Characterisation of seismic events using time-reverse imaging

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Structure

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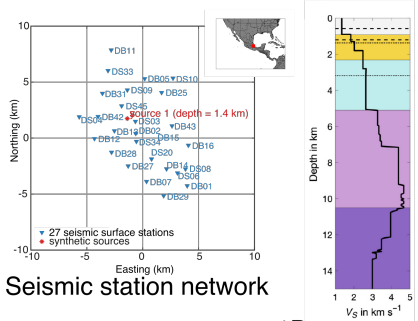
The Problem and The Solutions

The Problem

seismic events in geothermal reservoir

- low signal-to-noise ratio
- numerous events
- close in time and space
- unknown origin

The Site:
Los Humeros, Mexico



Seismic station network

1D velocity model

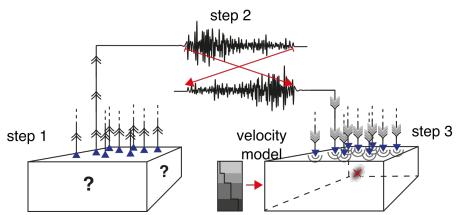
The standard solution

ray-based / travel-time based

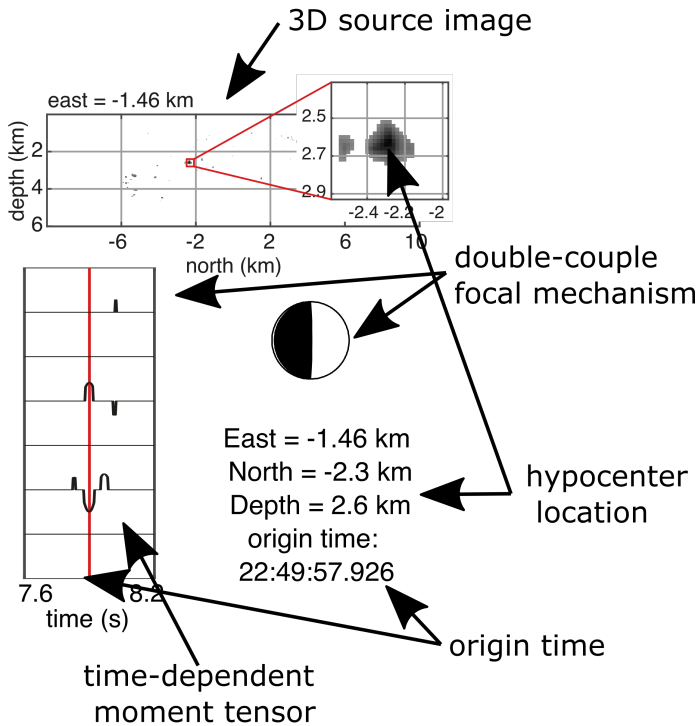
+ robust and fast results
- signal-to-noise ratio > 3
- assumptions about sources

The better solution:
Time-Reverse Imaging (TRI)

