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GFZ Helmholtz-Zentrum Potsdam

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Automatic transient signal detection and volcanic tremor extraction using music information retrieval strategies

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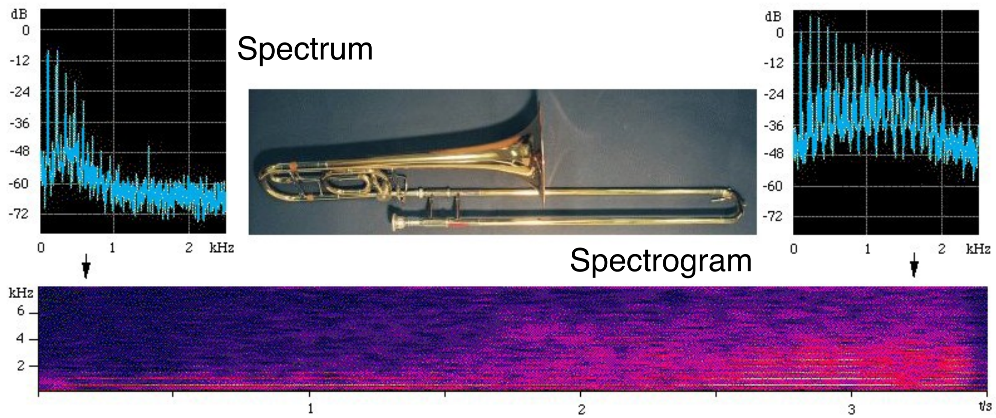
General purpose and outcome

Inspired by music information retrieval strategies, we introduce an algorithm to **1- extract (volcanic/non-volcanic) tremor signal** from seismic waveform and **2- detect transient signal arrivals**.

The second application could be a new method to detect and time earthquakes; especially low SNR seismic events in volcanic areas.

Similarity of harmonic sound in a music instrument and volcanic tremor in a volcano



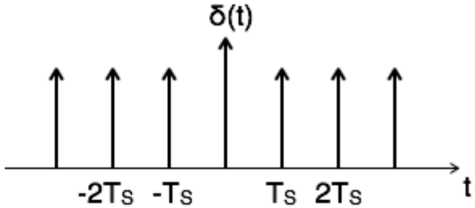
A trumpet exhibits natural resonant frequencies which follow a harmonic sequence

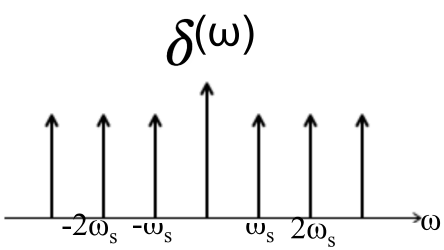
A volcano may exhibits a highly periodic ground vibration during unrest periods.
In the figure we see harmonic tremor of Lascar Volcano (April 1994).

Harmonicity in frequency domain = periodicity in time domain

Every periodic signal in time domain has a harmonic spectrum in frequency domain.

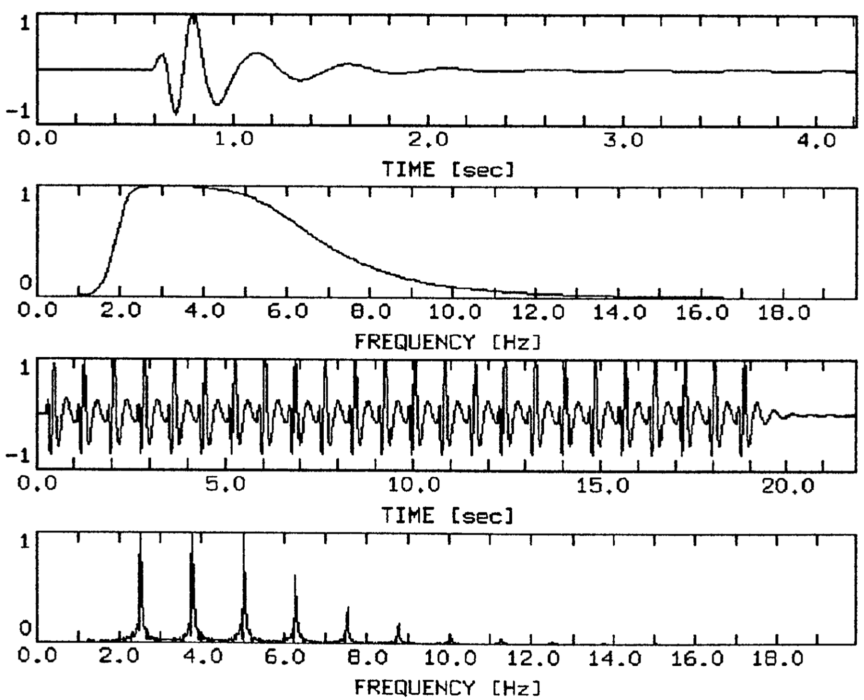
$$\delta(t) = \sum_{n=-\infty}^{\infty} \delta(t - nT)$$





$$\delta(\omega) = \frac{2\pi}{T_s} \sum_{n=-\infty}^{\infty} \delta(\omega - n\omega_s)$$

