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Application of a Seismic Sensor Temperature Testbed at Sandia National Laboratories

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Abstract

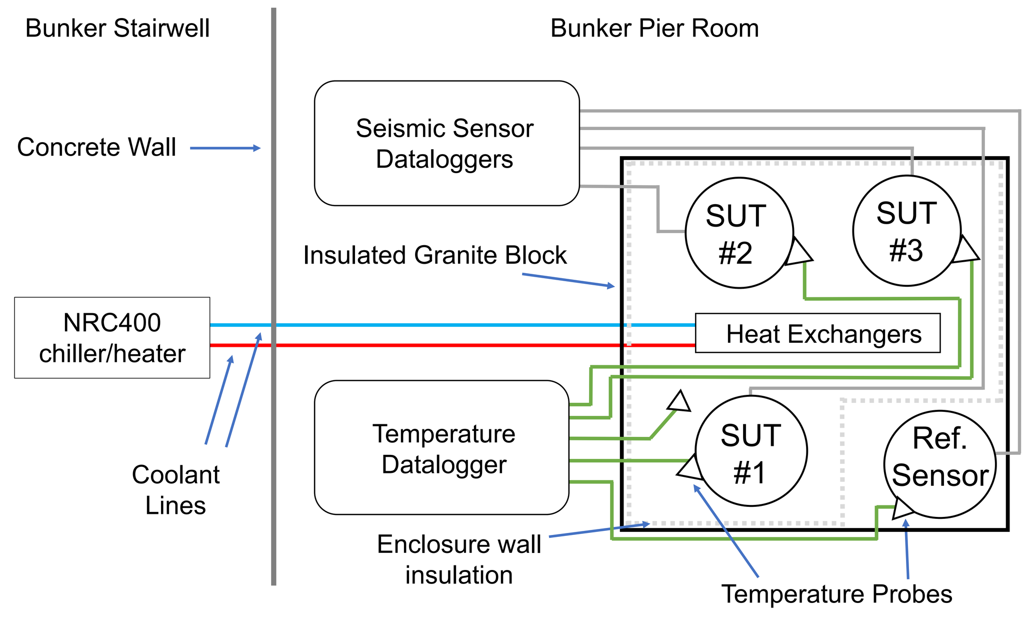
The Facility for Acceptance, Calibration and Testing (FACT) at Sandia National Laboratories has been a valued resource for the U.S. monitoring community for decades. The FACT site hosts a number of capabilities focused on component evaluation, some of which leverage custom designed hardware, refined and improved upon at Sandia. We are investigating the performance of a seismic sensor temperature testbed developed and fabricated at Sandia. The testbed leverages a highly efficient insulated enclosure which houses sensors under test installed on a granite pier shared with a reference seismic sensor exposed to relatively-stable ambient temperatures of the FACT site bunker. The insulated enclosure is cooled or heated, via a PID-controlled, Peltier-based, remote thermal unit which pumps coolant through copper/aluminum plate heat exchangers situated in the insulated enclosure. Individual sensors under test are further insulated to minimize temperature changes induced by the chiller unit's regulation of temperature of the coolant circulated through the heat exchangers. Precision thermistors are placed on the reference sensor and sensors under test to record the temperature differential to which the sensors under test are exposed.

We show preliminary results of sensor performance comparisons between sensors held at temperatures offset from ambient and a reference sensor exposed to ambient temperatures of the FACT site bunker.

System Components

The seismic sensor temperature testbed resides in the FACT site underground bunker. The bunker pier room offers just under a meter of overburden and modest temperature stability.

The insulated granite block, upon which the sensors are installed, is located on the contrete pier. The NRC-400 remote heater/chiller unit is situated in the bunker stairwell to best isolate the sensors from the heat extracted or added to the ambient air and to minimize the noise effects of its fans during operation.

