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An assessment of surface versus underground vault installations of broadband seismometers in the hard-rock terrain of the Deccan Volcanic Province, India

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Abstract Surface or ground-level installations of broadband seismic stations are routinely used in temporary seismic networks deployed in the Deccan Volcanic Province (DVP) of peninsular India. In this study, we assess the feasibility and utility of a shallow vault installation in this region, by installing a broadband station in an urban environment, with the sensor placed ~ 1 m below ground level. The noise characteristics of this station are compared with those of a co-located station installed at ground level, as well as a temporary station array deployed in rural areas of the DVP during 2024-25. The temporary array is shown to meet international standards of data quality, in terms of observed noise characteristics. However, at periods longer than ~ 10 s, the underground vault station, situated in the heart of Pune city, exhibits lower noise levels than all other stations. The difference in noise levels is up to ≈ 17 dB, and is predominantly seen on the horizontal components of motion, pointing to reduced pressure-induced tilt noise for the vault installation. These findings, though not surprising, serve to quantify the performance enhancement that can be achieved with a small departure from established practices in the field installation of seismic stations.

Non-technical summary Temporary Broadband seismic stations used in the Deccan Volcanic Province are often installed directly at the surface. We investigated whether placing a seismic sensor in a shallow underground vault could improve the quality of the recorded data. By comparing a vault-installed station with a nearby surface-installed station and several temporary stations across the Deccan Volcanic Province, we found that the shallow vault consistently recorded lower background noise, particularly for long-period ground motions. This improvement was most evident in the horizontal measurements, which are more susceptible to environmental disturbances.

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Our results demonstrate that even a simple, shallow underground installation can significantly improve data quality without requiring expensive infrastructure, offering a practical solution for future temporary seismic deployments.

1 Introduction

The quality of data that can be recorded at a broadband seismic station depends on the specifications of the instrument used, but also on the station location, its local site conditions and the type of installation. An observatory-grade seismometer may yield low signal-to-noise-ratio (SNR) recordings if the site selection is poor or if its installation violates standard best practices. It is universal practice to situate broadband seismic stations away from obvious sources of seismic noise such as urban centers or rail/road traffic, and on hard rock wherever possible, rather than on lossy overburden. However, the third factor affecting seismic data quality, the type of installation, sees more variability — across seismic networks, regions or countries — and is the focus of this study.

Permanent stations that constitute global-scale networks such as the Global Seismograph Network (GSN), employ very broad-band seismometers commonly deployed in boreholes, at typical depths of a few tens of metres (Ringler et al., 2022). The deep borehole emplacement ensures effective mitigation of temperature and pressure variations, which are responsible for the notorious horizontal "tilt noise" at low frequencies (Ackerley, 2014; Ringler et al., 2020). Such stations can therefore produce high-fidelity recordings of the lowest frequency seismic signals (< 1 mHz), such as the Earth's very low-frequency normal modes. While suppression of low-frequency noise is the primary motivation for borehole installations used in global earthquake monitoring, reduced noise levels in deep boreholes have also been reported at frequencies as high as 10 Hz, using local-scale networks (e.g. Sohn et al., 2025).

Temporary stations and networks, which are widely used in local-to-regional scale seismic studies, are not required to perform at the low-frequency limit of global seismology. Therefore, such stations have seismometers installed in shallower pits called postholes, or in seismic vaults (e.g. IRIS Transportable Array, 2003). A seismic vault is a near-surface structure, much shallower than a borehole, but nonetheless designed to minimize temperature-pressure variations, besides offering protection from wind, rain and other sources of ground-level noise (Ackerley, 2014). In low-budget seismic experiments, helmed by individual scientists or small collaborations and aimed at scientific research rather than national or regional earthquake monitoring, broadband stations are even set up at ground level, by constructing a 'surface vault'. In India, where the authors are based, there are numerous examples of such deployments in geological terrains ranging from the Himalayas (e.g. Ashish et al., 2009; Sharma et al., 2020) to the Deccan Volcanic Province (e.g. Rai et al., 1999; Tiwari et al., 2006; Rao et al., 2015; Saha et al., 2023). Different types of terrain present different challenges to the deployment of broadband seismic stations. In this study, we focus on the Deccan Volcanic Province (hereafter, DVP).

The DVP, in western peninsular India, is one of the largest continental flood basalt provinces on Earth (Kale, 2020). It is characterized by subhorizontal basaltic lava flows, commonly referred to as the Deccan Traps, overlying a gneissic, pre-Cambrian basement (Kale, 2020; Dole et al., 2022). The Traps are estimated to reach thicknesses of over 2000 m in some parts (Kaila et al., 1981; Dole et al., 2022). The widespread surface cover of extrusive basalts throughout the DVP render it a predominantly rocky terrain. This has contrasting implications for the set up of broadband seismic stations. On the one hand, hard rock is readily available everywhere, without having to dig too deep into the ground. On the other hand, in places where regolith cover is inadequate or entirely absent, underground seismic vaults cannot be constructed without drilling through hard rock — a proposition that is too expensive and impractical for most temporary seismic deployments. Besides the rocky terrain, another impediment to the construction of seismic vaults is the abundant rainfall that this region receives during the Southwest Monsoon season in India (June-September). Vaults must be carefully constructed to minimize the risk of flooding and consequent instrument damage. These challenges notwithstanding, the immense geological significance of the DVP has made it the subject of numerous seismic studies involving temporary local station networks, whether short-period (Srinagesh and Rajagopala Sarma, 2005; Dixit et al., 2014) or broadband (Rai et al., 1999; Rao et al., 2015; Sharma et al., 2018; Saha et al., 2023) or a mix of the two (Mohan and Kumar, 2004; Tiwari et al., 2006). To the best of our knowledge, most of the broadband deployments have utilized surface-level installations.

