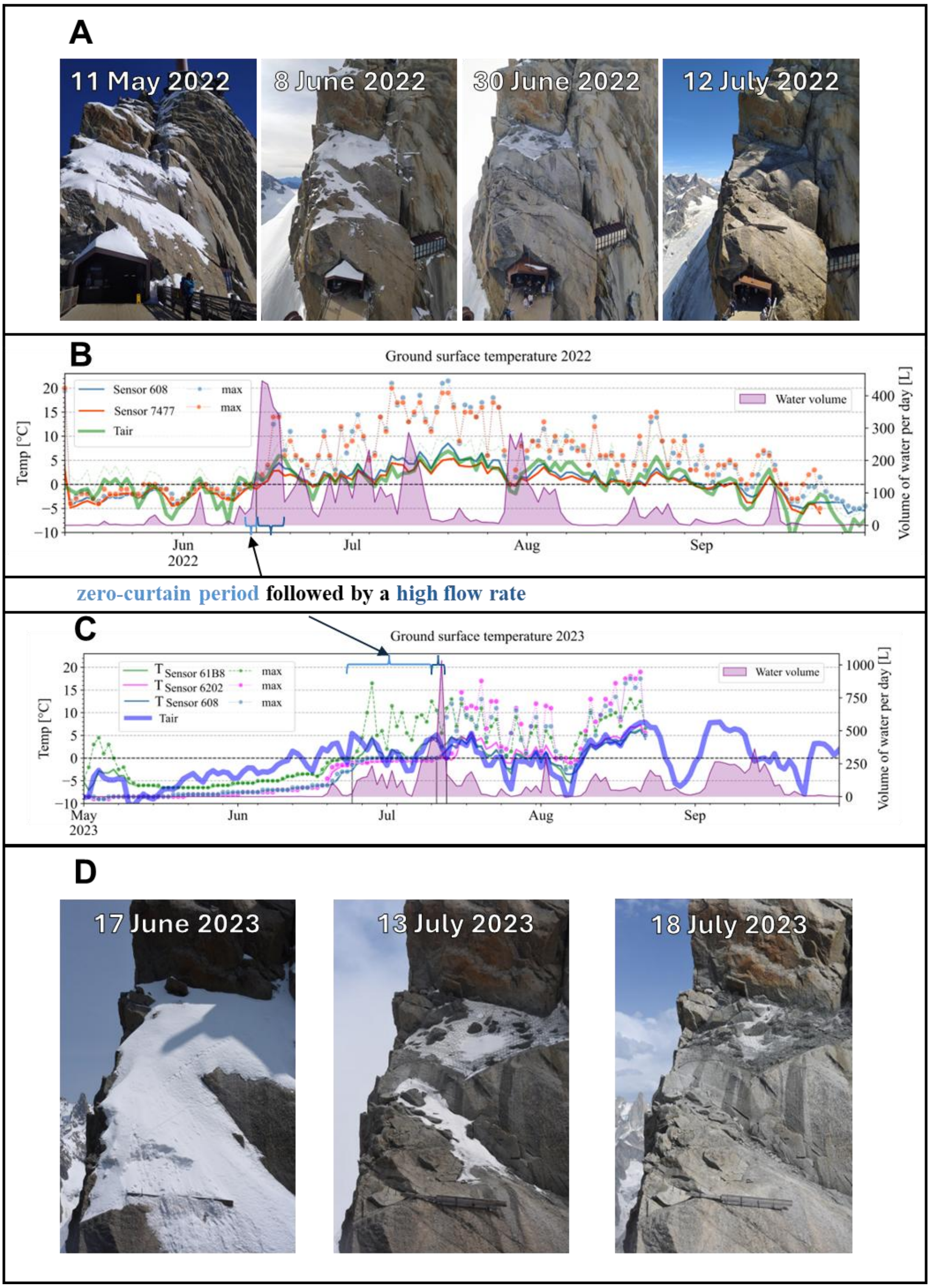

Figure 5: A) Photos showing the evolution of the snow cover on the NE face during the thawing seasons in 2022. Note the change in snow cover. B) 2022 season AT, GST measured on the NE face, above the tunnel entrance, directly above the monitoring system, and flow rate measured at output from rock fractures in the tunnel wall. 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 output from rock fractures in the tunnel wall. Solid lines