HYDROLOGY OF HIGH MOUNTAIN PERMAFROST

MONITORING OF WATER INFILTRATION AT THE AIGUILLE DU MIDI, MONT BLANC MASSIF

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Thesis report

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***Le Loup*, édition Casterman, 2019**
Jean-Marc Rochette

"De toutes parts, l'eau jaillit de la montagne, des cascades puissantes sautent des barres rocheuses, dessinant des gorges profondes où les torrents s'engouffrent, taillant la pierre éternellement. Une eau vive et pure se déverse à profusion vers les basses vallées. Une eau miraculeuse que l'homme va souiller en un jour."

Gaston Rébuffat

"La technique résout les problèmes et apporte des satisfactions mais elle n'est qu'un moyen et reste pauvre si on la sépare de l'esprit qui la guide."

RÉSUMÉ

Une augmentation de l'activité des écroulements rocheux a été observée dans les parois rocheuses de haute montagne depuis plusieurs années et notamment attribuée à la dégradation du permafrost (ou pergélisol). Ces écroulements présentent des risques pour la sécurité des personnes, les infrastructures ou encore les activités de haute montagne. La présence d'eau a été observée dans de nombreuses cicatrices d'écroulement. L'eau pourrait être ainsi un facteur déterminant dans la plupart des processus physiques qui façonnent les paysages périglaciaires montagneux. Mais à l'heure actuelle, il existe très peu de connaissances et d'observations sur l'origine, la quantité et le moment où l'eau s'écoule dans les parois rocheuses.

Dans le massif du Mont Blanc, les galeries artificielles du site de l'Aiguille du Midi (3842 m d'altitude) constituent une opportunité unique d'accéder à cet environnement particulier et spécifique. L'Aiguille du Midi sert ainsi de laboratoire naturel pour des mesures de terrain sur le pergélisol de montagne. Depuis mai 2022, un nouveau système de monitoring a été mis en place pour collecter des données en temps réel sur le débit, la conductivité ou encore la détection de traceurs qui ont été versés à la surface du manteaux neigeux en fin d'hiver.

Ces données peuvent être comparées à celles de température, aux informations climatiques et météorologiques provenant des stations météo ainsi qu'aux modèles numériques de bilan d'équilibre d'énergie, de chaleur et de masse d'eau, afin de fournir de nouvelles connaissances sur les processus hydrologiques. Elles pourront par la suite être utilisées pour contraindre les modèles numériques pour les rendre encore plus précis.

Le système expérimental de monitoring aide à mieux comprendre les interactions entre la surface et la subsurface dans le permafrost de haute montagne ainsi qu'à déterminer l'origine des écoulements, la quantité d'eau, la temporalité, la réaction au changement climatique et donc à l'augmentation des températures (de l'air et de la surface).

Une forte saisonnalité des écoulements a été observée notamment du à l'augmentation des températures qui fait fondre la couche de neige déposée sur la paroi. Cette neige représente la majorité des écoulements sur la saison. Les écoulements se répètent quotidiennement en réaction aux pics de température de l'air et de la surface de roche. La neige n'est pas la seule origine des écoulements, d'autres écoulements surviennent une fois la neige fondue. Cela pourrait provenir des précipitations estivales de pluie ou encore de la glace interstitielle représentant le réchauffement de la couche active et possiblement une dégradation du permafrost à l'origine d'écroulements rocheux.

Mots clés: Permafrost, monitoring, infiltration, neige, massif du Mont Blanc, changement climatique

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ABSTRACT

An increase in rockfall activity has been observed in high mountain rock slopes for several years and has been related to permafrost degradation. These rockfalls present risks for human security, infrastructure, and high mountain activities. Water has been observed in many rockfall scars. Moreover, water is a major driver in most physical processes that shape the mountainous periglacial landscapes. But at this time, there is very little knowledge and observation about the origin, quantity, or timing of water that flows into rock walls.

In the Mont Blanc massif, the man-made tunnels at the Aiguille du Midi (3842 m a.s.l.) is a unique opportunity to access this particular and specific environment and serves as a natural laboratory for field measurements in mountain permafrost. Since May of 2022, a new monitoring system has been set up to collect real-time data of flow rate, conductivity, and detection of fluorescent dyes that were inserted (in the snowpack) during the winter.

This data can be compared with temperature data, weather information from meteorological stations, and numerical models of heat and water mass balance, to provide new knowledge about hydrological processes. In turn, it can be used to constrain numerical models and make them more precise. The experiments help to understand surface-subsurface pathways in steep mountain permafrost and determine the water flow origin, water quantity, its timing, and the reaction of water runoff to climate change and the temperature increase.

A strong seasonality of flows has been observed, due in particular to the rise in temperature which melts the layer of snow deposited on the wall. This snow represents the majority of flows over the season. Flows are repeated daily in response to peaks in air and rock surface temperatures. Snow is not the only source of runoff; other runoff occurs once the snow has melted. This could come from summer rainfall, or from interstitial ice representing the warming of the active layer and possible permafrost degradation leading to rock falls.

Key words: Permafrost, monitoring, infiltration, Mont Blanc massif, climate change

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I would like to warmly thank my tutors at the EDYTEM laboratory, Matan and Florence, for giving me this wonderful opportunity to discover the glacial and periglacial domains up close. This atypical placement was a stroke of luck and also the reason why I decided to embark on new studies in 2021. Meeting the king of the Alps, Mister Mont Blanc, is humbling. Being able to witness the evolution of this massif at such close quarters during its transition from winter to summer has forged my desire to work even more and given me the strength to get involved in the fight against climate change. The preservation of these landscapes, which have shaped people and societies for thousands of years, is changing fast. Far too fast for ecosystems to adapt. Deeds and actions must take the place of words!

Un grand merci à Josué pour ses nombreux conseils sur l'évolution de mon travail ainsi que pour toute son aide, suspendu à une corde ou derrière l'ordinateur. Outre le permafrost, cela fait toujours du bien de partager sur des sujets ne concernant pas que le travail mais toujours avec un certain engagement.

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ACRONYMS AND MAIN DEFINITIONS

ACGR: Glossary of Permafrost and Related Ground-Ice Terms

ADM: Aiguille du Midi

ANR: Agence Nationale de la Recherche

ARPA: Agenzia Regionale per la Protezione dell 'Ambiente

CIP-MB: Carte d'Indice du Permafrost de paroi du massif du Mont Blanc / Permafrost Index Map of the Mont Blanc massif rock walls

CMB: Compagnie du Mont Blanc

CNRS: Centre National de Recherche Sciuentifique

CSV: Comma-separated values

AL: Active layer – Ground layer between the surface and permafrost experimenting annual freeze and thaw
ALT: Active layer thickness

EDYTEM: Environnements Dynamiques et Territoires de la Montagne

ERT: Electrical Resistivity Tomography

GIEC / IPCC: Groupe d'experts Intergouvernemental sur l'Evolution du Climat / Intergovernmental Panel on Climate Change

Surface offset: Surface Temperature – Air temperature, generally calculated with annual means

Thermal offset: Surface Temperature – Temperature at the top of permafrost, generally calculated with annual means

Temperature offset (specific to rock walls): Surface Temperature – Permafrost temperature at a depth chosen arbitrarily, generally calculated with annual means

PermaFrance: Réseau d'observation du Permafrost en France

Permafrost: Lithospheric (ground) layer having negative temperature for two consecutive years at least

PERMOS: Swiss Permafrost Monitoring Network

GIS: Geographic Information System

PISR: Potential Incoming Solar Radiation

MAAT: Mean Annual Air Temperature

MARST: Mean Annual Rock Surface Temperature

MART: Mean Annual Rock Temperature (below the active layer)

ZAA: Zero Annual Amplitude zone: Intrinsic layer to permafrost which temperature variation is <0.1°C in one year

Introduction

Mountain regions are more exposed to climate change than other areas. In recent years, temperature has risen twice as much at higher altitudes than in plains territory (*Haeberli and Beniston*, 2021). These higher temperatures are leading to rapid and brutal changes in local socio-ecological systems such as biodiversity changing or natural hazards increasing.

Permafrost is defined as all surface and subsurface which temperature are constantly below 0°C during at least two consecutive years with or without the presence of ice (*Gruber and Haeberli*, 2007). This thesis report deals with the evolution of mountain permafrost in the face of climate change, and more specifically at the potentially key role of hydrology (water flow, freeze-thaw processes) in the instability of rock faces (*Ravanel*, 2010; *Magnin*, 2015). Easy access to the high mountains at the Aiguille du Midi (3842 m a.s.l) in the Mont Blanc massif has enabled the EDYTEM laboratory's geomorphology team to set up a monitoring system in 2022 to monitor water flows in rock fractures.

The various data will be processed and analyzed in this report in order to gain a better understanding and insight about the hydrological processes that occurs in the steep rock walls of high mountains. This data will complement existing permafrost models such as CryoGrid, which is also used in the laboratory, and will be used to anticipate the risks associated with rockfalls.

Permafrost degradation can be summed up as both “a cause and a consequence of climate change” (*PermaFrance*). This is a cause in the sense that the degradation of permafrost, present mainly in high latitudes, releases large quantities of methane, contributing to the increase in greenhouse gases and consequently to global temperature rises.

In mountain environments, permafrost is found at higher altitudes. The consequence of permafrost degradation in high mountains is the risk of rockfalls. Many issues are thus threatened in this changing environment. Sports and recreational activities such as mountaineering are directly affected (disappearance of famous routes – e.g. Les Drus and the disappearance of the Bonatti Spur in 2017, as well as an increase in the risk to people from rockfalls, and infrastructures and refuges built on moving and unstable zones – e.g. the Cosmiques refuge (Duvillard, 2019). However, these direct issues can extend far beyond the realm of high mountains. Rockslides trigger cascading events that can affect people and property right down to the valley (e.g. Piz Cengalo in 2017).
Like glaciers or the destruction of biodiversity, permafrost is an indicator of climate change that is essential to understand and anticipate. However, a major difference lies in the fact that permafrost is an invisible indicator. Observing it is therefore a real scientific challenge, and improved monitoring techniques and numerical models are enable us to learn more about the subject.

The EDYTEM[1] laboratory was set up in 2003 to bring together researchers in the geosciences, humanities and social sciences. It uses a multidisciplinary approach to help understanding the environmental issues of mountain areas as a whole (climate, biodiversity, ecology, society). It is a

1 **E**nvironnements, **DY**namiques et **TE**rritoires de **M**ontagne / *Environments, Dynamics and Mountain Territories*

joint research unit of the Université Savoie Mont Blanc and the Centre National de Recherche Scientifique (CNRS) (*EDYTEM*, 2015).

The main tasks of these six months internship were to follow up and set up the monitoring system at the Aiguille du Midi, to process and analyze the data for comparison between 2022 and 2023, and to prepare water samples collected at each visit to the Aiguille du Midi for chemical analysis.

This monitoring work and the installations set up at the Aiguille du Midi will enable us to better understand the role of water behind permafrost degradation. These data will be used to constrain numerical models and thus better anticipate the impacts created by this degradation (rock falls, rock avalanches, etc.).

With this monitoring system, we will try to answer to the main question:

What is the connectivity between surface and subsurface in steep bedrock slop in high mountain?

In order to answer some of the questions raised by the problem, the thesis will be divided into four main parts.

First, a review of the state of the art will be carried out to clarify what we know about permafrost, what is at stake in its evolution for mountain environments, and the various means used to better define this phenomenon that affects mountains, mountainous landscapes, infrastructure, and population.

The second part takes a detailed look at the monitoring system installed at Aiguille du Midi. The sensors used, the information derived from them and the additional analyses that can be carried out subsequently will be explained.

The methodology will be followed by the results obtained during the two years of monitoring. The results for 2022 will be broadly presented, together with an analysis and significance of the various signals, and then compared with those obtained for the 2023 current summer season.

The fourth part will be the opportunity to take a more global look at the specific contributions of this internship, the questions raised by the research subjects and the study area (real touristic place) that is the Aiguille du Midi. Then, a feedback about the personal and professional assessment between the courses given in Toulouse and this internship with EDYTEM.

I. GENERAL CONTEXT

1.1. Presentation of the EDYTEM laboratory

Founded in 2003, the EDYTEM laboratory is a UMR under the supervision of the Université de Savoie Mont Blanc (USMB) and the CNRS.

The laboratory is located at Savoie Technolac, science Campus (Le Bourget-du-Lac, France). In 2008, it moved into new premises within the USMB "Pôle Montagne", which not only accommodate all its permanent, contract and doctoral staff, but also its scientific activities doctoral students and its collective scientific analysis activities (platforms). This geographical proximity to multidisciplinary training courses and other laboratories working in the mountain environment fosters synergies, which have led to the creation of a partnership in Ecology and Environment (DIPEE) (CNRS-INEE), a research federation (FLAME) and the co-sponsorship of national programs (“Programme d’Investissement d'Avenir (PIA), CNRS “Zone Atelier”, etc.). The laboratory is also very close to the industrial and economic world on campus (the nearby Technolac "technopole") (*HCERES*, 2019)

The unit has a single focus: mountain environments and territories. With interdisciplinary as the heart of its scientific policy, EDYTEM covers three main scientific fields (geosciences, environmental sciences, human and social sciences) focusing on mountain environments and, more specifically objects it describes as "emblematic": high mountains, hydrothermal systems, karsts, mountain lakes mountain lakes, geo-heritage and protected areas.

The unit is structured into four teams with complementary functions (Figure 1):

- **Team Society**
- **Team Critical Zones**
- **Team Materials**
- **Team Morphodynamics (where this internship belongs to)**

The morphodynanic team is led by Ludovic Ravanel and Yann Rolland. It focuses on the processes and dynamics of geomorphology such as:

- Relief evolution on different time scales (formation and long-term-short-term evolution of mountain ranges).
- Response to past and present climate change.
- Impacts on society (hazards, practices, management).
- Characterization and mapping of geomorphodiversity, methods and tools for revealing and managing "geomorphosites" (heritage geomorphology).

The main fields of study are high mountains and karstic environments, whose current evolution is controlled by thermal, physico-chemical, hydro-dynamic and mechanical processes of geological structures. The objects of study lie at the interface between snow and glacial cover, permafrost for the mountains and karstic networks, geological milieu, external environment for underground systems (website *EDYTEM*).

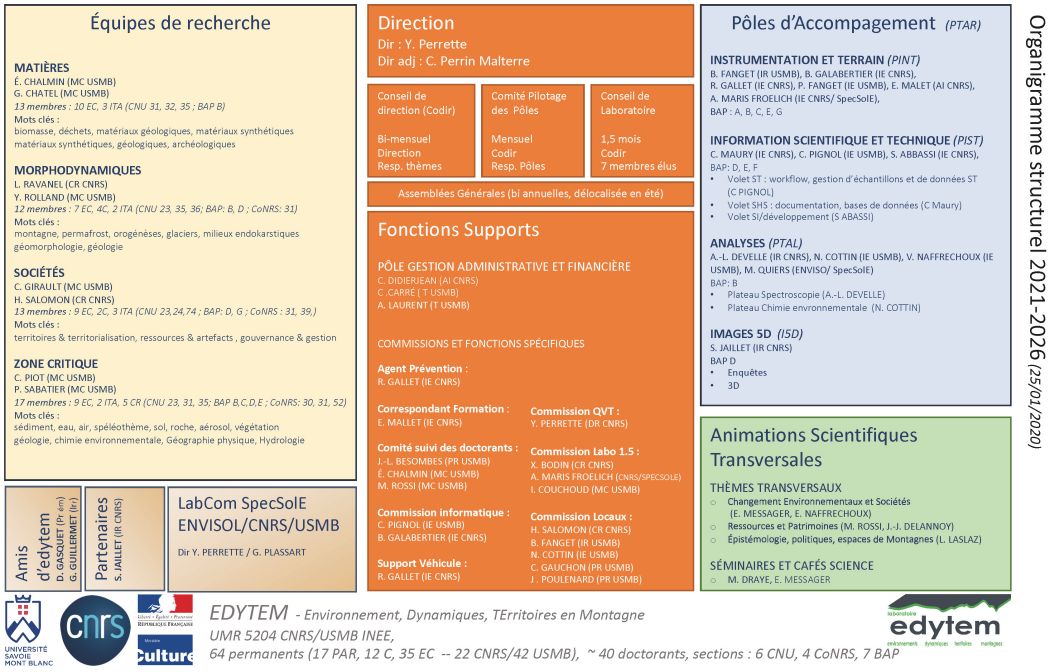


Figure 1: EDYTEM structure organisation (https://EDYTEM.osug.fr/)

1.2. Definition of permafrost and general notion

EDYTEM is one of the main academic actor in France for studying the dynamics and trajectories of mountain regions. Climate change is having a greater impact on mountain areas, so the themes and subjects addressed by the laboratory are increasingly numerous and important.

Risk management in these fragile areas is a key concern for the government, local managers and stakeholders, and has an impact on all socio-professional activities. This is why EDYTEM's morphodynamics team studies changes in the landscape of valleys all around the world accurately and in advance, as well as on an international level, through cooperation facilitated by the proximity of its Alpine arc neighbors such as Italy and Switzerland.

1.2.1. Context and definition

What is permafrost?

Permafrost (PERMAnent FROST (frozen)) is a thermal state of lithospheric materials. In 2007, European mountain permafrost specialists Gruber and Haeberli defined permafrost as all surface and subsurface which temperature is equal or below 0°C during at least two consecutive years (with or without ice). The notion about the presence of water is really important for this study.

In fact, the knowledge behind presence of water or the freezing point of water inside permafrost are important because many chemical, biological and mechanical processes in nature require and/or regulated by liquid water.

With temperatures rising rapidly (*Haeberli and Beniston*, 2021; *Francou*, 2021), the world's permafrost is changing and causing concern. Most of the permafrost is located at high latitudes (Siberia, Antarctica, Greenland, etc.), but some is also found in high latitudes in mountain ranges.

Alpine permafrost: definition, distribution characteristics and specific features of alpine permafrost

The presence of permafrost in mountain environments, and particularly in the Alps, depends on three very distinct scale factors represented in the figure 2 (adapted from *Gruber*, 2005).

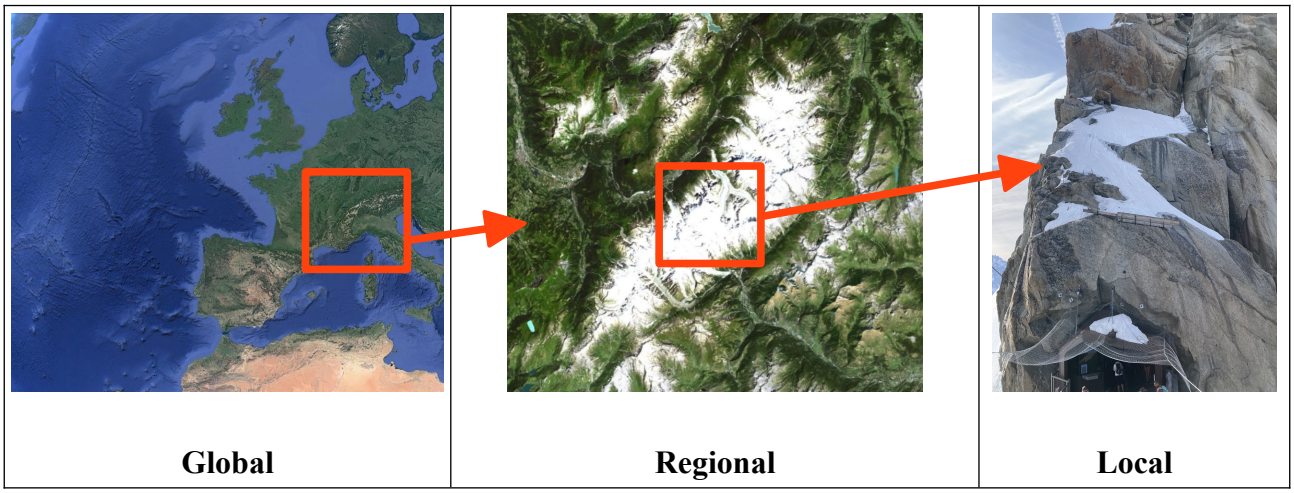


Figure 2: Nested scales of control for alpine permafrost (inspired by Gruber, 2005)

- **Global scale**: ***global climate and solar irradiance*** are the two main drivers of permafrost modification. The associated parameters are atmospheric temperature and solar radiation (long and shortwave).
- **Regional scale**: ***Topography, altitude and orientation*** will have a decisive influence on precipitation such as snow cover and direct rainfall on the walls.
- **Local scale**: From a very local point of view, permafrost is defined by two main parameters: ***the mean annual rock surface temperature (MARST) and its thickness***.

  Thickness is measured indirectly by the temperature at the bottom of the wall. The profile of a permafrost wall is made up of several "layers" (Figure 3). The main indicator of permafrost thickness is the ***active layer***, the thickness of which will change as a function of the temperature of the wall surface. The active layer is defined as the layer of ground that thaws on a seasonal basis (*ACGR*, 1988). Active layer is subject to seasonal freeze-thaw cycles (*PermaFrance*) and can become saturated with water during thaw phases. It is an important factor in the seasonal hydrological cycle, especially as its base corresponds to the permafrost ceiling. To sum up, ***as the active layer thickness is increasing, the permafrost***

depth is decreasing. This is why experimental studies focus on measuring the active layer and changes in its thickness in order to characterize and define the state of the permafrost at a given point (very local study). The active layer is representing the direct interaction between the ground surface, that is exposed to the atmosphere, and the permafrost below.

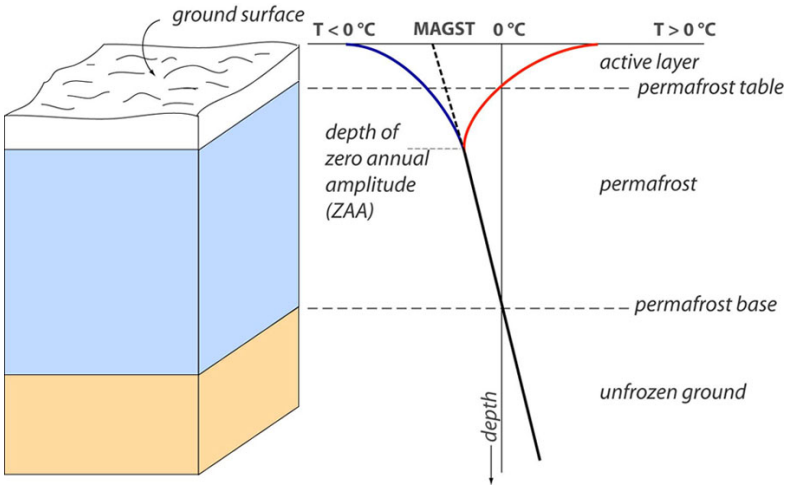


Figure 3: Active layer definition and thermal profile (PERMOS)

Table 1 summaries all these scaling factors and their associated parameters. The majority of these parameters were studied during the framework of this internship. A large amount of data were used to gain a better understanding of the thermo-mechanical mechanisms linked to the water runoff in the walls. The objective is to try to achieve a reference state of the connectivity between the wall surface and its subsurface.

Table 1: Scaling factors by surfaces type and the main parameters of mountain permafrost. between each layer, thermal offsets exist (Delaloye, 2004)

Scale	Physical representation	Main parameters and variables
Global	Climate, atmosphere	• Air temperature • Solar radiation
Regional	Snow cover and rainfall	• Duration • Thickness • Density • Temperature • Precipitation
	Ground surface	• Rock surface temperature • Type • Rugosity • Albedo • Orientation • Slope angle
Local	Active Layer	• Granulometry • Porosity

		• Thermal and hydraulic conductivity
	Permafrost table	• Temperature • Depth

Where is the permafrost found, especially in the Alps?

Although mostly present in cold regions at high latitudes (Arctic and Antarctic), it is also found at high altitudes (mountain permafrost).

Alpine permafrost is found in supra and periglacial zones. Periglacial areas are characterized by alternating periods of freezing and thawing and glaciers are not present. It is this phenomenon of thermal alternation that distinguishes them from glacial zones.

Global warming increases the freeze-thaw phenomenon in glacial and periglacial zones. The surface area of periglacial zones increases at the expense of glacial zones. Its presence is therefore influenced by the parameters seen in the previous paragraph and the proportion of the surface covered by permafrost, different types can be characterized (Table 2).

In the French Alps, there is an estimated 700 km² of permafrost compared with 275 km² of white glacier[2].

Alpine permafrost characteristics

The mountain permafrost environment is highly heterogeneous (Table 2), particularly outside of polar regions, as temperature and tropical mountains are subject to large spatial and temporal differences in climate conditions and ground conditions can vary substantially over short distances (*Arenson et al.* , 2022).

This study focuses on and high mountain permafrost, that is characterized by rock slopes at altitudes above 2500 m with a steep slope angle of more than 40°. Mountain permafrost is essentially discontinuous and sporadic and can be found at temperatures between -3°C and 0°C (*Boeckli*, 2012).

Table 2: Permafrost characteristics

Zonal type of permafrost	**Mean Annual Rock Surface Temperature characteristics MARST (*Boeckli*, 2012)**	**Estimated elevation (m a.s.l) (PERMOS)**	**Rate of permafrost cover over the total area of the zone**
Continuous	< -1,95 °C	> 4000 m	>80%
Discontinuous	-1,95°C < T <= 0°C	3000 m – 4000 m	Between 30% and 80%
Sporadic	0°C < T <= 3,9°C	2600 m – 3000 m	<30%

2 Journée de la Glaciologie, Nivologie, Hydrologie et Permafrost 2021, Présentation de Duvillard

Several periglacial morphologies are commonly associated with the presence of permafrost in high mountains such as steep rock walls at high altitudes but also in surface formations such as frozen debris (talus slope or high moraine field), the best known form of which is the rock glacier (Figure 4).

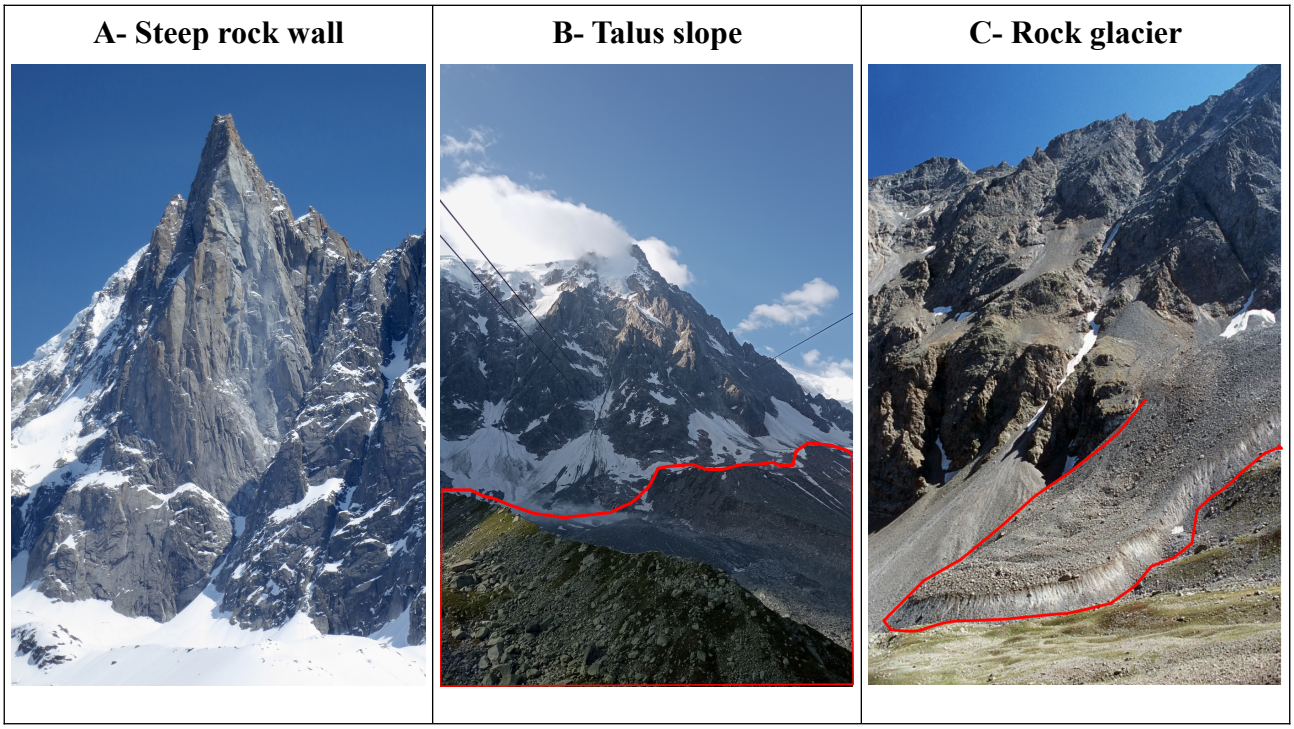


Figure 4: Different representations of mountain permafrost surface formations. A: West face of Drus in April 2013 (by O. Taris) B: North face of Aiguille du Midi in July 2023 (by A. Chabas) C: Laurichard (Hautes-Alpes) rock gkacier (by EDYTEM lab)

Two types of environment are being studied in particular: supra-glacial rock walls and superficial formations such as rock glaciers (*Bodin*, 2015). The table 3 summarizes the characteristics of these two dynamic morphologies.

Table 3: Characteristics comparison between rock walls and rock glaciers. Methods can be equal for studying some evolution but the reaction may not be the same (see section 2.2)

	Permafrost-affected rock walls	**Rock glaciers**
Composition	Single fractured boulder	A mixture of ice and rock debris
Altitude (in the Alps)	> 2500 m	2400-3000 m
Slope angle	> 40°	Around 40°
Ice content	Not mandatory but possible in the fractures	10-+60% of ice
Dynamics	Rock falls	Slow and constant creep
Reaction to climate change	Direct contact with the	climate signal is regulated by

	atmosphere and limited ice content make them highly sensitive to short-term climate	the seasonal presence of a "buffer" snowpack and high ice content

1.2.2. Challenges of mountain permafrost as recent research field

Mountain permafrost has not been studied to any great extent, despite the first observations being made in the mid-twentieth century when the first infrastructure was built in the high mountains (e.g. the Jungfraujoch railway (*Haeberli and Beniston*, 2021). Permafrost was first studied in high-latitude regions such as Siberia and Canada, due to the high economic stakes associated with the oil infrastructures built on these frozen soils.

Although high-latitude permafrost has been a subject of study for scientists for many years, it is only recently that mountain permafrost has been given due consideration in view of the direct issues linked to its evolution (*Noetzli*, 2019; *Haeberli and Beniston*, 2021). Research into mountain areas began in the 1970s but most research on mountain permafrost was made after the 1990s (*Haeberli et al.*, 2010). The major sensitivity of mountain and high mountain areas to climate change and the associated risks to society make this field of study essential today.

Permafrost research networks

Switzerland, Italy and France have each developed an observation network to study mountain permafrost:

- ***PERMOS*** (Swiss Permafrost Monitoring Network) documents the state and changes of mountain permafrost in the Swiss Alps. Researchers collect field data on permafrost conditions in the framework of climate monitoring, which are openly available. In its latest report (PERMOS, 2013), it lists three wall sites: Tsaté (Valais), which has been instrumented since 2004, the Matterhorn (Valais) since 2005, and Gemsstock (Uranese Alps) since 2006.
- ***ARPA*** is the Regional Environmental Protection Agencies of the Aosta Valley (ARPA VdA) and Piedmont (ARPA Piémont) and the municipality of Valtournenche are working with international partners such as EDYTEM with ALCOTRA project PrévRisk Haute Montagne about permafrost issue on human activities and infrastructures (website *ARPA Piemonte*)
- ***PermaFrance*** is the French permafrost observation network and operates on a system similar to the Swiss model. The network has mainly been recording surface temperatures since 2003, the movement of rock glaciers since 1985 and rock avalanches since 2005. The Aiguille du Midi is the only instrumented wall site in France, and completes the French network of sites for measuring the temperature of detrital terrain (*Schoeneich et al.*, 2010).

Permafrost degradation

Permafrost degradation is a slow process in which subsurface temperature fields are expected to deviate sharply from steady conditions in the future as shown in figure 5 (*Noetzli*, 2019). It refers to the decrease of permafrost volume (layer thickness).

Moreover permafrost thawing often lead to increasing liquid water content and other changes of physical characteristics in response to energy input within a body of rock or soil (*Krautblatter et al.*, 2013 ; *Colombo*, 2018). This is known as permafrost degradation.

Field observations of rockfalls and recent studies (*Kraublatter et al.*, 2013) show near-surface fractures in the active layer. The temperature of the walls are increasing as well as the active layer thickness. The thermal profile changes as a result, disturbing the active layer, which becomes increasingly thicker over a relatively short period of time.

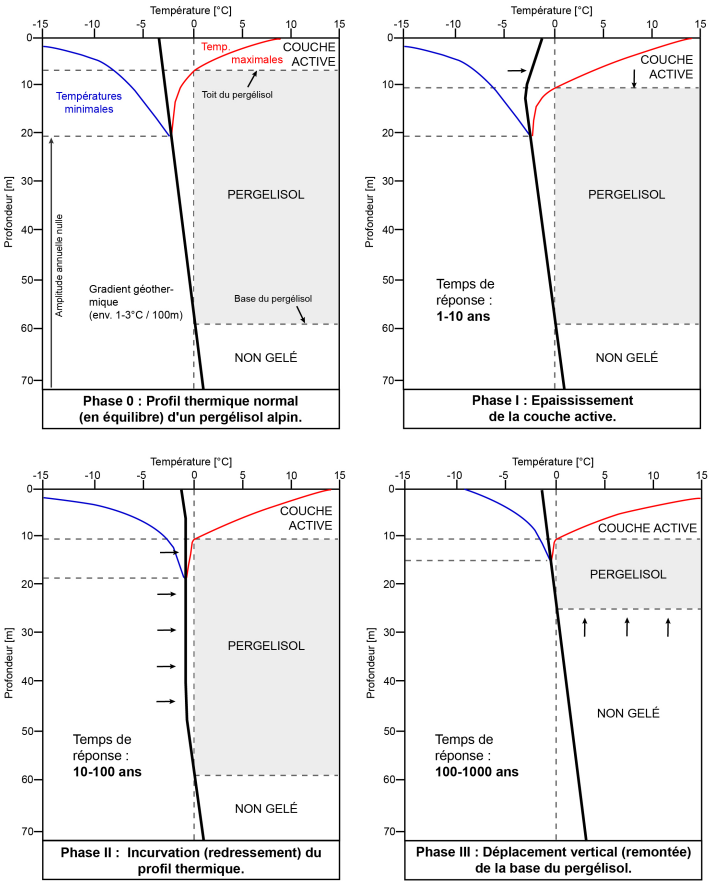


Figure 5: Evolution of permafrost thermal profile

The freezing and thawing cycle will weaken the walls as a result of the ***gelifraction*** caused by the frequent presence of interstitial ice. The volume of liquid water can increase by up to 9% of its initial freezing volume (https://geomorphologie-montagne.ch/2-3-la-gelifraction/).

Mountain permafrost research for natural risks and human issues

Mountain societies are at the mercy of many natural hazards. These risks are increasing sharply as a result of rapid climate change (*Morin*, 2022). They are the main reason why mountain permafrost is the focus of numerous studies in France and abroad, such as in the Swiss Alps. Permafrost is changing rapidly, and there are many consequences that can affect the populations of the valleys, as well as sporting and professional activities.

Rockfalls in permafrost-affected areas in the Mont Blanc massif are being studied and a participatory tool associated with a network of observers record gravity phenomena has been set up on the massif (*Ravanel and Deline*, 2013). This new knowledge and the involvement of local actors highlights this hazard. Public authorities is now alerted to the possible consequences of the massif's evolution on this invisible process.

Among the processes that affect high mountain walls, rockfalls (volume of rock between 100 and 100 000 m^3), rock avalanches (volume > 100 000 m^3) and torrential lava (debris flow) mobilize

large volumes of materials, that can travel long distances. These phenomena are therefore a major hazard both in the high mountains and in the valleys, where vulnerability generally increases (*Ravanel*, 2009).
Difficult to anticipate, one of the greatest dangers of rockfalls lies in the fact that they can be the initial point in a series of gravitational events, known as the "cascade effect", which will accentuate the severity and scope of the risk. This sequence of events complicates the understanding and consequences of an individual natural hazard through a chain of complex interactions.

In the Alps, recent examples have raised public awareness, disrupting many socio-professional activities and even causing personal injury leading to death:

- Collapse and rockfalls (300 000 m^3) of the Bonatti Spur in 2005 on the west face of the Drus (Figure 6) - disappearance of a mountaineering route (*Ravanel*, 2008)
- Rock avalanche (3 millions m^3) leading to a torrential lava flow from Piz Cengalo[3] in 2017 (Switzerland) – destruction of part of the village of Bondo and death of 8 hikers
- Most recent rock avalanche on the Fluchthorn[4] (11 June 2023) in Switzerland who took the summit (100 000 m^3) leading to a torrential lava and stopping less than 1 km from a historic refuge without causing any casualties for human or structure

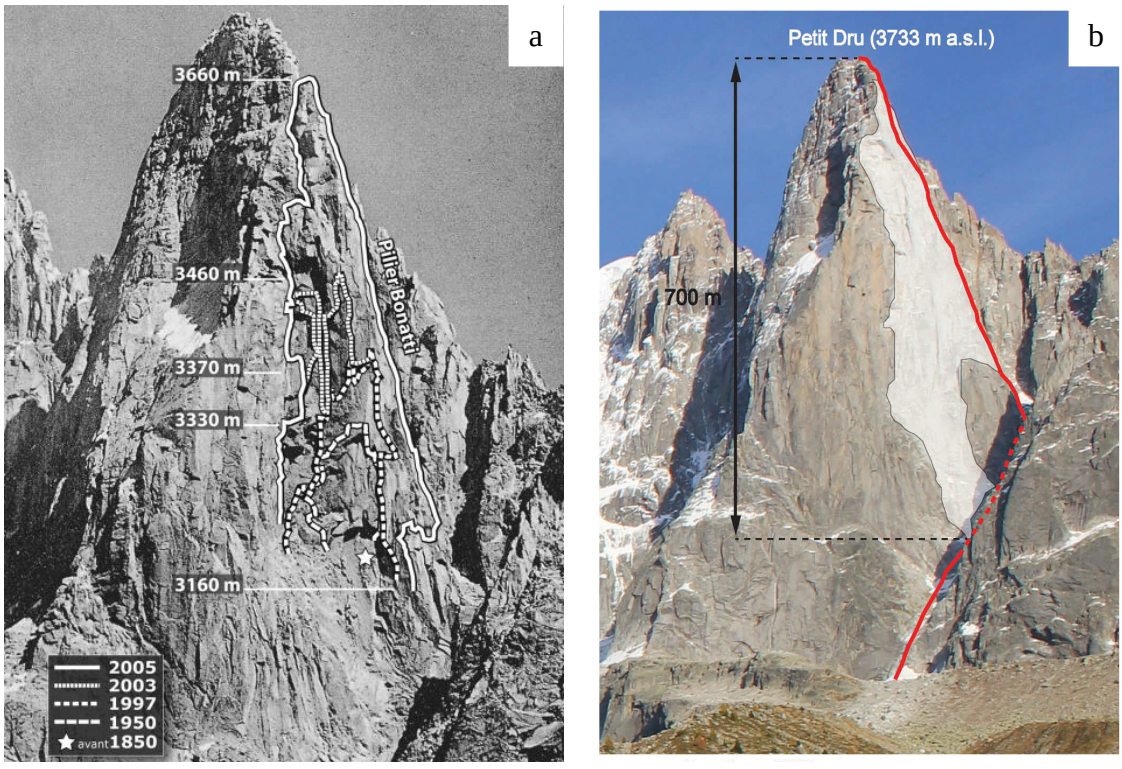


Figure 6: Collapse of Bonatti Spur in 2005 in Les Drus. a: All rockfalls that have occurred in the 20st century in Les Drus. There went higher and higher. ; b: 2005 rockfall scar and the old mountaineering route disappeared since 2005

3 http://www.risknat.org/alpes-climat-risques/Base_de_connaissances/Evenements_remarquables/fiches_evenements/2017/2017-08-23_MouvementsDeTerrain&ChutesDeBloc_Bondo.pdf
4 https://alpinemag.fr/fluchthorn-avalanche-rocheuse-face-ouest/

In addition to the risk to people, many infrastructures built on unstable permafrost ground are the subject of studies or questions about their future (e.g. the Cosmiques refuge in figure 7 (*Duvillard*, 2019)). High mountain infrastructures have to adapt to deal with ground movements created by freeze-thaw cycles, such as changing the way the structure is held together or lateral loading, in particular by using specific cement (*Gruber*, 2005). This can have a major economic impact on building managers.

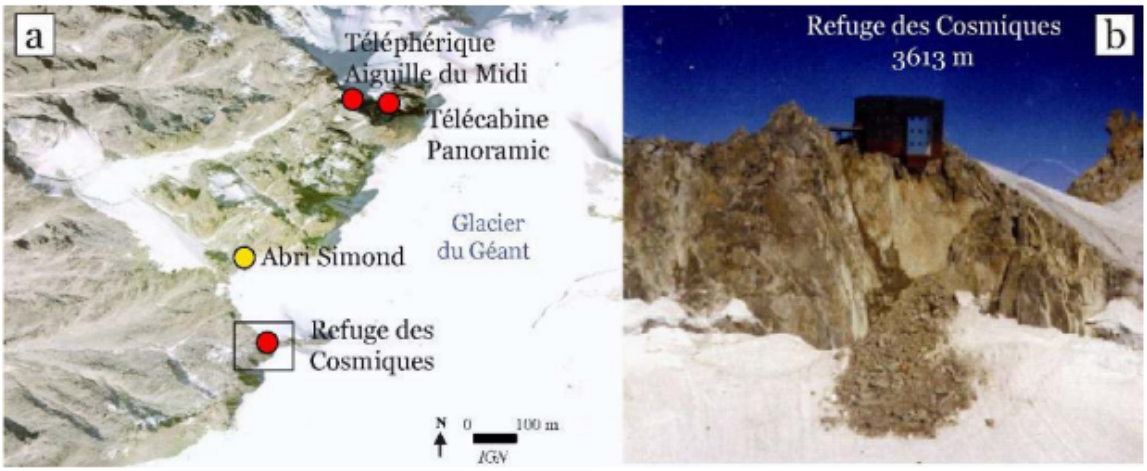


Figure 7: a: Infrastructures in the Aiguille du Midi sector – b: Collapse in August 1998 under the Cosmiques hut (ph. A. Sage) (Duvillard, 2015)

Economic activities (tourism, sporting activities or infrastructure) in the valleys are at risk or need to find ways of adapting to these rapid changes.

Why an increase of rockfalls activity the last decades?

Figure 8 shows that the frequent "extreme" heat waves of recent summers (e.g. 2003, 2015, 2018, 2022) have coincided with an increase in gravity events such as rockfalls during the summer (*Gruber et al*. 2004a; *Ravanel*, 2017).

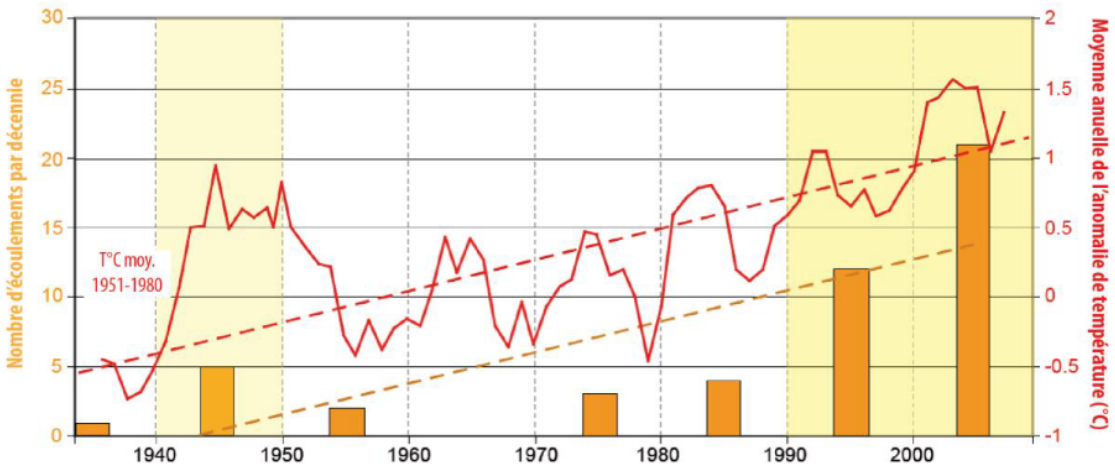


Figure 8: Relationship between air temperature and rockfalls events grouped by decade during the second half of the 20th century (Ravanel and Deline., 2015)

An opportunity for water cycle?

Permafrost degradation in high mountains can have can have multiple impacts on the mountain's hydrological cycle. This degradation can sometimes be seen as an opportunity, particularly in terms of its role as a water tower, so that in a high alpine catchment, *Rogger et al.* (2017) simulate that runoff in summer increases by 1–20% during permafrost degradation and its complete disappearance will reduce flood peaks by 5–15%. With the rapid melting of Alpine glaciers, water from the degradation of permafrost could be an interesting source of water in the European Alps (*Clow et al.* 2003). However, they did not consider subsidence due to melting ice in supersaturated talus slopes and rock glaciers, which can affect porosity and hydraulic conductivity.

Attention must also be paid to the quality of the water flowing from permafrost formations. This water will have a very different chemical composition to glacier meltwater. Runoff from thawing rock glaciers can export enriched-solute fluxes and thereby cause significant changes in water chemistry downstream (*Ilyashuk et al*. 2014). *Thies et al.* (2013) report pronounced differences in the concentration of major ions, heavy metals, species composition and biodiversity in streams emerging from active rock glaciers, which are attributed to seasonally increasing release of melt water.

What research methods are needed to analyze permafrost?

Three research methods are commonly used to analyze permafrost at different spatial and temporal scales: numerical modeling, ERT (electrical resistivity tomography) and monitoring (Figure 9).

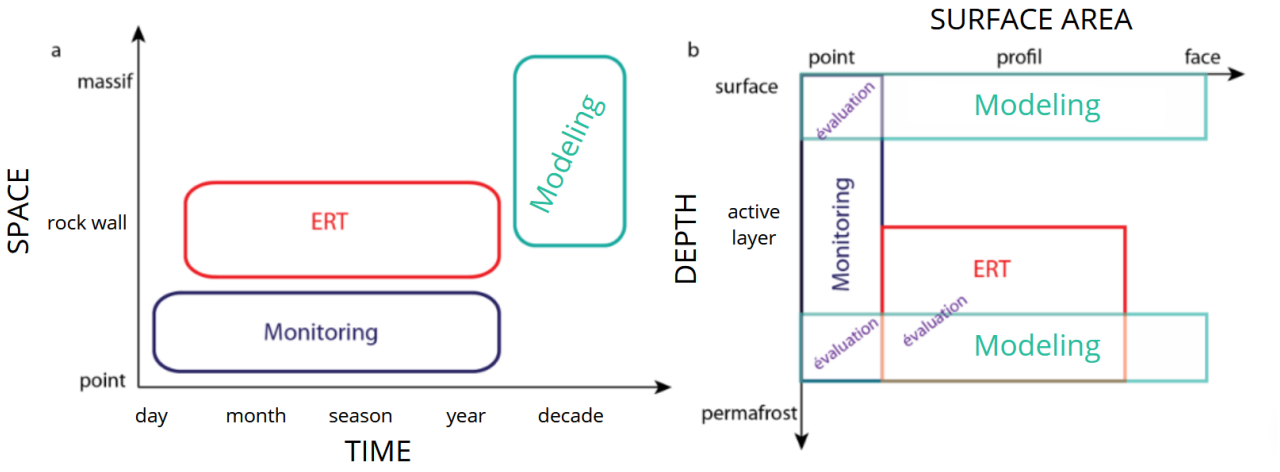


Figure 9: a: Spatial and temporal scales of the methods used in this study. ; b: Spatial dimensions of permafrost analyzed and overlap of methods (taken from Magnin, 2015)

A number of numerical models have been implemented since the beginning of permafrost research. Each new piece of knowledge or information obtained from analyses carried out in the field makes it possible to add a little more to these models. Numerical models are very important for studying the current state of permafrost, particularly as permafrost is generally not visible at the Earth's surface and there are only a limited number of measurement sites. In recent decades, land surface

models have become more complex, integrating a wide range of processes from various disciplines, such as biophysics, biogeochemistry, hydrology and ecology (*Fisher and Koven*, 2020).

The first permafrost models were developed in the 1970s using a statistical-empirical model (*Haeberli*, 1975). It was dedicated to surface formations and was based on field observations (sunshine, slope, vegetation, etc.). Models were then developed using GIS tools in the 1990s. The ability to spatialize the various elements means that permafrost distribution maps can be obtained. However, the input data for these statistical models is based on approximations of the main parameters, such as theoretical solar radiation or air temperature, without considering the internal heat transfer processes of the subsurface (*Magnin*, 2015). With the progress of research and methods, local-scale parameters are being added for a more accurate physical approach. This makes it possible to get as close as possible to the atmosphere-surface (energy balance) or surface-subsurface (transfer by conduction and advection) interfaces.

Improvements in measurement technologies and techniques for accessing these extreme environments have made it possible to obtain information on wall temperatures at depth (via boreholes (PERMOS, 2013) and thus develop a first permafrost distribution model for the Alps. This "rock model" developed by Boeckli is based on three main parameters: surface temperature (MARST), solar radiation (PISR) and air temperature (MAAT). This 30m resolution model was used for the Mont Blanc massif presentation map (Figure 13).

The new field measurements obtained from monitoring will be used to evaluate permafrost distribution models. The results specific to each method will then be used to test the geomorphological hypothesis on the rock faces of the Mont Blanc massif, and in the long term may help public decision-makers or better anticipate the risks associated with the evolution of permafrost on rock faces.

The motivation to have high-performance models on this issue of permafrost degradation on high mountain faces are:

- to anticipate the evolution of high mountain permafrost and its possible degradation in order to avoid or minimize natural hazards.
- the change in altitude in the availability of water in liquid form (rain) and solid form (snow) is very sensitive to climate change.
- the dominance and increase in the rate of melted snow and rainfall on rock faces will probably lead to more frequent boulder failures. This will increase the risk to people and human infrastructure both near and further away from the hazard.

1.3. General presentation of the study area covered and the internship missions

1.3.1. Study area: the Aiguille du Midi, a gateway to the realm of the high mountain permafrost

The Aiguille du Midi is located in the north-western part of the Mont-Blanc massif (Figure 10), above the Chamonix valley. Because of the extent of its supra-glacial rock faces, their particularly active dynamics, and the high levels of visitor numbers and occupation densities, this massif provides a relevant setting for our study.

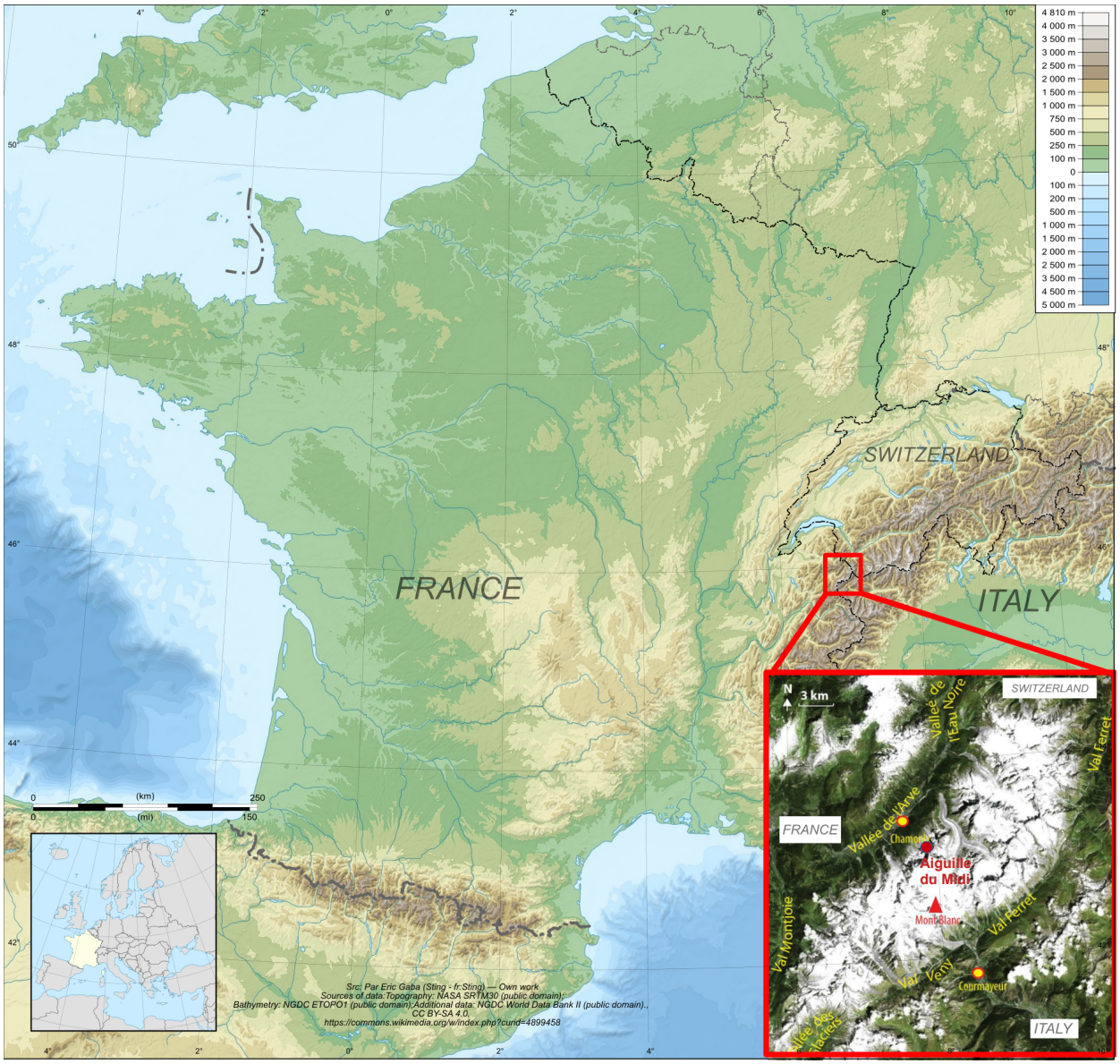


Figure 10: Mont Blanc massif localization

Its peak culminates at 3842 m a.s.l. and is made up of three peaks (North, Central and South) in porphyritic granite, facing Mont Blanc to the south and the famous Grandes Jorasses to the east (Figure 12). It is an important site for research into permafrost on rock faces.

This “natural” laboratory is an ideal location for the monitoring carried out as part of this course. The various galleries and the lift dug into the rock mass provide year-round access to an extreme environment that would otherwise be inaccessible. The fracture network at the Aiguille site is also well known and cataloged, making it easier to study the flow in the wall, especially with the direct link to the tourist galleries. The main network of fractures is intersected by a secondary network (*Leloup et al*. 2005).

This area is very popular with mountaineers and is also well known to the general public. The Aiguille du Midi is easily accessible thanks to a cable linking Chamonix to the Aiguille via mechanised "cable cars" (Figure 11). This unique opportunity to climb so high and so quickly has a number of implications:

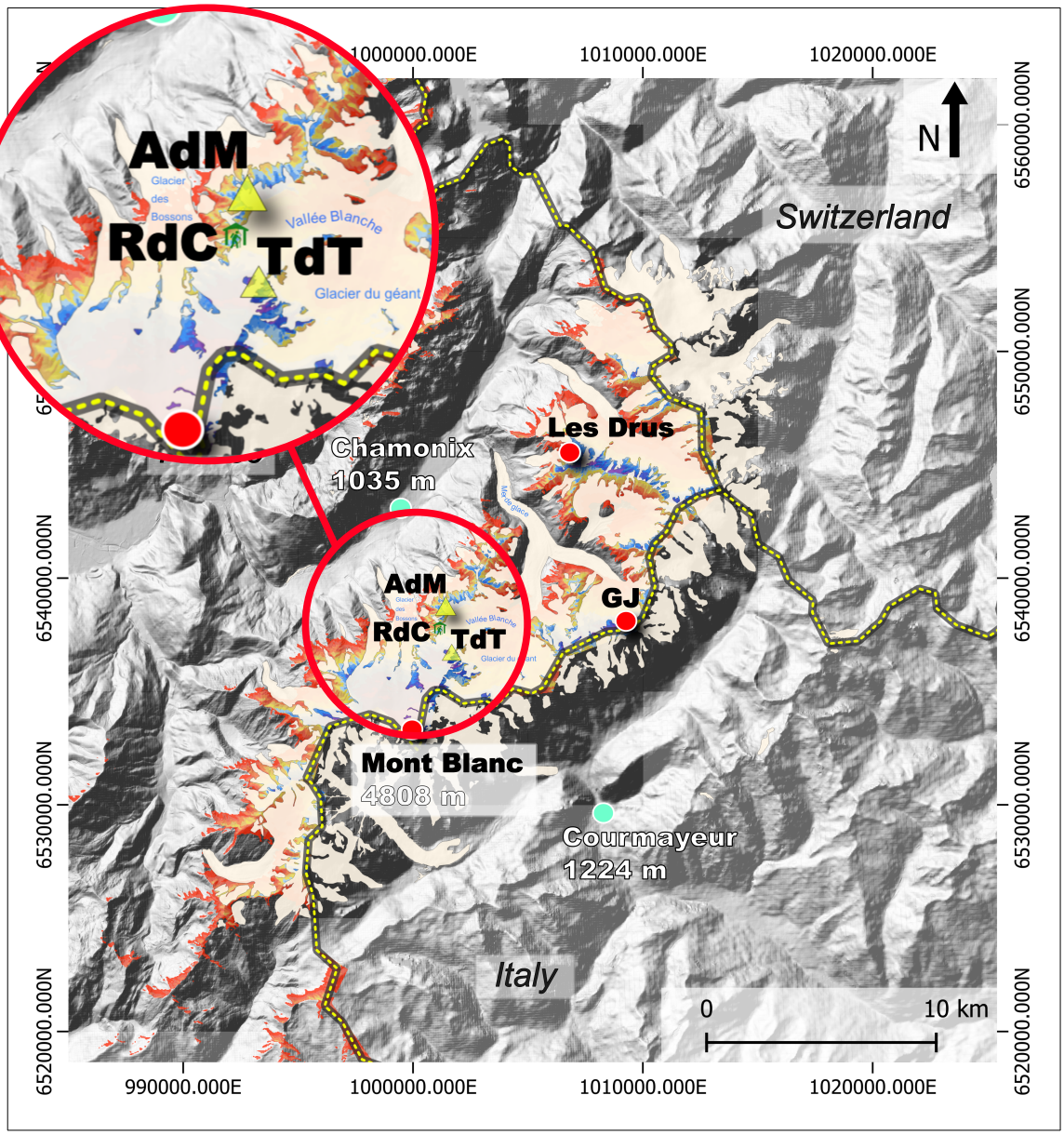
- infrastructures built in a permafrost environment, enabling direct studies and a real open-air laboratory
- mediation and direct scientific communication to a large public (~500,000 / year[5]) on the effects of climate change and the impact on mountain environments (in this case high mountain environments)



Figure 11: Cable car from Plan de l'Aiguille to the summit of the Aiguille du Midi

5 https://www.montblancnaturalresort.com/fr/aiguille-du-midi

Figure 12: Location of the Aiguille du Midi in the Mont Blanc massif with Boeckli permafrost distribution



Legend

Glaciers (BD Carthage, 2017 - data.gouv.fr)

MARST (Boeckli, 2012)

<-5°C	Continuous
-5°C to -3°C	
-3°C to -2°C	
-2°C to -1°C	Discontinuous
-1°C to 0°C	
0°C to 1°C	Sporadic
1°C to 2°C	
2°C to 3°C	
3°C to 4°C	
4°C to 5°C	

AdM: Aiguille du Midi – 3842 m
Les Drus – 3754 m
GJ: Les Grandes Jorasses – 4208 m
TdT: Triangle du Tacul – 3970 m
RdC: Refuge des Cosmiques – 3613 m

Author: A. Chabas
Date: 2023

1.3.2. The internship missions

Water presence observed by rockfall inventories

Generally speaking, the instability of high mountain rock faces has increased in recent decades with rising temperatures (*Ravanel*, 2013).

Research on mountain permafrost has also evolved, and a number of levers have been lifted. Energy transfer mechanisms between different scales of factors are better integrated into models. However, the energy balance does not easily take into account the role of water in the degradation and evolution of permafrost, which is at the origin of numerous rockfalls, including the Alps and the Mont Blanc massif.

Numerous observations showed the presence of water in liquid form or ice in the scars of rock falls (Figure 13). Water can play a dual role in these rock faces. Interstitial ice, which has long been present in fracture networks, acts as a cement that holds everything in place. However, as the walls warm up, the seasonal freeze-thaw cycle will have the opposite effect, weakening the walls and causing them to collapse (see 'Permafrost degradation' section).

