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Collection of Ambient Noise Data across California to Derive Horizontal-to-Vertical Spectral Ratios (HVSR)

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ABSTRACT

Microtremor-based horizontal-to-vertical spectral ratios (mHVSR) offer insights into subsurface seismic velocity structure, primarily through resonant features revealed by peaks in mHVSR curves. Typically derived from three-component broadband seismometers with high-pass corner frequencies of 0.0083 Hz over relatively short observation periods (1-2 hrs), mHVSR is a cost-effective and time-efficient method of site characterization. This approach has been shown to correlate with site-specific ground motion characteristics and recent studies suggest that mHVSR holds significant potential for improving ergodic ground motion models. This study produced mHVSR curves at 1,127 seismic stations with permanently installed broadband seismometers across California and neighboring states. Each mHVSR curve was uniformly processed using the Python library *hvsrprocpy* following standard procedures with minor modification. These data were added to the Community Shear-Wave Velocity (V_S) Profile Database (VSPDB; https://vspdb.org) and are being used in ongoing work seeking to develop mHVSR-conditioned site terms in GMMs for California.

Introduction

The Nakamura Method [1], also known as the horizontal-to-vertical spectral ratio (HVSR) method, is a frequency-dependent ratio of the horizontal-to-vertical components of Fourier amplitude spectra (FAS) from a three-component recording of either earthquakes (eHVSR) or microtremors (mHVSR). Originally proposed by Nogoshi and Igarashi [2] and later popularized by Nakamura [1], the method is based on the principle that the horizontal component of the wavefield is amplified relative to the vertical component. HVSR is useful for characterizing subsurface geological features, with spectral peaks indicating resonant frequencies associated with large impedance contrasts at a site.

The objective of this study was to assemble ambient ground motion data (i.e., microtremors) from permanently installed broadband seismometers in and around California for the purpose of developing mHVSR curves to enhance the Community Shear-Wave Velocity Profile Database (VSPDB) ([3]; https://vspdb.org).

Database

We downloaded data from 1,194 stations within California and neighboring states through the Incorporated Research Institution for Seismology (IRIS) Data Management Center [4], which archives data from various data

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centers, including the Southern California Earthquake Center (SCEDC) and the Northern California Earthquake Data Center (NCEDC) amongst others. We implemented quality control measures to ensure the reliability of the data, resulting in 1,127 stations, as described further below. These data centers provide records for both earthquakes and ambient noise (microtremors) from permanently and long-term, temporarily installed stations. Figure 1 illustrates the spatial distribution of the 1,127 stations from which usable data were downloaded. Also shown in Figure 1 are the sites with mHVSR in the VSPDB prior to the present work. There are some overlapping stations, but the points in green indicate a substantial increase in data compared to prior versions of the VSPDB.

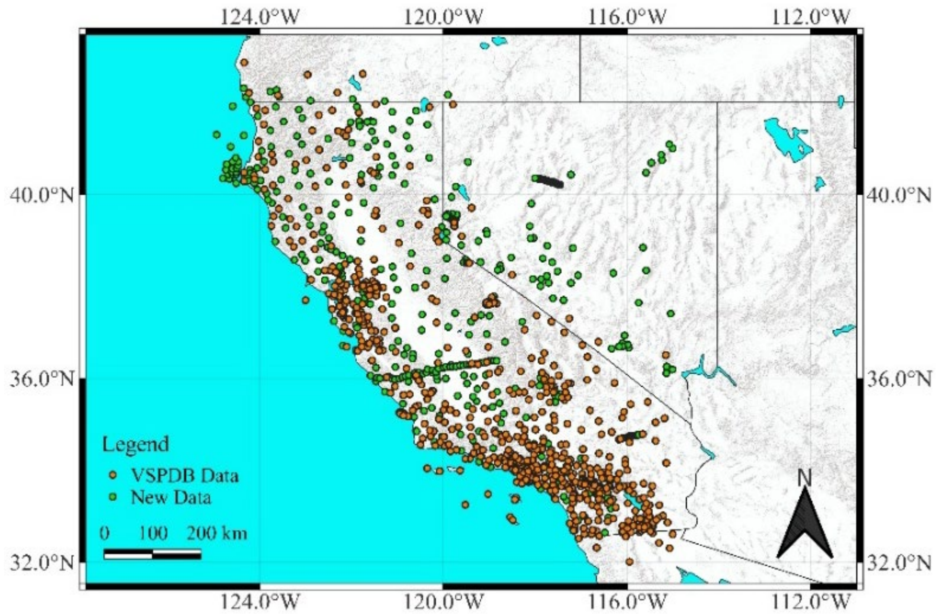

Figure 1. Locations of microtremor data downloaded from IRIS compared to what was in the VSPDB.

