CINTAL - Centro de Investigação Tecnológica do Algarve

Universidade do Algarve

K2D - Knowledge and Data from the DeepSpace

D4.2 - Exploratory acoustic data analysis

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Abstract	This document is expected to cover the requirements for deliverable D4.2 of project K2D, in what regards the requirements and management of acoustic data sets considering a standard data calibration method, visualization and data exchange policies.
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Executive Summary

Project Knowledge and Data from the Deep Space (K2D) aims at designing, developing and testing at sea a new concept for permanent ocean observation based on a new generation of submarine telecommunication cables - the SMART-cables.

The concept underpinning K2D involves the deployment of Environmental Observation Nodes (EONs) co-located with the cable repeaters, allowing for ocean monitoring through a variety of sensing elements and technical hubs for sensor equipped vehicles and platforms. Among those sensors it is foreseen to include a low-frequency hydrophone for ambient sound characterization, soundscaping and the detection and tracking of soniferous species. The telecommunication cables that connect Portugal mainland to Azores and Madeira are reaching the end of life and its replacement appears as an opportunity for installing EONs and its effective use as a SMART-cable. The new telecommunication infrastructure will form a closed loop departing from Portugal mainland to Azores, then to Madeira and back to mainland, and will be known as CAM-ring. The data collected in the vast Atlantic area potentially covered by this observation system could allow a significant advancement on the understanding of physical and biological processes vital for economic and strategic reasons, as well as for marine life conservation.

This area will be crisscrossed by a few thousands of kilometers of cables with hundreds of EONs delivering real time acoustic data in a massive amount. The processing of this data will require it to be comparable and accessible to multiple research teams in various institutions (possibly in various countries). In order to allow future comparisons and exploitation, data provided by the CAM-ring sensors should be appropriately calibrated, pre-processed and documented through a, as much as possible, data sharing standard format.

Hence, this report covers the necessary steps and recommendations to obtain meaningful and comparable acoustic data that can be used for soundscaping analysis purposes from the data recording and calibration up to the data visualization and data exchange. The methodology follows already existing recommended standards inline with the best practices adopted by international agencies, such as ICES and OSPAR. Due to the lack of representative experimental acoustic data, this report presents a simulation where an hypothetical EON records the shipping noise resulting from a real ship distribution gathered in July 2019 off the west-coast of Portugal. This simulation is the first step into the development of a prediction tool for evaluating SMART-cables soundscape performance. A similar analysis is carried out for a shallow water area near Sesimbra in the Setúbal plateau, where a K2D wet demonstrator is planned to be deployed.

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Abstract

This report aims to cover the requirements for task 4.2 - exploratory acoustic data analysis, of the K2D program of work, regarding the passive acoustic data for soundscape monitoring. Exploratory data analysis encompasses various stages such as 1) on-the-sensor hardware calibration, 2) pre-processing for security sensitivity mitigation and data reduction, 3) visualization for event identification and tracking and finally 4) data archiving in a well documented and open format, encouraging data sharing.

The various steps are detailed while insisting in the required system parameters: 1) for equipment calibration aiming at setting measurements that are hardware independent and comparable in international standards; 2) detailing the various options for on/off-the-sensor pre-processing, advantages and drawbacks; 3) the importance of data averaging and frequency domain representation for both sensitivity mitigation and data reduction purposes; and 4) the requirements for acoustic data archiving, re-usage and file sharing, with all its components and metadata descriptors. Tools, diagrams and examples are given to illustrate each step.

The link to K2D is done through two illustrative simulated data examples. The first one is based on the time series recorded on an hypothetical cable repeater module in a deep water area off the coast of Portugal mainland at the level of Figueira da Foz. The receiver is located in between the up and down going tracks of the TSS (Traffic Separation System) so that simulated shipping using real AIS data from 2019, is intense and representative. One of the open source available tools for data analysis is run on the simulated data to close the example. The second example is set on the scenario of the Setúbal plateau, near the town of Sesimbra where a project wet demonstrator is planned to be deployed.

The report is concluded on a number of requirements and recommendations to be taken into account for setting up a coherent data management system of the future CAM-ring infrastructure.

