Evaluation of low-cost 5 Hz geophones for regional earthquake monitoring: a field comparison with broadband seismometers

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Summary
Broadband seismometers are widely used in regional and global seismic monitoring networks due to their ability to record ground motion over a very wide frequency band. However, the relatively high cost of broadband sensors limits the spatial density of monitoring networks, particularly for temporary deployments and large-area dense monitoring of induced seismicity. In contrast, conventional geophones are inexpensive, rugged, and widely available but are generally considered unsuitable for recording low-frequency seismic signals because their sensitivity decreases rapidly below their natural frequency. In this study we investigate whether the effective bandwidth of a standard 5Hz geophone can be extended through instrument-response correction. A field experiment was conducted in Needville, Texas in March 2026 using two broadband Nanometrics Trillium Horizon120 seismometers and three standard 5Hz geophones. During this study, a M4.9 earthquake occurred in Louisiana at a distance of approximately 368 km from the test site. This event provided an opportunity to directly compare the recordings of broadband sensors and geophones for a regional earthquake. Raw waveform comparisons show that geophone amplitudes are significantly attenuated below their natural frequency. However, after removing instrument responses and applying appropriate band-pass filtering, the corrected geophone waveforms closely match those recorded by the broadband sensors. Cross-correlation coefficients between the two sensor types exceed 0.999 for the 0.1~40 Hz frequency band. Spectral analysis demonstrates that useful signal energy can be recovered down to about 0.08 Hz from the geophone recordings despite their nominal 5 Hz natural frequency. Noise analysis shows that although the broadband seismometer has lower intrinsic noise at long periods, the geophone self-noise remains below the New Low Noise Model down to about 0.17Hz. These results demonstrate that low-cost 5Hz geophones can achieve performance comparable to broadband seismometers for regional monitoring applications when the primary signals of interest occur above ~0.1 Hz. The results suggest that dense seismic monitoring networks could be deployed at substantially lower cost using geophones while maintaining high data quality.

Introduction
Modern seismic networks typically rely on broadband seismometers capable of recording ground motion over a wide frequency range, often extending from periods of hundreds of seconds to tens of Hertz. These sensors enable detailed analysis of earthquake source processes, regional wave propagation and long-period ground motion. However, broadband sensors are expensive instruments that require careful installation and maintenance. As a result, the spatial density of many seismic networks is limited by cost.

In contrast, moving-coil geophones are inexpensive sensors commonly used in exploration seismology, near-surface geophysics, and microseismic monitoring. Standard geophones typically have natural frequencies of 4.5~15 Hz and are designed to record relatively high-frequency seismic signals generated by controlled sources or small seismic events. Because the sensitivity of a geophone decreases rapidly below its natural frequency, these instruments are generally assumed to be unsuitable for recording low-frequency ground motion associated with regional or teleseismic earthquakes. Despite this limitation, the output of a geophone still contains information about lower-frequency ground motion, although the signal is attenuated by the instrument response. If the sensor response is known, the recorded signal can be corrected through deconvolution to recover the true ground motion. Several studies (Besedina et al., 2020; Hall et al., 2012; Rasmussen, 2019; Zou et al., 2010) have shown that the usable frequency range of geophones can extend well below the nominal natural frequency when signal-to-noise ratios are sufficient.

The ability to use inexpensive geophones for earthquake monitoring would provide significant advantages. Dense monitoring networks could be deployed at a fraction of the cost of broadband networks, improving earthquake detection capability and spatial resolution. This would be particularly valuable for induced seismicity monitoring, temporary deployments, and regional studies where high sensor density is beneficial.

Field experiment setup
A field experiment was conducted in Needville, Texas in March 2026 to compare recordings from broadband seismometers and geophones. The deployment consisted of two Nanometrics Trillium Horizon120 broadband seismometers and three standard 5Hz geophones (Figure 1). The broadband sensors were connected to REF Tek 130 digitizers sampling at 100Hz, while the geophones were connected to a SensorEra digitizer sampling at 250 Hz. On March 5, 2026 a M4.9 earthquake occurred in Louisiana at coordinates (32.038°N, 93.415°W) and a depth of about 11 km. The epicentral distance from the test site was approximately 368 km. This earthquake provided a suitable dataset for evaluating the performance of the two sensor types.

