Resolving subglacial hydrology network dynamics through seismic observations on an Alpine glacier.

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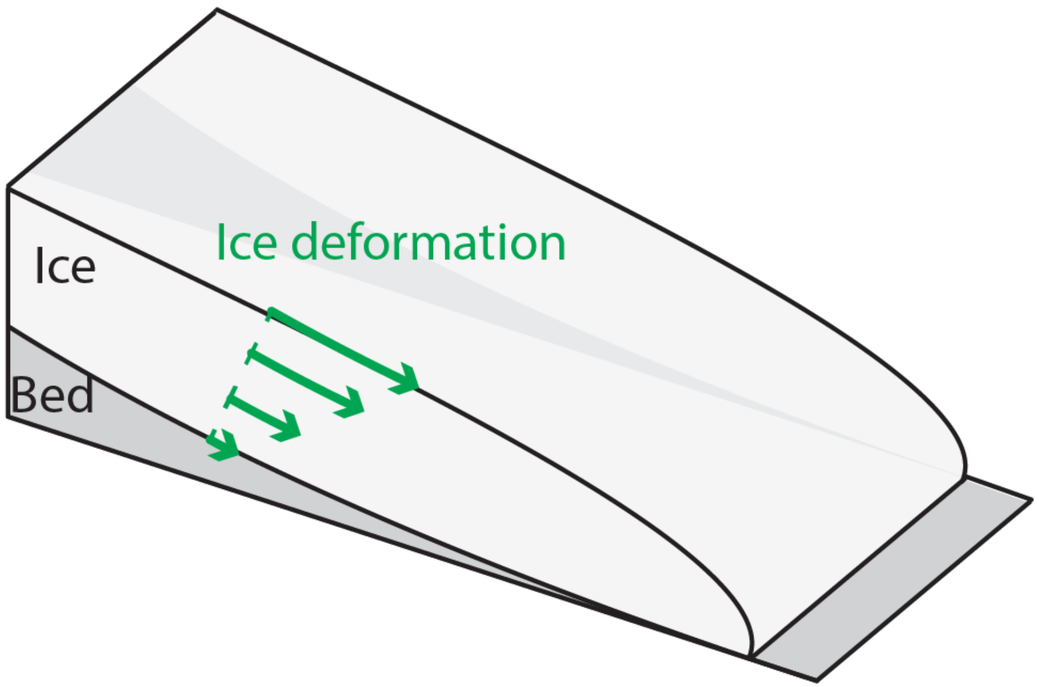
On the dynamics of glaciers

- Glaciers form by snow accumulation
- Ice slowly deforms and flows downhill



On the dynamics of glaciers

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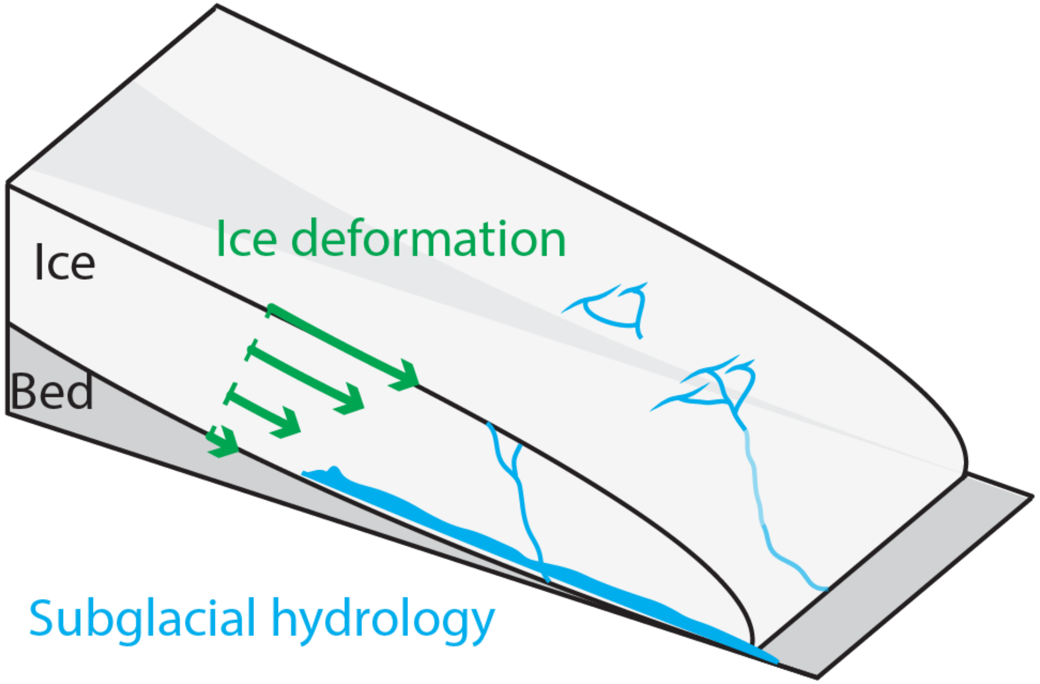
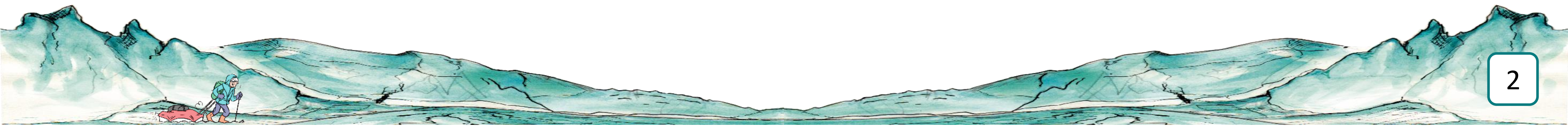
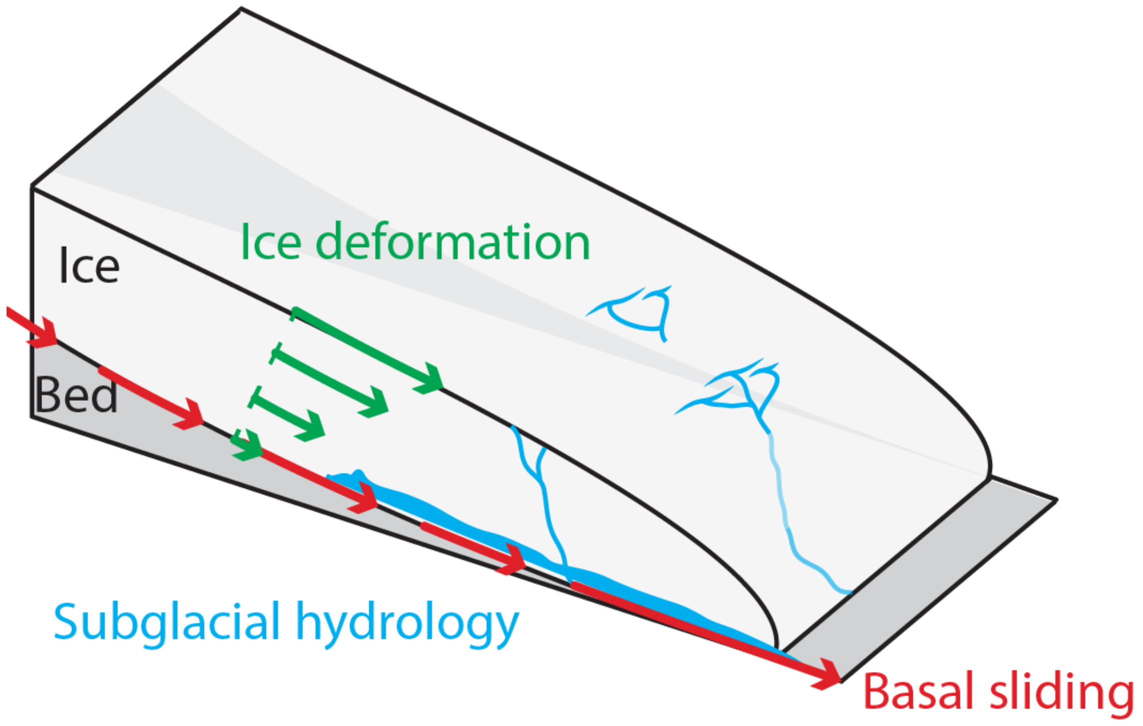
- At low altitudes surface melt occurs and meltwater penetrates glaciers





On the dynamics of glaciers

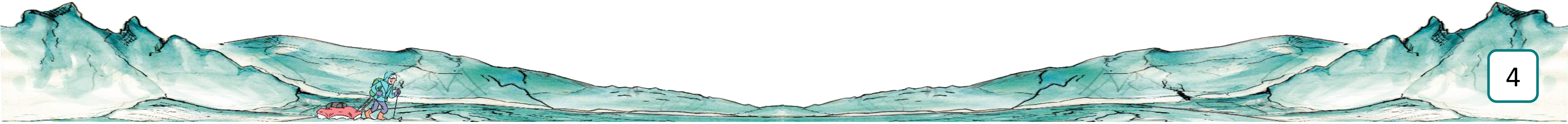
- Glaciers form by snow accumulation
- Ice slowly deforms and flows downhill
- In low altitudes surface melt occurs and meltwater penetrates glaciers
- Subglacial waterflow modulates sliding by lubrication



