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Dense seismic array observations of spatial and temporal channels in subglacial hydrology in an Alpine Glacier

Welcome to our online presentation.

We propose here a different format than the traditional oral presentation with more detailed and interactive materials.

Challenges

Investigating the spatial organisation of the **drainage system** through time is a challenge for both the glaciological and the seismological communities.

This study aims at bringing new insights on the subglacial hydrology spatial dynamics using **dense array seismic observations** and combining phase and amplitude approaches to locate subglacial water flow.

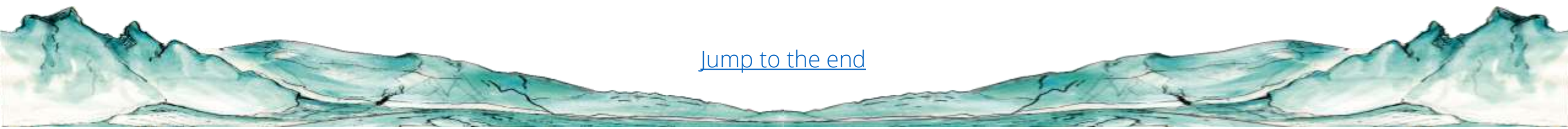
Outcomes

The phase-driven approach shows an evolution in noise sources that represents the **transition** from a **distributed** drainage system toward the development of one main subglacial **channel**.

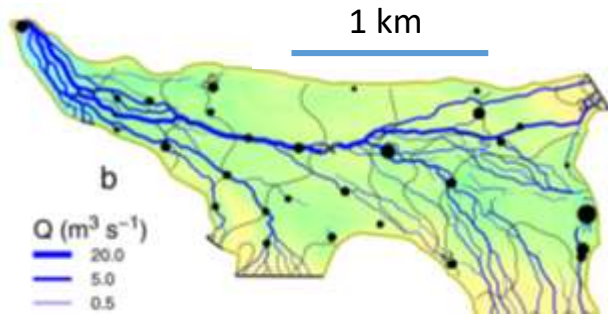
The amplitude-driven approach shows spatial pattern that are representative of the **subglacial water pressure**.

We are capable to investigate in **space** and **time subglacial water flow properties**.

[Jump to the end](#)



Challenges in subglacial hydrology and seismological opportunities



Subglacial drainage system as modelled by [Werder et al., \(2013\)](#)

Subglacial hydrology strongly modulates glacier basal sliding, and exerts a major control on ice loss and sea-level rise.

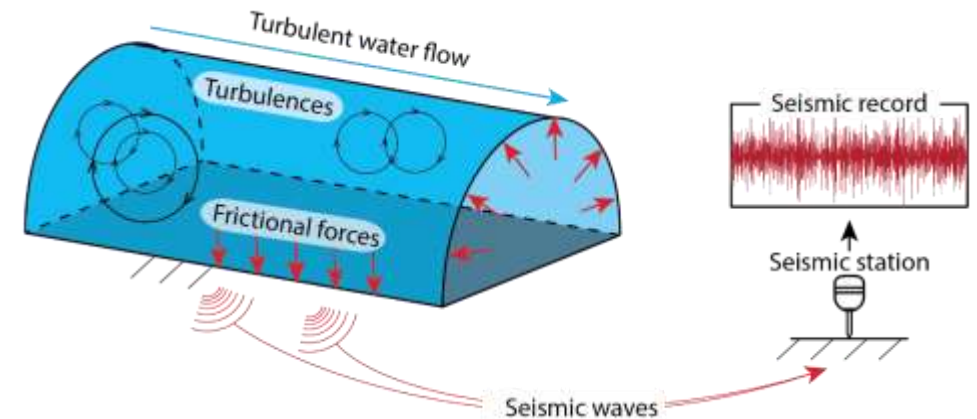
The subglacial drainage system of hard-bedded glacier is considered to be composed of a widespread inefficient drainage system with slow and pressurized water flow (**cavities**) and of a localized efficient drainage system with faster and less pressurized water flow (**channels** melted into the ice).

