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# Real-time monitoring of snowmelt infiltration in steep permafrost-affected rock slopes using fluorescent dyes

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## Background

Little is known about the connectivity between surface water and subsurface fractures in steep permafrost-affected rock slopes. Here we present a novel high-elevation field experiment designed to monitor real-time infiltration in rock fractures at Aiguille du Midi (3842 m a.s.l.), in the Mont-Blanc massif. An existing tunnel that was carved for access to visitors, allows the collection of water directly from fractures that cross the tunnel walls. We monitored the water flow rate, temperature, and electrical conductivity in two adjacent fractures. In addition we installed a fluorescence probe and inserted two different fluorescent dyes: amino-acid-G and sulphorhodamine-B, into snow patches at the surface, in two locations directly above the fractures (5-15 m) to track the water source. We sampled water from the monitored fractures and other locations in the tunnel.

## Study site – Aiguille du Midi (3842 m a.s.l), Mont-Blanc massif, French Alps.

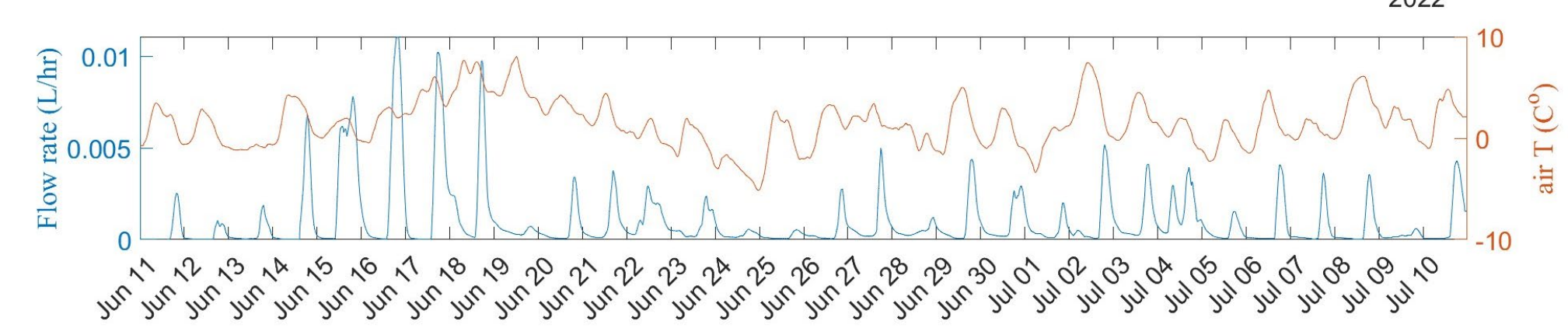
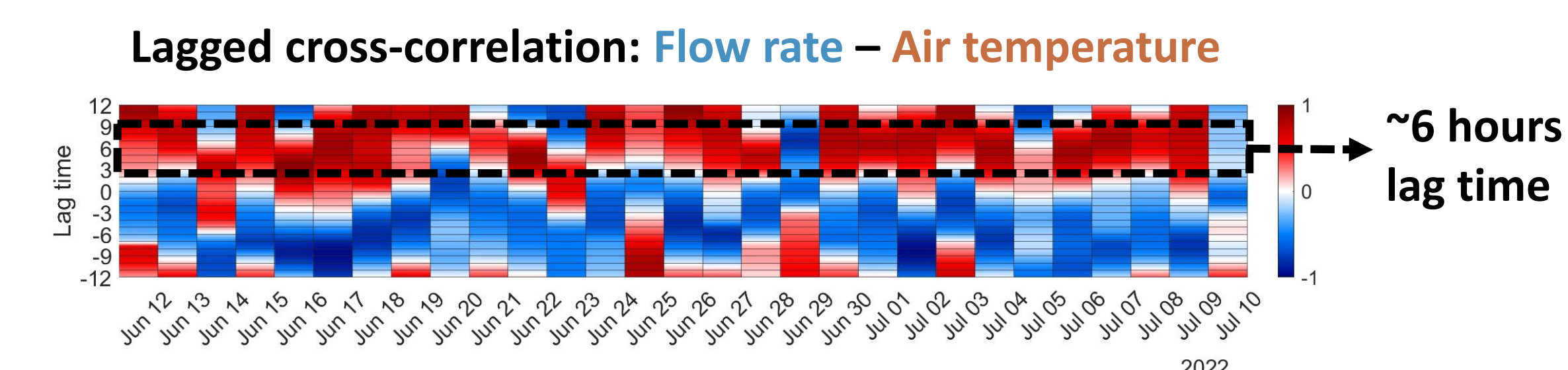
The Aiguille du Midi lies on the NW side of the Mont-Blanc Massif. Its summit consists of three granite peaks (North, Central. A tourist cable car runs from Chamonix to the north peak, where galleries and an elevator are carved in the rock mass, providing year-round access to the otherwise extreme and inaccessible environment.