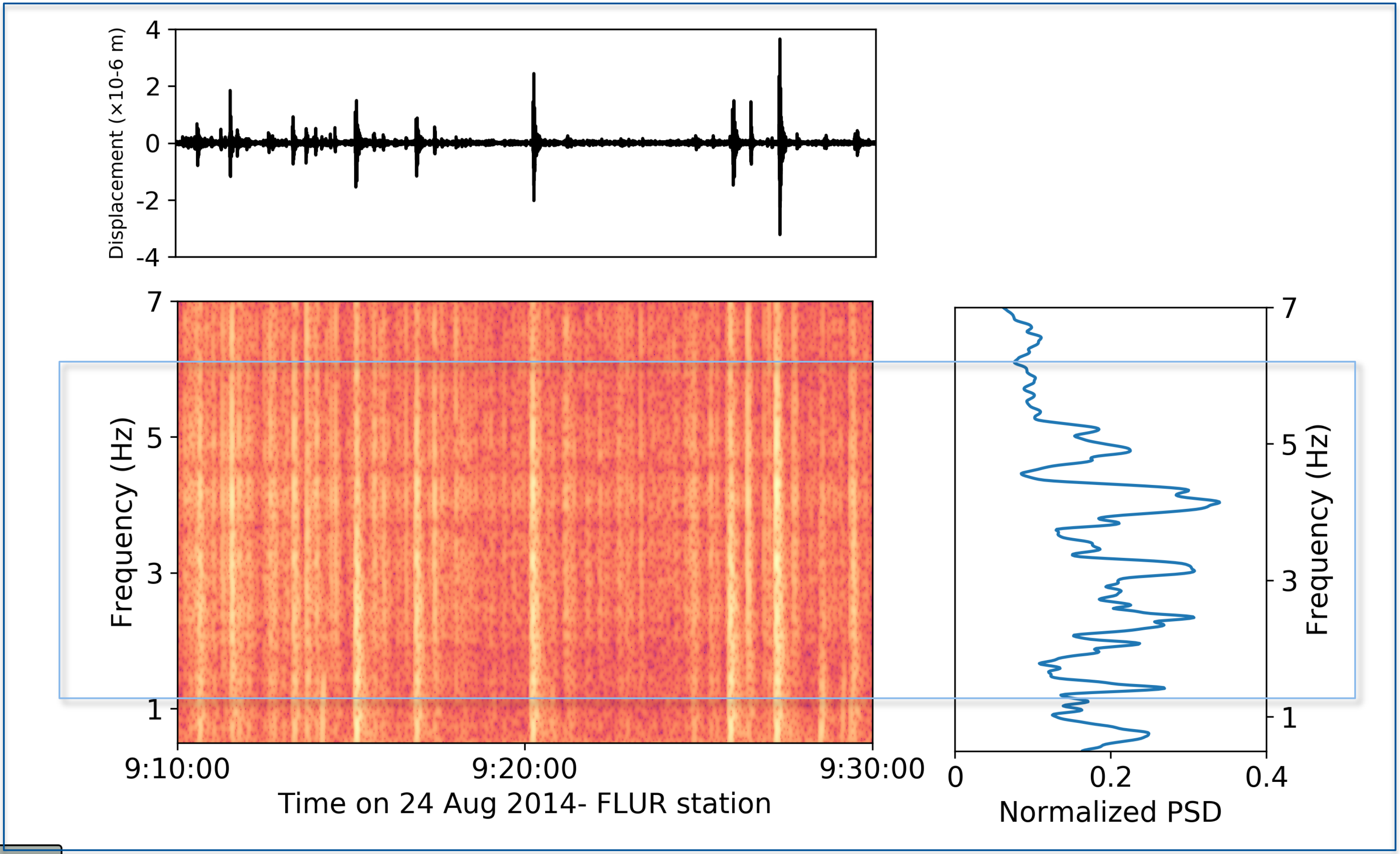
$$\omega_s = 2\pi/T_s$$



Schlindwein et al. (1995)