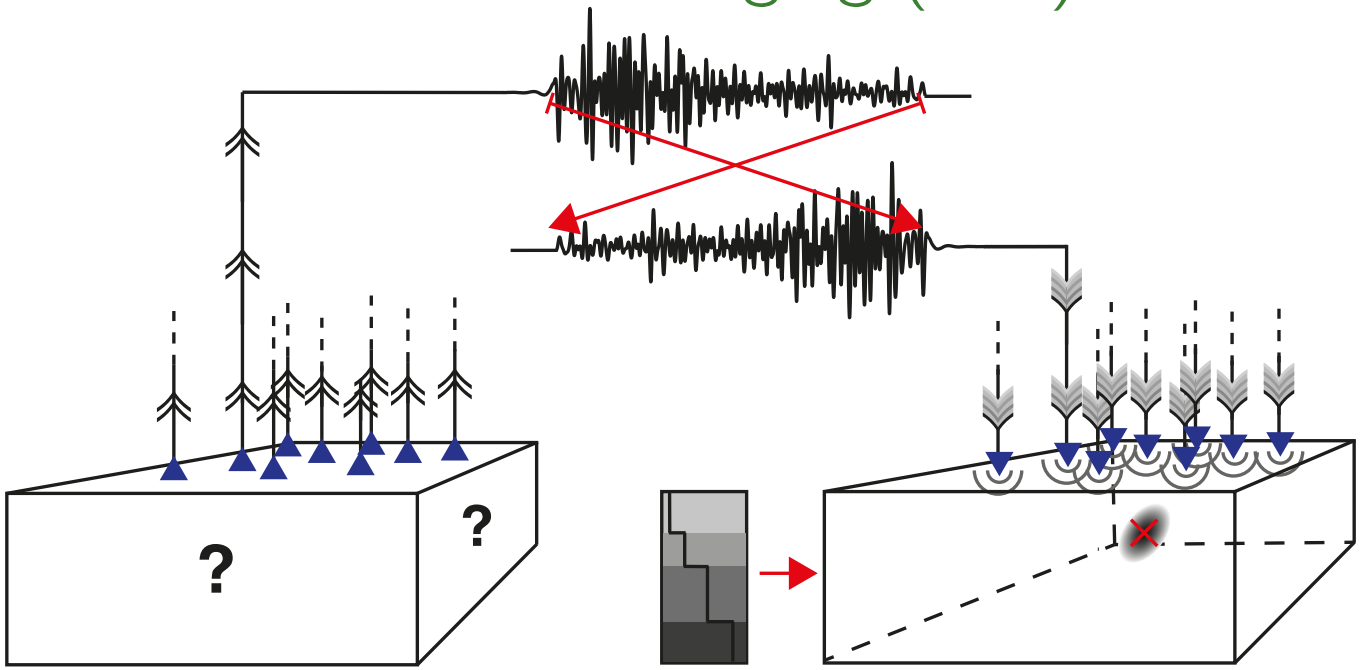
+ no assumptions about sources
+ signal-to-noise ratio < 1 no problem
+ high accuracy source images
- high computation time



