Hellenic Petroleum Exploration & Production of Hydrocarbons SA

KYPARISSIAKOS GULF ACOUSTIC MONITORING PROJECT

ITEM 1.B
"Seismic noise monitoring"

Technical Report

OCEANUS LAB

(Laboratory of Marine Geology & Physical Oceanography)

Department of Geology University of Patras

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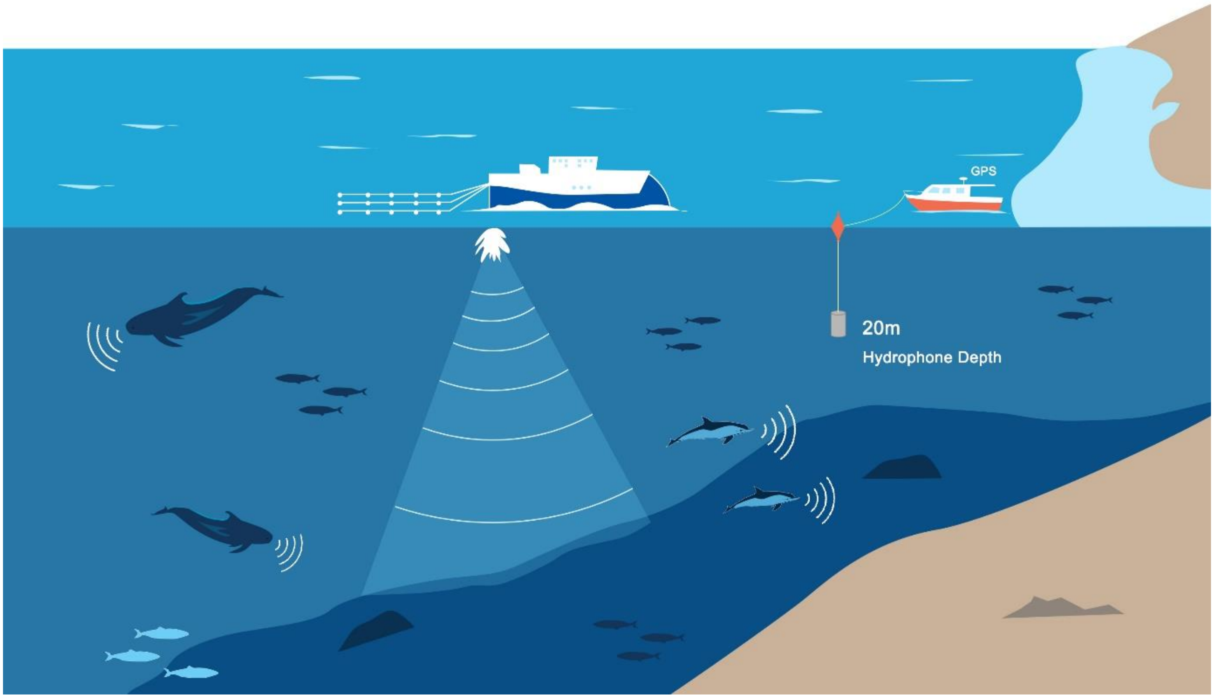

1. Introduction

The present report describes the data collection, data processing methods and the results of ITEM 1.B "Seismic noise monitoring", regarding the Kyparissiakos Gulf Acoustic Monitoring Project. The aim of the present acoustic survey was to assess the sound pressure level of the noise induced by the air-gun seismic sources to the 5 predefined sampling locations.

The Kyparissiakos Gulf Acoustic Monitoring Project has been planned and carried out by the Oceanus-Lab (Laboratory of Marine Geology and Physical Oceanography) of the Geology Department of the University of Patras, on behalf of the Hellenic Petroleum (HELPE).

Results presented in this report refer to acoustic data collected between December 18th and 29th 2022.

2. Data acquisition

During the seismic noise monitoring, which was carried out between December 18th and 29th 2022, a total of 9 deployments have been realized (Table 2.1). For each station, the Acoustic Monitoring Survey vessel “Sea Master” turned off the engines to avoid any mechanical acoustic and surveyors deployed a recording device carrying hydrophones, suspended 20 m below the sea surface (Fakiris et.al., 2019), attached through an elastic rope to an anti-heave buoy, acquyring sound data for approximately three hours per station. In each deployment the vessel was left drifting by the winds and the sea currents, hardly stabilized by using a floating anchor. Whenever the vessel has drifted far from the intending position, correction movements were realized, the time and duration of which were noted in the logbook to be excluded from the post-survey analysis. More than 30 hours of raw data recordings have been acquired.

The navigational data of Research/Survey Vessel “Ramform Hyperion” were sent to the data processing team in a daily fashion after a valid exchange data format had been agreed. Those included time stamped coordinates of the pulse emitting Airguns from time intervals where Airgun shots occurred. These data have been narrowed to the exact time periods where sound level recording had taken place.

Table 2.1. Seismic noise measurements sorted by date and station.

Date	Strofades (S1)	Zakinthos (S2)	Katakolo (S3)	Marathopoli (S4)	Methoni (S5)
18/12/2022	√				
19/12/2022			√		
20/12/2022			√		
23/12/2022					√
24/12/2022				√	
25/12/2022			√		
26/12/2022	√				
28/12/2022				√	
29/12/2022		√			

Fig. 2.1. Selected pictures from the field work survey during ITEM 1.2 phase.

