# Amplitude Spectra Comparisons between Landslides and Earthquakes

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**Key Points:**

- The amplitude spectra of three landslides are compared to spectra from nearby earthquakes
- The landslides are able to be separated from the earthquakes through frequency content, but also vary among the landslides

## Abstract

Landslides cause substantial damage and result in casualties every year around the world. In order to provide an alert for these mass-wasting events, early warning systems for landslides often utilize ground motion sensors to detect landslides when they occur. To be effective as an early warning system, sensors must be able to differentiate between possible sources of signals. I compare the amplitude spectra of three landslides (the Montecito debris flow, Oso landslide, and Tahoma Creek debris flow) to nearby earthquakes to investigate differences in the frequency content between these two sources. The amplitude spectra of the landslides were distinct from the earthquakes, but also varied among the landslides. In particular, the maximum amplitude of the Oso landslide spectrum was concentrated between about 0.3 Hz to 2 Hz, while the frequency content for the Tahoma Creek and Montecito debris flows were greatest between 2.5 Hz to 10 Hz and 5 Hz to 10 Hz, respectively. Variation in frequency content among the landslides could be caused by many factors, including unique characteristics of the mass-wasting event or the path a wave takes to a station.

## Plain Language Summary

In order to minimize further loss and destruction from landslides, efforts have been made to develop an early warning system to alert individuals when landslides occur. The ground motion produced by landslides can be recorded on seismometers and used in the early warning system. In order to be effective, however, the system should be able to distinguish between landslides and other ground motion sources like earthquakes. I compare the frequencies in the waves from three landslides and a collection of nearby earthquakes to determine if I can separate the two sources with only this data. While the frequency content between the landslides and the earthquakes are different, there is also great variation among the three landslides. Multiple factors could affect the results, including the distance between the landslide and the seismometer recording the ground motion. Since the landslides had different characteristics from the earthquakes, the frequencies in the data can still be a valuable component of an early warning system.

## 1 Introduction

Landslides cause extreme destruction and casualties in mountainous regions around the world. The Montecito debris flow, Tahoma Creek debris flow, and Oso landslide are just three examples of damaging mass-wasting events that occurred in the last ten years in the United States (Figure 1). The Montecito debris flow occurred on 9 January 2018 and swept through the city of Montecito, California, killing at least 20 individuals and causing severe property damage (Lai et al., 2018). In contrast, the Tahoma Creek debris flow occurred in an isolated location on the southwest side of Mount Rainier in Washington on 5 August 2019 (Beason, 2019). No casualties were reported in association with the event, but the Westside Road and Tahoma Creek Trail in Mount Rainier National Park were closed to the public due to damages. The Oso landslide on 22 March 2014 followed a period of heavy rain near Oso, Washington (Wartman et al., 2016). The event quickly became a debris flow that devastated a nearby community, resulting in 43 casualties.

