Seismic Moment Tensor Inversion Using 3D Velocity Model and Its Application to the 2013 Lushan Earthquake Sequence

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Outline

1. Moment tensor inversion for a general seismic source.
3. Application to southern California earthquakes.
4. Application to the 2013 Ms 7.0 Lushan earthquake sequence.
5. Conclusions
For a point seismic source of impulse source time function,

\[ u(t) = M_{ij} G_{ij}(t), \quad (1) \]

where \( M \) is the source moment tensor (symmetric, 6 independent components) and \( G(t) \) is the Green’s function.
Eq. (1) is a linear function of $M_{ij}$ when the Green’s functions are known. But imperfect velocity model and source location/origin time introduce a unknown time shift $\Delta t$,

$$u(t) = M_{ij} G_{ij} (t - \Delta t),$$

which makes the moment tensor inversion non-linear.
Parameterization of moment tensor

\[ M_{ij} = M_0 D_{ij}, \quad (|D| = \sqrt{2}) \]  \hspace{1cm} (3)

\[ D_{ij} = \zeta D_{ij}^{\text{ISO}} + \sqrt{1 - \zeta^2} \left( \sqrt{1 - \chi^2} D_{ij}^{\text{DC}} + \chi D_{ij}^{\text{CLVD}} \right), \]  \hspace{1cm} (4)

\[ D_{ij}^{\text{ISO}} = \sqrt{\frac{2}{3}} \delta_{ij}, \]  \hspace{1cm} (5)

\[ D_{ij}^{\text{DC}} = n_i v_j + v_i n_j, \]  \hspace{1cm} (6)

\[ D_{ij}^{\text{CLVD}} = \frac{1}{\sqrt{3}} (2b_i b_j - v_i v_j - n_i n_j), \]  \hspace{1cm} (7)

where \( M_0 \) is the scalar moment, \( \hat{n} \) is the fault normal vector (determined by the strike \( \phi \) and dip \( \delta \) of the fault plane), \( \hat{v} \) is the slip direction vector (determined by the rake \( \lambda \)), and \( |\zeta| \leq 1 \) and \( |\chi| \leq 1/2 \) are non-dimensional parameters quantifying the strength of isotropic and CLVD components, respectively.
gCAP3D uses a grid search to solve Eq. (2) for source parameters

\[ \mathbf{m} = (\zeta, \chi, \phi, \delta, \lambda)^T. \]  

(8)

For each possible set of source parameters, it first finds \( \Delta t \) by cross-correlating \( u(t) \) and \( s(t) = D_{ij} G_{ij}(t) \) and estimates the scalar moment,

\[ M_0 = \frac{\|u\|}{\|s\|}. \]

(9)

It then calculates the waveform misfit \( e \) using the \( L_2 \) norm of the difference between observed and predicted waveform,

\[ E = \sum_{i=1}^{N_s} \left( w^2 \left( \frac{r_i}{r_0} \right)^2 \left( e_i^{PnlZ} + e_i^{PnlR} \right) + \frac{r_i}{r_0} \left( e_i^{RaylZ} + e_i^{RaylR} + e_i^{Love} \right) \right), \]

(10)

\[ e = \|u(t) - M_0 s(t - \Delta t)\|^2. \]  

(11)
Zhen et al., 2013
Zhen et al., 2013
• EMOD3D code by R. Graves (1996).
• Staggered grid, 4th-order FD.
• $450 \times 450 \times 150$ km.
• Grid spacing 1 km, $f_{\text{max}}=0.4$ Hz.
• Use the reciprocity principle to reduce the number of FD runs.
• Takes $\sim 4$ Hrs. per station.
### Raw Text

**Event 2013**

**Model and Depth**

**geom_fix**

**FM** 222 42 90 Mw 6.52 E 6.528e+01 590 ERR 2 1 2 ISO 0.28 0.05 CLVD -0.13 0.03

Variance reduction 71.4

### Diagram

- **SMI**: 132.3/0.86, 0.40, 90, 0.40, 96, -1.10, 95, -1.10, 95, 1.00, 88
- **WCH**: 144.3/-1.01, 3.00, 87, 3.00, 92, 0.90, 95, 0.90, 85, 4.10, 89
- **HMS**: 159.5/0.19, 1.30, 85, 1.30, 90, 1.80, 95, 1.80, 94, -4.20, 35
- **MBI**: 169.9/1.28, 0.50, 95, 0.50, 97, 0.00, 93, 0.00, 94, -0.60, 92
- **JJS**: 170.4/0.77, 1.50, 71, 1.50, 71, 2.20, 89, 2.20, 62, -3.10, 51
- **YJJ**: 191.2/1.46, 0.30, 82, 0.30, 90, -1.50, 97, -1.50, 94, -1.20, 96
- **MEK**: 192.1/1.07, 2.00, 83, 2.00, 89, -1.00, 93, -1.00, 90, -0.60, 91
- **DFU**: 193.6/0.64, 1.30, 58, 1.30, 82, 0.00, 95, 0.00, 93, 2.00, 84
- **JLO**: 201.4/0.74, 0.50, 82, 0.50, 91, -1.10, 97, -1.10, 92, -0.80, 62

### Ticks

- 50 s
Event 20130424133635 Model and Depth 3D_fix
FM 28 27 72 Mw 3.36 E 4.584e-08 433 ERR 2 4 10 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 84.1

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<th>Pnlz</th>
<th>Pnlr</th>
<th>Raylz</th>
<th>RaylSr</th>
<th>Love</th>
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50 s
Conclusions

• We developed a method for determining moment tensors using 3D Greens functions.
• It uses grid search for the best source parameters that minimize waveform misfit.
• We applied the method to the 2013 Ms 7.0 Lushan earthquake sequence.
• We obtained 75 moment tensor solutions ranging from Mw 6.5 to 3.4.
• The mainshock is a reverse faulting on a plane dipping 40-47° to the NW.