Long-term self-noise estimates of seismic sensors from high-noise vault installations

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1. Motivation & Aims

- Ability to record seismic signals is partly dependent on sensor self-noise: accurate insights could lead to better practices in sensor installations, improving the overall station performance.
- The sources of noise inside sensors are difficult to discern: mechanical noise, electronic interference, Brownian motion.
- Measuring self-noise is challenging and subject to the data selection & calculation methods, and installation type.
- Self-noise is often calculated from hand-picked segments of seismic waveform data in quiet installations. Data are normally selected on a variety of criteria, which may lead to inconsistent self-noise estimates.

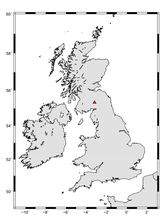
1. Can we accurately determine self-noise in relatively noisy vault installations?
2. What is the effect of small sensor misalignments on calculated self-noise?
3. How much does self-noise vary during an installation?
4. How does sensor installation style and thermal isolation affect self-noise estimates?

2. Sensors, data & processing steps

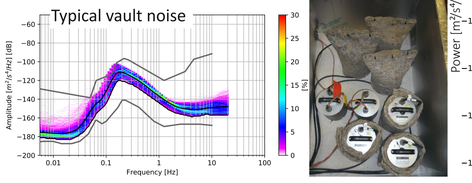
i) Instruments tested

Model	Resp.	Nom. gain	Serial nos
3T	120 s to 50 Hz	2000 V/m/s	T39335 T39373 T39372
3T	360 s to 50 Hz	4000 V/m/s	T39474 T39454 T39453
3ESPC	120 s to 50 Hz	2000 V/m/s	T39413 T39443 T39441

ii) Installation



- Eskdalemuir seismic observatory, Scotland.
- Purpose-built vault.
- Instruments installed on concrete pier.
- Felt blankets for insulation.



iii) Data processing

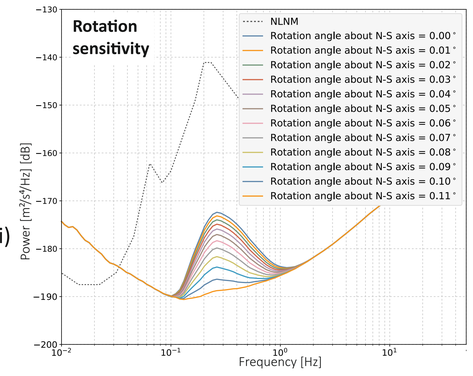
- 64x digitiser gain for seismometers.
- Data recorded at 200 sps and 1 sps streams.
- Long-term 1 sps stream was visually checked: day files rejected when human activity in the vault and/or mass centre / lock-unlock.
- Raw GCF day files converted to miniSEED for processing.

3. Sensor misalignment correction

- Leakage of microseismic noise in noisy vault.
- Effect of elevated self-noise estimates in the microseism band has been recognised by previous studies (Gerner et al., 2017).
- Contamination of microseismic noise into self-noise is due to the relative misalignment of co-located sensors.
- Vertical component tilt angles calculated in a two-step approach: (i) rotation about N-S comp.; (ii) rotation about E-W comp.:

$$Z_N = \cos(\tan^{-1}(E/Z) + \theta_N) \times \sqrt{E^2 + Z^2} \qquad Z_{N,E} = \cos(\tan^{-1}(N/Z_N) + \theta_E) \times \sqrt{N^2 + Z_N{}^2}$$

- Adaptive grid search method minimises magnitude-squared mean coherence over a bandpass of 0.1-0.4 Hz



4. Self-noise PDF calculation approach

PSD

- Merge 3 overlapping sample rates streams for wide spectral resolution without over-lengthening data segments
- Care taken to select PSD window lengths to negate possible effects from numerical instabilities; 7/8 Hann window overlap.
- Self noise: 3-channel correlation method (Sleeman et al., 2006).

