

# Characteristic of Background Seismic Noise of Local Tarutung Earthquake Based on Power Spectral Density and Probabilistic Density Function Method

Marzuki Sinambela<sup>1,2</sup>, Puji Hartoyo<sup>2</sup>

<sup>1</sup>Undergraduate Program in Applied of Instrumentation Meteorology, Climatology and Geophysics  
STMKG, Tangerang, Banten, Indonesia

<sup>2</sup>Program Studi Fisika, Fakultas Teknik dan Sains, Universitas Nasional, Jakarta  
Email [sinambela.m@gmail.com](mailto:sinambela.m@gmail.com), [phartoyo310@gmail.com](mailto:phartoyo310@gmail.com)

**Abstrak.** An evaluation of four broadband BMKG stations' ambient seismic noise is provided. Knowing the seismic ambient noise tiers confirmed by a community of seismic stations is essential for earthquake monitoring and detection purposes in the Sumatra area. Waveform records from May 2020 are used to calculate the power spectral density and likelihood density characteristic (PSDPDF) for a single day when an excessive noise stage is detected. This study aims to assess the vertical channel of waveform data using waveform information in miniSEED and SAC architecture. Because of their low probability of occurrence, the method used permits the use of data contaminated with earthquakes (a 4.8 magnitude earthquake occurred on May 11, 2020, at Tarutung, North Sumatera, Indonesia) and other demanding signals. The results obtained are extremely important for assessing the overall performance of the current seismic broadband stations, evaluating the web page resolution of new stations, and modifying the detection settings for the computerized processing machine in the Indonesia Seismic Network. Compared to TTSM, TKSM, and RSSM stations, the noise at LSTM stations is weaker, but the likelihood of an increase increases at high frequencies. Cultural noise in human endeavors produces certain noise and fluctuation over extended periods of time, which is typically certified for the process of earthquake signals.

**Keyword:** PSDPDF, Tarutung, background noise, digital broadband, seismic networks.

**Abstract.** Evaluasi kebisingan seismik dari empat stasiun BMKG broadband. Untuk memantau dan mendeteksi gempa bumi di wilayah Sumatra, sangat penting untuk mengetahui tingkat kebisingan seismik ambient yang dikonfirmasi oleh komunitas stasiun seismik. Rekaman gelombang dari Mei 2020 digunakan untuk menghitung kepadatan spektral daya dan karakteristik kepadatan kemungkinan (PSDPDF) untuk satu hari ketika terdeteksi tahap kebisingan berlebihan. Studi ini bertujuan untuk menilai saluran vertikal dari data gelombang menggunakan informasi gelombang dalam arsitektur miniSEED dan SAC. Karena probabilitas terjadinya yang rendah, metode yang digunakan memungkinkan penggunaan data yang terkontaminasi oleh gempa bumi (gempa bumi berkekuatan 4,8 terjadi pada 11 Mei 2020 di Tarutung, Sumatera Utara, Indonesia) dan sinyal-sinyal menuntut lainnya. Hasil yang diperoleh sangat penting untuk menilai kinerja keseluruhan stasiun broadband seismik saat ini, mengevaluasi resolusi halaman web stasiun baru, dan memodifikasi pengaturan deteksi untuk mesin pemrosesan terkomputerisasi di Jaringan Seismik Indonesia. Dibandingkan dengan stasiun TTSM, TKSM, dan RSSM, kebisingan di stasiun LSTM lebih lemah, tetapi kemungkinan peningkatannya meningkat pada frekuensi tinggi. Kebisingan budaya dalam upaya manusia menghasilkan kebisingan dan fluktuasi tertentu selama periode waktu yang panjang, yang biasanya disertifikasi untuk proses sinyal gempa bumi.