The results

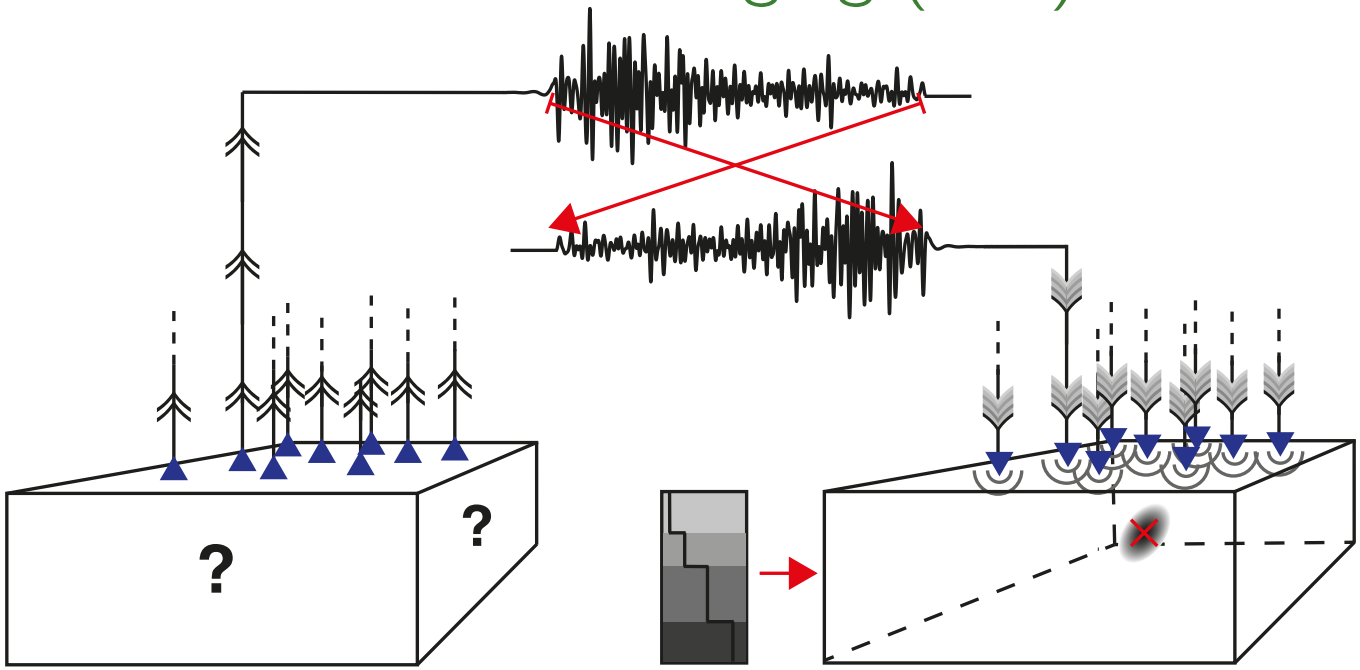


The method of time-reverse imaging (TRI)



1. record 3C wavefield at seismic stations
2. time-reverse wavefield
3. Back propagate time-reversed wavefield through adequate velocity model using FD simulation ▸ Saenger (2000) ▸ Saenger (2011)
4. Apply imaging conditions (see next slide)
5. Divide by illumination map ▸ Werner & Saenger (2018)
   ▸ Witten & Artman (2011)

The method of time-reverse imaging (TRI)



Imaging conditions

total energy density imaging condition

$$I_e(\vec{x}) = \max_{t\in[0,T]} \sum_i \sum_j [\sigma_{ij}(\vec{x},t)\varepsilon_{ij}(\vec{x},t)]$$

σ_{ij}: ij-th stress component, ε_{ij}: ij-th strain component, $\vec{x}$: spatial coordinate , t time, T max. simulation time

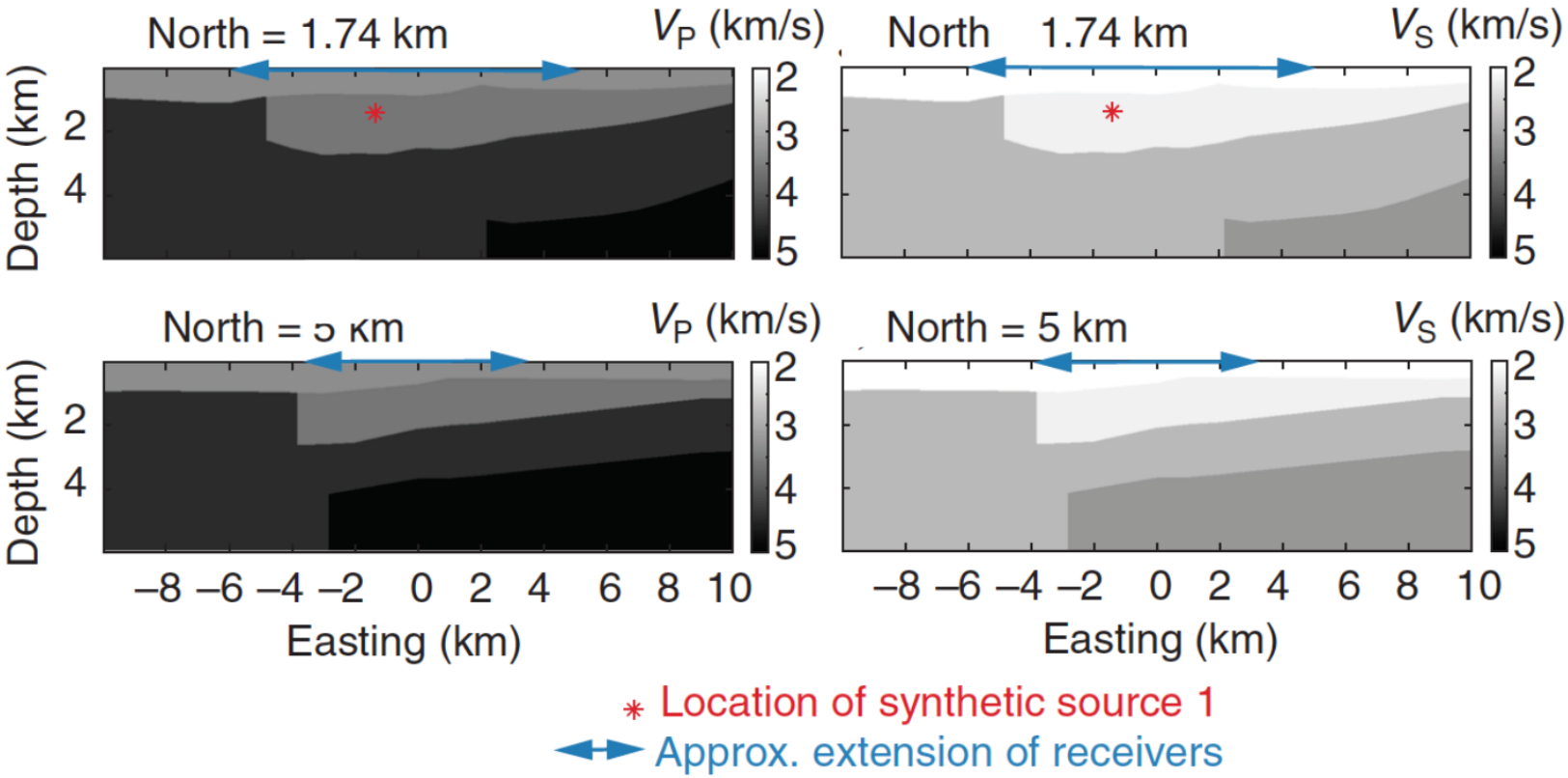
The method of time-reverse imaging (TRI)

