Automatic earthquake locating using characteristic functions in a source scanning method

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Objective

Microearthquakes are small magnitude earthquakes (M<2) that often occur in clusters with large numbers of events. Our goal is to find an automatic method that can efficiently and accurately find the location and timing of this type of events.

Method

We use a waveform-based method: Source Scanning Algorithm (SSA). We explore stacking several different types of Characteristic Functions (CFs) (Figure 1; Table 1) in SSA.

1. Calculate the Travel Time Model.
2. Calculate the CFs.
3. Calculate the Brightness Matrices (Br).

Define the grid (x, y, z, t).

For (x, y, z, t), sum up the values on the CFs at theoretical arrival times.

Find the onset of maximum stack in for (x, y, z, t).

Epicenter = argmax (Br\_onset)

Origin time = Br\_onset[Epicenter]

Synthetic Test Results

- It takes 1 min to compute on a 3.5 GHz, 6-core Intel Xeon E5 machine with 32 GB RAM for a 16 km x 16 km x 16 km x 4 sec grid with spacing 0.5 km, 0.1 s.
- The CFs involving ST/LT are more stable at high noise levels.
- Considering polarization gives more robust results for stochastic seismic noise.

Field Data Test

- 3-component field data (5 min long) recorded by 18 stations in the SIL Network at Reykjanes Peninsula, SW Iceland (Figure 3).
- Simplified 1D velocity model from Liu (2013).
- SSA grid spacing 0.5 km, 0.1 s.

Visualization of the brightness matrices

- CECM: Component energy comparison method.
- ST/LT: Short-term (ST) vs long term (LT) average amplitude.
- RP/LP: Right-part vs left-part of the time window.
- ST*LT: The cross-correlation coefficient between ST and LT (Figure 4).

Table 1. Abbreviations for the Characteristic Functions (CFs)

<table>
<thead>
<tr>
<th>CFs</th>
<th>Description</th>
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<tbody>
<tr>
<td>CECM</td>
<td>Component energy comparison method</td>
</tr>
<tr>
<td>ST/LT</td>
<td>Short-term (ST) vs long term (LT) average amplitude</td>
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</tr>
</tbody>
</table>

Results for scanning 215 events

- Compare SSA results with reference results determined by auto-picking and manual correction (Liu, 2013).
- ST/LT and RP/LP agree slightly better with the reference than their combined version: because human’s eyes are more sensitive to changes in amplitude in time.
- ST/LT-CECM and RP/LP-CECM have the smallest deviation and the fewest outliers (i.e. events with differences > 6 km or > 0.5 s) (Figure 4 and 5).

Conclusions

- Using CFs in SSA provides us with more flexibility and reliability in location problems with large event numbers and small event magnitudes.
- We can tailor a customized CF with various waveform characteristics and frequency ranges to focus on the target signal we are interested in.
- The combined CF: ST/LT-CECM and RP/LP-CECM provide advantages in:
  - More noise-robust.
  - Give more constrained solutions and reduce outliers.
  - Consider characteristics not obvious to human eyes and reduce human bias.

Future work

Use master events to update the velocity model and look at focal mechanisms.

References:


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Images:

Figure 1. The CFs calculated on an example 3-component seismogram.

Figure 2. The CFs that consider polarization: ST/LT, RP/LP.

Figure 3. The SIL Network in SW Iceland and reference event locations.

Figure 4. Moden of differences in event location and origin time.

Figure 5. (Up) Outliers in event location and origin time.

Figure 6. (Upper right) Waveform alignment for the example event using ST/LT-CECM (+ is the modelled arrival time based on the solution).