Probabilistic imaging of induced micro-seismicity

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the problem

automatically locate sources of micro-seismicity in space and time
the imaging method

**traveltime-based**

identify the sources from picked traveltimes and polarizations

**wavefield-based**

identify the sources by back-propagating full wavefields
the imaging method

traveltime-based
identify the sources from picked traveltimes and polarizations

wavefield-based
identify the sources by back-propagating full wavefields

use full wavefield imaging
monitor microseismicity with distant and sparse receivers
seek weak microearthquake energy in a noisy environment
focus on the source using time reverse wave propagation
focus on the source using time reverse wave propagation
focus on the source using time reverse wave propagation
focus on the source using time reverse wave propagation
the type of solution

deterministic
identify microearthquake positions and trigger times

statistical
evaluate the probability of microearthquake occurrence
the type of solution

deterministic

identify microearthquake positions and trigger times

statistical

evaluate the probability of microearthquake occurrence

use Bayesian inference

Tarantola (1987)
Bayesian inference

a process of information refinement

prior information  posterior information
prior information

\[ \rho (d, m) \]

- \textbf{m}: model
- \textbf{d}: data
prior information

\[ \rho (d, m) \]
theory

\[ \Theta (d, m) \]

- \(m\): model
- \(d\): data
$\Theta (d, m)$

de

theory
posterior information

\[ \sigma (d, m) \]

- **m**: model
- **d**: data
conjunction of probabilities

\[ \sigma (d, m) \approx \Theta (d, m) \rho (d, m) \]

- \textit{m}: model
- \textit{d}: data
$\sigma (d, m)$

posterior information
marginal probabilities

\[ \rho_M(m) = \sum_D \rho(d, m) \]

\[ \sigma_M(m) = \sum_D \sigma(d, m) \]
micro-earthquake imaging

use full wavefield imaging

use Bayesian inference
micro-earthquake imaging

definitions

the model

space-time coordinates

\{x, t\}

the data

seismic wavefields

\(W(x, t)\)
model \( m = \{ x_s, t_s \} \)
prior information

\[ W(x, t) \]

\( \{x, t\} \)

start with engineering data...
prior information

\[ W(x, t) \]

\( \{x, t\} \)

...use field observations...
acquisition noise
$d^{obs}$
theory

\[ W(x, t) \]

... add physics of wave propagation...
$G(m)$
\[ W \left( \mathbf{x}, t \right) \]

\[ \{ \mathbf{x}, t \} \]

... combine observations with theory...
posterior marginal probability
posterior information

\[ W(x, t) \quad \{x, t\} \]

\[ \ldots \text{narrow-down the range of possible solutions} \]
possible source location
example
$G(m)$: surface acquisition
$G(m)$: borehole acquisition
σ(m)
conclusion

- locate micro-earthquakes automatically
- identify micro-earthquake position and time
- provide uncertainty estimates
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