BASELINE MEASUREMENT OF UNDERWATER NOISE UNDER THE SURGE PROJECT

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1 INTRODUCTION

While wind energy devices have long time ago entered the commercial phase, and the large-scale implementation of offshore windparks is a reality, concepts for developing wave energy devices (WED) are generally considered to be in the pre-commercial phase, where a number of concepts have reached a relatively advanced stage.

These renewable energy devices are mechanical devices that generating electric current by the action of waves on moving and rotating parts. It is expected that this operation can produce noise that may propagate across the adjacent area. So far, the information on the noise produced by WEDs is scarce or nonexistent, and therefore, studies aiming at the evaluation of this descriptor of environmental performance are required as the first pilot device begin service. There has been some academical interest in modeling noise, however, with major limitations, due to the lack of real data on noise produced by WEDs [1, 2].

The Simple Underwater Renewable Generation of Electricity (SURGE) project aims at the demonstration of the Waveroller - a Wave Energy Device (WED) that has attained an advanced stage of development. During the SURGE project a Waveroller device will be installed near the shore in front of the town of Peniche (Portugal). Within this project, a task aiming at studying the underwater noise generated by this device is underway. This task foresees the baseline measurement of underwater noise, and the measurement of underwater noise during operation. The baseline measurement has been carried out in September 2010. Measurements of operational noise will begin during the Summer of 2012 after the installation of the Waveroller. Thus, the SURGE project is an opportunity for collecting valuable acoustic data for the assessment of the noise eventually introduced into the marine environment by the given WED type.

This paper presents a discussion on methods and acoustic equipments to be employed for the assessment of underwater noise throughout the SURGE project. Experimental results on field data collected during the baseline measurement of underwater noise are presented.

2 ASSESSMENT OF UNDERWATER NOISE: METHODS AND EQUIPMENTS

A complete Underwater Noise Monitoring Programme should, under certain circumstance include up to three components in order to produce a meaningful and comprehensive impact assessment: *in situ* recordings of noise; acoustic propagation modeling; impact evaluation of noise exposure.

These components may be seen as mutually complementing procedures of an impact assessment study of underwater noise produced by a given anthropogenic activity. In the case of WEDs, direct measurements of noise may be taken at several phases of the project, including a baseline measurement before any activity takes place, construction or installation works, operation, and decomissioning. Herein, baseline measurements and operational noise monitoring will be discussed.

2.1 BASELINE MEASUREMENTS

The marine environment is naturally noisy, as many natural phenomena introduce noise into the marine environment. The most dominant natural noise sources are wind and rain, and wave action in zones near the shore. In offshore waters, the natural noise level may vary significantly with distance to shore and with time, according to weather conditions and season of the year. In the presence of a harbor in the vicinity of the observation area, activiy of fisher and recreational boats should be taken into account, as these contributions to the total noise significantly vary over time and space.

Baseline measurements should be carried out before activities at sea take place, in order to characterise the background noise already existing in the area, which provides a reference for comparison against analysis results of acoustic data to be collected in the future, during device operation.

In order to assess the spatial variability of background noise, recordings should take place at multiple positions within the observation area. In the case of a single WED, the deployment position should be taken as the reference position. The baseline measurement may be performed over one or multiple ocean transects containing measurement stations, departing from that reference position. This allows for observation of a decay or a raise in the broadband sound pressure level across the distance, and simultaneously take samples throughout time. The maximum distance may ideally be chosen such that no significant changes in background noise are perceived anymore.

Regarding the time scale, a baseline measurement should ideally consist of long term recordings, more specifically, over a time scale of several weeks or months, over different seasons, as the climate and local boat traffic varies as a function of the season, which enables a robust baseline measurement of noise, truly accounting for different conditions. However, this is usually not affordable due to the costs with equipments and personell that this may involve. In practice, a time scale of only a few days is usually taken, or even a single day. The major drawback of a single day baseline measurement, is that this is, in principle carried out under good weather conditions, therefore preventing it from covering a diversity of situations, eventually suffering from lack of statstical representativity.