A field comparison of geophones and seismometers for regional earthquake monitoring

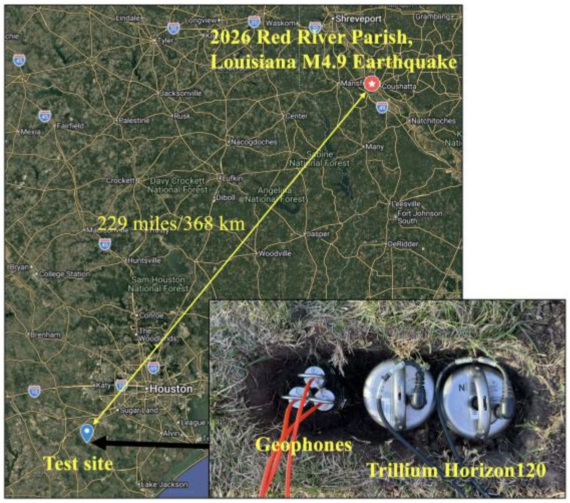

Figure 1: Deployment configuration at the Needville, Texas test site. Three 5 Hz geophones were clamped together and shallowly buried next to two Nanometrics Trillium Horizon120 broadband seismometers. The M4.9 earthquake in Louisiana is about 368 km away from the Texas test site.

Data analysis

Figure 2 compares the instrument responses of the Nanometrics Trillium Horizon120 broadband seismometer and a standard 5 Hz geophone. Geophones are commonly used in active seismic surveys and microseismic monitoring, where the dominant signal frequencies typically exceed 10 Hz. Because the sensitivity of a geophone decreases rapidly below its natural frequency, it is generally assumed that geophones are not suitable for recording low-frequency seismic signals. However, the low-frequency response of a geophone can be partially recovered through deconvolution by removing the instrument response from the recorded data.

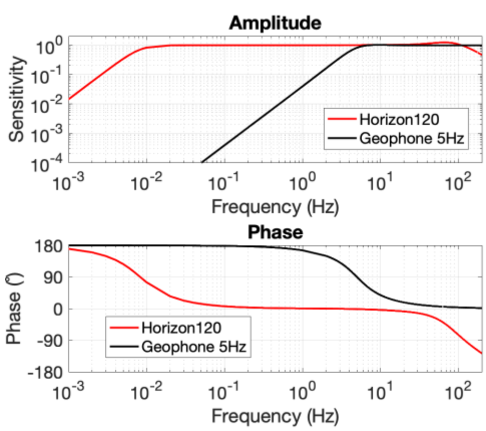

Figure 2: Instrument response comparison between the Trillium Horizon120 broadband seismometer (red) and the standard 5 Hz geophone (black).

As shown in Figure 3, the raw waveform recordings from the geophones exhibit significantly smaller amplitudes than those recorded by the broadband seismometer. This difference is expected because the geophone's sensitivity decreases substantially at frequencies below its natural frequency.

Figure 4 presents the waveform and spectral comparisons after removing the instrument responses of both the seismometer and the geophone. For the broadband seismometer, a stopband frequency of 0.005 Hz and a passband corner frequency of 0.0083 Hz were applied in the lower transition band. For the geophone data, a stopband frequency of 0.04 Hz and a passband corner frequency of 0.06 Hz were used. For both sensors, the upper passband corner frequency and stopband edge were set to 40 Hz and 45 Hz, respectively. After removing the instrument responses, the corrected waveforms recorded by the geophone and the seismometer show strong agreement. The amplitude spectra of the corrected geophone recordings match those of the broadband seismometer down to approximately 0.08 Hz.