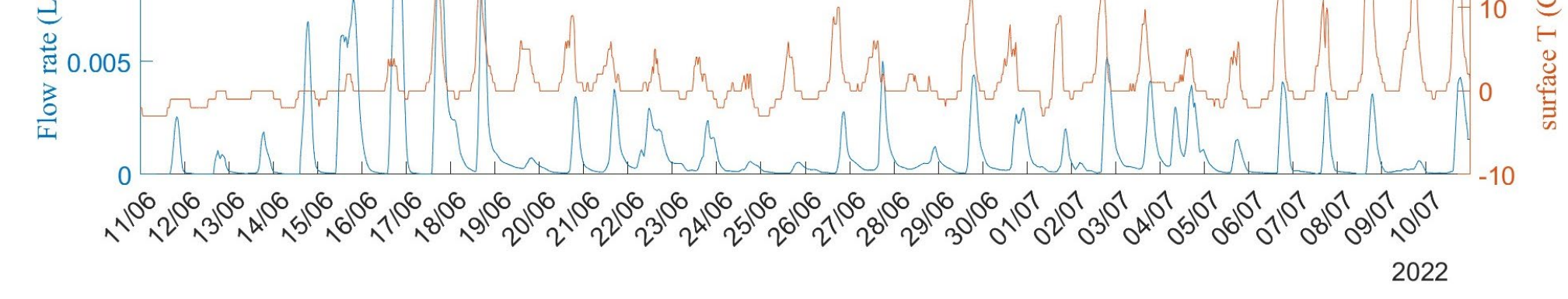
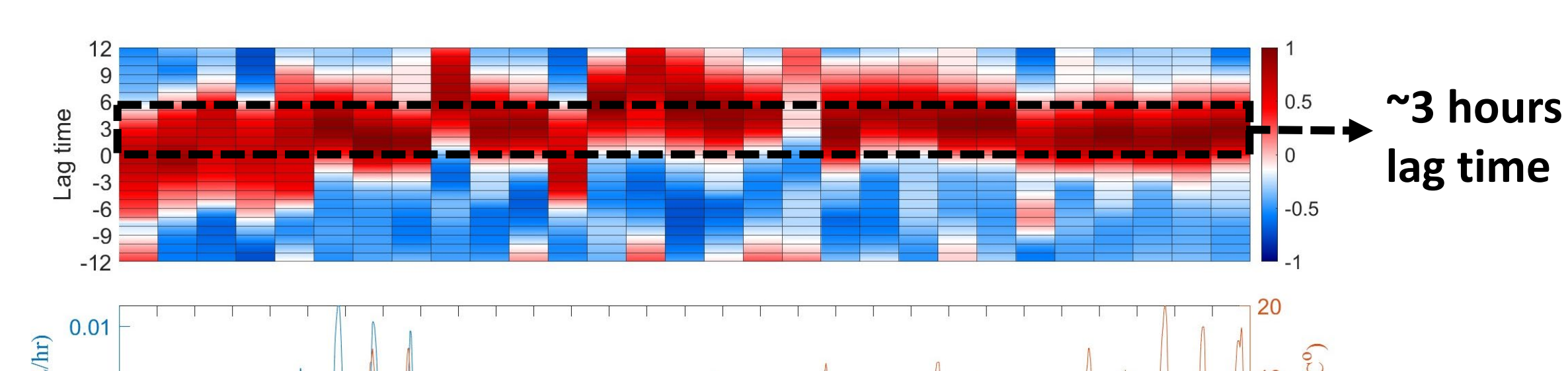
## Results

### Lag time of peak water flow during the melt season

Lagged cross-correlations analysis show that peak water flow is lagged by ~6 hours after peak air temperature outside and by ~3 hours after peak rock surface temperatures

