CAN 5-HZ GEOPHONES REPLACE BROADBAND SEISMOMETERS FOR INJECTION-INDUCED SEISMICITY MONITORING?

Xinding Fang, Siwei Li, Tianrun Chen & Nicholas Brooks, SensorEra Inc, Houston, Texas, USA

ABSTRACT

Broadband seismometers are widely used in regional and global seismic monitoring networks due to their ability to record ground motion over a broad frequency range. However, their relatively high cost limits the spatial density of monitoring networks, particularly for temporary deployments over large areas. In contrast, conventional geophones are inexpensive, rugged and widely available. They are sometimes considered, however, unsuitable for recording low-frequency seismic signals because their sensitivity decreases rapidly below their natural frequency. We investigate whether the effective bandwidth of a standard 5 Hz geophone can be extended through instrument response correction. Two test sites were established in Texas.

The first site, in Needville, TX, includes two broadband Nanometrics Trillium Horizon 120 seismometers and three standard 5 Hz geophones in a collocated configuration for direct comparison. During the experiment, a M4.9 earthquake in Louisiana, ~368 km from the site, provided an opportunity to compare recordings of a regional event. Raw waveform comparisons show that geophone amplitudes are significantly attenuated below their natural frequency. However, after removing instrument responses, the corrected geophone waveforms closely match those recorded by the broadband seismometer. Cross-correlation coefficients exceed 0.999 within the 0.1–40 Hz frequency band. Spectral analysis further demonstrates that usable signal energy can be recovered down to approximately 0.08 Hz from the geophone data.

The second test site, located in Big Spring, TX, includes a 5 Hz geophone installed adjacent to a public seismic station equipped with a broadband seismometer. A one-year dataset was analyzed to evaluate event detection performance, waveform consistency, and source parameter estimation across a wide range of magnitudes and distances (up to ~300 km). The results show that, after instrument response correction, waveform cross-correlation coefficients exceed 0.85 for events with magnitudes between M0.4-M3.3 within a 30 km radius, and exceed 0.9 for events >M3 at distances up to 300 km, provided that the signal-to-noise ratio is greater than 2.

These results confirm that low-cost 5 Hz geophones can achieve performance comparable to broadband seismometers for regional seismicity monitoring applications when the signals of interest are above 0.1 Hz. This suggests that dense seismic monitoring networks can be deployed at substantially lower cost using geophones while maintaining high data quality.

COMPARISON BETWEEN STANDARD GEOPHONE AND BROADBAND SEISMOMETER

5Hz Geophone

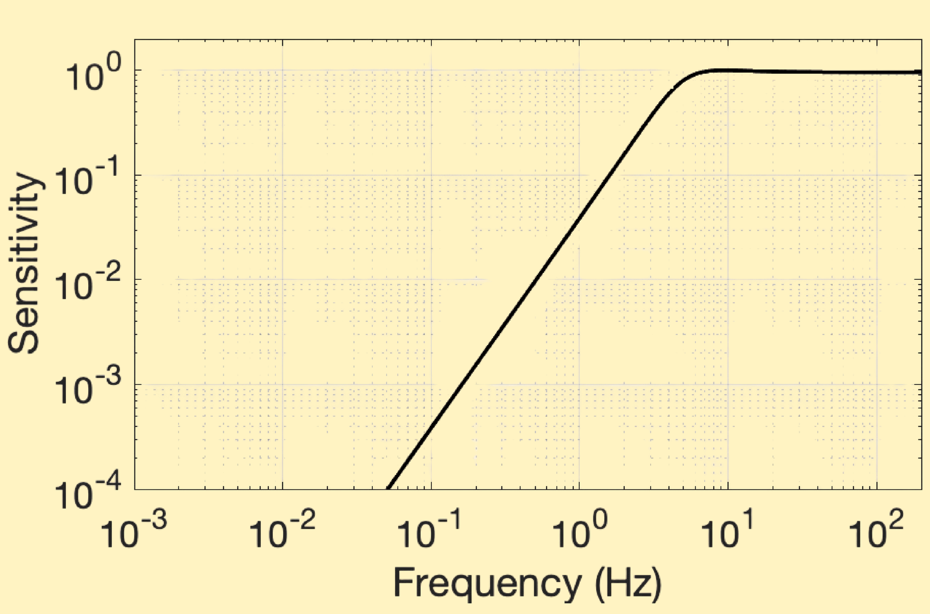
Pros
- Low cost $
- Easy deployment and minimum maintenance

