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). (Kao & Shan, 2004; Grigoli et al., 2013)
- We explore stacking several different types of Characteristic Functions (CFs) **(Figure 1; Table 1)** in SSA.

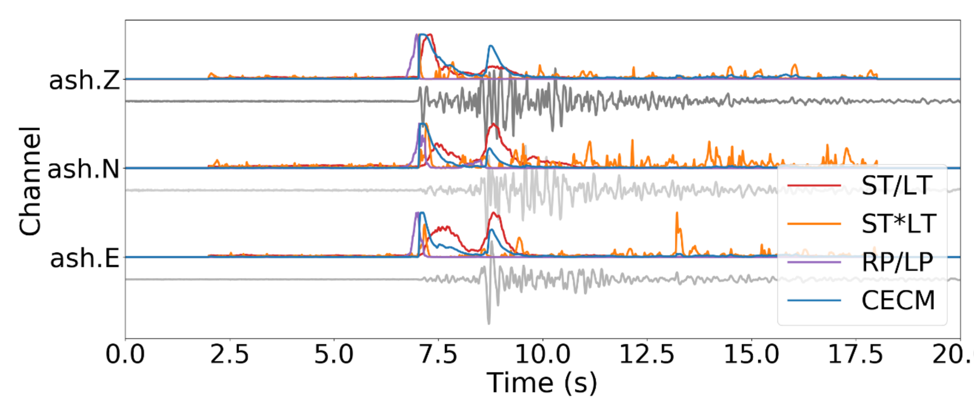
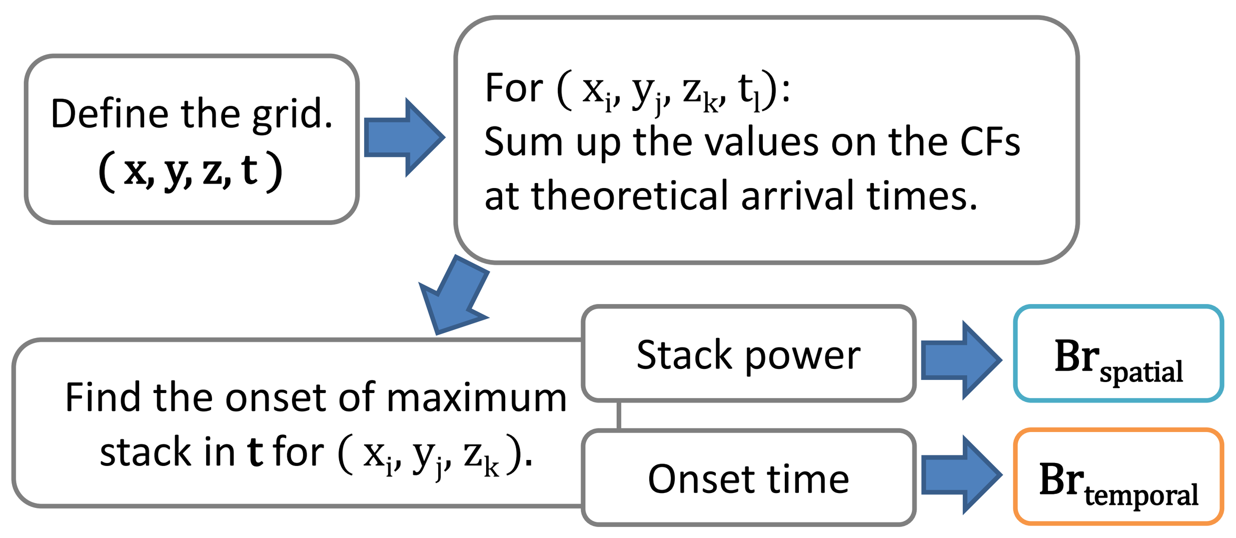


Figure 1. The CFs calculated on an example 3-component seismogram.

