Estimating the source-location accuracy in the geothermal site of Los Humeros (Mexico) using sensitivity maps for time-reverse imaging

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Why Time-Reverse Imaging (TRI)?

full waveform

no picking

all scales (lab, field, …)

quasi-simultaneous & low signal-to-noise ratio events

non-destructive testing, micro-seismic events, tremors, …

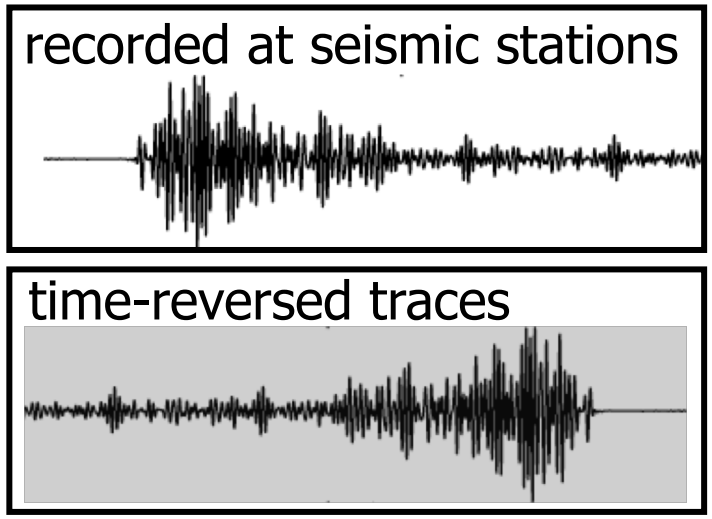
velocity model

computational cost

