Assessing OSOP Raspberry Shake and Boom sensors for recording African Elephant acoustic vocalisations

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ABSTRACT

In this work we assess the performance of the low-cost Raspberry Shake and Boom sensor package for detecting and monitoring African elephants (*Loxodonta africana*). This is the first documented test of this particular sensor package for recording animal behaviour; the unit was originally designed for detecting tectonic earthquakes and low frequency (<50 Hz) atmospheric acoustics. During a four day deployment in October 2019 in South Africa, we used five Raspberry Shake and Boom units to record acoustic and seismic vocalisations generated by a group of African elephants. Our results highlight a varied degree of success for the RS&B units in detecting the signals of interest. The acoustic microphone recorded intricate details of low-frequency (<50 Hz) vocalisations that were not clearly recorded by more sensitive instruments, but was not able to record higher frequencies due to the low sampling rate (100 Hz). The geophone was not able to consistently record clear seismic waves generated by vocalisations, but was able to record footsteps within a 50 m range. We discuss future directions and deployment strategies to improve the sensitivity of the sensor package. Nevertheless, we conclude that the RS&B unit shows great promise as a low-cost tool for monitoring African elephants.

KEYWORDS

Wildlife monitoring; Loxodonta africana; Low-cost sensor; Seismic; Acoustic;

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1. Introduction

Acoustics are an important component of many habitats and in-situ sound recordings offer potentially rich information about the abundance, distribution, and behaviour of vocalizing animals in the target area. Cost-effective and scalable acoustic sensors are therefore being increasingly used in ecological research and conservation efforts for monitoring animals (Blumstein et al. 2011; Browning et al. 2017). Results from these studies are providing new insights into animal acoustic signal features (e.g. Stoeger and Baotic 2016), communication processes within social groups (e.g. Poole et al. 1988), seasonal variability in acoustic behaviors, and spatio-temporal variability of acoustic habitats in which the animals reside (e.g. Thompson et al. 2009a). Acoustic techniques allow researchers to survey wild populations at ecologically meaningful scales without intruding on animal activity and causing unintended stress (Blumstein et al. 2011).

African elephants (*Loxodonta africana* and *Loxodonta cyclotis*) are the largest terrestrial herbivores and have been documented to make extensive use of strong low-frequency acoustic vocalisations commonly referred to as ‘rumbles’ (Poole et al. 1988; Langbauer Jr. 2000; Soltis 2009). Elephants have also demonstrated an ability to respond to seismic waves generated by the acoustic waves from ‘rumbles’ coupling with the ground as well as those generated by high-force locomotion behaviors such as stomping or rapid running (O’Connell-Rodwell 2007; Mortimer et al. 2018). This ability may provide elephants a means for long-range communication at distances up to and over 3 km (Garstang 2004; Mortimer et al. 2018). In addition, it has been demonstrated that the calling rate of ‘rumbles’ is a useful index of elephant abundance, as well as for detecting other vocal species and anthropogenic noises that may be associated with poaching (Payne et al. 2003; Thompson et al. 2009a,b). Presently, elephants remain under multiple threats including poaching, habitat loss, and human-elephant conflict where elephants destroy crops, damage buildings, and can occasionally kill people (Douglas-Hamilton 2008; Zeppelzauer et al. 2015). Acoustic and seismic recording devices offer a means for installing non-intrusive monitoring systems that can autonomously detect elephants and monitor their location, including real-time alarm systems for elephants approaching human settlements or sensitive food supplies (e.g. Zeppelzauer et al. 2015).

The choice of which instrumentation to purchase and deploy in a field study is fraught with trade-offs. Size, power demands, data format and storage, ease of deployment, sensor performance and costs (for purchase and deployment) must all be taken into consideration. Of these, performance of the sensor in recording acoustic and/or seismic waves across a broad range of frequencies may the most difficult to assess. In recent years, seismologists have begun exploring the use of low-cost, rapidly deployable sensor packages in temporary seismic deployments (e.g. Anthony et al. 2019). This includes recently developed low-cost seismic and acoustic sensor packages such as the Raspberry Shake and Boom (RS&B) that are designed as a plug-and-play solution. The device, and similar variations of the device, are becoming increasingly popular, mainly for home use, educational purposes, and outreach. However, the potential for using the RS&B device for ecological purposes is still unexplored. Here we present the first results of a pilot test performed in South Africa to record African elephant vocalisations and locomotions using multiple RS&B devices. In the following sections we provide a more detailed technical description of the device, describe our data acquisition set-up, and provide details on and discuss the performance of the RS&B.

