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Ground-Motion Database for Southeastern Australia

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ABSTRACT

A database of recordings from moderate-to-large magnitude earthquakes is compiled for earthquakes in the stable continental region of south-eastern Australia. Data are mainly recorded by Australian National Seismograph Network (ANSN), complemented with data from temporary deployments, and covering the period of 1990 to 2022. The time-series data are consistently processed to correct for the instrument response and to reduce the effect of background noise. A range of ground-motion parameters in the time and frequency domains are calculated and stored in the database. Numerous near-source recordings exceed peak accelerations of 0.10 g. In addition to its utility for engineering design, the dataset compiled herein will improve characterization of ground-motion attenuation in the region and will provide an excellent supplement to ground-motion datasets collected in analogue seismotectonic regions worldwide. This dataset will be also utilized to assess the suitability of candidate ground-motion models for use in the national seismic hazard assessment of Australia.

Keywords: ground-motion database, stable continental region, seismic hazard assessment, ground-motion model, Australia

INTRODUCTION

One of the key challenges in assessing earthquake hazard in Australia is understanding and modeling the attenuation of ground-motion through the stable continental crust. This can be achieved by fitting empirical models to the recorded and or simulated ground-motion data in Australia (e.g., [1-2]). There are now a handful of such ground-motion models (GMMs) that have been developed specifically to estimate ground-motions from Australian earthquakes. These GMMs, in addition to models developed outside Australia, are considered in the seismic hazard assessment studies in Australia [3-4]. It should be noted that the Australian GMMs are not based on a common ground-motion database. Furthermore, differences do exist between previous studies in Australia in terms of processing techniques applied in and metadata collected by each study. In practice, such differences make fair comparisons of GMMs more challenging [5].

To better understand the characteristics of ground-motions in Australia and also to select and rank proper GMMS for hazard studies, in this paper we compiled a comprehensive, digital ground-motion dataset for earthquakes in the stable continental region of south-eastern Australia. These data have been extracted from continuous waveforms recorded by the Australian National Seismograph Network (ANSN), from various temporary aftershock deployments, and other sources in a range of formats and sampling rates.

The high-quality data acquired from recent Australian earthquakes now have significant utility to enable more informed choices for GMMs for future hazard assessments and will support future empirical and simulated ground-motion studies for the nation (e.g., [1]). Underpinning this is the need for a database of uniformly-processed ground motion records from Australian earthquakes and accompanying site characterization information (e.g., [6]). This study provides a platform from which to compile a database of Australian-specific ground motions for engineering purposes. Such database can also be considered as a common database to study characteristics of ground-motions in Australia and development of GMMs for seismic hazard studies.

In this paper, we first review the ground-motion data and associated metadata compiled for the south-eastern Australia. We then present the processing schema followed in this study to obtain ground-motion records in physical unit (e.g., m/s or m/s^2) from raw data with “count” unit (i.e., the voltage measurement from a sensor). Finally, we list the computed parameters of engineering interest from the consistently processed waveforms, and outline the areas for future study.

GROUND-MOTION DATA

Data have been extracted from continuous waveforms recorded by the Australian National Seismograph Network (ANSN), from various temporary aftershock deployments, and from the Incorporated Research Institutions for Seismology (IRIS) data centre. Data from the IRIS data centre have been obtained from three networks: the Australian National Seismograph Network (AU); the Global Seismograph Network - IRIS/USGS (IU); and the Australian Seismometers in Schools (S1) network ([7]).

Data from the ANSN are typically streamed at sample rates from 20-40 Hz and high-sample-rate (HSR) data are downloaded on a manual basis following significant earthquakes. This manual download process at Geoscience Australia has been variable over time. Consequently, not all events of interest have these data available. However, where these data are available on local disk storage, HSR data supplant low-sample-rate data from IRIS and the internal continuous waveform buffer. The HSR data are archived in both CSS3.0 and miniSEED format. High-sample-rate data from temporary deployments are archived in PCSUDS and miniSEED format. For the compilation of this dataset, all raw data were first converted to a uniform miniSEED format ([8]).