2014–2015 eruption of Bárðarbunga

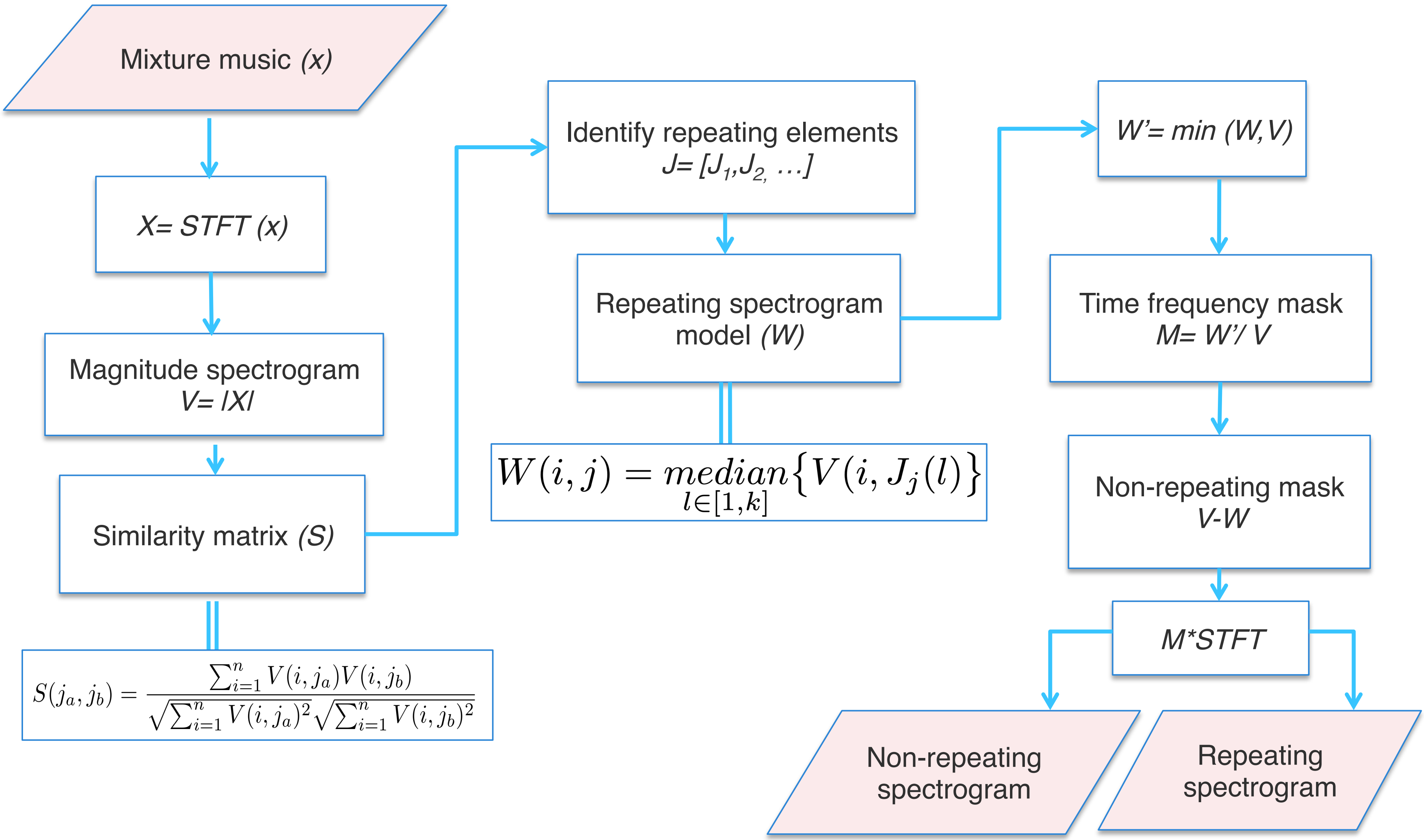
Large number of earthquakes mixed with volcanic tremor



Music/ Voice separation algorithm based on similarity

Identify repeating elements through looking for similarities, by means of a similarity matrix

Flowchart of Music/ Voice separation algorithm based on similarity

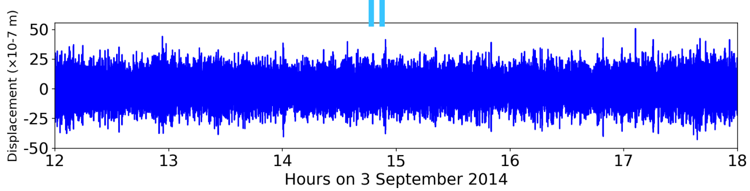


Method following Rafii et al., 2012

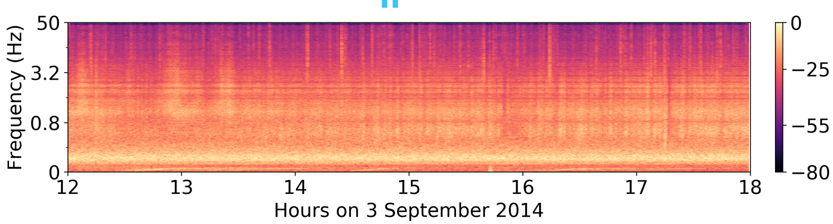
Flowchart of proposed method for harmonic tremor extraction and earthquakes detection

Step 1

Seismic waveform



STFT



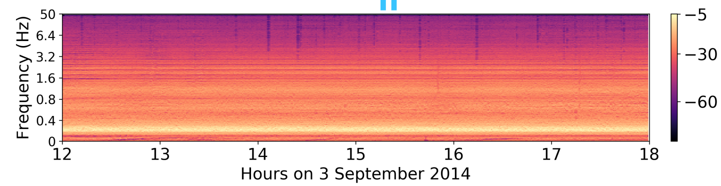
Derive a similarity matrix

Derive repeating spectrogram model by taking the median of repeating similar frames

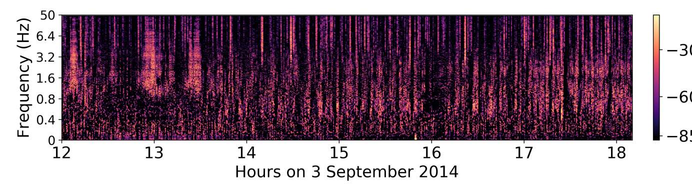
Derive time frequency masks and apply to STFT