2.2 OPERATION NOISE: DIRECT RECORDINGS

Direct *in situ* noise recordings are necessary for assessing noise characteristics both at the noise origin and over the area potentially affected. The objectives of this procedure are (a) to determine the scope of the affected area, (b) to characterise the spectral distribution of noise, more specifically, to assess the attenuation of the spectral components as a function of range, depth and azimuth, and (c) to precisely assess the noise characteristics at the origin of the noise source. To carry out (a) and (b) requires noise recordings to be taken at multiple positions with increasing distance from the noise source and possibly over multiple ocean transects. To carry out (c) requires to take direct measurements close to the noise source. The data collected for objectives (b) and (c) should be analysed in tandem: the recordings close to the WED, besides providing the observables of the instantaneous field, e.g. sound pressure level (SPL) and spectral power density, also provide a variability of those observables for a fixed position. In theory, that variability should be also perceived at a position away from the WED. However, this will become smeared off with increasing distance, due to existing background noise and variability in transmission loss.

The power spectrum density estimated from acoustic data acquired close to the WED can be used as the input of an acoustic modeling procedure. The data analysis results of data acquired away from the WED can be used for the validation of acoustic modeling results.

2.3 ACOUSTIC PROPAGATION MODELLING

The major difficulties associated to performing direct measurements are related to the size of the ocean volume potentially affected and the variability of operational noise over time. In other words, direct measurements are non-simultaneous, and to attain a significant spatial coverage may be time-consuming and cumbersome. Additionally, the requirement of taking long-term observations, and the impossibility to carry out monitoring activities due to extreme whether conditions may arise.

To cope with these difficulties, incorporating acoustic modeling in an underwater noise programme brings the possibility to cover a virtually unlimited ocean volume, and to produce space continuous maps of sound pressure level at any point within the observed volume, in opposition to *in situ* recordings consisting in a reduced number of points in the observed area. A number of accurate computer acoustic models are available to the acoustic community. Modern acoustic computer models take a description of the physical properties of the ocean as input, including sound-speed (of the water column and seafloor layers), geoacoustic properties, and emitter-receiver geometry, which are incorporated in the resolution of the wave equation. The so-called replica field, is highly dependent on the environmental and geometric inputs, and therefore, relatively accurate environmental data is a requisite for obtaining meaningful replica fields.

While bathymetric data is readily available in the majority of the cases, and watercolumn temperature can be made available either through direct measurements or from historical data bases, information on geoacoustic data is generally coarse or inexistent. Geoacoustic properties play an important role in the acoustic transmission loss in shallow waters. An alternative way to assess the missing environmental data is by means of the so-called acoustic inversion [3]. An acoustic inversion is a procedure where physical properties are determined from experimental field data. Once a physical model has been determined and the noise at the origin is accurately characterised, the user becomes able to generate maps of SPL for the whole volume.

The main advantages of this approach are: (a) the possibility of considering a diversity of WED operation regimes, from mild to extreme maritime agitation; also the environmental variability can be taken into account, more specifically, the temperature variabilty over the seasons; (b) it enables the experimenter to produce noise maps at multiple discrete depths; (c) for study and management purposes: acoustic modelling allows for taking into account scenarios where multiple WEDs are to be installed in given area; (d) finally, when it comes to impact evaluation, being able to accurately generate replica field from a noise source to any point as a function of frequency is very convenient for establishing the influence zones over a 2D space at different depths or in range-depth slices.

2.4 EQUIPMENTS FOR ACOUSTIC DATA ACQUISITION

Now existing autonomous recording systems appear to be suitable to respond to the main requisits involved in most complex underwater noise monitoring problems, as rapid advances of electronic parts and battery technology in the past 10 years has boosted the development of compact acoustic recording devices with suitable operational characteristics. These characteristics include large autonomy and storage capacity, small size, and attractive pricing. The operationality of such devices can be significantly improved by the inclusion of programmable functions.

In the present study, acoustic recordings are being carried out by means of the SR-1 autonomous hydrophone, designed by MarSensing Lda. (see Figure 1). This compact device uses an SQ26 transducer provided by Sensor Technology Limited, that has a nominal electrical sensitivity of -193.5 dB *re* 1 V / 1 μPa, and a flat response in the frequency range 1 Hz to 28 kHz. The amplification chain consists of a pre-amplifier with a nominal gain of 31$\times$ followed by a programmable gain amplifier (PGA) with gains of 1$\times$, 2$\times$, 4$\times$, ..., 64$\times$, which allows for setting the sensitivity according to the maximum expected noise levels.

The system is equipped with a 24-bit sigma-delta ADC, providing sampling rates of 50781 or 101562 samples per second. The usuable frequency band stop is at approximately 24.8 and 48 kHz, respectively. The data is stored on a removable card in 16 or 24-bit WAV format, with file lengths programmed by the user. Currently, it uses cards with up to 16 GByte of storage. The power supply is a 3.7 V lithium battery of type 18650 which enables continuous acquisition operation of approximately 11 hours, or 1 week in scheduled operation. For extended time applications, it is possible to exchange the external container tube with a battery pack, including then a total of 5 type 18650 batteries. This allows for a proportional extension in operation time.

