The Role of Instrument Depth in Seismic Signal Quality: Findings from a Vertical Array at Glasgow Observatory

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INTRODUCTION AND MAIN RESULTS

Urban noise motivates borehole sensors. Do deeper stations improve detectability? We test this with a five-sensor vertical array in Glasgow, comparing noise (PSDs) and event detectability via IDC-style relative SNR across six bands. Depth lowers noise and, for local/regional events, improves detectability at higher bands; low-frequency and teleseismic gains are limited. All results reference the instrument at 29 m depth.

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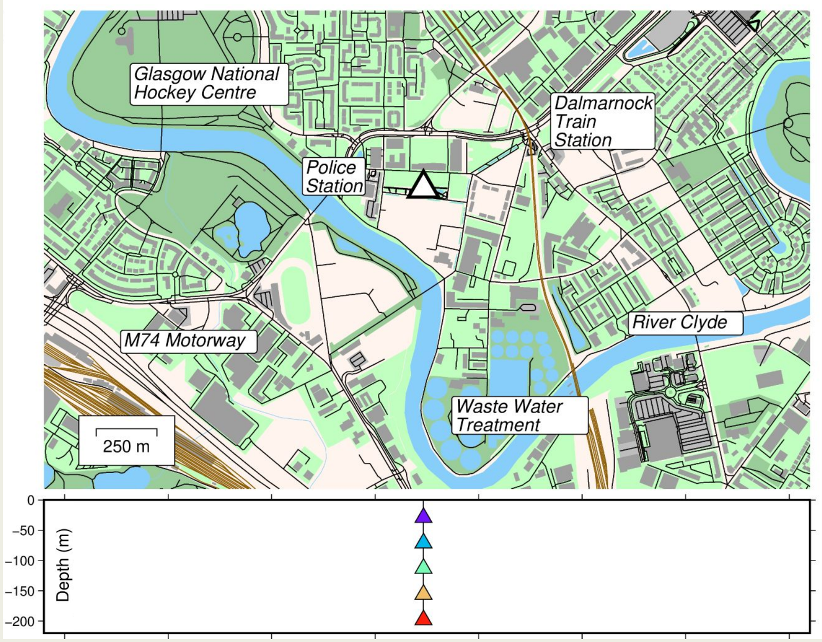
P3.1-233

Introduction

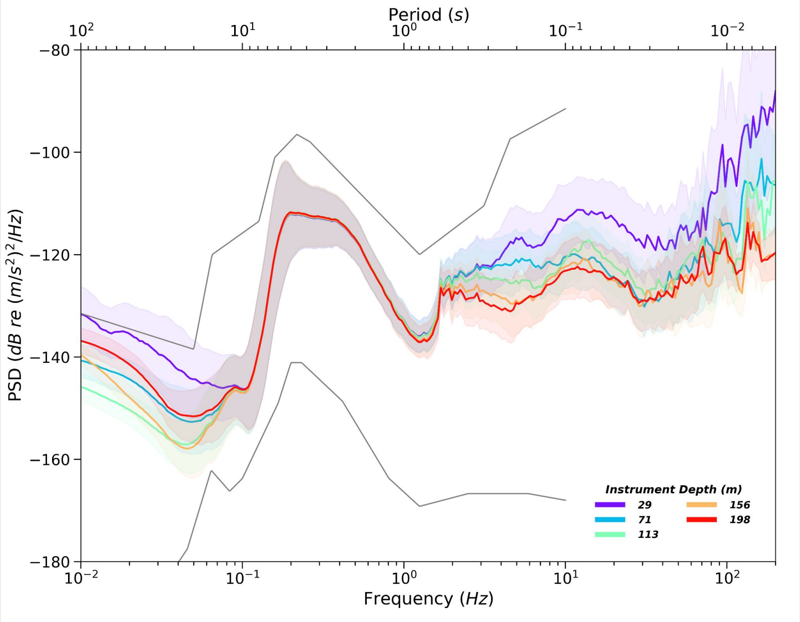
Rapid urbanization increases anthropogenic seismic noise around monitoring sites. A practical mitigation is to install sensors below the surface where surface-generated noise decay with depth. The operational question for global monitoring (e.g., the IMS) is whether “going deep” measurably improves **detectability** for earthquakes and explosions. Direct inter-station comparisons are limited by site effects, so we use a single-site vertical array at Glasgow with five colocated sensors at ~29, 71, 113, 156 and 198 meters to isolate depth effects. **We ask: How does instrument depth affects event detectability as a function of frequency and source–receiver distance?**



Site map with nearby noise sources and vertical profile of the Glasgow borehole array indicating sensor depths in meters.

1st Method - Background Noise

We processed ~19 months of continuous data to estimate power spectral densities (PSD) per instrument. We compare **median PSD vs. frequency** to assess baseline noise reduction with depth.

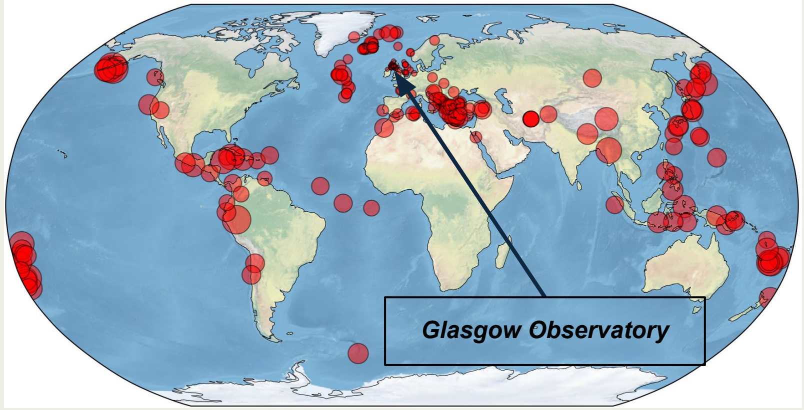


Median power spectral densities (PSDs) for five instruments at the Glasgow vertical array. Shaded areas in matching colors indicate the ±1 standard deviation range. The New High- and Low-Noise Models are shown in grey for reference.

