# Hellenic Petroleum Exploration & Production of Hydrocarbons SA

# IONIAN GULF ACOUSTIC MONITORING PROJECT

## ITEM 2
## "Verification of the exclusion zone"

Technical Report

**OCEANUS LAB**

**(Laboratory of Marine Geology & Physical Oceanography)**

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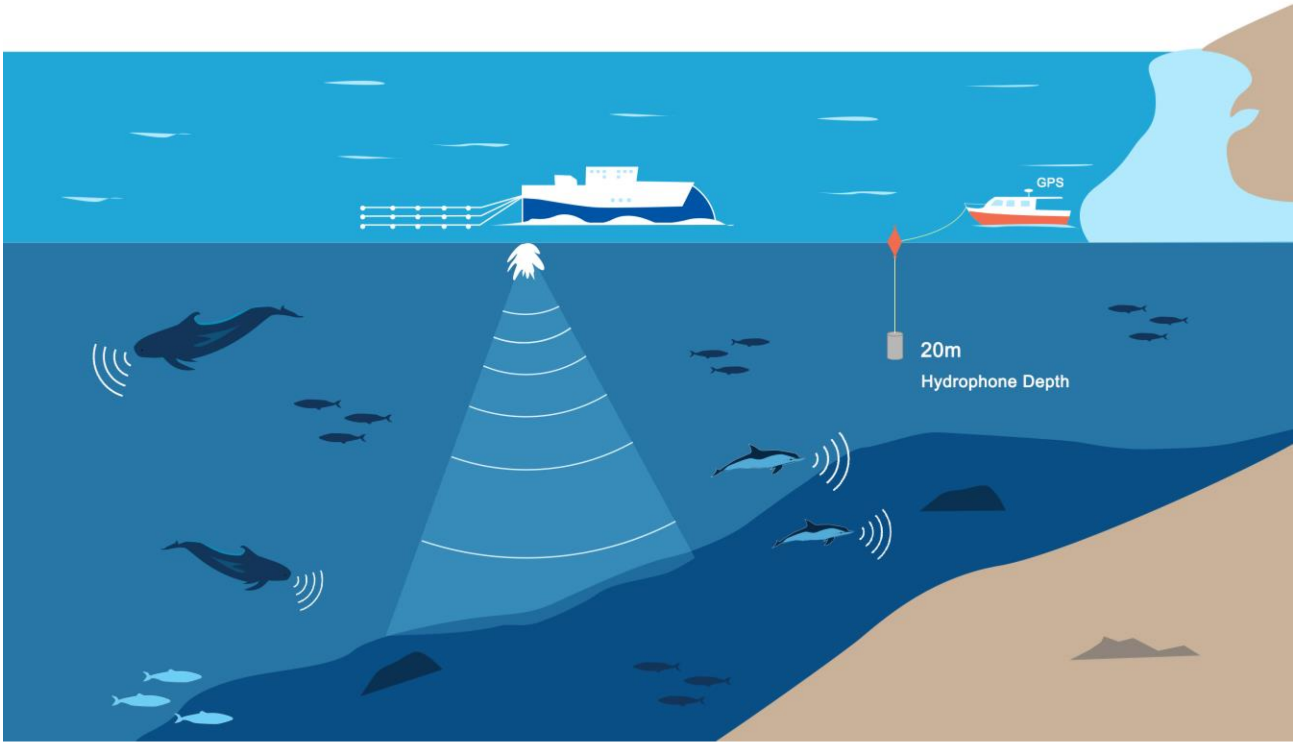

# 1. Introduction

The present report describes the data collection, data processing methods and the results of the ITEM 2 "Verification of exclusion zone" regarding the Ionian Gulf Acoustic Monitoring Project. The aim of the ITEM2 project survey is to monitor the propagation and attenuation rate of the impulse sounds around the seismic source (Airgun arrays) in order to validate the geometry of the predefined exclusion zone.

The Ionian 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.

Results presented in this report refer to acoustic data collected during December 12th of 2022.