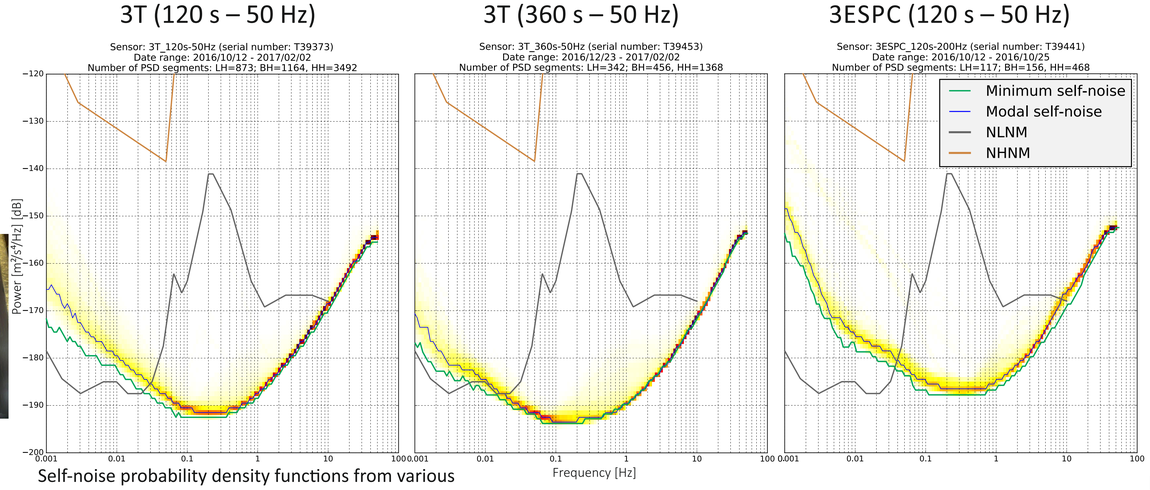
Sample rate	Coverage	Segment length
100 sps	16 s - 50 Hz	4,600 s (1.3 hr)
40 sps	100 s - 16 s	13,100 s (3.6 hr)
1 sps	> 100 s	16,320 s (4.5 hr)

PDF

- PDF calculation following McNamara & Buland (2004).
- Based on ObsPy's PPSD module.

Time segment overlap: 50%
Smoothing: 1/8 octave

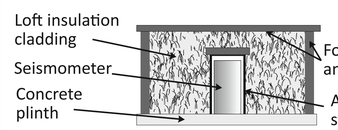
5. Self-noise PDF results



Self-noise probability density functions from various recording periods in 2016 and 2017 using the installation set-up shown in Section 2. Minimum and modal points in each distribution are shown. The New Low and High Noise Models are also shown as references.

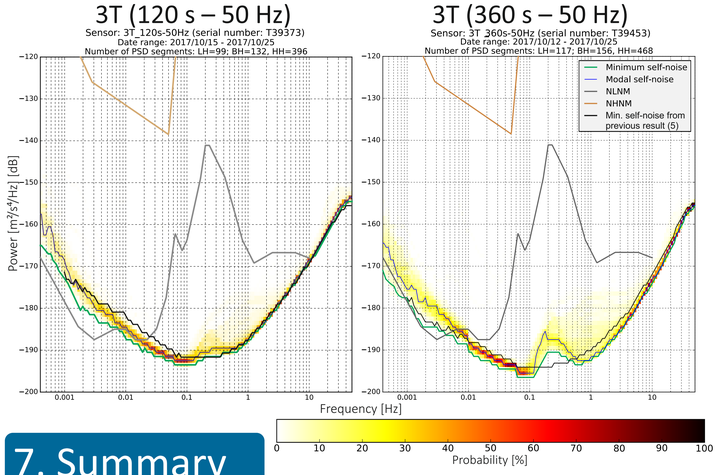
6. Effect of instrument isolation

i) Installation set-up



Installation photos

ii) Results



7. Summary

- Through use of probability density function analysis, we have been able to provide reliable estimates of self-noise for seismic sensors in a noisy seismic vault.
- Rotation of vertical-component waveforms is an important step for producing robust self-noise estimates in noisy installations
- Crossing points of min. self noise with New Low Noise Model: 3T (120 s) = 125 s; 3T (360 s) = 220 s; 3ESPC = 29 s.
- Thermally isolating and insulating each seismometer can improve long-period self-noise estimates by up to 4 dB.
- We plan to make a repository openly accessible on github containing our ObsPy self-noise toolbox and test data.

References

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