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Chapter 1

Introduction

Ocean monitoring is determinant to understand environmental climate changes, as sea level change, tsunamis, earthquakes, hurricanes, etc. However, monitoring the ocean as a whole is challenging for the technical difficulties due ocean vastness and large depth, not to mention the high costs involved. The idea originally suggested by You [3], of using transoceanic telecommunication cables for ocean monitoring has the advantage of being able to give a synoptic view of the ocean interior using an already existing resource, therefore at limited incremental cost. This idea was later expanded and popularized by Howe [4] under the name of SMART cables. The SMART cable concept aims at integrating seamless sensors in the cable repeaters, in order to offer a minimal or no burden during cable deployment. In all respects SMART cables will behave as non-SMART cables, apart from the fact that they will continuously gather oceanographic information transmitted in real time to land stations.

K2D explores and expands the SMART cable concept in the sense that K2D sensing modules will be connected to the repeaters but not integrated with them, so sensing options open up a number of other possibilities. Therefore they will require a specific deployment procedure. For the scope of this report we will call these modules Environmental Observation Nodes (EON). The ensemble of EONs attached along the cable may be viewed, from a data observation perspective, as a unique distributed ocean observatory covering thousands square kilometers. EONs will be themselves modular so their sensor package may vary according to the area being crossed by the cable. Although the final structure of the EONs is still being decided, it is certain that they will comprise acoustic receivers for at least three functionalities: passive acoustic sensing for soundscape monitoring, active acoustic communications and Autonomous Underwater Vehicles (AUV) localization. The main characteristic that sets receivers apart is the frequency being used, that will be in the low band (≤ 2 kHz) for passive monitoring and in the high band (≥ 10 kHz) for acoustic communications and AUV localization. This report will focus on the passive acoustic monitoring sensor data, while acoustic communications and AUV localization will be dealt with in other reports.

The telecommunication cables that connect Portugal mainland to Azores and Madeira are reaching the end of life in the next years. The new telecommunication infrastructure will form a closed loop departing from Portugal mainland to Azores, then to Madeira and back to mainland, and will be known as CAM-ring. The bid for cable replacement has been launched by the Portuguese Government and comprises the provision for specialized "scientific modules", which are left to the biding companies to specify. This creates the perfect opportunity for studying the possibility of installing the EONs and, potentially, a step increase in oceanic data coverage for multiple disciplines such as geophysics of ocean floor, ocean circulation, water column properties and biological indicators (ex. eDNA). Ocean sound has became an essential ocean variable (EOV)[1] and its impact trends highlighted on a recently included chapter 20 of the United Nations World Ocean Assessment II report [5].

Acoustic data analysis involves at least four important aspects: data calibration, processing, visualization and exchange. The importance of data calibration relies on the fact that it ensures that sound pressure level (SPL), obtained from one given equipment has the same real value than other sound measured with a different equipment. Data calibration is specially relevant when the purpose is to sense the ocean in a wider scale, since different EON may have sensing elements with different specifications.

The second aspect involved in acoustic analysis is the data preliminary processing. The objective of this stage is two fold: to anonymize the data (or to decrease its degree of security sensitivity) and to provide data volume reduction. This is accomplished through data averaging and by passing from time to frequency domain. In order to maintain data comparability, it is essential that this processing follows standard procedures and uses the same configuration parameters such as time averaging intervals, frequency bands, data weighting, and SPL estimation. This process should be as much as possible, automatic and transparent.

The third aspect is data visualization which covers the definition of the indicators that should be displayed to the user. There are at least two forms of visualization: one is performed on data snippets for online data quality control and feature tracking (for example marine mammals) and the other is for long term monitoring, ocean climate trends and for supporting marine life conservation policies.

Finally, data exchange and sharing, which is of paramount importance to encourage collaborative data analysis of various institutions, possibly from different countries, following the idea that ocean processes are not bounded by political borders and require global understanding. It is very important that the data is properly labeled, self-contained and the context where data was acquired (sometimes called metadata) is included in the sharing format. Data sharing policies, data privacy and data access are also of concern and should be described and agreed.