Several settings can be programmed, among others, the PGA gain; the acquisition rate; a time-table for scheduled acquisition; length of each WAV file.

Figure 1: Inside view of the SR-1 autonomous hydrophone used during the SURGE project.

The application of this recording device is convenient for the activities undertaken in the scope of the SURGE project, mainly for efficiently carrying out simultaneous recordings at multiple positions within the study; for carrying out recordings from the boat, which aids in preventing the noise caused by waves hitting the boat to reach the receiver with a noticeable level. Technical specifications such as operating bandwidth, memory size, and autonomy are adequate for the actual experimental scenario.

3 BASELINE MEASUREMENTS OF BACKGROUND NOISE

This section presents analysis results on the acoustic data collected during an experiment that took place during September 3, 2010, off the Portuguese West Coast near the city of Peniche, in a working box located on the North side of the Cape of Carvoeiro. The objective of this experiment was to perform the baseline assessment of the underwater noise in the site where the WED will be installed.

The maritime conditions were in general favourable with wave height of approximately 2 m, and moderate wind strength.

3.1 EXPERIMENTAL CONFIGURATION

The geometry of the experimental configuration was based on the waveroller's deployment position (see Figure 2). The noise measurement took place within a working box with northeast corner at coordinates 39°24.6'N, 9°20.7'W and southwest corner at coordinates 39°22.8'N, 9°17.7'W. The recording geometry consisted of two transects departing from the WED's deployment position - one with the azimuth of maximum bathymetric variability (Transect A), and the other with azimuth West (Transect B). The WED's deployment position will be taken as the reference point throughout this section. The

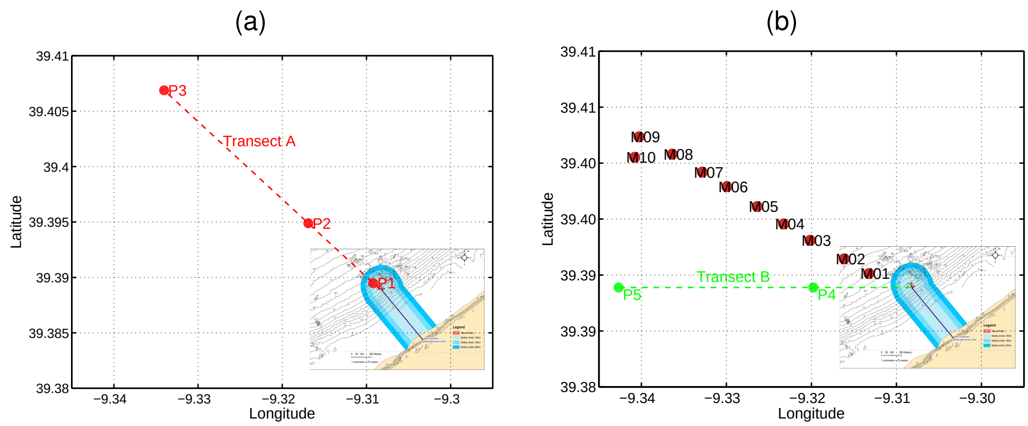

Figure 2: Experimental configuration for acoustic data acquisition. (a) First part on Transect A with moored recorders only. (b) Second part with moored recorders on Transect B and a moving recorder on Transect A.

experiment was divided in two parts. The first part took place on Transect A, consisting in mooring 3 autonomous acoustic recorders over that transect. Recorder Hyd01 was moored at the position where the WED is expected to be placed (P1), while recorder Hyd02 was moored at position P2, 1 km away from P1, and recorder Hyd03 was moored 3 km away from P1. The second part consisted of recorders Hyd01 and Hyd02 moored on Transect B, respectively at positions P4 and P5 at ranges of 1 km and 3 km from the reference point P1. Recorder (Hyd03) was operated from the boat to perform recordings over Transect A. The red dots marked with labels **M01** through **M10** indicate positions where recordings took place. Position M01 ranged 0.43 km from P1, and M10 ranged 3.07 km from P1. The water depth over Transect A varies from 11 m at P1 to 34 m at P3, while over Transect B the waterdepth has an approximately constant value of 20 m over transect B. For each mooring, the receiver was placed at approximately mid-waterdepth.