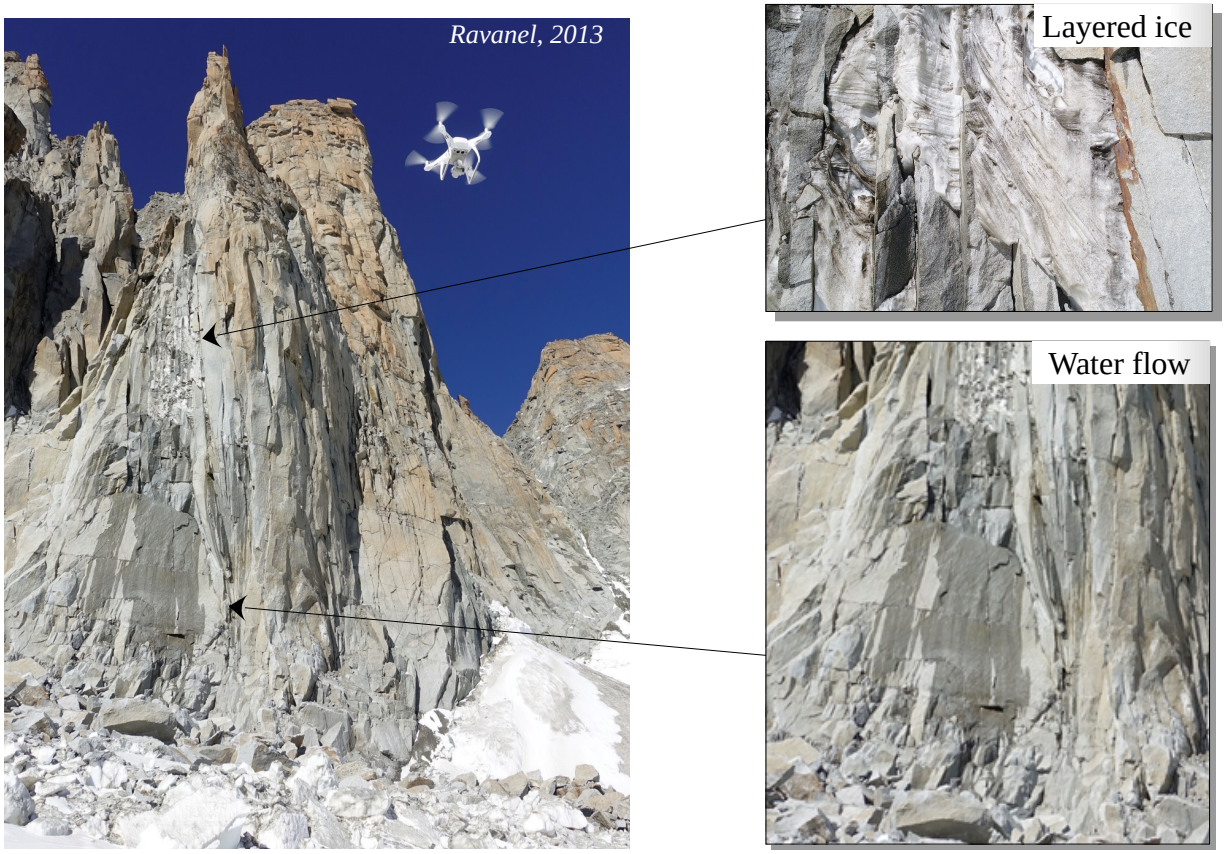


Figure 13: Liquid water and ice in the scar of a rock fall

WISPER (Water and Ice related thermo-mechanical processes in the fractures of Steep alpine bedrock) project[6]

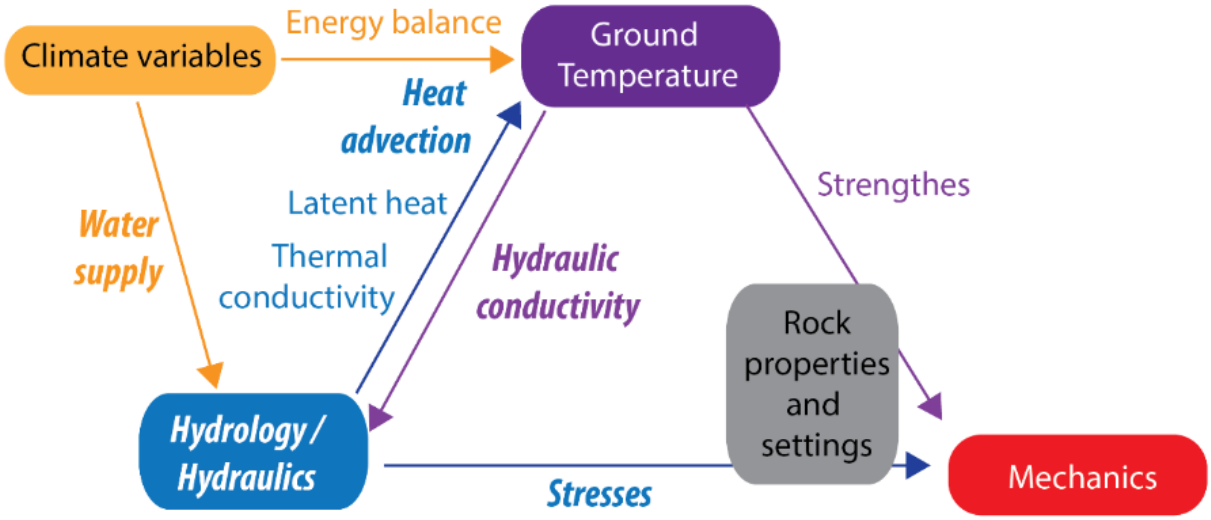


Figure 14: Qualitative model of the processes acting in the thermal regime and destabilization of rock wall permafrost. Processes studied in WISPER framework are in italic (WISPER presentation, 2019)

Following these observations, Florence Magnin proposed and launched a project dedicated to the study of water and its major role in the evolution and degradation of permafrost.

The aim is to integrate hydrological variables into the energy balance and energy transfer that takes place in the permafrost walls by means of monitoring systems, field measurements using geophysics (ERT method) and by coupling different numerical models.

The first hypothesis that lead the project is: ***"Hydraulics and hydrology process which take place in steep iced alpine bedrock are the main drivers of mechanical and thermal diffusion leading to rockfalls"***.

Various parameters that will be studied in the project are directly linked with the internship:

- Water supply: snow, rain, ice content
- Heat advection[7] by water infiltration
- Hydraulic conductivity

In order to better understand the hydrological processes, it is important to succeed in setting up monitoring systems capable of significantly increasing the number of available data that can be integrated into numerical models. The possibility of supplementing these models with hydrological

6 This research is funded by the Agence Nationale de la Recherche Françaises (French National Agency for Research), project: ANR-19-CE01-0018 WISPER.

7 Advection is the transport of heat, matter, etc. at the speed of the surrounding medium and conduction (or diffusion) is transport relative to the surrounding moving medium. (ENS Lyon)

measurements, meteorological data, or subsurface characteristics at different scales is one of the major challenges for the coming years in mountain permafrost research (*Beniston*, 2018).

Aim of the work placement

"*Beyond mechanical processes, the circulation of water in the active layer (i.e. the shallow layer thawing during summer and overtopping the permafrost body) is also suspected to accelerate permafrost degradation (i.e. active layer thickening and warming of the permafrost body towards the melting point) by creating a thermal shortcut between the surface and the subsurface*." (*Hasler et al*., 2011)

This internship is aimed to have better knowledge about the connectivity between the surface of the steep alpine wall and the subsurface (represented by the active layer) in a permafrost context.

As part of the WISPER project, a monitoring system was placed in 2022 in the galleries of the Aiguille du Midi, to collect water and measuring a certain amount of data continuously.

This experimental system, which is completely innovative in the context of research into Alpine permafrost, will make it possible to quantify and validate a number of hypotheses that were never tested. All this work is being carried out in collaboration with a post-doctoral employee (Matan Ben-Asher, 2021-2023) working on the implementation of these data in numerical models.

These "field" data will eventually be used to simulate the balance energy and hydrological flows of high mountain steep walls, particularly at the Aiguille du Midi (*Ben-Asher et al.*, 2023).

The time of this internship was divided between a consequent part in the field at the Aiguille du Midi monitoring system in order to:

- Understand the system set up last year with the two water collection points and the associated measurements of several parameters:
    - Flow rate
    - Water conductivity
    - Fluorescence rate for flow path tracing
- Improve and reflect on the current system
- Collect data on a regular basis between May and September: weekly visits to the Aiguille du Midi
- Analyze and interpret data with literature
- Realize laboratory analysis of collected water
    - Complementary fluorescence analysis of collected samples
    - Preparation of samples for "stable isotopes" and "major elements" analysis to be carried out in an external laboratory

II. HYDROLOGY OF HIGH MOUNTAIN PERMAFROST: STATE OF THE ART

2.1. Hydrology and mountain permafrost degradation: a definite role but still little-known

Hydrology can be defined as *"the geoscience that describes and predicts the occurrence, circulation, and distribution of the water of the earth and its atmosphere"* (*Dingman*, 2001).

Water therefore could play a role in the degradation of permafrost on rock walls. But what do we know about the importance of water and its role in wall infiltration? Its origins are relatively well known, but the quantity and occurrence of each of these water sources is still poorly defined. Many hypotheses have been put forward over the years, but nothing has yet been verified by measurements or experiments carried out directly in the field.

2.1.1. The origin of the water

In high mountain rock walls, water originate from precipitation and therefore from atmospheric conditions, whether in the form of rainwater or melting snow (Figure 15).

Nevertheless, it is difficult to know how water availability changes in time and space once it penetrates the surface and is inside. Thermal effects and reactions to changes in surface temperature over time are poorly understood. Thus, the duration of the water's passage and its path through time remain to be defined.

Hypothesis 1:
Water first comes from atmospheric precipitation (snow and rain).

Hypothesis 2:
Part of the precipitation leaves directly through sublimation.

Question 1:
Are the flows directly linked to current precipitation?
or is the interstitial ice in the wall flowing out, indicating permafrost degradation?
If so, how much of the flow is from snow melt, rain, sublimation...?

Question 2:
Is there a time lag between precipitation and infiltration?

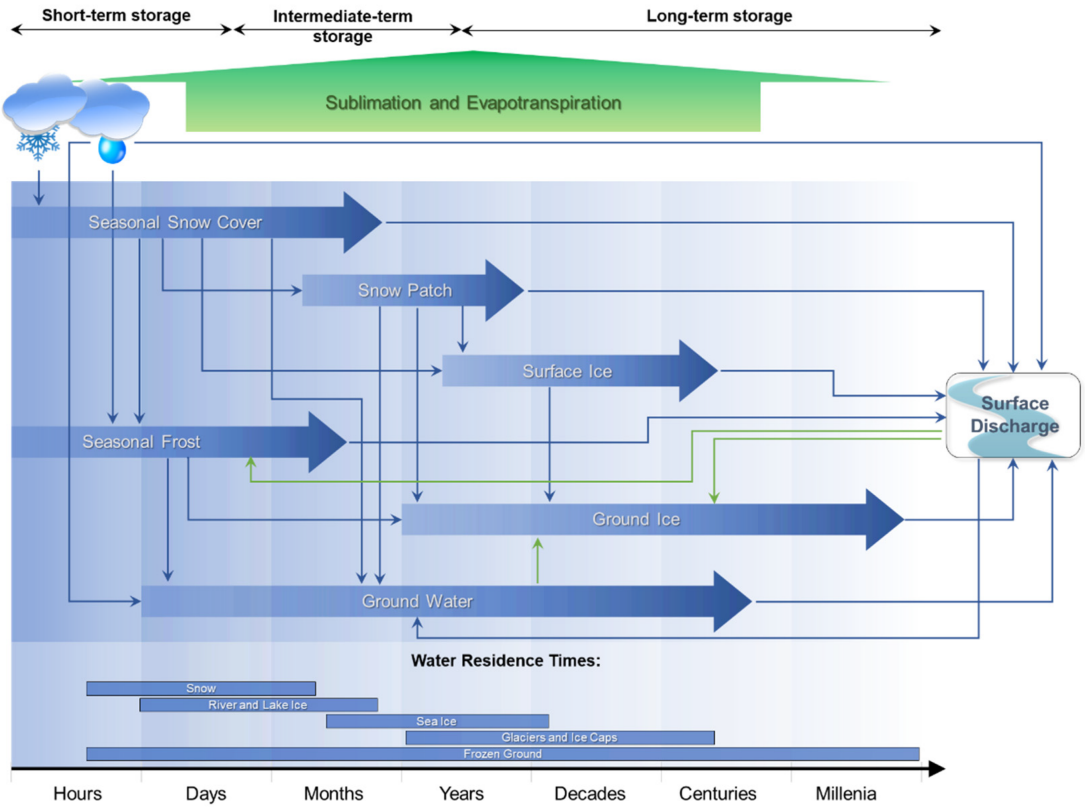


Figure 15: Flow diagram, illustrating main water storages available within the cryosphere and associated residence times from which water can contribute to runoff and how a drop of water may move through different storages. The green arrows indicate where water from surface discharge may flow back into a storage. (Lemke et al, 2007)

Question 3:
How much water circulates in the permafrost-affected rocks?

2.1.2. The occurrence and variation

The active layer reacts to climatic conditions, i.e. atmospheric temperature and precipitation (in its various forms: snow cover or rain). They are the main drivers of global scale (see section 1.2.1). The water content of permafrost-affected walls in high mountains is therefore directly dependent on the freeze-thaw action of the active layer, combined with atmospheric conditions (*Arenson et al.*, 2022).

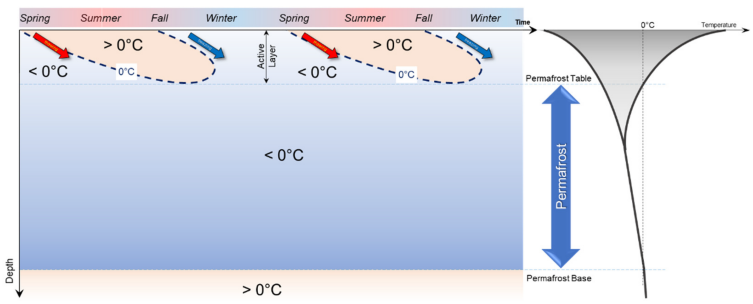


Figure 16: The active layer is season-dependent (Arenson, 2022)

As the active layer develops during the summer, modifying the overall flow regime as it becomes dependent on the hydrological characteristics of the ground and so as the active layer develops (Figure 16 and 17).

Only in late summer, when the active layer is fully developed, the frozen water could possibly be released in the permafrost if the active layer penetrates deeper than in previous years. Warmer conditions can lead to deeper thawing in summer (i.e. deepening of the active layer) and permafrost degradation. For now, no clear evidence shows that water flowing down permafrost-affected rocks comes out of the permafrost.

In fall, the active layer begins to refreeze, mainly from the surface, and flow may initially be limited to an increasingly thin layer that will eventually freeze. (*Arenson*, 2022).

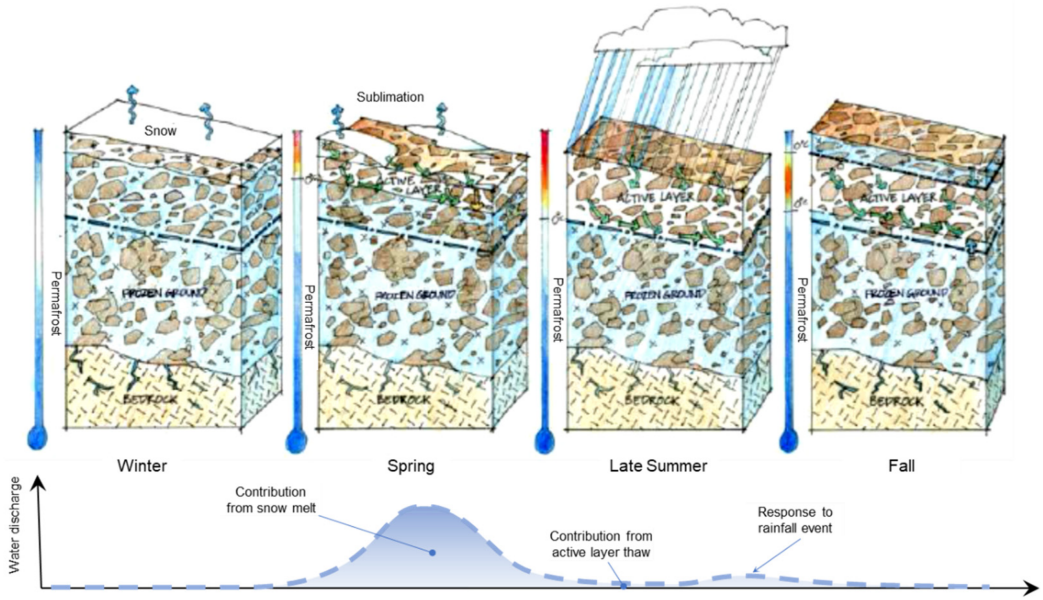


Figure 17: Water regime in permafrost soil following the season (Arenson, 2022)

Hypothesis 3:
Flows are seasonally dependent.

Question 4:
What role do global scale parameters (atmospheric conditions and solar radiation) on the flow regime?

In the bibliography, no information is given on water flows on a temporal scale finer than that of the seasons.

Question 5:
When and how does water circulate throughout the day?
To what parameters do flows react during the day?

2.1.3. Surface and subsurface connectivity

Arenson (2022) continues to report on observations of flow over permafrost formations. He observes a major difference between the melting of surface snow (winter deposition) and the melting of the active layer.

"Snow and surface ice respond instantaneously to atmospheric conditions" (because they are directly exposed) through various fact*ors (solar radiation and air temperature).* Moreover, observations and measurements made on glaciers show that surface ice melting generally takes place directly after the peak of the day's maximum temperature and solar radiation, i.e. in the afternoon.

Question 6:
Does the relationship between Air Temperature, Solar Radiation and flow reproduce the same pattern as for glaciers?

"The role of liquid water in the development of the active layer has not yet been studied." Ravanel, 2017.

Table 4: Influential parameters and period of evolution of the surface and subsurface (Arenson, 2022)

		SURFACE/ GROUND SURFACE	**SUBSURFACE ACTIVE LAYER**
Water phase		**Snow, rainfall and surface ice**	**Ground ice content**
Influential parameters		Direct atmospheric conditions • Solar radiation • Air temperature	Ground temperature variation because it is isolated from solar radiation in winter and from the rock in summer. Ground surface temperature depends on: • Thermal conductivity of the ground • Heat capacity of the ground • Heat transfer by convection or advection of water (latent heat)
Periodicity	*Annual*	Spring	Late Summer
	Daily	**For glaciers**: After the daily maxima of air temperature and solar radiation of the day (i.e. in the afternoon)	**No information**

The system of interactions between a permafrost formation and the various hydrological components that can play a role in the watershed's water balance is highly complex. It can be summarized in the figure 18 and table 4.

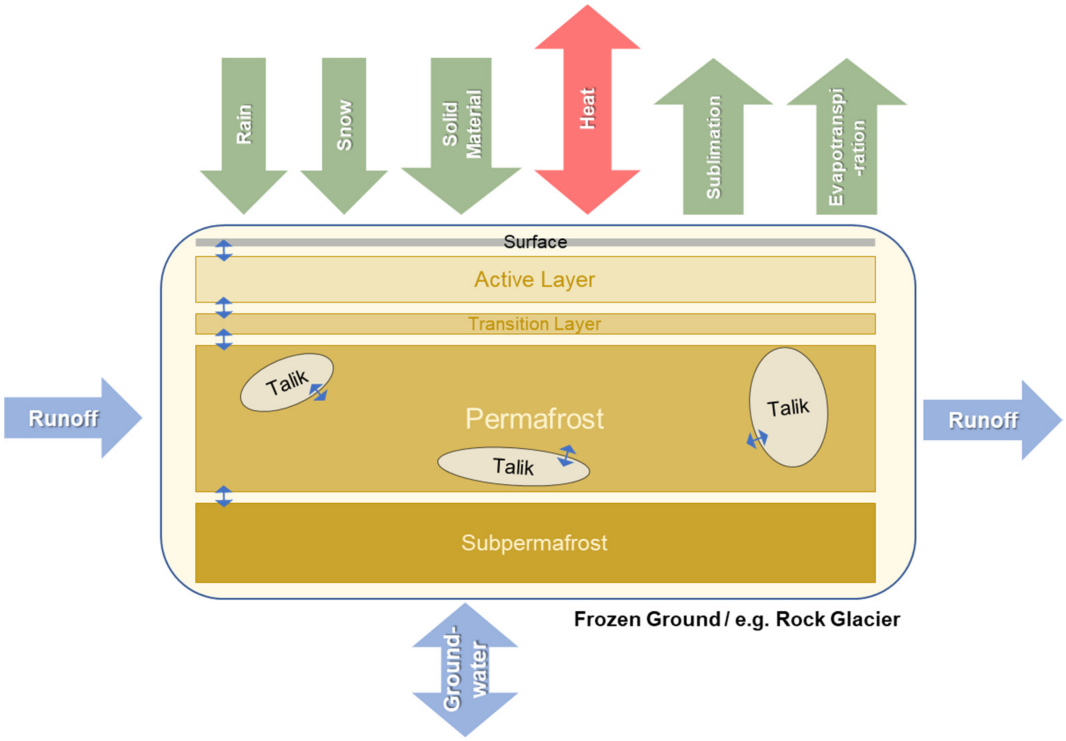


Figure 18: Hydrological system of a permafrost formation (Arenson, 2022)

2.1.4. Fluorescence dyes to trace the water path

Tracers are used to make inaccessible measurements on systems of interest (*Flury and Wai*, 2003), such as subsurface permafrost.

Dyes have proved to be powerful tracers (e.g. *Smart and Laidlaw*, 1977). Dyes can be directly observed or indirectly detected by analysis of a water sample. The dyes most commonly used in groundwater hydrology are fluorescent, enabling them to be detected at very low concentrations.

In our study, three types of fluorescent tracer were used. In 2022, Rhodamine and Amino-G were injected into the wall of the north face of the Central peak de l'Aiguille du Midi, while in 2023, Fluorescein and Amino-G were chosen. As Rhodamine was not detected in 2022, Fluorescein was chosen in the event of Rhodamine appearing in 2023.

- Amino-G is used for its fluorescence sensitivity as a function of pH, ionic strength, temperature and background fluorescence.
- Fluorescein is used for its strong fluorescence and limited soil adsorption properties (*Flury*, 2002). The Fluorescein ion can be associated with a proton or an alkali metal such as Na, denoted as Uranine.

Table 5: Pros and cons of fluorescent dyes (source: ONEMA and BRGM, 2010[8])

Advantages	Disadvantages
• Absorption often low • Natural background noise often low • Low detection limit • Generally good water solubility • Most often no impact on the natural environment • Low purchase and analysis costs	• Does not behave exactly like water • Most lose their fluorescence in the presence of strong oxidants (notably chlorine) or when exposed to light (mainly UV) • Sensitive to certain parameters (mainly pH)

Each tracer has its own characteristics, with a specific excitation and emission field (Table 6). This information will be used in the fluorescence analyses carried out at the EDYTEM laboratory on the Spectrophotometer.

Table 6: Main characteristics of each fluorescent dye. Yellow for the Fluorescein and Pink for the Amino-G

Nom du traceur	Excitation	Emission	Solubilité	Seuil détection	Couleur	Visibilité à l'oeil	Dégradation	Adsorption	Interférences
Uranine	491 nm	515 nm	600 g/L à 20°C	0,001 µg/L	Vert jaune	50 à 100 µg/L	UV ; pH < 7 ; micro-organismes ; oxydants	Faible	Eosine
Eosine	513 nm	537 nm	320 g/l	0,008 µg/L	Rouge	250 à 500 µg/L	UV ; oxydants; pH < 5	Faible	Uranine
Sulforhodamine B	565 nm	585 nm	50 g/L	0,01 µg/L	Rouge fuchsia	>500 µg/L	oxydants	Moyenne	Sulforhodamine G
Sulforhodamine G ou Amidorhodamine G	532 nm	552 nm	5 g/L	0,01 µg/L	Rouge orangé	>500 µg/L	oxydants	Moyenne	Sulforhodamine B
Naphtionate	320 nm	420 nm	240 g/L	0,1 µg/L*	Bleu pastel	Invisible	UV ; pH < 4 ou >10, oxydants micro-organismes	Moyenne à forte	Tinopal CBS- X, Amino-Acide-G
Tinopal CBS-X	350 nm	435 nm	25 g/L	0,1 µg/L*	Bleu pastel	Invisible	UV ; oxydants ; pH < 7	Moyenne à forte	Naphtionate, Amino-Acide-G
Amino-Acide-G	345 nm	452 nm	Très faible	0,1 µg/L*	Bleu pastel	Invisible	UV ; oxydants	Moyenne à forte	Tinopal CBS- X, Naphtionate
Duasyne	449 nm	477 nm	Liquide	0,01 µg/L	Vert sombre				aucune
Pyranine	452 nm	513 nm	178G/L	0,01 µg/l	Vert		UV, très sensible aux variations de pH	Faible	Uranine ; Eosine

Illustration 54 : Principales caractéristiques des traceurs Fluorescents

(*) Bruit de fond important dans les eaux naturelles lié aux matières organiques
(**) Très bon traceur. Ne se fabrique plus. Parfois encore disponible sur stocks

2.1.5. The key roles of the snow cover

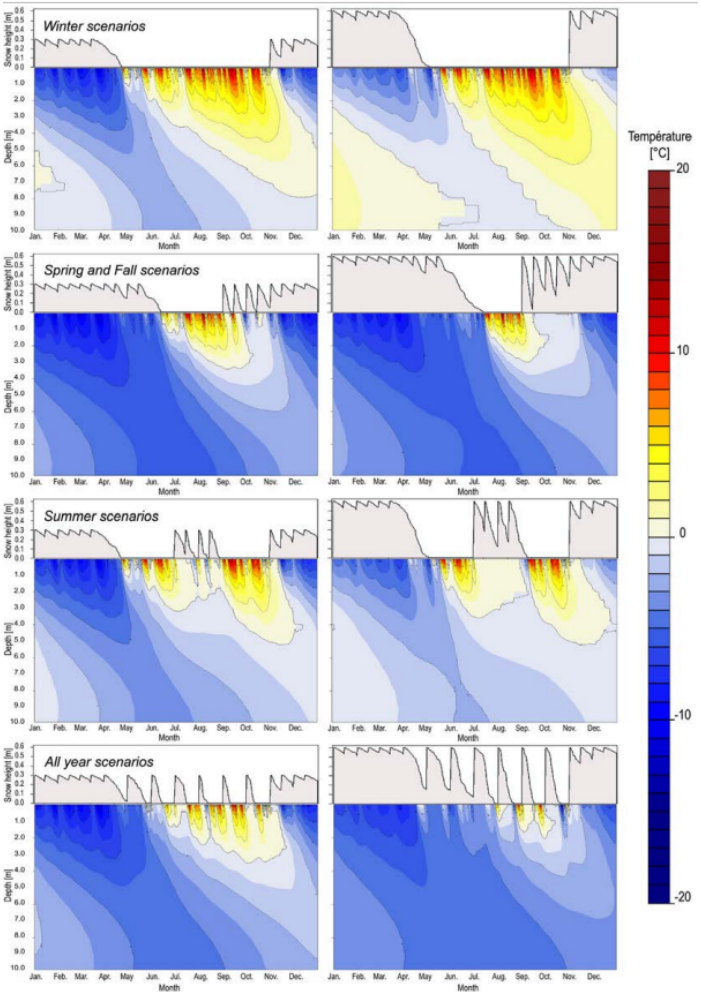
Snow cover has a dual role for permafrost, that of being an insulator and preserving low rock surface temperature by rejecting solar radiation (albedo effect), but also that of being the main source of water during melting in spring (*Colombo et al.*, 2018). Snowmelt and summer precipitation thus contribute to hydraulic processes that can accentuate potential mechanisms for triggering rockfalls (*Fischer et al.*, 2012; *Ravanel*, 2013).

8 https://professionnels.ofb.fr/sites/default/files/pdf/2010_068.pdf

Snow is indeed a major contributor to the volume of water in permafrost or that seeps in during the warmer seasons (see section 2.1.1). For example, water infiltration from melted snow will be different if the snowfall lasts until late spring, and in large quantities, compared with a short, dry winter.

In the other hand, *Magnin et al.* (2017) focus on the thermal effect of snow cover which represent the second major role of the snow on permafrost (see section 1.2.1). Snow cover will have very different influences depending on the time, the period and the quantity. Figure 29 shows that the active layer is protected by snow cover from the main global factors. Timing and thickness of this snow cover will have a considerable influence on the heat flux available at the rock surface, though on the thickness of the active layer, and on the rock surface temperature when atmospheric temperatures warm up in summer. Snow cover plays a key dual role in relation to global factors (air temperature and atmospheric radiation, for a reminder): respectively as a thermal insulator and as a reflector of the sun's rays, the so-called albedo effect.

Figure 19: Different snow cover scenarios and their impact on the active layer (Magnin et al., 2017)



2.2. Monitoring and measurements on rock glaciers runoff

There is no information on runoff from permafrost rock walls, but there is some information from rock glaciers in high elevation. Rock glaciers are a representation of permafrost presence in high mountains (see section 1.2.1). More accessible than steep permafrost-affected walls, more studies exists about them. An analogy could be made with results from the monitoring system.

Noetzli and Philip (2019) reports that measurements have been carried out to monitor the flows that take place on the permafrost of rock glacier, which are much more accessible and easily instrumented than steep walls.

Measurements of stream runoff rates, electrical conductivity and isotopes below rock glaciers have been used to show that snow melt is the dominant water source in spring, whereas rainfall dominates during summer and thawing permafrost increases base flow in late summer (*Colombo et al.,* 2018).

Measuring the temperature of the flowing water may provide additional information. Water temperature is generally below 1 °C below the permafrost at the base of the rock glacier (*Thies et al*. 2013), indicating water-ice contact either at the permafrost table (*Colombo et al*. 2018).

For the rock glacier, the actual fraction of the runoff contribution based on the melt of ground ice is hardly known and difficult to quantify because substantial amounts of water can be lost to subsurface infiltration and evaporation. Nevertheless, the lag between rock glacier temperatures and ground surface temperature changes is probably higher compared to other permafrost zones in the periglacial belt (*Arenson*, 2022).

Hypothesis 4:

► Highly season-dependent and weather conditions

► Origin of water is probably distributed differently following the difference of elevation between permafrost-affected rock walls and rock glaciers

► At high elevation, precipitation are mostly snowfall and rainfall is rare

Question 7:
How can we quantify the share of the various contributions between infiltration water in the evapotranspiration, sublimation and melted interstitial ice of the active layer?

Flows in permafrost-affected rock walls will not react in exactly the same way as rock glaciers. Nonetheless, the methods used to quantify and temporally monitor flows can be transposed or provide good methodological guidance.

2.3. CryoGrid: a numeric modeling for water infiltration in steep wall permafrost (Ben-Asher, 2023)

Due to the lack of bout the hydrology of permafrost-affected rock walls M. Ben-Asher developed a numerical tool to simulate infiltration in steep wall permafrost. The model is an alternative to an existing numerical model for cryosphere formations, CryoGrid, to simulate interactions between the surface of a rock face and its subsurface. The CryoGrid community model (version 1.0) is a multi-physics toolbox for climate-driven simulations in the terrestrial cryosphere (*Westermann S et al.*, 2023).

Measurements taken in the field on the south face of the Aiguille du Midi are coupled to the model in order to calibrate it as well as possible and compare the results obtained by the model and observations. The measurement tools used include:

- 3D high-resolution photogrammetry
- time-lapse photographs of the face and use of measuring snow pols to measure snow depth

- boreholes for ground temperature on different wall depth

2.3.1. Input data

Several models were used to provide the input data for CryoGrid, as summarized in the figure 20 below:

- ***S2M-SAFRAN*** is used to supplement data from Météo France weather stations at the Aiguille du Midi since 1959. Indeed, numerous gaps in the Météo France data have already been reported by Magnin (2015).
- ***CROCUS*** is a specific model for modeling snow, from distribution on a substrate to the various interactions between snow and substrate.

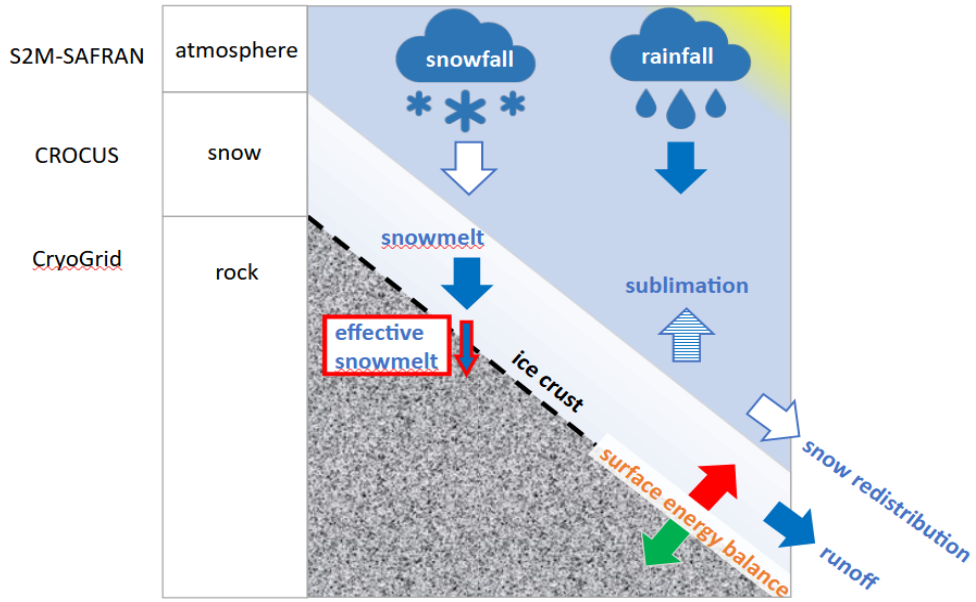


Figure 20: Input data for the water infiltration model (Ben-Asher, 2022)

2.3.2. The starting hypotheses

Several assumptions have been made to simplify the model. These are detailed below:

- ***Precipitation trends are similar or equivalent across the entire massif***. This means that regional and local factors scales linked to slopes and topography are not taken into account for precipitation.
- ***Snow melt hydrology is a gravity-driven vertical flow.*** This means that the fracture network and water paths are simplified as far as possible. The simulation does not take into account possible cross-cutting fractures that could create "dead zones". Dead zones are areas into the fractures blocked by rocks, sediments or ice that may prevent water from draining away.

In this study by *Ben-Asher et al.*, "effective snowmelt" is differentiated from “total snowmelt”. “Effective snowmelt" refers to the water that actually reaches the ground surface, and is available for infiltration. It occurs when the base of the snowpack is permeable, allowing infiltration to the rock surface. This melted snow is therefore one of the sources of water that seeps into the wall

through cracks in the rock. This depends on the thermal properties of the rock and its local characteristics.

water infiltration in the wall = effective snowmelt + direct rain

2.3.3. Modeling results

RESULT 1

Sublimation is systematically the main process of snow mass loss in our study site.

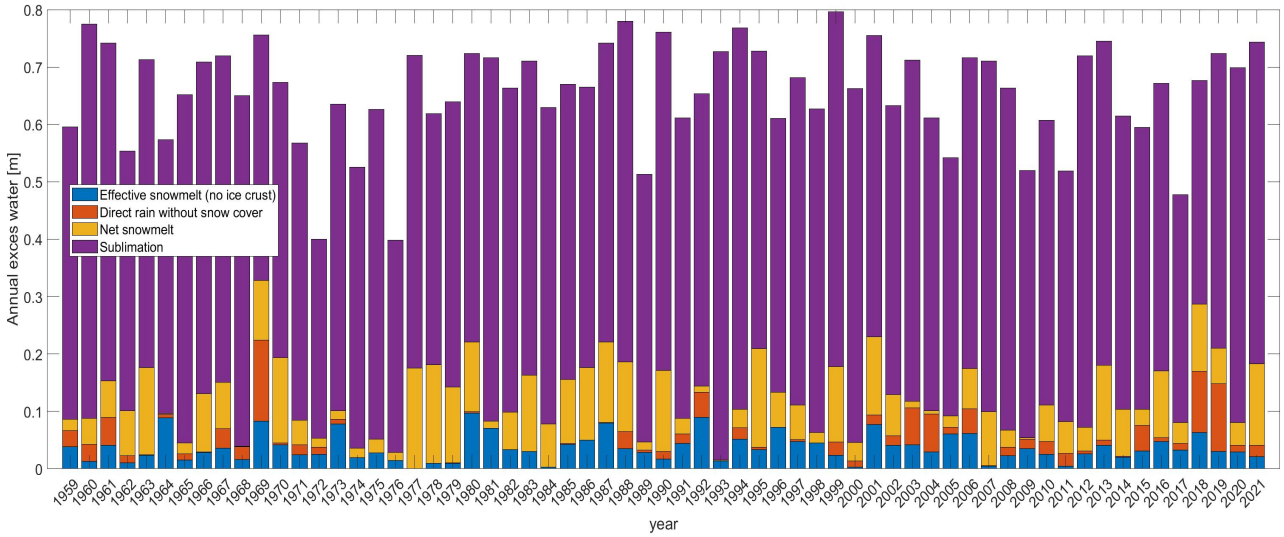


Figure 21: Distribution of water from precipitation that can enter the permafrost walls. Nearly 75% is sublimated or goes into evapotranspiration (Ben-Asher, 2023)

RESULT 2

Effective snowmelt is the main source of water for infiltration at elevation > 3600 m a.s.l.

RESULT 3

Snowmelt occurs between late spring and late summer (same as Arenson, 2022), nut most of it does not reach the rock surface due to the formation of an impermeable ice layer at the base of the snowpack.

As a result, south faces are more subject to infiltration than the north faces

notably due to the ice layer present for longer on north faces

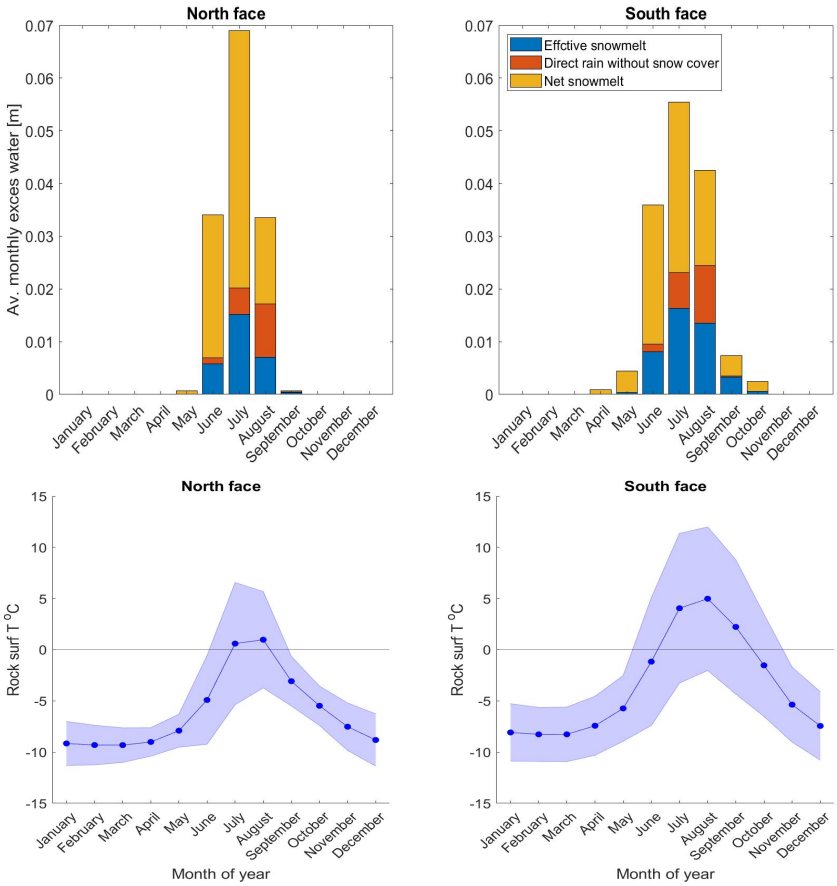


Figure 22: Difference in infiltration between north face and south face walls (Ben-Asher, 2023)

The results obtained from this numerical model give a good indication of the observations and measurements that can be carried out as part of the Aiguille du Midi monitoring program. The measurements will not be directly compared with those of the model, but the behavior and overall process of infiltration may or may not follow similar trends.

2.3.4. And now? Experimentation with real-time monitoring to confirm model calibration (2022-2023)

To build on this previous study, the major goal is to have the very first filed results of water infiltration that could help in the future to validate and calibrate this numerical study through experimentation.

An entire monitoring system has been set up at the Aiguille du Midi, enabling continuous real-time measurement of the flows occurring in the walls of the north face of the Aiguille du Midi's central peak. Since 2022, data have been recorded, enabling us to answer questions relating to time, space and connectivity between the surface and subsurface through water infiltration. The methodology adopted and the monitoring system will be presented in the following section, and will be the subject of my Master 2 internship.

III. MONITORING SYSTEM AT THE AIGUILLE DU MIDI AND METHODOLOGY

This section explains the monitoring system. The sensors and parameters measured will be detailed, as will the analyses that will be carried out upstream in the laboratory on the water samples collected every week. As Noetzli (2019) said: "*Long-term measurements and complementing observations are fundamental to better understand permafrost processes in high mountains*".

Our study is based on the visible flow process. The measurements will be applied directly to the flow at the outlet of the rock face inside the Aiguille du Midi galleries. This will enable us to gain a better understanding of the invisible permafrost process.

3.1. Real-time monitoring system of water infiltration in steep wall high mountain permafrost at the Aiguille du Midi (Mont Blanc massif)

3.1.1. The Aiguille du Midi monitoring history

The Aiguille du Midi is a key site for scientific instrumentation and permafrost monitoring for the EDYTEM laboratory. It is the only instrumented wall site in France, and completes the PermaFrance French network of sites for measuring the temperature of detrital terrain (*Schoeneich et al.*, 2010).

The first instrumentation started in November 2005 by S. Gruber (University of Zurich, former post-doc at EDYTEM): **4 temperature sensors** were installed at the surface of the summit walls of the Central peak, facing north, south, east and west (N1, S1, E1 and W1), taking hourly temperature readings at a depth of 10 cm.
Then a team from ARPA in the Aosta valley region (Agenzia Regionale per la Protezione dell'Ambiente) installed **5 sensor chains** close to the first ones (N2, S2, E2, W2), including one above a flat area favoring snow accumulation on the south face (S3). They have been recording hourly temperatures at depths of 3, 30 and 55 cm from December 2006, with the exception of W2, installed in April 2007.
In September 2009, **3 boreholes** were drilled by three EDYTEM team members and mountaineering guides in the lower section of the Central peak, at between 3738 and 3753 m a.s.l. recording temperatures down to a depth of 10m. There are 15 temperature sensors distributed between 30 cm and 10 m along the tube (*Ravanel et al*., 2017)
Several cameras have been installed then removed depending of the studies allowing time-lapse pictures of faces.

Moreover, Météo France installed a weather station measuring hourly temperature and precipitation at the top of the Central peak in 2006.

Monitoring equipment (temperature sensors and cameras) was mostly installed as part of the PERMAdataROC (2006–2008) and PermaNET (2008–2011) projects, funded by the European Union and run jointly by EDYTEM laboratory (France), ARPA VdA (Italy), and the Universities of Zurich (Switzerland), Bonn and Munich (Germany).

Most of these installations are presented in the figure 23.

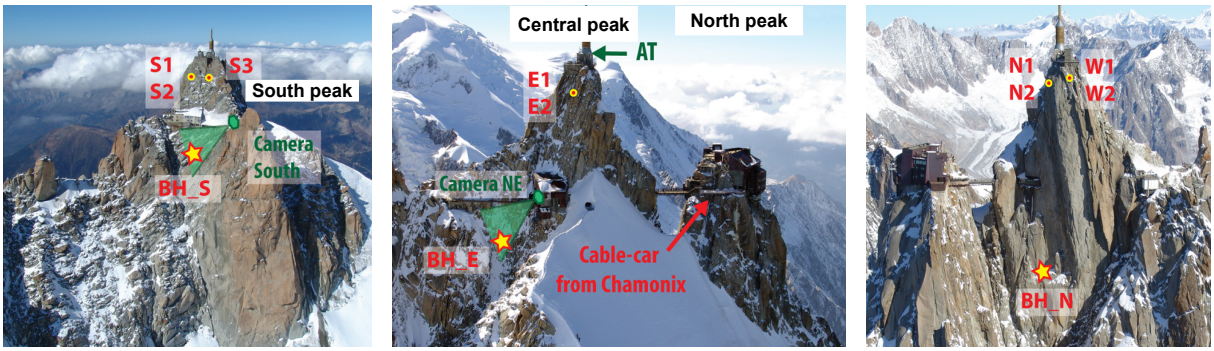


Figure 23: Aiguille du Midi instrumentation for permafrost studies

3.1.2. Water infiltration monitoring system

Protocol note

NB: A protocol note has been written for every steps to achieve before, during and after the field work on the water collecting system. This protocol note is in the Appendix 1.

The water collecting system

An existing tunnel, that was carved for access to visitors (tourism and mountaineering), allows the collection of water directly from fractures that cross the tunnel walls. Those open access galleries allowed the WISPER team project to set up a water collecting system in 2022 (Figure 24).

The water flow rate, temperature, and electrical conductivity in two adjutant fractures have been monitored (Box 1 and Box 2).

In addition, a fluorescence probe has been installed, to detect the two different fluorescent dyes that were sprayed on the slope above the gallery: Acid Amino-G and Sulphorhodamine-B in 2022 and amino-acid-G and Fluorescein in 2023, 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 (Figure 25).

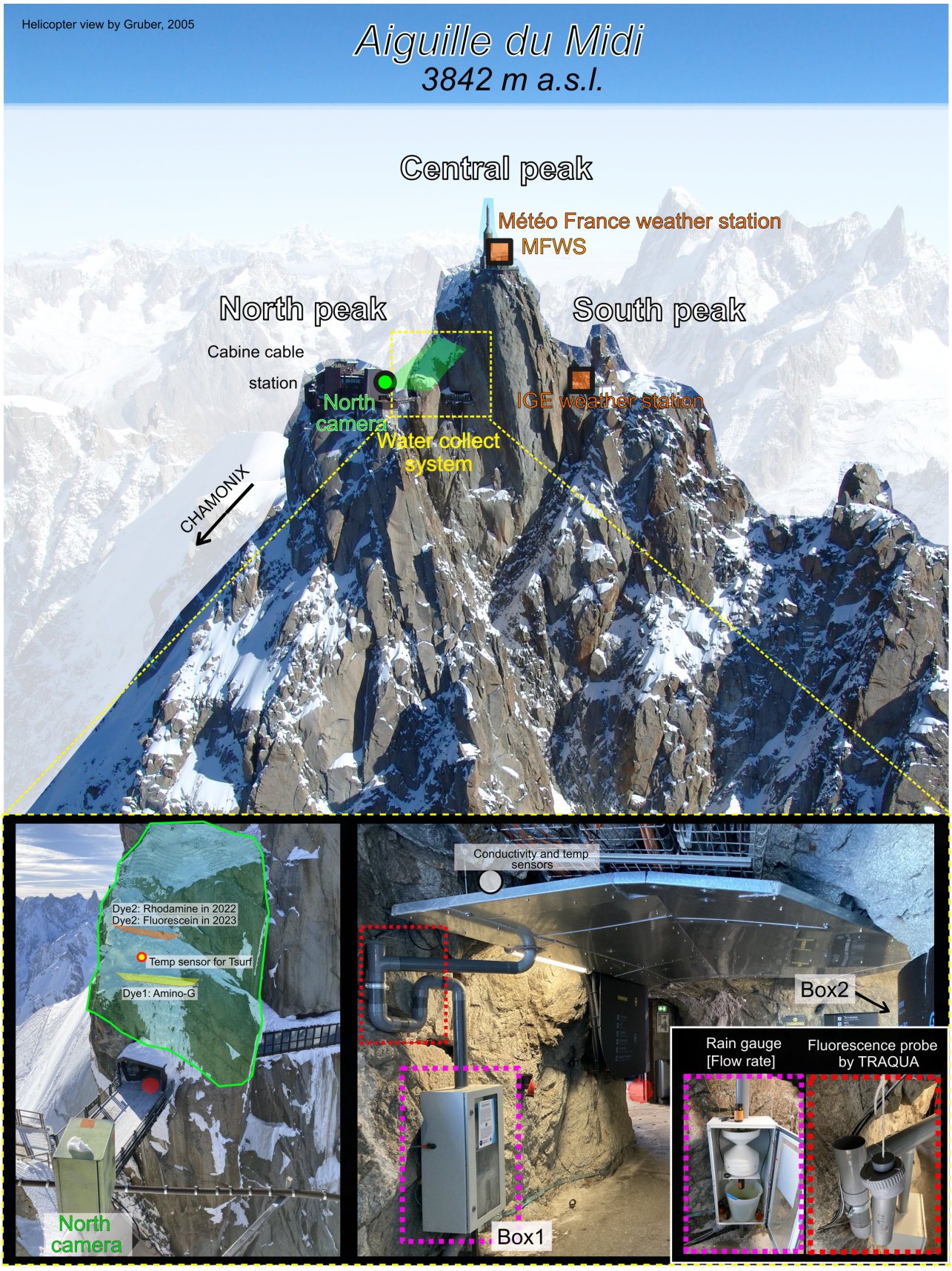


Figure 24: Overview of the water collecting system

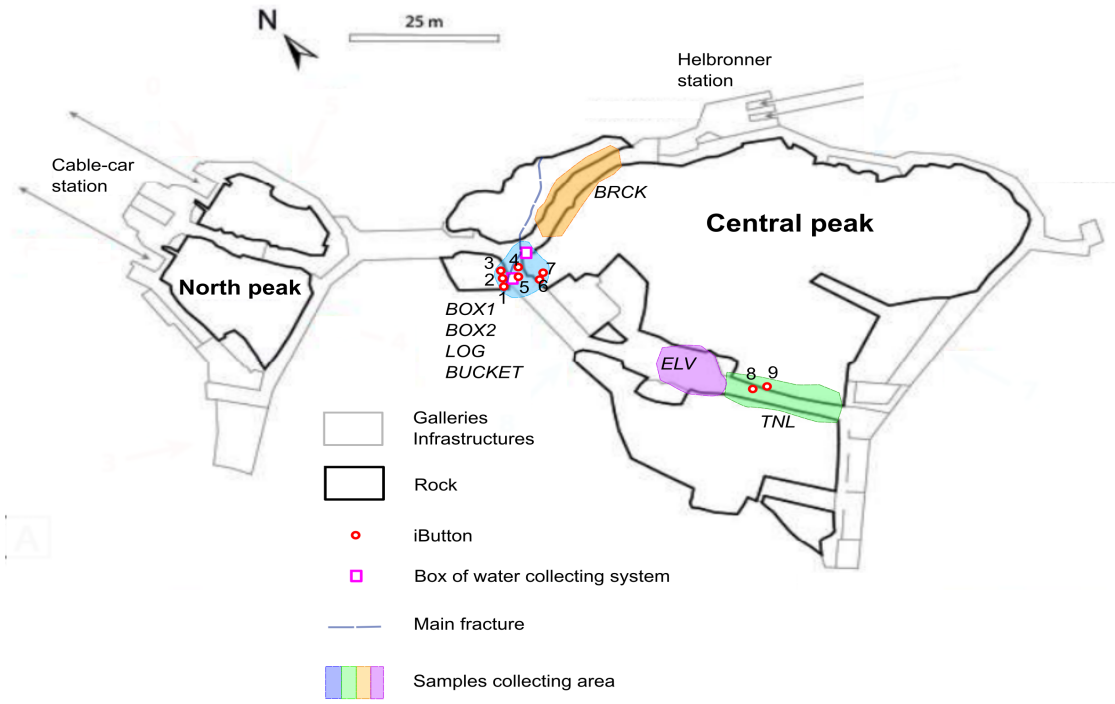


Figure 25: Location of sensors and samples collecting areas into the galleries
BRCK= brick wall ; LOG= logger near Box1 ; ELV= elevator room ; TNL= tunnel between elevator and restroom

Real-time measurements

The PC400 data logger from Campbell scientific records real-time measurements of water infiltration in the two boxes. In fact, the data logger make an average of 5 measurements every 10 minutes. All these variables are studied:

- Flow rate in mm
- Water fluorescence rate in ppm
- Water temperature in °C
- Water conductivity in S/cm

Nine temperature sensors (iButtons ®) have been installed at different location in the galleries (Figure 25) in order to measure the surface temperature inside. The iButton number 5 is not directly installed on the rock surface. It is on a speaker and it is measuring the air temperature inside the gallery.

Other temperature sensors are installed directly on the north face rock surface outside. In September 2022, only one of these iButtons has been found (reference 7077). The 22nd of August, Josué and I found 3 others iButtons on the North face (references: 61B8; 608D; 6202). The 608D iButton is the only one to have recorded 2 summer seasons (2022 and 2023). 7077 is our reference for summer

2022 and iButtons 61B8 and 6202 have been installed on the face on September 2022, so they recorded only rock surface temperature of summer 2023 (see section 4.2.3).

All these data (times series) are collected every weeks in 'CSV' files and are analyzed from Python code. The visualization and data treatment code in Python took a major part of the internship.
Every graphs in the results part have been realized during these 5 months facilitating analysis of the extensive data collected. Python is a powerful programming tool that enables advanced statistical analysis and relatively simple manipulation of large datasets. Thus, it is possible to compare them over time such as on figure 26.
The programming codes will be available for the laboratory at the end of the internship to keep on working on the data.

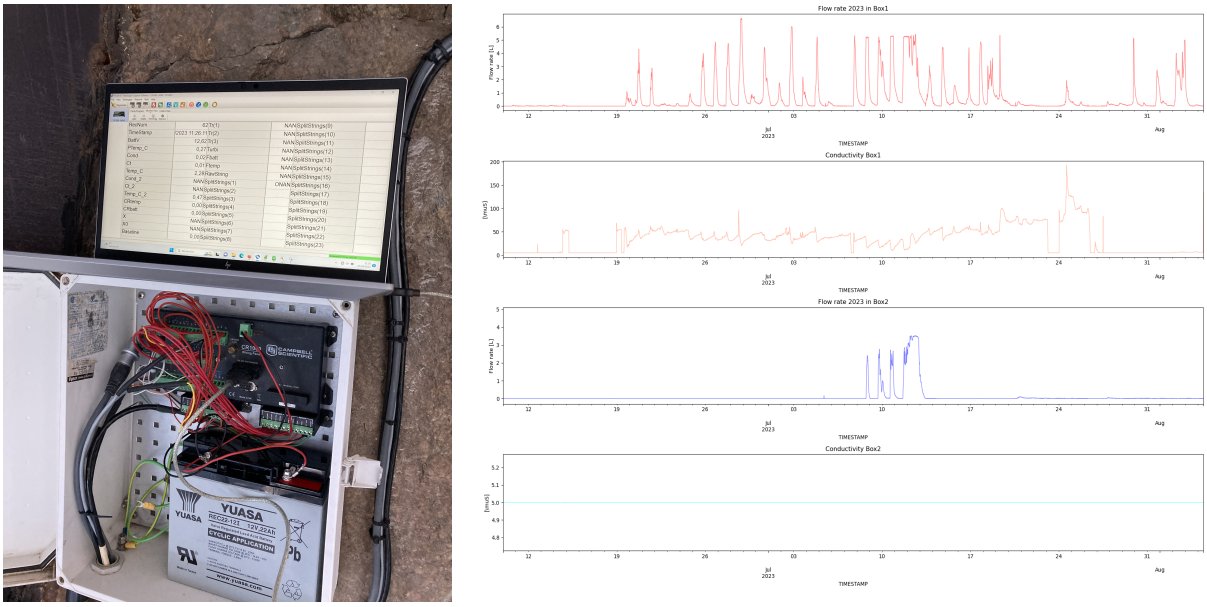


Figure 26: Example of data first look after Python treatment

The « moving window cross-correlation » method

In order to see the influence and the links of parameters on each other, and in particular which factors influence the flow rate and in what way, the "moving window cross-correlation" or "time lagged cross-correlation" method was used.

Correlation studies a link rather than causality. Correlation enables us to determine the presence or absence of a relationship, a significant link between two variables.

Two important pieces of information need to be analyzed to interpret the correlation coefficient (Figure 27):

- The direction of the relationship: is the correlation positive or negative (coefficient greater or less than zero)?

- The strength of the relationship: the closer the value of the coefficient is to +1 or –1, the stronger the association between the two variables. On the contrary, the closer the coefficient is to zero, the less covariance the variables share and, therefore, the weaker the association.

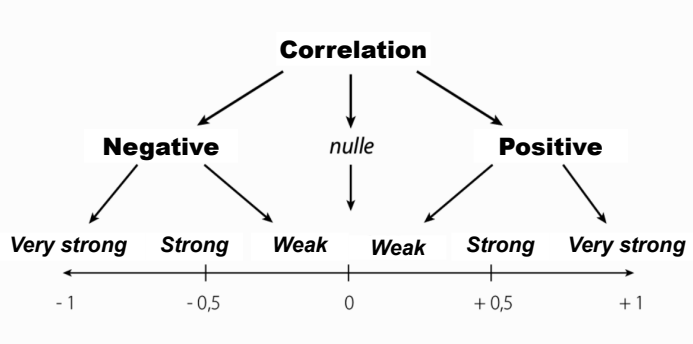
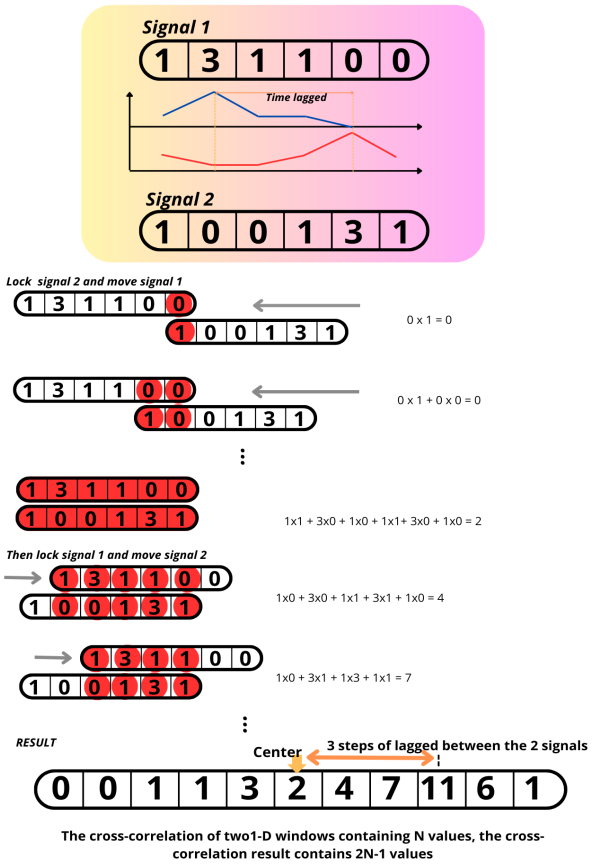


Figure 27: Correlation coefficients

How does moving window cross correlation method work?

This method is also used for pictures comparison with pixels values. Correlation coefficients are then calculated for different shifts between series (Figure 28).




```python
def crosscorr(datax, datay, lag=0, wrap=False):
    """ Lag-N cross correlation.
    Shifted data filled with NaNs

    Parameters
    ----------
    lag : int, default 0
    datax, datay : pandas.Series objects of equal length

    Returns
    ----------
    crosscorr : float
    """
    if wrap:
        shiftedy = datay.shift(lag)
        shiftedy.iloc[:lag] = datay.iloc[-lag:].values
        return datax.corr(shiftedy)
    else:
        return datax.corr(datay.shift(lag))
```

Figure 28: Time Lagged cross-correlation method simple explanation (left) and the Python formula translation (right)

In this way, it is possible to detect whether two series are related to each other, and if so, whether there is also a regular offset between them. This can provide good information on the influence and time lag between these variables (thermal lag or offset, flow lag, etc.).

The aim is to gain a better understanding of the reaction of water flow in the permafrost wall to the main factors of air temperature, surface temperature and solar radiation.

If we have a data table with several quantitative variables that we want to cross-tabulate, we can check whether they are correlated two by two with a correlation matrix.

Water samples collect

One of the aims of this experiment at the Aiguille du Midi is to gain a temporal and spatial vision and how representative the water flows are in taking place in the rock faces of the Aiguille du Midi.

Right from the start of the course, regular visits (one per week) to the Aiguille du Midi site were organized so as not to miss the first flows. From the moment the flows began, weekly visits were made to ensure the best possible temporal representativeness.

The collection of water samples was not limited to the collection and measurement system at the entrance to the central peak gallery. Samples were also collected at various points in the galleries, as shown in figure 25.

Water from run-off is collected in 125 ml bottles with brown glass. The brown glass filters out the radiation, so as not to interfere with any fluorescent tracers in the water.

Electrical conductivity measurements are taken directly from the samples at the Aiguille du Midi. This conductivity information provides an initial indication of the water's origin. If the water comes from melted snow, then conductivity is low (for example, pure water has zero conductivity, and the snow sample collected in 2023 has a conductivity of 9 µS/cm).



Figure 29: Water samples collect steps. a: Pierrick helps to collect water from TNL location beneath the trap ; b: 125 ml bottle samples with references ; c: Conductivity measurement

Once collected, these bottles must comply with special storage requirements to avoid any disturbance on the molecules, isotopes or fluorescence dyes that are really sensitive to radiation and heat:

- remain in a dark place
- be stored in a refrigerated area (the laboratory has a number of available fridges).

All collected water samples will then undergo further chemical analysis in the laboratory. The list of samples collected during these first 5-months internship this year is available in Appendix 2.

Additional laboratory chemical analysis of samples

Once the samples have been returned to the EDYTEM laboratory, three further analyses will be carried out for every samples:

- ***Fluorescence analysis*** by Spectrophotometer carried out directly in the laboratory. The aim is to see if the fluorescent tracer can be found in different parts of the galleries. This would imply a more complex path through the known fracture network. The fluorescence results also confirm the signals received continuously by the fluorescence sensor on the Aiguille du Midi.
- ***Chemical analysis for "stable isotopes"***. This analysis is prepared in the laboratory but will be carried out by an external service provider. Sample preparation is described in the protocol note (see Appendix 1). Isotope analysis enables us to reconstruct the precise origin of the water flowing down the walls. Water isotopes change simultaneously with water phase/state changes. This is particularly interesting in the case of water with high conductivity.
- ***Chemical analysis for "major elements"***. This analysis is also carried out by an external service provider, with preparation carried out directly in the laboratory. The aim of this analysis is to determine the exact composition of the water collected.

With the exception of the fluorescence analyses, the results of the chemical analyses will not be included in this report. However, sample preparation was carried out during the course of the internship.

The ERT method (Josué Bock, post-doctoral position on WISPER project)

At the same time, geophysic monitoring has been set up at the Aiguille du Midi to acquire an independent dataset that will also serve to improve our understanding of hydrogeological processes. The ERT method was implemented on the Aiguille du Midi as part of the WISPER project. This method quantifies the conductivity or resistivity of a medium along a segment as shown in figure 30 (otherwise known as a transect).

The inverse of resistivity is conductivity so if resistivity is high (so conductivity is low) then we can assume the presence of permafrost (ice content rock or air are not good conductor materials). This method can be used to model the active layer and its depth along a profile.

Compared with boreholes, this technique offers a wide spatial coverage (information along the length of a rock face in our case). ERT method offers a quantitative study of complex terrain such as rock faces. In the case of permafrost walls, this technical advance could make it easier to obtain information on the evolution of permafrost and the water content of the walls.

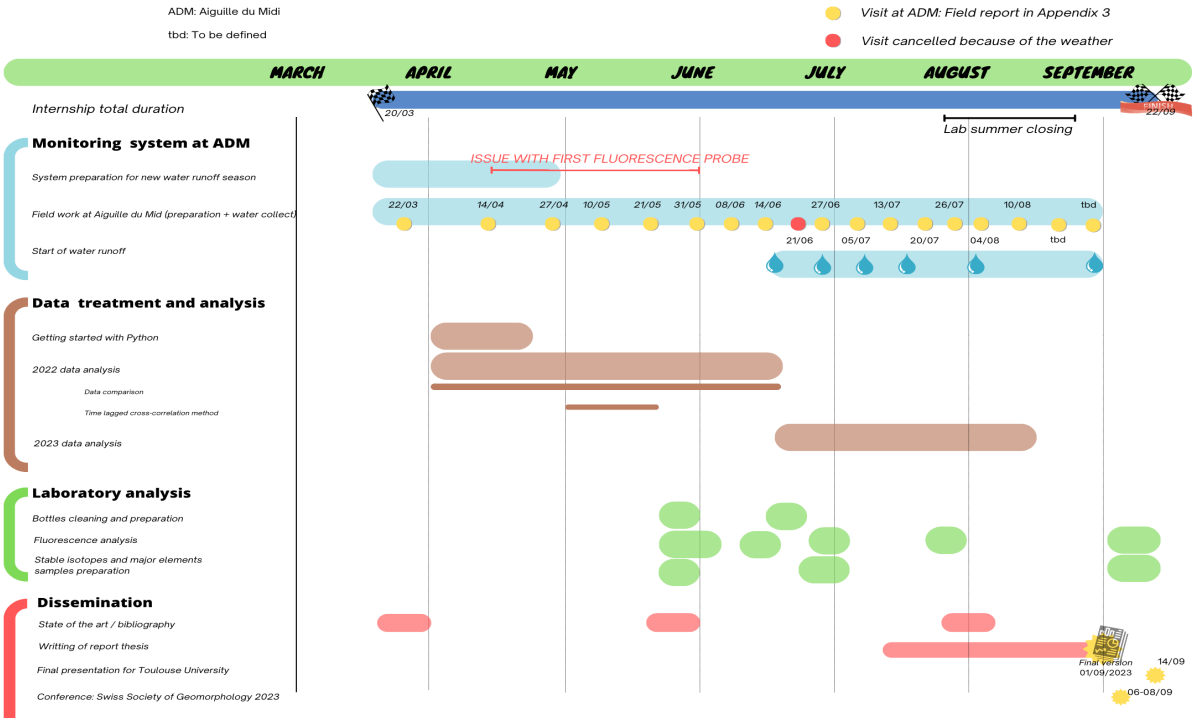


Figure 30: ERT method presentation at the Aiguille du Midi

This internship enabled us to have someone from the laboratory in the field on a very regular basis. This meant that any problems with one of the instrumentation systems could be dealt with quickly. During several of my visits at the Aiguille du Midi, I had to check the ERT device (ABEM) under the control of Josué Bock because the device is submitted to a lot of weather constraint such as storm, rock falls, etc. This brief method explanation can help to understand some the filed reports in Appendix 3.