Step 2

Horizontal median filtering on tremor spectrogram

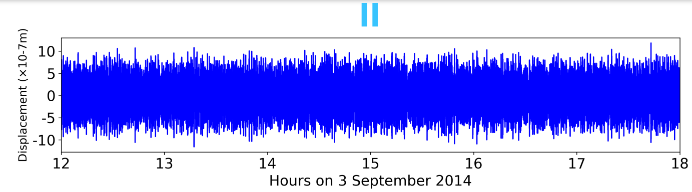


Vertical median filtering on percussive spectrogram

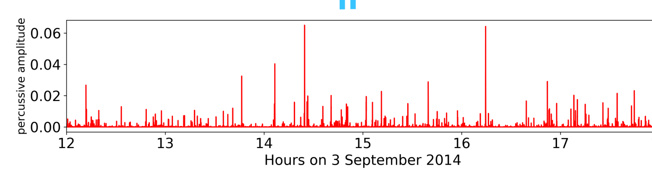


Step 3

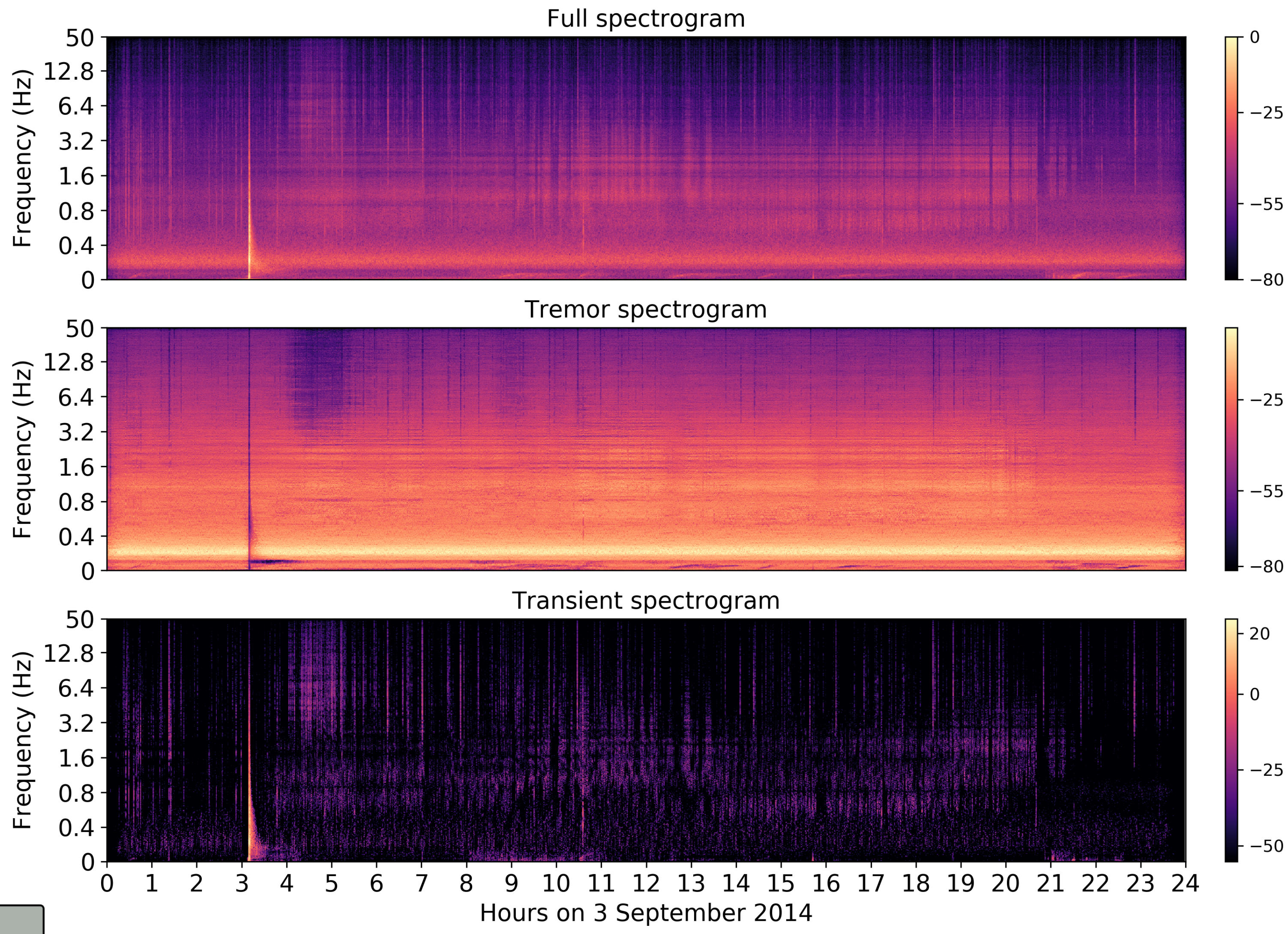
Reconstruct signal by adding phase to tremor spectrogram and ISTFT