A typical station design consists of a concrete pier built on an exposed basalt outcrop, and covered by a brick-and-mortar structure resembling a miniature room. The sensor is placed on the concrete pier, sheltered by a thermally insulating case or container. Peripherals including the digitizer and battery are placed within the room-like structure (avoiding contact with the sensor pillar), while the solar panel and GNSS receiver are mounted outside. In this study, we compare the noise characteristics of this type of installation (we call it a 'surface vault') to those of a shallow underground vault. The simple question we want to answer is: does an underground vault in the DVP region ensure lower noise levels than a surface vault, and if so, by how much?

2 Data

In April 2026, we installed a broadband seismograph in a shallow vault on the campus of the Indian Institute of Science Education and Research (IISER) Pune, located in Pune city, Maharashtra, India. The vault was constructed in a garden by excavating topsoil until hard-rock was found (at a depth of ≈ 1 m) and fitting an empty 1000-litre water tank into the excavated pit, with concrete poured onto the rocky bottom of the pit (Figure 1). A hole was made in the bottom of the plastic tank to accommodate a plastic bucket (with its bottom cut off) which is also press-fitted into the concrete base, thereby enclosing the sensor pad. The seismometer rests on the concrete base inside the bucket and is covered by the proprietary insulating case provided by the seismometer manufacturer. The peripherals of this seismic station — battery, digitizer and GNSS receiver — are installed above-ground about 5 m away from the mouth of the sensor vault. This station is assigned the station code ISRP.

With the aim of comparing the noise characteristics of ISRP with a surface installation, we installed another seismograph in a surface vault barely 40 m away from ISRP. This station, coded ANX, is housed in the service bay area of a building known as the Mendeleev Annexe. We note that the vault for ANX was not built on an exposed basalt outcrop, but on 4-feet deep basalt, on which a concrete pier of height 4 feet was constructed such that its top (the sensor pad) is at ground level. ANX and ISRP are situated on either side of a pedestrian walkway in the heart of the institute campus and as such, are subject to high levels of cultural noise. The nearest city road, carrying moderately

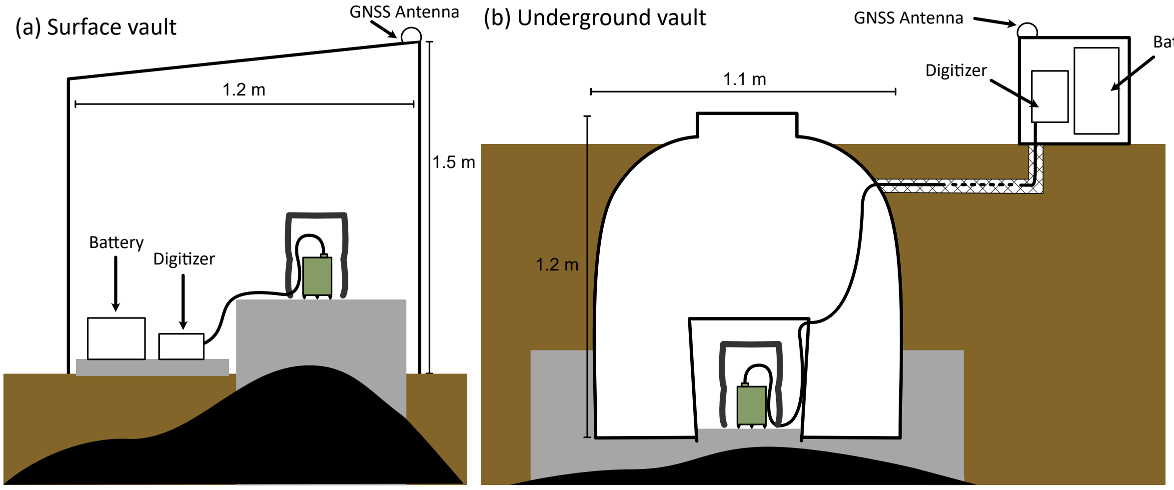

Figure 1 Surface (a) and underground (ISRP) (b) vault installations used in the study.

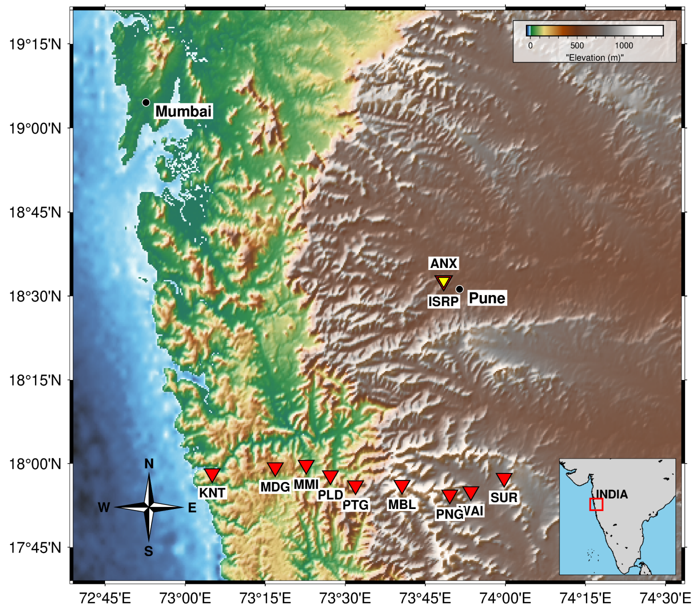

Figure 2 Geographic location of the Mahabaleshwar profile. The stacked inverted triangles highlight the co-located ISRP and ANX stations at the IISER Pune campus.

heavy traffic, is about 200 m away.

For further benchmarking, we use data from an actual field deployment of broadband stations in the DVP region, far away from Pune city. In a follow-up experiment to Saha et al. (2023), a nine-station, East-West trending linear array (Figure 2) was deployed during 2024-2025, with the aim of imaging the crust and lithospheric mantle beneath the array. This seismic profile ran through the popular tourist town of Mahabaleshwar (station code MBL) in the Indian state of Maharashtra, and we therefore refer to it as 'the Mahabaleshwar profile'. The profile was deployed in two phases – 7 of the total 9 stations were installed in April-May2024, while two stations were added on the western end in April 2025. Detailed station information for the Mahabaleshwar profile is provided in Table 1. All stations in this profile were installed in surface vaults built on exposed basalt outcrops, and used the same seismometer-digitizer pair as the campus stations ANX and ISRP. Most of the stations were located in rural areas.

