Sensitivity maps for Los Humeros: Enhance localization results using time-reverse imaging to locate and characterize seismic events

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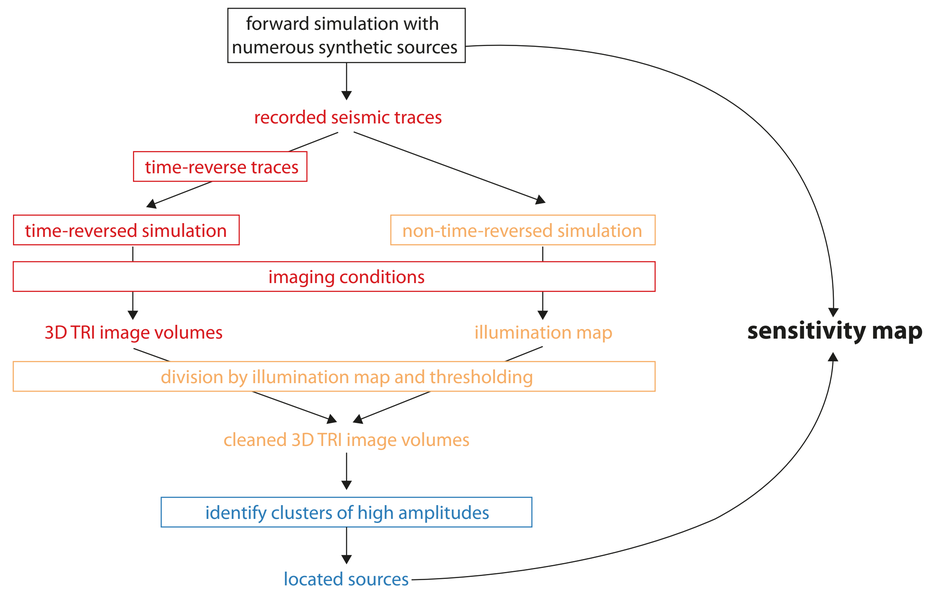
1. Introduction

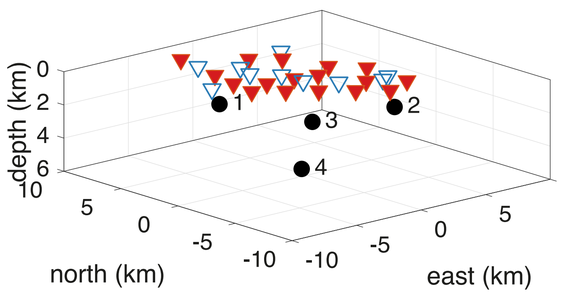
Locating and characterizing seismic events is a crucial step in any reservoir characterization and monitoring scheme. The location of events may reveal the fault network and the brittle-ductile transition zone, while the characterization permits to estimate the local and regional stress regime and may allow for a distinction between tectonic and anthropogenically induced events. Time-reverse imaging (TRI) (e.g. Saenger 2011) is a migration-based localization method that uses the whole time-reversed waveform. Therefore, even smaller events occurring close in space and time may be located using TRI.

Previous studies have shown that the station network influences the obtainable source-location accuracy significantly using TRI (Werner 2018). In this study, a workflow is developed to create sensitivity maps that reveal the spatial variability of the source-location accuracy for the temporary passive seismic network installed above the geothermal field of Los Humeros, Mexico. To create these sensitivity maps, numerous synthetic sources are distributed in the model and excited simultaneously during a forward simulation. Afterwards, TRI is used to locate these events. An automatic and user-independent workflow is proposed for the identification and accuracy determination of convergence spots. The workflow can be divided into three parts: (i) time-reversed simulation to locate the synthetic sources, (ii) processing of the TRI images to distinguish sources from the background and (iii) obtaining the location of focus points automatically.



