Source location by waveform inversion in Argentière glacier

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1. Context: The Resolve project

The global objective of the Resolve project is to use **sensor networks** to provide a better understanding of **subsurface dynamic processes** in different geophysical objects. A sensor network of **98 3-component seismic stations** recording during **35 days** in **early spring 2018** has been deployed on the Argentière glacier (French Alps).

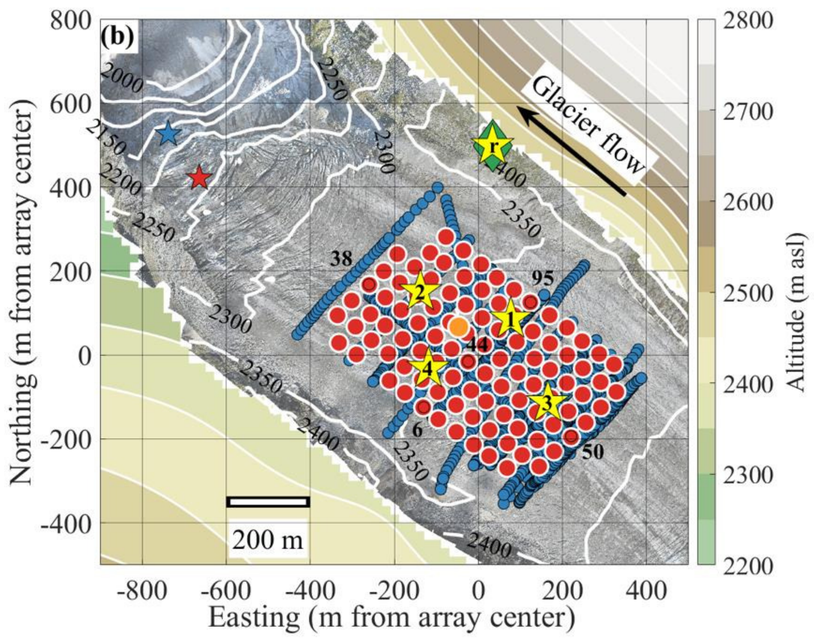

Figure 1: Argentière glacier map with the sensor network (taken from [1]).

PhD goal: Development of a **3D joint inversion method** using **full waveforms** allowing,

- to spatially **locate the icequakes** responsible for the recorded signals,
- to characterize the **temporal signature/mechanism** of these icequakes,
- to reconstruct the **structure of the glacier**.

2. Matched Field Processing (MFP)

A **single type of wave** is assumed to propagate spherically in the medium, at a **constant velocity** (velocity of **Rayleigh wave** most of the time) for a given frequency. The method is based on a **shift** and a **summation of phases** of the recorded signals.