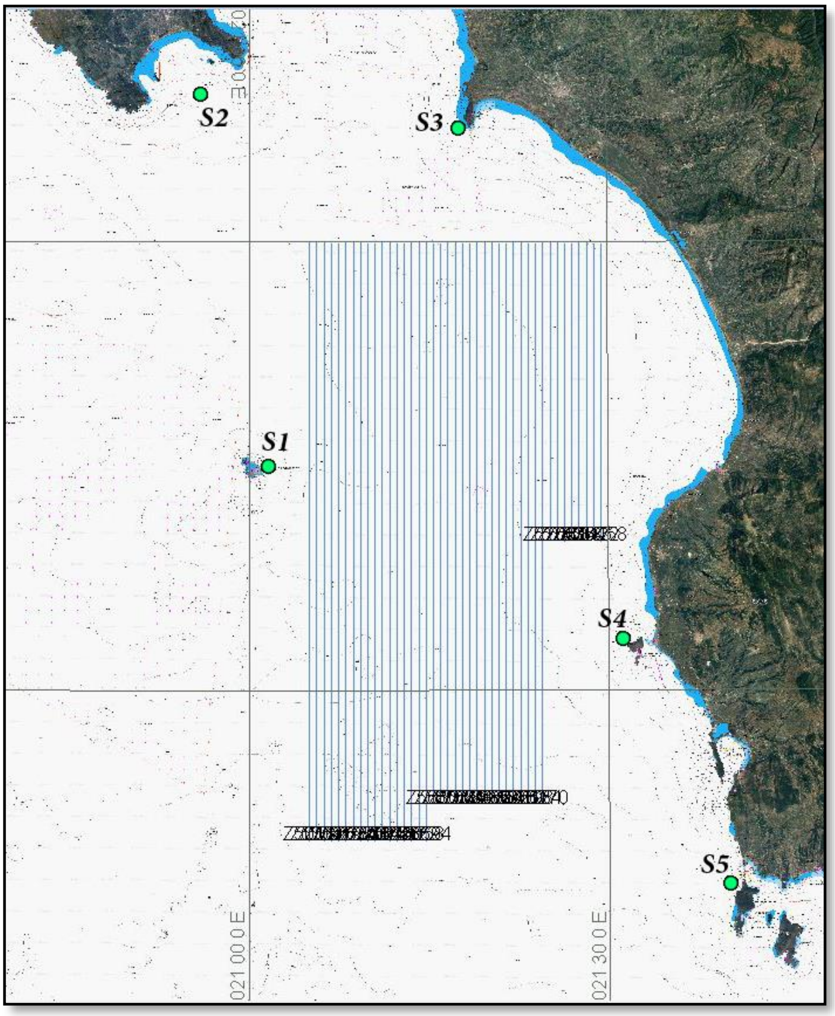

Fig. 2.2. Map showing the seismic survey area (tracklines) and the five (5) locations where spot acoustic measurements took place in the seismic monitoring phase.

3. Data Processing Methodology

3.1. Methodology overview

The objectives of ITEM 1.B are to measure sound pressure levels induced to the predefined monitored locations by the seismic source (Airguns), in regard to their distance to the seismic source. To meet the above, a suite of MATLAB codes has been implemented by the Oceanus-Lab. The data processing steps were as follows:

1. Apply queries based on the operator's digital logbook entries to narrow data exclusively to effective recording times. List files by date/time and location.
2. Apply hydrophone sensitivity and digital conversion gain to digital recording units to convert to fully calibrated micropascals (μPa).
3. Apply high pass filter over 5Hz to remove the continuous components.
4. Determine start times of seismic pressure signals in digital recordings via the stored mission files by the recording unit and generate time tagged recordings.
5. Associate recording time tags to GPS fixes to georeference the recordings.
6. Calculate the instantaneous sound pressure level in dB re 1μPa.
7. Detect any Airgun pulses in the sound waveforms and specify time occupied by the central portion of the pulse, where 90% (T5% - T95%) of the pulse energy resides.
8. Calculate SPLp-p, SPLpeak, SPLrms and SEL (as defined in the following) for every detected impulse sound (associated to air-gun pulses). All sound pressure metrics are estimated with an integration time equal to the T5% - T95% of each Airgun pulse.
9. Calculate the Power Spectrum Density (PSD) for sliding time windows of 30 seconds duration throughout the sound recordings, integrated over 1Hz (*as described in paragraph 3.4.*).
10. Estimate the distance and the azimuth between "Sea Master" and SW COOK for each detected impulse sound, considering their synchronized navigational data. Use polar (θ - d) or Cartesian (x - y) coordinates to estimate relative positions of the Research/Survey Vessel "Ramform Hyperion" and the Acoustic Survey Vessel "Sea Master".

3.2. Airgun pulse detection and T_5-T_{95} estimation

Pulse detection and 90% pulse energy duration estimation was performed in an automatic manner first by applying a peak detector to the RMS smoothed signal and then by determining the 5% - 95% rise time of the cumulative squared signal (see Fig 3.1.).