2. Materials and Methods

2.1. The Raspberry Shake and Boom sensor

The RS&B is an all-in-one plug-and-go sensor package designed for seismological and atmospheric acoustic applications developed by OSOP, S.A. in Panama (Fig. 1A). The unit integrates vertical geophone and omni-directional pressure sensors together with a 24-bit digitizer, period-extension circuits, and Raspberry Pi 3 Model B computer into a single enclosure with dimensions of 135x110x70 mm. The power supply is 5 Volts DC (2.5 A) and consumption is estimated as 3.1 W at start-up and 1.9 W during running time. Data is recorded at sampling rates of up to 100 Hz and are saved on a local SD card (8 Gb, but larger cards can be installed if needed) with an estimated data amount per channel of $\sim$15 Mb/day. By default, time synchronisation is based on Network Time Protocol, but a USB GPS module can be connected for situations where an internet connection is not available. Further technical details on the RS&B sensor and other similar units are available at the following website: https://raspberryshake.org/(last accessed 08 April 2020). Other units similar to RS&B developed by OSOP, S.A. include that with a single vertical geophone

(Raspberry Shake 1D), three orthogonal geophones (Raspberry Shake 3D), 1 vertical geophone with 3 orthogonal MEMs accelerometers (Raspberry Shake 4D), and a single pressure sensor (Raspberry Boom). So far, two studies have evaluated the performances of the above sensors for monitoring environmental seismology. Raspberry Shake 1Ds were successful in recording and discriminating rockfall activity above a glacier in the Swiss Alps, demonstrating their potential for use in scientific investigations (Manconi et al. 2018). Raspberry Shake sensors were also used to estimate local magnitudes for earthquakes recorded in Oklahoma, USA, and were found to be suitable for the characterisation of local and regional seismicity (Anthony et al. 2019). Both studies concluded that the relatively low cost of the units make them a realistic candidate for complementing existing seismic networks or for deployment in locations unfeasible for other sensors.

2.2. Experimental set-up

Seismic and acoustic recordings were collected from three female, two male, and two juvenile African elephants aged between 3 and 23 years located at Adventures with Elephants, Bela Bela, South Africa (http://adventureswithelephants.com; last accessed 08 April 2020). The elephants were fully habituated to human presence and free to roam around in a 300 ha savannah reserve. This location was chosen for our study as it enables us to capture data in controlled settings within the natural habitat of African elephants. Vocalisations were recorded during two social contexts: spatial separation and subsequent bondings (henceforth referred to as ‘reunions’; Fig. 1B). Over the course of 4 days, six reunions were recorded at distances <50 m to ~ 2 km to the installed RS&B sensors.

In this situation, we installed a local network composed of 5 RS&B sensors, each with a solar panel and battery to allow continuous recording during the course of the experiment. Internet was not available at the deployment locations so the sensors were configured to store data locally to be downloaded during their recovery at the end of the test. To power the sensor, each unit was deployed with a car battery along with a 60 W solar panel. The standard RS&B enclosure is made of 5mm thick plastic plates and not suitable for outdoor use, therefore each sensor was placed within a sealable plastic box that was itself buried up to 30 cm into the ground. As the acoustic sensor relies on direct measurement of the atmosphere, we included a hollow rubber tube of up to 1 m length to allow the recording of acoustics outside the plastic box; the tube itself was capped with a porous plastic container designed to reduce wind noise. For comparison purposes, we also installed several stations with more costly but more sensitive sensors. This includes a Lennartz vertical component seismometer (LE-1DV MkIII), InfraBSU infrasound logger (V2; Marcillo et al. 2012), and Chaparral infrasound sensors (Model 60). Data from these sensors were recorded at sampling rates of 400 Hz on DiGOS DATA-CUBE[3] data recorders (type 2). Data recorded by all sensors were recorded as or converted to MiniSEED format and visualised using the ObsPy python package (Beyreuther et al. 2010). All seismic and acoustic data was analysed visually to find and study signals of interest.

