Performance of Raspberry Shake vs. Kentucky Seismic and Strong-Motion Network Instruments

Kentucky Geological Survey

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Introduction and Motivation

Earthquakes in Kentucky and Seismic Monitoring by KGS

- Kentucky is affected by three seismic zones: the New Madrid (NMSZ), Wabash Valley, and Eastern Tennessee Seismic Zones (Fig. 1).
- Producing at least 3 magnitude ≥ 7 earthquakes in 1811-1812 and the highest seismicity rate in the Central and Eastern U.S., the NMSZ is the greatest source of seismic hazard for Kentucky.
- The Kentucky Geological Survey (KGS) operates a network of 24 seismic and strong-motion stations in and near these seismic zones (Fig. 1)
- Toward densifying this seismic network, the Kentucky Seismic and Strong-Motion Network (KSSMN), KGS tested affordable Raspberry Shake instruments at five KSSMN stations.

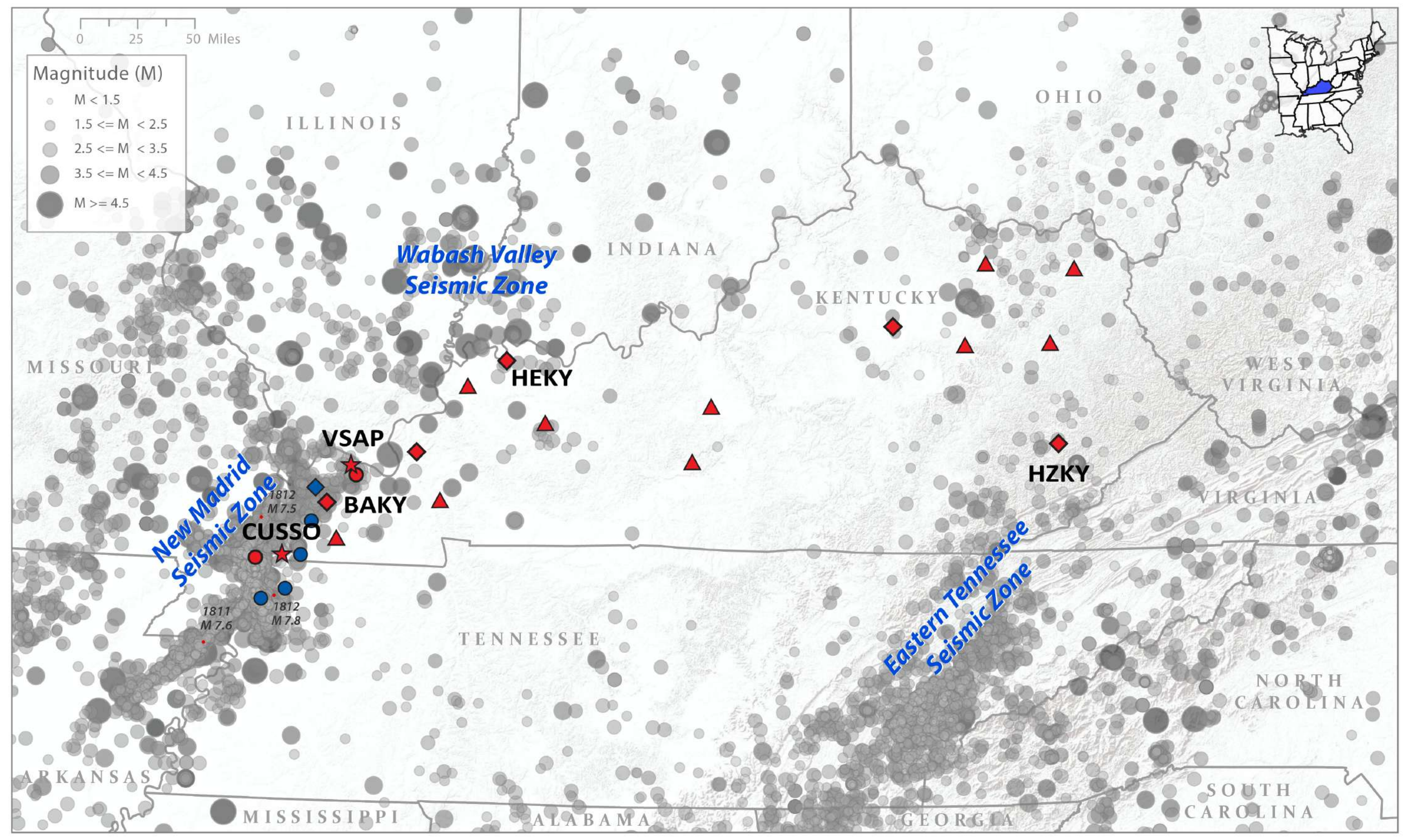

Figure 1. Historical earthquakes and seismic zones in and around Kentucky, and the 24-station KSSMN. stations where Raspberry Shake instruments were installed are labeled by name.

