# Anthropogenic noise prediction for light seismic surveys off the SW coast of Portugal

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***Abstract*—Marine seismic sources use extremely powerful sound pulses to penetrate the ocean bottom, which in consequence may be harmful for numerous marine species in the surrounding area. During the last decade the Portuguese Government has granted rights for oil and gas exploration in several offshore slots along the SW coast. In contrast to what happens in deep water seismic surveying, which is well studied and described, shallow water surveying effects, that usually rely on light seismic techniques, are under-investigated. Numerous cetaceans sightings along that coast denote a rich ecosystem, which may be subject to marine life harmful noise levels resulting from light seismic techniques and which may have acute, cumulative and chronic effects on marine organisms. The results suggest that there is an important contribution of the bathymetry transition from offshore to inshore for the propagation of the noise resulting from seismic sources. Indeed, it was observed that the continental platform works as a natural barrier precluding the sound resulting from offshore sources (located at more than 50km from the shore) to propagate towards land. It was also shown that sound level of sources located near the shore attenuate more rapidly than those offshore, even though high sound exposure levels may be reached due to shore proximity.**

***Index Terms*—Marine light seismic surveys, sparker sources, noise prediction, Portuguese SW coast.**

## INTRODUCTION

During the last decade, the Portuguese Government has granted rights for oil and gas exploration in several offshore slots along the SW coast, between Sagres and Sines [1], [2]. Although the "under-exploited", the hydrocarbon potential of this area has attracted attention of the petroleum industry [3], [4]. Preliminary seismic surveying was initially scheduled for the second half of 2018 to detect and estimate the size of potential sub-bottom deposits [3]. Even if seismic exploration may take place in both deep ocean, across the continental slopes and along the shallow continental platforms, the effects of the latter are less studied [5]–[7]. Shallow water up to, say, 100 m depth usually requires relatively light seismic surveying apparatus, that is both less expensive and more maneuverable. Light seismic surveying aims at high resolution layering estimation in the first tens of meters or more into the bottom, for pipeline laying and sub-bottom structure anchoring. Such light surveys may include one or more sparker-type seismic sources. Due to their relatively simple operating principle and cost, they are widely used in seismic surveying, combining seismic sources with an horizontal hydrophone array towed by a single ship, emitting loud broadband acoustic probes (usually in the band 100–2500 Hz) [8], [9].

Several authors indicate that there are reasons for concern about the adverse impact of seismic source surveying on numerous marine species, including habitat displacement, disruption of biologically important behavior, masking of communication signals, chronic stress, and in extreme cases the potential auditory damage or even death [10]–[13].

It is known that the Portuguese coastline is an important spot in terms of cetacean biodiversity. Throughout the years, an important number of cetaceans sightings has been registered in this region of the Atlantic, specially common dolphins (*Delphinus delphis*) [14]–[17]. Fig. 1 shows the common dolphin distribution along the Portuguese SW coast numerically modelled using species sightings from SPEA, OBIS seamaps SeaEO Tours company and iNaturalist databases and data from Copernicus, Emodnet and NOAA for the environmental layers. The results were obtained through maximum entropy models (MaxEnt software [18]), with a 1km x 1km resolution in the framework of the JONAS project (*www.jonasproject.eu*).

