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The seismic network in the Carpathian region of Ukraine

Tetiana Amashukeli[*,1,2], Liudmyla Farfuliak[2], Oleksandr Haniiev[2], Bogdan Kuplovskyi[3], Vasyl Prokopyshyn[3], Kostiantyn Petrenko[2], Thomas Zieke[1], Laura Hillmann[1], Andres Heinloo[1], Angelo Strollo[1], Luca Malatesta[1], Dmytro Levon[2,4]

(1) GFZ Helmholtz Centre for Geosciences, Potsdam, Germany

(2) Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine, Department of Seismic Hazards, Kyiv, Ukraine

(3) Subbotin Institute of Geophysics of National Academy of Sciences of Ukraine, Department of Seismic Activity of Carpathian Area, Lviv, Ukraine

(4) Institute of Geology, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

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Abstract

The Carpathian region of Ukraine plays a critical role in seismic monitoring due to its tectonic setting and proximity to the Vrancea Seismic Zone, which is known for its deep-focus earthquakes. The regional seismic network across western Ukraine, covering the Carpathian and adjacent areas, currently comprises 22 stations, of which 5 are not operational, 18 stations continue to operate with Soviet-era long- or short-period sensors. Data from these stations are archived locally and are not publicly accessible. Five stations in the Carpathians (UT.BRIU, UT.KSV, UT.MEZ, UT.RAKU, UT.STNU) were recently upgraded with modern broadband sensors (deployed alongside the existing instruments) under the ORFEUS Data Integration Grant. This grant, funded through the Geo-INQUIRE Project and supported by in-kind contributions from GFZ Helmholtz Centre for Geosciences, GaiaCode, and CNRS Geoazur, provided instruments and technical support that strengthened the network and enabled the station upgrades between September 2024 and March 2025. Data from the upgraded stations are available in real time through the European Integrated Data Archive (EIDA) under the FDSN network code UT, Ukrainian National Seismic Network, and can be accessed via the National Institute for Earth Physics (NIEP) EIDA node in Romania. For the first time, data from Subbotin Institute of Geophysics seismic network have been integrated into EIDA, significantly improving data accessibility and fostering international collaboration. These stations also contribute to the AdriaArray initiative, providing a dense seismic network for monitoring the Adriatic Plate and its active margins. This paper discusses the background, current state, and recent advancements in the region's seismic network, with a focus on the upgrade of selected stations.

Keywords: Passive Seismic Broadband Network; Monitoring; Instruments; Noise; Seismology; Open Data; AdriaArray; Ukraine

1. Introduction

Seismological monitoring plays a crucial role in advancing geophysical research and in contributing to public safety. It relies on seismic networks to detect ground motion, analyze data, and uncover insights into earthquake activity and Earth's structure. Beyond research, these networks are essential for education, urban planning, and infrastructure safety. Even in regions with low seismic activity, maintaining an operational seismic network can be critical to better monitor regional seismicity and potentially induced local seismicity.

In Ukraine, this need is particularly urgent due to ongoing recovery and modernization efforts against the backdrop of the war. The country's seismic network has long faced challenges, including outdated equipment and limited upgrades since Ukraine's independence (Amashukeli et al., 2024). The war further worsened the situation, leading to funding cuts, damaged infrastructure, and a loss of skilled personnel.

Efforts to modernize Ukraine's seismic network, especially in the Carpathian region, began in 2024 with international support. Seismic monitoring in Ukraine has a rich history, dating back to the first station established in Lviv in 1899 under the Austro-Hungarian Empire. Today, the Subbotin Institute of Geophysics (IGPH) is working to upgrade the network to meet international standards, enhancing cross-border collaboration and improving seismic hazard assessment.

2. Seismic network history in the Carpathian region of Ukraine

In the second half of the 19th century, the first seismic stations capable of recording seismic events were established in Europe. The first station in the Carpathian region of Ukraine, then part of the Austro-Hungarian Empire, was set up in June 1899 in Lviv by the Seismological Commission of the Austro-Hungarian Academy of Sciences. Located at the Astronomical-Meteorological and Seismological Observatory of Lviv (Lemberg) Technical University, it operated under the direction of Professor V. Láska. This station, known as Lvov (Lemberg), was initially equipped with a Rebeur-Ehlert 3-component horizontal pendulum system, manufactured by T. and A. Bosch's mechanical workshop in Strasbourg, utilizing an optical recording system (Plešinger and Kozák, 2003). Later, this was replaced with two horizontal Bosch-Omori seismographs.

The second seismic station, known as Czernowitz, was established in 1907 at Chernivtsi University, also within the Austro-Hungarian Empire at the time. This station was equipped with a Mainka seismograph manufactured by J. and A. Bosch, featuring two 450-kilogram masses. Data were recorded on smoked paper mounted on a rotating aluminum cylinder.

Another station, UZH, was opened in 1934 in Uzhhorod, which at that time was part of Czechoslovakia. It was located at the city's higher secondary school and marked another step in the development of seismic monitoring in the Carpathian region. These early stations were primarily capable of recording major seismic events occurring globally but lacked the technical capacity to detect smaller local earthquakes. The early seismic stations experienced significant interruptions due to the impact of military actions during World War I and World War II.

After World War II, seismic monitoring resumed, and in 1948, the Lviv station was reconstructed, with the installation of new equipment, including a set of Kirnos seismographs and pendulum clocks paired with a nautical chronometer for precise timekeeping. This marked the beginning of significant development in seismic monitoring in the Carpathian region.

From the 1950s to the 1990s, during the Soviet era, the seismic network in the Carpathians expanded further. Several new stations were established, including UZH (Uzhhorod, 1951), RAKU (Rahiv, 1956), MEZ (Mizhhirya, 1961), KSV (Kosiv, 1961), ONO (Onokivtsi, 1976), MORU (Morshyn, 1978), TRSU (Trosnyk, 1987), and NSLU (Nyzhne Selyshche, 1987). These stations were equipped with SKD long-period seismometers and SM-3/SM-3KV short-period seismometers, which were designed as electromagnetic moving-coil pendulum instruments with electromagnetic damping.

Since Ukraine's independence in 1991, the development of the Carpathian seismic network has continued with several new sites including HORU (Horodok, 1991), KORU (Korolevo, 1998), MUKU (Mukachevo, 1999), BERU (Berehove, 2000), BRIU (Brid, 2000), KMPU (Kamyanets-Podilskyi, 2005), NDNU (Novodnistrovsk, 2006), SHIU (Shidnytsia, 2006), STNU (Starunia, 2007), STZU (Stuzhytsa, 2011), HOLU (Holmets, 2014), and LUBU (Liubeshivka, 2019). All these stations were equipped with either SKD long-period or SM-3, SM-3KV short-period seismometers.

In 1998, the Department of Seismic Activity of the Carpathian Area developed and produced the digital automatic recorder (DAS) (Verbytskyi and Verbytskyi, 2011), which was implemented with SKD, SM-3 and SM-3KV seismometers at these seismic stations.

Since the 2000s, the Carpathian seismic network has relied on a combination of Soviet-era sensors and digitizers producing data in non-standard formats. Due to limited funding, comprehensive network upgrades were not possible. The data from these stations are transmitted via mobile routers and stored in the local data center of the Department of Seismic Activity of the Carpathian Area (Lviv), but they are not openly shared with the seismic community and are not transmitted to European archives.

From September 2024 to March 2025, five stations (BRIU, KSV, MEZ, RAKU, STNU) were upgraded within the framework of the ORFEUS Data Integration Grant, funded through the EU Project "Geo-INQUIRE." For the first time, data from the Subbotin Institute of Geophysics network are available in EIDA, with real-time waveforms and station metadata accessible via the NIEP node. These five upgraded stations are operated under the network code UT (Ukrainian National Seismic Network). More detailed information about the upgrading is provided in Section 3.

