

SEISMIC BACKGROUND NOISE ANALYSIS OF BRTR (PS-43) ARRAY

by

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B.S., Geophysical Engineering, İstanbul University, 2008

Submitted to

Boğaziçi University

Kandilli Observatory and Earthquake Research Institute

in partial fulfillment of the requirements for the degree of

Master of Science

Graduate Program in Geophysical Engineering

Boğaziçi University

2012

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my advisor Assoc. Prof. Nurcan Meral Özel not only for her guidance throughout the thesis but also giving me research opportunities. She is also being a role model for me as an academician.

I would like to thank to Mr. Korhan Umut Semin and Mr. Öcal Necmioğlu for their suggestions about data analysis. I also would like to thank to Dr. Serdar Koçak for supporting me throughout my thesis.

Also, I would like to thank Dr. Onur Tan for helping to me in the creation of GMT contour maps.

I thank all the faculty members and staff of the Boğaziçi University, Department of Geophysics, especially my genuine friends Derya Aydın and Sezim Ezgi Güvercin for being amazing roommates.

I would like to thank Mr. Baransel Erkan for sustaining me when I needed.

At last but definitely not least, I would like to thank my family members for supporting me with endless love, patience and encouragement.

ABSTRACT

The seismic background noise variation of BRTR array, composed of two sub arrays located in Ankara and in Kırıkkale-Keskin, has been investigated by calculating Power Spectral Density and Probability Density Functions for seasonal and diurnal noise variations between 2005 and 2011. PSDs were computed within the frequency range of 100 s – 10 Hz. The results show us a little change in noise conditions in terms of time and location. Especially, noise level changes were observed at 3-5 Hz in diurnal variations at Keskin array and there is a 5-7 dB difference in day and night time in cultural noise band (1-10 Hz). On the other hand, noise levels of medium period array are high in 1-2 Hz frequency range. High noise levels were observed in daily working times when we compared to night-time in cultural noise band. The seasonal background noise variation at both sites also shows very similar properties to each other. Since both arrays consist of borehole instruments and away from the coasts, we saw a small change in noise levels caused by microseism. Comparison between Keskin short period array and Ankara medium period array show us Keskin array is quieter than Ankara array. Finally, to analyze contribution of BRTR array to IMS network for detection capabilities, six-year long event bulletin data were retrieved between 2005 and 2011 to create annual seismic detection threshold maps for BRTR. The contribution of BRTR array to IMS is related to distance and data availability of array. These results also depend on the changes in IMS network configuration and IMS network stations data availability.

ÖZET

Ankara ve Kırıkkale-Keskin’ de iki alt dizinim şeklinde bulunan BRTR diziniminin 2005 ve 2010 yılları arasında mevsimsel ve günlük gürültü değişimleri için güç spektrum yoğunluğu ve olasılık yoğunluk fonksiyonu hesaplanmıştır. Güç spektrum yoğunlukları, 100 s – 10 Hz frekans aralığında hesaplanmıştır. Sonuçlar bize zaman ve yer bakımından gürültü koşullarında küçük bir değişiklik olduğunu göstermektedir. Özellikle, Keskin diziniminin günlük değişimlerinde, 3-5 Hz arasında gürültü seviyesi değişimleri gözlemlenmiştir ve yerel gürültü bandındaki (1-10 Hz) gece ve gündüz zamanında 5-7 dB’lik fark tespit edilmiştir. Diğer yandan, 1-2 Hz arasında orta periyotlu dizinimin kısa periyoda kıyasla gürültü seviyesi daha yüksektir. Yerel gürültü bandında, günlük çalışma saatlerini gece saatleriyle karşılaştırıldığında daha yüksek gürültü seviyelerinin olduğu gözlemlenmiştir. Her iki bölgedeki mevsimsel değişimlerin, kendi aralarında benzer özellikler gösterdiği gözlemlenmiştir. Bu istasyonların kuyu sismometresi olması ve kıydan uzak olmalarından dolayı, microseismden kaynaklı küçük değişimler olduğu görülmüştür. Keskin kısa periyot dizinimiyle, Ankara orta periyotlu dizinim kıyas edildiğinde; Keskin diziniminin daha sessiz olduğu görülmüştür. Son olarak BRTR diziniminin duyarlılık kapasitesi için, 2005 ve 2011 arasında 6 yıllık veri analiz edilmiştir. Ayrıca, minimum tespit edilebilir magnitüd kontür haritaları oluşturulmuştur. Elde edilen değerler, IMS ağındaki konfigürasyon değişikliklerine ve istasyon verilerinin nitel ve nicel değerlerine de bağlıdır.

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LIST OF SYMBOLS/ABBREVIATIONS

CTBT	Comprehensive Test Ban Treaty
d	Horizontal distances
f	Frequency
i	Angle of incidence
IDC	International Data Center
IMS	International Monitoring System
N	Number of samples in each time-series segment
N_{PTc}	The number of spectral estimates into a 1 dB power bin
N_{Tc}	Total number of spectral estimates over all powers with a T_c
P_a	Acceleration power spectral density
P_d	Displacement power spectral density
P_k	Total power
P_v	Velocity power spectral density
PDF	Probability Density Function
PSD	Power Spectral Density
REB	Reviewed Event Bulletin
SEL3	Standard Event List 3
SNR	Signal to noise ratio
T_c	Center period
T_l	Long period corner

T_r	Window length
T_s	Short period corner
v_{app}	Apparent velocity
v_c	Crustal velocity
v_z	Horizontal velocity
x	Horizontal coordinate
y	Vertical coordinate
Δt	Sample interval
Φ	Backazimuth
Θ	Azimuth

1. INTRODUCTION

Seismic noise is generally described as the disturbance of the signal representing the unwanted component of the recorded information with respect to a specific noise. It exists permanently on the recordings, thus it is necessary to identify and specify the characteristics and the spectrum of the seismic noise by extracting its frequency response. Seismic noise is divided into four categories as local noise, microseisms, wind and system noise thus, we can understand that seismic noise exists everywhere on the Earth surface so it can mask seismic signals completely (Davies, 1973; Bormann, 2002). The seismometers can detect not only the seismic events but also other natural vibrations such as cultural activities, wind and ocean waves which referred to seismic noise (Jamshaid *et al.*, 2004; Havskov and Alguacil, 2002; Wielandt, 2002; Bormann, 2002).

The most essential advantage of a seismic array is to provide high quality data for earthquake-monitoring and detection purposes but noise levels affect the quality of data (McNamara and Buland, 2004). Thus, it is needed to know the seismic noise levels of a seismic station or an array. If the aperture (diameter) of the sensor group is within the correlation radius of the signals it is called a seismic array; otherwise the group of sensors form a station network (Schweitzer *et al.*, 2002). Seismic array is a system which is composed of seismographs in a regular geometric pattern to enhance sensitivity for detecting an event. Arrays have an aperture of more than one and less than a thousand kilometers and types of arrays are small aperture, medium aperture and large aperture arrays also, they have regular instrumentation and recordings (Davies, 1973). The aim of the construction of an array is not only supplying better data for the examination of seismic signals but also improving the SNR so we have to know the nature of noise (Davies, 1973).

The difference between a seismic array and a local network is techniques which are used for data analysis (Schweitzer *et al.*, 2002). If we expect that the noise is random within the array when the signal is coherent, even a simple direct summation of the n sensor outputs would generate SNR improvement (Figure 1.1) (Bormann, 2002). If the direction and velocity of travel of a signal through an array is known, one can compensate for the differences in arrival time at the individual sensors and then sum-up all the n record

traces (beam forming) (Bormann, 2002). By beamforming method seismic array can separate coherent signal and noise (Rost *et al.*, 2002). Beamforming suppresses the noise while keeping the signal, thus increasing the signal-to-noise ratio (SNR). By using beamforming method, signal-to-noise ratio (SNR) of a seismic signal can be improved by summing the coherent signals from the single array sites (Schweitzer *et al.*, 2002). Arrays can also give us estimates of the station-to-event azimuth (backazimuth), and of the apparent velocity of different types of signals (Figure 1.3. and Figure 1.4). These estimates are significant not only for event location aims but also for classifying of signals (Schweitzer *et al.*, 2002).

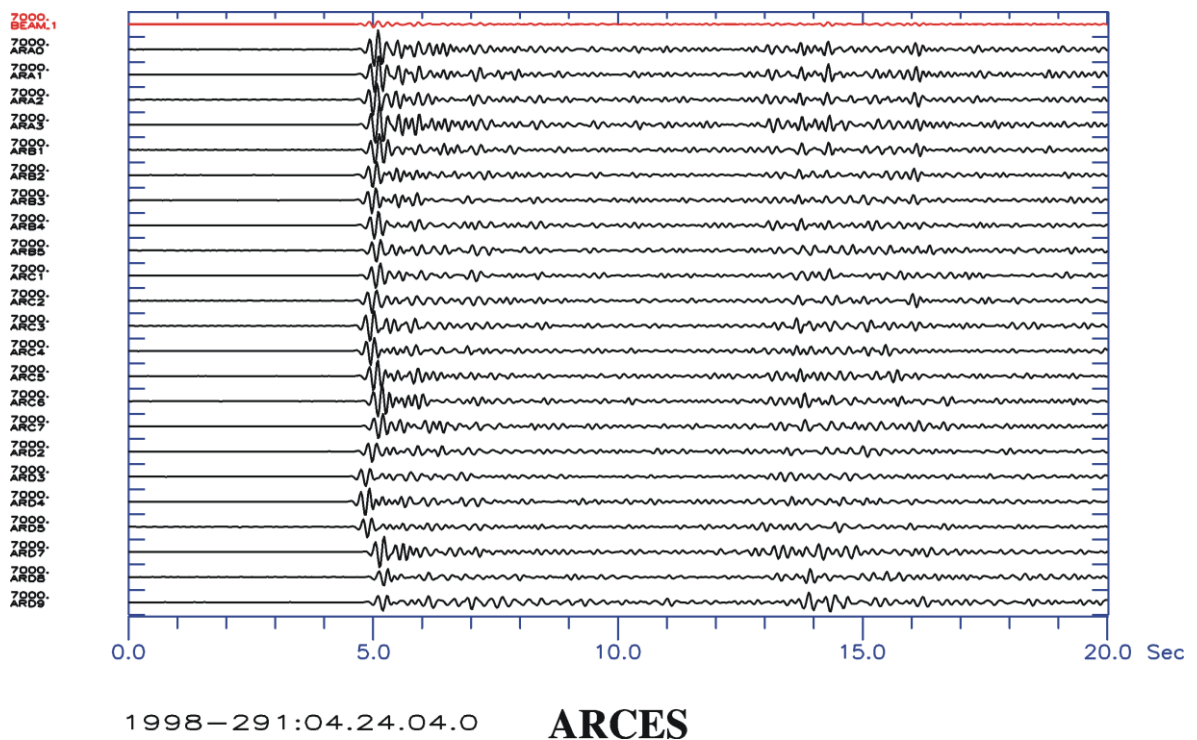


Figure 1.1. The figure shows P-phase onsets of a regional event observed with the vertical short period seismometers of ARCES (Schweitzer *et al.*, 2002)

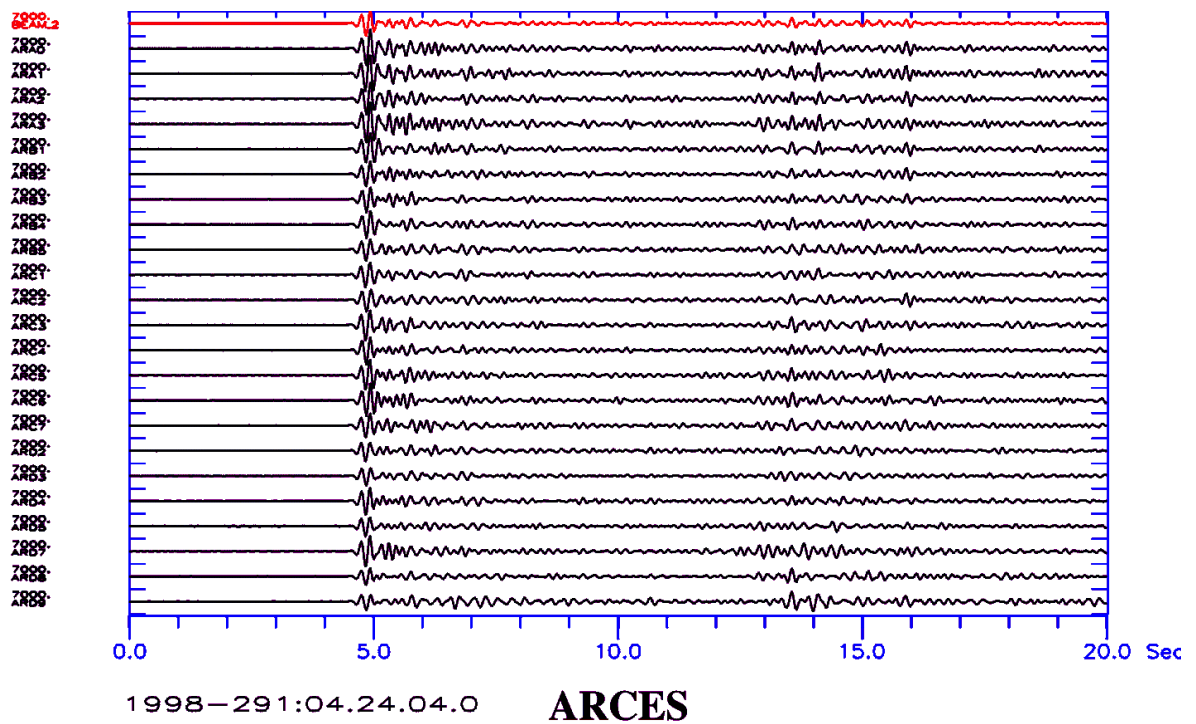


Figure 1.2. This figure shows P-phase onsets of a regional event observed with the vertical short-period seismometers of ARCES as in Fig. 1.1 but the single traces were first aligned and then summed (beam trace in red) (Schweitzer *et al.*, 2002)

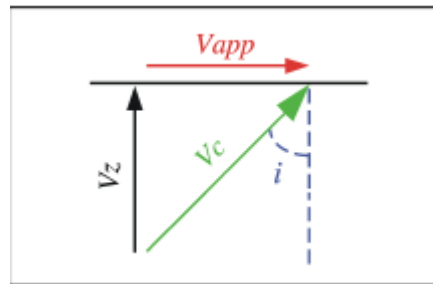


Figure 1.3. A plane wave propagating with the velocity v_c reaches the Earth's surface. The splitting of this velocity in a vertical component v_z and a horizontal component v_{app} is directly dependent on the incidence angle i . The horizontal velocity component is only equal to the propagation velocity v_c for waves propagating parallel to the surface; in all other cases v_{app} is higher than v_c . It is called the apparent velocity (Schweitzer *et al.*, 2002)

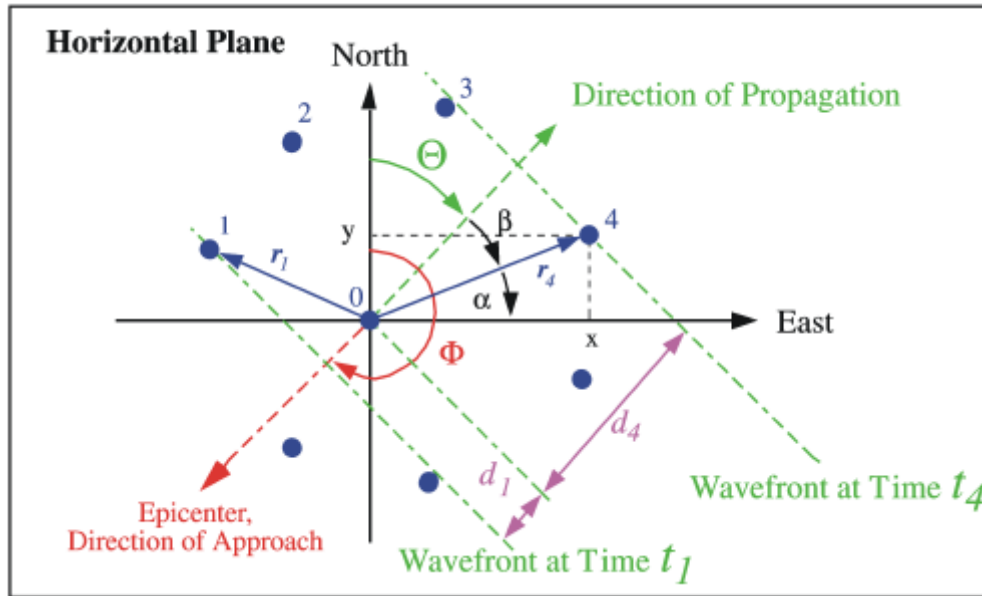


Figure 1.4. Illustration (horizontal plane) of a plane wave, coming from south-west (backazimuth Φ), crossing an array and propagating in a north-easterly direction (Θ) (Schweitzer *et al.*, 2002)

Bogazici University Kandilli Observatory and Earthquake Research Institute (KOERI) is operating BRTR array (PS-43) which is one of International Monitoring System (IMS) primary seismic station under Belbasi Nuclear Monitoring Center for the verification of compliance with the Comprehensive Nuclear-Test-Ban Treaty (CTBT) since February 2000. PS-43 is composed of two sub arrays and they deliver data online to the International Data Center (IDC) in Vienna. The medium-period array with about 38 km diameter located in Ankara and the short-period array with about 3 km diameter located in Keskin (Figure 1.5). These two arrays have a circular geometry and are equipped with a broadband element located in the middle of this circular geometry (Figure 1.6). Short period instruments (Geotech 23900A) are installed at depth 30 meters from the surface while medium (Geotech KS54000) and broadband instruments (Geotech KS54000) are installed at depth 60 meters from surface. Medium period instruments are operating with 4 sps (sample-per-second) sampling rate, broadbands at 40 sps and short period ones are operating at 20 sps. The frequency band of medium and broad band sensors is 0.003-16 Hz and generally frequency band of short period sensors is 1-100 Hz but sampling rate of Geotech 23900A is 20 sps thus it records signals up to 10 Hz.

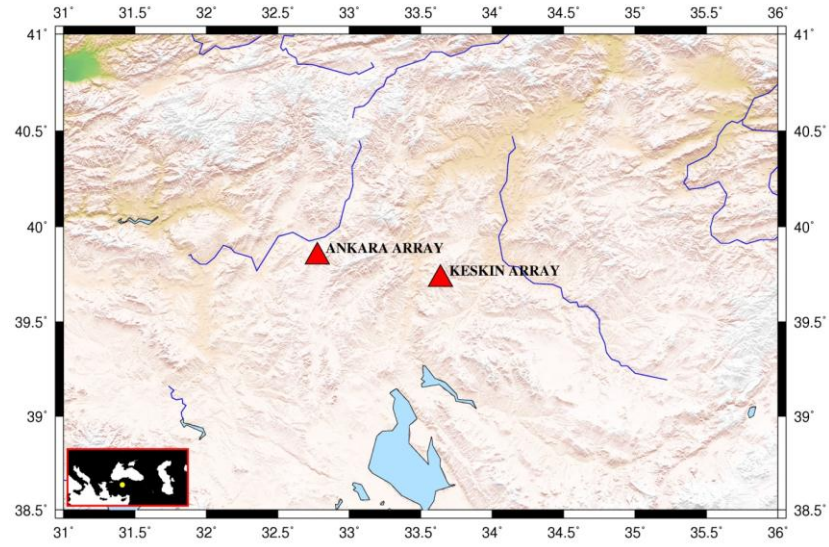


Figure 1.5. Location of Ankara and Keskin arrays

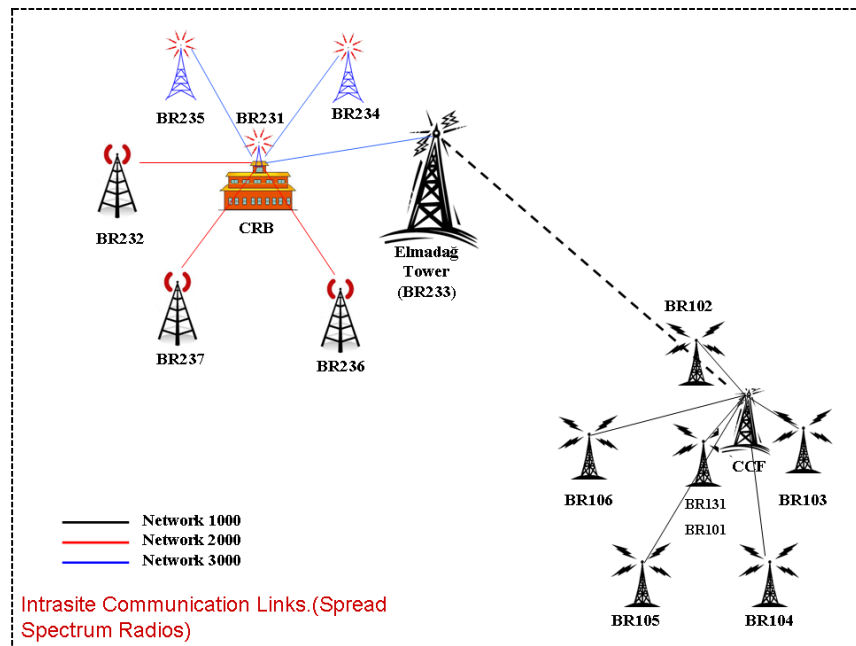


Figure 1.6. Structure Scheme of BRTR array

The aim of this study is to analyze the background seismic noise and see the contribution of BRTR (PS 43) to IMS to event detection. For this purpose, 6-year period data set recorded by BRTR SP Keskin array was used. As mentioned previously, seismic background noises are sometimes referred as ambient earth vibration and include: cultural

noise, wind, water, geological noise, microseisms (Brune *et al.*, 1959). In this study, our aim is to investigate diurnal and seasonal variations to analyze seismic background noise. For this purpose, power spectral density (PSD) was calculated for all the stations of the BRTR array and probability density functions (PDFs) were computed using the PASSCAL Quick Look eXtra (PQLX) software package (McNamara and Boaz, 2006). Analysis of Power spectral density and probability density function give us the information about the precise frequency characteristics of the background noise, which will help us to assess the station sensitivity (McNamara and Buland, 2004). PDF analysis is very important for monitoring the array performance and noise level changes of stations can be identified, also investigation of significant sources of noise at different period bands and variations of background seismic noise levels associated with diurnal and seasonal changes (Diaz *et al.*, 2010). Diurnal and seasonal variations plots were created by Generic Mapping Tools (GMT) (Wessel and Smith, 1991) in order to observe noise level changes and contribution of BRTR array to IMS network for event detection.

The thesis includes 6 chapters. Chapter 1 is the introduction part of the thesis describing the aim of the study. Chapter 2 includes the history of BRTR array, site survey and geology, meteorological information and seismic background noise characterization. Chapter 3 informs on the methodology used in the analysis and provides information about power spectral density and probability density function methods. Chapter 4 gives information on data preparation, analysis and software. Chapter 5 contains results of the thesis and the conclusions are presented in the last part of thesis.

2. THE INFORMATION ABOUT BRTR ARRAY AND SEISMIC BACKGROUND NOISE CHARACTERIZATION

2.1. The History of BRTR (PS-43) Array

The Belbasi array firstly was formed as a four-element (Benioff 1051) seismic array as part of the international agreements (NATO and DECA) in 1951) (Kuleli *et al.*, 2001). At that time the station code of Belbasi array was BSRS (Belbasi Seismic Research Station) (Kuleli *et al.*, 2001).

In 1966, the number of seismometers were increased from 4 to 16 and there were short period arrays (Kuleli *et al.*, 2001). After that, these seismometers were replaced with 23900 instruments in 1972 (Kuleli *et al.*, 2001). In 1978, a three component Teledyne Geotech 18300 seismometer was added to array (Kuleli *et al.*, 2001).

