# Differential arrival time for event location with DAS data

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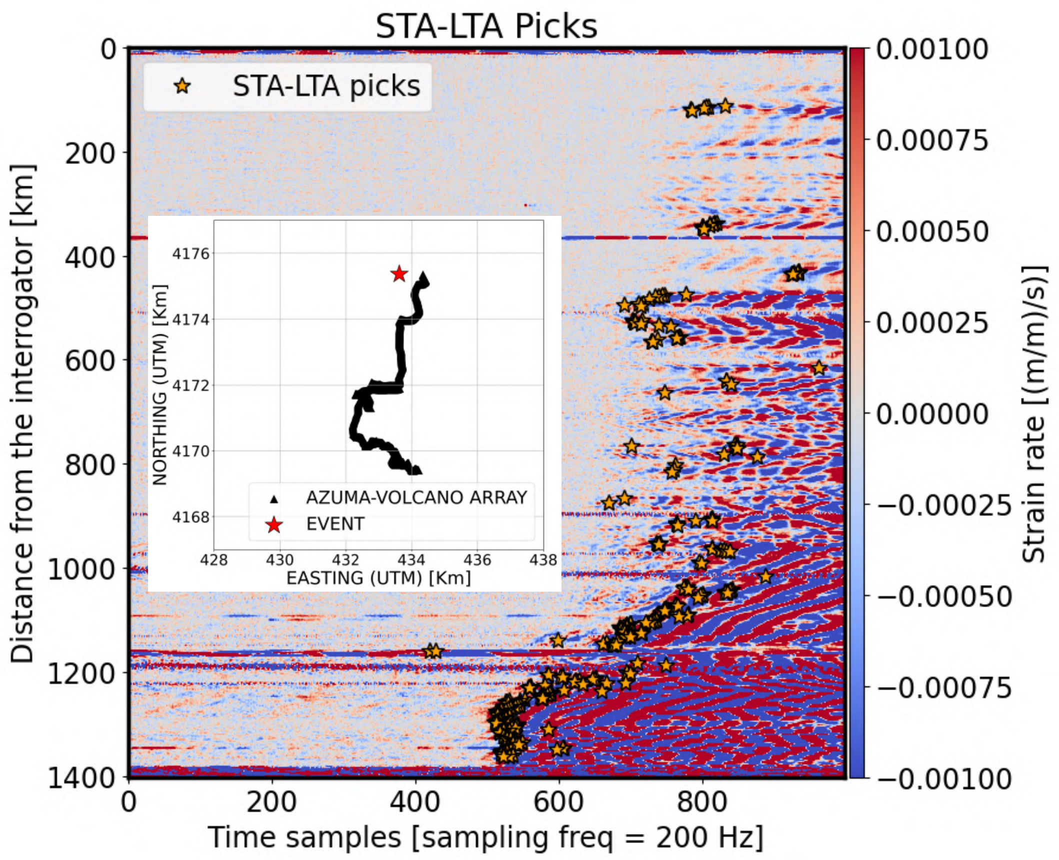
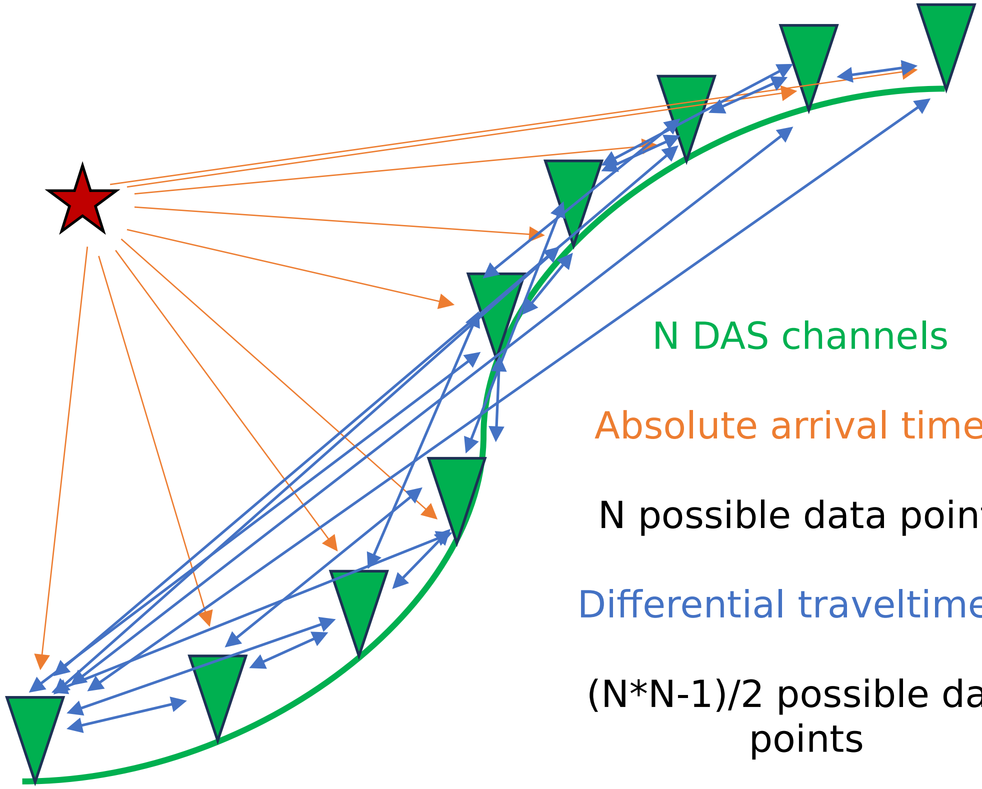
# Distributed Acoustic Sensing (DAS) arrays provide dense strain wavefield sampling