Our entire analysis uses a single instrument type, the Nanometrics Trillium Compact 120s seismometer, paired with the Nanometrics Centaur digitizer.

Station	Latitude (°N)	Longitude (°E)	Elevation (m)	Start Date	End Date
SUR	17.957206	73.996089	714.0	2024-04-18	2025-11-28
WAI	17.916914	73.892130	722.0	2024-04-17	2025-09-29
PNG	17.907193	73.826343	1234.0	2024-04-20	2026-03-07
MBL	17.936088	73.677222	1226.0	2024-04-23	2025-11-28
PTG	17.934813	73.531928	198.0	2024-04-19	2025-12-09
PLD	17.964680	73.453516	107.0	2024-04-19	2025-12-09
MMI	17.996017	73.377920	15.0	2024-05-28	2025-08-26
MDG	17.988636	73.281278	239.0	2025-04-05	2025-11-27
KNT	17.970658	73.084401	241.0	2025-04-02	2026-03-03

Table 1 Station details and deployment period for the Mahabaleshwar profile.

3 Analysis and Results

In this section we evaluate station performance by quantifying background noise and presenting visualizations of earthquake waveforms.

3.1 Noise quantification

3.1.1 Methodology

Ambient seismic noise is universally quantified in terms of the power spectral density (PSD) of recorded data. McNamara and Buland (2004) developed a statistical approach to characterizing long-term seismic noise by computing PSD estimates from continuous waveform data, which contains background noise as well as transient signals. In this method, probability density functions (PDFs) of the PSD are obtained over a relatively long period of time (e.g. one month or one year) by computing a large number of PSD estimates over successive, shorter time segments (e.g. one hour). The method is implemented in ObsPy (Beyreuther et al., 2010, Probabilistic Power Spectral Density) and is widely used to characterize frequency-dependent noise levels at broadband seismic stations worldwide (e.g. Sharma et al., 2020; Sohn et al., 2025).

We apply the ObsPy-PPSD algorithm on three-component waveform data from each of our stations, selecting a duration of time and parsing the continuous records into one-hour segments with 50% overlap. This produces PSD-PDFs for each station-component pair, following the series of processing steps detailed in McNamara and Buland (2004) and McNamara and Boaz (2005). We note that the algorithm includes removal of instrument response and conversion to decibels with respect to an acceleration of $1\left(\mathrm{m/s^2}\right)^2/\mathrm{Hz}$, thus facilitating direct comparison of the resulting PSDs with the new noise models of Peterson (1993). The PSD-PDFs describe the variability of ambient seismic noise throughout the time period of interest. Statistical quantities such as the median, mean, mode, and selected percentile curves can be derived from the distribution to characterize the long-term seismic noise levels at each station.

3.1.2 Findings

We use over two months of data from the campus stations ANX and ISRP, covering the period 11 April - 17 June 2026 (Julian days 101-168, 2026). The PSD-PDFs for these two stations are shown in Figure 3, which shows that: 1. for both stations, long-period (> 10 s) noise is stronger in the horizontal components, than in the vertical component.

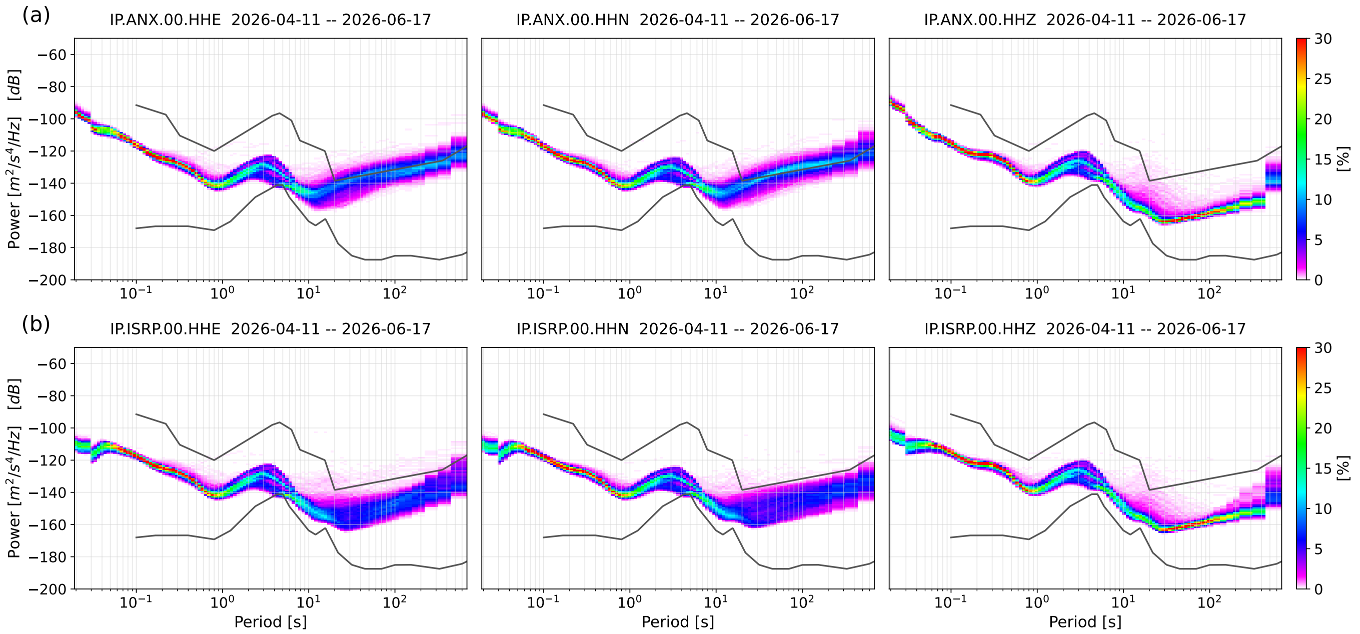

Figure 3 PSD-PDFs for stations (a) ANX and (b) ISRP on the three components, E, N and Z from left to right respectively. The global noise models of Peterson (1993), NLNM and NHNM, are plotted in gray as reference. The color scale denotes probability density.

