COMPARING INEXPENSIVE RASPBERRY SHAKES TO BROADBAND SEISMOGRAMS IN ESTIMATING DEEP EARTH STRUCTURE THROUGH THE USE OF RECEIVER FUNCTIONS

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INTRODUCTION

An inexpensive, three-component Raspberry Shake and a research-grade broadband seismometer were compared in performance via receiver function analysis. The seismometers were located 33 km apart in the Black Hills (fig. 1). A crust-mantle boundary depth (Moho) was calculated for both seismometers. The Raspberry Shake was found to be accurate in predicting similar interpretations as the broadband seismometer, implying that the Raspberry Shake may have potential to be used in more advanced scientific research.

METHODS

Thirty four seismic events with the parameters of magnitude >5.5 and distance 30° to 90° from the seismic stations were recorded from the deployment of the Raspberry Shake (fig. 2, December 9th, 2021) until February 28th 2022. One earthquake occurring on February 03rd, 2022 in northern Peru provided sufficient data from both the Raspberry Shake and broadband seismometer.

Raw data were processed using Seismic Analysis Code (Goldstein, 2003 and Goldstein, 2005), removing the instrument response for each component of both seismometers via several steps:

- applied bandpass filter of 0.1 to 8.0 Hz.
- removed the mean and trend.
- tapered the ends of the waveforms.
- rotated horizontal to a radial and tangential waveform in the earthquake reference frame.
- applied iterative, time-domain deconvolution (Ligorría and Ammon, 1999) to radial and vertical waveforms.
- applied three Gaussian filters to remove high-frequency noise.

Important considerations in interpreting receiver functions:

- positive spike shows increase in velocity with depth; negative spike implies decrease (fig. 3).
- magnitude of the amplitude of the spike contrast to the magnitude of the velocity contrast.
- materials making up the crust and mantle layers are very different in velocity, resulting in a large, positive amplitude spike at this boundary.
- time delay of the spike is used to calculate depth at which velocity change occurs.
- general rule of thumb, one second translates to about 8 km of depth.
- crust-mantle boundary averages 30 to 50 km in depth for the Black Hills—should produce large amplitude spikes about between 4 and 6 seconds.

RESULTS

Below are the raw waveforms, processed radial and tangential waveforms, and receiver functions.

The event shown was a 6.5 magnitude earthquake at a distance of 74.1 km, occurring on February 03rd, 2022 in northern Peru (Crotwell and Owens, 2005 and Trabant et al., 2012).

MOHO DEPTH FORWARD MODEL

The Mohorovicic discontinuity (Moho, the crust and mantle boundary), produces a positive waveform spike due to changing from a higher velocity mantle to a lower velocity crust (velocity increase with depth). The general equation used to forward model this depth (Zhu and Kanamori, 2000) is:

\[ h = \frac{1}{2} \times \frac{1}{V_s^2} \times \frac{1}{V_p^2} \times \frac{t_{ps}^2}{t_{pp}^2} \]

The crust-mantle boundary was calculated for both seismometers via this equation, giving a depth of 47.9 km beneath the Raspberry Shake and 50.8 km beneath the RDSI.

DISCUSSION

The waveforms in figures 4.3 and 6, & 9, collectively suggest that a Raspberry Shake can provide similar results as that of a high grade, advanced seismometer.

The earthquake can clearly be seen in both seismometer records (fig. 4). Because the earth structure below each station is different, the horizontal signals are not expected to be similar, while the vertical signals are not affected by the subsurface earth structure as much, resulting in little difference between the two station recordings. This is due to the receiver function method, in which the source is on the vertical and the earth response, or conversions, are seen on the horizontals (figs. 5 & 7).

The large amplitude spikes at 5.6 seconds at the broadband and 5.2 seconds at the Raspberry Shake, in the receiver functions, are interpreted as the Moho boundary (figs. 6 & 8). This spike is observed in both the Raspberry Shake and broadband seismometers. These arrival times were used to calculate the crustal thicknesses of 47.9 and 50.6 km for the Raspberry Shake and broadband, respectively.

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There exist to many people Ward, who proposed the research, taught me everything I know about seismology thus far, and has been a consistently encouraging, patient, and inspiring mentor. We also would like to thank the Sanford Underground Research Facility (SURF) for allowing us to use their space to deploy our Raspberry Shake seismometer (www.sanfordlab.org.)

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CONCLUSIONS

This novel and exciting research suggests that Raspberry Shakes have strong potential as instruments capable of more advanced research in the geosciences. However, more work is needed to statistically and robustly confirm the findings presented here. It is suggested that the following parameters are investigated, which include:

- co-locating the Raspberry Shakes with broadband stations
- changing the study area to a more complex region
- adding more events to the Raspberry Shake analysis

The values are in the acceptable range for the average crustal thickness. However, the thicknesses are difficult to calculate those from a HK stack of events for the broadband station (fig. 9). This is because our results are from a single event, whereas the HK stack solutions include >200 events. Presumably, the HK solutions are more robust measurements. However, HK stack solutions still show a bimodal distribution of Moho depths.