Sensitivity measurements for locating microseismic events

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Outline:

- Commercials
  - Papers
  - EOM
  - Modelling with diffractions
- Microseismic
- Apollonius
- Coplanar
- Collinear
- Vertical array
Naser Yousef-Zadeh

- Least-squares migration
- Multigrid approach
Baolin Qiao

- PSPI migration
- Microseismic
  - Covariance matrix approach
EO hyperbola
Conventional prestack migration
Modelling with diffractions
Modelling with diffractions

Aliased energy

Unaliased energy
Microseismic work:

- Location and clock-time of a microseism
- Analytic solutions
- Part of a larger system of receivers
- Simple model: constant velocity (RMS OK)
- Evaluate the sensitivity of receiver clock-times
- Help set standards for estimating first arrival clock-times
Receiver clock-times: Joe and Lilly

- Difficult to identify absolute clock-times of an event
- Greater relative accuracy between associated traces
- How accurate do we need to be?
Analytic methods:

- **(1) Apollonius solution**
  - Four arbitrarily located receivers
  - No coplanar
  - No collinear

- **(2) Four coplanar receivers on square grid at the surface**

- **(3) Three collinear equally spaced receivers**

- Perturb the receiver clock-times … jitter
- Simple visual analysis of the distribution
(1) Apollonius method

- Two solutions
- Both are possible
- Can be difficult to choose the correct solution
(1) Apollonius method

- Gaussian noise
- 100 trials
- Std = 0.1 ms
- \( z_s = 1000 \text{m} \)

Elongated cloud of source estimates
Error in the source location

Depth 500 m
Noise 1 ms

-1000 < x < 2000
-1000 < y < 1000

Display ± 20 m
(2) Four receivers on a square grid

\[ t_0 = \frac{t_1^2 - t_2^2 - t_3^2 + t_4^2}{2(t_1 - t_2 - t_3 + t_4)} \]

\[ x_0 = \frac{v^2 \left[ 2t_0 (t_2 - t_1) - (t_2^2 - t_1^2) \right] + h^2}{2h} \]

\[ y_0 = \frac{v^2 \left[ 2t_0 (t_3 - t_1) - (t_3^2 - t_1^2) \right] + h^2}{2h} \]

\[ z_0 = -sqrt\left[ v^2 (t_1 - t_0)^2 - (x^2 + y^2) \right] \]

Simple equations

\( t_0 \) is independent of the geometry
Four receiver in a square on the surface

Std = 0.1 ms

Very sensitive to noise

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**Side view z vs x**

**Side view z vs y**

**Plan view y vs x**

**Perspective view**
Four receiver in a square on the surface

Depth 500 m
Noise 1 ms

\(-1000 < x < 2000\)
\(-1000 < y < 1000\)

Display ± 50 m
Three vertical receivers

Only a 2D solution possible (no azimuth)
Radial and depth

Three receivers

\[
t_0 = \frac{t_1^2 - 2t_2^2 + t_3^2 - 2t_h^2}{2(t_1 - 2t_2 + t_3)}
\]

\[
r_0 = \sqrt{v^2 (t_1 - t_0)^2 - (z_1 - z_0)^2}
\]

\[
z_0 = \frac{1}{2h} \left[ 2t_0v^2 (t_2 - t_1) + v^2 (t_1^2 - t_2^2) + h^2 + 2z_1h \right]
\]
Three vertical receivers

Std = 0.1 ms
Two sets of 3 receivers

Std = 0.1 ms

- 50 m spacing
- 100 m aperture

- 20 m spacing
- 40 m aperture

Note the difference in the spreads due to receiver aperture

Note the direction of the spread
Vertical array of receivers

- Find combinations of three equally spaced receivers

For 7 receivers, there will be 9 combinations,

1  Rec.. 1  2  3
2  Rec.. 1  3  5
3  Rec.. 1  4  7
4  Rec.. 2  3  4
5  Rec.. 2  4  6
6  Rec.. 3  4  5
7  Rec.. 3  5  7
8  Rec.. 4  5  6
9  Rec.. 5  6  7
16 receivers, 56 combinations

1 ms noise

56 estimated solution
16 receivers, 56 combinations

Compute the mean location “P”
Notice the vectors from source to center of receivers.

Estimated source locations (computed)

- Receivers
- Defined Srs.
- Est. Source

Radial distance (m)

Depth z (m)

Std = 1 ms
Notice the vectors from source to center of receivers.

Estimated source locations (computed)

(4) Use least-squares to get the best solution “V”
Vertical array

• Two solutions
  – Direct point computation ($P$)
  – Least-squares of the slope vectors ($V$)

• 100 trials to get the mean and SD of the source location
  – Different noise on the receiver clock-times

• Vary the source location

• Plot the SD of the estimated source

• Vary the amplitude (SD) of the clock-time error
Comparing $P$ and $V$ solutions

Noise 0.1 ms

$r = 1000\text{m}$

$V = 3000 \text{m/s}$

$N = 16$

$Z_{r\text{-max}} = 300 \text{m}$
Comparing $P$ and $V$ solutions

Noise 1.0 ms

<table>
<thead>
<tr>
<th>Depth z (m)</th>
<th>Distance r (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1000</td>
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<tr>
<td>-900</td>
<td>200</td>
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<tr>
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<tr>
<td>-600</td>
<td>800</td>
</tr>
<tr>
<td>-500</td>
<td>1000</td>
</tr>
</tbody>
</table>

Std error for $P$ (error = 1 ms)

- Receivers
- Sources
- Distribution

Std error for $V$ (error = 1 ms)

- Receivers
- Sources
$P$ - wave

Noise $1.0 \text{ ms}$

$r = 500\text{ m}$

$V = 3000 \text{ m/s}$

$N = 8$

$Z_{r\text{-max}} = 600 \text{ m}$
**S-wave** (lower velocity)

- Noise 1.0 ms
- \( r = 500 \text{ m} \)
- \( V = 1500 \text{ m/s} \)
- \( N = 8 \)
- \( Z_{r\text{-max}} = 600 \text{ m} \)
Compare $P$- and $S$-wave

$V_p = 3000$  $V_s = 1500$
Compare $P$- and $S$-wave $V$ solution

$V_p = 3000$  $V_s = 1500$
Conclusions and comments

1. Analytic solutions
2. Part of a larger grid system
3. Ideal conditions, constant velocity
4. Only error on the receiver clock-times
5. Least squares vector solution
6. Showed expected errors for vertical arrays
Thanks for your attention
Clocktime circles for receivers with two solutions, \((t_0 = 1)\)