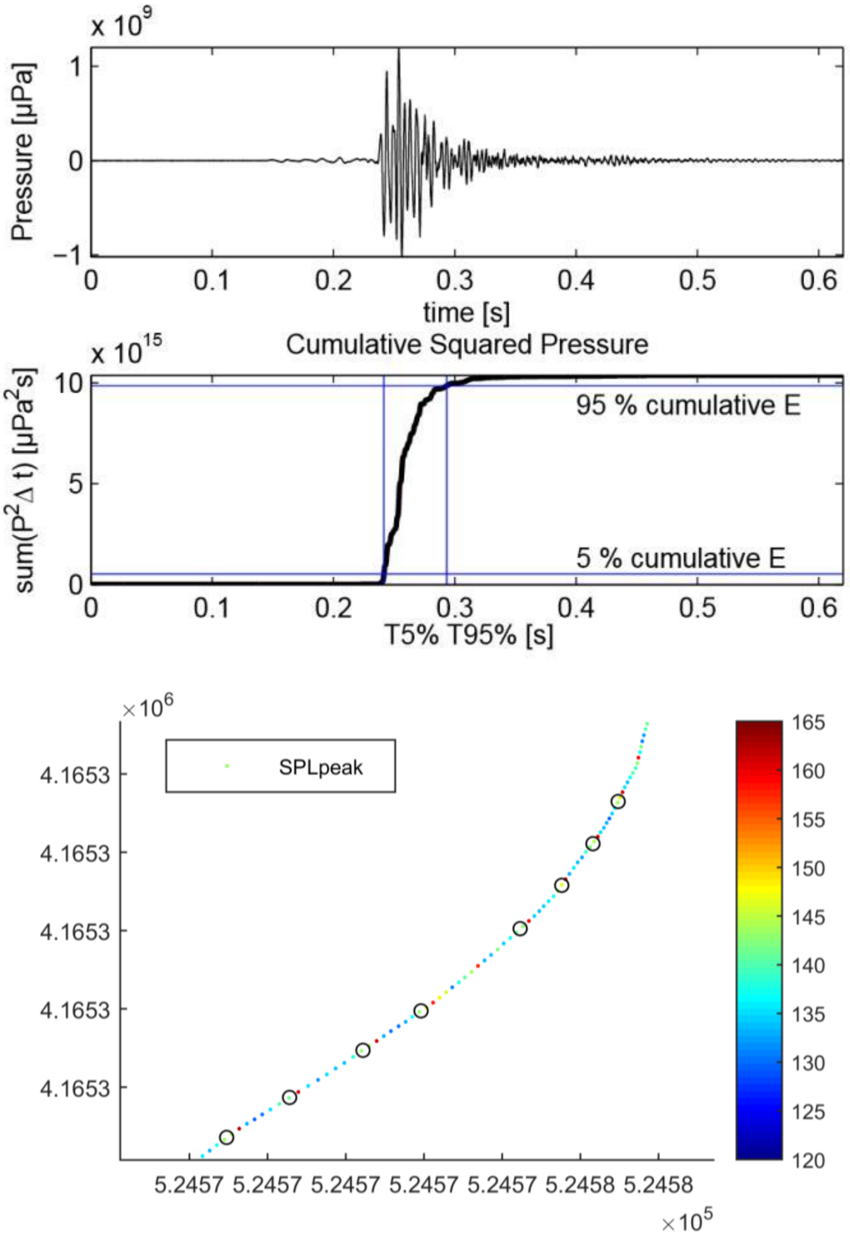

Fig. 3.1. Estimation of the 5% - 95% energy time intervals for an Airgun impulse sound through the cumulative squared pressure of the raw signal (Top Figures). SPLrms recorded on the monitoring line (colored dots) and detected impulses (circles). Colorbar corresponds to SPLrms dBre1μPa (Bottom Figure).

3.3. Sound Pressure Levels

For each second of the sound recordings the SPLp-p, SPLpeak and SPLrms metrics have been calculated while the SEL has additionally been calculated for each detected Airgun impulse sound (T5% - T95% integration time) using the follows formulas:

1. Peak to peak Sound Pressure Level (SPLp-p). The sum of the peak compressional pressure and the peak refractional pressure during a stated time interval. This quantity is typically most useful as a metric for a pulsed waveform. $\mathrm{SPL_{p-p}} = 20\log_{10}\frac{\mathrm{P_{p-p}}}{1\cdot\mu Pa}$ where P_{p-p} is the difference between the minimum and the maximum pressure in the time interval.
2. Peak sound pressure level (SPL_{peak}) is the maximum absolute amplitude value in the signal during a specified time interval: $\mathrm{SPL_{peak}} = 20\log_{10}\frac{\mathrm{P_{peak}}}{1\cdot\mu Pa}$ where Ppeak is the peak pressure and units are dB re 1 μPa.
3. Root mean square (RMS) sound pressure level (SPL_{rms}) is the log transformed square root of the average square pressure of the signal over a specific time interval: $\mathrm{SPL_{rms}} = 20\log_{10}\frac{\mathrm{P_{rms}}}{1\cdot\mu Pa}$ where Prms is the root mean square (rms) pressure and units are dB re 1 μPa.
4. Sound exposure level (SEL), is the squared sound pressure integrated over a specific duration: $\mathrm{SEL} = 10\log_{10}\left(\frac{\sum_{i=1}^{n}\mathrm{P_i^2(t)}}{1\cdot\mu Pa}\cdot\Delta t\right)$ where P is the pressure and units are dB re 1 $\mu Pa^2\cdot s$.

3.4. Power Spectrum Density

Power spectral density (PSD) is the power in the signal per unit frequency (1Hz in the present case) over the duration of the signal (30secs in the present case). The PSD was computed using Welch’s method, which divides the signal into overlapping segments that are windowed. The window function was set to be a hamming one, which is optimized to decreasing the amplitude of the side-lobes in the spectrum. Frequency components have been estimated via Fast Fourier Transform (FFT). Units are dB re 1 $\mu Pa^2/Hz$.

3.5. Approximation of relative position of the Acoustic Survey Vessel "Sea Master" around the Research/Survey Vessel "Ramform Hyperion"

In order to study the attenuation of impulse sounds around the seismic source the relative position of "Sea Master" and each emitting Airgun of "Ramform Hyperion" needs to be estimated, such as "Ramform Hyperion" is considered stationary and "Sea Master" is moving around it collecting sound level samples. An obvious solution towards the above is to estimate the polar coordinates of "Sea Master" in regard to "Ramform Hyperion" at a specified time (t1), using the heading and x, y position of "Ramform Hyperion", the distance (d) between the two vessels and the X, Y position of "Sea Master". "Ramform Hyperion's" heading can be estimated using its position at two consecutive times (t1 and t2) while the azimuth between the two vessels (θ) can easily be specified using the defined triangle between "Sea Master" and the two consecutive positions of "Ramform Hyperion".