The city of Ankara has extended since the system was established. New housing, industrial facilities and nearby quarries have caused to increase in noise levels; therefore, data quality has been decreased (Kuleli *et al.*, 2001). Due to the high seismic noise, the number of instruments was decreased from sixteen short-period seismometers to seven between the years of 1983 and 1993 (Kuleli *et al.*, 2001). New array locations throughout central Anatolia were appraised because spreading out the city caused to descend seismic operations (Kuleli *et al.*, 2001). An array location near the town of Keskin which is approximately 120 km away from the original Belbasi seismic station, was chosen because of the necessity of a silent site to increase data quality and detection capability of array and also its appropriate geological setting and low noise level (Kuleli *et al.*, 2001).

Comprehensive Nuclear Test Ban Treaty was signed between the Turkish Government and CTBTO on 24 September 1996. This treaty was ratified by Turkish Grand National Assembly on 16 February 2000 (BRTR Certification Report, 2003).

The installation of Keskin array had begun in 1995. This site was chosen as a primary seismic array for the International Monitoring System and was assigned the name

BRTR for the Comprehensive Nuclear Test Ban Treaty. Keskin array installation was completed in 2000 consisting of six short-period vertical-component Geotech 23900A seismometers and one three-component broadband KS54000 seismometer. In addition to the Keskin array, a new array equipped with six long period and one broadband seismometer was installed in the vicinity of Ankara (Table 2.1. and 2.2). After these installations the old Belbasi Array was deactivated (Kuleli *et al.*, 2001).

Belbasi seismic array was certified with code name PS43 by CTBTO on 22 December 2003, meaning that Belbasi seismic station is one of the primary stations of IMS network with real-time data transmission (Figure 2.1).

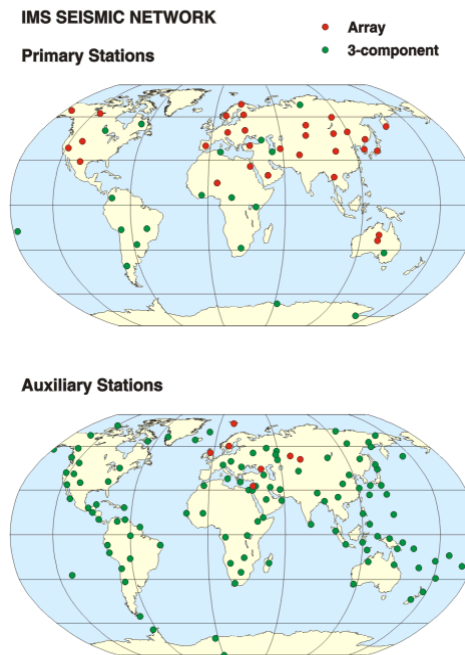


Figure 2.1. Primary and Auxiliary Stations of IMS Seismic Network

Table 2.1. Keskin short period array data sheet

Station Code	Location	Period	Depth(m)	Seismometer	Elev. (m)	Global coordinates
BR101	Keskin	Short	26.5	23900	1438	39.7254 N 33.6391 E
BR102	Keskin	Short	26.5	23900	1511	39.7355 N 33.6486 E
BR103	Keskin	Short	26.5	23900	1471	39.7196N 33.6570 E
BR104	Keskin	Short	28.0	23900	1377	39.7074N 33.6414 E
BR105	Keskin	Short	27.1	23900	1445	39.7180 N 33.6173 E
BR106	Keskin	Short	27.4	23900	1365	39.7338N 33.6180 E
BR131	Keskin	Broadband	62.8	KS54000	1440	39.7250 N 33.6390 E

Table 2.2. Ankara medium period array data sheet

Station Code	Location	Period	Depth(m)	Seismometer	Elev.(m)	Global coordinates
BR231	Ankara	Broadband	61.7	KS54000	1252	39.8417 N 32.7759 E
BR232	Ankara	Medium	61.6	KS54000	1107	39.9285N 32.9820 E
BR233	Ankara	Medium	60.5	KS54000	1827	39.7935 N 32.9813 E
BR234	Ankara	Medium	61.9	KS54000	1052	39.6518 N 32.8000 E
BR235	Ankara	Medium	62.2	KS54000	1259	39.7412 N 32.5915 E
BR236	Ankara	Medium	63.2	KS54000	1070	39.8794 N 32.5510 E
BR237	Ankara	Medium	63.1	KS54000	1073	40.0186 N 32.7303 E

2.2. The Site Survey and Geology

Ankara, the capital city of Turkey, is located in mountainous Anatolian plateau, extends from the Mediterranean Sea to the Black Sea and eastward into Iran and Iraq. Ankara, has an elevation about 800 meters, is in a mountain basin surrounded on all sides by higher terrain. The altitude of these basins is approximately 760 – 1100 meters, where the surrounding mountains have 1200-1500 meters elevation. Besides, in late winter through early summer, seasonal streams and rivers drain into the basin from all directions. Apart from these seasonal rivers and streams, a durable river drains from the northeast through Ankara and westward past the two main airports, Güvercinlik (elevation 821 meter) and Esenboga (elevation 806 meters) with several branches. In addition, a lake fills in the river valley northeast of Ankara behind a large dam. There is a natural lake located south of town of Golbasi (BRTR Certification Report, 2003).

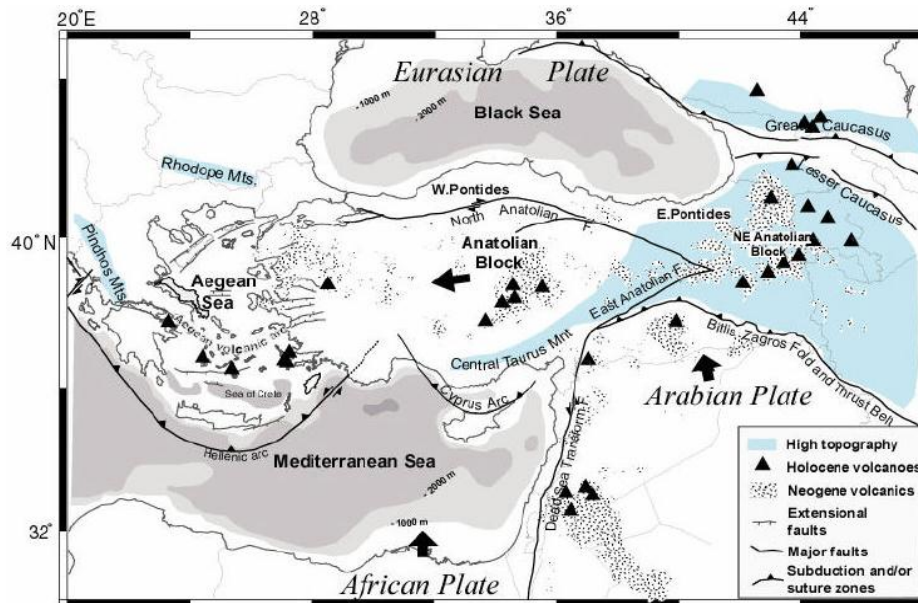


Figure 2.2. Map of major tectonic boundaries and plate motions together with physiographic features and volcanics in and around Turkey (Kuleli *et al.*, 2001)

Turkey has seven natural regions, these are Black Sea, Mediterranean, North Anatolian and Taurus mountain ranges, Anatolian plateau, eastern highlands, and Arabian Platform. The present day tectonic system of Anatolia started to form in the early Miocene

period (Sengör *et al.*, 1985). Turkey involves within the Eastern Mediterranean sector of the Alpine-Himalayan orogenic system. This orogenic system was eventuated before about 65 million to 1.6 million B.C (Tertiary Period). The Arabian African, and Indian continental plates started to collide with the Eurasian plate, and it caused the sedimentary layers laid down by the prehistoric Thetas Sea sprained, folded, and contorted. These uplifting and folding process was accompanied by intensive volcanic activity and intrusions of ignaeous rock material, followed by extensive faulting during the Quaternary Period, which began about 1.6 million B.C. This process is still live, and as the Turkish and Aegean plates, moving south and southwest continue to collide. Periodic movements happen along two main faults, the North Anatolian fault and the East Anatolian fault. This tectonically complex region is characterized by significant seismic activity. This seismotectonic regime has caused devastating earthquakes in the region. As a consequence, lots of earthquakes occur in Turkey because of its tectonic structure (Kuleli *et al.*, 2001).

2.3. Meteorological Information

Weather conditions have an important role in this study because seasonal variations were observed to analyze seismic background noise analysis of BRTR array. Therefore, the meteorological conditions as a seismic noise background should be understood:

In this region the weather is primarily affected by Azores, Asiatic highs and the polar front. The Asiatic high over Central Asia and Siberia which pushes the polar front into the Mediterranean causes cold, dry air over the region. The Azores high slides south and weakens, which cause the polar front to shift into the northern Mediterranean (BRTR Certification Report, 2003).

Winter (December - February): Winter weather changes in Turkey depend on far to the west. Foggy weather is more observable in winter in Ankara. Even though the rainy season of Ankara is in winter, it does not get large amounts of precipitation (BRTR Certification Report, 2003).

Spring (March-May): Spring weather acts like a bridge between the stormy winter to the dry summer. The Azores high intensifies and extends eastward over Europe and slowly interrupts the southern storm track as it slides the polar front northward. The Asiatic high of winter changes in Spring, which also allows the polar front to shift northward, but the asiatic low has improved by the end of May. A little wetness affect Ankara because of mountainous terrain. Also, only local thunderstorms and rain showers bring rainfall to Ankara (BRTR Certification Report, 2003).

Summer (June-August): The weather of summer is warm to hot and dry. Storms starts to move from Europe to the north so this region cannot be affected. The Azores high influences the weather which spreads out its inversion over Europe and the Mediterranean. This inversion causes rain showers and isolated thunderstorms to bring rainfall to the region (BRTR Certification Report, 2003).

Fall (September-November): Like the Asiatic low of summer starts to lose its effect in early fall, the Azores high decreases and begins to come back westward out of Europe and the Mediterranean. This generally lets the polar front to shift southward and decreases once more enter the Mediterranean (BRTR Certification Report, 2003).

Table 2.3. Average maximum, minimum temperature and precipitation
(BRTR Certification Report, 2003)

Month	Average Max Temp. (F°)	Average min. Temp. (F°)	Monthly Precipitation. Average (inches)
January	41	24	2,0
February	43	26	1,5
March	52	30	1,6
April	63	39	1,6
May	72	47	1,8
June	79	53	1,3
July	85	59	0,3
August	86	59	0,1
September	78	50	0,5
October	79	41	1,0
November	56	33	1,4
December	45	28	2,0

2.4. Characterization of Seismic Background Noise

Seismic noise exists everywhere on the Earth surface and it refers to the ambient ground motion within which signals of interest are to be detected. If seismic noises are required to be categorized, they will be characterized as described below:

2.4.1. Cultural Noise

Cultural noise is the most common type of seismic noise generated by the actions of human activity at or near the surface of the Earth (McNamara *et al.*, 2004). The frequency band of this noise is from 1 to 10 Hz (1-0.1s) (Figure 2.4.). Cultural noise originates from the human activity into the earth such as traffic and machinery energy and also cultural noise levels vary by one site to another because of the distance to the settlement area, road, industrial area and towns (Webb, 2002; Havskov and Alguacil, 2002; McNamara and Buland, 2004). Cultural noise illustrates very strong diurnal variations and generally they produce high frequency noise signals (1-10Hz, 1-0.1s) which attenuate with several kilometers in distance and depth thus boreholes, deep caves and tunnels decrease cultural noise levels and also these types of noises are incoherent (McNamara and Buland, 2004).

2.4.2. Wind, Water, and Geological Noise

The wind can cause to move objects thus the wind and the movement can be a major source of noise (McNamara and Buland, 2004). Also, movement of trees and their roots will produce high frequency noise signals. In addition, running water, surf, volcanic activity or long period tilt due to thermal instabilities from poor station design are included as sources of seismic noise (McNamara and Buland, 2004).

2.4.3. Microseisms

The term is most commonly used to refer to the dominant background seismic noise signal on Earth, which are caused by water waves in the oceans and lakes. Atmospheric disturbances and oceanic storms are the main causes of microseism. There are two dominant peaks in the seismic noise spectrum. One peak is the single frequency peak ($T=10-16s$) that is produced in shallow coastal waters where ocean wave energy is transformed into seismic energy either through vertical pressure variations. The other peak is the double frequency peak ($T= 4-8s$) that is produced by the superposition of ocean waves of same period traveling in opposite directions (Figure 2.4.) (McNamara and Buland, 2004).

2.4.4. System Noise

The seismometer amplifiers and recorders have an internal noise and noise level of this type of noise is low. Also system noise is related to atmospheric pressure changes which affect the mass of a seismometer (Davies, 1973). System noises are system transients as data gaps and sensor glitches (Figure 2.3). Data gaps are data loss by hardware or communication problems and are filled by zero. Sensor glitches are divided in two parts: calibration pulse and auto mass re-center (Figure 2.3 and 2.4). Calibration Pulses are pulses used to test the calibration of the seismic sensor according to the manufacture calibration sheet. Auto mass re-center are pulse send to the seismic sensor to center the mass when it loss the middle position (McNamara and Buland, 2004).

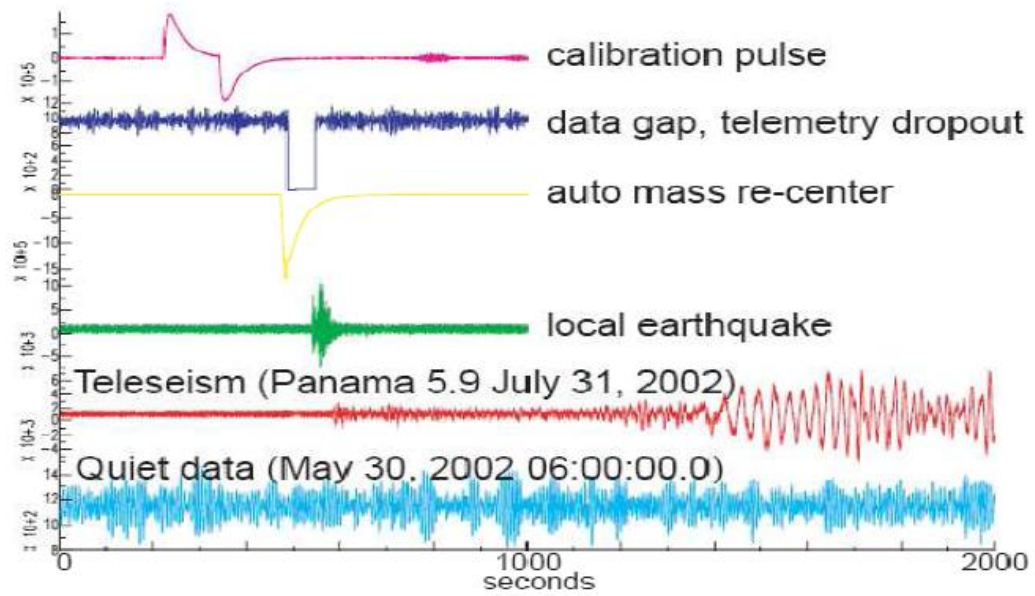


Figure 2.3. System artifact (McNamara and Buland, 2004)

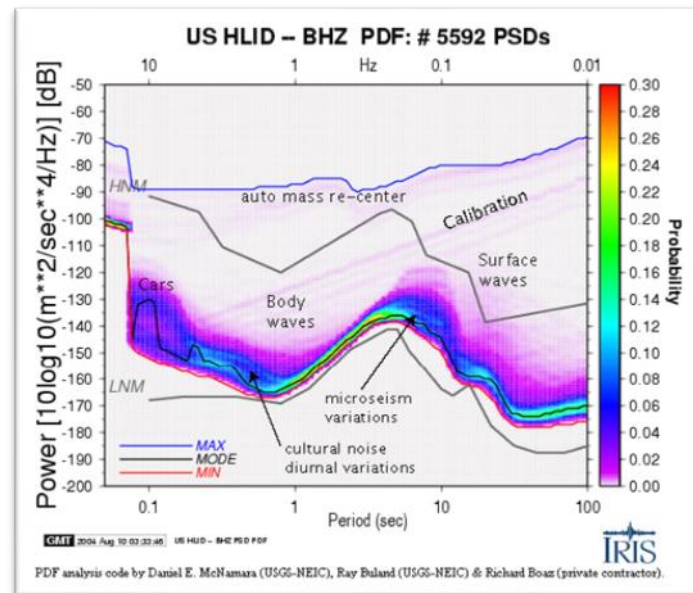


Figure 2.4. Cultural, microseism and system noise (McNamara and Boaz, 2006)

3. METHODOLOGY

McNamara and Buland (2004) suggested a new statistical approach to calculate probability density functions from power spectral densities. Their method is different from other noise studies because this new approach includes all signals; these signals such as system artifacts are included in these processing because these types of signals are generally low probability occurrences that are not more effective on high probability ambient seismic noise observed in the Probability Density Functions (PDF). McNamara and Buland (2004) used same algorithm with Peterson (1993) to calculate PDFs which are obtained from PSDs.

3.1. Power Spectral Density

Computation of the Power Spectral Density (PSD) is the standard method for analyzing seismic background noise and it describes the distribution of power with frequency. The direct Fourier transform or Cooley-Tukey method is the most widespread method for calculating the PSD for random seismic data (Cooley *et al.*, 1965). Because a seismographic record is a stochastic signal, its checking with PSD can be calculated by means of averaging (Bendat and Piersol, 1986).

The method calculates the PSD via a finite length fast Fourier transform (FFT) of the raw data and it is very helpful for its calculation efficiency (McNamara and Buland, 2004).

The finite-length Fourier transform of a periodic time series $y(t)$ is given by:

$$Y(f, Tr) = \int_0^{Tr} y(t) e^{-i2\pi ft} dt \quad (3.1)$$

Where Tr = length of time series segment(s),

f = Frequency [Hz].

For discrete frequency values, f_k The Fourier components are specified as:

$$Y_k = \frac{Y(f_k, Tr)}{\Delta t} \quad (3.2)$$

for , $f_k = k/N\Delta t$ when $k = 1, 2, \dots, N-1$,

where Δt = sample interval,

N = number of samples in each time-series segment, $N = Tr/\Delta t$.

Thus, using the Fourier component above then, the total power spectral density calculation is defined as:

$$P_k = \frac{2\Delta t}{N} |Y_k|^2 \quad (3.3)$$

It is obvious that from this equation, the total power P_k , is the square of the amplitude spectrum with a normalization factor of $2\Delta t/N$ (McNamara and Boaz, 2006). The normalization factor is very important when comparing PSD estimates with NLNM (McNamara and Boaz, 2006).

Consequently, instrument response of the seismometer is removed by dividing the PSD estimate by the instrument transfer function to acceleration (Havskov *et al.*, 2002; McNamara and Buland, 2004), in the frequency domain.

To compare the low noise model and high noise model (Figure 3.1), the PSD estimate is altered into decibels (dB) with respect to acceleration $(m/s^2)^2/Hz$ (McNamara and Boaz, 2006).

When conveying the power spectral density in units of dB referred to $1 (m/s^2)^2/Hz$, can be written as:

$$Pa[dB] = 10 \log (Pa / 1 \text{ (m/s}^2\text{)}^2/\text{Hz}) \quad (3.4)$$

Peterson (1993) presented a new global noise model in these units. It shows the upper- and lower-boundaries curves. The names of the models are called New High Noise Model (NHNM) and New Low Noise Model (NLNM), respectively (Figure 3.1) and they were accepted as standard curves of seismic noise (Peterson, 1993).

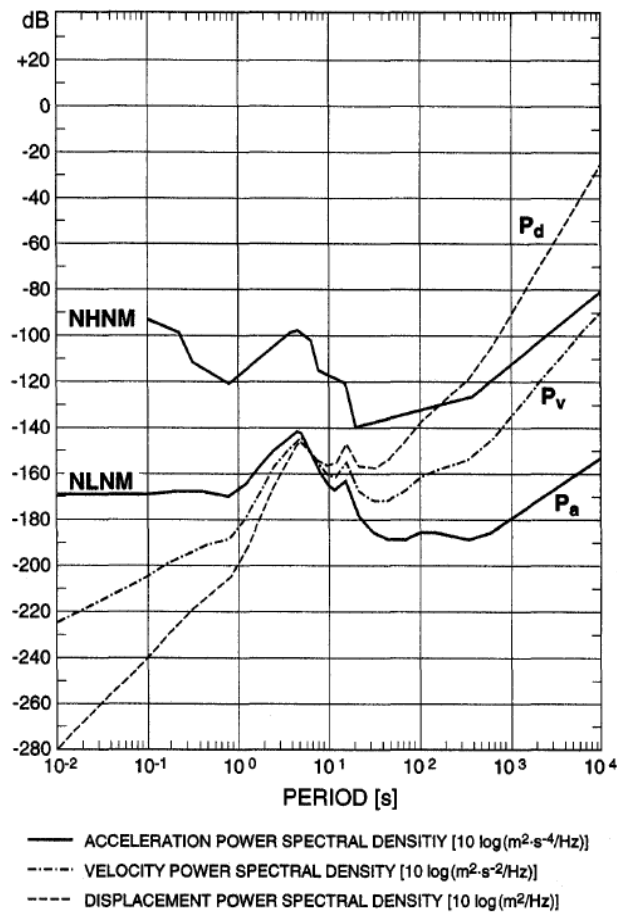


Figure 3.1. The dark lines represent the new high and low noise models (Peterson, 1993)

3.2. Probability Density Function

The aim of this study is to obtain proper variation of seismic noise at a given station. To do it, Probability Density Functions are calculated from thousands of PSDs (McNamara and Boaz, 2006). Firstly, full octave averages is computed per 1/8 octave intervals. This processing helps to decrease the number of frequency from the number of

fast fourier transform, so the average of the power is calculated between a high frequency(short period) corner, T_s and a long period (low frequency) corner of T_l , with a center period (T_c). The formula of long period corner is $T_l = 2 * T_s$ and also the formula of center period is $T_c = \sqrt{T_s * T_l}$ which is referred geometric mean period within the octave. Period range from short period corner to long period corner, the average power of this octave is stored with T_c period of that octave. Center period corner and long period corner are recalculated, the average of powers are calculated within the next period range from short period corner to long period corner and these calculations maintain until reaching the longest resolvable period given the time series window length of the original data, $T_r / 10$. This process is repeated for every one hour PSD estimate, resulting of thousands of smooth PSD estimates for each station component. Powers are accumulated in 1 dB intervals to generate frequency distribution plots for each period (McNamara and Buland, 2004).

The PDF, for a given center period, T_c can be calculated as:

$$P(T_c) = N_{PT_c} / N_{T_c} \quad (3.5)$$

Where N_{PT_c} is referred the number of spectral estimates into a 1 dB power bin, P , with a range from -200 to -80 dB, and N_{T_c} is referred the total number of spectral estimates over all powers with a center period, T_c (McNamara and Buland, 2004).

4. DATA SELECTION

4.1. Data preparation

In this study, six-year period data from January 2005 to December 2010 was retrieved from BRTR array for background noise analysis.

After getting these data, they were converted from the format of CSS3.0 (wfdisc) to the SAC format by GEOTOOL program. Geotool allows researchers to easily and conveniently display and analyze data from seismic stations (Figure 4.1).

