A New Method for Detecting Non-volcanic Tremor

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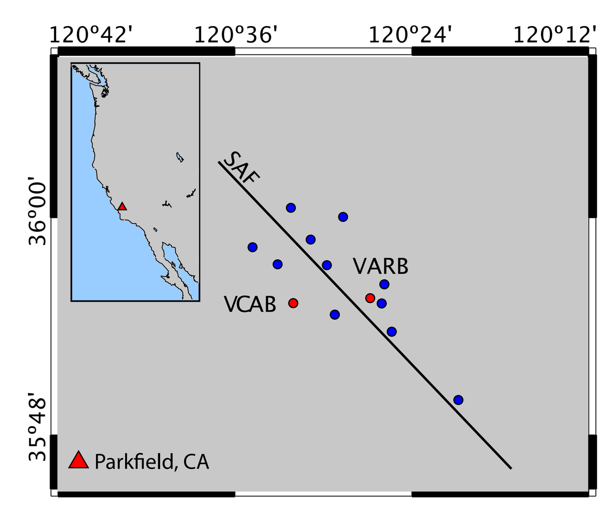
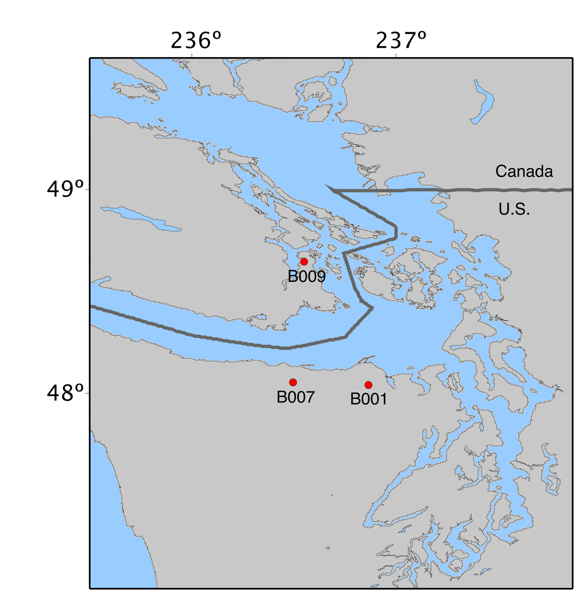
1. Introduction

Mapping the global distribution of tremor might provide valuable insight into fault mechanics and how fault slip is influenced by fluids and mineralogy. A method for detecting tremor that does not require a dense seismic array would make a global study possible. Tremor is normally characterized as an emergent signal with a relatively long duration and relatively low amplitudes. In the frequency domain much of its power is focused between 1 and 5 Hz. Due to its lower amplitude tremor is difficult to distinguish from noise, and this is often achieved by waveform stacking and cross correlation among many nearby stations (often 5 or more). Our method uses one 24 hour waveform that has been filtered multiple times at varying bandwidths between 1 and 5 Hz. We then compare the results between two stations to eliminate any remaining noise. The number of false detections and the amount of tremor detected are dependent upon the threshold and the signal quality of the station (or stations) used.

2. Data



We developed the method using 5 months of continuous waveform data from the High Resolution Seismic Network (HRSN). The horizontal components from stations VARB and VCAB were used (red filled circles).



We tested the algorithm using 3 months of continuous waveform data from the Plate Boundary Observatory Borehole Seismic Network (PBO). The vertical component from stations B001, B007, and B009 were used (red filled circles). The time chosen spans a period of high tremor activity identified using the interactive tremor map available on the Pacific Northwest Seismic Network web page.