**Kata Kunci:** PSDPDF, Tarutung, kebisingan seismik, broadband digital, jaringan seismik

## INTRODUCTION

Due to its location along the seismically active Sumatran Fault System, where dextral strike-slip faulting frequently creates earthquakes and complex subsurface dynamics, seismic monitoring is essential in Tarutung, North Sumatera. A crucial location for geophysical research, the Tarutung Basin is a tectonic pull-apart basin influenced by both active faulting and geothermal activity. Analyzing digital seismic noise history from broadband stations is equally significant since it offers information on the region's underlying tectonic behavior, anthropogenic influence, and shifting stress



conditions. Researchers have identified differences in ambient noise across several stations by examining power spectral densities and noise probability density functions. These variances suggest variations in seismic energy that could be related to geothermal or tectonic activity. Regretfully, there is no obvious correlation between the strength of the tectonic activity that follows an earthquake and the energy of the sign. The magnitude or intensity of upcoming tectonic events cannot always be predicted by seismic energy release, even though it is frequently seen as a sign of geological processes at work. This discrepancy makes earthquake forecasting and hazard assessment more difficult, especially in geologically active areas like Sumatra where tectonic plate interactions are dynamic and variable and fault lines are intricate. In this study, we analyzed waveform data from the May 2020 Tarutung event with the goal of assessing the efficacy of station networks in the Sumatra region. We sought to evaluate the sensitivity, coverage, and general efficacy of the seismic stations in obtaining pertinent ground motion signals by focusing our investigation on this specific occurrence. Despite the unpredictability of tectonic responses to seismic energy, this method sheds light on how well the existing monitoring infrastructure supports seismic analysis and early warning initiatives.

In order to improve the national and international seismic monitoring network, Indonesia must choose a permanent seismic station location. The placement of seismic stations must be optimized for early warning and catastrophe mitigation since Indonesia, which is located on the Pacific "Ring of Fire," is extremely susceptible to earthquakes and volcanic activity. Throughout the archipelago, a broadband seismic network has been actively developed and implemented from 2008. International partnerships including China's Earthquake Administration (CEA), Japan's JISNET, the German Research Centre for Geosciences (BMKG), Indonesia Libra Network, and the CTBTO's International Monitoring System (INA) are among those that have contributed to this network. These networks offer top-notch seismic data that aids in real-time monitoring, earthquake hazard assessment, and scientific study. However, a seismic station's efficacy is highly dependent on its site location, which includes accessibility, noise levels, and geological characteristics. In order to ensure thorough coverage and minimize blind spots, choosing the ideal location for permanent installations is therefore both a technical and a strategic issue. Indonesia's position in the international geophysical community is strengthened and its resilience to seismic hazards is increased via a broadband seismic network that is widely dispersed and cooperatively administered. The significance of worldwide collaboration in earthquake monitoring is reflected in the integration of efforts.

Due to its location near the meeting point of many tectonic plates, Indonesia, which is part of the Pacific Ring of Fire, frequently experiences earthquake activity. The layout and location of this region's seismic network have a significant impact on how well earthquakes are monitored and predicted. The "variance of the seismic network" most likely refers to variations in data consistency, sensor sensitivity, and station coverage around the nation. More precise seismic event detection and localization are made possible by lowering this variance through network expansion and calibration. In order to obtain high-quality data—which is essential for figuring out important earthquake parameters like magnitude, depth, and epicenter—a dependable and consistent network is essential. Furthermore, understanding seismicity patterns can be greatly improved by analyzing earthquake data using clustering techniques. Researchers can find regions of concentrated tectonic activity and more accurately estimate earthquake risks by classifying similar seismic occurrences according to spatial, temporal, or magnitude characteristics. These clusters support predictive models of tectonic motion and aid in the forecasting of possible seismic hotspots. Clustering analysis aids in the creation of more precise and timely earthquake early warning systems when paired with an optimized seismic network. Such integration of enhanced network architecture and cutting-edge data analysis techniques is crucial for efficient seismic monitoring and disaster risk reduction in Indonesia's complicated geological setting. Pre-processing digital waveform data from Indonesian broadband seismometers requires great attention to detail, especially when following international standards like the Standard for the Exchange of Earthquake Data (SEED). SEED is well known for storing and exchanging digital seismological data in an organized manner. Waveform data is particularly handled by the MiniSEED



format inside SEED, and necessary metadata, including instrument response and station information, is contained in companion dataless SEED files. Depending on the analytical requirements, waveform data and its contextual metadata can be processed separately or in tandem thanks to this separation, which enables effective data handling. Additionally, the MiniSEED format is essential for enabling interoperability with a number of seismic analysis tools, such as the Seismic Analysis Code (SAC), which interprets waveforms and characterizes events using binary input. Researchers can perform a variety of analytical techniques, including filtering, graphing, and spectrum analysis, on seismic occurrences by transforming waveform recordings into binary formats that are compatible with SAC. Seismological observations from Indonesian stations may be readily shared, verified, and interpreted by the international scientific community because of the incorporation of SEED standards and SAC technologies, which also improves data interoperability [1]–[3].