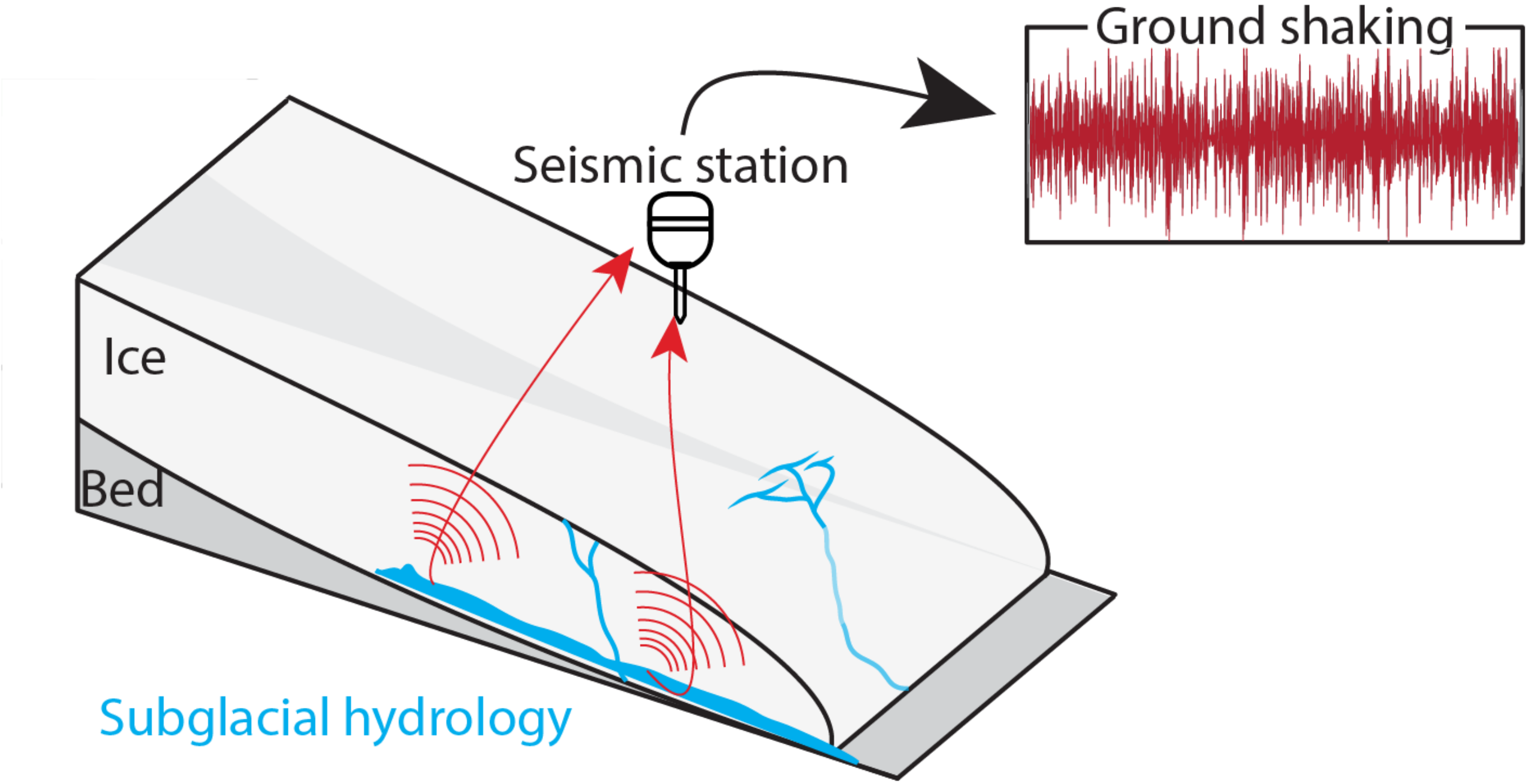
Up to 50 to 90% of ice flow

Key questions remain

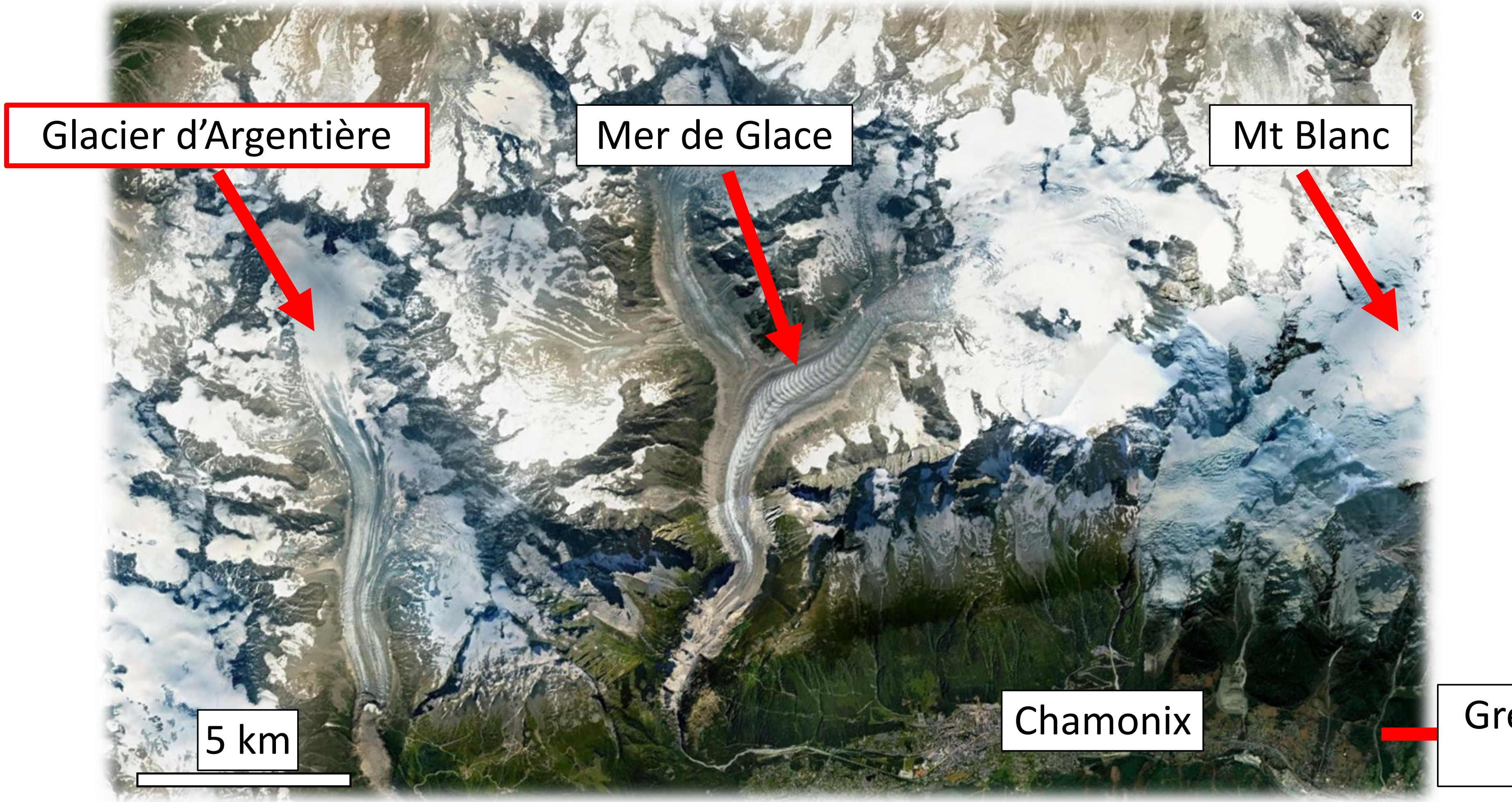
- Where are cavities and channels?
- How do they develop?
- What are their hydraulic properties?



Can seismology help?

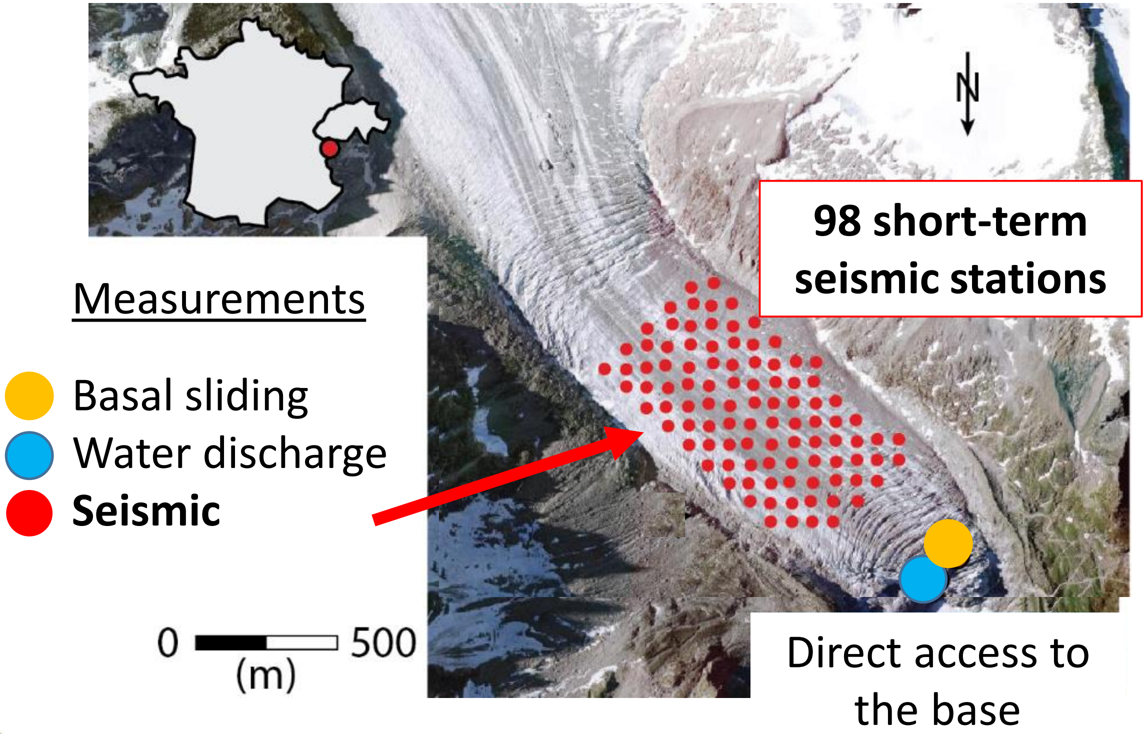


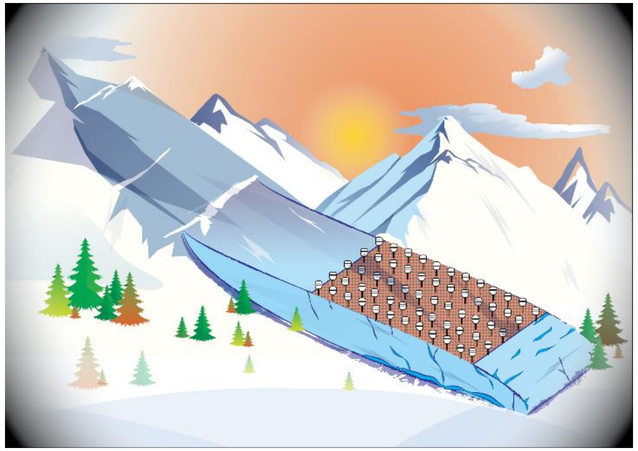
Glacier d’Argentière: a field-scale laboratory



Seismic measurements: **spatial**

- 98 seismic stations maitained for one-month in spring 2018
- A cross-disciplinary and cross-institutes collaboration

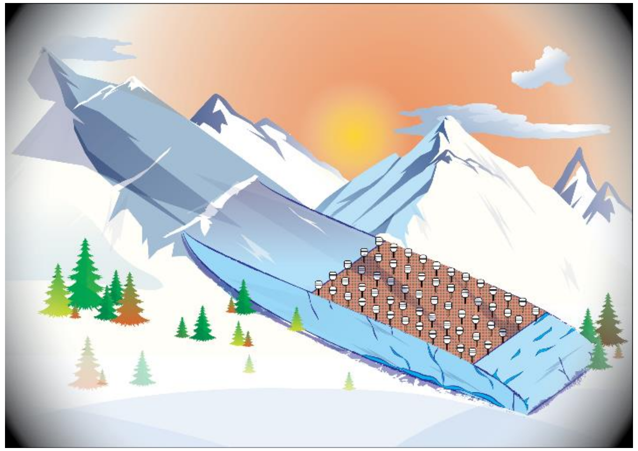


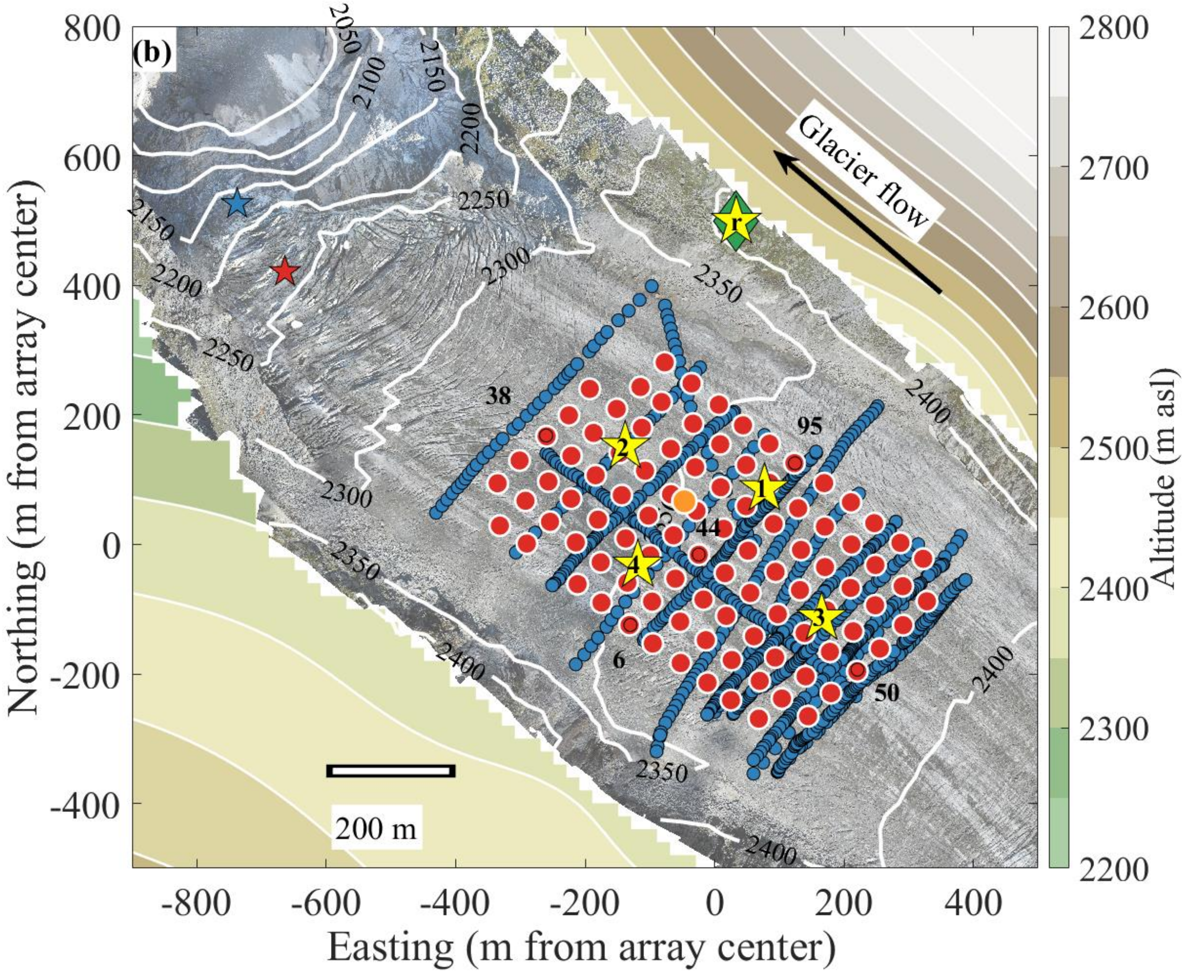


ISTerre

In collaboration with the RESOLVE project: a development of a multi-instrument platform for interdisciplinary research.