PSDs diverge above ~1 Hz, with systematically lower noise at greater depth, while differences diminish toward lower frequencies. This establishes that **depth lowers background noise in the band most relevant to local/regional events**. However, noise alone does not determine event detectability.

2nd Method - Event Detection

We analyzed ~300 events using an **IDC-style workflow**: band-pass filtering in six frequency bands, followed by SNR = max(STA)/LTA computed with a 6-s signal window and a 60-s pre-signal noise window.



Earthquakes from the British Geological Survey (BGS) and European-Mediterranean Seismological Centre (EMSC) catalogs used in this study. Marker size scales with magnitude (0.4–8.2).

We compute **relative SNR** as the ratio of each deeper sensor’s SNR to that of the shallowest sensor (29 meters) for the same event. We then assess how this ratio varies with **source–receiver distance** and **frequency band**, using per-band log–log 2D histograms of relative SNR versus distance, with per-depth summaries on the next page. This design isolates depth effects while holding the event and path fixed, and enables comparison between local/regional (≤ 1000 km) and teleseismic ranges.

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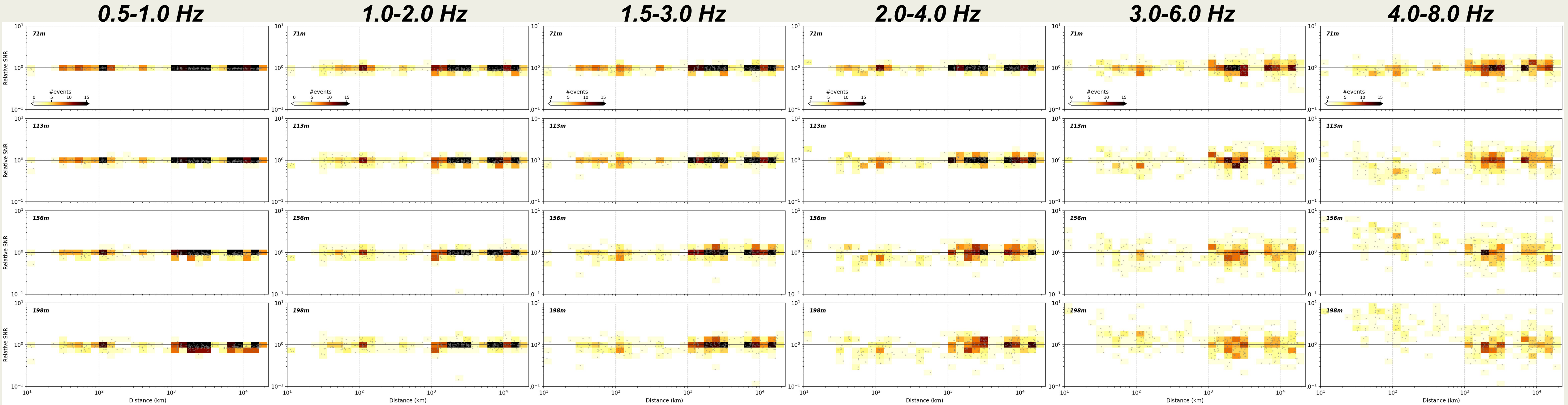

Each panel shows SNR relative to the shallowest instrument (29 meters) versus epicentral distance. Rows are depths (71, 113, 156, 198 meters), and columns are band-pass filters (0.5–1, 1–2, 1.5–3, 2–4, 3–6, 4–8 Hz). Background colors (2D histogram) indicate the number of events per bin; faint points show individual events. The horizontal line at 1 marks parity with the shallowest sensor and its bin is between 0.85 to 0.16. Values >1 indicate improved detectability at depth, <1 indicate reduced.

At low frequencies (0.5–1 and 1–2 Hz), depth shows no consistent advantage and often yields **up to ~30% lower** SNR. The 1.5–3 Hz band is similarly mixed—slight gains at long distances but declines for nearer events. In 2–4 Hz, relative SNR clearly **worsens with depth** for distances ≤ 1000 km and is mixed beyond. In contrast, 3–6 Hz and 4–8 Hz show **strong depth benefits**, especially locally/regionally, reaching **~8–10×** at 198 m. Both high-frequency bands exhibit a dip around **113 m** before improving at greater depth. At teleseismic ranges in these bands, results remain mixed with modest gains and occasional declines.

Conclusions & Implications

All comparisons are referenced to the **29 m sensor** (not the surface), so depth benefits relative to true surface would likely be larger. Installing at **~200 m** yields **meaningful detectability gains primarily for local/regional events** in higher-frequency bands (e.g., 3–6, 4–8 Hz); results for **teleseismic distances are generally inconclusive**, with mixed small gains and occasional declines. Depth reduces noise and can enhance signal content, but the improvement is frequency- and distance-dependent rather than universal.

- For **IMS or national networks**, deeper deployments are **justified where anthropogenic noise is high** and **budgets allow**.
- **Leveraging existing boreholes** (e.g., abandoned wells) can **cut costs and accelerate deployment**.
- Ideally, **co-locate a deep instrument** with a surface sensor to benefit from lower noise at depth and potential surface amplification.

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