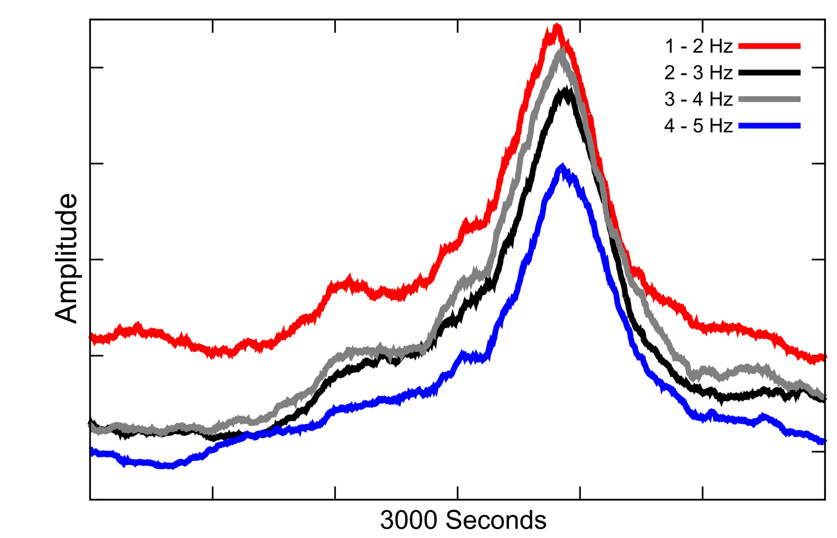
3. Method

All data is decimated to 20 Hz and we remove the trend and mean. Each 24 hour long seismogram is then filtered 1 to 2 Hz, 2 to 3 Hz, 3 to 4 Hz, and 4 to 5 Hz. These 4 filtered seismograms are analyzed as follows:

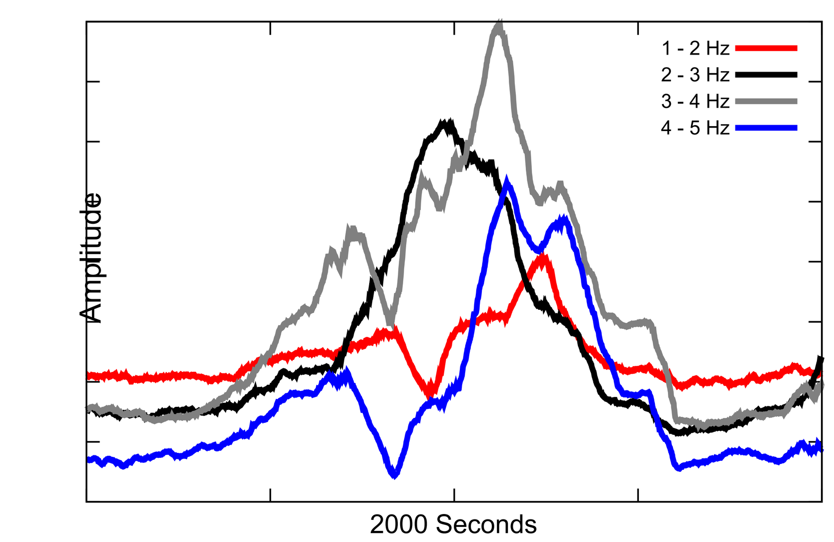
1. Calculate a running mean and running standard deviation (SD) using a 301 sample sliding boxcar window.
2. Peaks that exceed 3 times the SD are removed (earthquakes and spikes).
3. A threshold level for tremor is established using the 24 hour running mean. A new threshold is calculated for each day and each filtered seismogram.
4. Search for tremor using a 30 second sliding window. If the maximum amplitude in the 30 sec window exceeds the threshold it is flagged. The window is advanced 1 sec and the threshold check is repeated. If the duration lasts for 3 minutes or longer the time period is flagged as possible tremor.
5. The final step is to compare the results for each filtered seismogram. A time period flagged as possible tremor must be consistent between all four seismograms for it to be considered tremor.

Some false detections may remain depending on the signal quality of the station being used. Comparing two stations can eliminate the false positives, and what remains is usually an underestimation of the total amount of tremor.