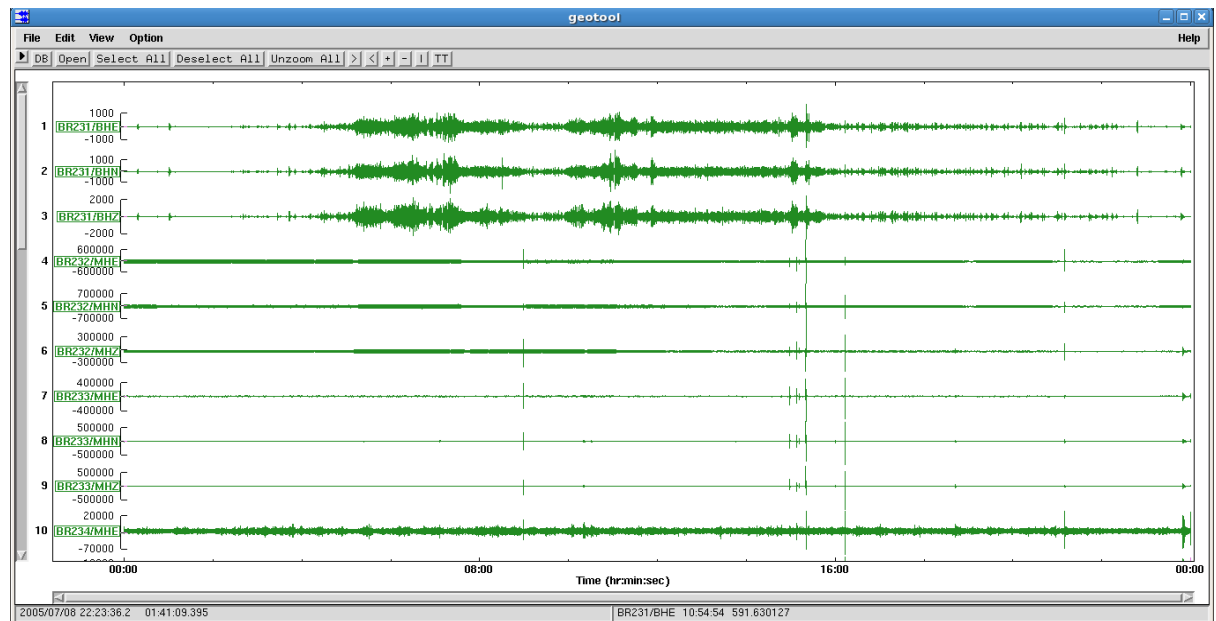


Figure 4.1. The example of GEOTOOL program

Then, PASSCAL Quick Look eXtra (PQLX) software package was installed. PQLX is open-source software system for assessing seismic station performance and data quality. PQLX software was advanced by Boaz (McNamara and Boaz, 2006, 2011). Given waveform data and instrument response files, PQLX server calculates trace statistics, Power Spectral Densities (PSD), and Probability Density Functions (PDF) and writes the results to a MySQL database for quick access (Rastin *et al.*, 2010) (Figure 4.2).

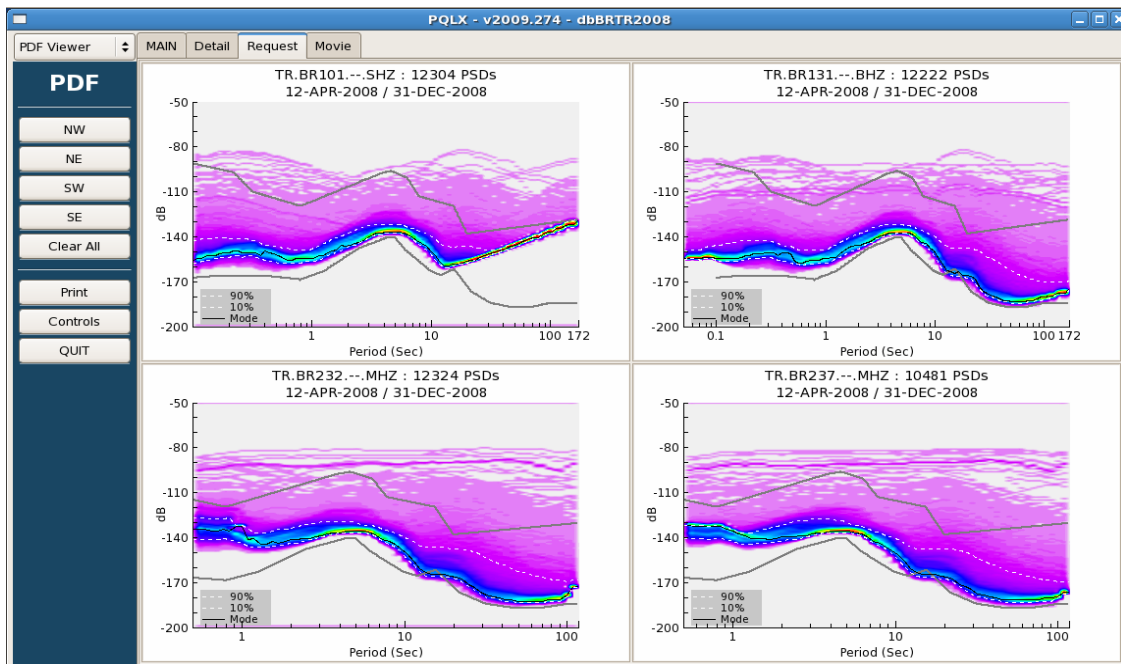


Figure 4.2. The example of PQLX program

Both GEOTOOL and PQLX programs run in a LINUX, MAC OS and SOLARIS.

The background noise power spectral density (PSD) was systematically estimated for all the stations of the BRTR array and was statistically analyzed to compute Probability Density Function (PDFs) using PQLX. Statistical analysis of PDFs was performed for each station. PDF median curve was used because, the mode curve is often affected by system transients or, at higher frequencies, displays jumps that are related to the diurnal variations in cultural noise, and the comparison of the noise level at different stations is thus more difficult (Diaz *et al.*, 2010). In order to make the comparison between stations easier median curves were used, as they generate smoother results and are less affected by the presence of outliers (Diaz *et al.*, 2010). Also, system transients can affect the mode and 90th percentile (McNamara and Buland, 2004). After getting PDFs median, diurnal and seasonal variations plots were created using GMT. Diurnal variations are the variation of the amplitude of the acceleration in dB respect to $1(\text{m}^2/\text{s}^4)/\text{Hz}$ during the hours of the day respect to period ranging from 0.1-1 s for short period seismometers also period ranging from 0.5-100 s for medium period and period ranging from 0.1-100 s for broad band seismometers. The diurnal variations of seismic noise were analyzed by gathering the PSDs in hourly bins and computing a PDF for each hour of the day over a six-year period

at all stations in our study. Six year period data is divided into two groups because quarry activities has been started in the vicinity of BRTR array (especially medium period array) since 2008, thus we wanted to understand that how BRTR array was affected. The first group includes 2005-2007 period data and the second one includes 2008-2010 data. After that the statistical median was computed at all periods. Finally, diurnal variation plots were created by using GMT.

Seasonal variations were calculated in the same manner as diurnal variations. They were computed a separate PDF for each month of the year over a six-year period. We then computed the statistical median for all periods for each monthly PDF. Then, seasonal variation plots were created by using GMT.

Finally, annual seismic detection threshold maps for BRTR array were created by retrieving event information from CTBTO-REB bulletins to assess the contribution of BRTR to IMS network.

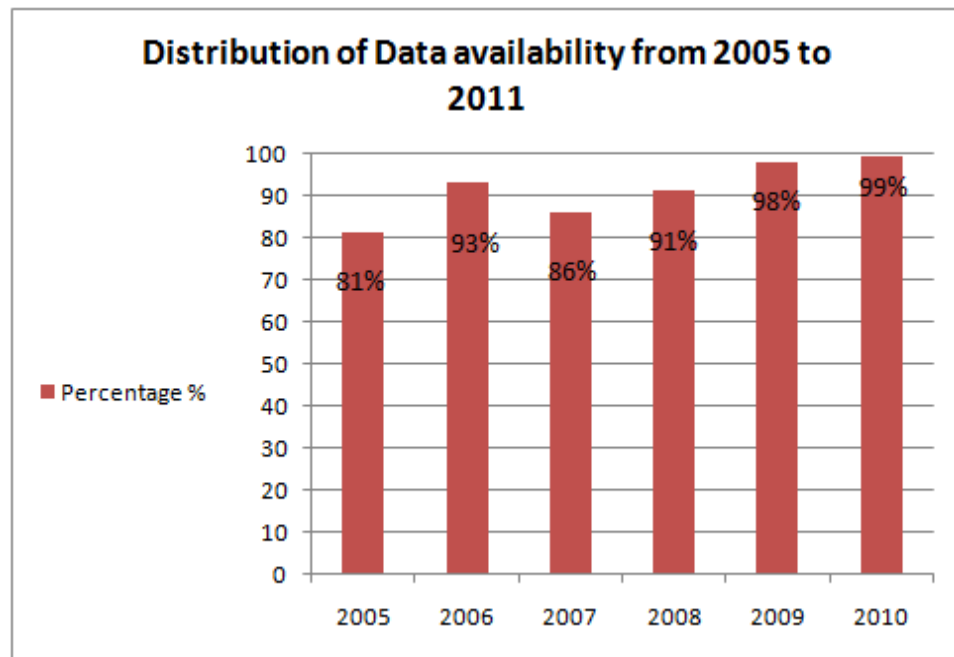
4.2. Contribution of BRTR Array to IMS for Event Detection

Detection capability of a seismic station is defined as a measure of how well the seismic station in its current state is able to serve its aim, to properly detect and locate seismic events anywhere on the globe (Wüster *et al.*, 2000). IMS network is providing a global coverage with the aim of detection of any seismic event in order to differentiate nuclear test explosions from any other seismic observation. The International Data Centre (IDC) is the main area for collecting, analyzing, storing, and reporting the information collected by the stations that form the International Monitoring System (IMS) (CTBTO, Annual Report, 2008). Reviewed Event Bulletin (REB) is a product of CTBTO listing events built from waveform data that have been analyzed by a human analyst. Using the Standard Event List 3 (SEL3) formed within the first six hours after event occurrence, the analyst corrects mistakenly identified events, removes bogus events, improve and where necessary correct event parameters such as hypocenter and magnitude using all seismic phases associated to that particular event and lists them in the REB.

In this scope, six-year period seismic event data from 2005 to 2010 in which a seismic phase recorded at BRTR has been associated to, were retrieved from International Data Center (IDC) Reviewed Event Bulletin (REB). Then, the value of latitude, longitude and network magnitude were obtained from the data set. After getting these, minimum detectable magnitude values were selected and contour maps were created by using GMT.

Also, data availability of BRTR is very important for event detection because it illustrates the contribution of BRTR array to IMS. Table 4.1 represents the data availability of BRTR array since 2005.

Table 4.1. Data availability at BRTR array since 2005



5. THE RESULTS

In this study, we wanted to see the differences between day time and night time noise levels at cultural period band, microseism and long period band for diurnal variations from 2005 to 2010. Also, we wanted to see seasonal noise level changes at cultural period band, microseism and long period band for seasonal variations from 2005 to 2010.

5.1. Keskin Short Period Array

5.1.1. BR101

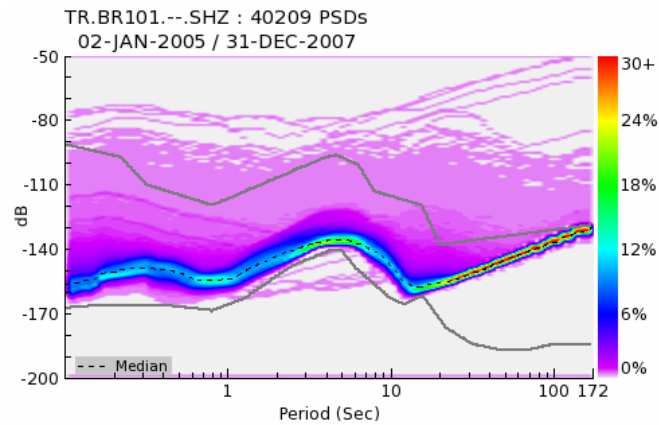


Figure 5.1. BR101 PDF plot between 2005-2007. Scale bar represents probability of occurrences

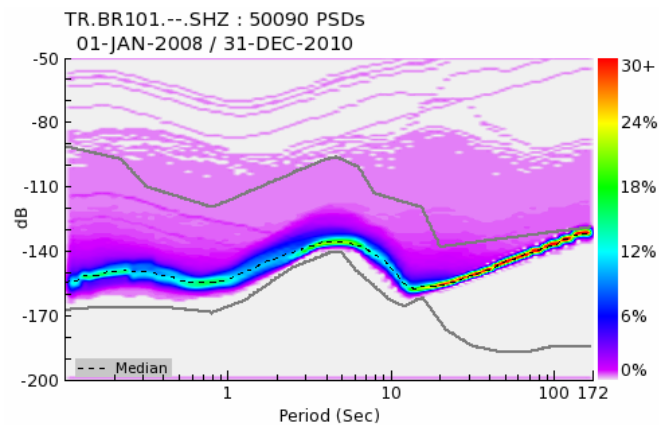


Figure 5.2. BR101 PDF plot between 2008-2010. Scale bar represents probability of occurrences

Station of BR101 has a good performance from 2005 to 2007 and from 2008 to 2010, as we can note with respect to NHNM and NLNM curves. BR101 presents a low noise level close to NLNM.

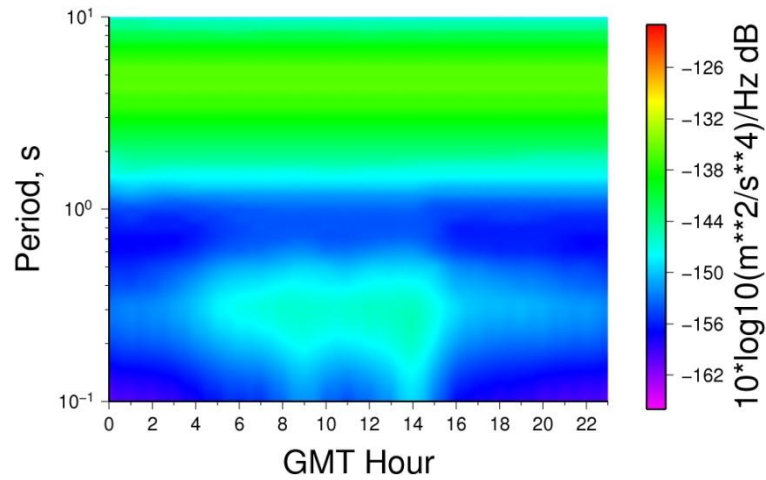


Figure 5.3. Diurnal variation plot of BR101 between 2005 and 2007

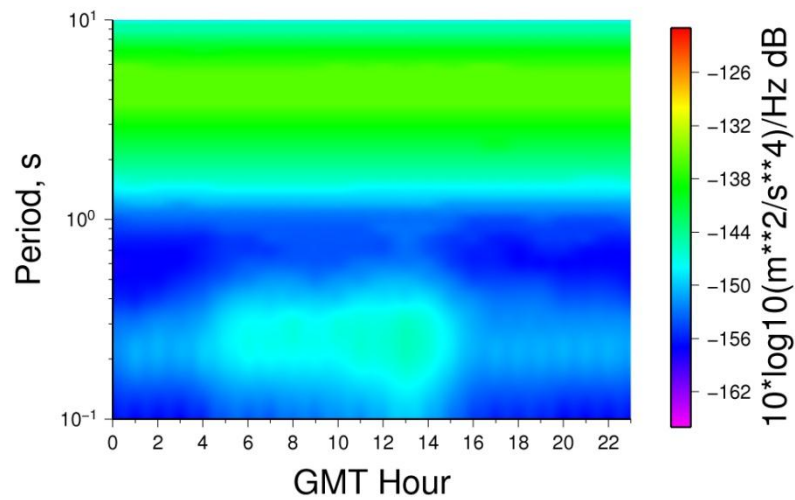


Figure 5.4. Diurnal variation plot of BR101 between 2008 and 2010

Figure 5.3 and 5.4 represent diurnal variations of BR101 station from 2005 to 2010. The value of the power vary by 1 to 7 dB in cultural period band between night time and day time from 2005 to 2007, whereas the value of the power vary by 1 to 6 dB in cultural period band between night time and day time from 2008 to 2010.

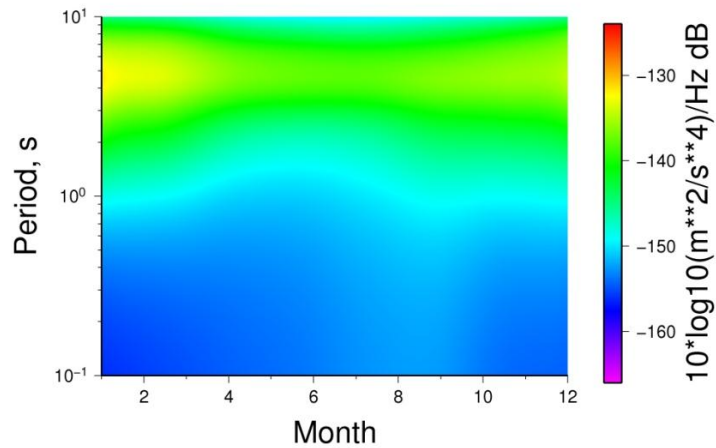


Figure 5.5. Seasonal variation of BR101 station between 2005 and 2007

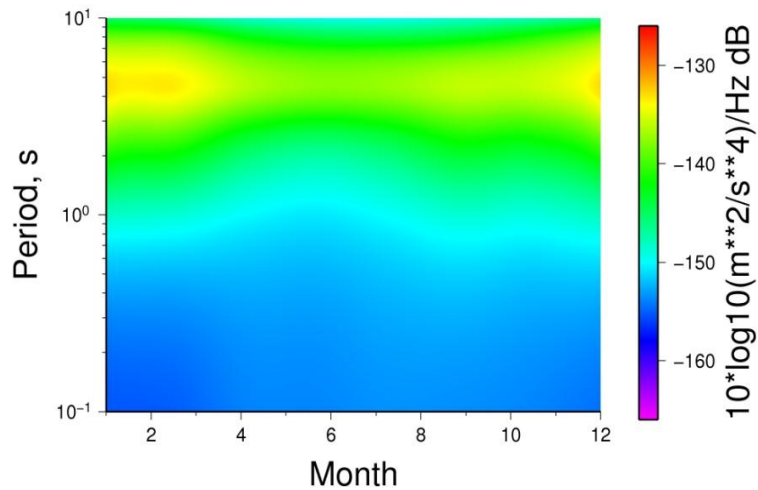


Figure 5.6. Seasonal variation of BR101 station between 2008 and 2010

Figure 5.5 and 5.6 represent seasonal variations of BR101 station from 2005 to 2010. The value of the power vary by 1 to 3 dB in cultural period band between winter and summer from 2005 to 2007. The value of the power vary by 1 to 3 dB in cultural period band between winter and summer from 2008 to 2010. A double frequency peak (4-8 s) for microseism in seasonal variation of BR101 has also been observed. In this scope, the power vary by 1-3 dB from 2005 to 2007 and vary by 1-5 dB from 2008 to 2010.

5.1.2. BR102

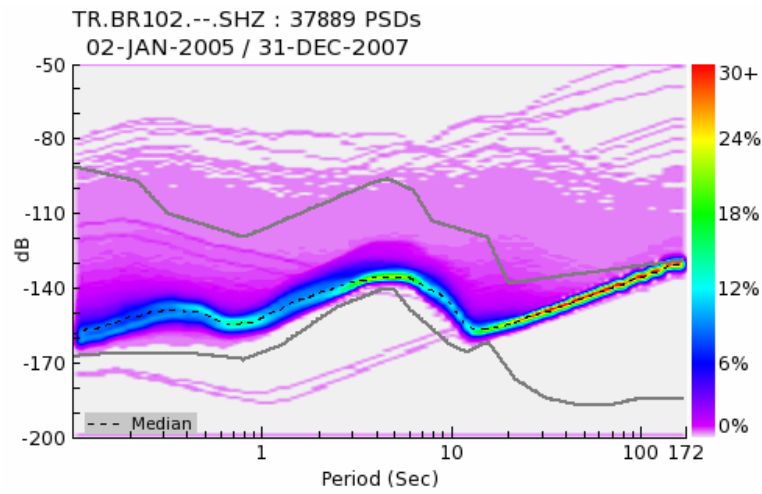


Figure 5.7. BR102 PDF plot between 2005-2007

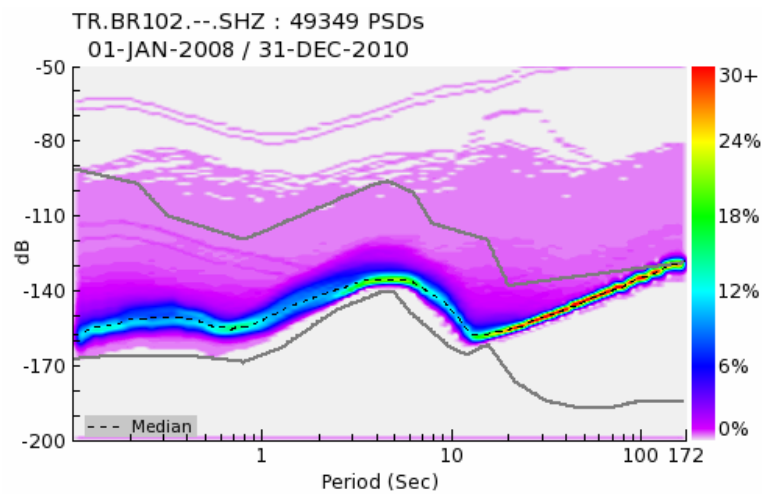


Figure 5.8. BR102 PDF plot between 2008-2010

Station of BR102 has a good performance from 2005 to 2007 and from 2008 to 2010, as we can note with respect to NHNM and NLNM curves. BR102 presents low noise levels.

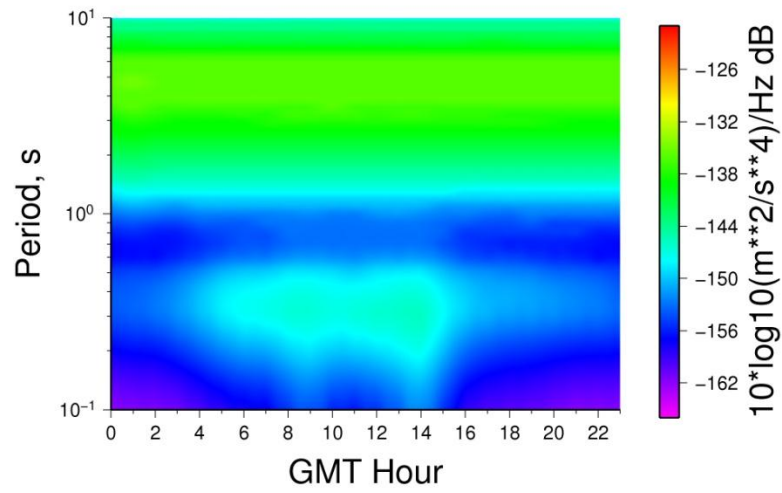


Figure 5.9. Diurnal variation plot of BR102 between 2005 and 2007

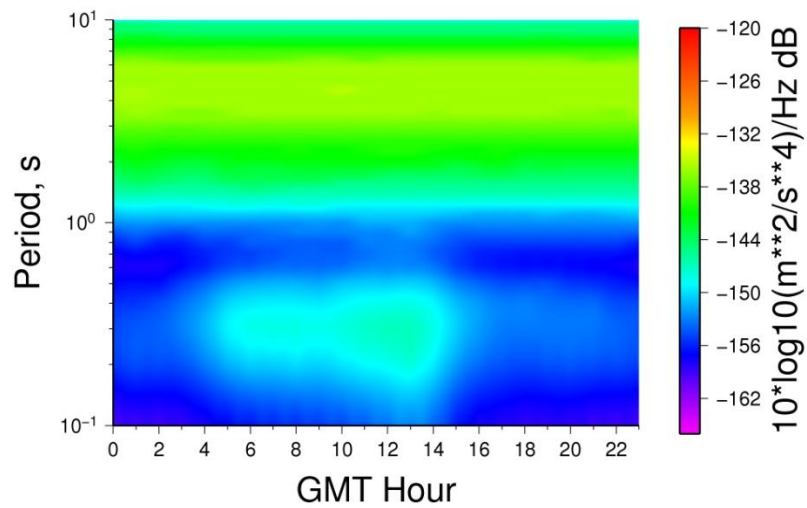


Figure 5.10. Diurnal variation plot of BR102 between 2008 and 2010

Figure 5.9 and 5.10 illustrate diurnal variations of BR102 station from 2005 to 2010. Between the year of 2005 and 2007, the value of the power vary by 1 to 8 dB in cultural period band between day and night time. Also, the value of the power vary by 1 to 8 dB in cultural period band between night and day time from 2008 to 2010.