3. Results

3.1. Acoustic

Acoustic data recorded by three stations during a reunion event are plotted in Fig. 2 and serves to highlight the general performance of RS&B units for recording acoustics during the sensor test. In ideal conditions, the RS&B was able to record complex vocalisations at low (<50 Hz) frequencies (Fig. 2A). These low frequency vocalisations were often not clearly recorded by more sensitive acoustic microphones such as the InfraBSU (Fig. 2B). However, due to the low sampling rate of the RS&B unit (100 Hz) it was not able to record any vocalisations at frequencies >50 Hz. These higher frequency vocalisations are clearly seen in the acoustics recorded at higher sampling rates with the DATA-CUBE data recorder (Fig. 2B). In addition, it is clear that the RS&B has a limited range in detecting clear vocalisations as signals were lost to background noise at distances >400 m (Fig. 2C).

3.2. Seismic

Seismic data recorded by three stations during a reunion event are plotted in Fig. 3 and serves to highlight the general performance of RS&B units for recording seismics during the sensor test. Generally, the geophone in the RS&B unit was able to capture faint signals of interest related to elephant vocalisations and only at short distances (≤100 m; Fig. 3A, C). More sensitive instruments such as the Lennartz seismometer were able to capture broadband signals of interest up to 200 Hz; these signals are likely related to acoustic waves coupling with the ground to generate seismic signals (Fig. 3B). Close inspection of the seismic record reveals that the RS&B unit was successful in recording seismicity generated by locomotion activity by individual animals at distances <50 m from the sensor (Fig. 4).

3.3. Noise

Noise from anthropogenic and natural sources were prevalent throughout the seismic and acoustic data recorded by the RS&B sensors during the test (Fig. 5). Seismicity from blasting activity at mines in the region around the testing location would dominate the seismic record (Fig. 5A). Acoustic noise from light aircraft and/or helicopters flying over the site would also be clearly seen in frequency spectrograms as they can be recognized by the apparent doppler effect (Fig. 5B). Other sources of anthropogenic noise possibly seen in the seismic and acoustic record include those from land vehicles moving past the sensor plus their engines, and humans walking close to the sensor. The largest source of noise during the test was introduced by wind blowing across the site. Wind introduces broadband frequencies that can obscure signals of interest for periods of time lasting up to several hours (Fig. 5C).

4. Discussion

The overall goal of this test was to assess the viability of a low-cost off-the-shelf sensor package for detecting and monitoring African Elephants. The RS&B unit was designed for detecting tectonic earthquakes as well as recording atmospheric acoustics waves at infrasonic frequencies. However, as we demonstrate here, the unit may be a viable option for recording acoustic vocalisations or ‘rumbles’ (Fig. 2A), and for detecting seismics generated by locomotion activity from nearby elephants (Fig. 4). Here we discuss and draw conclusions from the performed test and summarise future directions in the context of African elephant detection and monitoring.

Comparisons between atmospheric acoustics recorded by the RS&B unit and other more sensitive sensors indicate that the former may provide information that the latter cannot (Section 3.1). In particular, complex details of low-frequency (<50 Hz) ‘rumble’ vocalisations during a reunion event were more clearly recorded by the RS&B sensor while these details were obscured or not detected by the more sensitive microphone

(Fig. 2A, B). It's likely that low frequency acoustics were obscured at the more sensitive sensor as they were not deployed with a device to reduce wind noise, unlike the RS&B unit. Nevertheless, these low-frequency details may be advantageous as such vocalisations could be used to distinguish individual animals by age and size (Stoeger and Baotic 2016). However, the sensors would likely have to be located relatively close to the individual animals (<400 m; Fig. 2C) in order to clearly capture clear and usable acoustic data. Therefore, the RS&B (or it's variation, the Raspberry Boom) would only be viable for deployment in locations where African elephants are known to congregate (e.g. waterholes, subsistence crops, high value tree species).