Within the Subbotin Institute of Geophysics of the National Academy of Sciences of Ukraine, the upgraded stations are maintained by the Department of Seismic Hazard (Kyiv), the soviet-era stations are maintained by the Department of Seismic Activity of the Carpathian Area, based in Lviv.

A map (Fig. 1) illustrating the current distribution of seismic stations in the western part of Ukraine is presented below.

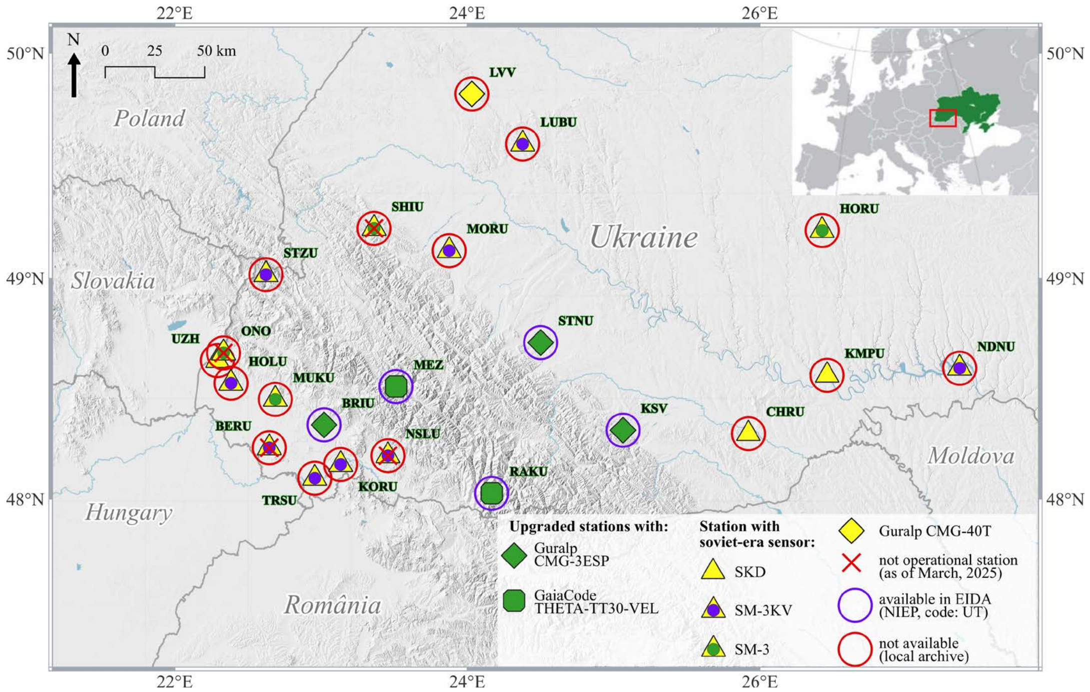

Figure 1. Map of permanent seismic stations in the western region of Ukraine. Note: the upgraded instruments were deployed on the same piers, operating in parallel with the legacy sensors (SKD, SM-3KV, SM-3; see Table 1).

3. Upgrading the seismic network in the Carpathian region of Ukraine

The seismic network in the Carpathian region of Ukraine faces numerous challenges, including outdated equipment, non-standard data formats, and increased anthropogenic noise due to urban expansion. Even before the war in Ukraine, which began in February 2022, the network was in need of modernization. The ongoing war has significantly contributed to the deterioration of an already precarious situation, leading to infrastructure damages and disruptions to station operations, thereby increasing the need for modernization to improve overall network performance.

The first steps toward reorganizing the seismic network in the Carpathian region of Ukraine were initiated through a successfully evaluated proposal of the Subbotin Institute of Geophysics for an ORFEUS data integration grant, funded through the EU Project “Geo-INQUIRE”. The proposal, titled “Integration in EIDA of continuous real-time open seismological waveform data and associated station/site metadata for stations of the Ukrainian seismic network” included a detailed upgrade plan for selected stations of the network. The primary goal was to integrate data from the upgraded Carpathian stations into the European Integrated Data Archive (EIDA) (Strollo et al., 2021) continuous, real-time seismological waveform data in miniSEED format and corresponding station/site metadata in stationXML format. This marks the first time that Ukrainian stations are served through EIDA, with free, immediate access. As part of this effort, three new sensors were donated by seismometer manufacturer Gaiacode in collaboration with Geoazur research lab. Three additional sensors and five dataloggers (refurbished from the Geophysical Instrument Pool Potsdam, GIPP), as well all new accessories for communication and power supply were provided by the GFZ German Research Centre for Geoscience. Huddle tests and short training modules were organized and carried out at the GFZ premises in Potsdam; training also included test and configuration of the SeisComP (Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences and gempa GmbH, 2008) acquisition data flow from the stations to the National Institute for Earth Physics (NIEP) data center in Romania via the VPN network in Kyiv.

The sensor types of the upgraded seismic stations in the Carpathian region are Gaiacode THETA-TT30-VEL and Guralp CMG-3ESP, along with EarthData PR6-24 digitizers (three-channel, 24-bit). For this project, the embedded Linux PC board originally included in the PR6-24 has been removed to improve reliability and reduce power consumption. The EarthData PR6-24 digitizer is connected via serial cable to a Teltonika RUT956 router on which a special version of SeisComP, compiled for OpenWRT, is installed. A local seedlink server enables real-time streaming capability (Fig. 2).[1]