represent the daily mean. Note the zero curtain period which marks the thawing of the snowpack and exposure of the rock surface to atmospheric heating. D)) Photos showing the evolution of the snow cover on the NE face during the thawing seasons in 2023.

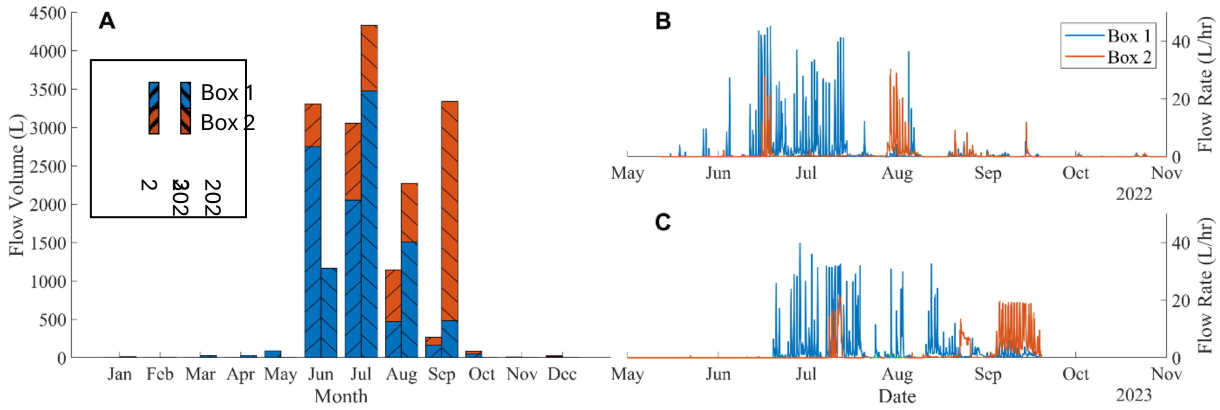

Figure 6: A) Monthly distribution of flow volume in Box 1 and Box 2 during the 2022 and 2023 seasons. B) Measured flow rate vs. time in 2022. C) Measured flow rate vs. time in 2023.