Cons
- Sensitivity decreases below natural frequency

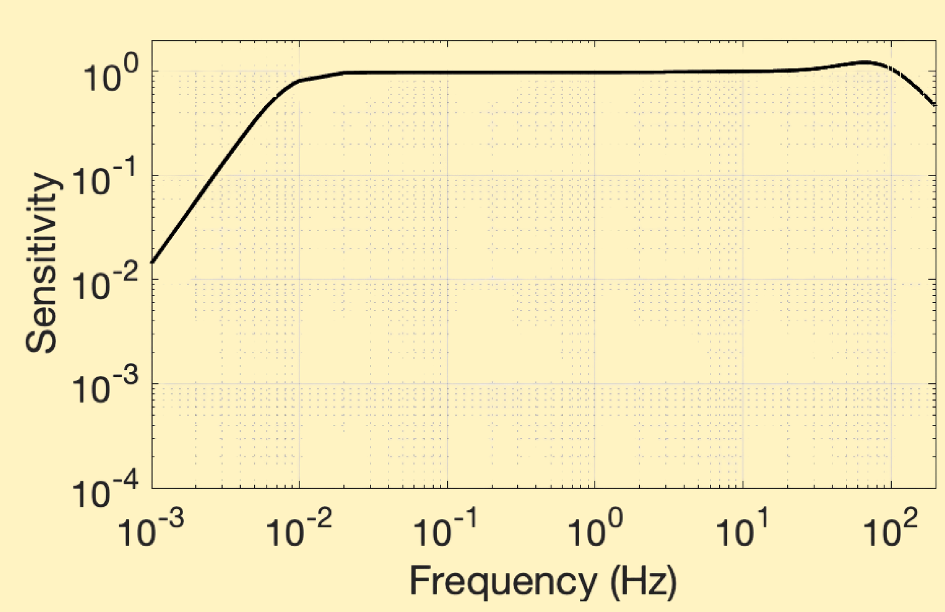
Broadband Seismometer

Pros
- Flat response to very low frequencies

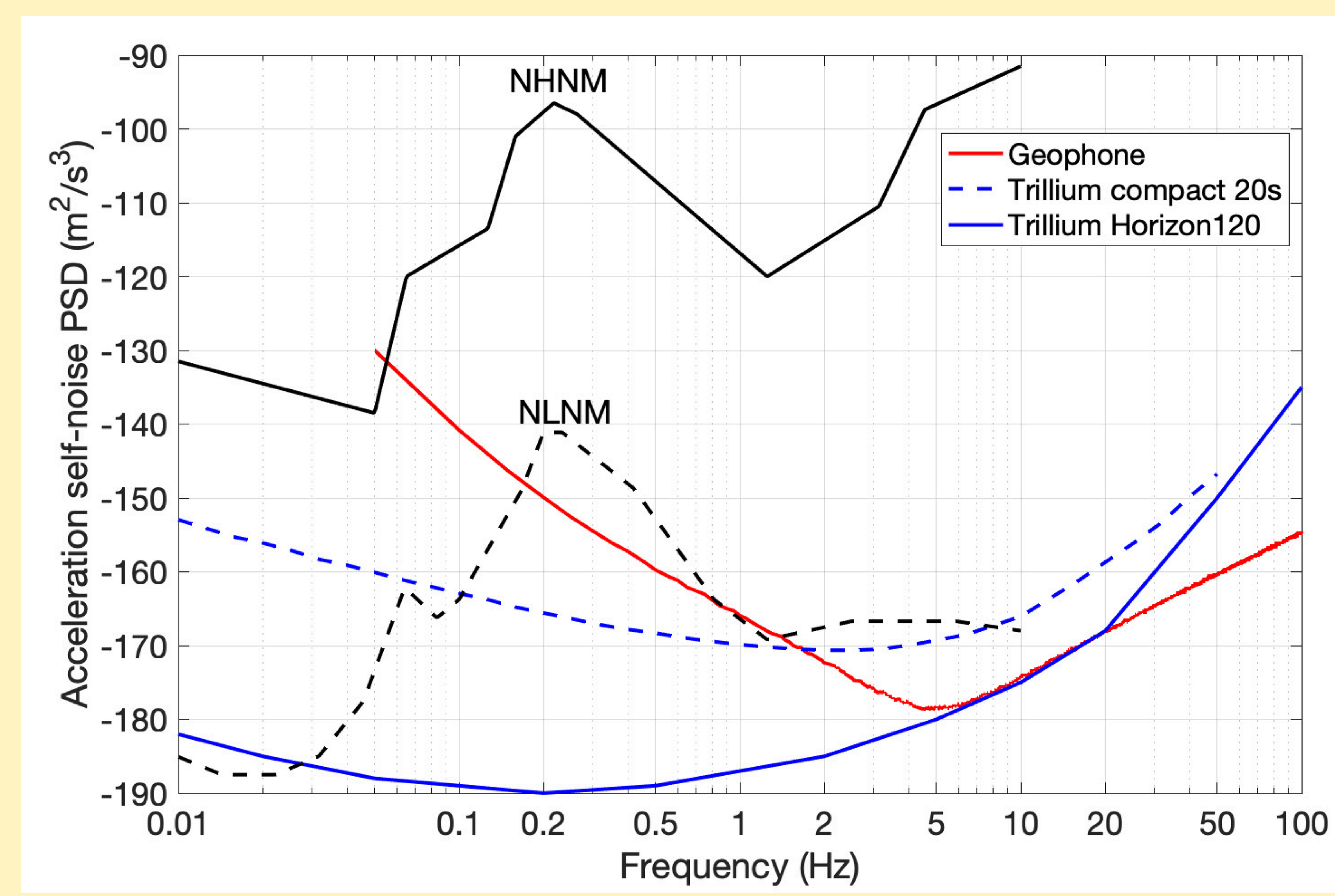
Cons
- High cost $$$
- Requires careful installation & regular maintenance



5Hz geophone response function



120s broadband seismometer response function



NLNM: New Low Noise Model **NHNM:** New High Noise Model

Geophone noise level
- Below the NLNM at frequencies > 0.17 Hz
- Below the NHNM at frequencies > 0.1 Hz.