- DAS usually provides 100s up to 1000s of measurment points (**dense spatial sampling**)
- However, absolute phase arrival times are prone to local and intrinsic noise sources (reducing the number of useful data points) >> Effects on location uncertainty
- Nevertheless, DAS is ideal to exploit the redoundant information provided by **time delays between DAS channels** as a data space to be inverted for event location
- **Thus, here we test an Hamiltonian Monte Carlo method to locate a test-earthquake and a small blast, with differential arrival times.**



# Data: differential arrival times



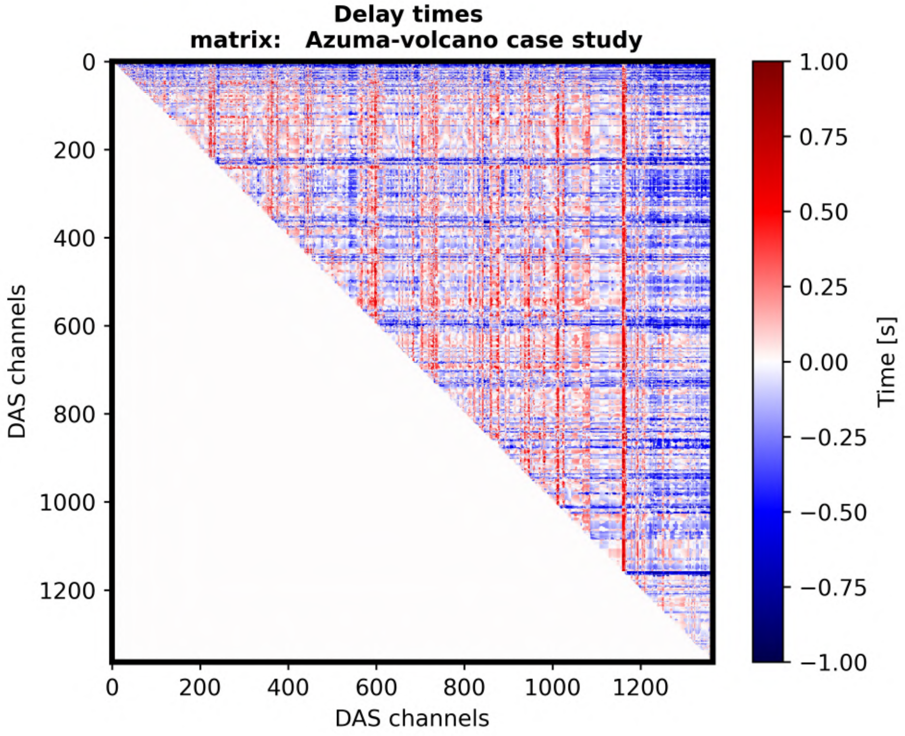
N DAS channels

Absolute arrival times:

N possible data points

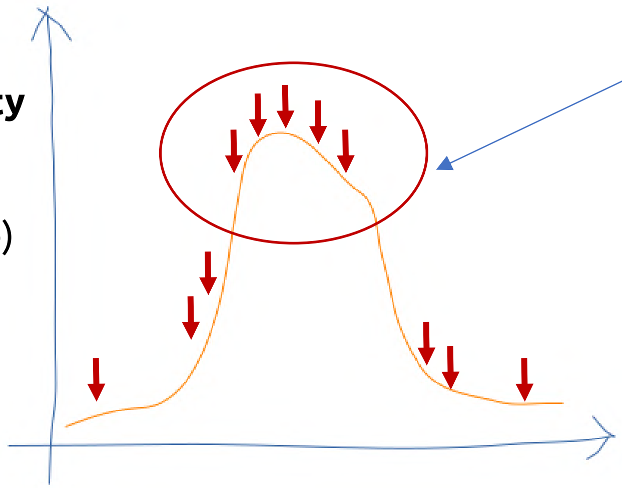
Differential traveltimes:

(N*N-1)/2 possible data points




TEST: **We invert both absolute arrival times and differential arrival times to compare location uncertainties** . **The solution is** not **provided as** a single value but **a probability distribution** (combination of Prior + Likelihood, Bayesian approach)

**Posterior Probability Distribution (PPD)**
(e.g., event's latitutude, longitude)

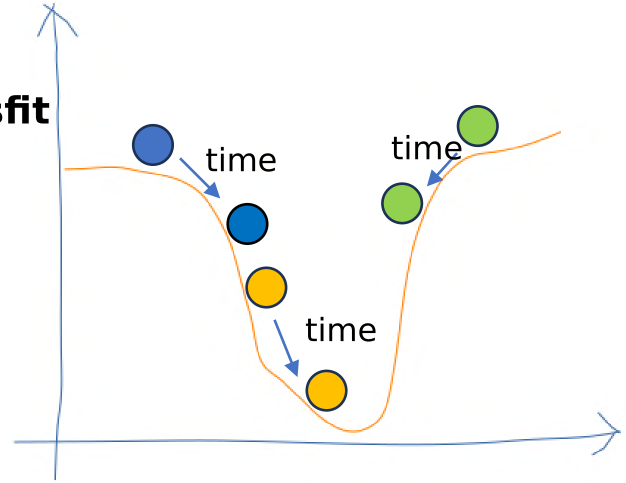


1. We want to converge faster to the peak (regions of higher posterior probability)

2. HMC >> Model "particles" (a value for each model parameter), which are ideally exploring the misfit function topography, are randomly proposed (Monte Carlo) and guided along chains by the misfit (Markov Chain). However they are further "informed" in their movement by the influence of misfit gradient (Hamiltonian)