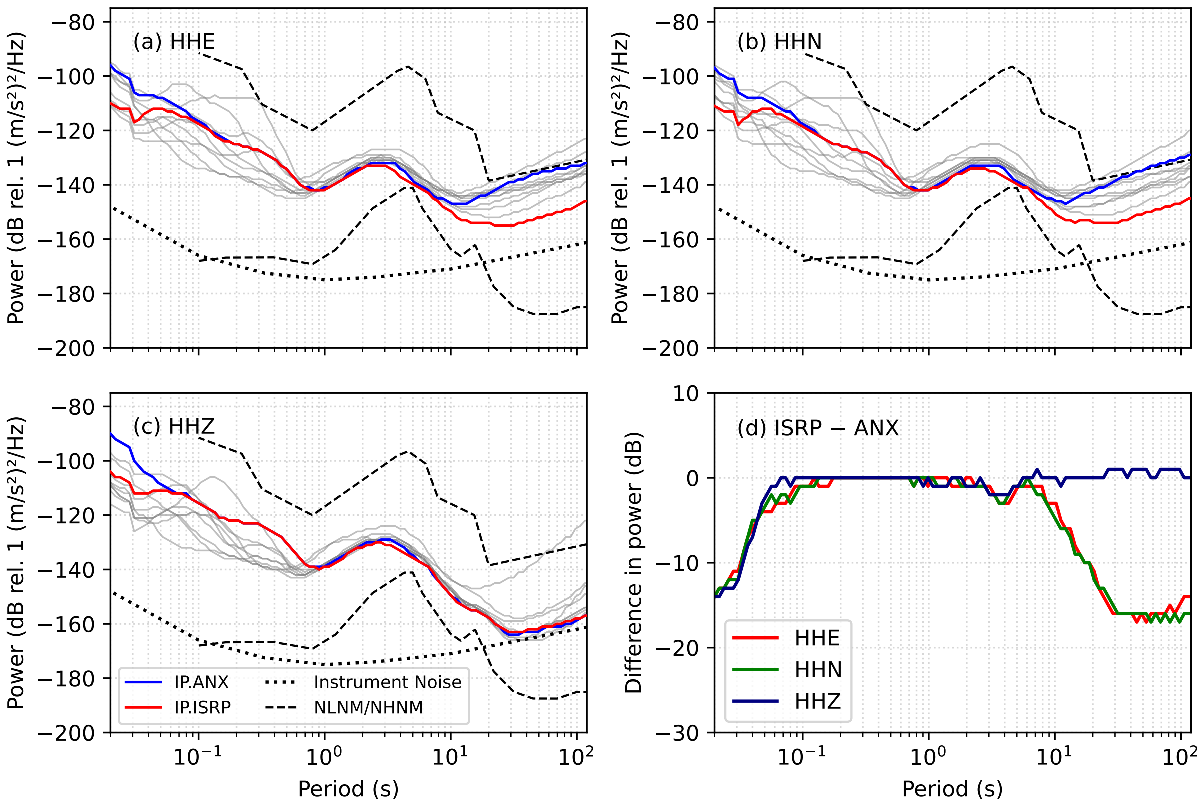

Figure 4 Median PSD of ANX (blue) and ISRP(red) seismic stations compared with other stations in the network (gray) during day of year 101-168 over all years for components E (a), N (b) and Z (c). (d) represents the difference in power spectra between ISRP and ANX.

2. between the two stations, ISRP (underground vault) has lower levels of long-period horizontal component noise than ANX (surface vault), while there is no significant difference in the vertical component.

Noise levels across stations are easier to compare in terms of a single statistic derived from the PSD-PDFs, as shown with the PDF median in Figure 4. In this figure, we have included the median PSD of the stations in the Mahabaleshwar profile, to serve as a benchmark or reference. The Mahabaleshwar profile was active at a different time and over a much longer duration, but for the comparison in Figure 4, we have considered the same Julian day window (101-68) in the years when the Mahabaleshwar profile stations were active. This ensures a fair comparison by excluding the Mahabaleshwar profile data recorded during the relatively noisier monsoon months. The seismic signature of rainfall has been documented in the literature (e.g. Sohn et al., 2025) and is also visible in the Mahabaleshwar profile data. Complete PSD-PDFs for the Mahabaleshwar profile stations, over their entire deployment duration, are presented in the Supplement (Figures 7-9).

Focusing on the co-located campus stations ANX and ISRP, we make the following detailed observations from Figure 4:

1. ISRP has the lowest long-period horizontal noise levels among all stations considered. Compared to ANX, noise is up to 17 dB lower for periods longer than 8 s, with the largest reduction occurring between 30 and 100 s.

2. At ANX, both horizontal channels approach the NHNM in the period range 20-120s.

3. In the vertical component, both stations approach the instrument self-noise at the long periods.

4. At short periods (<1 s), both stations have high noise levels relative to the Mahabaleshwar profile, likely due to their urban siting. Below 0.1s, ISRP again exhibits lower noise than ANX in all components.

3.2 Earthquake Waveforms

The co-located stations ANX and ISRP can be expected to record earthquakes near-simultaneously. Here we present earthquake waveforms recorded at these two stations, from four regional or teleseismic events that occurred during the data acquisition window mentioned in the previous section. Waveforms from each event are windowed from the origin time to one hour after the event, and filtered in the period range $10 - 50$ s (Figure 5) or $50 - 150$ s (Figure 6).