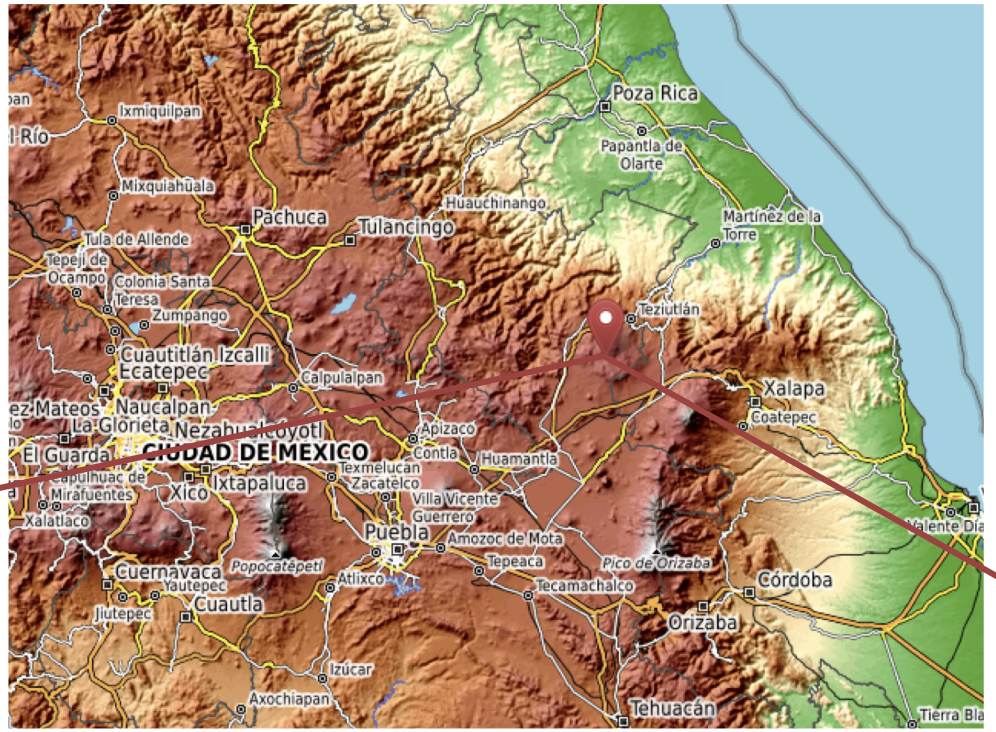
unknown constraints on station network

This study

The method of TRI



Los Humeros geothermal field

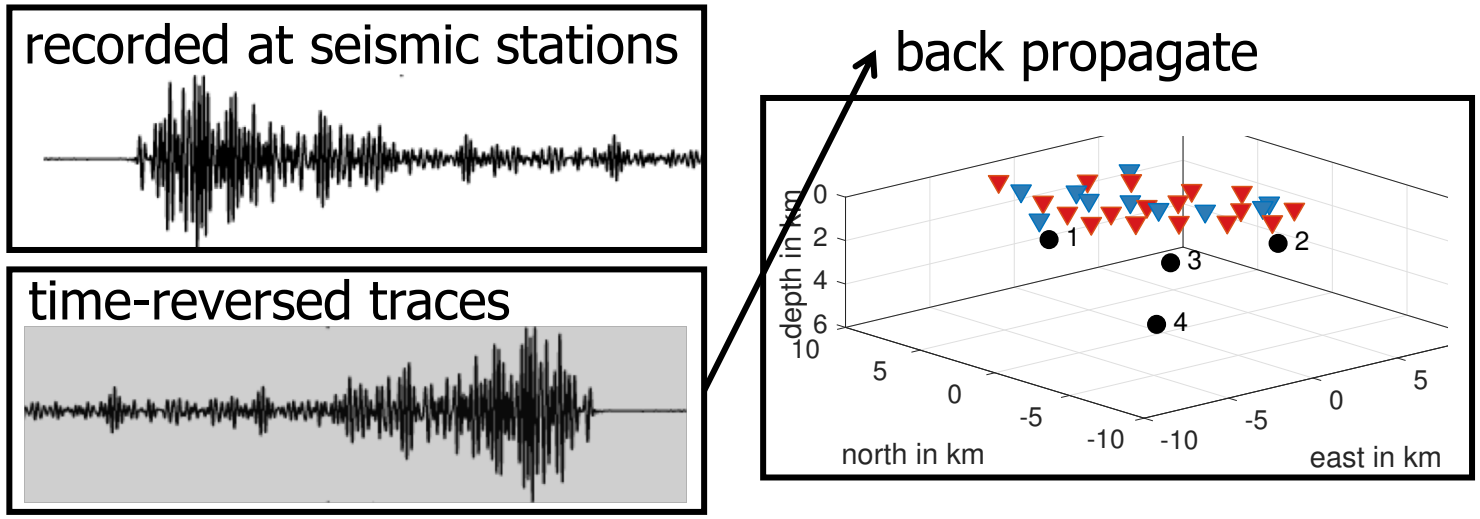


part of Trans-Mexican Volcanic Belt

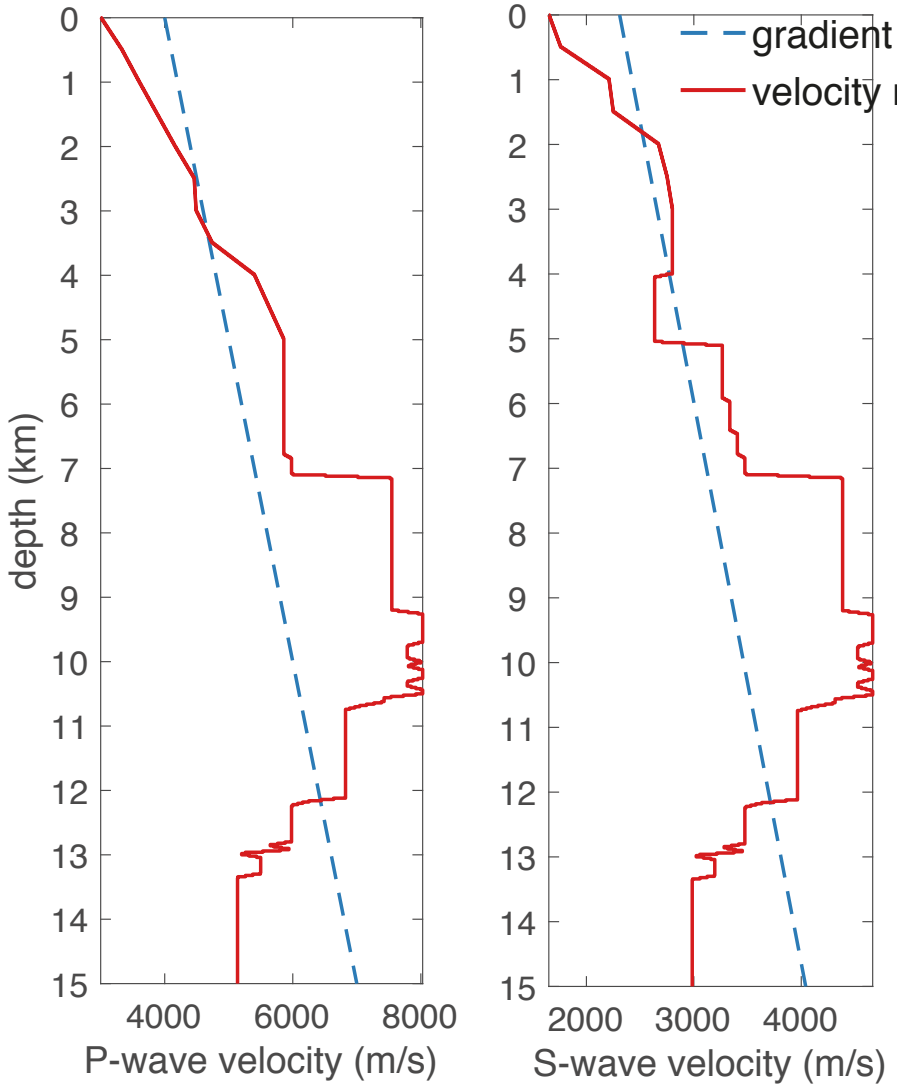
multi-caldera structure

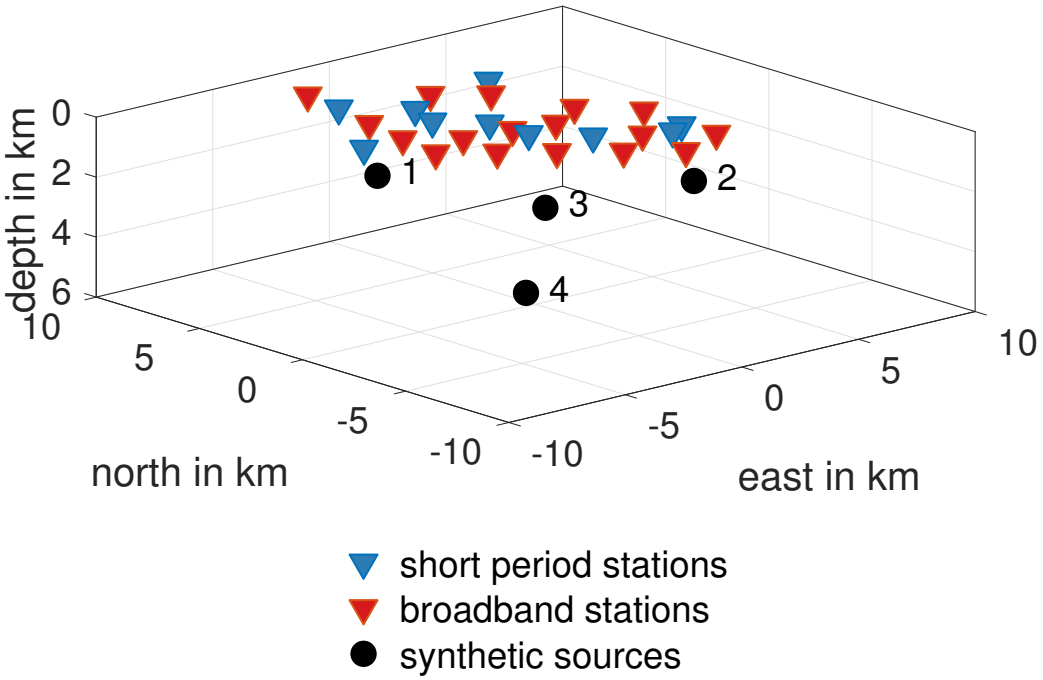
superhot geothermal system

The method of TRI



Los Humeros geothermal field: model set-up

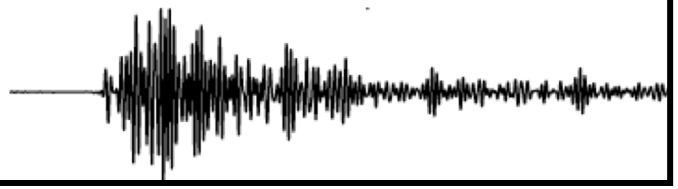