3.2. Planning of internship missions and tasks

This frequency of visits to the Aiguille du Midi was the guideline for the course, which had to adapt tasks and the organization of missions accordingly. The schedule below shows the various activities and actions carried out during the course.



IV. RESULTS AND ANALYSIS

In this section, the results obtained directly from the monitoring system will be presented for the last two years (2022 and 2023). This will enable us to compare these two years and look for relation, or not, between different factors, particularly climatic factors, but also to gain a better understanding of the overall flow process within a permafrost rock face, in terms of time, space and conditions favorable to this flow.

4.1. Real-time monitoring system results

4.1.1. The 2022 season as a first reference year of water infiltration

Flow rate in the two locations Box 1 and Box 2: a seasonal occurrence?

In 2022, flow rate on the north face of the central peak are highly seasonal, with the majority of flows occurring between the months of June and September during the summer period (Figure 31).

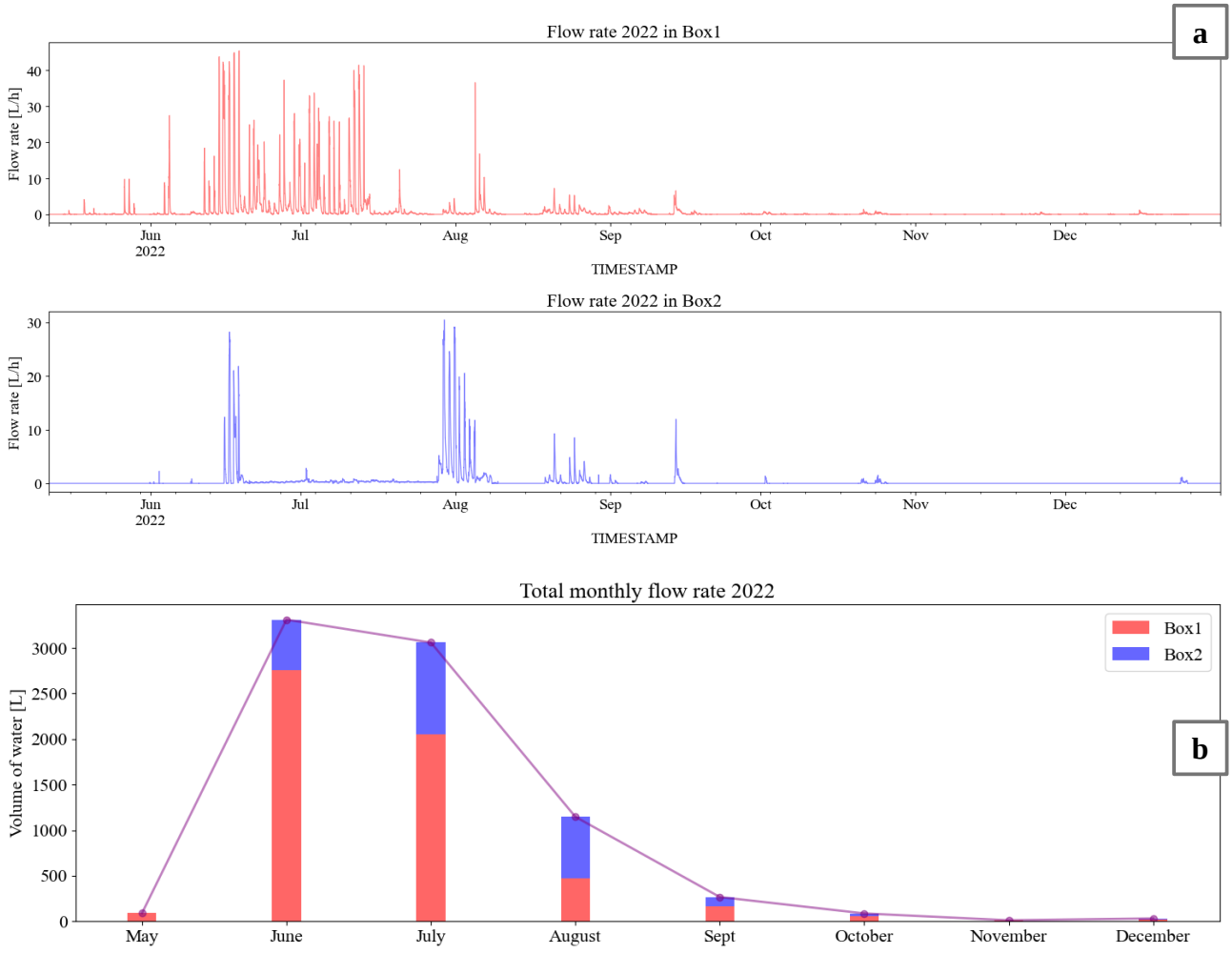


Figure 31: a: Flow rate signals in the two boxes in 2022 ; b: Volume of water per month

There is also a difference in flow between the two boxes. The cumulative volume of water flow shows two distinct periods of strong flow in the rock face (Figure 32).

1. Between mid-June (late Spring) and mid-July (Summer), most of the water flowed through box 1.
2. This second flow occurs at the level of box 2 in August with some flows remaining during September (late Summer).

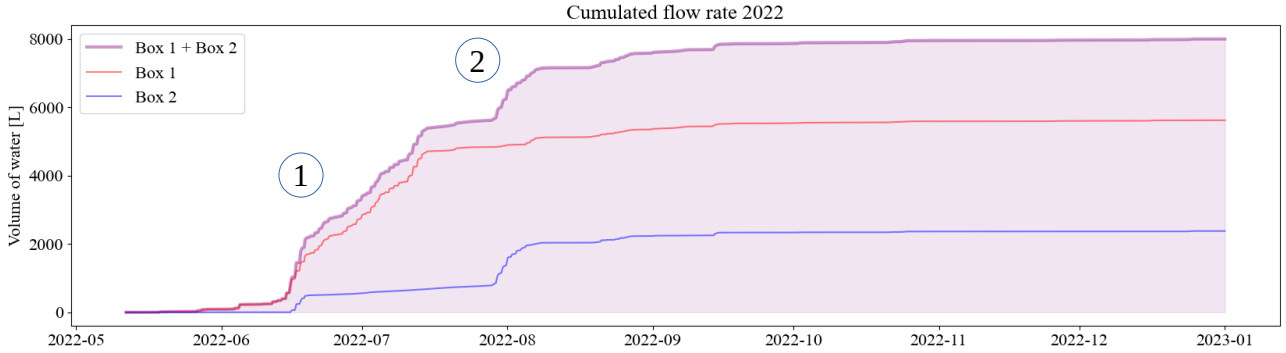


Figure 32: Cumulative flow rate in the two boxes in 2022

So, it appears that the two boxes do not react in the same way. A number of hypotheses are possible. The main hypothesis could be that they are located under two different fractures that do not react in the same way to climatic factors. It is also possible that Box 2 is positioned under the same fracture but further in the center of the peak. Heating of the wall could therefore be delayed in relation to Box 1 that could explain the water discharge of Box 2 at the end of July and beginning of August.

The total volume of drained water in box 1 and box 2 is 8002 L, the equivalent of 8 m³.

One big question remains: how much of this is from snow, rain, interstitial ice or whatever? We will try to respond to that in the analysis part, from the field observation of the snow cover or with the fluorescence analysis.

The daily variation

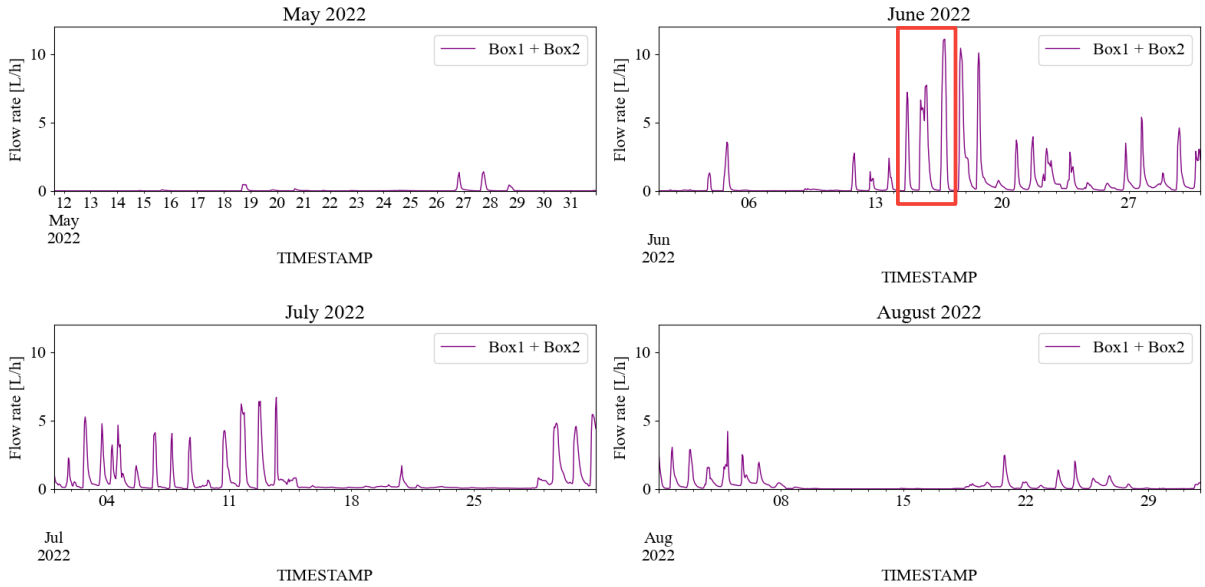


Figure 33: Daily flow rates

A closer look at the flows reveals a daily variation that is repeated for each flow (Figure 33).

The flows in the walls of the Aiguille du Midi therefore seem to be linked to factors that also vary over the course of the day.

It can be assumed that the water trapped in the active layer in the form of interstitial ice will warm up in line with the temperature trend of the active layer. Once the temperature of the inner wall is high enough to allow the ice at the interface of the ice-filled fractures to melt, it will discharge in the form of liquid water.

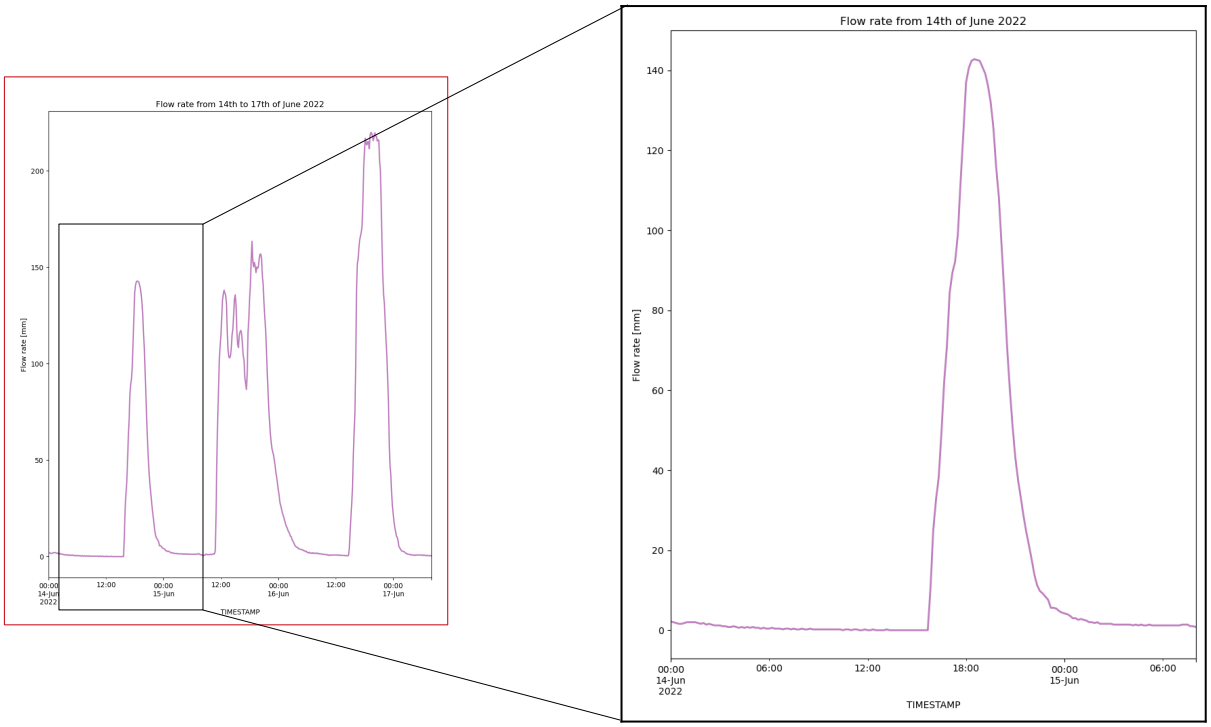


Figure 34: Daily variation of the flow rate in the Box 1

During periods of flow, the signals have daily periodic similarities to the flow curves common in hydrogeology (Figure 34). Flows start in the middle of the afternoon. These flows increase progressively until the early evening to reach maximum flow rate between 18h and 20h and then begin the phase of recession of nocturnal flows (Table 7).

Diurnal fluctuations in flow rate range between less than 1 liter per hour in the morning to plus 10 liter per hour in the late afternoon. With data analysis, the average hours for water flow start and maximum flow rate have been calculated for each months:

Table 7: Daily variation in 2022

	Resample rate	**Number of water flow days**	**Mean hour of max flow rate**
June 2022	1 hour	19 days	**18h15**
July 2022	1 hour	16 days	**18h20**

August 2022	1 hour	8 days	**19h50**

The general hypothesis of this daily periodicity is based primarily on changes in air and ground temperatures over the course of the day, which would tend to warm up and thus cause these flows. This hypothesis will be examined in the next section.

Water conductivity

Water conductivity is an indicator of the type of water flowing through the wall.

In a crystalline environment at Alps latitudes, electrical conductivity between 50 and 150 µS/cm is expected (*Freeze and Cherry*, 1979 and personal discussion with Jean-Yves Josnin, hydrogeologist on WISPER). It may be even lower, indicating a very short time course into the fractures. Then, electrical conductivity can be compared with the tracer travel times to confirm the hypothesis. High values (over 200 µS/cm) would tend to indicate either a very slow path (perhaps storage over several years), or almost exclusive circulation in the sands and fine particles that clog certain fractures.

So, water with relatively low conductivity (< 150 µS/cm) will show values closer to water from precipitation such as snow or rain. Conversely, water with a higher conductivity may indicate water from deep within the wall (water with more minerals), such as pore water. High-conductivity water can be a marker of permafrost degradation.

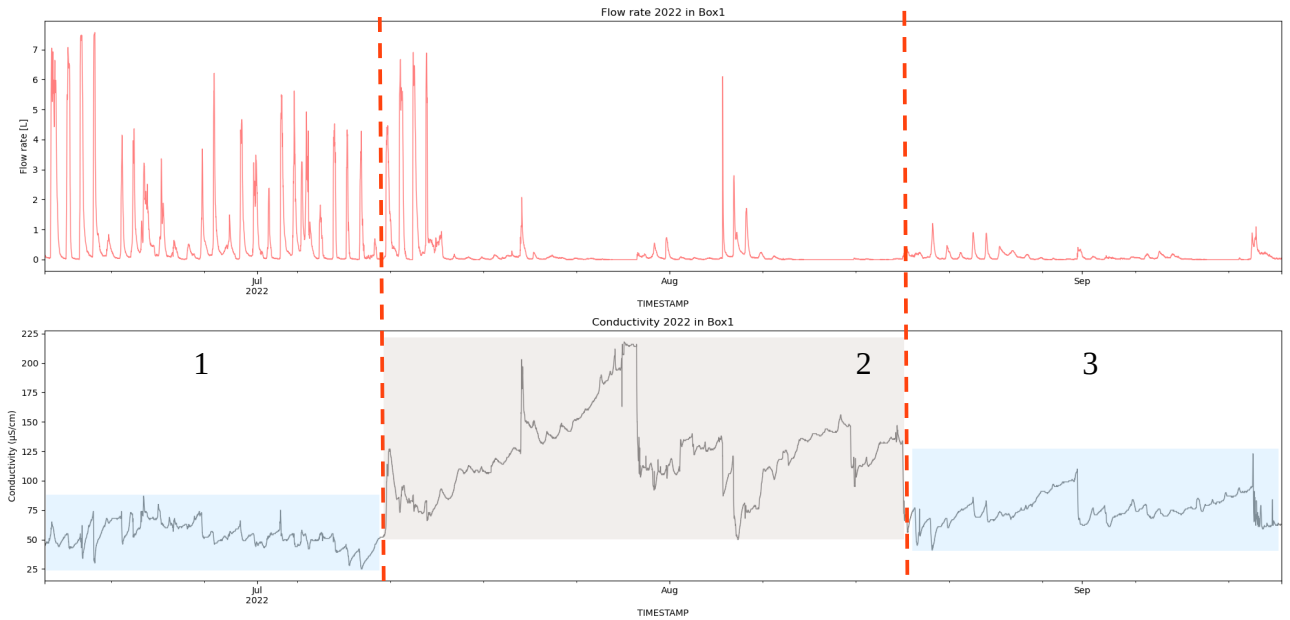


Figure 35: Conductivity related to the Box 1 in 2022

Firstly, in the figure 35, electrical conductivity seems to have three quite distinct phases during the flow season:

- Water from the first flow phase between mid-June and early July (the most important, as we recall) has a conductivity that varies between 20 and 75 µS/cm. This period may mark the

moment when the air temperature rises, causing the snow to melt, which by gravity would flow relatively directly into the wall (hence a minimal mineral contribution).

- Following this period, and until mid-August, conductivity rises to reach variations ranging from 50 to around 200 µS/cm and more. The water's journey through the wall was therefore longer, indicating that it had reached a frozen surface containing ice.
  But it is also period with almost no flow rate at all. Measurements during times without water flow will not indicate any information about the water because electrical conductivity can increase in standing water that evaporate.
- At the end of summer, during the month of September, water's conductivity drops again to near early-season values. We can assume that precipitation in the form of snow, which would melt instantly because of the rock surface temperature is probably warmer than 0 °C. It could also be from rain falls bringing a new water supply to the wall.

Fluorescence probe results

As mentioned in the methodology section, two fluorescent tracers (dyes) were introduced at two different locations on the north face.

In 2022, the fluorescence probe (located in Box 1) in the monitoring system detected only one of the two tracers (Figure 36). In fact, Rhodamine was never detected, whereas Amino-G was. Several hypotheses were raised: either, this may be due to under-dosing of the tracer, or also to a more complex fracture pattern than imagined.

In hindsight, the second year of experimentation in 2023 suggests an under-dosing of Rhodamine. This year, Fluorescein (at much higher dose than Rhodamine) was inserted in the same place as last year than Rhodamine, and Fluorescein has been detected by the sensor.

The graph presented in figure 36 shows the presence of the tracer Amino-G in 2022 compared with the average flow rate per hour every day.

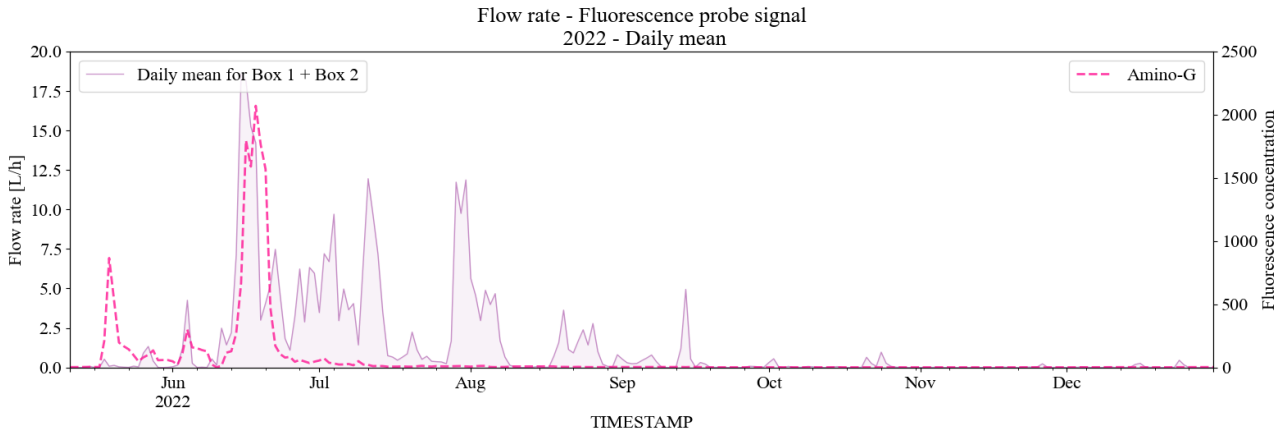


Figure 36: Fluorescence signal in Box1 of Amino-G acid dye in 2022

Analysis of fluorescence from 2022 (i.e. using only Amino-G detection) clearly shows that the first flows into the wall came from melting snow.

The high concentration of Amino-G in the flows from May to the end of June may mean that snow is the main, if not the only, source of the water flowing down. Then, a slight presence of Amino-G is still detected from end of June until the 10th of July, possibly signifying the end of the melting of the residual winter snow layer with water of a different origin (rain or deep ice).

If the fluorescence signal is compared with the electrical conductivity (see section above), the conductivity after the 10th of July could suggest also water from precipitation such as rain or deep ice.

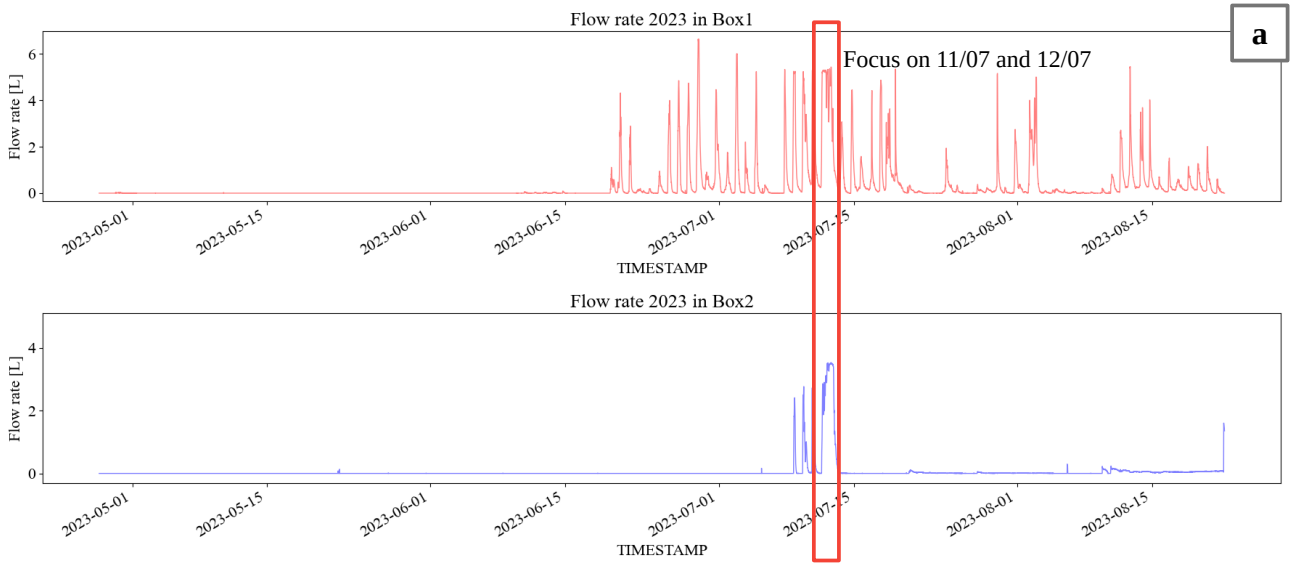
During summer 2022, fluorescence has only been measured in Box 1. Analysis supposed that Amino-G has been all the way down to Box 1 following a simple fractures. One of the monitoring improvement in 2023 is to check and analyze every water samples collected into the galleries by photospectometry in the laboratory. It will give a better vision on the water path?

Key observations

- The fluorescent tracer from the lower terrace (Amino-G) was found in the water from the first flow events which occurred in mid-May and remained in the water until mid-June (around 1 month duration).
- The tracer from the upper terrace was never observed.
- Significant water continued for 3 weeks after the fluorescent tracer disappeared from the water.
- Perhaps the tracer introduced in March 2022 entered the wall outside the thaw period. When tracers are introduced, a mixture of water and diluted tracer is poured in. The water injected into the wall is therefore at a temperature above 0 °C, so some of the liquid could already have penetrated the rock surface before re-freezing at depth.

4.1.2. The 2023 for a first year comparison: same scheme as 2022?

Flow rate in the two locations Box 1 and Box 2



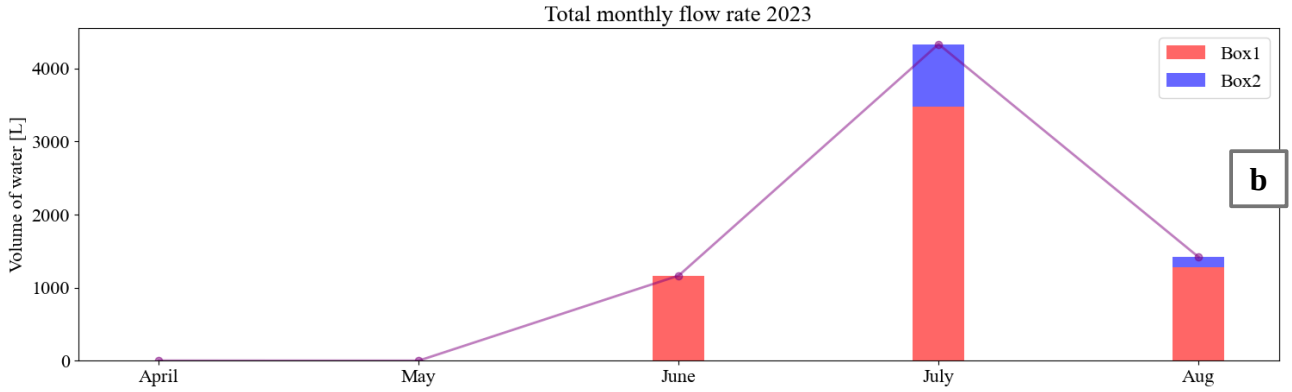


Figure 37: a: Flow rate signals in the two boxes in 2023 ; b: Volume of water per month

Compared to the 2022 flows, the 2023 water infiltration started later (Figure 37), the 19th of June. There is almost 1-month of time lag between the first flows of the 2022 monitoring season.

However, the seasonality of the phenomenon seems to remain the same. The majority of flows seems to take place during the summer, between mid-June and mid-July. Moreover, the two adjacent fractures show different flow regimes (Box 1 and Box 2), same as during 2022.

An exception can be observed between the 11 July to 12 July (Figure 38). The daily occurrence has been missed those days with no recession time during the night. Several explanation can explained this fact (e.g. Field report of 13 July in Appendix). This can be explained by the weather: indeed, some thunderstorms occurred during these days. Maybe during the night, a lot of rain felt and water from rain has run down the walls.

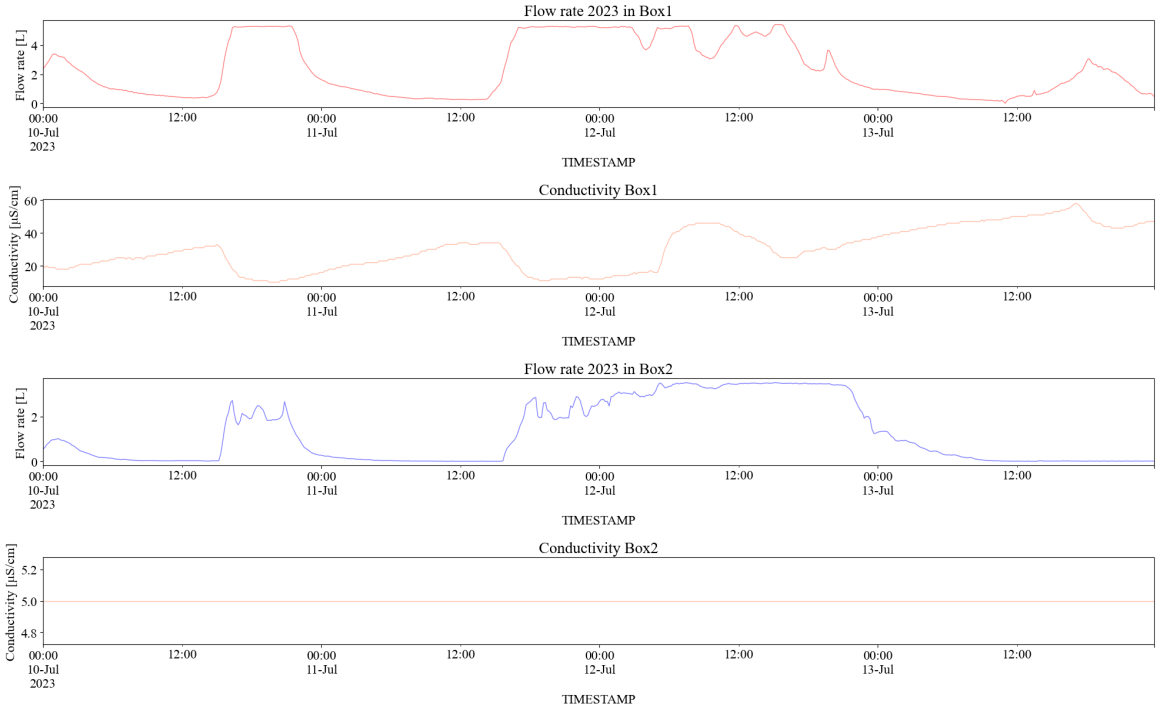


Figure 38: Exception in the daily occurrences for Flow Rate in the middle of July

At the time of writing (last data from 22 August), the total quantity flowing through the two Boxes is 7000L. The 7000L had been reached at the beginning of August in 2022. The 1-month time lag therefore continues unabated between the two years.

Water conductivity

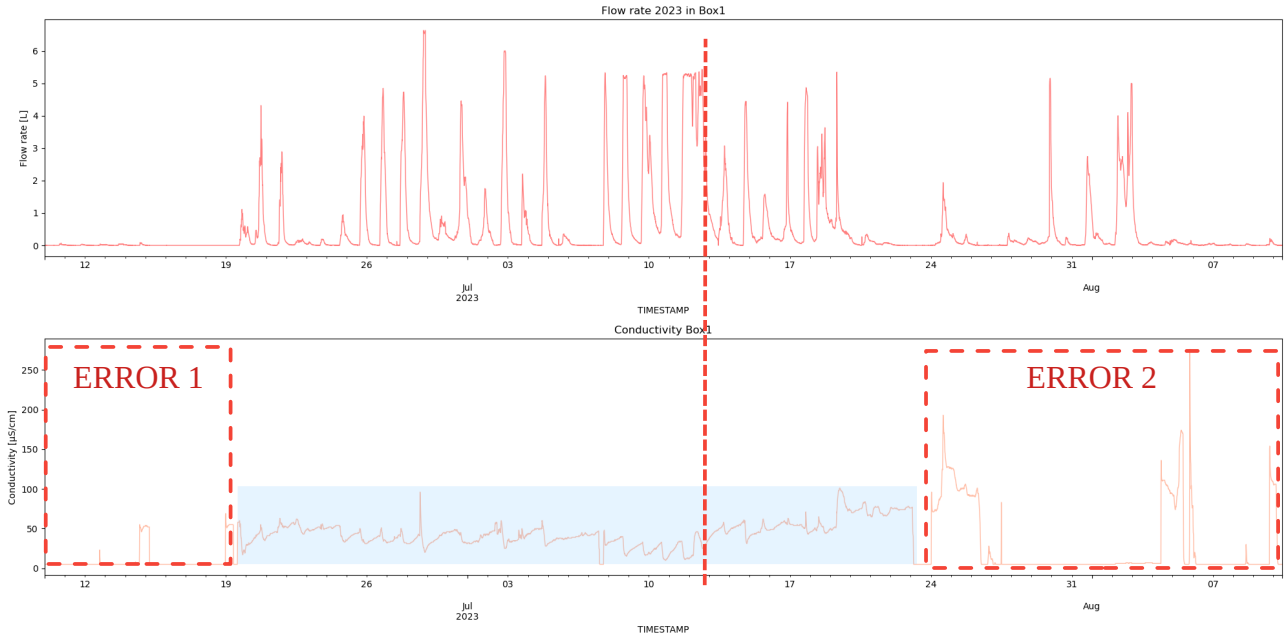


Figure 39: Conductivity signal above Box1 in 2023

Over the period of operation of the conductivity sensor, no major variations are observed throughout the season. In fact, since the start of the first flows in the walls (June 19), conductivity has been within a range of 15 µS/cm to 100 µS/cm. This could mean the presence of a single source of water in the walls at the moment, with a short passage time.

However, it looks that in this range, electrical conductivity of flow events seems increase a little bit in mid-July (around the 12 July), suggesting maybe a mixture of water sources between snow and another one (rain, ice). It corresponds with the storm event reported in the section above.

The errors in the signals are due to incorrect positioning of the sensor on the collector ceiling. It may have been moved during external handling, or by severe weather conditions, such as a period of cold and freezing of the water in the device, causing it to tip over. Nevertheless, during “error 2”, it seems that the conductivity of the water passing through the device was higher and of the order of magnitude of the second period notified in 2022.

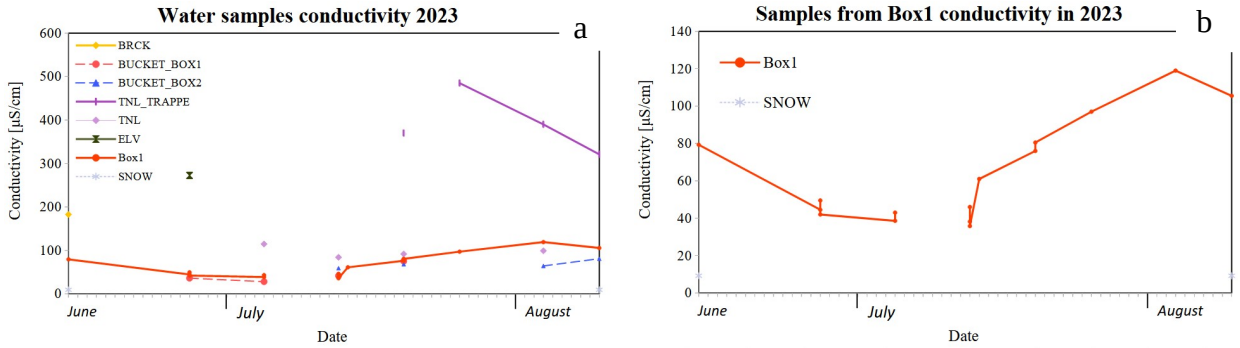


Figure 40: Water samples conductivity. a: For every water samples ; b: Only of Box1 located samples

Additional conductivity measurements (Figure 40) were carried out during water sampling through the Aiguille du Midi galleries. These measurements confirm that the conductivity of the water collected in Box1 does not exceed 120 µS/cm. For the moment, there seems to be no big difference in the origin of the water flowing down the walls of the north face in 2023.

Fluorescence probe results

Amino-G and Fluorescein have been inserted the 22th of March 2023 respectively on the lower part of the wall and the upper part (Figure 25)

Starting with a better dosage of Fluorescein than Rhodamine 2022, both tracers are well detected by the sensor (Figure 41). Amino-G came out first with the first flows on the 19 June. From 26 June onwards, Fluorescein appeared in the signals detected alongside Amino-G.

It can be explained by a difference of infiltration at the two spots delaying the Amino-G because of a re-freezing each night with a less thawing during the day, or more probably by a difference into the fracture network under each spot of infiltration, the fracture network under the Fluorescein being less complex with no "dead zone".

Fluorescein's signal is quite brief, and although it persists over time. Unlike Amino-G, which persists massively until the 8 July. Traces of both tracers remained in low concentrations until the end of July, suggesting that all the snow that had fallen during the winter and spring was on the face by the 27 July.

Thereafter, the water flowing down the face will be either direct precipitation or possibly deep ice melting as the face warms up.

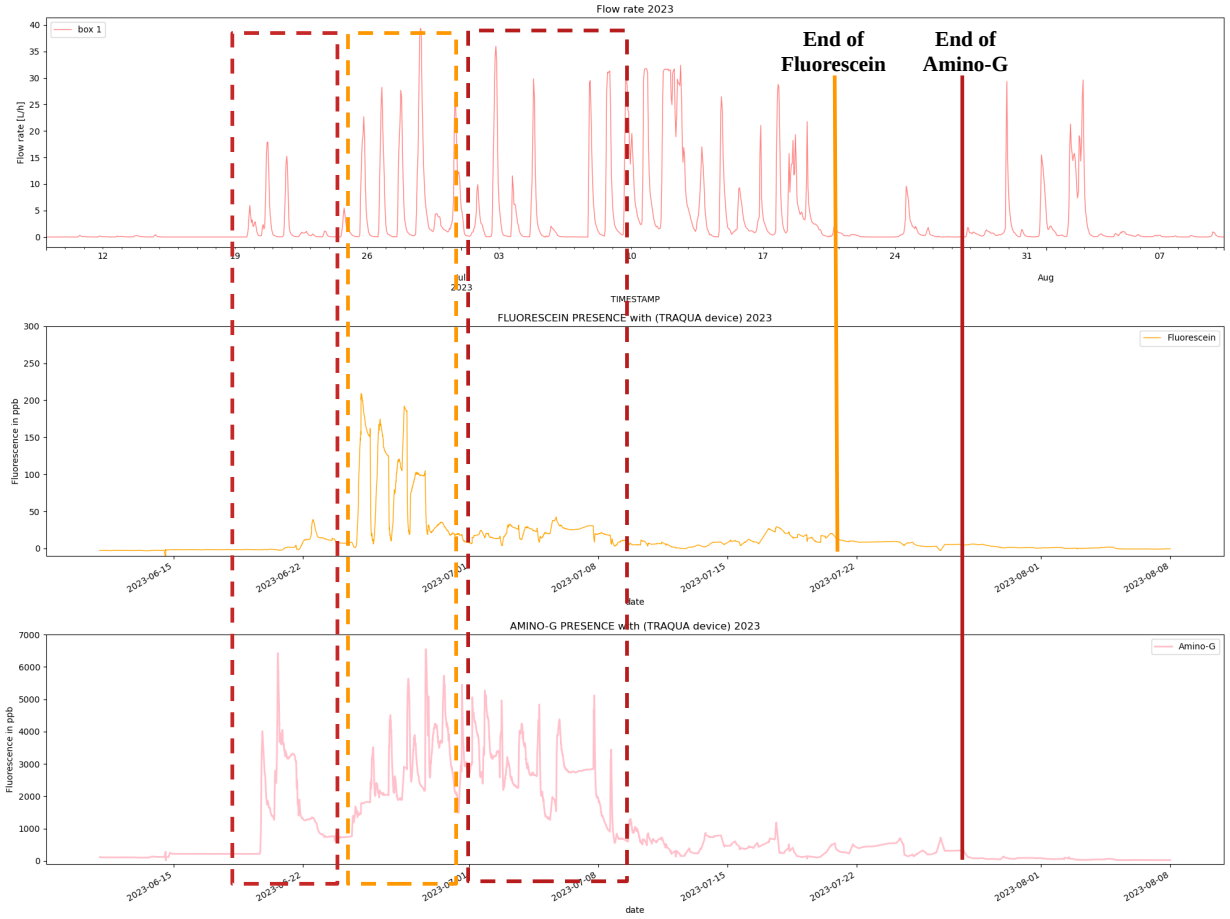


Figure 41: Fluorescent signal in 2023: Fluorescein and Amino-G detected

Complementary fluorescence lab analysis

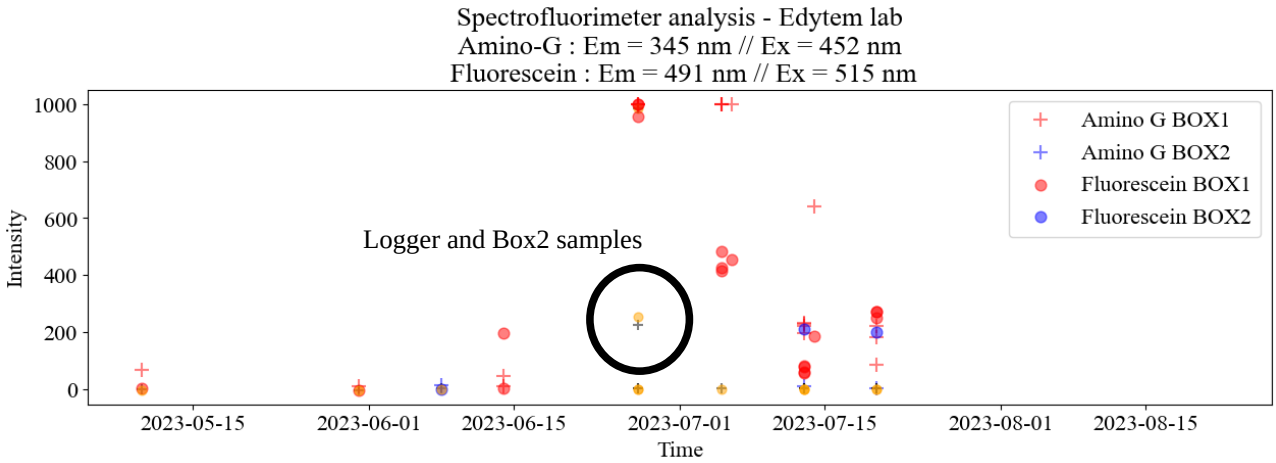


Figure 42: Lab analysis of water samples fluorescence by spectrophotometer

Analyses at the EDYTEM laboratory were carried out on water samples collected between May and mid-July. They confirm the data from the fluorescence probe in place in the monitoring system on the Box1. The signals for Fluorescein and Amino-G show peaks at the same periods, i.e. at the end

of the month of June and beginning of July. The Fluorescein signal is very short-lived, unlike Amino-G, which continues to appear over a longer period.

It is interesting to note the presence of Amino-G signals in Box 2 in June (black circle), as well as on one of the samples collected near the Logger not far from Box1. Fluorescein appears in Box 2 around mid-July. However, no other samples collected in other areas of the galleries show the presence of tracers.

4.1.3. Comparison and assumptions

Although the 2023 summer season is not yet over, and flows may still occur, some similarities and differences have been observed and noted (Figure 43). Table 8 provides an overview.

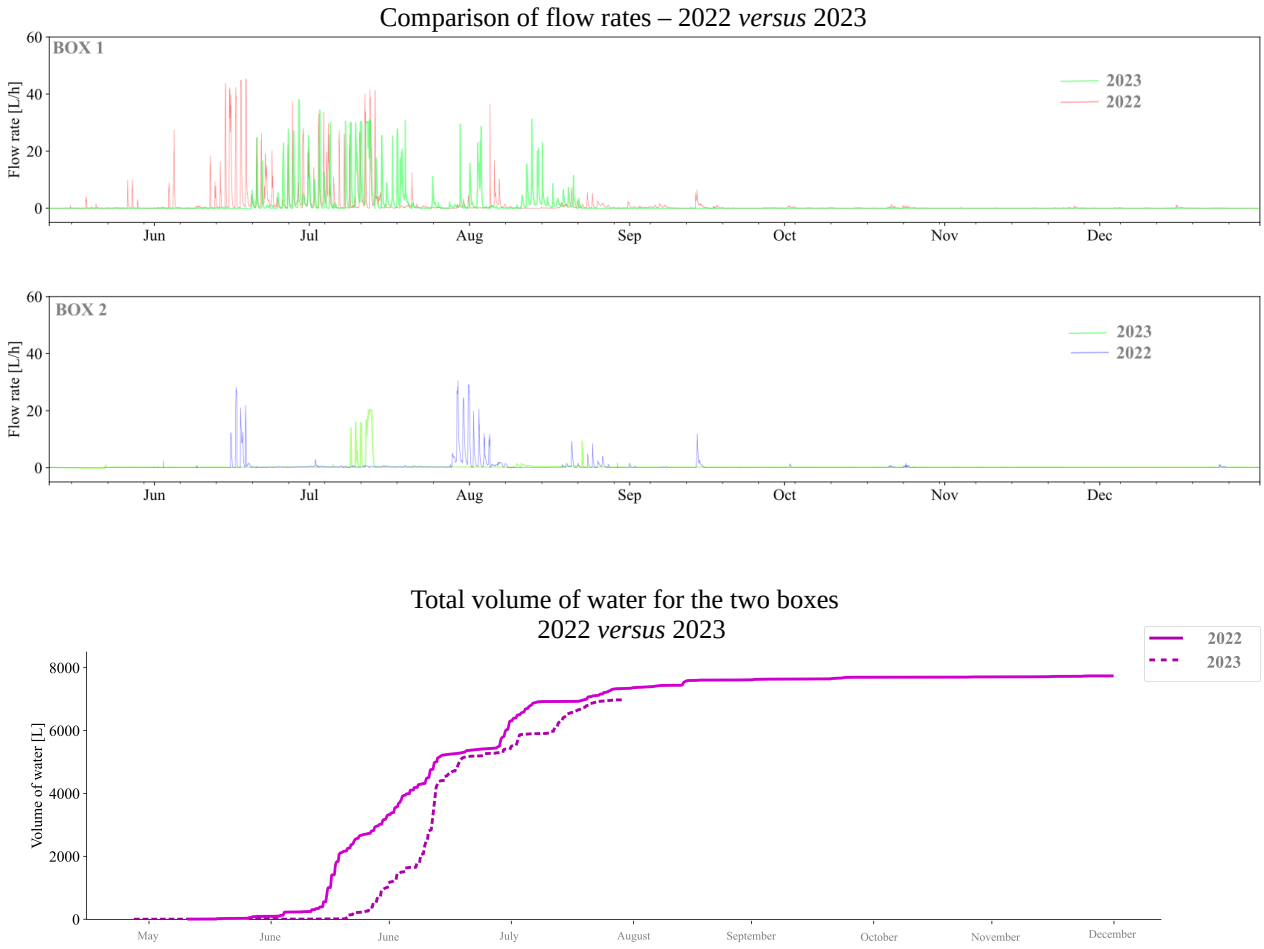


Figure 43: Comparison of flow rates and volume for the two years 2022 and 2023

Table 8: Comparison of the 2022 and 2023 monitoring seasons

	Similarities	**Differences**
Flow rate	Season dependent Same scheme of the daily variation (maximum flow rate at the end of afternoon)	1 month time lagged between the start of infiltration (2023 delayed)

Flow rate	Flow regime between Box1 and Box2 is different in 2022 and 2023	Maximum flow rate is different Box 1 and Box 2: Max 2022 flow rate = 50 L/h Max 2023 flow rate = 40 L/h
Conductivity	Low conductivity value at the start	2022 gets higher values in the middle of the season
Fluorescence	Appearance since the first water flows and almost 5 months of detection The end of fluorescence corresponds roughly to a change in the conductivity of the measured water.	Only 1 dye detected in 2022 2 dyes detected in 2023

Some hypotheses behind the data

Several hypotheses can be put forward linked to the similarities and differences in the signals over the last two years. The surface of the rock face and its subsurface evolve according to numerous parameters that follow the scaling factors set out by Gruber in his thesis in 2005.

- It is therefore possible that the influence of global parameters such as air temperature and exposure to solar radiation is important in this transfer of energy and heat, leading to water infiltration into the walls through a chain reaction: air – surface – subsurface.
- Snow cover, from a much more local point of view, can have an impact on the wall's water supply, as well as on the wall surface's protective role against solar radiation through the albedo effect or air temperature (see section 2.1.5). As a result, the thermal profile of the wall and its evolution during the summer period could change depending on snow conditions in winter. About albedo effect, we could easily compare the two years to confirm and validate results from Magnin (2017).
- Furthermore, the results for both years show differences in the flow regime between Box1 and Box2. Several hypotheses remain about it, such as the presence of a network of secondary fractures within the main fracture itself, but also the positioning of Box2 at greater depth and therefore with a larger delay between infiltration occurring above Box1.

All these hypotheses will be analyzed in the following section, by comparing the values collected by the monitoring system with external variables or photo comparisons.

4.2. Data analysis

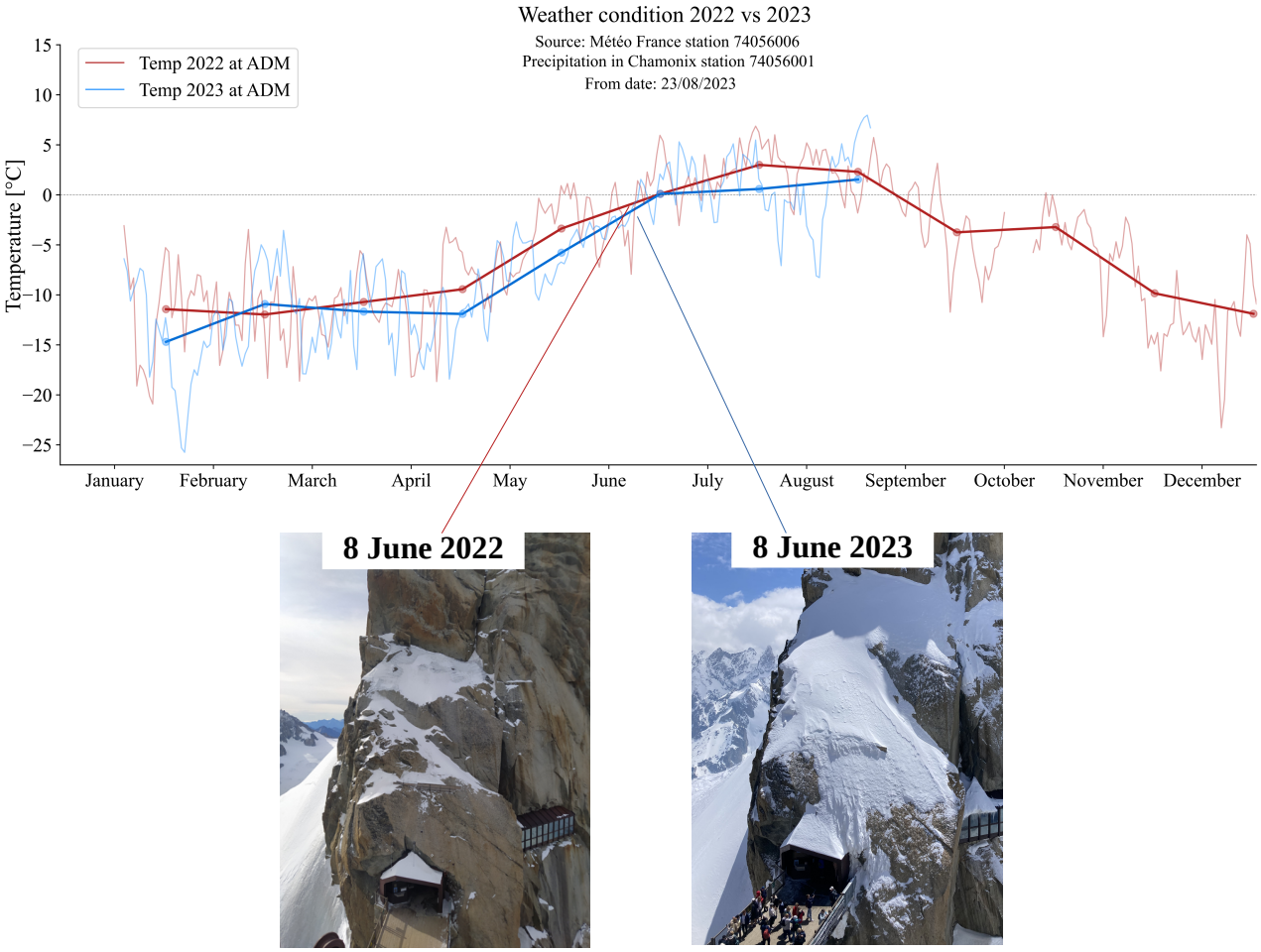
The initial question leads us to wonder about the link between the steep wall surface and its subsurface, which may contribute to the flows observed inside permafrost walls. Measurements taken over the last two years show similarities in the reaction of this hydrological phenomenon. There appears to be a link between surface temperatures or atmospheric and meteorological conditions.

These various parameters and external factors (shown in the table of scaling factors) will be studied in comparison with hydrological fluctuations within the wall. Certain relationships will be demonstrated in our case, providing a better understanding of the phenomena in time and space.

4.2.1. Weather conditions (years 2022 and 2023)

The winter months of 2022 were relatively dry and lacking in snowfall across the French Alps. This was also the case on the Aiguille du Midi, where the snow cover on the north face melted rapidly during the year, giving way to a bare rock face early in May.

The year 2022 saw above-average summer temperatures. It was also one of the driest summers in recent years, putting a large part of the region on maximum drought alert. This was reflected in the rainfall.



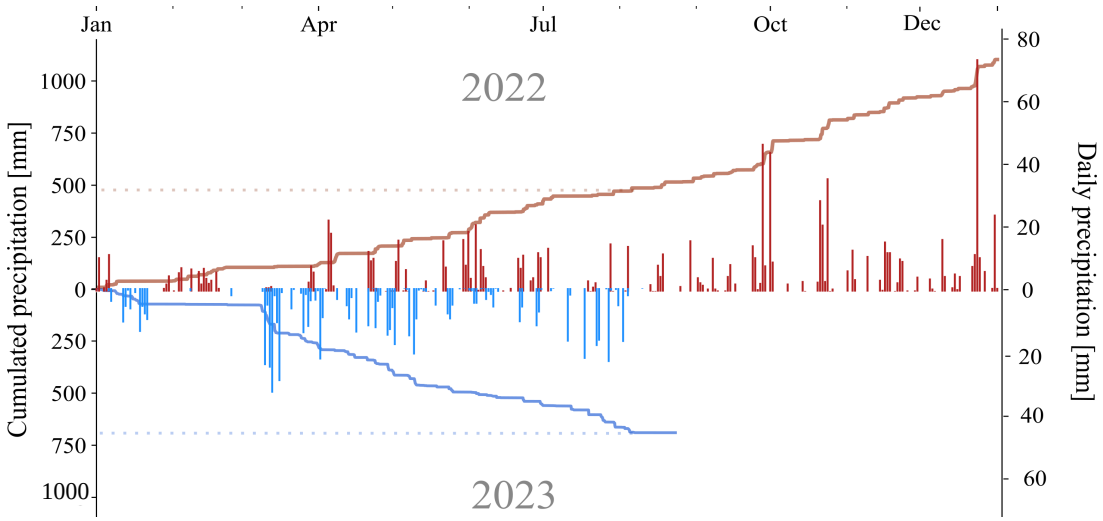
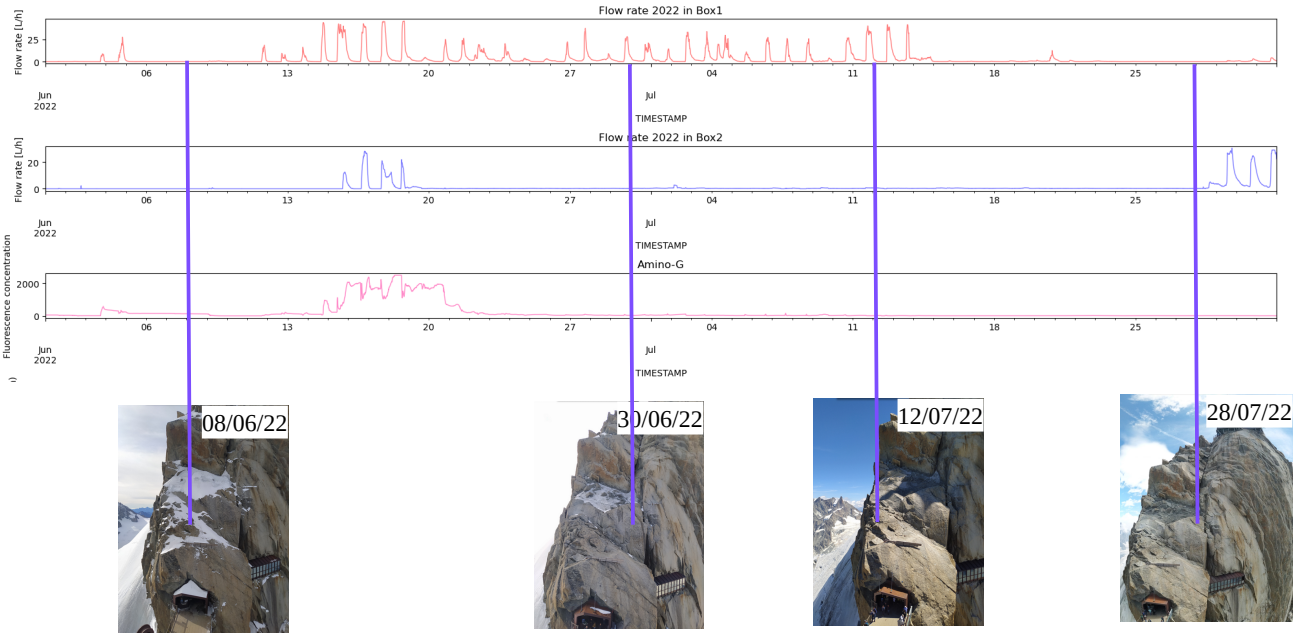


Figure 44: Weather condition: temperature from weather station at Aiguille du Midi and precipitation from weather station in Chamonix) by Météo France in 2022 and 2023

It is interesting to have the year 2023 as a comparison. Firstly, we are already seeing a different year from a meteorological point of view (air temperature and precipitation – snowfall and rainfall). Spring temperatures are lower than in 2022, but above all, the snow cover is completely different. Precipitation continued late in the spring season, with a snow cover that remained on the wall until the middle of June. The impact of a deeper and later snow coverage will be observed and compared with the study by Magnin (2017).

4.2.2. Influence of the snow coverage

Spring 2023 was colder in comparison with 2022 and with late snowfall as for mid-June 2023 no flow appeared.



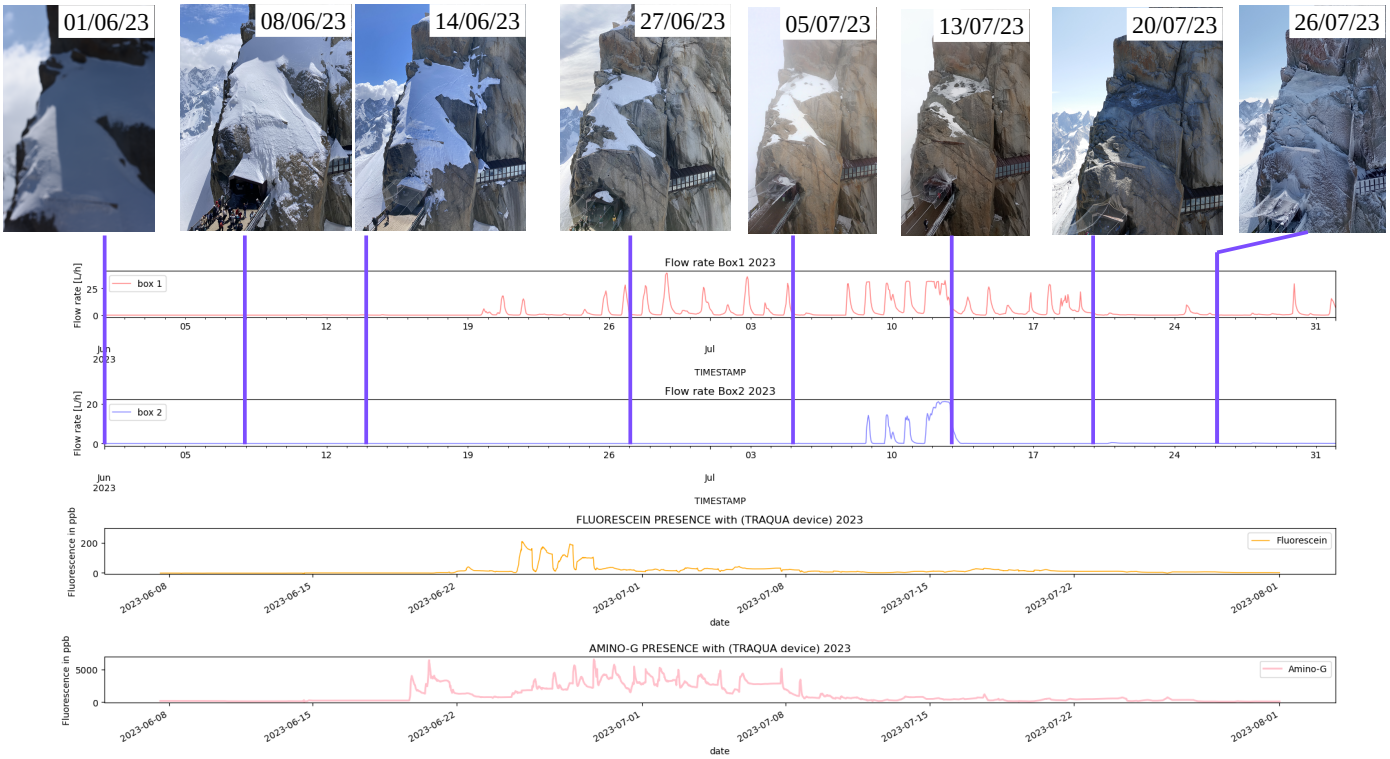


Figure 45: Difference of snow cover between 2022 and 2023

Snow cover seems to have a direct influence on water flows. The snow cover deposited and accumulated during the winter months will therefore have an impact on the initial date of onset of flow.

In 2022, the lower snow cover enabled the rock face to warm up more quickly, so that the first flows began as early as May, whereas in 2023, with its deeper snow cover and longer snow cover period, the rock face remained cold and the first flows were delayed until mid-June (Figure 45).

In the next paragraph, the impact on the rock surface temperature in 2022 and the resulting flow response will be studied.