The vertical components of both stations yield comparable recordings, while the horizontal components at ISRP demonstrate substantially reduced noise levels. In Figure 5, we see that the two teleseismic events (M7.8 in Philippines and M6.9 in Chile) are reasonably well resolved on both sensors, while the regional earthquakes (M5.0 in Pakistan and M5.6 in Bhutan) are better resolved in the underground vault. In Figure 6, tilt noise dominates the horizontal components at the surface vault and completely masks the signals from regional events (plots (C,D)) or teleseismic events with large epicentral distances (plot (B)). Only the large-magnitude Philippines event appears similar on both stations, as it produces very high amplitude ground motions (2-3 orders of magnitude higher than the other events) that rise well above background noise levels.

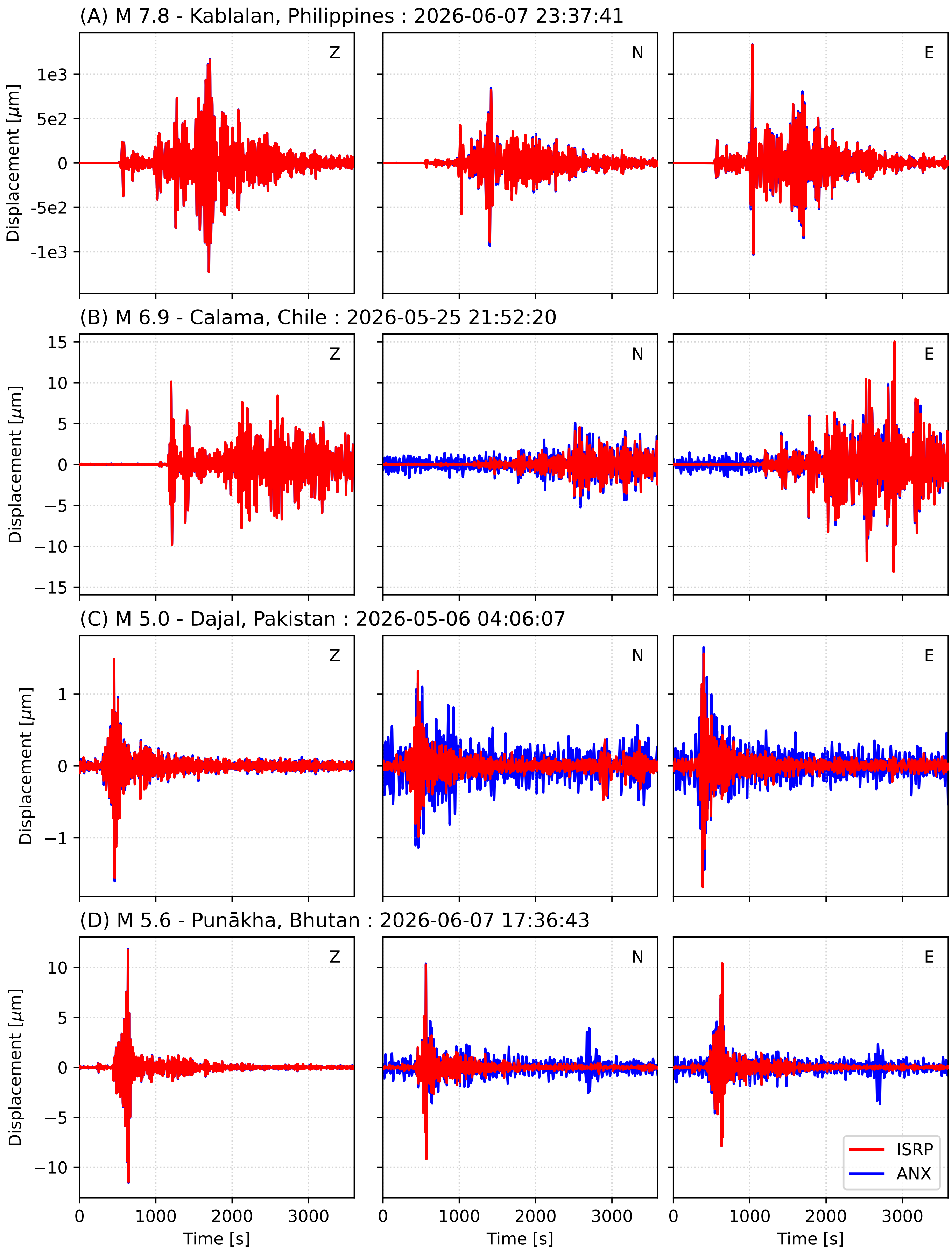

Figure 5 Observed teleseismic (A & B) and regional (C & D) earthquake signals on stations ANX (blue) and ISRP (red) in the period band 10s - 50s. Note the different amplitude scales used for each event. Event details obtained from USGS.