The local geology and the existence or lack of outside noise sources have a significant impact on the background noise in seismic monitoring systems. Background noise is typically lower in areas with solid geological characteristics and little human activity, which enhances the clarity of recorded seismic signals [4], [5]. The entire noise environment at seismic stations, however, is influenced by a number of factors, including natural seismic events like earthquakes, cultural noise (like traffic or industrial activity), and even artifacts created by the apparatus itself. The accuracy and dependability of the interpretation of seismic data can be greatly impacted by these many noise sources. It is essential to evaluate the detectability performance of the Sumatra region's seismic network, which has been in operation for more than ten years. The network's ability to identify and describe seismic events may be impacted over time by elements like aging equipment, shifting ambient conditions, and changing noise profiles. In addition to detecting any possible flaws or sensitivity degradation, a thorough evaluation of the stations' performance will aid in maintenance optimization, technological advancement, and improving the network's overall data quality. There are four seismic BMKG stations had been deployed in Sumatra Island, LSTM, TTSM, RSSM, and TKSM. The information is in SAC and generic mini seed format. The chosen station was picked in order to analyze the impact on the historical noise and file of the May 11, 2020 earthquake. For four broadband BMKG-IA stations of three components (North (N)-South (S), East (E)-West (W), and Vertical (V), the characteristics impact of seismic noise computed the power spectral densities (PSD) of history noise at station communities in Sumatra. Additionally, they use the Peterson model's new high/low-noise model (NHNM/NLNM) to measure the received effects [6]–[9]. The main aim study is to evaluate of performance of some of BMKG station which deployed in Sumatra based on the characterizing source of local earthquake noise and signal with vertical components of waveform. The four broadband seismic stations, contain the same types of broadband sensor with data acquisition systems continually sampling at 20 samples per second.

In order to improve the detection and interpretation of local earthquake events, the study's main objective is to use Power Spectral Density (PSD) and Probabilistic Density Function (PDF) methods to analyze the background seismic noise characteristics in the Tarutung region. This analysis will help determine the noise levels, frequency content, and temporal variations in seismic signals. This study advances our knowledge of Tarutung's seismic noise environment, which is essential for enhancing the precision and dependability of regional earthquake monitoring systems. The study can be used to improve seismic station siting, improve data quality for earthquake analysis, and promote regional efforts to mitigate seismic hazards by identifying the main sources and patterns of seismic noise.

## THE MATERIAL AND METHODS

The research focuses on identifying the problem of the lookup region in Tarutung, North Sumatera, Indonesia, gathering the raw records from selected the broadband seismic community in Sumatera. After that, inspecting the performance of seismic station using the PSD and PDF methods



### A. Identifying Problem of Tarutung Event

The earthquake in Tarutung brought on by means of the activity of the Sumatra Fault Zone and in Toru segment. Tarutung is a viable geothermal was controlled through both the Sumatra fault device and younger arc volcanism. In this study, we targeted to pick out and monitoring the seismic station which deployed in Sumatra fault from BMKG Network and had been recorded the waveform on 11 May 2020 as shown in Fig 1.

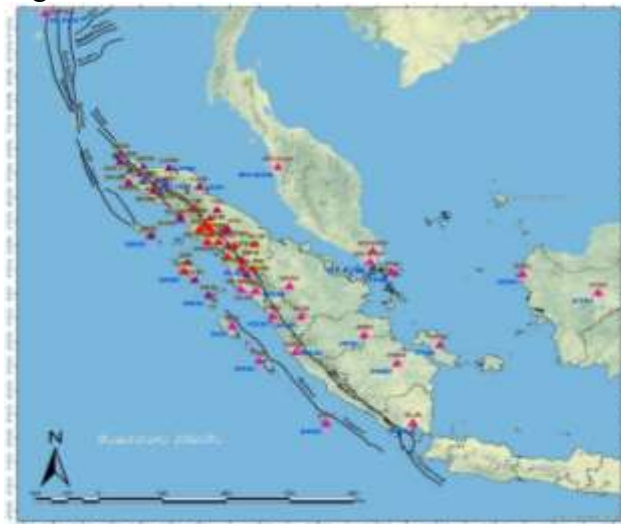


Fig 1. Network Seismic Station in Northern Sumatera

Fig. 1 shows the seismic installed stations and described the Tarutung event, May 11, 2020. In this case, we solely used four stations which recorded the waveform of the Tarutung earthquake in May 2020.