The **limited** direct and **spatialized observations** make difficult to assess the physical processes involved in its development.

Recent work shows that **seismic noise** analysis may be used to retrieve the **physical properties** of subglacial channelized water flow (e.g. [Vore et al., 2019](#); [Lindner et al., 2020](#); [Nanni et al., 2020](#)).

The capability to investigate the drainage system **spatial** organisation and evolving properties remains to be demonstrated.

A major challenge lies in the seismic source of the subglacial channel flow that is a **continuous** source of noise distributed in space and likely strongly **varying** in time.



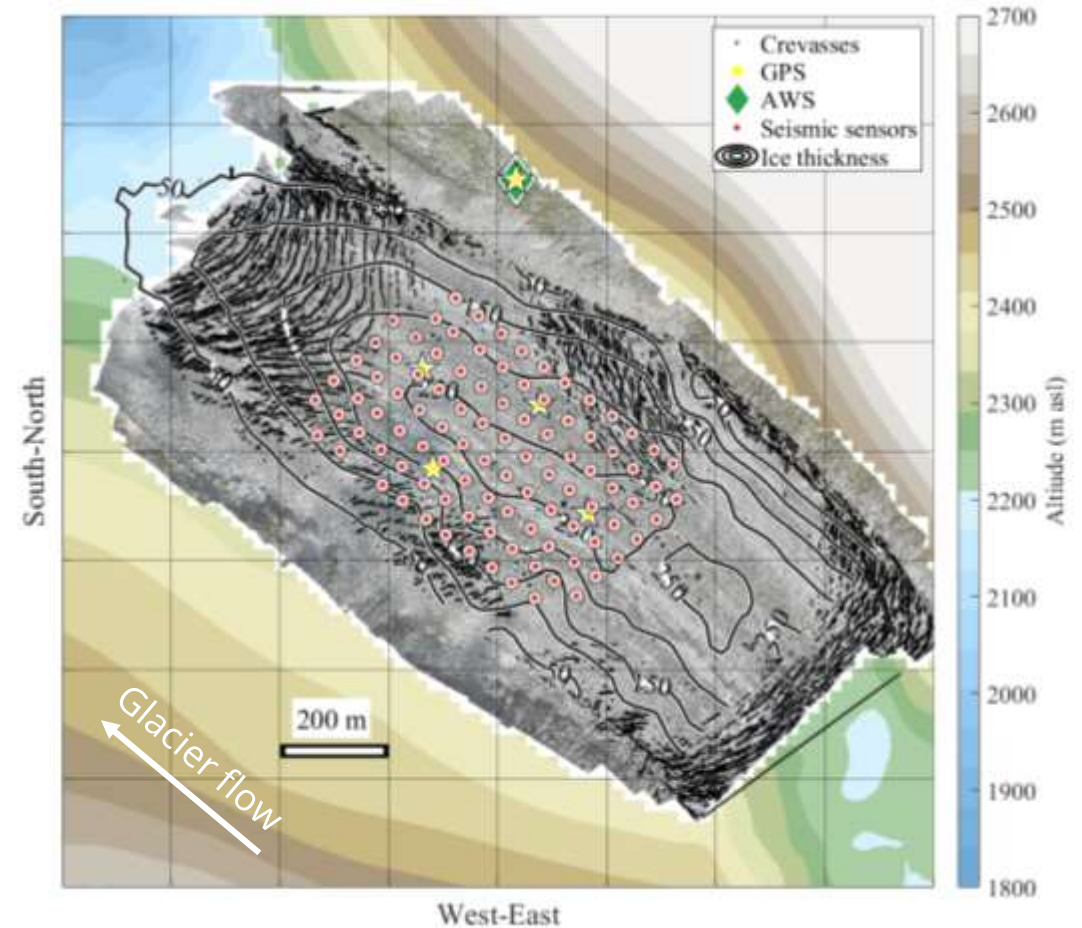
Schematic representation of subglacial channel-flow-induced seismic noise from [Nanni et al., \(2020\)](#)

Dense seismic array and complementary measurements

We use the setup of the [RESOLVE-Argentière](#) experiment that consists in a **one-month deployment of 98 seismic** stations on the glacier d'Argentière (French Alps) at the onset of the melt season.