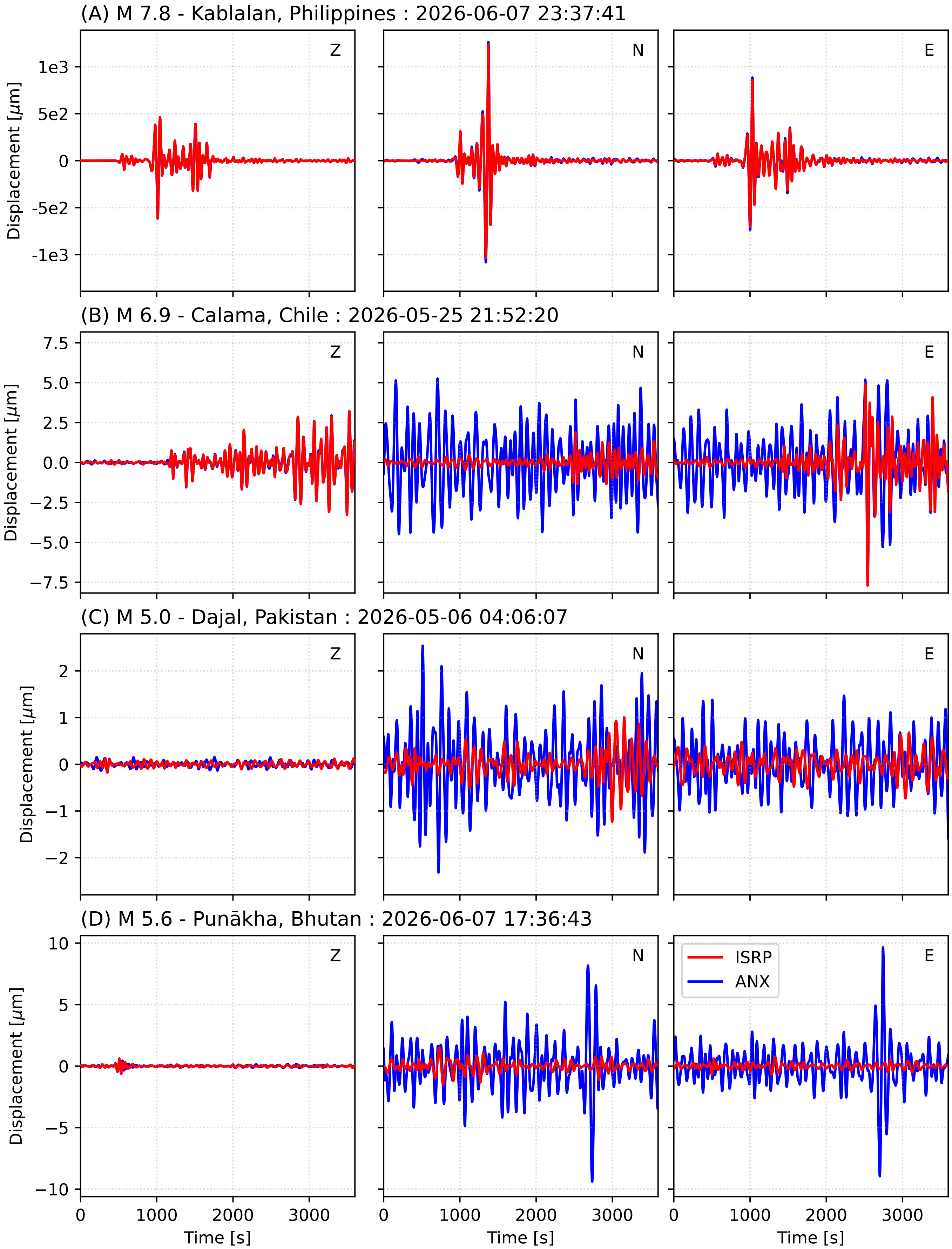

Figure 6 Same as Figure 5, but with data filtered in the period band $50 - 150$ s.

4 Conclusions

Based on the analysis of the previous section, we draw the following conclusions about the noise levels at the co-located stations ISRP and ANX:

(i) At long periods (> 10 s or frequency < 0.1 Hz) the observed reduction in noise PSD at ISRP compared to ANX, suggests that shallow sensor burial substantially decreases the susceptibility of the station to pressure-induced tilt noise.

(ii) At short periods (< 1 s or frequency > 1 Hz), the limited improvement of ISRP over ANX indicates that shallow burial alone is insufficient to mitigate high-frequency cultural noise associated with the urban setting.

Separately, we conclude that the Mahabeleshwar profile meets international standards of data quality, with noise levels lying well within the NLNM-NHNM bounds for all but one station (MDG), which exhibits median noise PSD higher than the NHNM at long periods. We suspect that this is due to a problem with the digitiser used at MDG.

5 Discussion

We have presented a feasibility study on using an underground vault to set up a broadband seismic station in the Deccan Volcanic Province, a region which presents the dual challenges of a rocky terrain and high levels of precipitation. The test station used in this study is approximately 1 m deep, and it exhibits discernibly lower levels of long-period noise than ten other stations that it has been compared with, which were all installed in overground vault-like structures.

There are two primary deterrents to the construction of underground vaults in the DVP region — economic cost, and the risk of flooding during the Indian monsoon. Both of these competing factors are addressed by our study. We make the case for an installation depth as shallow as 1 m, using an inexpensive and commonly available item, the plastic water tank. This restricts the cost of vault construction to something comparable to, or even lower than, that of the extensively used surface vaults. The tank-based vault design, which we have tried out for the first time, offers a low-cost alternative to the more sophisticated vaults that are used in big-budget deployments (e.g. IRIS Transportable Array, 2003). As regards the question of flooding, we are confident that the vault is impervious to rainwater from the top and the sides. It remains to be seen whether water can breach the structure through its open bottom, and this question can only be properly answered once our test station has endured at least one entire monsoon season (ongoing at the time of writing this manuscript).

We do not claim that the vault design trialed in this study is optimal or flawless. Further refinements are possible (EarthScope Primary Instrument Center (EPIC), n.d.) and can be expected to further enhance the station's performance in future. For example, the vault's thermal insulation can be improved by lining the shell walls. However, the existing pilot vault design has already demonstrated a notable drop in noise levels compared to the commonly used surface vaults. These findings can guide station installation choices for future seismic studies in the DVP region, where improved data quality at long periods, such as in regional and teleseismic earthquake signals, is desirable.

As an aside, this study also serves as a data report for the 9-station broadband array deployed across the Western Ghats around Mahabaleshwar. Data from this array is being used for velocity structure estimation and this will be the subject of future contributions.

Acknowledgements

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Data and code availability

The seismic broadband stations used in this study were deployed under a collaborative effort between Indian Institute of Science Education and Research (IISER) Pune and CSIR-4PI. They are part of a Government of India-funded project that terminates in 2027. Two years after the completion of the project, the data will be made available following the data sharing policies of the funding agency.

Competing interests

The authors have no competing interests.