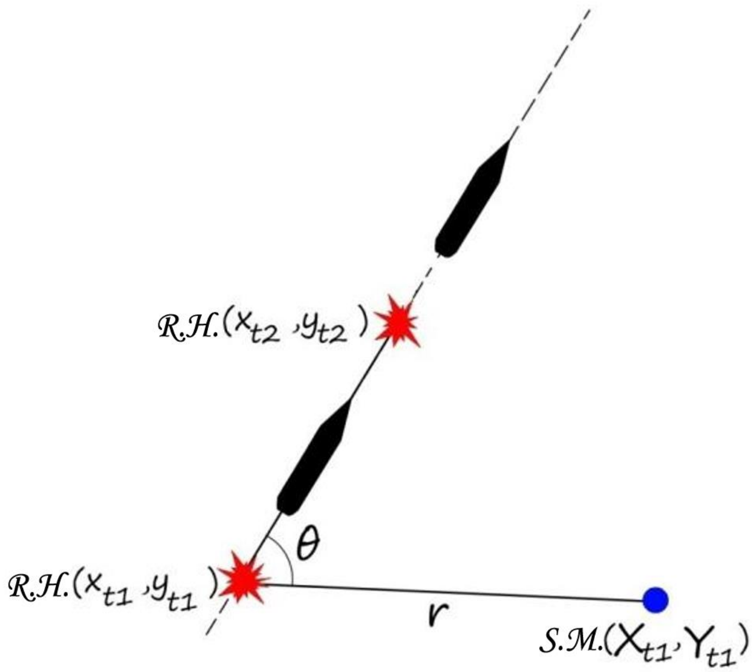

Fig. 3.2. Estimating the polar coordinates (Θ, d) for the relative position of "Sea Master" (S.M.) around "Ramform Hyperion" (R.H.) at time 1.

4. Reporting material

The main body of the reporting material involved the following visualizations for each station:

a) **Spatial representation of the sound pressure levels** of the detected seismic pulses in relation to the position of the "Ramform Hyperion" while executing the seismic lines. "Ramform Hyperion" positions were delivered on a daily basis to the sound processing team and associated to the sound recordings via UTC time. Apart from the geographic coordinates, spatial representations also included a polar grid centered on the average location of the sound recordings and extended over the maximum distance between the "Ramform Hyperion" and the "Sea Master", having radial axes with a 15 degrees angular interval.

b) **PSD plots**. The sliding 10 seconds window integrated PSDs were combined under a single graph, using their rms value and their relative occurrence densities over 1dB intervals. The frequency axis was set to logarithmic scale to enhance low frequency components. The relative density of the PSDs (one for each 10 seconds) in the frequency versus PSD Euclidean space was presented using yellow to red color-scale, with red denoting dominant frequencies, i.e. those occurring most often in time. The lower 5% and the upper 95% quartiles have also been provided.

4.1. Strofades Station

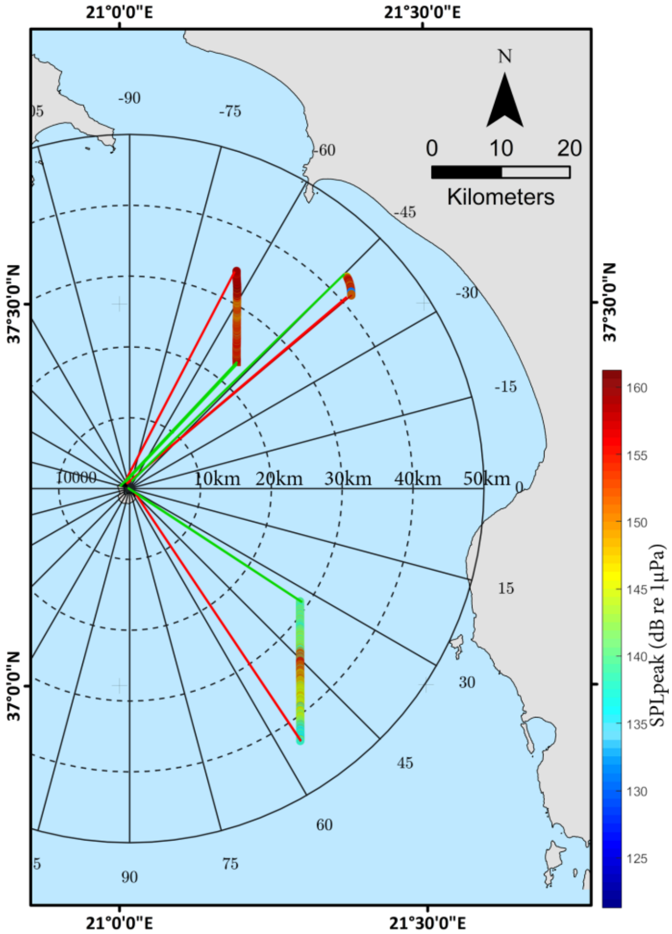

Fig. 4.1. Spatial representation of the SPLpeak of the detected seismic pulses in Strofades station, with regard to the position of the "Ramform Hyperion" while executing seismic lines.