This report covers the essential steps for acoustic data analysis considering equipment at different locations and periods of time, and presents two practical case of acoustic recording for the CAM-ring cable nodes based on simulated data. The first example takes into account the cable departure point in Figueira da Foz and considers an hypothetical deep water EON off to the west of the continental platform. The actual AIS[2] data shipping distribution of June 2019 was used to simulate the measured SPL generated at the bottom EON acoustic sensor. The second is a shallow water example near the town of Sesimbra in the Setúbal plateau, where the testing of an experimental wet demonstrator is being planned. The first example is representative of a deep water EON, the most common along the CAM-ring, while the first example is expected to envision the expected soundscape for the planned sea trial.

This report is structured as follows: section 2 describes the aspects to be taken into account in hardware data calibration; section 3 defines the steps involved in preliminary data processing; section 4 gives an overview on the data visualization aspect and some insight into acoustic data exchange; sections 5 and 6 present simulations for a typical

[1] By the Global Ocean Observation System (GOOS)

[2] Automatic Identification System

deep water soundscape recording and a shallow water realistic case, respectively. Finally section 7 draws some conclusions and makes recommendations for forthcoming work.

Chapter 2

Hardware data calibration

Hardware data calibration aims at making the measurement independent from the sensing element. In this report the term "calibration" will be relative, in the sense of inter nodes. It will be assumed that the sensor of each node is calibrated in absolute terms by appropriate calibration practice. Therefore, raw data from different sensors is guaranteed to be fully quantifiable and comparable. The final specifications of the EON will allow its mass production for the few hundreds of units required for the CAM-ring. It is well known that even a careful production will not lead to fully identical units, which characteristics will vary from one to the other within certain bounds. Also, EONs deployed at different depths and at different temperatures will suffer from an inevitable shift of acoustic sensitivity, which should be properly taken into account during the hardware data calibration phase. Calibration is a way to overcome these differences and allow to quantify which sound pressure corresponds to a given audio level in a different equipment. Figure 2.1 shows a typical signal/calibration chain/sequence, since the point where the acoustic pressure is captured by the sensor up to the creation of a digital recording audio file.

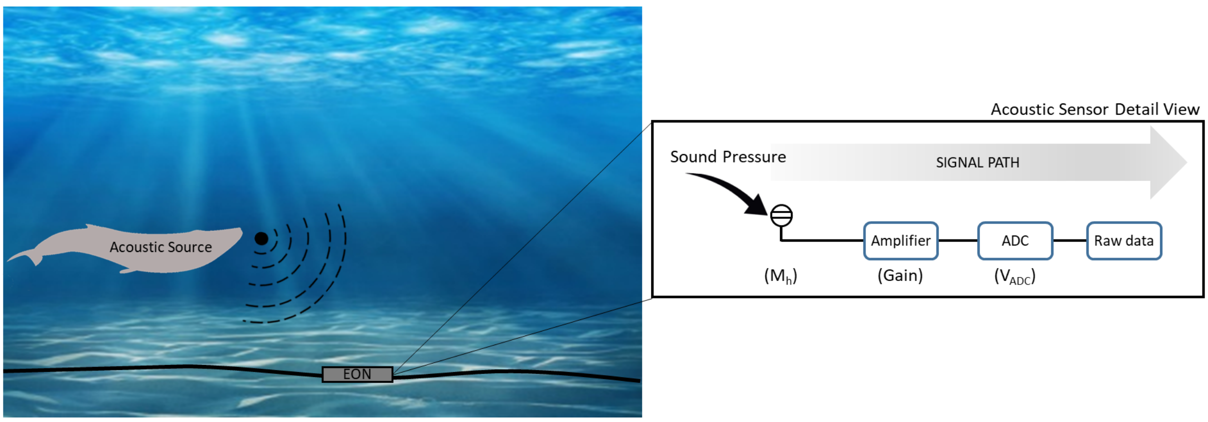

Figure 2.1: *Generic acoustic signal path, since source sound until the corresponding sound level being stored in an digital audio file.*

There are three essential parameters that should be taken into account in order to perform data calibration at the hardware level: transducer sensitivity ($M_h(f)$ in dB re 1V/μPa), the system gain at the frequency of interest ($G(f)$ in dB) and the analog-to-digital converter (ADC) input zero-to-peak voltage (V_{ADC}). The signal voltage power transfer function $S(f)$, in dB, from sensor input to digital file at frequency f, may be quantified by the following expression:

$$S(f) = M_h(f) + G(f) + 20\log_{10}\left(\frac{1}{V_{ADC}}\right) + 20\log_{10}(2^{N_{bit}-1}), \tag{2.1}$$

where N_{bit} is the number of bits used for data quantification, typically set to 16 or 24 bits.