The recordings took place according to a pre-programmed time table, which was set in order to start a new recording every 10 minutes during 5 minutes each, which allows for another 5 minutes of idle mode. Unfortunately there was a mistake on programming the recording length on recorder Hyd03, that resulted in data files of 2m30s (only half the length).

Two of the hydrophones were prototype versions, with storage capacity limited to 2 GByte. One of reasons to adopt this scheme was to save storage capacity, in order to avoid interruptions for memory card exchange. The other reason was to use the idle mode intervals for transit from one recording station to the next, without generating motor noise contaminated data. This acquisition scheme has a duty cycle of 50%, which is considered sufficient, as natural background noise phenomena evolve slowly, within a time scale of hours.

3.2 ANALYSIS OF ACOUSTIC DATA

The objective of collecting this acoustic data set was to perform a baseline study of the noise produced in the area. It is expected that the contributions to the total noise level come mainly from the ambient background noise generated by natural phenomena (wave breaking, wind, rain) and shipping noise, mainly from fisher and leisure boats, as there is a harbor in the vicinity. The natural noise is relatively stationary, since its characteristics change with maritime regime and meteorologic conditions, which in turn also evolve in a scale of hours.

The analysis of this data will serve the purpose of establishing sound pressure levels (SPL) measured over the study area under the actual maritime and weather conditions. Also a frequency and time-frequency analysis is carried out in order to obtain the power distribution of the noise over the spectrum. The data processing is carried out with the following steps:

1. The data contained in each data file is Fourier-transformed with observation windows of 8192 samples (approximately 0.1613202 s).
2. For each interval of 8192 samples the SPL is calculated by integrating the instantaneous spectral density power in the interval 100 Hz to 25435 Hz(half of sampling frequency).
3. For each measurement station an average power spectrum is obtained as a representative noise spectral estimate. The integration of that spectral estimate yields the broadband SPL observed at that station.

SPL estimates and spectral estimates obtained in the present studies will serve as reference for comparison with acoustic data to be acquired in future campaigns, after the WED has come in operation.

3.2.1 First part - recordings at fixed positions over Transect A

Figure 3(a) shows the instantaneous SPL estimated for Transect A. Each curve represents 5 minutes of recording. These SPL curves were obtained by calculating the instantaneous SPL for each Fourier observation window, and then a 10 s moving average window was applied for smoothing. The broadband SPL for position P1 is approximately 102 dB during most of the observation time (red curve). Several measurements present an increased sound level, which is related to the presence of boats

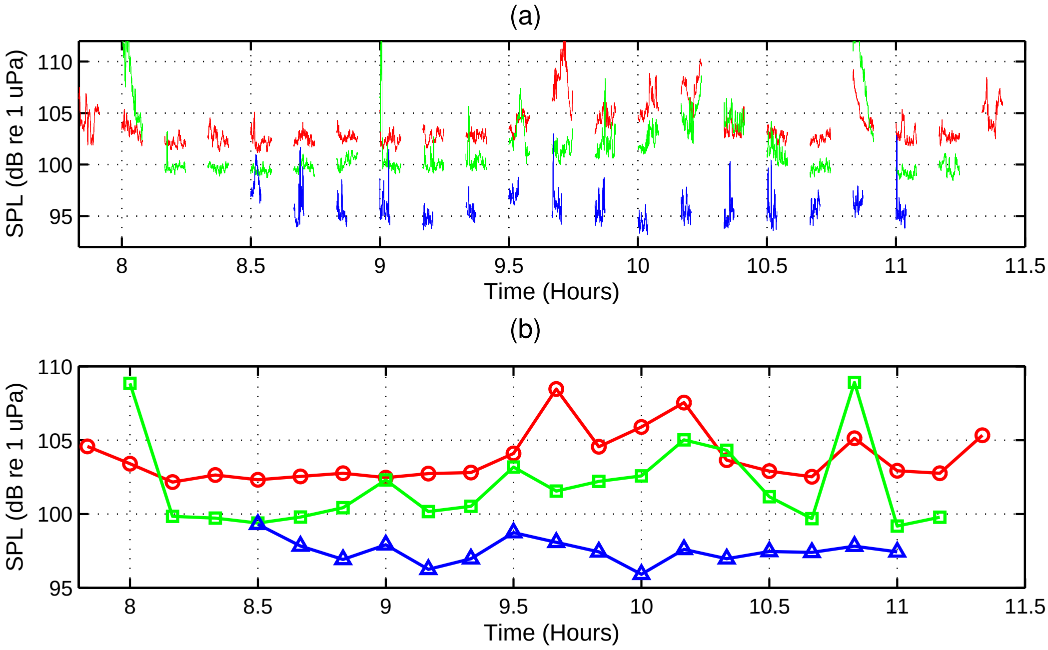

Figure 3: Sound pressure level estimates for fixed positions over Transect A: (a) instantaneous SPL; (b) rms SPL. Position P1 (red); Position P2 (green); Position P3 (blue).