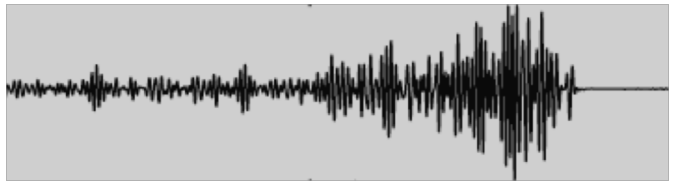
27 stations (deployed 09/2017 – 09/2018) and a 1D P- and S-wave velocity model are available

The method of TRI

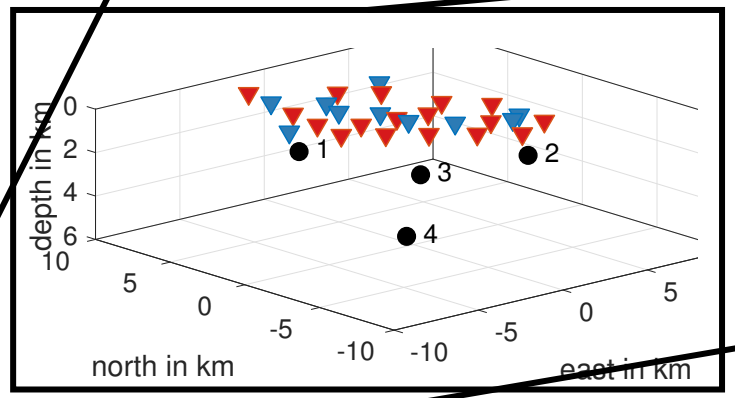
recorded at seismic stations



time-reversed traces



back propagate



imaging conditions

total energy density:

$$\mathbf{I}_e(\mathbf{x}) = \max_{t\in[0,T]} \sum_i \sum_j \left[\sigma_{ij}(\mathbf{x},t)\ \varepsilon_{ij}(\mathbf{x},t)\right]$$