The RESOLVE-Argentière project



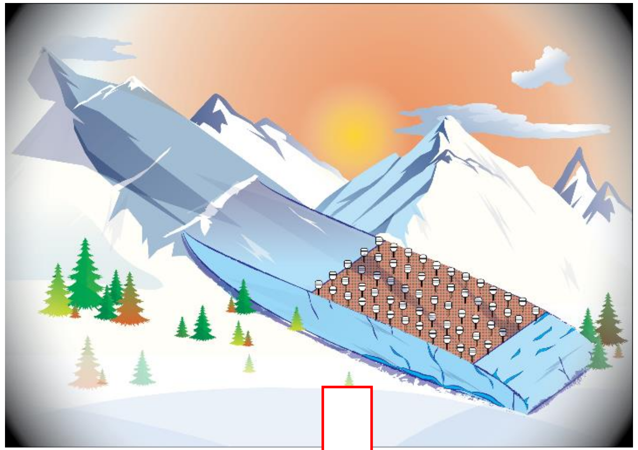


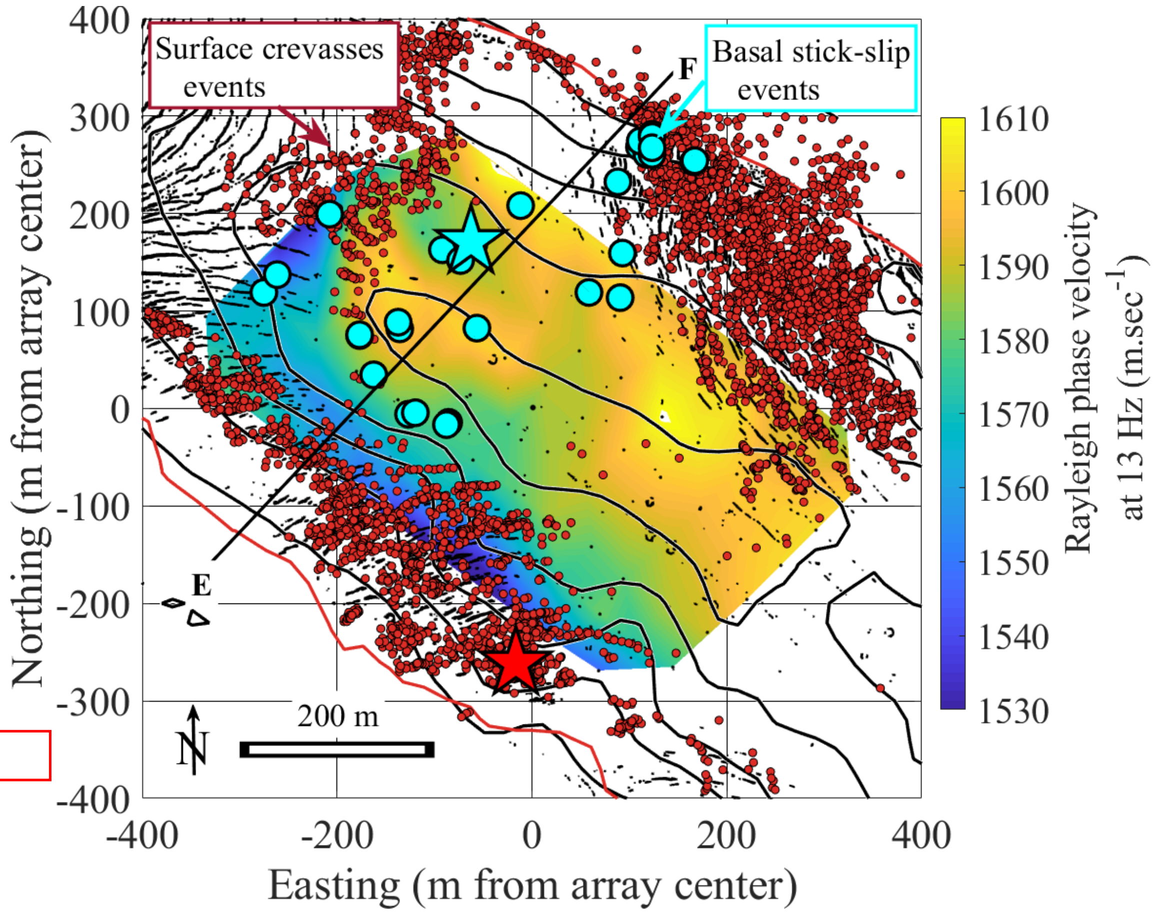
Seismic measurements
- Nodes sensors
- Surface borehole seismometer

Complementary measurements
- GNSS antennas
- GPR tracks
- Subglacial wheel
- Weather station
- Water discharge gauge

(Gimbert, **Nanni**, Roux et al., 2020)

The RESOLVE-Argentière project

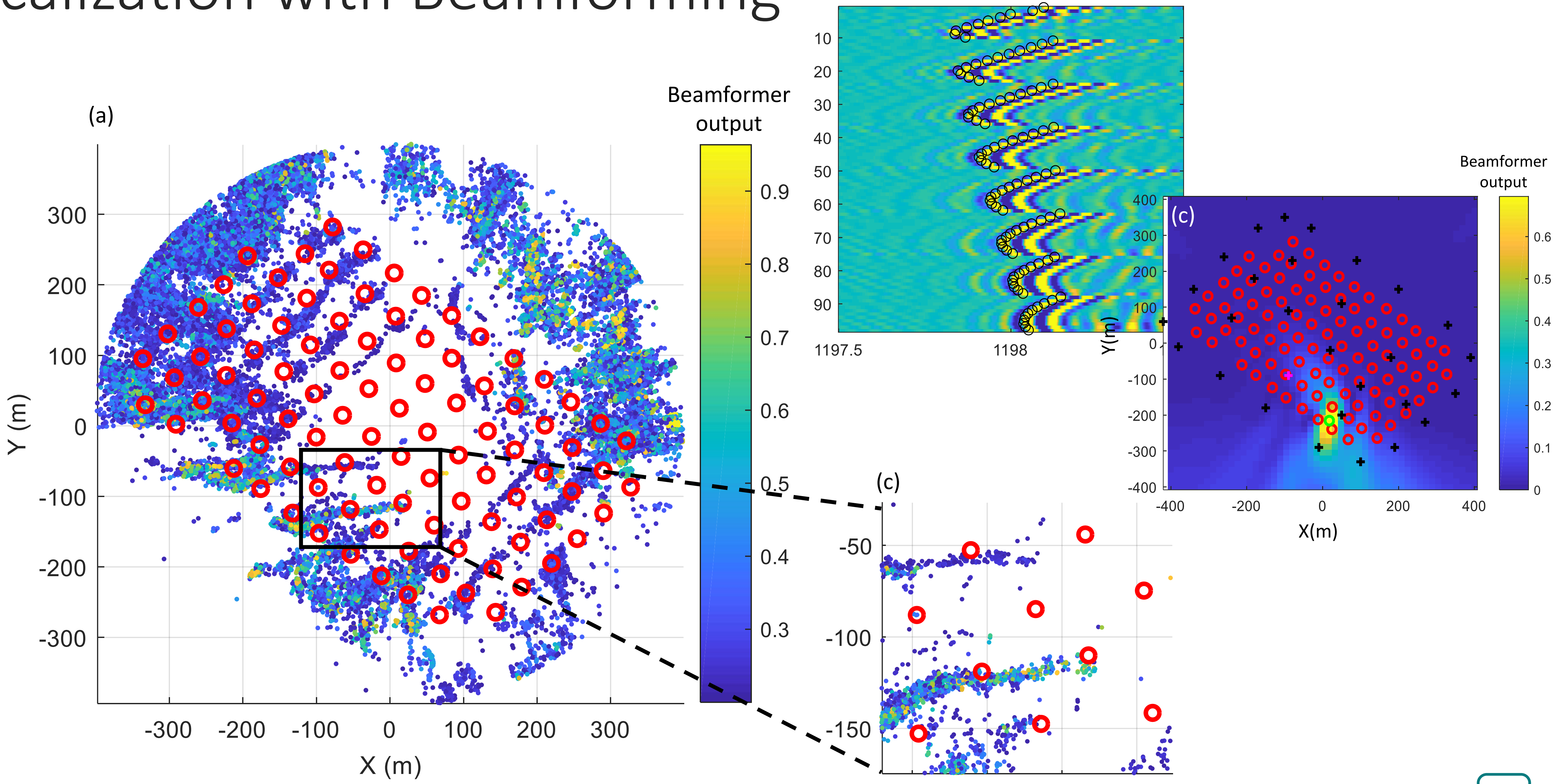




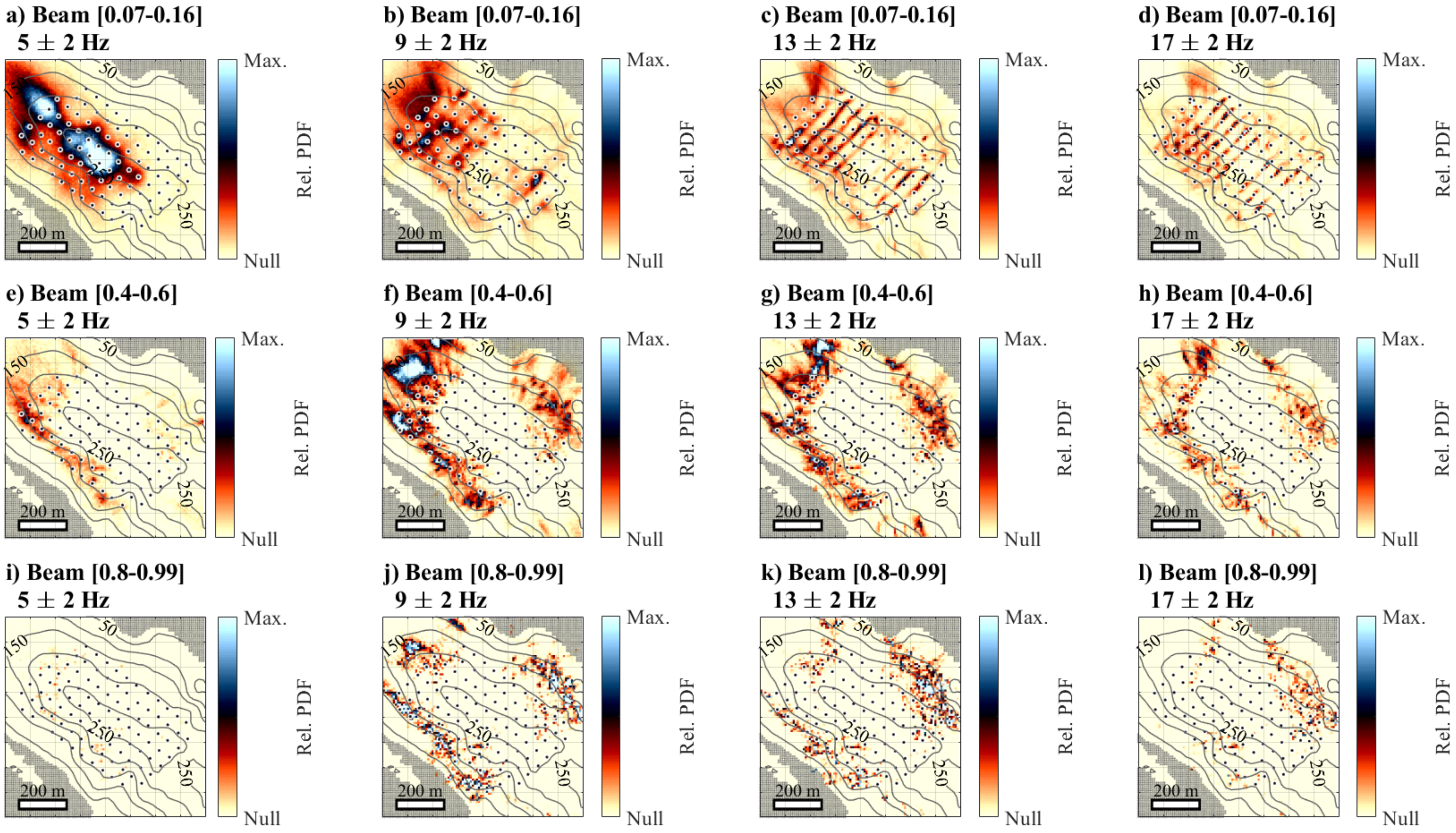
A wide range of **seismic analysis** presented in our community paper.