The ground-motion dataset compiled in this study contains 721 records from 87 earthquakes occurring in the period of 1991 to 2022. The included events have moment magnitudes in the range of 3.2 to 5.9, recorded at the distances in the range of 8 km to 1500 km. The distribution map of earthquake epicenters and recording stations are shown in Figure 1.

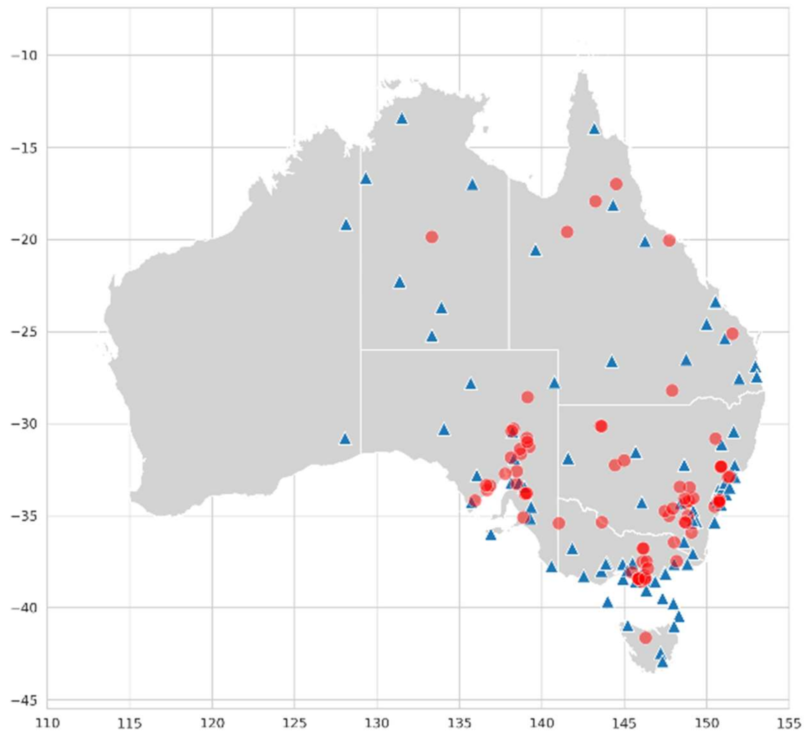

Figure 1. The location of the earthquakes (circles), and recording stations (triangles) in the compiled dataset.

The collected time-history data are raw data with "count" unit, i.e., the voltage measurement from a sensor. For each time-series data the corresponding instrument transfer function of the recording station, is computed from sensor/digitizer technical specifications (i.e., pole and zero values, and the normalization constant). Such information is either retrieved from IRIS data centre, or, if not available in IRIS, from nominal technical specifications of the sensors deployed at the recording stations of interest. All station metadata, including instrument transfer functions are combined and stored in a standard StationXML format. The compiled inventory for south-eastern Australia includes 94 stations from 9 monitoring networks (Figure 1).

GROUND-MOTION PROCESSING

In this study, we used the USGS automated ground-motion processing software to process ground-motion waveforms, and compute intensity metrics ([9-10]. The collected time-history data are raw data with "count" unit (i.e., the voltage measurement from a sensor). To correct for the instrument response and return the ground-motion in physical unit (e.g., m/s or m/s^2), the instrument transfer function, imported from the database, is deconvolved from the raw time-series to obtain acceleration waveforms in m/s^2. Prior to correcting for instrument response, the baseline of raw data was adjusted by removing the mean followed by 5% cosine tapering. To avoid over-amplification during deconvolving instrument transfer function, the waveform data were also filtered with corner frequencies at 0.001 Hz, and Nyquist frequency. The velocity seismograms were then differentiated to obtain ground acceleration. The acceleration time-series are resampled to 200 sps for consistency and enhancement of temporal resolution.

To account for low- and high-frequency noise, records were padded with zeros, then filtered using acausal, fourth order Butterworth filters. Acausal filters are applied to achieve zero phase shift. Furthermore, unlike causal filters, the computed spectral ordinates within the passband of the acausally filtered accelerations are not sensitive to the filter corner frequencies.