Extract the values of percussive spectrogram. Peaks show events



One day spectrogram, extracted tremor spectrogram and earthquakes spectrogram



Extracted tremor matches the original seismic signal

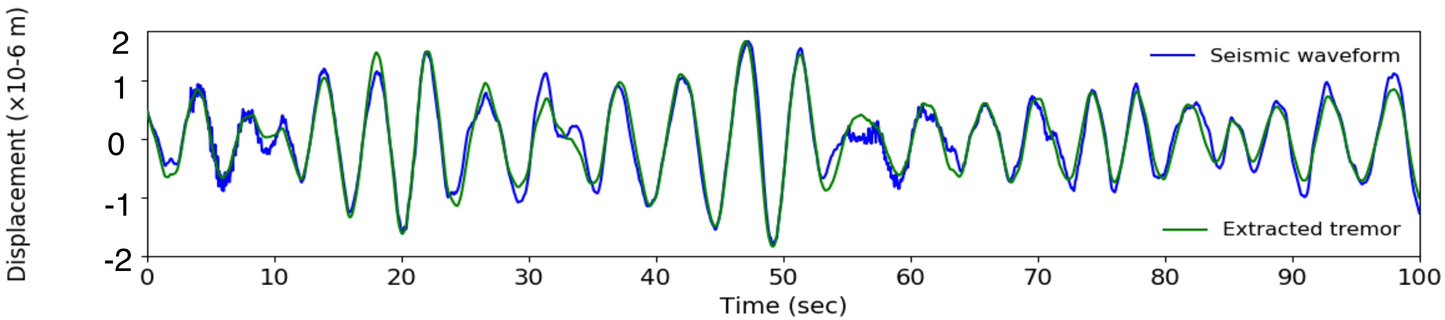


Fig.1. Seismic waveform and extracted tremor signal

Based on synthetic tests, the method is able to extract tremor from a signal with minimum SNR = 0.1 (harmonic to noise ratio)

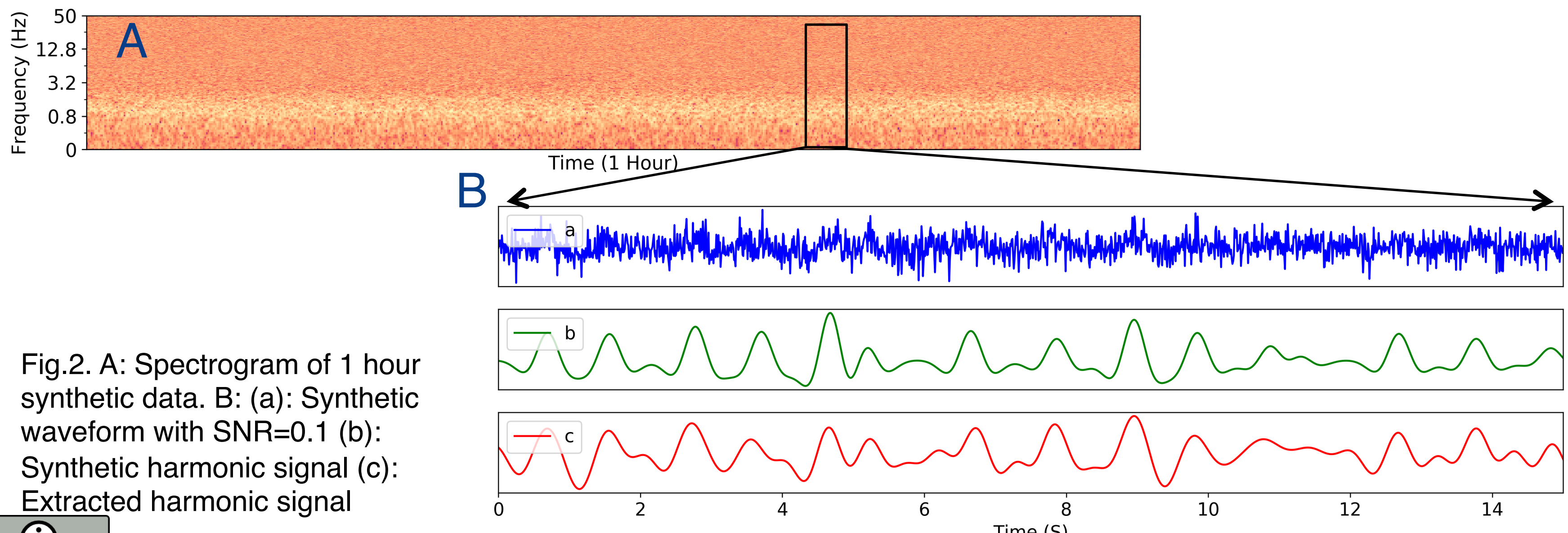


Fig.2. A: Spectrogram of 1 hour synthetic data. B: (a): Synthetic waveform with SNR=0.1 (b): Synthetic harmonic signal (c): Extracted harmonic signal

Seismic waveform → Extracted tremor
→ Extracted transients (earthquakes)