In contrast to the acoustic microphone, the geophone sensor inside the RS&B unit was not able to consistently and clearly record seismic activity generated by'rumbles' during the reunions (Fig. 3). Inspection of seismic data recorded at higher sampling rates (Fig. 3B) suggests that the geophone could have had greater success if the sampling rate was higher than 100 Hz. Nevertheless, the RS&B unit was successful in recording seismicity generated by locomotion activity from elephants as they moved within <50 m of the unit deployment location (Fig. 4). Footsteps were not clearly seen in the seismic record at greater distances which is contrary to previous studies that suggested detection ranges of up to 3.6 km (e.g. Mortimer et al. 2018). The apparent low seismic sensitivity may be due the design of the sensor deployment (i.e. the unit was placed inside the sealable plastic case, itself buried up to 30 cm depth) that may have reduced the geophone sensitivity. Tests on other derivations of this sensor unit ensured proper ground-coupling by screwing the sensor unit directly to the rock face using bolt anchors (Manconi et al. 2018). For future, long-term (i.e. months to years) monitoring of elephants using the RS&B unit, it is recommended that a similar anchoring strategy is adopted, if possible. Nevertheless, despite the low sensitivity of the geophone in the unit, it was still successful in recording seismicity thought to be generated by blasting activity from mines in the region (Fig. 5A). There has been some interest in the effects of anthropogenic activity on elephant behaviour (e.g. from oil prospecting; Wrege et al. 2010). Our observations here suggest that the RS&B unit would be useful for future studies on animal behaviour in regions where they may be affected by mining or oil activity.

Future deployments with the RS&B unit must take into account that noise from wind or human activity is likely to be recorded (Fig. 5). Therefore, strategies to reduce wind noise around the acoustic sensor must be incorporated into the deployment design. Furthermore, the power demands of the unit reduces the potential for using it in remote locations where power may not be readily provided. Our stations were powered by large car batteries that were themselves charged by 60 W solar panels; this design would not be feasible for studies of African forest elephants (*Loxodonta cyclotis*) as the forest habitat would not allow enough daily sunshine to keep the station powered. Furthermore, all the signals described in this study have been interpreted visually from data recorded at individual stations. Future work will be aimed at implementing an algorithm for automatically detecting and classifying seismic and acoustic events (e.g. Zeppelzauer et al. 2015), as well as developing a deployment strategy that would allow automatic location and tracking of animals. Such a system can form the basis for a future automated early warning system for elephants.

To summarise, we demonstrate the performance of the Raspberry Shake and Boom (RS&B) sensor package for detecting and monitoring African elephants (*Loxodonta africana*). The aim was to test the low-cost, off-the-shelf sensor as an option for recording acoustic and seismic waves that can be generated by the animals during vocalisations and locomotion. Our results highlight a varied degree of success for the RS&B units in detecting the signals of interest. The acoustic microphone was able to record intricate details of low-frequency (<50 Hz) vocalisations that were not clearly recorded by more sensitive instruments, but was not able to record higher frequencies due to the low sampling rate (100 Hz). The geophone was not able to consistently record clear seismic waves generated by vocalisations, but was able to record locomotion activity within a 50 m range. Comparison with more sensitive instruments suggests the RS&B unit would have greater success with a higher sampling rate. Future work is aimed at reducing noise from wind, developing an improved deployment configuration to improve the geophone sensitivity, and implementing an automated system for detecting and classifying seismo-acoustic signals. Nevertheless, the RS&B unit shows great promise as a low-cost tool for monitoring African elephants which could work well for complementing an existing array of instruments.

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Disclosure statement

Since one author (Sean Hensman) was employed by a commercial company the authors want to declare that the company did not pay for using the equipment nor for doing any research with the elephants at Bela Bela. Furthermore, we want to declare that OSOP Raspberry Shake did not pay for any of the research detailed here.