# 2. Data acquisition

“Sea Master” vessel stood in positions agreed with the “Ramform Hyperion” navigation team, deploying the sound recorder at 20m depth, at distances no less than 900m from the seismic source (air-guns) and while “Ramform Hyperion” executed its prearranged survey lines. Pictures from the fieldwork survey are presented in Figure 2.1. Attention has been paid so that sound measurements were obtained from both the forward and broadside directions relative to the fore-aft axis of the seismic source. Each recording station lasted for about 30-40 minutes intended to acquire sound pressure levels regarding more than 3km distance both fore and aft sides of the seismic vessel. Due to harsh weather conditions and time constrains, only the port side of the seismic source has been monitored. The vessel’s engines were set on for retaining the desired position as well as for safety reasons. Figure 2.2 shows the positions where sound level recordings took place with respect to the seismic lines.

The navigational data of “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.

Fig. 2.1. Selected pictures from the field work survey during ITEM 2 phase.

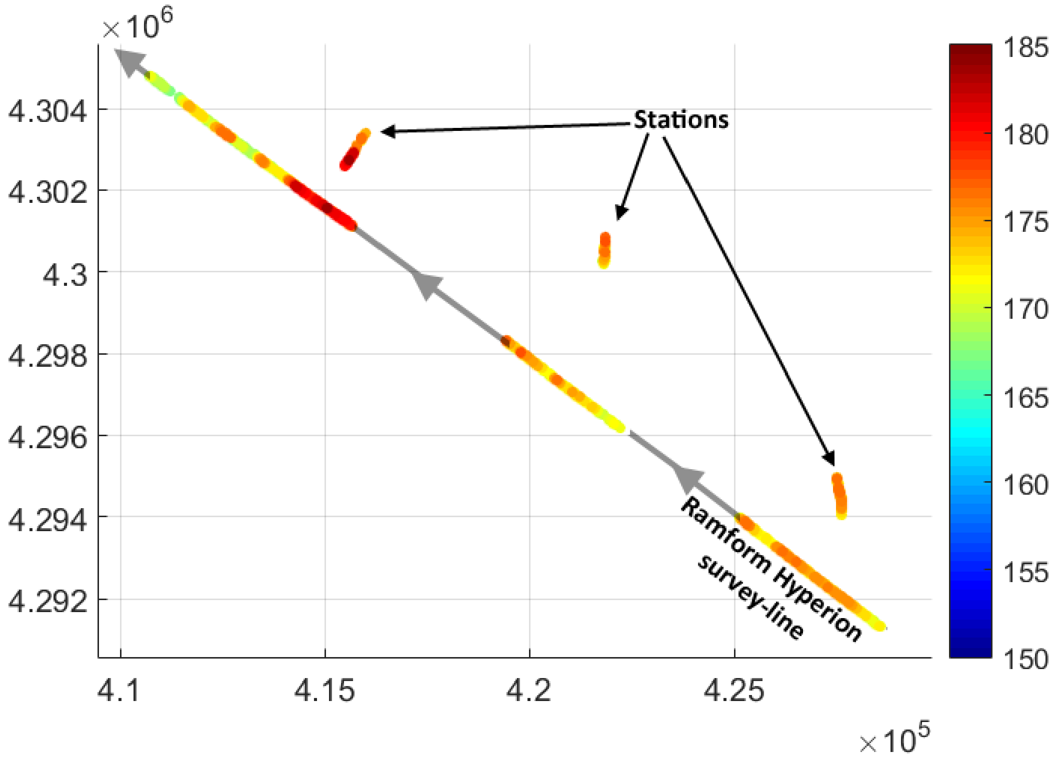


Fig. 2.2. The "Sea Master" stations and the relative seismic line of "Ramform Hyperion" that have been monitored for seismic impulse noise on December 12$^{th}$, 2022. Here SPLp2p is illustrated and georeferenced in regard to both the seismic survey line and the monitoring stations. **Coordinates in UTM 34N.*

# 3. Data Processing Methodology

The objective of ITEM 2 is to measure impulse sound pressure levels around the seismic source (Airguns) in order to record and study the seismic noise attenuation levels and validate specified mitigation zones. 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 sound 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. Estimate the distance and the azimuth between "Sea Master" and "Ramform Hyperion" for each detected impulse sound, considering their synchronized navigational data. Use polar ($\theta$ - $d$) or Cartesian (x - y) coordinates to estimate relative positions of "Ramform Hyperion" and "Sea Master".

## 3.1. Airgun pulse detection and $T_5$-$T_{95}$ estimation

Impulse sound detection and 90% impulse energy duration estimation was performed in an automatic manner first by applying a peak detector to the RMS smoothed sound waveform and then by determining the 5% - 95% rise time of the cumulative of the squared signal (see fig 3.1.) around each detected impulse sound.

