Towards a Systematic Search for Triggered Seismic Events in the USA

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ABSTRACT

Dynamic triggering of small earthquakes and tectonic tremor by passing surface waves from large-magnitude earthquakes may provide useful information on the background stress status and faulting processes. In this study, **we systematically search for triggered seismic events in the United States following ten teleseismic earthquakes with magnitude ≥ 7.5 during the deployment of the USArray from 2004 to 2017**. We found several triggered earthquakes and triggered tremor along the western plate boundary of North America where triggered seismic events have been reported previously. We also newly report observed triggered tremor in eastern Oregon and Yellowstone and triggered earthquakes in Colorado and Utah. To enhance our understanding of conditions needed for dynamic triggering, we apply a simple machine learning algorithm to evaluate the potential for dynamically triggered tremor and earthquakes. Our findings confirm that the source characteristics of the triggering teleseismic earthquakes as well as the stress in the triggered fault zone are two important factors in dynamic triggering.

Introduction

Surface waves of large magnitude earthquakes (e.g., Mw≥7.0) can triggered small magnitude seismic events that occur thousands of kilometers away, such as earthquakes (Mw≤3.0) and tremor (Fig. 1).

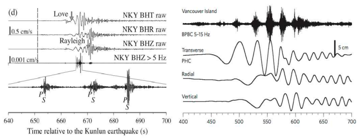

Figure 1. dynamically triggered earthquakes [*Wu et al.*, 2011] (Left panel) and triggered tremor [*Peng and Gomberg*, 2010] (Right panel) .

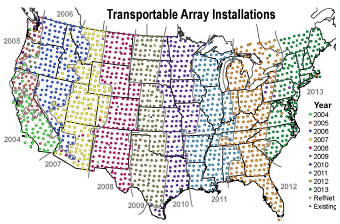

Figure 2. Map for Transportable Array Stations from 2004 to 2017. Stations are separated by approximately 70 km. Figure from www.iris.edu.

Each of the 10 selected earthquakes has been recorded by hundreds of USArray TA stations and other US seismic networks such as PB, UW, and SPREE (Wolin et al., 2015). A systematic search for dynamically triggered seismic events thus requires examining thousands of seismograms.

Two quick ways to search for triggered seismic events are using the CrazyTremor package [Chao and Yu, 2017] (Fig. 3) and computing the high-frequency signal to noise (S/N) ratio in the teleseismic surface-wave window (Fig. 4) [Chao and Obara, 2016]. To obtain a signal value, we applied a 2-8Hz band-pass (for triggered tremor) and a 5Hz high-pass filter (for triggered earthquakes) on three-component USArray seismograms.

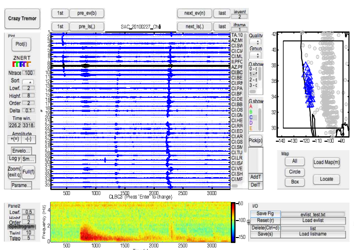

Figure 3. Snapshot of CrazyTremor, a newly developed MATLAB GUI-based Package [Chao and Yu, 2017]. The blue triangles mark ~30 USArray stations in the southern California that recorded triggered earthquakes following the 27 Feb. 2010 Mw8.8 Chile earthquake. Triggered earthquakes appeared on the 2–8 Hz band-pass filtered seismograms at ~2300 seconds. The bottom panel shows the spectrum of one selected station.

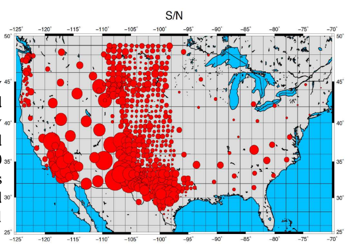

Figure 4. High-frequency signal to noise (S/N) ratios for 641 USArray stations. The observed signal (S) is measured in the Z-component surface-wave window of the 27 Feb 2010 Mw8.8 Chile earthquake.

Machine-learning Algorithm

To develop a systematic search for triggered seismic events we are looking at machine-learning algorithms. We begin by introducing a decision tree algorithm to maximize the success of a quick search for triggered seismic events. Our decision tree is trained by a data set with known instances of triggered seismic tremor from (Chao et al., 2012). The decision tree can process target parameters (attributes) and predict which combination of attribute values leads to triggering. Our simple decision tree quantifies that the most important attribute for triggered tremor is the dynamic stress from teleseismic surface waves as represented by their peak ground velocity (PGV).