Beyond data calibration it is important to take into account the last stage of the signal chain: the digital file creation. This stage allows to store raw data into a digital file that is later processed to obtain calibrated sound pressure levels. There are several options in what concerns the raw data format files. The only restriction is that the chosen file format should exclude data compression in order to avoid information loss. File formats such as .WAV, .FLAC or AIFF may be considered since these are lossless open formats supported by a large number of public domain readers and applications.

Additionally, even though an acoustic recording is always dependent on the purpose of the measurement and that there is no standard in what concerns equipment specification, some recommendations are made in order to achieve the best equipment performance when recording ocean sound, as for example a frequency band between 10Hz and a maximum frequency of 1, 2 or more kHz, up to 20 kHz, depending on the objective range and sound impacts, a minimum dynamic range of 16 bit (ideally 24 bit), a transducer sensitivity from -165 to -185 dB re 1V/μPa, and a self-noise ideally of at least 6 dB below the lowest measurable sound level.

Chapter 3

Data preliminary analysis

The evolution of underwater acoustics research was triggered by the second world war and then by the cold war until early 90s of the XXth century. In the last two decades ocean sound became really dual use, with its traditional military scope of submerged target detection and localization and a number of civilian applications for oil & gas exploration, geophysics, underwater communications, bottom mapping, bio-acoustics, marine life preservation, fisheries, and many others. Dual use means that underwater recorded data in the open ocean may have hidden information about vehicles or passing by submarines sometimes, several tens of kilometers away. This makes any underwater acoustic recording security sensitive what, to date, has been a strong argument preventing its wide sharing for ocean sound monitoring purpose civilian usage. As stated above, the scope of data preliminary analysis is two fold: decrease the degree of data sensitivity and provide some degree of data reduction, the overall objective being that of encouraging or facilitating data sharing.

3.1 On-the-sensor vs. off-the-sensor processing

In recent years, with the advent of inexpensive and fast computer technology, on the sensor processing became a reality, effectively reducing the amount of data to be transmitted to onshore premises. Alternatively, when there are no stressing data communication limitations, raw data may be transferred to onshore stations for later processing. This on-the-sensor/off-the-sensor processing trade off is sketched in Figure 3.1: in case 1) preprocessing is on-the-sensor and only averaged SPL levels are being transmitted to shore, and in case 2) raw data is fully transmitted to shore for later processing and archiving. In both cases SPL averaged data is visualized and shared as required. The first case shown in Figure 3.1 involves data calibration and processing directly in the EON, resulting in the transmission of average levels and statistics to land/database. The second case considers only the hardware calibration to be performed directly on the sensor, raw data being entirely transmitted to the shore base station for later preliminary processing, and obtaining SPL averaged levels. The following considerations should be taken into account for opting between the two cases of Figure 3.1:

- **on-the-sensor** processing will be preferred whenever data transfer throughput is low and the ratio of energy consumption for processing and for transmission is lower than one;

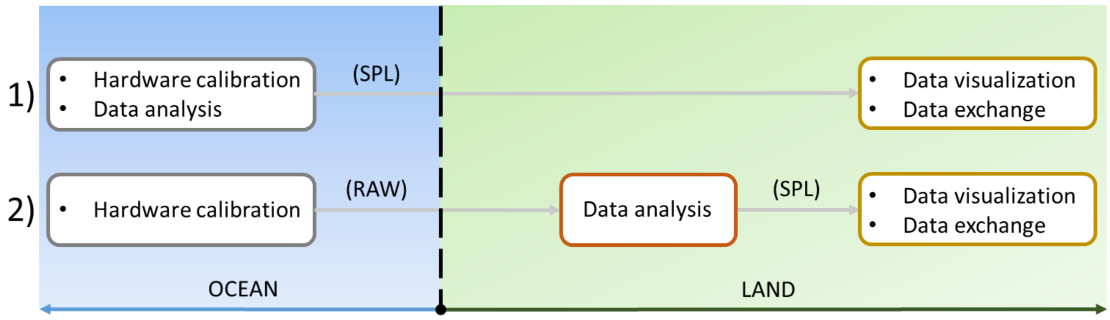

Figure 3.1: *Preliminary data analysis scenarios for decreasing security sensitivity and data reduction: 1) on-the-sensor and 2) off-the-sensor processing.*

- **off-the-sensor** processing should be chosen when data communication throughput is high, whenever processing may require human intervention or maintenance, or when onshore archiving of raw data is a requirement/priority.