- ➢ Multi-characteristic CF.
- ➢ Multi-scaled CF.
- ➢ Combine CF by multiplication.
- ➢ Accommodate signals with expected characteristics. within an expected frequency band.

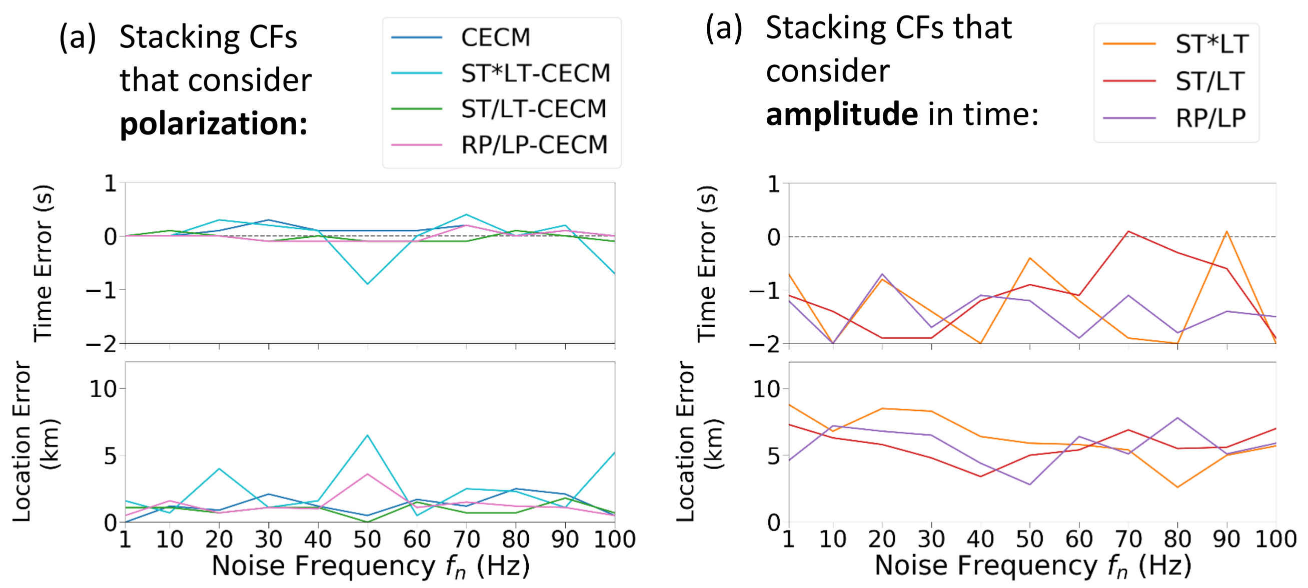
- Procedure: (Grigoli et al. 2013)
  1. Calculate the Travel Time Model.
  2. Calculate the CFs.
  3. Calculate the Brightness Matrices (**Br**).



4. **Epicenter** $= \text{argmax}\,(\mathbf{Br}_{spatial})$
5. **Origin time** $= \mathbf{Br}_{temporal}[\text{Epicenter}]$

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 grid 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 **(Figure 2).**



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).**
- 215 events (M<2) during Aug. 2010 ~ Dec. 2011.
- Simplified 1D velocity model from Liu (2013).
- SSA grid spacing 0.5 km, 0.1 s.

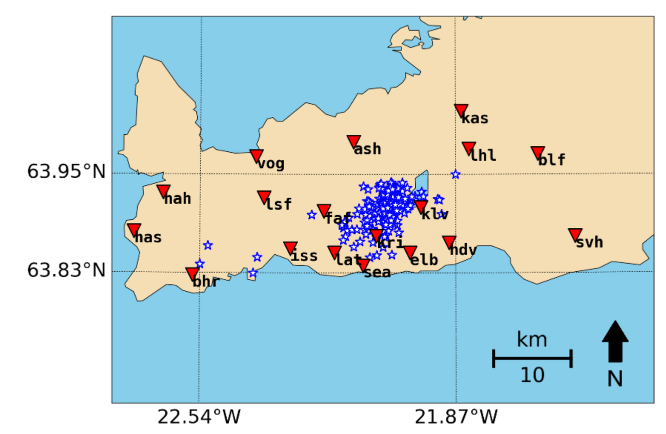


Figure 3. The SIL Network in SW Iceland and reference event locations.