Trillium Horizon 120 noise levels:
- Below the NLNM at frequencies > 0.03 Hz

Trillium compact 20 noise levels:
- Below the NLNM at frequencies > 0.1 Hz

Geophones have a lower noise level at frequencies >15 Hz, suggesting that they are better suited for monitoring of local and regional small-to-moderate seismic events.

TEST SITES AND INSTRUMENTATION

Test Site 1: Needville, TX

Two Nanometrics Trillium Horizon120 broadband seismometers and three standard 5Hz geophones were installed in a co-located configuration in our Needville test site for direct side-by-side comparison.

Event analyzed:
Louisiana M4.9 earthquake (3/5/2026, ~368 km)

Test Site 2: Big Spring, TX

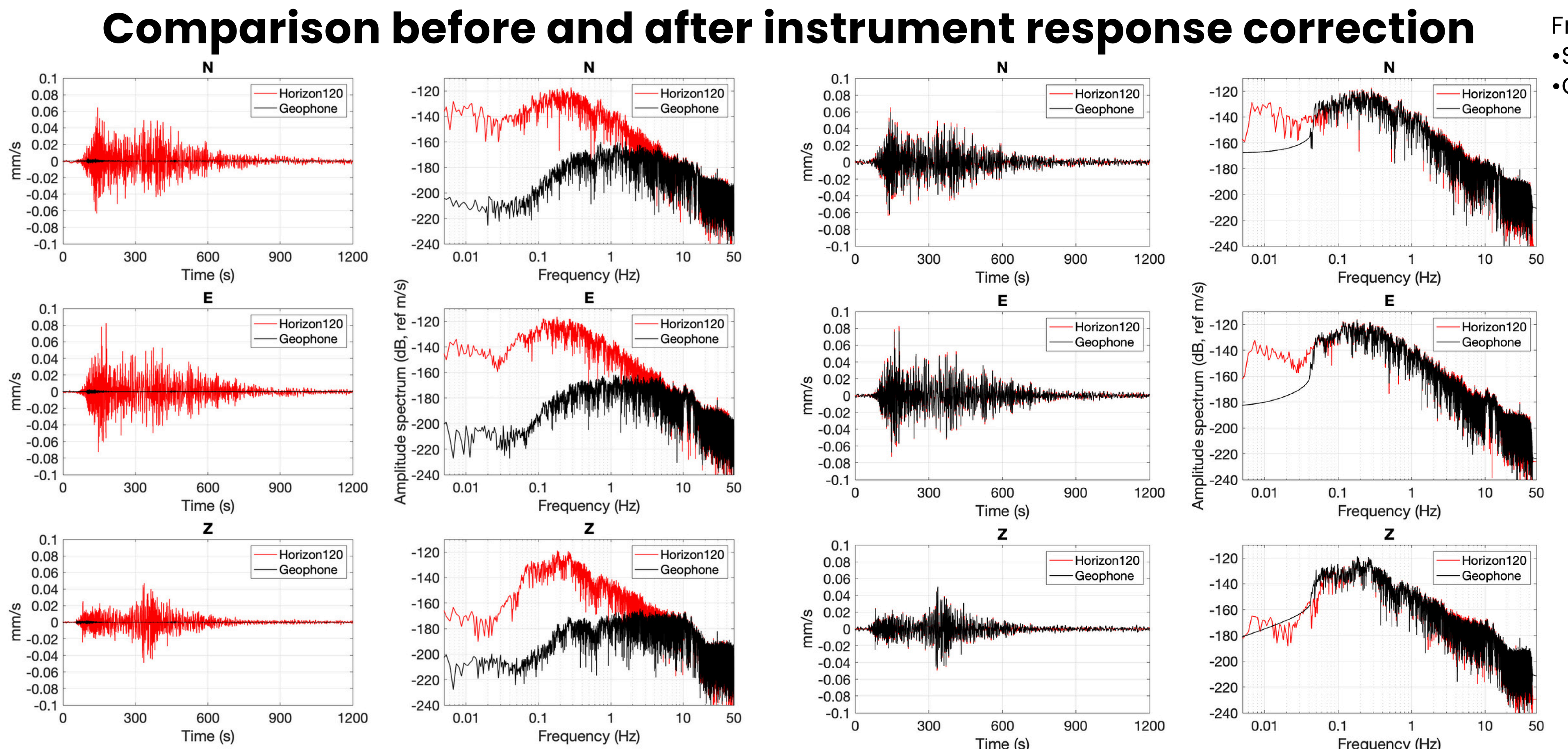
Station S8.MB01 (5Hz geophone) was deployed adjacent to the TexNet station TX.MB12 (broadband seismometer).

Data from both stations are publicly available through the IRIS Data Management Center (IRIS DMC).