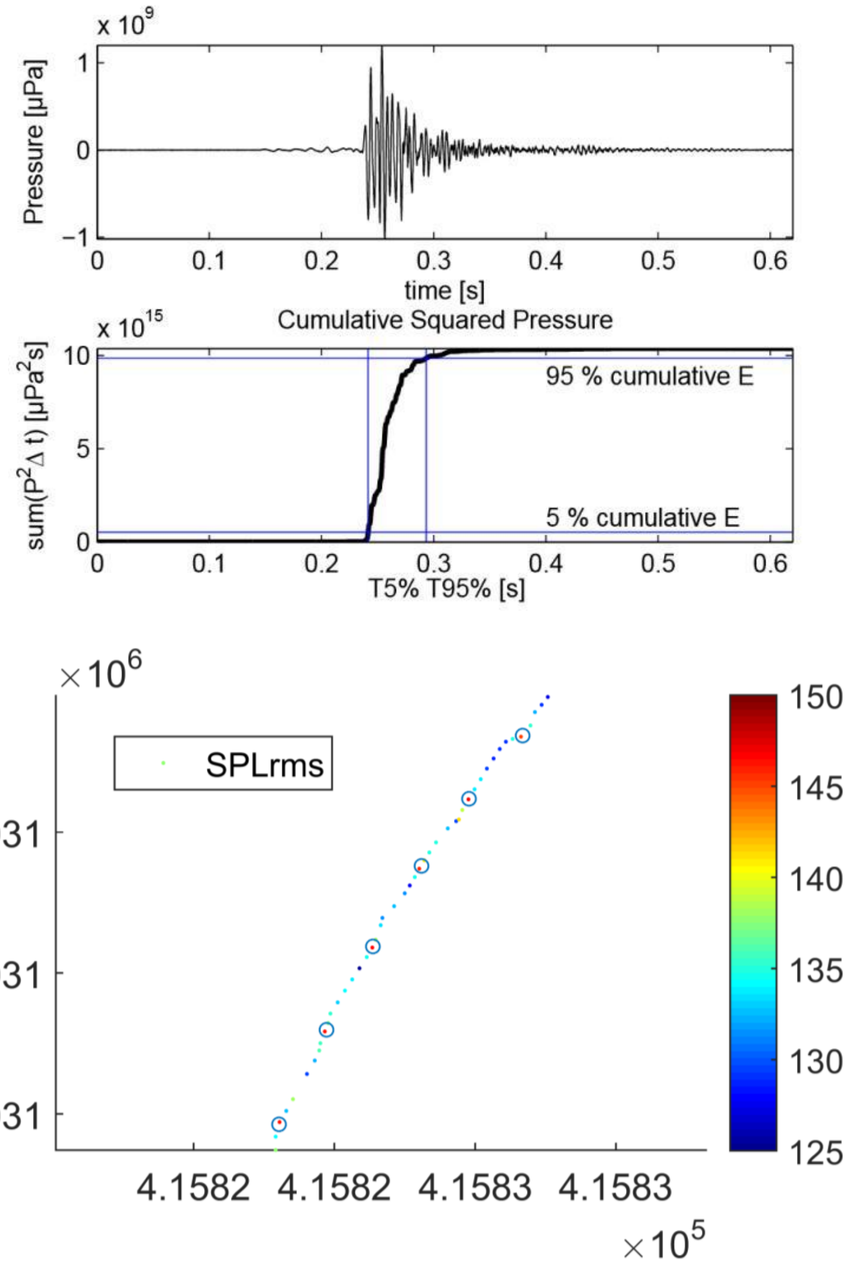


Fig. 3.1. Estimation of the 5% - 95% energy time intervals for an Airgun impulse sound through the cumulative squared pressure of the raw signal (Top Figures). SPLrms recorded on the monitoring line (colored dots) and detected impulses (circles). Colorbar corresponds to SPLrms dBre1μPa (Bottom Figure).