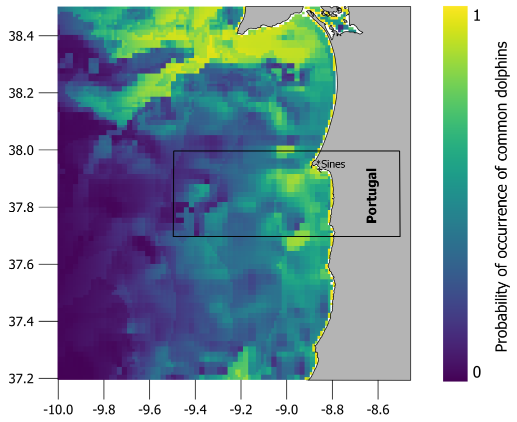


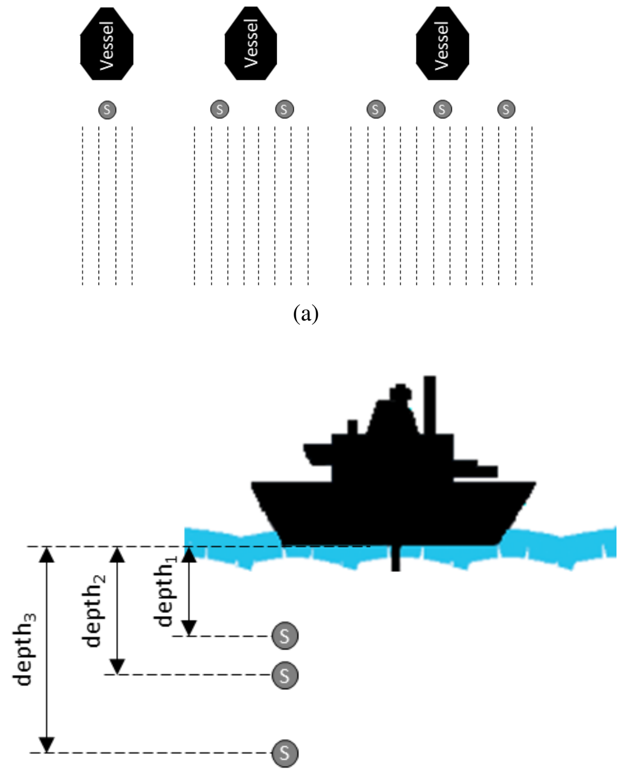
Fig. 1: Common dolphin distribution along the Portuguese SW coast modelled in the framework of JONAS project.

Although the common dolphin may be found anywhere in the whole water column, the majority of their time is spent close to the surface, specially due to their feeding behaviour, which primarily occurs between 20 and 30 m depth [19].

The impact of highly energetic acoustic signals, as those generated for seismic surveying, on the regularly sighted cetaceans and other marine species, common along the Portuguese coast, is actually not well known. The objective of the present work is to determine the anthropogenic noise distribution resulting from light seismic surveys potentially under operation in this area, considering various positions in shallow and deep water, as well as various source depths, ultimately leading to endangered species risk estimation.

## MATERIALS AND METHODS

The most common approach in marine seismic acquisition is to use a single vessel towing a number of streamers and one, two or three sources (Fig. 2a). Since the streamer-source configuration determines the data quality, it is usually used a single or a dual source setup usually submerged at depths between 0.3 and 1 m, depending on the geophysical and geological objectives (Fig. 2b).



(a)

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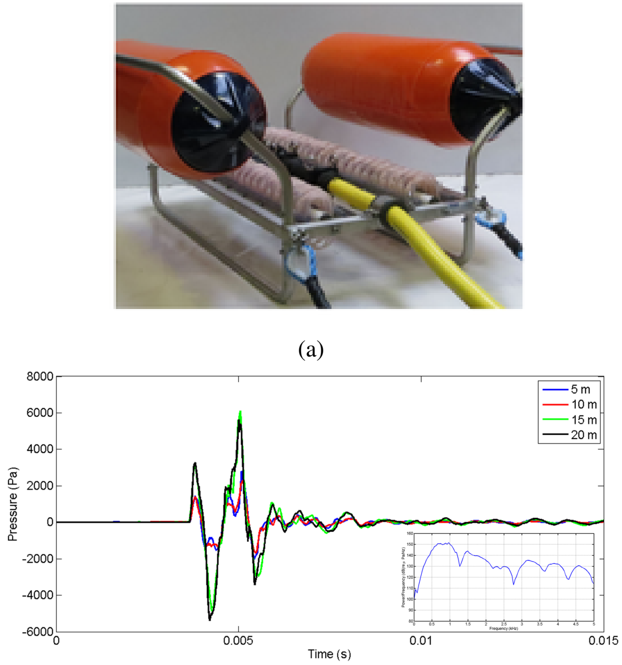
Fig. 2: Common source configurations (a) and source depths (depth$_1$=0.3m, depth$_2$=0.5m, depth$_3$=1m) (b).