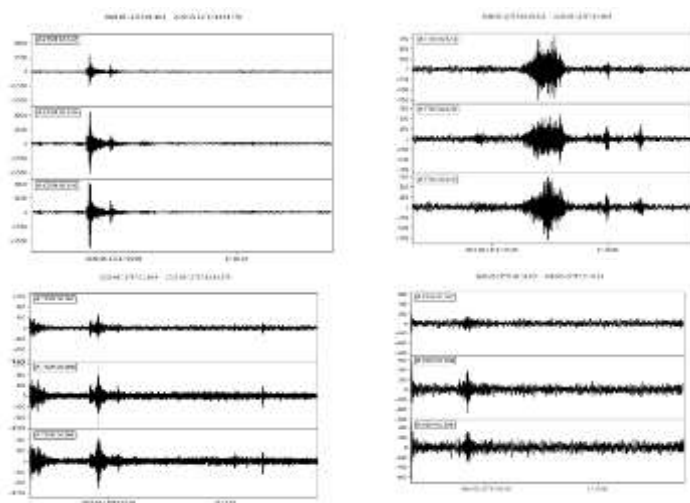


Fig. 2 The waveform recorded with station seismic LSTM, TTSM, TKSM, and RSSM.

Fig. 2 indicates the waveform of the seismic sign recorded at BMKG Network Seismic station. In this case, we use the seed row information and we convert to SAC with three components SHE, SHN and SHZ. The table II suggests the predominant earthquake and aftershock in Tarutung event in May 2020.

### B. Methods

The seismic sign waveform obtained at the BMKG station is shown in Fig. 2. Here, we utilize the information from the seed row and convert it to SAC using the three components SHE, SHN,

and SHZ. The discrete Fourier transform is the most often used method for approximating a PSD for stationary unsystematic seismic statistics. This method uses a finite-range fast Fourier transform (FFT) of the special facts to compute a PSD, and it works well in terms of computing [9]–[14]. The finite-range Fourier renovate of a periodic time series  $y(t)$  is given by Eq. 1.

$$Y(f, T_r) = \int_0^{T_r} y(t)e^{-i2\pi ft} dt \tag{1}$$

$$Y(f_k) = \frac{Y(f_k, T_r)}{\Delta t} \tag{2}$$

$$P_k = \frac{2\Delta t}{N} |Y(f_k)|^2 \tag{3}$$

$$P_{dB} = 10 \log_{10}(P_k) \tag{4}$$

$$P(T_c) = N_{PTc}/(N_{ctc}) \tag{5}$$

The frequency is denoted by  $f$ , while the length of the time sequence segment is denoted by  $t$ . The discrete FFT, whose Fourier frequency factors are described by Equation 2, is required for computer use. When  $N$  is the number of samples in each time series segment and  $t$  is the sample intermission, then  $N = t/\Delta t$  for  $k/Nt$  with  $k = 1, 2, \dots, N - 1$ . Applying the Fourier segments found in [9], [15], the total PSD assessment [14] is defined as the regularized square of each component in Eq. 3. The 13 scattered time series components that were discussed in the pre-processing section are then subjected to this PSD expansion once more. Following the completion of the segment PSD estimates, the 13 distinct time segments' PSD estimations are averaged. The total power, is the amplitude spectrum in square with a normalization factor of  $2t/N$ , as is evident from Eq. 3. In seismology, the standardization factor is frequently used to determine the physical acceleration units. The PSD estimate is then adjusted to reflect the 10% cosine taper that was used in the pre-processing phase.

