Effects of 1-D versus 3-D velocity models on moment tensor inversion in the Dobrá Voda locality at Malé Karpaty region

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http://sw3d.cz

Idea of the moment tensor inversion

Seismic source parameters \times \text{Response of the medium} \Rightarrow \text{Seismic signal in the receiver}
Idea of the moment tensor inversion

\[
\text{Seismic source parameters} \times \text{Response of the medium} \Rightarrow \text{Seismic signal in the receiver}
\]

\[
\text{Moment tensor} \times \text{Green function} \Rightarrow \text{Recorded seismogram}
\]
Idea of the moment tensor inversion

Seismic source parameters * Response of the medium => Seismic signal in the receiver

Moment tensor * Green function => Recorded seismogram

Moment tensor <= Green function + Recorded seismogram
Idea of the moment tensor inversion

Seismic source parameters \* Response of the medium => Seismic signal in the receiver

Moment tensor \* Green function => Recorded seismogram

Moment tensor <= Green function + Recorded seismogram

P.B.
Idea of the moment tensor inversion

Seismic source parameters $\times$ Response of the medium $\Rightarrow$ Seismic signal in the receiver

Moment tensor $\times$ Green function $\Rightarrow$ Recorded seismogram

Moment tensor $\Leftarrow$ Green function $+\text{ Recorded seismogram}$

Z.J. \hspace{1cm} P.B.
Dobrá Voda locality on a map
1-D model of the Dobrá Voda locality
3-D model
3-D model
3-D model
3-D model
Synthetic test of moment tensor inversion

- synthetic test designed to mimic the configuration of the Malé Karpaty network
- synthetic seismograms calculated in the 3-D model
- MT inversion performed in both 3-D and 1-D models
- MT inversion performed with P&S wave data, with P wave data, and with vertical component of P wave data only
- MT inversion performed also for the data with 10% and 20% of noise
Synthetic test of moment tensor inversion

Source model
- pure double couple (DC)
- black lines - nodal lines of the DC part
- triangle up – tension axis
- triangle right - pressure axis
- triangle left - N axis
- green zone - compressions

Results of MT inversion in 3-D model

Results of MT inversion in 1-D model

=> orientation of DC part of the mechanism was retrieved well also for 1-D model and noisy input data
# Synthetic test of moment tensor inversion

<table>
<thead>
<tr>
<th>3-D model</th>
<th>P &amp; S waves</th>
<th>P wave</th>
<th>P wave vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>noise free</td>
<td>DC 100.0% V 0.0% CLVD 0.0%</td>
<td>DC 99.7% V 0.0% CLVD(T) 0.3%</td>
<td>DC 99.4% V 0.0% CLVD(T) 0.6%</td>
</tr>
<tr>
<td>10% noise</td>
<td>DC 97.2% V(imp) 0.8% CLVD(P) 2.0%</td>
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<table>
<thead>
<tr>
<th>1-D model</th>
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<th>P wave vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>noise free</td>
<td>DC 91.4% V(exp) 2.9% CLVD(T) 5.7%</td>
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\[
\text{MT} = \text{DC} + \text{nonDC}
\]

\[
\text{MT} = \text{DC} + \text{V} + \text{CLVD}
\]
## Synthetic test of moment tensor inversion

### 3-D model

<table>
<thead>
<tr>
<th>P &amp; S waves</th>
<th>P wave vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>noise free</strong></td>
<td><strong>100.0%</strong></td>
</tr>
<tr>
<td><strong>V</strong></td>
<td><strong>0.0%</strong></td>
</tr>
<tr>
<td><strong>CLVD</strong></td>
<td><strong>0.0%</strong></td>
</tr>
</tbody>
</table>

### 1-D model

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<tbody>
<tr>
<td><strong>noise free</strong></td>
<td><strong>DC 91.4%</strong></td>
</tr>
<tr>
<td><strong>V(exp)</strong></td>
<td><strong>2.9%</strong></td>
</tr>
<tr>
<td><strong>CLVD(T)</strong></td>
<td><strong>5.7%</strong></td>
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### Results