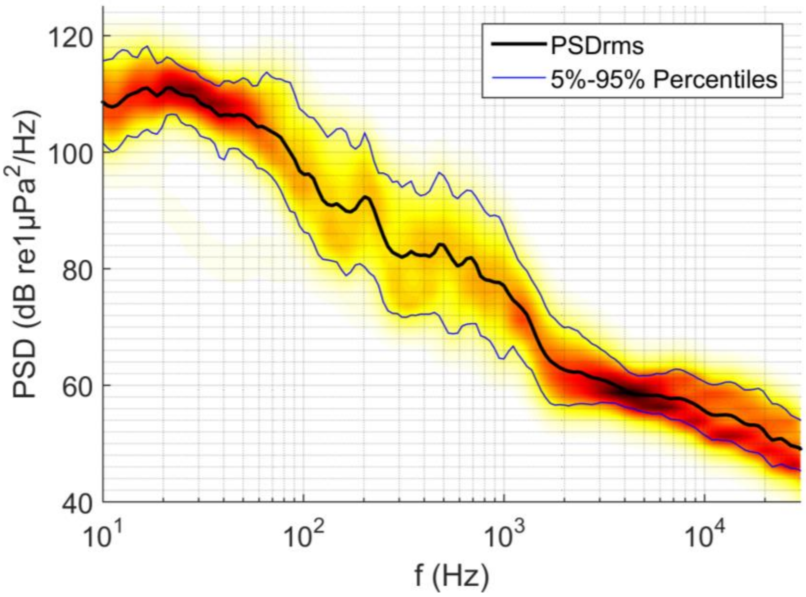

Fig. 4.2. Aggregated 10 sec PSDs concerning Strofades station

4.2. Zakynthos Station

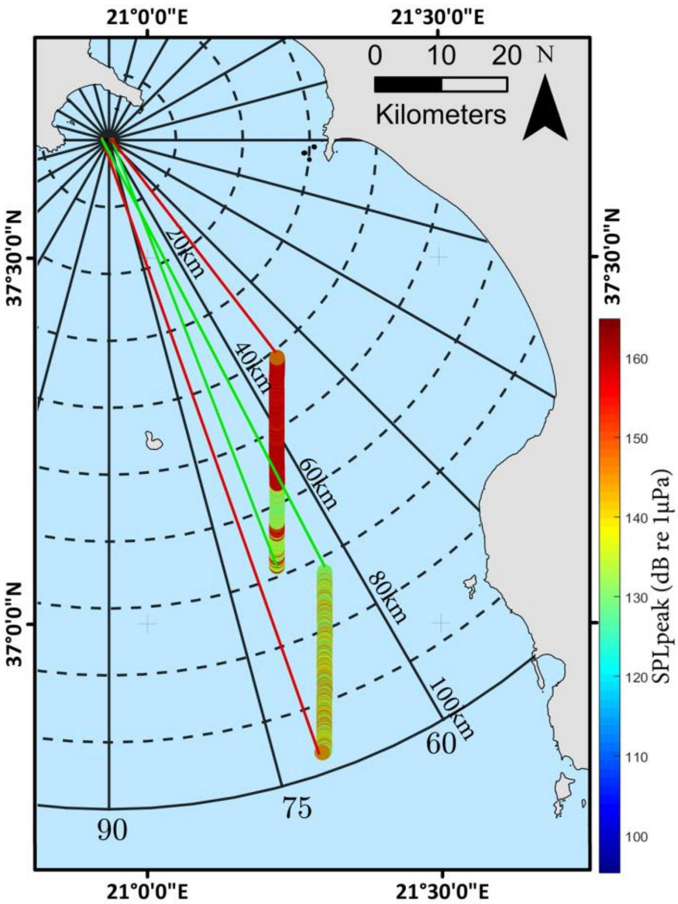

Fig. 4.3. Spatial representation of the SPLpeak of the detected seismic pulses in Zakynthos station, with regard to the position of the "Ramform Hyperion" while executing seismic lines.

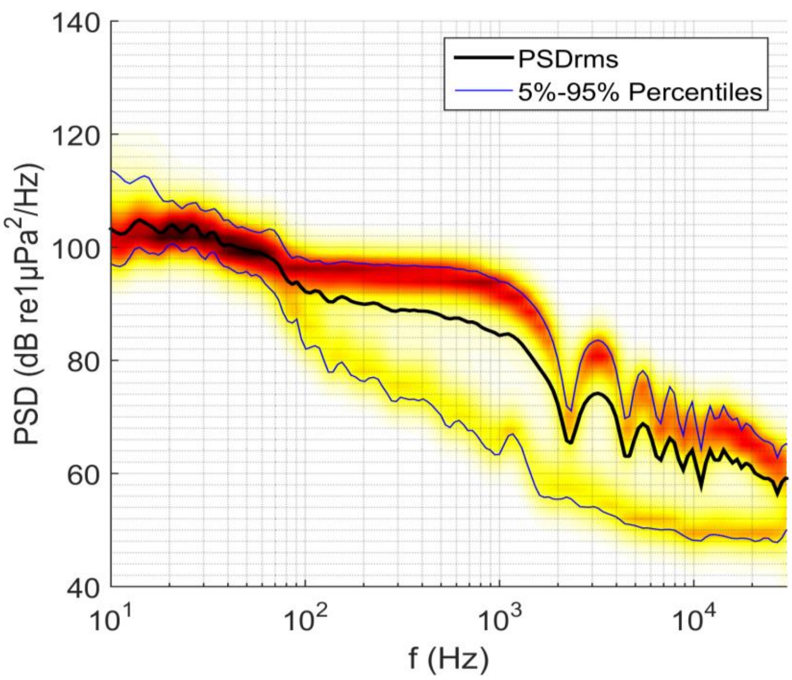

Fig. 4.4. Aggregated 10 sec PSDs concerning Zakynthos station.

