SEISMIC NOISE ANALYSIS IN THE MICROSEISMIC AND HIGH-FREQUENCY DOMAIN AT THE BURAR SEISMIC STATIONS

A. TOLEA$^{1,2}$, B. GRECU$^1$, C. NEAGOE$^1$, I. A. MOLDOVAN$^1$, V. E. TOADER$^1$

$^1$National Institute for Earth Physics, 12 Calugareni Street, Magurele, Ilfov, Romania
$^2$Faculty of Physics, University of Bucharest, 405 Atomistilor Street, POBMG-11, RO-077125 Bucharest-Magurele, Romania
E-mail: tolea.andreea@infp.ro

Received October 5, 2022

Abstract. In the absence of earthquakes, seismic stations continuously record the Earth’s vibrations, called ambient seismic noise (ASN). The main concern regarding the ASN records is improving the seismic data quality using different tools developed especially for this purpose. Power Spectral Densities (PSD) and their corresponding Probability Density Functions (PDF) are tools used to evaluate the station performance and reveal the noise level at the station’s site. For high frequencies (>1 Hz), the noise sources are from cultural activities and show diurnal variation, while for low frequencies (<1 Hz), the noise is generated by natural sources and shows seasonal variation. In this study, we analyzed the vertical components of the Bucovina array seismic network (BURAR) to characterize the noise levels at the stations and investigate noise variations in space and time. We computed four-year spectrograms for some elements of the array that revealed an increase of ASN in the 2–5 Hz frequency range during the warmer seasons, contrary to the colder months. On the other hand, at lower frequencies (0.5–1 Hz), the power of seismic noise increases during the year’s colder months. We examined the relationship between noise levels and weather parameters (e.g., wind speed) for the station where the seismic sensor is collocated, with a weather station. We observed that an increase in wind speed leads to an increase in the noise level at high frequencies (> 2 Hz).

Key words: Ambient seismic noise, wind speed, single and double frequency peak, seasonal variations.

DOI: https://doi.org/10.59277/RomRepPhys.2023.75.705

1. INTRODUCTION

Romania is one of the European countries with high seismicity generated mainly by the intermediate-depth earthquakes in the Vrancea zone. Crustal earthquakes are also generated in different seismogenic areas of the country. To monitor this seismicity, the National Institute for Earth Physics (INFP) developed over the years one of the largest seismic networks in Europe (Fig. 1). A prevailing
focus of the Romanian Seismic Network (RSN) is to provide high-quality data for different seismological studies: seismic source and Earth structure investigations, microzonation and seismic hazard studies, early warning, monitoring nuclear explosions and data exchange with international seismic data centers. To achieve this, INFP has implemented various procedures to ensure high-quality seismological data. One of them is based on the analysis of the small continuous vibrations of the Earth recorded anywhere on our planet’s surface. These vibrations, known as ambient seismic noise (ASN), may have either natural or anthropogenic origin. The background noise level at seismic stations depends on the noise sources, the distance to them and the quality of the installation of the seismic sensor. Human activities—traffic, power plants and factories—generate the anthropogenic origins of seismic noise that is well observed at frequencies above 1 Hz. The seismic noise of natural origin is generated by wind, oceanic and coastal waves [1, 2] and can be observed at low frequencies (0.05–0.5 Hz). The anthropogenic noise is characterized by diurnal variations [3–6], while the natural origin seismic noise is characterized by seasonal variations [3, 5, 7].

Fig. 1 – Map showing the locations of the stations belonging to the Romanian Seismic Network. The white circle represents the studying zone – Bucovina array.
2. DATA AND METHODS

The seismic data used in this study originate from RSN, from Bucovina array seismic network (BURAR). The network consists of 9 stations equipped with short-period velocity sensors (GS21, Geotech Instruments, SUA), 1 broadband velocity sensor (CMG3T, Guralp) and 3 broadband velocity sensors (CMG40T, Guralp) distributed over an area of 5 km² (Fig. 2) [8]. The BURAR stations continuously record the ground motion parameters and data are sent in real-time to the Romanian National Data Center, where they are processed, analysed, disseminated and archived [9]. Data from the BURAR array were used by [10] to estimate the detection capability for Vrancea intermediate-depth and crustal earthquakes in Romania. We used in our analysis only the vertical components of the velocity sensors. Also, the atmospheric data is provided by the INFP weather network (www.geobs.infp.ro), composed of 11 weather stations with Boltek lightning detection system and 7 more weather stations. The weather stations are collocated with seismic stations belonging to RSN.

Fig. 2 – Aperture of Bucovina array seismic network (BURAR).
The background noise at seismic stations is generally evaluated using tools developed based on Power Spectral Densities (PSD) and their corresponding Probability Density Functions (PDF) [5]. This method assumes that the entire data set has been sampled in continuous time segments of 1 h length that overlap by 50%. For each segment and each channel, the PSDs are calculated, the frequency distributions being constructed by summing the individual PSDs in the following way: (1) grouping the periods in 1/8 octave intervals; (2) grouping the powers in 1 dB intervals. Then, PDFs are constructed by normalizing each frequency group to the total number of PSDs. The results of the analysis are processed and presented graphically by comparison with the noise models of [11]. For the computation of PSDs and PDFs, we used the commercial version of the open-source PQLX software package (PASSCAL Quick Look eXtended) [12], namely SQLX.