- MT = DC + V + CLVD

- Results for 3-D noise free good => station coverage is good
## Synthetic test of moment tensor inversion

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<thead>
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\[ MT = DC + V + CLVD \]

- results for 3-D noise free good  => station coverage is good
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\[ \text{MT} = \text{DC} + \text{V} + \text{CLVD} \]

- results for 3-D noise free good => station coverage is good
- for 3-D:  - more noise => more data required
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\[ MT = DC + V + CLVD \]

- results for 3-D noise free good => station coverage is good
- for 3-D: - more noise => more data required
  - less data => quality of the data is more important
- for 1-D: - DC vs. non-DC content was distorted unless both P & S wave amplitudes were inverted
  - effect of incorrect velocity model overrides the effect of noise largely: we observe bigger distortion for noise free data than for data contaminated by noise
Synthetic test of moment tensor inversion – new in 2013

- synthetic test designed to mimic the configuration of the Malé Karpaty network
- synthetic seismograms calculated in the 3-D model
- MT inversion performed in both 3-D and 1-D models
- MT inversion performed wit P&S wave data, with P wave data, and with vertical component of P wave data only
- MT inversion performed also for the data with 10% and 20% of noise
- 100 data sets are generated for each level of noise
Synthetic test of moment tensor inversion – new in 2013

Results of MT inversion in 3-D model

Results of MT inversion in 1-D model
### Synthetic test of moment tensor inversion – new in 2013

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<td>V 0.0%</td>
<td>CLVD 0.0%</td>
</tr>
<tr>
<td>10% noise</td>
<td>DC 68.0±7.6%</td>
<td>V -0.7±2.7%</td>
<td>CLVD -1.7±12.1%</td>
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<tr>
<td>V -0.7±2.7%</td>
<td>DC 90.1±6.2%</td>
<td>V -1.5±0.8%</td>
<td>CLVD -7.7±6.7%</td>
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<td>CLVD -1.7±12.1%</td>
<td>DC 88.4±6.4%</td>
<td>V -1.2±1.0%</td>
<td>CLVD -9.7±7.1%</td>
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<tr>
<td>20% noise</td>
<td>DC 70.6±18.2%</td>
<td>V 0.0±7.3%</td>
<td>CLVD 2.6±29.1%</td>
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<td>V 0.0±7.3%</td>
<td>DC 84.4±10.7%</td>
<td>V 0.2±2.0%</td>
<td>CLVD 0.9±17.3%</td>
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<td>CLVD 2.6±29.1%</td>
<td>DC 82.4±11.1%</td>
<td>V 0.1±2.5%</td>
<td>CLVD 0.1±18.9%</td>
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<td>V 1.3±5.0%</td>
<td>CLVD 1.4±21.7%</td>
</tr>
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<td>V 1.3±5.0%</td>
<td>DC 86.9±7.5%</td>
<td>V 2.5±1.4%</td>
<td>CLVD -4.8±12.2%</td>
</tr>
<tr>
<td>CLVD 1.4±21.7%</td>
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<td>20% noise</td>
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<td>V 1.6±9.2%</td>
<td>CLVD 6.6±33.5%</td>
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<td>V 1.6±9.2%</td>
<td>DC 79.5±12.7%</td>
<td>V 3.6±2.3%</td>
<td>CLVD 2.4±20.7%</td>
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<tr>
<td>CLVD 6.6±33.5%</td>
<td>DC 72.5±18.6%</td>
<td>V 5.0±2.4%</td>
<td>CLVD 17.6±22.8%</td>
</tr>
</tbody>
</table>

- Strange results of better solution for more noisy data disappeared
Dobrá Voda sample events  =>  2012