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Figures

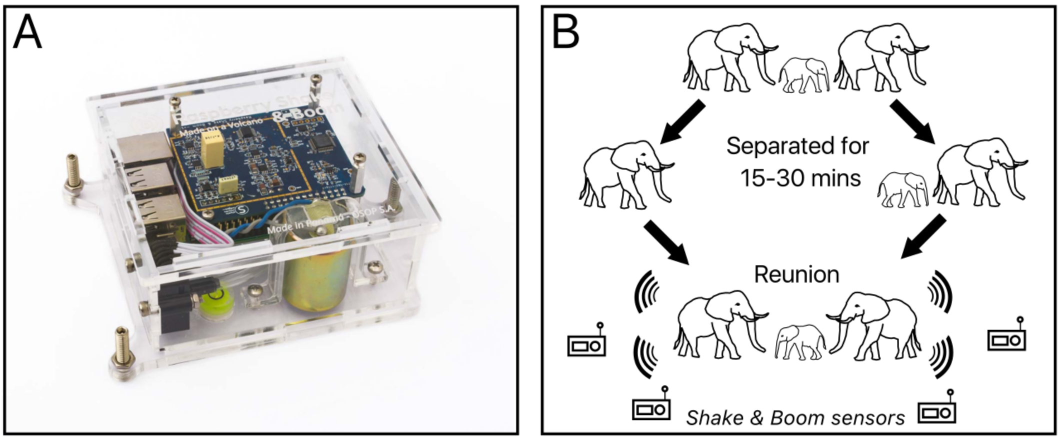

Figure 1. (A) Example of Raspberry Boom and Shake unit (image adapted with permission from https://raspberryshake.org/; last accessed 08 April 2020) (B) Schematic of reunion event recorded by the sensors.

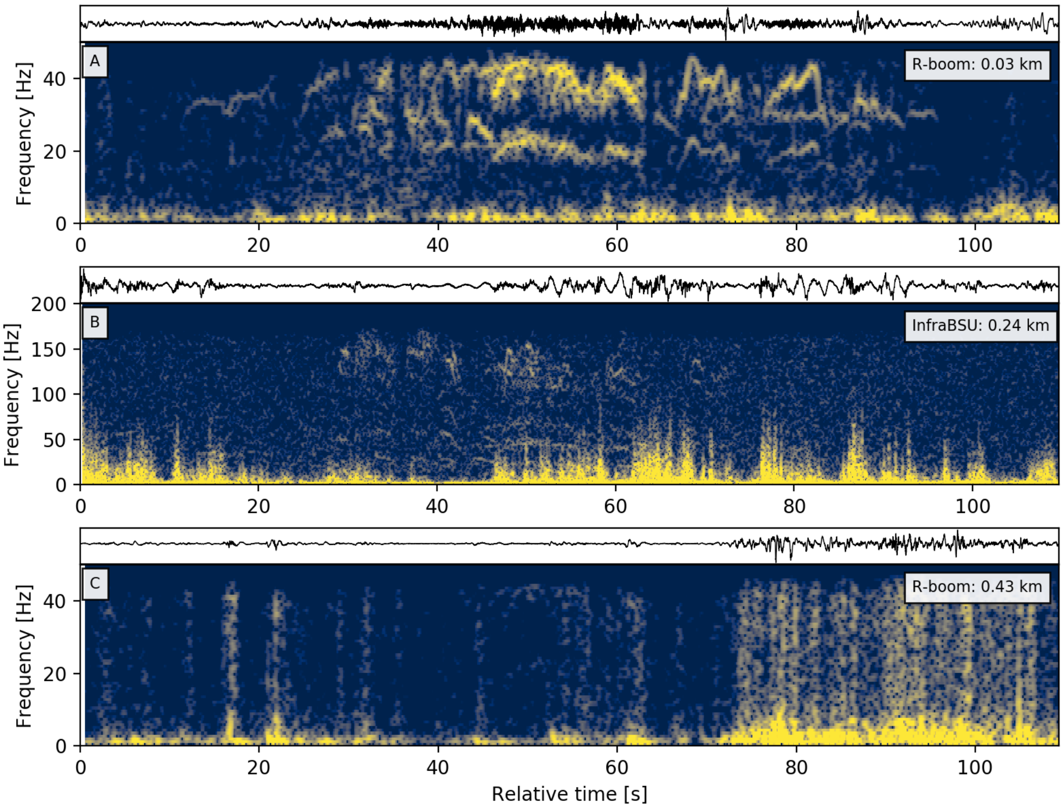

Figure 2. Acoustic waveforms (top panel) and their spectrograms (bottom panel) as recorded by acoustic sensors at three different stations during a reunion. The sensors and distances to the reunion of each station are indicated in the top right of each spectrograms. Note the differing y-axes for the spectrograms due to different sampling rates across sensors.