This site is ideal to study **subglacial hydrology** and its link with glacier dynamics.

In this location subglacial water flow strongly influence **glacier dynamics** ([Vincent et al., 2016](#); Gimbert et al., accepted in Nature) and generate a continuous seismic noise ([Nanni et al., 2020](#)) which is expected to be both **spatially continuous** outside and inside of our seismic array.



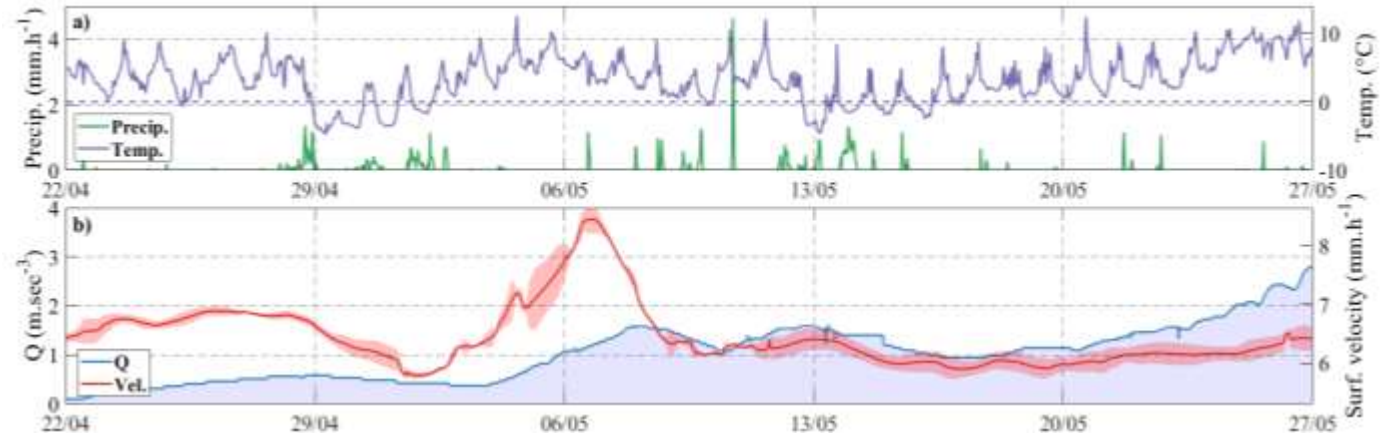
Monitoring setup with aerial view of the field on top of the surface elevation.

Seismological and glaciological context

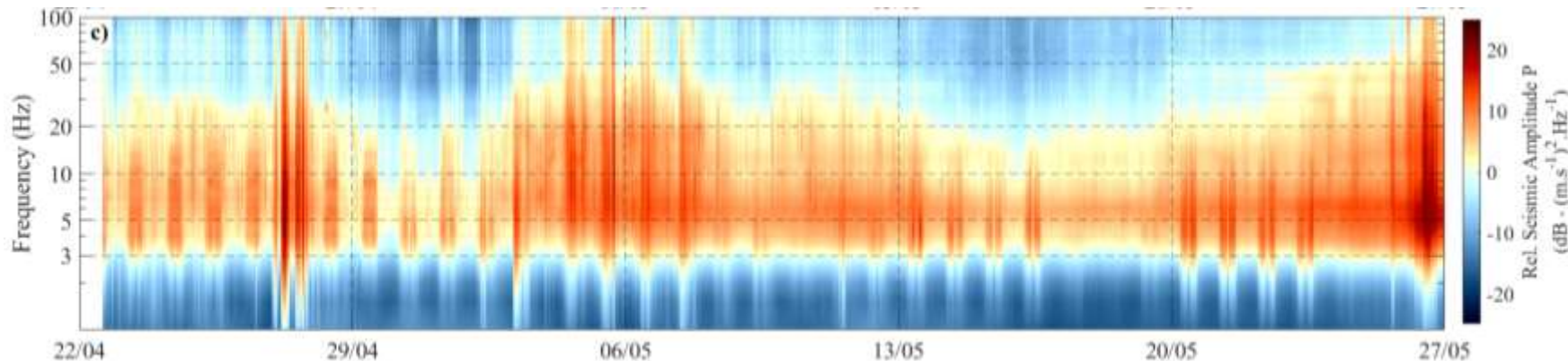
The early spring period is the **onset of the melt season**, when the subglacial hydrology network strongly evolves.