Table 1

Elements belonging to BURAR array

<table>
<thead>
<tr>
<th>Station Code</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Channel</th>
<th>Start Time (year/day)</th>
<th>Instrument type</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUR01</td>
<td>47.6148</td>
<td>25.2168</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR01</td>
<td>47.6148</td>
<td>25.2168</td>
<td>BHZ</td>
<td>2008/058</td>
<td>CMG40T</td>
</tr>
<tr>
<td>BUR01</td>
<td>47.6148</td>
<td>25.2168</td>
<td>HHZ</td>
<td>2018/319</td>
<td>CMG40T</td>
</tr>
<tr>
<td>BUR02</td>
<td>47.6187</td>
<td>25.2209</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR03</td>
<td>47.6085</td>
<td>25.2179</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR04</td>
<td>47.6182</td>
<td>25.2122</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR05</td>
<td>47.6326</td>
<td>25.2176</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR05</td>
<td>47.6326</td>
<td>25.2176</td>
<td>BHZ</td>
<td>2008/011</td>
<td>CMG40T</td>
</tr>
<tr>
<td>BUR05</td>
<td>47.6326</td>
<td>25.2176</td>
<td>HHZ</td>
<td>2018/306</td>
<td>CMG40T</td>
</tr>
<tr>
<td>BUR06</td>
<td>47.6169</td>
<td>25.2444</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR07</td>
<td>47.6427</td>
<td>25.2324</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR08</td>
<td>47.6441</td>
<td>25.2003</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR09</td>
<td>47.6164</td>
<td>25.1901</td>
<td>SHZ</td>
<td>2002/220</td>
<td>GS21</td>
</tr>
<tr>
<td>BUR32</td>
<td>47.633</td>
<td>25.1805</td>
<td>BHZ</td>
<td>2008/011</td>
<td>CMG40T</td>
</tr>
<tr>
<td>BUR32</td>
<td>47.633</td>
<td>25.1805</td>
<td>HHZ</td>
<td>2018/306</td>
<td>CMG40T</td>
</tr>
<tr>
<td>BURAR</td>
<td>47.644</td>
<td>25.2002</td>
<td>BHZ</td>
<td>2017/278</td>
<td>CMG3T</td>
</tr>
</tbody>
</table>

Elements belonging to BURAR array are presented in Table 1: BUR01-BUR09 (SHZ channels) are short-period velocity sensors (GS21) placed in boreholes at 30 m depth, BURAR is a broadband velocity sensor (CMG3T) placed
at 50 m below surface and BUR01, BUR05, BUR32 (BHZ and HHZ channels) are broadband velocity sensors (CMG40T) located at the surface. A channel change from BHZ to HHZ, took place in 2018, due to a change in sampling rate.

3. RESULTS AND DISCUSSIONS

The PDFs have been used in many studies [3, 5–7] to describe the general features of the background noise levels. Figure 3 compares the PSDs obtained for the BURAR and BUR32 elements of the BURAR array. Both stations are located in the Northern part of Romania, far from any large urban areas and the distance between them is almost 2 km. The PDF statistical mode of both stations lies between the two standard noise models of [11], the New High Noise Model (NHNM), and the New Low Noise Model (NLNM), indicating a low background noise level for the stations.

The low noise level observed for periods smaller than 1 s agrees with the station’s position relative to the noise sources of anthropogenic origin. However, we can observe a few differences between the two stations at lower periods. Station BUR32 shows a slighter increase in the noise level for periods smaller than ~0.15 s than station BURAR, suggesting that the BUR32 station is more affected by anthropogenic noise sources than the BURAR station.

In the microseismic band, i.e., between 2 s and 20 s, the noise level has a natural origin and is characterized by two significant peaks connected to oceanic waves. The first one is called double-frequency peak (1–8 s) and is associated with ocean waves propagating in opposite directions generating waves that interact with the ocean floor, resulting in elastic waves that seismic stations record as seismic noise. The second one is called single-frequency peak (8–14 s) and is interpreted as the result of ocean waves hitting the coast and transferring energy into Rayleigh waves through the Earth’s surface. We observe similar features related to the double-frequency peak for both stations and a big difference for the single-frequency peak. For periods larger than 15 s, the difference in the PDFs of the two stations is given by the poor thermal isolation of the BUR32’s broadband sensor. It is interesting to note the shift towards a smaller period of the single-frequency peak for BURAR with respect to the NLNM.