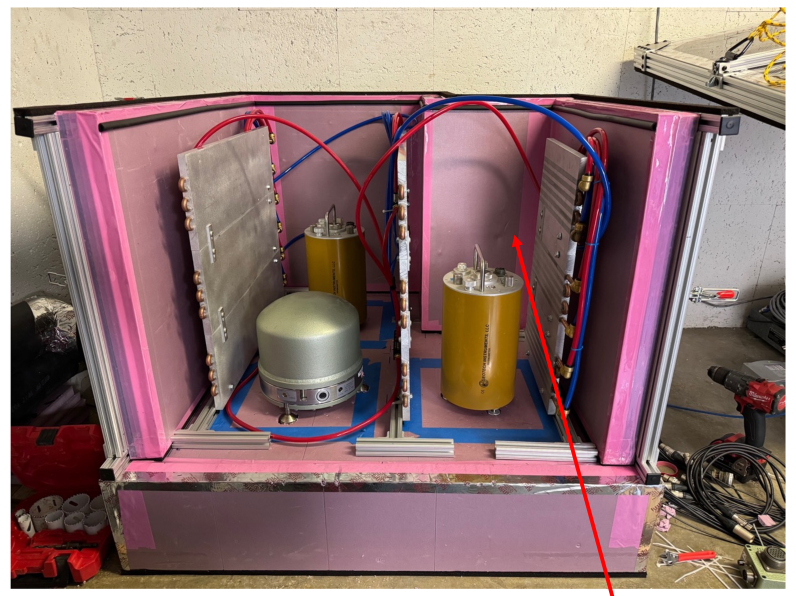


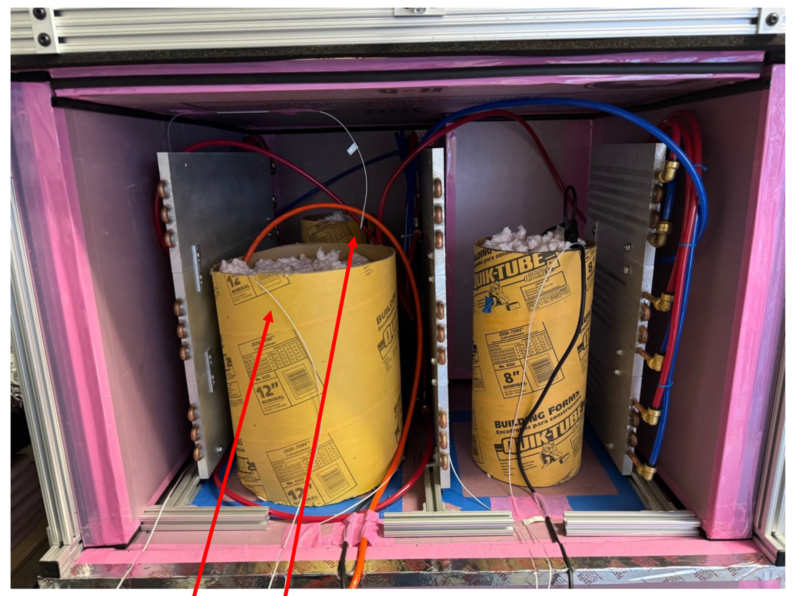
The Laird Thermal NRC-400 (left) is a PID-thermostatically controlled heater/chiller unit. There is no refrigerant compressor as the unit relies upon the Peltier effect for heat transfer. The unit is capable of adding or extracting up to 400 W of heat and, under steady state conditions, can maintain set temperature to within 0.05 C.

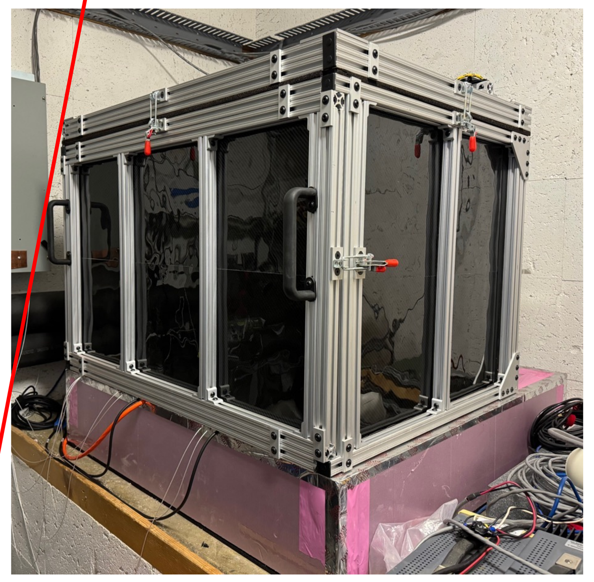
A water/anti-freeze coolant mixture is pumped, in a closed loop, from the NRC-400's coolant reservoir through insulated pipe to aluminum/copper heat exchangers within the enclosure.