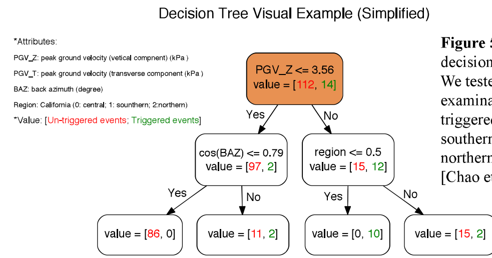

Figure 5. A simplified decision tree example. We tested with the examination results of triggered tremor in southern, central, and northern California [Chao et al., 2012].

Mw 8.6 Sumatra earthquake

With the eventual aim of developing an informed machine-run systematic search for triggered seismic events, we first interactively examined each of 1030 seismograms of the 11 Apr 2012 M8.6 Sumatra earthquake (Figures 3 and 4). First, we rejected 617 seismograms because they either showed no high-frequency energy in the surface wave window or had issues with high noise, data gaps, calibrations, or mass centerings. Next, we visually inspected the surface-wave window of the remaining 413 candidate seismograms with potentially triggered signals in multiple frequency bands. We kept 78 candidate seismograms with potentially triggered signals because they showed either distinct possible P and S arrivals from a local earthquake or potentially triggered tremor somewhat modulated by the longer-period teleseismic surface wave. ➘

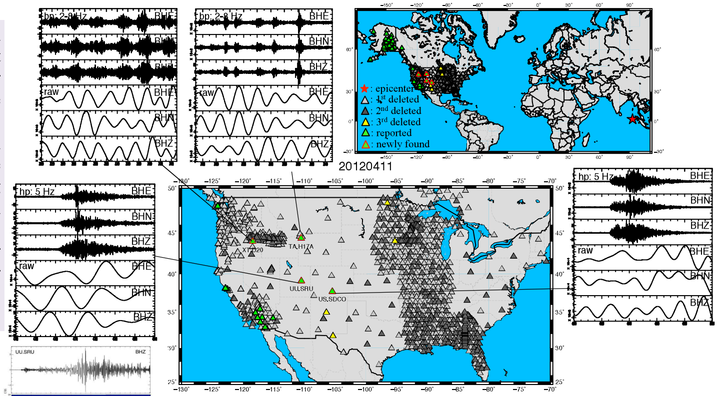

Figure 6. Sumatra earthquake and examined stations. Three-component seismogram panels show raw data (bottom) and high-passed data (top) for the newly found triggered tremor and triggered earthquakes.

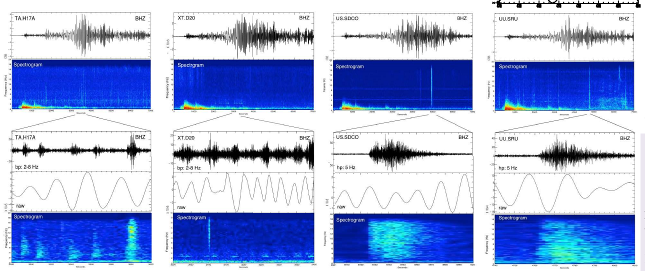

Figure 7. Spectrograms of the newly found events triggered by the 2012 Sumatra earthquake.

➘ We rejected a further four of these because the potentially triggered earthquakes had a high probability of being coincidental, judging from similar signals occurring before and after the surface wave window. Of the remaining 74 seismograms, 70 are from stations near the western plate boundary where triggered events have previously observed. **We found newly observed triggered tremor sources in the eastern Oregon and Yellowstone and triggered earthquake sources in Colorado and Utah.**

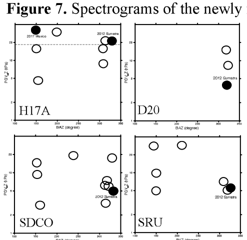

Figure 8. Triggered (black circles) and no triggered events (open circles) plotted vs. PGV stress proxy and incidence angle (BAZ, back azimuth) at four stations that recorded newly found triggered events during the M8.6 Sumatra surface waves. The dashed line indicates the decision tree's threshold above which triggering is more likely.

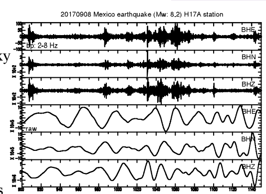

Figure 9. Triggered tremor at the same H17A (Yellowstone), but from the 8 Sep. 2017 Mw8.1 Mexico.

References

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