The tested acoustic source used as reference for seismic survey modelling was a GEO-Source 200 sparker[1] shown in Fig. 3a with two arrays of 100 electrode tips each and reaching a peak sound pressure level (SPL) of 223 dB for 1000 Joule. The signature plot and its spectrum at low power of 300 Joule, recorded 15 m away is shown in Fig. 3b where significant energy can be seen to reach 3-5 kHz. Based on the manufacturer indications, this type of source allows for a penetration up to 200-300m below the seabed (depending on bottom type), with a vertical resolution up to 0.2-0.3 m and is especially suited to be used up to 500 m water depth.



(a)

(b)

Fig. 3: Sparker test data acquired during the WiMUST 2017 sea trial in Sines (Portugal): sparker Geo-Source 200 (a) and pulse signature and power spectrum at 300 J (b).

### A. *Environment variables*

The bathymetric data of Portuguese SW coast was obtained from the General Bathymetric Chart of Oceans (GEBCO) (*www.gebco.net*). The GEBCO 2019 Grid Version was used with 15 arc-second interval generated by the assimilation of heterogeneous data, all referred to mean sea level [20].

Figure 4 shows a bathymetric longitudinal slice near the town of Sines approximately at mid-latitude of the target area. An almost flat continental platform extends up to approximately 30 km from the coastline, where the water depth reaches 200 m. The maximum operating depth of the sparker seismic source (500 m) is reached at approximately 50 km off the coast.

### B. *Sound Speed Profile*

The sound speed profile (SSP) dependency on temperature, salinity and depth allows for time and space variability, specially along the vertical depth axis [21]. The water-column was parameterized based on temperature and salinity models provided by the Copernicus database (*www.copernicus.eu*),

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[1] developed by GEO Marine Survey Systems b.v., The Netherlands

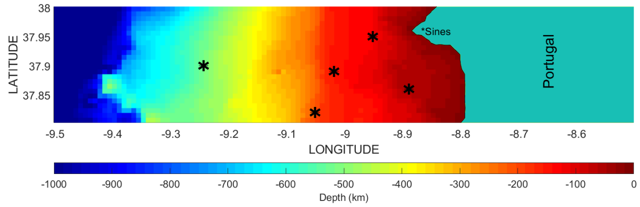

Fig. 4: Target area bathymetry and seismic sources location.

from which sound speed was calculated with the approximated Mackenzie [22] nine-term equation. To illustrate water column variability it was considered the SSP mean values for the month of July 2019. As an example Fig. 5a shows the sound speed lat-lon variation for the target area close to the surface, and along depth for various water depths at fixed latitude (37.86º) in Fig. 5b.

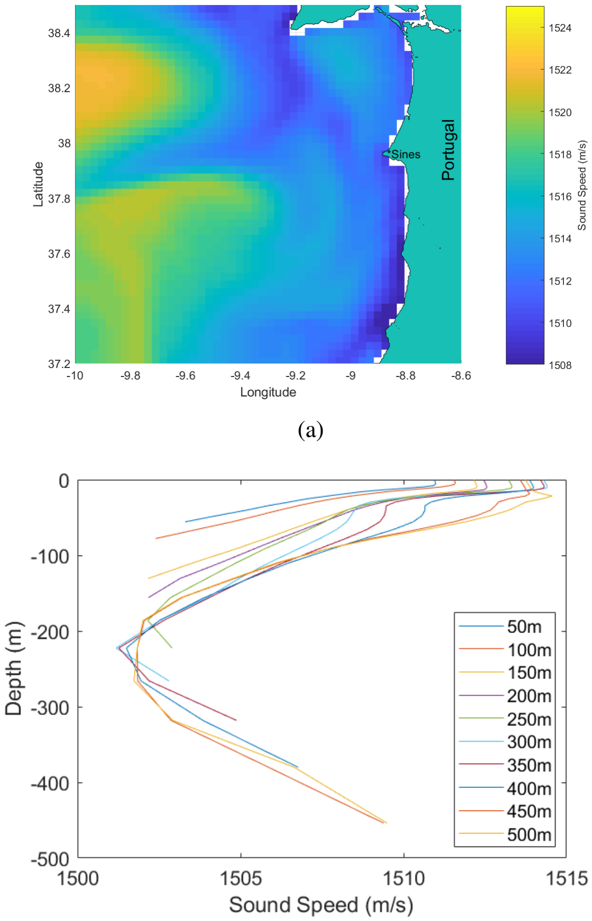

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Fig. 5: Sound speed for the 20th of July 2019: superficial layer (a), fixed latitude (37.86º) profiles at various water depths (b).