Approach: Testing Raspberry Shakes

- Toward densifying this seismic network, the Kentucky Seismic and Strong-Motion Network (KSSMN), KGS tested affordable Raspberry Shake instruments at five KSSMN stations (Fig. 1)
- Analyze earthquake seismograms from RS and KSSMN instruments recorded during a two-year period.
- This poster presents comparisons made on these recordings to evaluate the RS instruments relative performance.

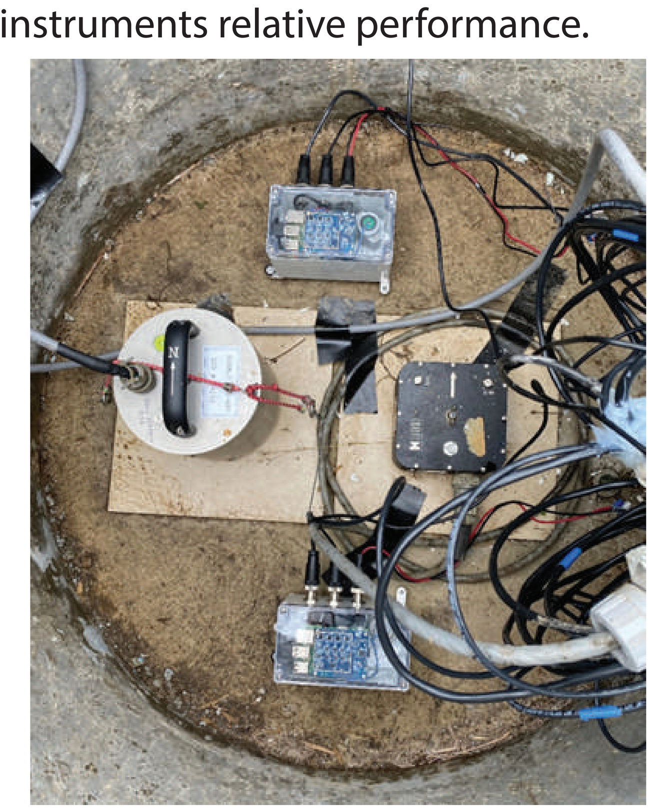

Figure 2. KSSMN and RS instruments installed in a vault at KSSMN station CUSSO. Counterclockwise and from the top, the instruments: RS-3D –short-period seismograph, FBA-23 – 2g strong-motion accelerometer, RS-4D –MEMS strong-motion accelerograph and a vertical seismometer, CMG-40T – 30s medium-period seismometer. All instruments have 3-components.

Table 1. RS and KSSMN instruments used in this study. Strong-motion accelerometers' full-scale ranges and the natural frequencies of seismometers are given.