Events analyzed:
448 local events within 30km distance
93 regional events with M ≥ 3.0 within 300km

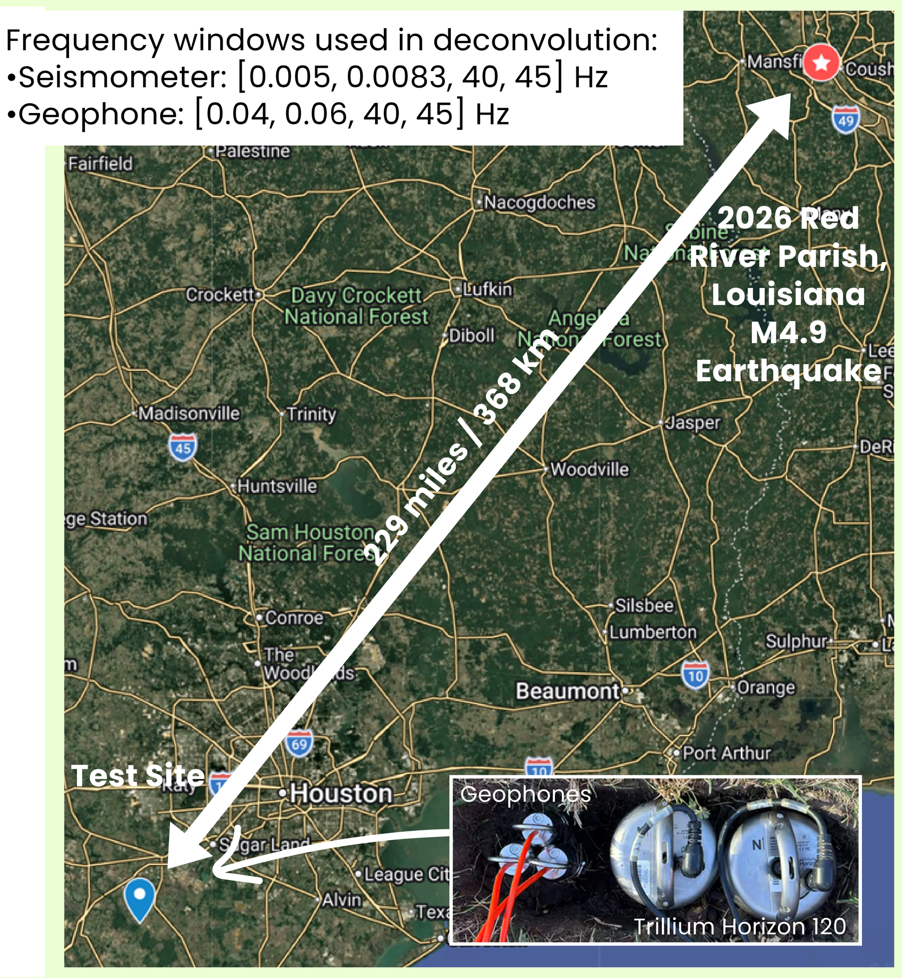
STUDY OF THE DATA FROM A M4.9 EARTHQUAKE FROM NEEDVILLE SITE

Comparison before and after instrument response correction



Raw data **before** instrument response removal ⟶ **After** instrument response removal

Frequency windows used in deconvolution:
•Seismometer: [0.005, 0.0083, 40, 45] Hz
•Geophone: [0.04, 0.06, 40, 45] Hz