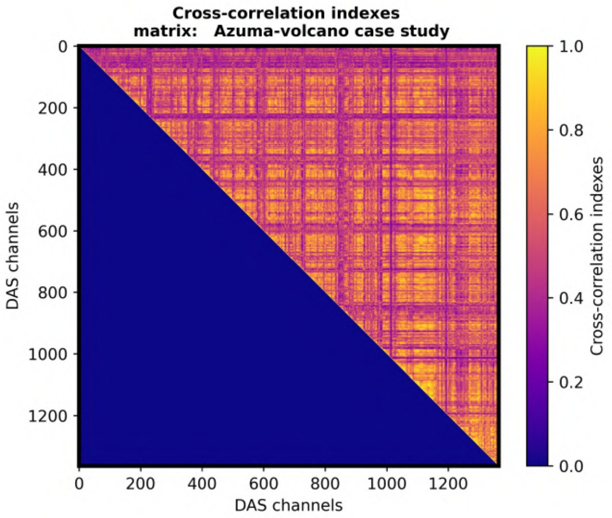
# Getting some intuition of the Hamiltonian Monte Carlo method

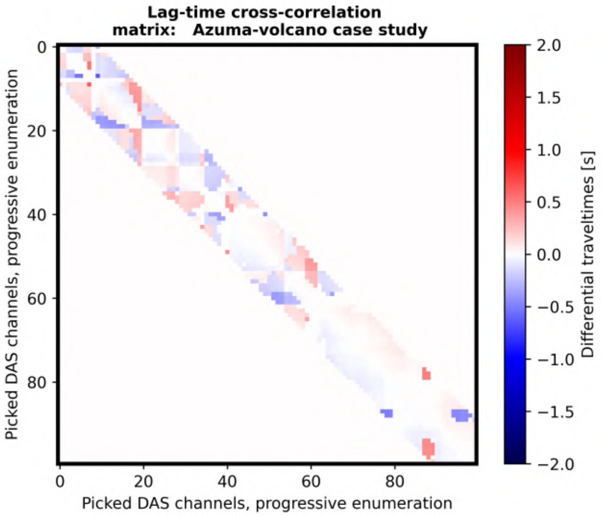
**Misfit**




Compared to a more standard Markov Chain Monte Carlo aproach, the misfit gradient is additionally exploited as an information for *a faster convergence* to the minimum

# Hamiltonian Monte Carlo to locate the events with differential arrival times

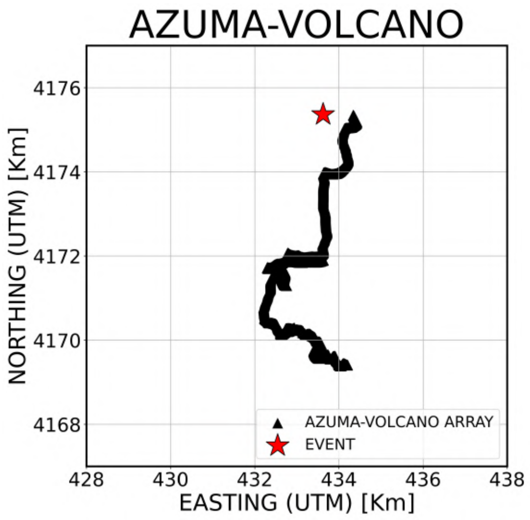


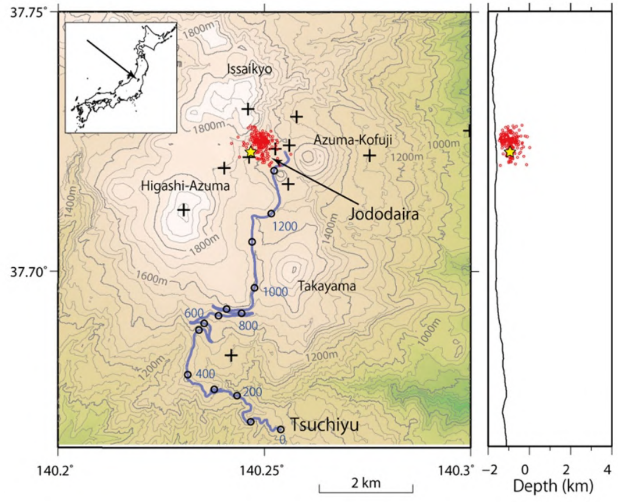





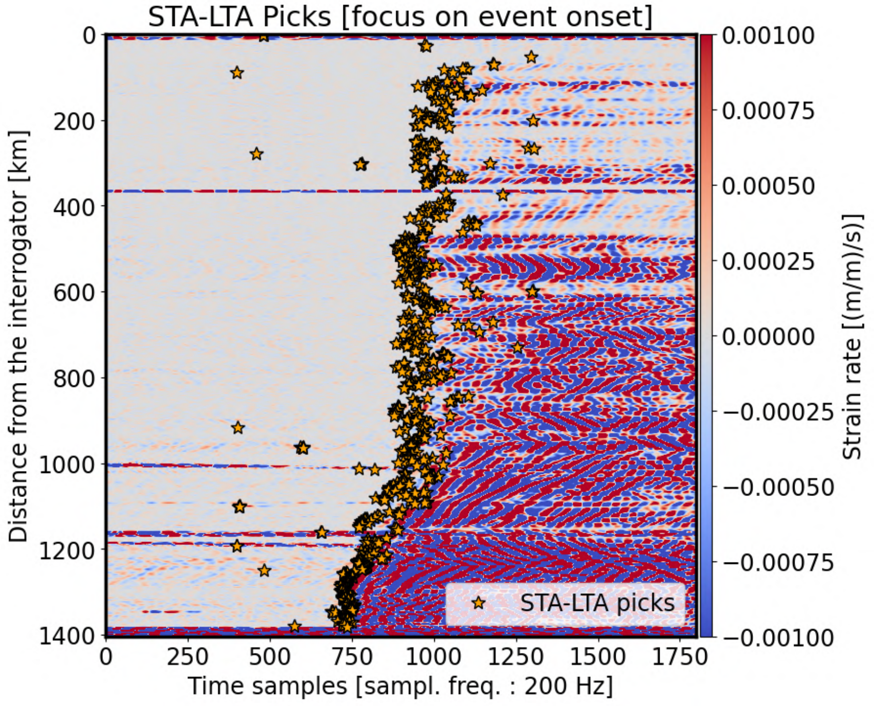
- We start from the Hamiltonian Monte Carlo (Zunino et al., 2023) code, originally developed for absolute arrival times, and modify it to deal with differential arrival times,
- We **select differential arrival times** based on two thresholds: **minimum cross-correlation index and maximum interchannel distance** to use meaningful delay times (expert selection),
- Two well-known events are the test environment for comparing location uncertainties (absolute and differential arrival times)