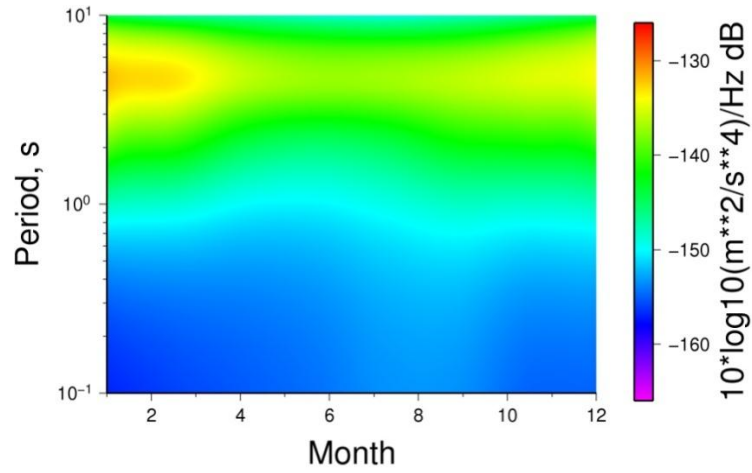


Figure 5.11. Seasonal variation of BR102 station between 2005 and 2007

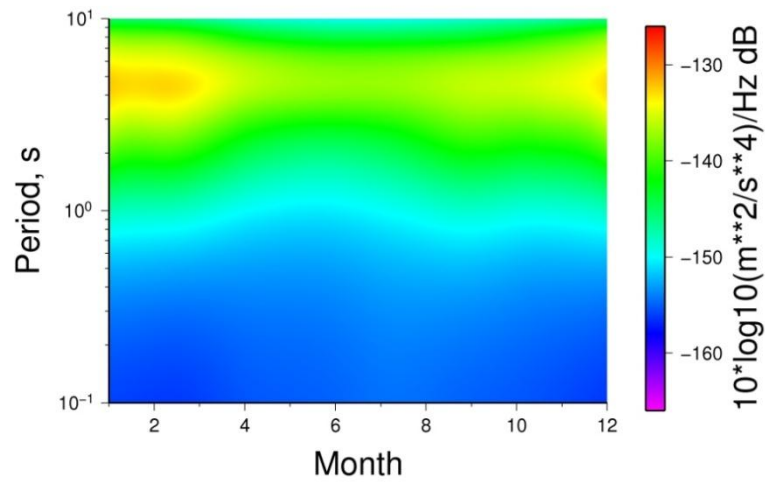


Figure 5.12. Seasonal variation of BR102 station between 2008 and 2010

Figure 5.11 and 5.12 show seasonal variations of BR102 station from 2005 to 2010. In cultural period band, the value of the power vary by 1 to 13 dB between the years of 2005 and 2007 and the value of the power vary by 1 to 9 dB between the years of 2008 and 2010. Moreover, in double frequency peak (4-8 s) the power vary by 1-5 dB from 2005 to 2007 and vary by 1- 4 dB from 2008 to 2010.

5.1.3. BR103

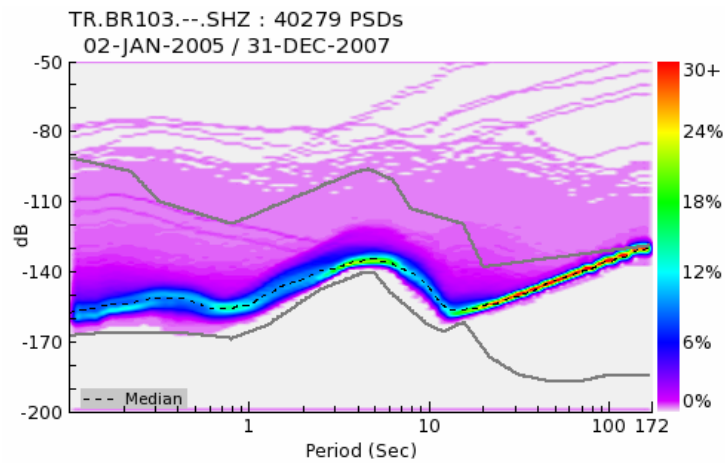


Figure 5.13. BR103 PDF plot between 2005-2007

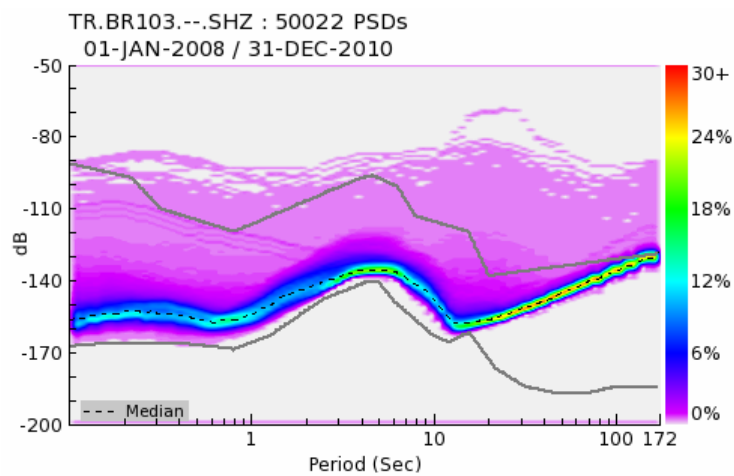


Figure 5.14. BR103 PDF plot between 2008-2010

Station of BR103 has a good performance from 2005 to 2007 and from 2008 to 2010, as we can note with respect to NHNM and NLNM curves. BR103 presents low noise levels.

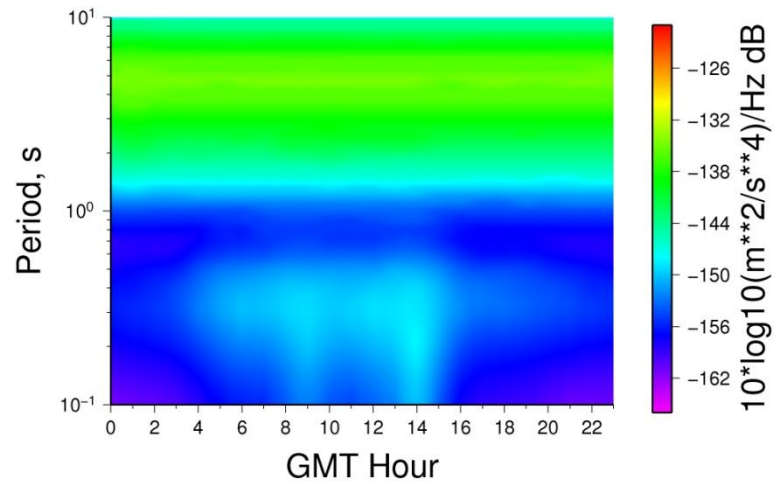


Figure 5.15. Diurnal variation plot of BR103 between 2005 and 2007

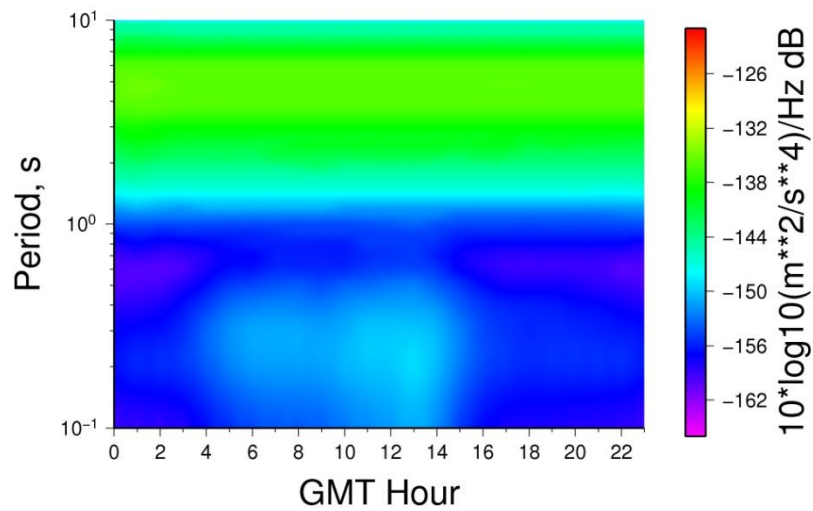


Figure 5.16. Diurnal variation plot of BR103 between 2008 and 2010

Figure 5.15 and 5.16 give us the information about diurnal variations of BR103 station from 2005 to 2010. The value of the power vary by 1 to 7 dB in cultural period band between day and night time from 2005 to 2007. Figure 5.16 shows us the value of the power vary by 1 to 7 dB in cultural period band between day and night time from 2008 to 2010.

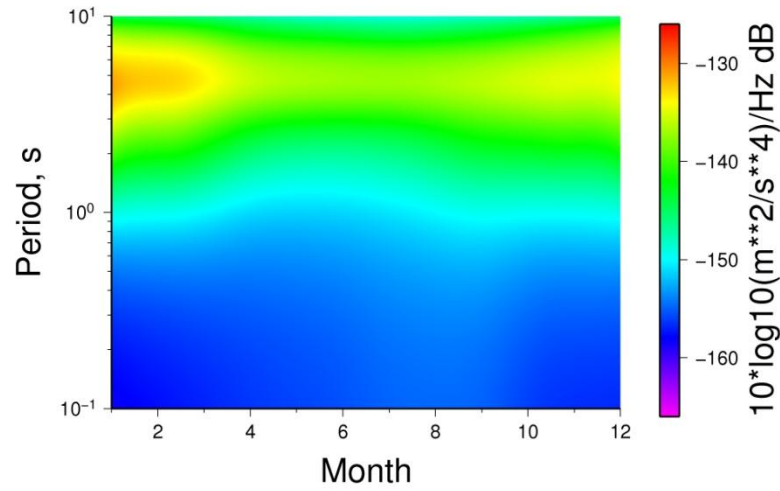


Figure 5.17. Seasonal variation of BR103 station between 2005 and 2007

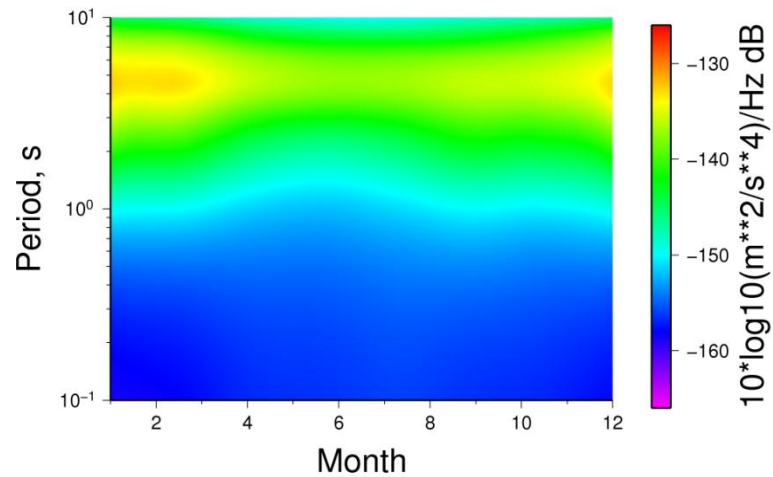


Figure 5.18. Seasonal variation of BR103 station between 2008 and 2010

Figure 5.17 and 5.18 represent seasonal variations of BR103 station from 2005 to 2010. We can see that the value of the power vary by 1 to 10 dB in cultural period band between the years of 2005 and 2007 and the value of the power vary by 1 to 6 dB in cultural period band between the years of 2008 and 2010. Moreover, the power vary by 1-5 dB from 2005 to 2007 and vary by 1-3 dB from 2008 to 2010 in double frequency peak at microseism band.

5.1.4. BR104

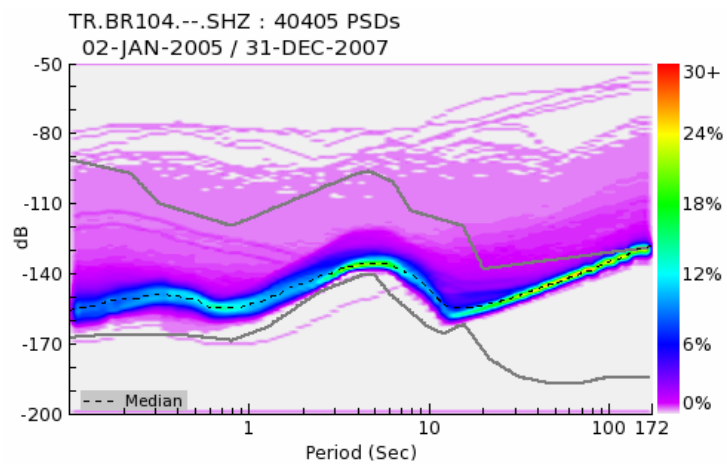


Figure 5.19. BR104 PDF plot between 2005-2007

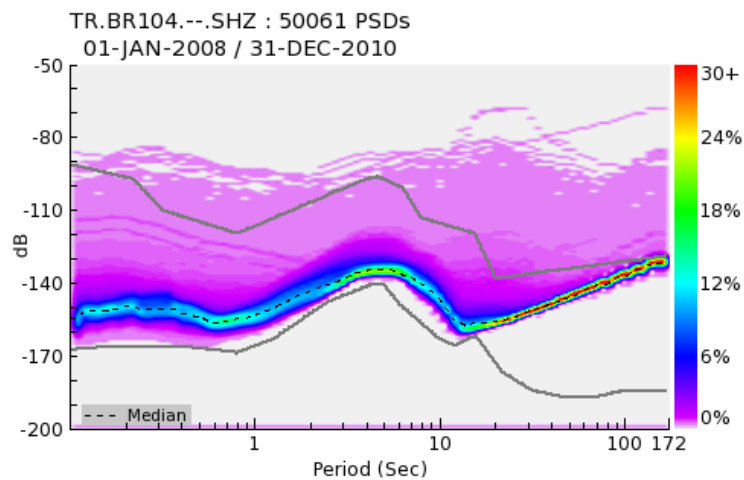


Figure 5.20. BR104 PDF plot between 2008-2010

Station of BR104 has a good performance from 2005 to 2007 and from 2008 to 2010, as we can note with respect to NHNM and NLNM curves. BR104 presents low noise levels.

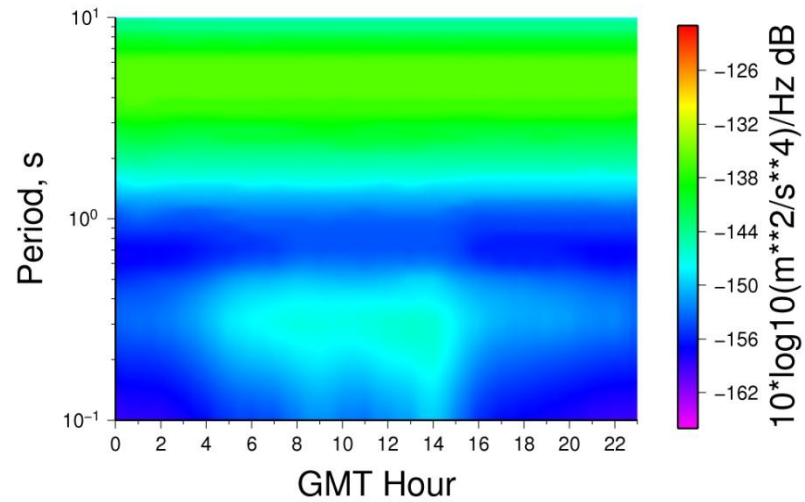


Figure 5.21. Diurnal variation plot of BR104 between 2005 and 2007

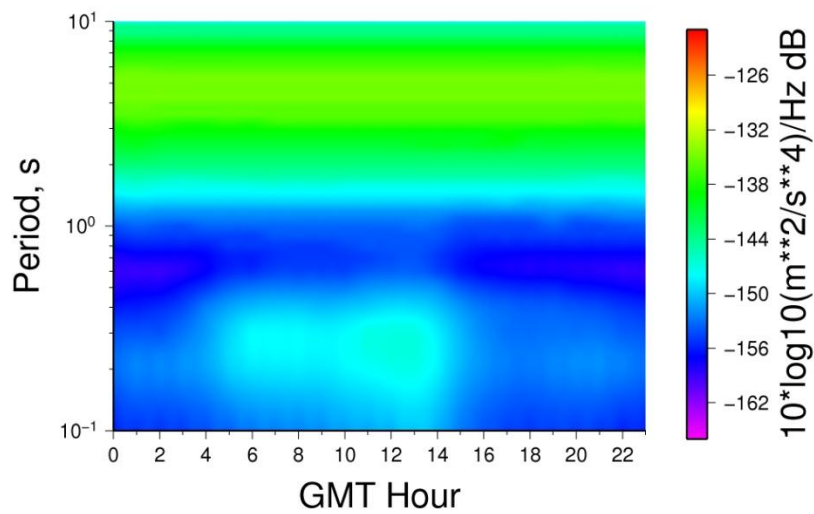


Figure 5.22. Diurnal variation plot of BR104 between 2008 and 2010

Figure 5.21 and 5.22 illustrate diurnal variations of BR104 station from 2005 to 2010. Figure 5.21 give us the information about noise changes from 1 to 7 dB in cultural period band between day and night time from 2005 to 2007. Also, we can see that the value of the power vary by 1 to 7 dB in cultural period band between day and night time from 2008 to 2010.

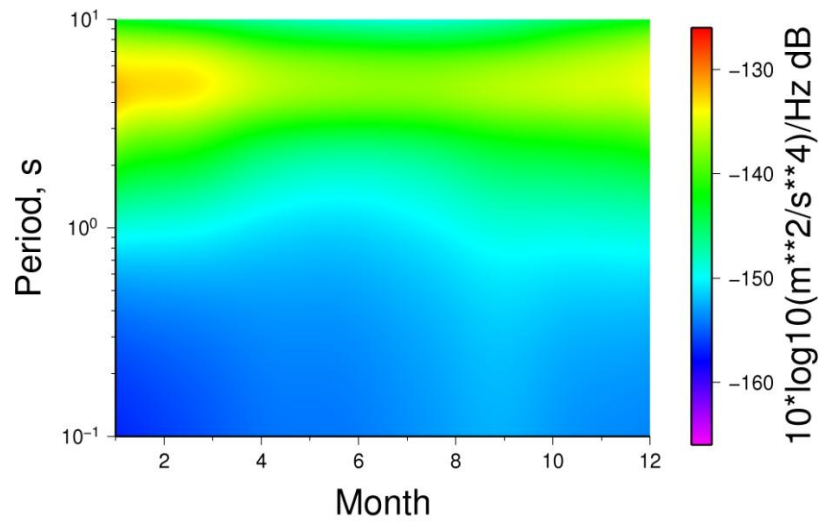


Figure 5.23. Seasonal variation of BR104 station between 2005 and 2007

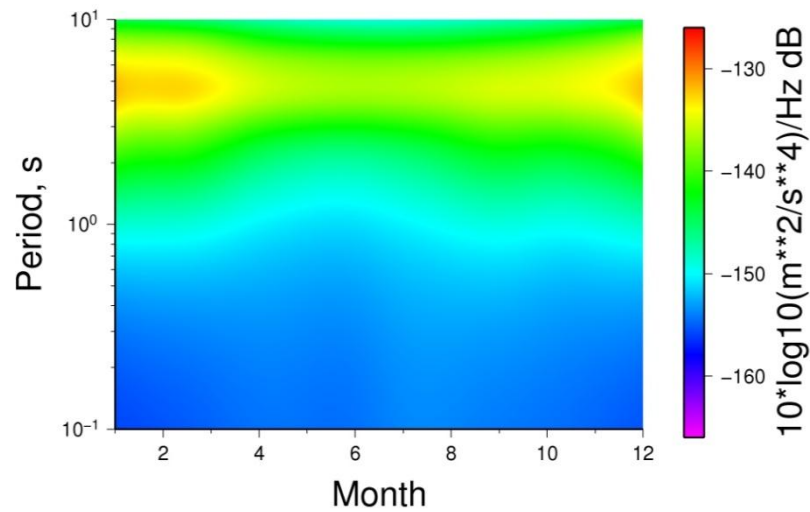


Figure 5.24. Seasonal variation of BR104 station between 2008 and 2010

Figure 5.23 and 5.24 represents seasonal variations of BR104 station from 2005 to 2010. The value of the power vary by 1 to 11 dB in cultural period band between winter and summer from 2005 to 2007. The value of the power vary by 1 to 8 dB in cultural period band between summer and winter from 2008 to 2010. Moreover, the power vary by 1-5 dB between summer and winter in microseism band (double frequency peak) from

2005 to 2007 and the power vary by 1-4 dB between summer and winter in microseism band (double frequency peak) from 2008 to 2010.

5.1.5. BR105

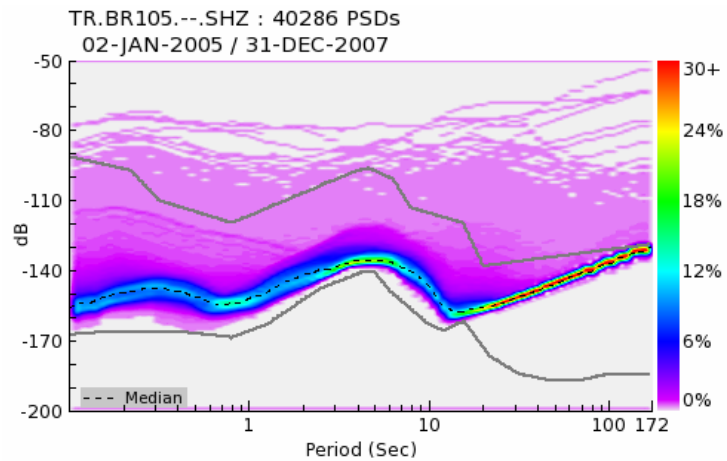


Figure 5.25. BR105 PDF plot between 2005-2007

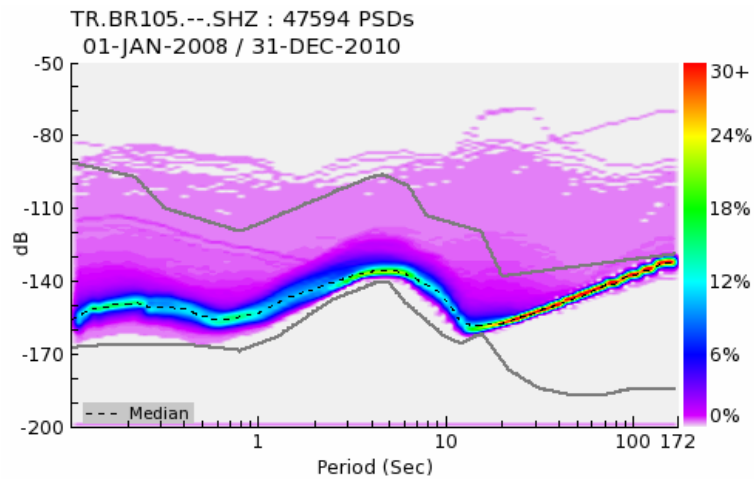


Figure 5.26. BR105 PDF plot between 2008-2010

Station of BR105 has a good performance from 2005 to 2007 and from 2008 to 2010, as we can note with respect to NHNM and NLNM curves. BR105 presents low noise level.