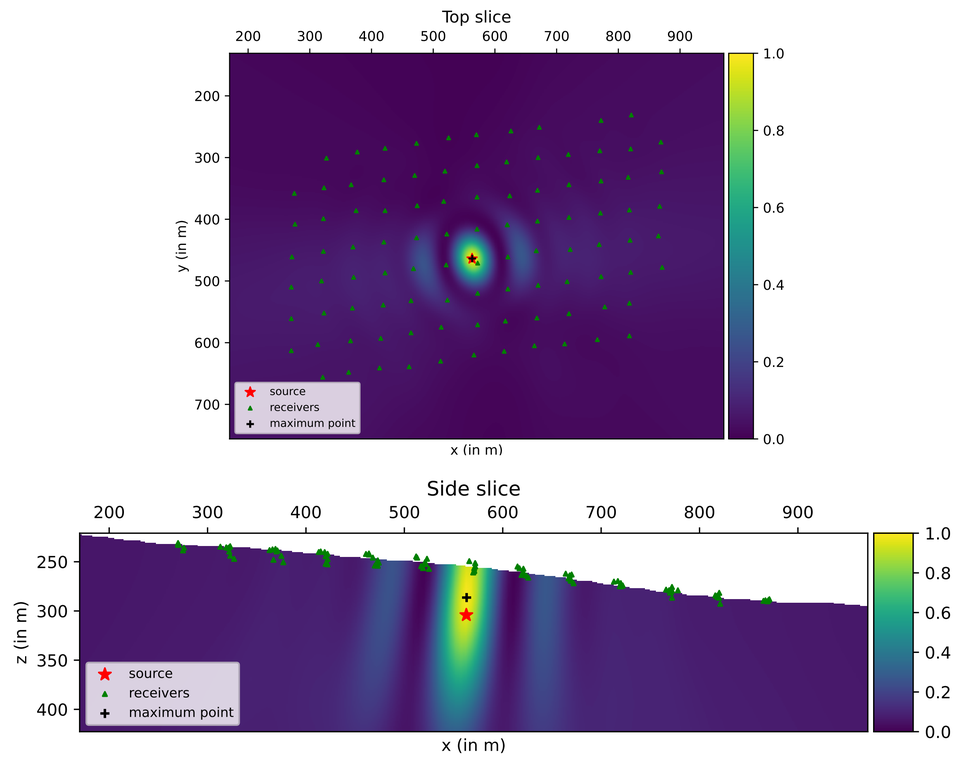

Figure 2: MFP result on a 3D elastic simulation in the Argentière glacier structure.

The MFP method shows some **limitations** related to its **simple assumptions**, especially when the source is not near the surface. **Velocity variations** and **heterogeneities** within the glacier are not taken into account.

3. Time-reverse principle

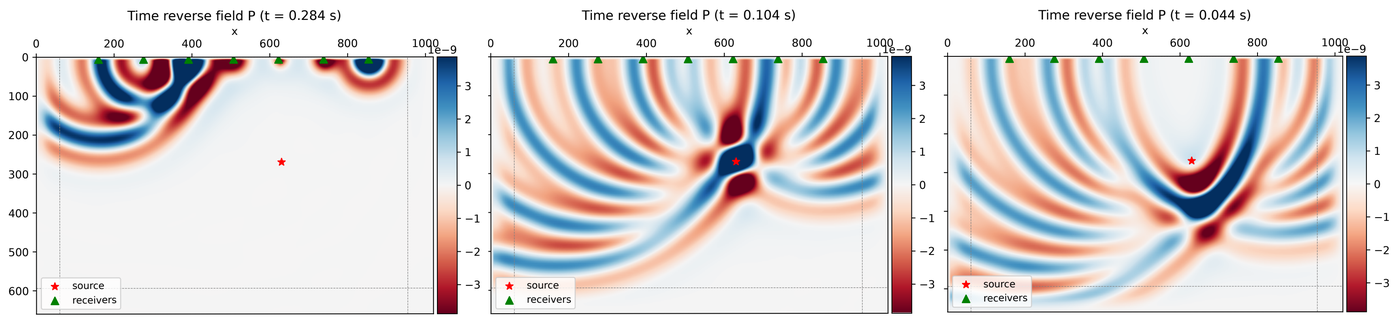

Figure 3: Illustration of the principle of data back-propagation with focus on the source position.

The principle is to **reverse in time the data** $\{d_i(t)\}_{i=1,\dots,N_r}$ recorded at the receivers and to use them as sources to simulate the **back-propagated field** in the medium,

$$\forall i = 1, \dots, N_r, \quad A(m)\lambda_i(\boldsymbol{x}, t) = d_i(T-t)\delta(\boldsymbol{x} - \boldsymbol{x_i}) \qquad (1)$$

where $A(m)$ is the propagation operator depending on the model parameters m.

As the data are assumed to be **generated by the same source**, by back-propagating them from all receivers simultaneously, a **focus on the source position** occurs at a certain time corresponding to the **source emission time**.