Water discharge increases from 0.1 to 5 $\text{m}\cdot\text{sec}^{-3}$ because of increasing **surfaced melt** driven by c. 5°C increase in surface temperature.
<https://soundcloud.com/user44994492/son-4>

The glacier surface **velocity** shows a clear peak as Q reaches its first peak. As Q reaches its higher values, surface velocity is however near its minimum.



The median **seismic power** over the 98 nodes shows variations with discharge that are most pronounced in the **[3-7] Hz** frequency band. We focus on this band to study subglacial hydrology.



Timeseries of physical quantities measured at Glacier d'Argentière during the RESOLVE-Argentière field survey.



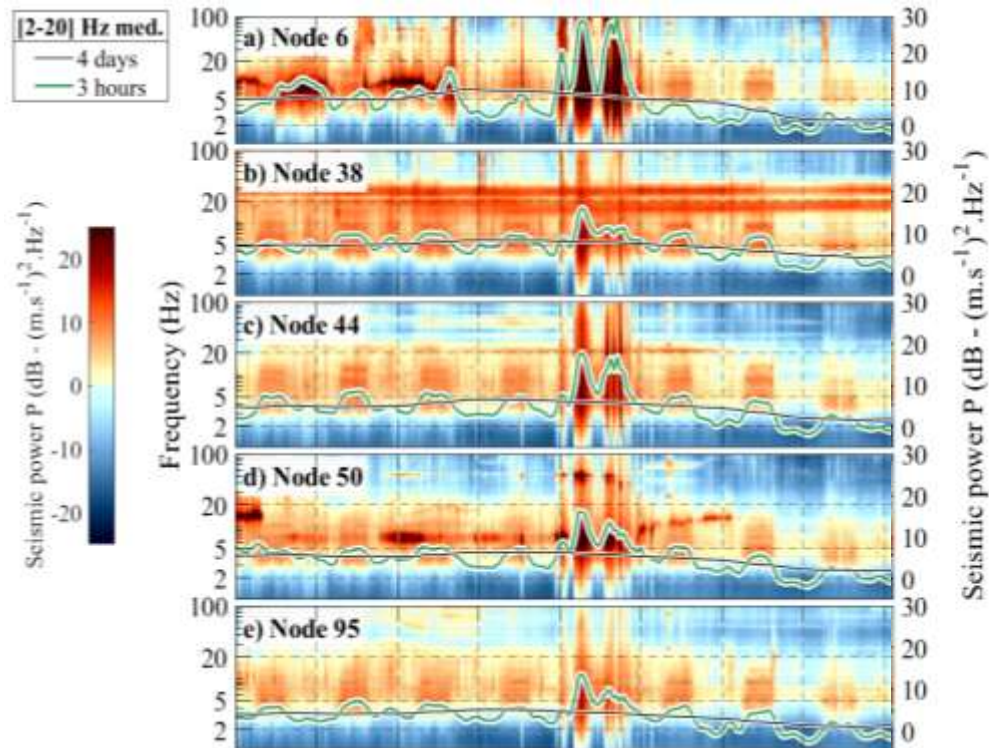
[To the sound of subglacial water flow](#)

Seismological methodology: amplitude and phase analysis

Amplitude analysis:

Investigate **spatial heterogeneity** in the amplitude.