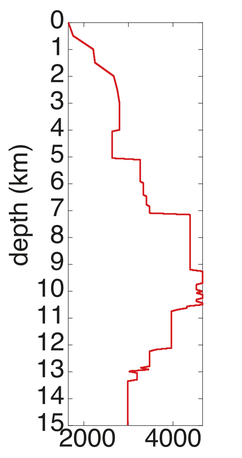
2. Time-Reverse Imaging (TRI)

a. placing synthetic sources in the model
b. forward simulation
c. recording complete waveform at discrete recording positions at the surface
d. time-reversing the waveforms
e. back propagating the time-reversed wavefield through the velocity model



stations in Los Humeros:
- short period stations
- broadband stations
- synthetic sources

Seismic dataset: oledo (2019)



based on Löer (2020)

3. Image Processing

P-wave energy density imaging condition

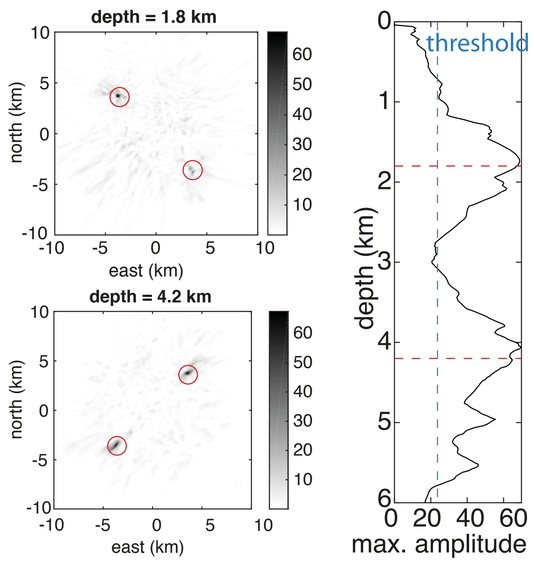
$$\mathbf{I}_p(\vec{x}) = \max_{t\in[0,T]} (\lambda + 2\mu)[\nabla \cdot \vec{u}(\vec{x},t)]^2$$

Total energy density imaging condition

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

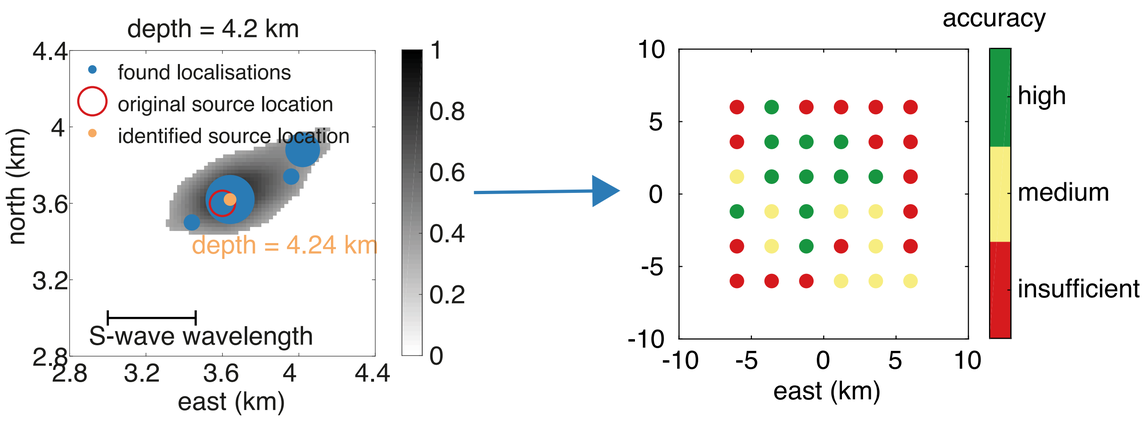
Thresholding to remove background noise

$$T_{h,k} = \frac{1}{3}\sum_{i=1}^{3}\left(\frac{1}{n_i}\sum_{j=1}^{n_i}\mathbf{I}_k^{max}\right)$$



4. Obtain source locations

Automatic and user-independent workflow for the identification of source localisations in three-dimensional TRI images. Comparison with original synthetic sources gives accuracy.



5. Sensitivity Maps

Sensitivity maps report on the source-location accuracy in the model and may be used to assess existing networks for their location capabilities or help to improve the design of future networks. Additionally, they provide an uncertainty estimation for real-life located events and thus, allow the distinction between artificial convergence of the wave field and actual source localizations. The sensitivity maps for Los Humeros reveal a non-linear influence of the station distribution and the velocity model on the source location accuracy.

Finger, C. and Saenger, E. H. (2020): Sensitivity Maps for Time-Reverse Imaging: An Accuracy Study for the Los Humeros Geothermal Field (Mexico), GJI, in Review

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