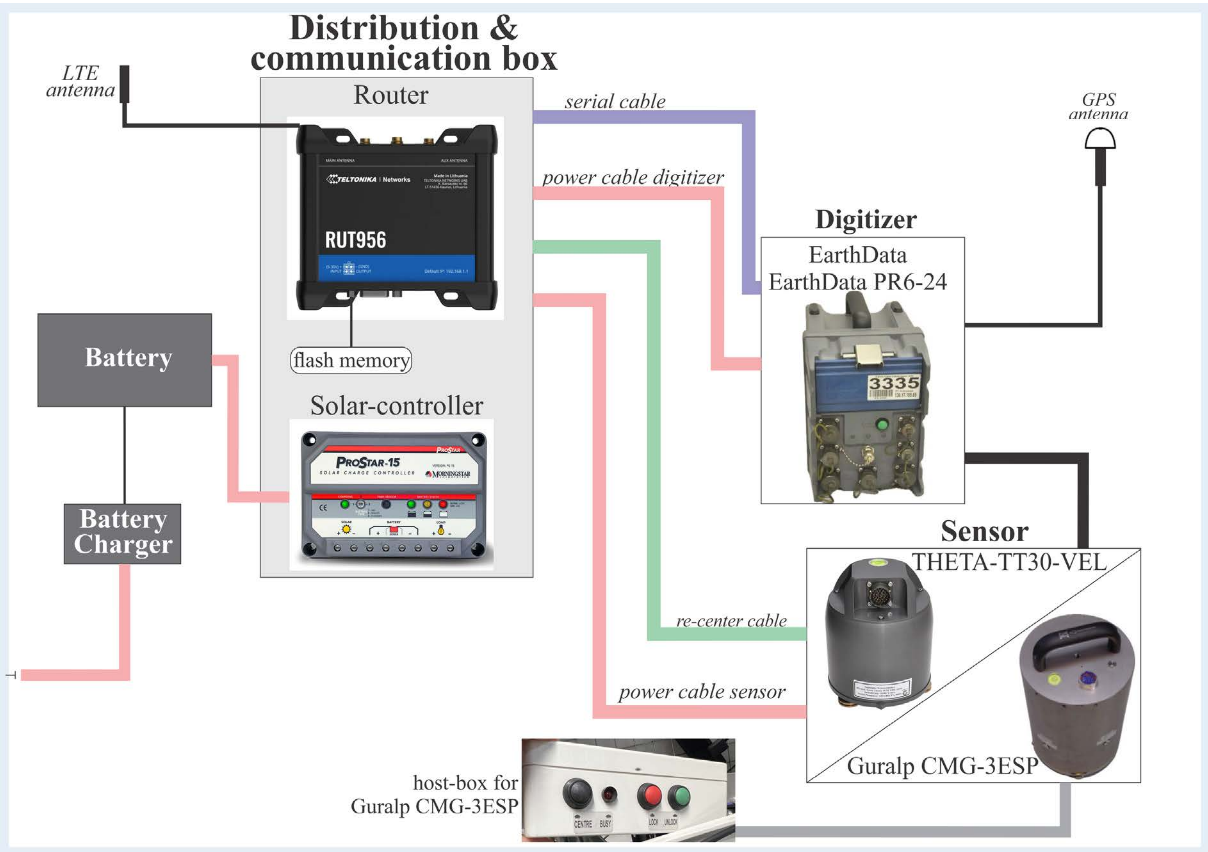

Figure 2. Schematic configuration of the upgraded seismic broadband stations.

1 The modification of the PR6-24 digitizer means that the internal computer and transmission board have been removed, eliminating onboard data storage. However, the core digitizer board remains identical to that of the PS6-24 (EDD), allowing full configuration and data streaming via serial connection (RS232) through the connector labeled as ETHERNET. Features previously available with the PR6-24, such as data storage and status LEDs, are no longer present. The SeedLink streaming and remote monitoring control options have been implemented in the router to enhance functionality.

The Teltonika RUT956 allows remote maintenance actions like mass centering of the sensor, power cycle of the digitizer and monitoring of other state of health parameters. Actions can be triggered via SMS, ssh or via the web interface. All stations are connected to a central SeisComP system deployed at the Subbotin Institute of Geophysics Data Centre. Stations and central server are connected through a secure Virtual Private Network (VPN), and the OpenVPN server runs at the central SeisComP acquisition system with all stations connected as clients. The setup can scale up and support additional secure connections in the future.

A tailored Distribution and Communication Box has been developed for the stations, which integrates power distribution, controllers and communication devices. The solar controller disconnects the system from the battery if the voltage decreases below a defined threshold (11.5V), providing deep discharge protection. The Guralp CMG-3ESP is equipped with a host-box that facilitates the handling of the seismometer, including the lock-unlock function and centering mechanism of the masses. Power is supplied by a 12V battery, charged via a surge-protected adapter connected to mains power. This setup ensures uninterrupted operation and robust data transmission capabilities.

During deployment, the stations were installed in secure buildings, previously identified during a dedicated site survey campaign. Each features a concrete pedestal designed to host seismic sensors. A foam plastic casing was used during deployment to mitigate diurnal temperature variations (Fig. 3).

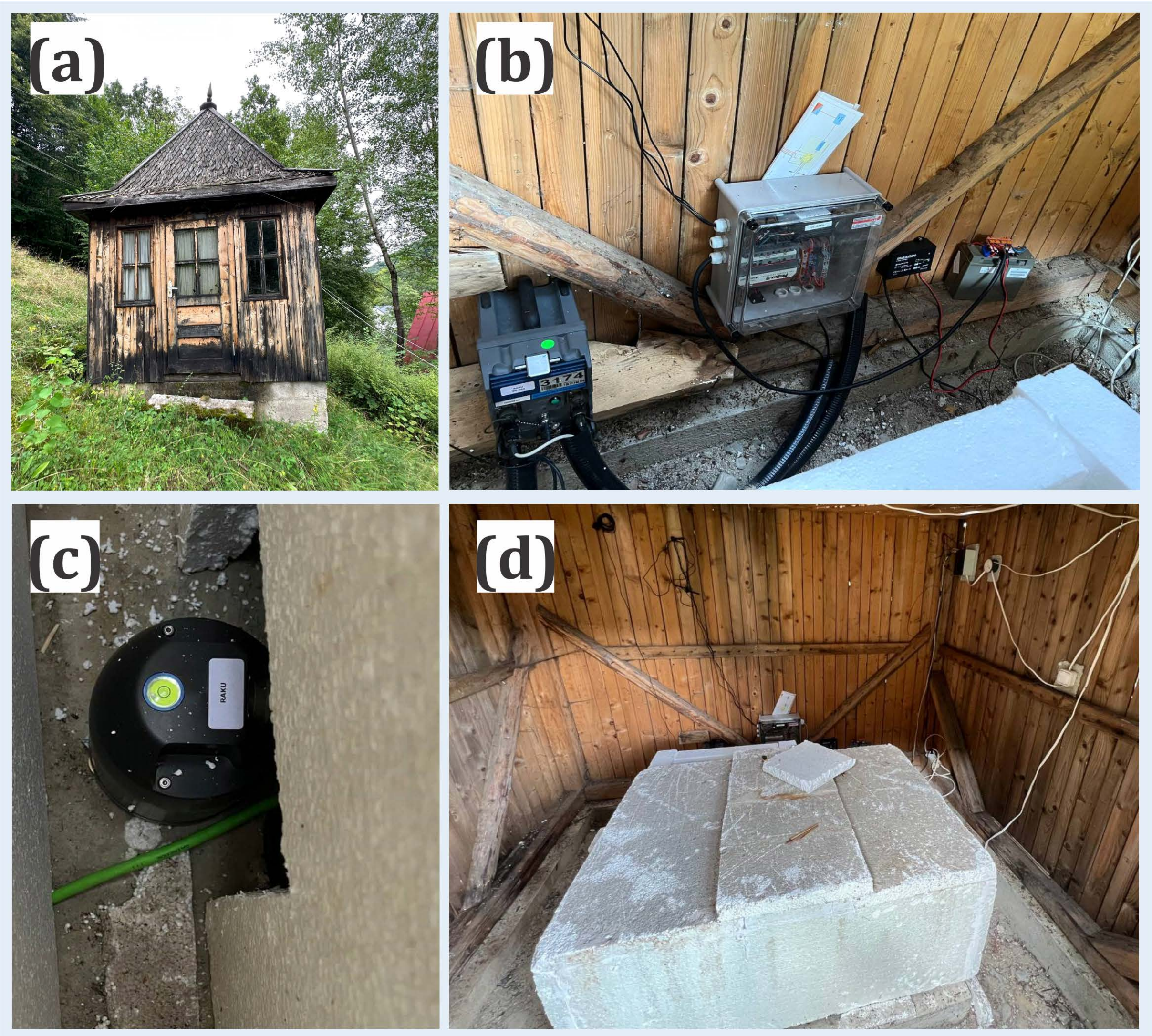

Figure 3. Deployment details of the upgraded seismic station RAKU (Rakhiv): (a) wooden building in the forest housing the instruments; (b) communication box mounted on the wall with cables protected by tubing to prevent damage from small animals; (c) sensor placed on a concrete pedestal alongside SKD sensors; (d) sensors covered with foam plastic for thermal insulation.

Stations KSV, MEZ, and RAKU were deployed in September 2024, STNU in December 2024, and BRIU in March 2025. As an illustration of the performance of the upgraded network, Fig. 4 shows the recordings of two local earthquakes registered by the stations. The ML 3.2 event of 23 October 2024 was recorded at three stations at epicentral distances of 174-285 km. The ML 2.7 event of 10 September 2025 was recorded at five stations at epicentral distances of 46-126 km.