1. record 3C wavefield at seismic stations
2. time-reverse wavefield
3. Back propagate time-reversed wavefield through adequate velocity model using FD simulation ▸ Saenger (2000) ▸ Saenger (2011)
4. Apply imaging conditions (see next slide)
5. Divide by illumination map ▸ Werner & Saenger (2018) ▸ Witten & Artman (2011)
6. Find potential **source locations**
7. Repeat step 3 with stress receivers at source locations (found in step 6)
8. Supress noise in stress recordings to obtain **time-dependent 6C moment tensor**
9. find origin time and relative amplitudes of 6C stress component for evaluation of focal mechanism

▸ Finger & Saenger (2021)

Proof of Concept: Synthetic realistic simulations

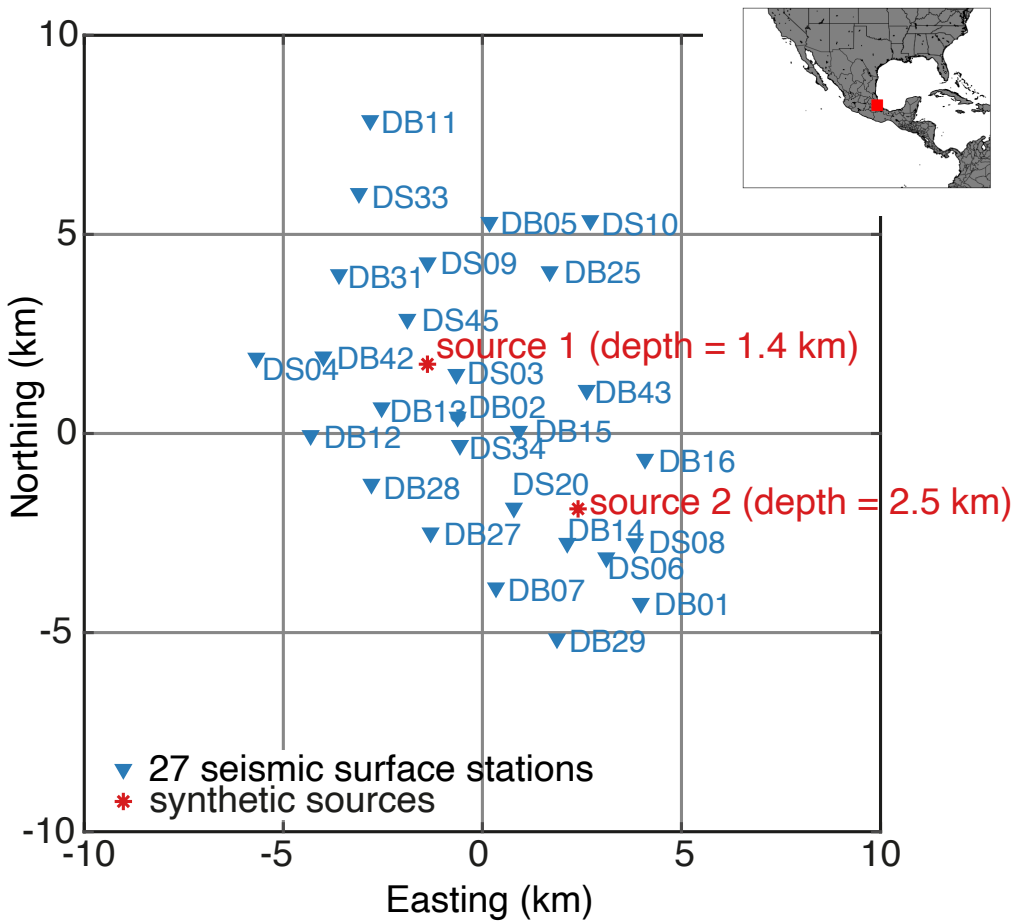
- create 3D realistic velocity model with heterogeneous layers to test method
- total extent: 20 km x 20 km x 6 km