Vacuum insulated panels, similar to the one on the right, serve as the primary insulating material in the testbed's enclosure. Even though the panel is just under 1 inch in thickness, it offers an effective thermal resistance, or an "R-value", of over 30 for the larger panels utilized to construct the enclosure. To place this into perspective, common home construction, extruded polystyrene foam (the pink boards, also used in the testbed), would require a thickness of at least 6 inches to have an equivalent thermal resistance. The vacuum insulated panels are fragile; we laminate them between two carbon-fiber sheets and place plastic channel around their perimeter.

Test Configuration







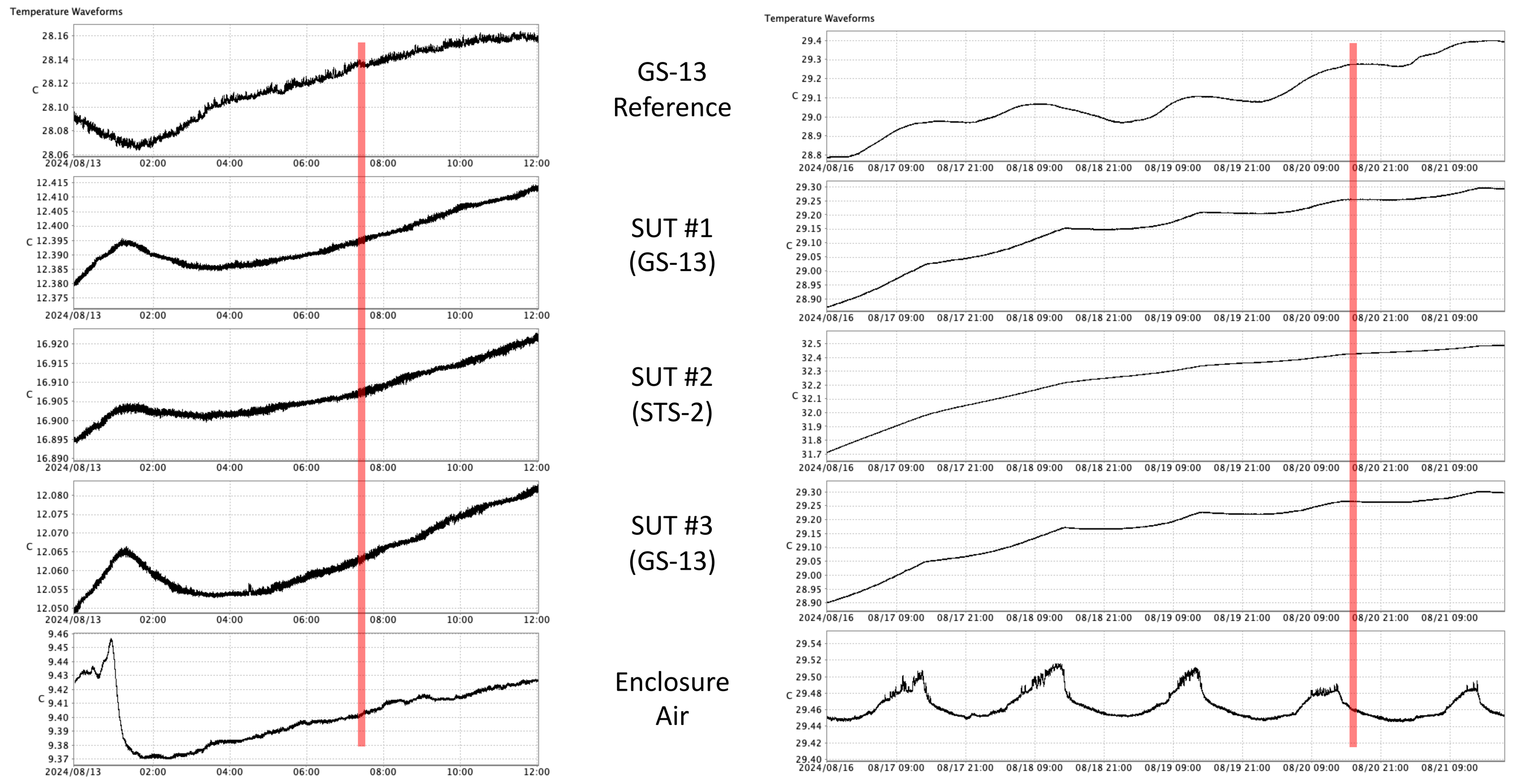
GS-13 reference sensor:

- Positioned immediately behind the right sensor in the above photo, outside of the enclosure, yet still on the insulated granite block to ensure maximum signal coherence.
- Uninsulated, directly exposed to temperature fluctuations of the bunker.

The sensors under test are further insulated with cellulose insulation, to reduce the relatively small temperature variation inherent with use of the NRC-400.

Thermistors are attached to the top of each GS-13 and on the side of the sensor base of the STS-2 (the unpainted steel section where the sensor plug resides). A fifth thermistor samples enclosure air temperature.

Temperatures within the Testbed



The left group of plots include approximately 12 hours of data. The SUT temperatures varied no more than 0.011 C over the 7 hours of data available prior to the August 14th earthquake (left red line).

The right group of plots spans 4.5 days of data. Approximately 6 days had elapsed between changing the thermostat set point from 10 C to 30 C.

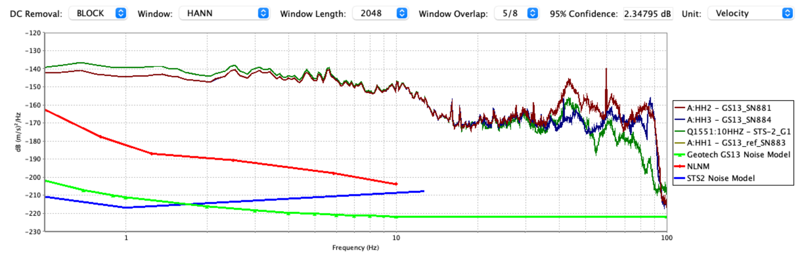
Notice, while the enclosure ambient air has essentially reached a stable equilibrium, requiring less and less heat to maintain temperature, the temperatures of the SUT are still slowly rising, though the rate of temperature rise diminishes significantly by the time of the August 20th earthquake (right red line). We suggest the gradual, asymptotic-like approach to temperature equilibrium may be indicative of the SUT conducting heat to the cooler granite block through the sensor feet.

Analysis and Results

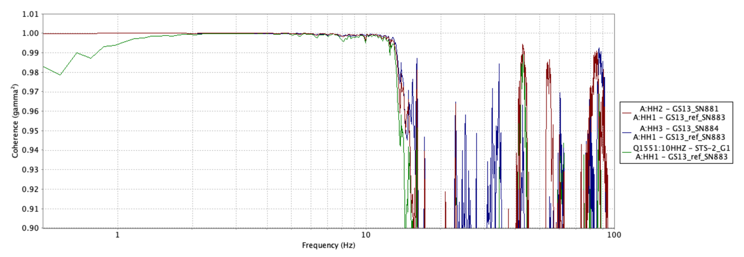
Below, on the left, are instrument-corrected power spectra density (PSD) plots of the August 14th event, the August 20th event, and typical night time background noise.

The earthquake PSD windows are 2.5 minutes in length and span the P and S wave arrivals of the earthquakes through the duration of the coda. The bottom PSD plot, utilizes a 2.5 hour window and illustrates typical night time background noise levels at the FACT site. Note the discrepancy between the power calculated for the STS-2 and the GS-13 sensors. We attribute this to the input impedance of the Guralp Affinity digitizer affecting the damping of the GS-13 sensors.

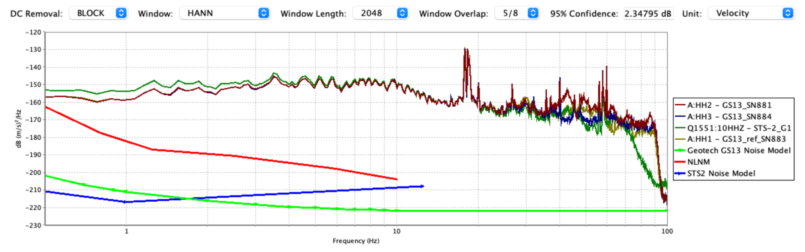
Below, on the right, are plots of coherence between the reference sensor and the sensors under test, for both earthquakes.