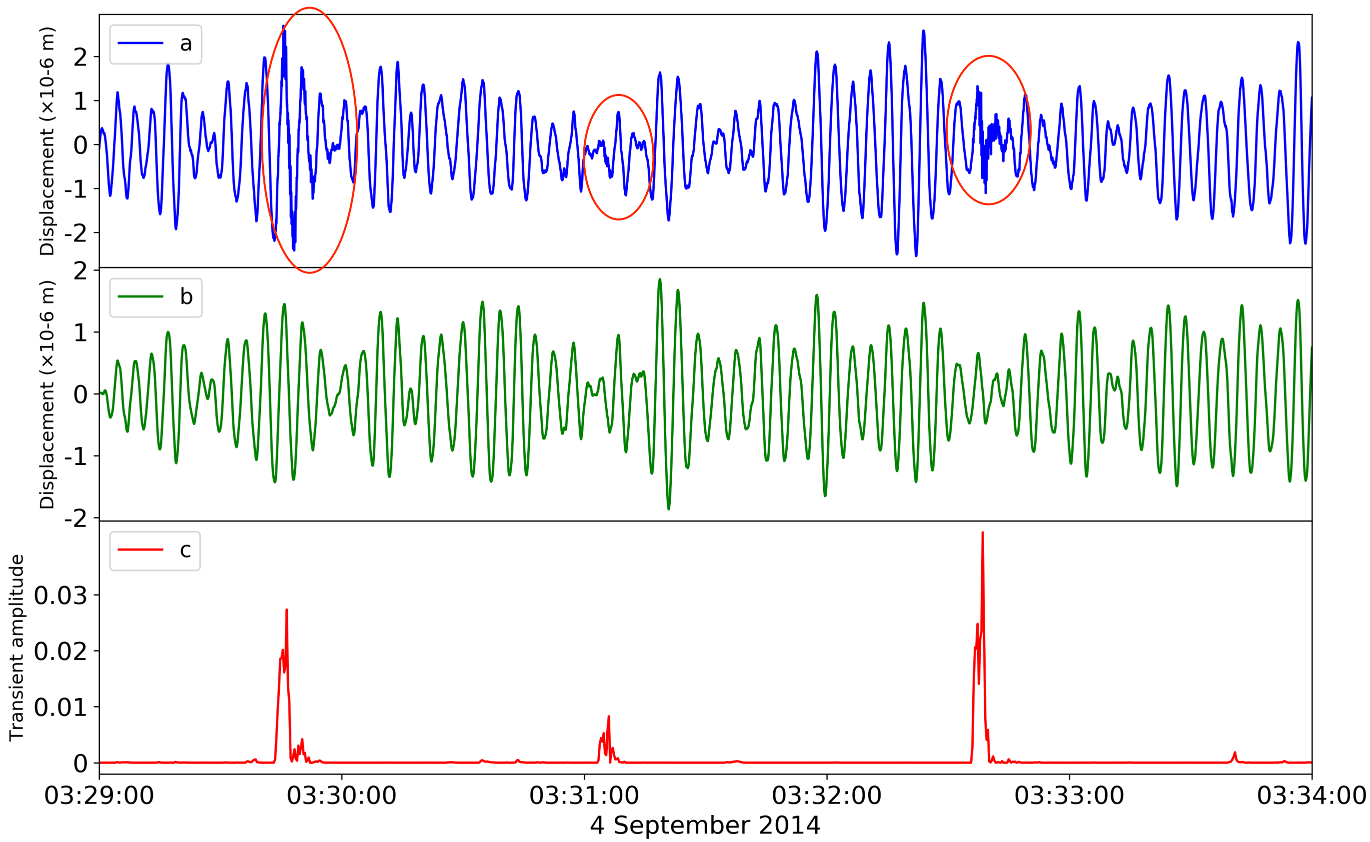
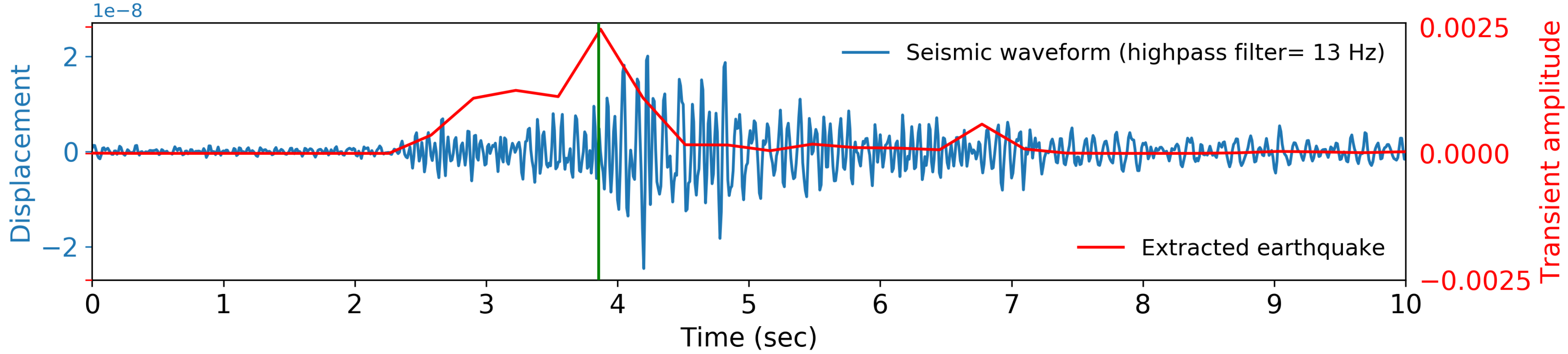


Fig.1. (a): Seismic waveform (b): Extracted tremor (c): Extracted characteristic function for detecting transient events.