▸ Finger & Saenger (2021)

Proof of Concept: Synthetic realistic simulations

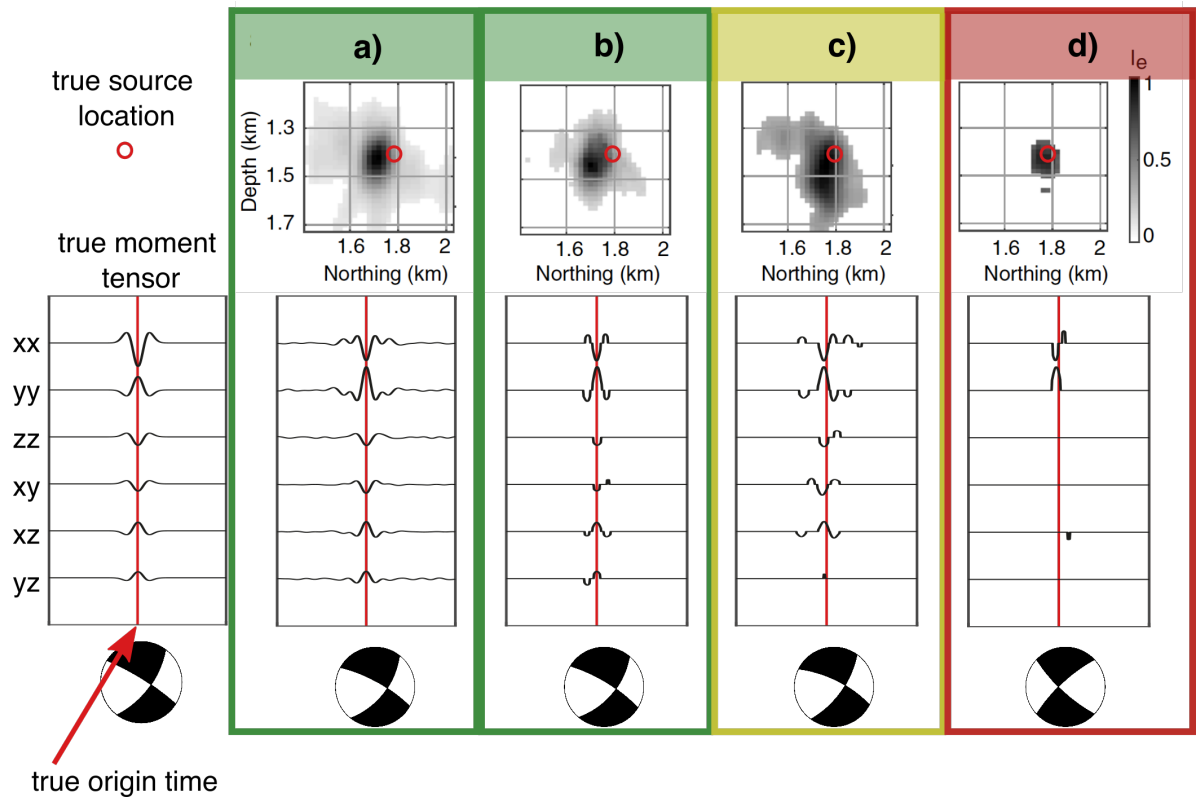
- use station positions from network in Los Humeros, Mexico (deployed 2017 - 2018)