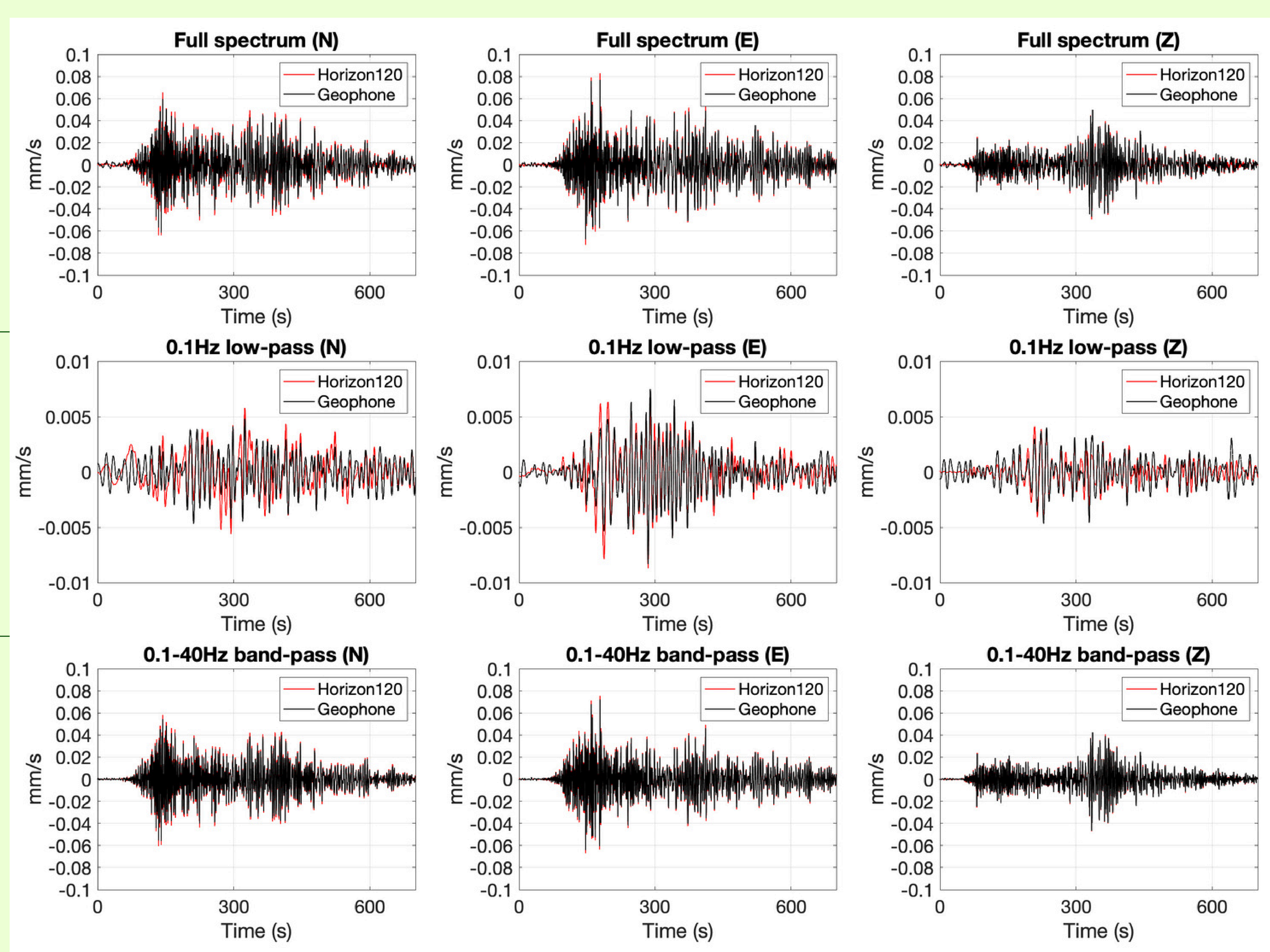


The broadband sensors were connected to REF Tek 130 digitizers sampling at 100Hz, while the geophones were connected to a SensorEra digitizer sampling at 250 Hz. On March 5, 2026 a M4.9 earthquake occurred in Louisiana at coordinates (32.038°N, 93.415°W) and a depth of about 11 km. The epicentral distance from the test site was approximately 368 km. This earthquake provided a suitable dataset for evaluating the performance of the two sensor types.

Left: 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.

Right: 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.