For through comparison to the original standard NLNM baseline [14], [16], [17], Equation 4 is utilized to convert the PSD estimate to decibels (dB) in relation to acceleration  $(m/s^2)^2/Hz$ . For assessing the amplitude-frequency distribution of a finite-length time series, the PSD approach mentioned above is helpful. These PSDs are utilized by seismologists in a variety of applications, such as determining the spectral content material of a floor motion for specific transitory earthquakes and learning about the properties of seismic power that is not caused by earthquakes [15]–[19]. Below, we outline the method for applying a probability density function (PDF) of the PSDs to show the spectral content material of floor motions over extended time periods. We create a PDF from undoubtedly hundreds of PSDs processed using the method described in the previous section in order to estimate the long-term variation of seismic ambient noise at a specific station. We next go over how to merge these several PSDs into a single, long-term PSDPDF representation.

First, to condense the facts storeroom necessities of the PSDs and simplify the visualization of the data, full-octave geometric skill are taken in 1/8 octave intervals [18]. This smoothing phase has the drawback of removing some detail, such as the perfect shape of the microseisms, even if it cuts down on calculation time and information storage needs. For every PSD estimate, this smoothing process is repeated, perhaps producing hundreds of decimated PSD estimates for every pair of stations and components. Eq. 5 provides an approximation of the PDF for a certain middle period,  $T_c$ . With a central time  $T_c$ ,  $N_{PTc}$  is the broad range of spectral approximations that fit inside a 1-dB electricity bin,  $P_{Nctc}$  is the total number of spectral estimations with a center period over all powers. From the resulting statistical picture of these accumulated PSDs, a multitude of seismic noise data may also be purchased.

The proposal demonstrates how to classify movement photos using PSDPDF techniques. As can be seen, each phase involves a number of stages, including pre-processing the collected



waveform, frequency analysis using FFT to calculate the average power, smoothing by final time and frequency, and waveform performance based entirely on PSDPDF.

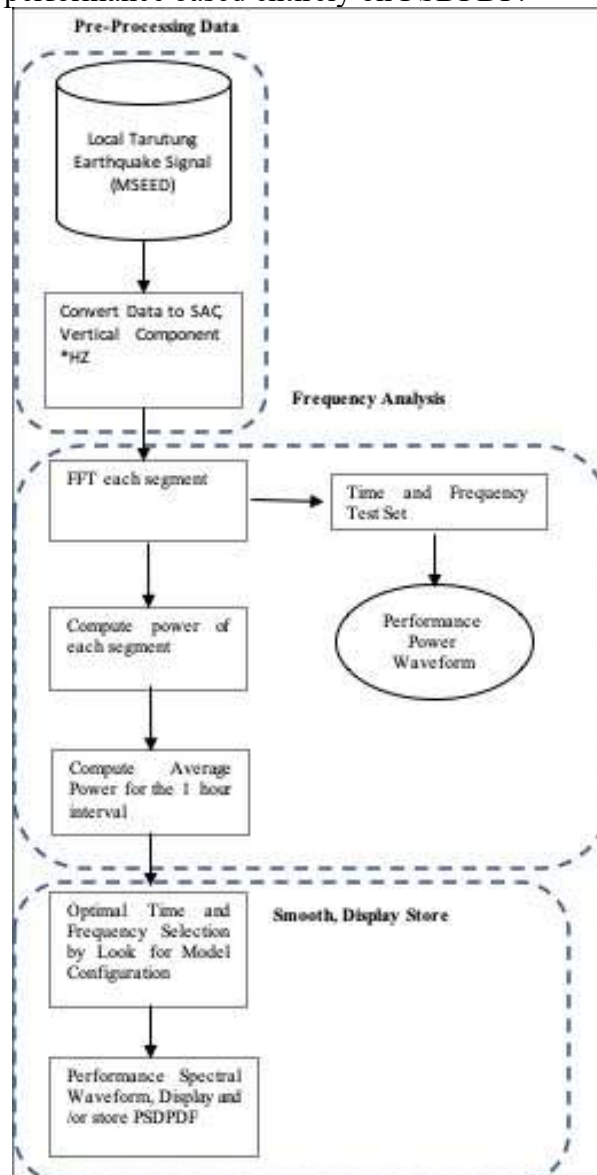


Fig. 3. The flow chart above illustrates the steps of the designed PSDPDF

## RESULT AND DISCUSSION

The study's findings show how the PSDPDF, which maps different and overlapping PSDs into a probability distribution, enhances the depiction of spectrum critical points. In order to understand how to use the waveform from the channel BMKG station with vertical channel, the procedure begins with an instrument-corrected vertical thing of motion displacement seismic time series.