Station	Instrumentation	Full-scale range or Natural Frequency	Installation type
BAKY	RS-3D Nanometrics Titan	0.5 Hz 4 g	direct burial posthole
CUSSO	RS-3D RS-4D Kinemetrics FBA-23 Guralp CMG-40T	0.5 Hz 2 g 2 g 30 s	vault vault vault vault
HEKY	RS-3D Guralp CMG-5Tc	0.5 Hz 2 g	direct burial shallow vault
HZKY	RS-3D Guralp CMG-5Tc GeoSpace HS-1-LT	0.5 Hz 2 g 2 Hz	direct burial vault vault
VSAP	RS-3D Nanometrics Titan	0.5 Hz 4 g	direct burial shallow vault

Time-Series Analysis

Earthquakes Recorded

- 56 M ≥ 2.5 earthquakes within 250 km of one or more of the RS stations during the 2-year project period

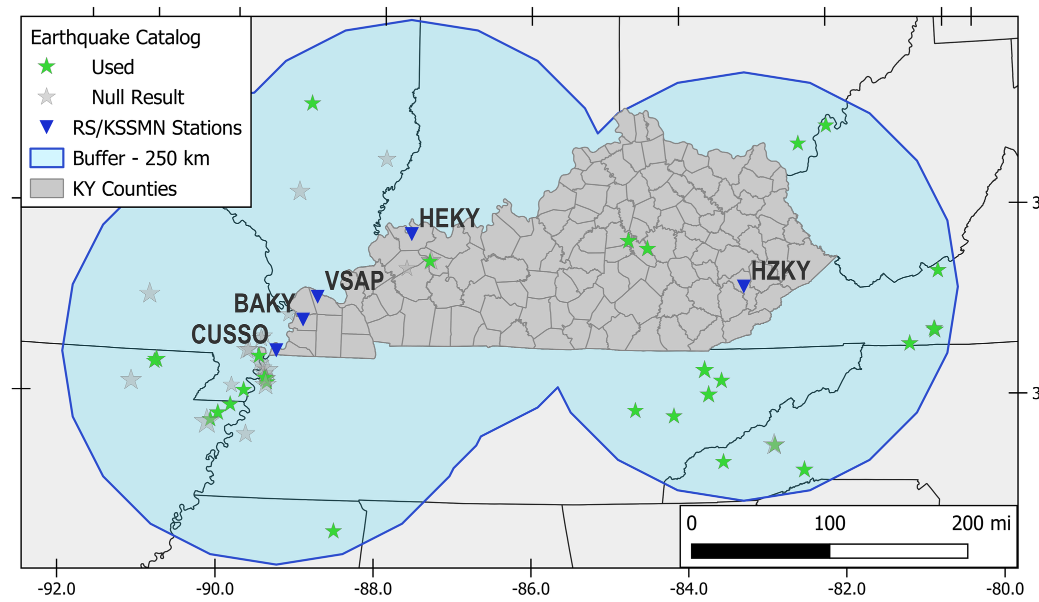

Figure 3. A regional map displaying earthquakes (stars), station locations (blue triangles) and 250 km buffer region wherein earthquakes were considered. A total of 23 (green stars) of the 56 earthquakes that occurred during deployment produced usable ground motions for evaluation. Stars are scaled by magnitude.

Data Processing and Parameter Extraction

- Data processing using Earthworm and Obspy
- KSSMN and RS data acquired and archived in real-time via Earthworm
- **Latency** - i.e., data-handling latency at the remote site (i.e., at the data logger) + telemetry latency
  - Data handling latency
    - UDP - RS's User Datagram Protocol (UDP) - collect and send 0.25 s packets of data, sent when full. Thus data-handling latency is a minimum of 0.25 s.
    - TCP - SeedLink protocol on the RS. Use Earthworm to request and receive these packets and sniffwave to estimate this latency metric
  - Telemetry latency: difference of data-packet arrival time and time of last sample in the packet
- Time-series preliminary processing
  - 240 s, starting 60 s prior to origin time
  - Remove mean and taper using a 5 % Hann taper
  - Remove instrument response
- **Peak ground acceleration (PGA)** - measured between the P arrival and four times the S-P time on accelerograms
- **Peak ground velocity (PGV)** - window +/- S-P s around the PGA time on velocity seismograms
- **Shaking Duration** - Duration of signal exceeding 0.01% g.
- **Arias Intensity** - Starting 1s prior to the P-wave and calculated as

$$I_a = \frac{\pi}{2g}\int_0^\infty [a(t)]^2 dt$$

- **Spectral Amplitudes** - 12 s windows starting 0.5 s prior to the S-wave arrival. Calculate spectra via FFT.