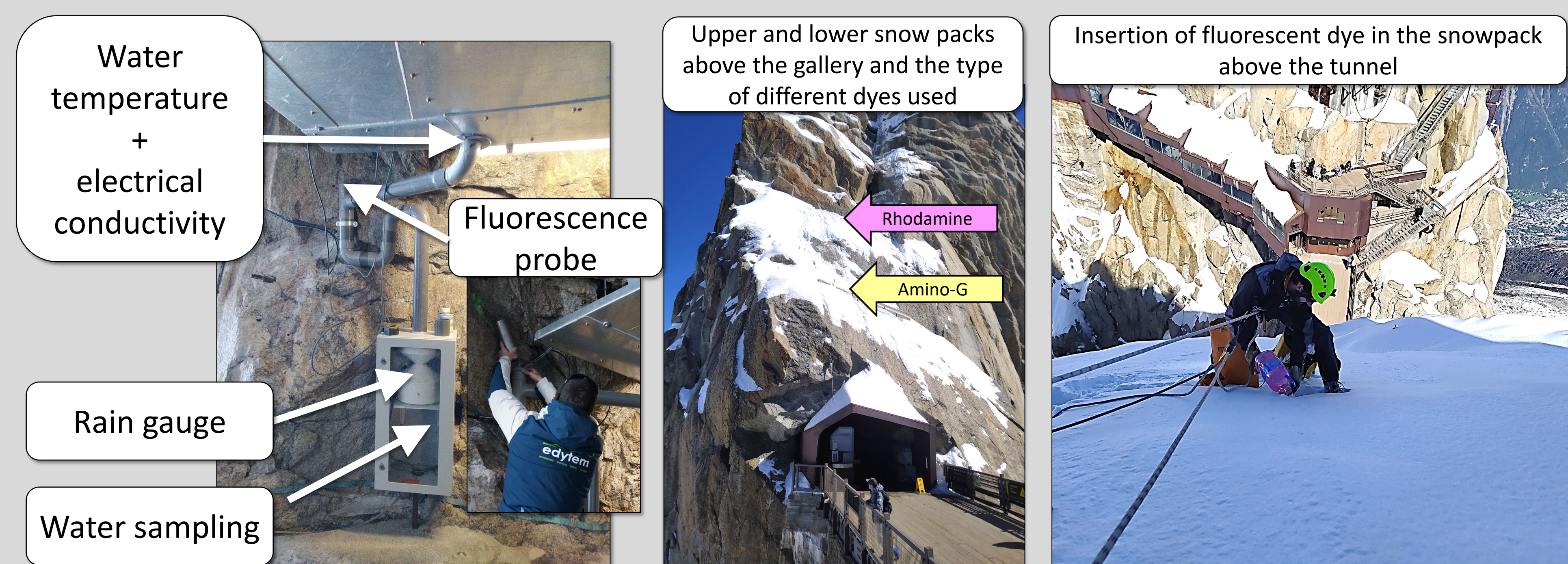


### Lagged cross-correlation: Flow rate – Rock surface temperature



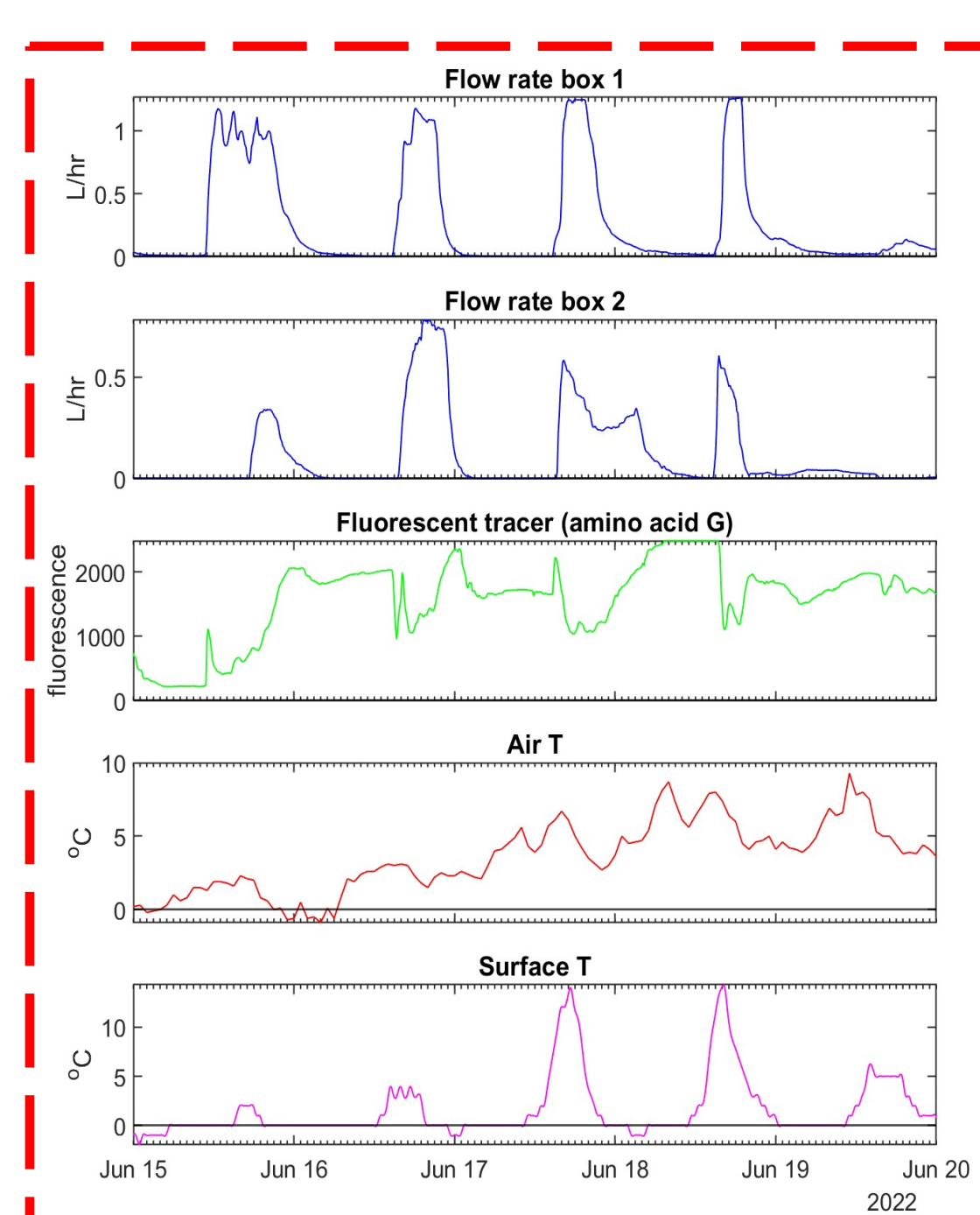
## Experimental setup

- Real-time measurements of:
  - Flow rate in two locations
  - Water fluorescence
  - Water temperature
  - Water conductivity
- Rock surface temperature
- Water sampling for
  - Stable isotopes (<sup>18</sup>O/D)
  - Major elements
  - Fluorescence