### A. LSTM Sensor Network

The seismic noise history recorded at station TTSM is depicted in Figures 4 using the probability density feature (PDF) of the energy spectral density (PSD) of floor motion. The seismic facts channel LSTM.—SHZ PSDPDF (Fig. 4) contains a good-sized element at both short and long periods that is obscured by several overlapping man or woman PSDs but may be easily seen in the PSDPDF.



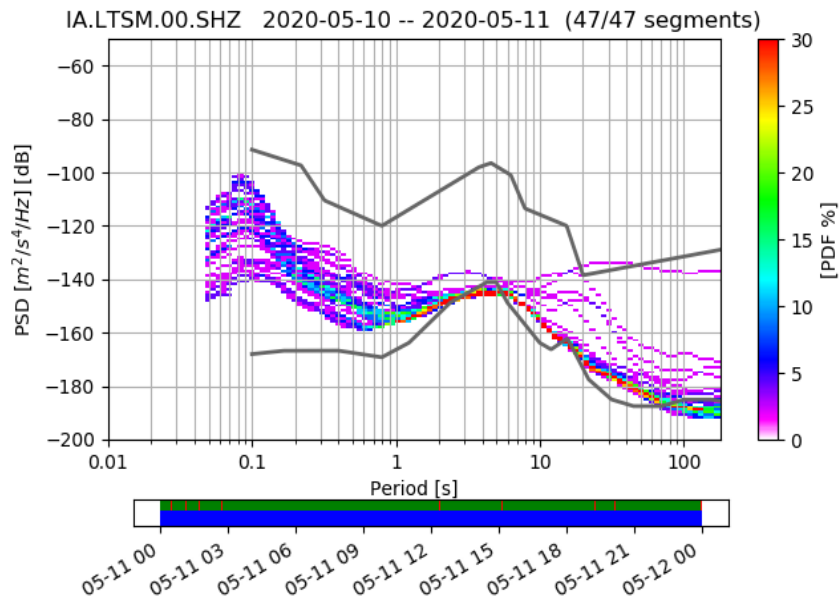


Fig. 4 PSDPDF of station LSTM.SHZ

Station LSTM..SHZ concept's PSDPDF for nine days (47/47 segments) was gridded for the PDF computation. In Figure 4, the NLNM and NHMN are indicated by the dotted line. By placing the station far from roads or in boreholes, caverns, or tunnels, the lifestyle noise can be significantly decreased. It is evident by comparing the power distribution that the low probability of earthquakes and aftershocks is significant.

#### B. TTSM Seismic Network

The PSDPDF result is displayed in Fig. 5 as an energy amplitude (dB) vs interval (s) plot. Seismic recording at each TTSM is influenced by the magnitude of historical prior noise at each epoch.SHZ station, purchasing a graph with a light color pattern.