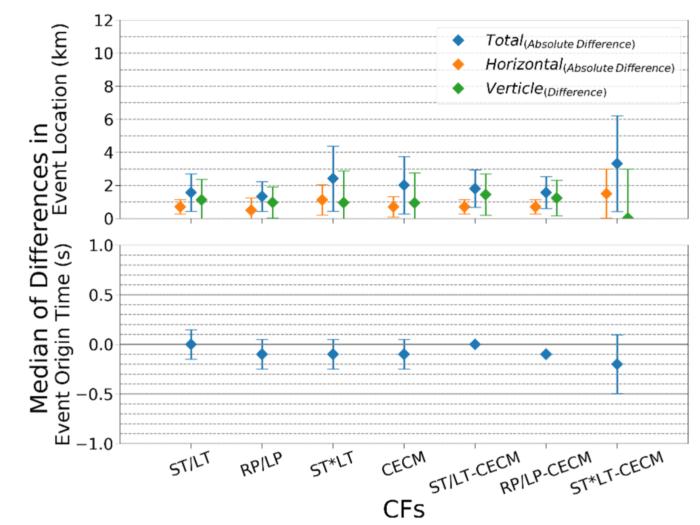
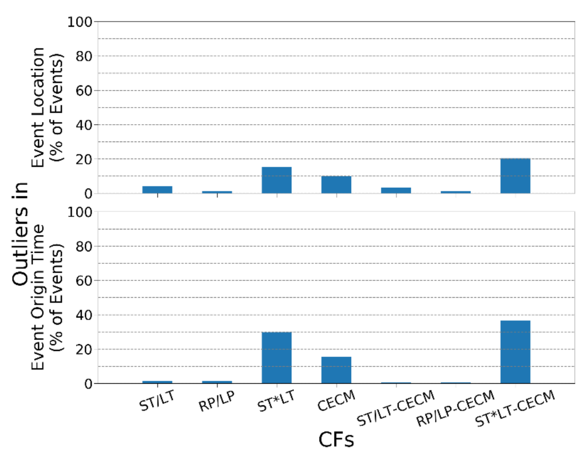


Figure 4. Median of differences in event location and origin time.

Results for scanning 215 events

- Compare SSA results with reference results determined by auto-picking and manual correction (Liu, 2013).
- ST/LT, RP/LP, ST/LT-CECM, and RP/LP-CECM can locate 80% of the source with maximum error 2.7 km.
- 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).**