It should be noted that the noise characteristics of each of the ground-motion records is unique and even may vary from one component to another; hence, ideally, each ground-motion record should be filtered with record specific corner frequencies. For each time-series, the corner frequencies of the passband filter are chosen automatically from signal-to-noise ratio (SNR) curve. Record specific SNR curves are computed by dividing the smoothed Fourier Amplitude Spectrum of the signal window with that of the noise window. The passband of the filter is the frequency range in which the SNRs are above 3.0.

Figure 2 shows an example of processed ground-motion record at hypocentral distance of 104 km from an earthquake in Victoria with M_W 5.0. The Fourier amplitude spectra of signal and noise windows as well as the computed SNR curve are also displayed.

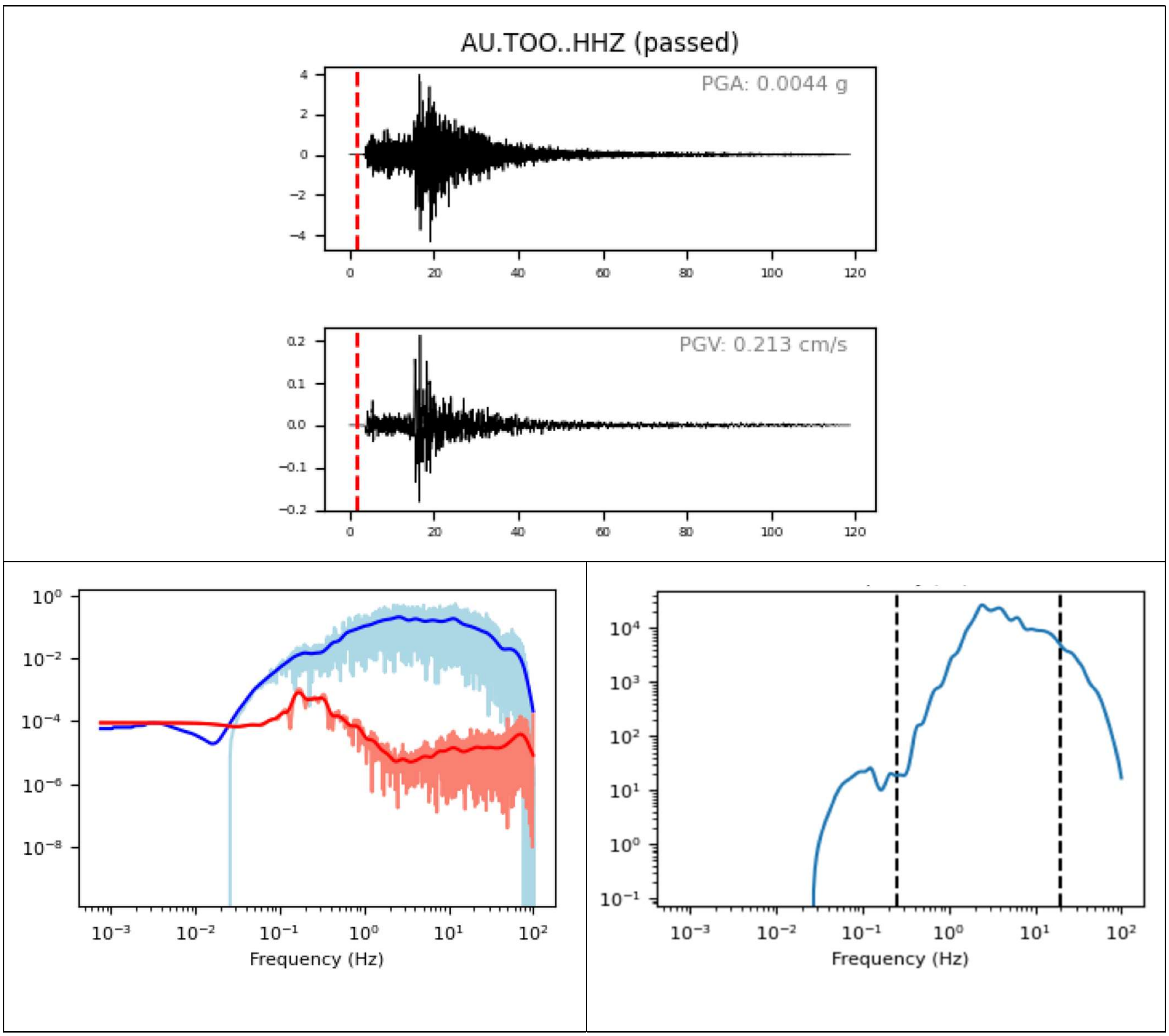

Figure 2. (a) Processed acceleration and integrated velocity time-series for 2012 Moe earthquake (M_W 5.0) recorded at one of the ANSN stations. The vertical dashed line indicates the theoretical P-wave arrival time (b) The signal and noise Fourier

amplitude spectra, and (c) computed signal-to-noise ratio are also displayed. The vertical dashed lines indicate the selected corner frequencies of the filter.

To define signal and noise windows in an automatic manner for each record, first the theoretical P-wave arrival time is calculated for the observed source-to-site distance based on the IASP91 velocity model. In case of waveforms with timing issues, the theoretical P-wave time may not be within the record time. In such cases, the automatic picker algorithms implemented in ObsPy [11] are used to estimate the onset of the P-wave. This P-wave time is then used as the split between the noise and signal windows. The end of the signal window is computed by adding the significant duration of the record to the P-wave time. The significant duration is defined as 5-95% interval of the Arias intensity (Table 1).

Each of the velocity and displacement time-series obtained through integration of the filtered acceleration were visually inspected to check whether or not they appear to be reasonable. The acceleration time-histories that produced unphysical velocity and displacement records were not considered for further processing.