4.2.3. The influence of global and local parameters

Relation between rock surface temperature and flow rate

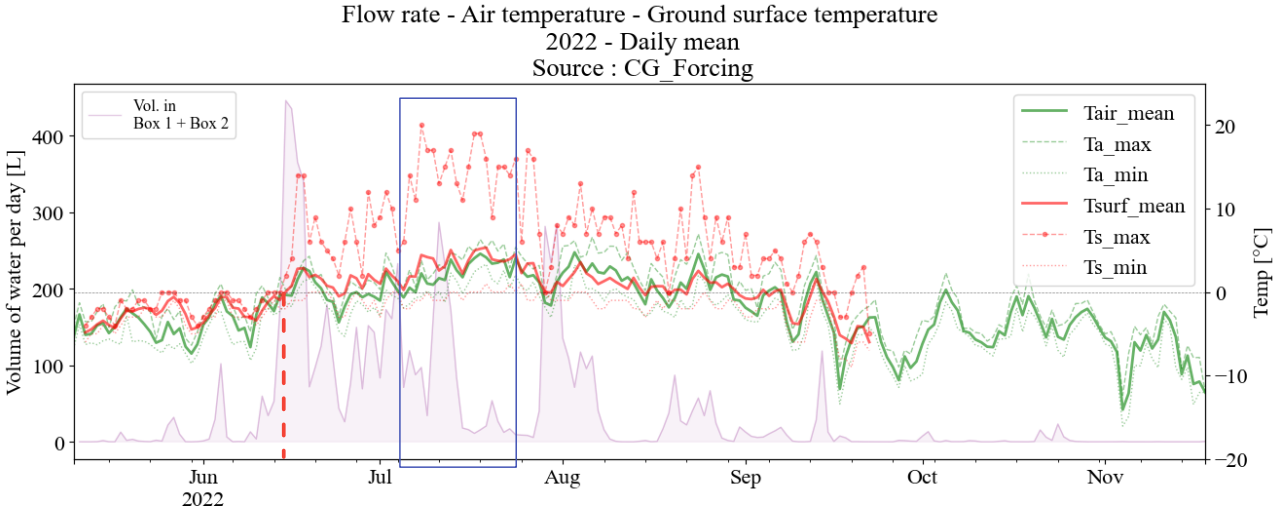


Figure 46: Air and Surface temperatures evolution in 2022 compared with flow rate

Figure 46 shows similar trends for air temperature (green line) and rock surface temperature[9] (red line). Maximum flow rate is in mid-June (red dotted line). Prior to this, small events had been occurring on a very sporadic basis, with maximum air temperatures close to or even above 0 °C.

A strong transition can be seen as soon as the daily averages are above 0 °C. This also marks a major shift in the daily range of rock surface temperatures. This may mean that the water that initially infiltrates is the snow on the wall. That also corresponds with the fluorescent signal appearance. Figure 45 shows that this is the period when the snow on the surface disappears. The snow on the rock surface acted as an insulating layer and the albedo effect largely rejected solar radiation. Once the wall is exposed, it is subject to much greater heating by solar radiation.
This initial event is followed by a succession of snowfalls or colder periods.

On the other hand, the month of July (blue rectangle) has large, continuous temperature variations. This may indicate that during this period, the snow is totally absent, leaving the wall in direct contact with the solar radiation and the air temperature. Flow during this period may therefore be either water from rainfall or interstitial ice.

Despite the possible absence of snow, there are still continuous flows down the walls during the summer period between mid-July and the end of August. The water that flows down can have different origins from indirect sources, such as run-off from up-slope, direct rainfall or interstitial ice.
Heat transfer by convection and advection (by the flowing water) will tend to warm the wall at depth and thus reach the interstitial ice (ice storage). This ice acts as a “cement” and its deterioration could be one of the causes of the rockfalls that have occurred in these high mountain areas.

9 From temperature sensor iButton ref 7477 – data collected at the end of September 2022

Nevertheless, several method bias can be noted such as the rock surface temperature data comes from a single sensor. It is therefore possible that this sensor is positioned in an area where the snow has melted more quickly than on the rest of the wall.

The 22 August 2023, several iButtons (rock surface temperature sensors) have been found to collect the data. It is interesting to see the difference between them unlike in 2022 (Figure 47).

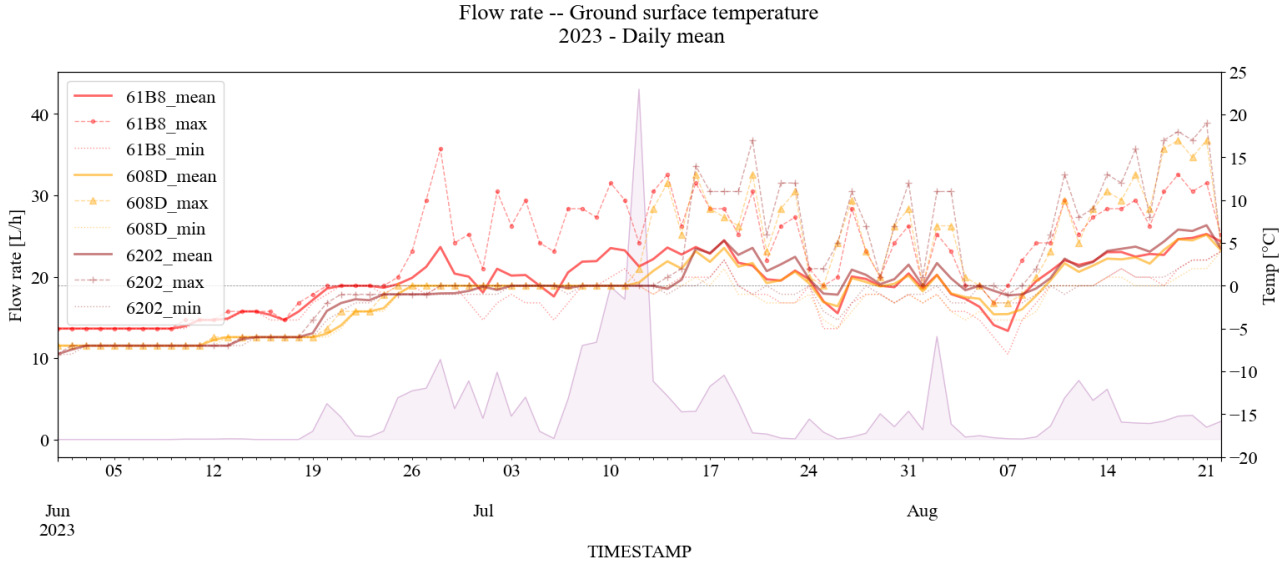


Figure 47: Rock surface temperature of 2023 from 3 different sensors (iButton) collected the 22 August on the north face

The location of temperatures sensors allow a temporal and spatial distribution of snow melting period. Figure 45 shows clearly that sensors have high range of values when no snow is covering them. Sensor number 61B8 is so the first sensors to be uncovered of snow in the end of June following in mid-July by the sensor 608D and 6202 few days later.

The temperature sensor 608D (in yellow) is the only one to have the two consecutive summer data (Figure 49). In 2022, the two iButton (7477 in brown used for the previous study in Figure 46 and 61B8 in red) follow the same patterns which can mean that there are both placed in a location near from one another. However, in 2023, iButton 61B8 shows period of same values indicating no local variation of rock surface temperature during several days. Another difference between the two years is the negative values in summer 2023 in the second part of July. It can be explained by the presence of new snow and low air temperature (see section 4.2.1).

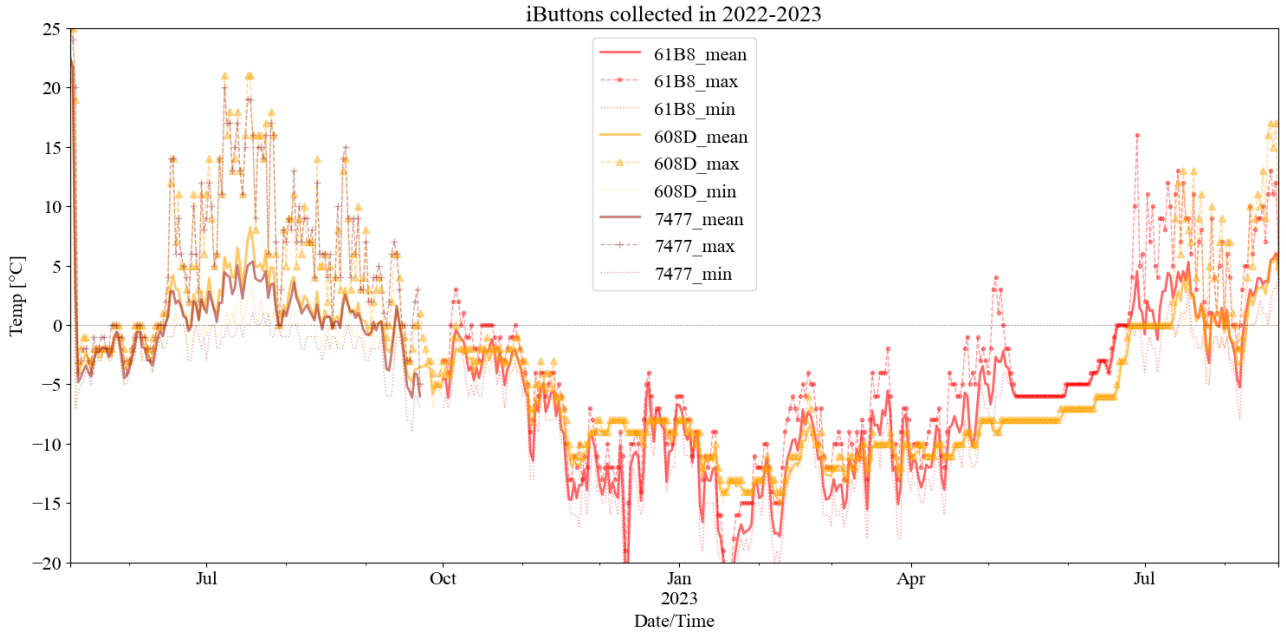


Figure 48: Rock surface temperture data in 2022 and 2023 from iButtons on north face

The evolution of the internal surface temperature (in the galleries)

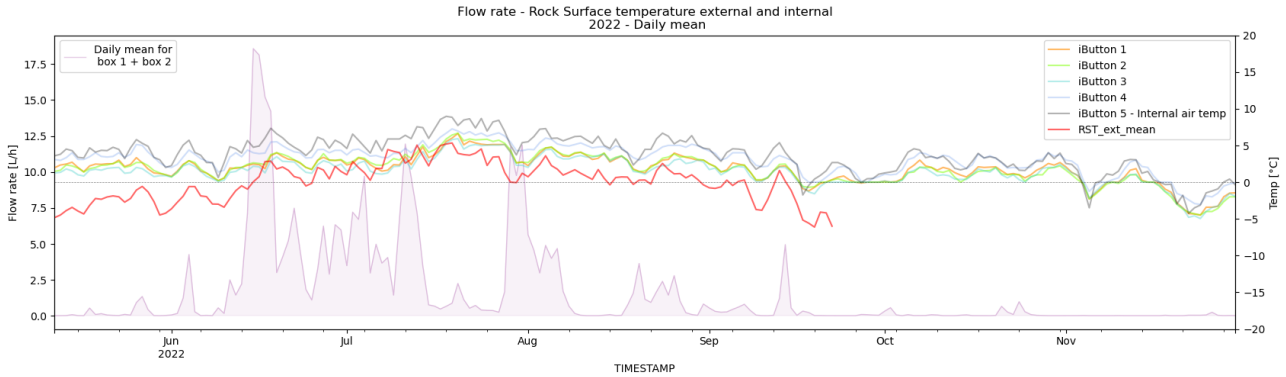


Figure 49: Evolution of internal temperature in 2022

The rock surface temperatures between the sensors on the outside wall and sensors present in the gallery (Figure 25) are also compared. The internal surface temperatures are relatively stable and varies not so much during the summer period, remaining between 0 °C and 5 °C. Surprisingly, the internal surface temperature is already positive in May.

Time lagged cross-correlation analysis: lag time between temperatures and flow rates?

The graphs in figure 50 show the result of signals analysis using the Time Lagged Cross-Correlation method.

This shows whether there are any systematic shifts between our different signals. Analyses have been realized with 3h mean for all signals.

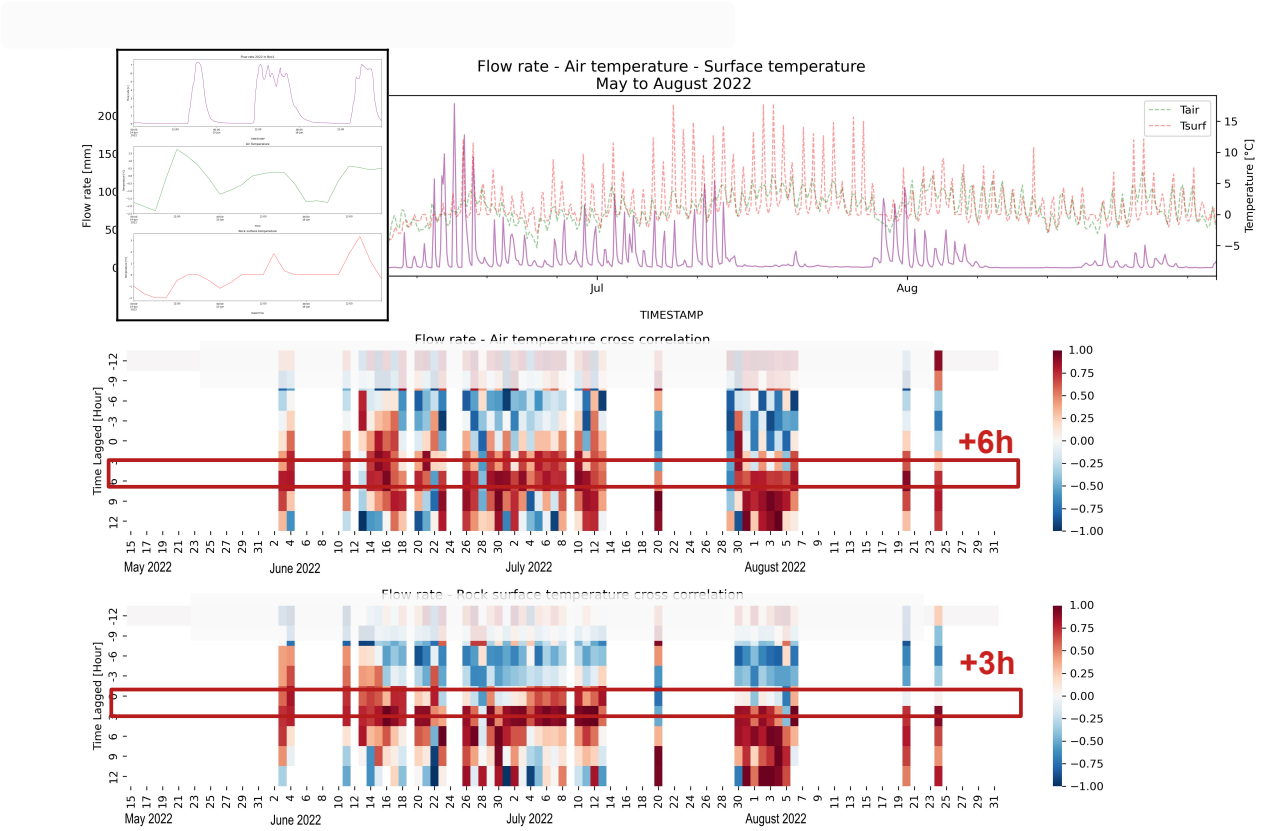


Figure 50: Time lagged cross-correlation results for 2022

The time lagged cross-correlation analysis shows that peak water flow lags peak air temperature by about 6 hours and peak rock surface temperature by about 3 hours.

Another way of observing this shift is to look at the times of each maximum flow, air temperature and rock surface temperature such as in figure 51. We thus find signal shifts similar to the Time Lagged Cross-Correlation method, but here we can estimate quite easily the average times when these maximums are reached for each month.

A reversal of this shifted correlation can be observed on certain days. For example, on 22 June, 2022, the maximum flow rate occurred relatively early in the day, preceding the maximum air and rock surface temperatures. It would be interesting to have a more precise view of the meteorological events on this day to understand the phenomenon. It is possible that rainfall occurred during the day and continued during the night, causing early run-off, or that the temperature did not drop sufficiently the previous night. A photo interpretation could also help.

For further work, it would have been possible to focus on particular periods. Thus, it could be interesting to compare over the year 2023 if this pattern recurs.



Figure 51: Comparison of the maximum values of Air Temp, Surface Temp and Flow Rate each day for 2022

Table 9: Time Lag between the Air Temperature – Rock Surface Temperature – Flow rate

	Number of water flow days	Mean hour of max Air Temp	Mean hour of max Surf Temp	Mean hour of max flow rate	Time Lag Tair → Flow Rate	Time Lag Tsurf → Flow Rate
June 2022	19	13h00	14h30	18h15	**+ 5h15**	**+ 3h45**
July 2022	16	12h45	14h50	18h20	**+ 5h35**	**+ 3h20**
August 2022	8	12h30	14h45	19h50	**+ 7h30**	**+ 5h**
June 2023	5	11h00	15h20	18h45	**+ 7h45**	**+3h25**
July 2023	18	12h30	14h45	18h	**+5h30**	**3h15**

Table 9 shows that the time lag between temperature and flow is not constant across the season in 2022 and 2023. June 2023 is a good example for showing the dumping role of the snow cover on surface temperature and flow rate.

Air temperature reaches its maximum earlier and earlier, while flow is delayed over time. This can be explained in a number of ways:

- Firstly, at the start of the flow, the snow on the wall reacts more quickly and almost directly to the warming as main source of water.
- The angle of the sun changes over time and season and so is the time of exposure.
- In July and August, after the snow is totally melted, rainfall can be the main source of flow, and it is less sensitive to air temperature.
- At the end of the summer, if the water is flowing from the inside of the rock face, it is necessary to wait for the rock face to warm up, which delays the flow phenomenon.

Conclusions

Results from real-time monitoring of water flow from fractures in a permafrost-affected rock slope clearly show that there is strong connectivity between the snowpack at the surface and sub-surface fractures and it is the first time that a monitoring system could showed that directly in the field. Some conclusions can be highlighted:

- The initiation of a continuous flow period corresponds to an increase of surface temperatures above 0 °C with high range variation of rock surface temperatures.
- The infiltration that occurs in the walls is highly season dependent.
- Most water flowing in late Spring and early Summer results from snowmelt, while direct rainfall is the major source of infiltration during the late summer.
- Strong diurnal changes in flow rate are observed and correlate with air and surface temperatures, linked with the solar radiation influence.
- This time lag phenomenon is accentuated when seasonal snowpack has completely melted/disappeared.
- The time lag between air temperature and flow rate stay stable but the maximum flow rate takes more time to be reached in the late summer.
- The impact of snow is major if it is a thick and late snow coverage. This considerably delays the first flows and keeps the wall cooler for longer, probably preventing the interstitial ice from melting (too much) in summer. The observation of flow after no snow cover was visible (mid-July in 2022 and August in 2023) points to potential indirect sources such as runoff from up-slope, ice storage in the fractures or direct precipitation such as rainfall or snow that melts immediately on the warm rock.

At the time of writing, the summer season has not yet come to an end. Some of the conclusions may of course change slightly, or provide relevant new information.

In addition, all chemical analyses of the water samples collected have not yet been carried out. These could provide unique information on the origin of the water flowing through the walls, particularly those with high conductivity.

V. DISCUSSION

5.1. Feedback: benefits and limits/difficulties

General feedback on this multidisciplinary experience

Over the past two years, the monitoring of infiltration water at Aiguille du Midi has provided new insights into summer flows on a high-altitude, north-facing rock face. The strong and present relationship between surface and subsurface is further demonstrated by this monitoring system and confirm the first numerical models.

Access to these extreme environments is not easy, so instrumentation of a second site will be difficult. However, this could be an opportunity to explore in the coming years, in order to understand even more about these phenomena, which seems to be evolving very quickly in the face of climate change.

I was given a great deal of autonomy, which was very instructive. Through this internship, I have had the chance to apply all my past experience, from my engineering school to this master's degree in the environment, not forgetting my passion for the mountains. For example, I could help Emmanuel Malet (Research engineer in charge of the monitoring installation) to design new 3D-printed part for the conductivity sensors (Figure 52) in order to add new larger cones to collect water from the roof. I used my mechanical engineer skills to take this action and Emmanuel could do take care of other project instead.

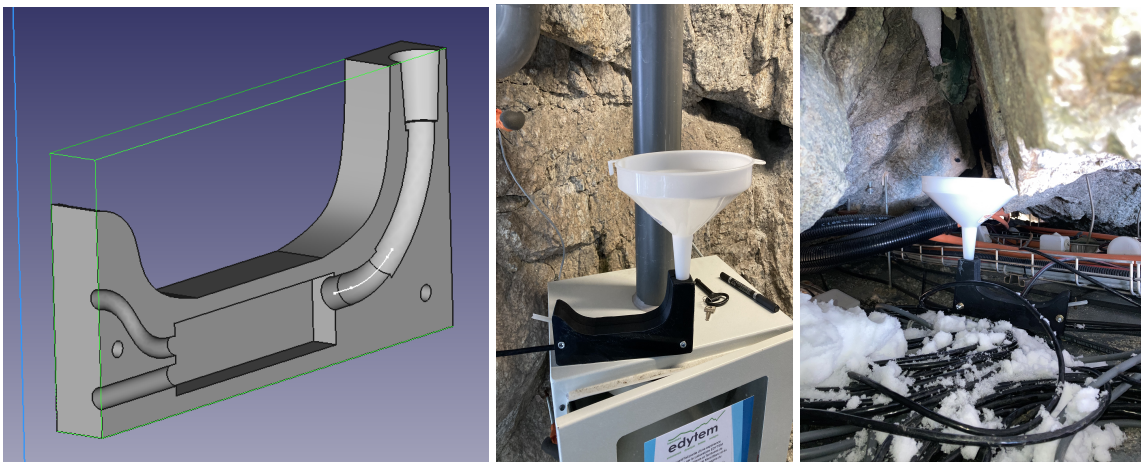


Figure 52: 3D printed part designed for conductivity sensors

I will long be grateful to the laboratory and to Florence for giving me so much autonomy and the chance to get up close and personal with this glacial and periglacial environment.

Methodological limits and issues

However, a number of methodological limitations and difficulties has been identified.

Study on visible process of infiltration… what about the invisible part?

The initial approach is to observe and measure the flows visible in the galleries. Based on this information, relationships and links between different parameters are established to provide hypotheses or conclusions for this scheme. Tracers may be used to check whether the path is straightforward (depending on the complexity and profile of the fracture), but the assumption is made that if none of the tracers are found elsewhere, then everything has passed into the measured flows.
This assumption is mandatory in our study to simplify the process and understanding of the flows, but it must be kept in mind that the fracture pattern inside the wall may be much more complex.

Very local information

Ongoing data from the 2023 season provides an initial comparative basis for taking a step back from the first results of 2022. It should be kept in mind that this represents an idea about a relatively singular area. It is also difficult to know the exact proportions of the different types of water that can flow through rock faces. No instrumentation has been set up to estimate changes in snow cover over time. However, with the results of Ben-Asher's study in 2022, we can attempt to estimate the limits of possible snow depth depending on slope inclination.

Similarly, the lack of knowledge of the exact surface and topography of the wall means that many local factors cannot yet be exploited in this study.

Experiments at high altitude require the body and equipment to adapt to extreme conditions (cold, lack of oxygen, strong winds, etc.).

- *Regarding the extreme cold temperature*

During my first follow-ups in March and April, it turned out that the fluorescence probe was no longer recording any measurements on the logger (Figure 53). With Emmanuel's help, we had to find solutions and carry out a number of tests to try and get it working again. This period required considerable teamwork between Emmanuel, Matan and myself in order to react quickly to avoid missing the first flows. The aim was to have everything up and running by May in case of an early flow. At present, we still don't know the reasons for the malfunction, but the cold may have played a major role on this sensitive device. Finally, an arrangement with the TRAQUA company (in Belgium) enabled us to obtain a replacement fluorimeter on loan for this year, which is working well. This new fluorimeter is totally independent, with its own internal battery and WiFi connection for data collection.

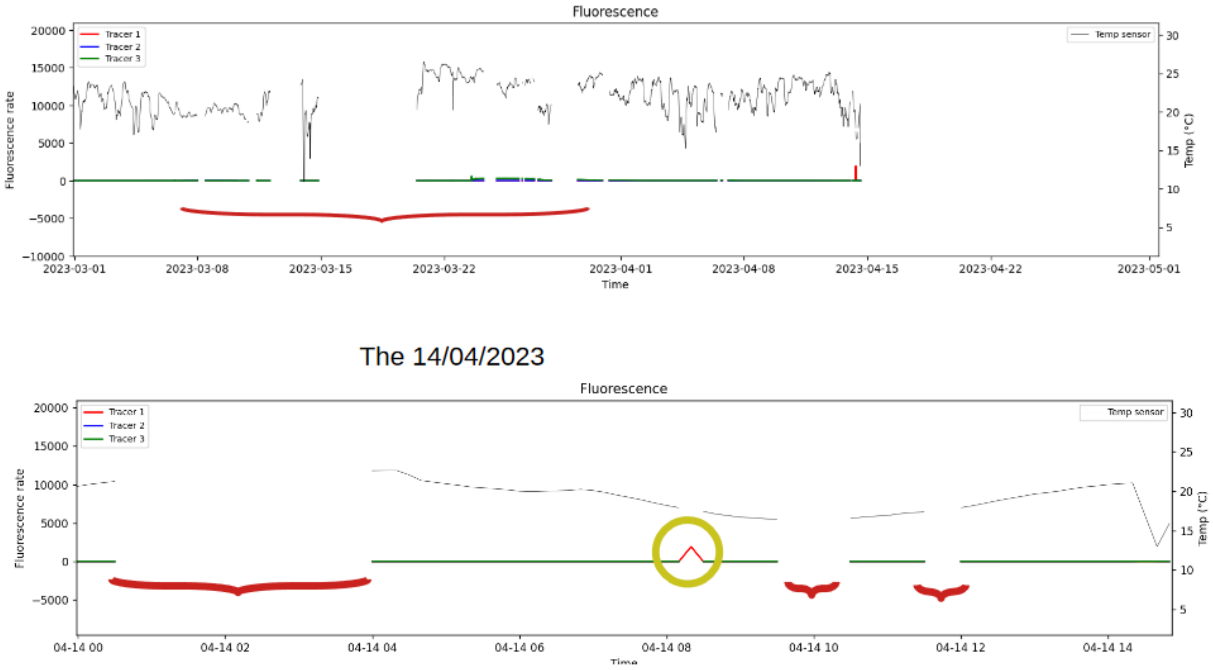


Figure 53: Fluorescence signal issue in April 2023 (see the 14 April field report)

The entire monitoring system remained in place throughout the winter period. Despite the use of a heating wire to keep tubes and equipment at an acceptable temperature, some of them probably did not manage to pass through the winter and kept on recording data, which could explain the difficulties and problems with the first fluorescence probe. This was also the case with Box 2, less protected from the cold by the heating cable and directly in the icy airstream at the entrance to the central peak, which turned out to be a veritable block of ice that had to be broken with an ice axe before the first flow (Figure 54).

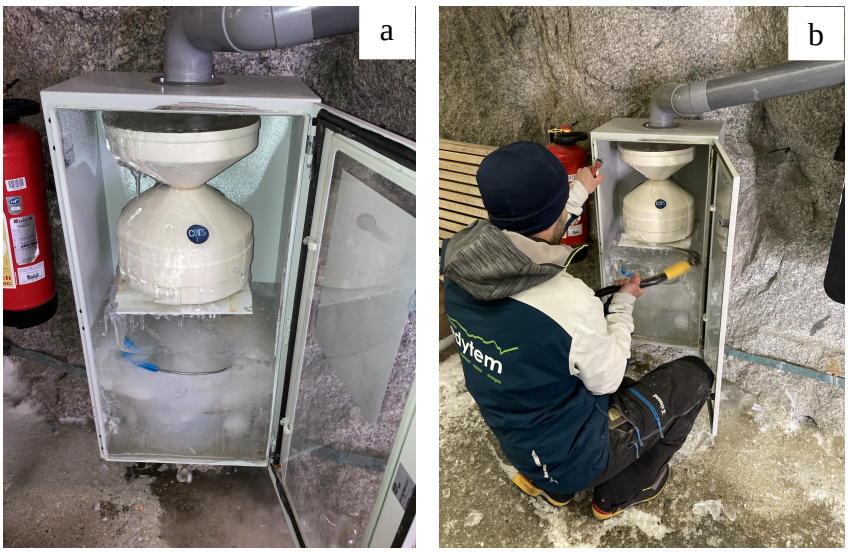


Figure 54: Extreme conditions are hard for monitoring tools. a: Box 2 totally frozen in May 2023 ; b: Matan trying to remove the ice with an ice axe

It is also very difficult to work in extreme cold temperature (e.g. on 14 April temperature was -24 °C at the Aiguille du Midi). All manual handling is a real challenge, from the simple manipulation of a bucket to the use of a computer.

- *Regarding the extreme and variable weather event such as storm or wind*

2023 was a very windy year (discussion with Youri Demarchi, chief officer at Compagnie du Mont Blanc). It is very rare for the cable car not to operate for several days in a row, and this proved to be the case several times during the summer. On the first occasion, I had to make a round trip (Chambéry to Chamonix = 90 km x 2) without being able to access the Aiguille du Midi. Of course, this also has an impact on the measurements and, above all, on the reaction of the snow cover and temperatures.

This wind factor is not taken into account in my results, even though it may well be an important climatic element. Severe thunderstorms also challenged the ERT device with a few possible lightning strikes.

Data with no explanation or acquisition data can not be analyzed

This first monitoring experience also taught me how to manipulate and analyze data. However, it is important to know how the raw data was acquired and obtained. For example, the electrical conductivity data from 2022 is distorted and unreliable. The sensor was moved several times in 2022 by the team in place. As a result, the measured data do not give a continuous indication of conductivity at a single location, as I attempted to do in section 4.1.1. A history of manipulations is more than essential if an experiment is to last over time and be easily taken over by others. For this reason, I hope that the field reports in the Appendix 3 will be useful for the continuation of experiments at the Aiguille du Midi.

Similarly, the lack of information on the location of temperature sensors on the north face makes it difficult to retrieve them and thus have long-term data that can indicate the same information (see section 4.2.3).

A human-modified environment

In the context of this internship, it is important to bear in mind that the Aiguille du Midi study site is a highly anthropized environment. All the man-made infrastructures that make it possible to welcome so many tourists are likely to disrupt the wall's reaction (just as they may not change anything at all). As far as I am concerned, it is difficult to know how much all these structures have altered the flow phenomena and permafrost on these walls.

Thermal effect by heated rooms, air circulation in the galleries (galleries are like big fractures that could interact with natural ones that we are studying) could affect rock temperature, and so the water circulation in fractures too.

The accessibility of some devices such as cameras on steep bedrock wall

In order to retrieve numerous data, rope handling is required (rock surface temperatures, camera as shown in figure 55). I was therefore dependent on the availability of my colleagues trained for rope work at EDYTEM.



Figure 55: Josué manipulating the North camera to collect the SD card

Mass tourism in the middle of experimentation

As already mentioned, Aiguille du Midi is huge touristic place, which means that all the system and work is done in middle of lot of people (Figure 56). It is a good opportunity for direct communication and mediation about climate change and the high mountain permafrost studies progress, but it also not always easy because a lot of them do not care about our research devices or presence (skis on water collector, rope, site touristic information request, etc..)



Figure 56: Aiguille du Midi: Between science experiment and mass tourism

Carbon footprint of this internship

One of the last points I would like to raise is the impact of research on participation in certain programs. Zero impact is impossible, but I think it is necessary for everyone to question the impact of their actions, so as to think about reducing them in the future.

Research is more than essential to understanding the environment and changing our habits, but it also has a duty to report these emissions. This incredible course at the Aiguille du Midi is not without consequences. A great deal of data was generated during the 5 months of internship, as well as frequent trips to Chamonix, often alone.

That is why, in Appendix 5, I wanted to draw up a carbon footprint of the CO_2 equivalent emissions generated by my work at EDYTEM. This is not a reproach, but a communication and mediation

initiative to make anyone reading this manuscript aware that all actions entail responsibilities.

5.2. Link with master's degree (GEMO)

This internship provided an opportunity to apply an interdisciplinary approach to research. During the two years of the Master's program, numerous approaches were studied in classes on different themes. Having a global vision but also the opportunity to tackle a wide range of subjects made it easier to adapt quickly to the subject of the internship and to the theme of high mountain natural hazards.

Moreover, understanding mountain socio-ecosystems makes it easy to see what is at stake in this type of research and the associated funding. During this internship, it was really important to understand all the players and issues involved in natural hazards just as the linked trajectory of a valley with its environment and economic evolution (mass tourism, risk research, evolution of an environment in the face of climate change).

However, the Master's degree is evasive on the many practical and applicative methods linked to research on mountain environments. We learn about the global and general evolution of the environment and associated ecosystems, but not about the research methods needed to obtain this information and trace environmental trajectories. So, learning how to process data using programming tools has been self-taught and autonomous. I think that some knowledge of the subject might have enabled us to go further on certain points.

In the same way, I think we are sorely lacking in knowledge of how to read mountain landscapes and the geomorphology specific to these environments.

5.3. Perspectives

Relation between rockfalls and infiltration?

The direct relation between water infiltration and rockfalls in time and space still not totally defined

The first observation made prior to this study was the presence of water in liquid form and ice in the scars of rockfalls, representing a major risk for mountain populations and infrastructures. The question was therefore to gain a better understanding of the hydrological phenomena at the very heart of these rock faces, in order to determine the impact of this water on gravity phenomena. *Ravanel et al.* (2017) and Pierrick Jean's internships (2022-2023) have noted a greater number of collapses during extremely hot summers.

For our part, the major finding of the monitoring system over the past two years is that the vast majority of runoff comes from infiltrating winter snow. The snow layer also plays a protective role for the surface and subsurface, limiting variations in wall temperature (same finding as Magnin (2017)). It seems that the pattern studied over two years shows rapid infiltration of the snow cover into the wall.

Several questions arise such as:

Is water flow rate fast enough to not affect the development of the active layer by heat advection and convection? Although water temperature sensors have been installed in conjunction with the conductivity meters, the presence of the heating cables disturbs these values. So we do not know whether the water flowing through the wall is hot enough to significantly heat up the active layer and degrade the permafrost.

Global warming will continue, so there will be consequences such as a modification in precipitation. Isotherm line will go up over the years (in 2023, isotherm reach 5300 m a.s.l. in the Alps the 20 August[10]), snow line will also go up and be replace by rain a part of the year. Regarding these general hypotheses, what will happen when snowfall is completely replaced by rain? Will this precipitation have a greater impact on the wall's thermal regime than the overall air temperature in the absence of winter snow?

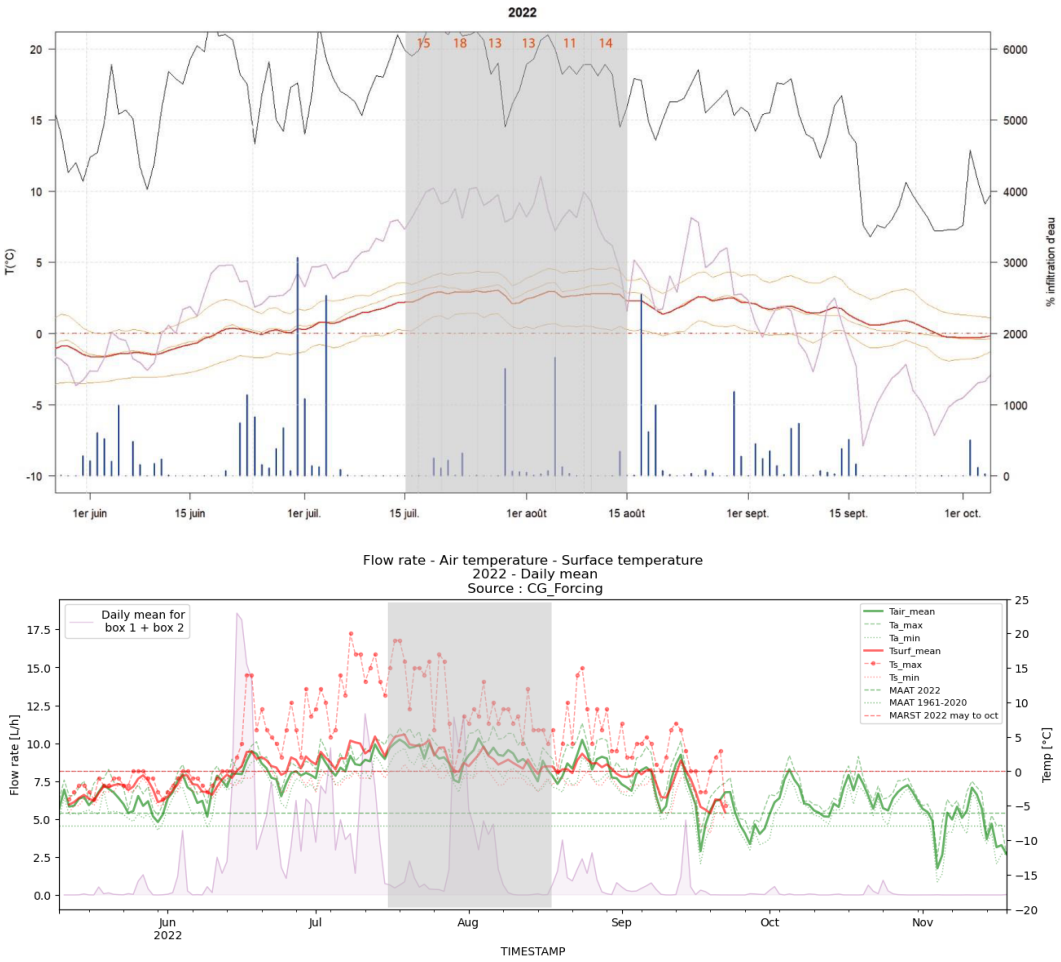


Figure 57: Comparison between rockfalls analysis by P. Jean (2023) and the actual analysis of flow rate for the year 2022

Most of the rockfalls occurred after most of the water flows (mainly from melting snow cover). The relationship between water infiltration and the occurrence of rockfalls is not clear-cut. However, there does appear to be a strong relation when the rock face is free of snow cover and therefore in direct contact with solar radiation. As a result, the rock surface warms up, and the surface

10 https://www.euronews.com/green/2023/08/21/switzerland-meteorologists-reach-record-5298-metres-before-finding-zero-degrees

temperature varies considerably from day to day (see section 4.2.3). It could be that these huge variations in wall temperature are the primary factor in the growth of the active layer and hence the degradation of permafrost.

About the monitoring system

Better measurements of snow depth over time to better understand infiltration phenomena?

As for now, it is still difficult to measure the real part of precipitation that leaves directly through sublimation whereas these phenomena have regularly been singled out as important in the water system of mountain permafrost environments (*Arenson*, 2022). The use of snow depth measurement tools on steep high mountain faces has already been tested on other faces of the Aiguille du Midi in the past. Regular photographs of the face equipped with snow sticks provided a good estimation of the snowpack thickness. However, extreme conditions tore off many of the sticks. For the face, the installation of a camera on the North peak provides an objective view of the snow cover, but without being able to quantify it. As a result, it is difficult to estimate the exact infiltration of snow into the walls among the flows recorded... perhaps the subject of a future study?

Develop an acoustic method as new monitoring tools to better understand the steep bedrock walls from the inside?

It is just an idea, but acoustic monitoring method is more and more used in research (especially for animals). Talking to a mountaineer on the Aiguille du Midi, he mentioned the noise coming from the wall during a high-mountain run, on which a collapse occurred just after they had passed. Perhaps this is a possible way forward, as equipment evolves and it becomes possible to hear hydrological gravity movements even in winter, or at times when no flow is visible to the naked eye.

However, we must be aware that the presence of tourists and machinery at the Aiguille du Midi could also be a source of excessive noise and a nuisance to the experiment.

About numeric modeling

Less frequent snowfall versus more rain: what impact will this have in the future?

It could be interesting to try to anticipate the change of precipitation from snow in rain for the future with temperature increase and what it could change in the infiltration or the hydrological cycle in steep wall in high mountain in order to anticipate the climate change effect.

Two years' experience, already a lot but probably just the beginning

A two-year experiment like the one we ha just carried out has many imaginable prospects. There is not yet enough feedback to be able to provide definite answers to the initial questions, and further research, possibly involving the installation of a monitoring system in a different location, could lead to even more answers and questions.

The personal investment made in this project will, I hope, have provided new knowledge and good report information to continue future research on alpine permafrost.

Conclusion

This 6-month internship in the EDYTEM laboratory has enabled us to continue the experiments at the Aiguille du Midi in the Mont Blanc massif.

The monitoring system developed as part of the WISPER project is designed to study in real time the water flows occurring in rock faces at high altitudes. Observations over the past few years during rockfall surveys suggest that water plays a role in the degradation of permafrost, leading to an increase risk of rockfall as a result of rising temperatures and climate change.

Numerical models have long been available to simulate the behavior of permafrost in different environments, and in particular its evolution with climatic parameters from a global scale to the more local characteristics of the field. However, the influence of water from external sources, such as that present in the subsurface, has been little observed and documented, for a number of reasons, such as the difficulty of accessing these environments to set up hydrogeological equipment, the invisibility of the phenomenon, and so on.

The Aiguille du Midi, with its galleries carved into the rock, offers unique access to this environment. This is why the EDYTEM laboratory's experiments provide an opportunity to open up this young field of research to new horizons.

The aim of this unique internship is to collect, for the second year running, data on water flow in the north face of the Aiguille du Midi's Central peak. The aim of this mission is twofold: firstly, to have a comparative series of data with that of 2022, and secondly, to improve the frequency of water sampling through the galleries. A regular presence on the experimental site enables us to observe events and changes in the immediate environment, as well as react quickly to any mishaps.

The results of this second year confirm many of the points made last year, such as:

- a marked seasonality for summer flows. The initiation of a continuous flow period corresponds to an increase of surface temperatures above 0 °C
- a daily variation linked to variations in air and surface temperatures following a regular time shift over 2022 and to be verified for 2023
- the importance of snow cover on the wall to provide water for the first infiltration and run-off, but also to protect the wall from external climatic factors (solar radiation and air temperature)

This last point underlines the importance of a second year of experimentation, as conditions at the end of the winter were so different from one year to the next, particularly in terms of snow distribution, which seems to be an essential factor in the reaction of the wall in summer.

- The observation of flow after no snow cover was visible (mid-July) points to potential indirect sources such as runoff from upslope or interstitial in the fractures

In response to the initial problem, which questions the relationship between factors and events occurring at the surface of the wall and the evolution of the inside of the wall itself (the subsurface, in our case represented by the active layer and its progressive deepening), it seems that 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.

Moreover, climatic conditions in the high mountains evolve rapidly and appear to be very different locally. These results provide an initial insight into the reaction of permafrost on rock faces at high altitudes, but do not represent a generality. Although costly and very complex to set up, this type of experiment should be multiplied across different mountain areas and in collaboration with neighboring research teams to feed the field data.

Although snow seems to play a major role in the water that flows down rock faces, the direct impact on rockfall is still far from known. Moreover, anticipation of less snow, increased rainfall in summer and even in other seasons, and more windy and/or stormy periods are all external factors that could also play an extremely important role in permafrost degradation in the years to come.

At the time of writing, the internship has not yet been completed because meltong season will end at the end of September for the late Summer. Numerous analyses have yet to be carried out to clarify certain relationships, such as the origin of the water that runs off once the snow layer has completely melted.

Research work: so much to do, so much to learn, so much to know…



Chabas, 2023

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VIDEO

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Appendices

Appendix 1: Protocol note for the water infiltration monitoring systematic

Protocol note for the water monitoring system at Aiguille du Midi (samples preparation – data collect – water collect)

Author: Antoine CHABAS – Intern at EDYTEM

1. Introduction

1.1. The locations of work field



2. Before the field work

2.1. Glass 125 ml bottles cleaning

1. Rinse the bottle once with the distilled water and empty the bottle in the sink

2. Refill the bottle with distilled water

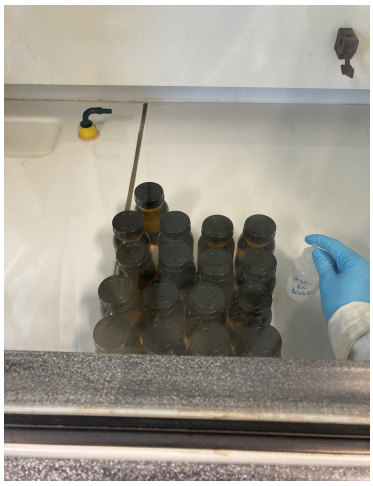
3. Under the chemical hood, put drop by drop the HNO3 (nitric acid) in the bottle full with distilled water.

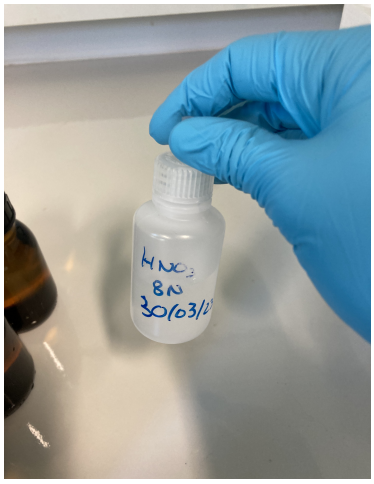
Put enough drops until the pH solution gets to 2 (enough to measure once).

4. Leave the solution under the chemical hood during 24 hours. Leave a note with your name, the description of the solution and your phone number

5. **24 hours later**, empty the bottle in the sink

6. Rinse the bottle with distilled bottle then let it dry





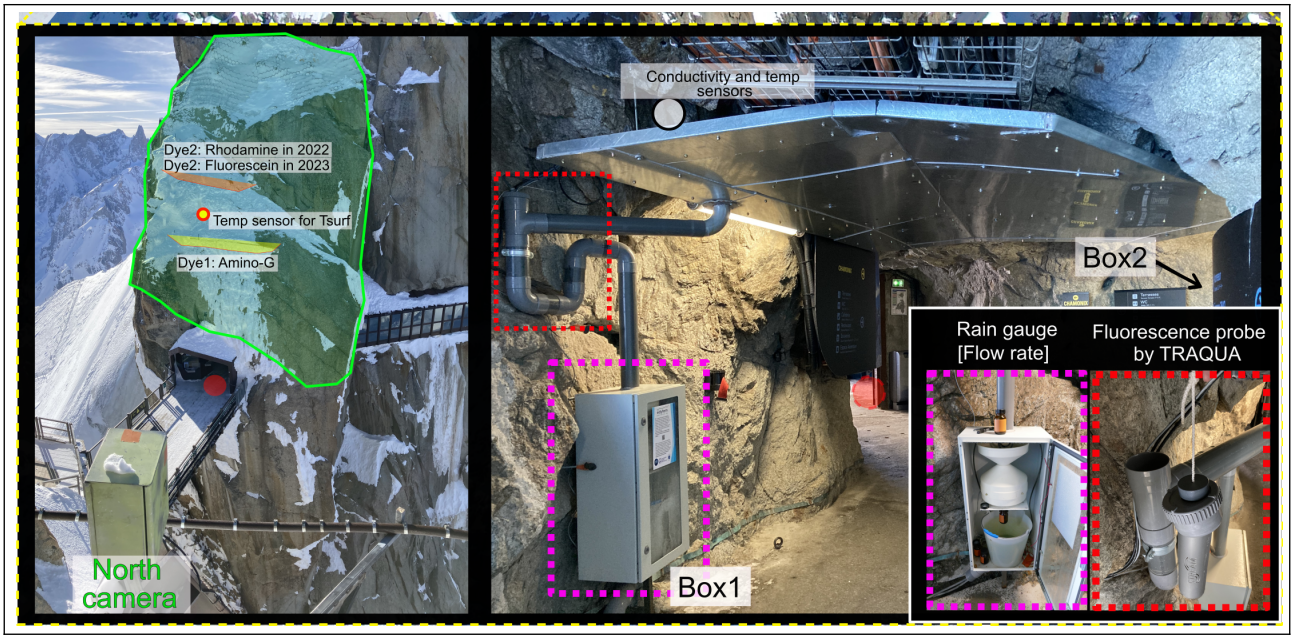


2.2. Calibrate the conductimeter

Refer to the device notice book.

3. During the field work

3.1. The water collector and monitoring system



The water monitoring system is composed of :

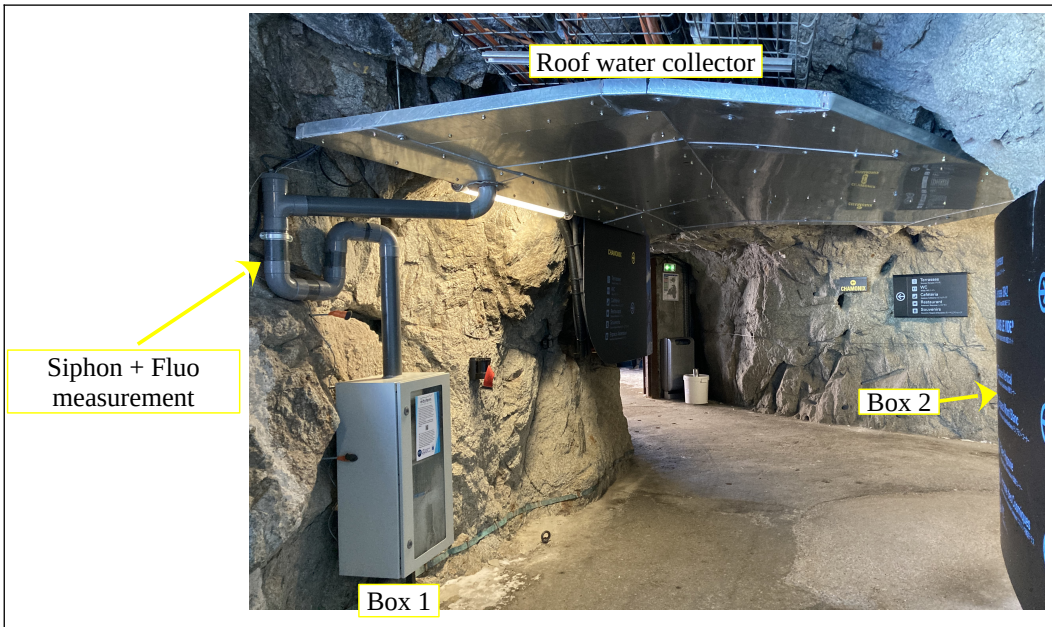
- **1 camera** on the north face (green)



Figure : Camera on N face (green)

- **1 water monitoring system** inside the gallery of the central peak with 2 boxes:
  - **Box 1** can measure continuously:
    - Water flow rate
    - Fluorescence presence
    - Water conductivity

Box 1 has a water collector system.





Data monitoring for box 1



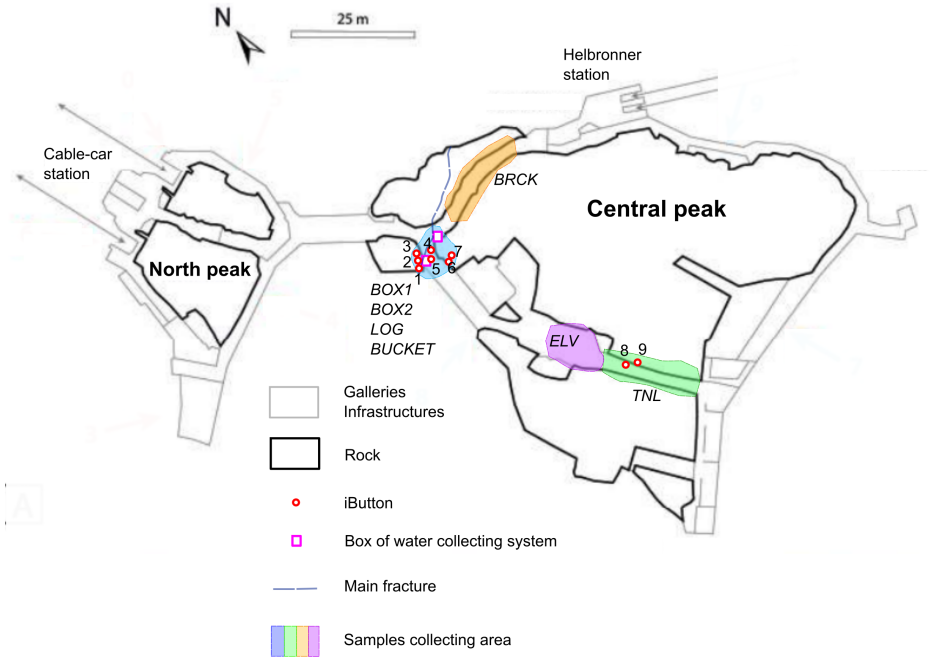
Water collector: in red is the place where the bottle (125 ml) is located

	 Water flow rate measurement = rain gauge

- **Box 2** can only collect water.

- **Other places can be used to collect water**. Three of them are shown in the figure (red point).
  - Water source « TNL » located in the tunnel
  - Water source «ELV»
  - Water source « BRCK » near to a brick wall.

Nota: But every places where water is cooling down could be used to collect water during the field work.



The basic protocol to collect data and water samples is explained below:

Step 1*: Open the Box 1 with the key*

Nota: The key is in the samples box which is staying in the staff office in the North Peak

Step 2*: Collect the water sample bottle (125 ml)*

- Take the bottle (red circle) and write the reference on it.
- Reference it such as: **BOX1** + **Date of the day** + **Time** (example : For a bottle collected the 22th of March 2023 at 10:00 ⇒ ***BOX1 22/03/2023 10h00***
- Put another bottle instead and collect it 3 times in a day (morning / noon / afternoon)

  Nota: This water will be analysed in Edytem laboratory for fluorescence and chemical analysis.

Step 3*: Collect the water sample for stable isotopes (20 ml brown glass bottles)*

- Collect the water in the bucket with the small bottle
- Be careful of not letting air in it as much as possible

Step 4*: Collect any water dropping in the galleries with the small bottle (20 ml)*

- There are 3 particular places already indicated “TNL”, “ELV” and “BRCK” but it is possible to get more water dropping place
- Measure time of filling
- Take note of the place if different of those indicated above

Step 5*: Take the bucket*

- Collect the sediments
- Check the water flow rate device
- Empty the bucket on the floor next to the box.

Step 6*: Clean and check the fluorescence device and siphon if there is no mud or sediments in it.*

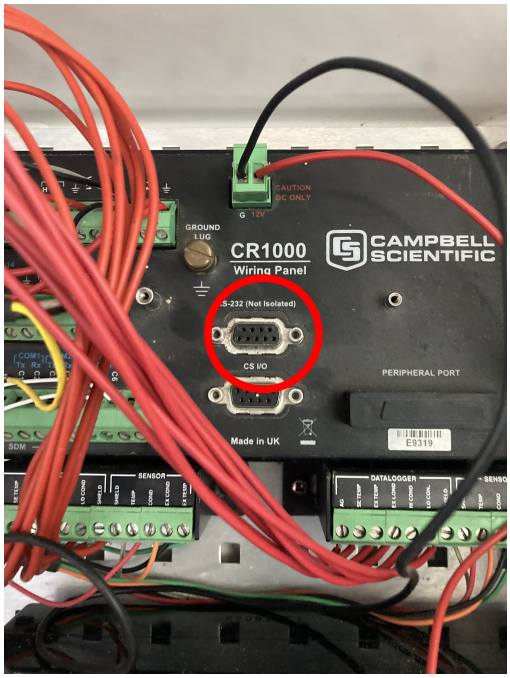




Step 7: *Put everything back as it was*

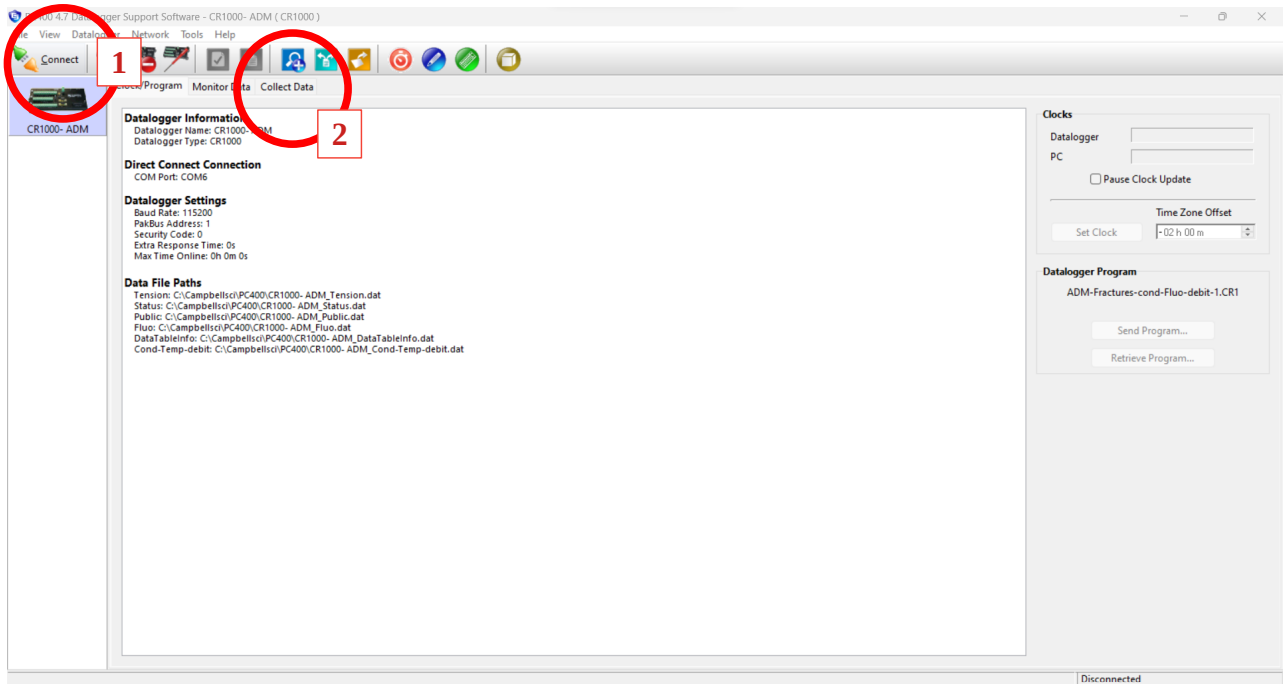
Step 8*: Transfer the data from the monitoring devices to the laptop*





Connect the laptop to the plug RS-232 (red circle)

Once the laptop is connected, go to the software "PC400 by Campbell Scientific" and charge the data (Collect Data → Charge all data). You can transfer all the data on USB key.



For the Box 2, just do the steps 2 and 3.

4. After the field work

4.1. Chemical analyses

There will be 3 different analyses on every samples:

- Fluorescence

- Major elements

- Stable isotopes

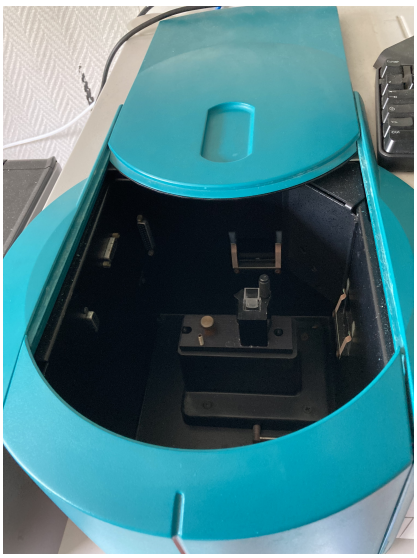
1/ Fluorescence

The fluorescence analysis is realized directly in Edytem laboratory.

1) **Rinse** the fluorescence cube 3 times in the row with distilled water and **dry** it in shaking it

2) Put the cube in the fluorescence device (CARV ECLIPSE Fluorescence Spectrometo VARIAN) - Open the appliance from the left using the green cover which translates towards the bottom – Put the cuve with the writing turned to the left





3) Always make an empty test with distilled water

4) **Open "SCAN" software** >> *"SET UP"* on the left >> Chose both *"3D-mode"* "Excitation and Emission"

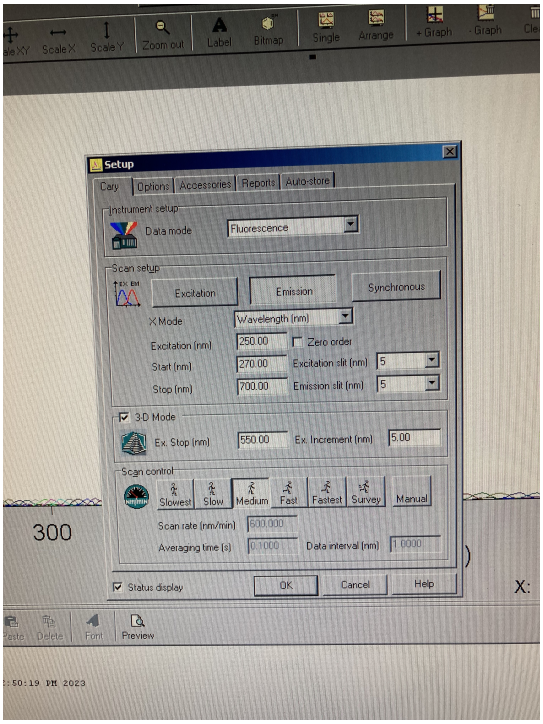
→ Increment = 5 (steps of emission)

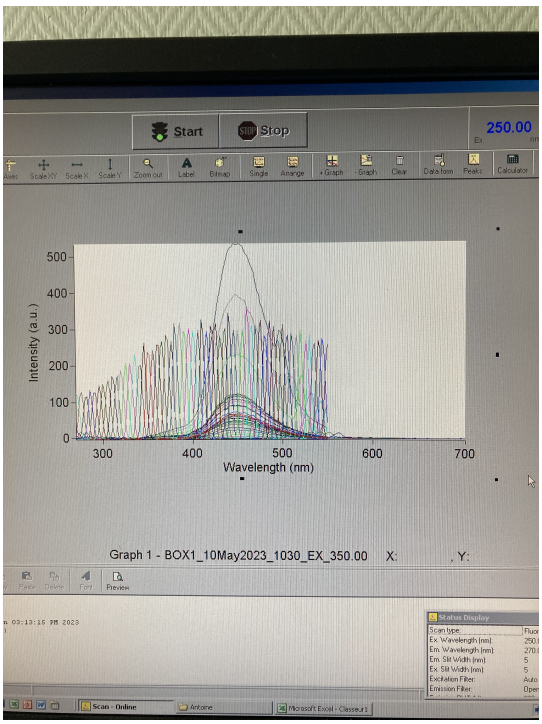
→ Excitation = 250 – 550 nm (Ex)

→ Emission = 270 – 550 nm (Em)

→ Scan control = Medium or Fast (enough to have good signals without noise)

→ START (do not forget to give a name to the sample)





2/ Major elements present in the water sample

The analysis is made by an external provider but the sample preparation is realized in Edytem laboratory.

Equipments used:

1 Polyethylene tube	1 Syringe	1 Filter and its support
		  

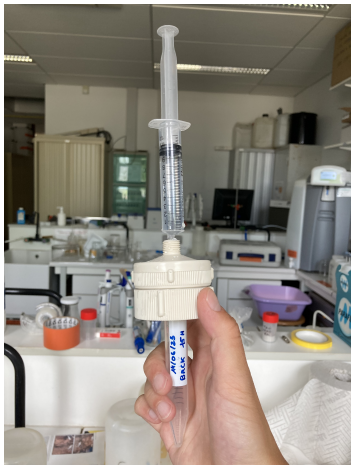
1) ***Clean*** and ***rinse*** twice the polyethylene tube with distilled water

2) Take the syringe and ***rinse*** it twice with distilled water

3) Take the filter support and ***rinse*** it with distilled water

4) Put a new filter in it. ***Rinse*** the support with the filter using the syringe with distilled water

5) From the water sample collected at AdM (125 ml), **collect 10 ml** the water sampled with the cleaned syringe and **put it in the polyethylene tube**.