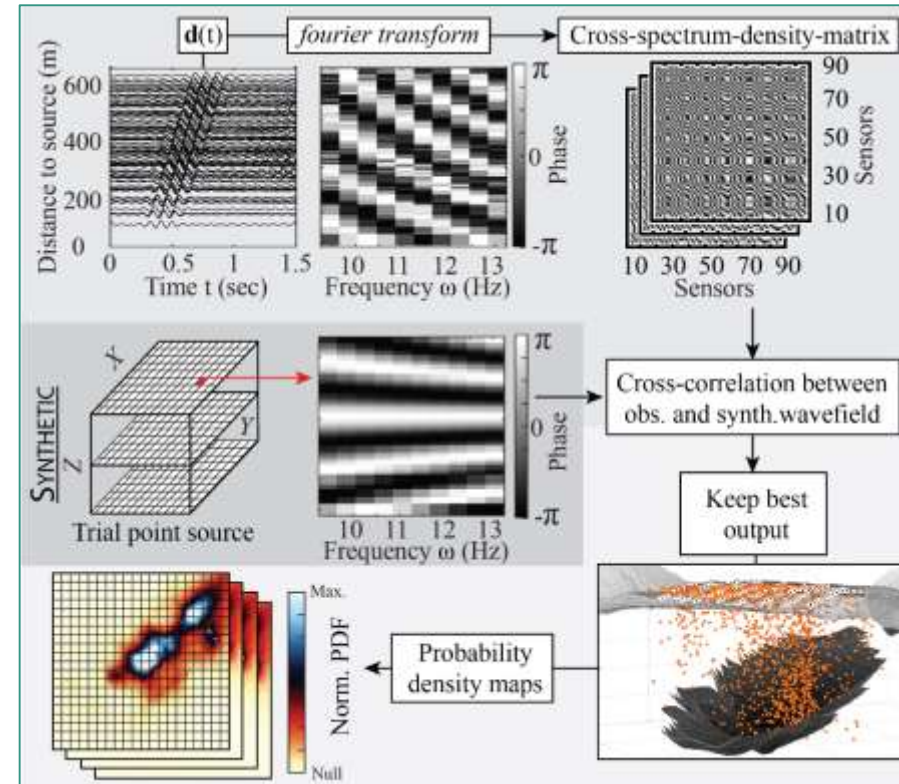
The closer to the sources the higher the amplitude.



Phase analysis:

We **recursively** match the phase delays of a model-based **synthetic** wave field ("trial source") to the phase delays **observed** between the sensors over the array.

We use here a probabilistic approach to locate up to **29 sources per second** and then stack sources over time.