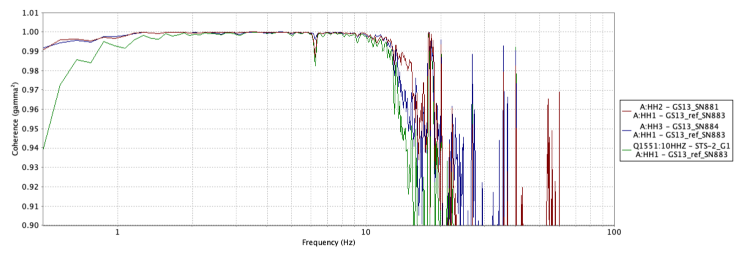
PSD of the August 14, M=3.6 earthquake @ 9.4 C



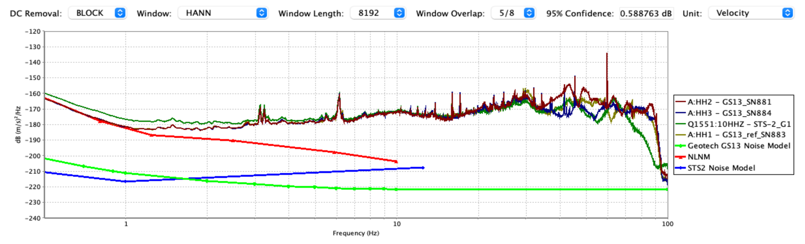
Coherence for the August 14, M=3.6 earthquake



PSD of the August 20, M=3.0 earthquake @ 29.5 C



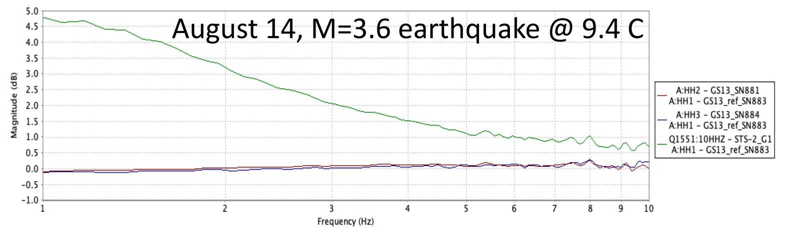
Coherence for the August 20, M=3.0 earthquake