Figures 5 and 6 show consistency checks for the geophone and seismometer recordings. For the geophone data, the cross-correlation coefficients among the three geophones are 0.9985, 0.9984, and 0.9975 for the N, E, and Z components, respectively. For the two broadband seismometers, the cross-correlation coefficients are 0.9962, 0.9979, and 0.9996 for the N, E, and Z components. These high correlation values indicate excellent consistency among sensors of the same type. Therefore, in the following analysis we only compare the recordings from one representative geophone and one broadband seismometer.

Figure 7 compares the corrected waveforms under three different processing scenarios. The top row shows the waveforms after removing the instrument responses, which we refer to as the full-spectrum case, although the two sensors use different lower stopband frequencies. The middle row shows the waveforms after applying a 0.1 Hz low-pass filter, while the bottom row shows the waveforms after applying a 0.1~40 Hz band-pass filter. Table 1 summarizes the cross-correlation coefficients calculated using the data in the 0~700 s time window for these three scenarios.

For the full-spectrum case, the cross-correlation coefficients exceed 0.99 for all three components, indicating strong agreement between the geophone and seismometer recordings despite some spectral differences at the lowest frequencies, as shown in Figure 4. In contrast, the differences in the 0.1 Hz low-pass filtered waveforms highlight the limitations of geophones in detecting very low-frequency signals. When signals below 0.1 Hz are removed, the cross-correlation coefficients exceed 0.999 for all three components. This result indicates that, after correcting for the instrument response, a 5 Hz geophone can reliably record seismic signals above 0.1 Hz.

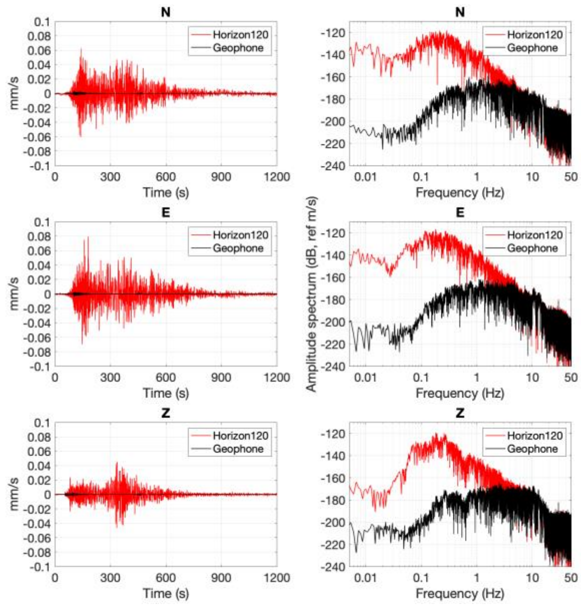

Figure 3: Raw waveform recordings (left) and amplitude spectra (right) from the broadband seismometer (red) and geophone (black).

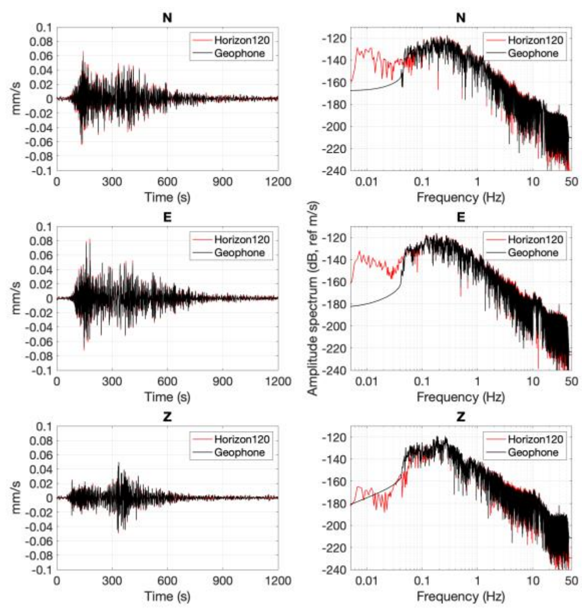

Figure 4: Comparison after removing the instrument responses of both sensors.

Table 1: Cross-correlation coefficients of the seismometer and geophone data in different filtering conditions.