### 3.2. Sound Pressure Levels

For each Airgun impulse sound, and considering a T5% - T95% time duration, the following parameters have been calculated:

1. Peak to peak Sound Pressure Level (SPLp-p). The sum of the peak compressional pressure and the peak refractional pressure during the T5% - T95% 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 $P_{p\text{-}p}$ 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 the specified time interval:

   $$\mathrm{SPL_{peak}} = 20\log_{10}\frac{\mathrm{P_{peak}}}{1\cdot\mu Pa}$$

   where $P_{peak}$ 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 the specific time interval:

   $$\mathrm{SPL_{rms}} = 20\log_{10}\frac{\mathrm{P_{rms}}}{1\cdot\mu Pa}$$

   where $P_{rms}$ 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 the specific duration:

   $$\mathrm{SEL} = 10\log_{10}\left(\frac{\sum_{i=1}^{n}\mathrm{P_i^2}\,(\mathrm{t})}{1\cdot\mu Pa}\cdot\Delta t\right)$$

   where P is the pressure and units are dB re 1 $\mu Pa^2 \cdot s$.

### 3.3. Approximation of relative position of "Sea Master" around "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 ($\theta$) can easily be specified using the defined triangle between "Sea Master" and the two consecutive positions of "Ramform Hyperion".

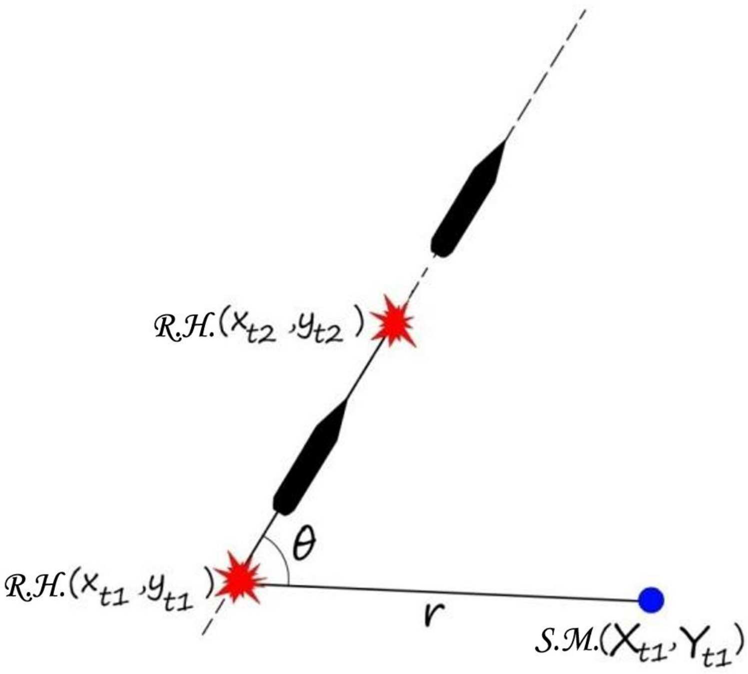


Fig. 3.2. Estimating the polar coordinates ($\Theta$, d) for the relative position of Sea Master (S.M.) around "Ramform Hyperion" (R.H.) at time 1.

# 4. Results

## 4.1. Relative position of “Sea Master” around “Ramform Hyperion”

Figure 4.1. presents the relative positions of “Sea Master” around “Ramform Hyperion” during all effective recordings on December 12th 2022. Relative coordinates between the two vessels are represented in polar fashion to illustrate the SPL levels eith regard to the along and across track axes, centered to the seismic source.