6) **Write the same reference as the bottle** (Location + Date + Hour)

7) Insert in the polyethylene tube **1% of the water volume** (in our case it represents 0,1 ml) **of nitric acid (HNO3)** under the chemical hood (with lab coat + gloves + glasses)



8) Your sample for major elements is now ready and can stay in the fridge :)

9) Write in the follow-up spreadsheet (Z:/WISPER/MATAN/Antoine/Terrain - Monitoring/Work field follow-up_CHABAS.odt → Sheet "SAMPLES" in red) that is done for the sample

3/ Stable isotope

The analysis is made by an external provider but the sample preparation is realized in Edytem laboratory.

Equipments used:

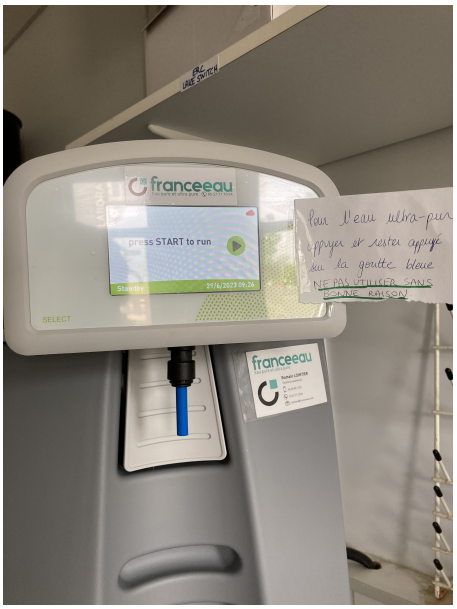
1 glass bottle of 20 ml	1 Syringe	1 Filter and its support
		

1) ***Clean*** and ***rinse*** once the glass bottle with distilled water



2) ***Clean*** and ***rinse*** a second time with double distilled water (top faucet with blue electric button (tactil screen)).

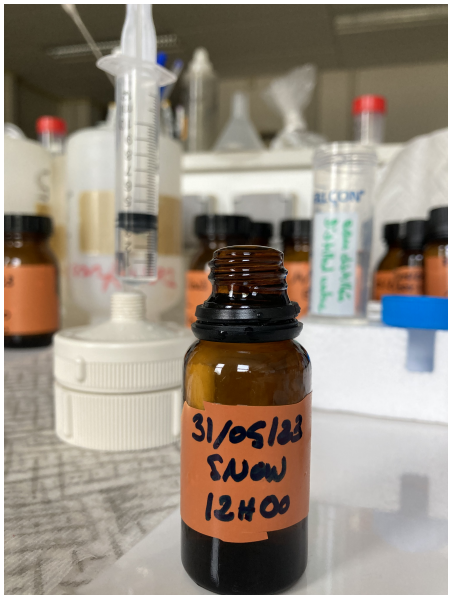


3) Take the syringe and ***rinse*** it twice with distilled water

4) Take the filter support and ***rinse*** it with distilled water

5) Put a new filter in it. ***Rinse*** the support with the filter using the syringe with distilled water

6) From the water sample collected at AdM (125 ml), **fill the 20 ml glass bottle entirely and take care that any air stays in it!**



7) **Write the same reference as the bottle** (Location + Date + Hour)

8) Your sample for stable isotopes is now ready and can stay in the fridge :)

Appendix 2: List of samples collected

Copy / Paste from worksheet for B to F		General information				Conductivity	Fluorescence	Chemical analysis preparation		FULL ANALYSIS DONE ?
#	ID Samples	Date	Time	Localisation	Bottle size	Instantanous Conductivity MicroS/cm	Fluorescence in lab.	Major elements *10ml Polyethylene tube*	Stable isotopes *only for 20ml bottle*	YES / NO
1	2023510_AdM_Box1_1	10/05/23	10:30:00	Box1	125 ml	NA	OK	OK	OK	YES
2	2023510_AdM_ELV_2	10/05/23	15:30:00	ELV	125 ml	NA	OK	OK	OK	YES
3	2023531_AdM_Box1_1	31/05/23	15:30:00	LOG	125 ml	27,3	OK	OK	OK	YES
4	2023531_AdM_Snow_2	31/05/23	12:00:00	Snow	125 ml	NA	OK	OK	OK	YES
5	202368_AdM_TNL_1	08/06/23	14:00:00	TNL	125 ml	163	NOK	OK	OK	YES
6	202368_AdM_Box2_2	08/06/23	15:00:00	Box2	125 ml	NA	OK	NOK	NOK	NO
7	2023614_AdM_Box1_1	14/06/23	11:40:00	Box1	125 ml	79,3	OK	OK	OK	YES
8	2023614_AdM_TNL_2	14/06/23	14:20:00	TNL	125 ml	221	OK	OK	OK	YES
9	2023614_AdM_Box1_3	14/06/23	15:00:00	LOG	125 ml	61	OK	OK	OK	YES
10	2023614_AdM_BRCK_4	14/06/23	15:00:00	BRCK	125 ml	182,5	OK	OK	OK	YES
11	2023627_AdM_Box1_1	27/06/23	08:45:00	Box1	125 ml	44,5	OK	OK	OK	YES
12	2023627_AdM_BUCKET_2	27/06/23	08:45:00	BUCKET_BOX1	125 ml	36	OK	OK	OK	YES
13	2023627_AdM_ELV_3	27/06/23	09:43:00	ELV	125 ml	273	OK	OK	OK	YES
14	2023627_AdM_ELV_4	27/06/23	13:10:00	ELV	125 ml	272	OK	OK	OK	YES
15	2023627_AdM_Box1_5	27/06/23	13:20:00	Box1	125 ml	49,5	OK	OK	OK	YES
16	2023627_AdM_LOG_6	27/06/23	15:45:00	LOG	125 ml	43	OK	OK	OK	YES
17	2023627_AdM_Box1_7	27/06/23	16:10:00	Box1	125 ml	42	OK	OK	OK	YES
18	202375_AdM_Box1_1	05/07/23	09:15:00	Box1	125 ml	38,6	OK	NOK	NOK	NO
19	202375_AdM_BUCKET_2	05/07/23	09:20:00	BUCKET_BOX1	125 ml	28	OK	NOK	NOK	NO
20	202375_AdM_TNL_3	05/07/23	12:45:00	TNL	125 ml	114,6	OK	PRIORITY 1	PRIORITY 1	NO
21	202375_AdM_BOX1_4	05/07/23	12:50:00	Box1	125 ml	43	OK	NOK	NOK	NO
22	202376_AdM_Box1_1	06/07/23	14:00:00	Box1	125 ml	NA	OK	NOK	NOK	NO
23	2023713_AdM_Box1_2	13/07/23	10:20:00	Box1	125 ml	46	OK	NOK	NOK	NO
24	2023713_AdM_BUCKET_BOX1_3	13/07/23	10:25:00	BUCKET_BOX1	125 ml	41,4	OK	NOK	NOK	NO
25	2023713_AdM_BUCKET_BOX2_4	13/07/23	10:30:00	BUCKET_BOX2	125 ml	59	OK	NOK	NOK	NO
26	2023713_AdM_TNL_5	13/07/23	11:00:00	TNL	125 ml	84	OK	NOK	NOK	NO
27	2023713_AdM_Box1_6	13/07/23	14:30:00	Box1	125 ml	38,2	OK	NOK	NOK	NO
28	2023713_AdM_PMB_7	13/07/23	14:50:00	PMB	125 ml	108,6	OK	PRIORITY 1	PRIORITY 1	NO
29	2023713_AdM_TNL_8	13/07/23	15:00:00	TNL	125 ml	91,6	OK	NOK	NOK	NO
30	2023713_AdM_Box1_9	13/07/23	15:05:00	Box1	125 ml	35,8	OK	NOK	NOK	NO
31	2023714_AdM_Box1_1	14/07/23	13:24:00	Box1	125 ml	61	OK	NOK	NOK	NO
32	2023720_AdM_Box1_2	20/07/23	11:00:00	Box1	125 ml	76	OK	NOK	NOK	NO
33	2023720_AdM_BUCKET_Box1_3	20/07/23	11:05:00	BUCKET_Box1	125 ml	75	OK	NOK	NOK	NO
34	2023720_AdM_BUCKET_Box2_4	20/07/23	11:10:00	BUCKET_Box2	125 ml	68	OK	NOK	NOK	NO
35	2023720_AdM_TNL_5	20/07/23	12:50:00	TNL	125 ml	99	OK	NOK	NOK	NO
36	2023720_AdM_TNL_6	20/07/23	14:00:00	TNL	125 ml	370	OK	PRIORITY 1	PRIORITY 1	NO
37	2023720_AdM_Box1_7	20/07/23	15:00:00	Box1	125 ml	80,5	OK	NOK	NOK	NO
38	2023726_AdM_Box1_1	26/07/23	11:20:00	Box1	125 ml	97	NOK	NOK	NOK	NO
39	2023726_AdM_TNL_2	26/07/23	14:55:00	TNL	125 ml	485	NOK	NOK	NOK	NO
40	2023726_AdM_Snow_3	26/07/23	14:00:00	Snow	125 ml	9,2	NOK	NOK	NOK	NO
41	202384_AdM_Box1_1	04/08/23	10:20:00	Box1	125 ml	119	NOK	NOK	NOK	NO
42	202384_AdM_BUCKET_Box2_2	04/08/23	10:20:00	BUCKET_Box2	125 ml	64,2	NOK	NOK	NOK	NO
43	202384_AdM_TNL_3	04/08/23	12:30:00	TNL	125 ml	390	NOK	PRIORITY 1	PRIORITY 1	NO
44	2023810_AdM_Box1_1	10/08/23	10:30:00	Box1	125 ml	105,5	NOK	NOK	NOK	NO
45	2023810_AdM_BUCKET_Box2_2	10/08/23	10:30:00	BUCKET_Box2	125 ml	80,8	NOK	NOK	NOK	NO
46	2023810_AdM_TNL_3	10/08/23	13:15:00	TNL	125 ml	321	NOK	NOK	NOK	NO
47	2023822_AdM_Box1_1	22/08/23	10:20:00	Box1	125 ml	89	NOK	NOK	NOK	NO
48	2023822_AdM_Box2_2	22/08/23	10:25:00	Box2	125 ml	82,8	NOK	NOK	NOK	NO
49	2023822_AdM_TNL_3	22/08/23	15:00:00	TNL	125 ml	264	NOK	NOK	NOK	NO
50	2023822_AdM_ELV_4	22/08/23	15:15:00	ELV	125 ml	358	NOK	NOK	NOK	NO

Appendix 3: Field reports

Field work report: Aiguille du Midi, 22/03/2023

Participants: Antoine Chabas, Josué Bock, Matan Ben-Asher, Simon Filhol
Weather: perfect: sunny, no wind
Timing:

- left EDYTEM around 6:10, arrived in Chamonix 7:42
- left AdM at 16:20 (last cable car with tourists)
- back at EDYTEM shortly before 19:00

Fieldwork was scheduled for Thursday the 23rd but was rescheduled to a day earlier and the preparation was made in a haste.

1 Water sampling device

1.1 Camera N face

(report by Matan)
I placed a wider lens (35 mm) instead of the one installed (85 mm), to have a larger coverage of the slope with the dye tracers. When I arrived, the camera box was loose. I added another screw to reinforce the mounting of the box. The key to the camera box is with the key that opens the boxes of the fluo system. The image now covers the main part of the slope with the two snowpacks with the dye tracers. It would be better to have an even wider view.



Figure 1: Matan checking the camera N face after changing the lens. *(pictures by Antoine).*

1.2 Fluorescence dye preparation

(report by Matan)
Me and Antoine bought four 4 L and six 1.5 L bottles of 'Condine' mineral water that we used to prepare the tracers. We inserted the dye powder directly into the bottles with the original mineral water. In each 4 L bottle, we inserted 50 g of amino-acid-G that dissolved almost completely. A total of 200 g. In each 1.5 L bottle we inserted 1 g of fluorescein. A total of 6 g. A sample on the 'condine' mineral water was taken.



Figure 2: Dye preparation. (left) 4 L bottles with amino-acid-G. (center) 1.5 L bottles with fluorescein. (right) mineral water used.

1.3 Fluorescence dye insertion

(report by Matan)
Me and Marc (journalist), abseiled down the north face to insert the dye traces in the same locations as last year.

All six 1.5 L bottles with fluorescein were emptied on the upper snowpack. Each bottle was emptied in 3-4 points to avoid spreading on the surface of the snow because the fluorescein is very visible (bright green/yellow).

All four 4 L bottles with amino G were emptied in a similar method to the fluorescein but with more spreading on the surface because it is colorless. The amino G solution actually turned pink after several minutes on the snow.

1.4 Logger and sensors check

(report by Antoine)

Recorded data:
Data from hydrologic monitoring system (Box1) has been charged on computer - Matan

Comments:
NA

To do next / actions:

Who	What	When
Antoine	Set up a protocole note about the hydrologic system	
Antoine	Install the water cone collector	Next visit



Figure 3: Places where the dyes were sprayed. Marc abseils down while Simon is checking no tourist is coming from the gallery.



Figure 4: A few pictures of the water monitoring system *(pictures by Antoine)*.



Figure 5: A few more pictures of the water monitoring system *(pictures by Antoine)*.

2 ERT device

(report by Josué)

2.1 work done

- add nylon screw ES10-64 (check contact with voltmeter: no contact between ES10-64 and box, see Fig. 6)
- add a 60W light bulb for heating in the box
- replace USB stick, the previous one is no longer working (tested with laptop: not recognized and become burning hot after a few minutes)
- bring back socket timer, returned to Castorama for reimbursement (Fig. 8)
- pour salty water S face, lower half: e#18 to e#32 (except e#22 under ice)
- upgrade to software 2.6.2, run measurements. The "ES10-64 not ready" error occurs several times. Downgrade to 2.5.2b
- pour salty water on S face, upper half: e#1 under ice, e#2 to e#9, e#12, e#14 - e#15 (see Fig. 7).

Pictures of some electrodes are available on the NAS:
`WISPER/field_work/2023-03-22_AdM/pictures_Josue`

2.2 open questions

- e#22 under ice related to:
  - high/low contact resistance?
  - stable contact resistance?
  - negative resistivities?
  - low/high resistivities?
  - IP?

3 Dismantle S face camera

(report by Josué)
After fieldwork 3 March 2023, we discovered that no pictures had been taken since mid September 2022. We decided to dismantle the camera.
Matan belayed me to get to the top of the S piton, Simon helped while I was going down. Detailed information in case similar system would be reinstalled in the future:

- dismantle the solar panel (2 bolts – nuts and washers left on the bolts). All rilsan / nylon parts removed from the rock.
- dismantle only the camera box from the black steel bar, which was left on the rock (4 nuts, the threaded rod was damaged, which made it quite tricky to dismantle).

4 Ideas

- Set up a better weather station – Simon
- LIDAR system use? - Simon
- Pollution impact on permafrost degradation?
- Acoustic monitoring of the hydrology ? Just a proposition and idea → GAAP (Glace arctique et Acoustique Passive) project from ANR program in Arctic
  - Possible issue: interference with all Aiguille du Midi structure and external noises with machines and people but maybe it is possible to filter the frequencies?



Figure 6: Check the absence of electrical contact between the ES10-64 switch and the box. Left: perfect contact between 2 screws of the ES10-64. Right: no contact between one screw and the box *(pictures by Antoine)*.



Figure 7: Josué pouring salty water onto electrode #3 (from top) South face *(picture by Antoine)*.



castorama

Chambéry
73000 Chambéry
04 79 68 55 55

QTE	DESCRIPTION	PRIX	MONTANT	T
-1	PRISE PROGRAMMABLE DIGITALE			
	5059340051697		-12,90	V5

NOMBRE D'ARTICLES: 1

TOTAL -12,90 €
Carte Bancaire 12,90 €

CARTE BANCAIRE
a0000000422010
CB
LE 23-03-23 A 12-09-02
CASTORAMA
73000
CHAMBERY
30002
2902617
45167897300905
XXXXXXXXXXXX9555
918 001 918006 002448
C
MONTANT
12.90 EUR
CREDIT
TICKET CLIENT
A CONSERVER
-

DETAIL TVA

V5 TVA 20,00%	-2,15	-10,75 HT

RT1469146936230323001661

23/03/2023 12:09 1469 036 0016

Conformément au code de la consommation, tous nos produits bénéficient d'une garantie légale de conformité d'une durée minimale de 2 ans à compter de leur délivrance.

"Simplifiez-vous la vie"
Echange ou remboursement avec la carte Castorama:
plus delai, plus de ticket
Les tuyaux et accessoires gaz ouverts ne seront ni repris, ni échangés

Figure 8: reimbursement of the socket timer

GENERAL INFORMATION			General comments
Date:	**14/04/23**		- The 2 Box are frozen. We try to unfreeze the Box to empty the bucket at least and put another bottle (the one from last time has broken and stuck in the ice). Except the collector from above (full of unfrozen water), everything was frozen in Box1. Impossible to open Box2. - We took the data. Still some issue with fluorimeter in March : a long stop between the 14/03 to the 20/03 and several small ones. Since one week, it seems to be quite stable. - Alimentation wire of the datalogger has been reconnected (seems not so well fixed) - Tr(1) has been detected today at 8:20am
Weather:	**Sunny until 3pm. Cold : -24°C at 9am. Little bit of wind**		
Timing:	Departure:	**06:00:00**	
	Return:	**18:45:00**	
Participants:	**Antoine Chabas**		
	Josué Bock		
	/		
	/		
	/		

**Complete all cells in yellow*

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?
Vérifier fluorimètre (câble blanc à retirer et remettre exactement au même emplacement)	OK
Visser et dévisser les cosses	OK
Changer le programme (retarder les délais d'enregistrement) du fluorimètre – voir avec Manu	NOK
Changer batterie	OK
Voir pour récupérer de l'eau si premier écoulement	NOK
Mesurer conductivité directe	NOK
Mettre les collecteur conique sur le plafond (attente de l'impression 3D de Manu)	NOK

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1 and 2 frozen.
BOX1:
Bucket of box1 full and frozen with broken bottle in it.
Top of water collector full of liquid water
We left the bucket in a warm room to be able to empty the ice block.
Antoine put another bottle under the rain gauge.

BOX2:
Box2 could not be opened because of the ice. The right side of the door (hinge side) was fully covered with a column of ice (~ 3 − −4 cm thick). Impossible to open the door.

The roof full of snow.

Pictures:







Box 1



Box 2



The roof



2. Logger and sensor check

Comments:

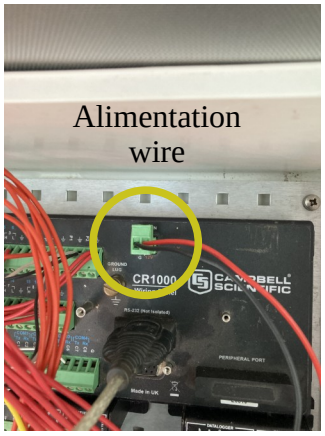
We downloaded the data from the logger. It seems that the fluo sensor had only a few fail (NaN values) during the last 2 weeks.
Biggest cut of the recording : between the 14/03/2022 to 20/03/2022

Antoine cleaned the syphon (it was clean, no deposits).

The fluorometer detected tracer #1 this morning at 8:20 (CEST), thus shortly before we arrived. Surprising.
Antoine checked that the logger time was properly synchronised with his computer time.

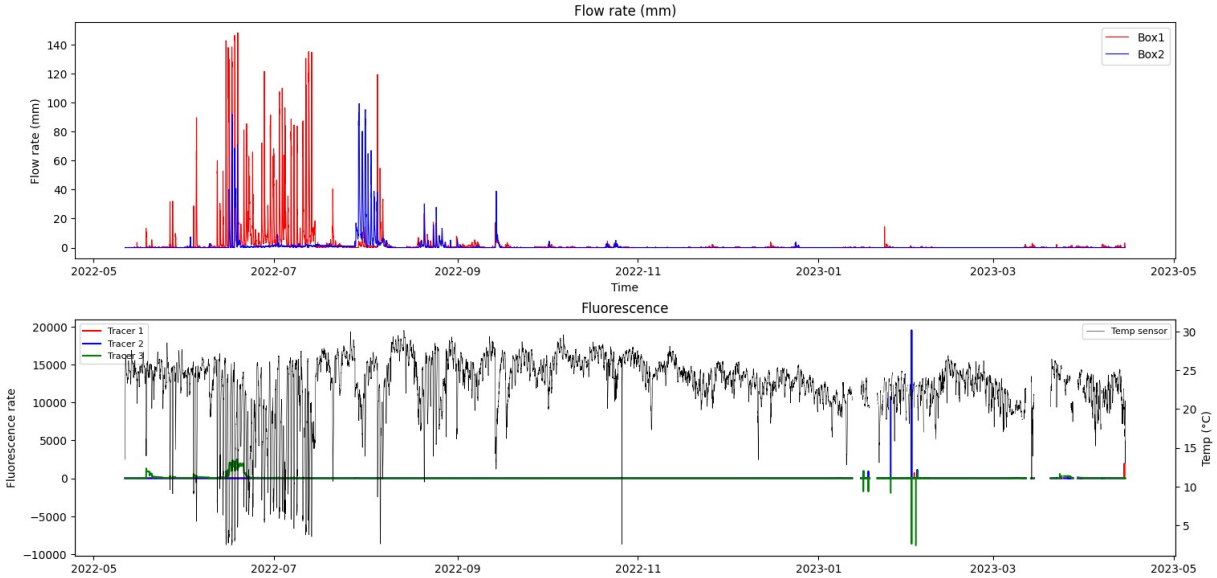
Monitoring data (live data) did not show any issue (no NaN) when checking at AdM.

Pictures:





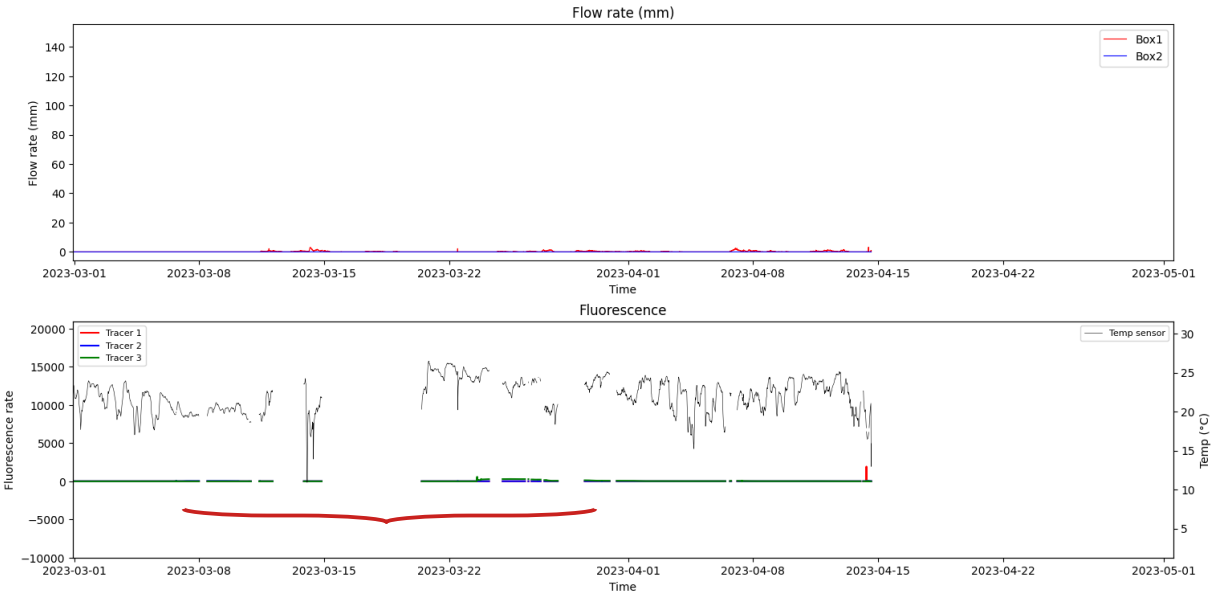
Global data recordings 2022-2023



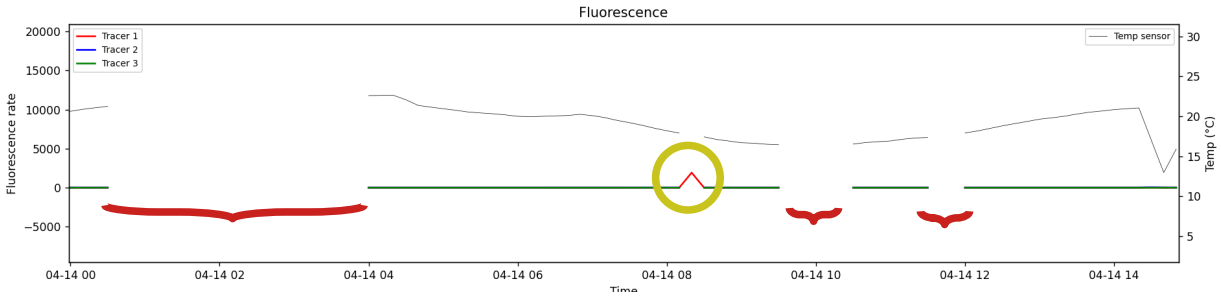
2023-04-14_AdM

Time

Recording of March and April 2023 (several cut-off)



The 14/04/2023



Tracer 1 at 8:20

Some cut-off in the recording during wthe day even after the alimentation wire reconnected correctly...

Water collect and measures

Comments:

Box1 frozen and bottle is broken.
Impossible to open the bottle 2.

NO COLLECT AND NO MEASURES.

	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Size	Instantanou Conductivit	Check
1	2023414_AdM__1	14/04/23					NOK
2	2023414_AdM__2	14/04/23					NOK
3	2023414_AdM__3	14/04/23					NOK
4	2023414_AdM__4	14/04/23					NOK
5	2023414_AdM__5	14/04/23					NOK
6	2023414_AdM__6	14/04/23					NOK
7	2023414_AdM__7	14/04/23					NOK
8	2023414_AdM__8	14/04/23					NOK
9	2023414_AdM__9	14/04/23					NOK
10	2023414_AdM__10	14/04/23					NOK
11	2023414_AdM__11	14/04/23					NOK
12	2023414_AdM__12	14/04/23					NOK

Actions check list (cf. Protocol note)	Box 1	Box 2
> Step 1: Open the Box 1 with the key		
> Step 2: Collect the water sample bottle (125 ml)		
Reference it such as : BOX1 + Date of the day + Time		
Measure the conductivity		
> Step 3: Collect the water sample bottles (20 ml) in the bucket		
Reference it such as : BOX1 + Date of the day + Time		
> Step 4: Collect any water dropping in the galleries with the small bottle		
> Step 5: Check the devices + Take the bucket and collect the sediments + Empty the bucket		
> Step 6: Check the fluorescence device and siphon		
> Step 7: Transfer the data from the logger		
fluorescence.dat conductivity-temp.dat Tension.dat		

GENERAL INFORMATION			General comments
Date:	**27/04/23**		Things done : - Solar panel camera North face cleaned from snow accumulated - Box 1 cleaned (initial glass bottle broken) but nothing frozen in it - Box 2 still frozen - Fluorimeter issue : Not working ! Battery changed, test in 12V continue alimentation (nothing changed), test in program changing (nothing changed)... Not fluo data recorded since 19/04... - Re-installation of the TerraMeter in south terrasse
Weather:	**Quite sunny all the time (spring weather); no wind. Temperature quite good (around 0°C)**		
Timing:	Departure:	**06:00:00**	
	Return:	**17:30:00**	
Participants:	**Antoine Chabas**		
	/		
	/		
	/		
	/		

**Complete all cells in yellow*

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?
1. Collecter les données du DataLogger et changer batterie	OK
2. Tester solution pour fluometer	OK
Test 1 Fluo : Mettre en alimentation 12V continu et checker au bout de 2h – Voir plus tard si batterie okay	OK
Test 2 si Test 1 ne fonctionne pas : Changer de programme avec temps de mesure et enregistrmeent = 10 min	OK
3. Remettre en place le TerraMeter	OK
Voir pour récupérer de l'eau si premier écoulement	NOK
Mesurer conductivité directe	NOK
Mettre les collecteur conique sur le plafond (attente de l'impression 3D de Manu)	NOK

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1 : Not frozen, bottle broken. Little sediments in the syphon.

Box 2 still frozen

Little bit a sediments in the siphon

Still some snow on the roof

Pictures:



Box 1





Sihpon cleaning



The roof

2. Logger and sensor check

Comments:

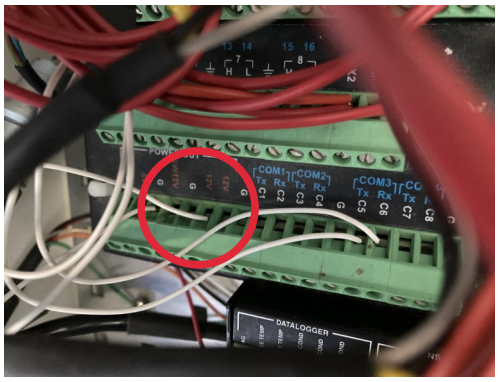
Fluo sensor issue :
- No record between 15/04 and 17/04 and from 19/04 to 27/04 (today) !!!
So 2 big cuts since last time (14/04/2023)

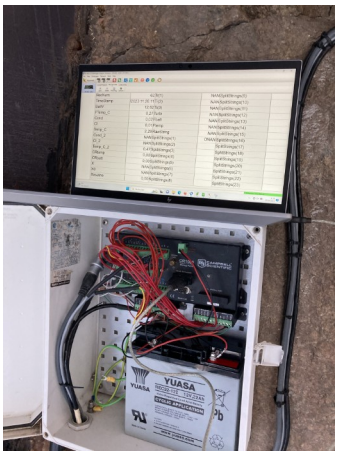
Several data collected during the day to see if anything change with some testing solution (seen with Manu)
- Data at 9:00 for initial data since 14/04
- Data at 11:30 after test 1 (alimentation in 12V not SWIFT) ==> **nothing changed**
- Data at 13:00 after test 2 (change the datalogger program with 10 min steps in recording et measurment) ==>
Nothing changed but all previous data has been deleted of future data file .dat

Initial program has been put before leaving AdM

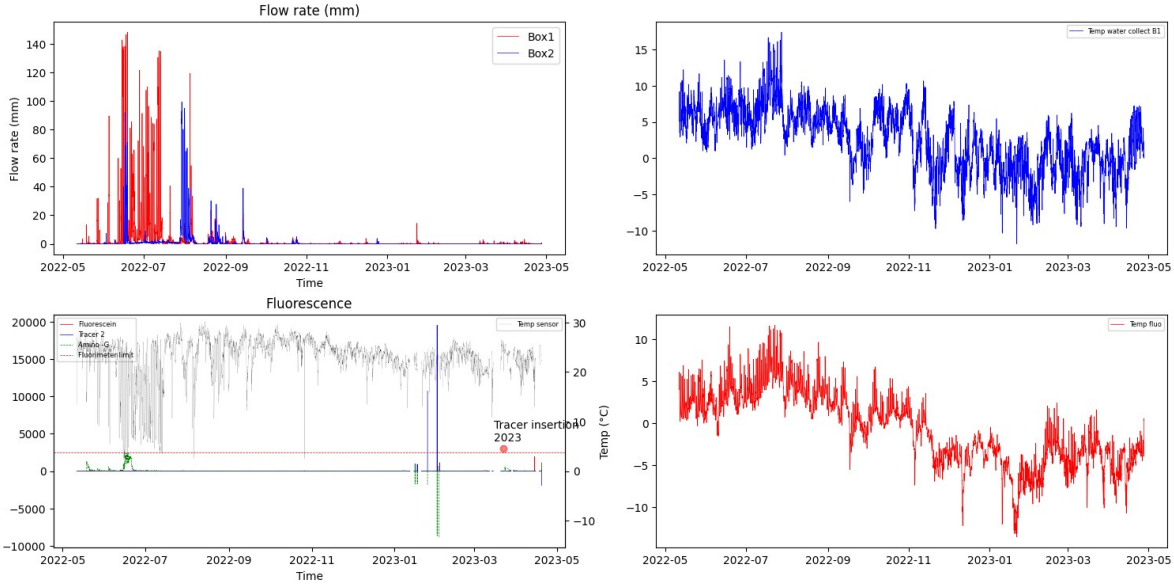
Pictures:



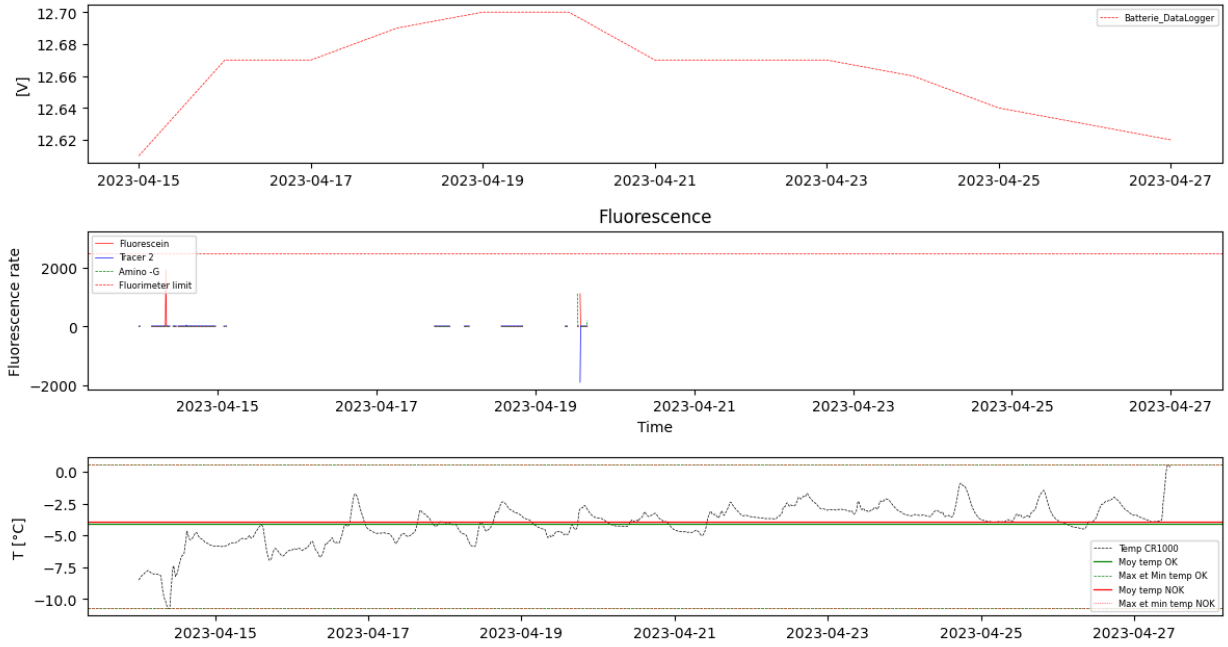




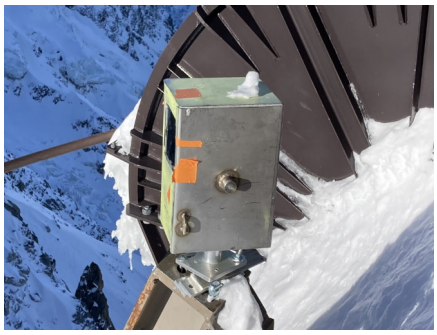
Global data recordings 2022-2023



Recording of fluo device (with Battery and CR1000 information)
14/04/2023 --> 27/04/2023



3. Camera on North Face





14/04/2023



27/04/2023



8:30



9:00 after pushing the snow with the fishsticks :P



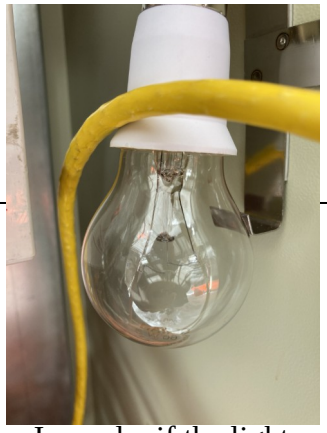
15:00

4. TerraMeter installation





Installation went well and Josué could connect from the lab



I wonder if the light filament is broken ? (see nothing on the picture..)

Water collect and measures

Comments:

Box1 bottle was broken.
Impossible to open the bottle 2.

NO COLLECT AND NO MEASURES.

	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Size	Instantanou Conductivit	Check
1	2023427_AdM__1	27/04/23					NOK
2	2023427_AdM__2	27/04/23					NOK
3	2023427_AdM__3	27/04/23					NOK
4	2023427_AdM__4	27/04/23					NOK
5	2023427_AdM__5	27/04/23					NOK
6	2023427_AdM__6	27/04/23					NOK
7	2023427_AdM__7	27/04/23					NOK
8	2023427_AdM__8	27/04/23					NOK
9	2023427_AdM__9	27/04/23					NOK
10	2023427_AdM__10	27/04/23					NOK
11	2023427_AdM__11	27/04/23					NOK
12	2023427_AdM__12	27/04/23					NOK

Actions check list (cf. Protocol note)	Box 1	Box 2
> Step 1: Open the Box 1 with the key		
> Step 2: Collect the water sample bottle (125 ml)		
Reference it such as : BOX1 + Date of the day + Time		
Measure the conductivity		
> Step 3: Collect the water sample bottles (20 ml) in the bucket		
Reference it such as : BOX1 + Date of the day + Time		
> Step 4: Collect any water dropping in the galleries with the small bottle		
> Step 5: Check the devices + Take the bucket and collect the sediments + Empty the bucket		
> Step 6: Check the fluorescence device and siphon		
> Step 7: Transfer the data from the logger		
fluorescence.dat conductivity-temp.dat Tension.dat		

GENERAL INFORMATION			General comments
Date:	**10/05/23**		Very foggy day except at 15pm with beautiful view on Mt Blanc :)
Weather:	**Foggy**		1st toursit cabin has been delayed at 10 am because of snowfall (40 cm). Temperature still cold in the morning but sweeter in the afternoon. First runoff around 15pm near to the elevator.
Timing:	Departure:	**08:00:00**	- Box 1 : First bottle collected !
	Return:	**18:30:00**	- Box 2 : Still really frozen. A real ice cube. I try to heat the box with a thermal cleaner. It helps a little bit but still really icy.
Participants:	**Antoine Chabas**		Ibuttons data collected expect for the #5 and #6
	/		Conductivity support with the cone has been installed
	/		**Fluorimeter still doesn't work !**
	/		SD card changed in the TerraMeter
	/		

**Complete all cells in yellow*

Pictures link : Z:\WISPER\MATAN\Antoine\Terrain – Monitoring\20230510_ADM\Photos

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?
1. Collecter les données du DataLogger	OK
2. Tester solution pour fluometer	OK
3. Mettre carte SD dans TerraMeter	OK
4. Collecter donner données iButtons	OK
Voir pour récupérer de l'eau si premier écoulement	OK
Mesurer conductivité directe	NOK
Mettre les collecteur conique sur le plafond	OK

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1 : First bottle collected at 10.30 am. Little bit of sediments in the siphon.
The conductivity support 1 with the bigger cone has been installed on the roof.

Box 2 still frozen. I tried to heat the box with a heat cleaner but it to much frozen.

Still some snow on the roof. I also observed how some snow is entering in the gallery as powder from fractures near to the bench of the collector.

Pictures:



Box 1



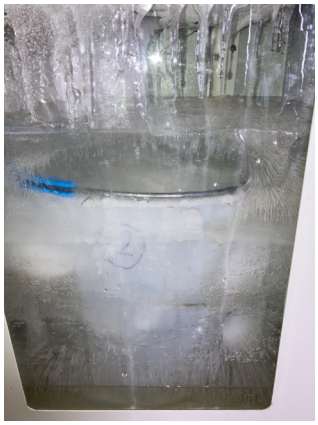




Conductivity support and cone collector







Box 2

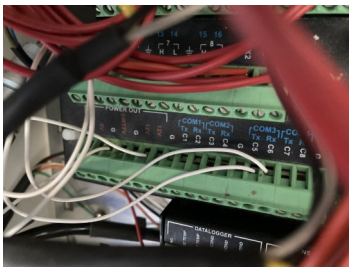
2. Logger and sensor check

Comments:

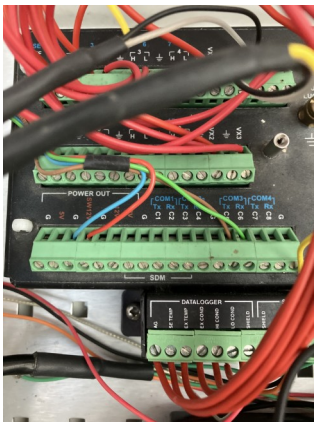
Fluorimeter still dead.
I changed the wires connection for fluorimeter but does not work. Nevertheless, we can observe a signal during 30 minutes just after the manipulation and then, nothing again.

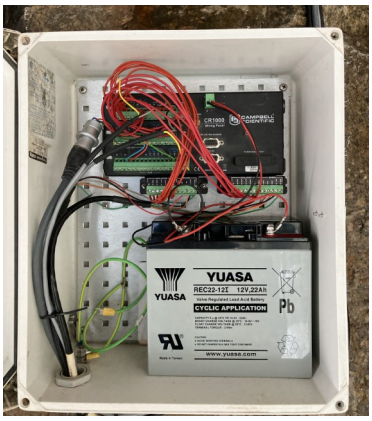
Ibuttons data collected except 5 and 6 -->

Pictures:



Before

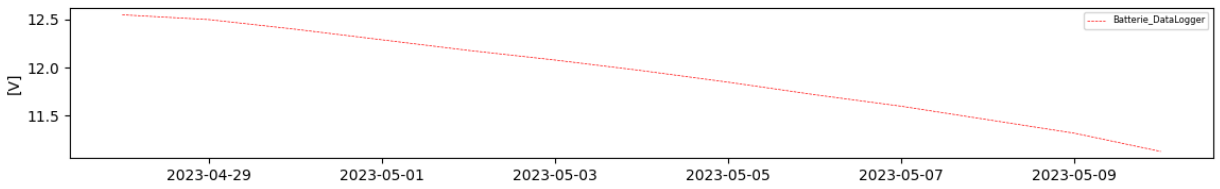


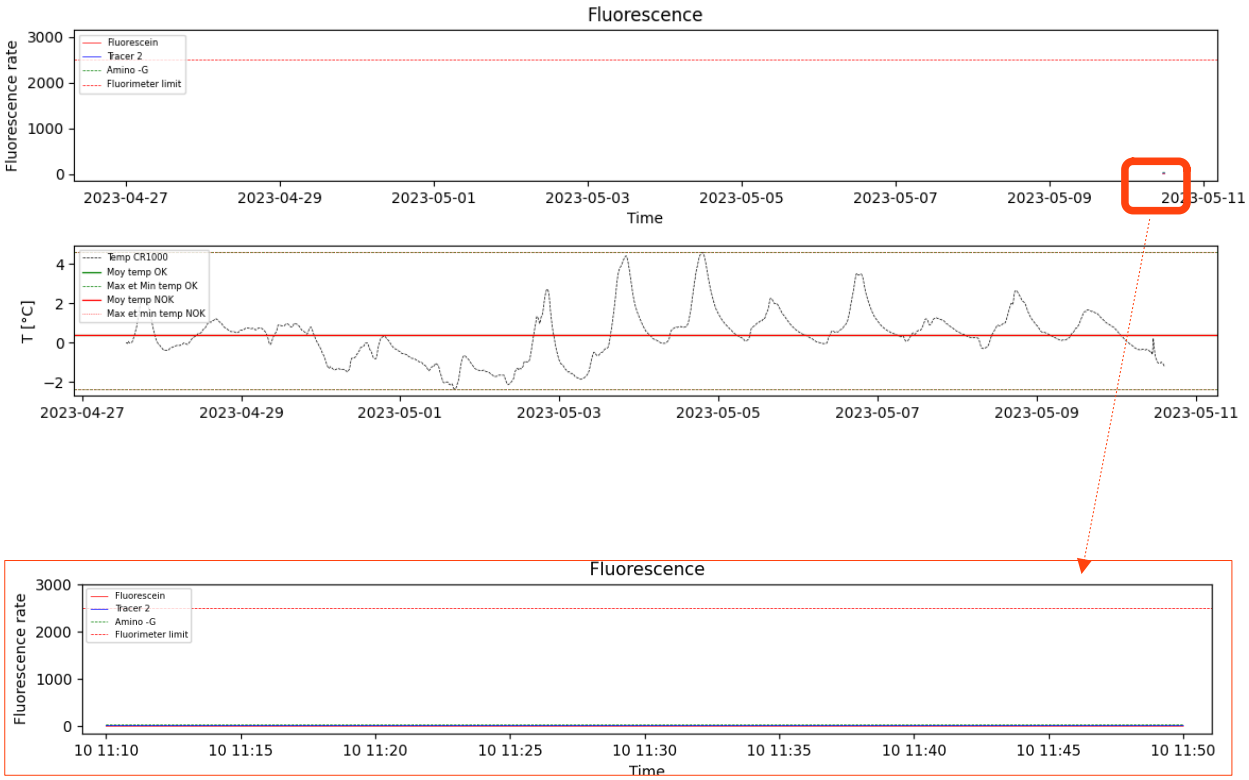


After

Recording of fluo device (with Battery and CR1000 information)

27/04/2023 --> 10/05/2023





3. Camera on North Face

Solar panel was under the snow and I did not have the fish stick to clean it.





4. Faces pictures

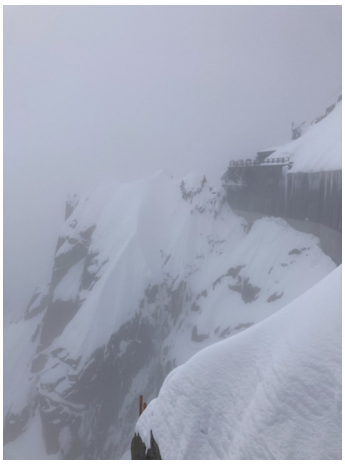
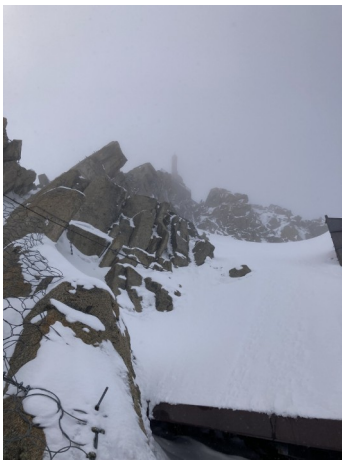
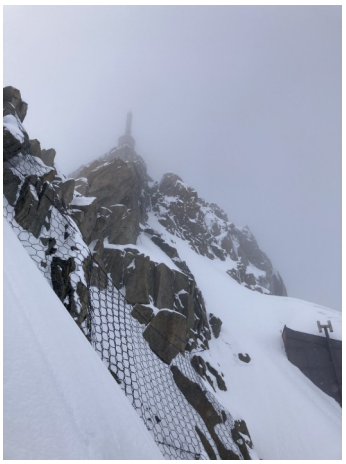


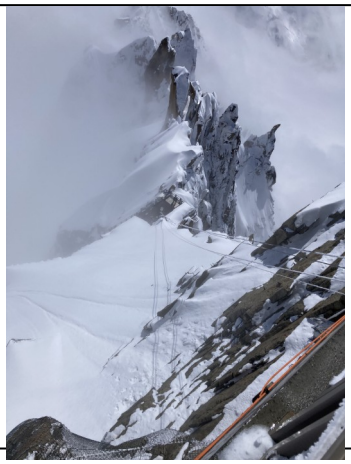











Water collect and measures

Comments:

**First bottle of 2023 collected in the Box1
At 10:30 :-)**

A second one from runoff in the gallery just after the elevator near to iButtons 8 and 9.



Box1 / E
BRCK / ELV / other

	ID Samples	Date	Time	Localisation	Bottle Size	Conductivit	Check
1	2023510_AdM_Box1	10/05/23	10:30:00	Box1	125 ml		NOK
2	2023510_AdM_ELV_	10/05/23	15:30:00	ELV	125 ml		NOK
3	2023510_AdM__3	10/05/23					NOK
4	2023510_AdM__4	10/05/23					NOK
5	2023510_AdM__5	10/05/23					NOK
6	2023510_AdM__6	10/05/23					NOK
7	2023510_AdM__7	10/05/23					NOK
8	2023510_AdM__8	10/05/23					NOK
9	2023510_AdM__9	10/05/23					NOK
10	2023510_AdM__10	10/05/23					NOK
11	2023510_AdM__11	10/05/23					NOK
12	2023510_AdM__12	10/05/23					NOK

THE VIEW OF THE DAY :)



GENERAL INFORMATION			General comments
Date:	**22/05/23**		
Weather:	**Good weather : sunny in the morning, cloudy and a bit snowy in the afternoon. Good temperature in South face but in the gallery still <0°C**		Good weather but still winter conditions on North Face at ADM. ==> No water runoff !
Timing:	Departure:	**06:00:00**	General checking of water collecting system23/05/23. Box 1 had no water inside. Box 2 has been unfrozen with ice pick
	Return:	**16:00:00**	
Participants:	**Antoine Chabas**		Fluorimeter has been removed and bring back to the lab. Still did not work.
	Matan Ben-Asher		Battery has no more tension since 18/05 so no data between 18/05 and 22/05. Battery has been changed
	/		
	/		Check of North face camera. All was ok.
	/		

**Complete all cells in yellow*

Pictures link : Z:\WISPER\MATAN\Antoine\Terrain – Monitoring\20230522_ADM\Photos

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?
Change the fluorimeter	
Matan has to contact Amael for fluorimeter to have it asap	

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1 : No water collected

Box 2 still frozen. Marc (the journalist) was here and let us use one of these ice pick to remove the ice. All the box has been cleaned and is ready for futur runoff.

Pictures:





Box 1



Box 2

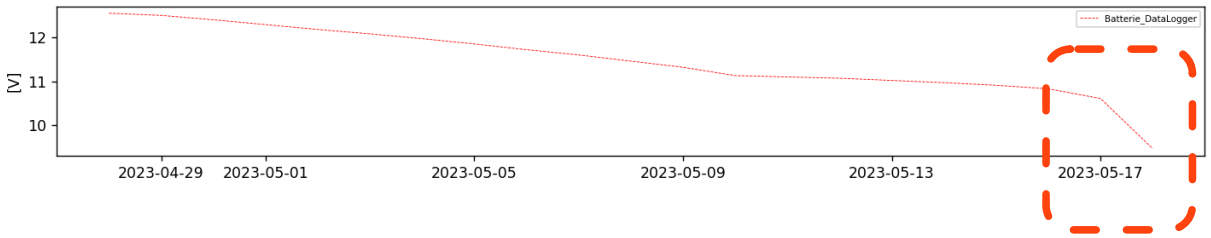
2. Logger and sensor check

Comments:

No more battery when we arrived. So no data has been recorded between the 18/05 and the 22/05.
The battery has been changed.

Battery data (Tension.dat)

27/04/2023 --> 18/05/2023 then stop



3. Camera on North Face



4. Others





Water collect and measures

Comments:

No sample collected

	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Size	Conductivi	Check
1	2023522_AdM__1	22/05/23					NOK
2	2023522_AdM__2	22/05/23					NOK
3	2023522_AdM__3	22/05/23					NOK
4	2023522_AdM__4	22/05/23					NOK
5	2023522_AdM__5	22/05/23					NOK
6	2023522_AdM__6	22/05/23					NOK
7	2023522_AdM__7	22/05/23					NOK
8	2023522_AdM__8	22/05/23					NOK
9	2023522_AdM__9	22/05/23					NOK
10	2023522_AdM__10	22/05/23					NOK
11	2023522_AdM__11	22/05/23					NOK
12	2023522_AdM__12	22/05/23					NOK

Actions check list (cf. Protocol note)	Box 1
> Step 1: Open the Box 1 with the key	
> Step 2: Collect the water sample bottle (125 ml)	
Reference it such as : BOX1 + Date of the day + Time	
Measure the conductivity	
> Step 3: Collect the water sample bottles (20 ml) in the bucket	
Reference it such as : BOX1 + Date of the day + Time	
> Step 4: Collect any water dropping in the galleries with the small bottle	
> Step 5: Check the devices + Take the bucket and collect the sediments + Empty the bucket	
> Step 6: Check the fluorescence device and siphon	
> Step 7: Transfer the data from the logger	
fluorescence.dat conductivity-temp.dat Tension.dat	

GENERAL INFORMATION			General comments
Date:	**31/05/23**		Things done : - General check of the 2 boxes: nothing abnormal detected (nad) **- Install and Set up the new fluorimeter** - Change the second conductivity support and cone - Collect a little quantity of snow on the Rebuffat terrasse - Collect of dropping water near the Box 1 (half of a bottle) - Bring back cleaned brown glass bottle - Collect data from iButton 5 and 6 **- Talk with employees telling some interesting things such as an increase of wind during winter period since 5 years.**
Weather:	**Completely cloudy on the Aiguille. No view. Air temperature is increasing slowly and it is around 0°C.**		
Timing:	Departure:	**07:50:00**	
	Return:	**18:30:00**	
Participants:	**Antoine Chabas**		
	Line Gervais		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230531_ADM/Photos*

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1 : No water collected

Box 2 : No water collected

Pictures:



10:30



Second conductimeter
Support and cone has been changed

2. Logger and sensor check

Comments:

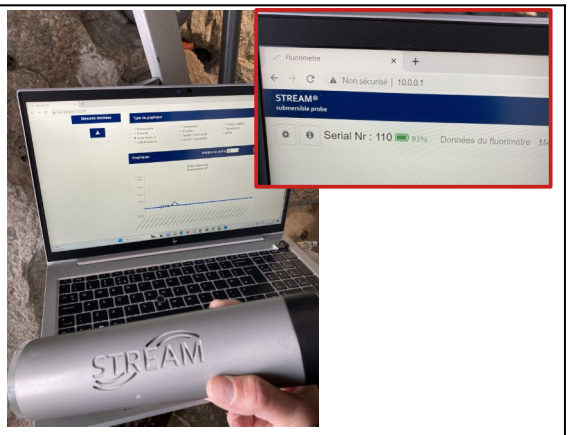
Data from logger : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Traitement donnees/WATER MONITORING/20230531*

Data from iButton 5 and iButton 6: *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Traitement donnees/TEMPERATURE/MAGST/20230531*

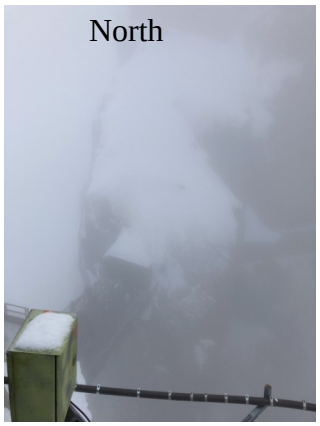
We collected the 2 remaining iButton (number 5 and 6).

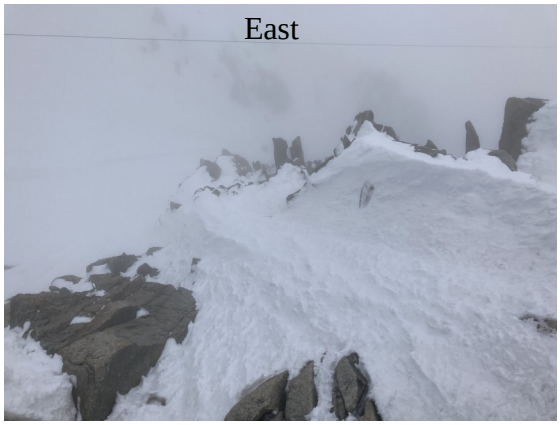
Fluorimeter has finally been changed with the one lent by TRAQUA. Measurement seemed working during the day. Nevertheless, we have to be careful with the battery charge because it could be an issue. At 11h00, we installed it with 96% battery charge and when we checked the measurements at 14:00, the battery was at 89%. Measurement steps is set up on 5 minutes per measurements which normally allow 50h autonomy. Battery was 91% charged when we left.
The data is in the fomder with other logger data (link above).



3. Some pictures of faces for snow cover







Water collect and measures

Comments:

Some water drops were falling from the roof into the galleries (near Box1 et Elevator) from lunch time. But it was a runoff drop by drop every 30 sec – 1 min. We try for 1 hour to collect 1 sample bottle near Box 1 and only the half has been fulled.

One bottle of snow (near Rebuffat terrasse) has been sampled.

	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Size	Instantanous Conductivity	Check
1	2023531_AdM_Box1_1	31/05/23	15:30:00	Box1	125 ml	27,3	NOK
2	2023531_AdM_Snow_2	31/05/23	12:00:00	Snow	125 ml	0	NOK





GENERAL INFORMATION			General comments
Date:	**08/06/23**		Good weather conditions No runoff yet in the galleries except a drop by drop runoff in the tunnel near to the elevator. One bottle of this water has been collected in the afternoon. We tried to change the ABEM because of a WiFi issue but no connection was possible with the other one by Josué from the Lab. Si we let the old one in place at AdM.
Weather:	**Sunny and good temperature**		
Timing:	Departure:	**09:00:00**	
	Return:	**17:30:00**	
Participants:	**Antoine Chabas**		
	Florence Magnin		
	Matan Ben-Asher		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230608_ADM/Photos*

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

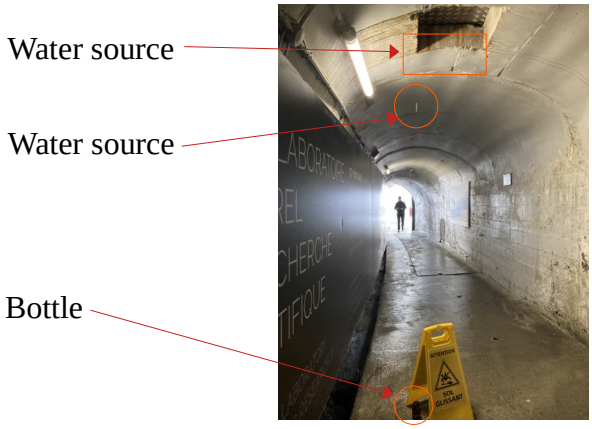
Comments:

Box 1 : No water collected

Box 2 : Half of a bottle collected during the day.

TNL: Some water dropped from a human trap in the tunnel (TNL) near to the elevator (see picture) so we collected one bottle of it. The conductivity is much higher than the water collected the week before near to the Box1.

Pictures:



TNL bottle

2. Logger and sensor check

Comments:

Data from logger : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Traitement donnees/WATER MONITORING/20230608*

Most of the flow signals are due to handling on days when visitors are at the Aiguille du Midi and represent very low values.

Fluorimeter seems working and the battery was good. It still difficult to have a good vision of the battery charge.
At first view, we have data that have been recorded for Fluorescein and Amino G but quite weird data.

- Possible presence of Fluorescein detected by the TRAQUA device the 3rd of June but no Flow Rate the same day recorded...
- The signals for Amino G (in green) represents the differents test realised the 30rd and 31st of May in the lab and during the installation.

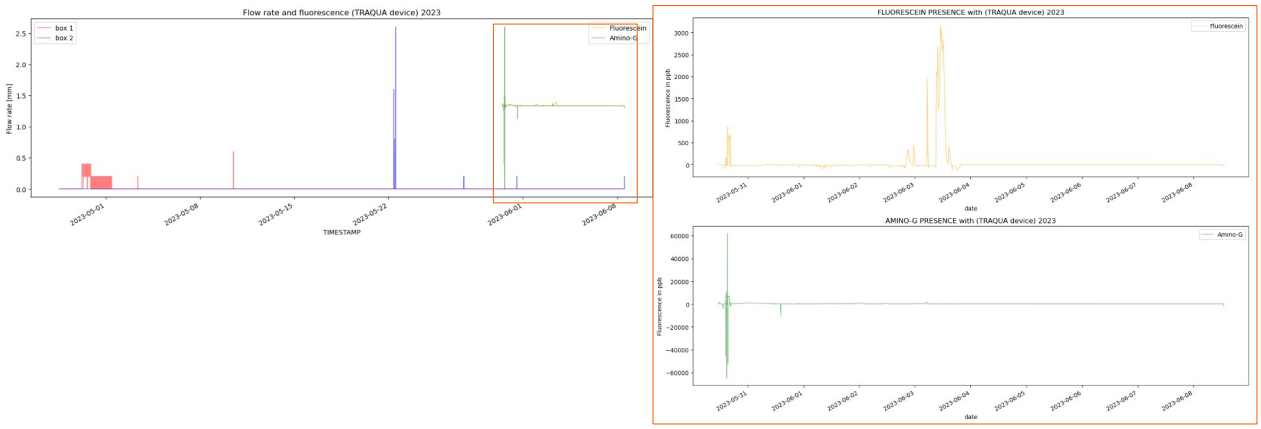
==> Is that normal that there are some negative values ? What represents the values in ppb around +/-60 000 for Amino G and 3000 for Fluorescein.

Other information / question :

- The water samples of Box from 10/05/2023 and 31/05/2023, Amino-G has been detected in the lab during the fluorescence test ! Does that mean that is old Amino-G from 2022 ?

- Is that possible that for the samples from 10/05 collected directly in the Box1, the water came from the snow accumulated on the roof blown by the wind and some of the snow covering the North face wall where the dyes have been inserted the 22/03 have been blown all the way into the gallery on the roof ?

Pictures:

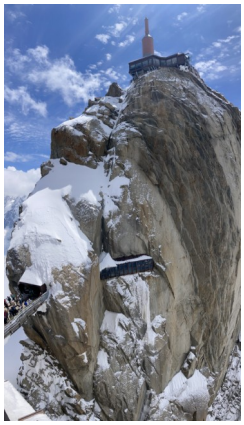


3. Some pictures of faces for snow cover

North



North extended



East



Water collect and measures

Comments:

Collect one full bottle in the tunnel (TNL) near to the elevator.

Collect of half a bottle from Box2 from a small runoff (drop by drop every 30 sec.) These may be the remains of the frozen rain gauge.

	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Size	Instantanous Conductivity	Check
1	202368_AdM_TNL_1	08/06/23	14:00:00	TNL	125 ml	163	NOK
2	202368_AdM_Box2_2	08/06/23	15:00:00	Box2	125 ml	NA	NOK

GENERAL INFORMATION			General comments
Date:	**14/06/23**		It's the start of the flow. There have been daily run-offs for the last 4 days. I received a message from Marc (Ice Melting Project journalist on Sunday) to tell me that the bucket and bottle were full. The logger has been recording run-offs since 10 June. However, there's still no trace of the dyes in the TRAQUA fluorometer. --> To be verified by analysis in the lab.
Weather:	**Good weather and T>0°C in South Face outside // Still a bit cold in the galleries**		
Timing:	Departure:	**08:30:00**	
	Return:	**18:00:00**	
Participants:	**Antoine Chabas**		
	Pierrick Jean		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230614_ADM/Photos*

FORECASTED ACTIONS / TO DO LIST :	OK / NOK ?

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: Almost half the bucket was filled with water. The bottle was totally filled with water. At the beginning of the afternoon, some water dropped from the rocks near to the logger and 1/2 bottle was collected. During the time spend at the AdM, no water flowed into Box1.

Box 2: No water and it seems still a bit frozen. A little ice cap found at the bottom of the bucket.

TNL: Behing the human trap, we can access to the bare rock and it was flowing a lot. We could collect a bottle there in the afternoon.

BRCK: One bottle collected.

Pictures:



Box 1 in the morning



BRCK runoff





TNL runoff

Video link for TNL runoff : VIDEO TNL in the picture folder.