	N	E	Z
Full spectrum	0.9922	0.9968	0.9911
0.1Hz low-pass filtered	0.7092	0.9216	0.7944
0.1~40Hz band-pass filtered	0.9992	0.9995	0.9992

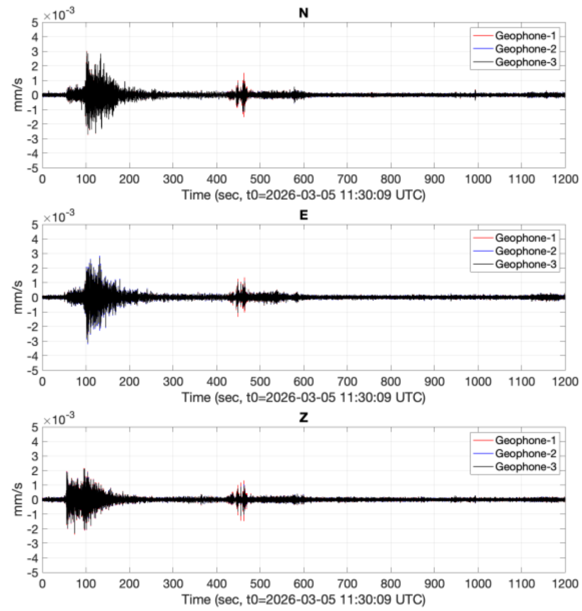

Figure 5: Consistency check among the three geophones showing high cross-correlation.

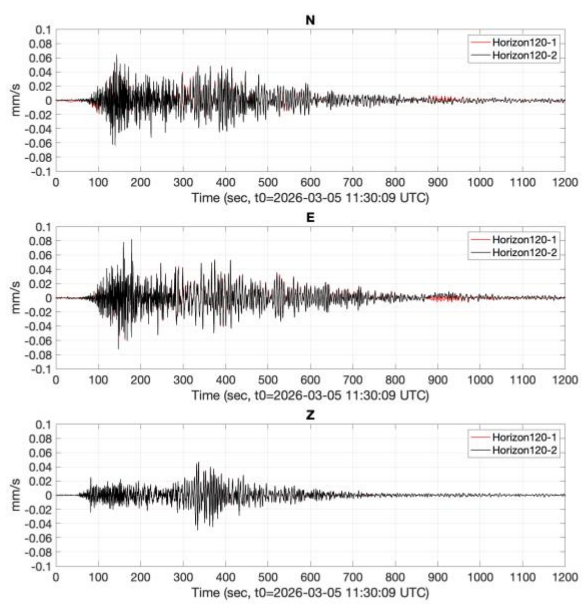

Figure 6: Consistency check between the two broadband seismometers.

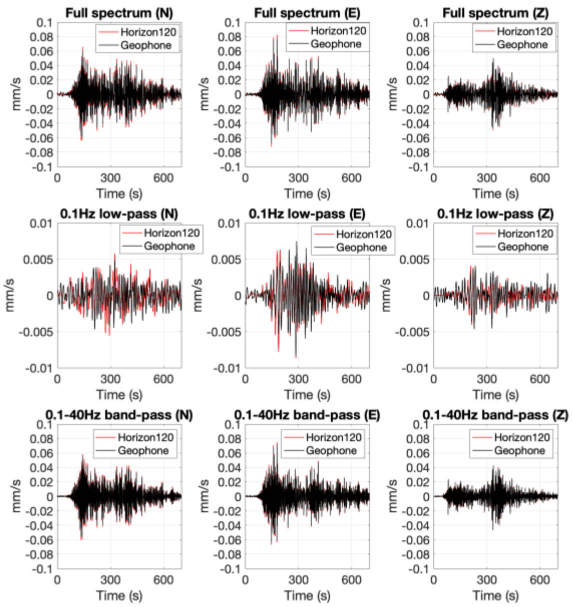

Figure 7: Comparison of waveforms under different filtering conditions.

