Seismic event detection in suburban Chicago using a single broadband seismic station

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Abstract

On November 4, 2013, residents near a quarry in the western suburbs of Chicago felt shaking from a rare, small earthquake. The USGS reported a magnitude of 3.2 and Dr. Robert Herrmann reported a dip-slip source mechanism from analyzing surface wave amplitudes recorded by USArray stations. With the goal of detecting potential aftershocks in this region of low seismicity and possibly gaining more insight into the source mechanism, a broadband seismic station was installed in the source region by researchers of Northwestern University. Due to the station's suburban setting and proximity to various transportation arteries, industrial operations, and city infrastructure including a deep tunnel and reservoir, detecting and discriminating small earthquakes from urban noise events poses a serious challenge. Average daily noise levels can be 50 dB above typical noise levels for broadband seismometers in Illinois in pertinent frequency bands, so aftershock signals can be buried deep within the noise, rendering typical STA/LTA detection methods relatively ineffective. A preliminary analysis of several months of waveform data identified seismic signals from ~1000 events. None of these events occurred on a Sunday or at night, implying an anthropogenic origin and further illustrating the challenge. Recorded signals from these events span a wide range of waveforms, rendering popular detection methods like template matching less effective than in other settings. We aim to define and engineer a set of waveform features to aid with seismic event detection using data from a single broadband station in a noisy, urban environment. To identify useful spectral parameters, we first computed power spectral density (PSD) estimates using segments ranging from the hour-scale to the second-scale. Week-long spectrograms of the PSD estimates revealed characteristic frequencies that are likely associated with routine quarry operations. Select features were then tested for their ability to detect regional and local seismic events for one month of data. We will present the results of this analysis, including the performance of several features and discuss their respective benefits and limitations for seismic event detection in an urban environment.

Seismic event detection in suburban Chicago using a single broadband seismic station

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Overview: We have developed a single-station event detection approach, based on the first four moments of a statistical distribution in both the time and frequency domain, that can identify a wider range of events than the conventional STA/LTA ratio method. We present the results of its preliminary application to seismic data in the Greater Chicago Area, which is characterized by high levels of urban and industrial noise.

Background

In the past few decades, a small number of low-magnitude earthquakes have occurred near a limestone quarry in the western suburbs of Chicago. Given their occurrence in a region of historically low seismicity and proximity to large-scale industrial operations, it is probable that these earthquakes were induced by local quarry or reservoir activities. To better understand the origin of the earthquakes, a broadband seismometer was installed in the area to detect potential aftershocks. Since the seismometer is in close vicinity of the quarry, major highways, residential areas, and a commercial airport, its data are characterized by high levels of urban noise (Fig. 1). The conventional STA/LTA ratio method [1] detected event signals (with the highest ratios) with similar waveform features (Fig. 4A) and time of occurrence (Fig. 6). These events were identified as local quarry blasts. To detect other types of events and better understand the nature of our data, we developed an alternative detection method based on different features than average amplitude in the time domain (STA/LTA).