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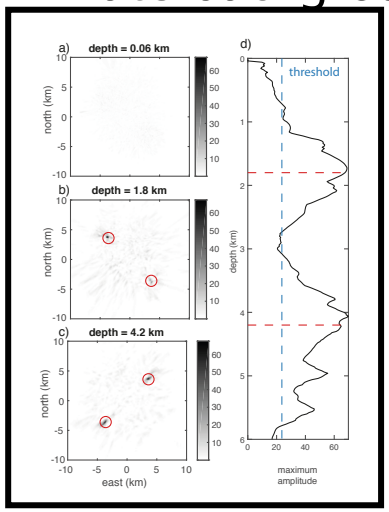
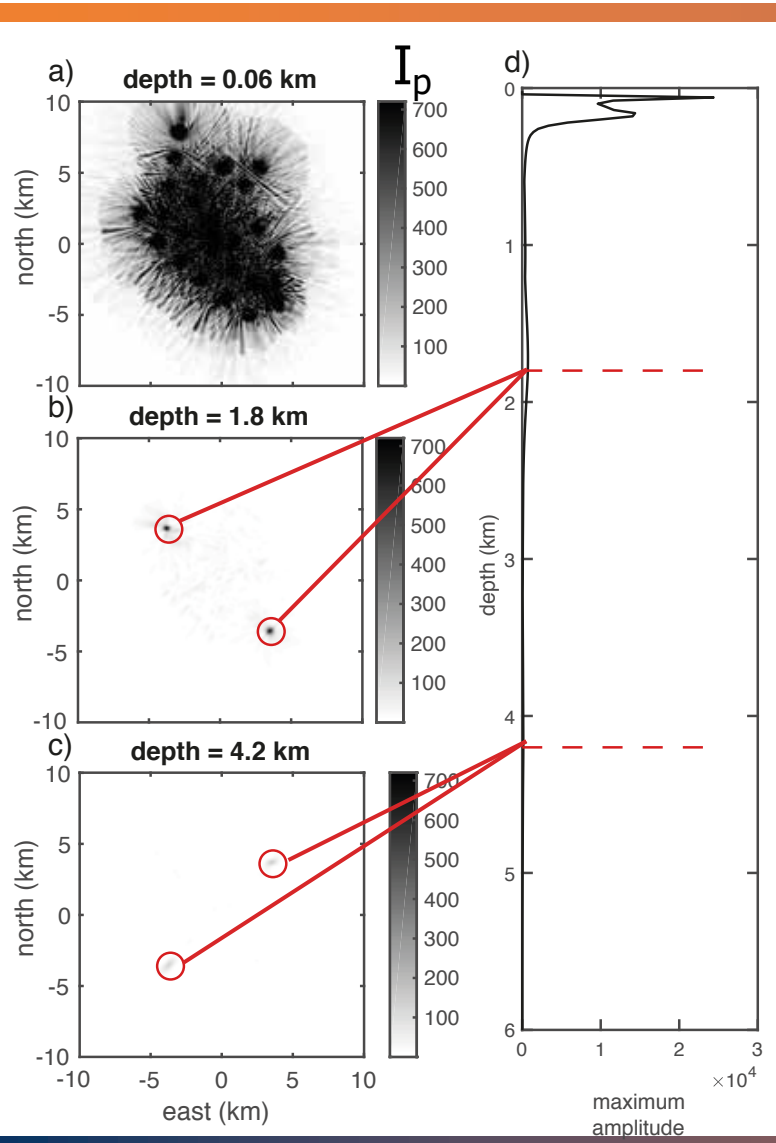
Saenger (2011), NDT&E International