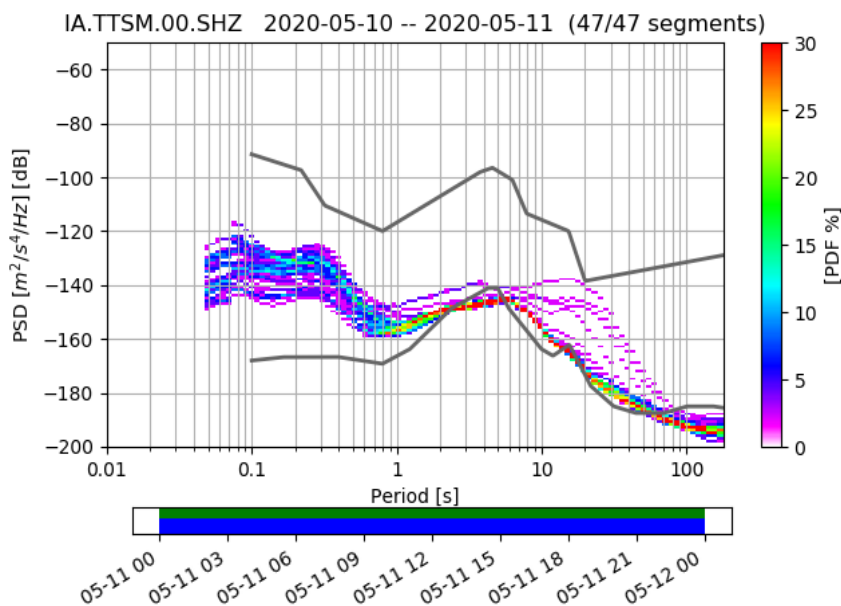


Fig. 5 PSDPDF of TTSM..SHZ station



The NLNM and NHMN are shown by the higher black solid line in each graph in Figure 6. The PSDPDF result at the TTSM..SHZ station (Fig. 5) demonstrated an amplitude between -200 dB and -110 dB. The segments' close adherence to the NLNM line suggests that the background noise in the TTSM..SHZ is minimal. The imply's highest point was performed for periods ranging from 2 to 10 seconds (0.2 to 1 Hz).

### C. TKSM Seismic Network

Probability density characteristic (PDF) of the energy spectral density (PSD) of the heritage noise recorded at station TKSM, channel SHZ (vertical). The evaluation concerns information recorded by means of the broadband STS-2 sensor from May 10 through May 11, 2020. The backside row shows the data used in the analysis: inexperienced patches represent accessible data, crimson patches symbolize gaps in streams that were introduced to the PSD, and blue patches characterize the single PSD measurements that go into the histogram. The station of TKSM has a lower noise stage at longer periods compared to the noise degree at shorter periods. At all frequencies the noise is between the low noise stage and the high noise level [9], [19]. There is a full-size variability in the noise at all frequencies. The noise variability at long periods is usually qualified to earthquake alerts and atmospheric processes [20]. The variability of seismic noise at greater frequencies is commonly attributed to human activities and wind. This plot was once generated with ObsPy [3], [21], [22].

The PSDPDF of TKSM..SHZ station represented between NHMN and NLNM.

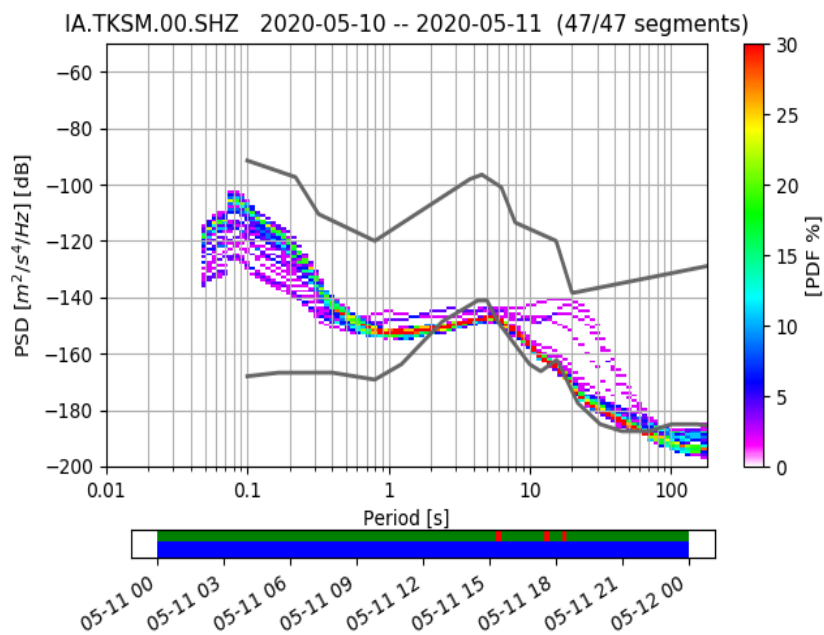


Fig. 6 PSDPDF of TKSM..SHZ station

The spectra in Fig. 6 show the profile of the maximal recorded levels, while the average of the waveform data in time series more closely reflected the mode. The amplitude background noise in Fig. 6 ranging from -200 dB to -90 dB, with PDF about 10 – 30 %. The segment TKSM..SHZ station sticks closely to NHLNM. The result of PSDPDF, in this case, has a high background noise.

