SAND2025-10275C

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Impact of Temperature on GS-13 Seismometer Calibration Results

Doug Bloomquist
John Merchant

Sandia National Laboratories, Albuquerque NM, USA

INTRODUCTION AND MAIN RESULTS

In this study we investigate how the operating temperature of GS-13 seismometers impacts their calibration results. We continuously calibrate the sensors using two independent methods for more than a year to obtain a large and robust dataset. The data are processed and analysed using the CalxPy software package developed by the PTS.

We find that the calibration results have a temperature dependence that changes with frequency. We compare the measured temperature dependency to that predicted with equations developed by Natural Resources Canada (NRCAN).

SnT 2025
8 SEPTEMBER ONLINE DAY
9 TO 12 SEPTEMBER AT HOFBURG PALACE, VIENNA & ONLINE
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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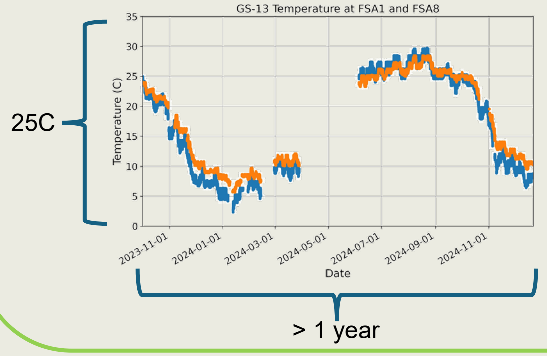
Introduction

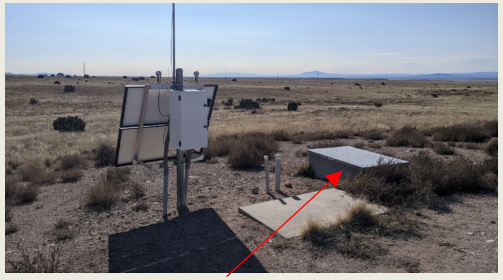
The calibration of sensors in the IMS is important to ensure that the recorded data are accurate and can be analysed with confidence. In this study, we evaluate the impact that operating temperature has on calibration results for GS-13 seismometers.

Background

At SnT2023, Natural Resources Canada (NRCAN) demonstrated that calibration results for S-13 seismometers are significantly impacted by operating temperature (Ackerley & Gias, 2023)

GS-13s are of a similar design to S-13 sensors and are widely used in the IMS. How does temperature impact their calibration results?





FSA8 Vault – contains collocated GS-13 and CMG-3T seismometers

PT-100 on GS-13

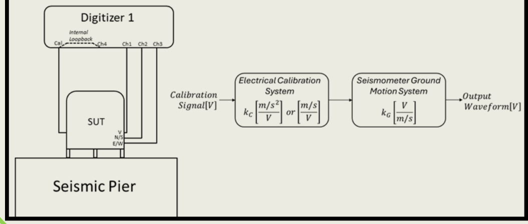
Data Analysis

- Collocate GS-13 and CMG-3T seismometers in the same vault, within 0.3 m of each other.
- Perform daily electrical calibrations on GS-13 and CMG-3T seismometers for more than 1 year (Oct 1, 2023 – Dec 20, 2024)
- Outside the electrical calibration periods, the sensors operate normally and respond to ground motion. We assume the ground motion input signal is the same, which allows the Reference Calibration method to be used.
  - GS-13: Sensor under test
  - CMG-3T: Reference
- Continuously record operating temperature of seismometers
- Use CalxPy to analyze calibration dataset (Doury & Ketata, 2023)
  - CalxPy enables rapid processing of large calibration datasets and performs advanced analysis.
  - We use CalxPy to analyze data for both calibration methods
- Bin the results from CalxPy based on the operating temperature of the sensor
- Plot the amplitude and phase response of the GS-13 based on the binned calibrations

Calibration Methods

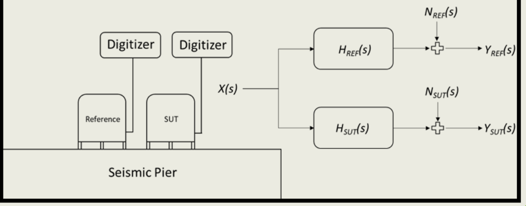
Electrical Calibration

- Requires only a single sensor with a calibration interface
- Electrical signal mimics a ground motion signal
- Temperature coefficient of the sensor's ground motion system and electrical calibration system will be lumped in the single calculated coefficient.
- For an active force feedback seismometer, depending on how the calibration system has been implemented, electrical calibrations may be unable to detect the temperature coefficient.