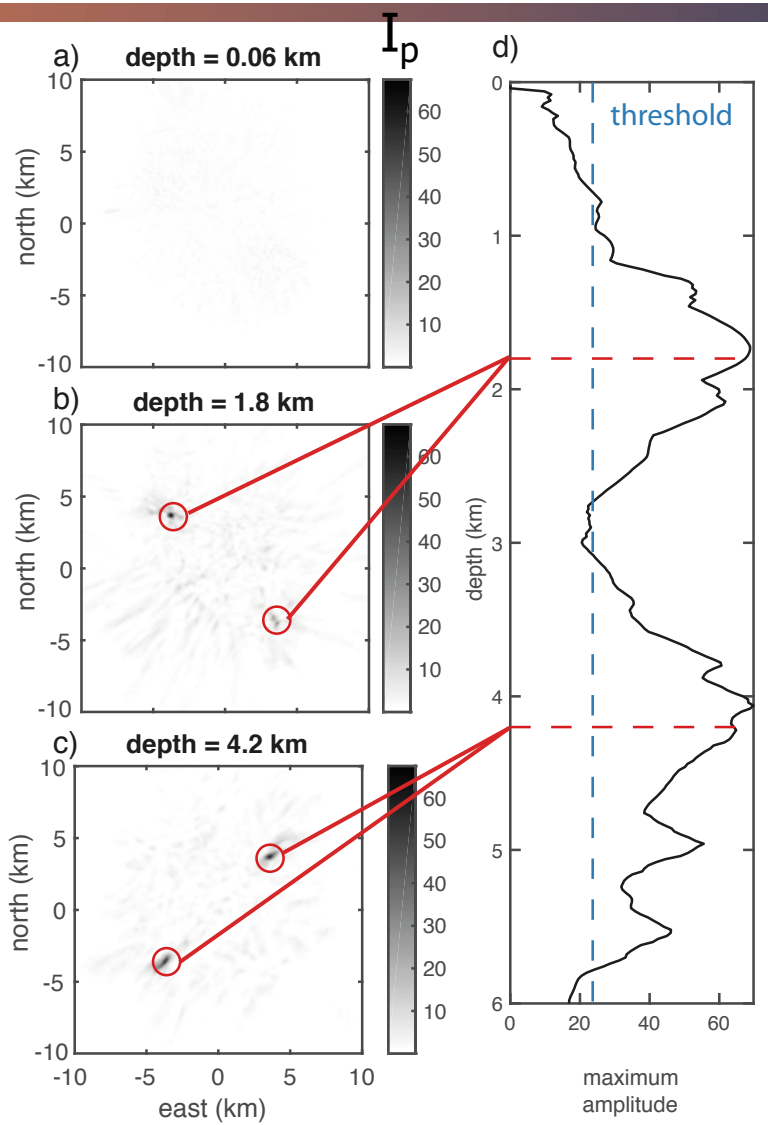
eliminate background noise



Removing artificial high amplitudes



divide by illumination map



remove background noise

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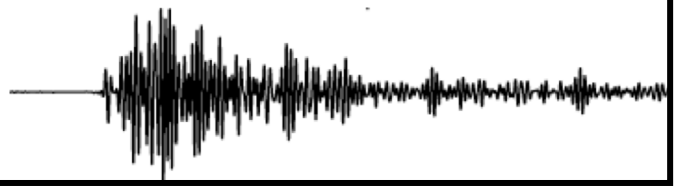
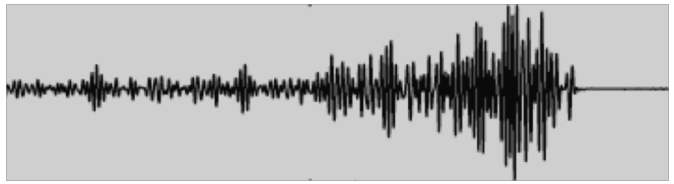
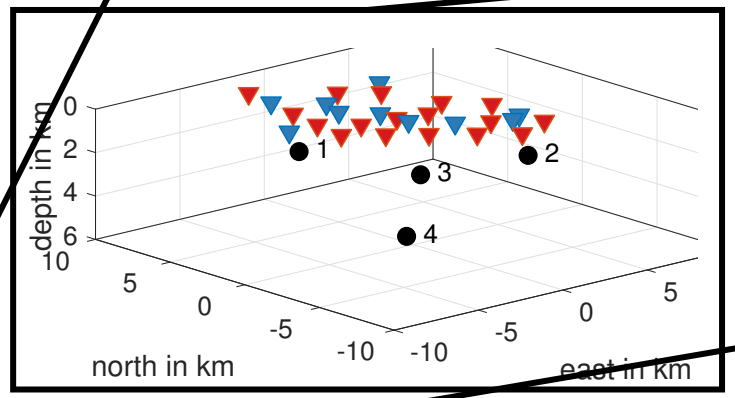


time-reversed traces



back propagate



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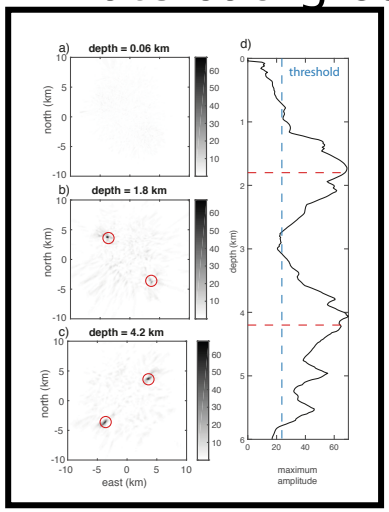
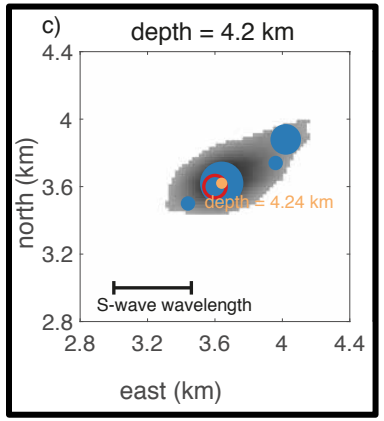
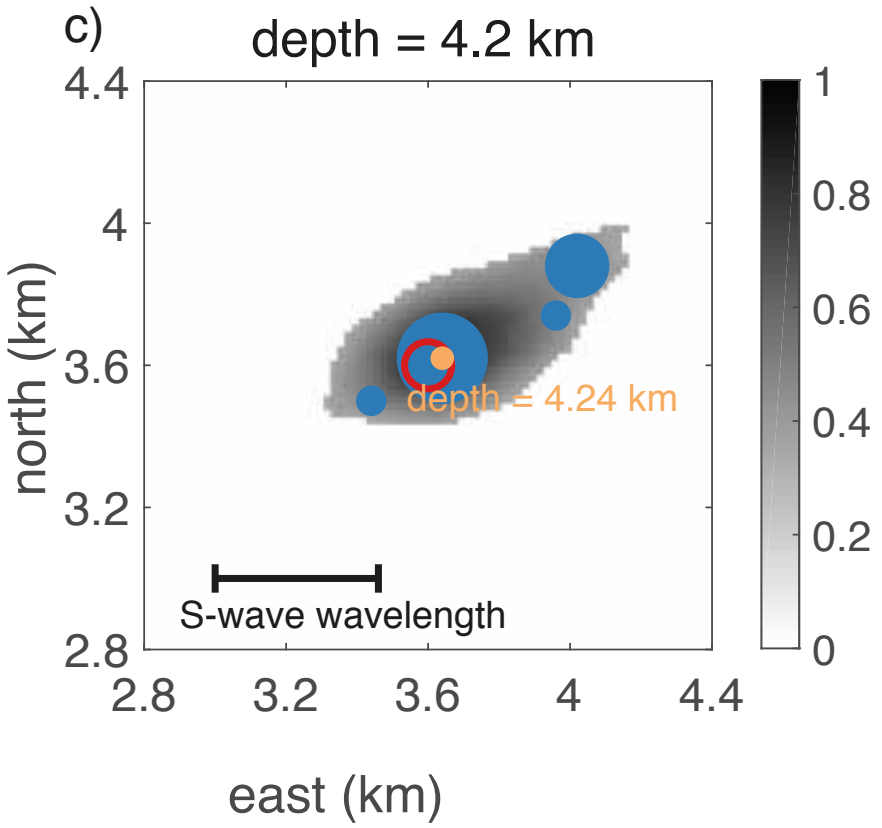


find source localisations



compare to initial sources

Automatic identification of localisations



- found localisations (larger circles are closer to source depth)
- original source location
- identified source location

find absolute maximum amplitude

mute sphere around found point

→ multiple localisations

synthetic sources:

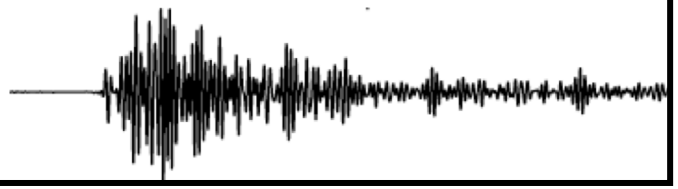
find maximum amplitude localisation close to initial sources

→ found localisations

→ compare to → accuracy

The method of TRI

recorded at seismic stations



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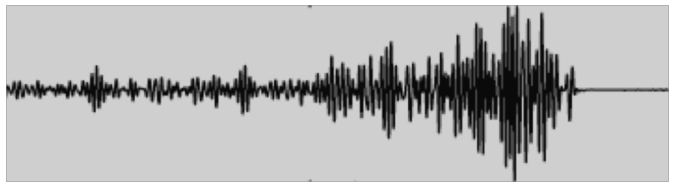

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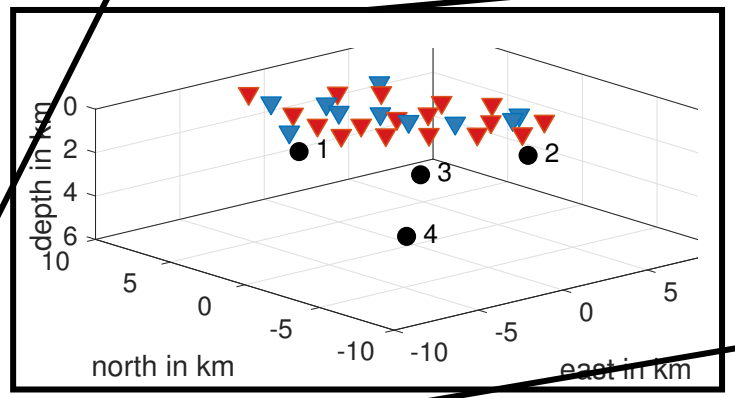

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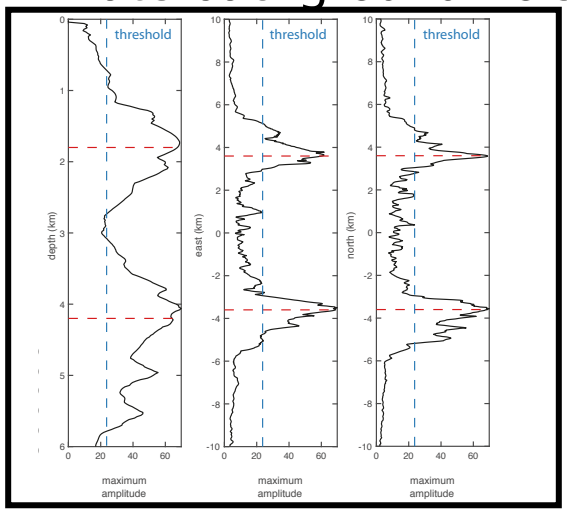

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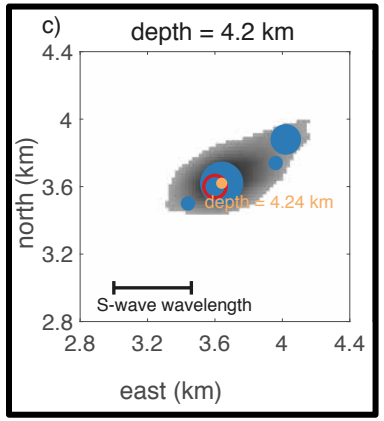


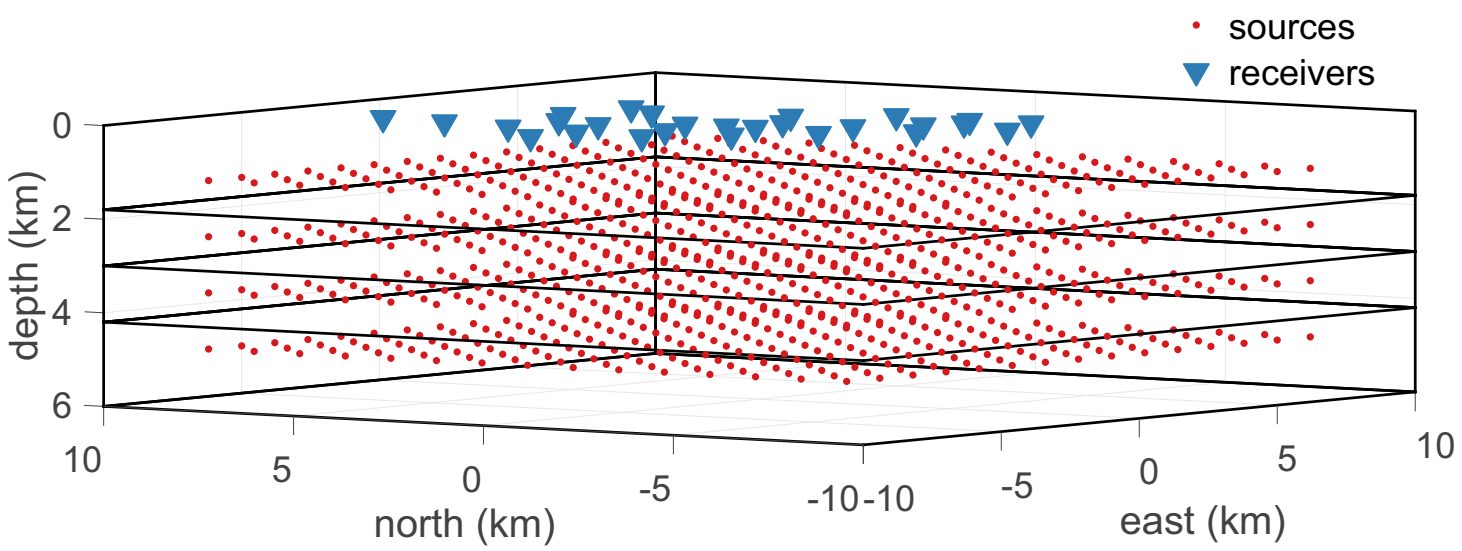
compare to initial sources → **Sensitivity Maps**