### D. RSSM Sensor Network

The PSDPDF of RSSM..SHZ station in Fig. 7 respective plotted in the power amplitude (dB) versus seconds (s). Fig. 7 shown the spectral probability closer to the upper line or NHMN. The calculated of PSDPDF in this case, performed the frequency spectral and the profile of the maximal recorded levels.



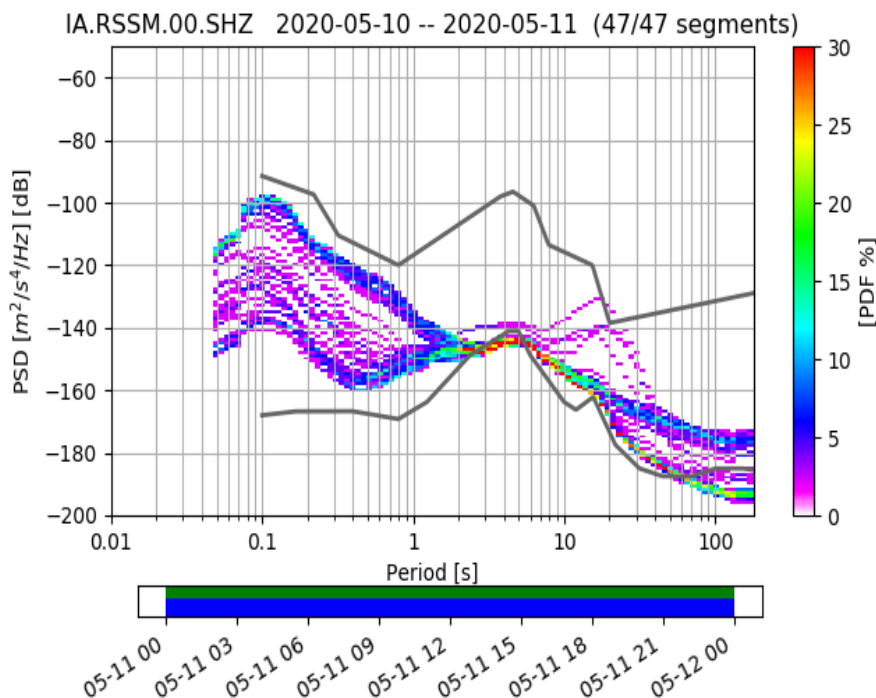


Fig. 7 PSDPDF of RSSM..SHZ station

In PSDPDF of RSSM..SHZ station in Fig. 11 shown the amplitudes ranging from  $-200$  dB to  $-95$  dB. The PDF about 5 - 30 %. The highest peak of mean archived during periods between 1 – 20 seconds (0.1 – 2 Hz). The PSDPDF in all stations in a period including the earthquake on May 11, 2020, computed with nine days (47 segments). The background noise spectrum between 1-20 s, with recorded by very broadband seismometer – STS-2). There are no gaps in the periods of all stations in this study. The gaps can be represented in the period in the green patches to indicated the available data.

Compare to each station array, we expected that the sensors places, in different vault types would contrast noise levels by PSDPDF estimated. The low background noise level indicated of LSTM..SHZ station and other stations in TKSM..SHZ, RSSM..SHZ and TTSM..SHZ stations have the highest background noise level. Both of all seismic sensors, the P wave detected in frequency 2-10 seconds. The small magnitude earthquake (M 4.8) in Tarutung, North Sumatera is the most sensitive to the noise level in the 0.5-10 Hz frequency band, which dominated by cultural noise sources such as cars and equipment.

## CONCLUSIONS

The evaluation of the background noise stage at the chosen station of BMKG station is presented. The waveform data used in this study are now not screened out for the Tarutung earthquakes and instrumental failures. The PSDPDF strategies had been implemented in the computation of historical past noise. The level of heritage noise as well as the full range aspect influencing the fine of waveform data. The PSDPDF of LSTM station is similar to NLMN in frequency 2-10 s. For the TTSM, TKSM and RSSM stations are similar to NHHM, the PSDPDF estimation around the double frequency is with 1-20 s background noise. The find out about of historical past noise stage indicates that the selected station is located at the most fabulous websites and very exact performance of the new broadband seismometer in Sumatra Region.



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