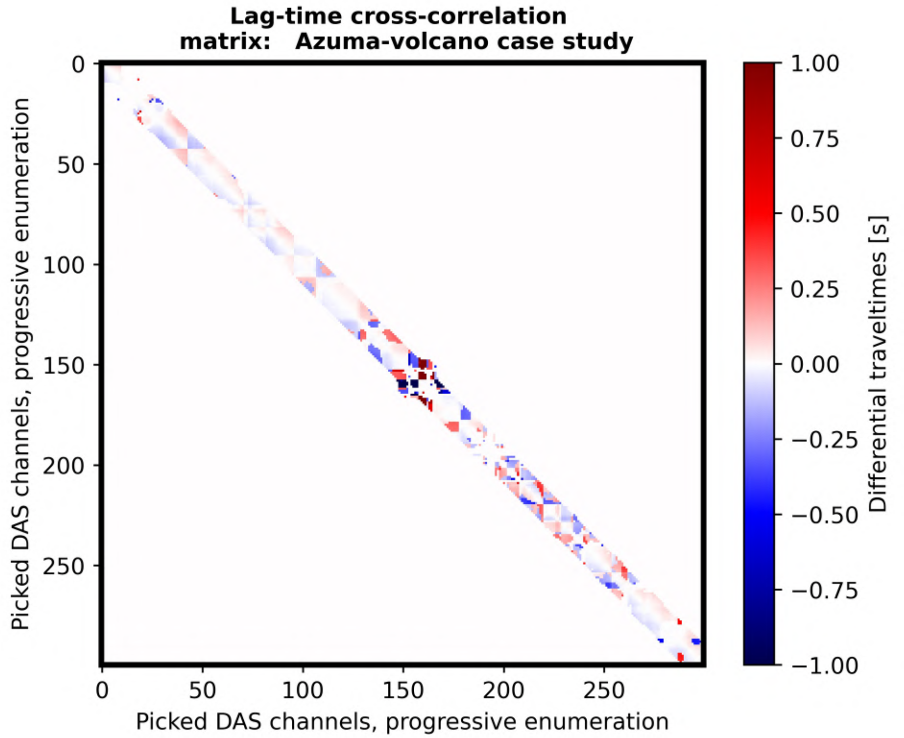
# Applications to well-known case studies: Azuma Volcano (Japan)