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263 # 6 Supplement

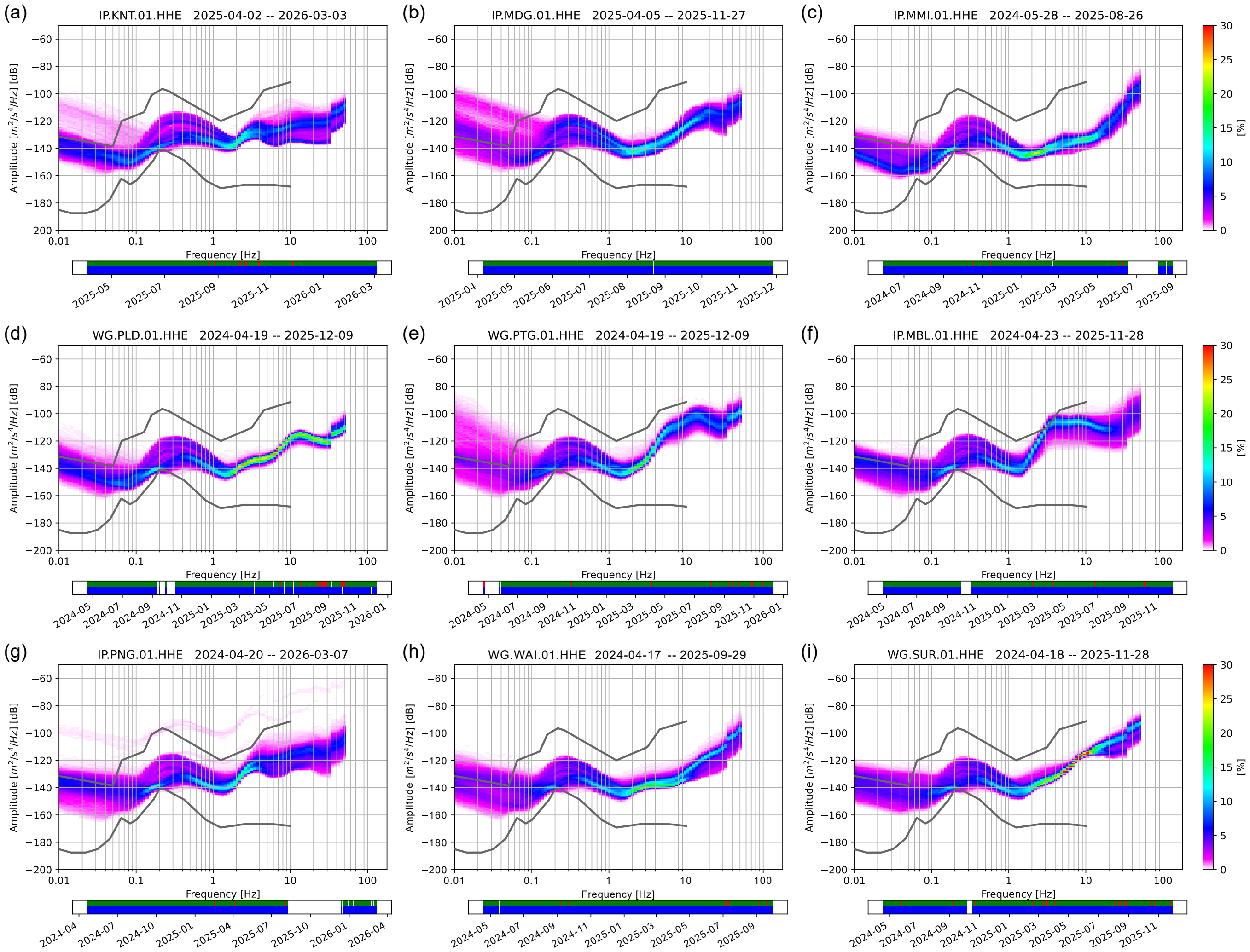

Figure 7 PSD-PDFs for the stations in the Mahabaleshwar profile, E-component. Station name and data recording duration are mentioned at the top of each plot. The blue/green bar below each plot indicates data gaps.