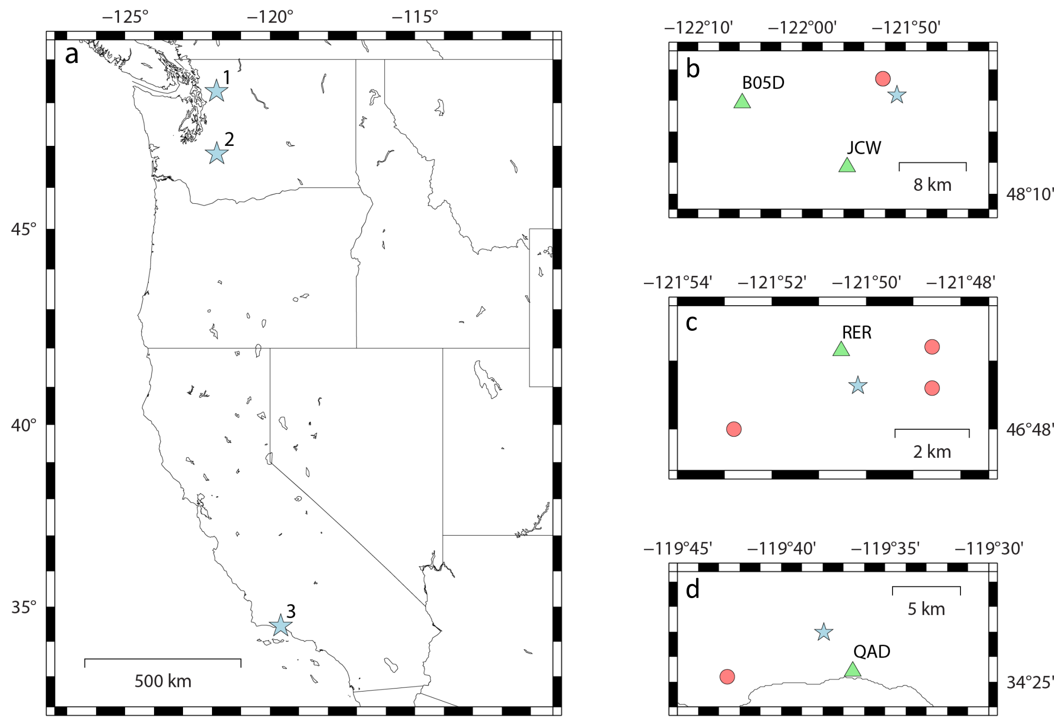



**Figure 1.** Map with locations of landslides (blue stars), earthquakes (red circles), and seismograph stations (green triangles). The station names are labeled. **a)** Map of the western coast of the United States. The star labeled 1 gives the location for the Oso landslide, the star labeled 2 gives the location for the Tahoma Creek debris flow, and the star labeled 3 gives the location for the Montecito debris flow. **b)** Area around the Oso landslide. **c)** Area around the Tahoma Creek debris flow. **d)** Area around the Montecito debris flow.

In response to the continued threat of landslides, efforts have been made to create early warning systems for locations particularly prone to these mass-wasting events. Ground vibration sensors such as geophones, velocimeters, and accelerometers are often utilized in early warning systems as these instruments are able to be installed away from potentially hazardous locations and are able to detect the event before it reaches the instrument (Arattano & Marchi, 2008; Burtin et al., 2009; Coviello et al., 2019). In order to be effective for early warning, signals from landslides must be distinct from other sources. I compared the amplitude spectra of the Montecito debris flow, Tahoma Creek debris flow, and Oso landslide to the amplitude spectra of nearby earthquakes to investigate potential distinguishing characteristics between these sources.

## 2 Methods and Data

I acquired earthquake and landslide seismic recordings from the Incorporated Research Institutions for Seismology (IRIS) through ObsPy. The Montecito debris flow was recorded on station QAD in southern California. Station RER was the closest seismometer to the Tahoma Creek debris flow in Mount Rainier National Park in Washington. The two closest stations to the Oso landslide were JCW and B05D. QAD, RER, and JCW are all short-period seismometers with a sampling rate of 100 Hz. Seismic data was obtained from channel EHZ for the three short-period stations. B05D was a part of the USArray Transportable Array and was a broadband seismometer with a sampling rate of 40 Hz. I retrieved seismic recordings from channel BHZ for station B05D. Station information is provided in Table 1.

| Station | Network | Channel | Location | Type | Sampling Rate |
|---|---|---|---|---|---|
| QAD | CI | EHZ | 34.424°N, -119.609°E | Short-period | 100 Hz |
| RER | UW | EHZ | 46.819°N, -121.842°E | Short-period | 100 Hz |
| B05D | TA | BHZ | 48.264°N, -122.096°E | Broadband | 40 Hz |
| JCW | UW | EHZ | 48.195°N, -121.927°E | Short-period | 100 Hz |

**Table 1.** Information for the seismograph stations used in this study. Locations are plotted in Figure 1.

I searched through the IRIS database to find earthquakes that occurred geographically close to each landslide in order to compare the two sources. Table 2 provides information for the earthquakes.