Reference Calibration

- Requires two collocated seismometers. One is a reference (known response), and the other is a "sensor under test" (SUT, unknown response)
- Ground motion is the input signal and is assumed to be identical for both sensors
- Temperature coefficient from both sensors will be lumped into the single calculated coefficient.



Passband Temperature Coefficient Equations for GS-13s

Electrical Calibration Estimate

$$k_C = -TCR_{Cu} * \left(\frac{1}{1+\frac{R_d}{R_g}} + \frac{1}{1+\frac{Z_{Cal}}{R_{CalCoil}}}\right) + 2 * \alpha_{SmCo5}$$

k_C at $3.98Hz = -0.033$ %/°C + 2 * (-0.04 %/°C)

k_C at $3.98Hz = -0.113$ %/°C

OBSERVED Temperature Coefficient at 3.98Hz = −0.125%/°C

Reference Calibration Estimate

$$k_G = -TCR_{Cu} * \left(\frac{1}{1+\frac{R_d}{R_g}}\right) + \alpha_{SmCo5}$$

$k_G = -0.033$ %/°C – 0.04 %/°C

$k_G = -0.073$ %/°C

OBSERVED Temperature Coefficient at 3.98Hz = -0.17 %/°C

TCR_{Cu} = 0.393 %/°C
R_d = 100.45 kΩ
R_g = 9090 Ω
$R_{CalCoil}$ = 29 Ω
Z_{cal} = 1.912 µF (20.9 kΩ at 3.98Hz)
α_{SmCo5} = -0.04 %/°C ("Cobalt rare earth")

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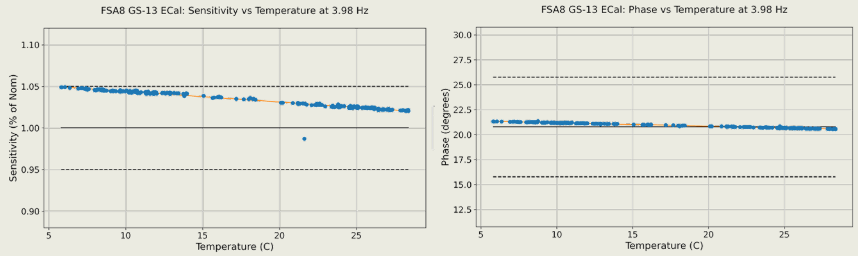
Results

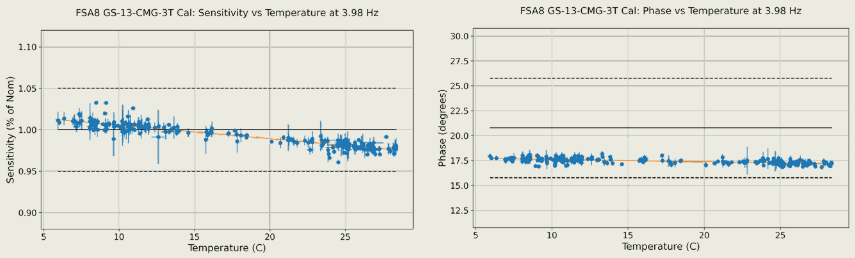
Impact of Temperature on GS-13's Passband (3.98Hz)

Electrical Calibration Results



Electrical calibration results are very consistent and show a strong linear relationship with temperature. The slope of the temperature relationship is much stronger for the amplitude response than the phase response.