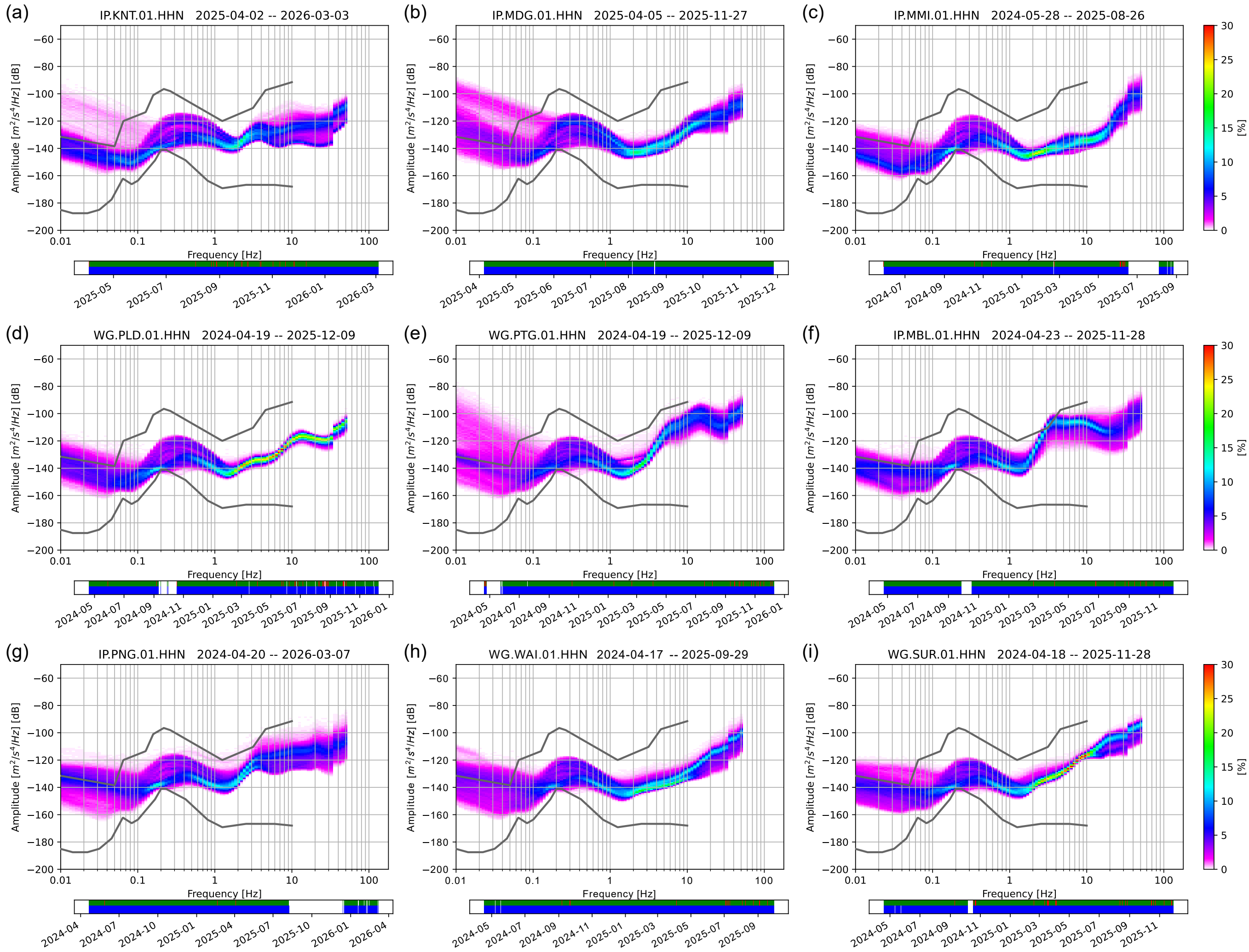

Figure 8 Same as Figure 7 but for N-component data.

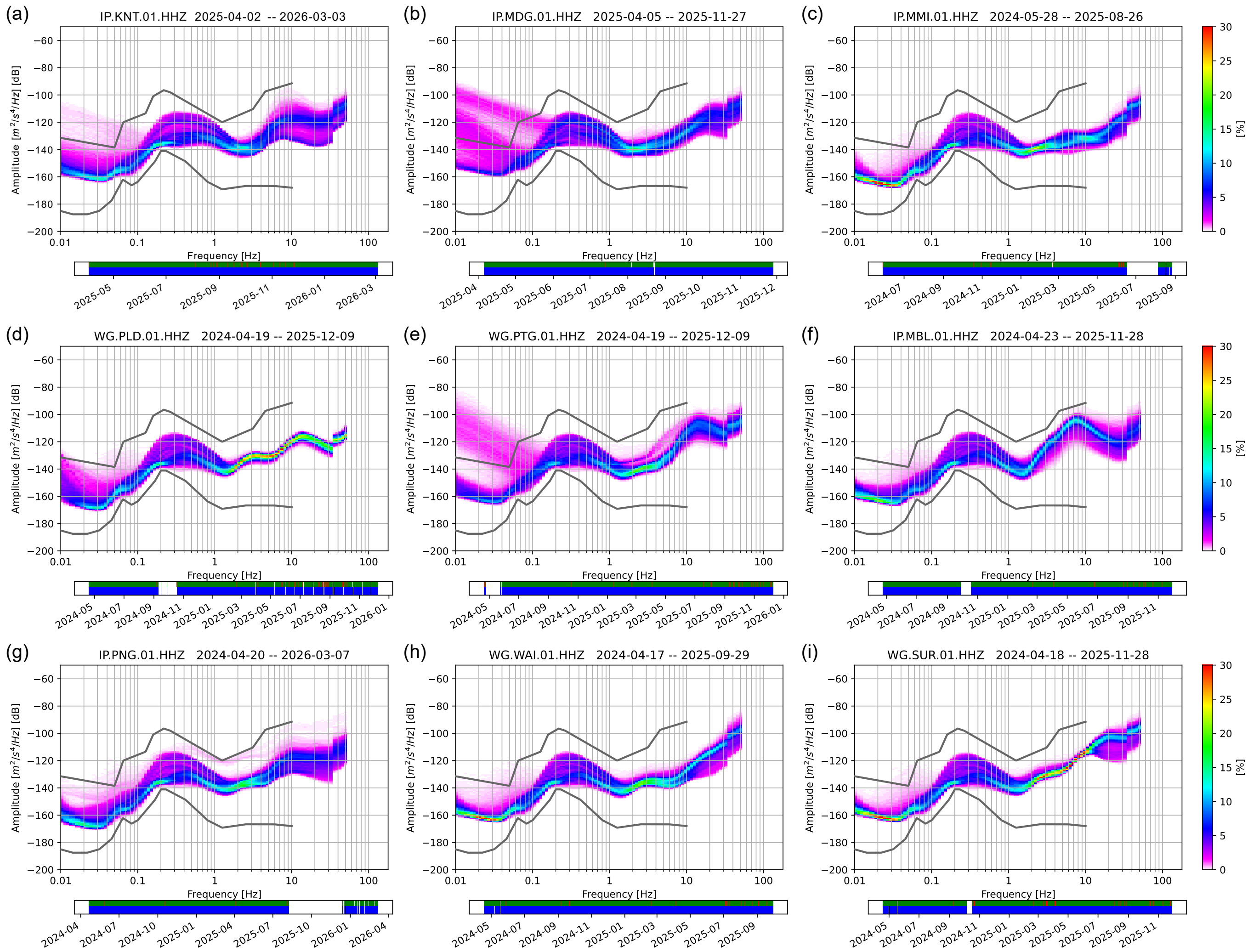

Figure 9 Same as Figure 7 but for Z(vertical)-component data.