(Gimbert, **Nanni**, Roux et al., 2020)

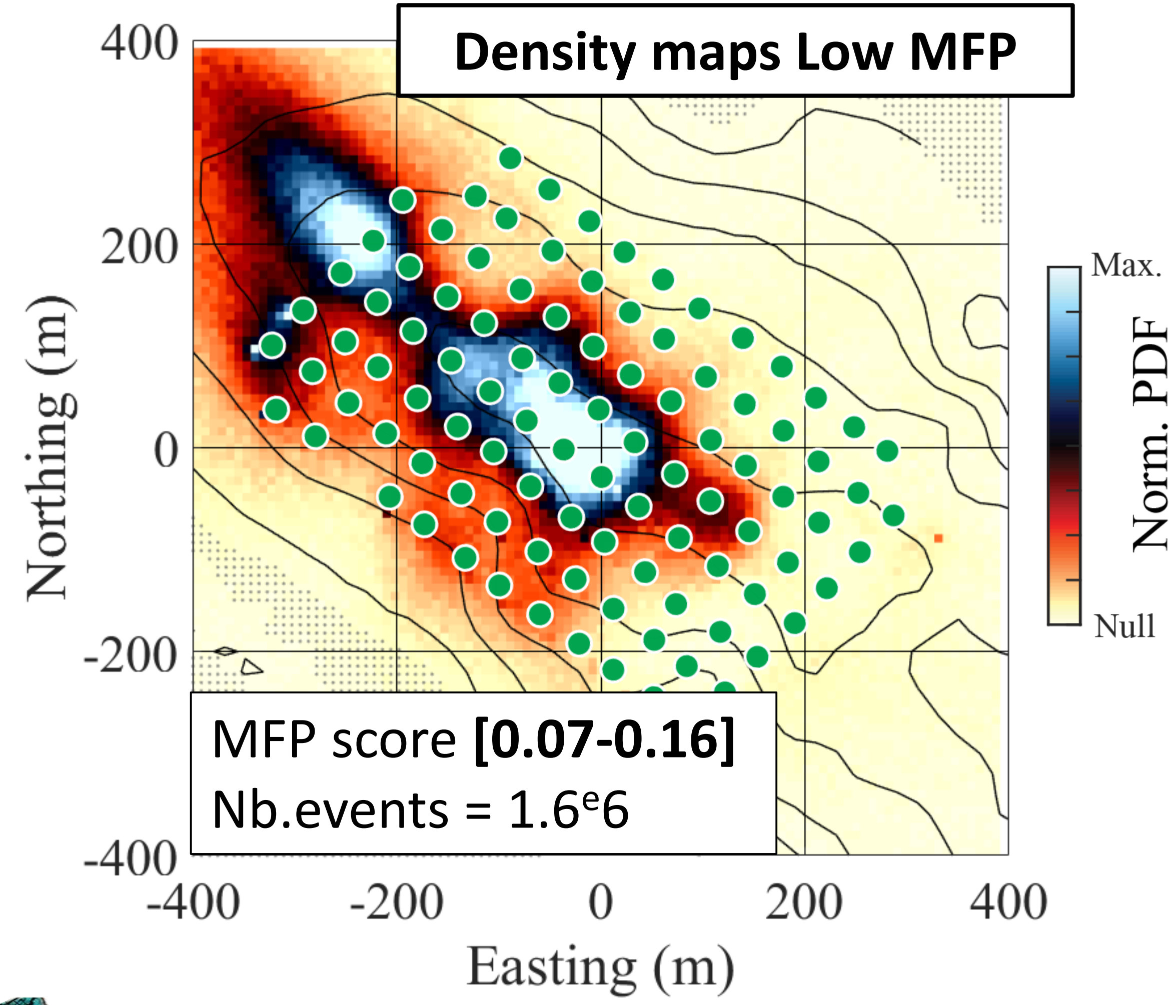
Localization with Beamforming

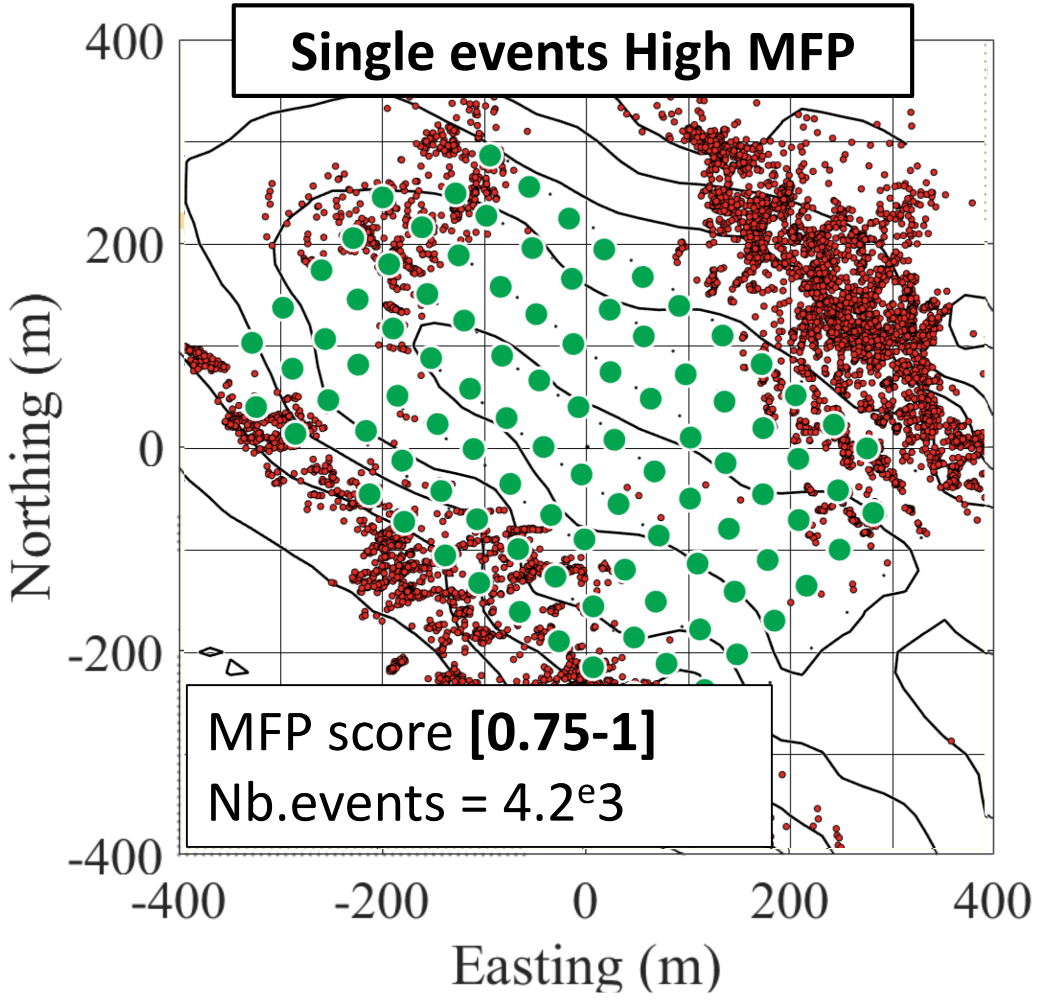


Beamforming Results : complicated patterns accross frequency / Beam output



Patterns of noise and punctual sources





(Nanni et al., GRL)

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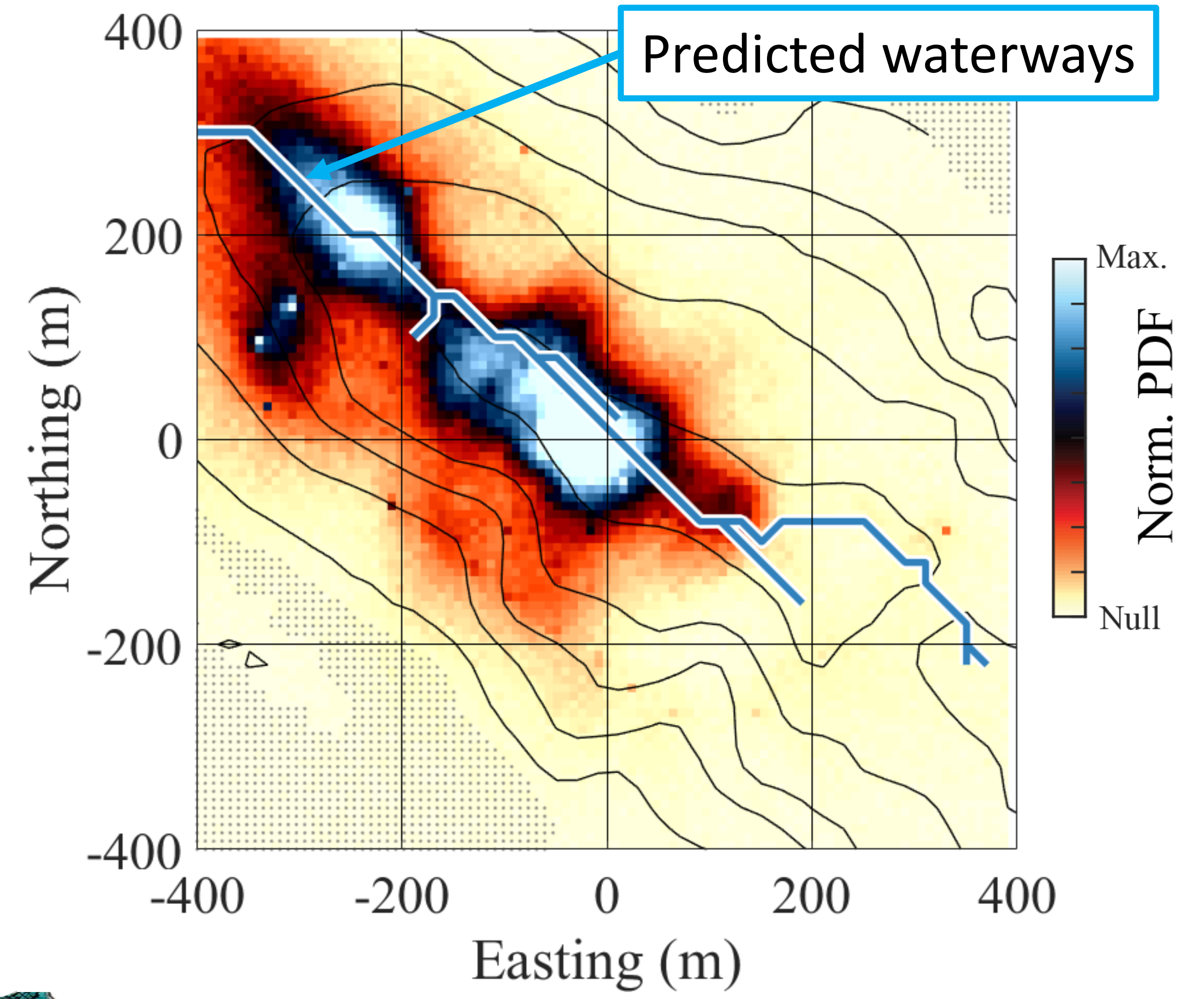
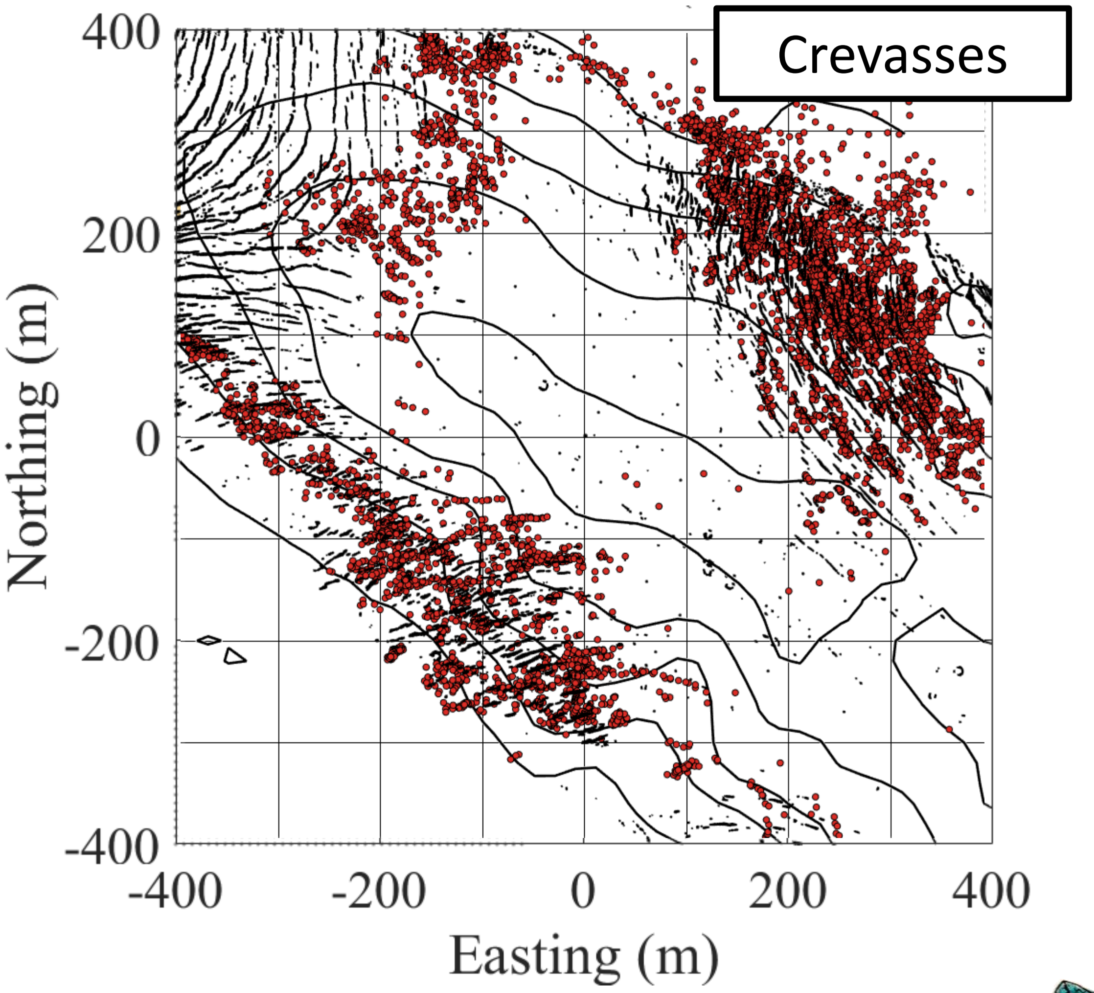