Our selection criteria focused exclusively on high-gain broadband seismometers, identified as "HH" stations following the Standard for the Exchange of Earthquake Data (SEED) channel codes [5]. The majority of the selected stations exhibited a flat frequency bandwidth ranging from 0.0083 to 100 Hz (0.01 to 120 sec), with sampling rates between 80 and 250 Hz.

Data Processing

The microtremor data from each station were uniformly processed following the procedures outlined in Wang et al. [6], with an additional preprocessing step applied to the raw data as described by Ornelas et al. [7]. The processing was carried out using the Python library *hvsrprocpy* [8]. An example of the functionality of *hvsrprocpy* can be found in the *GitHub* repository (https://github.com/fjornelas/hvsrprocpy), which we do not show for brevity. Moreover, this library is based on *hvsrProc* [9], an HVSR processing tool implemented in R.

Figure 2 provides an example of the windowed time-series, along with the FAS and the resulting mean HVSR and standard deviation for the Barra Winery station (BARR) in the Berkeley digital seismic network (BK). We compared mHVSR curves in which anti-triggering was and was not implemented; such anti-triggering has previously been recommended to remove time windows (shown in various colors) with spikes such as window 7 (shown in pink) in Figure 2a-c. As shown in Figure 3, mean mHVSR curves for these two cases are similar. Similar results for most of the 1,194 sites led us to conclude that the inclusion of such windows had minimal impact on the overall average used to derive the mHVSR mean curve. As a result, we processed the data from all stations downloaded from IRIS without manually rejecting windows that exhibited spikes from anthropogenic noise sources or other natural sources.

Quality Control Procedures

We conducted quality control (QC) checks on all processed mHVSR curves to ensure that (1) there was sufficient data to perform the processing (e.g., at least ten 300 sec windows with meaningful data in the time-domain), (2) no systematic differences between the three time-series components (i.e., no apparent gain inconsistencies), and (3) no individual windows that introduced issues that could significantly affect the mean mHVSR. Out of the 1,194 stations for which we downloaded data, only 1,127 produced mHVSR curves that passed these QC checks. Typical reasons for rejecting data from a particular station included the following:

- Inconsistent gain of the three components that results in an offset in amplitudes (five stations).
- Anomalies in one or more of the individual component FAS (e.g., flatlining) (14 stations).
- Missing data in one or more of the individual components (41 stations).

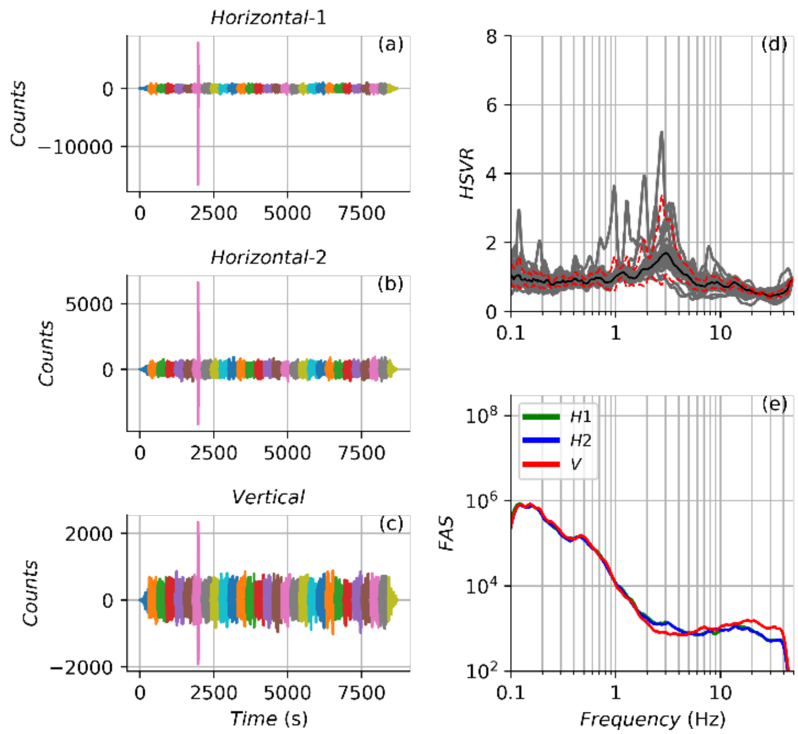

Figure 2. Results for station BK.BARR, (a-c) presents the windowed time series for three different components; (d) presents the mean HVSR (black) and individual windows (gray), as well as the standard deviation (red); (e) presents the mean FAS used to derive the mean HVSR.