4.3. Katakolo Station

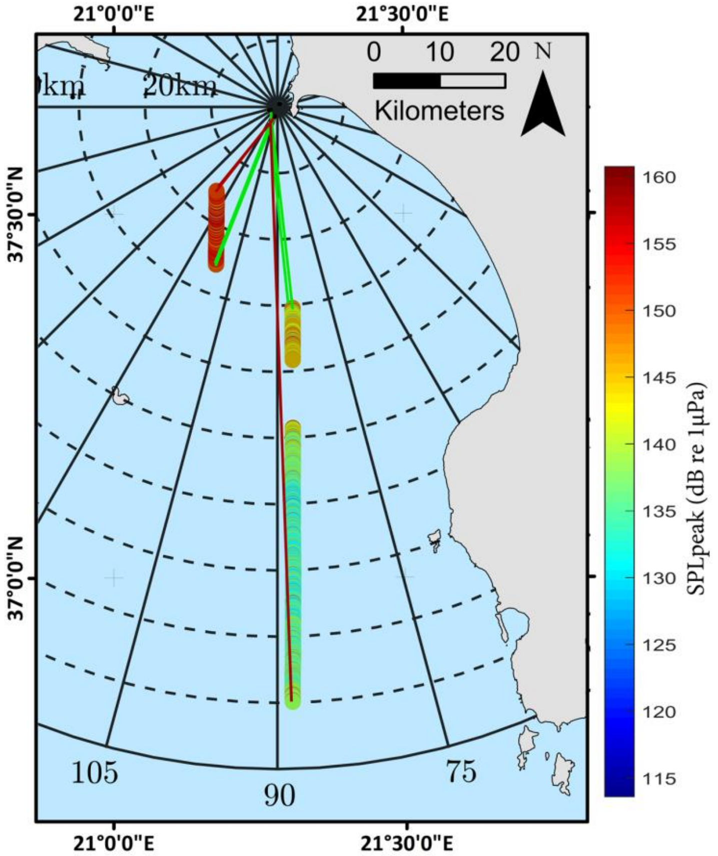

Fig. 4.5. Spatial representation of the SPLpeak of the detected seismic pulses in Katakolo station, with regard to the position of the “Ramform Hyperion” while executing seismic lines.

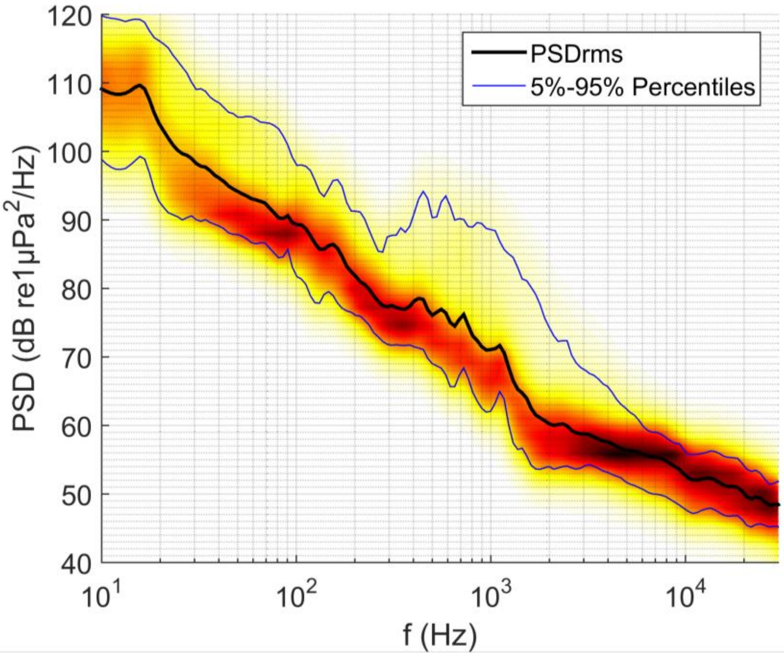

Fig. 4.6. Aggregated 10 sec PSDs concerning Katakolo station.

4.4. Marathopoli Station

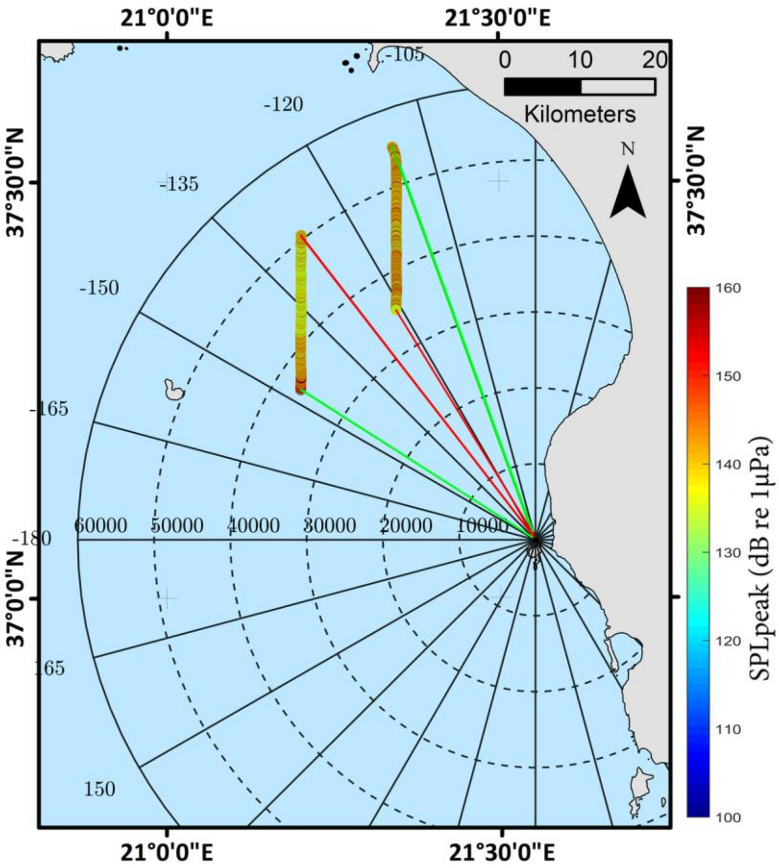

Fig. 4.7. Spatial representation of the SPLpeak of the detected seismic pulses in Marathopoli station, with regard to the position of the "Ramform Hyperion" while executing seismic lines.