4. Comparison of filtered data

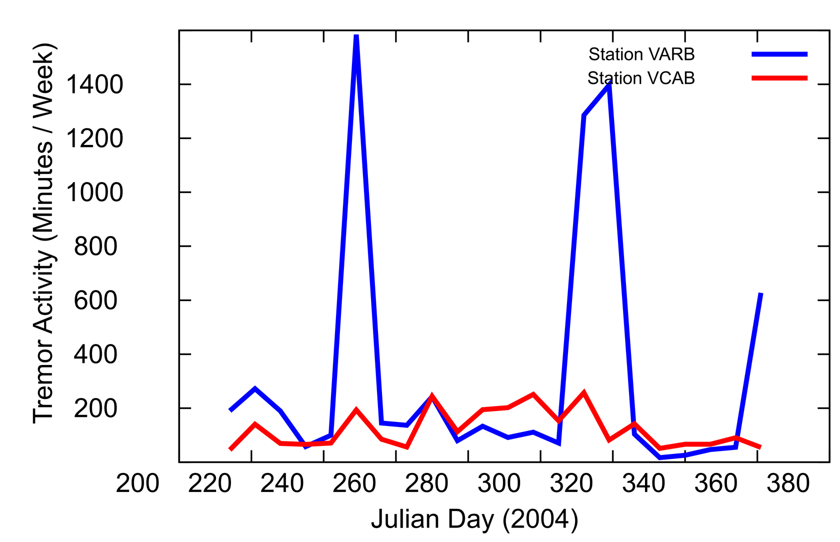


Example of tremor with a duration of approximately 3000 seconds. Each colored line represents a seismogram filtered at a different bandwidth (see legend). Tremor has similar amplitude and duration for each filtered trace.

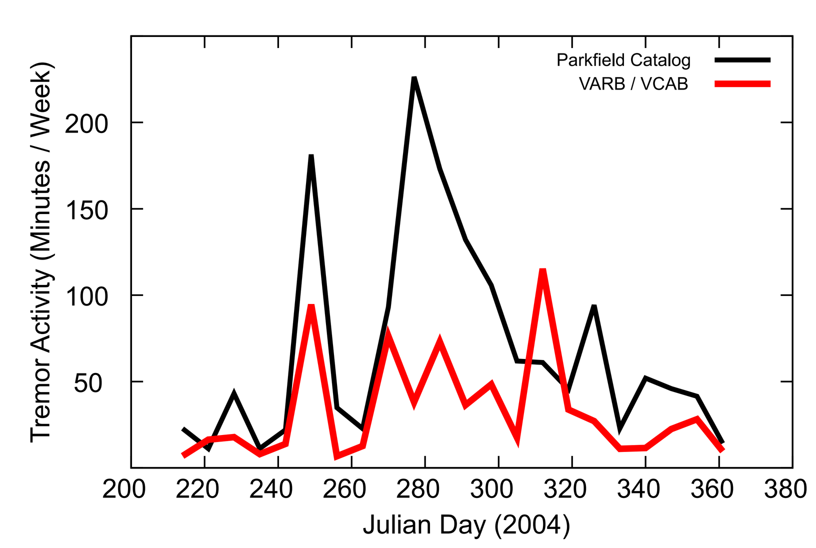


Example of noise with a duration of approximately 2000 seconds. The noise has different amplitudes and duration for each filtered trace. This will be eliminated as tremor since it is not consistent between all four seismograms.

5. Parkfield Results

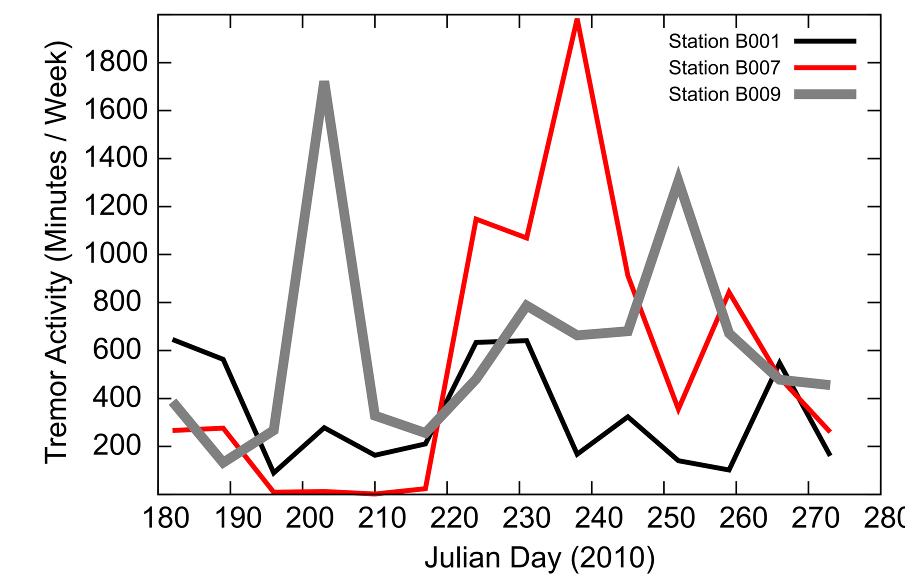


Individual results form stations VARB and VCAB. The two large peaks (blue trace, VARB) are mostly noise. Comparing the results between the two stations eliminates these false detections (see below).