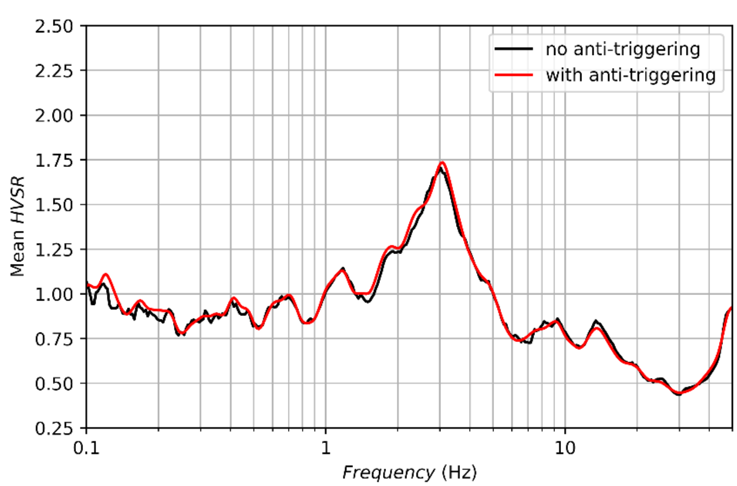

Figure 3. Comparison between mean mHVSR curves for a case when applying anti-triggering and not applying anti-triggering.

Peak Identification

One application of mHVSR curves is for modeling seismic site response. Peaks are a useful feature of mHVSR curves. The use of peaks requires two steps – deciding if a peak is present and parameterizing peaks where they exist. Parameters describing mHVSR peaks have been demonstrated to correlate to features in site response estimated through non-ergodic methods (e.g., [10]). For this reason, we provide a Jupyter notebook for users to visualize the mHVSR curves developed in this dataset [11] and to identify whether a peak is present using the algorithm presented in [12]. Figure 4 shows an example of an mHVSR curve with a peak, and the fit to that peak using a Gaussian pulse function [13]:

$$F_{H/V} = c_0 + c_1 \exp\left[-\frac{1}{2}\left(\frac{\ln(f/f_p)}{2w_p}\right)^2\right] \tag{1}$$

in which c_0 is a frequency-independent constant indicating the amplitude of the peak-adjacent flat tails, c_1 is the peak amplitude relative to c_0, f is frequency in Hz, f_p is the fitted peak frequency, and w_p is the fitted peak width. If multiple peaks are identified, the Gaussian pulse is only fit to the lowest-frequency peak. The frequency range can be adjusted between which the search algorithm considers to fit suspected peak features. If an mHVSR curve has no peaks, then no fitting is applied.

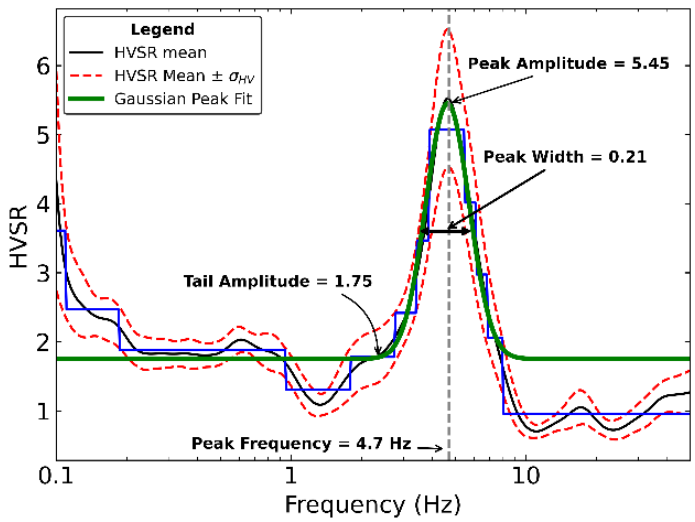

Figure 4. Example mHVSR mean curve (and mean ± one standard deviation, σ_{HV}) that has a peak and the fitting of that peak using Eq. (1). The four fit parameters are identified.

Conclusions

We present a dataset comprising microtremor measurements from 1,127 stations across California and surrounding regions that were used to derive mHVSR [11]. The data processing workflow, tools employed, and the criteria used to evaluate data quality and usability are presented. We also present methods for parameterizing mHVSR peaks, facilitating their application in ground motion modeling for site amplification studies. The dataset is publicly accessible via the VSPDB and can be readily queried. We anticipate that this resource will support and advance future research utilizing mHVSR in a variety of seismological applications.

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