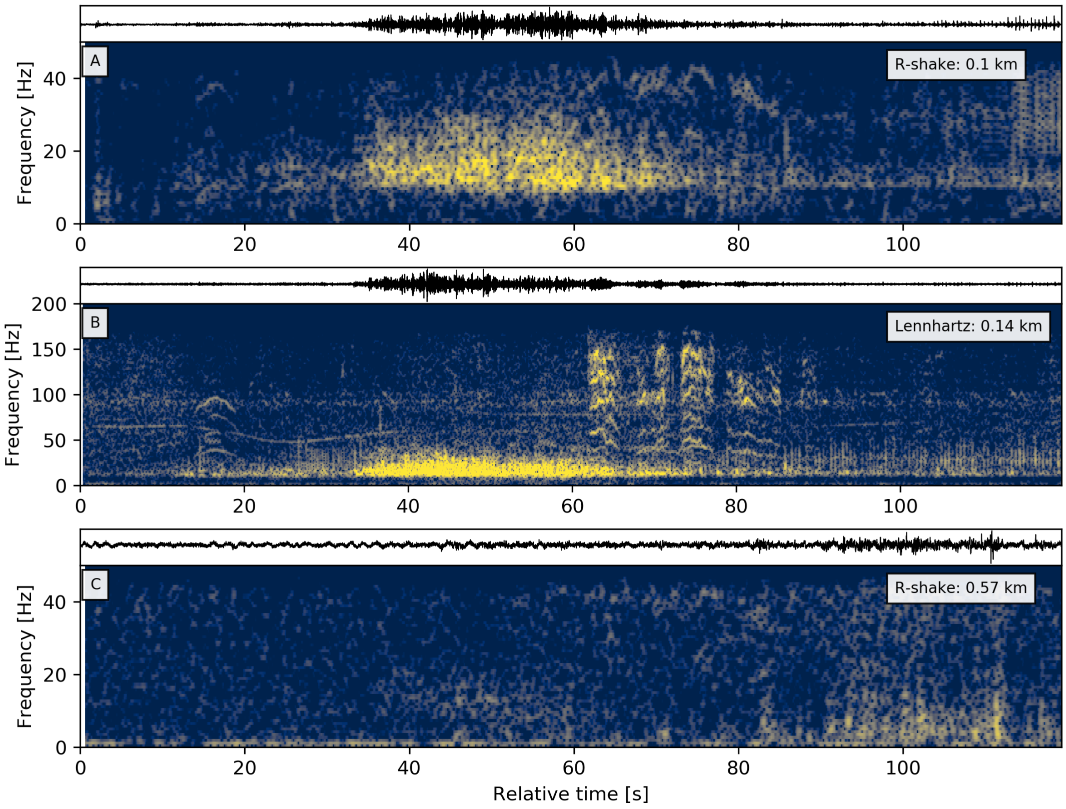

Figure 3. Seismic waveforms (top panel) and their spectrograms (bottom panel) as recorded by seismic sensors at three different stations during a reunion. The sensors and distances to the reunion of each station are indicated in the top right of each spectrograms. Note the differing y-axes for the spectrograms due to different sampling rates across sensors.