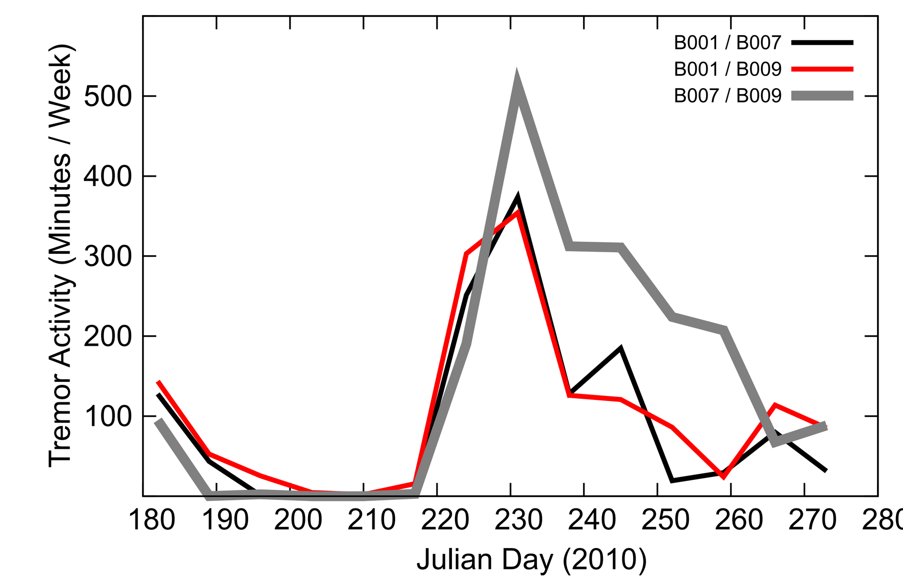


Results from a comparison between VCAB and VARB (red) and the Parkfield catalog created by Nadeau and Guilhem (2009). Our threshold was set to minimize false detections so the results underestimate the actual amount of tremor. The peak at day 312 is shorter duration tremor not listed in the catalog, most likely because of the duration.

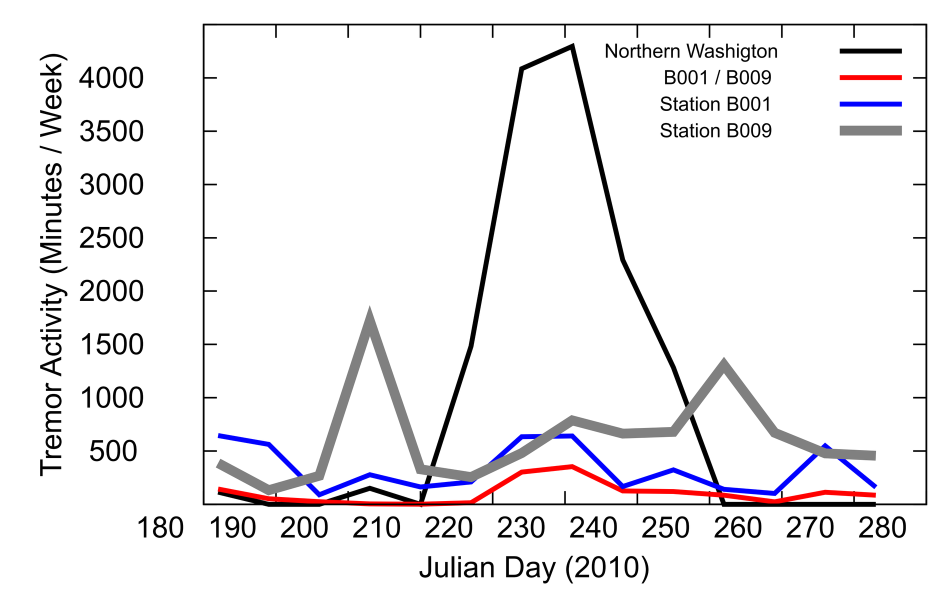
6. Northern Washington Results



Results from the 3 PBO stations prior to comparisons between stations. All three stations are similar with a some noise present in each.



Results from comparing all two station pairs. Similar results are obtained regardless of which two stations are selected.



Comparison between Northern Washington tremor catalog, two stations from the PBO, and a comparison between two PBO stations to eliminate noise. The threshold for this test was set exactly as it was for the HRSN data. Better tuning would increase detection capabilities, but the objective was to determine how well the method would work in another area with no adjustments.

Acknowledgements

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