## *C. Bottom properties*

Accurately describing seabed properties is a great challenge. Very often either there is no available information on the sub-bottom structure or that information is only descriptive for the bottom surface and geological history, for the materials and fractures in the sub-bottom. Another difficulty is that the bottom composition may vary from one location to another and, consequently, many studies refer the usage of a generic bottom description, considering a two layer bottom, composed of a fluid sandy sediment layer over a rocky infinite sub-bottom for that area as shown in table I [21], [23].

TABLE I: Seabed parameters

| Model Parameter (units) | Value |
|---|---|
| Sediment speed (m/s) | 1650 |
| Sediment density (g/cm$^3$) | 1.9 |
| Sediment attenuation (dB/$\lambda$) | 0.8 |
| Sediment thickness (m) | 10 |
| Sub-bottom speed (m/s) | 1800 |
| Sub-bottom density (g/cm$^3$) | 1.9 |
| Sub-bottom attenuation (dB/$\lambda$) | 0.2 |

## *D. Sound field calculation*

Noise distribution was predicted using the pulse data of the sparker source described above and the corresponding sound field calculated in two separate steps. First the estimation of acoustic transmission loss and second converting the range-azimuth discs to latitude, longitude and depth and their sum at a given time to obtain the actual SPL in the area. The first step uses the normal mode propagation model KRAKEN [23], [24] in combination with the water column, bathymetry and seafloor parameters described above. This was used to calculate the transmission loss (TL) from each seismic source position to every point in a spatial grid defined by a disc of variable range $R_r$ and azimuth $\theta_r$ for a fixed depth. The received root-mean-square (rms) power spectral density $Y_n(R_r, \theta_r)$ is given by

$$Y_n(R_r,\theta_r) = \sqrt{\sum_{k=1}^{K} |S(\omega_k)|^2 |\mathrm{TL}_n(\omega_k, R_r, \theta_r)|^2}, \tag{1}$$

where the summation is performed over a given discrete number of frequencies $K$, at which the TL (in rms power units) is calculated, and where $S(\omega_k)$ is the power spectrum of the $n$th source. In a second step, SPL is obtained as the range-azimuth discs of each individual source are converted to latitude-longitude-depth coordinates, and then summed over all $N$ sources, in the case more than one source is used, at any given time.

$$\mathrm{SPL}(lat, lon, depth) = 10\log_{10}\sum_{n=1}^{N}|Y_n(lat, lon, depth)|^2. \tag{2}$$

A spatial grid with a resolution of 1 km x 1 km was considered.

## RESULTS AND DISCUSSION

This section evaluates the influence of source depth and bathymetry in the acoustic propagation of seismic source emissions.

## E. *Influence of the source depth*

As described above, seismic surveys may be designed to consider seismic sources at different depths (Fig. 2b). Based on the literature and seismic sources manufacturers, sources are normally located between 0.3 m to 1 m depth. In this study three source depths were considered: 0.3, 0.5 and 1 m at four different off the coast locations at variable water depth of 50, 100, 150, 200 and 500 m (Fig. 4). The receiver was located always at 1 m depth.

TABLE II: Influence of the source depth in the resulting maximum sound pressure level (dB)

| Source depths (m) | 50m | 100m | 150m | 200m | 500m |
|---|---|---|---|---|---|
| 0.3 | 177.7 | 181.4 | 184.6 | 173.0 | 173.6 |
| 0.5 | 183.0 | 186.8 | 189.0 | 177.9 | 178.0 |
| 1.0 | 189.0 | 191.5 | 193.0 | 184.0 | 183.8 |

As it may be observed in Table II, source depth variation influences the maximum sound pressure level, where more than 10 dB difference between a source placed at 0.3 m and a source placed at 1 m depth was registered at all considered locations. This observation indicates that the water depth has a small influence in the noise pressure level obtained for sources at different depths revealing that there is no source depth indication depending on the water depth of the area. However, to approximate our model to, as much as possible, a realistic scenario, it is important to note that due to the surface wave agitation it is relatively difficult to precisely position a source at a depth less than 1 m, which will be the canonical source depth considered in the sequel.