(Nanni et al., GRL)

Patterns of sources due to scattering

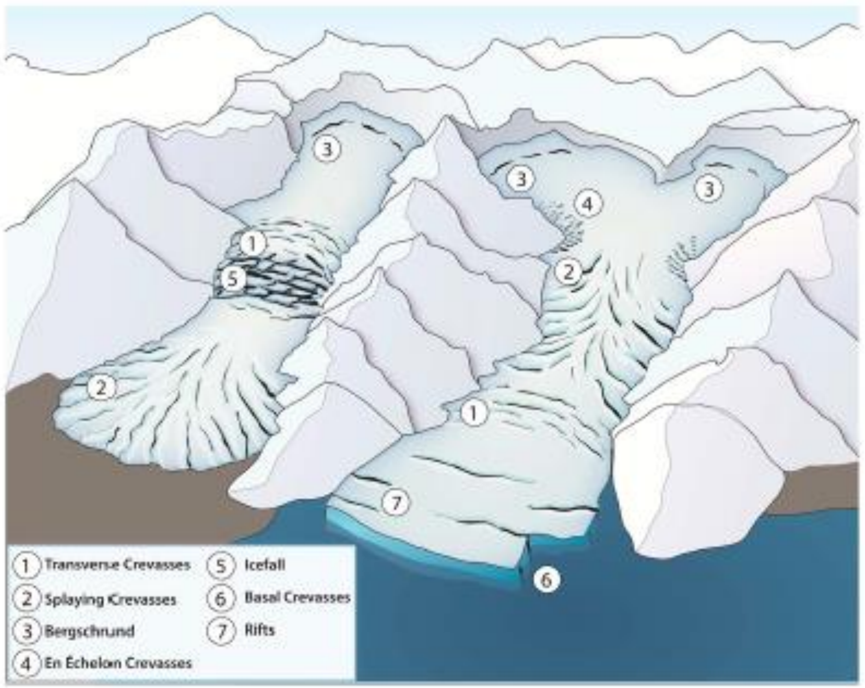
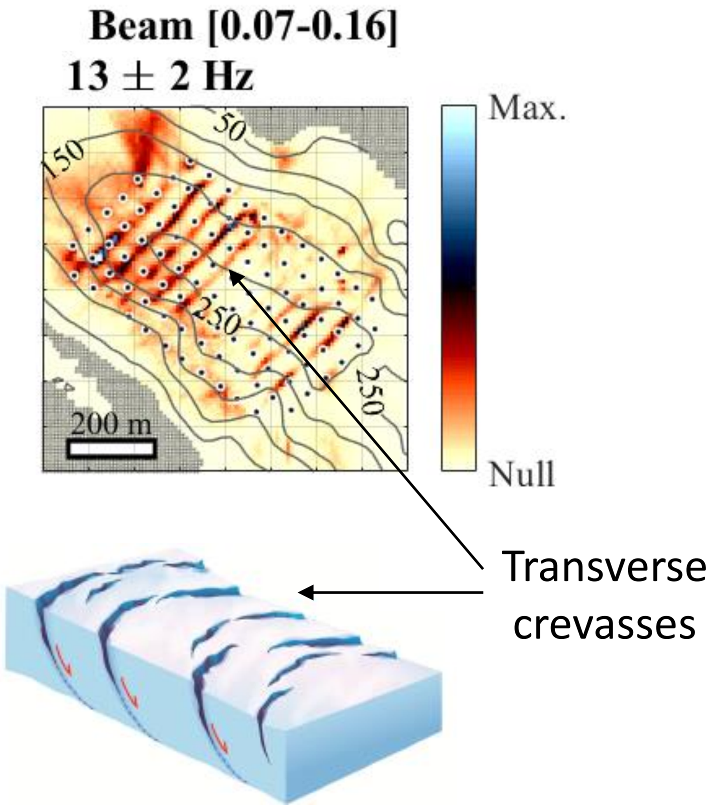
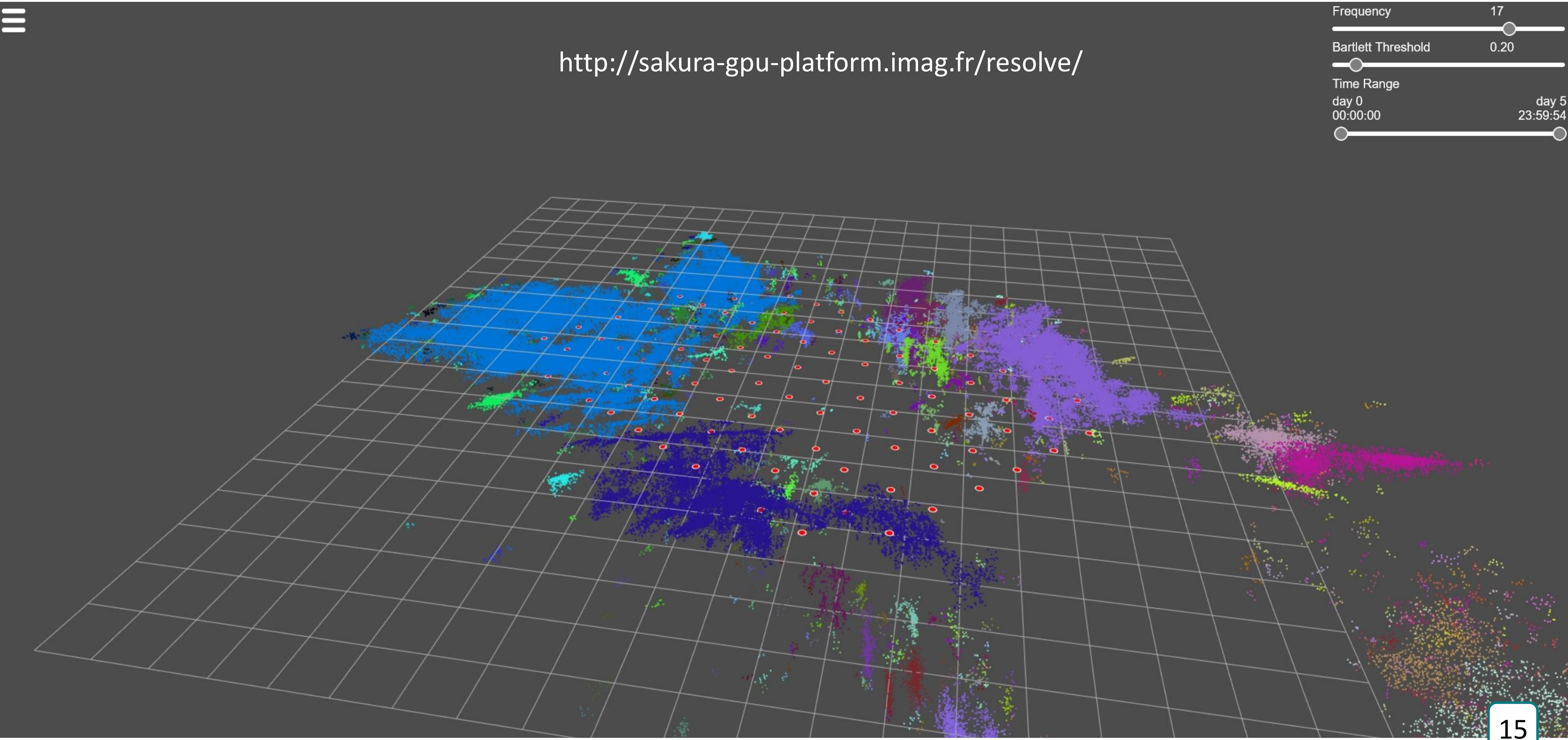


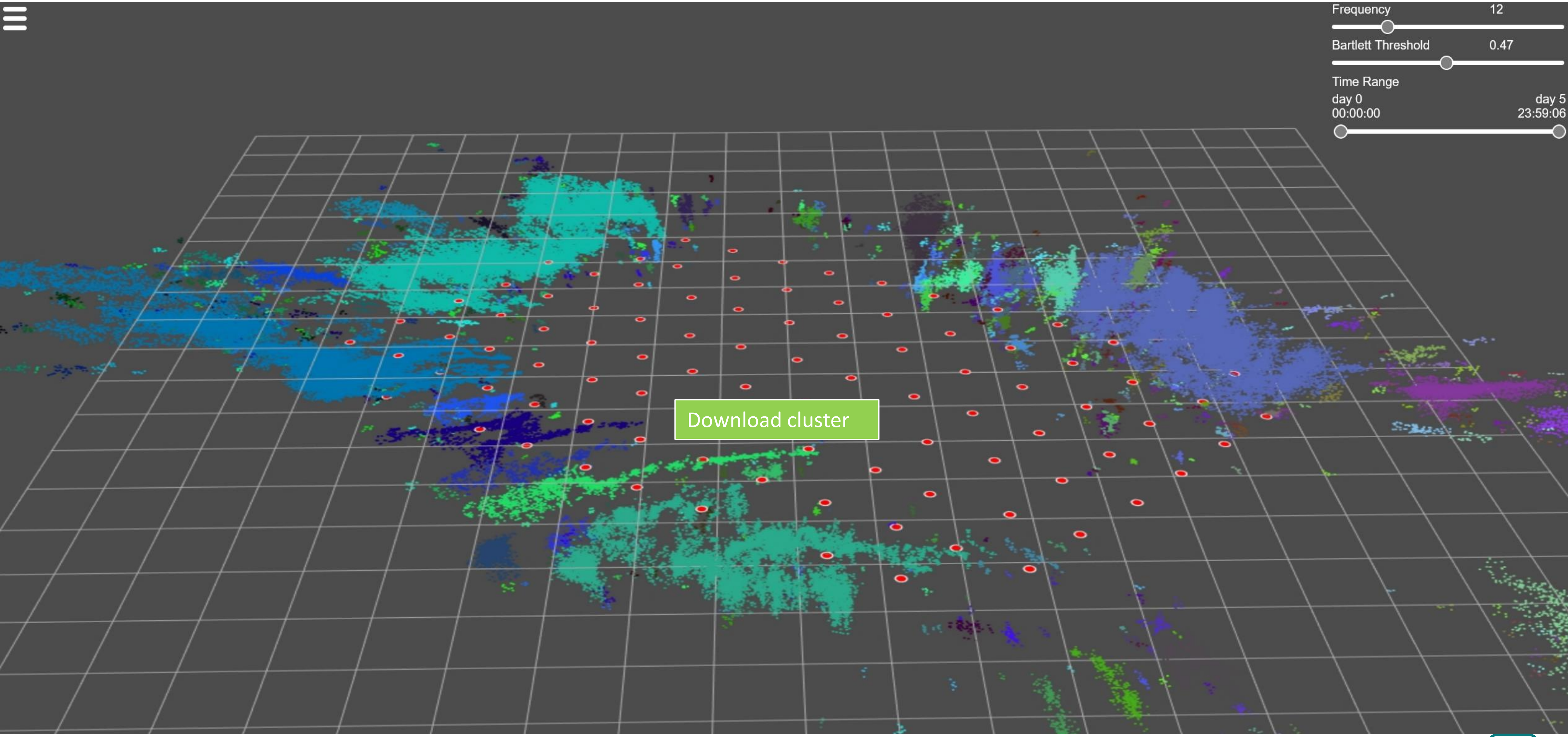
Figure 1. Illustrative schematic of various crevasse types.