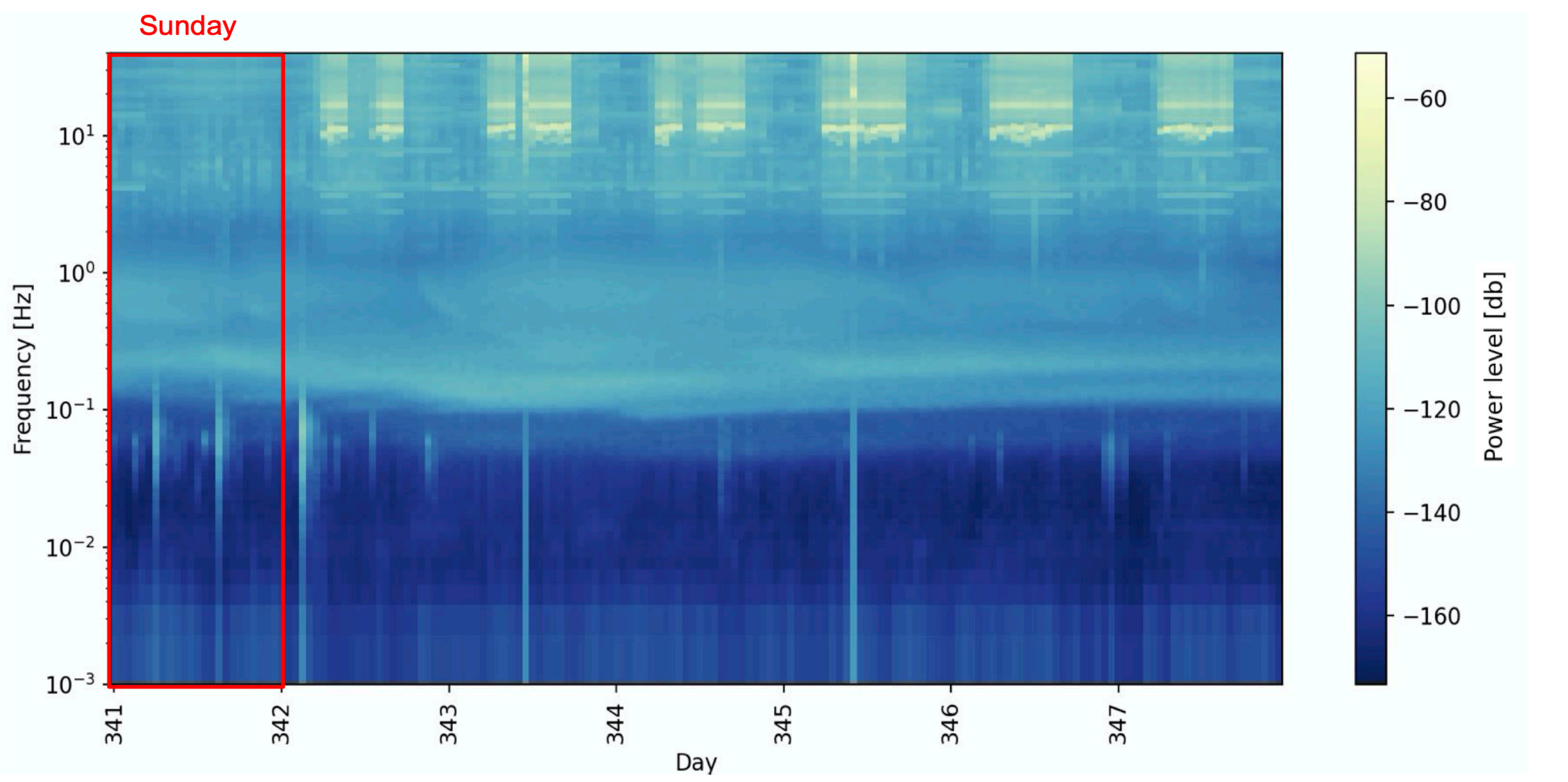

Figure 1. Vertical-component spectrogram of the week of December 7, 2014, created from 1-hour power spectral density (PSD) segments, showing high levels of urban noise during working hours. PSDs were computed using the approach described by McNamara and Buland (2004) [2].

Methods

Figure 2 and **Table 1** show the procedure and parameters, respectively, of the detection method developed for this study. This procedure was applied to the station data for the month of April 2015, using a short-term window of 0.3 s, a long-term window of 3 s, and a step interval of 0.05 s. For both time-domain and frequency-domain amplitude distributions of the data, four statistical moments (visualized in Fig. 3) were computed. For these 8 different features (4 moments x 2 domains) listed to the right, waveforms corresponding to the **50 most extreme ratios** were analyzed

	Abbreviation	
Moment	**Time Domain**	**Frequency Domain**
Mean	*Tavg* (STA/LTA)	*Favg*
Standard deviation	*Tstd*	*Fstd*
Skewness	*Tskw*	*Fskw*
Kurtosis	*Tkur*	*Fkur*