▸ Finger & Saenger (2021)

Proof of Concept: Synthetic realistic simulations

a. true 3D model, no noise
b. true 3D model, incoherent noise (signal-to-noise ratio ≈ 1)
c. mean 1D model, no noise
d. mean 1D model, incoherent noise (signal-to-noise ratio ≈ 1)



Description on next slide

▸ Finger & Saenger (2021)

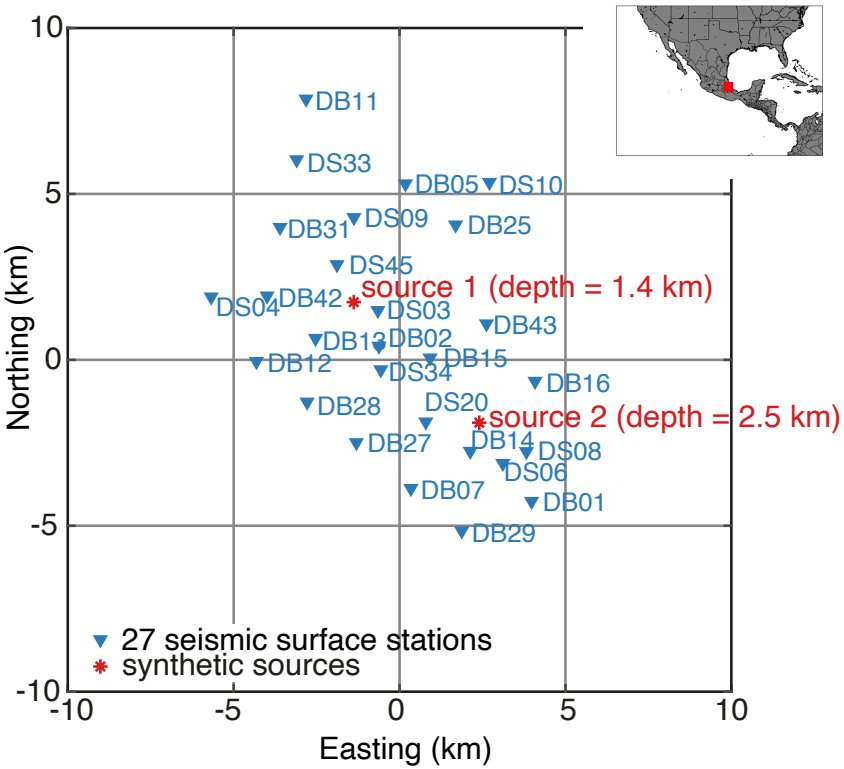
Proof of Concept: Synthetic realistic simulations

- source locations are found for all test cases but with smaller focus shape for d.
- origin time is found correctly for all cases
- double-couple focal mechanism is found correctly for a.,b.,c. and rotated for d. (but correct mechanism)
- time-dependent source signal can be recovered for a. and b. but only with decreased quality for c. and d.