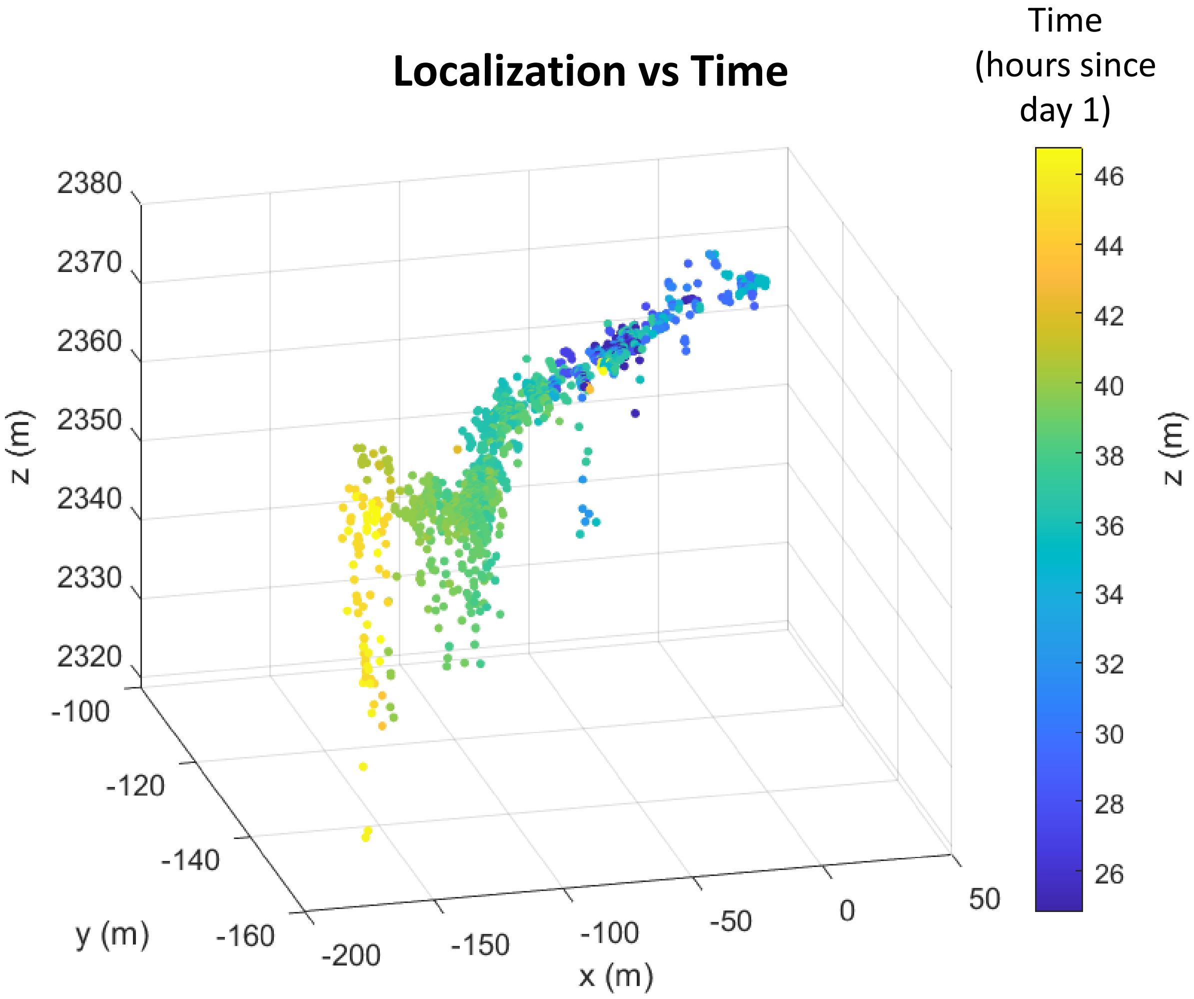
Visualization tool developed at LIG (Michael Ortega)

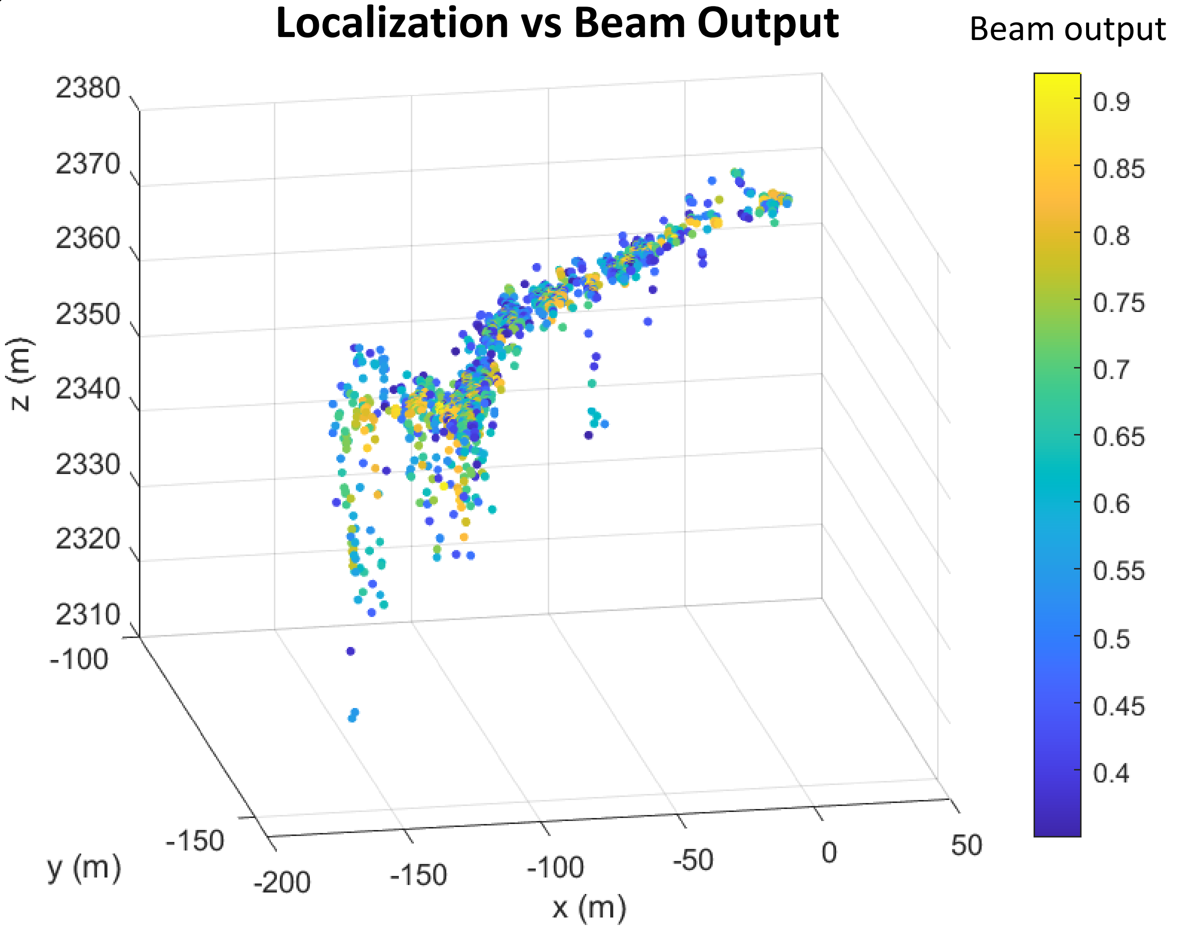


Interactive parameter selection



Data analysis and interpretation





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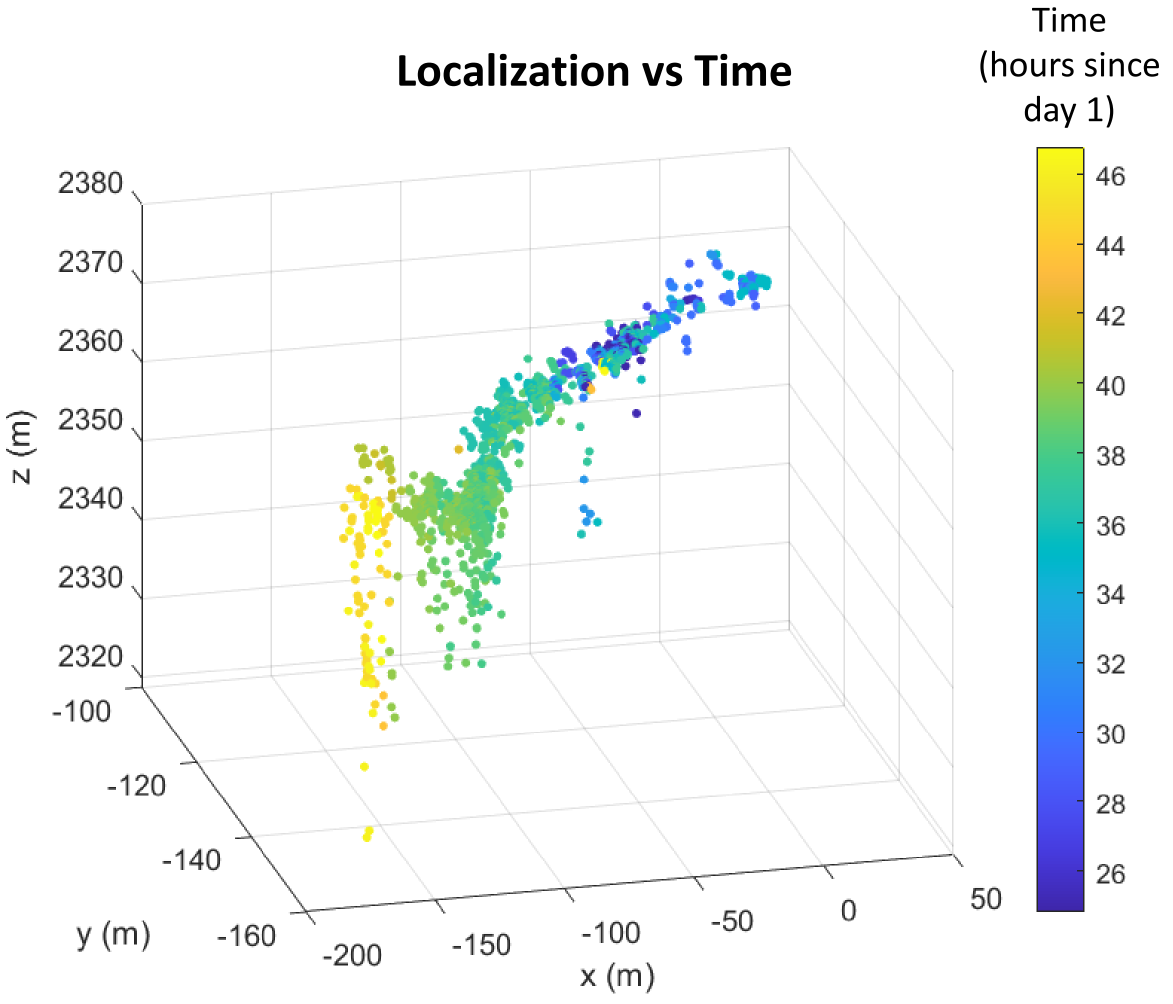
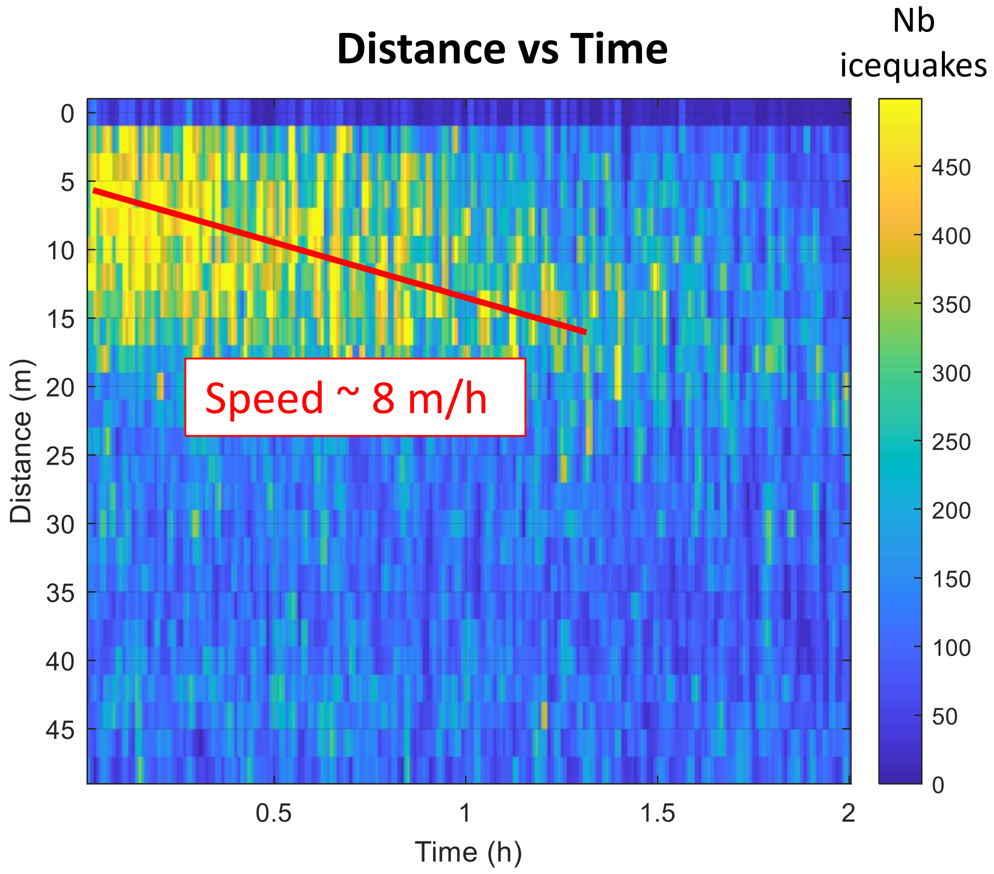




Glacier average downhill displacement from GPS ~ 0.1 m/Day

To be done…

- Process 33 days instead of 6 days (Michael Ortega)
- Add localizations to the catalog (IA, Piero Poli)
- Go further in the clustering mode
- Finalize result on crevasses dynamics :

Why 8 m/h? Is it stable over the 33-days period?
Is it the same for all crevasses?