passing in the area. The SPL for P2 is about 100 dB, which is slightly less than that observed at P1. Simultaneous recordings allow to observe the contribution of boats passing in the area both at P1 and P2 for intervals with outlyer SPL values. In some cases the increment in SPL is higher for P1 than in P2, e.g., the recording started at time 09h40, and in other cases the increment in SPL is higher for P2, e.g., the recording started at time 10h50. According to this observation, the activity in terms of boat traffic in this area tends to be more significant after 09h30 GMT. Finally, the broadband SPL estimates for position P3 tends to show a higher instantaneous variability than in the other two (blue curve), with a more diffuse behaviour, with SPL estimates ranging from 94 to 102 dB. In opposition to the other positions, here a clear distinction of two regimes is not noticeable. Figure 3(b) shows the average SPL within each recording interval. There is an unambiguous tendency for a decrease of the broadband SPL with distance to the shore. These curves allow to conclude that under the actual conditions the average noise level was approximately 103 dB for P1, 100 dB for P2, and 96 dB for P3. During the interval 09h30 to 10h30 it appears that P1 and P2 are perturbed by the same noise sources, mostly by boats passing in the area. The variation peak observed for the green curve (P2) is also observed with noticeable intensity in the red curve (P1), but only very slightly for the blue curve (P3).

Finally, figure 4 shows the spectral densities of times 08h50m (panel (a)) and 09h10m (panel (b)). The curves show average spectral densities within a single recording interval for P1 (red), P2 (green), and P3 (blue). These plots allow a direct comparison between spectral densities obtained at different positions. In the 30-100 Hz band, P3 is that with highest spectral density, with a peak outstanding at a frequency of 60 Hz. At frequency above 100 Hz, the noise at P3 decays faster than at P1 and P2.

3.2.2 Second part - recordings at fixed postions over Transect B

During the second part of the campaign only hydrophones Hyd01 and Hyd02 were moored over Transect B, a straight line departing from P1 with West azimuth. Hydrophone Hyd01 was moored at P4, 1 km away from P1, and hydrophone Hyd02 was moored at P5, 3 km away from P1. Hydrophone Hyd03 was used for recordings over positions M01 through M10 on transect A.

Figure 5 summarizes the SPL estimates obtained during the second part of the campaign. The broadband SPL for position P4 as a function of time (red curve), presenting levels from 107 dB at the

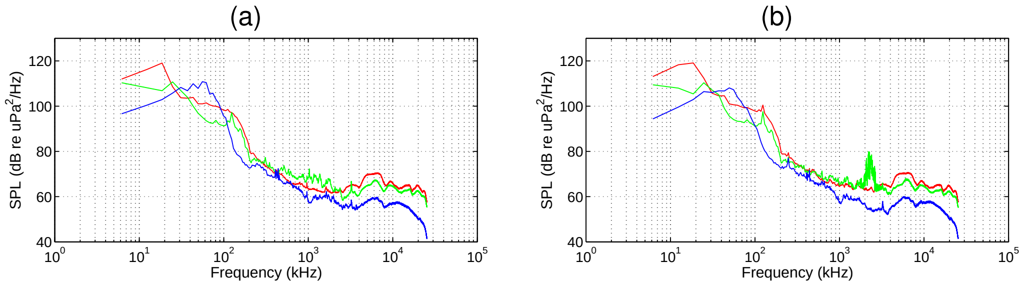

Figure 4: Spectral density for acoustic data recorded over Transect A. Position P1 (red); Position P2 (green); Position P3 (blue); Panel (a) is for time 08h50m, and panel (b) is for time 09h10m.