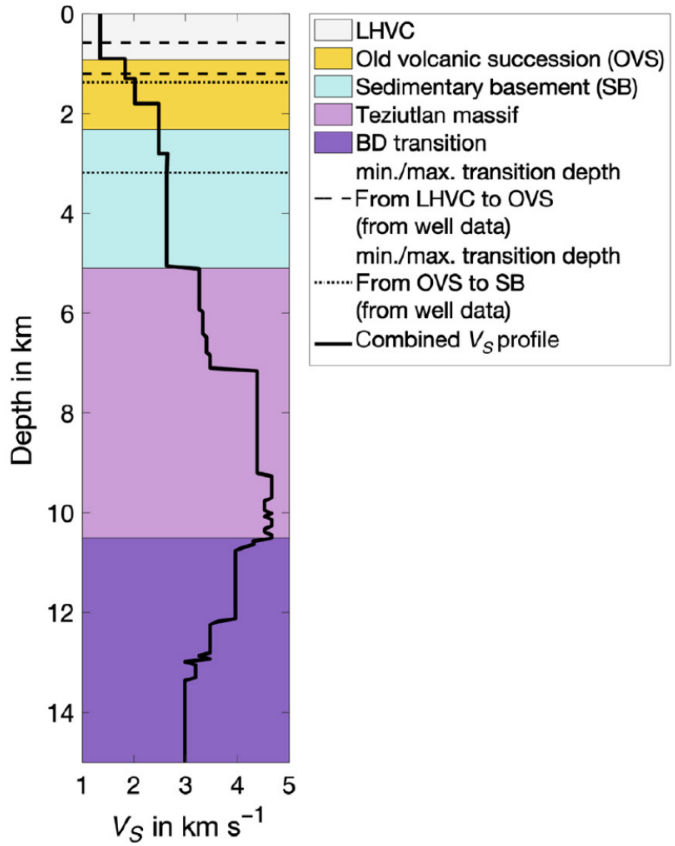
- **The method works well even with high noise levels or mean 1D models but not so well when high noise levels are present and the velocity structure is not known well.**

▸ Finger & Saenger (2021)

The Site: geothermal reservoir Los Humeros, Mexico



station network deployed in Los Humeros 2017 - 2018

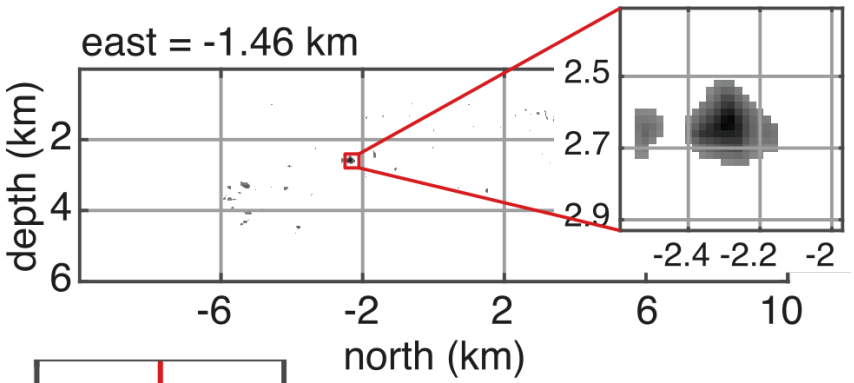


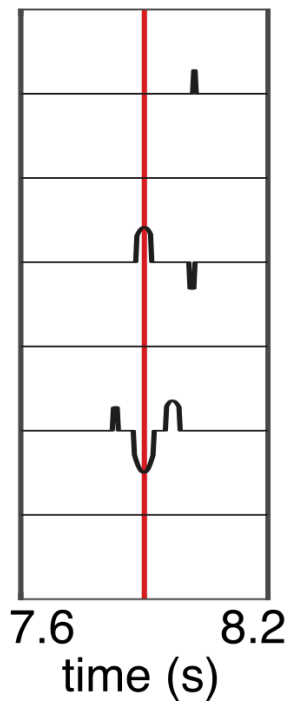
1D shear velocity profile from three-component ambient-noise beamforming

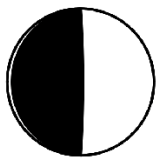
▸ Finger & Saenger (2021)

▸ Löer et al. (2020)