Additionally, it was observed that for sources placed near the surface the signal emitted from the source is cancelled with the signal reflected from the surface due to the opposition of the phase (Fig.6) which corroborates the findings of Jesus [25]. This fact is indeed a pre-requisite in seismic surveying since the goal is to steer the sound to the bottom avoiding surface reflection paths.

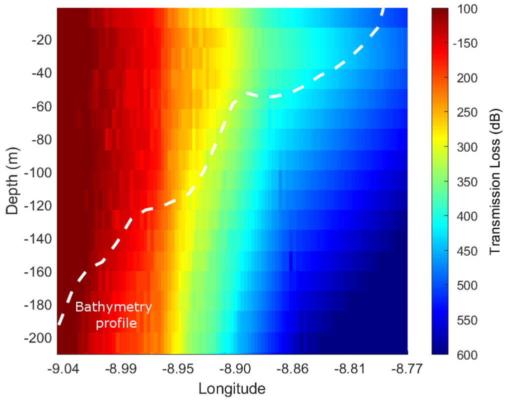
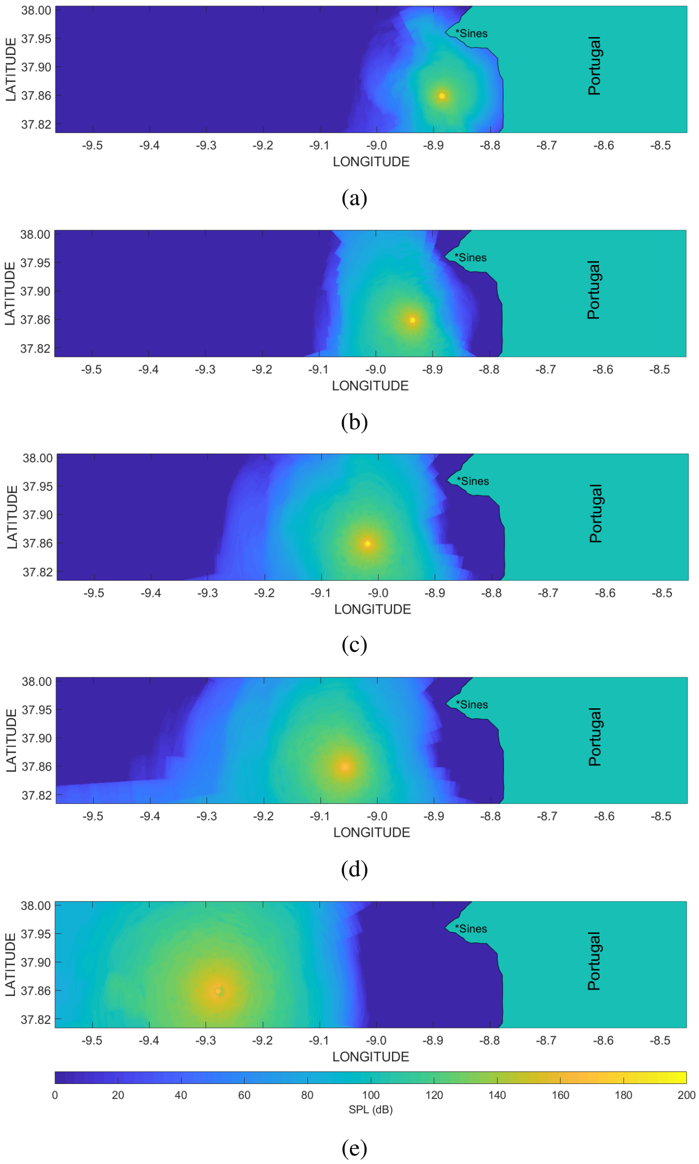


Fig. 6: Transmission loss for a source at 1 m depth, emitting a tone at 500 Hz in a location of 200 m water depth.

## F. *Static sources*

One way to evaluate the sound pressure level resulting from seismic surveys is to evaluate individually the effect of a sound source at each specific location with different water depth. Five different locations were considered, as shown in Fig. 4.