2. Logger and sensor check

Comments:

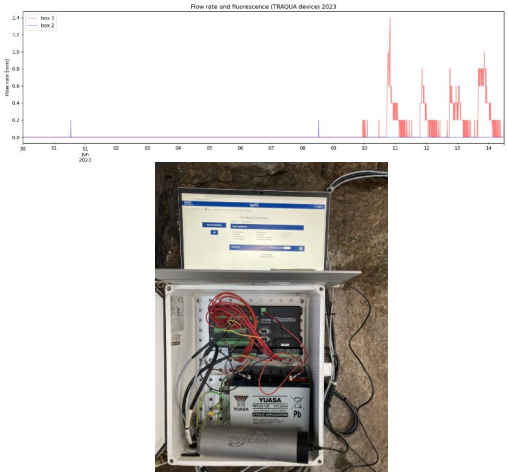
Data from logger : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Traitement donnees/WATER MONITORING/20230614*

Despite the fact of water flowing in the Box1, no tracers have been detected by the fluorimeter. Some lab tests could confirm this analysis.

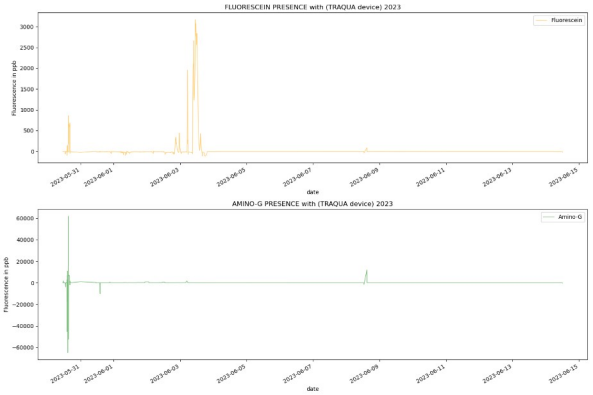
The battery was still good (>85%). But still difficult to have a good and stable vision of the battery charge.
At first view, we have data that have been recorded for Fluorescein and Amino G but quite weird data.

Pictures:

Flow rate

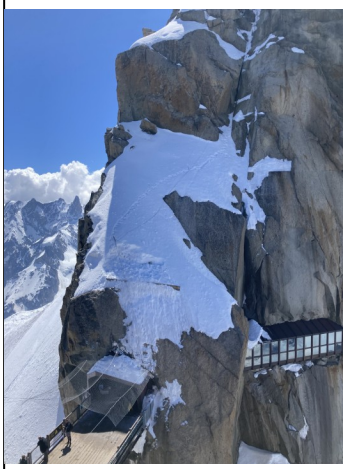


Fluorescence



3. Some pictures of faces for snow cover

North



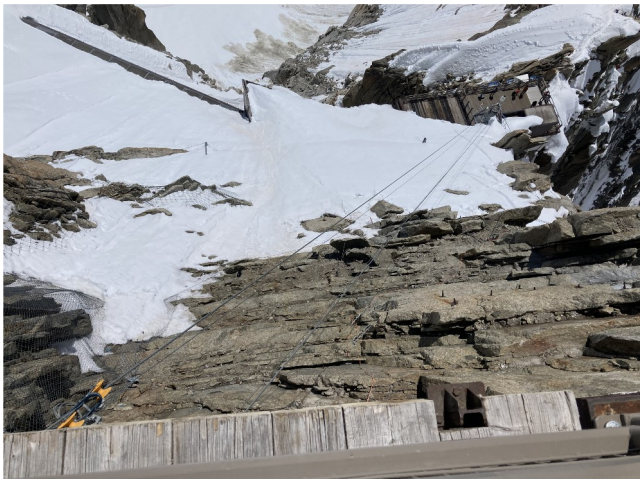
North extended



North East



South from the top



Water collect and measures

Comments:







Box1 / Box2 / TNL / BRCK / ELV / other

	ID Samples	Date	Time	Localisation	Bottle Size	Instantanous Conductivity	Check
1	2023614_AdM_Box1_1	14/06/23	11:40:00	Box1	125 ml	79,3	NOK
2	2023614_AdM_TNL_2	14/06/23	14:20:00	TNL	125 ml	221	NOK
3	2023614_AdM_Box1_3	14/06/23	15:00:00	Box1	125 ml	61	NOK
4	2023614_AdM_BRCK_4	14/06/23	15:00:00	BRCK	125 ml	183	NOK
5	2023614_AdM__5	14/06/23					NOK

GENERAL INFORMATION			General comments
Date:	**21/06/23**		**Too much wind at the Aiguille du Midi so no cable car between Chamonix to AdM.** **The days before, weather forecast seemed not so bad with some wind in the afternoon (around 45 km/h). Finally, it is a wind speed to 150 km/h announced.** **So lesson learnt: always look at the weather in the lab before going ^^"**
Weather:	**Good weather and T>0°C in South Face outside // Still a bit cold in the galleries**		
Timing:	Departure:	**08:30:00**	
	Return:		
Participants:	**Antoine Chabas**		
	/		
	/		
	/		
	/		

**Complete all cells in yellow*

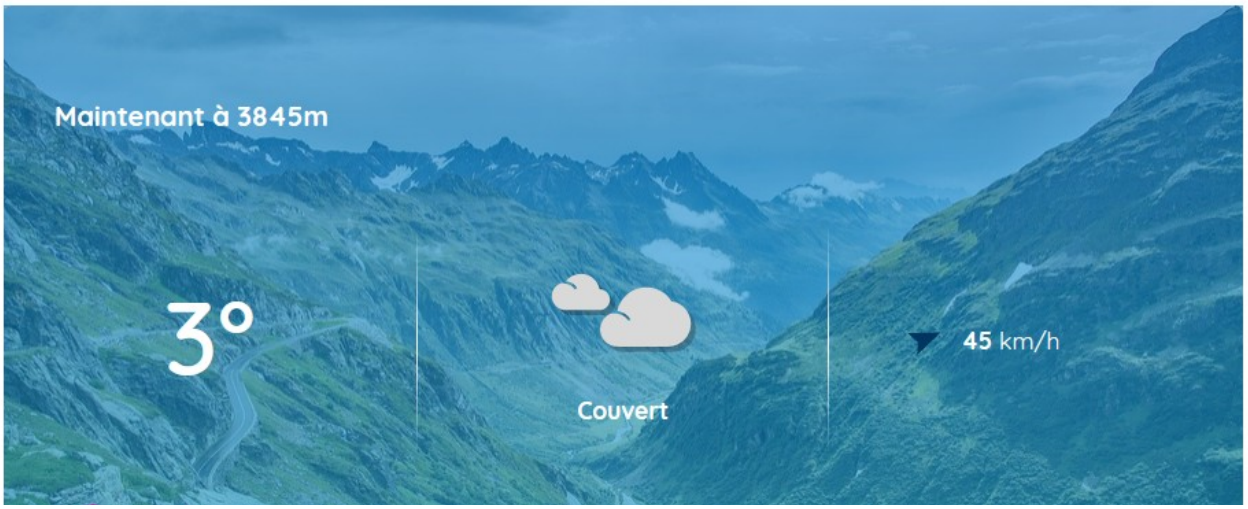
Pictures link :

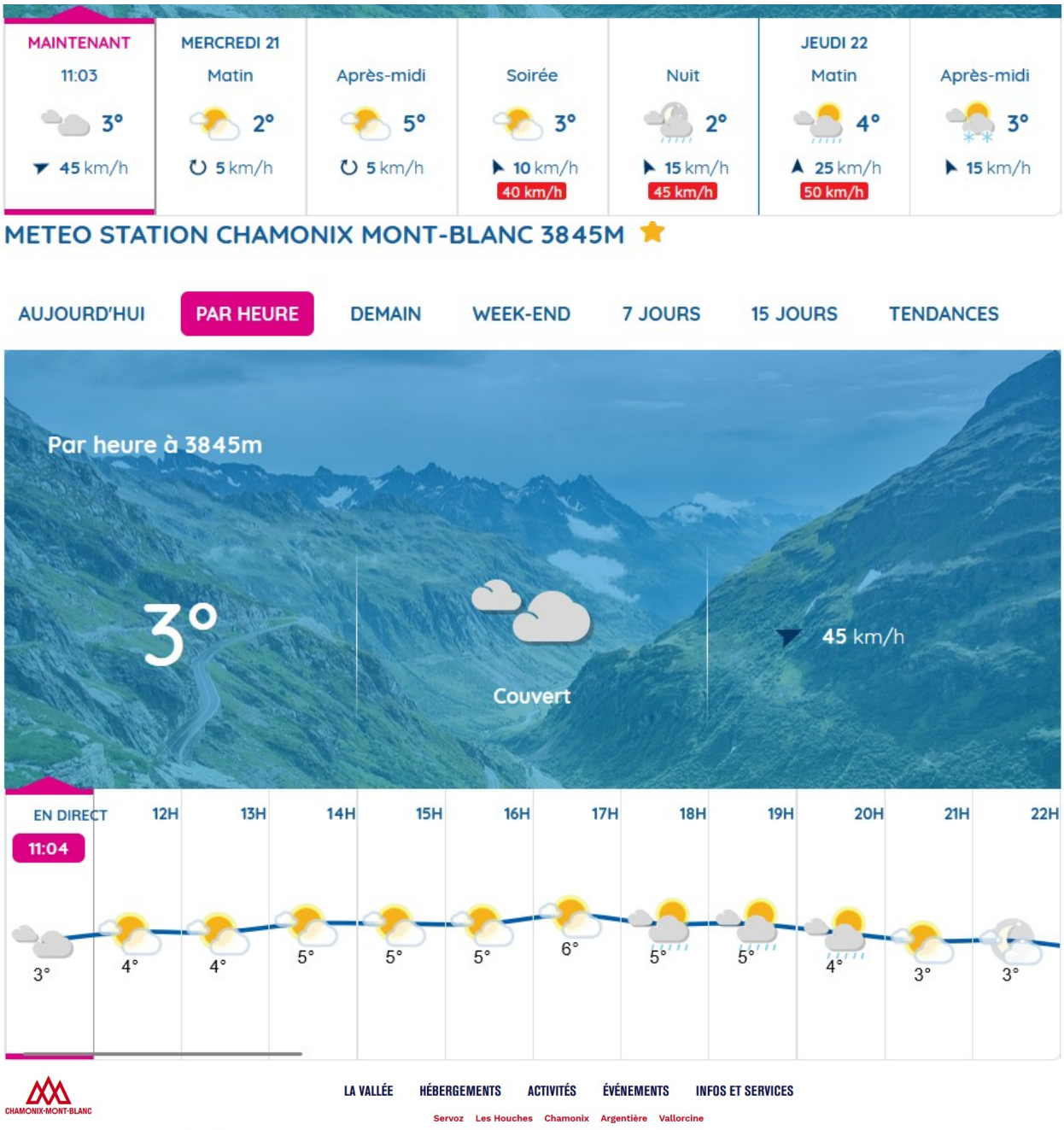





VENT FORT,
AIGUILE DU MIDI
FERMÉE
JOURNÉE;
Embarquement
Boarding access
MONT-BLANC
NATURAL RESORT
Cash
PART/BOARDING



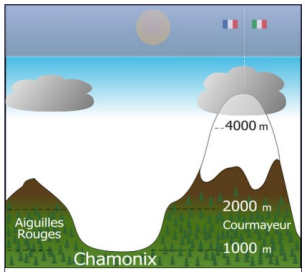

METEO STATION CHAMONIX MONT-BLANC 3845M
AUJOURD'HUI
PAR HEURE
DEMAIN
WEEK-END
7 JOURS
15 JOURS
TENDANCES
Maintenant à 3845m
3°
Couvert
45 km/h



MÉTÉO DU *MERCREDI 21 JUIN*

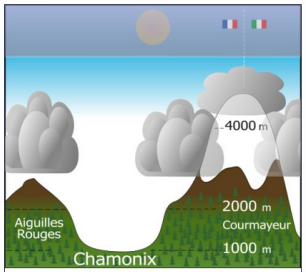
En matinée : Ciel voilé à haute altitude. Belles éclaircies. Nuage sur le sommet du Mont-Blanc.
L'après-midi : Belles éclaircies mais nuages sur le relief. Ciel voilé à haute altitude.
La nuit : Ciel voilé à haute altitude. Quelques nuages en haute montagne.

Mercredi matin



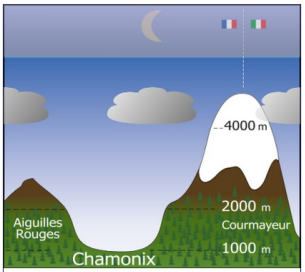
1000m	15°C	5km/h NE	0cm
2000m	13°C	40km/h SW	0cm
4000m	2°C	120km/h	0cm

Mercredi après-midi



1000m	30°C	10km/h NE	0cm
2000m	22°C	30km/h S	0cm
4000m	5°C	120km/h SW	0cm

Mercredi nuit



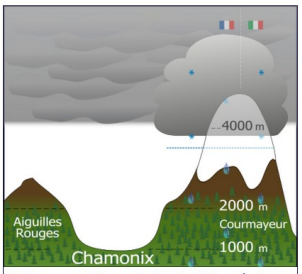
1000m	19°C	20km/h NW	0cm
2000m	18°C	50km/h S	0cm
4000m	1°C	120km/h	0cm

SW		SW

MÉTÉO DU *JEUDI 22 JUIN*

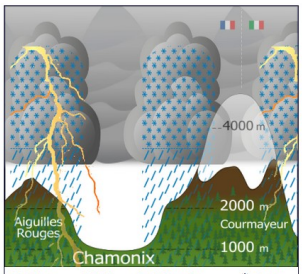
En matinée : voilé puis couvert. Quelques gouttes (flocons à partir de 3500 m).
L'après-midi : Couvert. Fréquentes averses (neige à partir de 3500 m). Fort risque d'orage.
En Soirée : Couvert. Fréquentes averses (neige à partir de 3500 m). Fort risque d'orage. Risque d'avalanche en haute montagne.
La nuit : Couvert. Averses (neige à partir de 3200 m). Risque d'avalanche en haute montagne.

Jeudi matin



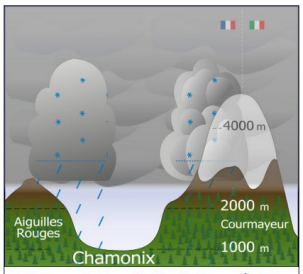
1000m	16°C	5km/h NW	0cm
2000m	12°C	40km/h S	0cm
4000m	2°C	130km/h S	1cm

Jeudi après-midi



1000m	30°C	25km/h SW	0cm
2000m	21°C	40km/h S	0cm
4000m	3°C	130km/h S	10cm

Jeudi nuit



1000m	14°C	5km/h E	0cm
2000m	8°C	30km/h SW	0cm
4000m	-3°C	60km/h NW	10cm

Water collect and measures

Comments:

	ID Samples	Date	Time	Localisation (Box1 / Box2 / TNL / BRCK / ELV / other)	Bottle Size	Instantanous Conductivity	Check
1	2023621_AdM__1	21/06/23					NOK
2	2023621_AdM__2	21/06/23					NOK
3	2023621_AdM__3	21/06/23					NOK
4	2023621_AdM__4	21/06/23					NOK
5	2023621_AdM__5	21/06/23					NOK

GENERAL INFORMATION			General comments
Date:	**27/06/23**		**- Bucket in the box 1 was full of green water (fluorescein presence). It has been confirmed by the TRAQUA sensor. - Still no water in the box 2. - In the morning, water was already flowing near to the elevator. - Around 3pm, plenty of water near to the logger, flowing from metalic strcutures. One bottle has been collected. I define them by 'LOG' - So the box1 is really collecting flow rate qickly (see video).**
Weather:	**Good weather the morning despite a pollution fog abovez the valley and T>0°C in South Face outside. Fog in the afternoon**		
Timing:	Departure:	**06:15:00**	
	Return:	**20:15:00**	
Participants:	**Antoine Chabas**		
	Josué Bock		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link :

FORECASTED ACTIONS / TO DO LIST :	
Washed bottles in the lab and bring some at ADM – Left 5 and still 10 clean bottle at my desk	
Do lab analysis on samples bring at EDYTEM	

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: **3 bottles in a day for the Box1 and one from the bucket. The bottle and the bucket was full of green water. The fluorescein preence has also been detected by the TRAQUA fluorimeter. The new bottle keep being filled by water until 9am.**
We have to wait until 3pm to get new water flowing and at 4pm it was a continuous flowing.
ELV : 2 bottles from water dropping from the roof near to the elevator have been collected. It has been flowing during the whole day at this place.

Box 2: The box 2 is still empty and no water is flowing from here. It is repeating the same sheme than last year.
TNL: Not much water in the TNL near to the elevator. No sample has been collected.
BRCK: No water from brick tunnel near PMB (Panorama Mont blanc)

Pictures:

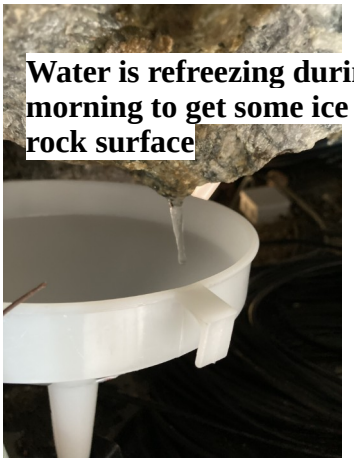




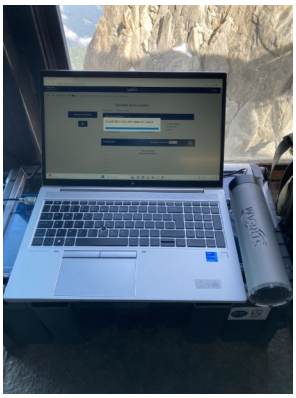


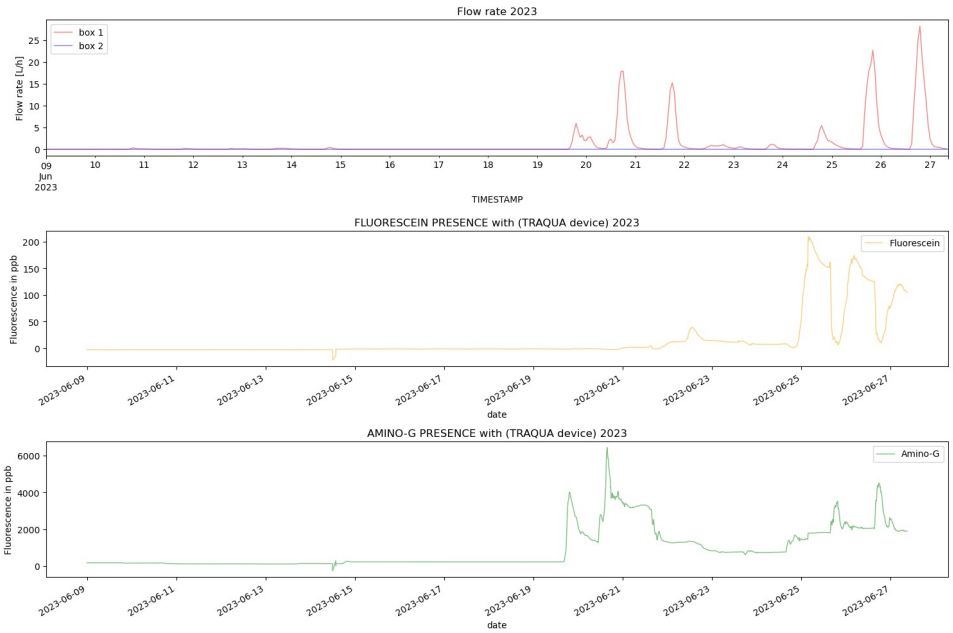






2. Logger and fluorimeter





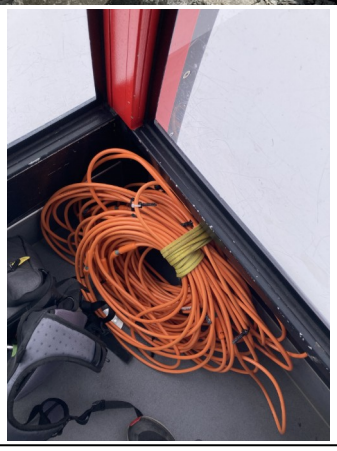
3. Josué work on South East Face to remove the cable

Josué spent the whole day fighting to remove the orange cable on the South East face under the snow and the ice.

But mission accomplished ! :D







4. Some pictures of the beauty of the mountain







Water collect and measures

Comments:

One botlle has been let in the logger box in case of Marc is here and can change the bottle to allow some more sample.



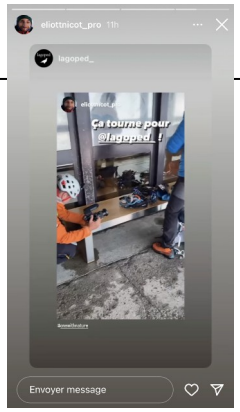


Box1 / Box2 / TNL / BRCK / ELV / other

	ID Samples	Date	Time	Localisation	Bottle Size	Instantanous Conductivity	Check
1	2023627_AdM_Box1_1	27/06/23	08:45:00	Box1	125 ml	44,5	NOK
2	2023627_AdM_BUCKET	27/06/23	08:45:00	BUCKET	125 ml	36	NOK
3	2023627_AdM_ELV_3	27/06/23	09:43:00	ELV	125 ml	273	NOK
4	2023627_AdM_ELV_4	27/06/23	13:10:00	ELV	125 ml	272	NOK
5	2023627_AdM_Box1_5	27/06/23	13:20:00	Box1	125 ml	49,5	NOK
6	2023627_AdM_LOG_6	27/06/23	15:45:00	LOG	125 ml	43	NOK
7	2023627_AdM_Box1_7	27/06/23	16:10:00	Box1	125 ml	42	NOK

Other information

I have been interviewed (filmed and recorded) by 2 people from the brand Lagoped about Climate change. I did the interview speaking about myself and what I was doing in my life and wear the Edytem jacket.
They also interviewed guide or employees from CMB.
Suivre Lagoped, Solidrusk production ou Eliott Nicot.



GENERAL INFORMATION			General comments
Date:	**05/07/23**		*- Bucket in the box 1 was full of green water (still fluorescein presence). It has been confirmed by the TRAQUA sensor.* *- Still no water in the box 2 but I tested it and everything work and ready for future runoff* *- Completely different day compared to last week with lower air temp felt and wind. Water runoff was delayed in the day.* *- I left Adm around 13 pm and not really water runoff.* *- All sensors are working well.*
Weather:	**Cold and windy. Windspeed measured at 47 km/h in the morining.**		
Timing:	Departure:	**07:00:00**	
	Return:	**16:00:00**	
Participants:	**Antoine Chabas**		
	Marc (journalist)		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link :

FORECASTED ACTIONS / TO DO LIST :	

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: **2 bottles in a day for the Box1 and one from the bucket. The bottle and the bucket was full of green water. The fluorescein preence has also been detected by the TRAQUA fluorimeter. The new bottle keep being filled by water until 9am.**
We have to wait until 3pm to get new water flowing and at 4pm it was a continuous flowing.
ELV : Only some drops during the morning so no water has been collected this day.
Box 2: No water in Box2 but **think to delete the values of flow rate next time because of the test**
TNL: 1 bottle from tunnel was colleted under the information panel.
BRCK: No water from brick tunnel near PMB (Panorama Mont blanc)

Pictures:

Morning at 9:00

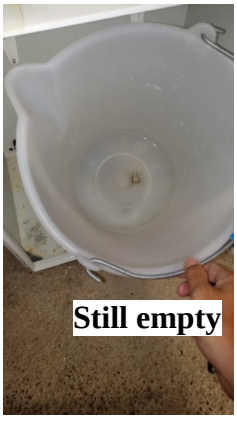


Box 1



Box 2



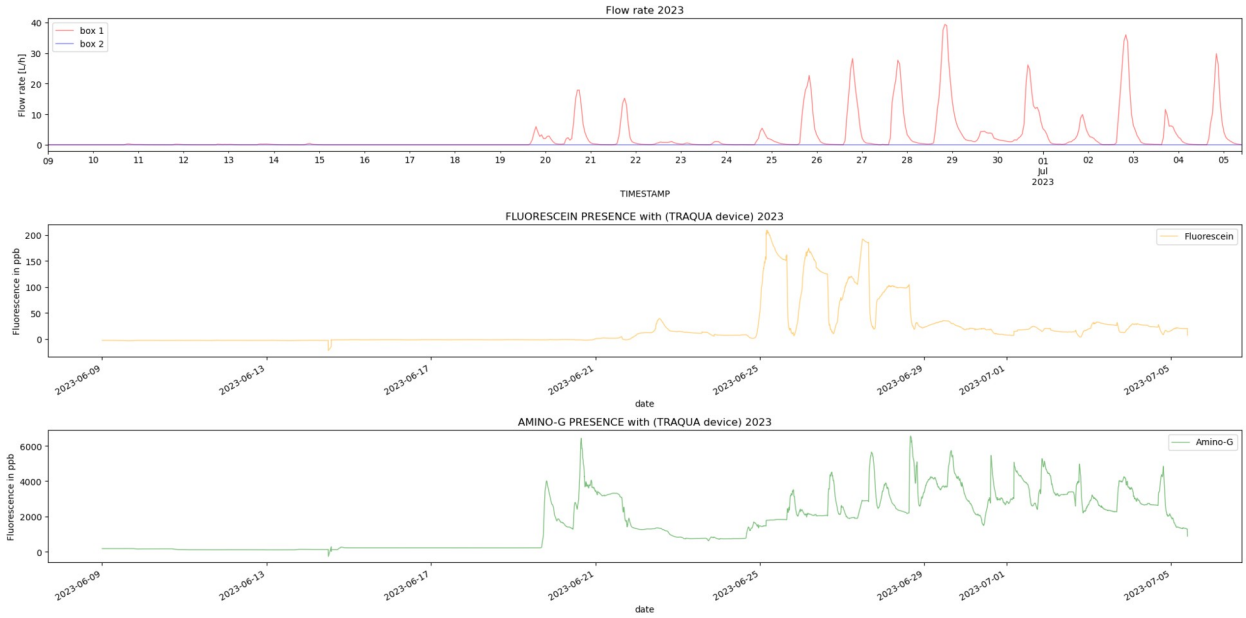






Marc helped me to check if everything was okay with the pipe of Box 2.
Box 2 is ok and water flows normally.

2. Logger and fluorimeter

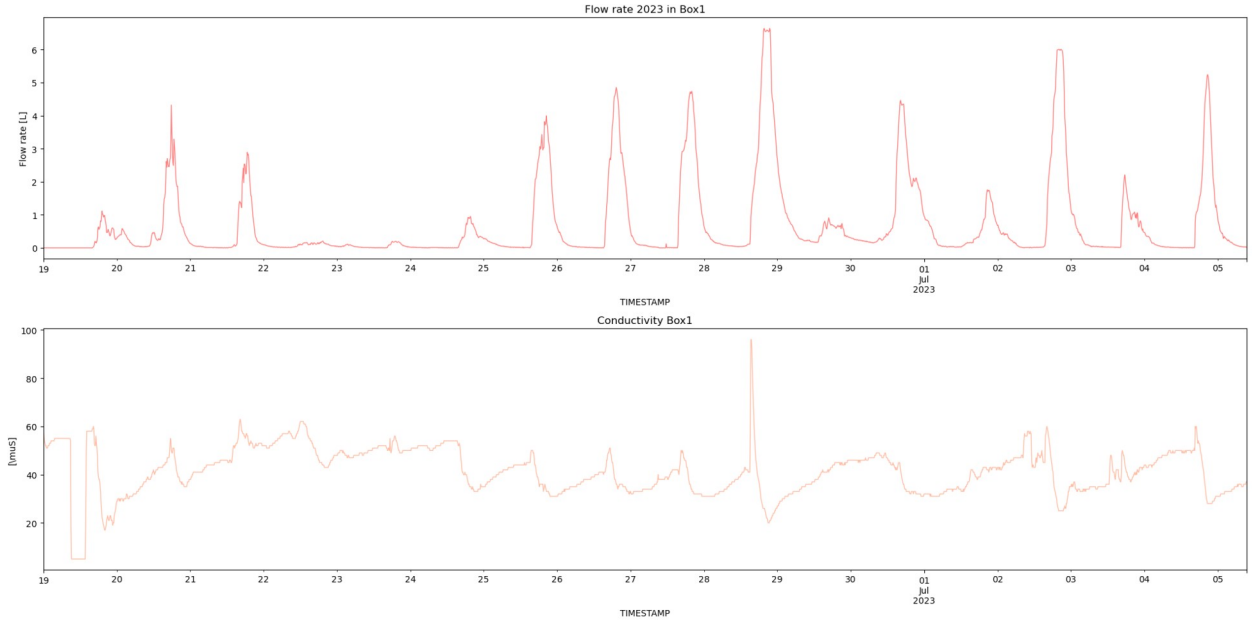


Comments:

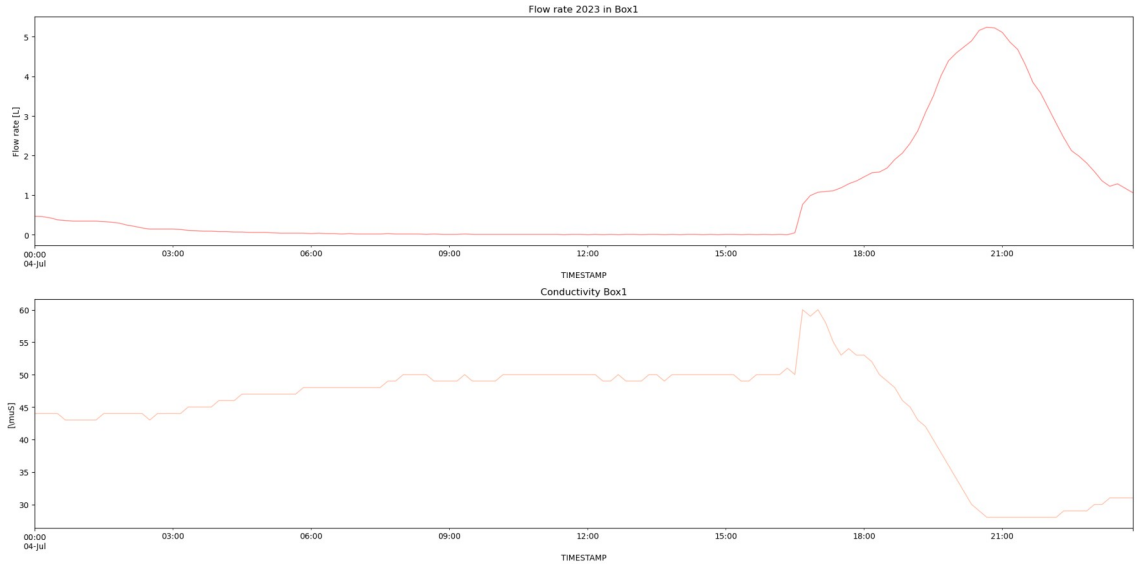
It seems that most of fluorescein is gone between the 24th and the 27th of June. We are still detecteing the Amino G.

How explain the fact that Amino G has been detected the first the 20th of June and is still flowing with water now (and not the fluorescein ?)

3. Logger and conductivity



Comments:

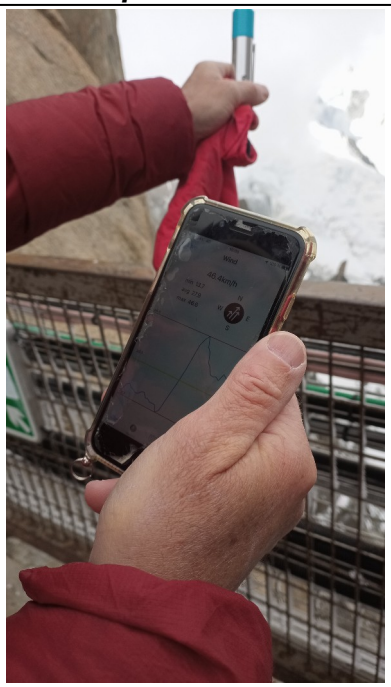


Example on the 4th of July

Interesting to see the daily variation of conductivity which could indicate that maybe the first water that flows is more charged with minerals.

When the maximum flow rate occurs, the conductivity is at his lowest point. It could mean that the high quantity of water flowing during the day could come from the snow cover that manage to infiltrate the bedrock wall.

4. Wind speed



We used Marc sensor to measure wind speed on the bridge between North piton and Central piton

Max Wind Speed measured the morning = 47 km/h

5. Faces views

N Face



Camera N Face + Solar panel re-installed



S-E Face



S Face from Cosmiques



S Face from upper terrasses



Water collect and measures

Comments:





	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Size	Instantanous Conductivity	Check
1	202375_AdM_Box1_1	05/07/23	09:15:00	Box1	125 ml	38,6	NOK
2	202375_AdM_BUCKET_	05/07/23	09:20:00	BUCKET	125 ml	28	NOK
3	202375_AdM_TNL_3	05/07/23	12:45:00	TNL	125 ml	114,6	NOK
4	202375_AdM_BOX1_4	05/07/23	12:50:00	BOX1	125 ml	43	NOK

Other information

GENERAL INFORMATION			General comments
Date:	**13/07/23**		*Marc joined me for the day. Still good flow rate in the Box1 and stard of flow rate detected the last 3 days in the Box2. Still not water flowing near the brick wall but we collected one bottle from the machine roon above the Panoramic Mt Blanc. Some water has been collected in the tunnel.* *SD Card from camera N face changed (the old one was 4Go since 22nd of May... No more pictures since the 24th of June – Marc helped me.*
Weather:	**Mostly cloudy and a little bit cold. Some sunny periods during the afternoon.**		
Timing:	Departure:	**08:00:00**	
	Return:	**18:30:00**	
Participants:	**Antoine Chabas**		
	Marc (journalist)		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230713_ADM/Photos*

Data link : *Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\WATER MONITORING\20230713*

FORECASTED ACTIONS / TO DO LIST :

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

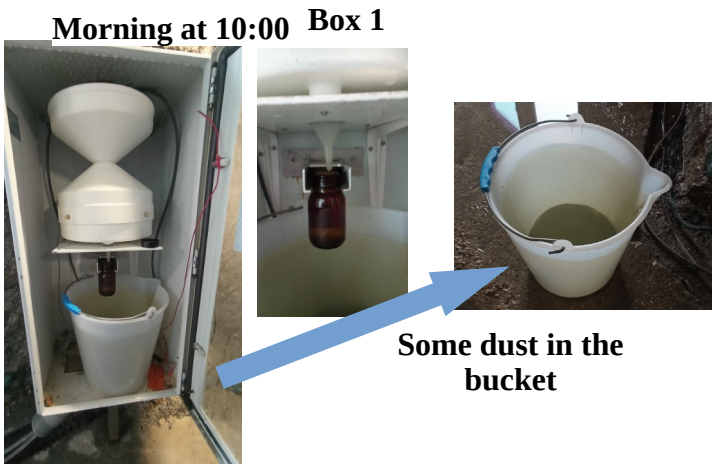
1. Water collect

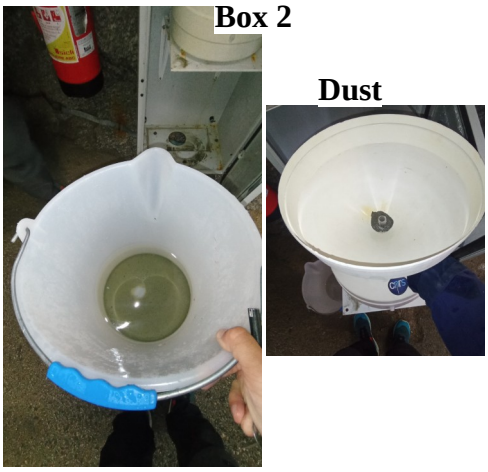
Comments:

Box 1: **4 bottles in a day for the Box1 and one from the bucket.**
Box 2: 1 bottle has been collected in Box2 directly from the bucket. The last 3 days, some flow rate has been detected (see graphs below)
TNL: 2 bottlew from tunnel was colleted under the information panel out of a pipe
BRCK: No water from brick tunnel near PMB (Panorama Mont blanc) but half of a bottle has been collected in the machine room of Panoramic Mont Blanc (PMB) around 3pm.
ELV : Only some drops during the morning so no water has been collected this day.

Quite a lot of dust in the bucket and the rain gauge. All have been cleaned.

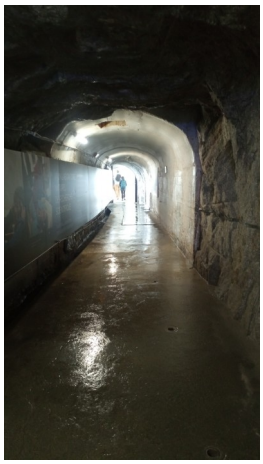
Pictures:

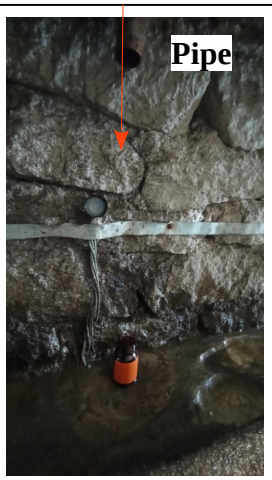












2. Logger and fluorimeter

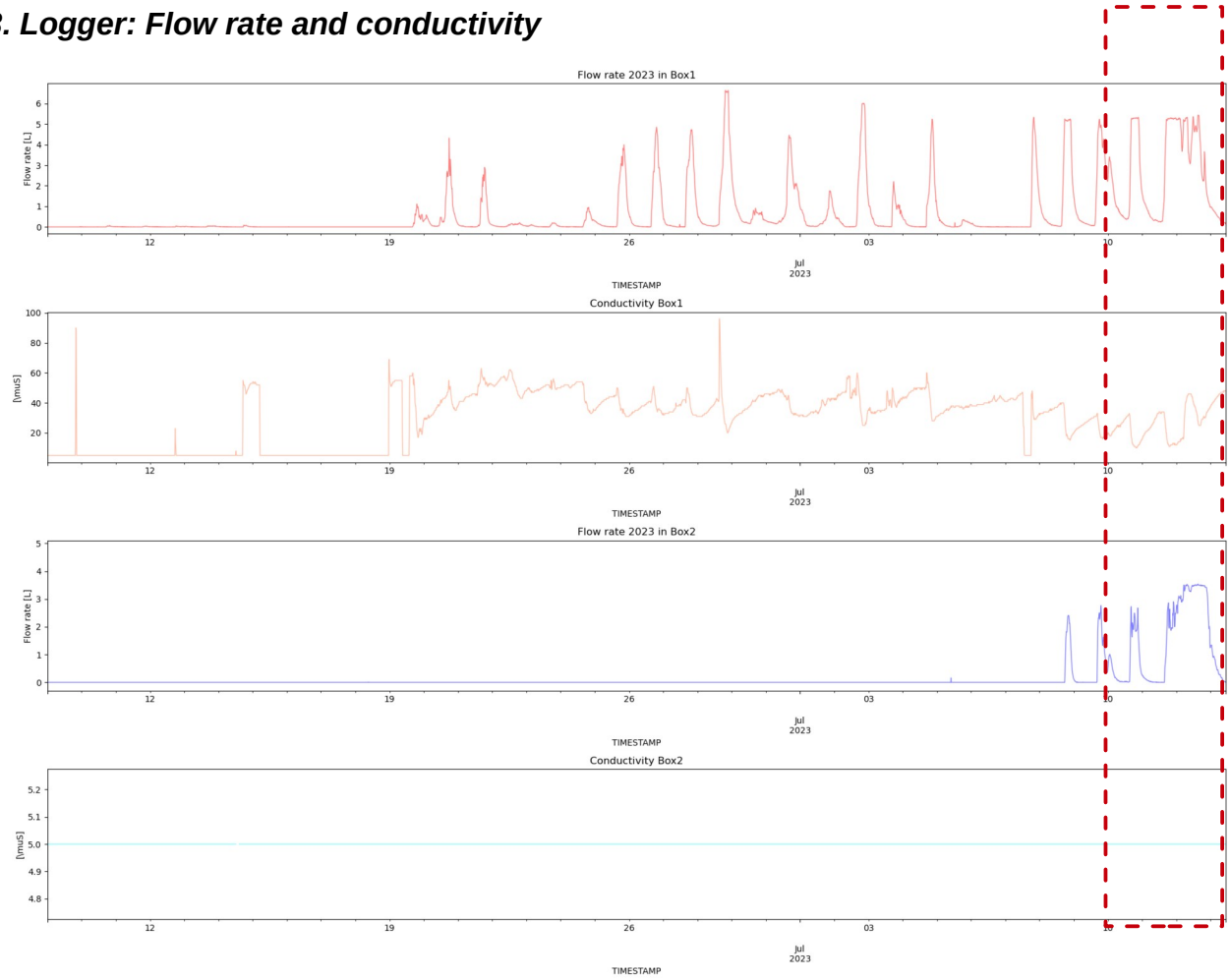


11/07/2023

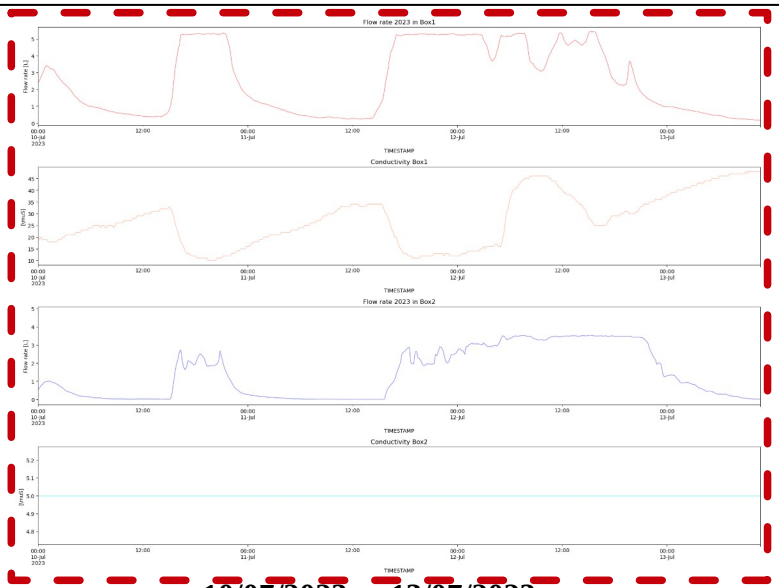
Comments:

Apparently, the two dyes are completely passed and their appearance is nil around 11/07

3. Logger: Flow rate and conductivity



Comments:



10/07/2023 to 13/07/2023

Between the 11/07 and the 13/07, no daily variation occured. There was no recession phase during the night of the 12/07.

This can be explained by the weather. Some thunderstorms occured during these days. Maybe, even during the night, a lot of rain felt and water from rain has run down the walls.

4. SD card from North face camera has been changed





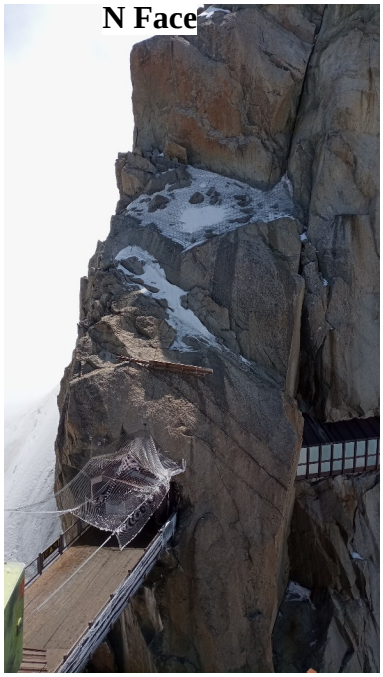
SD Card from camera N face changed (the old one was 4Go since 22nd of May... No more pictures since the 24th of June – Marc helped me.
Moreover, some other pictures were in the SD Card from 2022.

All pictures have been downloaded on the NAS.



5. Faces views

N Face



Mont Blanc



Jorasses



S Face from Cosmiques



S Face from upper terrasses



Water collect and measures

Comments:

RAS

	ID Samples	Date	Time	Localisation (Box1 / Box2 / TNL / BRCK / ELV / other)	Bottle Size	Instantanous Conductivity
1	202376_AdM_Box1_1	06/07/23	14:00:00	Box1	125 ml	NA
2	2023713_AdM_Box1_2	13/07/23	10:20:00	Box1	125 ml	46
3	2023713_AdM_BUCKET_BOX1_3	13/07/23	10:25:00	BUCKET_BOX1	125 ml	41,4
4	2023713_AdM_BUCKET_BOX2_4	13/07/23	10:30:00	BUCKET_BOX2	125 ml	59
5	2023713_AdM_TNL_5	13/07/23	11:00:00	TNL	125 ml	84
6	2023713_AdM_Box1_6	13/07/23	14:30:00	Box1	125 ml	38,2
7	2023713_AdM_PMB_7	13/07/23	14:50:00	PMB	125 ml	108,6
8	2023713_AdM_TNL_8	13/07/23	15:00:00	TNL	125 ml	91,6
9	2023713_AdM_Box1_9	13/07/23	15:05:00	Box1	125 ml	35,8

GENERAL INFORMATION			General comments
Date:	**20/07/23**		*On the last 3 days, no cable cars were able to run because the wind was too strong. It remains to be seen whether this will have an impact on water infiltration - rainfall hasn't been very frequent over the last few days either. Yesterday was perfect, very sunny and above all very busy.* *Box1 continues to work well. The daily run-off is still present and Marc allows us to have an intermediate sample during the week.* *Box2 has become completely blocked by debris and rock dust drained out with the water... I think we've lost a little signal over the last week, but this part of the fracture is still fairly dry.* *Attempt to change the position of Conduit 2 but it's very dry at this level of the fracture - see Box2.* *Collecting water at the tunnel (TNL) with high conductivity water at the upper trap.* *Overall, the conductivity measured on the samples is higher everywhere.*
Weather:	**Sunny after 2-3 days off because of wind**		
Timing:	Departure:	**08:00:00**	
	Return:	**18:30:00**	
Participants:	**Antoine Chabas**		
	/		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230720_ADM/Photos*

Data link : *Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\WATER MONITORING\20230720*

FORECASTED ACTIONS / TO DO LIST :	
Collect the Rock Surface temperature of North Face in August with Josue or Manu – see with Josue the locatio	
Collect iButton data at the end of Summer	
Ask for weather station data of 2022 and 2023 – Meteo France or IGE ?	

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: 3 bottles in a day for the Box1 and one from the bucket. Still, the water in the bucket of the Box1 seems a little bit green. But no more Fluorescein is detected by the fluorimeter. On Monday or Tuesday (before the lab summer closing, I will try to do all fluo analysis in the lab)
Box 2: 1 bottle has been collected in Box2 directly from the rain gauge. ***Box2 has become completely blocked by debris and rock dust drained out with the water... I think we've lost a little signal over the last week, but this part of the fracture is still fairly dry.***
TNL: 2 bottles from tunnel was colleted- one under the information panel out of a pipe and the other one above the trap. High conductivity measured on it --> 370 µS
BRCK: No water from brick tunnel near PMB (Panorama Mont blanc)
ELV : No water collected here

==> Warning: Almost no more bottles in the lab to collect water. Matan and I are recontacting the supplier

Pictures:







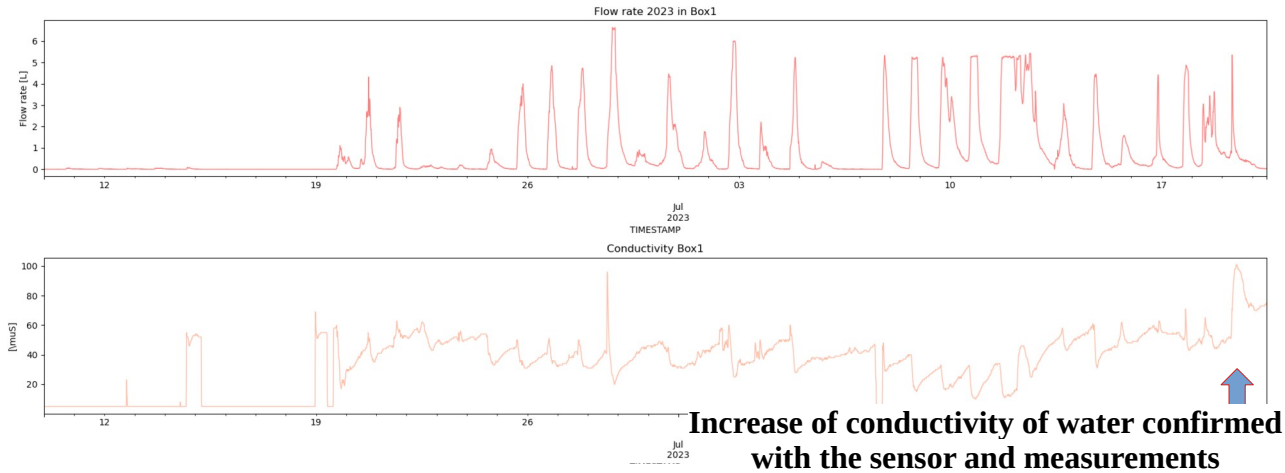




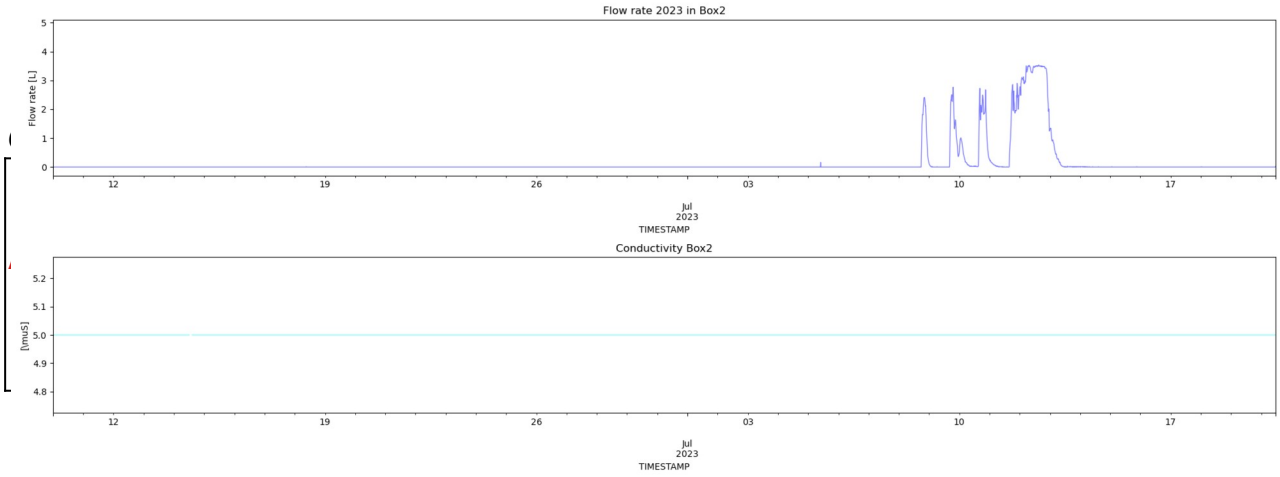




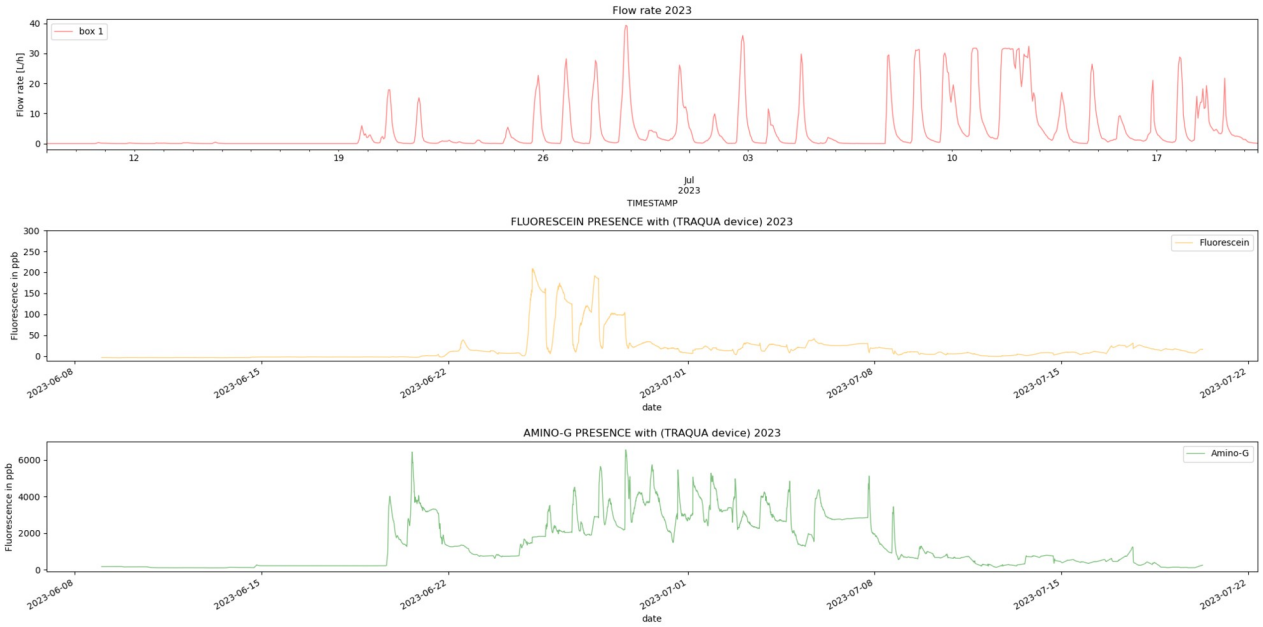
2. Logger and conductivity



Increase of conductivity of water confirmed with the sensor and measurements

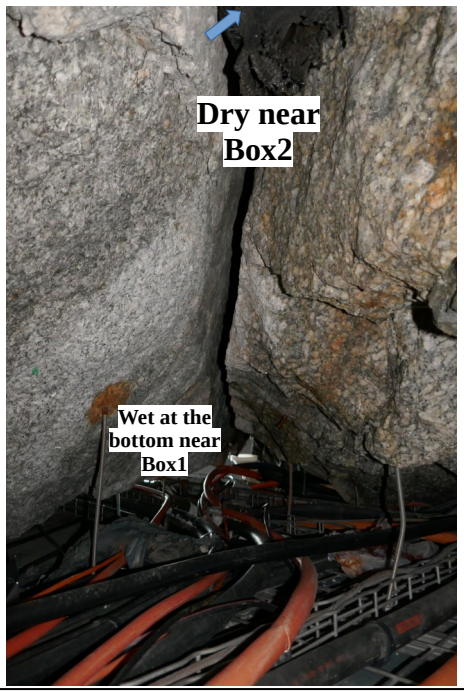


3. Logger: Flow rate and fluo



Comments:

4. Conductivity 2 change of location trying to get a place with runoff



On the other side of the roof near to the entrance and the Box2, the rock is almost totally dry. I had to remode the cone to put the 2nd conductimeter under the most wet rock of this side.

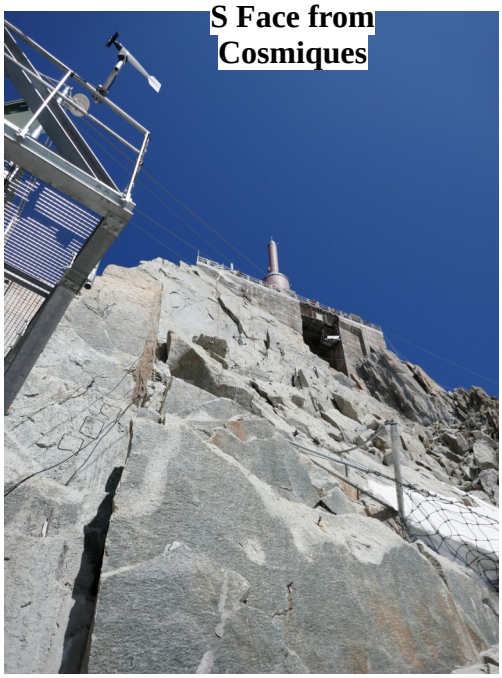


5. Faces views





S Face from Cosmiques



S Face from upper terrasses



Water collect and measures

Comments:

Overall, the conductivity measured on the samples is higher everywhere.

That means that the current infiltration comes from depper water ?

If you look at the pictures of N face, no more snow is present on the rock.

	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Si	Instantanous Conductivity	
1	2023714_AdM_Box1_1	14/07/23	13:24:00	Box1	125 ml	61	
2	2023720_AdM_Box1_2	20/07/23	11:00:00	Box1	125 ml	76	
3	2023720_AdM_BUCKET_Box1_3	20/07/23	11:05:00	BUCKET_Box1	125 ml	75	
4	2023720_AdM_BUCKET_Box2_4	20/07/23	11:10:00	BUCKET_Box2	125 ml	68	
5	2023720_AdM_TNL_5	20/07/23	12:50:00	TNL	125 ml	99	tuyau
6	2023720_AdM_TNL_6	20/07/23	14:00:00	TNL	125 ml	**370**	trappe
7	2023720_AdM_Box1_7	20/07/23	15:00:00	Box1	125 ml	80,5	

GENERAL INFORMATION			General comments
Date:	**26/07/23**		*There are still days to go before this Wednesday's visit. Heavy thunderstorms were forecast for Tuesday.* *This Wednesday, cold temperatures at the top. The valley is covered in clouds but the summits are clear. A thin layer of snow covers the mountains, including the North Face.* *In the galleries, Box2 suffered a frostbite in the rain gauge, as did the conduci on the ceiling of the monitoring system.* *The ABEM, which had been unresponsive for 2 days on the remote connections (as a result of the storms or the closure)? Finally, after several tests, the device seems to be working again.* *Still many problems with the fluorometer connection and impossible to recover the data (contact Amael P).* *Little water collected, but once again a full bottle at the TNL hatch with high conductivity.*
Weather:	**Cold and cloudy above the valley but sunny at elev. >3000m**		
Timing:	Departure:	**08:30:00**	
	Return:	**18:30:00**	
Participants:	**Antoine Chabas**		
	Anais Fichot		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230720_ADM/Photos*

Data link : *Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\WATER MONITORING\20230720*

FORECASTED ACTIONS / TO DO LIST :	
Collect the Rock Surface temperature of North Face in August with Josue or Manu – see with Josue the locatio	
Collect iButton data at the end of Summer	

Ask for weather station data of 2022 and 2023 – Meteo France or IGE ? - **Wait for end of August**

WATER SAMPLING DEVICE

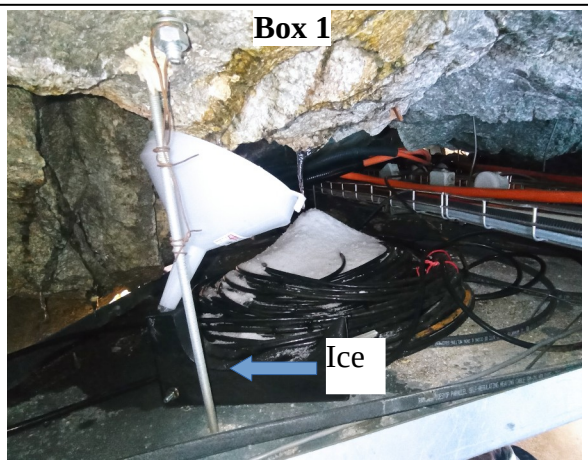
Study of permafrost thaw hydrology

1. Water collect

Comments:

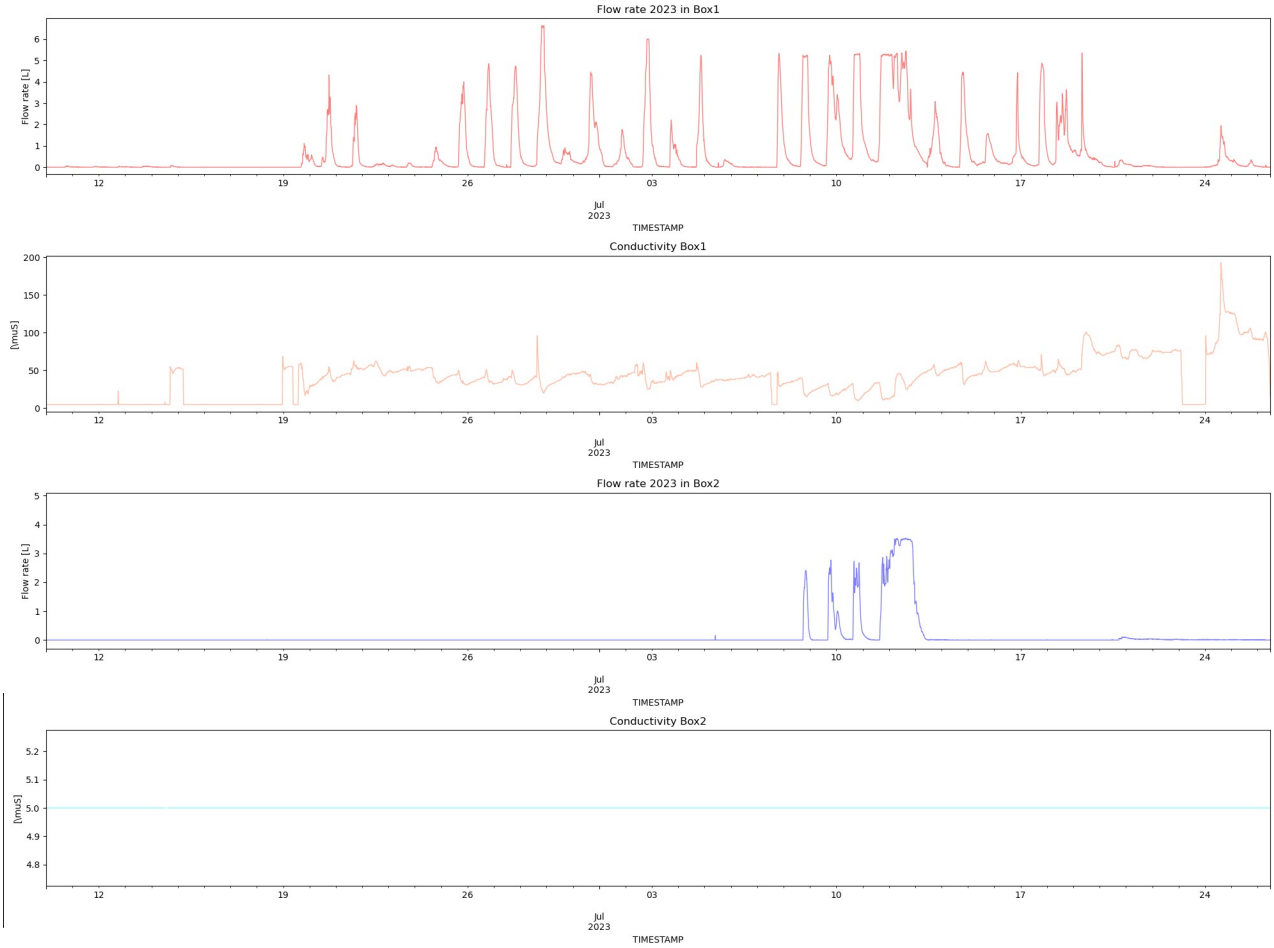
Box 1: 1 bottle collected.
We will try to limit the number of samples in relation to the number of flasks available to ensure that we continue to have good temporal and spatial representativeness.
Box 2: No bottle collected
TNL: 1 bottle from the trap in the TNL. The conductivity is even higher than last week. The same for the water of Box1, still a bit high week after week.
BRCK: No water collected here
ELV : No water collected here
SNOW : I took advantage of the snow that had fallen the day before to collect some and check its conductivity. In fact, it's relatively low (around 9) but I imagine that the density of the snow can affect this conductivity as well as other parameters.