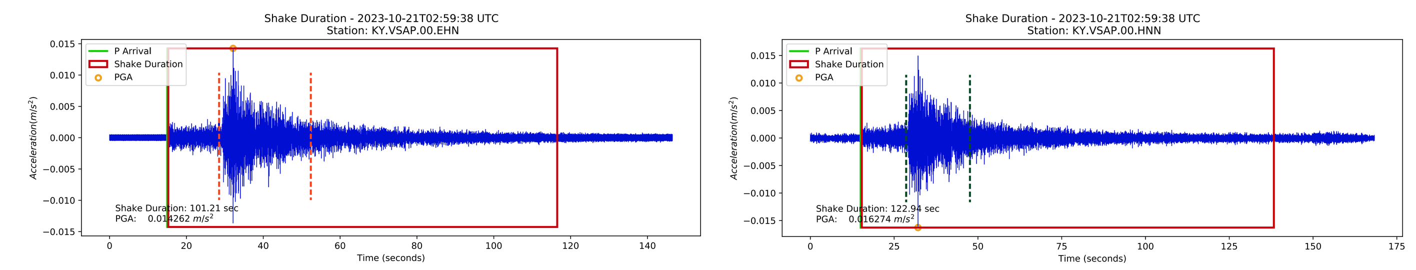

Figure 4. Example of parameter extraction using recordings from VSAP: RS-3D (left) and the Titan accelerometer (right). Note time axes are slightly different. P-wave onset is marked with green lines. Shaking durations are boxed in red. PGA measurements are indicated by orange circles. The dotted vertical lines delineate the S-wave windows for which the amplitude spectra were calculated.

Results

Waveform Comparisons

- RS waveforms: generally comparable to those from the KSSMN instruments.
- Cross correlation of 12 second S window resulted in 96% correlation between RS and KSSMN BB for 2023-10-21 Md 3.3.
- RS amplitude spectra: similar to those from the KSSMN instruments at most sites in the common passband between all instruments, ~1-20 Hz.
- RS-4D's MEMS's recordings were exceptions: generally incomparable due to very low signal-to-noise ratios.
- RS devices with different installation types from the co-located permanent instruments (Table 1), slight variations in spectral amplitude peaks were observed.
- Figure 5 shows example waveform and amplitude-spectra comparison from the CUSSO site, where the installation types were identical.