How to create Sensitivity Maps

place numerous sources throughout the model following some guidelines:

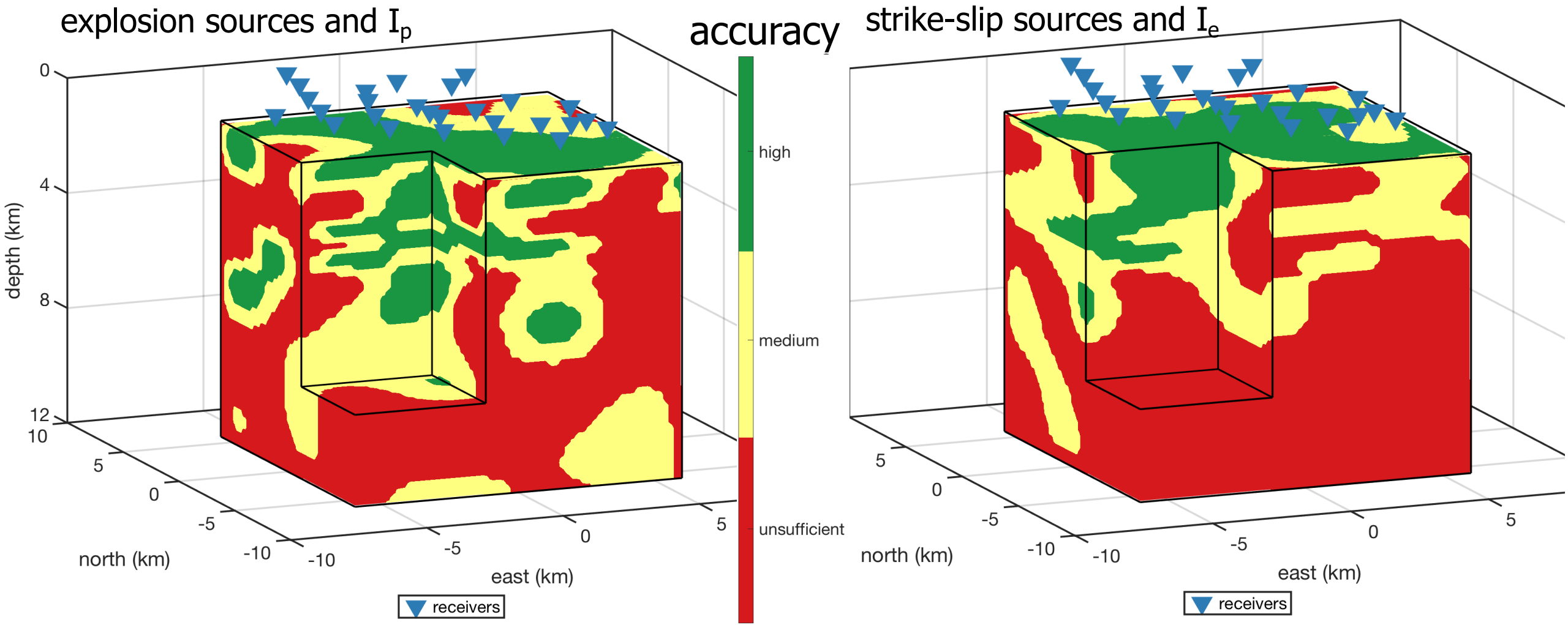
1) inter-source distance > maximum inter-station distance (here: > 2.1 km)
2) sources in only one depth per simulation
3) not too closer than 2 S-wave wavelengths to boundary

Then locate these sources with TRI and investigate the achieved spatial and temporal error.



A fast way to evaluate the location accuracy with a given station distribution and velocity model.