<table>
<thead>
<tr>
<th>Date</th>
<th>Origin time</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Depth</th>
<th>M_L</th>
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</thead>
<tbody>
<tr>
<td>20.7.2011</td>
<td>18:30:58.0</td>
<td>48.620</td>
<td>17.870</td>
<td>16.0</td>
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<td>5.3.2012</td>
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<td>3.1</td>
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<td>05/03/12</td>
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<td>DC 95.9%</td>
<td>DC 64.2%</td>
<td>DC 75.9%</td>
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<tr>
<td></td>
<td>V(imp) 0.5%</td>
<td>V(imp) 8.2%</td>
<td>V(exp) 6.2%</td>
<td></td>
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<tr>
<td></td>
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- 3 real events inverted for moment tensors
- results indicate the dominance of the DC components, the non-DC part remaining low
Dobrá Voda sample events
full MT and pure DC inversions, probability F-test
Dobrá Voda sample events
full MT and pure DC inversions, probability F-test

unconstrained full MT inversion:
- search for full moment tensor describing the source
- linear inversion
- 6 degrees of freedom

pure DC inversion:
- search for a pure double couple source
- nonlinear inversion
- 4 degrees of freedom (dip, strike, rake, scalar moment)
Dobrá Voda sample events
full MT and pure DC inversions, probability F-test

unconstrained full MT inversion:
- search for full moment tensor describing the source
- linear inversion
- 6 degrees of freedom

pure DC inversion:
- search for a pure double couple source
- nonlinear inversion
- 4 degrees of freedom (dip, strike, rake, scalar moment)

The noise in the data, mismodeling of the Green’s function, and other uncertainties of the MT inversion manifest themselves mostly in the non-DC part of the MT solution =>
=> need to estimate the significance of the non-DC components retrieved in the MT inversion
Dobrá Voda sample events  
full MT and pure DC inversions, probability F-test

unconstrained full MT inversion:  
- search for full moment tensor describing the source  
- linear inversion  
- 6 degrees of freedom

pure DC inversion:  
- search for a pure double couple source  
- nonlinear inversion  
- 4 degrees of freedom (dip, strike, rake, scalar moment)

The noise in the data, mismodeling of the Green’s function, and other uncertainties of the MT inversion manifest themselves mostly in the non-DC part of the MT solution  =>
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probability F-test:  
- quantifies the confidence of the MT model with respect to the pure DC one by comparing the fits achieved by unconstrained MT and pure DC models
- 100%  =>  the same confidence of MT and DC solutions
- 50% and less  =>  the MT solution is less confident than the pure DC one
Dobrá Voda sample events
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5 real events inverted for MT and DC source models
Dobrá Voda sample events

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Dobrá Voda sample events => 2013

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<tr>
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<td>CLVD -3.6%</td>
<td>CLVD 0.4%</td>
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<td>DC 75.2%</td>
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<tr>
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Dobrá Voda sample events => 2013

20/07/11

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MT  DC  MT  DC

100%  100%

95%  99%

93%  94%

31%  91%

67%  86%

=> using of 3-D model in MT inversion enables more reliable estimation of the DC versus non-DC components of the moment tensor

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Analysis of the depth of the location of the strongest event

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Analysis of the depth of the location of the strongest event

- location from national network => 5 km depth
- location from local network => 14 km depth
Analysis of the depth of the location of the strongest event

- location from national network => 5 km depth
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Analysis of the depth of the location of the strongest event

- location from national network => 5 km depth
- location from local network => 14 km depth

=> with increasing depth DC content increases and NRMS decreases
Acknowledgments

- ProgSeis for providing the seismic data
- European Commission for funding the FP7 Consortium Project AIM "Advanced Industrial Microseismic Monitoring"
- Grant Agency of the Czech Republic for funding Projects P210/10/1728  P210/10/0736
- members of the consortium “Seismic Waves in Complex 3-D Structures“ for the support

http://sw3d.cz