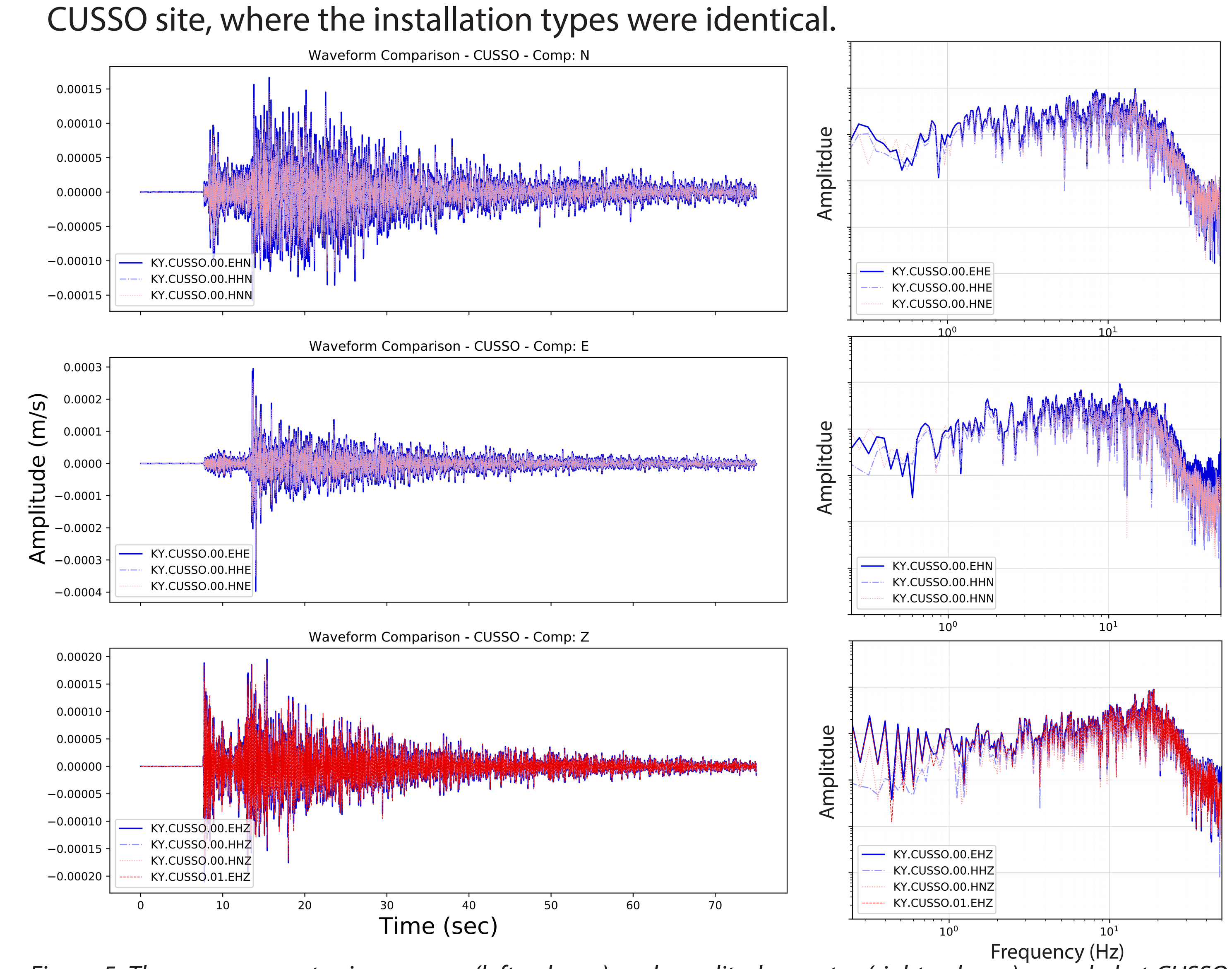

Figure 5. Three-component seismograms (left column) and amplitude spectra (right column) recorded at CUSSO from the 2023-10-21 Md 3.3 earthquake, 42 km to the south. RS-3D (00.EH channels) are compared against both of CUSSO's surface instruments: FBA-23 (00.HN*) and CMT-40T (00.HH*). The recording from the RS-4D vertical-component seismometer (01.EHZ) is also shown.*

Latency

- Average UDP transport latency (HEKY to server) 0.51 s (0.25 s of data per packet)
- Remote/limited bandwidth connections may drop important UDP packets.
- Average TCP transport latency at all RS locations was 2-4 seconds per packet.
- Reduced MSEED compression during strong shaking decreases lag time between packets but increases demand on bandwidth.

Ground-Motion Comparisons

- Ground-motion parameters determined from the RS-3D and KSSMN instruments were comparable.
- For most earthquakes, peak ground motions, measured on all components, are slightly higher on the RS recordings compared to those made by the KSSMN instruments.
- Calibrated RS instruments may offer improved consistencies with calibrated KSSMN instruments.
- Peak-ground-motion differences between the RS and KSSMN instruments are slightly larger for lager ground motions but are not strongly correlated with the level ground-motion.
- The vertical-geophone recordings from both RSs at CUSSO (RS-3D and RS-4D) are consistent.