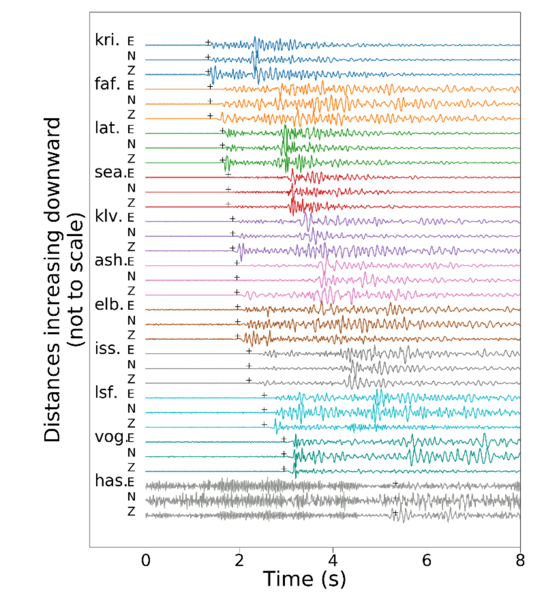


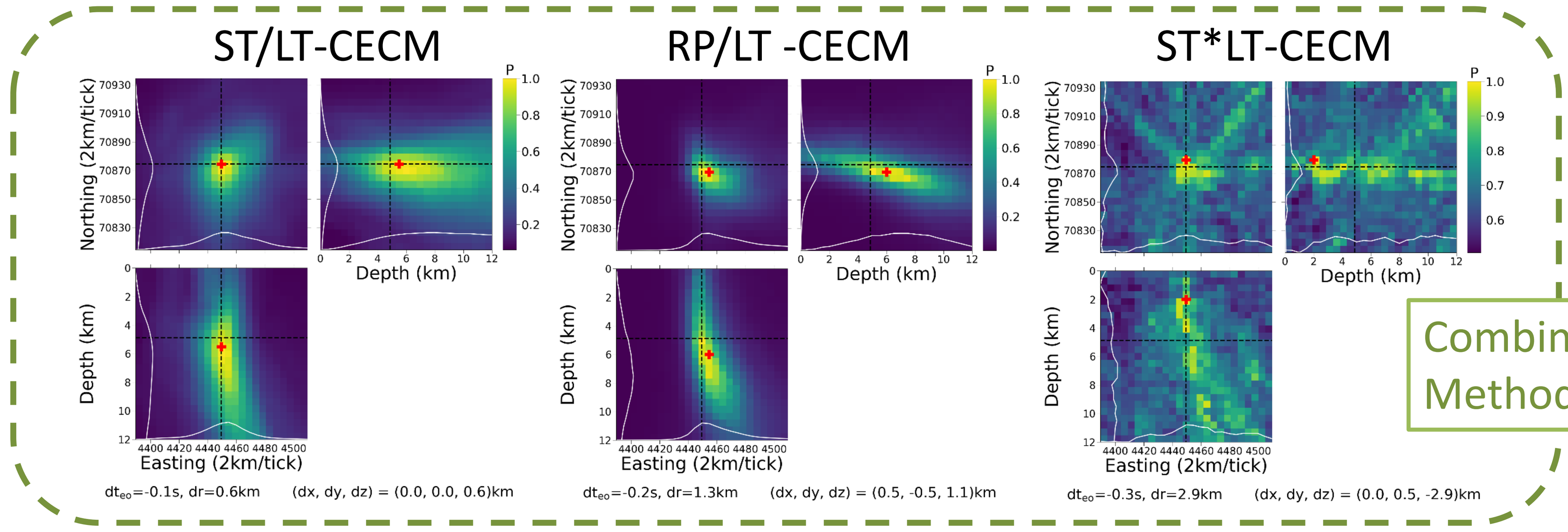
Figure 5. (Up) Outliers in event location and origin time.

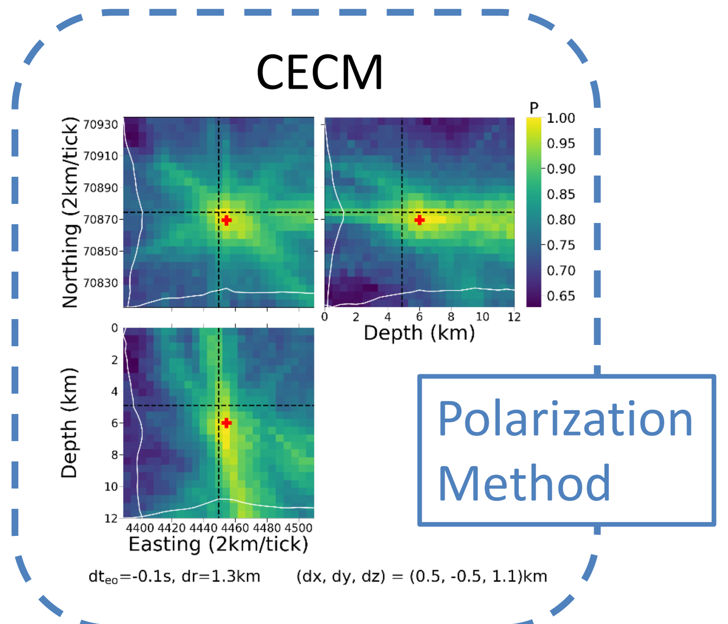
Figure 6. (Upper right) Waveform alignment for the example event using ST/LT-CECM (+ is the modelled arrival time based on the solution).