The processed waveforms as well as all of the processing parameters (e.g., filter corner frequencies) are added into the database file in ASDF format.

GROUND-MOTION PARAMETERS

Several engineering ground-motion parameters in time and frequency domains are computed for each of the processed records in the database. Table 1 lists the selected ground-motion parameters along with their definitions. These engineering parameters are widely used to describe the key characteristics of the ground motions and their damage potential. The computed ground-motion parameters are also added into the database.

Table 1: definition of selected ground-motion parameters and their physical units

Parameter	Unit	Definition
Peak ground acceleration	cm/s/s	The largest (absolute) value of ground acceleration
Peak ground velocity	cm/s	The largest (absolute) value of ground velocity
Spectral acceleration	cm/s/s	Maximum acceleration response of a single-degree-of-freedom system to the input ground-motion
Fourier amplitude spectrum	cm/s	The amplitude of the ground-motion with respect to frequency
Arias intensity	cm/s	time-integral of the square of the ground acceleration
duration	s	Total time of ground shaking from P-wave arrivals until the return to background condition

Although the metrics can be accessed directly from the ASDF file, it is also feasible to save the metrics (both station and waveform) into a “flatfile” where each row corresponds to a single record. Such flatfiles can easily be used to study characteristics of the ground motions and develop ground-motion models for seismic hazard studies.

Figure 3, as an example, shows the computed spectral acceleration values at period of 1.0 sec versus distance for a M_W 4.4 event in Victoria. The predictions by NGA-east model [12] is also displayed for comparison. For this particular earthquake, the selected GMM under predicts the observations at distances less than ~ 200 km while the opposite holds for distances above 200 km. It should be noted that to verify the performance of any GMM for SHA studies, we do need to take into account more data points from earthquakes with wide magnitude and distance ranges.