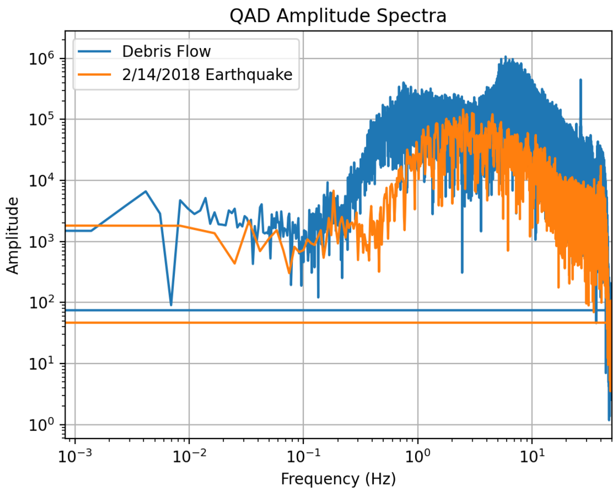
| Date | Time (UTC) | Location | Magnitude | Depth (km) | Station |
|---|---|---|---|---|---|
| 2/14/2018 | 14:58:59 | 34.42°N, -119.71°E | 2.43 $M_L$ | 10.74 | QAD |
| 2/11/2018 | 19:16:57 | 46.81°N, -121.81°E | 0.47 $M_L$ | 2.04 | RER |
| 5/20/2020 | 11:35:37 | 46.82°N, -121.81°E | 0.45 $M_L$ | 3.59 | RER |
| 8/17/2018 | 01:28:39 | 46.80°N, -121.88°E | 0.51 $M_L$ | 8.76 | RER |
| 9/23/2015 | 01:05:26 | 48.29°N, -121.87°E | 1.2 $M_L$ | 10.16 | B05D, JCW |
| 4/5/2015 | 01:19:12 | 48.29°N, -121.87°E | 2.5 $M_L$ | 5.7 | B05D, JCW |

**Table 2.** Information for the earthquakes used in this study. Earthquakes recorded on station QAD were located near Montecito, California, earthquakes recorded on RER were near Tahoma Creek in Washington, and earthquakes recorded on B05D and JCW were near Oso, Washington. Locations are plotted in Figure 1.

After acquiring the full waveforms for each landslide and earthquake, I used the Python library NumPy to calculate the amplitude spectra for each event.

## 3 Results

The amplitude spectrum of each landslide was plotted with the amplitude spectra of the nearby earthquakes. In general, there are significant amounts of variance in each spectra, but trends can be identified in the data. Figure 2 shows the spectrum of the Montecito debris flow as recorded at station QAD. The debris flow has more high frequency data than the earthquake. In particular, there appears to be a peak in the debris flow spectrum between about 5 Hz and 10 Hz that isn’t present in the earthquake spectrum. The earthquake instead has a gradual increase in amplitude up to about 2.5 Hz, and then starts to decrease.



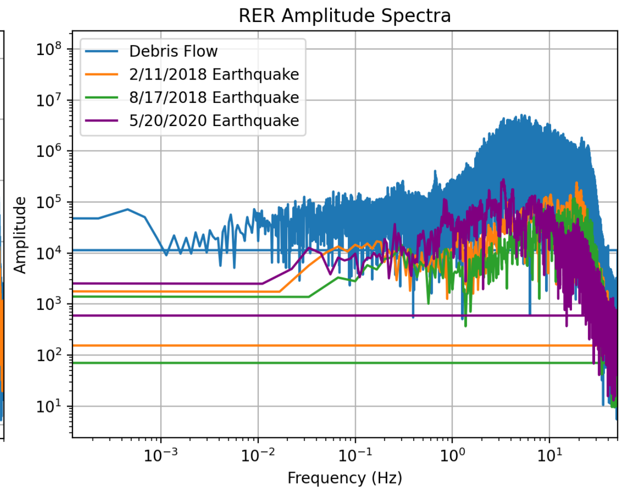




**Figure 2 (left).** Amplitude spectra from station QAD. The blue spectrum is from the Montecito debris flow and the orange spectrum is from a nearby earthquake.
**Figure 3 (right).** Amplitude spectra from station RER. The blue spectrum is from the Tahoma Creek debris flow. The orange, green, and purple spectra are from nearby earthquakes.

The spectra of the Tahoma Creek debris flow and three nearby earthquakes are shown in Figure 3. The debris flow appears to primarily contain frequencies between roughly 2.5 Hz and 10 Hz where there is a broad peak. Two of the earthquakes peak at a much higher frequency, about 20 Hz, while the third earthquake has a relatively flat spectrum on average with a maximum at about 3 Hz.