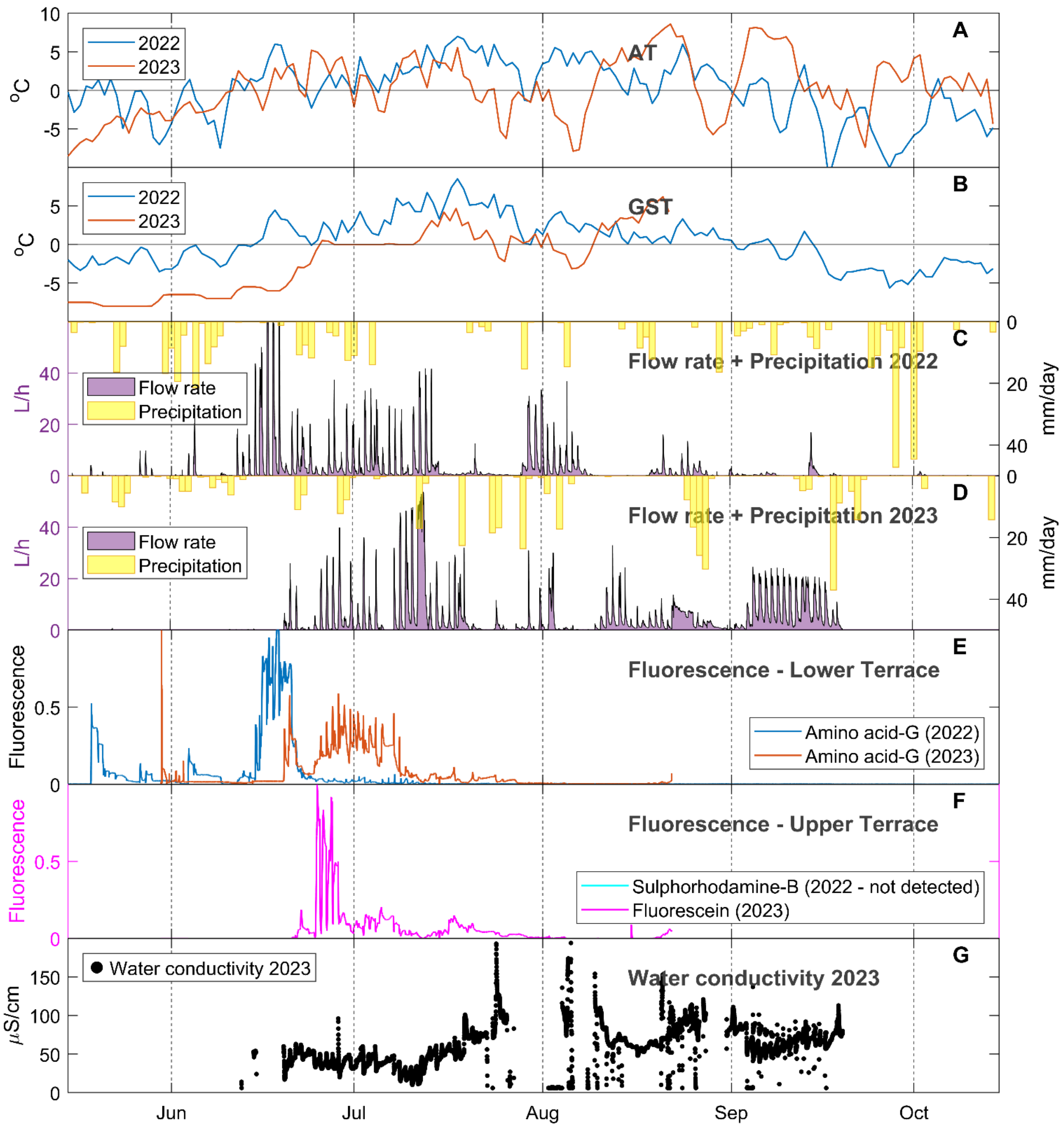

Figure 7: Annual time series. A) Air temperature (AT) measured by Météo-France in Aiguille du Midi. B) Ground surface temperatures (GST) measured using iButtons at the rock surface on rock slope above the water collecting system, near the location of fluorescent dyes injection. C-D) Flow rate measured in both box 1 + box 2 (purple) and daily precipitation measured in Chamonix meteorolocical station (Météo-France) (yellow bars). E) Normalized fluorescence signal of amino acid-G dye tracer that was inserted in the upper terrace in both seasons (2022 and 2023). F) Normalized fluorescence signal of Sulphorhodamins-B (inserted in 2022) and Fluorescence (inserted in 2023) dye tracers. The Sulphorhodamins-B dye was never detected. G) Water conductivity that was monitored continuously at the outlet of water from the fracture in the tunnel.