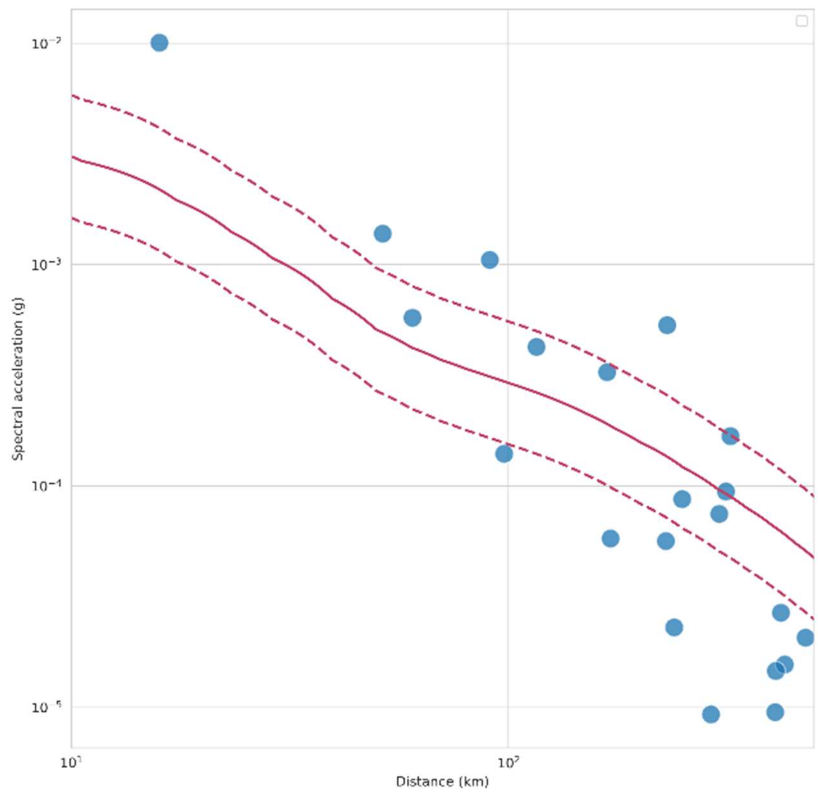

Figure 3. Comparison of the observed spectral accelerations at period of 1.0 sec with the ground-motion model of NGA-East. The observations (blue circles) are recorded during a magnitude 4.4 (M_W) earthquake at depth of 12 km. The mean and standard deviation curves of the selected empirical model are shown as tick and dashed lines, respectively.

CONCLUSIONS

This paper describes the compilation and processing of the ground-motion data in south-eastern Australia to support the selection and development of GMMs for the seismic hazard assessment for Australia. In total, some 721 instrument-corrected earthquake recordings are compiled in this dataset. The records are from 87 earthquakes, occurring between 1991 to 2022.The magnitudes of earthquakes within the dataset range from M_W 3.2 to 5.9 and hypocentral distances up to 1500 km. The collected time-series data were consistently processed to correct for instrument response and account for low- and high-frequency noise. The ground-motion parameters of engineering interest were also computed from processed waveforms and stored in the database.

In next stage, we will further investigate potential data and metadata quality issues. Figure 4, as an example, shows the distribution of the residuals of an empirical model that is fitted to the data compiled in this study. The residuals follow the zero mean normal distribution; however a large scatter can be observed in the distribution. Such scatter, to some extend can be attributed to the aleatory variability in ground motion distribution which reflects the natural randomness in the process; however, especially for outliers, it may also indicate not accurate metadata, such as instrument response information, for certain observation points.