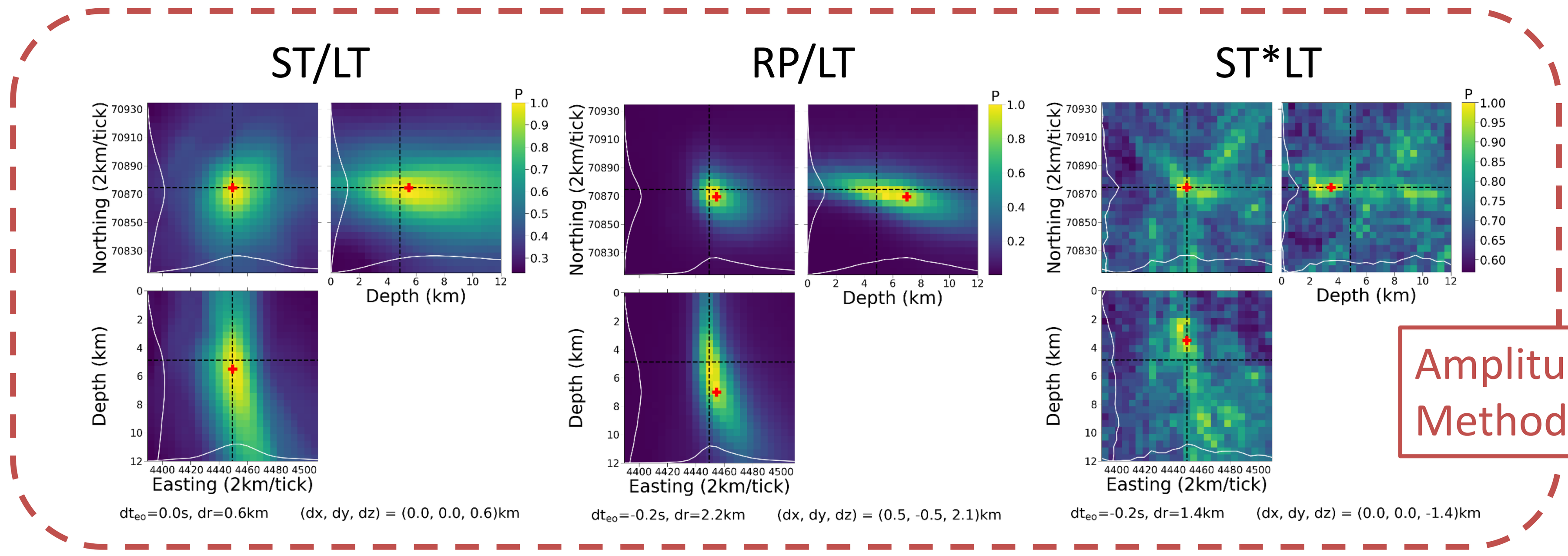
Visualization of the brightness matrices

- **CECM:** Component energy comparison method (Nagano et al. 1989)
- **ST/LT:** Short-term (ST) vs long term (LT) average amplitude (Allen, 1982)
- **RP/LP:** Right-part vs left-part of the time window (Zahradnik et al., 2015)
- **ST*LT:** The cross-correlation coefficient between ST and LT (Massin and Malcolm, 2016)

Table 1. Abbreviations for the Characteristic Functions (CFs).







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.

Photography encouraged

EGU Outstanding Student Poster & PICO Contest

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