Reference Calibration Results

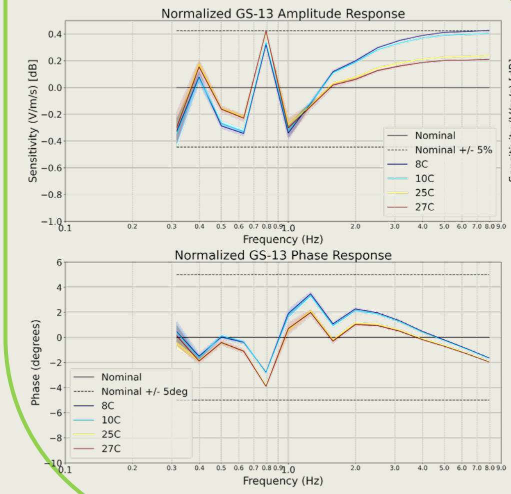


Reference calibration results show more variability than electrical calibration results. However, the temperature effects are still highly linear and stronger for the amplitude response than the phase response.

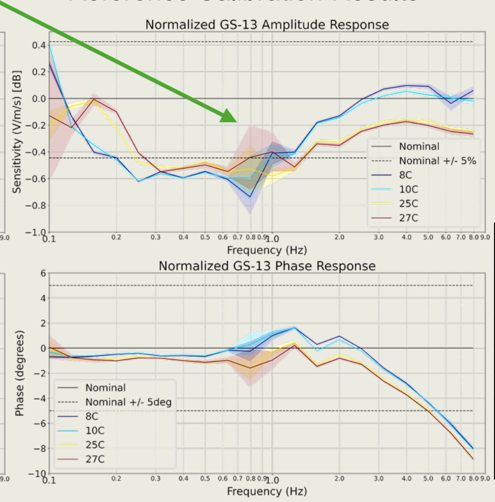
Impact of Temperature on GS-13's full Frequency Response

Shaded regions represent an estimate of the Type A (statistical) uncertainties expressed with k = 2 (95% confidence)

Electrical Calibration Results



Reference Calibration Results



Amplitude Response:
- Temperature impacts are greatest above 2 Hz
- For frequency $f > 1.0$ Hz, temperature coefficient is negative
- For 0.2 Hz $< f < 1.0$ Hz, temperature coefficient is positive and small
- Reference calibration results show more variability, but cover a larger bandwidth

Phase Response:
- Temperature impacts to the phase response are largest for 0.8 Hz $< f < 2.0$ Hz
- Temperature coefficient is negative for all frequencies
- Variability in phase response is smaller than variability in amplitude response.

	Amplitude Coefficient (%/˚C)		Phase Coefficient (Degrees/˚C)	
Frequency (f)	Electrical Calibration	Reference Calibration	Electrical Calibration	Reference Calibration
0.2	n/a	0.144	n/a	-0.019
0.5	0.086	0.048	-0.027	-0.027
1	0.041	-0.110	-0.077	-0.074
2	-0.086	-0.130	-0.067	-0.087
3.9811	-0.125	-0.173	-0.035	-0.051
7.9433	-0.134	-0.204	-0.017	-0.046

Conclusions

- GS-13 seismometers' response depends on temperature. The impact on amplitude response is strongest for frequencies above the 1 Hz corner. The impact on phase response is strongest around the1 Hz corner.
- The temperature dependence can be identified with both calibration methods. However, each calibration method lumps the temperature effects of two linear systems into a single value.
  - For electrical calibration results, this lumping is accounted for in the temperature coefficient equations, and we see good agreement.
  - For the reference calibration results, this lumping is not accounted for in the equations and may be why the agreement is less strong than what we see with the electrical calibration results.
- For the shallow seismic vaults used in this study, the sensors spend most of their time operating at their summer high and winter low temperatures. The transition in the spring and fall is rapid and results in minimal calibration results for temperatures between the high and low levels. This dynamic should be kept in mind when selecting time periods to perform calibrations.

References

Ackerley, N., & Gias, Z. (2023, June 20). *Temperature Dependence of Frequency Response of Short Period Seismometers* [E-poster]. SnT2023, Hofburg Palace, Vienna. https://conferences.ctbto.org/event/23/contributions/4925/

Doury, B., & Ketata, I. (2023, June 20). *CalxPy: A Software for Calibration Against a Reference* [E-poster]. SnT2023, Hofburg Palace, Vienna. https://conferences.ctbto.org/event/23/contributions/4930/