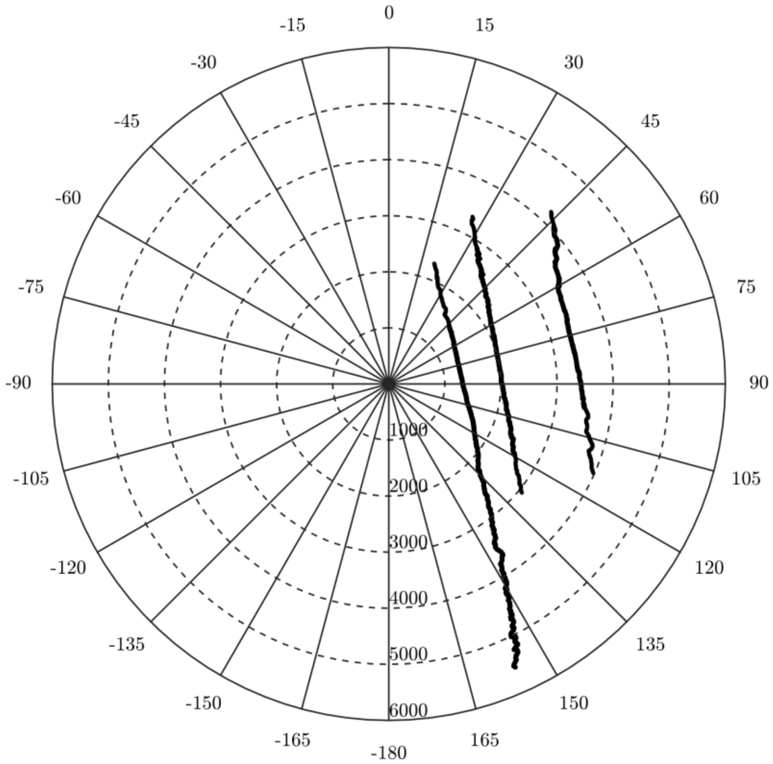


Fig. 4.1. The relative positions of “Sea Master” around the sound emitting Airgun during all effective recordings on December 12th 2022, using polar coordinates.

A total number of 3 effective stations has been realized, having relative distances to the “Ramform Hyperion” from -5500 to +3000m (negative values indicate the sound recorder being on the aft side of “Ramform Hyperion”) in the along-track direction and from +1200 to +3300m in the across-track direction. Due to safety reasons, recordings have been obtained at least 1200m away from any side of the seismic source in the across-track direction.

## 4.3. Reporting results

Figure 4.2. shows an example of the recorded SPLpeak around the seismic vessel, where the impulse sounds are clear (peaks) reaching around 180-182 dBre1μPa. Figure 4.3. shows a representative PSD spectrogram of the recorded impulse sound data. Figure 4.5, presents the SPLpeak in polar coordinates around “Ramform Hyperion”, including SPL values modelled via a quadratic fit. It should be noted that monitoring data were acquired only in regard to the port side of the seismic vessel and so the starboard side was considered to receive equal values, catoptric in the Y-axis.

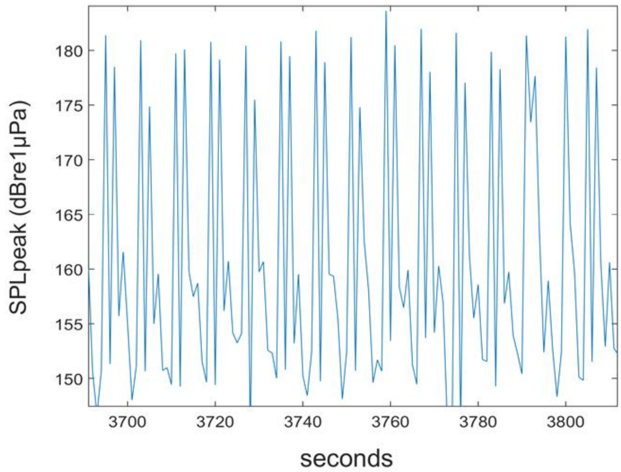


Fig. 4.2. An example of the recorded SPLp-p around the seismic vessel.

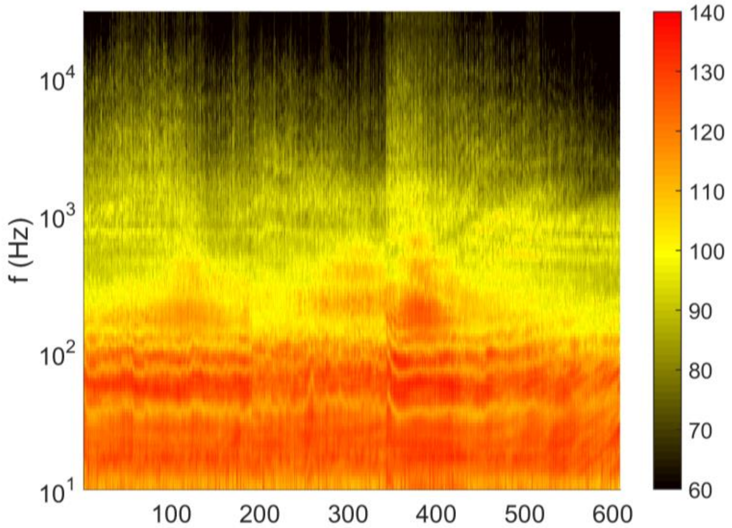


Fig. 4.3. A representative PSD spectrogram of the recorded sound data around the seismic vessel. **Colorbar units: dB re 1μP$^2$/Hz. Y-axis represents 10sec integrations.*