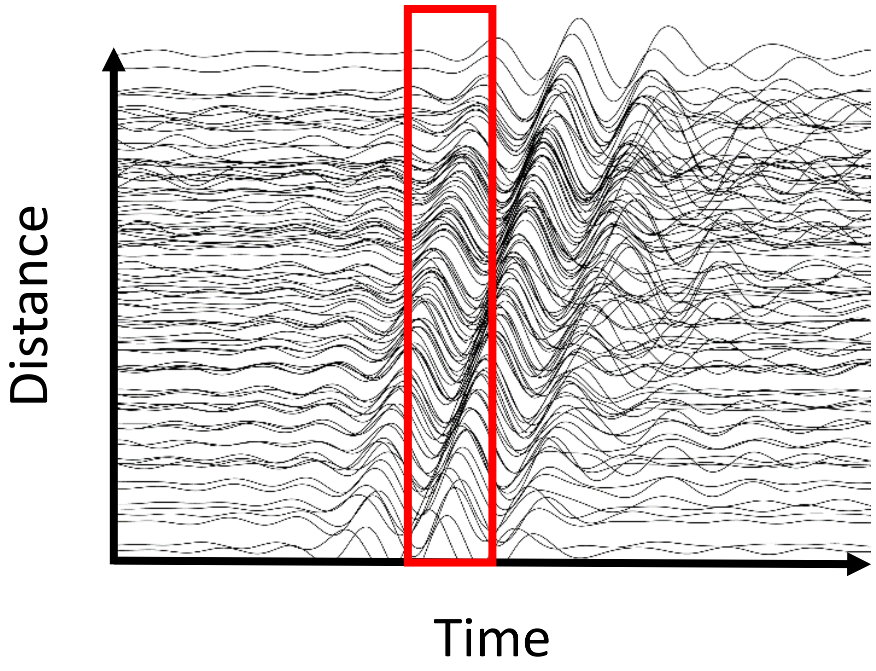
- Data analysis for transverse crevasses

How to locate **punctual** sources ?

$$u(t) = Ae^{i\omega t}$$

Amplitude **Phase**

Phase differences ~ time delays



Phase coherence for a punctual source

Wavefront when throwing
a stone in a lake

Phase coherence for a punctual source

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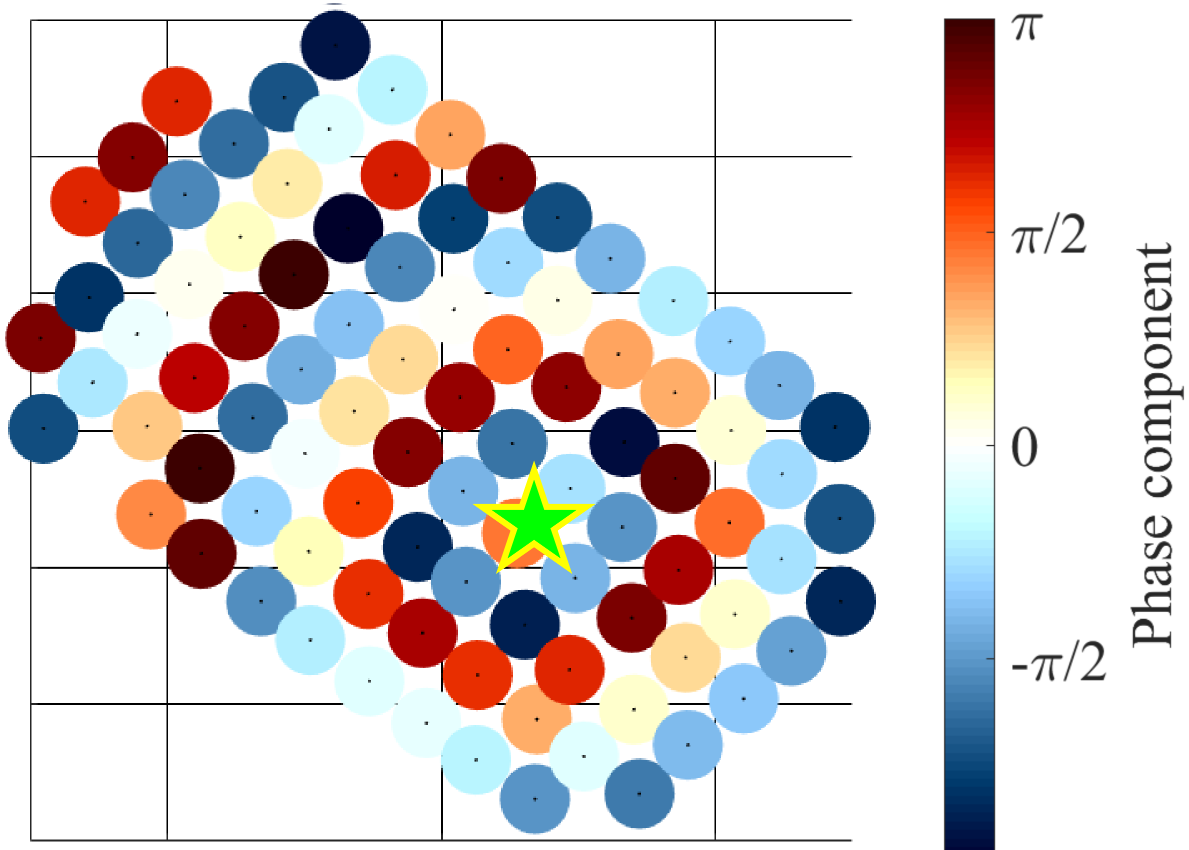
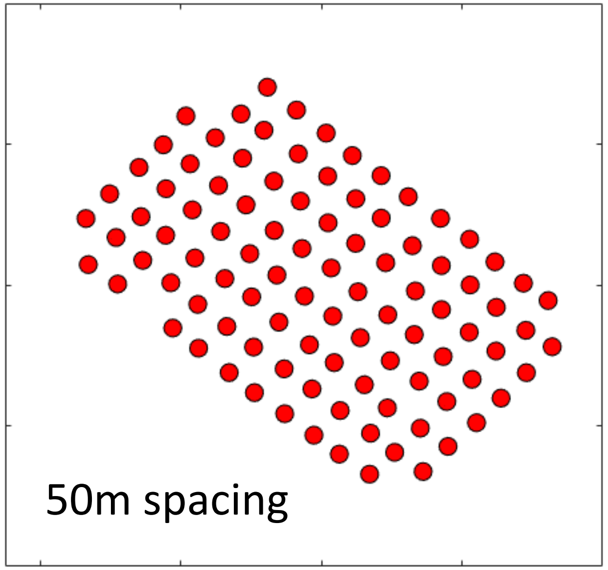


Wavefront from an impulsive event

MFP: the Match-field-processing method

- Assume a unique source over 1 second-signal
- Minimize misfit $|\text{Phase}_{\text{model}} - \text{Phase}_{\text{observed}}|$ (*gradient-based minimization*)

Seismic array



(e.g. Kuperman et al., 1997; Corciulo et al., 2013; Chmiel et al., 2019)

MFP: the Match-field-processing method

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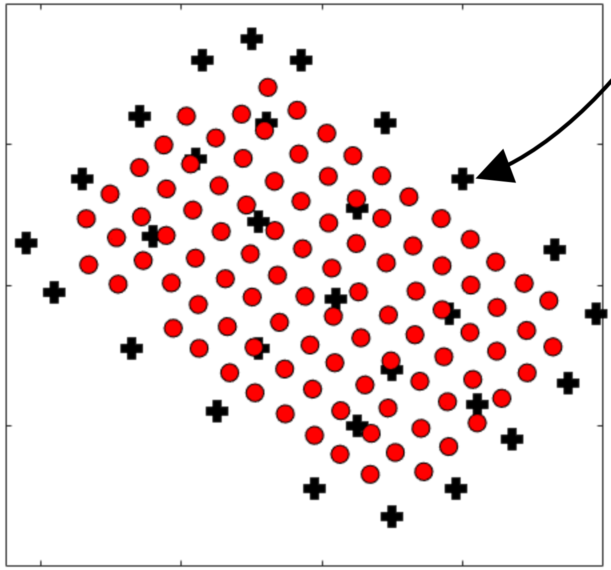
Find local and global minima

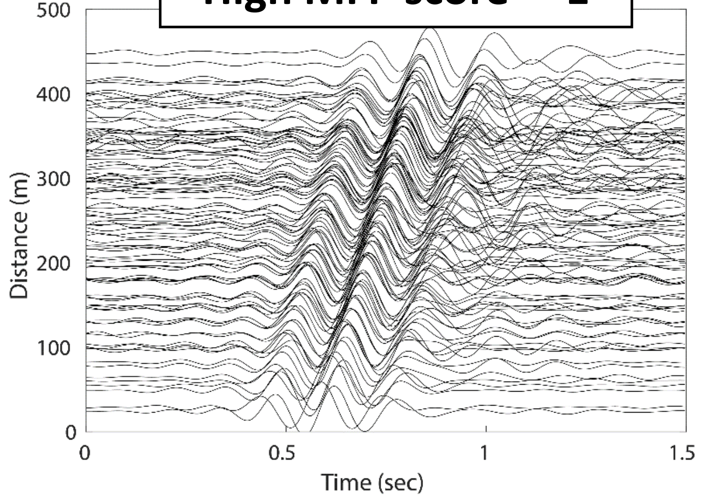
29 starting points



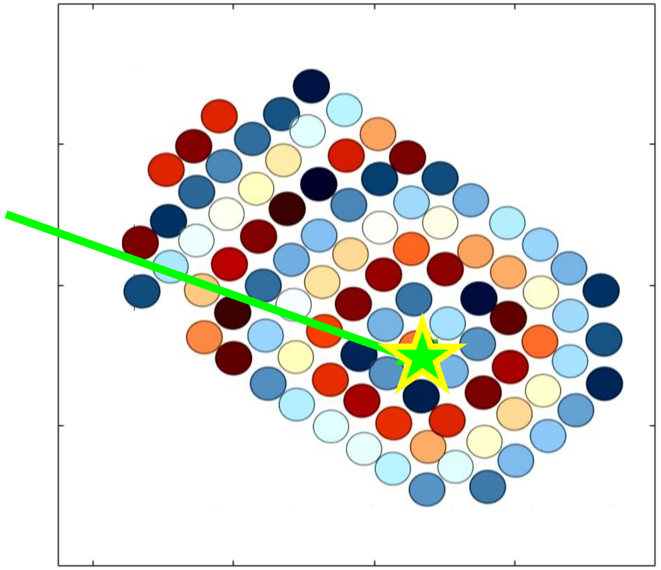
Punctual source: easy

- Assume a unique source over 1 second-signal
- Minimize misfit $|\mathrm{Phase}_{\mathrm{model}} - \mathrm{Phase}_{\mathrm{observed}}|$ (*gradient-based minimization*)
- MFP score $\propto$ phase coherency over the array

Impulsional signal:
High MFP score ~ 1



Unique location



Distributed sources: tricky

- Assume a unique source over 1 second-signal
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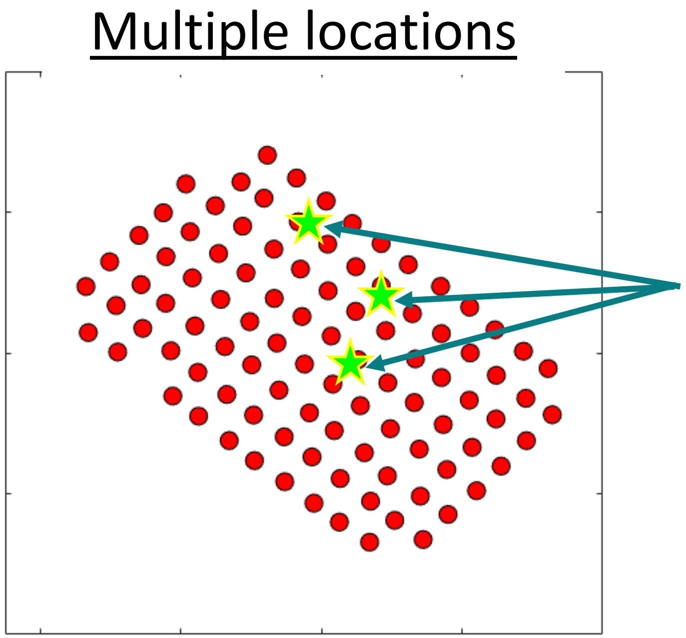