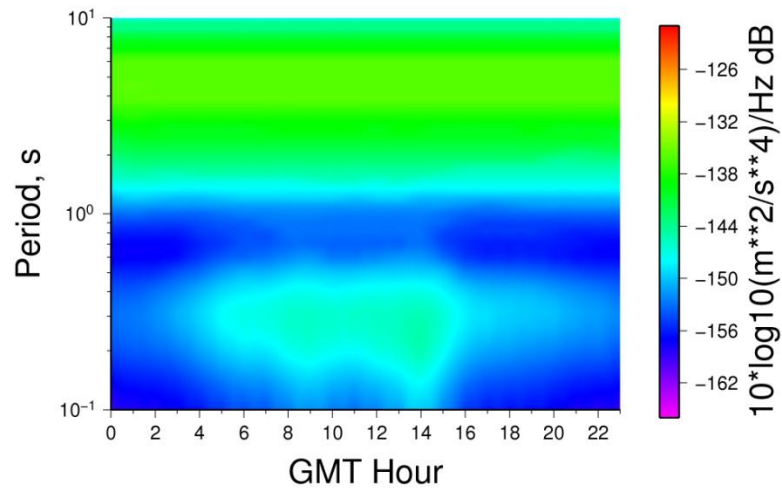


Figure 5.27. Diurnal variation plot of BR105 between 2005 and 2007

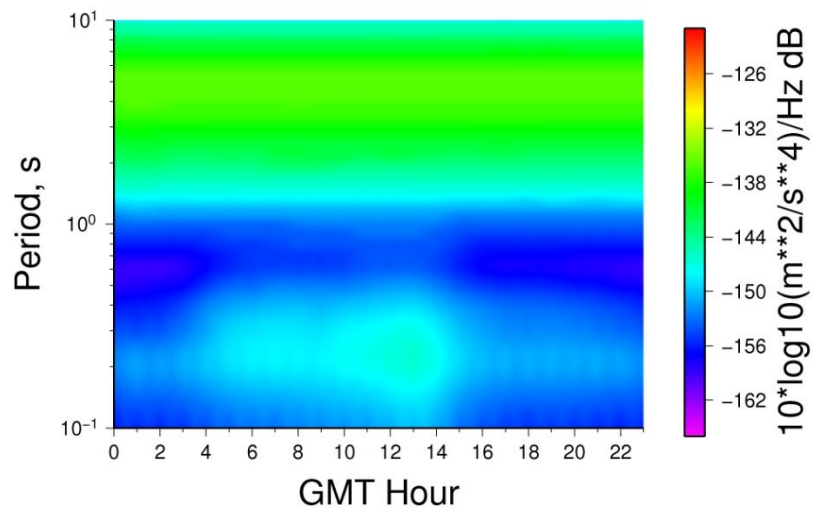


Figure 5.28. Diurnal variation plot of BR105 between 2008 and 2010

Figure 5.27 and 5.28 shows diurnal variations of BR105 station from 2005 to 2010. In cultural period band, the value of the power vary by 1 to 7 dB between day and night time from 2005 to 2007 and the value of the power vary by 1 to 8 dB between day and night time from 2008 to 2010.

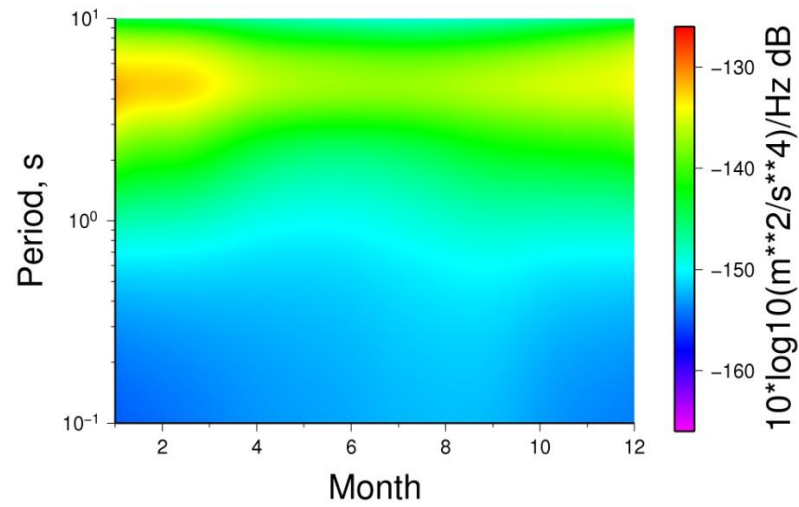


Figure 5.29. Seasonal variation of BR105 station between 2005 and 2007

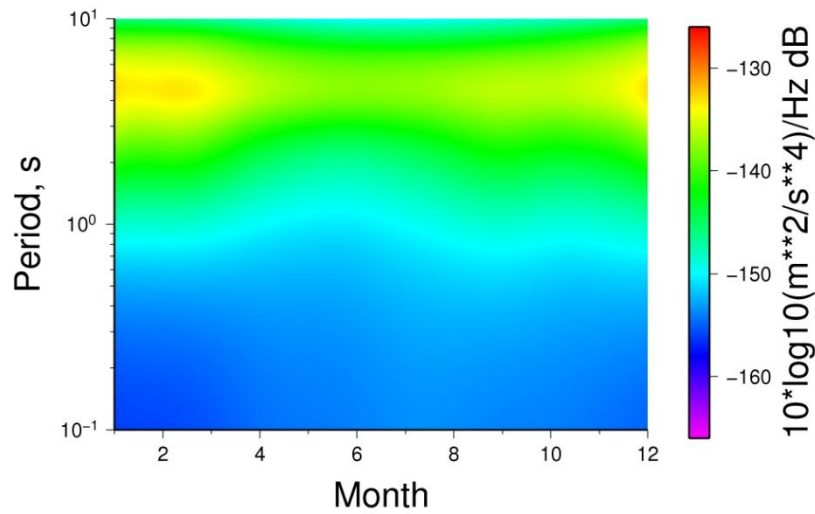


Figure 5.30. Seasonal variation of BR105 station between 2008 and 2010

Both Figure 5.29 and 5.30 represents seasonal variations of BR105 station from 2005 to 2010. In cultural period band, we can see that the value of the power vary by 1 to 9 dB in cultural period band between winter and summer from 2005 to 2007 and the value of the power vary by 1 to 7 dB between winter and summer from 2008 to 2010. In microseism band (double frequency peak), the power vary by 1-5 dB between summer and

winter from 2005 to 2007 and the power vary by 1-3 dB between summer and winter from 2008 to 2010.

5.1.6. BR106

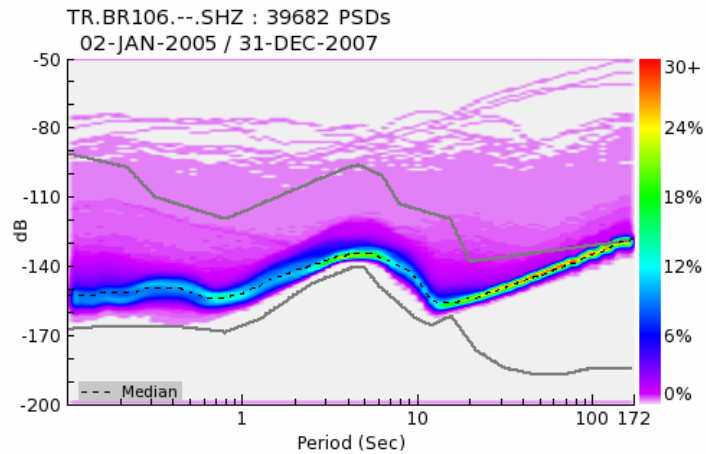


Figure 5.31. BR106 PDF plot between 2005-2007

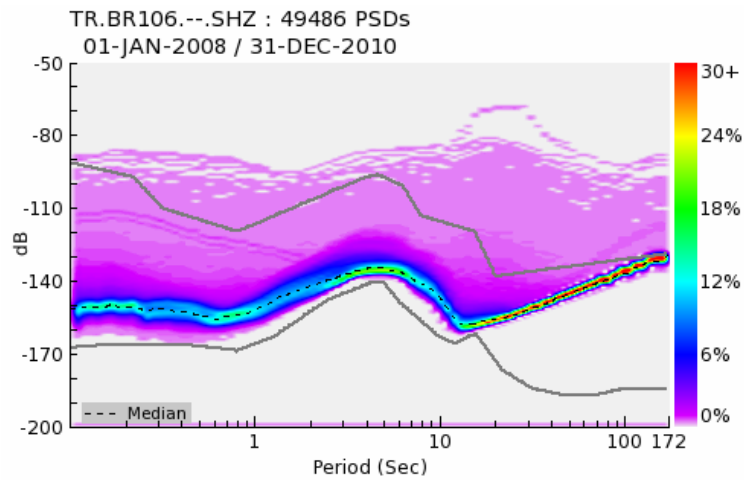


Figure 5.32. BR106 PDF plot between 2008-2010

Station of BR106 has a good performance from 2005 to 2007 and from 2008 to 2010, as we can note with respect to NHNM and NLNM curves. BR106 presents low noise level.

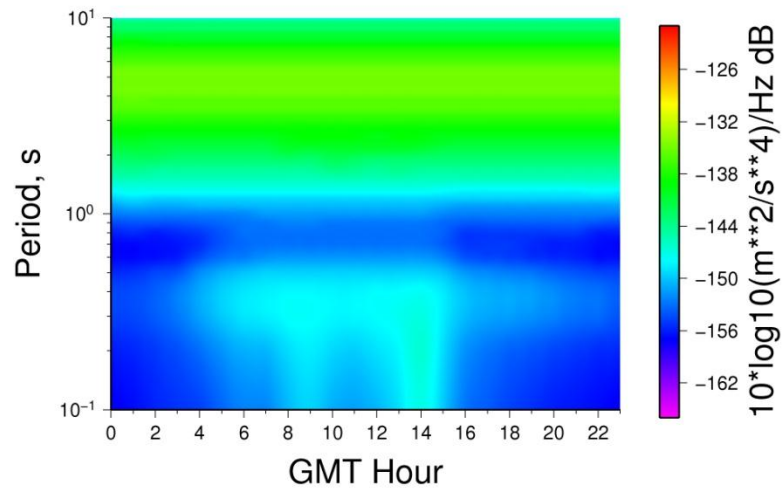


Figure 5.33. Diurnal variation plot of BR106 between 2005 and 2007

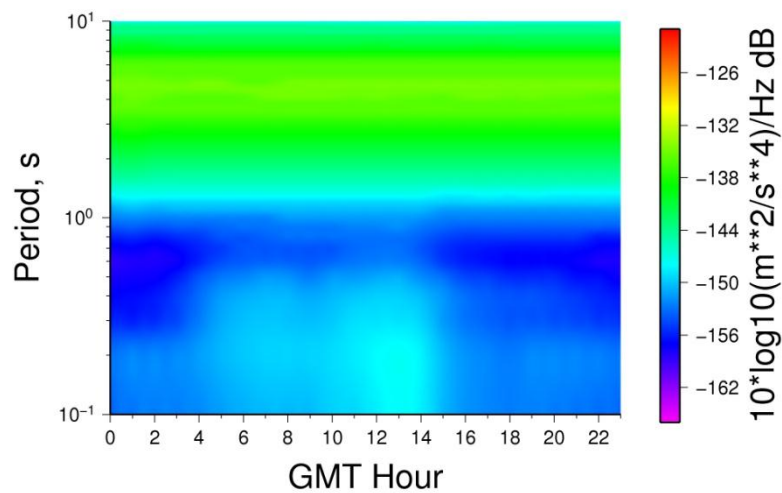


Figure 5.34. Diurnal variation plot of BR106 between 2008 and 2010

Figure 5.33 and 5.34 represent diurnal variations of BR106 station from 2005 to 2010. When we look at Figure 5.33 and 5.34, we can see that the value of the power vary by 1 to 6 dB between day and night time from 2005 to 2007 and the value of the power vary by 1 to 7 dB between day and night time from 2008 to 2010 in cultural period band.

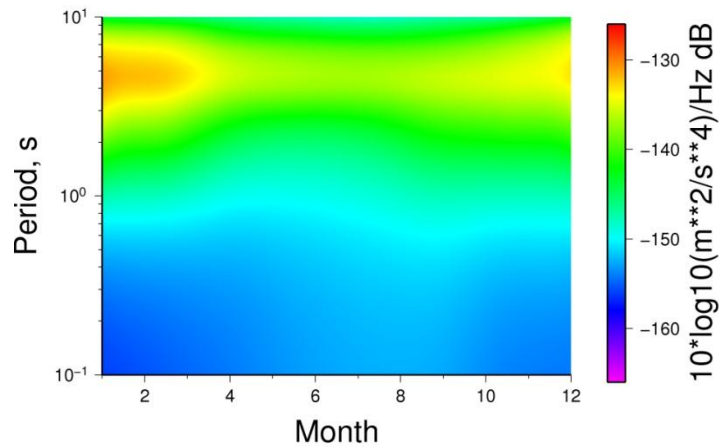


Figure 5.35. Seasonal variation of BR106 station between 2005 and 2007

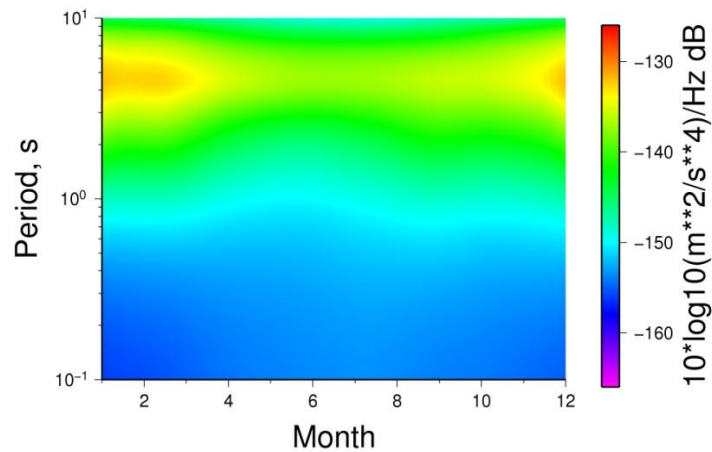


Figure 5.36. Seasonal variation of BR106 station between 2008 and 2010

Figure 5.35 and 5.36 show seasonal variations of BR106 station from 2005 to 2010. Figure 5.35 and 5.36 give us the information about noise level changes for about 1 to 7 dB in cultural period band between winter and summer from 2005 to 2007 and from 2008 to 2010. In microseism band (double frequency peak), the power vary by 1-4 dB between summer and winter from 2005 to 2007 and the power vary by 1-3 dB between summer and winter from 2008 to 2010.

5.1.7. BR131

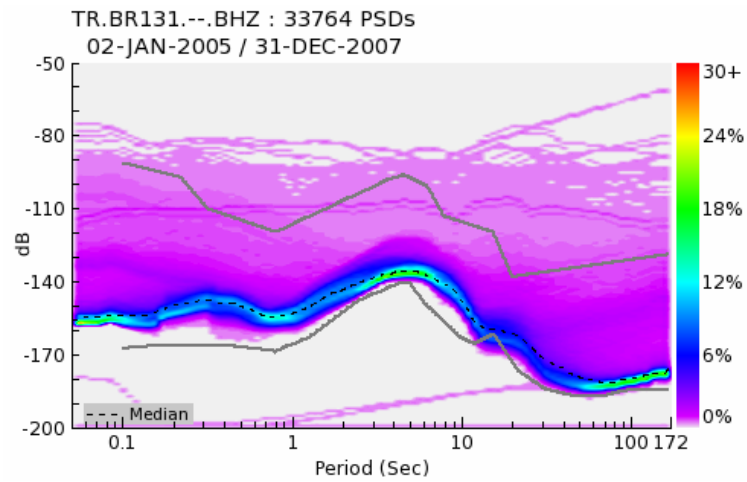


Figure 5.37. BR131.BHZ PDF plot between 2005-2007

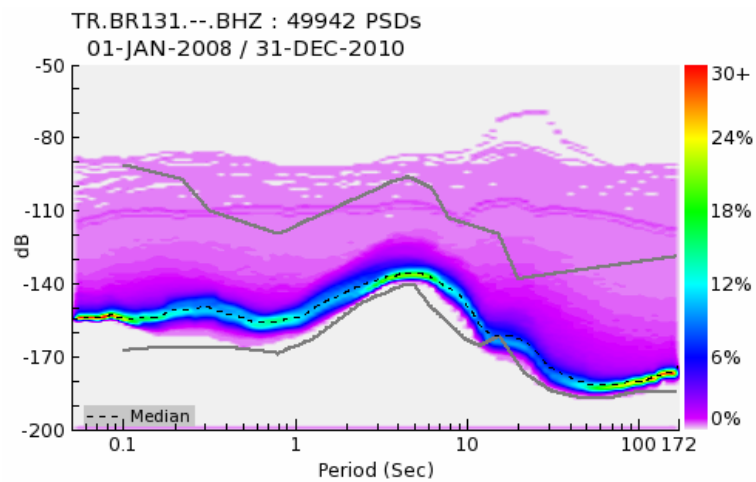


Figure 5.38. BR131.BHZ PDF plot between 2008-2010

BR131.BHZ has a good performance from 2005 to 2007 and from 2008 to 2010 as we can note with respect to NHNM and NLNM curves. BR131.BHZ presents low noise level.

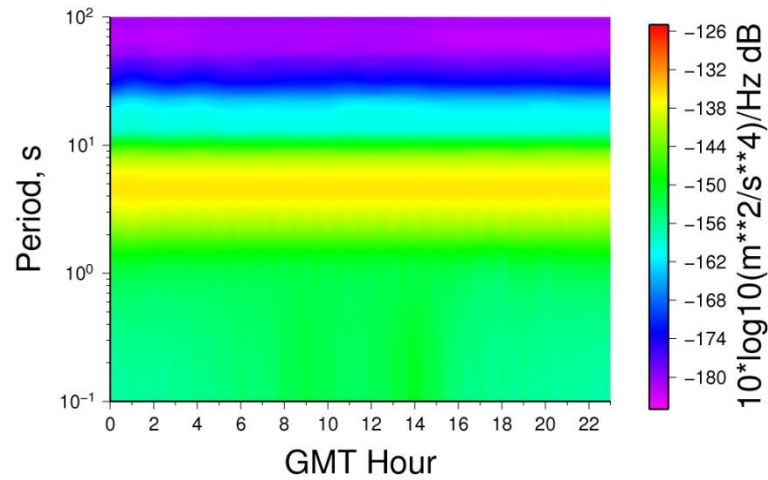


Figure 5.39. Diurnal variation plot of BR131.BHZ between 2005 and 2007

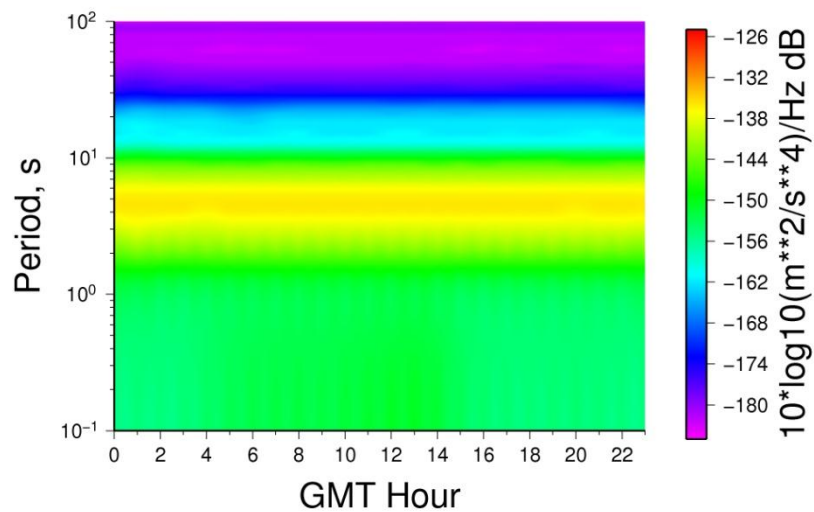


Figure 5.40. Diurnal variation plot of BR131.BHZ between 2008 and 2010

Figure 5.39 and 5.40 indicate diurnal variations of BR131.BHZ from 2005 to 2010. Between the years of 2005 and 2007, the value of the power vary by 1-6 dB in cultural period band, it was not observed any noise level changes in microseism period band and in long period band between day and night time. On the other hand between the years of 2008 and 2010, the value of the power vary by 1 to 6 dB in cultural period band, also we did not observe any noise level changes in microseism period band and in long period band between day and night time.

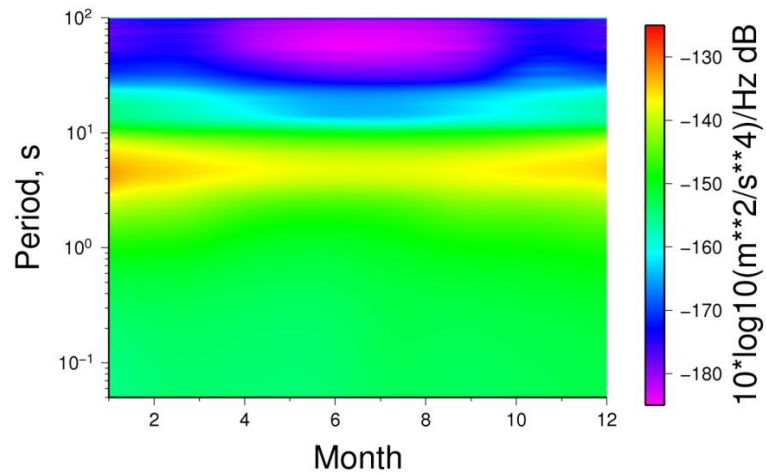


Figure 5.41. Seasonal variation plot of BR131.BHZ between 2005 and 2007

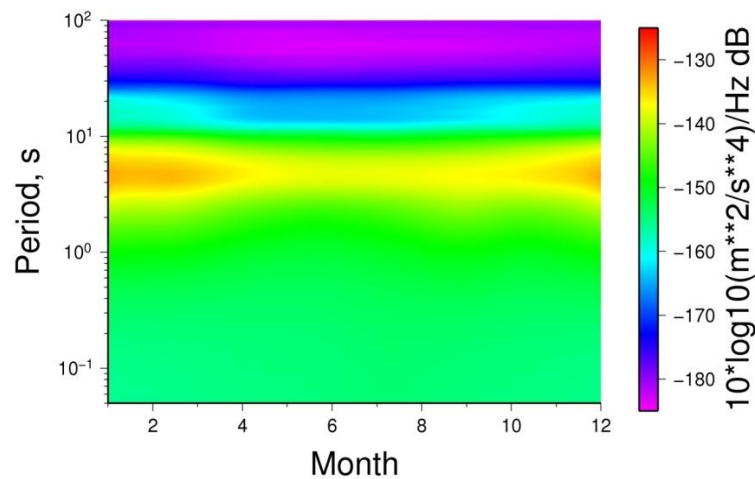


Figure 5.42. Seasonal variation plot of BR131.BHZ between 2008 and 2010

Both Figure 5.41 and 5.42 represent seasonal variations of BR131.BHZ from 2005 to 2010. Between the years of 2005 and 2007, the value of the power vary by 1-3 dB in cultural period band, the power vary by 1-8 dB in microseism period band and also the power vary by 16 dB in long period band between summer and winter. On the other hand between the years of 2008 and 2010, the value of the power vary by 1 to 3 dB in cultural period band, the power vary by 1-7 dB in microseism period band and also the power is almost the same in long period band between summer and winter.