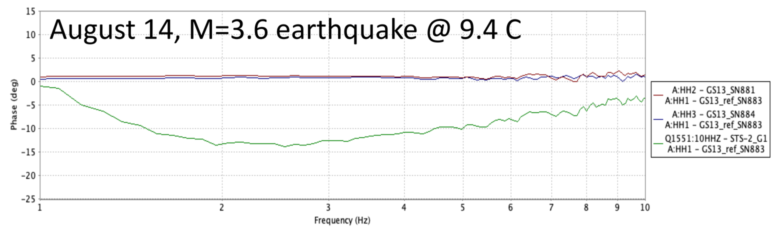


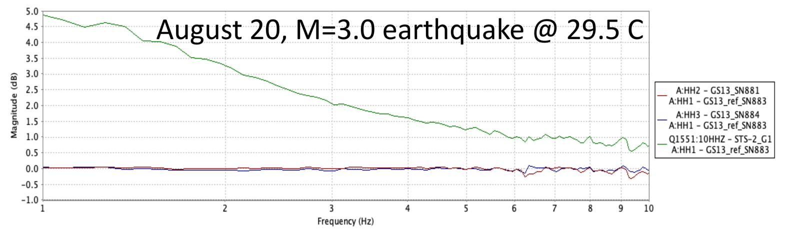
PSD of Quiet (Night-time) Background

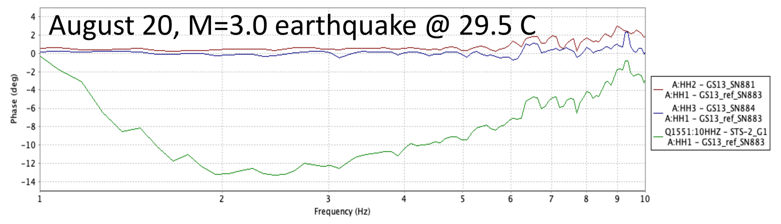
- Coherence between the reference sensors and the sensors under test for the August 14 event (top) exceeds 0.995 gamma^2 from 1.07 Hz through 9.96 Hz.
- Coherence for the August 20 event (bottom) exceeds 0.995 gamma^2 from 1.17 Hz through 9.18 Hz, with the exception of a drop between 6.15 Hz to 6.35 Hz for GS-13 # 881 and the STS-2.

Amplitude and Phase Response Residuals









The response residuals are calculated at 3.51 Hz.

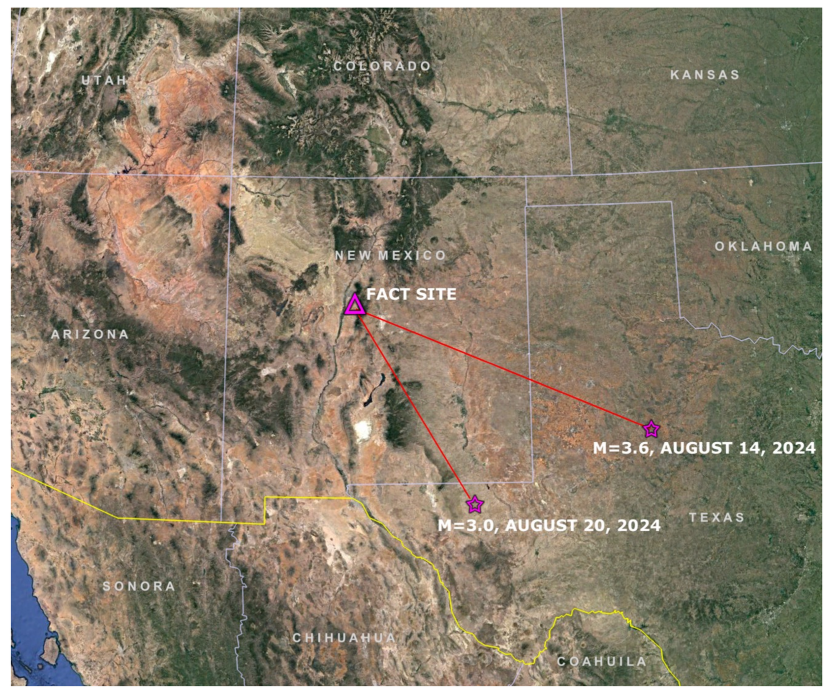
- 3.51 Hz is above the low frequency corner of a GS-13 (~ 1Hz) and well within the passband of the STS-2
- Signal power from the earthquakes at 3.51 Hz is relatively high, when compared against background noise levels
- Signal coherence at 3.51 Hz is among the highest available, 0.9998 gamma^2.

Environment Temperature (event date)	Rel. Amp. Sensitivity GS-13 #881	Rel. Phase GS-13 #881	GS-13 #881 Temp.	Rel. Amp. Sensitivity GS-13 #884	Rel. Phase GS-13 #884	GS-13 #884 Temp.	Rel. Amp. Sensitivity STS-2	Rel. Phase STS-2	STS-2 Temp.
29.5 C August 20	0.0138 dB	0.519 deg	29.25 C	-0.02833 dB	0.157 deg	29.26 C	1.774 dB	-10.95 deg	32.43 C
9.4 C August 14	0.1186 dB	1.105 deg	12.39 C	0.06599 dB	0.865 deg	12.06 C	1.776 dB	-11.64 deg	16.91 C
Differences	0.1048 dB	0.59 deg	-16.86 C	0.09432 dB	0.71 deg	-17.20 C	0.0023 dB	-0.69 deg	-15.52 C
Rate of Sensitivity Change	-0.072%/C	-0.035 deg/C		-0.063%/C	-0.041 deg/C		-0.001%/C	-0.044 deg/C	