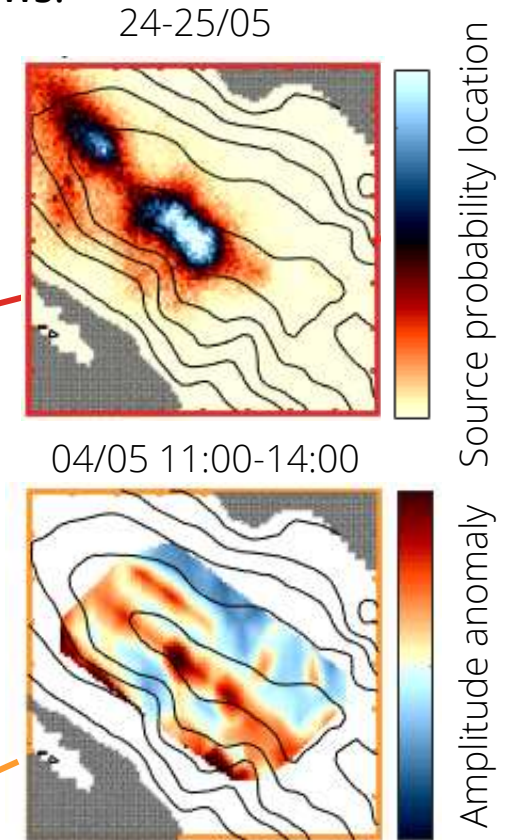
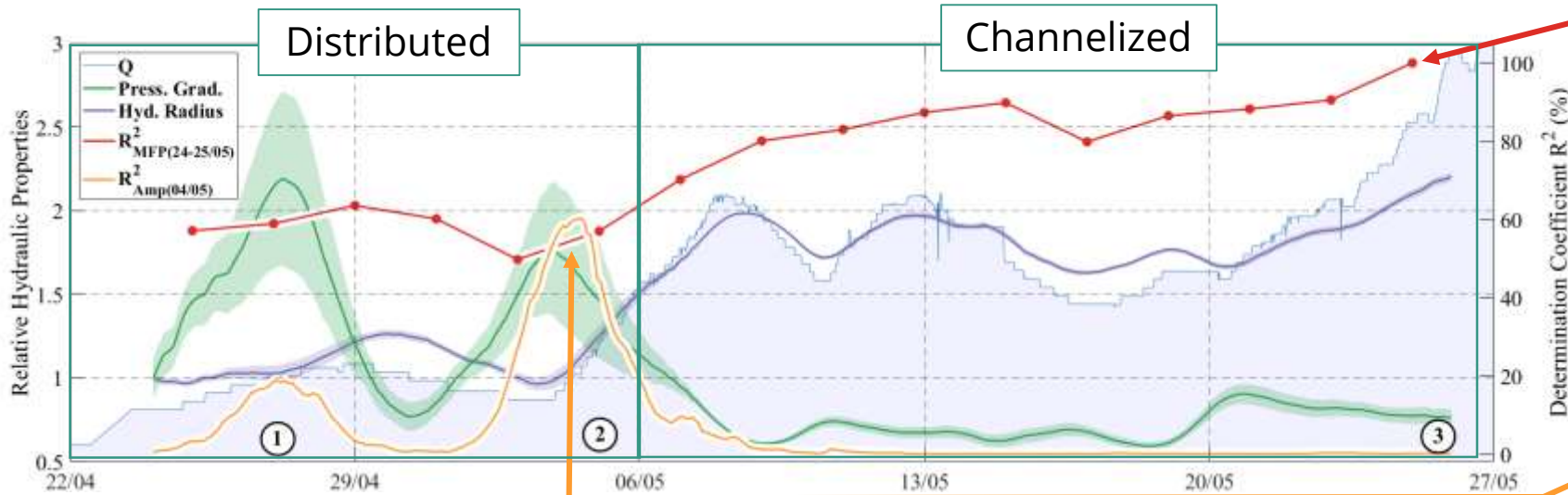
Spatial seismic properties and inversion of hydraulic properties

We selected **one pattern** from the phase and amplitude outputs and compared its **temporal evolution** to hydraulic properties.

Temporal evolution is evaluated from **2D cross-correlation** of the selected pattern to the other temporal windows.

The amplitude anomalies suggest **two main channels** at the centre of the glacier with a similar orientation as the highest probability of location.

Hydraulic properties are inverted from the seismic and discharge measurement ([Nanni et al., 2020](#))



Amplitude anomalies are sensitive to change in **pressure conditions**.

Phase's source location is sensitive to **channels size** development.

Ongoing work, perspectives and opportunities ...

Take home message(s)

Dense seismic observations:

- **Directly map** spatial evolution of subglacial hydrology
- Capture distributed and channelized systems



Easily deployable in remote areas (Greenland, Antarctic ...)

Subglacial hydrology:

- **Cavity-channels** transition in less than 4 days
- Main channel at the minimum of **hydraulic potential**
- New constrains for subglacial hydrology **models**



One of the first direct observation

Papers on this study and the RESOLVE-Argentière experiment soon to be out ...

About me :

- Finishing my Phd in September after 3 years in Grenoble
- Looking to further investigate glacier processes using passive/active seismic
- Looking to test our approaches on **new glaciological context**



About my works



Some of our projects



Eager to have further discussions with you !!

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Have a look at our drawings about glaciology