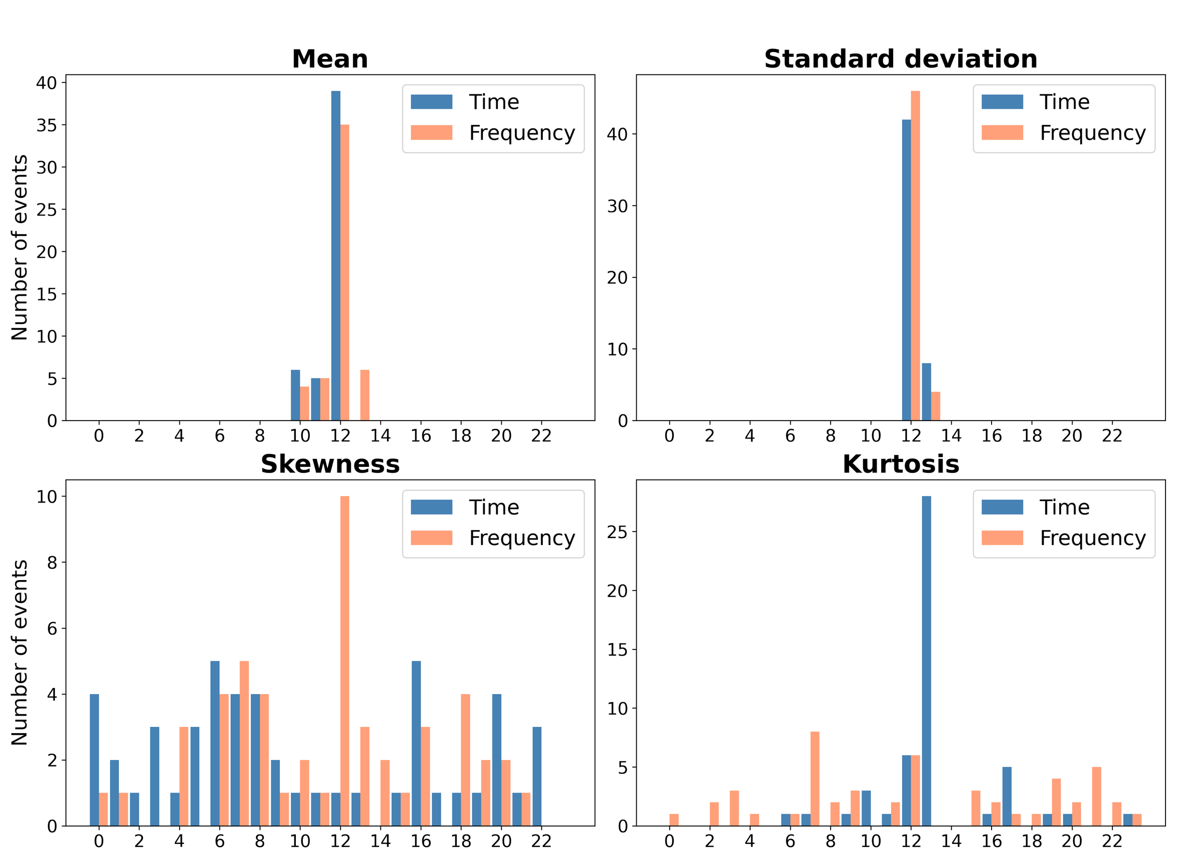

Figure 6. Hour of day occurrence for events in the 50 extreme ratios for each moment-domain implementation. Method based on the mean in the time domain (blue bars) is the same as the STA/LTA method.

