Bayesian Moment Tensor Inversion

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MIT Earth Resources Laboratory
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• Research motivation – Source mechanisms and uncertainty quantification

• Method – Waveform-based Bayesian moment tensor inversion

• Examples – From micro-seismicity to pico-seismicity
Motivation

- Fractures in Multi-scales
- Source mechanisms & uncertainties

Field, ~km

\[ \mu \text{-EQ} \]

\[ p \text{-EQ} \]

\[ \sigma_H = 2500 \text{ psi} \]
\[ \sigma_V = 3500 \text{ psi} \]

TerraTek report, 2014

Core Sample, ~cm

Sarkar, 2008

Gu, 2016
Methodology – Bayesian Machine

Simplest Bayesian Formulation

Input

Waveforms from all M >= 3 local earthquakes from station RS from 2013 to 2015

Output

Prior
\[ \pi_0(M_{ij}) \]

Posterior
\[ \pi(M_{ij} | d) \]

Polarity

M_{ij} solution distribution

High Probability
\[ M^1 \]

Low Probability
\[ M^2 \]

Likelihood
\[ P(d | M_{ij}) \]

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Methodology – Bayesian Machine

Simplest Bayesian Formulation

\[ P(m|x^*, d) \]

Location Sampling

\[ \log P(x|d) \]

Input

Output

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Methodology – Bayesian Machine

Input

Simplest Bayesian Formulation

\[ P(m|x^*, V^*, d) \]

Location Sampling

Velocity Model Sampling

Output

\[ \log P(x_i, V_j | d) \]

\[ x^i \]

\[ V \]

\[ Z \]

\[ V_p \]

\[ V_s \]
Induced Seismicity in Oman

- More high-quality data
- In predictable places

Sarkar, 2008
Induced Seismicity in Oman

Slide 8
Induced Seismicity in Oman

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Local Earthquakes in Kuwait

Kuwait Seismicity 1997-2015

Note: Earthquakes occur in the same place of Oil/gas fields
Local Earthquakes in Kuwait

Kuwait Seismicity 1997-2015

Waveform matching of the 08/18/2015 Mw 4.1 EQ

Waveform matching of the 03/21/2015 Mw 4.5 EQ

Source mechanism of the 08/18/2015 Mw 4.1 EQ

Source mechanism of the 03/21/2015 Mw 4.5 EQ
Acoustic Emissions

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Acoustic Emissions

Slip of a fracture plane in a saw-cut Lucite sample:

- Acoustic emissions from 8 PZT sensors
- Audio recording (e.g., use an iphone)

This Experiment is conducted by Saied Mighani.
Acoustic Emissions

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Hearing What Fractures Say

Events detected from the 8-channel PZT sensors
Real Earthquake Cycle

\[ M(t) = M_0 \times (1 - e^{-\frac{t}{\tau}}) \]

- \( M_0 \) is the initial moment
- \( \tau \) is the time constant

Parameters:
- \( t_0 = 1906.30 \)
- \( t_f = 1991.96 \)
- magnitude indeterminate
- \( m_{\text{free}} = -0.5506 \)

Patek and Baio, 2007

California Spiny Lobster

Bue and Vanes, 1993
We studied the source mechanisms of micro- and pico-earthquakes occurred in multi-scales, from oil/gas fields in Oman and Kuwait, to small cylinder laboratory rock samples.

The micro-seismicity that occurred in the oil/gas fields in Oman and Kuwait is probably induced by fluid injection and extraction in oil/gas fields. In both cases, we use a new waveform based Bayesian moment tensor inversion to obtain the source mechanisms, as well as uncertainties. The importance of the regional stress field and local fault networks (Oman) in generating that micro-seismicity is observed.

Laboratory generated pico-seismicities (AE) can be used to mimic different rupture processes (e.g., hydraulic fracturing, stick-slip). We show a pioneering work of combining PZT and audio signals to characterize laboratory fracturing processes.
This research is supported by MIT ERL, TOTAL, and Kuwait Foundation for the Advancement of Sciences.
Thank you!
• Bayesian moment tensor inversion and uncertainty quantification for induced seismicity -- uncertainties from both the location and velocity model

  **Session ID:**  PS 2  
  **Presentation Date and Time:**  9/26/2017 2:15:00 PM  
  **Room:**  362D, in the George R. Brown Convention Center

• Hearing what fractures say: A combination of seismic and speech recognition methods

  **Session ID:**  RP 7  
  **Presentation Date and Time:**  9/28/2017 11:25:00 AM  
  **Room:**  351D, in the George R. Brown Convention Center
We studied the source mechanisms of micro- and pico-earthquakes occurred in multi-scales, from oil/gas fields in Oman and Kuwait, to small cylinder laboratory rock samples.

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Kuwait Seismicity 1997-2015

Kuwait oil fields

Note: Earthquakes occur in the same place of Oil/gas fields
Local Earthquakes in Kuwait

All Located Earthquakes

M>=3 Earthquakes

U.S.-Iraq War

Build Broadband Network

Earthquake count

Year

0
100
200
300
400
500
600
700
800
900
1000

Year


Kuwait Al Wafra Bubyan Island Al-Salmi Oil fields Failaka Island Kuwait Bay 46˚45' 47˚00' 47˚15' 47˚30' 47˚45' 48˚00' 48˚15' 48˚30' 48˚45'

28˚45' 29˚00' 29˚15' 29˚30' 29˚45' 30˚00'

S E N W

Build Broadband Network

U.S.-Iraq War
Local Earthquakes in Kuwait

Waveforms from all the M >= 3 local earthquakes from station RS from 2013 to 2015