Application to geothermal reservoir Los Humeros, Mexico





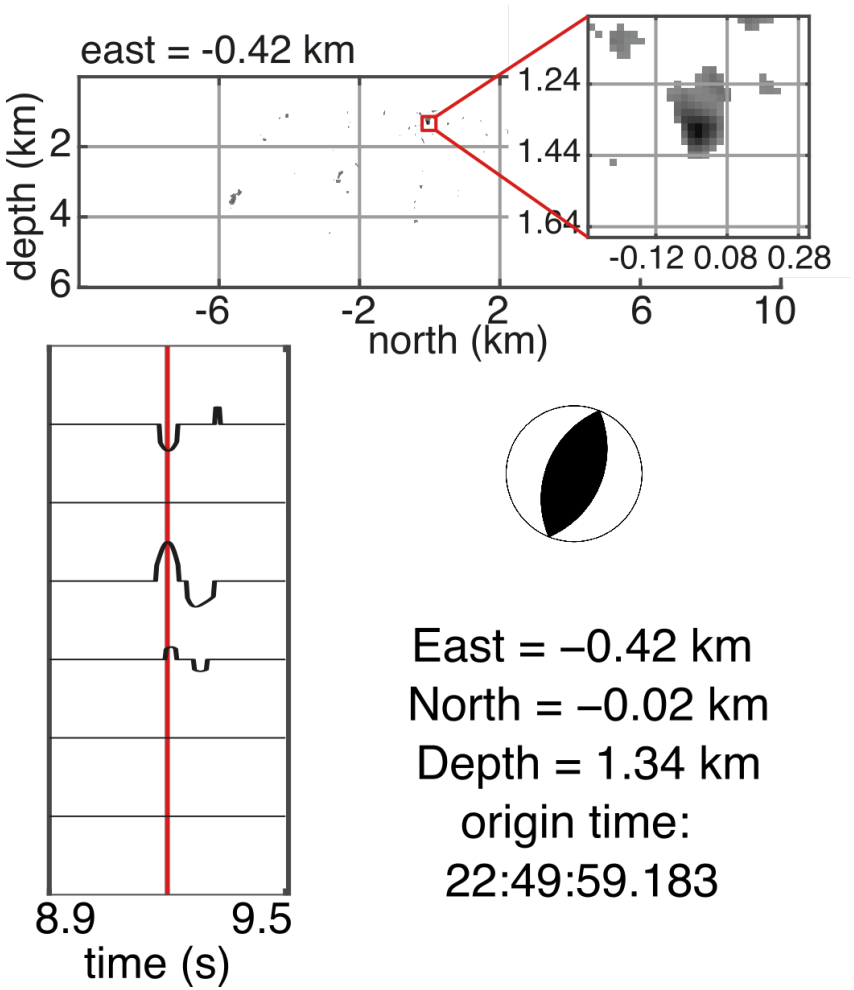


East = -1.46 km
North = -2.3 km
Depth = 2.6 km
origin time:
22:49:57.926

- Source image, time-dependent moment tensor, double-couple focal mechanism, hypocenter location and origin time for one event recorded on 2018/04/29
- Strong resemblance to results from travel-time based method
- numerous artificial focusing spots in TRI images due to only 1D model and high noise levels

▸ Finger & Saenger (2021)

Application to geothermal reservoir Los Humeros, Mexico



- Source image, time-dependent moment tensor, double-couple focal mechanism, hypocenter location and origin time for a second event recorded on 2018/04/29 (same simulation)
- about 1 second after first event but in very different part of the model
- this could have been missed due to overlapping waveforms
- **previously undetected event?**

▸ Finger & Saenger (2021)

Conclusions

- This study shows the capability of TRI to provide moment tensors
- moment tensors (and source locations) are either roughly correct or not obtainable at all (no convergence of the wavefield)
- velocity model and noise level have high influence on quality of results
- There is a high potential to automise this method and thus obtain hypocenter locations and moment tensors for a large number of microseismic events that were previously not possible to locate and characterise
- Next steps include optimisation of the process and application to large datasets with high-resolution 3D velocity models

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Thank you for reading until the end!