Automatically detecting and locating induced and natural earthquakes using Multichannel Coherency Migration (MCM)

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1. Theory

Multichannel Coherency Migration (MCM)

Our goal is to create a method to automatically detect and locate seismic events in noisy environments using sparse networks of passive seismic (broadband) sensors. We take pairs (or d-wise sets) of stations and migrate the absolute correlation coefficient \(|r|\) (coherency) between each pair. Conventional migration approaches stack characteristic functions of individual stations, leading to a fold of \(N\) for the MCM, the fold is \((N(N-1))/2\). Importantly, \(r\) does not depend on amplitude, so we do not need to deal with changes of polarity due to the event radiation pattern, and incoherent noise cannot affect the procedure.

![Cartoon of MCM procedure](image)

The subsurface is discretised into imaging points, and we take each pair of stations, shift them according to the travel time predicted for the phase of interest at that point and calculate \(r\) within a time window. At the correct imaging point (yellow star) the two traces correlate well and \(|r|\) is large. Elsewhere (e.g., red point) the traces do not correlate. We sum the \(N(N-1)/2\) values of \(|r|\) to obtain our coherency value throughout space and time in a 4-D migration volume.

\[
\sum \text{over window of length } L \times T \quad \text{Shift at imaging point } t_i
\]

\[
\text{Data for trace } j \quad \text{Data for trace } j \quad \text{Mean of data in window}
\]

\[
p(x, y, z, t_0) = \frac{1}{N(N-1)} \left( \sum_{i=1}^{N} |r_{ij}|^2 + \sum_{i=1}^{N} |r_{ij}|^2 \right)
\]

2. Synthetic tests

Comparison with other migration methods

![Comparison of MCM with other migration methods](image)

We migrate synthetics (top middle) for a 1D layered model (top left) after application of noise (top right). Migrating waveforms envelopes, short-term- to long-term-average ratio or the forward derivative of waveform kurtosis sometimes produce acceptable results, though MCM maintains accuracy when noise-to-signal ratio (NSR) is high. Bottom row shows horizontal slices through migration volume.

3. Volcano-tectonic seismicity

![Velocity model used in the migration for events](image)

Above Velocity model used in the migration for events.

Left Map of region around Uturuncu volcano showing stations (triangle). White box is extent of migration volume.

Seismicity triggered by 2010 Maule M8.8 earthquake

The passage of the surface waves from the 27 February 2010 Maule earthquake nearby triggered hundreds of detectable events beneath the volcano. These were detected by Jay et al. (Bull. Volc., 2012) by manual inspection.

Upper left Example data for station UTCA

Vertical component, bandpass filtered between 4.2 and 24 Hz) after instrument response removal, showing multiple events throughout the period after the arrival of the Rayleigh wave at ~06:40 UTC.

Left Maximum coherency of MCM throughout imaging volume through time (time sampling 0.08 s). Red dots show maxima associated with manually verified seismic events.

Bottom left Record section for event marked EQ on map, above. Blue and red marks are MCM arrival picks for P- and S-wave respectively.

Below Slices through migration volume for event marked EQ, an example of one not in the Jay et al. catalogue from manual picking.

4. Conclusions

- We propose the Multichannel Coherency Migration, which uses the correlation coefficient between pairs of channels (or combinations with greater numbers) of continuously-recorded seismic data to automatically detect and locate seismic events.
- The method is robust to noise and often performs better than existing migrations, especially in noisy settings.
- We automatically detect ~320 volcano-tectonic earthquakes beneath Uturuncu volcano, triggered by the passage of surface waves.
- The MCM is computationally expensive but suitable for real-time monitoring.