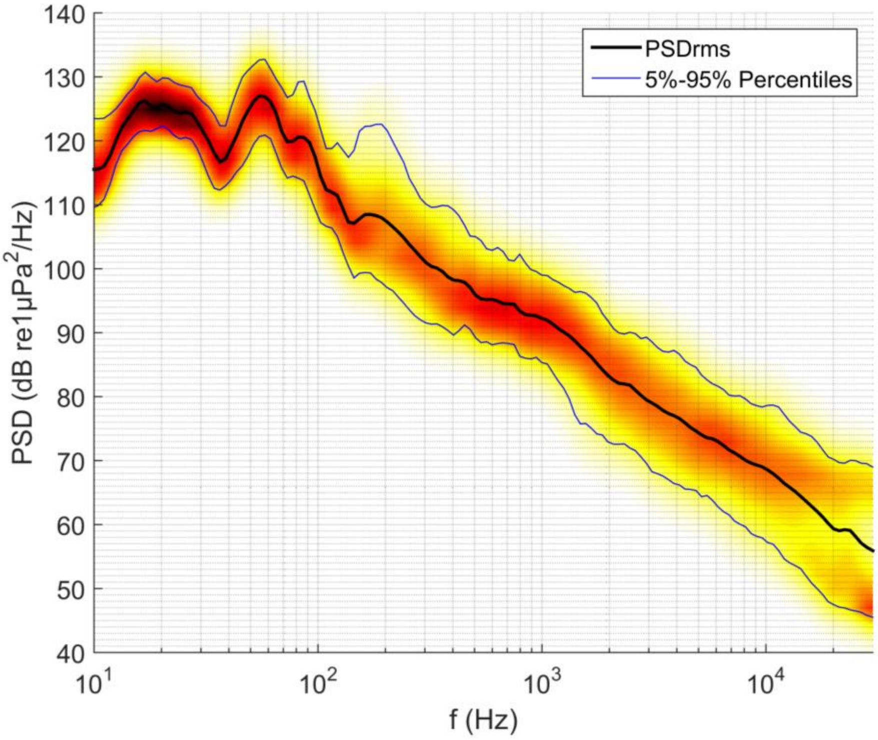


Fig. 4.4. Aggregated 10 sec PSDs concerning the full exclusion zone sound recording dataset.

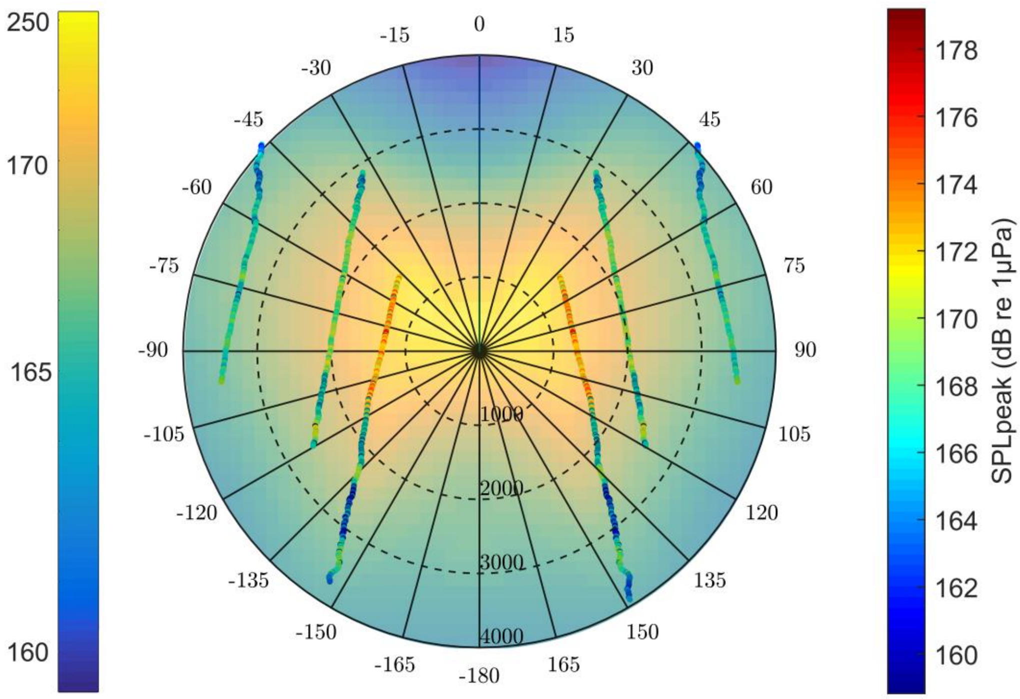


Fig. 4.5. Spatial distribution of estimated SPLpeak around the seismic source, integrated for each single $T_5$-$T_{95}$ impulse sound duration (background color-scale is modelled).