Nishimura et al., 2021

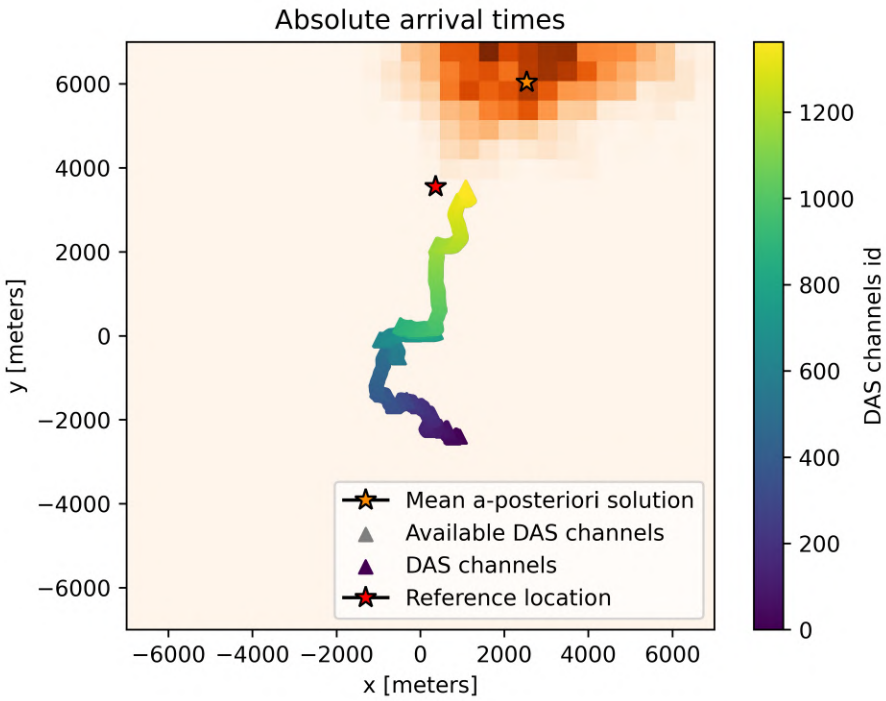


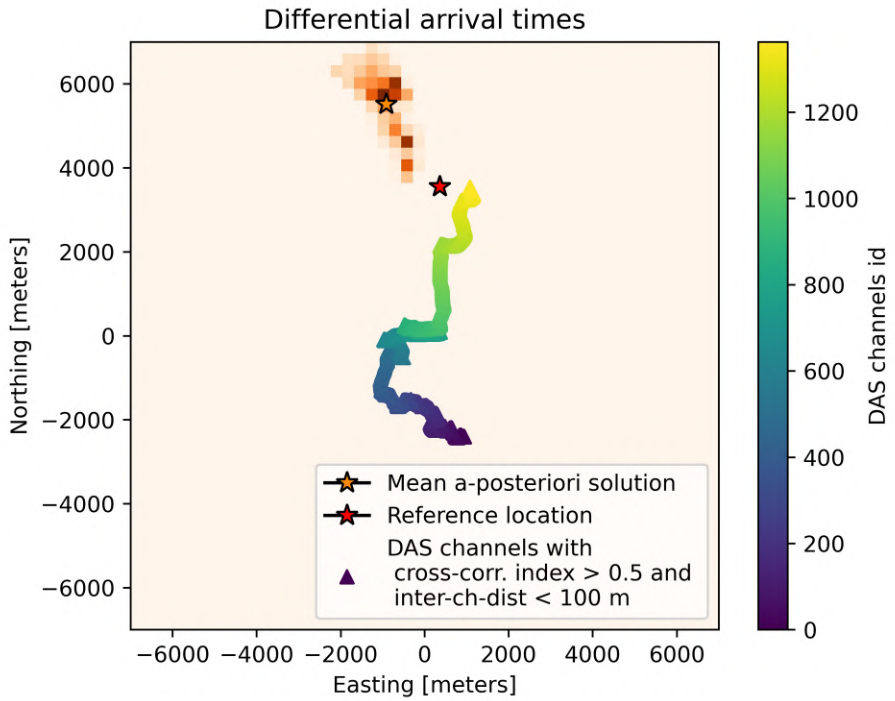




The event location is known from a local network of nodes and previous seismicity clustering in the same area.

# Results: Azuma Volcano (Japan)

**NW directionality**

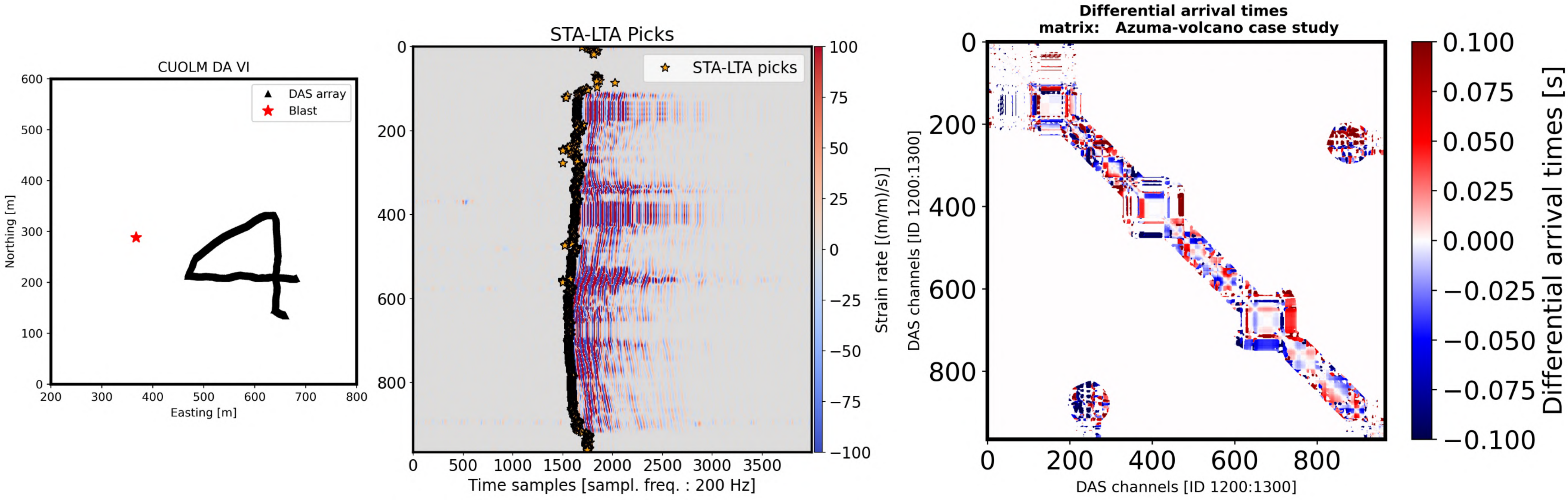




Please note that the density distributions are different, given the amount of explored models (500.000 vs 1000).