Sensitivity Maps for the geothermal site Los Humeros

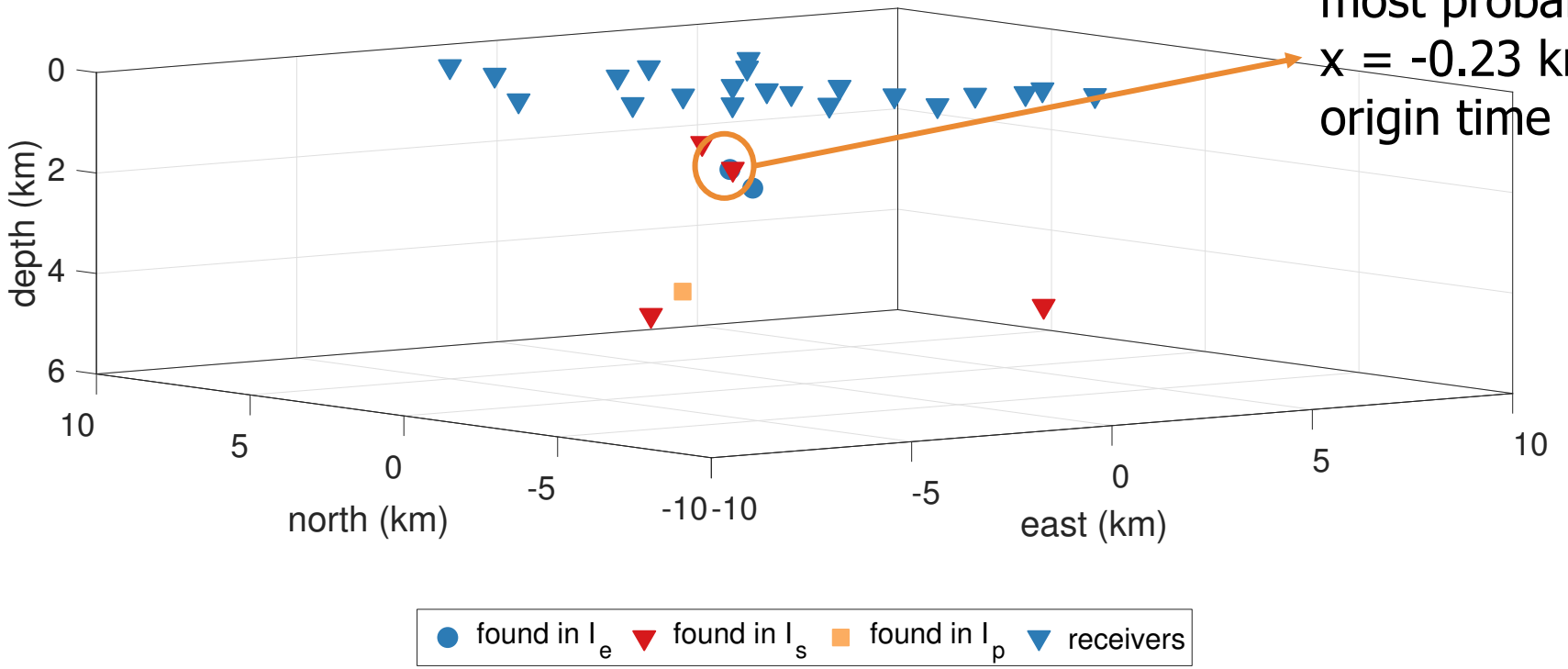


Accuracy is influenced by: station distribution, velocity model & source type.

Located real-life micro-seismic event (magnitude ~2.2)

recorded 2018/04/22 with 21 stations

After muting areas with insufficient accuracy and elimination of unrealistic localisations: 2 localisations in I_e, 1 localisation in I_p and 4 localisations in I_s.



most probable event localisation:
x = -0.23 km, y = 2.08 km, z = 1.89 km
origin time = 21:03:50 (I_e) or 21:03:52 (I_s)

Sensitivity Maps allow the localisation of real-life events

Conclusions

Work flow for the evaluation of source-location accuracy using TRI

→ **Sensitivity Maps** ←

work flow:

user-independent

low computational costs

intuitive results

application:

evaluate existing networks

plan and optimise new networks

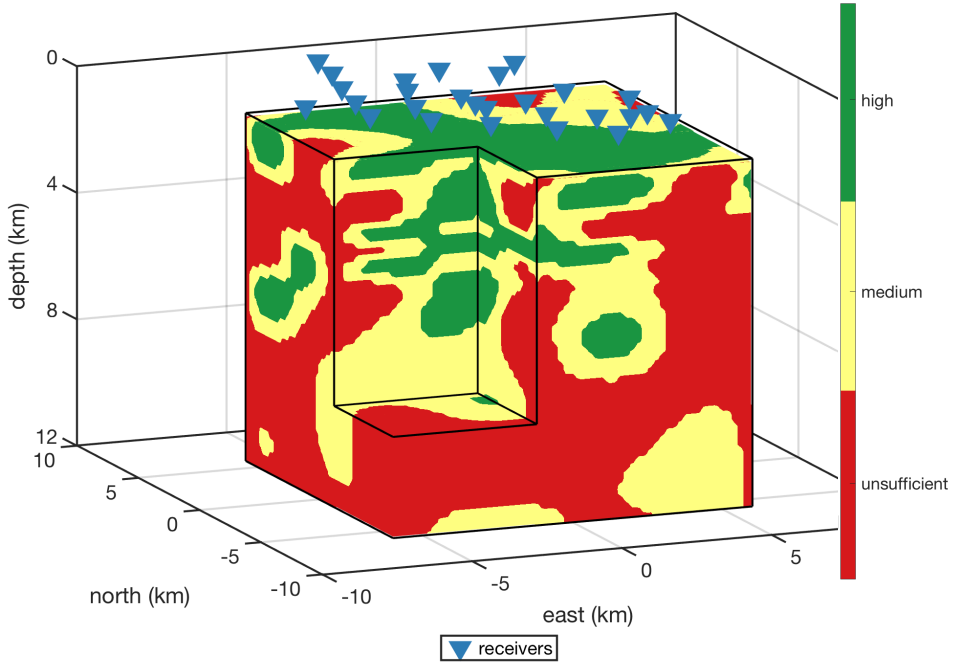
enhance localisation of real-life events

next steps:

Compare to localisations from other methods

Identify source type

Acknowledgements



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We also acknowledge our **Mexican and European colleagues** for their help and collaboration in deployment, maintenance and retrieval of the stations.

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