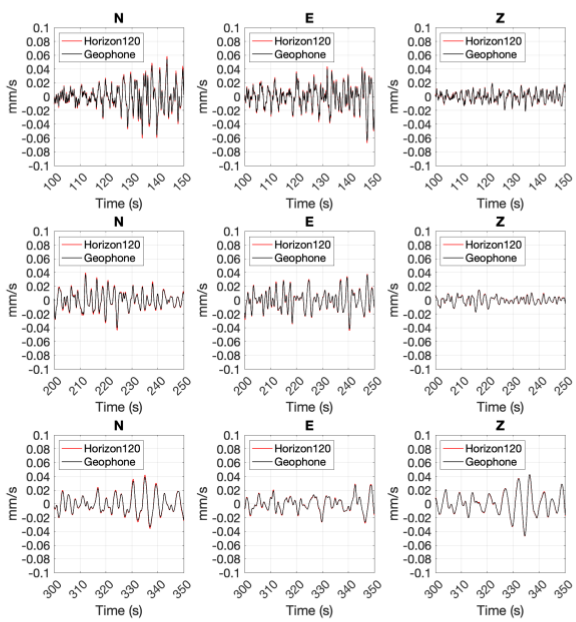

Figure 8: Expanded views of the 0.1–40 Hz band-pass filtered waveforms.

Figure 8 shows expanded views of the 0.1–40 Hz band-pass filtered waveforms within three different 50 s time windows. In these windows, the geophone and broadband seismometer recordings are nearly indistinguishable, demonstrating that the geophone can exactly reproduce the broadband waveform characteristics within this frequency band.

Noise analysis

Figure 9 compares the self-noise levels of the Trillium Horizon120 broadband seismometer and the 5 Hz geophone. Below about 15 Hz, the intrinsic noise level of the Trillium Horizon120 is lower than that of the geophone. However, the geophone's self-noise remains below the New Low Noise Model (NLNM) down to approximately 0.17 Hz. Above 15 Hz, the seismometer exhibits higher self-noise than the geophone, indicating that geophone is more suitable for monitoring small seismic events (e.g., M<2). In many field environments, ambient seismic noise is significantly higher than the intrinsic noise of either sensor. As a result, the practical detection limit is often controlled by environmental noise rather than instrument noise. The test site of this study is located near an urban area and is therefore considered a relatively high-noise environment. Despite this, the geophones were still able to detect clear seismic signals that are consistent with those recorded by the broadband seismometers down to approximately 0.08 Hz for the M4.9 earthquake located more than 300 km away. For regional earthquakes, significant seismic energy below 1 Hz is typically generated only by relatively large events (e.g., M4 and above). Such events can produce strong ground motions that significantly exceed the self-noise level of geophones at moderate distances (e.g., ~100 km). Therefore, for seismic signals above 0.1 Hz, a 5 Hz geophone can provide performance comparable to that of a broadband seismometer when instrument response is properly removed.

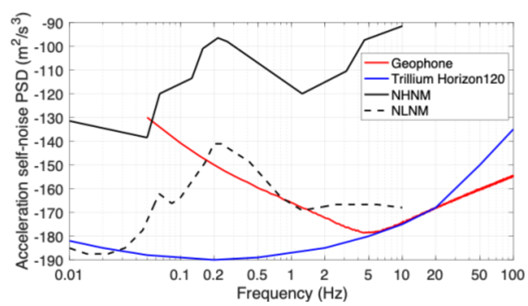

Figure 9: Comparison of the self-noise levels of the Trillium Horizon120 (blue) and the 5 Hz geophone (red). The sold and dashed black curves respectively represent the New High Noise Model (NHNM) and New Low Noise Model (NLNM).

Conclusion

This study demonstrates that standard 5 Hz geophones can provide recordings comparable to broadband seismometers for regional earthquake signals above approximately 0.1 Hz when instrument responses are corrected. Waveform correlations exceeding 0.999 were observed in the 0.1–40 Hz band. Because geophones are significantly less expensive than broadband sensors, they offer a promising option for deploying dense seismic monitoring networks at substantially lower cost.