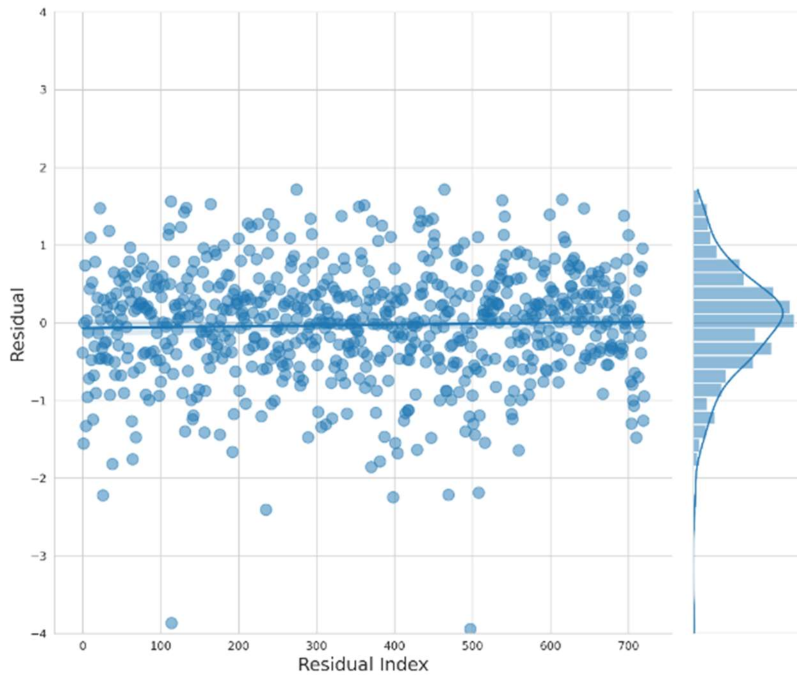

Figure 4. Distribution of the residuals of an empirical model that is fitted to the data. Histogram of the residuals along with the fitted normal distribution are also displayed.

We are in the process of developing a web interface to allow users to query the database and visualize the waveforms and ground-motion parameters. Database queries would be based on events, stations, and records parameters. The users will be also able to export the data and metadata to standard formats. These data will support the improvement of seismic hazard assessments and will have utility for engineering applications, both in Australia and analogue tectonic regions worldwide.

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REFERENCES

[1] Allen T. (2012). "Stochastic ground-motion prediction equations for southeastern Australian earthquakes using updated source and attenuation parameters". *Geoscience Australia Record 2012/69*, Canberra, Australia.

[2] Somerville P., Collins N., Graves R., Song S-G., and Ni S. (2009). "Ground motion models for Australian earthquakes". URS Corporation, Pasadena, CA.

[3] Ghasemi H., and Allen T. (2018). "Selection and ranking of ground-motion models for the 2018 National Seismic Hazard Assessment of Australia: summary of ground-motion data, methodology and outcomes". *Geoscience Australia Record 2018/29*. Canberra, Australia

[4] Allen T., Griffin J., Leonard M., Clark D., and Ghasemi H. (2020). "The 2018 National Seismic Hazard Assessment of Australia: quantifying hazard changes and model uncertainties". *Earthquake Spectra 36(1)*.

[5] Chiou B., Darragh R., Gregor N., and Silva W. (2008). "NGA project strong-motion database". *Earthquake Spectra 24(1).*

[6] Ghasemi H., and Allen T. (2021). "Engineering Ground-Motion Database for Western and Central Australia". *Australian Earthquake Engineering Society 2021 virtual Conference*.

[7] Balfour N., Salmon M., and Sambridge M. (2014). "The Australian Seismometers in Schools Network: education, outreach, research, and monitoring". *Seismological Research Letters 85(5)*.

[8] Standard for the Exchange of Earthquake Data. Incorporated Research Institutions for Seismology (IRIS). (2013).

[9] Hearne, M., E. M. Thompson, H. Schovanec, J. Rekoske, B. T. Aagaard, and Worden, B. (2019). "USGS automated ground motion processing software", USGS Software Release, doi: 10.5066/P9ANQXN3.

[10] Thompson, E., Aagaard, B., Hearne, M., Ferragut, G., Parker, G., Brandenberg, S., Ramos-Sepulveda, M., Stewart, J., Ghasemi, H., Schleicher, L., Gee, L. Steidl, J., Hagos, L., Haddadi, H. (2023). "Ground Motion Processing Software at the U.S. Geological Survey: New Collaborations and Contributions". SSA annual meeting. San Juan, Puerto Rico.

[11] Krischer, L., Megies, T., Barsch, R., Beyreuther, M., Lecocq, T., Caudron, C., and Wassermann, J. (2015). "ObsPy: a bridge for seismology into the scientific Python ecosystem". *Computational Science & Discovery*, 8 (1), 014003.

[12] Goulet A., Bozorgnia Y., Kuehn N., Al Atik L., Youngs, R., Graves, R., and Atkinson, G. (2021). "NGA-East Ground-Motion Characterization model part I: Summary of products and model development". *Earthquake Spectra 37(1).*