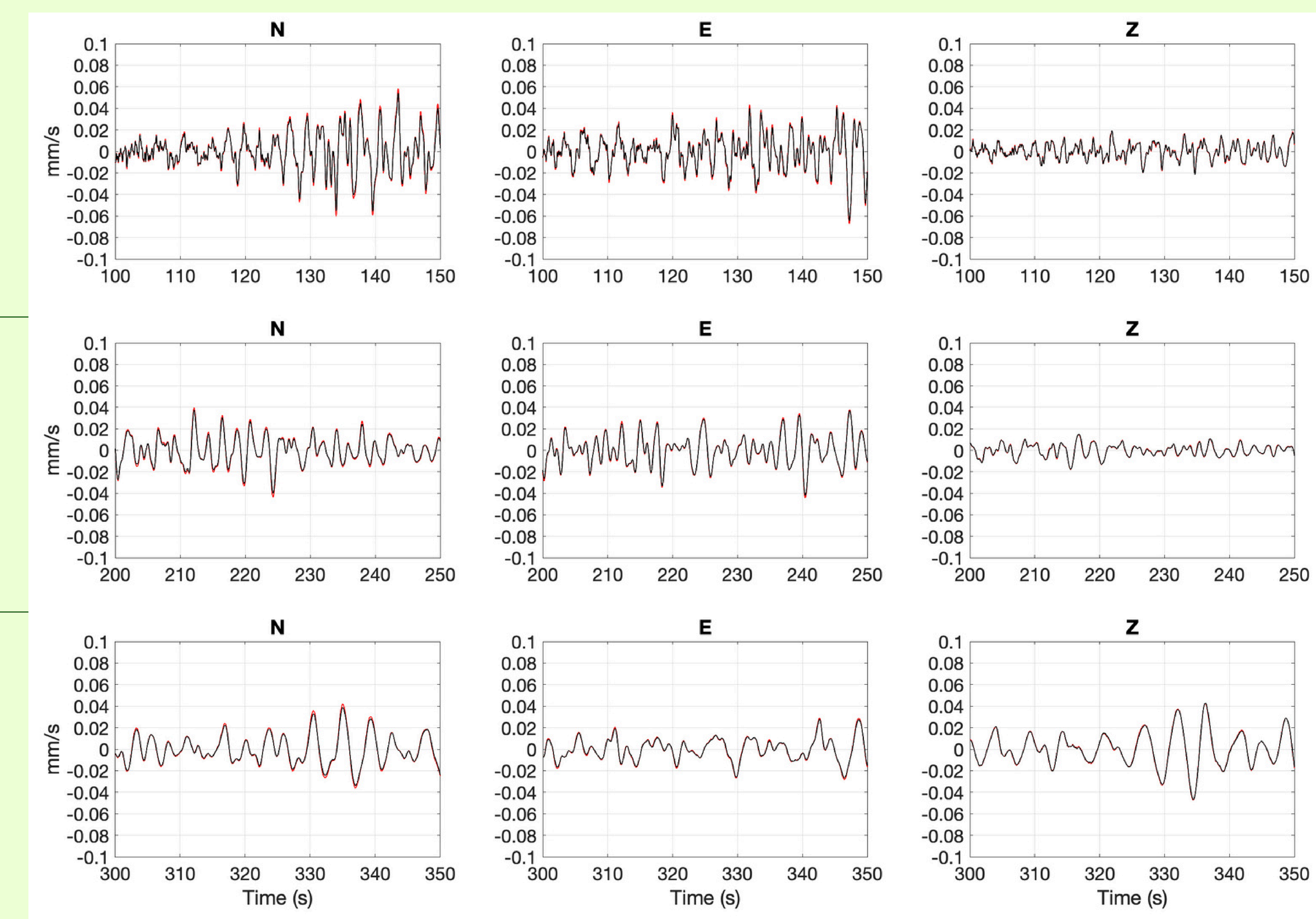
Waveform cross-correlation analysis



	Cross-correlation coefficients:	
Full spectra	•N: 0.9922 •E: 0.9968 •Z: 0.9911	**>0.99**
0.1Hz low-pass	•N: 0.7092 •E: 0.9216 •Z: 0.7944	
0.1~40Hz band-pass	•N: 0.9992 •E: 0.9995 •Z: 0.9992	**>0.999**

Waveform cross-correlation coefficients **exceed 99.9%** for all components after filtering above 0.1Hz

Expanded views of the waveforms (0.1~40Hz band-pass)

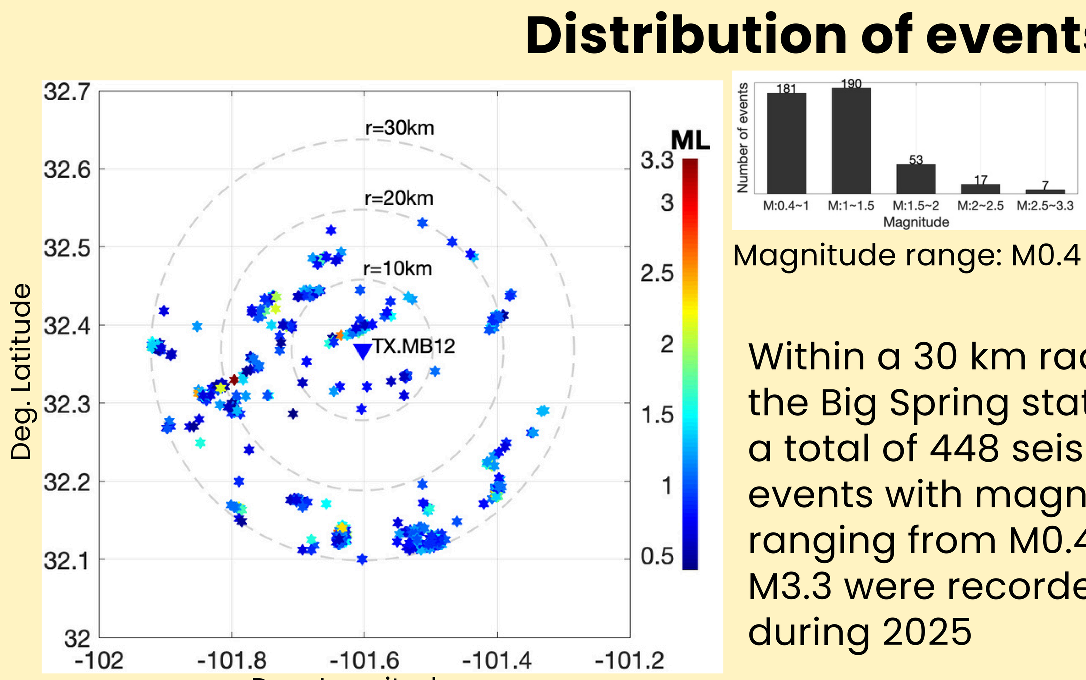


Time window: 100 ~ 150 s; 200 ~ 250 s; 300 ~ 350 s

Seismometer (red) versus Geophone (black)