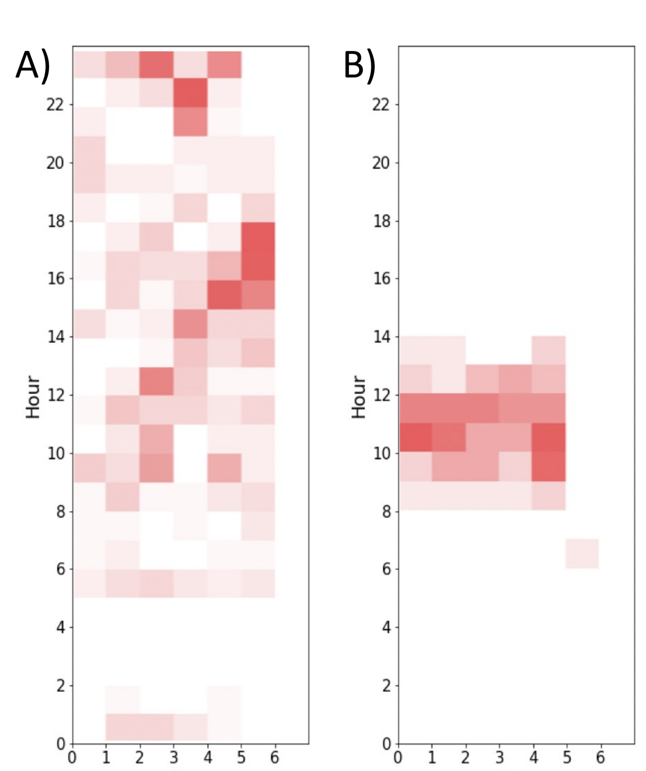

Figure 7. Temporal distribution for events detected by template matching, where a) used a wide range of events and b) only used events with high STA/LTA ratios as templates.

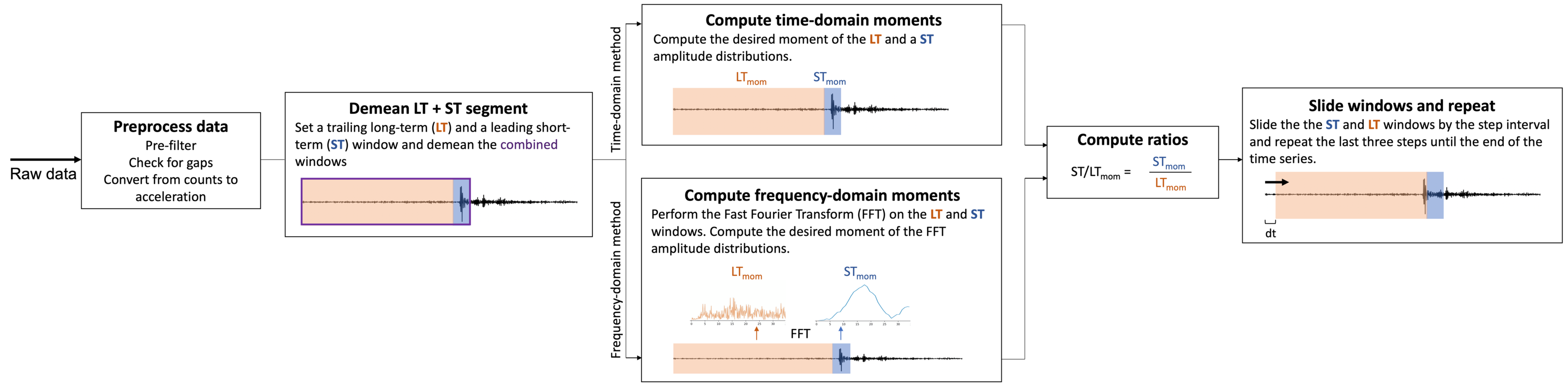

Figure 2. Flowchart of the ratio-based detection method, showing both the time-domain and the frequency-domain option for moment computation.

Table 1. Parameters for the detection method.

Name	Description
mom	Statistical moment to be computed for each window amplitude distributions
domain	Domain (time or frequency) at which statistical moments should be computed
s_ST	Time duration of Short-Term (ST) window
s_LT	Time duration of Long-Term (LT) window
dt_step	Time step to slide ST and LT windows
cutoff	Threshold ratio or percentile of total ratios to analyze