In 2002, the U.S. National Marine Fisheries Service (NMFS) Ocean Acoustics Program assembled a panel of scientists to address the challenging task of auditory hazards in marine mammals. They reviewed all available information and developed methods to evaluate and quantify noise exposure levels for different anthropogenic sources expected to cause (1) behavioral responses of varying severity and (2) reductions in auditory sensitivity changes, including both temporary threshold shifts (TTS) and permanent threshold shifts (PTS). This resulted in the auditory exposure criteria described in Southall et al. (2019). Of all the criteria specified within this document, the worst-case scenario drawn is for very high-frequency cetaceans, including dolphins and physeters, that may experience temporary auditory effects over 196 dB re 1μPa. Figure 4.10 shows the comparison of these limits to the average and maximum expected SPL at the limits of the exclusion zone, making clear that they are well below the specified risk levels.

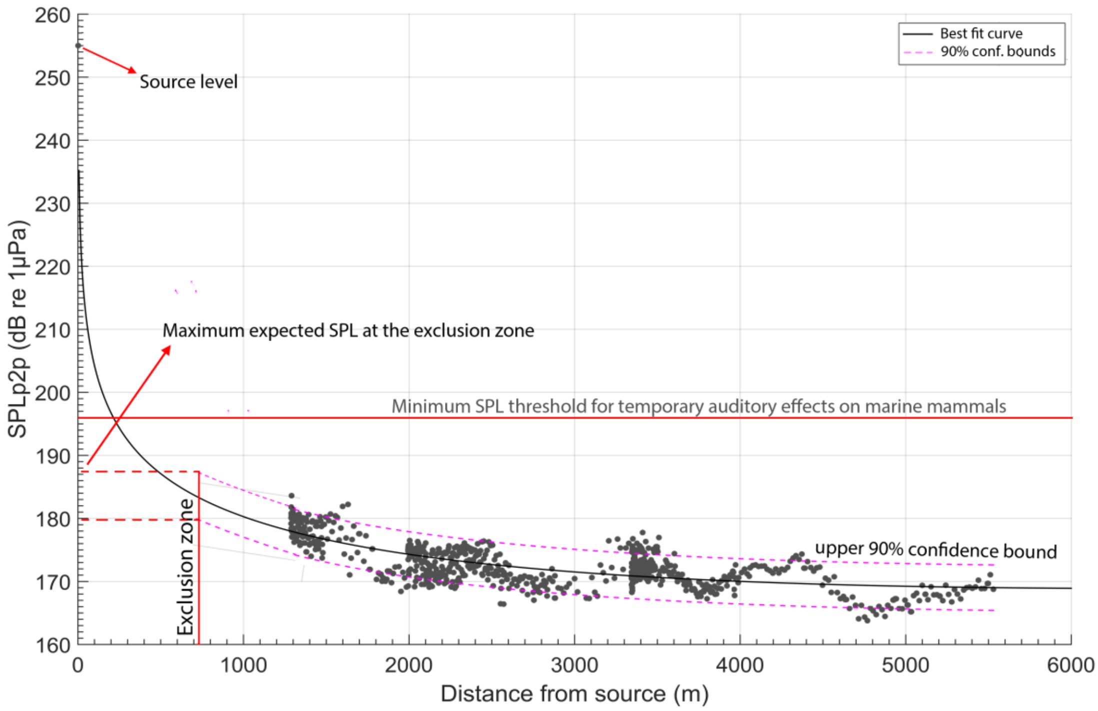


Fig. 4.10 The peak-to-peak SPL (SPLp-p) of each detected airgun impulse sound versus the absolute distance to the seismic source. The average and maximum expected SPL at the limits of the exclusion zone are compared to the minimum SPL threshold for temporary auditory effects on dolphins and physiters, as reviewed in Southall et al. (2019).