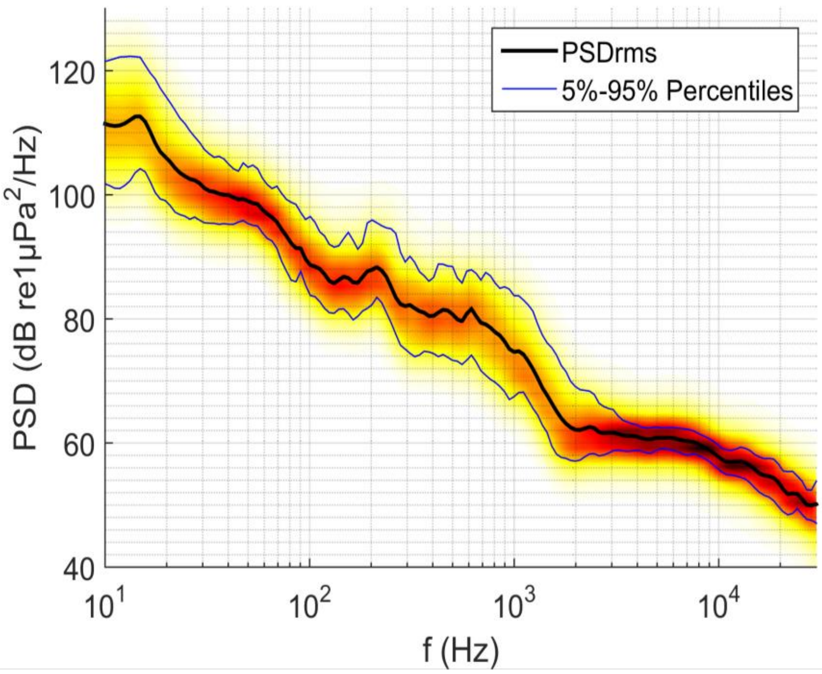

Fig. 4.8. Aggregated 10 sec PSDs concerning Marathopoli station.

4.5. Methoni Station

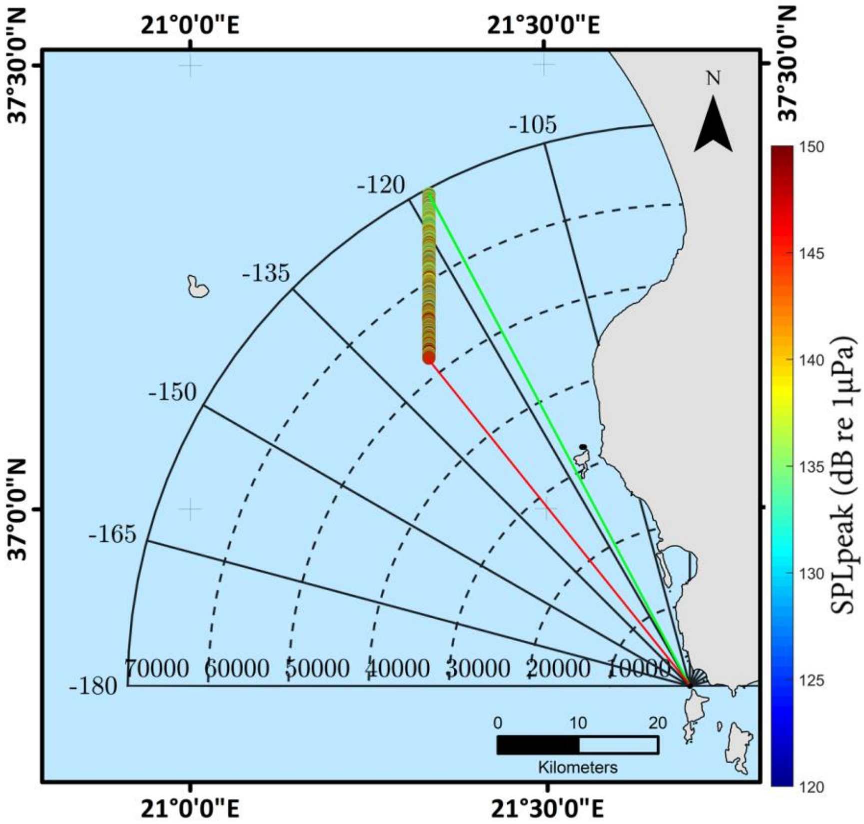

Fig. 4.9. Spatial representation of the SPLpeak of the detected seismic pulses in Methoni station, with regard to the position of the “Ramform Hyperion”, executing seismic lines.