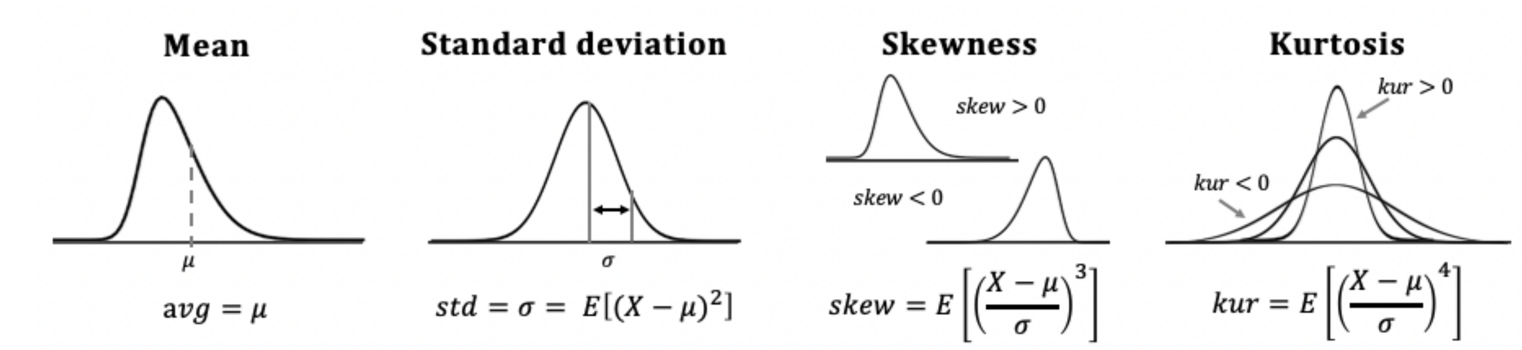

Figure 3. Visualizations and equations of the four statistical moments used in this study.