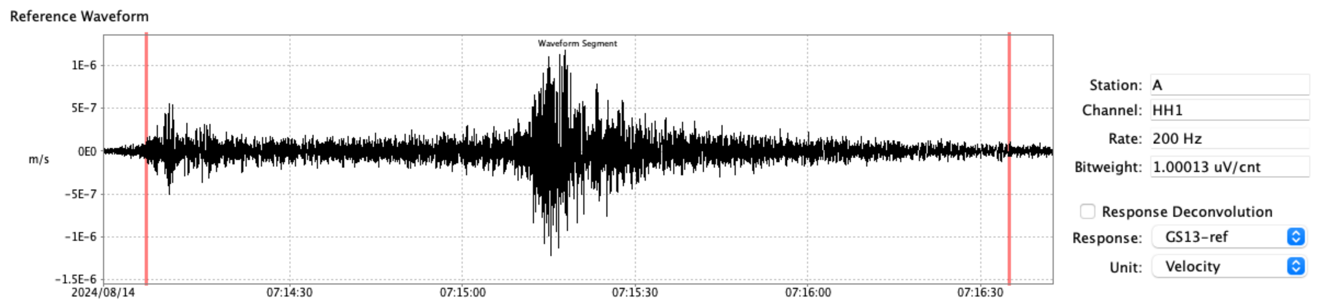
Energy Sources

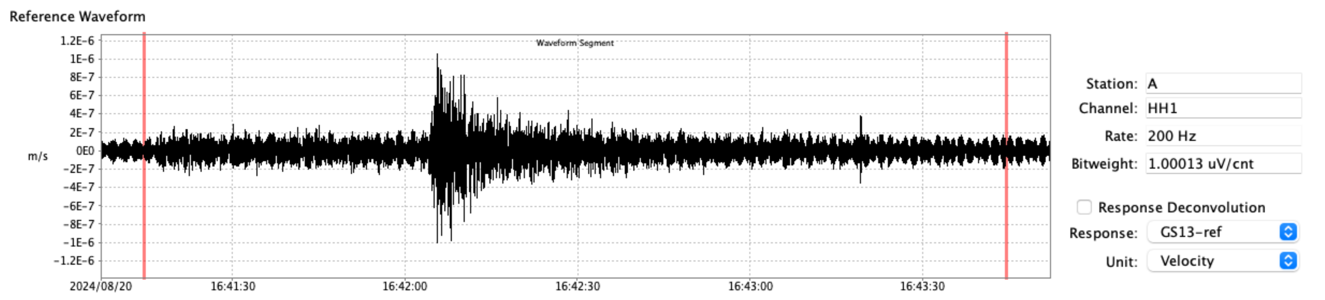
Two regional earthquakes, located in the Permian Basin, provide suitable signals to compare sensor sensitivity.

- M=3.6 event which occurred on August 14, 2024 at 07:12 UTC near Hermleigh, Texas, 584 km east-southeast of the FACT site.
- M=3.0 event on August 20, 2024 at 16:40 UTC near Toyah, Texas., 421 km south-southeast of the FACT site



Waveforms Utilized in the Analysis





Red lines denote start and end of 2.5 minute time window analyzed.

- August 14, M=3.6 event near Hermleigh, Texas
- August 20, M=3.0 event near Toyah, Texas. (Plotted data are band-pass filtered between 1 Hz and 16 Hz to provide visual clarity)

Conclusions and Future Work

- This preliminary evaluation has illustrated an apparent sensitivity of the GS-13 amplitude and phase response to the temperature of its environment. The evaluation though, has been made with observations at only two temperatures.
- The calculated rates of change in amplitude sensitivity and phase, range from -0.072%/C to -0.063%/C and -0.035 deg/C to -0.041 deg/C, respectively.
- Uncertainties in the measurements are not presently known and, if relatively large with respect to the rates observed, could impact the estimated rate of change versus temperature.
- Additional work to validate these measurements include:
  - Confirmation of any potential temperature gradients across each seismometer
  - Determining whether or not measurements are repeatable (at each temperature step, analyzed over longer time-durations and with higher SNR signals for analysis).
  - Accounting for measurement uncertainty to confirm if the observed response residuals are significant.
  - Testing over a wider range of temperatures, that would potentially result in more significant frequency response residuals.

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