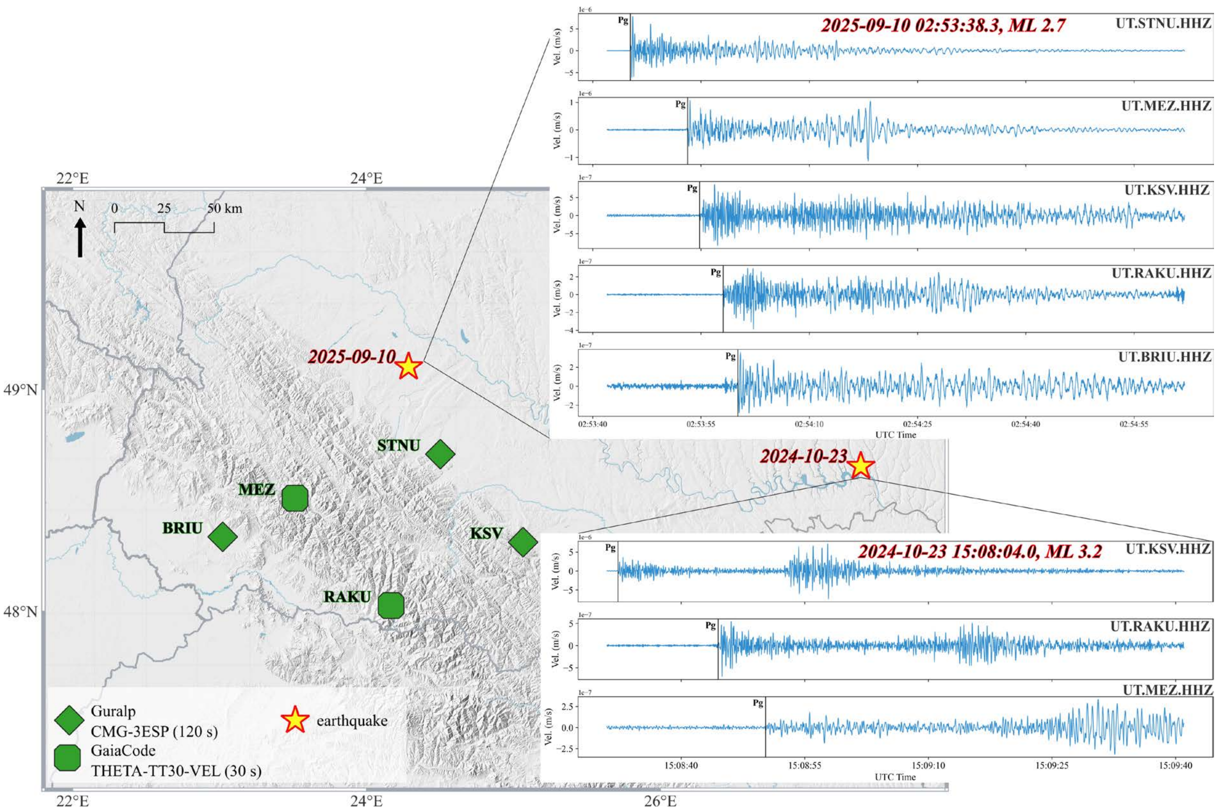

Figure 4. Recorded waveforms of the ML 3.2 earthquake on 2024-10-23 15:08:04 UTC at stations KSV, RAKU, and MEZ, and the ML 2.7 earthquake on 2025-09-10 02:53:38 UTC at all five upgraded stations.

4. Instrumentation

The current seismic network in the Carpathian region of Ukraine, operated by the Subbotin Institute of Geophysics, is presented in Table 1 and Fig. 1. Note: at the upgraded stations, new instruments were installed alongside the existing sensors at the same sites, with the legacy instruments remaining operational.

The SKD sensors (Fig. 5a) deployed at stations CHRU, KMPU, KSV, MEZ, RAKU, UZH, were widely used from the 1960s to the 1990s. They are long-period instruments with electromagnetic damping, primarily designed for galvanometric recording of both vertical and horizontal displacement components. These pendulum-type seismometers are equipped with a moving-coil transducer, and the signal, damping, and calibration coils are wound on the same nonmagnetic plate placed within the air gap of a stationary permanent magnet. SKD sensors were specifically suited for detecting low-frequency signals. The short-period SM-3KV sensors (Fig. 5b) deployed at stations BERU, BRIU, HOLU, KORU, LUBU, MORU, NDNU, NSLU, STZU, TRSU, and SM-3 sensors (Fig. 5c) deployed at stations HORU, MUKU, ONO, SHIU, STNU, also widely used during the same period. They are electromagnetic, moving-coil, pendulum instruments with electromagnetic damping designed to measure higher-frequency seismic events compared to the SKD sensors.

The DAS recorder, designed by the Department of Seismic Activity of the Carpathian Area, is used at seismic stations in the Carpathian region of Ukraine. The DAS recorder (Fig. 5d) (3-channel, sample rate 50 or 100 sps) are still operational. However, these recorders output data in a non-standard format (REG format), causing compatibility

Table 1. Permanent seismic stations in the Carpathian region of Ukraine operating as of March 2025.

Station Code	Station Name	Latitude N	Longitude E	Elevation m	Sensor/Digitizer
BRIU	Brid	48.338	23.0203	167	SM-3KV (2 s)/DAS
CHRU	Chernivtsi	48.29750	25.92170	240	SKD (25 s)/DAS
HOLU	Holmets	48.52740	22.38430	134	SM-3KV (2 s)/DAS
HORU	Gorodok	49.2138	26.4263	340	SM-3 (2 s)/DAS
KMPU	Kamyanets-Podilsk	48.5630	26.4600	121	SKD (25 s)/DAS
KORU	Korolevo	48.15732	23.1339	150	SM-3KV (2 s)/DAS
KSV	Kosiv	48.31369	25.06453	449	SKD (25 s)/DAS
LUBU	Liubeshka	49.59866	24.37829	355	SM-3KV (2 s)/DAS
LVV	Lviv	49.81864	24.0318	320	Guralp CMG-40T (30 s)
MEZ	Mizhgir'ya	48.51207	23.51235	471	SKD (25 s)/DAS
MORU	Morshyn	49.1241	23.8762	262	SM-3KV (2 s)/DAS
MUKU	Mukachevo	48.4536	22.6874	125	SM-3 (2 s)/DAS
NDNU	Novodnistrovsk	48.59470	27.36640	242	SM-3KV (2 s)/DAS
RAKU	Rahiv	48.02602	24.16632	448	SKD (25 s)/DAS
STNU	Starunia	48.7106	24.5014	391	SM-3 (2 s)/DAS
STZU	Stuzhytsa	49.01619	22.62305	385	SM-3KV (2 s)/DAS
TRSU	Trosnyk	48.0950	22.9570	120	SM-3KV (2 s)/DAS
UZH	Uzhgorod	48.6289	22.2908	160	SKD (25 s)/DAS
Not-operational stations					
BERU	Beregovo	48.2336	22.6460	140	SM-3KV (2 s)/DAS
NSLU	Nygne Selysche	48.1976	23.4571	250	SM-3KV (2 s)/DAS
ONO	Onokovtsy	48.664	22.333	168	SM-3 (2 s)/DAS
SHIU	Shidnytsya	49.2234	23.3621	580	SM-3 (2 s)/DAS
Upgraded stations (in September, 2024 – March, 2025) (new instruments were deployed alongside existing sensors (SKD, SM-3KV, SM-3) at the same site)					
BRIU	Brid	48.338	23.0203	167	Guralp CMG-3ESP (120 s)/ EarthData PR6-24
KSV	Kosiv	48.31369	25.06453	449	Guralp CMG-3ESP (120 s)/ EarthData PR6-24
MEZ	Mizhgir'ya	48.51207	23.51235	471	THETA-TT30-VEL (30 s)/ EarthData PR6-24
RAKU	Rahiv	48.02602	24.16632	448	THETA-TT30-VEL (30 s)/ EarthData PR6-24
STNU	Starunia	48.7106	24.5014	391	Guralp CMG-3ESP (120 s)/ EarthData PR6-24