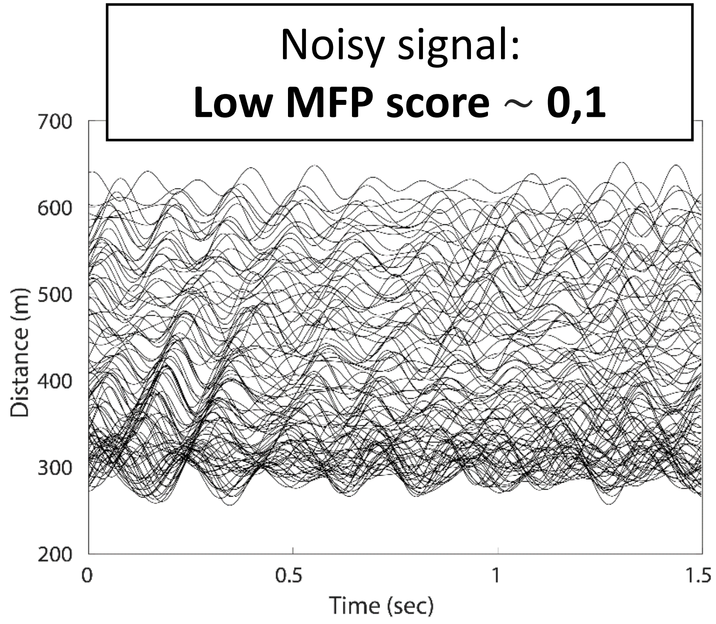

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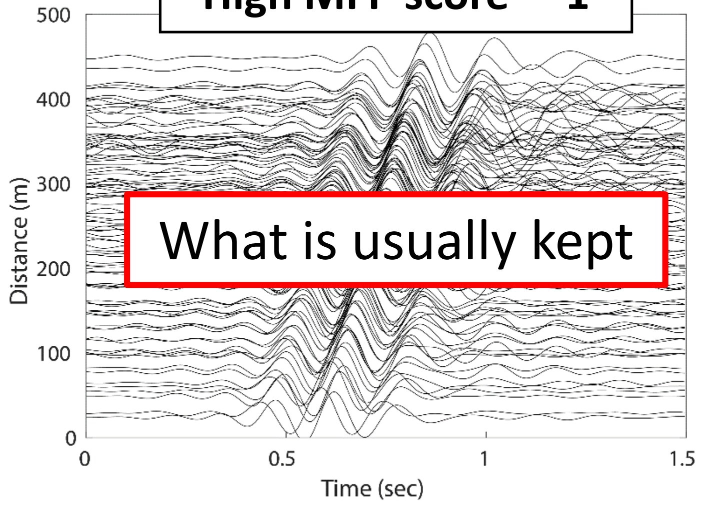
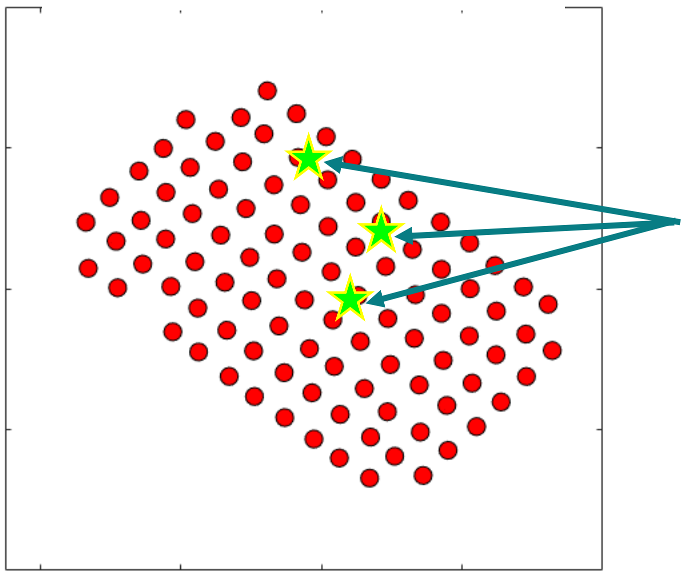
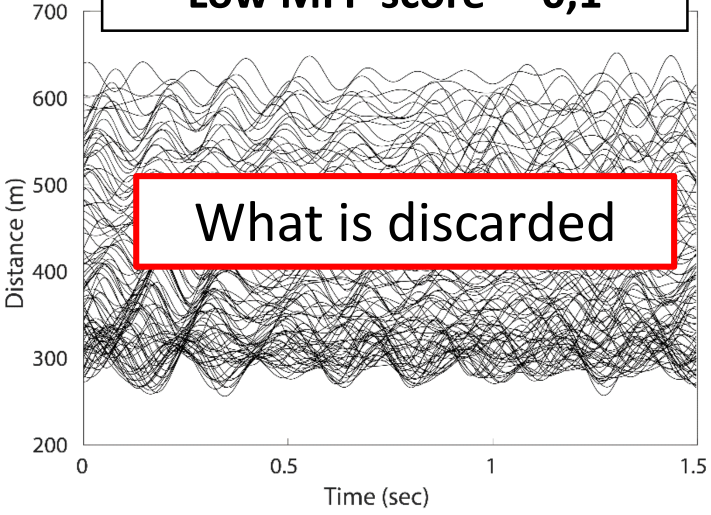


Multiple locations



Noisy signal:
Low MFP score ~ 0,1



A CONCEPTUAL ADVANCE!

- Assume a unique source over 1 second-signal
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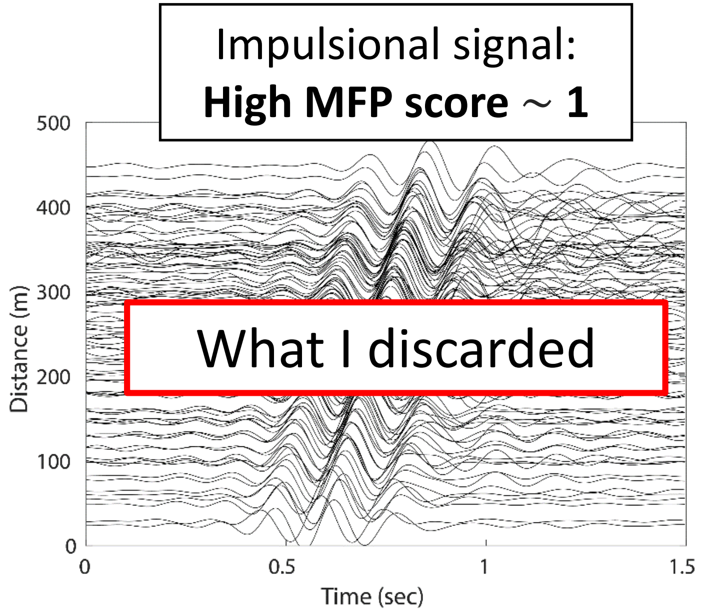

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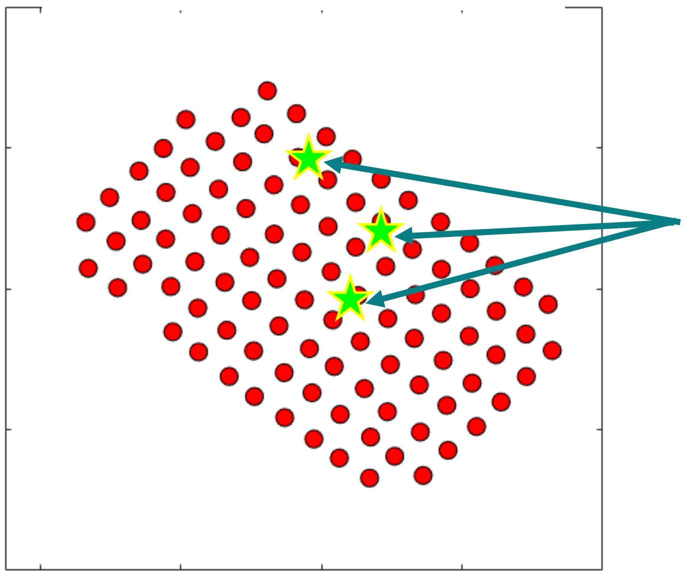
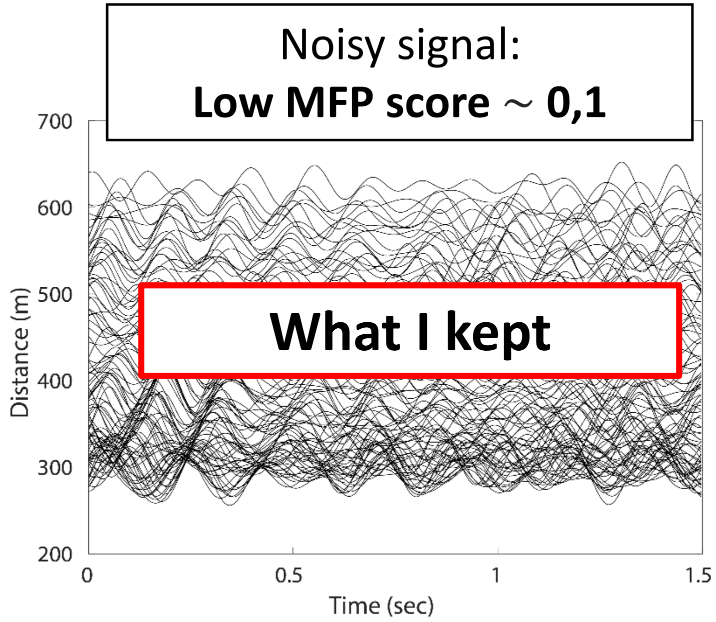
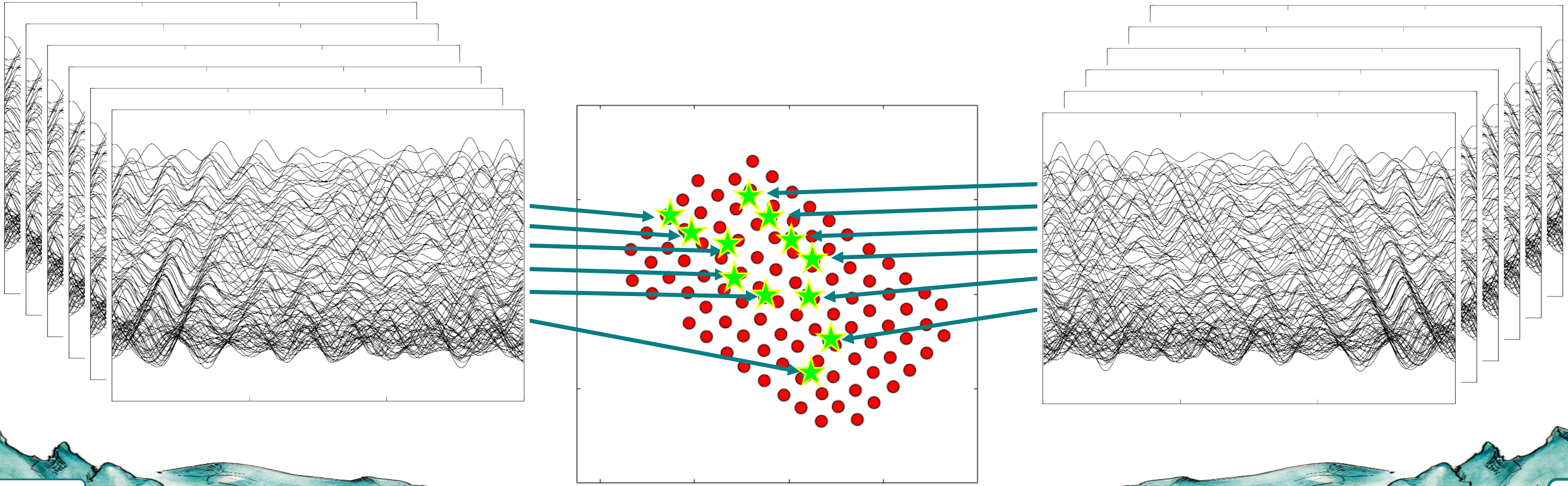


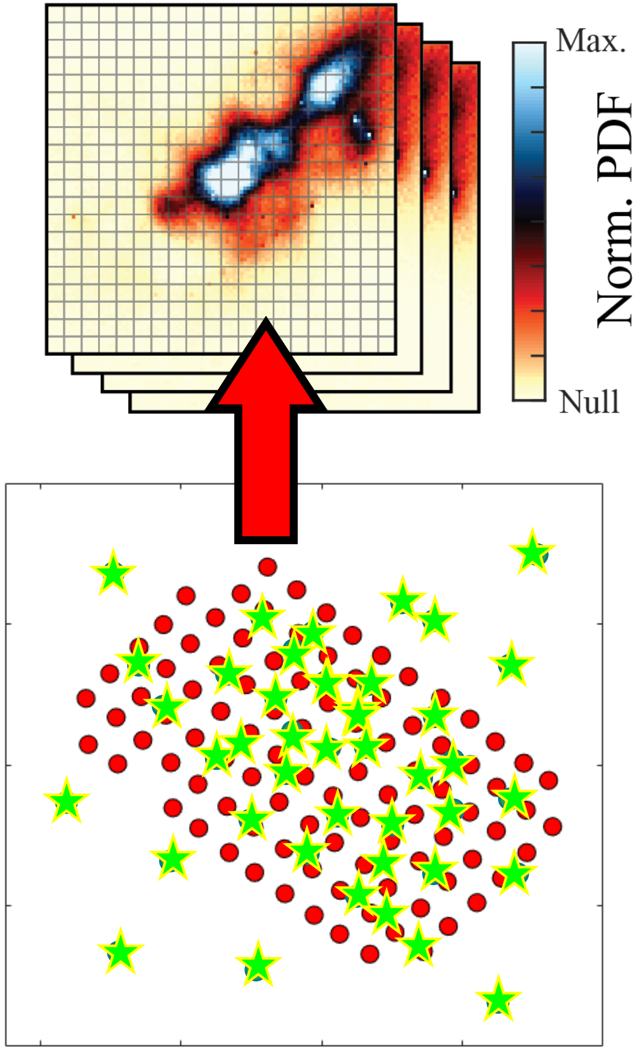


A CONCEPTUAL ADVANCE!

- Subglacial water flow: **low MFP** score (several sources are active simultaneously)
- I stack each 1 second-location over long time periods (~ days)



Making density probability maps



Up to 50+ millions potential locations per day

I selected realistic values:

- Phase velocity
  [1500-3600 m.sec^{-1}]

- Source positions
  ± 400m from array center in (x,y,z)