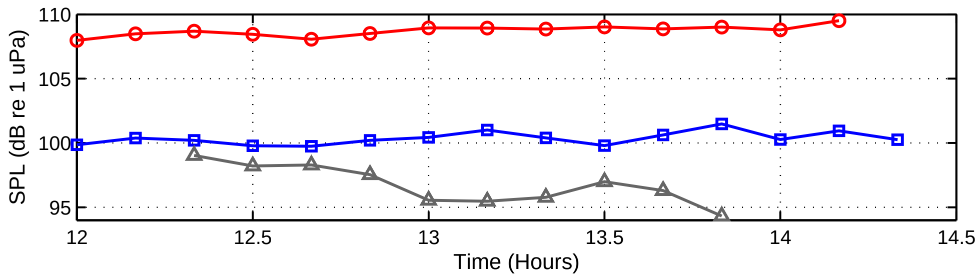

Figure 5: Average sound pressure level estimates for fixed positions over Transect A: Position P4 (red); Position P5 (blue); Mobile positions M01 to M10 (gray).

beginning of the run and 109 dB at the end of the run. The SPL at position P5 presents a level of 100 dB most of the time (blue curve), with momentaneous increments, possibly with origin in boats passing near. Finally, the gray curve presents a progressive decrease over range, starting with 99 dB at approximately 0.4 km from P1 and with aproximately 95 dB at the end of the run, approximately 3 km from P1. This result is compatible with the SPL estimated for moored recordings during part A, where an SPL of 102 dB was observed at P1 and SPL estimated around 97 dB were obtained.

Figure 6 shows spectral densities for data collected during the second part. Panel (a) is for data collected at position P4 (red), position P5 (green), and position M10 (gray). Panel (b) shows spectra for data collected on mobile position M01 (lightest), M04, M07, and M10 (darkest). These plots show a progressive decrease in spectral level with increasing distance relative to P1, specially for frequencies below 1 kHz.

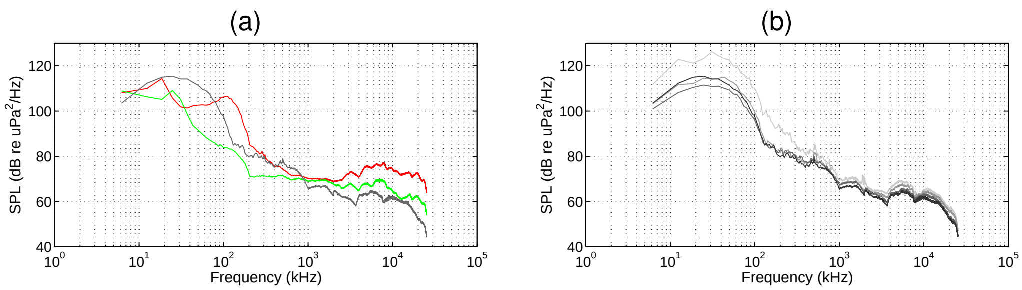

Figure 6: Spectral density for acoustic data recorded during part 2. Panel (a) is for time 13h50m: Position P4 (red); Position P5 (green); Position M10 (gray). Panel (b) is for mobile positions M01 (lightest), M04, M07, and M10 (darkest).

4 CONCLUSIONS

Acoustic data was collected during September 3, 2010, in a site of future deployment of a wave energy device, in order to complete a baseline measurement of underwater noise, within the SURGE project. The acoustic recordings took place over two transects departing from the reference position, one with azimuth Northwest, and the other with azimuth West, with moored and moving acoustic recorders. The objective of the data analysis was to obtain sound pressure level (SPL) estimates and spectral density (SD) estimates as function of range, for future reference.

A consistent decreases in SPL for increasing distance to shore was in general observed. Over the Northwest transect, the average broadband SPL measured with moored recorders was respectively 103 dB for P1 (closest position), 100 dB for P2, and 96 dB for P3 (furthest position). A similar tendency was observed over a second run with 10 measurement stations using a mobile recorder, where 99 dB was obtained for the position closest to P1, decreasing consistenly down to 95 dB at the station furthest from P1.

Over the West transect, a transect along Cape Carvoeiro, the average broadband SPL measured with moored recorders was respectively 108 dB for P4 (1 km from P1), and 100 dB for P5 (3 km from P1). Cape Carvoeiro is a rocky formation, and therefore, this increment in background noise, in comparison to that observed on the Northwest transect, is explained by the interaction of waves with that rocky formation.

Regarding anthropogenic noise, it is observed that local boat traffic makes a noticeable contribution, as on positions P1 and P2, the variation in SPL attributed to motor noise was within 5 to 10 dB.

The variability average SPL observed during this baseline measurement illustrates the importance in accounting for the *a priori* background noise distribution in a specific site for future reference.

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