4. Imaging conditions from back-propagated fields

Imaging conditions aim to create **static images** from the **back-propagated fields** $\{\lambda_i(\boldsymbol{x}, t)\}_{i=1,\dots,N_r}$ from each of the receivers, with a **focal spot on the source position**. For example:

- Zero-lag auto-correlation,

$$\forall \boldsymbol{x} \in \Omega, \; C(\boldsymbol{x}) = \int_0^T \left(\sum_{i=1}^{N_r} \lambda_i(\boldsymbol{x}, t) \right)^2 dt \qquad (2)$$

- Couple by couple (zero-lag) cross-correlation,

$$\forall \boldsymbol{x} \in \Omega, \; C(\boldsymbol{x}) = \max \left\{ \sum_{1 \le i < j \le N} \int_0^T \lambda_i(\boldsymbol{x}, t).\lambda_j(\boldsymbol{x}, t)\, dt, \; 0 \right\} \qquad (3)$$

- Zero-lag correlation between S and P modes [2],

$$\forall \boldsymbol{x} \in \Omega, \; C(\boldsymbol{x}) = \int_0^T P(\boldsymbol{x}, t) S(\boldsymbol{x}, t)\, dt \qquad (4)$$

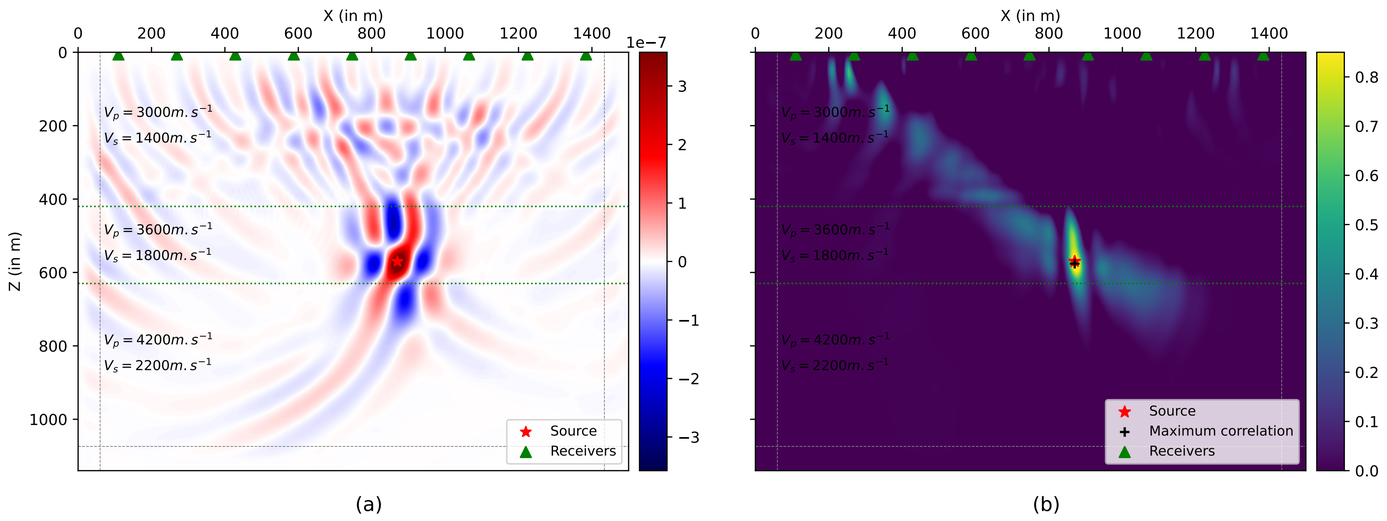

Figure 4: Couple by couple cross-correlation (b) corresponding to back-propagated field (a) (at source focus time).

5. Conclusion & Perspectives

- The MFP shows **limitations** which **motivate full waveform** localization methods,
- **Time-reversal approach** and the use of **imaging conditions** are part of these methods,
- Good match for **joint use with full waveform inversion** to reconstruct the 3D structure.
- Future work: investigate other **potential imaging conditions** and work on a **joint inversion method** allowing the reconstruction of the glacier structure.

References

[1] Florent Gimbert et al. "A Multi-Physics Experiment with a Temporary Dense Seismic Array on the Argentière Glacier, French Alps: The RESOLVE Project". In: *Seismological Research Letters* 92.2A (Feb. 2021), pp. 1185–1201.

[2] Brad Artman, Igor Podladtchikov, and Ben Witten. "Source location using time-reverse imaging". In: *Geophysical Prospecting* 58.5 (2010), pp. 861–873.