ANALYSIS OF ONE YEAR OF SEISMIC EVENT DATA FROM BIG SPRING SITE

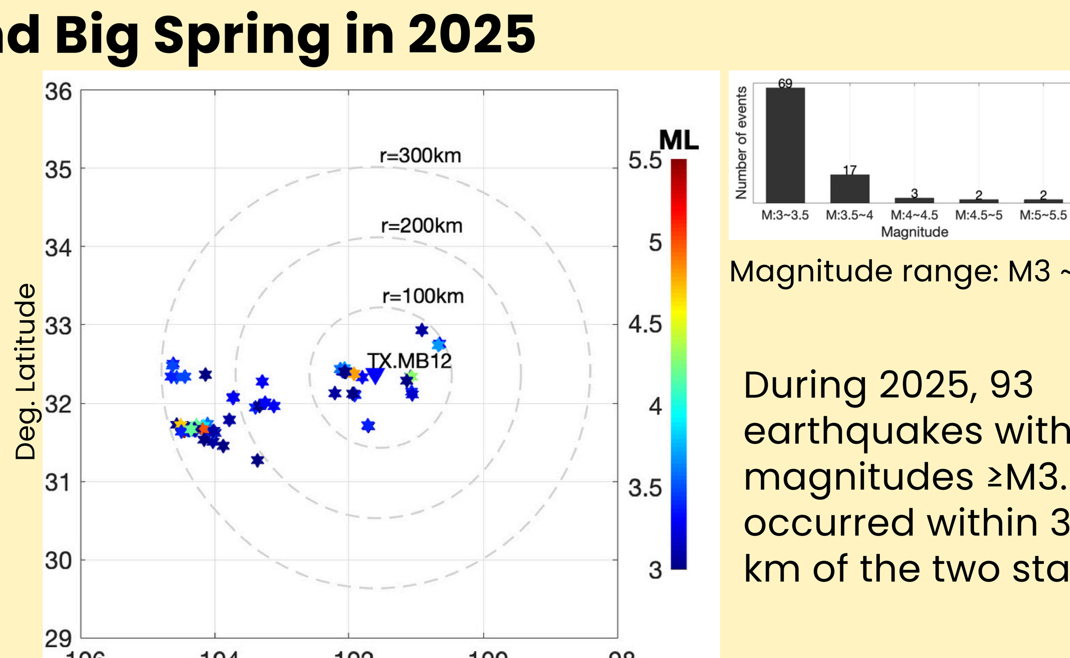
Distribution of events around Big Spring in 2025



Magnitude range: M0.4 ~ M3.3

Within a 30 km radius of the Big Spring stations, a total of 448 seismic events with magnitudes ranging from M0.4 to M3.3 were recorded during 2025

448 local events within 30km



Magnitude range: M3 ~ M5.4

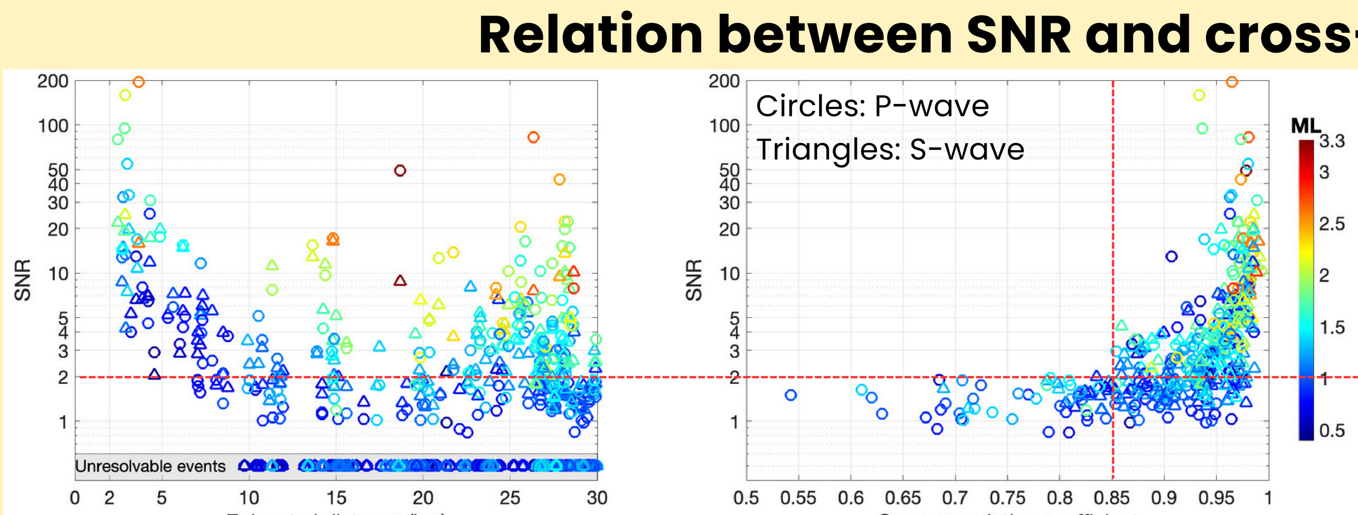
During 2025, 93 earthquakes with magnitudes ≥M3.0 occurred within 300 km of the two stations