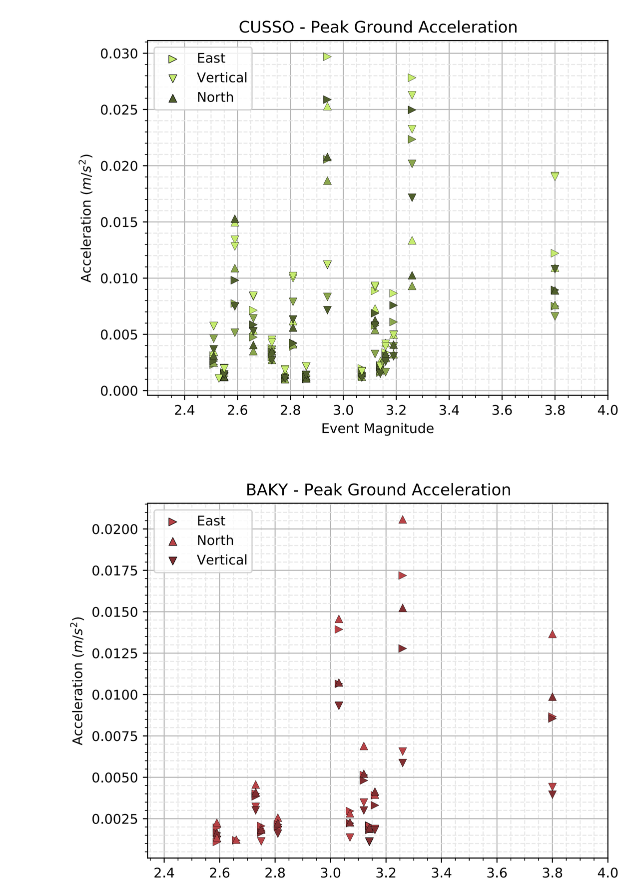

Figure 6. Comparisons of peak ground acceleration for each earthquake recorded at CUSSO (top) and BAKY (bottom). Symbols correspond to the recording component. Lighter colors of the same symbols correspond to RS recordings, while darker ones are for the KSSMN. The plot includes PGAs from both vertical-component RS geophones that operated at CUSSO.

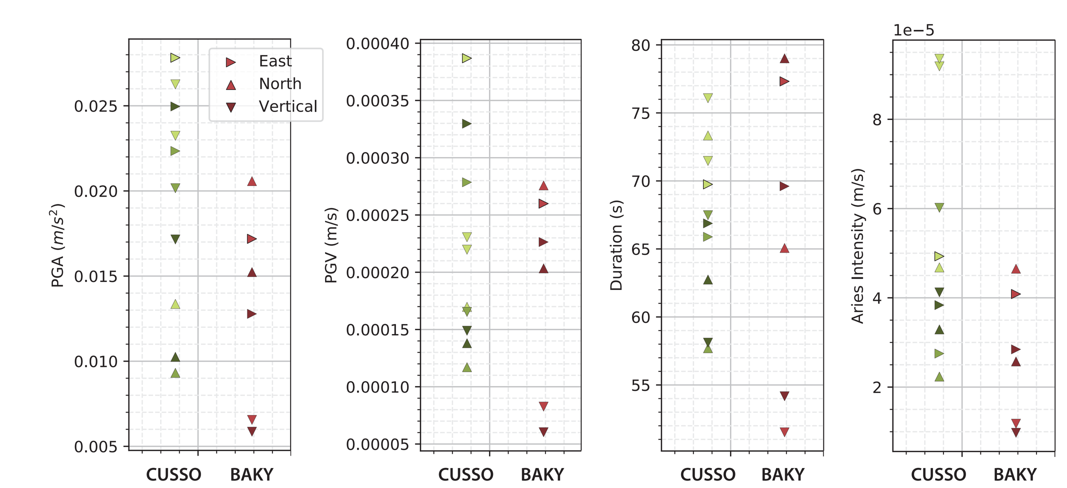

Figure 7. Ground-motion parameters determined at CUSSO and BAKY for the 2023-10-21 Md 3.3 earthquake. Symbols are as in Figure 6.

Summary and Future Work

- Within their passband, the RS geophones record ground motions similar to permanent KSSMN instruments
- This study presents an optimist comparison, suggesting RS may provide reliable ground-motion measurements in and around Kentucky.
- More, stronger-motion recordings are needed to more fully assess RS instrument performances, particularly the RS-4D.
- RS latency using TCP could be improved by reducing the size of packets before sending.
- Latency with TCP falls below EEW systems requirement of 5 second of acquired data for accurate magnitude determination.
- UDP transmission is not recommended at weak telemetry sites.

Acknowledgements

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