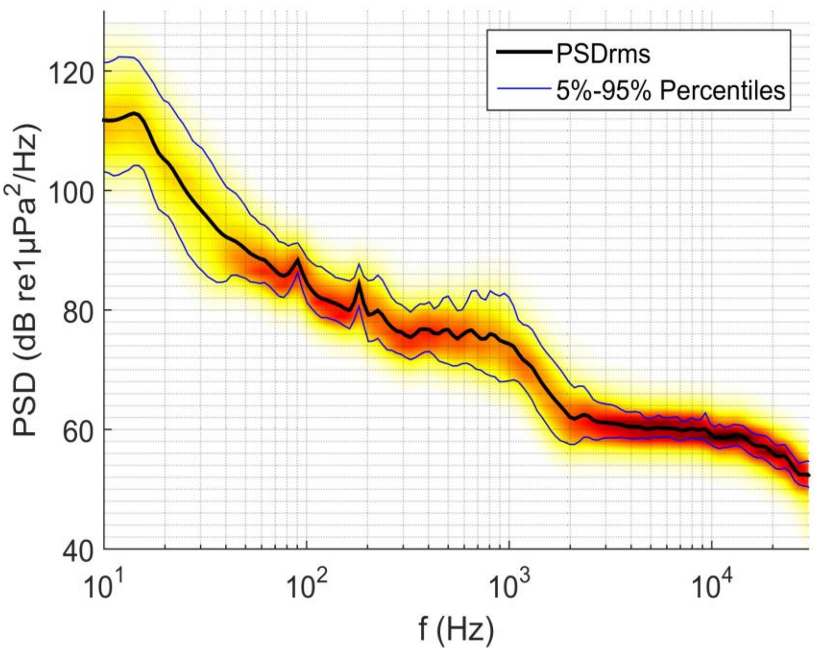

Fig. 4.10. Aggregated 10 sec PSDs concerning Methoni station.

4.6. Seismic noise VS distance to the source

SPLp-p received levels of the detected seismic pulses versus the distance between "Ramform Hyperion" and the sound recording are given either in logarithmic (Figure 4.11) or linear (Figure 4.12) distance axis format. The data acquired during the exclusion zone verification were included in the diagrams to input estimations for the close ranges to the seismic source. A logarithmic fit has been applied to the data while its upper 90% confidence interval has been drawn to exploit the trend of the maximum received levels over distance. The maximum seismic noise presents a sharp decrease from 255 dB to 168 dB in shorter distance than 5km from the source while it gradually decreases to below 140 dB further than 90 km away.

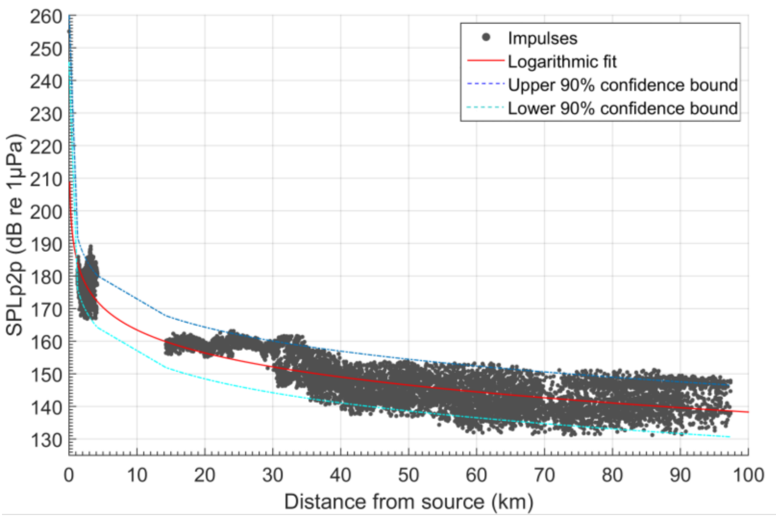

Fig. 4.11.
The peak-to-peak SPL (SPLp2p) of each detected airgun impulses versus the linear distance to the seismic source, recorded during the seismic monitoring and exclusion zone verification phases of the project, superimposed by a logarithmic fit and its upper and lower 90% confidence intervals.

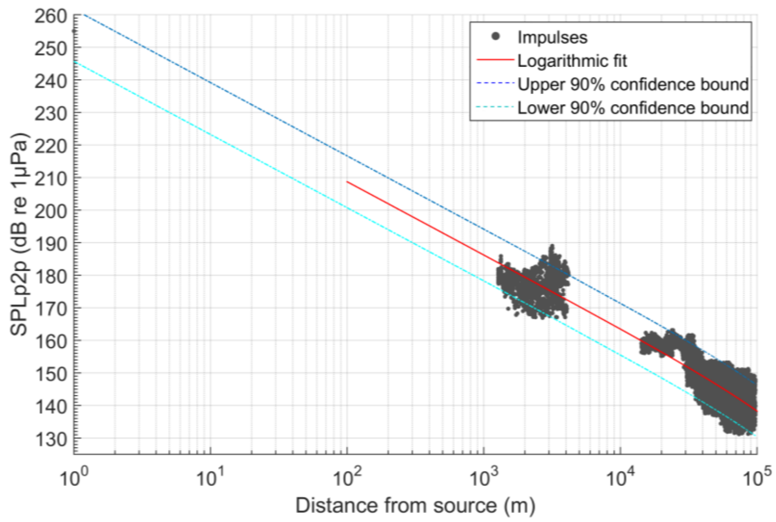

Fig. 4.12.
The peak-to-peak SPL (SPLp2p) of each detected airgun impulses versus the logarithmic distance to the seismic source, recorded during the seismic monitoring and exclusion zone verification phases of the project, superimposed by a logarithmic fit and its upper and lower 90% confidence intervals.

5. REFERENCES

Fakiris, E, Christodoulou, D, Georgiou, N, Dimas, X, Papatheodorou, G, Blondel, P, Mikionatis, G, Zafiropoulos, G and Symeonidis, F 2019, 'he soundscape of the Inner Ionian Archipelago as evinced through the West Patraikos Gulf Ambient and Seismic Noise Monitoring Project', Paper presented at Underwater Acoustics Conference and Exhibition UACE-2019, Hersonissos, Greece, 8/07/19 - 12/07/19 pp. 3151-3158.