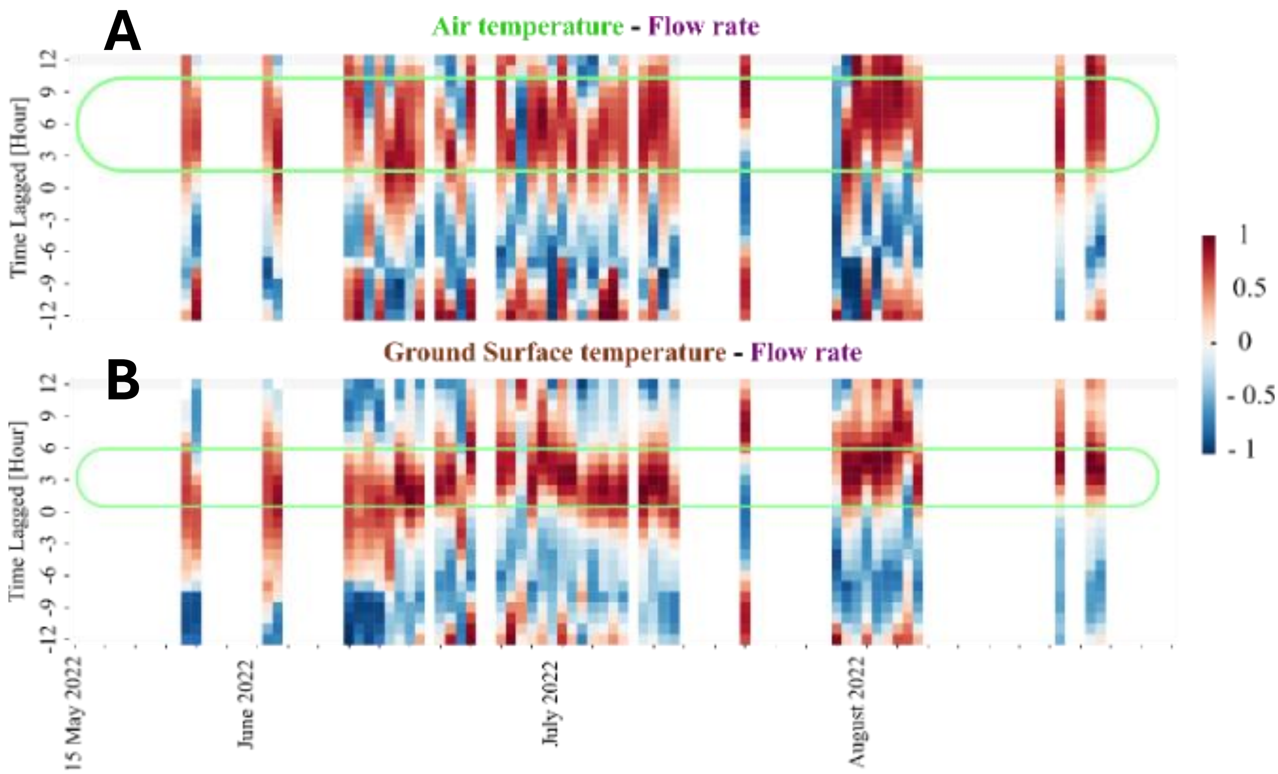

Figure 8: Results of moving-window cross-correlation analysis of water flow with (A) air temperatures (AT) and (B) ground surface temperatures (GST), during 2022 season. The horizontal axis represents the days, and the vertical axis represents the size of the lag time, in hours, between the flow rate time series with AT (upper plot) and GST (lower plot). The color bar represents the value of the Pearson correlation coefficient (PCC) (1: high correlation, 0: no correlation, -1: reverse correlation). The green frame marks the range of lag times that show high PCC. Results of the cross-correlation analysis of 2023 season show similar results and can be found in the supplementary materials, in figure S3.