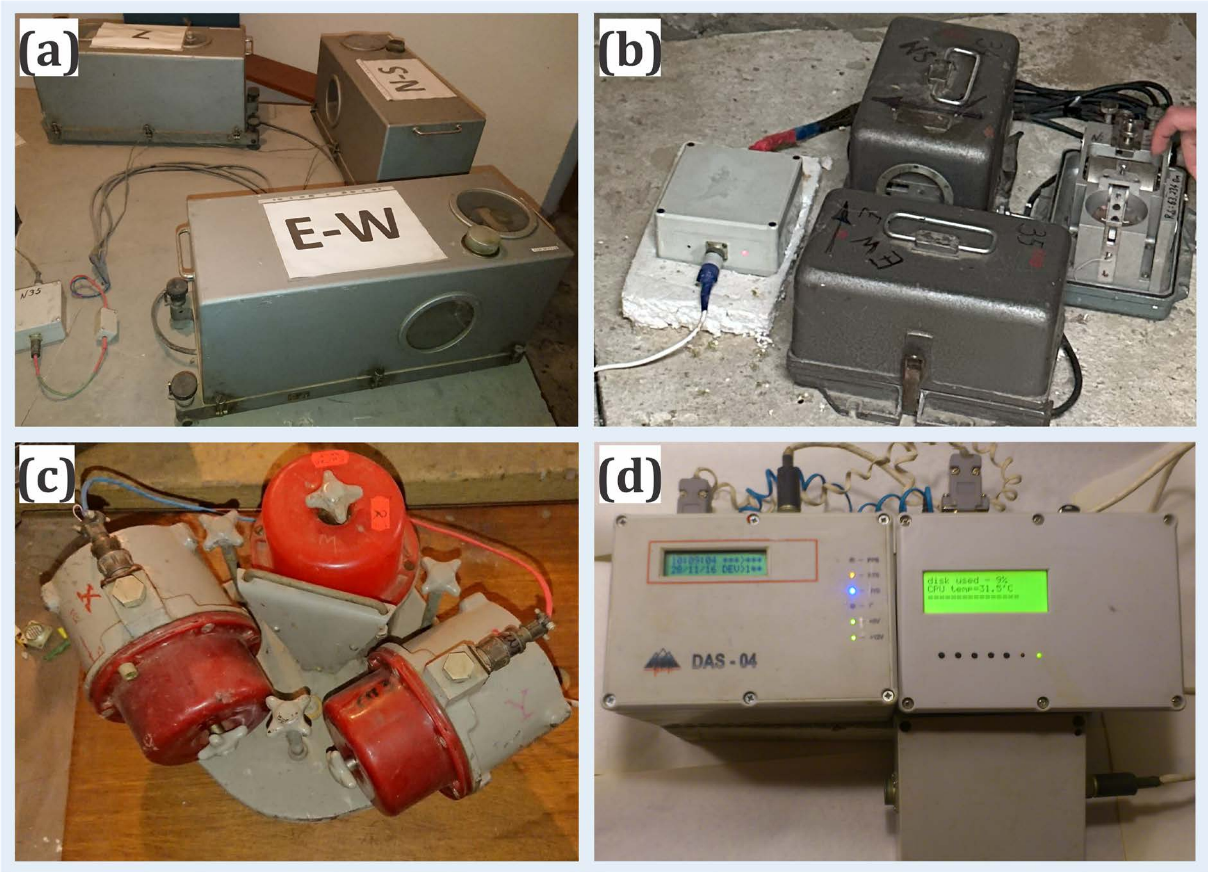

Figure 5. Seismic sensors of the Soviet era: (a) SKD sensor, (b) SM-3KV sensor, (c) SM-3 sensor, and (d) their associated DAS recorder.

issues with modern processing systems, complicating integration with international seismic networks, and preventing real-time data transmission. Currently, five upgraded stations (BRIU, KSV, MEZ, RAKU, and STNU) operate in parallel with the SKD, SM-3KV, SM-3 sensors and DAS-recorders at the same locations, and only data from these upgraded stations are transmitted to EIDA. The archive of SKD, SM-3KV, SM-3 sensors with DAS-recorders is maintained locally within the Subbotin Institute of Geophysics (Department of Seismic Activity of the Carpathian Area) and remains available on the local server. Future plans include resolving the data format issues from the DAS recorder, calibrating the Soviet-era sensors, and preparing the corresponding inventory (XML/SEED) for these stations, but specific timelines cannot be provided at this moment.

The sensors at the upgraded seismic stations include GaiaCode THETA-TT30-VEL and Guralp CMG-3ESP, with EarthData PR6-24 digitizers. The GaiaCode THETA-TT30-VEL seismometer is a mid-range, portable feedback broadband instrument, housed in a durable, sealed, and waterproof aluminum enclosure, with a flat frequency response ranging from 0.033 Hz (30 seconds) to 150 Hz. The Guralp CMG-3ESP is a force-balance broadband seismometer designed for ground velocity measurements, with a frequency response ranging from 120 seconds to 50 Hz. Figure 6 illustrates the amplitude and phase response curves for stations equipped with these instruments, highlighting their sensitivity and operational frequency ranges. The Guralp CMG-3ESP sensor (newly deployed at stations KSV, STNU, BRIU, blue curve) shows a flat amplitude response starting at 0.1 Hz, suitable for detecting long-period signals. The GaiCode THETA-TT30-VEL sensor (newly deployed at stations RAKU and MEZ, orange curve) exhibits a flat amplitude response starting at 1 Hz, which is more focused on higher-frequency seismic signals. The phase response curves indicate minimal distortion within their respective frequency ranges, with the KSV station maintaining a low self-noise performance down to lower frequencies than RAKU and MEZ.