Previous studies [5] showed that the noise level with the highest probability for a station is best approximated by the statistical mode curve of the PDF. So, therefore, the statistical mode curve was computed for all the BURAR station elements to get an overview of how the stations of the arrays perform. We can observe from Fig. 4 that all modes of the BURAR stations lie between NHNM and NLNM, closer to the latter.
We observed some similarities and differences among them:

i) for periods smaller than 1 s the noise level increases and is related to the human activity near the stations;

ii) for periods from 1 s – 20 s the noise level is related to ocean activity and is similar for all the broadband stations in the 1–12 s range;

iii) for periods over 20 s, an increase in the noise level is given by the poorer thermal isolation of the sensors for surface-placed stations contrary to the borehole broadband sensor.
If at periods larger than one second (frequency below 1 Hz) the seismic noise is generated by natural sources and shows seasonal variations, at periods shorter than one second (frequencies above 1 Hz) seismic noise is caused mainly by human activity and its level shows significant variations between night-time and day-time.

To investigate seismic noise variations, four years spectrograms were computed for the BUR01 components. They are presented in Fig. 5. The spectrogram for BUR01, short period velocity sensor, highlights an increase of ASN during the day between ~ 4 AM and 4 PM GMT hours, in the 2–20 Hz frequency range. For broadband velocity sensor, the spectrogram emphasizes higher noise level during the cold months of the year.

We computed the spectrograms for the 2012–2015 period to better understand the seasonal noise variations, as is shown in Fig. 6. We compare two short-period sensors (BUR05 and BUR07) located in boreholes at 30 m depth and two broadband sensors (BUR05 and BURAR), the former located at the surface and the latter in the borehole at 50 m depth. It is interesting to note that all four

![BURAR station PSDDPDF mode](image)
stations exhibit seasonal variations both at lower frequencies (< 1 Hz) as well as at higher frequencies (> 2 Hz).

Fig. 5 – Spectrograms showing a) seasonal and b) diurnal variations for BUR01.

However, the period when the noise power increases differs depending on the frequency. The noise power increases during the colder months at low frequencies, while for the higher frequencies, the noise power increases during the warmer periods of the year. In the first case, as we are close to the microseismic domain, the increase of the noise power is related to the harsher winter weather conditions. In contrast, at frequencies above 2 Hz, the noise power increase is related to agricultural work performed in the area during the warmer months. The differences in the noise power as a function of depth for higher frequencies are also worth mentioning. The deeper the sensor is, the lower the noise power.
Fig. 6 – Noise level spectrograms over 4 years (from January 1st 2012, to December 31th, 2015) at BUR05, BUR07 and BURAR elements.

Also, if we compare BUR07 and BUR05 stations at the same depth, we observe an increase in the noise power for station BUR07 compared to station BUR05. The former station is closer to a rural road, which might explain the noise level increase.

Taking advantage of a weather station located in the same place with the BUR04 seismic station, we investigated the influence of local atmospheric parameters (e.g., wind speed) on seismic noise. We considered seven days of data for this analysis between February 3rd and February 9th, 2020. A report from the National Meteorological Administration [13] reveals that the analyzed period marks a cyclone crossing above Romania. February 05 and 06 is the climax of it, causing temperature drops, rainfalls, snowfalls, wind, and wind gusts in the northern Oriental Carpathians with a speed that can reach 100–110 km/h. In Fig. 7, we show the spectrograms computed in the high-frequency band (4–10 Hz) for the analyzed period at three stations: BUR01 (borehole and surface sensors), BUR04 (borehole sensor), BUR32 (surface sensor), and the diagram with the wind speed measured at the weather station collocated with BUR04 seismic station. We observe a good correlation between the increase in the noise level and the increase in the wind speed. However, for the stations located at the surface (BUR01 HHZ and BUR32), the increase in the noise level is more pronounced during the period with stronger winds than for the stations located in boreholes (BUR01 SHZ and BUR04).
Comparison between the spectrograms of the seismic noise computed for stations: a) BUR01 SHZ in borehole; b) BUR01 at surface; c) BUR04 in borehole; d) BUR32 at surface and the wind speed diagram; e) for the period between February 3rd and February 9th, 2020.

4. CONCLUSIONS

Bucovina array seismic network (BURAR) is part of the Romanian Seismic Network, located in northern Romania, which has been upgraded and improved continuously. Therefore, noise investigations at seismic stations should be performed regularly to provide high-quality seismological data. We investigated
the background seismic noise characteristics at different elements belonging to BURAR. For all the array elements, the seismic noise measured by the Power Spectral Density and the corresponding Probability Density Functions lies between the two standard noise models, NHNM and NLNM, indicating a low background noise level for BURAR. Minor differences between the elements are observed at high frequencies, related to human activities near the station, and low frequencies (< 0.5 Hz) caused by the poorer thermal isolation of the sensors installed at surface as compared with those installed in boreholes.

Our study reveals that wind speed significantly impacts ASN in the 4–10 Hz frequency range. For the warm season, we observed an increase in seismic noise for frequencies from 2–5 Hz. An increasing trend was also observed in the noise level for the cold season in the 0.5–1 Hz frequency band.

Acknowledgements. Part of the work has been supported by the following national funded projects: National Core Funding Program (NUCLEU) program Multidisciplinary Program research on the seismic phenomenon in order to increase resilience (MULTIRISC), supported by the Ministry of Education (MEC), project no. PN19080201, and Phenomenal Project PN-III-P2-2.1-PED-2019-1693, 480PED/2020, by UEFISCDI.

REFERENCES