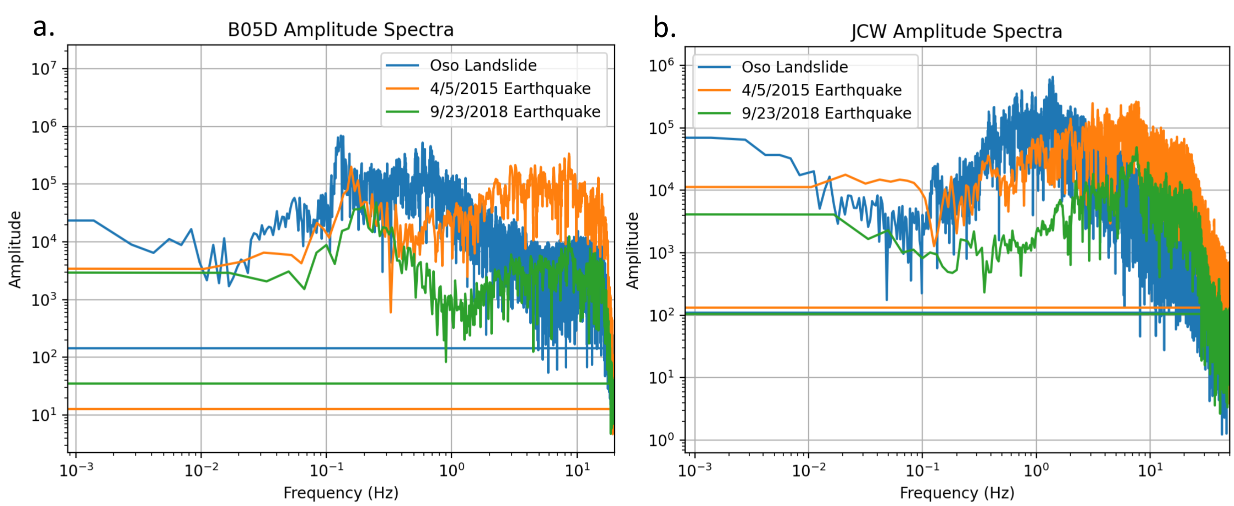



**Figure 4.** Amplitude spectra from the Oso landslide (blue spectrum) and nearby earthquakes (green and orange spectra). **a)** Amplitude spectra from the station B05D. **b)** Amplitude spectra from the station JCW.

Figure 4 contains the amplitude spectra of the Oso landslide at stations JCW and B05D.

The spectrum at B05D has more low frequency content than the spectrum at JCW. This variation is best exhibited by the peak at roughly 0.1 Hz. Both spectra have a peak at this frequency, but it is overshadowed by a gradual increase in amplitude to a broad peak between about 0.3 Hz to 2 Hz in the JCW spectrum. In the data from B05D, the maximum amplitude is obtained at the 0.1 Hz peak. The spectra of the earthquakes at each station are similar in shape, though at different amplitudes. The earthquake spectra has two peaks in seismic data from B05D, a narrower peak at around 1.5 Hz and a broader peak at roughly 7 Hz. The data from JCW only clearly shows a gradual amplitude increase up to the 7 Hz peak.

## 4 Discussion

In general, the amplitude spectra of the landslides analyzed in this study are distinct from nearby earthquakes, but there is not enough information to identify an aspect of the frequency content that would separate the landslides from the earthquakes with only the spectra. In particular, there is a substantial difference between the amplitude spectrum of the Oso landslide and the other two mass-wasting events. Both the Montecito and Tahoma Creek debris flows reach a maximum amplitude at relatively high frequencies, though they exhibit different amplitude peaks. The Oso landslide spectrum, however, peaks between 0.3 Hz and 2 Hz.

The variations in frequency content among the landslides could be caused by many factors. For example, the Oso landslide originated as primarily solid flow that transitioned into a debris flow over time (Wartman et al., 2016). Differences in composition could account for some of the variation among the landslides. Additionally, JCW, the closest seismometer to the Oso landslide, was roughly 10 km away. This is a significantly greater distance than the seismic waves traversed from the Tahoma Creek and Montecito debris flows to their closest stations. High-frequency waves attenuate faster than low-frequency waves, which may help explain why the Oso landslide amplitude spectrum had so little high-frequency content compared to the other landslides. It is also entirely possible that individual landslides have distinct frequency characteristics that are not easily generalized.

While the three landslide amplitude spectra used in this study did not provide a diagnostic characteristic that would enable an early warning system to separate the landslides from the earthquakes, the amplitude spectra does provide valuable information. The frequency content of the landslides are noticeably different from neighboring earthquakes. Further investigation with tapering, filtering, or data from other channels and stations could provide better insight into the amplitude spectra of the landslides.

## Acknowledgments

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