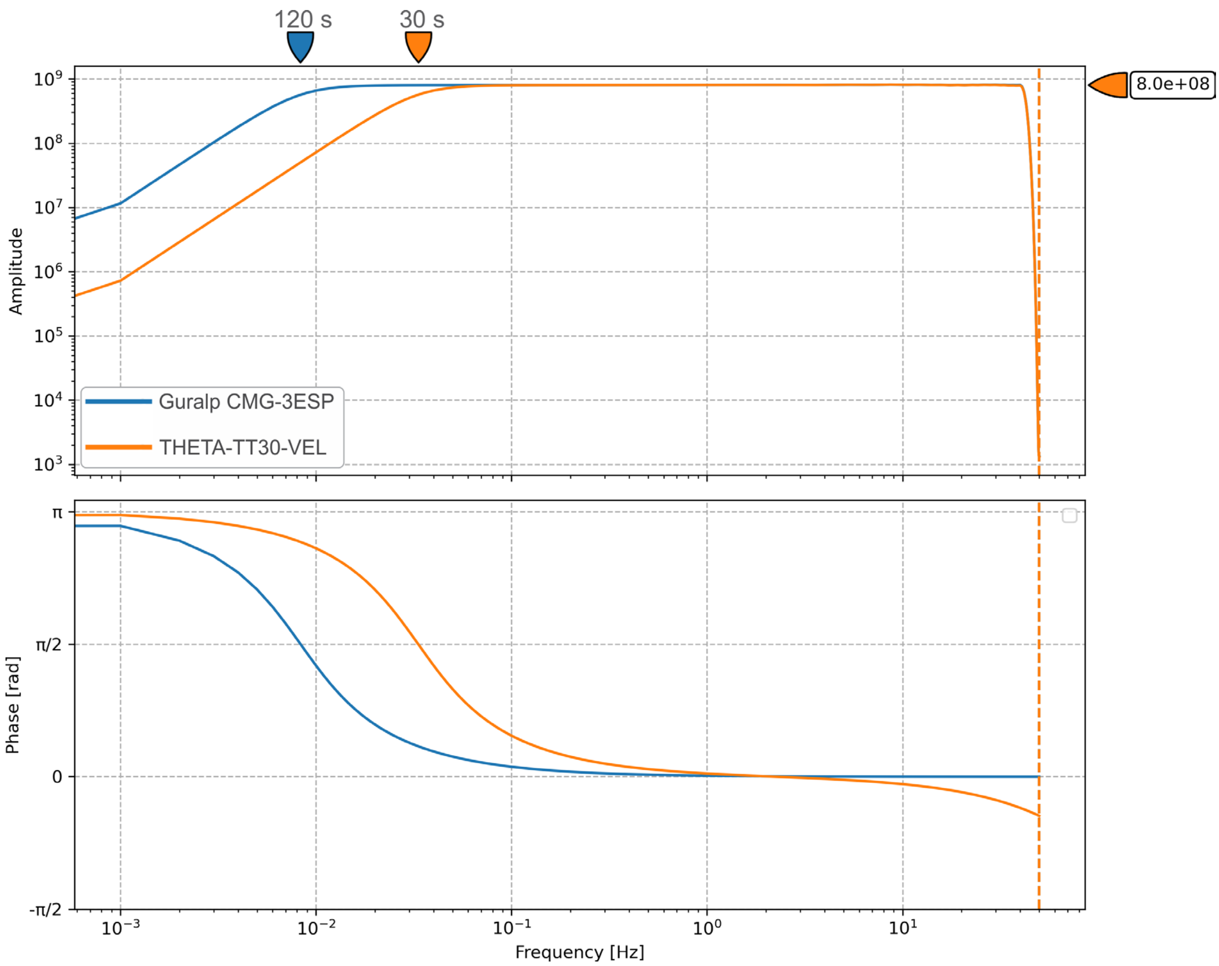

Figure 6. Amplitude and phase response curves for stations BRIU, KSV and STNU equipped with a Guralp CMG-3ESP 120-s seismometer (blue line), and for stations MEZ and RAKU equipped with a THETA-TT30-VEL 30-s seismometer (orange line). The vertical dotted line represents the Nyquist frequency, with the corner frequencies marked at 120 s for BRIU, KSV and STNU and 30 s for RAKU and MEZ.

5. Data quality in terms of background noise level

One of the primary objectives of a seismic network is to provide high-quality recordings of seismic events. However, the quality of these recordings is heavily influenced by ambient noise from various sources, including temperature fluctuations, weather conditions, and anthropogenic activity. Understanding the probabilistic distribution of ambient seismic noise is crucial for earthquake monitoring, as noise significantly impacts magnitude detection threshold (Nakata et al., 2019). Low-frequency noise (<0.05 Hz) is typically caused by temperature changes and atmospheric conditions, while high-frequency noise (>1 Hz) is primarily associated with human activities (McNamara and Buland, 2004). Additionally, microseismic noise, generated by sea activity, dominates the 4-8 s range (Longuet-Higgins, 1950). The noise levels at the sites of newly deployed stations play a critical role in determining the overall data quality. Understanding the ambient seismic noise levels across the network allows for better assessment of each station's ability to detect seismic signals against the backdrop of environmental and anthropogenic interference.

The Probabilistic Power Spectral Density (PPSD) method is one of the most common approaches to characterizing ambient seismic noise and instrument self-noise. PPSDs provide an overview of noise levels at each station, enabling comparisons with global noise models, such as Peterson's New High Noise Model (NHNM) and New Low Noise Model (NLNM) (Peterson, 1993). Figure 7 shows the PPSDs for the vertical component, and Fig. 8 presents the mean PPSD curves for the horizontal components of the five upgraded stations (BRIU, KSV, MEZ, RAKU, STNU) from their deployment until 1 August 2025, calculated using the ObsPy package (Krischer et al., 2015).

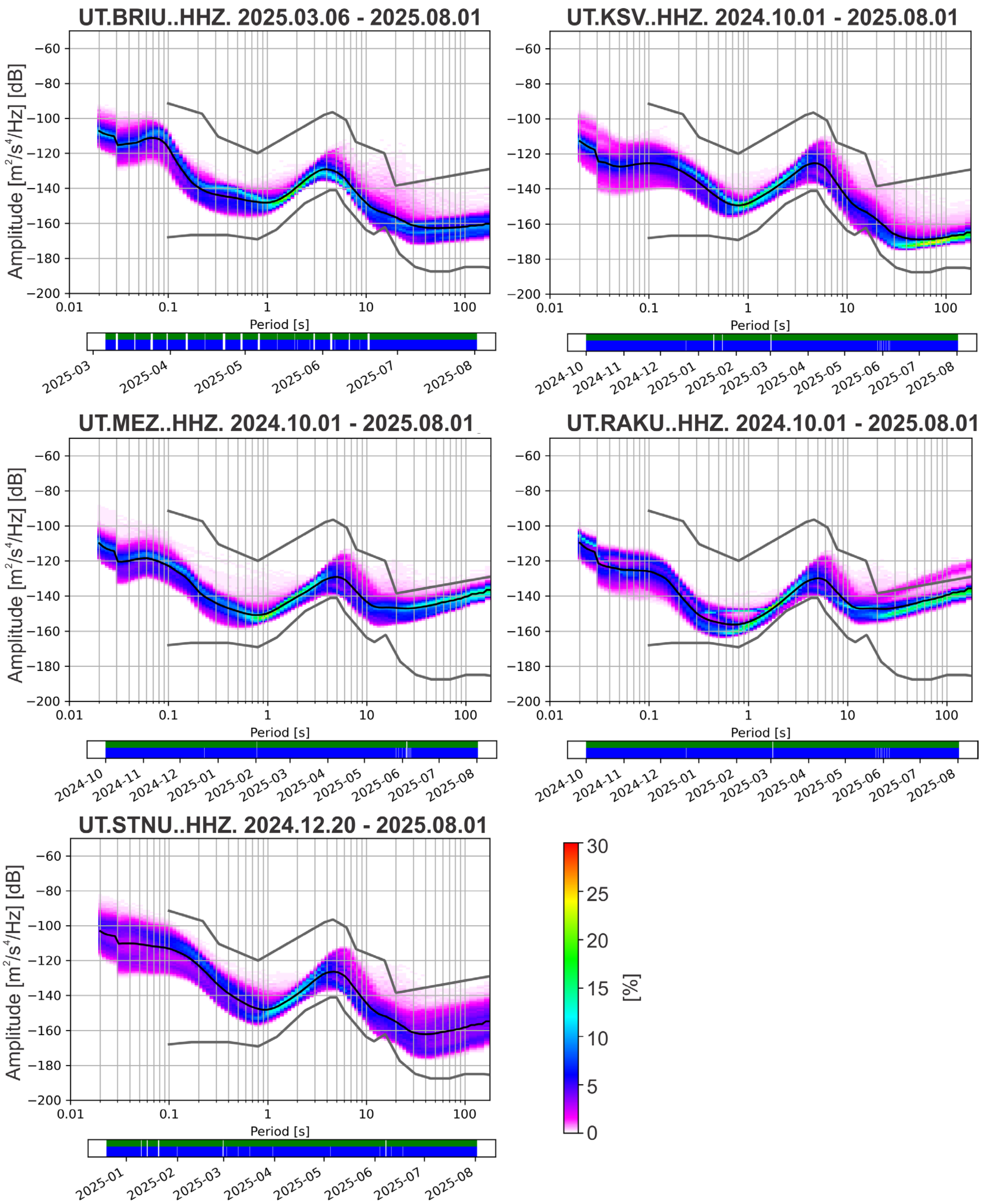

Figure 7. Probabilistic Power Spectral Densities (PPSDs) for stations UT.BRIU, UT.KSV, UT.MEZ, UT.RAKU, UT.SNTU for vertical component during the period from deployment time to 01.08.2025. The black central lines represent the median curves of each PPSD. The PPSDs are compared to Peterson's New High Noise Model (NHNM) and New Low Noise Model (LHNM), represented by dark gray lines (Peterson, 1993).