93 regional events with M≥3.0 within 300km

Analysis workflow

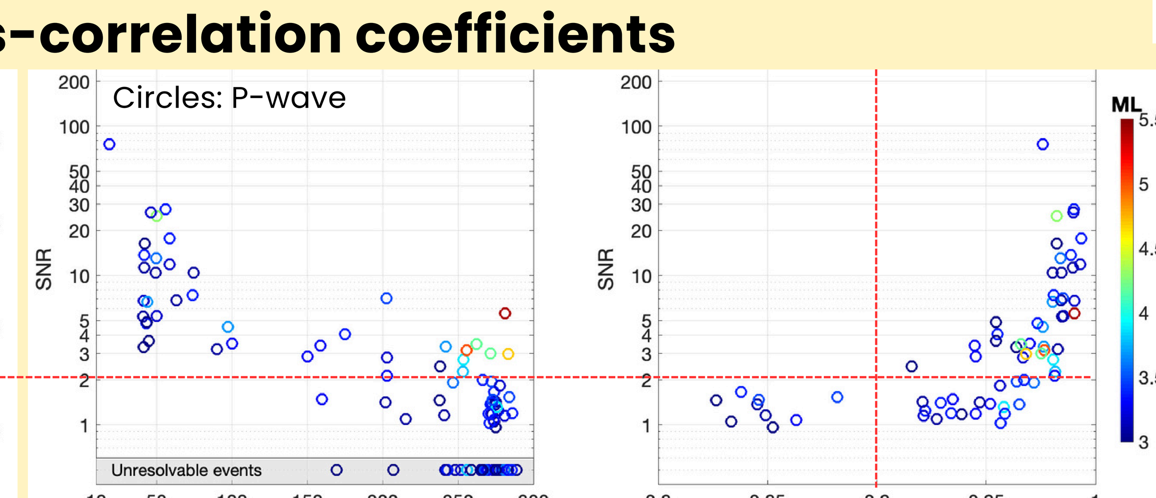
- Download event waveforms from IRIS DMC for both TX.MB12 and S8.MB01 based on TexNet's earthquake catalog
- Manually pick the P- and S-wave onset times for each event
- Calculate the P- and S-wave signal-to-noise ratios (SNRs)
  - P-wave SNR: ratio of the standard deviations of the vertical-component data in 1s windows after and before the P-wave onset.
  - S-wave SNR: root-mean-square of the SNRs from the two horizontal components.
- Compute the cross-correlation coefficients of the P- and S-wave waveforms (after instrument response removal) recorded at TX.MB12 (seismometer) and S8.MB01 (geophone)
- Compare the source parameters (based on Brune's source model) derived from the data recorded at TX.MB12 and S8.MB01

Relation between SNR and cross-correlation coefficients



448 events within 30km distance

Cross-correlation coefficients between the data recorded by TX.MB12 and S8.MB01 exceed 0.85 when SNR>2.



93 events with M≥3.0 within 300km

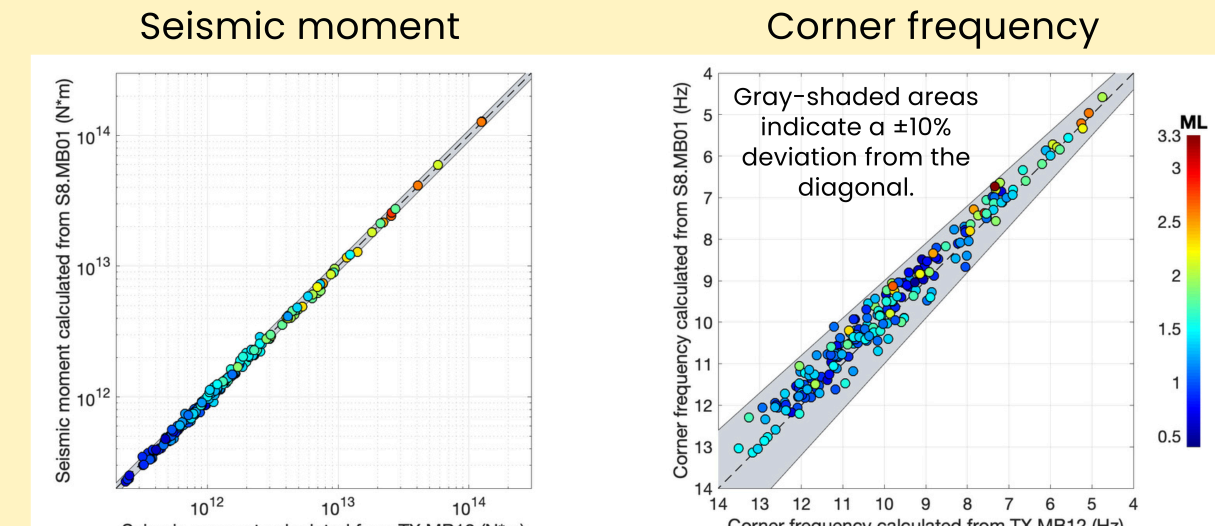
Only P-wave data are analyzed for distant events as S-waves are strongly affected by surface waves at large distances.

Cross-correlation coefficients >0.9 when SNR>2.

Comparison of estimated source parameters

For events with clear S-wave arrivals (within 30km), source parameters were derived independently from TX.MB12 (seismometer) and S8.MB01 (5Hz geophone) recordings using Brune's source model (Brune, 1970).

Seismic moment — Corner frequency



The differences in seismic moment and corner frequency derived from the TX.MB12 and S8.MB01 data are within approximately 10% and can largely be attributed to the influence of high-frequency surface noise.

SUMMARY

- Standard 5Hz geophones, after instrument response correction, record regional earthquake signals (≥ 0.1 Hz) that are highly comparable to those from broadband seismometers.
- Due to their substantially lower cost, 5Hz geophones provide a practical and efficient solution for building dense seismic monitoring networks.