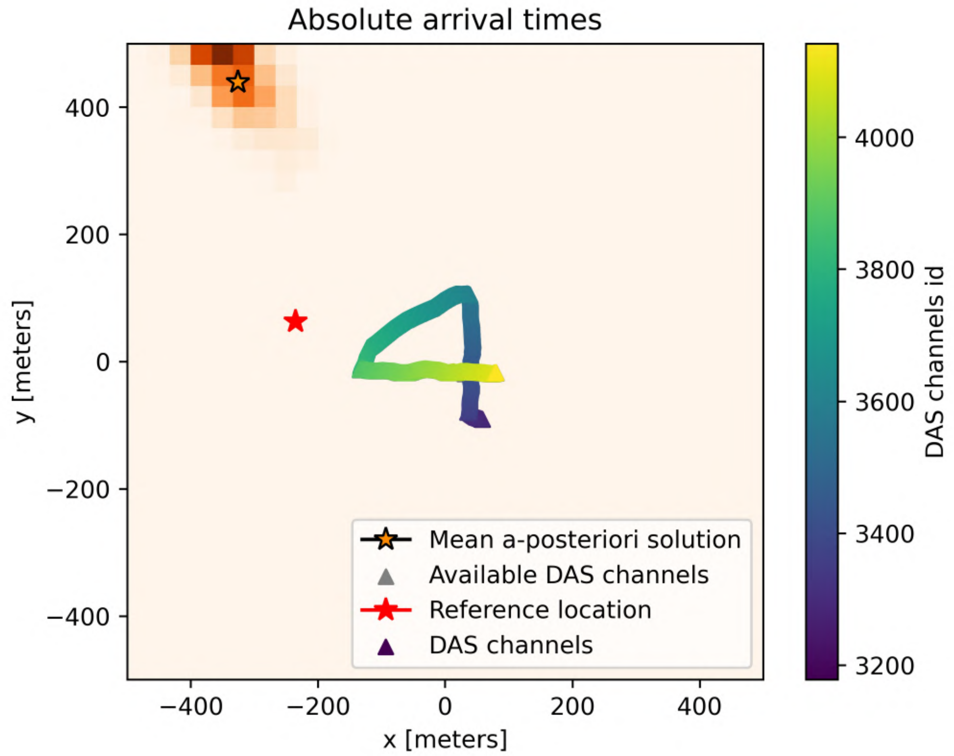
**Differential arrival times seem to better constrain the known directionality (NW) of the event**

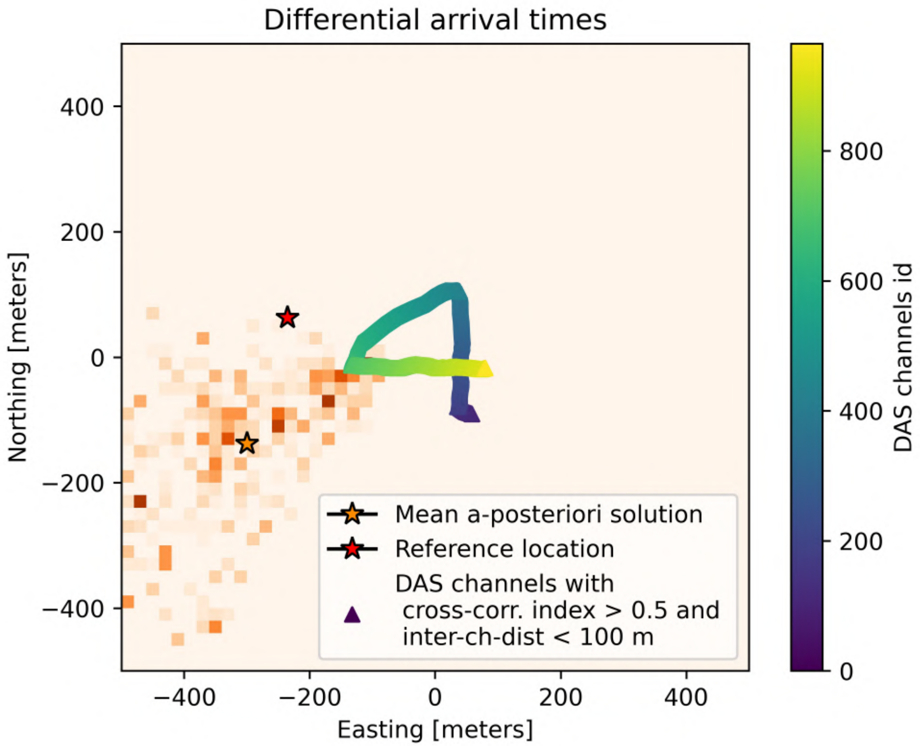
# Applications to well-known case studies: Cuolm da Vi (Switzerland)




The blast location is already known with high precision. Our focus here is on a specific section of a longer DAS cable, which is utilized for monitoring the natural seismicity associated with localized slope instabilities (as discussed in Tjeerd Kiers' PhD thesis).