For short periods (<10 s), vertical (Fig. 7) and horizontal components (Fig. 8) of most stations show low noise levels relative to the NHNM. RAKU station demonstrates the best performance, with median values more than 35 dB below the NHNM, making it the quietest station. BRIU station maintains stable values around 30 dB below the NHNM, though it shows elevated noise in the 0.04-0.1 s range. MEZ station remains within 25-30 dB below the NHNM, while

KSV is slightly noisier, with the HHZ component 20-25 dB below the NHNM. STNU station exhibits the highest noise levels, only 10-15 dB below the NHNM.

At long periods (>30 s), RAKU and MEZ stations, both equipped with GaiaCode sensors, show elevated values across all three components. This behavior is linked to the 30 s corner period of GaiaCode sensors, which limits their sensitivity to long-period signals. For both stations, the vertical-component median curves remain below the NHNM, while the horizontal components are slightly above or near the NHNM. KSV station shows the best performance on the vertical component at long periods, with median values more than 25 dB below the NHNM. STNU station shows the highest noise compared to KSV and BRIU, with horizontal components particularly noisy: short-period values are only 10-15 dB below the NHNM, and long-period levels remain consistently close to or exceed it. Elevated noise on horizontal components across all five stations is likely caused by tilt due to thermal effects. Improved thermal insulation could help reduce this issue, as the sensors were only covered with foam plastic and installed in the basements of brick buildings.

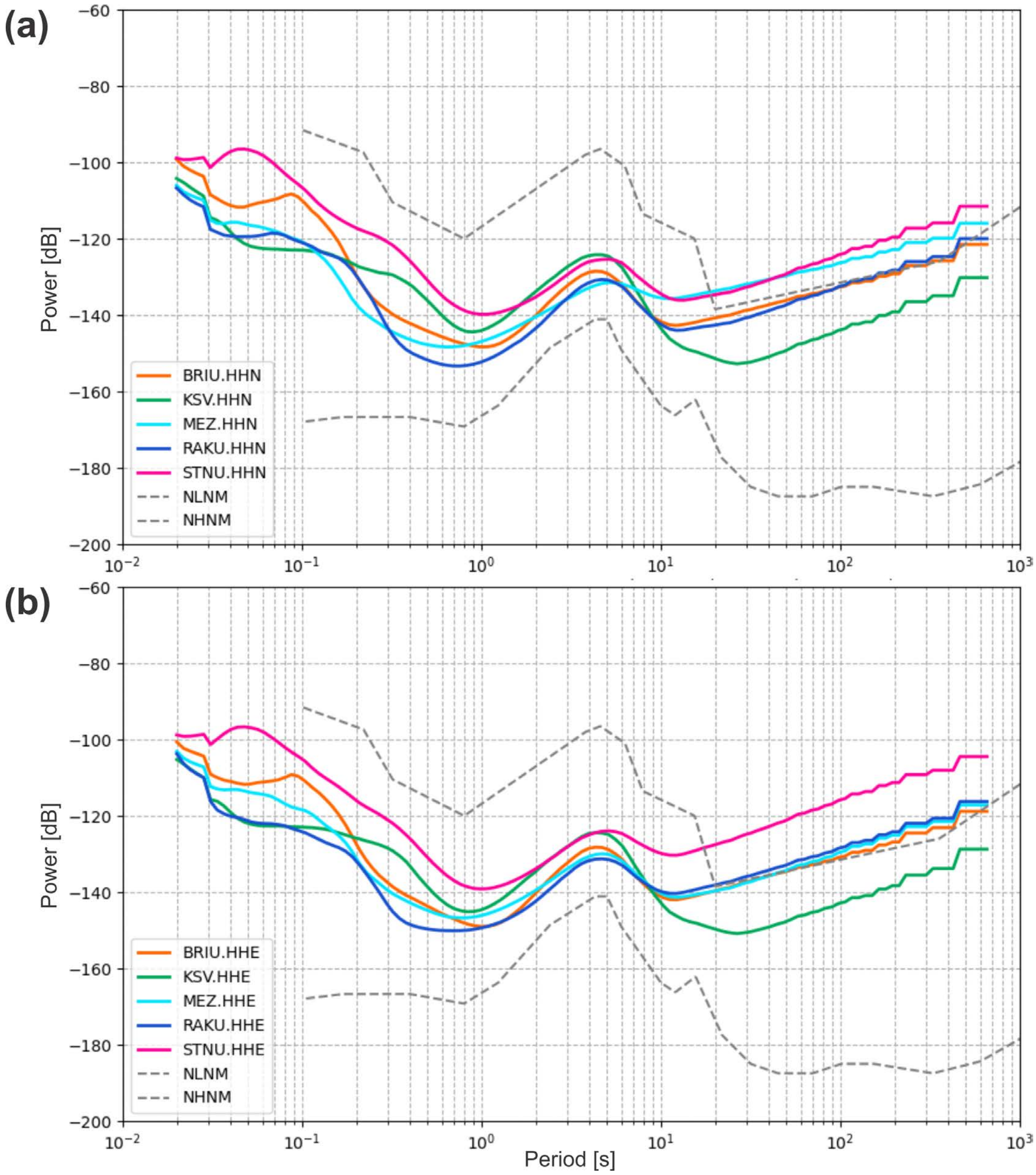

Figure 8. The median curves of PPSD for the horizontal components HHN (a) and HHE (b) for stations UT.BRIU, UT.KSV, UT.MEZ, UT.RAKU, UT.SNTU during the period from deployment time to 01.08.2025. The median curves of PPSDs are compared to Peterson's New High Noise Model (NHNM) and New Low Noise Model (LHNM), represented by dark gray lines (Peterson, 1993).

Within the secondary microseism band of 4-8 s period, elevated noise levels are observed across all stations. This microseismic noise peak is ubiquitous on broadband stations globally, its presence at inland stations underscoring the long-range propagation of ocean wave activity through the solid earth.

On typical seismic stations, anthropogenic cultural noise exhibits a pronounced diurnal pattern, being stronger during the daytime hours and on weekdays than during nighttime and on weekends. This becomes evident when filtering to frequencies of 4-14 Hz, well above the microseismic noise band, as shown in Fig. 9 for the vertical displacements at the five upgraded stations calculated using the SeismoRMS package developed by Lecocq et al. (2020). Figure 9 reveals a distinct daily periodicity, with higher noise levels observed during daytime at all stations. A weekly periodicity is also evident, as noise levels decrease over the weekends compared to weekdays, particularly at station RAKU.

Among the five stations, RAKU consistently records the lowest displacement amplitudes. Located in a quiet forested area away from roads, it shows values typically between 0.5 and 1.5 nm. STNU station represents the noisiest site, with displacement amplitudes frequently exceeding 6 nm and occasionally reaching 10 nm. The persistently elevated noise levels are likely driven by continuous anthropogenic or environmental influences, as the station is located near an occupied building. The remaining stations exhibit intermediate noise conditions. KSV records daytime amplitudes mostly between 2 and 8 nm, with peaks above 10 nm observed from November 11 to November 15, coinciding with road construction activities near the site. MEZ shows typical daytime values in the range of 1-3 nm, with sporadic increases, particularly in early May, attributed to local disturbances. BRIU maintains relatively stable amplitudes around 2 nm, with only occasional brief increases.