5.2. Ankara Medium Period Array

5.2.1. BR231

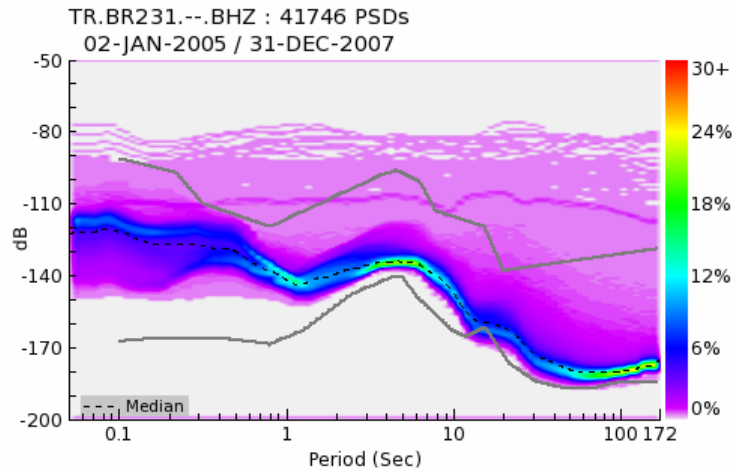


Figure 5.43. BR231.BHZ PDF plot between 2005-2007

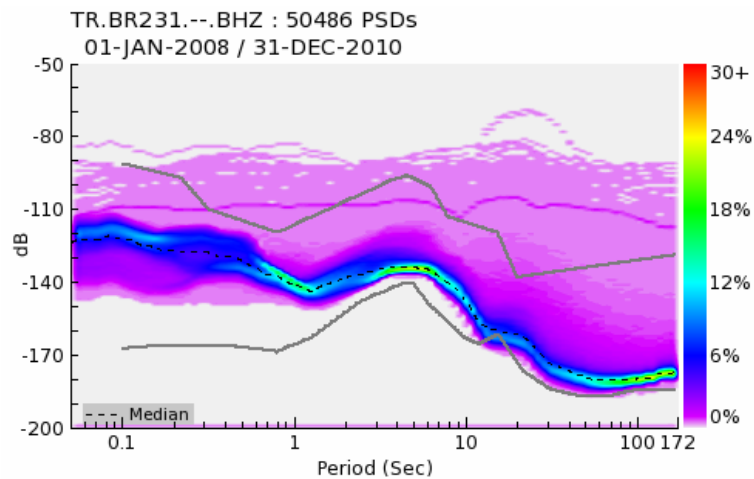


Figure 5.44. BR231.BHZ PDF plot between 2008-2010

BR231.BHZ has a good performance from 2005 to 2007 and from 2008 to 2010 as we can note with respect to NHNM and NLNM curves, but we also note that noise levels are higher when we compare it others.

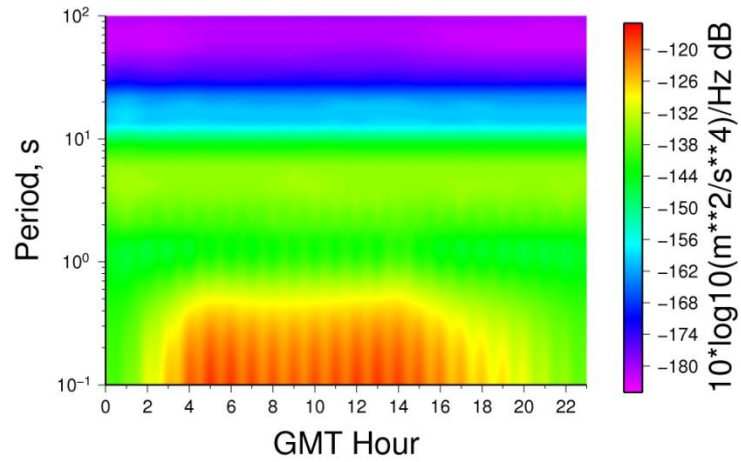


Figure 5.45. Diurnal variation plot of BR231.BHZ between 2005 and 2007

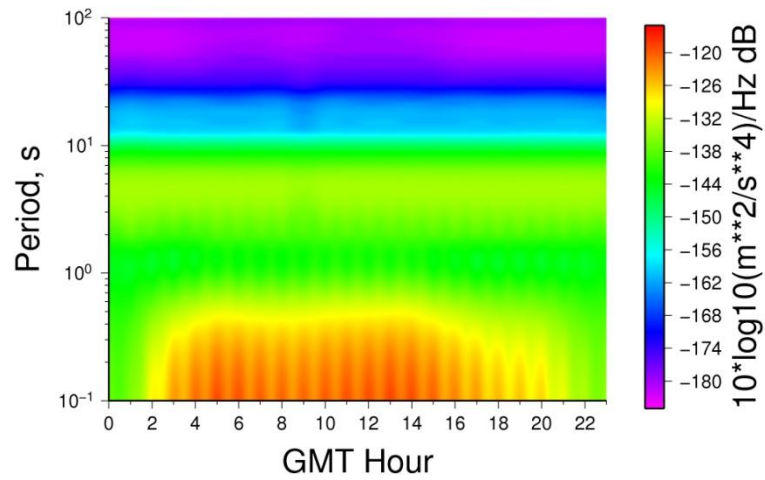


Figure 5.46. Diurnal variation plot of BR231.BHZ between 2008 and 2010

Figure 5.45 and 5.46 represent diurnal variations of BR231.BHZ from 2005 to 2010. Figure 5.45 indicates that noise level changes for about 1-14 dB in cultural period band, it was not observed any noise level changes in microseism period band and in long period band between day and night time. On the other hand, Figure 5.46 shows noise level changes from 1 to 13 dB in cultural period band and also it was not observed any noise level changes in microseism period band and in long period band between day and night time.

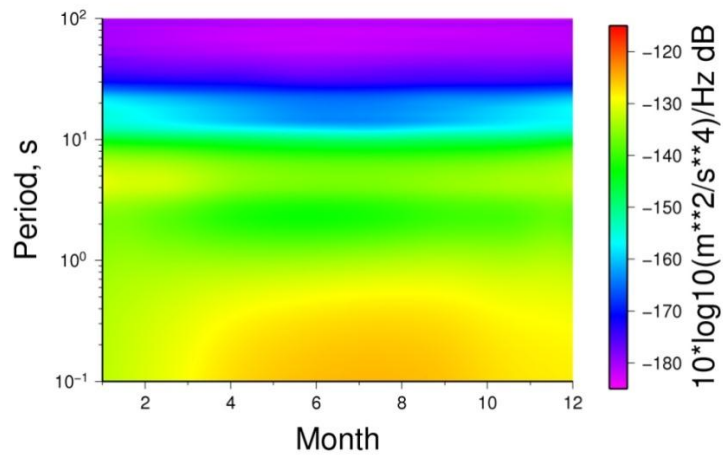


Figure 5.47. Seasonal variation plot of BR231.BHZ between 2005 and 2007

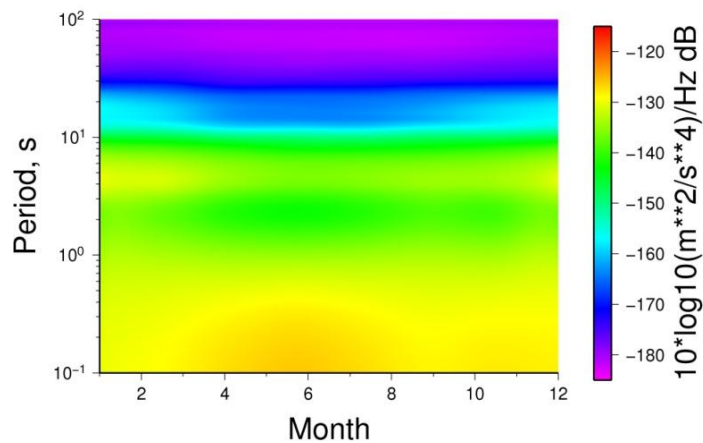


Figure 5.48. Seasonal variation plot of BR231.BHZ between 2008 and 2010

Figure 5.47 and 5.48 give us the information about seasonal variations of BR231.BHZ from 2005 to 2010. Between the years of 2005 and 2007, the value of the power vary by 1-5 dB in cultural period band, the power vary by 1-3 dB in microseism period band and also the power 1-2 dB in long period band between summer and winter. On the other hand between the years of 2008 and 2010, the value of the power vary by 1 to 4 dB in cultural period band, the power vary by 1-3 dB in microseism period band and also the power is almost the same in long period band between summer and winter.

5.2.2. BR232

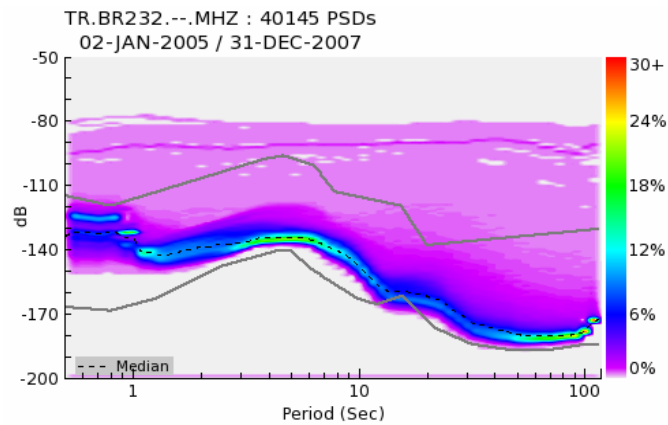


Figure 5.49. BR232.MHZ PDF plot between 2005-2007

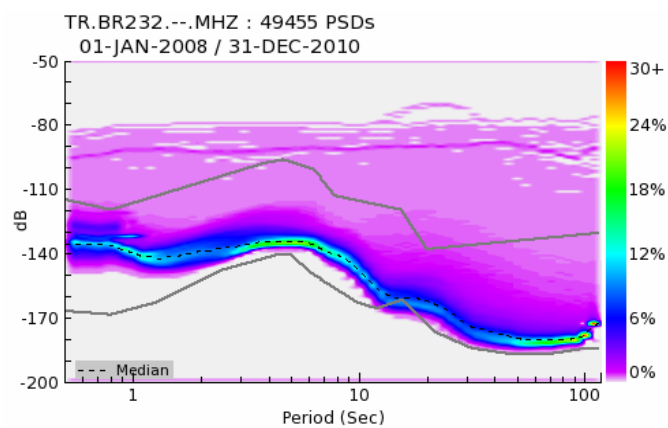


Figure 5.50. BR232.MHZ PDF plot between 2008-2010

BR232.MHZ has a good performance from 2005 to 2007 and from 2008 to 2010 as we can note with respect to NHNM and NLNM curves. BR232.MHZ presents low noise level.

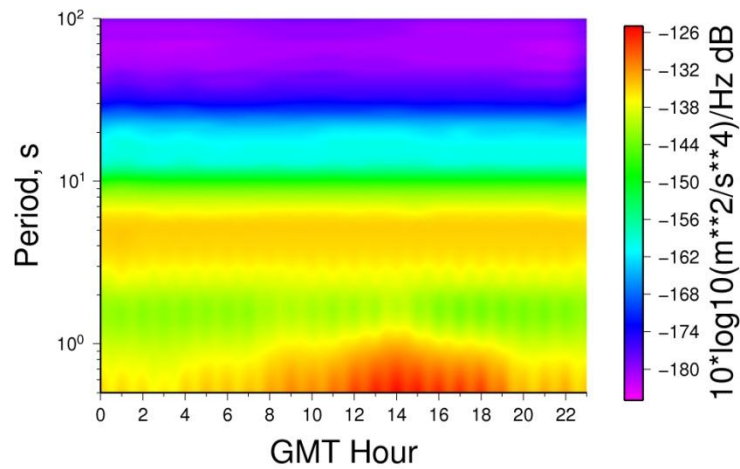


Figure 5.51. Diurnal variation plot of BR232.MHZ between 2005 and 2007

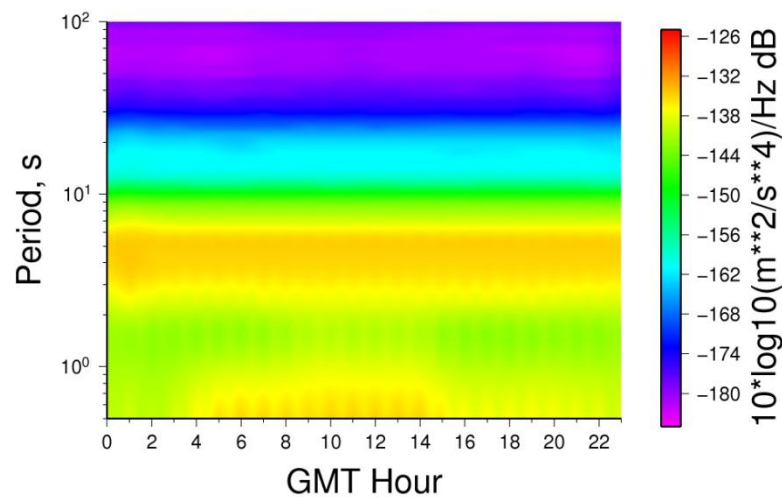


Figure 5.52. Diurnal variation plot of BR232.MHZ between 2008 and 2010

Figure 5.51 and 5.52 represent diurnal variations of BR232.MHZ from 2005 to 2010. In Figure 5.51, the value of the power vary by 1-9 dB in cultural period band. On the other hand between the years of 2008 and 2010, the value of the power vary by 1 to 7 dB in cultural period band. It was not observed any noise level changes in microseism period band and in long period band between day and night time both in Figure 5.51 and in Figure 5.52.

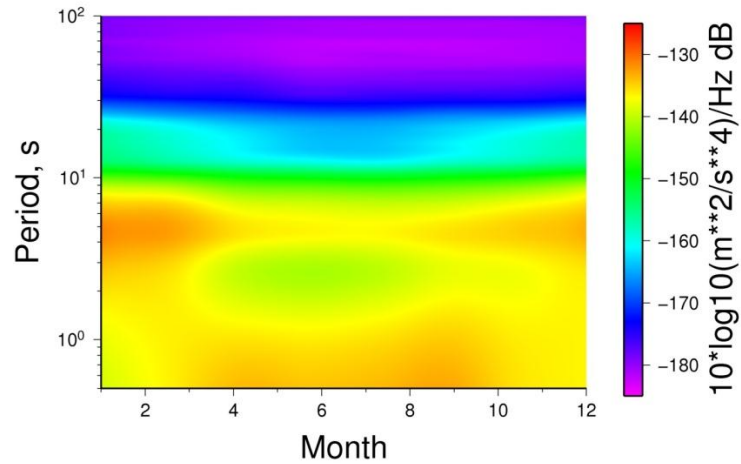


Figure 5.53. Seasonal variation plot of BR232.MHZ between 2005 and 2007

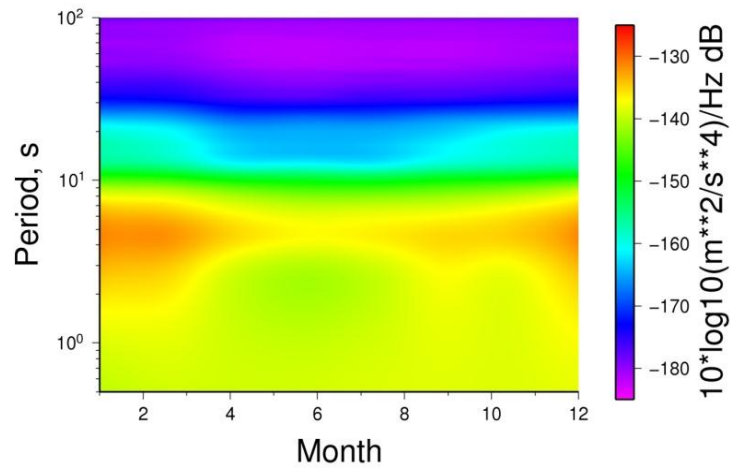


Figure 5.54. Seasonal variation plot of BR232.MHZ between 2008 and 2010

Figure 5.53 and 5.54 represent seasonal variations of BR232.MHZ from 2005 to 2010. In cultural period band, the power vary by 1-6 dB in Figure 5.53 and the power vary by 1-3 dB in Figure 5.54 between winter and summer. In microseism band, the power vary by 1-7 dB in microseism period band both in Figure 5.53 and 5.54. Also, we did not see any noise level changes in long period band from 2005 to 2007 and from 2008 to 2010 between summer and winter.

5.2.3. BR233

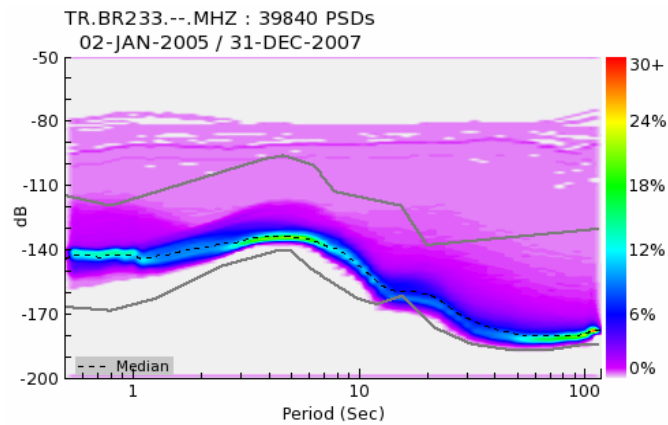


Figure 5.55. BR233.MHZ PDF plot between 2005-2007

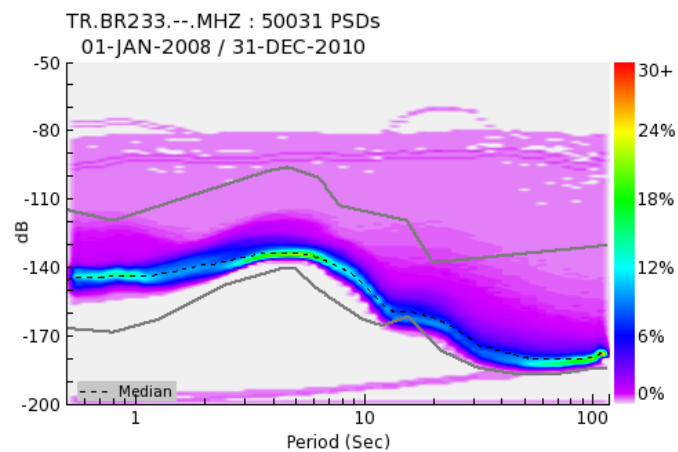


Figure 5.56. BR233.MHZ PDF plot between 2008-2010

BR233.MHZ has a good performance from 2005 to 2007 and from 2008 to 2010 as we can note with respect to NHNM and NLNM curves. BR233.MHZ presents low noise level.

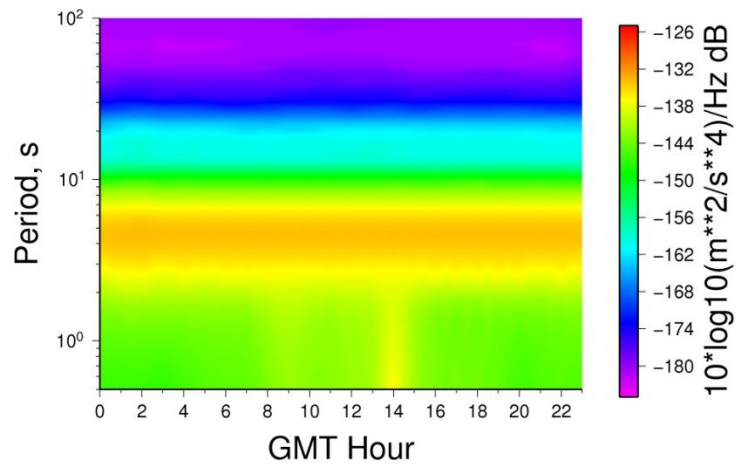


Figure 5.57. Diurnal variation plot of BR233.MHZ between 2005 and 2007

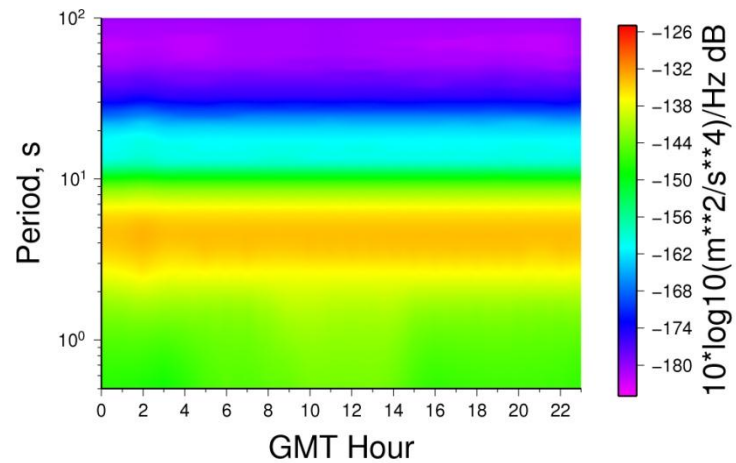


Figure 5.58. Diurnal variation plot of BR233.MHZ between 2008 and 2010

Figure 5.57 and 5.58 represent diurnal variations of BR233.MHZ from 2005 to 2010. In Figure 5.57, the value of the power vary by 1-7 dB in cultural period band, whereas the value of the power vary by 1 to 5 dB in cultural period band in Figure 5.58. It was not observed any noise level changes in microseism period band and in long period band between day and night time from 2005 to 2007 and 2008 to 2010.

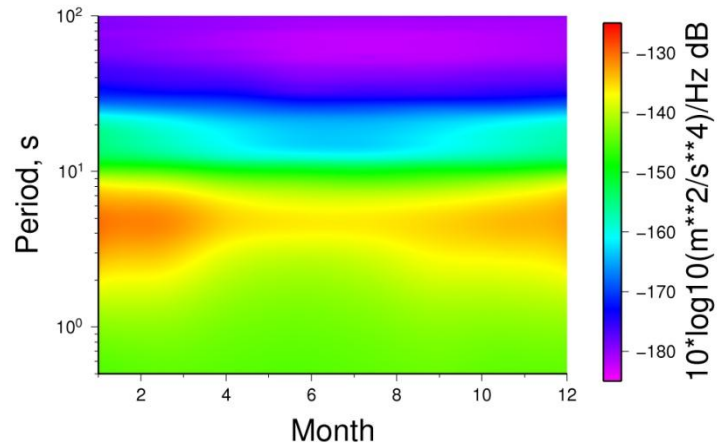


Figure 5.59. Seasonal variation plot of BR233.MHZ between 2005 and 2007

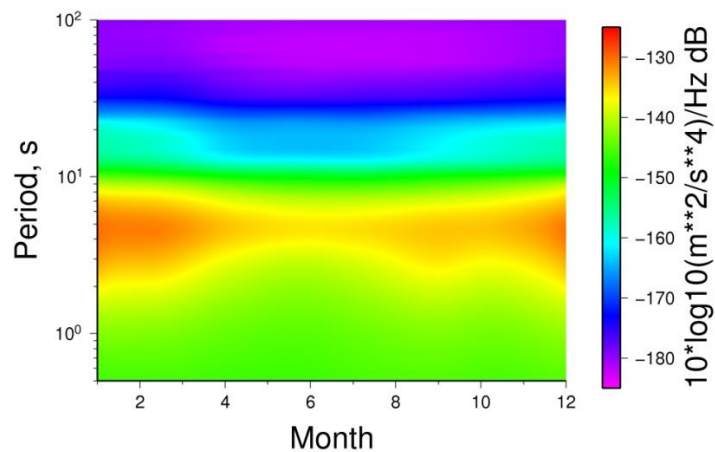


Figure 5.60. Seasonal variation plot of BR233.MHZ between 2008 and 2010

Figure 5.59 and 5.60 show seasonal variations of BR233.MHZ from 2005 to 2010. Between the years of 2005 and 2007, the value of the power vary by 1-3 dB in cultural period band, the power vary by 1-7 dB in microseism period band and also the power vary by 1-3 dB in long period band between summer and winter. On the other hand between the years of 2008 and 2010, the value of the power vary by 1 to 3 dB in cultural period band, the power vary by 1-8 dB in microseism period band and also the power vary by 1-3 dB in long period band between summer and winter.