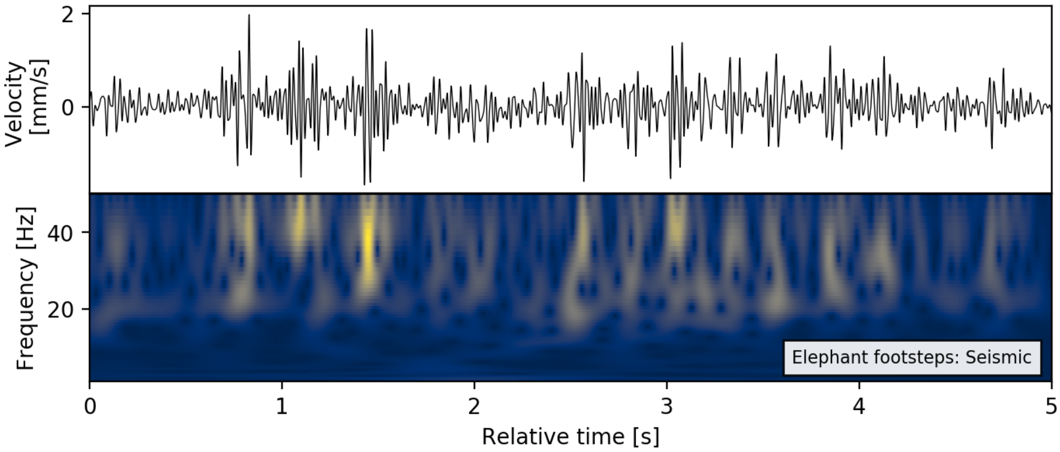

Figure 4. Seismic waveform (top panel) and spectrogram (bottom panel) of footfalls as recorded by a Raspberry Shake and Boom geophone sensor during a reunion. The station was located ∼30 m from the reunion location. The spectrogram was calculated using a continuous wavelet transform due to the small time window.

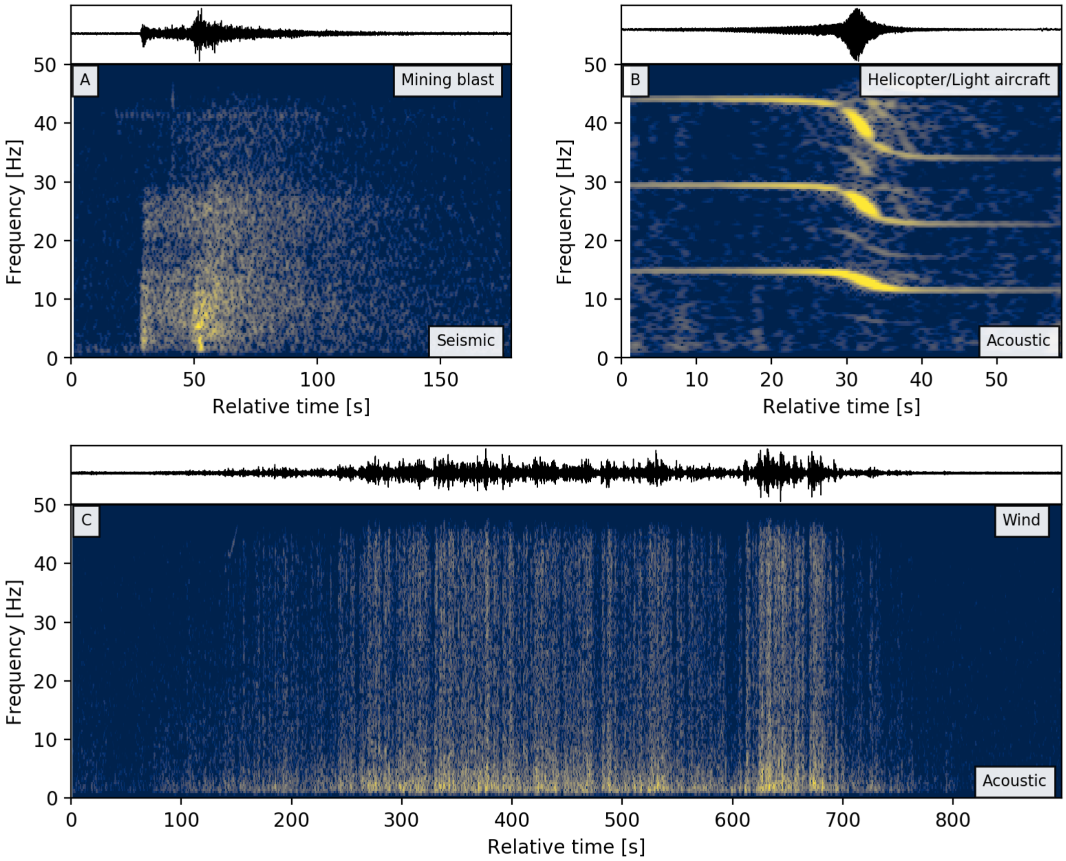

Figure 5. Examples of noise recorded by Raspberry Shake and Boom units, including (A) a mining blast as recorded by the geophone, (B) a helicopter or small aircraft doing a flyby, as recorded by an acoustic sensor, and (C) noise generated by wind, as recorded by an acoustic sensor. Each example includes the recorded waveform (top panel) and the frequency spectrogram (bottom panel).