# Results: Cuolm da Vi (Switzerland)



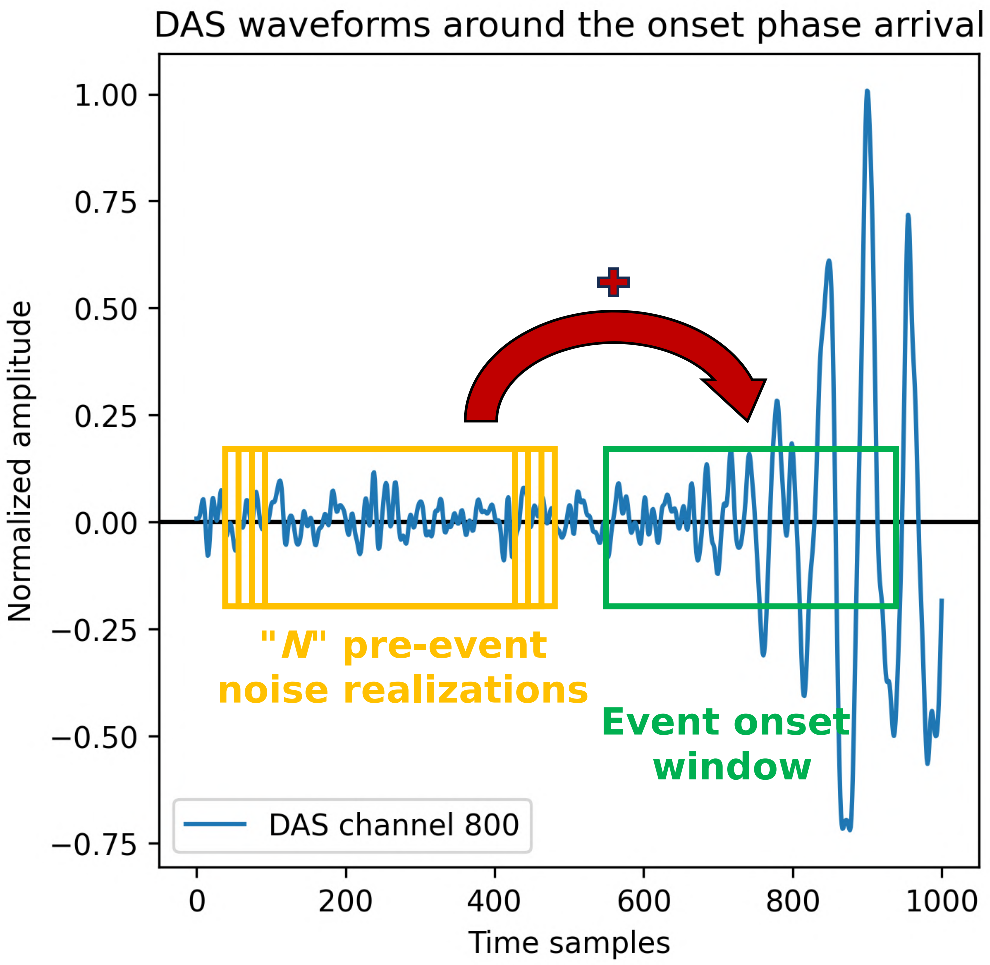




The solution with differential arrival times is slightly more accurate.

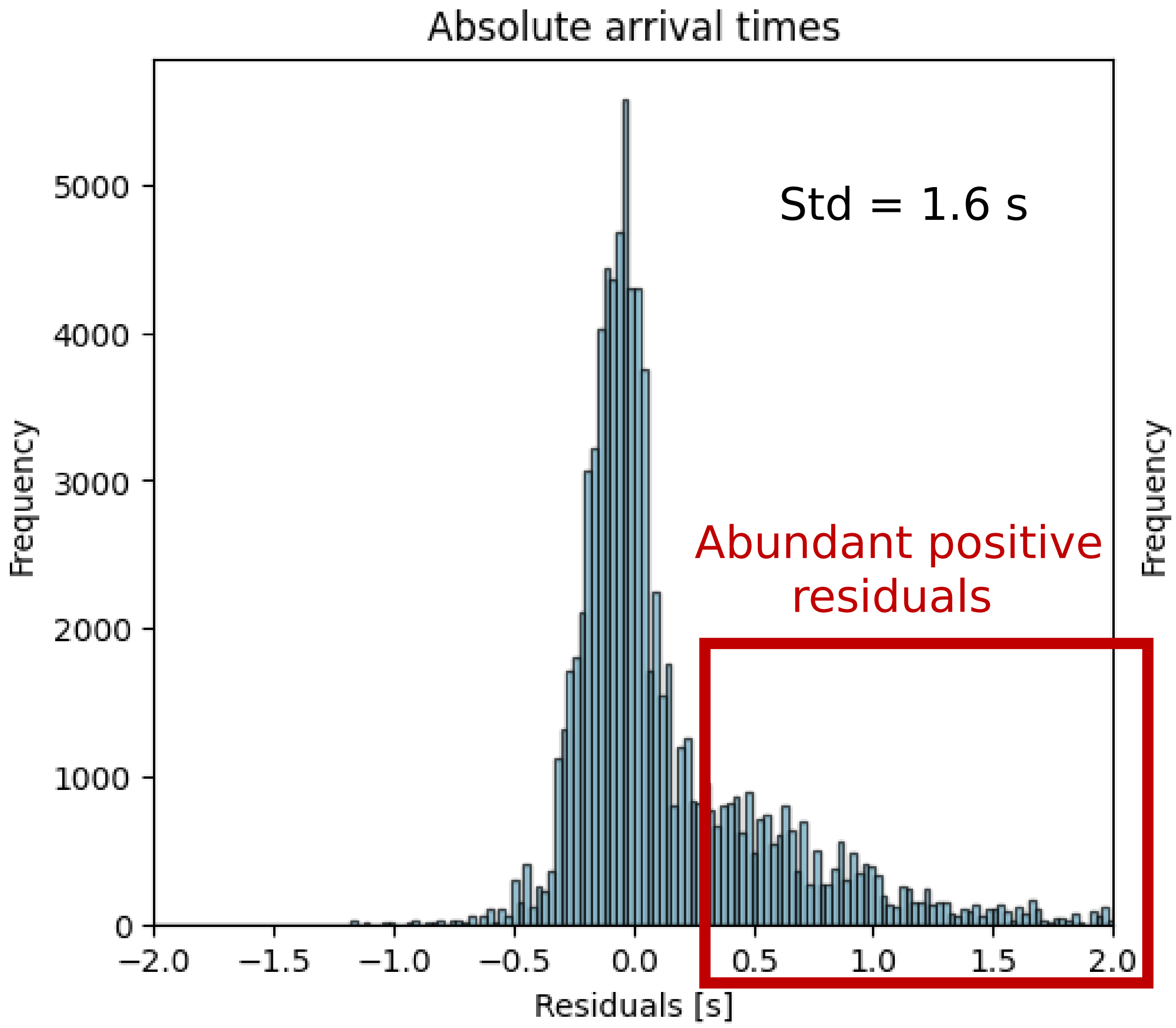
# Absolute and differential arrival times: estimating the uncertainties