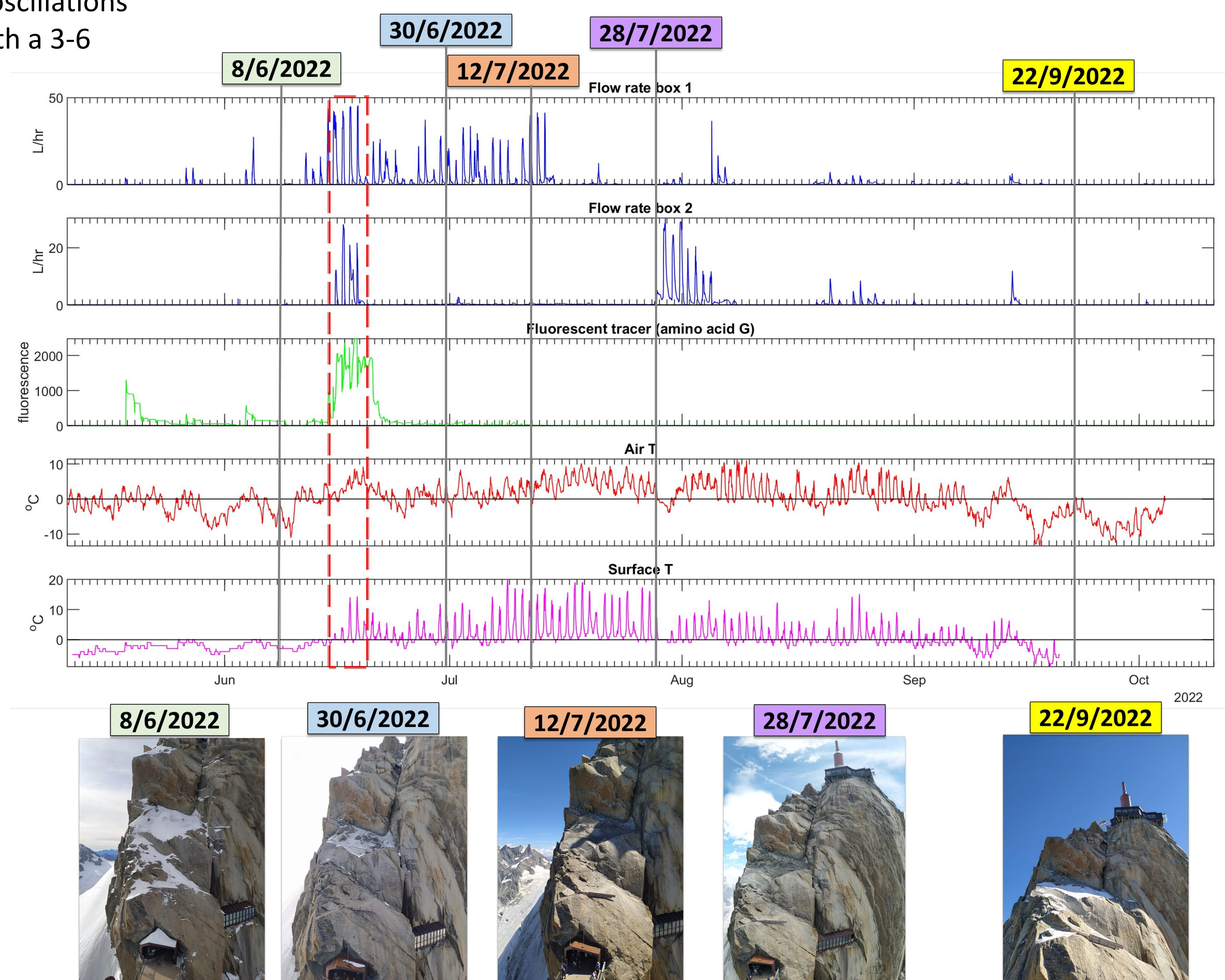


## Diurnal changes

Diurnal fluctuations in flow rate range between <1 L/hour in the morning to >10 L/hour in the late afternoon, and correlate with oscillations in air and surface temperatures, with a 3-6 hours lag time, respectively



## Real-time flow monitoring system



## Comparison of June 2022 with 2023

June 2023 was significantly colder in comparison with June 2022 and with late snowfall – As of mid-June 2023 no flow documented



## Key observations

- The fluorescent tracer from the lower terrace was found in the water from the first flow events until mid-May and remained in the water until mid-June.
- The tracer from the upper terrace was never observed.
- Significant water continued for 3 weeks after the fluorescent tracer disappeared from the water.
- Flow continued after all snow cover was gone
- The two adjacent fractures show different flow regimes (box 1 and box 2).
- Initiation of continuous flow follows the heating of the rock surface and air temperatures above 0°C.

## Summary and conclusions

- Our results from the real-time monitoring of the water flow from fractures in permafrost-affected rock slope show clear evidence of high connectivity between snowpack at the surface and sub-surface fractures.
- The initiation of a continuous flow period corresponds to an increase of surface temperatures above 0°C
- Strong diurnal changes in flow rate are observed and correlate with surface temperatures.
- The observation of flow after no snow cover was visible (mid-July) points to potential indirect sources such as runoff from upslope or ice storage in the fractures.

## Further work

In April 2023 two fluorescent tracers were inserted again in the same location: 1) amino acid G – lower terrace (same as in 2022). 2) fluorescein (new tracer) – Upper terrace (same location as sulphorhodamine-B in 2022). Monitoring continues with more frequent water sampling (once a week) for laboratory analysis, including major elements and stable isotopes

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