5.2.4. BR234

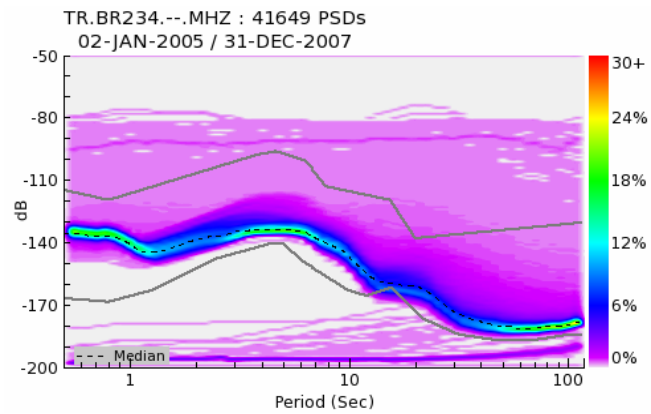


Figure 5.61. BR234.MHZ PDF plot between 2005-2007

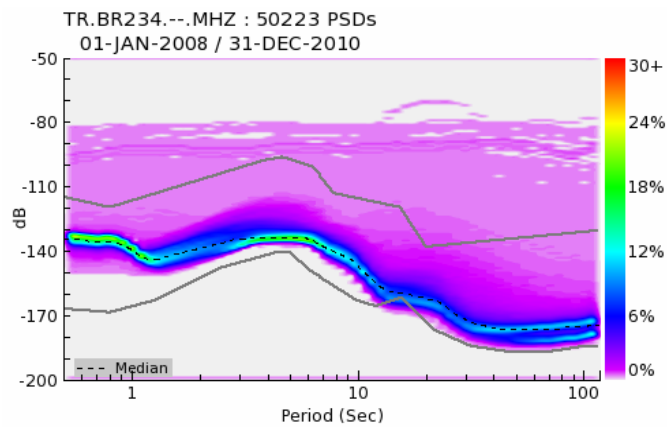


Figure 5.62. BR234.MHZ PDF plot between 2008-2010

BR234.MHZ has a good performance from 2005 to 2007 and from 2008 to 2010 as we can note with respect to NHNM and NLNM curves. BR234.MHZ presents low noise level.

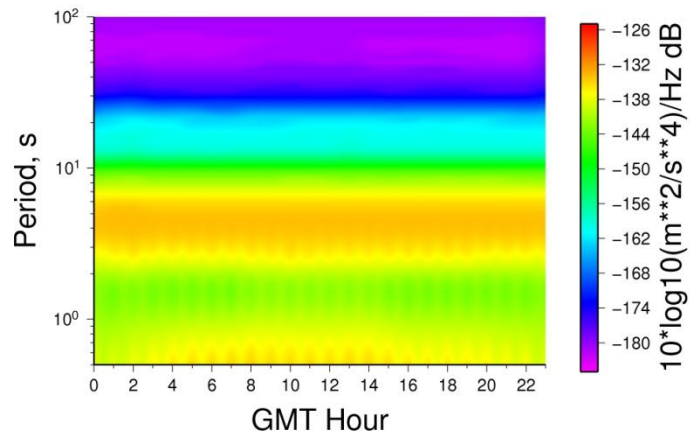


Figure 5.63. Diurnal variation plot of BR234.MHZ between 2005 and 2007

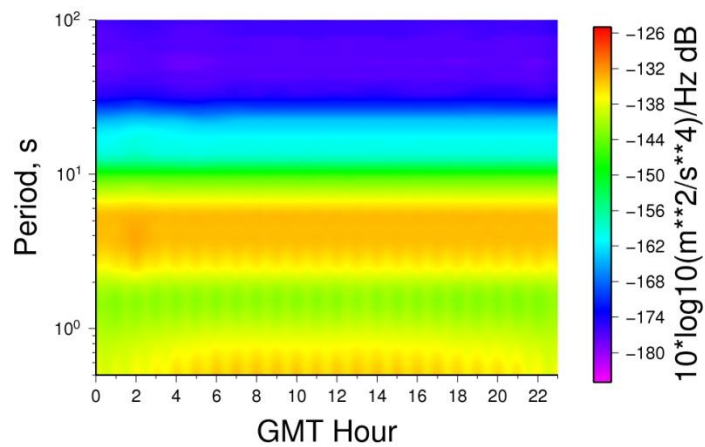


Figure 5.64. Diurnal variation plot of BR234.MHZ between 2008 and 2010

Figure 5.63 and 5.64 indicate diurnal variations of BR234.MHZ from 2005 to 2010. Figure 5.63 give us the information about noise level changes from 1 to 8 dB in cultural period band, it was not observed any noise level changes in microseism period band and in long period band between day and night time. On the other hand between in Figure 5.64, the value of the power vary by 1-6 dB in cultural period band, also it was not observed any noise level changes in microseism period band and in long period band between day and night time.

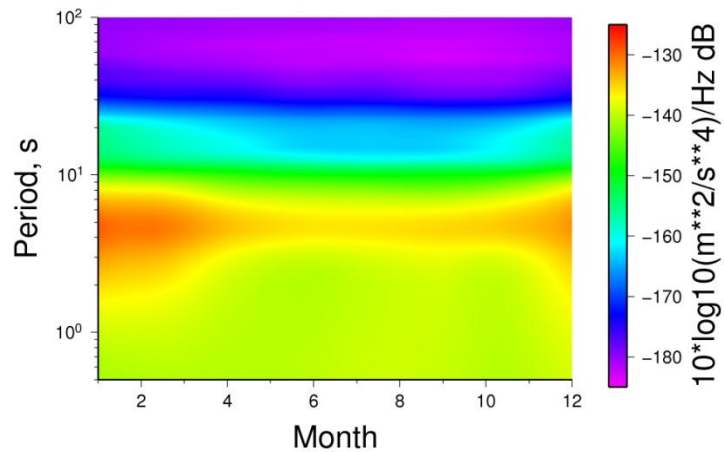


Figure 5.65. Seasonal variation plot of BR234.MHZ between 2005 and 2007

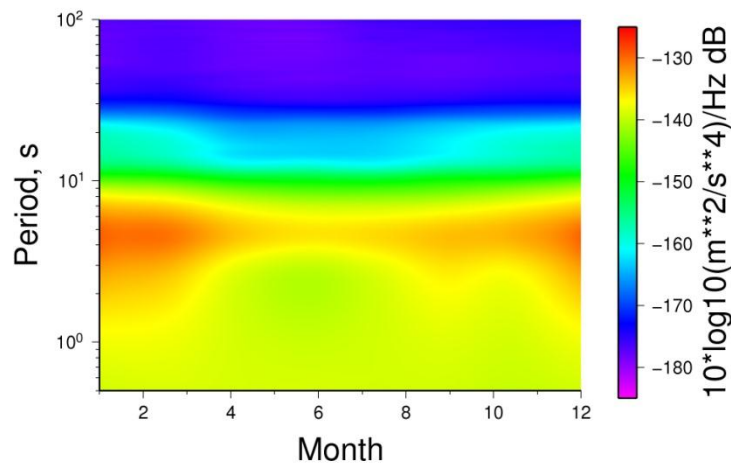


Figure 5.66. Seasonal variation plot of BR234.MHZ between 2008 and 2010

Figure 5.65 and 5.66 illustrate seasonal variations of BR234.MHZ from 2005 to 2010. Between the years of 2005 and 2007 (Figure 5.65), the value of the power vary by 1-3 dB in cultural period band, the power vary by 1-7 dB in microseism period band and also the power vary by 1-3 dB in long period band between summer and winter. On the other hand between the years of 2008 and 2010 (Figure 5.66), the value of the power vary by 1-3 dB in cultural period band, the power vary by 1-7 dB in microseism period band and also the power vary by 1-2 dB in long period band between summer and winter.

5.2.5. BR235

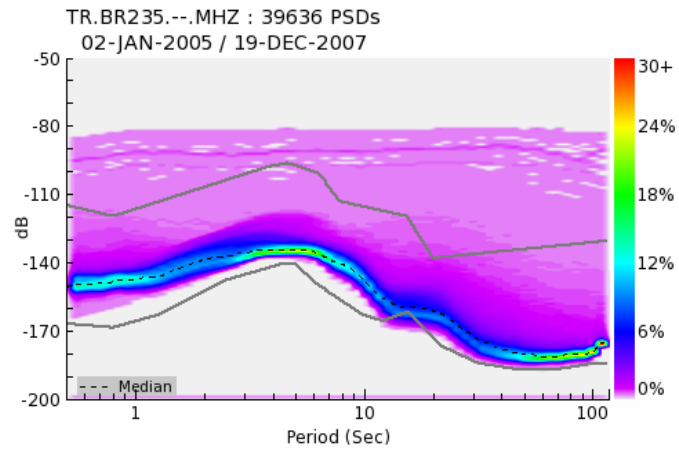


Figure 5.67. BR235.MHZ PDF plot between 2005-2007

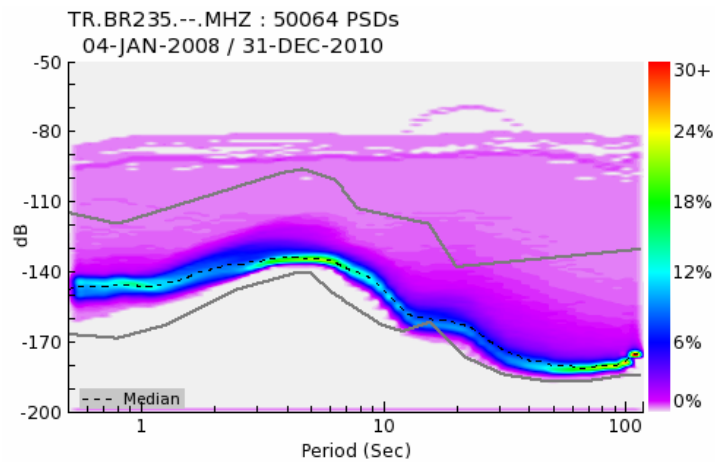


Figure 5.68. BR235.MHZ PDF plot between 2008-2010

BR235.MHZ has a good performance from 2005 to 2007 and from 2008 to 2010 as we can note with respect to NHNM and NLNM curves. BR235.MHZ presents low noise level.

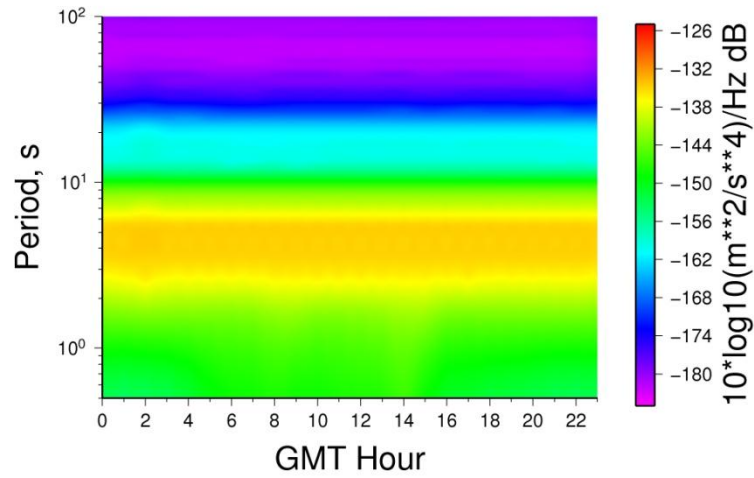


Figure 5.69. Diurnal variation plot of BR235.MHZ between 2005 and 2007

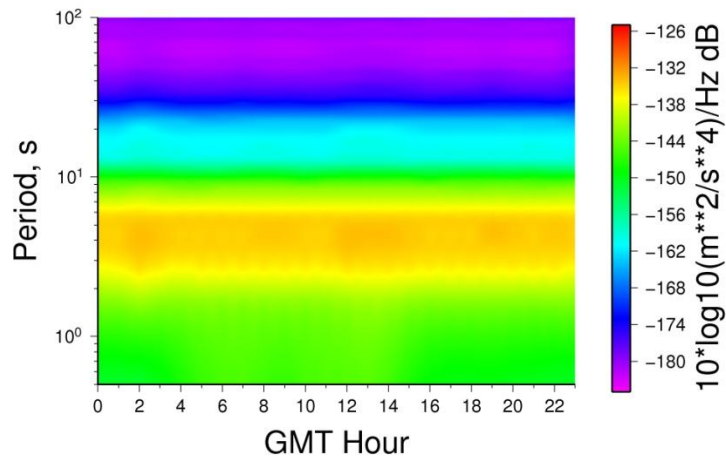


Figure 5.70. Diurnal variation plot of BR235.MHZ between 2008 and 2010

Figure 5.69 and 5.70 represent diurnal variations of BR235.MHZ from 2005 to 2010. We can see that the value of the power vary by 1-6 dB in cultural period band, when we look at microseism period band and long period band we did not see any noise level changes between day and night time in Figure 5.69. On the other hand between the years of 2008 and 2010 (Figure 5.70.), the value of the power vary by 1-5 dB in cultural period band, we did not see any noise level changes both in microseism period band and in long period band between day and night time.

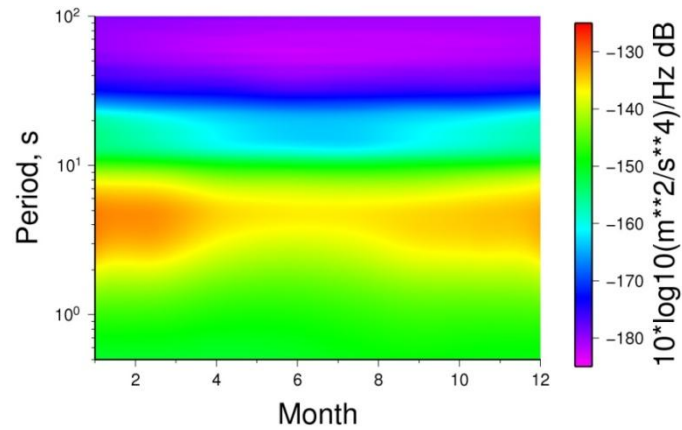


Figure 5.71. Seasonal variation plot of BR235.MHZ between 2005 and 2007

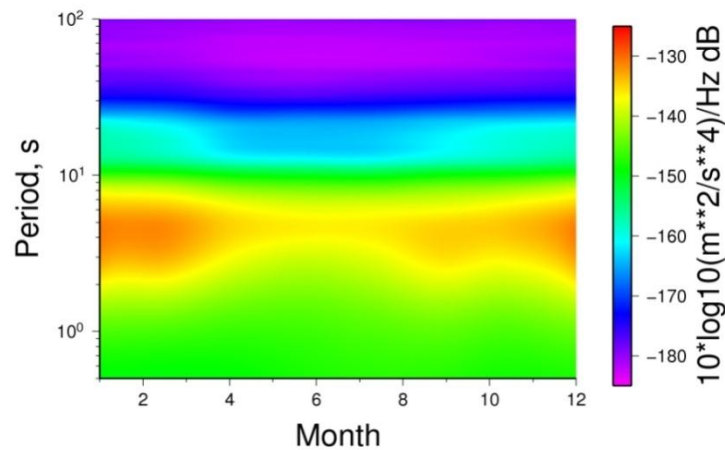


Figure 5.72. Seasonal variation plot of BR235.MHZ between 2008 and 2010

Figure 5.71 and 5.72 give us the information about seasonal variations of BR235.MHZ from 2005 to 2010. Between the years of 2005 and 2007, the value of the power vary by 1-3 dB in cultural period band the power vary by 1-7 dB in microseism period band and also the power vary by 1-2 dB in long period band between summer and winter. On the other hand between the years of 2008 and 2010, the value of the power vary by 1-3 dB in cultural period band, the power vary by 1-7 dB in microseism period band and also the power vary by 1-2 dB in long period band between summer and winter.

5.2.6. BR236

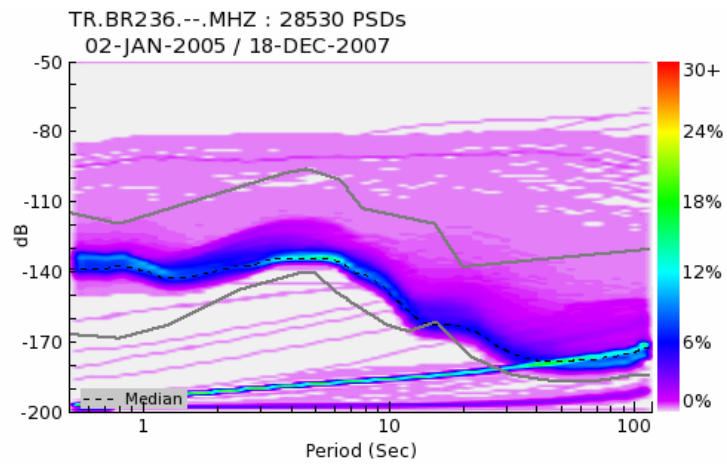


Figure 5.73. BR236.MHZ PDF plot between 2005-2007

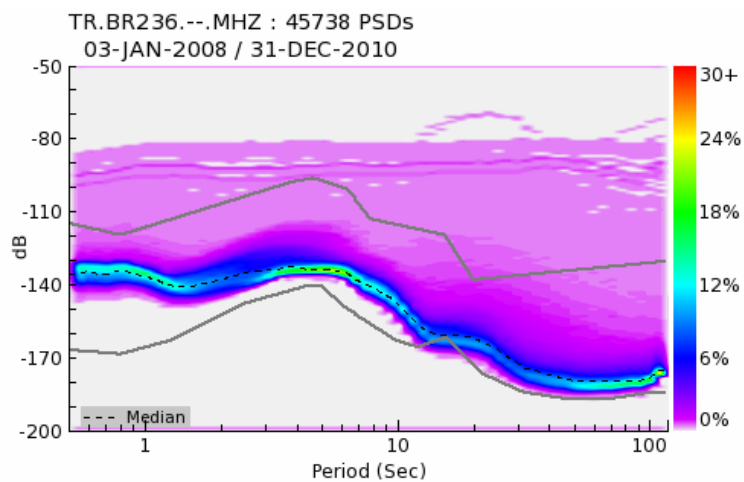


Figure 5.74. BR236.MHZ PDF plot between 2008-2010

BR236.MHZ has not a good performance from 2005 to 2007 because of unavailability of data

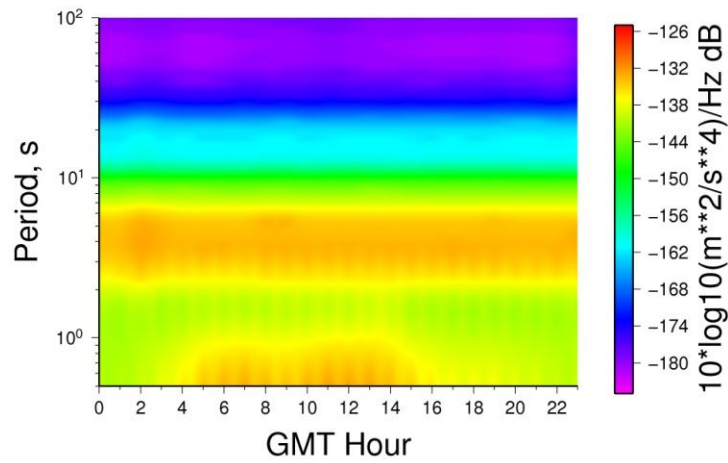


Figure 5.75. Diurnal variation plot of BR236.MHZ between 2008 and 2010

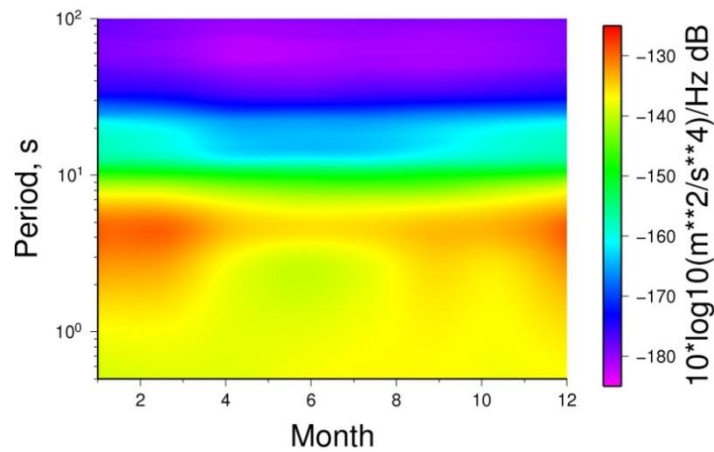


Figure 5.76. Seasonal variation plot of BR236.MHZ between 2008 and 2010

Figure 5.75 represents diurnal variations and figure 5.76 illustrates seasonal variations of BR236.MHZ from 2008 to 2010. Between the years of 2005 and 2007, the diurnal and seasonal plots could not be analyzed because PDF noise plots did not maintain between NHNM and NLNM, the noise levels decrease almost -200 dB and data availability were unavailable because of vandalism and lightning and it continued for a long time. On the other hand between the years of 2008 and 2010, the value of the power vary by 1-8 dB in cultural period band, we did not observe any noise level changes among daily working and night time both in microseism period band and in long period band. For seasonal variations, the value of the power vary by 1-5 dB in cultural period band, the

power vary by 1-7 dB in microseism period band and we did not observe any noise level changes in long period band between summer and winter.

5.2.7. BR237

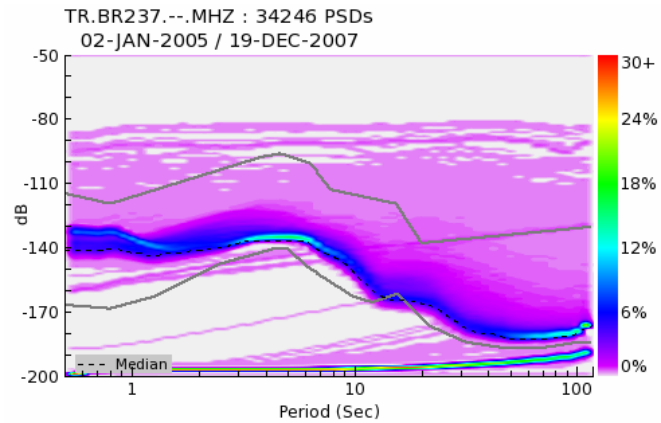


Figure 5.77. BR237.MHZ PDF plot between 2005-2007

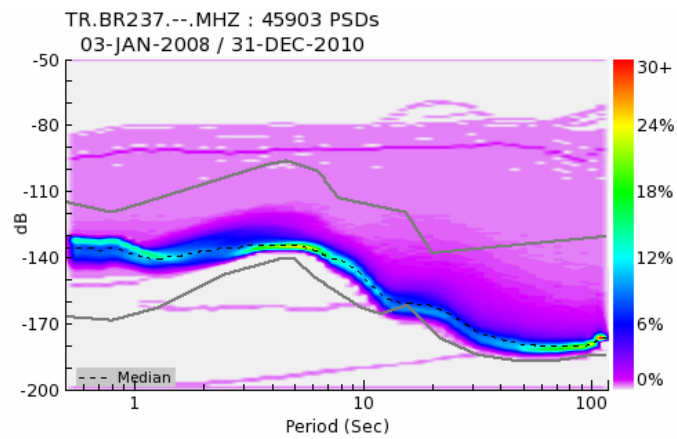


Figure 5.78. BR237.MHZ PDF plot between 2008-2010

BR237.MHZ has not a good performance from 2005 to 2007 because of data unavailability.