Pictures:

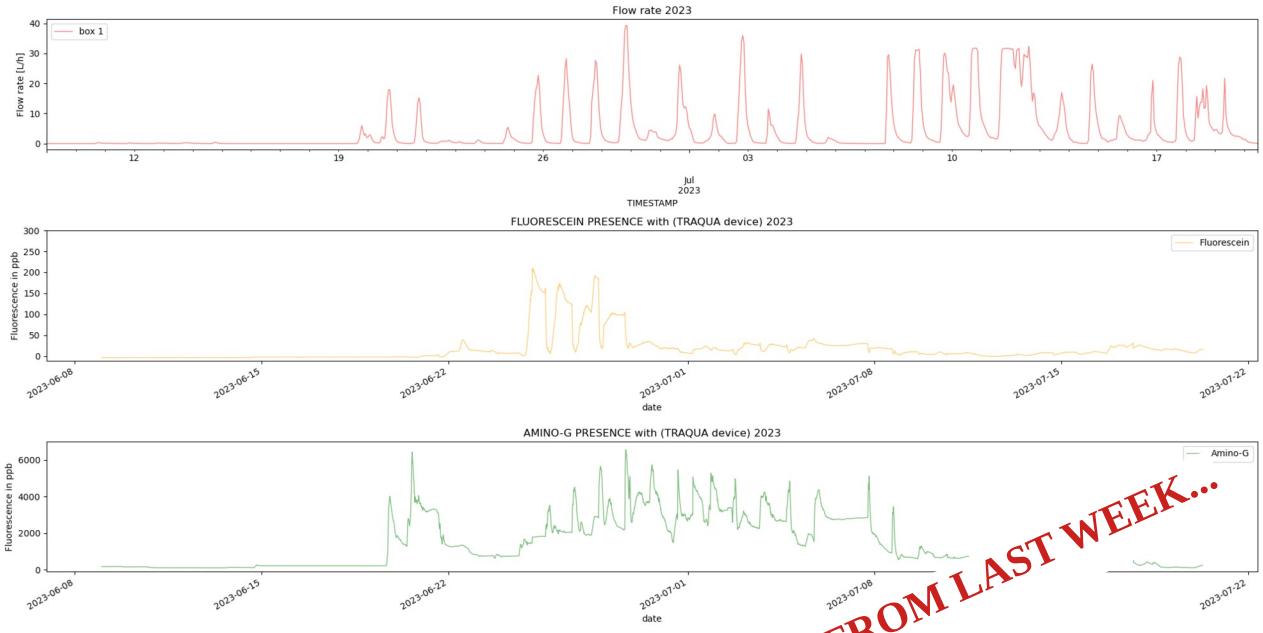




2. Logger and conductivity



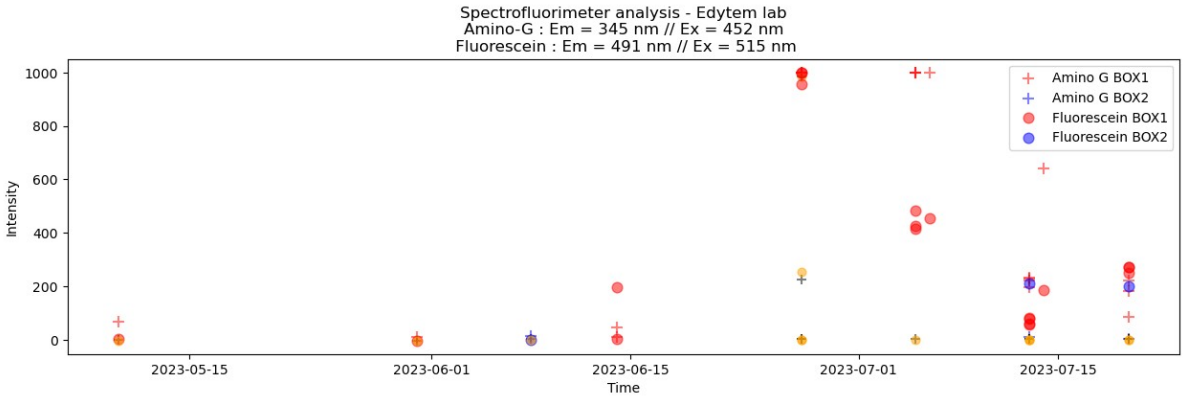
3. Logger: Flow rate and fluo



NO DATA FROM LAST WEEK...

Comments:

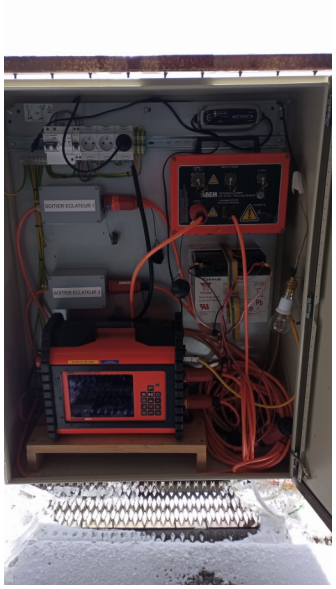
No data from the week.
For the past 3 weeks, the sensor has had great difficulty loading data onto the computer.
The last two times I've always managed to do it, but after a lot of plugging and re-plugging, after an hour or two it finally worked, but not yesterday...
I'm thinking of emailing Amael Poulain at Traqua to get some feedback. The problem is that the sensor disconnects quickly during charging. In the manual, this is one of the problems that is explained but the proposed solutions don't work. Perhaps there's too much data? In any case, it's annoying to struggle with this sensor just to load the data. Otherwise, it is still recording.



Comments:

Last week, I carried out all the fluorescence analyses in the laboratory on the samples collected since we started in May. The maximum values are stuck at the machine's maximum measurement, so we can expect even higher values in July. This will allow us to take the other July values for Box1 relatively. Because they still indicate a presence of tracers in the water, but I think it's very low if you compare it with the fluorometer in place.

4. ABEM check

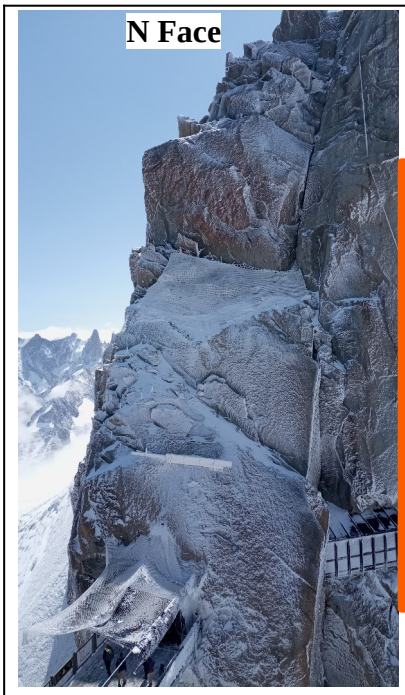


Reconnexion done and measurements launched for the Thursday.





5. Faces views



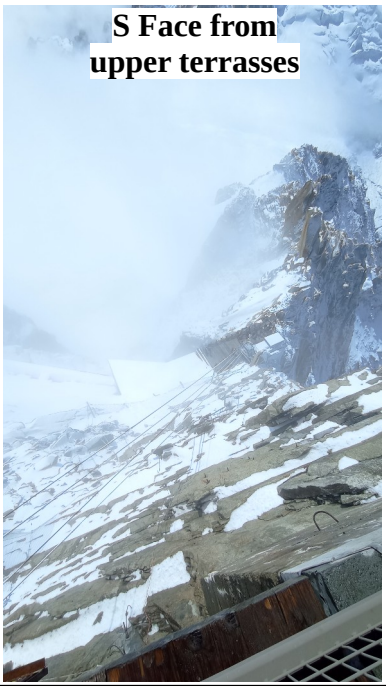




S Face from Cosmiques



S Face from upper terrasses



Water collect and measures

Comments:

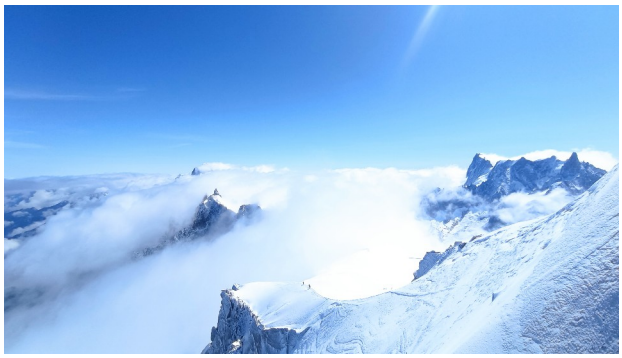
CONDUCTIVITY RECORD !!!



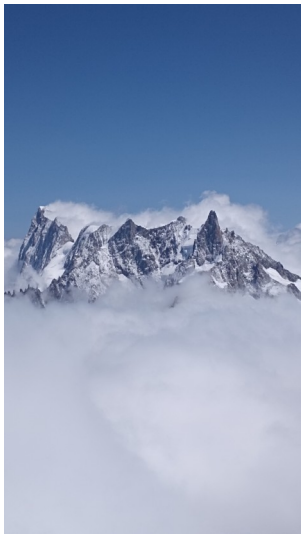


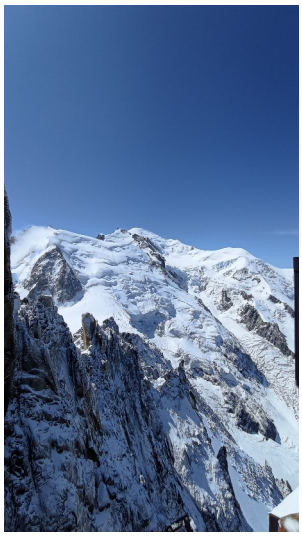
Box1 / Box2 / TNL / BRCK / ELV / other

	ID Samples	Date	Time	Localisation	Bottle Si	Instantanous Conductivity	
1	2023726_AdM_Box1_1	26/07/23	11:20:00	Box1	125 ml	97	
2	2023726_AdM_TNL_2	26/07/23	14:55:00	TNL	125 ml	**485**	Trappe
3	2023726_AdM_Snow_3	26/07/23	14:00:00	Snow	125 ml	9,2	









GENERAL INFORMATION			General comments
Date:	**04/08/23**		
Weather:	**Very cloud and humid conditions in the valley. Some clearing skies above. Some snow on the walls. Temperature ok, colder than last week.**		
Timing:	Departure:	**07:30:00**	
	Return:	**18:00:00**	
Participants:	**Antoine Chabas**		
	/		
	/		
	/		
	/		

L'Aiguille has been closed for the last 4 days due to strong or very strong winds (120 kmh announced on their website on Wednesday).

Box2 is still as cluttered as ever with sediment and rock dust. However, the bucket had time to fill up before being completely blocked.

The conductivity meters are back in place. Observing the progress of the wet section in the main fracture. There may soon be water in the 2nd conductivity meter.

Successful (strangely enough) collection of data from the fluorometer.

The wall of the North Face is once again covered with a thin layer of snow.

The Abem machine has been struggling since mid-July. Another test today with Josué operating the machine and remotely.

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230804_ADM/Photos*

Data link : *Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\WATER MONITORING\20230804*

FORECASTED ACTIONS / TO DO LIST :	
Collect the Rock Surface temperature of North Face in August with Josue or Manu – see with Josue the locatio	
Collect iButton data at the end of Summer	

Ask for weather station data of 2022 and 2023 – Meteo France or IGE ? - **Wait for end of August**

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: 1 bottle collected.

Box 2: 1 bottle collected in the directly in the bucket

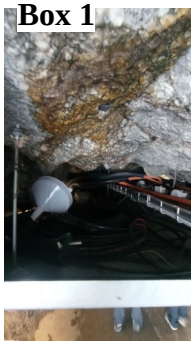
TNL: 1 bottle from the trap in the TNL. The conductivity is even higher than last week. The same for the water of Box1, still a bit high week after week.

BRCK: No water collected here

ELV : No water collected here

Pictures:





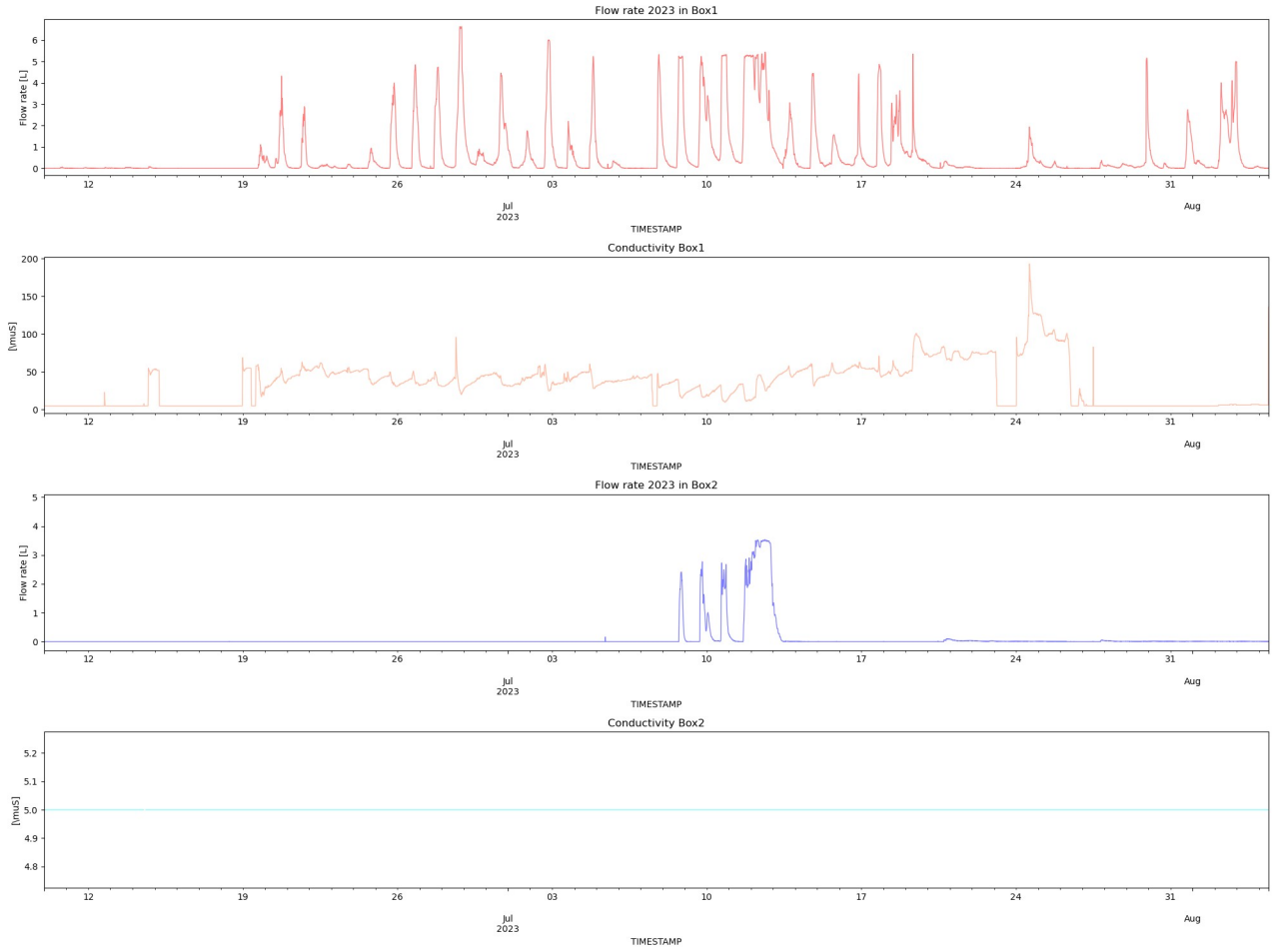








2. Logger and conductivity

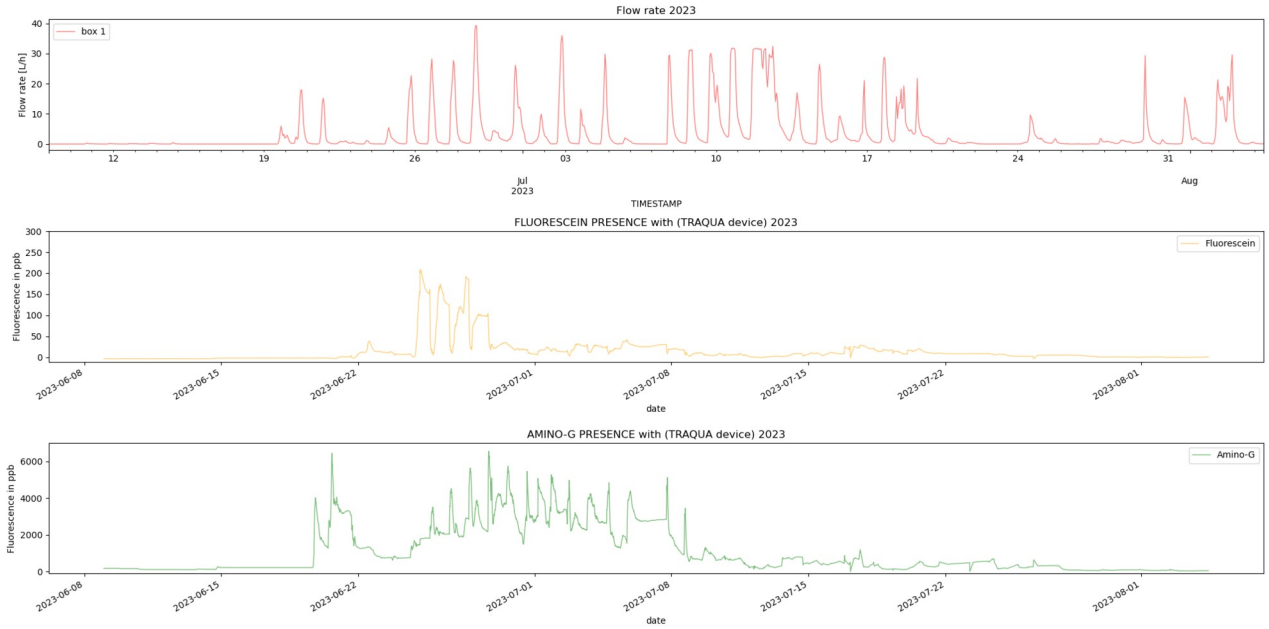


Comments:

The signal from Box2 hasn't shown any flow for weeks, even though the bucket was full when it arrived. This could mean that the rain gauge clogs up very quickly when there is run-off at this level of the main fracture.

Otherwise, the conductivity meters were on their sides and were unable to measure any data for the week. This may be due to the wind or to certain periods of frost that cause the funnel to move slightly and lose the precarious balance of the conductivity meter.

3. Logger: Flow rate and fluo

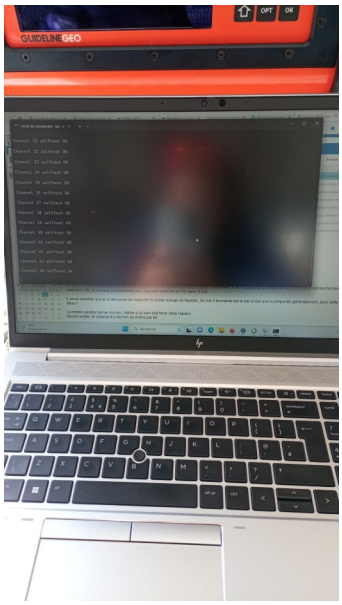


Comments:

Amino G is likely to be present in small quantities until the end of July.

4. ABEM check

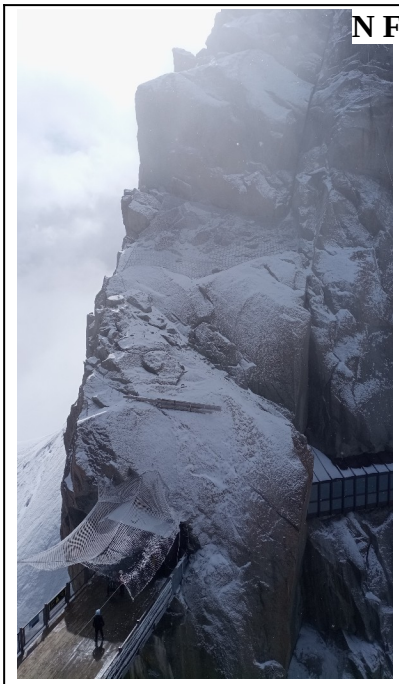




All test were OKAY

5. Faces views

N Face





South East face



S Face from Cosmiques

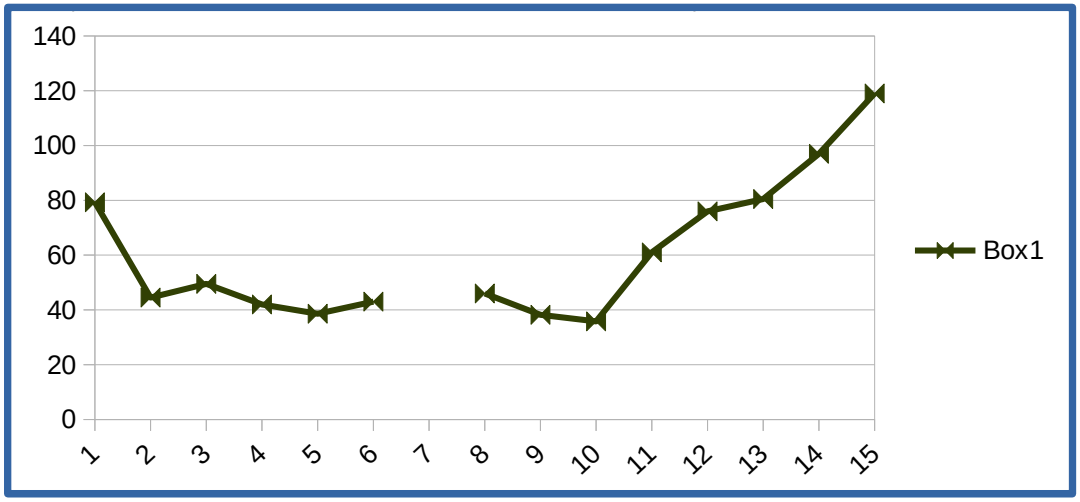


S Face from upper terrasses



Water collect and measures

Comments:



	ID Samples	Date	Time	Localisation (Box1 / Box2 / TNL / BRCK / ELV / other)	Bottle Si	Instantanous Conductivity	
1	202384_AdM_Box1_1	04/08/23	10:20:00	Box1	125 ml	119	
2	202384_AdM_BUCKET_Box2_2	04/08/23	10:20:00	BUCKET_Box2	125 ml	64,2	
3	202384_AdM_TNL_3	04/08/23	12:30:00	TNL	125 ml	390	Trappe





GENERAL INFORMATION			General comments
Date:	**10/08/23**		
Weather:	**Sunny day. Still closed in the 9th the afternoon cause of wind. After discussion with Youri, he told me that it was exceptional to close that much of days this year.**		
Timing:	Departure:	**07:45:00**	
	Return:	**17:00:00**	
Participants:	**Antoine Chabas**		
	/		
	/		
	/		*Sunny days and a lot of people.*
	/		*Nothing particular to notice. Same actions as usual have been done up there.*

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230810_ADM/Photos*

Data link : *Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\WATER MONITORING\20230810*

FORECASTED ACTIONS / TO DO LIST :	
Collect the Rock Surface temperature of North Face in August with Josue or Manu – see with Josue the locatio	
Collect iButton data at the end of Summer	

Ask for weather station data of 2022 and 2023 – Meteo France or IGE ? - **Wait for end of August**

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: 1 bottle collected. Following the Flow rate, not so mucn of runoff the last days. Proobably no precipitation during last days on the ADM.

Box 2: 1 bottle collected in the bucket. Not so much water in it and almost no sediments were present in the rain gauge. We can simply assume that there was no runoff in this location last days.

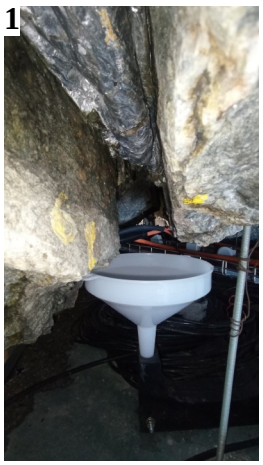
TNL: 1 bottle from the trap in the TNL.

BRCK: No water collected here

ELV : No water collected here

Pictures:

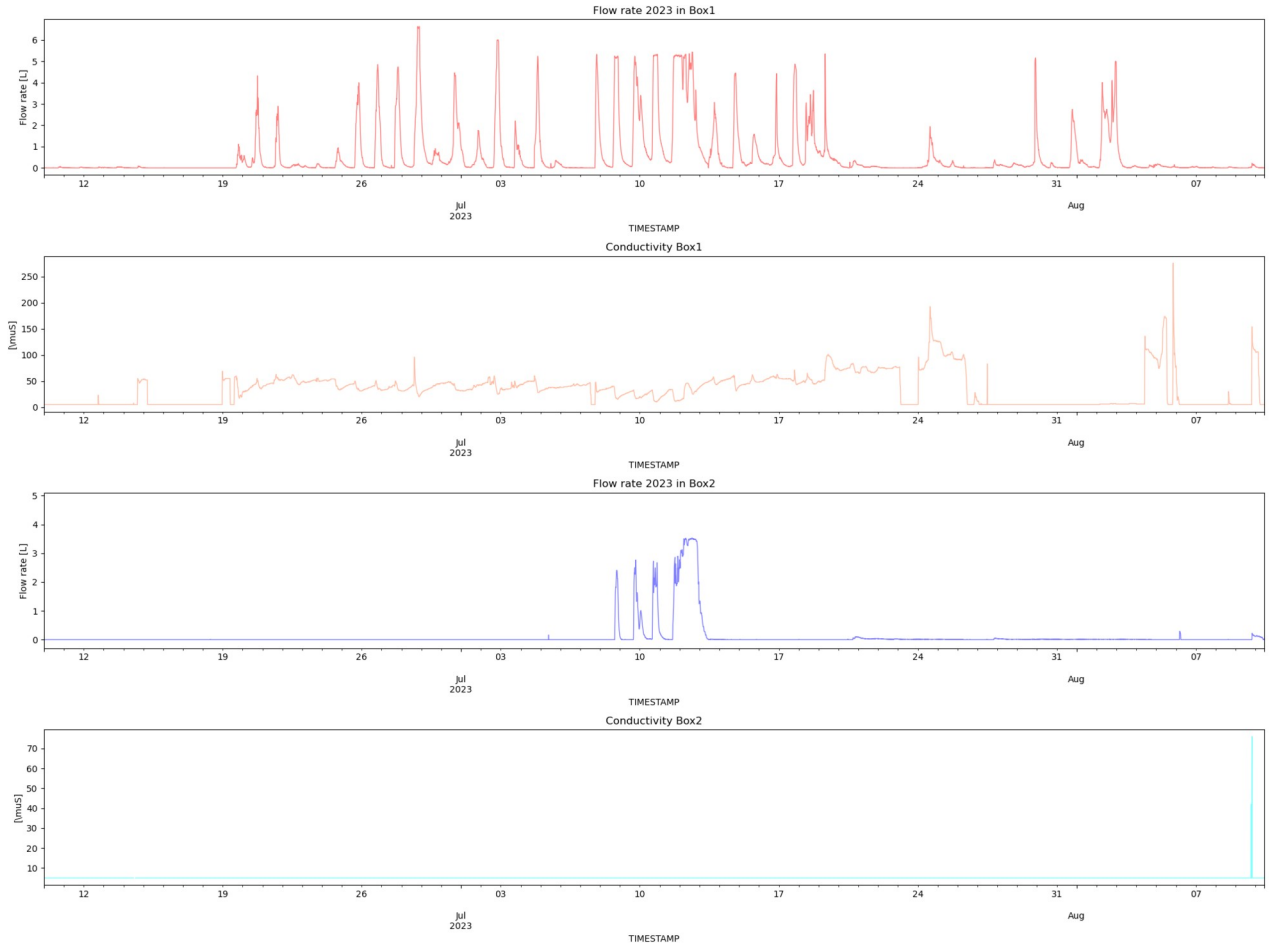








2. Logger and conductivity



Comments:

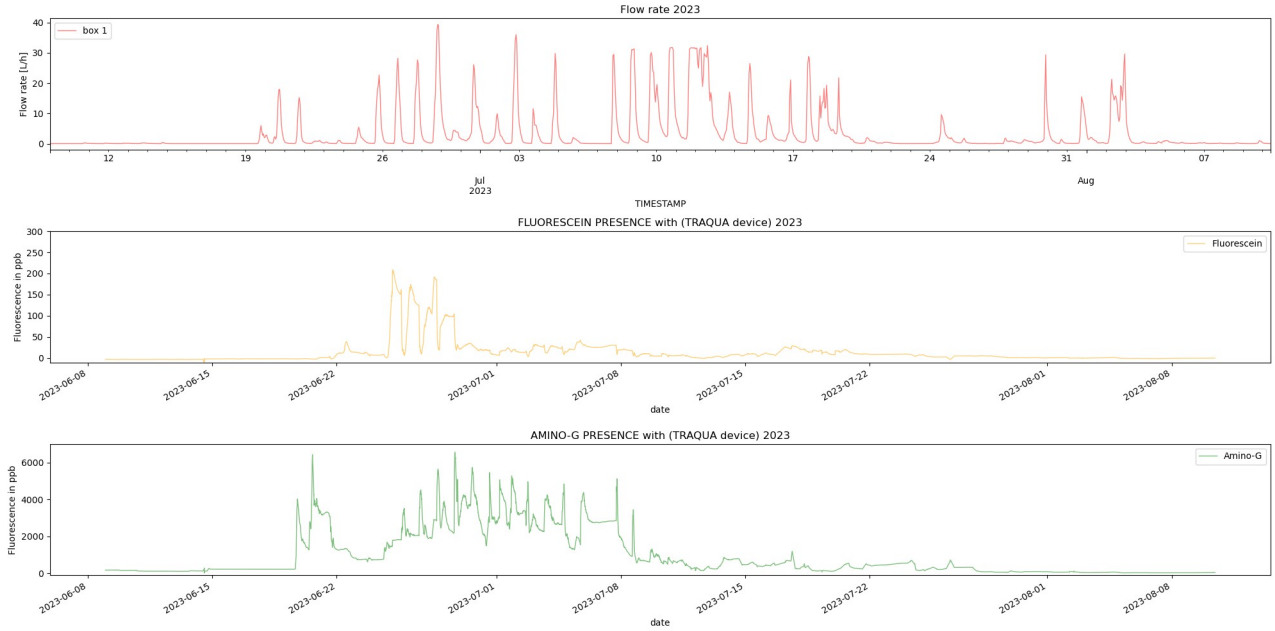
Very little runoff in the galleries probably due to the lack of precipitation last days. We can observe that on the glaciers below and their brown colors.

The flow rate from Box1 is probably linked to the snow thawing presents on the face last week.

Still no flow rate in Box 2 despite the fact that no sediments bloked the rain gauge. Probably just the reality because no much water in the bucket.

For conductivity sensors, I think it depend of the runoff location directly from the fractures. It will be different from the Boxes flow rate because, the rain gauge measure all water coming from the fracture with the roof. The conductivity sensors measure only on 1 point.

3. Logger: Flow rate and fluo

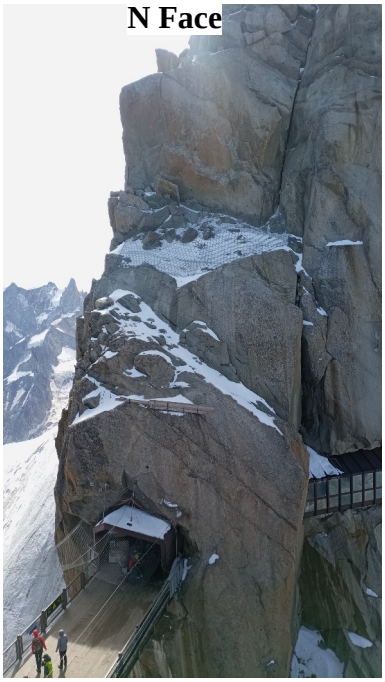


Comments:

No more fluorescence detected.

4. Faces views

N Face



South East face



S Face from Cosmiques

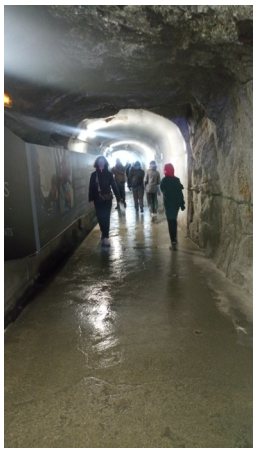


South Face from upper terrasses



Water collect and measures

Comments:







	ID Samples	Date	Time	Localisation (Box1 / Box2 / TNL / BRCK / ELV / other)	Bottle Si	Instantanous Conductivity	
1	2023810_AdM_Box1_1	10/08/23	10:30:00	Box1	125 ml	105,5	
2	2023810_AdM_BUCKET_Box2_2	10/08/23	10:30:00	BUCKET_Box2	125 ml	80,8	
3	2023810_AdM_TNL_3	10/08/23	13:15:00	TNL	125 ml	321	Trappe





GENERAL INFORMATION			General comments
Date:	**22/08/23**		*Sunny days, extremely hot and a lot of people.* *Several collapses reported in recent days. A collapse seen live under the footbridge at 11am.* *Recovering data from iButtons on the North Face. 3 found by Josué.* *Data from 5 iButtons near to the Boxes has been collected.* *Box2 clogged again and probably lost data on flows at Box2. Cleaning the filter because it was flowing all morning when we arrived and was still flowing at 12:30.*
Weather:	**Sunny days, no cloud. High temperature since several days. 10°C measured**		
Timing:	Departure:	**07:30:00**	
	Return:	**20:15:00**	
Participants:	**Antoine Chabas**		
	Josué Bock		
	/		
	/		
	/		

**Complete all cells in yellow*

Pictures link : *Z:/WISPER/MATAN/Antoine internship - Hydrology of permafrost degradation/Terrain – Monitoring/20230822_ADM/Photos*

Data link : *Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\WATER MONITORING\20230822*

FORECASTED ACTIONS / TO DO LIST :	
Collect the Rock Surface temperature of North Face in August with Josue or Manu – see with Josue the locatio	OK
Collect iButton data at the end of Summer	OK
Ask for weather station data of 2022 and 2023 – Meteo France or IGE ? - **Wait for end of August**	

WATER SAMPLING DEVICE

Study of permafrost thaw hydrology

1. Water collect

Comments:

Box 1: 1 bottle collected. Following the Flow rate, not so mucn of runoff the last days. Proobably no precipitation during last days on the ADM.

Box 2: 1 bottle collected in the bucket. Not so much water in it and almost no sediments were present in the rain gauge. We can simply assume that there was no runoff in this location last days.

I think that filter was full of sediments so maybe most of flows at box2 havent been recorded for 2023. When we left the Aiguille around 18:00, there was a huge flow in the Box2.
One suggestion for next year would be to clean the collecting roof during winter to avoid max of sediments.

TNL: 1 bottle from the trap in the TNL.

ELV : 1 bottle collected near to the elevator with high conductivity.

BRCK: No water collected here



Box 1



Box 2 – 10h15



Box 2 – Full of sediments



No water in the bucket or flow rate recorded but a flow was still occuring in the morning – Data probably lost this year on Box2

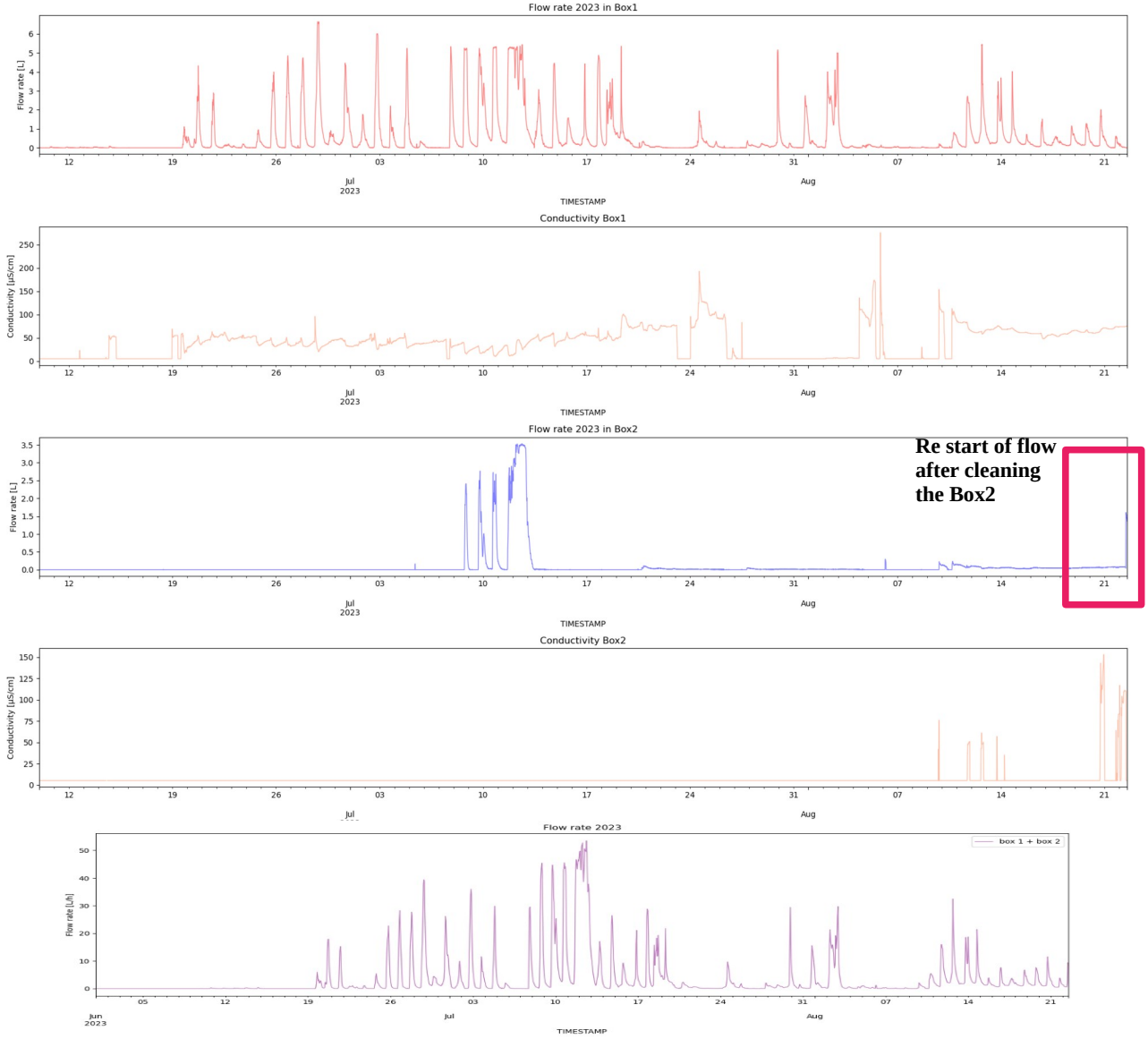


The filter of the raingauge wae full of dirt. Everything has been cleaned. Even a little rock was stuck in the raingauge.



A lot of water was flowing into the Box2 (not in the Box1). Even the bucket was full whereas there are holes at the bottom.,

2. Logger and conductivity

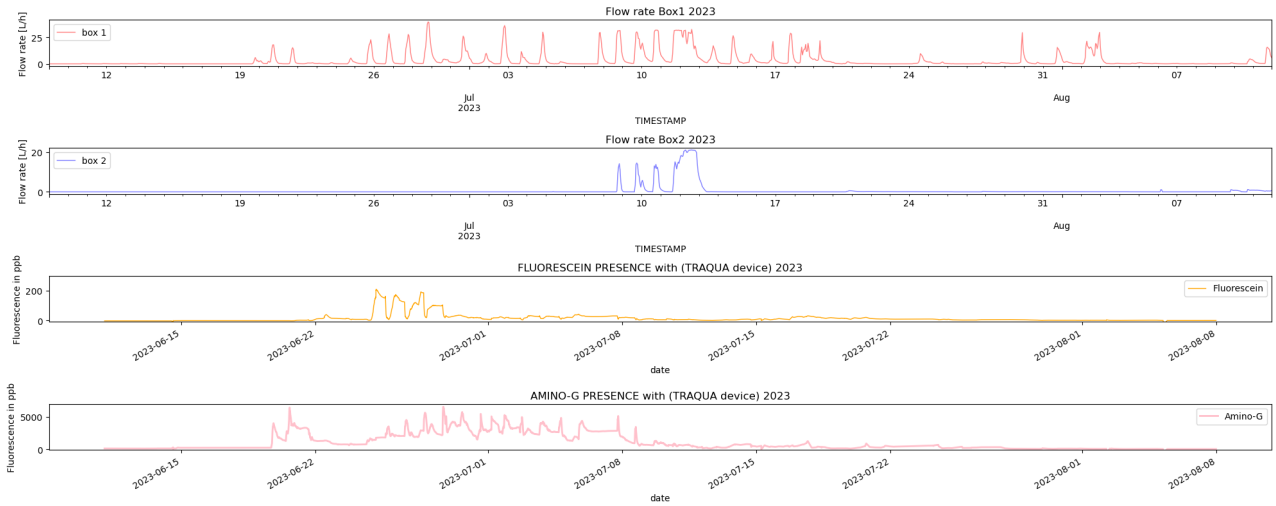


Comments:

A lot of water flows through the gallery probably due to the high temperature of last days.

It seems that flows occurs in the Box2 more than in the Box1 but the sediments that blocked the raingauge prevented from recording data... Maybe some data missed this year from the Box2. But Box2 was really cleaned and seems well working the whole day. Maybe good info to come for end of August and September.

3. Logger: Flow rate and fluo



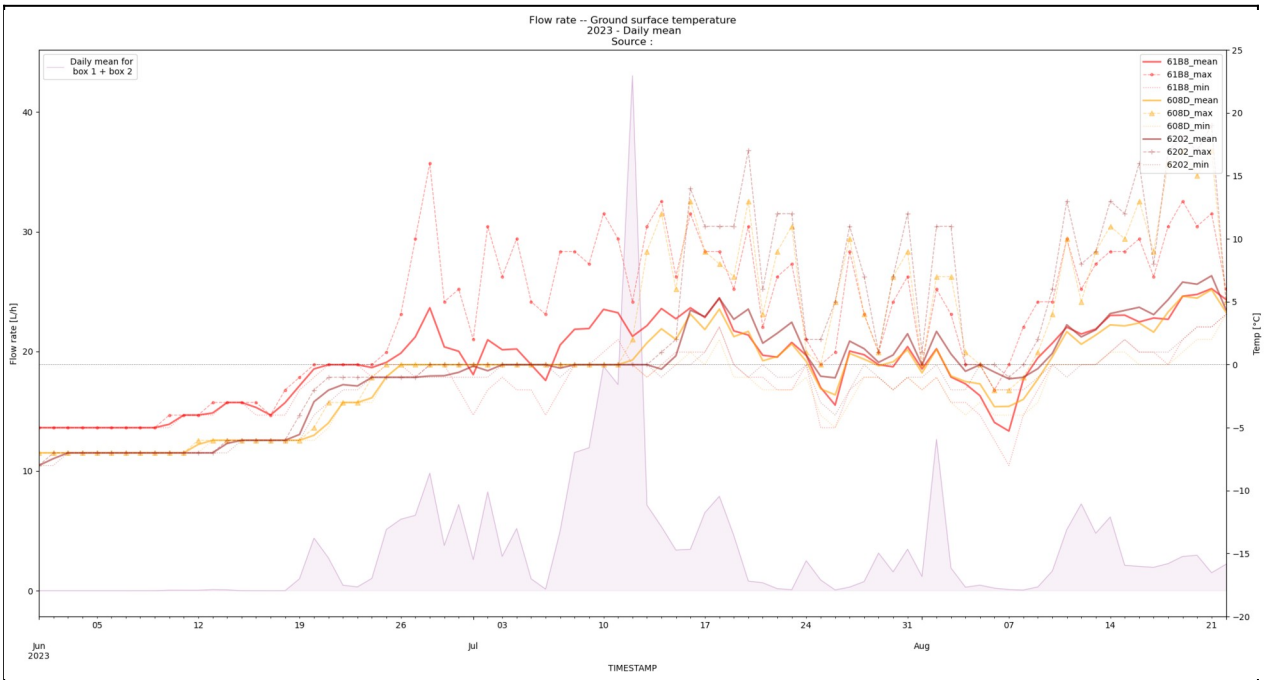
4. Data from iButtons (north face and gallery)

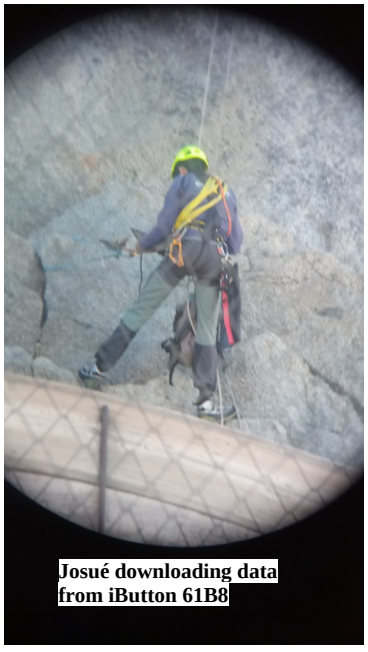
Josué collected iButtons on the north face.
3 iButtons were found (vs only one last year). Josué observed also some borehole for iButtons empty or falling rocks with holes. Probably old iButtons lost in rocks falls.
Ibuttons found:
- 61B8 at 11h15 – from 9/05/2022 to 22/08/2023
- 608D at 11h50 - from 9/05/2022 to 22/08/2023
- 6202 at 12h10 – from 06/09/2022 to 22/08/2023

The data are here: ***Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\TEMPERATURE\MAGST\MAGST_2023***

I collected the data of the 5 iButtons in the gallery near to the Box1.

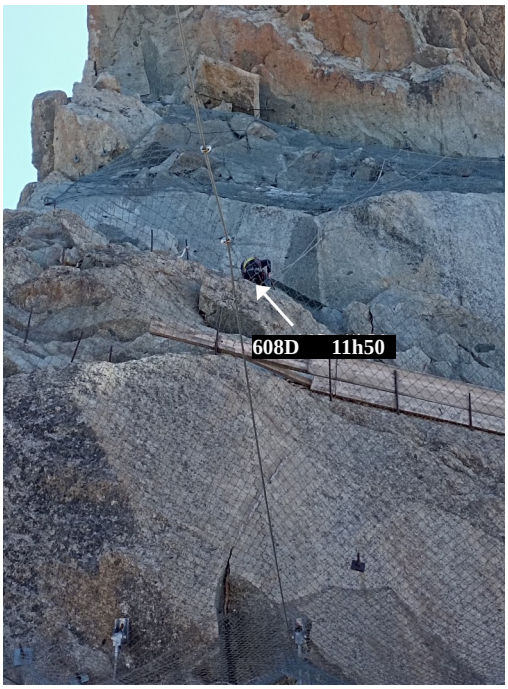
The data are here: ***Z:\WISPER\MATAN\Antoine internship - Hydrology of permafrost degradation\Traitement donnees\TEMPERATURE\MAGST\20230822***





Josué downloading data from iButton 61B8





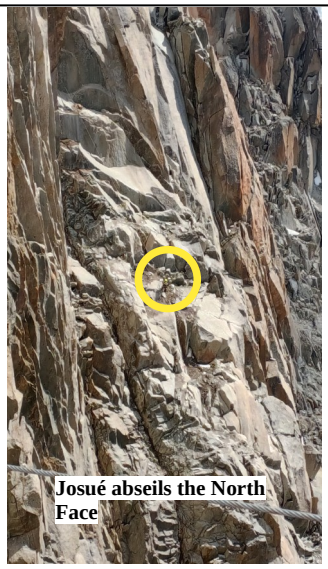


5. ABEM and ERT maintenance

Josué checked on the North face the ERT cable because of malfunctions.

He found the part of the cable damaged, probably rock shock then short circuit between electrical cables. (Josué got more pictures).

Finally, we dismantle the ABEM on the upper terrace and take it back to the laboratory to check certain functions.

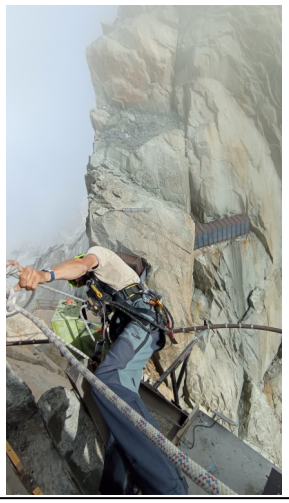


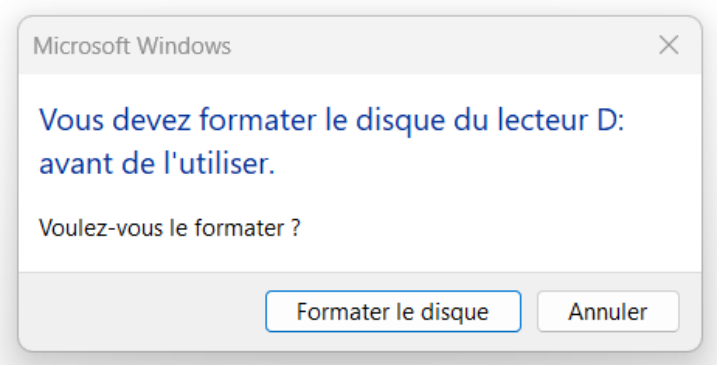


6. Change SD card of the N face camera

Josué change the SD card of the N face camera. New SD card capacity = 8GB so around to month of autonomy

One issue when I try to download the pictures on the PC from the SD card (64GB micro SD), is that it proposes me to format the disk (using the green USB adapter)... I will try with SD card adapter on my Mac, maybe it will works... Other wise, no pictures since end of June...





7. Faces views







Rock falls under the footbridge at 11 a.m.
Video in the pictures file



Aiguille du Midi with plenty marks of water on rock walls

Water collect and measures

Comments:





	ID Samples	Date	Time	Box1 / Box2 / TNL / BRCK / ELV / other Localisation	Bottle Si	Instantanous Conductivity	
1	2023822_AdM_Box1_1	22/08/23	10:20:00	Box1	125 ml	89	
2	2023822_AdM_Box2_2	22/08/23	10:25:00	Box2	125 ml	82,8	
3	2023822_AdM_TNL_3	22/08/23	15:00:00	TNL	125 ml	264	Trappe
4	2023822_AdM_ELV_4	22/08/23	15:15:00	ELV	125 ml	358	

Appendix 4: Python code example for 2022 data analysis

```
import os
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import datetime as dt
get_ipython().run_line_magic('matplotlib', 'inline')
import seaborn as sns
import scipy.stats as stats
from scipy.signal import correlate


plt.rcParams['font.size'] = 16
plt.rcParams["font.family"] = "Times New Roman"
```

```
# # 1. Open the files
# ## 1.1. Opening and pre treatment for flow rate

# On cherche le fichier, on l'ouvre puis on le lit. Ensuite on pense bien à
supprimer les premières lignes inutiles du fichier tout en mettant en index les
dates (essayer index_col='TIMESTAMP' dans read_csv)

# On indique bien les bons formats aussi à chaque colonne.

# On cherche le fichier Conducto_Flow rate
if not os.path.isfile('C:/Users/Antoine Chabas/Desktop/Traitement donnees/WATER
MONITORING/20230414/Apres midi/20230414_CR1000- ADM_Cond-Temp-debit.dat'):
print("Le fichier n'existe pas !\n")
else :
print("Le fichier existe :)\n")
try:
ttab1 = open('C:/Users/Antoine Chabas/Desktop/Traitement donnees/WATER
MONITORING/20230414/Apres midi/20230414_CR1000- ADM_Cond-Temp-debit.dat', 'r')
except:
print("Erreur d'ouverture de fichier\n")
else:
print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df1 = pd.read_csv(ttab1) #TTAB1 = Flow - Conductivity

###changement de l'en tête index 0 par la première ligne initiale
df1.columns = df1.loc[0]
entete1 = df1.columns
###suppression des lignes de description sur index 0,1, 2
df1.drop([0,1,2],axis=0,inplace=True)
df1.index=df1['TIMESTAMP']
print(df1.head(),'\n')
# In the logger flow is reported in mm for each time step of 10 minutes.
```

```
# The funnel diameter is 25.5 cm.

# To convert mm to mm3:
# Funnel radius = 12.75 cm = 127.5 mm
# Funnel area = 127.5^2*pi = 51070.5 mm2 = 510.7 cm2

# To get convert the flow from mm to volume mm3 you need to multiply by 51070.5
mm2.
# Then you can multiply by 1E-6 to convert mm3 to Litres or by 1E-9 to m3.
# Remember that the time step is 10 minutes. You can convert to Litre/hour by
multiplying by 6.

###changement des types de champs afin d'effectuer des calculs numériques dessus
df1.index= pd.to_datetime(df1.index, format= "%Y-%m-%d %H:%M:%S")
df1['TIMESTAMP'] = pd.to_datetime(df1['TIMESTAMP'], format= "%Y-%m-%d %H:%M:%S")
df1['Cond_Avg'] = df1['Cond_Avg'].astype(float)
df1['Temp_C_Avg'] = df1['Temp_C_Avg'].astype(float)
df1['Cond_2_Avg'] = df1['Cond_2_Avg'].astype(float)
df1['Temp_C_2_Avg'] = df1['Temp_C_2_Avg'].astype(float)
df1['Rain_mm_Tot'] = df1['Rain_mm_Tot'].astype(float)
df1['Rain_mm_2_Tot'] = df1['Rain_mm_2_Tot'].astype(float)
df1['Rain_L_Tot'] = df1['Rain_mm_Tot']*(51070.5*10**-6) #to convert to mm to L
(cf explanation above)
df1['Rain_L_2_Tot'] = df1['Rain_mm_2_Tot']*(51070.5*10**-6) #to convert to mm to
L (cf explanation above)


# ## 1.2. Opening and pre-treatment of Air temperature Tair MAAT (CG_forcing)

# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
S2MSAFRAN/CG_forcing.csv'):
          print("Le fichier n'existe pas !\n")
          else :
                    print("Le fichier existe :)\n")
          try:
                    ttab2 = open('C:/Users/Antoine
Chabas/Desktop/Traitementdonnees/TEMPERATURE/S2M SAFRAN/CG_forcing.csv', 'r')
          except:
                    print("Erreur d'ouverture de fichier\n")
else:
                    print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df2 = pd.read_csv(ttab2) #TTAB2 = données météo CG forcing

df2.index=df2['Time']
print(df2.head(),'\n')
```

```
###changement des types de champs afin d'effectuer des calculs numériques dessus
df2.index= pd.to_datetime(df2.index, format= "%d/%m/%Y %H:%M:%S")
df2['Time'] = pd.to_datetime(df2['Time'], format= "%d/%m/%Y %H:%M:%S")
df2['Tair'] = df2['Tair'].astype(float)
df2['Sin'] = df2['Sin'].astype(float)
df2['snowfall'] = df2['snowfall'].astype(float)
df2['rainfall'] = df2['rainfall'].astype(float)


# ## 1.3. Opening and pre-treatment of Surface temperatureTsurf MAGST (MAGST_2022)

# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/Antoine
Chabas/Desktop/Traitementdonnees/TEMPERATURE/MAGST/MAGST_2022.csv'):
          print("Le fichier n'existe pas !\n")
else :
          print("Le fichier existe :)\n")
try:
          ttab3 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/MAGST_2022.csv', 'r')
except:
          print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")


# lecture de la table
df3= pd.read_csv(ttab3) #TTAB3 = données des Ground Surface Temp of outdoor rockwall
from MAGST_2022 file

df31 = df3.copy()
df32 = df3.copy()
df31['Date/Time'] = pd.to_datetime(df31['Date/Time'], errors='coerce', format="%m/%d/%Y
%H:%M")
df32['Date/Time'] = pd.to_datetime(df32['Date/Time'], errors='coerce', format="%d/%m/%y
%H:%M:%S")
df3 = pd.concat([df31,df32], ignore_index=True)
df3.index=df3['Date/Time']
print(df3,'\n')

###changement des types de champs afin d'effectuer des calculs numériques dessus
df3['Value'] = df3['Value'].astype(float)
# ### 1.4. 1. Opening and pre-treatment of Surface temperature gallery Tsurf
GSTint from iButton 1 (DC7E)

# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/1_9A0000000EDC7E53_051023.csv'):
          print("Le fichier n'existe pas !\n")
else :
```

```
          print("Le fichier existe :)\n")
try:
          ttab5 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/1_9A0000000EDC7E53_051023.csv', 'r')
except:
          print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df5 = pd.read_csv(ttab5)
print(df5.head())

df5.index=df5['Date/Time']
print(df5.head(),'\n')


# ### 1.4. 2.Opening and pre-treatment of Surface temperature gallery Tsurf
GSTint from iButton 2
#

# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/2_AC0000000F04D953_051023.csv'):
          print("Le fichier n'existe pas !\n")
else :
          print("Le fichier existe :)\n")
try:
          ttab6 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/2_AC0000000F04D953_051023.csv', 'r')
except:
print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df6 = pd.read_csv(ttab6)
print(df6.head())

###changement des types de champs afin d'effectuer des calculs numériques dessus
df5.index= pd.to_datetime(df5.index, format= "%d/%m/%Y %H:%M:%S")
df5['Date/Time'] = pd.to_datetime(df5['Date/Time'], format= "%d/%m/%Y %H:%M:%S")
df5['Value'] = df5['Value'].astype(float)

df6.index=df6['Date/Time']
print(df6.head(),'\n')

###changement des types de champs afin d'effectuer des calculs numériques dessus
df6.index= pd.to_datetime(df6.index, format= "%d/%m/%Y %H:%M:%S")
df6['Date/Time'] = pd.to_datetime(df6['Date/Time'], format= "%d/%m/%Y %H:%M:%S")
df6['Value'] = df6['Value'].astype(float)
# ### 1.4. 3.Opening and pre-treatment of Surface temperature gallery Tsurf
```

```
GSTint from iButton 3
#

# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/3_630000000EF37C53_051023.csv'):
          print("Le fichier n'existe pas !\n")
else :
print("Le fichier existe :)\n")
try:
          ttab7 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/3_630000000EF37C53_051023.csv', 'r')
except:
          print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df7 = pd.read_csv(ttab7)
print(df7.head())

df7.index=df7['Date/Time']
print(df7.head(),'\n')

###changement des types de champs afin d'effectuer des calculs numériques dessus
df7.index= pd.to_datetime(df7.index, format= "%d/%m/%Y %H:%M:%S")
df7['Date/Time'] = pd.to_datetime(df7['Date/Time'], format= "%d/%m/%Y %H:%M:%S")
df7['Value'] = df7['Value'].astype(float)
# ### 1.4. 4.Opening and pre-treatment of Surface temperature gallery Tsurf
GSTint from iButton 4

# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/4_560000000EDFC953_051023.csv'):
          print("Le fichier n'existe pas !\n")
else :
          print("Le fichier existe :)\n")
try:
          ttab8 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230510/4_560000000EDFC953_051023.csv', 'r')
except:
          print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df8 = pd.read_csv(ttab8)
print(df8.head())

df8.index=df8['Date/Time']
print(df8.head(),'\n')
```

```
###changement des types de champs afin d'effectuer des calculs numériques dessus
df8.index= pd.to_datetime(df8.index, format= "%d/%m/%Y %H:%M:%S")
df8['Date/Time'] = pd.to_datetime(df8['Date/Time'], format= "%d/%m/%Y %H:%M:%S")
df8['Value'] = df8['Value'].astype(float)
# In[24]:
df8.index=df8['Date/Time']
print(df8.head(),'\n')
# ### 1.4. 5.Opening and pre-treatment of Surface temperature gallery Tsurf
GSTint from iButton 5



# On cherche le fichier CG forcing
if not os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230531/5_480000000C376153_053123.csv'):
          print("Le fichier n'existe pas !\n")
else :
          print("Le fichier existe :)\n")
try:
          ttab9 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/TEMPERATURE/
MAGST/20230531/5_480000000C376153_053123.csv', 'r')
except:
          print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df9 = pd.read_csv(ttab9)
print(df9.head())

df9.index=df9['Date/Time']
print(df9.head(),'\n')

###changement des types de champs afin d'effectuer des calculs numériques dessus


df9.index= pd.to_datetime(df9.index, format= "%d/%m/%Y %H:%M:%S")
df9['Date/Time'] = pd.to_datetime(df9['Date/Time'], format= "%d/%m/%Y %H:%M:%S")
df9['Value'] = df9['Value'].astype(float)
# In[28]:
df9.index=df9['Date/Time']
print(df9.head(),'\n')
# ## 1.5. Opening and pre-treatment of fluorescence



# On cherche le fichier MAGST_2022
if not
os.path.isfile('C:/Users/AntoineChabas/Desktop/Traitementdonnees/WATERMONITORING/
20230303/ADM-CR1000-fracture_Fluo.dat'):
          print("Le fichier n'existe pas !\n")
```

```
else :
          print("Le fichier existe :)\n")
try:
ttab4 = open('C:/Users/AntoineChabas/Desktop/Traitementdonnees/WATERMONITORING/
20230303/ADM-CR1000-fracture_Fluo.dat', 'r')
except:
          print("Erreur d'ouverture de fichier\n")
else:
          print("Fichier ouvert : le traitement va commencer\n")
# lecture de la table
df4 = pd.read_csv(ttab4) #TTAB4 = données fluo

###changement de l'en tête index 0 par la première ligne initiale
df4.columns = df4.loc[0]
entete1 = df4.columns
###suppression des lignes de description sur index 0,1, 2
df4.drop([0,1,2],axis=0,inplace=True)
df4.index=df4['TIMESTAMP']
print(df4.head(),'\n')

###changement des types de champs afin d'effectuer des calculs numériques dessus
df4.index= pd.to_datetime(df4.index, format= "%Y-%m-%d %H:%M:%S")
df4['TIMESTAMP'] = pd.to_datetime(df4['TIMESTAMP'], format= "%Y-%m-%d %H:%M:%S")
df4['Tr(1)'] = df4['Tr(1)'].astype(float)
df4['Tr(2)'] = df4['Tr(2)'].astype(float)
df4['Tr(3)'] = df4['Tr(3)'].astype(float)
```

2. Graphs

```
# Il est possible d'avoir un affiche par sélection sur la DateTimeIndex par la
fonction loc['']
# C'est pourquoi il est important de mettre en index les dates des fichiers de
données en premier lieu
```