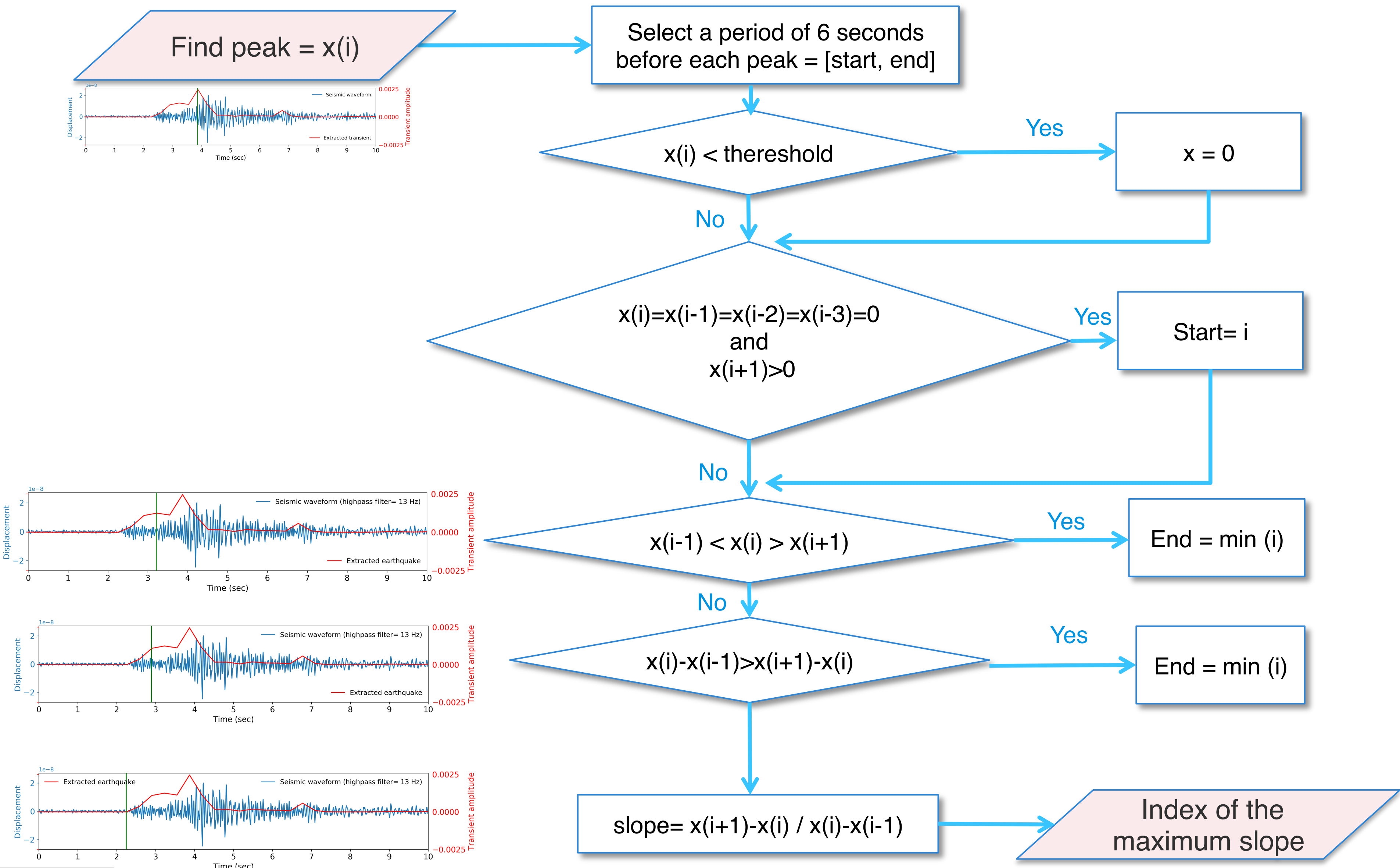
Earthquakes (transient signal) detection



We detected an earthquake by finding the peak (green line) in the extracted characteristic function.

Now how can we find P arrival time here?