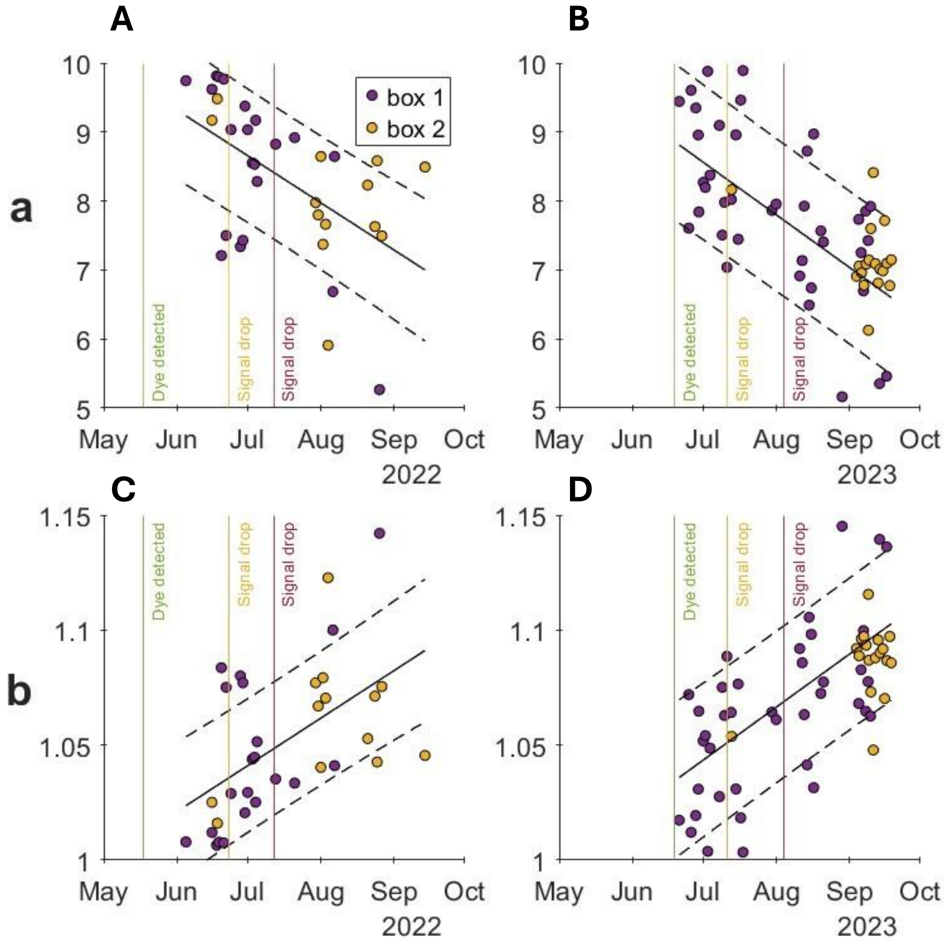

Figure 9: Values of the recession curve exponential coefficients a (top) and b (bottom) in 2022 (left) and 2023 (right) vs. time. A) values of the 'a' coefficient of the recession curves of flow events in 2022 in box 1 (purple circles) and box 2 (yellow circles). B) values of the 'a' coefficient of the recession curves of flow events in 2023 in box 1 (purple circles) and box 2 (yellow circles). C) values of the 'b' coefficient of the recession curves of flow events in 2022 in box 1 (purple circles) and box 2 (yellow circles). D) values of the 'b' coefficient of the recession curves of flow events in 2023 in box 1 (purple circles) and box 2 (yellow circles). Values obtained from curves with R^2 values below 0.8 were omitted from the analysis. The black line is the linear regression of all the points (box 1 + box 2) with ±standard error (dashed black lines). The vertical lines indicate the timing of the detection of the fluorescent dye in the water that exits the fractures (green), the rapid drop of the signal intensity (orange), and the disappearance of the signal (red).