(a)

(b)

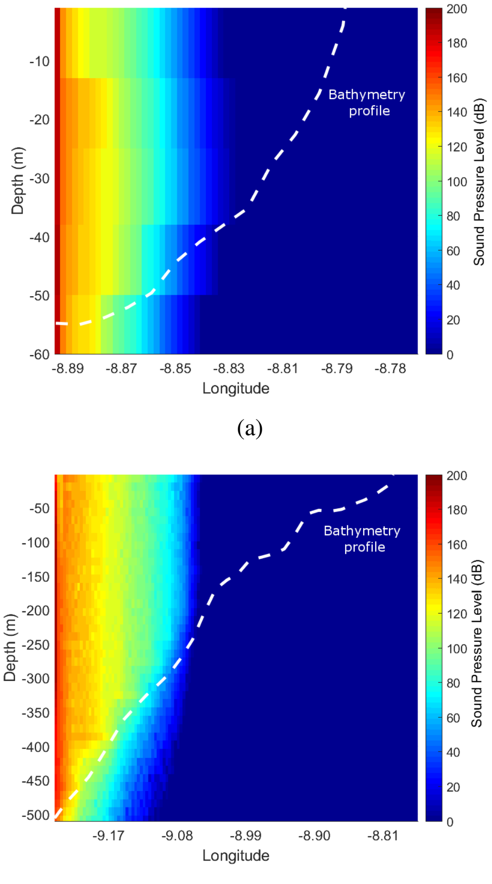
(c)

(d)

(e)

Fig. 7: Sound pressure level map resulting from one seismic source at various locations with different water depths: a) 50m, b) 100m, c) 150m d) 200m and e) 500m, and offering different propagation profiles towards the coast.

The results suggest that the sparker emitted signal for the deep water position is strongly attenuated by the bathymetry slope towards the continental platform. In Fig. 7 it is clearly observed that sources placed in shallow water, say between 50 and 150 m water depth, show highly concentrated SPL near the source location than in the other cases Figures 7d and 7e). In the deep water cases, specially at 500 m water depth, a large westward spread of the acoustic wave may be observed indicating a strong bathymetry slope attenuation creating a barrier towards the continental platform and the coast. This effect is also visible taking into account the propagation along the vertical axis Fig. 8.



(a)

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Fig. 8: Broadband sound pressure level in the frequency range 500 to 1000Hz in one-third octave bands [26] at: shallow (50m water depth) (a) and deep (500m water depth) (b) water.

In any case, the noise generated by this seismic source largely exceeds the typical mean ambient noise of 65-75 dB in that frequency band and shows a large excess noise level in the audible band of a number of species at potentially harmful levels.

## CONCLUSIONS AND FUTURE WORK

The noise resulting from seismic surveying may affect numerous marine species in the area surrounding a seismic exploration survey. Even if those effects, in terms of propagation, are well investigated in deep water, they are less known in more coastal areas. The Portuguese SW coast is rich in terms of cetaceans sightings and many studies, throughout the years, have revealed an important community of common dolphin in this region. Knowing that the Portuguese Government has granted rights for oil and gas deposits exploration in several offshore slots along the Portuguese SW coast it was imperative to assess the anthropogenic noise that could result from such surveys in the target area. Results shows that the most significant and concentrated noise level were registered in shallow water which were influenced by the bathymetry of the area that may work as an obstacle in terms of sound propagation. This natural barrier is particularly interesting and useful to protect coastal species when a deep water seismic surveying is being carried out (for example at 500 m water depth) since, even if there are a wider propagation in deep water (westward), it is attenuated on the east side due to the bathymetry. Additionally, even if only one seismic source was used in this study, the resulting noise largely exceeds the mean ambient noise in that frequency band, therefore considering that other possible configurations encompass the sustained use of several synchronized sparker sources of several types, such as the more powerful model 800 that reaches 230 dB peak SPL, moving along the coast, the noise levels presented in this study tend to increase and consequently raise the traumatic exposure to this effects. In the foreseeable future it is planed to investigate the effects of moving seismic sources along a wider area in the Portuguese coast (from Peninsula of Setúbal to Sagres) during different periods of the year and then cross our findings with species distribution maps to evaluate the possible effects on those species.

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