Results

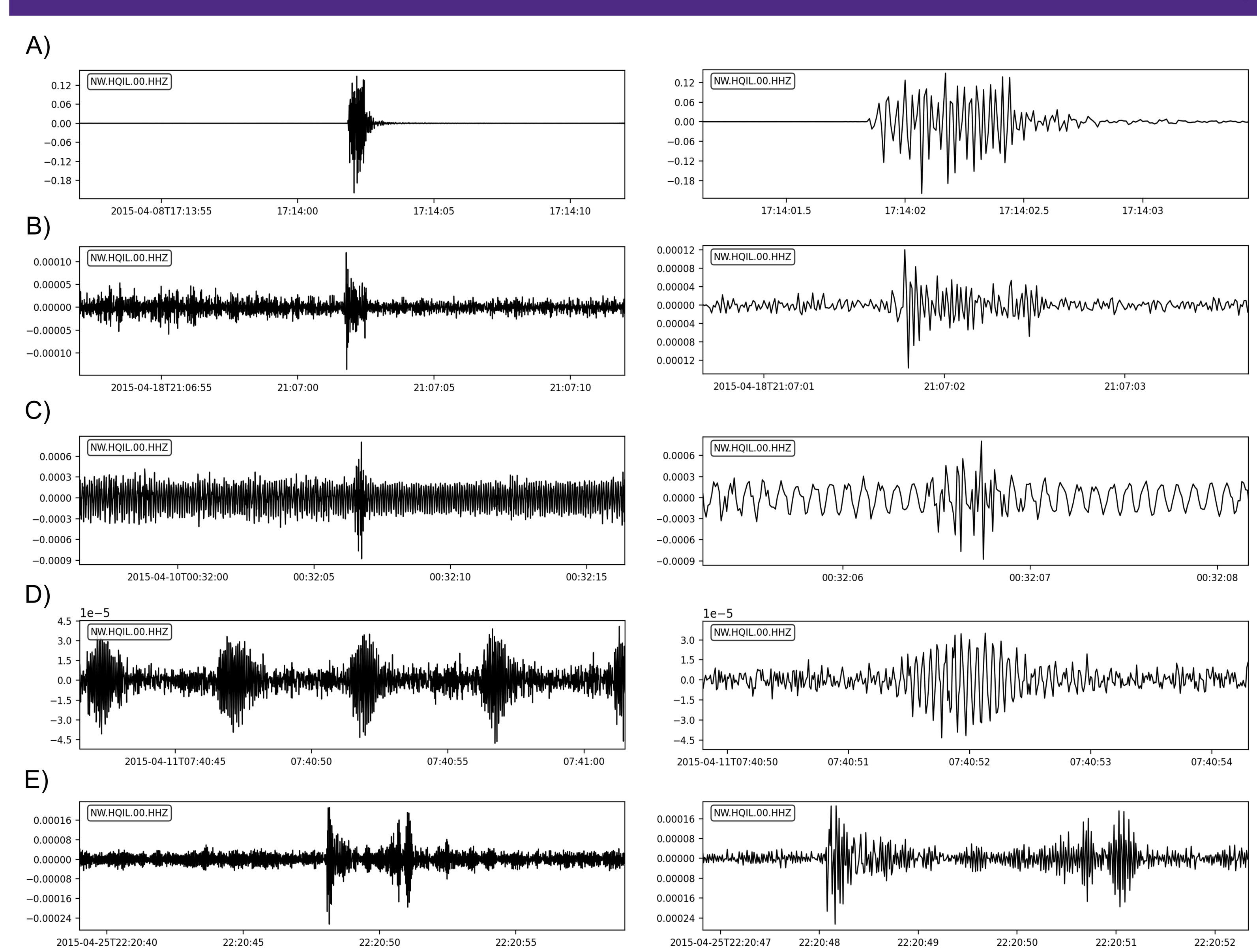

Figure 4. Events of Classes A-E, as detailed in the text to the right. Plots in the left panel are time series of 20-s duration and the right panel show their zoomed-in views. Units are in acceleration (m/s²).

- Methods based on *Tavg*, *Tstd*, *Favg*, and *Fstd* detected similar events. Events within their 50 extreme ratios were mostly local quarry blasts, that shared similar waveform features (Fig. 4A) and time of day occurrence (Fig. 6).
- Methods based of *Tskw* and *Fstw* detected events with a wider range of waveform features and time of day occurrence (Fig. 6), with some blast-like events (Fig. 4B) and some regularly-occurring noise events, which are possibly related to construction operations (Fig. 4D). Most detections in the 50 ratios, however, did not look like clear events. Further study of these events is needed.
- Methods based on *Tkur* and *Fkur*, especially the latter, were the **most successful in detecting a wide range of unique events**. These included local quarry blasts (Fig. 4A), other blast-like events (Fig. 4B), partially-hidden events in high-amplitude noise (Fig. 4C), regularly-occurring noise events (Fig. 4D), and a couple, anomalous "butterfly" events (Fig. 4E).
- When tested with a ST window of 3 s, LT window of 30 s, and step interval of 0.5 s, the method based on *Fkur* was also able to detect many events (within the 50 extreme ratios) that were operational changes ("Turning Off/On" signals, Fig. 5).

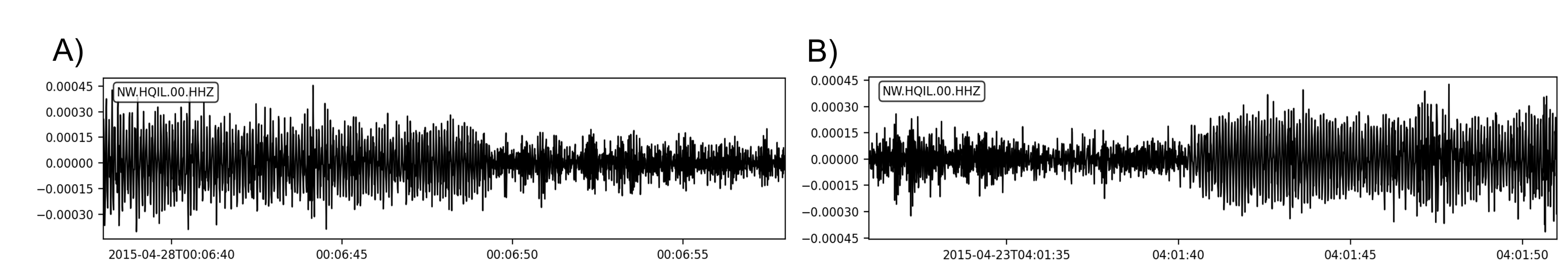

Figure 5. Examples of "Turning OFF" (A) and "Turning ON" (B) signals, as detected by the method based on kurtosis in the frequency domain. Units are in acceleration (m/s²).

Discussion

Event detection based on kurtosis in the frequency domain offers an effective means to gather a wide range of waveforms that can be used in methods like template matching and machine learning. The detection of Class C events (Fig. 4C) is especially promising because it demonstrates our potential to detect small, distinct signals, which are partially-hidden in high-amplitude noise; these events would be missed by the sole use of the STA/LTA method. Previous analyses of the same urban station data (Fig. 7) have shown the benefits of including a wide range of templates for event detection. Since data exploration and selection of templates/samples can be time-intensive, our developed ***Fkur*-based method can be used to systematically identify a wide range of unique signals, without knowing prior information about the data's frequency content**.

References

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