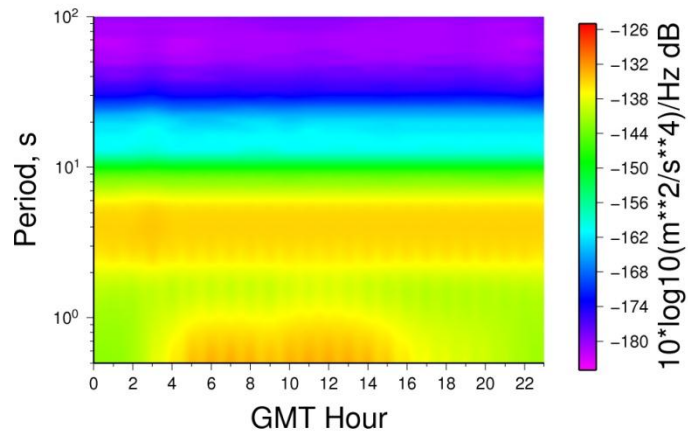


Figure 5.79. Diurnal variation plot of BR237.MHZ between 2008 and 2010

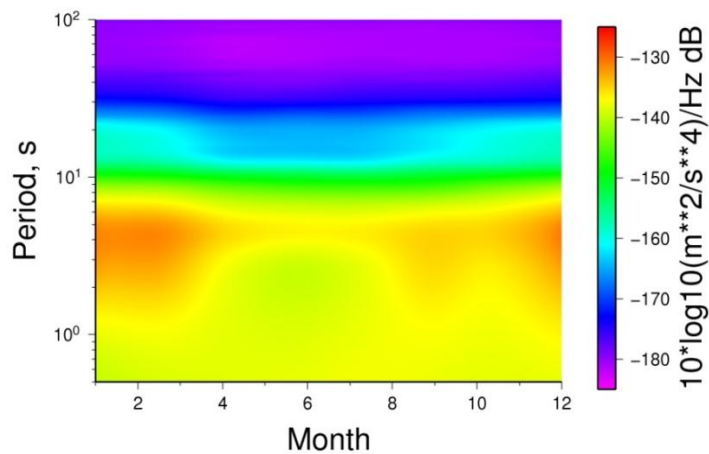


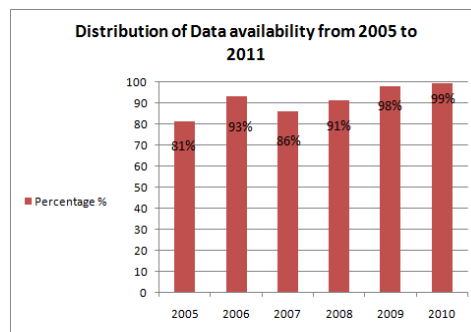
Figure 5.80. Seasonal variation plot of BR237.MHZ between 2008 and 2010

Figure 5.79 shows diurnal variations and Figure 5.80 indicates seasonal variations of BR237.MHZ from 2008 to 2010. Between the years of 2005 and 2007, the diurnal and seasonal plots could not be analyzed because, the noise levels decrease almost -200 dB because data availability were unavailable and it continued for a long time. For diurnal variations between the years of 2008 and 2010, the value of the power vary by 1-10 dB in cultural period band, we did not observe any noise level changes both in microseism period band and in long period band between day and night time. For seasonal variations, the value of the power vary by 1-4 dB in cultural period band, the power vary by 1-8 dB in microseism period band and the power is almost the same in long period band.

5.3. Contribution of BRTR Array to Detect an Event for CTBT Verification Purposes

The description of detection capability of a seismic station mentioned previous section. We can see the seismic detection threshold maps of BRTR array from 2005 to 2011 below. When we select the network magnitude from IDC REB, we specifically requested events with associated seismic phases at BRTR of P-type such as Pg, Pn, P, PcP, PKP, PKIKP. Moreover, global event detection capability of a network depends heavily on the data quality and availability of each station (Table 5.2).

Table 5.2. Number of events vs years



Years	Number of events
2005	5855
2006	8414
2007	2625
2008	9123
2009	10945
2010	11214

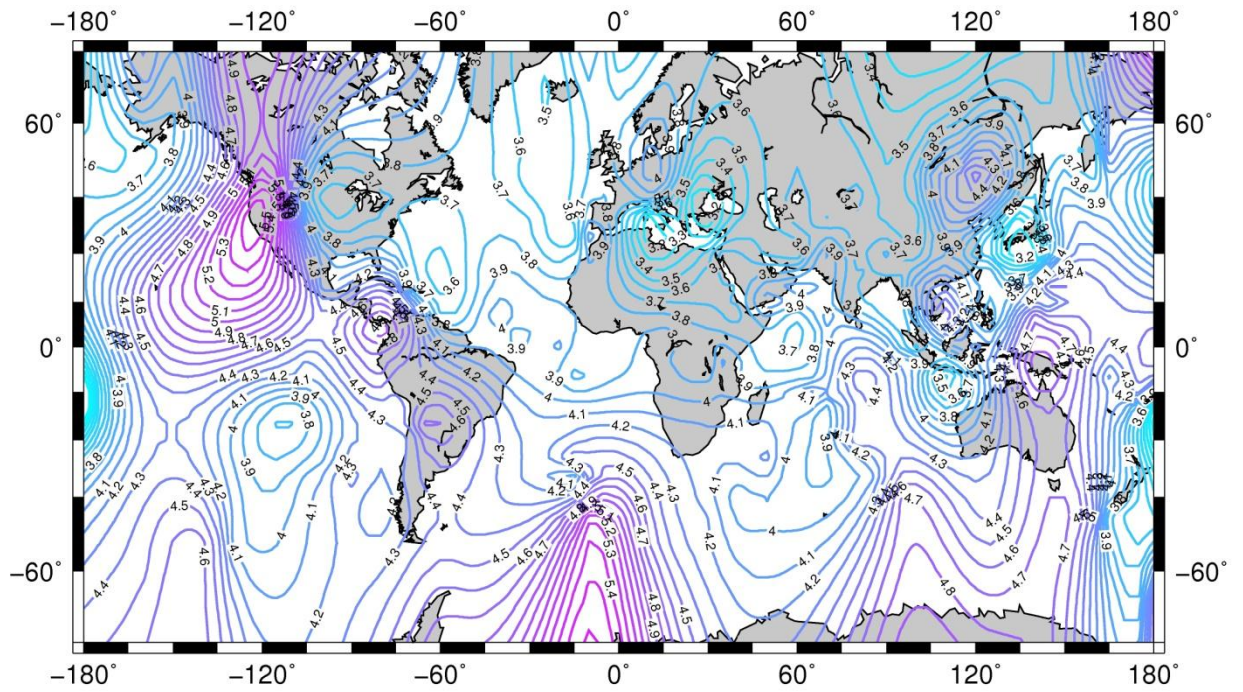


Figure 5.81. Detection threshold contour map of IMS which contains BRTR array in 2005

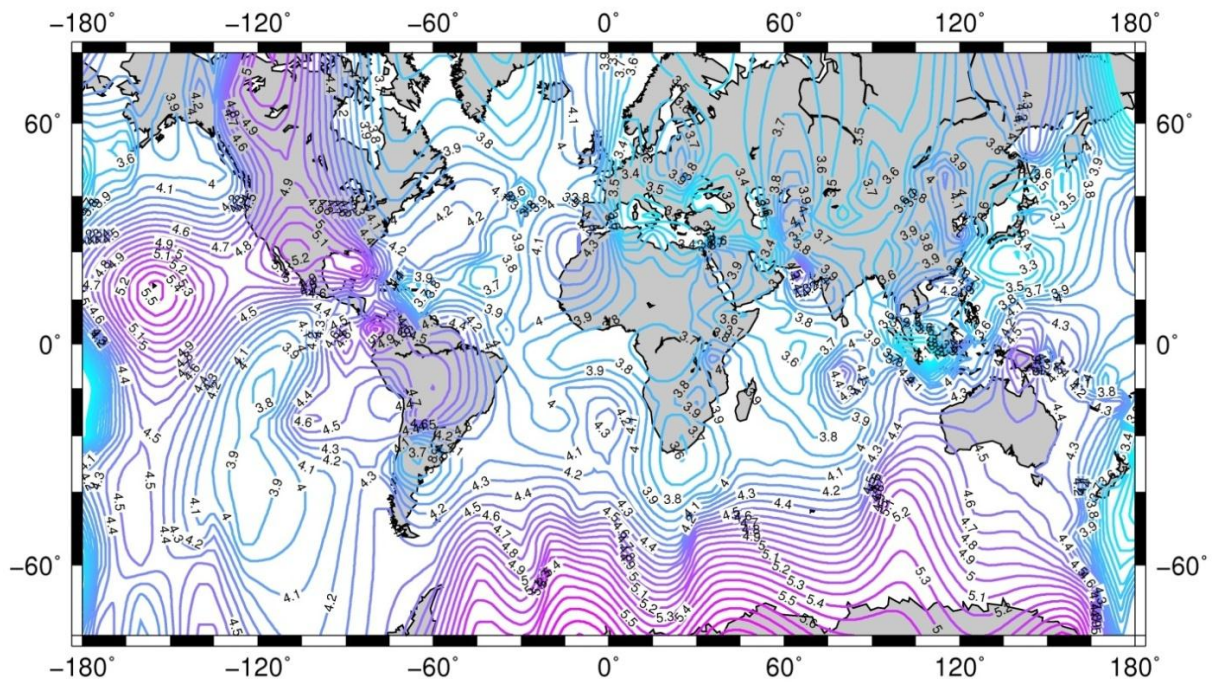


Figure 5.82. Detection threshold contour map of IMS which contains BRTR array in 2006

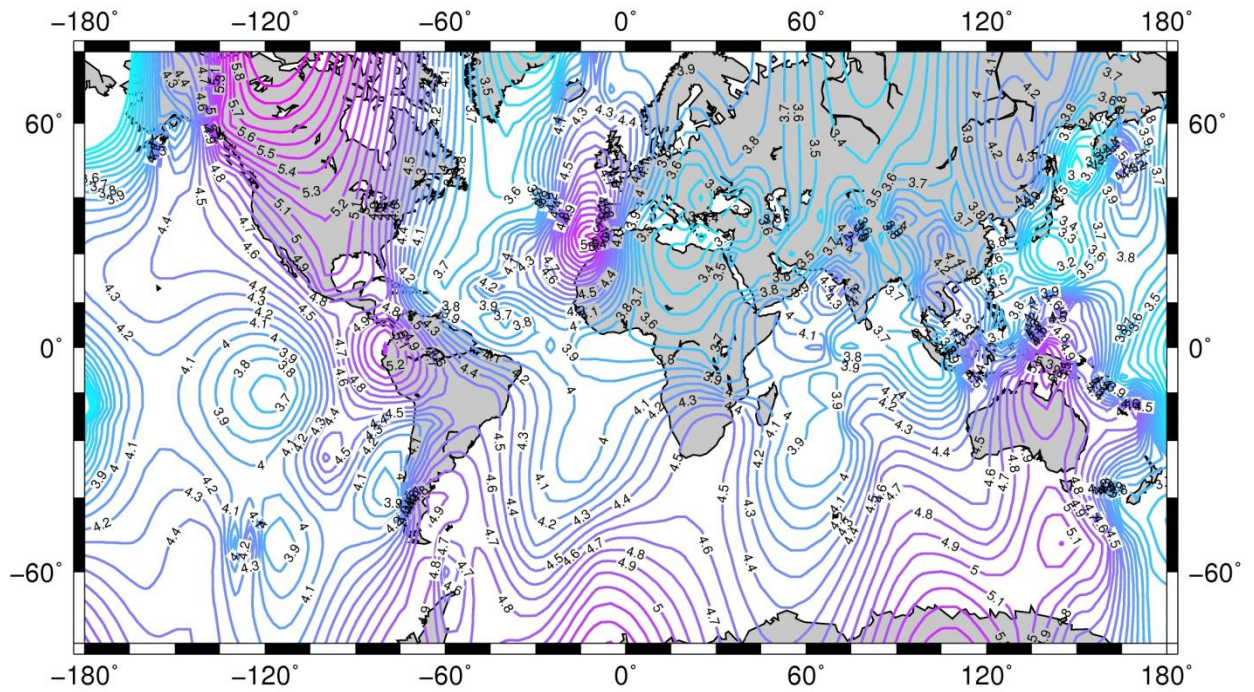


Figure 5.83. Detection threshold contour map of IMS which contains BRTR array in 2007

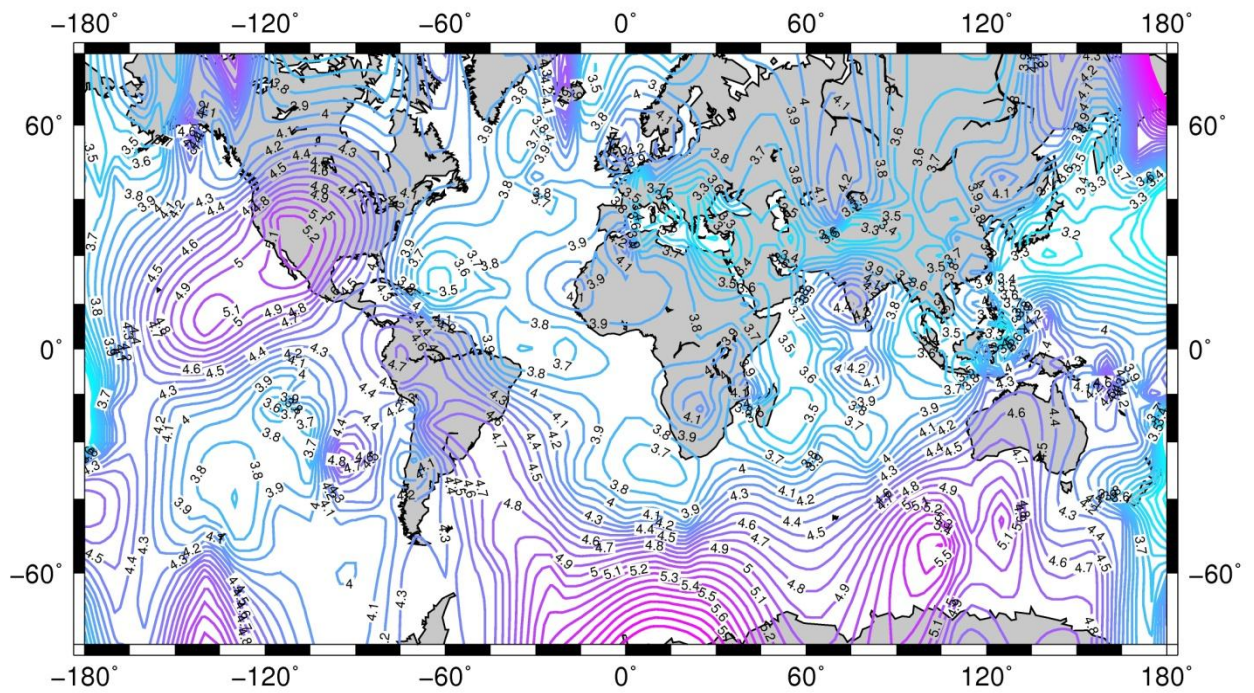


Figure 5.84. Detection threshold contour map of IMS which contains BRTR array in 2008

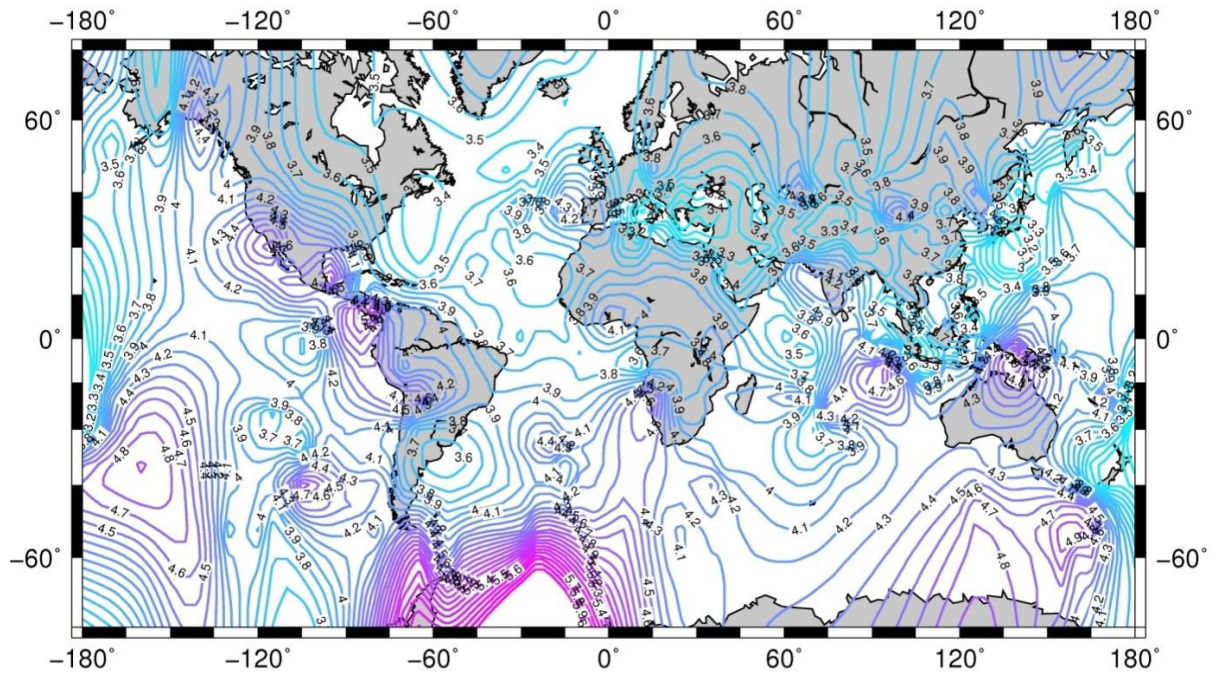


Figure 5.85. Detection threshold contour map of IMS which contains BRTR array in 2009

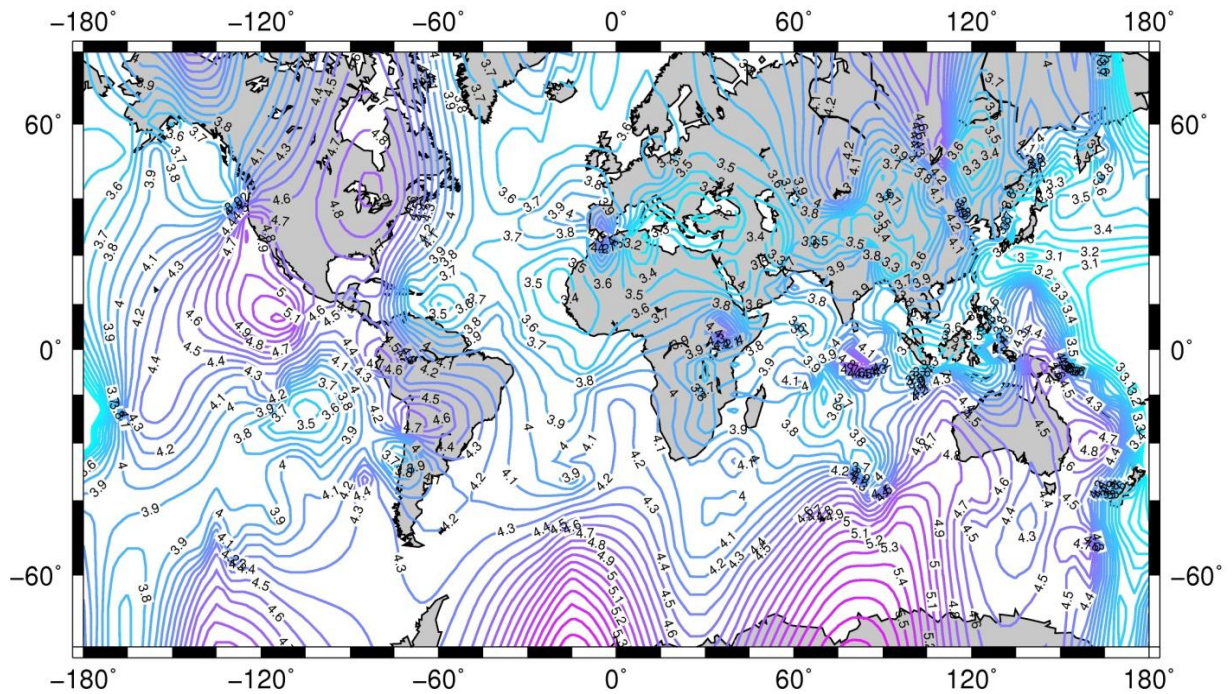


Figure 5.86. Detection threshold contour map of IMS which contains BRTR array in 2010

As we understood that these results depend on both distance and phases. Also IDC has a different method of magnitude calculation that is not comparable to USGS magnitude values. Amplitude and period measurements for mb calculations are made on a vertical component with a filter of 0.8 and 4.5 Hz. For arrays, the beam is steered to the azimuth and slowness of the detecting channel. For 3-C stations the vertical channel is used. The waveform is screened for small excursion peaks and troughs that do not exceed a specified percentage of the maximum amplitude in the window. The amplitude is then measured as half the maximum peak-to-trough (or trough-to peak) amplitude difference in the window. This window starts 0.5 seconds prior to the automatically picked arrival time and ends 5.5 seconds after this arrival time. The period associated with the measured amplitude is calculated as twice the time between the two peaks used for the amplitude. After the period is known, the amplitude is corrected for the response of the band-pass filter and the instrument. The correction consists in dividing the measured amplitude by the absolute value of the filter or instrument transfer function, evaluated at the frequency corresponding to the measured period (IDC Documentation: IDC Processing of Seismic, Hydroacoustic and Infrasound Data).

Also, we see that data availability and increase in the network coverage due to new stations in IMS operations have an important role because increasing of data availability does lead to an increase in number of events (Table 5.2). When we analyze maps year by year, we observed almost the same magnitude values in South Pole, South-East Pacific, Turkey and surroundings.

6. DISCUSSION AND CONCLUSIONS

The main purpose of this work is to analyze noise level changes of BRTR array and its detection capabilities. The data were collected from Keskin short period array and Ankara medium period array in the region between January, 2005 and December, 2010.

We analyzed the background noise levels of BRTR array for the period of 2005 - 2011. The results show us a little change in noise conditions in terms of time and location. We compared diurnal background noise levels and seasonal background noise levels at Keskin short period array and Ankara medium period array from 2005 to 2007 and from 2008 to 2010.

In Keskin array, the figures show us the diurnal variations and seasonal variations at both sites are almost the same. Especially, noise level changes were observed at 3-5 Hz in diurnal variations at Keskin array and there is a 5-7 dB difference in day and night time (lower noise) in cultural noise band (1-10 Hz). As we understood that high noise levels were observed in daily working times when we compared to night time in cultural noise band. The seasonal background noise variation at both sites also show very similar properties at Keskin short period array. Since these stations are borehole instruments and away from the coasts, we saw a small change in noise levels caused by microseism. During winter months, cultural noise levels lowers while microseism noise (5-8 s) gets higher compared to summer time. From 2005 to 2007 winter time there was a water leak in the borehole of site BR131.BHZ which caused a very high noise levels as can be seen from the seasonal graph in the long period band. Also it is understood that microseisms are more observable in seasonal plots than diurnal plots. From 2005 to 2010, noise changes were low among stations for about 1-3 dB in cultural noise band and small noise level changes were observed in microseism band.

In Ankara medium period array, the figures illustrate us the diurnal variations and seasonal variations of stations have small noise changes. In 1-2 Hz frequency band, BR232 and BR233 are noisier than BR235. From 2005 to 2010, it was observed that noise levels of BR232.MHZ and BR234.MHZ decreased in cultural noise band. Due to the quarry

activities around array, BR232.MHZ and BR234.MHZ indicate high noise levels compare to other stations in medium period array. Daily working times are noisier than night time among stations. Noise levels increase from 2 to 3 dB from 2005 to 2010 at BR235.MHZ in cultural noise band. Due to closer to settlement area, BR231.BHZ shows high noise levels in both diurnal variations and seasonal variations. BR236.MHZ and BR237.MHZ had a problem with data availability between 2005 and 2007 because of vandalism and lightning.

Noise levels of Keskin short period array are low when it is compared to Ankara medium period array. In conclusion, medium period array are noisier than short period array due to closer to settlement area and quarry activities around array.

For contribution of BRTR array to IMS seismic network, 6 year seismic event data were obtained from International Data Center. In addition that minimum detectable magnitude contour maps of IMS which contain BRTR array were created by using GMT. We observed that data availability of BRTR array increased the detection of number of events and also it affected network magnitude coverage. Also, changes of IMS network configuration by adding seismic stations and impairing seismic stations can affect event detection.

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