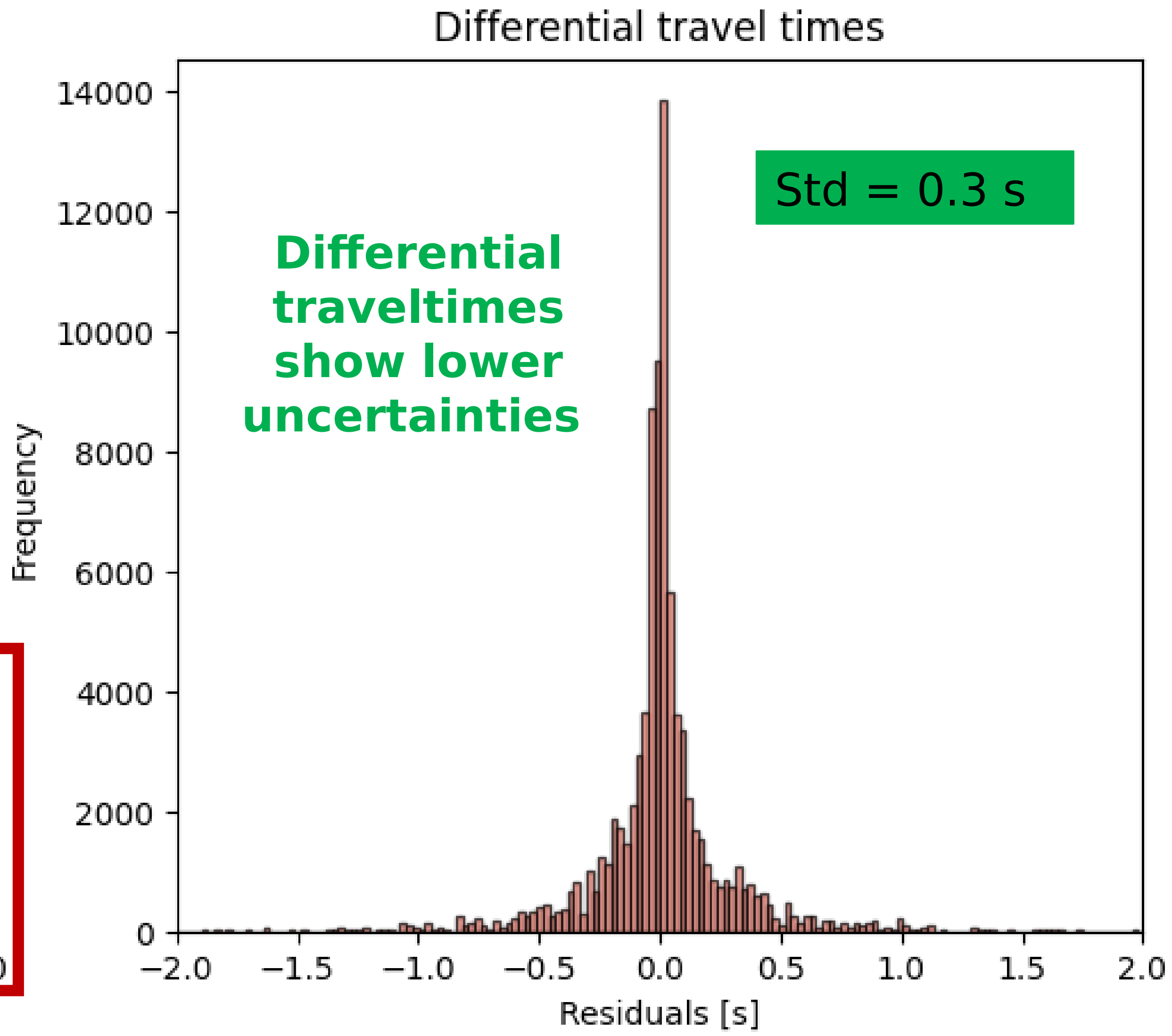
Absolute and differential traveltimes are two different data spaces. How to compare their uncertainties?

1. Define *N* noise realizations from pre-event recording
2. Add the noise realizations to the event onset
3. Apply the picker or perform cross-correlation around the event onset
4. For each channel compute the average absolute arrival time or differential traveltimes
5. Compute the residuals and its statistics



# Statistics of the residuals (Azuma-Volcano)



# Differential arrival times and DAS data

## PRO

**Data redoundancy:** DAS provides an ideal environment for leveraging time delays in event characterization, thanks to its high spatial sampling.

**Selection procedure:** A selection of delay times based on cross-correlation index and interchannel distance reduces the number of data points, thereby decreasing computational costs.

**Statistical distribution:** The distribution of differential arrival times is closer to normal.

**Event location:** Differential arrival times seem to better constrain the event location.

## CONS

**Delay time estimation**: The onset timing of P-waves must be estimated along the DAS array to define a cross-correlation window. However, directional sensitivity, cable coupling, and local velocity anomalies might influence P-wave amplitude and shape, leading to mixed-phase differential arrival times.

**Computational costs**: Even for a selected dataset, differential arrival times are significantly greater than absolute arrival times, impacting computational costs.

# Conclusions

- We successfully tested and adapted a Hamiltonian Monte Carlo (HMC) algorithm for locating events with differential arrival times in DAS data.
- We conducted a comparison of location uncertainties by inverting absolute and differential arrival times for two well-known case studies (a volcanic event and a local explosion).
- Preliminary results indicate that selected differential arrival times provide a better constraint on the event solution in these two well-known case studies.
- To further confirm the improvements in location accuracies and the robustness of the algorithm, additional case studies (including various DAS deployments and event properties) are needed.
- Moreover, more objective methods for setting cross-correlation index and interchannel distance thresholds to select data points are required.

# Thank you for your attention

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