 # ## 2.1. Flow rate 2022

```
# loc[] permet d'avoir une date choisie de l'index
# resample prends toutes les t de temps choisi pour pouvoir faire des calculs
statistiques comme la moyenne (mean()) ou encore le min ou le max... Possible de
faire un aggrégat de toutes ces données

#Nouvelle figure
plt.figure(figsize=(20,10))


plt.subplot(411)
(df1.loc['2022-07-10':'2022-07-14']['Rain_L_Tot']).plot(label='box 1',
color='red', linewidth=1, alpha=0.5)
plt.title('Flow rate 2022 in Box1')
```

```
plt.ylabel('Flow rate [L]')


plt.subplot(412)
(df1.loc['2022-07-10':'2022-07-14']['Cond_2_Avg']*1000).plot(label='Cond box 1',
color='black', linewidth=1, alpha=0.5)
plt.title('Conductivity 2022 in Box1')
plt.ylabel('Conductivity (\u03bcS/cm)')


plt.subplot(413)
(df1.loc['2022-07-10':'2022-07-14']['Rain_L_2_Tot']).plot(label='box 2',
color='blue', linewidth=1, alpha=0.5)
plt.title('Flow rate 2022 in Box2')
plt.ylabel('Flow rate [L]')


plt.subplot(414)
(df4.loc['2022-07-10':'2022-07-14']['Tr(3)']).plot(label='box 1',
color='deeppink', linewidth=1, alpha=0.5)
plt.title('Amino-G')
plt.ylabel('Fluo')
plt.tight_layout()
plt.show()

#Nouvelle figure
plt.figure(figsize=(20,12))


plt.subplot(411)
(df1.loc['2022']['Rain_L_Tot']*6).plot(label='box 1', color='red', linewidth=1,
alpha=0.5)
plt.title('Flow rate 2022 in Box1')
plt.ylabel('Flow rate [L/h]')


plt.subplot(412)
(df1.loc['2022']['Rain_L_2_Tot']*6).plot(label='box 2', color='blue',
linewidth=1, alpha=0.5)
plt.title('Flow rate 2022 in Box2')
plt.ylabel('Flow rate [L/h]')


plt.subplot(413)
(df4.loc['2022']['Tr(3)']).plot(label='box 1', color='deeppink', linewidth=1,
alpha=0.5)
plt.title('Amino-G')
plt.ylabel('Fluorescence concentration')


plt.subplot(414)
(df1.loc['2022']['Cond_2_Avg']*1000).plot(label='Cond box 1', color='black',
linewidth=1, alpha=0.5)
```

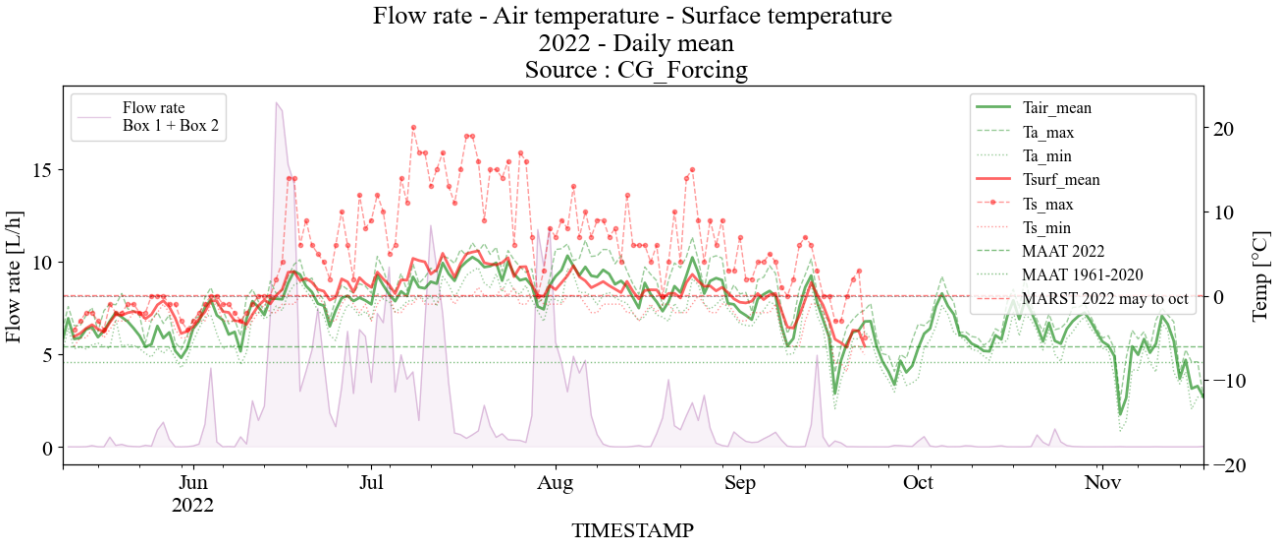
```
plt.title('Conductivity 2022 in Box1')
plt.ylabel('Conductivity (\u03bcS/cm)')
plt.tight_layout()
plt.show()

#Nouvelle figure
plt.figure(figsize=(20,10))


plt.subplot(211)
(df1.loc['2022-06-15':'2022-09-15']['Rain_L_Tot']).plot(label='box
1',color='red',linewidth=1, alpha=0.5)
plt.title('Flow rate 2022 in Box1')
plt.ylabel('Flow rate [L]')


plt.subplot(212)
(df1.loc['2022-06-15':'2022-09-15']['Cond_2_Avg']*1000).plot(label='Cond box
1',color='black', linewidth=1, alpha=0.5)
plt.title('Conductivity 2022 in Box1')
plt.ylabel('Conductivity (\u03bcS/cm)')
plt.tight_layout()
plt.show()

#Nouvelle figure
plt.figure(figsize=(18,8))


plt.subplot(211)
(df1.loc['2022']['Rain_L_Tot']*6).plot(label='box 1', color='red', linewidth=1,
alpha=0.5)
plt.title('Flow rate 2022 in Box1')
plt.ylabel('Flow rate [L/h]')


plt.subplot(212)
(df1.loc['2022']['Rain_L_2_Tot']*6).plot(label='box 2', color='blue',
linewidth=1, alpha=0.5)
plt.title('Flow rate 2022 in Box2')
plt.ylabel('Flow rate [L/h]')
plt.tight_layout()
plt.show()

#Nouvelle figure
plt.figure(figsize=(18,8))


plt.subplot(211)
(df1.loc['2022']['Rain_L_Tot']*6).plot(label='box 1', color='red',
linewidth=1,alpha=0.5)
plt.title('Flow rate 2022 in Box1')
plt.ylabel('Flow rate [L/h]')
```

```
plt.ylim(-5,60)


plt.subplot(212)
(df1.loc['2022']['Rain_L_2_Tot']*6).plot(label='box 2', color='blue',linewidth=1,
alpha=0.5)
plt.title('Flow rate 2022 in Box2')
plt.ylabel('Flow rate [L/h]')
plt.ylim(-5,60)
plt.tight_layout()
plt.savefig("flow rate 2022.svg",dpi=900)
plt.show()

tair =df2.loc['2022/06/14':'2022/06/16']
['Tair'].resample('3H').agg(['max','min','mean'])
tsurf =df3.loc['2022-06-14':'2022-06-16']
['Value'].resample('3H').agg(['max','min','mean'])
#Nouvelle figure
plt.figure(figsize=(15,15))


plt.subplot(311)
(df1.loc['2022-06-14':'2022-06-16']['Rain_L_Tot']).plot(label='box 1',color='purple',
linewidth=1, alpha=1)
plt.title('Flow rate 2022 in Box1')
plt.ylabel('Flow rate [L]')


plt.subplot(312)
tair['mean'].plot(label='Air Temp', color='Green', linewidth=1, alpha=1)
plt.title('Air Temperature')
plt.ylabel('Temperature [°C]')


plt.subplot(313)
tsurf['mean'].plot(label='Surf Temp', color='red', linewidth=1, alpha=1)
plt.title('Rock surface temperature')
plt.ylabel('Temperature [°C]')
plt.tight_layout()
plt.show()

#Nouvelle figure : Sum of Box 1 and Box 2
plt.figure(figsize=(18,5))
barWidth = 0.2
y1 = (df1.loc['2022']['Rain_L_Tot']).resample('m').sum()
y2 = (df1.loc['2022']['Rain_L_2_Tot']).resample('m').sum()
y3 =
(df1.loc['2022']['Rain_L_Tot']+df1.loc['2022']['Rain_L_2_Tot']).resample('m').sum()
r = range(len(y1))
plt.plot(r,y3, marker='o', color='purple', linewidth=2, alpha=0.5)
plt.bar(r, y1, width = barWidth, color = ['red' for i in y1],linewidth = 1,
label='Box1', alpha=0.6)
```

```
plt.bar(r, y2, width = barWidth, bottom = y1, color = ['blue' for i in y1],
linewidth = 1, label='Box2', alpha=0.6)
plt.xticks(range(len(y1)), ['May', 'June', 'July', 'August','Sept', 'October',
'November', 'December'])

plt.ylabel('Volume of water [L]')
plt.title('Total monthly flow rate 2022')
plt.legend()
plt.show()


# ## 2.2. Volume of water during 2022

y1 =(df1.loc['2022']['Rain_L_Tot']+df1.loc['2022']['Rain_L_2_Tot']).cumsum(axis=0,
skipna = True)
y2 = df1.loc['2022']['Rain_L_Tot'].cumsum(axis=0, skipna = True)
y3 = df1.loc['2022']['Rain_L_2_Tot'].cumsum(axis=0, skipna = True)
Maxcum = round(y1.max())
print('The total volume of water is ',Maxcum,' L')


#Nouvelle figure
plt.figure(figsize=(20,5))
plt.plot(y1, label='Box 1 + Box 2', color='purple', linewidth=3, alpha=0.4)
plt.fill_between(df1.loc['2022'].index,y1,y2=0,color='purple', alpha=0.1)
plt.plot(y2, label='Box 1', color='red', linewidth=1.5, alpha=0.5)
plt.plot(y3, label='Box 2', color='blue', linewidth=1.5, alpha=0.5)
plt.ylabel('Volume of water [L]')
plt.title('Cumulated flow rate 2022')
plt.legend()
plt.savefig("Voltot2022.svg",dpi=900)
plt.show()



water =((df1.loc['2022']['Rain_L_Tot']+df1.loc['2022']['Rain_L_2_Tot'])*6).resample('d'
).mean() #x6 is to convert inn L per hour because it was in L per 10 min
tair = df2.loc['2022/05/10':]['Tair'].resample('d').agg(['max','min','mean'])
tsurf = df3.loc['2022-05-12':]['Value'].resample('d').agg(['max','min','mean'])


plt.figure(figsize=(15,5))
plot1 = water.plot(label='Daily mean for\n box 1 + box 2', color='purple',
linewidth=1, alpha=0.2)
plt.fill_between(water.index,water,y2=0,color='purple', alpha=0.05)
plt.ylabel('Flow rate [L/h]')
plt.legend(loc=2)
plot2=plot1.twinx()
tair['mean'].plot(label='Tair_mean', linestyle='-', color='green', linewidth=2,
alpha=0.6)
tair['max'].plot(label='Ta_max', linestyle='--', color='green', linewidth=1,alpha=0.4)
```

```
tair['min'].plot(label='Ta_min', linestyle=':', color='green', linewidth=1,
alpha=0.4)
tsurf['mean'].plot(label='Tsurf_mean', linestyle='-', color='red', linewidth=2,
alpha=0.6)
tsurf['max'].plot(label='Ts_max', marker='.', linestyle='--', color='red',
linewidth=1, alpha=0.4)
tsurf['min'].plot(label='Ts_min', linestyle=':', color='red', linewidth=1,
alpha=0.4)
plt.ylabel('Temp [°C]')
plt.ylim((-20,25))
plt.axhline(y=0, linestyle='--', color='black', linewidth = 0.5, alpha=0.5)
plt.title('Flow rate - Air temperature - Ground surface temperature\n 2022 -
Daily mean\n Source : CG_Forcing')
plt.legend(loc=1)
plt.show()

water =
((df1.loc['2022']['Rain_L_Tot']+df1.loc['2022']['Rain_L_2_Tot'])*6).resample('d'
).mean()
tair = df2.loc['2022/05/10':]['Tair'].resample('d').agg(['max','min','mean'])
tsurf = df3.loc['2022-05-12':]['Value'].resample('d').agg(['max','min','mean'])
MAAT_2022 = df2.loc['2022':]['Tair'].mean()
MARST_2022 = df3.loc['2022-05-12':]['Value'].mean()
MAAT_19612020 = df2.loc['1961-01-01': '2020-12-31']['Tair'].mean()
plt.figure(figsize=(15,5))
plot1 = water.plot(label='Daily mean for\n box 1 + box 2', color='purple',
linewidth=1, alpha=0.2)
plt.fill_between(water.index,water,y2=0,color='purple', alpha=0.05)
plt.ylabel('Flow rate [L/h]')
plt.legend(loc=2)
plot2=plot1.twinx()
tair['mean'].plot(label='Tair_mean', linestyle='-', color='green', linewidth=2,
alpha=0.6)
tair['max'].plot(label='Ta_max', linestyle='--', color='green', linewidth=1,
alpha=0.4)
tair['min'].plot(label='Ta_min', linestyle=':', color='green', linewidth=1,
alpha=0.4)
tsurf['mean'].plot(label='Tsurf_mean', linestyle='-', color='red', linewidth=2,
alpha=0.6)
tsurf['max'].plot(label='Ts_max', marker='.', linestyle='--', color='red',
linewidth=1, alpha=0.4)
tsurf['min'].plot(label='Ts_min', linestyle=':', color='red', linewidth=1,
alpha=0.4)
plt.ylabel('Temp [°C]')
plt.ylim((-20,25))
plt.axhline(y=0, linestyle='--', color='black', linewidth = 0.5, alpha=0.5)
plt.axhline(y=MAAT_2022, label='MAAT 2022', linestyle='--', color='green',
linewidth=1, alpha=0.5)
plt.axhline(y=MAAT_19612020, label='MAAT 1961-2020', linestyle=':',
color='green', linewidth=1, alpha=0.5)
```

```
plt.axhline(y=MARST_2022, label='MARST 2022 may to oct', linestyle='--',
color='red', linewidth=1, alpha=0.5)
plt.title('Flow rate - Air temperature - Surface temperature\n 2022 - Daily
mean\n Source : CG_Forcing')
plt.legend(loc=1, fontsize=8)
plt.show()
```




```
water =(df1.loc['2022']['Rain_L_Tot']*6+df1.loc['2022']['Rain_L_2_Tot']*6).resample('d'
).mean()
tsurf_ext =
df3.loc['2022-05-12':]['Value'].resample('d').agg(['max','min','mean'])
tsurf_int_1 = df5.loc['2022-05-12':
'2022-11-30']['Value'].resample('d').agg(['max','min','mean'])
tsurf_int_2 = df6.loc['2022-05-12':
'2022-11-30']['Value'].resample('d').agg(['max','min','mean'])
tsurf_int_3 = df7.loc['2022-05-12':
'2022-11-30']['Value'].resample('d').agg(['max','min','mean'])
tsurf_int_4 = df8.loc['2022-05-12':
'2022-11-30']['Value'].resample('d').agg(['max','min','mean'])
tsurf_int_5 = df9.loc['2022-05-12':
'2022-11-30']['Value'].resample('d').agg(['max','min','mean'])
plt.figure(figsize=(20,5))
plot1 = water.plot(label='Daily mean for\n box 1 + box 2', color='purple',
linewidth=1, alpha=0.2)
plt.fill_between(water.index,water,y2=0,color='purple', alpha=0.05)
plt.ylabel('Flow rate [L/h]')
plt.legend(loc=2)
plot2=plot1.twinx()
tsurf_int_1['mean'].plot(label='iButton 1', linestyle='-', color='darkorange',
linewidth=1.5, alpha=0.6)
tsurf_int_2['mean'].plot(label='iButton 2', linestyle='-', color='chartreuse',
linewidth=1.5, alpha=0.5)
tsurf_int_3['mean'].plot(label='iButton 3', linestyle='-',
color='mediumturquoise', linewidth=1.5, alpha=0.4)
```

```
tsurf_int_4['mean'].plot(label='iButton 4', linestyle='-',
color='cornflowerblue', linewidth=1.5, alpha=0.3)
tsurf_int_5['mean'].plot(label='iButton 5 - Internal air temp', linestyle='-',
color='black', linewidth=1.5, alpha=0.3)
tsurf_ext['mean'].plot(label='RST_ext_mean', linestyle='-', color='red',
linewidth=1.5, alpha=0.6)
plt.ylabel('Temp [°C]')
plt.ylim((-20,20))
plt.axhline(y=0, linestyle='--', color='black', linewidth = 0.5, alpha=0.5)
plt.title('Flow rate - Rock Surface temperature external and internal\n 2022 -
Daily mean')
plt.legend(loc=1)
plt.show()

water =(df1.loc['2022']['Rain_L_Tot']*6+df1.loc['2022']['Rain_L_2_Tot']*6).resample('d'
).mean()
aminoG = df4.loc['2022']['Tr(3)'].resample('d').agg(['max','min','mean'])
plt.figure(figsize=(18,5))
plot1 = water.plot(label='Daily mean for Box 1 + Box 2', color='purple',
linewidth=1, alpha=0.4)
plt.fill_between(water.index,water,y2=0,color='purple', alpha=0.05)
plt.ylabel('Flow rate [L/h]')
plt.legend(loc=2)
plt.ylim((0,20))
plot2=plot1.twinx()
aminoG['mean'].plot(label='Amino-G', linestyle='--', color='deeppink',
linewidth=2, alpha=0.8)
plt.ylabel('Fluorescence concentration')
plt.ylim((0,2500))
plt.title('Flow rate - Fluorescence probe signal\n 2022 - Daily mean')
plt.legend(loc=1)
plt.show()

water =
(df1.loc['2022']['Rain_L_Tot']+df1.loc['2022']['Rain_L_2_Tot']).resample('d').me
an()
solar = df2.loc['2022/05/10':]['Sin'].resample('d').agg(['max','min','mean'])
print(solar.head())
plt.figure(figsize=(15,5))
plot1 = water.plot(label='box 1+box 2', color='purple', linewidth=1, alpha=0.2)
plt.fill_between(water.index,water,y2=0,color='purple', alpha=0.05)
plt.ylabel('Flow rate [L]')
plt.legend(loc=2)
plot2=plot1.twinx()
solar['mean'].plot(label='Sol_mean', linestyle='-', color='orange', linewidth=2,
alpha=0.6)
solar['max'].plot(label='Sol_max', linestyle='--', color='orange', linewidth=1,
alpha=0.4)
plt.ylabel('Solar radiation')
plt.axhline(y=0, linestyle='--', color='black', alpha=0.2)
```

```
plt.title('Flow rate - Solar radiation\n 2022 - Daily mean\n Source :
CG_Forcing')
plt.legend(loc=1)
plt.show()

water =(df1.loc['2022']['Rain_L_Tot']*6+df1.loc['2022']
['Rain_L_2_Tot']*6).resample('d').mean()
fluo1 = df4.loc['2022']['Tr(1)'].resample('d').agg(['max','min','mean'])
fluo2 = df4.loc['2022']['Tr(2)'].resample('d').agg(['max','min','mean'])
fluo3 = df4.loc['2022']['Tr(3)'].resample('d').agg(['max','min','mean'])
plt.figure(figsize=(20,5))
plot1 = water.plot(label='Daily mean Flow rate\n for box 1 + box 2',
color='purple', linewidth=1, alpha=0.2)
plt.fill_between(water.index,water,y2=0,color='purple', alpha=0.05)
plt.ylabel('Flow rate [L/h]')
plt.legend(loc=2)
plot2=plot1.twinx()
fluo3['mean'].plot(label='Amino-G', linestyle='-', color='red', linewidth=0.8,
alpha=1)
plt.ylabel('Fluo rate concentration')
plt.axhline(y=0, linestyle='--', color='black', alpha=0.2)
plt.title('Flow rate - Fluo\n 2022 - Daily mean')
plt.legend(loc=1)
plt.show()


# # 2.2. Ecoulement mai/juin/juillet/aout

# loc[] permet d'avoir une date choisie de l'index
# resample prends toutes les t de temps choisi pour pouvoir faire des calculs
statistiques comme la moyenne (mean()) ou encore le min ou le max... Possible de
faire un aggrégat de toutes ces données

#Nouvelle figure
plt.figure(figsize=(15,8))


plt.subplot(2,2,1)
(df1.loc['2022-05']['Rain_L_Tot']+df1.loc['2022-05']
['Rain_L_2_Tot']).resample('H').mean().plot(label='box 1 + box2', color='purple',
linewidth=1, alpha = 0.2)
df1.loc['2022-05']['Rain_L_Tot'].resample('H').mean().plot(label='box 1',
color='red', linewidth=0.5, alpha=0.8, linestyle='--')
df1.loc['2022-05']['Rain_L_2_Tot'].resample('H').mean().plot(label='box 2',
color='blue', linewidth=1, alpha=0.8, linestyle='--')
plt.ylabel('Flow rate [L/h]')
plt.title('May 2022')
plt.ylim((0,12))
plt.legend()
```

```
plt.subplot(2,2,2)
(df1.loc['2022-06']['Rain_L_Tot']+df1.loc['2022-06']
['Rain_L_2_Tot']).resample('H').mean().plot(label='box 1 + box2', color='purple',
linewidth=1, alpha = 0.2)
df1.loc['2022-06']['Rain_L_Tot'].resample('H').mean().plot(label='box 1',
color='red', linewidth=1, alpha=0.8, linestyle='--')
df1.loc['2022-06']['Rain_L_2_Tot'].resample('H').mean().plot(label='box 2',
color='blue', linewidth=1, alpha=0.8, linestyle='--')
plt.ylabel('Flow rate [L/h]')
plt.title('June 2022')
plt.ylim((0,12))
plt.legend()


plt.subplot(2,2,3)
(df1.loc['2022-07']['Rain_L_Tot']+df1.loc['2022-07']
['Rain_L_2_Tot']).resample('H').mean().plot(label='box 1 + box2', color='purple',
linewidth=1, alpha = 0.2)
df1.loc['2022-07']['Rain_L_Tot'].resample('H').mean().plot(label='box 1',
color='red', linewidth=1, alpha=0.8, linestyle='--')
df1.loc['2022-07']['Rain_L_2_Tot'].resample('H').mean().plot(label='box 2',
color='blue', linewidth=1, alpha=0.8, linestyle='--')
plt.ylabel('Flow rate [L/h]')
plt.title('July 2022')
plt.ylim((0,12))
plt.legend()


plt.subplot(2,2,4)
(df1.loc['2022-08']['Rain_L_Tot']+df1.loc['2022-08']
['Rain_L_2_Tot']).resample('H').mean().plot(label='box 1 + box2', color='purple',
linewidth=1, alpha = 0.2)
df1.loc['2022-08']['Rain_L_Tot'].resample('H').mean().plot(label='box 1',
color='red', linewidth=1, alpha=0.8, linestyle='--')
df1.loc['2022-08']['Rain_L_2_Tot'].resample('H').mean().plot(label='box 2',
color='blue', linewidth=1, alpha=0.8, linestyle='--')
plt.ylabel('Flow rate [L/h]')
plt.title('Aug. 2022')
plt.ylim((0,12))
plt.legend()
plt.tight_layout()
plt.show()

plt.figure(figsize=(16,8))


plt.subplot(2,2,1)
(df1.loc['2022-05']['Rain_L_Tot']+df1.loc['2022-05']
['Rain_L_2_Tot']).resample('H').mean().plot(label='Box1 + Box2', color='purple',
linewidth=1)
plt.ylabel('Flow rate [L/h]')
```

```
plt.ylim((0,12))
plt.title('May 2022')
plt.legend()


plt.subplot(2,2,2)
(df1.loc['2022-06']['Rain_L_Tot']+df1.loc['2022-06']['Rain_L_2_Tot']).resample('
H').mean().plot(label='Box1 + Box2', color='purple', linewidth=1)
plt.ylabel('Flow rate [L/h]')
plt.ylim((0,12))
plt.title('June 2022')
plt.legend()
plt.subplot(2,2,3)
(df1.loc['2022-07']['Rain_L_Tot']+df1.loc['2022-07']
['Rain_L_2_Tot']).resample('H').mean().plot(label='Box1 + Box2', color='purple',
linewidth=1)
plt.ylabel('Flow
 rate [L/h]')
plt.ylim((0,12))
plt.title('July 2022')
plt.legend()
plt.subplot(2,2,4)
(df1.loc['2022-08']['Rain_L_Tot']+df1.loc['2022-08']['Rain_L_2_Tot']).resample('
H').mean().plot(label='Box1 + Box2', color='purple', linewidth=1)
plt.ylabel('Flow rate [L/h]')
plt.ylim((0,12))
plt.title('August 2022')
plt.legend()
plt.tight_layout()
plt.show()
```

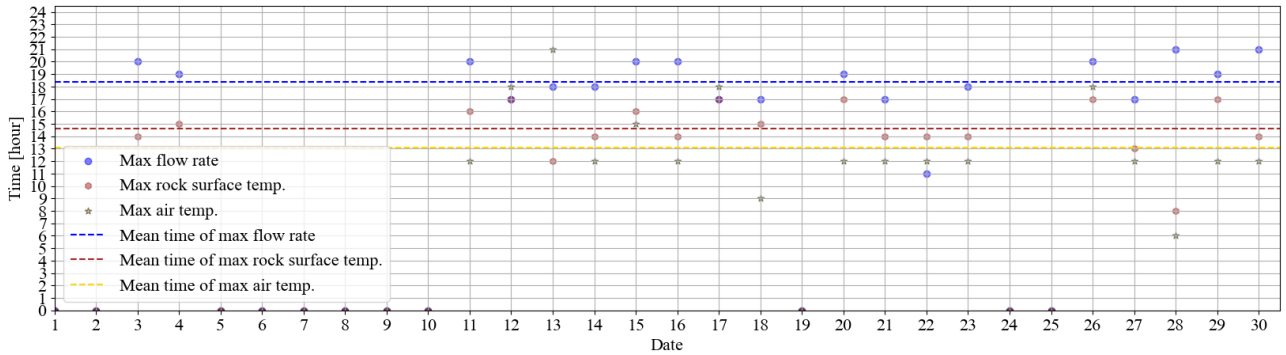
 # # CORRELATION TEMPERATURE AND FLOWRATE

```
water =(df1.loc['2022-06-01':'2022-06-30']['Rain_L_Tot']+df1.loc['2022-06']
['Rain_L_2_Tot']).resample('3H').mean()
tair =df2.loc['2022/06/01':'2022/06/30']
['Tair'].resample('3H').agg(['max','min','mean'])
tsurf =df3.loc['2022-06-01':'2022-06-30']
['Value'].resample('3H').agg(['max','min','mean'])
plt.figure(figsize=(15,5))
plot1 = water.plot(label='box 1 + box2', color='purple', linewidth=2, alpha=0.2)
plt.ylabel('Flow rate [L]')
plt.ylim((0,12))
plt.legend(loc=2)
plot2=plot1.twinx()
tair['mean'].plot(label='Tair_mean', linestyle='--', color='green', linewidth=1,
alpha=0.6)
tsurf['mean'].plot(label='Tsurf_mean', linestyle='--', color='red', linewidth=1,
```

```
alpha=0.6)
plt.legend()
plt.title('June 2022\n 3h mean')
plt.show()


# ## JUNE 2022 : resample_rate = 1H

##------- resample_rate represents the rate used to have the mean() of each
values
resample_rate = 1
water = (df1.loc['2022-06-01':'2022-06-30']['Rain_mm_Tot'] +
df1.loc['2022-06']['Rain_mm_2_Tot']).resample(resample_rate*('H')).mean()
tair =
df2.loc['2022/06/01':'2022/06/30']['Tair'].resample(resample_rate*('H')).mean()
tsurf =
df3.loc['2022-06-01':'2022-06-30']['Value'].resample(resample_rate*('H')).mean()


# Now, I try to have the hour corresponding to the max per day of Water flow,
Air Temperature, Rock surface Temperature
d1 = water.reset_index(drop = True)
d2 = tair.reset_index(drop = True)
d3 = tsurf.reset_index(drop = True)


#----- Parameters
day_size = 24/resample_rate
nb_jours = len(d1)/(day_size)
t_start = 0
print('Day_size = ',day_size,' index et nombre de jours calcule
=',nb_jours,'\n')
rss1_1=[]
rss1_2=[]
rss1_3=[]
for t in range (0 , int(nb_jours)):
          d11 = d1.loc[t*day_size : ((t+1)*(day_size))-1 ] #flow rate
          d22 = d2.loc[t*day_size : ((t+1)*(day_size))-1 ] #tair
          d33 = d3.loc[t*day_size : ((t+1)*(day_size))-1 ] #tsurf
          if d11.max() > 20:
                    rs1_1 = np.argmax(d11) #returns the index of max water flow per
day
                    rs1_2 = np.argmax(d22) #returns the index of max tair per day
                    rs1_3 = np.argmax(d33) #returns the index of max tsurf per day
                    rss1_1.append(rs1_1)
                    rss1_2.append(rs1_2)
                    rss1_3.append(rs1_3)
          else :
                    a = 0
                    b = 0
                    c = 0
```

```
            a*int(day_size)
            b*int(day_size)
            c*int(day_size)
            rss1_1.append(a)
            rss1_2.append(b)
            rss1_3.append(c)


# For the index of the new dataframe
days=[]
i = 0
for t in range(0,int(nb_jours)) :
i=t+1
days.append(i)
df_Hour_max = pd.DataFrame((zip(days,rss1_1,rss1_2,rss1_3)), columns =
['Days','Hour_max_FlowRate', 'Hour_max_Tair', 'Hour_max_Tsurf'])
df_Hour_max['Diff_FR-Tair'] = df_Hour_max['Hour_max_FlowRate'] -
df_Hour_max['Hour_max_Tair']
df_Hour_max['Diff_Tsurf-Tair'] = df_Hour_max['Hour_max_Tsurf'] -
df_Hour_max['Hour_max_Tair']


Mean = df_Hour_max[df_Hour_max.Hour_max_FlowRate > 0].mean()
print(Mean,'\n')


x=df_Hour_max['Days']
y1=df_Hour_max['Hour_max_FlowRate']
y2=df_Hour_max['Hour_max_Tair']
y3=df_Hour_max['Hour_max_Tsurf']
plt.figure(figsize=(20,5))
plt.scatter(x,y1, label='Max flow rate',color='blue', marker='o', alpha = 0.5)
plt.scatter(x,y3, label='Max rock surface temp.',color='brown', marker='h',alpha = 0.5)
plt.scatter(x,y2, label='Max air temp.',color='gold', edgecolor='black',marker='*',
alpha = 0.5)
plt.axhline(y=df_Hour_max[df_Hour_max.Hour_max_FlowRate >0]
['Hour_max_FlowRate'].mean(), label='Mean time of max flow rate',
linestyle='--', color='blue')
plt.axhline(y=df_Hour_max[df_Hour_max.Hour_max_FlowRate >0]['Hour_max_Tsurf'].mean(),
label='Mean time of max rock surface temp.',
linestyle='--', color='brown')
plt.axhline(y=df_Hour_max[df_Hour_max.Hour_max_FlowRate >0]['Hour_max_Tair'].mean(),
label='Mean time of max air temp.', linestyle='--',color='gold')
plt.xlabel('Date')
plt.ylabel('Time [hour]')
plt.legend()
plt.ylim((0,24.5))
plt.yticks(np.arange(0, 25, step=1))
plt.xticks(np.arange(1, len(x)+1, step=1))
plt.xlim((1,len(x)+0.5))
plt.grid()
```

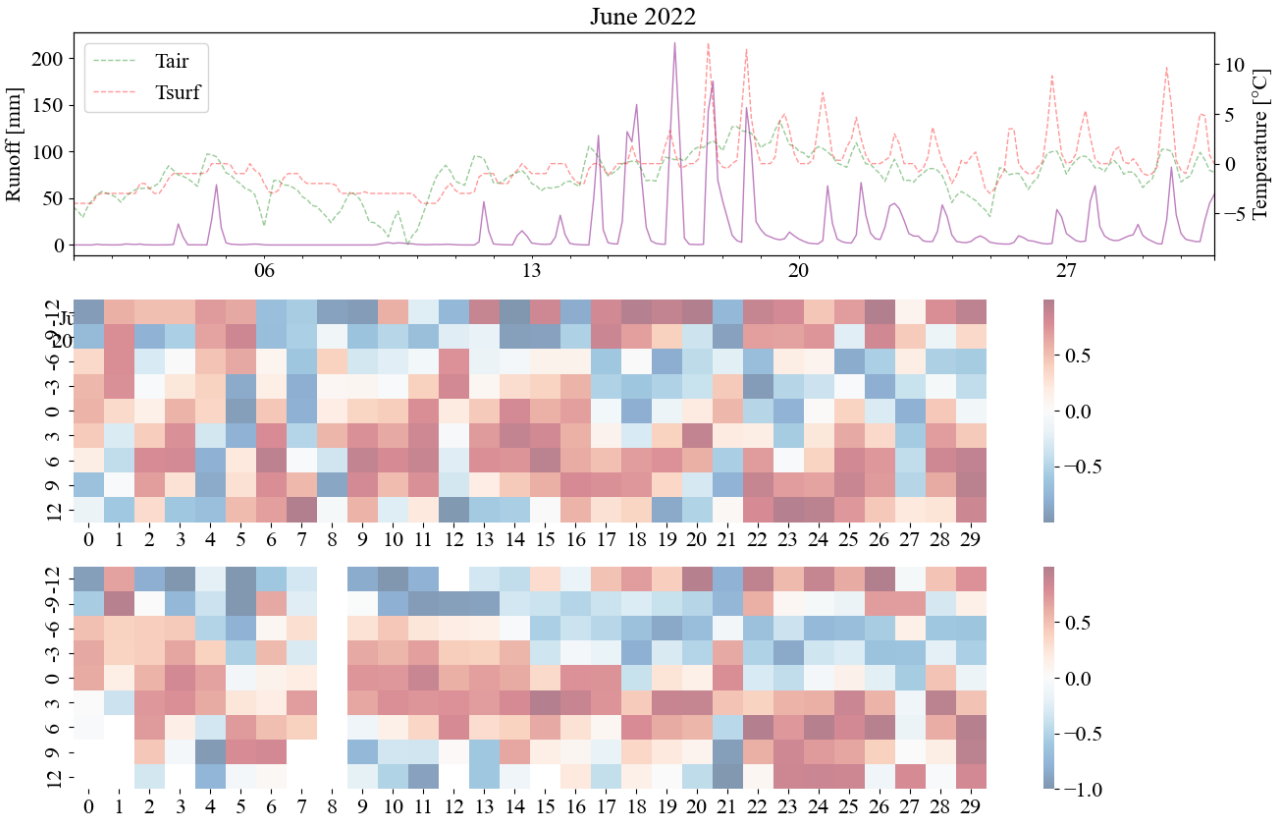
```
plt.show()
```



TIME LAGGED CROSS-CORRELATION

```
def crosscorr(datax, datay, lag=0, wrap=False):
""" Lag-N cross correlation.
Shifted data filled with NaNs
Parameters
----------
lag : int, default 0
datax, datay : pandas.Series objects of equal length
Returns
----------
crosscorr : float
"""
if wrap:
          shiftedy = datay.shift(lag)
          shiftedy.iloc[:lag] = datay.iloc[-lag:].values
          return datax.corr(shiftedy)
else:
          return datax.corr(datay.shift(lag))


water = (df1.loc['2022-06-01 00:00:00' : '2022-06-3023:59:59']['Rain_mm_Tot']
+df1.loc['2022-06-01 00:00:00' : '2022-06-30
23:59:59'['Rain_mm_2_Tot']).resample('3H').mean()


tair = df2.loc['2022/06/01 00:00:00' : '2022/06/30
23:59:59'['Tair'].resample('3H').mean()


tsurf = df3.loc['2022-06-01 00:00:00' : '2022-06-30
23:59:59']['Value'].resample('3H').mean()


d1 = water.reset_index(drop = True)
d2 = tair.reset_index(drop = True)
d3 = tsurf.reset_index(drop = True)
```

```
#JUNE 2022
f= plt.figure(figsize=(15,10))
ax=plt.subplot(311)
plot1 = water.plot(label='box 1 + box 2', color='purple', linewidth=1,
alpha=0.5)
plot1.set_ylabel('Runoff [mm]')
plot2 = plot1.twinx()
#Tair
tair.plot(label='Tair', linestyle='--', color='green', linewidth=1, alpha=0.4)
#Tsurf
tsurf.plot(label='Tsurf', linestyle='--', color='red', linewidth=1, alpha=0.4)
plt.title('June 2022')
plot2.set_ylabel('Temperature [°C]')
plt.legend()
# ------- Windowed time lagged cross correlation -----
#----- Parameters
##------- resample_rate represents the rate used to have the mean() of each
values
resample_rate = 3
day_size = 24/resample_rate
nb_jours = len(d1)/(day_size)
t_start = 0
print('Day_size = ',day_size,' index et nombre de jours calcule =',nb_jours)
rss1_2=[]
rss1_3=[]
for t in range (0 , int(nb_jours)):
          d11 = d1.loc[t*day_size : ((t+1)*(day_size))-1 ] #flow rate
          d22 = d2.loc[t*day_size : ((t+1)*(day_size))-1 ] #tair
          d33 = d3.loc[t*day_size : ((t+1)*(day_size))-1 ] #tsurf
          rs1_2 = [crosscorr(d11,d22,lag) for lag in
range(-int(day_size/2),int(day_size/2)+1)]
          rs1_3 = [crosscorr(d11,d33,lag) for lag in
range(-int(day_size/2),int(day_size/2)+1)]
          rss1_2.append(rs1_2)
          rss1_3.append(rs1_3)
          rss1_2=pd.DataFrame(rss1_2).transpose()
          rss1_3=pd.DataFrame(rss1_3).transpose()


ax=plt.subplot(312)
sns.heatmap(rss1_2,cmap='RdBu_r', alpha= 0.5)
ax.set_yticklabels([-12,-9,-6,-3,0,3,6,9,12])
ax=plt.subplot(313)
sns.heatmap(rss1_3,cmap='RdBu_r', alpha= 0.5)
ax.set_yticklabels([-12,-9,-6,-3,0,3,6,9,12])
```




```
# On ferme les fichiers
ttab1.close()
ttab2.close()
ttab3.close()
ttab4.close()
ttab5.close()
ttab6.close()
ttab7.close()
ttab8.close()
```

Appendix 5: Carbon footprint of the internship

CARBON FOOTPRINT
20/03/2023 -- 30/08/2023

This carbon footprint does not include structural functions.

Transport

Source: ADEME

17 round trip Le Bourget-du-Lac to Chamonix

17 x 190 km = 3230 km



- 8 solo trips = 8 x 41 kg CO2e
- 7 trips for 2 people = 7 x 21 kg CO2e
- 1 trip for 3 people = 1 x 14 kg CO2e
- 1 trip for 4 people = 1 x 10 kg CO2

Total CO2e for transport = 499 kg CO2e



The equivalent to 192 trips in train between Lille to Marseille

Lille - Marseille in train = 2.6 kg CO2e for 966 km (source SNCF) == 192 x 966 km = 185 472 km

Nota: Transport with cable cars in Chamonix to Aiguille du Midi are considered in this balance sheet

Field data (pictures, field report)

Source: https://blog.antimuonium.com/blog-post/l-empreinte-carbone-du-stockage-des-donnees

For data: 0.176 g CO2e / Mo / year

- Field report + pictures files size = 6.88 Go

Total CO2e for field data = 1.211 kg CO2e

Data analysis and treatment (raw data, Python code) + North face pictures

- Files size = 627 Mo + 13.3 Go

Total CO2e for data analysis = 2.45 kg CO2e

Mails + Writting files

- Files size = 576 Mo + 9.55 Go

Total CO2e for mails = 1.78 kg CO2e kg CO2e

* Most files are stored in duplicate, which is not taken into account in this carbon footprint.

Samples storage in fridge

Source: ADEME

For using a fridge: 15.1 kg CO2e but only water samples only use 1/4 so = 3.77 kg CO2e

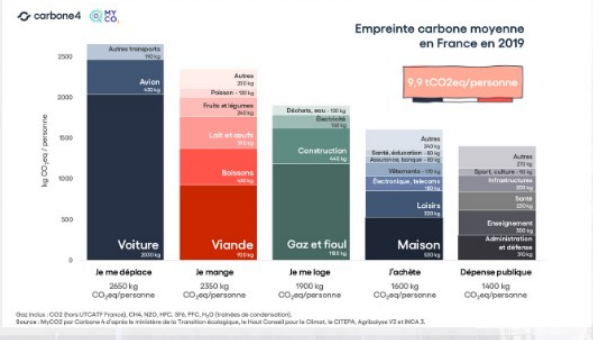
Total CO2e for storage = 3.77 kg CO2e

TOTAL BALANCE

504.2 kg CO2e

to compare, in 2019 the CF of one person (in France) was **9.9t CO2e.**





Appendix 6: Communication document

HYDROLOGIE DU PERMAFROST DE HAUTE MONTAGNE

MONITORING DES INFILTRATIONS D'EAU DANS LES PAROIS ROCHEUSES DE L'AIGUILLE DU MIDI, MASSIF DU MONT BLANC

Contexte général

L'augmentation de la température liée au changement climatique touche les systèmes montagnards de haute altitude. En milieu montagnard, le permafrost (sol ou surface dont la température est égale ou inférieure à 0°C au moins durant 2 années consécutives) est très présent à ces altitudes sous différentes formes comme les glaciers rocheux ou les parois rocheuses. Des années d'observations montrent une augmentation croissante des évènements gravitaires tels que les écroulements rocheux dans les zones de présence du permafrost notamment en paroi rocheuse. L'impact du réchauffement de la paroi sur la dégradation du permafrost n'est plus à démontrer, néanmoins le rôle de l'eau est lui méconnu. Le système de monitoring mis en place dans le cadre du projet WISPER cherche à mieux connaître la connectivité entre l'eau de surface et la subsurface dans les parois rocheuses affectées par le permafrost.

Présentation du stage

Depuis 2022, une nouvelle expérience de terrain en haute altitude a été mise en place par le laboratoire EDYTEM. Tout un système de monitoring a été conçu et installé dans le but de surveiller en temps réel l'infiltration dans les fractures rocheuses à l'Aiguille du Midi (3842 m d'altitude), dans le massif du Mont Blanc. Un tunnel existant, creusé pour l'accès des visiteurs, permet de collecter de l'eau directement dans les fractures qui traversent les parois du tunnel.

Le débit des écoulements, la température et la conductivité électrique de l'eau dans deux fractures adjacentes sont ainsi mesurés en continu. Une sonde de fluorescence a été ajoutée au système pour suivre deux traceurs fluorescents différents insérés dans le manteau neigeux à deux endroits situés directement au-dessus des fractures (5-15 m) afin de suivre la source d'eau issue de la fonte de neige. Des échantillons d'eau et à d'autres endroits du tunnel ont été prélevés de manière hebdomadaire sur lesquels des analyses complémentaires chimiques seront réalisées ultérieurement. Le stage est l'occasion de faire un premier bilan comparatif entre les deux années : 2022 et 2023

Site d'étude : l'Aiguille du Midi, la haute montagne à portée de main



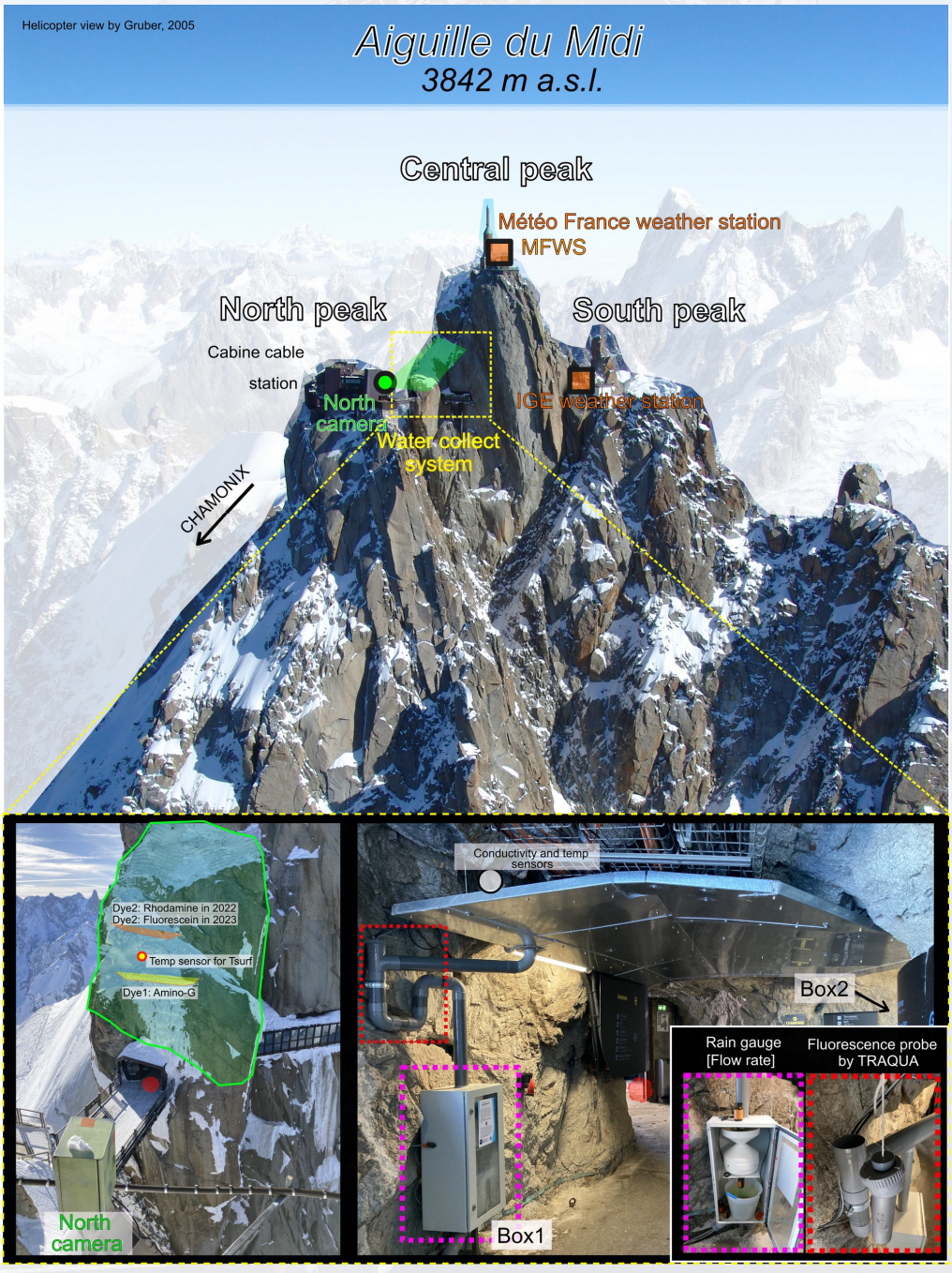
L'Aiguille du Midi se trouve sur le versant nord-ouest du massif du Mont Blanc. Son sommet culmine à 3842 m. et est constitué de trois pitons de granit. Un téléphérique touristique relie Chamonix au piton nord, où des galeries et un ascenseur sont creusés dans la masse rocheuse, ce qui permet d'accéder toute l'année à cet environnement extrême et inaccessible.

La démarche : partir des écoulements visibles pour comprendre l'invisible

Cette étude commence par l'étude des différents éléments visibles et mesurables au niveau de l'Aiguille du Midi. Des capteurs permettent de mesurer les écoulements visibles à travers les parois de l'Aiguille qui peuvent être récupérés dans les galeries directement. Ainsi la vitesse d'écoulement, le volume d'eau ainsi que la temporalité pourront être visualisés. Ces données à une si haute altitude représentent les toutes premières sur les sujets en lien avec la dégradation du permafrost de montagne.

Une fois ce processus visuel compris, des analyses plus poussées sont effectuées en comparant les deux années de mesure entre elles, mais également en mettant en parallèle des facteurs extérieurs et plus globaux comme les paramètres climatiques représentés par les température de l'air, les radiations solaires mais également avec des facteurs locaux comme les précipitations ou la couverture neigeuse sur la paroi.

Le système de monitoring, en place depuis 2022



Principaux paramètres mesurés

- **Mesures continues de :**
  - Taux d'écoulement
  - Fluorescence de l'eau
  - Température de l'eau
  - Conductivité de l'eau
- **Température de surface de la roche**
- **Échantillonnage temporel et spatial de l'eau des galeries :**
  - Fluorescence
  - Stabilité d'isotopes (18O/D)
  - Éléments majeurs

Des photos prises de la face Nord 4 fois / jour pour le suivi de la courverture neigeuse

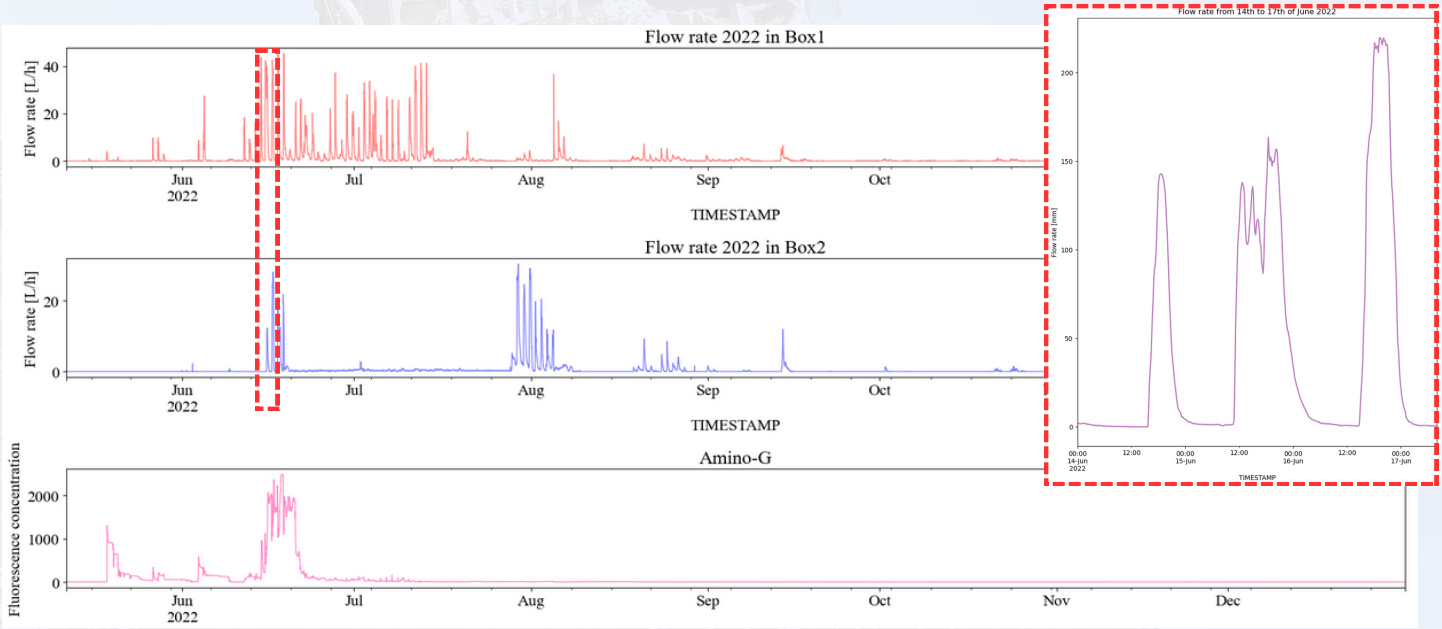
Deux traceurs insérés dans le manteau neigeux en 2022 et 2023



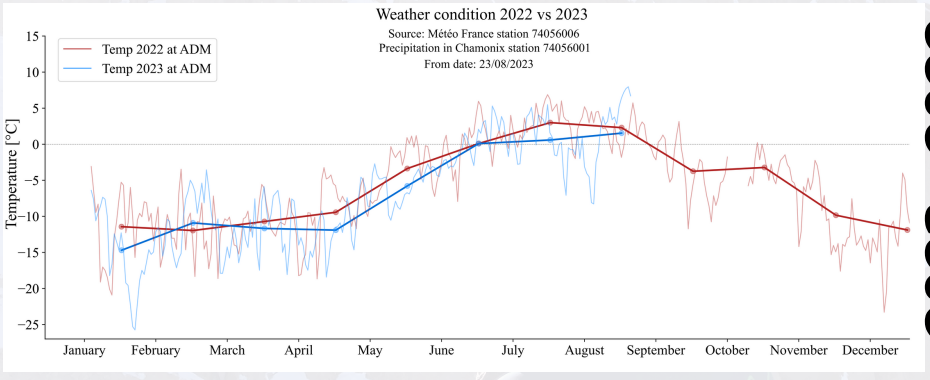
2022, une première année et des résultats prometteurs

Cette première année de monitoring permet d'avoir de premières informations qui serviront de base pour la suite :

- Les écoulements sont saisonniers et se déroulent entre la fin du printemps et la fin de l'été
- Des variations journalières des écoulements sont observées avec des débits faibles (<1L/H) dans la matinée et un débit maximum (>10 L/H) se produisant en fin d'après-midi avant le début de la phase de récession nocturne
- La première phase d'écoulement semble être fortement liée à la neige présente sur la paroi bien que les écoulements continuent une fois la couverture neigeuse partie (soit par la pluie soit par la fonte de glace interstitielle)
- Le seul traceur retrouvé (sur les 2) est présent dès les premiers écoulements
- Les deux fractures ont des régimes d'écoulements différents (Box1 et Box2)



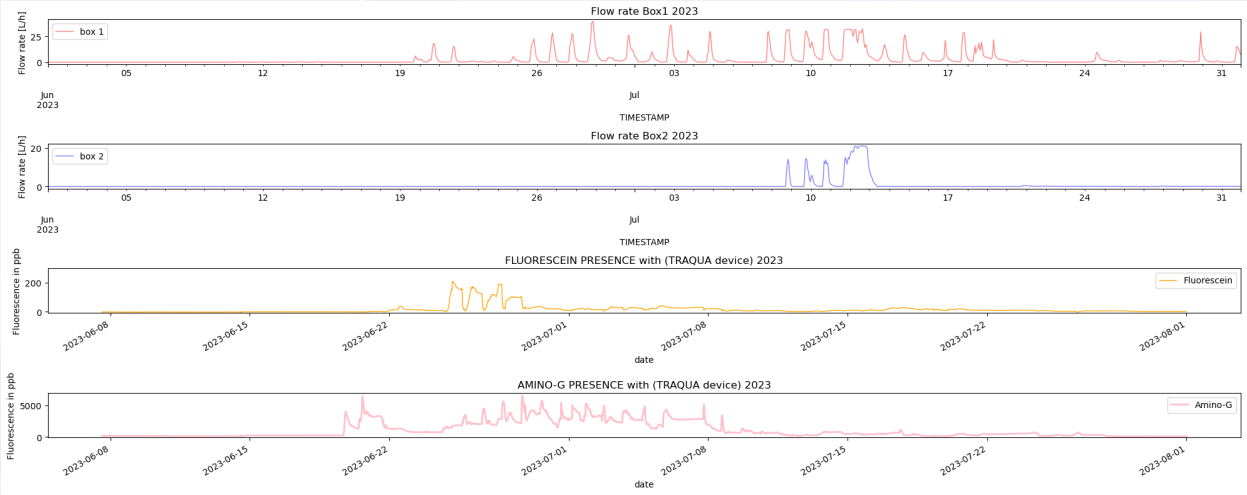
2023 confirme et appuie encore un peu plus l'importance des variables locales (précipitations et couverture neigeuse)





Les conditions météorologiques sont différentes entre 2022 et 2023 avec des températures plus basses en moyenne de 3 à 4°C et des précipitations plus nombreuses également sur le massif représentées par une couverture neigeuse de la face nord plus conséquente en 2023 et qui a duré plus longtemps.

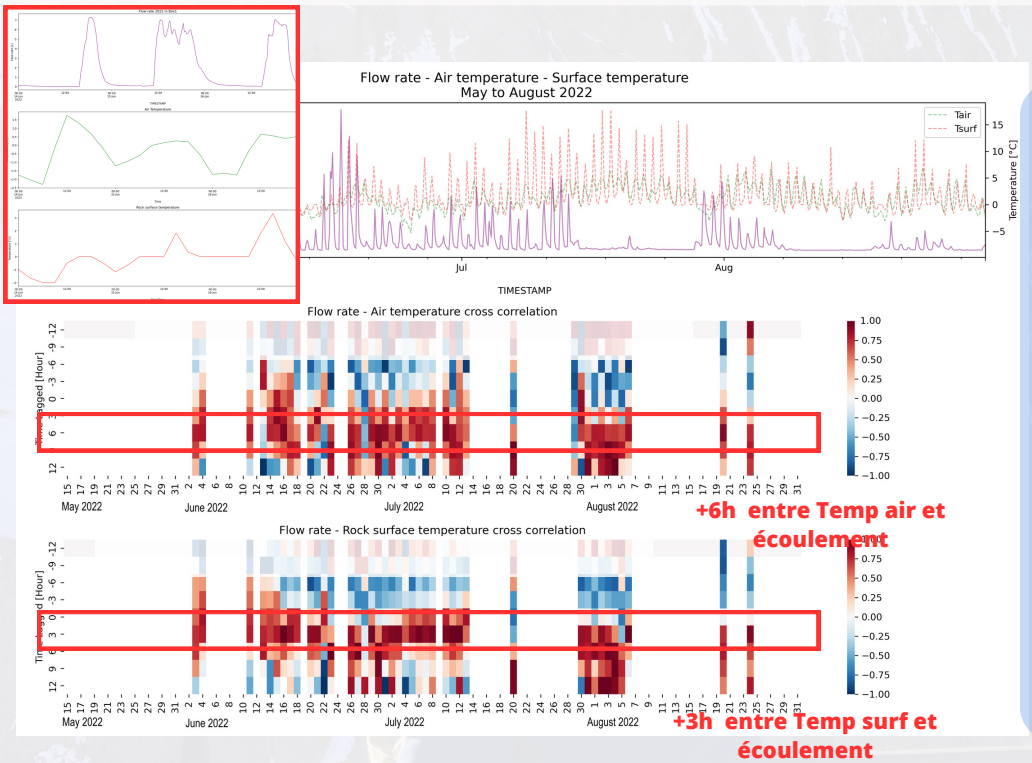
L’hiver plus froid en moyenne de 2023 ainsi que des précipitations plus nombreuses montrent un décalage du début des écoulements de 1 mois en comparaison à 2022 (mi juin contre mi mai). Ce décalage semble rester constant durant tout l’été.
La neige est confirmée comme premier contributeur d’eau des écoulements qui traverse la paroi par la présence des deux traceurs (Fluorescéine et Amino-G) mais également comme une couche protectrice importante pour garder la température de paroi froide et isolée des conditions extérieures.



Une corrélation entre écoulements, température de l’air et de surface

Les écoulements réagissent directement aux variations de températures. Une corrélation peut exister entre les facteurs météo comme les précipitations ou la température de l’air. Cette corrélation a été démontrée pour 2022 par la méthode du “time lagged cross-correlation” entre la température de l’air, la température de la roche et les écoulements en paroi. La relation entre ces signaux existe avec un décalage relativement régulier :

- **de +3h entre les écoulements et la température de roche**
- **de +6h entre les écoulements et la température de l’air**



Résumé et petite conclusion

Les résultats issus du monitoring sur l'écoulement de l'eau à partir de fractures dans une paroi rocheuse affectée par le permafrost montrent clairement une forte connectivité entre le manteau neigeux à la surface et les fractures en subsurface.
Le début d'une période d'écoulement continu correspond à une augmentation des températures de surface au-dessus de 0°C elle-même liée à la disparition du manteau neigeux.
De fortes variations diurnes du débit sont observées et sont en corrélation avec les températures de l’air et de surface.
L'observation d'un écoulement alors qu'aucune couverture neigeuse n'était visible indique des sources indirectes potentielles telles que le ruissellement en amont ou le stockage de glace dans les fractures.

2023 n’est pas finie et des surprises peuvent encore arriver.

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HYDROLOGY OF HIGH MOUNTAIN PERMAFROST

MONITORING OF WATER INFILTRATION THE AIGUILLE DU MIDI, MASSIF DU MONT BLANC

Résumé

Une augmentation de l'activité des écroulements rocheux a été observée dans les parois rocheuses de haute montagne depuis plusieurs années et notamment attribuée à la dégradation du permafrost (ou pergélisol). Ces écroulements présentent des risques pour la sécurité des personnes, les infrastructures ou encore les activités de haute montagne. La présence d'eau a été observée dans de nombreuses cicatrices d'écroulement. L'eau pourrait être ainsi un facteur déterminant dans la plupart des processus physiques qui façonnent les paysages périglaciaires montagneux. Mais à l'heure actuelle, il existe très peu de connaissances et d'observations sur l'origine, la quantité et le moment où l'eau s'écoule dans les parois rocheuses.
Dans le massif du Mont Blanc, les galeries artificielles du site de l'Aiguille du Midi (3842 m d'altitude) constituent une opportunité unique d'accéder à cet environnement particulier et spécifique. L'Aiguille du Midi sert ainsi de laboratoire naturel pour des mesures de terrain sur le pergélisol de montagne. Depuis mai 2022, un nouveau système de monitoring a été mis en place pour collecter des données en temps réel sur le débit, la conductivité ou encore la détection de traceurs qui ont été versés à la surface du manteaux neigeux en fin d'hiver.
Ces données peuvent être comparées à celles de température, aux informations climatiques et météorologiques provenant des stations météo ainsi qu'aux modèles numériques de bilan d'équilibre d'énergie, de chaleur et de masse d'eau, afin de fournir de nouvelles connaissances sur les processus hydrologiques. Elles pourront par la suite être utilisées pour contraindre les modèles numériques pour les rendre encore plus précis.
Le système expérimental de monitoring aide à mieux comprendre les interactions entre la surface et la subsurface dans le permafrost de haute montagne ainsi qu'à déterminer l'origine des écoulements, la quantité d'eau, la temporalité, la réaction au changement climatique et donc à l'augmentation des températures (de l'air et de la surface).
Une forte saisonnalité des écoulements a été observée notamment du à l'augmentation des températures qui fait fondre la couche de neige déposée sur la paroi. Cette neige représente la majorité des écoulements sur la saison. Les écoulements se répètent quotidiennement en réaction aux pics de température de l'air et de la surface de roche. La neige n'est pas la seule origine des écoulements, d'autres écoulements surviennent une fois la neige fondue. Cela pourrait provenir des précipitations estivales de pluie ou encore de la glace interstitielle représentant le réchauffement de la couche active et possiblement une dégradation du permafrost à l'origine d'écroulements rocheux.

Mots clés: Permafrost, monitoring, infiltration, neige, massif du Mont Blanc, changement climatique

Abstract

An increase in rockfall activity has been observed in high mountain rock slopes for several years and has been related to permafrost degradation. These rockfalls present risks for human security, infrastructure, and high mountain activities. Water has been observed in many rockfall scars. Moreover, water is a major driver in most physical processes that shape the mountainous periglacial landscapes. But at this time, there is very little knowledge and observation about the origin, quantity, or timing of water that flows into rock walls.
In the Mont Blanc massif, the man-made tunnels at the Aiguille du Midi (3842 m a.s.l.) is a unique opportunity to access this particular and specific environment and serves as a natural laboratory for field measurements in mountain permafrost. Since May of 2022, a new monitoring system has been set up to collect real-time data of flow rate, conductivity, and detection of fluorescent dyes that were inserted (in the snowpack) during the winter.
This data can be compared with temperature data, weather information from meteorological stations, and numerical models of heat and water mass balance, to provide new knowledge about hydrological processes. In turn, it can be used to constrain numerical models and make them more precise. The experiments help to understand surface-subsurface pathways in steep mountain permafrost and determine the water flow origin, water quantity, its timing, and the reaction of water runoff to climate change and the temperature increase.
A strong seasonality of flows has been observed, due in particular to the rise in temperature which melts the layer of snow deposited on the wall. This snow represents the majority of flows over the season. Flows are repeated daily in response to peaks in air and rock surface temperatures. Snow is not the only source of runoff; other runoff occurs once the snow has melted. This could come from summer rainfall, or from interstitial ice representing the warming of the active layer and possible permafrost degradation leading to rock falls.

Key words: Permafrost, monitoring, infiltration, Mont Blanc massif, climate change