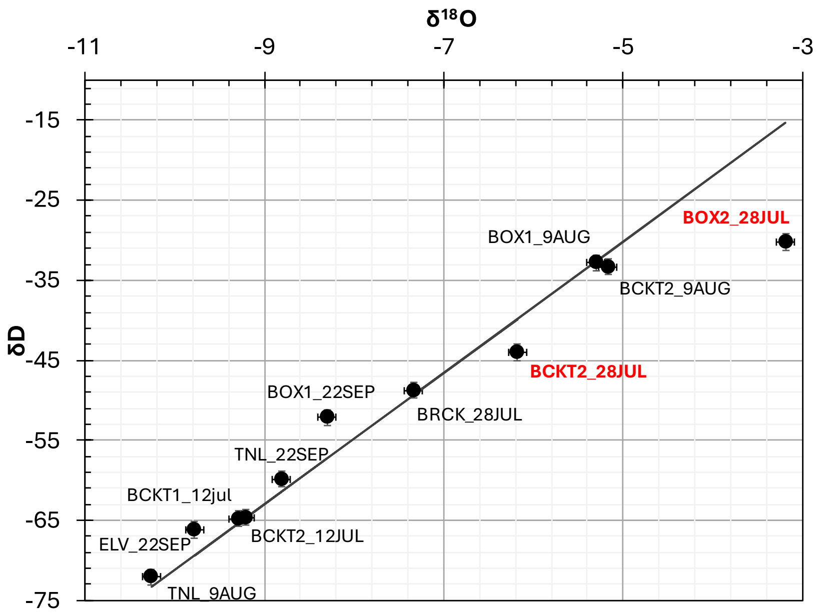

Figure 10: Stable isotopes $\delta^{18}O$ and δD in water samples. Note the two outliers (labeled in red) from the global meteoric water line (GMWL, black line) in samples taken from Box 2 on 28 July 2022.

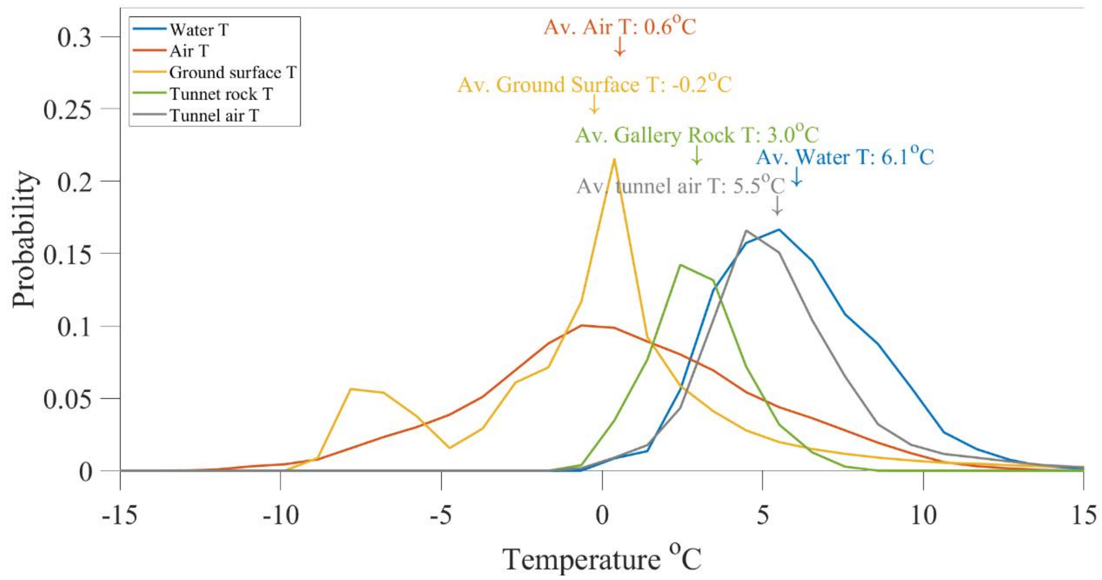

Figure 11: Probability distribution of temperatures monitored during flow events (blue), atmospheric ATs (orange), ground surface temperatures (yellow), and tunnel wall (green). All distributions show data from the thawing season in 2022 and 2023 (15 May – 15 September). Note that the water temperature distribution (blue) shows only data when water flow was detected in the monitoring system, while the other temperature distributions represent the entire data within the thawing season.