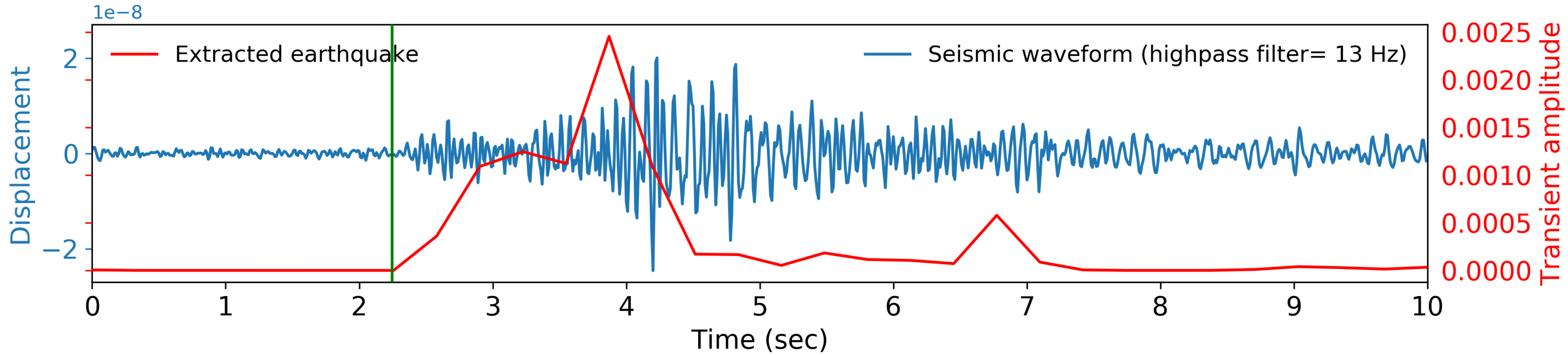
Flowchart of proposed method for finding P arrival time



P arrival time uncertainty

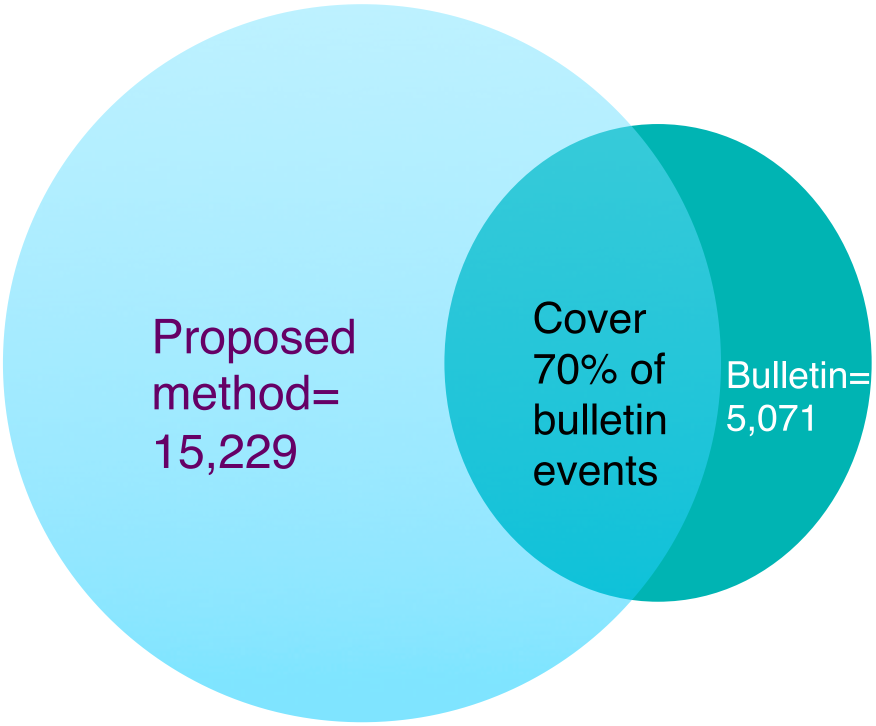
Uncertainty in this example = 0.1 second

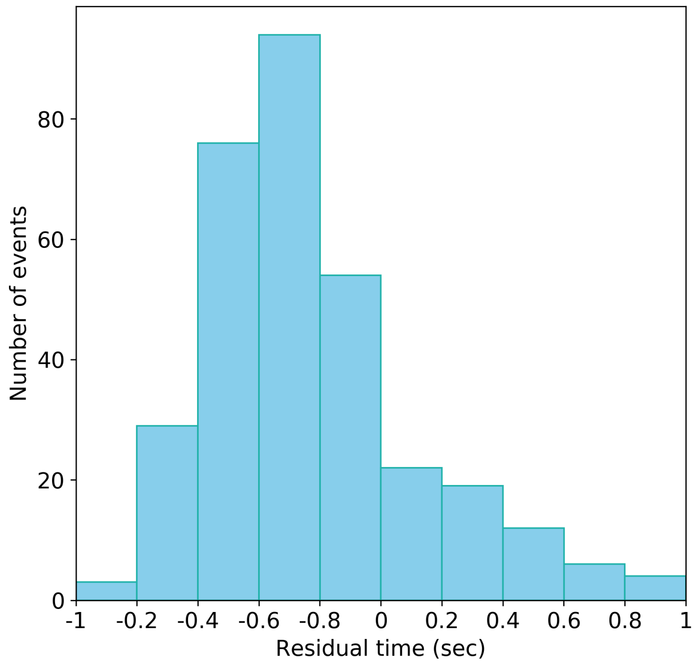
Uncertainty in this method = size of hop length = 0.32 seconds



Green line shows detected P arrival time

Compare number of detected earthquakes through one station and one component for 1 month with a presented bulletin in Woods et al., 2018.





P arrival time residuals for 1 day; proposed method and bulletin

Further synthetic tests are on-going to determine limitations and applications.

Acknowledgments

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