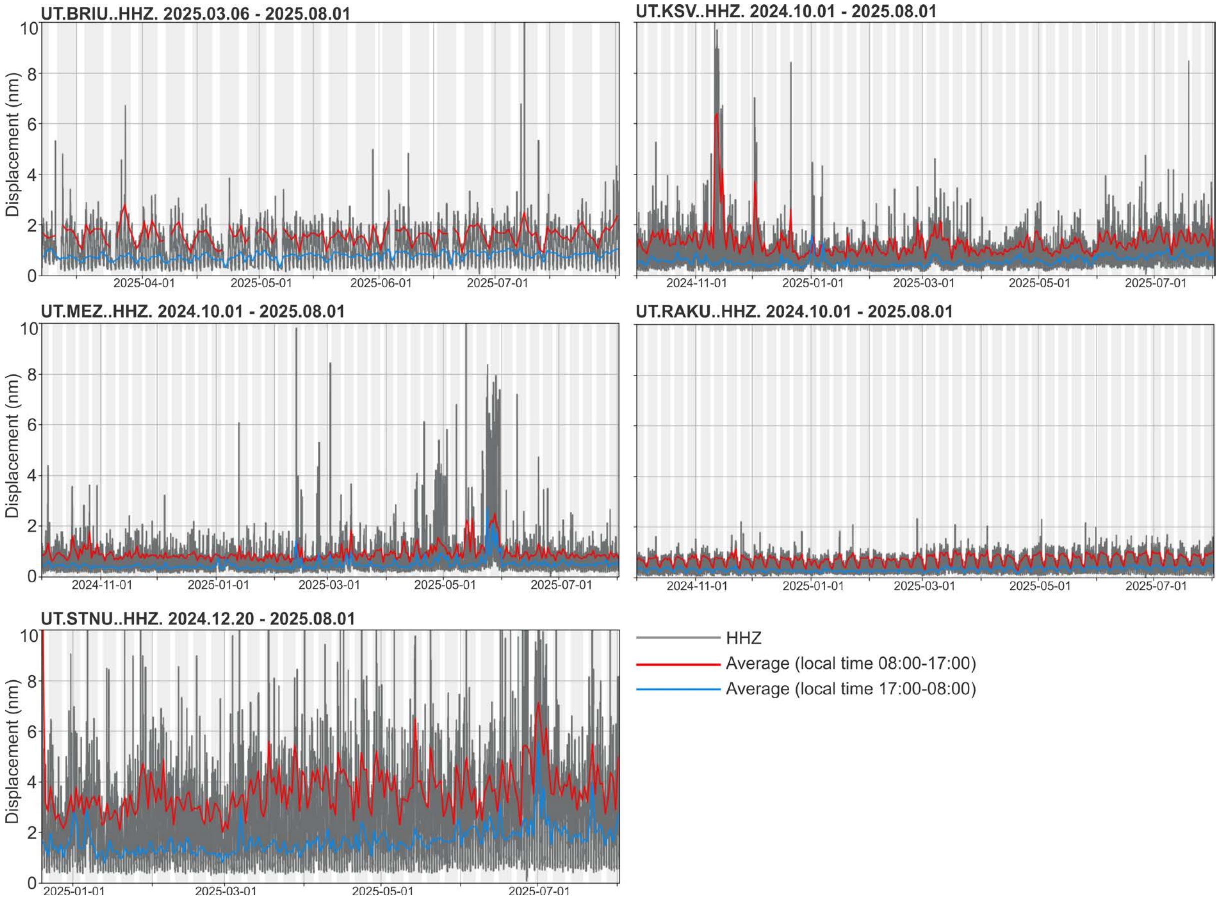

Figure 9. Time-continuous displacement seismograms of the vertical components of stations UT.BRIU, UT.KSV, UT.MEZ, UT.RAKU, UT.SNTU filtered to 4-14 Hz, a high-frequency band strongly affected by anthropogenic noise. The period is identical to that in Figs. 7-8. The gray blocks represent work days, the white blocks weekends. Red lines show the average displacement during daytime hours (08:00-17:00 local time), blue lines trace the average displacement values during evening/nighttime hours (17:00-08:00 local time).

6. Data access and availability

Data from stations CHRU, HOLU, HORU, KMPU, KORU, LUBU, LVV, MORS, MUKU, NDNU, STZU, TRSU, UZH, as well as from the old sensors of BRIU, KSV, MEZ, RAKU, and STNU is transmitted in real-time via mobile internet to the Department of Seismic Activity of the Carpathian Area, located in Lviv. Continuous data from these stations is archived exclusively at this department for further analysis and storage, without being uploaded to any European or other external archives.

Data from the upgraded stations (BRIU, KSV, MEZ, RAKU, STNU) are acquired in real-time from the central SeisComP server at the Subbotin Institute of Geophysics Data Centre by the National Institute for Earth Physics (NIEP) which as EIDA (European Integrated Data Archive) node makes them available openly to the seismological community via standard FDSN web services and seedlink. Data are archived in EIDA with the FDSN network code: UT, Ukrainian National Seismic Network (Subbotin Institute, 2023) and licensed under CC-BY 4.0.

The upgraded stations (BRIU, KSV, MEZ, RAKU, STNU) have been integrated into the AdriaArray virtual network, thus contributing to collaborative efforts to strengthen seismic monitoring and research capabilities across southeastern Europe (Kolínský et al., 2025).

7. Conclusions

The modernization of the Ukrainian seismic network (FDSN code UT) in the Carpathian region of Ukraine marks a significant step toward improving seismic monitoring capabilities in this tectonically active area. The deployment of five upgraded stations (BRIU, KSV, MEZ, RAKU, STNU) in September 2024-March 2025, supported by the ORFEUS Data Integration Grant under the Geo-INQUIRE Project, represents a critical milestone. For the first time, waveform data from the Institute of Geophysics seismic network have been integrated with an open data policy into the European Integrated Data Archive (EIDA), enhancing data accessibility and international collaboration. Participation in the AdriaArray project strengthens scientific partnerships and provides access to advanced methodologies for seismic data analysis. This collaboration enhances regional seismic monitoring capabilities and enables the Ukrainian seismic network to contribute to international studies of tectonic processes. Contributions from GFZ Helmholtz Centre for Geosciences, Gaia Code, and Geoazur provided essential instruments and technical support, enabling these advancements. Combined with ongoing international collaboration, these efforts will help align Ukraine's seismic monitoring system with European standards.

The five upgraded stations show good performance in terms of seismic noise levels, with results aligning well with expectations for their respective environments. The anthropogenic noise observed is closely related to the stations' specific locations.

Despite these achievements, challenges persist. Many stations in the Carpathian network remain equipped with outdated Soviet-era sensors, such as SKD, SM-3, and SM-3KV, which, while functional, limit the overall network's sensitivity and performance. Another significant issue is their use of non-standard data formats (REG-format), which complicates integration with modern data processing systems and international archives. Addressing these challenges will require ongoing efforts, including further station upgrades, as well as calibrating Soviet-era sensors and preparing the corresponding inventory (XML/SEED) for these stations, although specific timelines for these actions cannot be provided at this time.

Data availability statement. Waveform data from the upgraded stations are openly available through the NIEP node of ORFEUS EIDA, under the network code: UT, Ukrainian National Seismic Network (Subbotin Institute, 2023) and licensed under CC-BY 4.0. This work has benefited from open-source tools, including ObsPy (Krischer et al., 2015) and SeisComP (Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences and gempa GmbH, 2008). Data analysis used the publicly available SeismoRMS code developed by Thomas Lecocq (Lecocq et al., 2020).

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***CORRESPONDING AUTHOR: Tetiana AMASHUKELI**,
GFZ Helmholtz Centre for Geosciences, Potsdam, Germany
e-mail: amashuke@gfz.de