The advantage of case 1) compared with case 2) relies on the fact that a smaller amount of data is transferred through the cable. However it precludes the use of the raw data for other purposes besides soundscaping, for example marine mammals localization and tracking or surface ship noise identification. Knowing that the amount of data transmitted depends essentially on the sampling frequency (Fs), it can be easily estimated at approximately 100 kbits/s for a Fs = 3 kHz at 4 bytes per sample. Considering the capacity of actual telecommunications cables, this amount of data is insignificant even considering several hundreds of EONs on the same cable. This may justify for the transmission of the raw data instead of just the average levels as suggested in case 1). For this reason scenario depicted in case 2) will be considered throughout this report.

Preliminary data analysis involves: (1) the extraction of necessary timing data from the recording files and (2) the estimation of the Power Spectrum Density (PSD) using a time window of pre-selected duration on each recording. The following section describes some basic notions regarding the signal processing steps that allow to convert raw data into averaged levels and its statistics. The data analysis comprehend the following dimensions according to international recommendations [6, 7, 8, 9, 10, 11] :

- frequency: one-third octave (base 10) bands center frequencies (ex.: 10Hz to 20kHz).
- physical: sound pressure level (SPL), measured in decibels relative to one micropascal (dB re 1μPa);
- temporal: SPL percentiles (ex.: 5th, 10th, 25th, 50th, 75th, 90th, and 95th) based in 1 s time duration;

3.2 Power spectral density estimation

Power spectral density (PSD) estimation may be classically obtained through the Welch's periodogram, through the averaging of the sample power spectrum over a series of 50% overlapped time intervals with Hann windowing, over a given frequency band [12] [13]. The following steps (3.1) to (3.3) are taken in order to obtain the power spectrum estimate:

- sample power spectrum computed from the Discrete Fourier Transform (DFT) for the m-th segment, where N is the number of samples in each segment:

$$p^m[k] = \frac{|X^m[k]^2|}{N}, \tag{3.1}$$

- single-sided power spectrum (Parseval's Theorem scaling method) where $0 < k < \frac{N}{2} - 1$:

$$P_{ss}^{(m)}[k] = 2P^{(m)}[k], \tag{3.2}$$

- power spectrum estimate by averaging over M segments:

$$P_{ss}[k] = \frac{1}{M} \sum_{m=1}^{m=M} P_{ss}^{(m)}[k]. \tag{3.3}$$

The final expression for the PSD is the time average of the sample spectrum (3.1) over the M time segments, distributed within each frequency bin width $\Delta f = \frac{F_s}{N}$, given by

$$PSD[k] = \frac{1}{M} \sum_{m=1}^{m=M} 2\frac{|X^m[k]|^2}{NB\Delta f}. \tag{3.4}$$

where $B = \frac{1}{N} \sum_{n=0}^{N-1} \left(\frac{w[n]}{\alpha}\right)^2$ is the normalization factor related to the time window $w[n]$ being used and F_s is the sampling frequency.

3.3 Frequency bands

Is it becoming a well accepted standard to estimate sound pressure level by frequency bands according to the well known 1/3-octave (base 10) bands determined according to the American National Standards Institute (ANSI) [7],

- 1/3-octave band center frequencies

$$f_{ci} = f_{ref} 10^{\frac{i-1}{10}}, \tag{3.5}$$

  where f_{ref} is the standardized reference frequency of 1 kHz, $i \geq 1$ corresponds to $f_c \geq 1$ kHz and $i < 1$ corresponds to $f_c <$1 kHz,

- i-th sub-band upper bound

$$f_{upper} = f_{ci} 10^{\frac{1}{20}}, \tag{3.6}$$

- i-th sub-band lower band

$$f_{lower} = f_{ci} 10^{\frac{-1}{20}}. \tag{3.7}$$

3.4 Sound pressure level

Sound pressure level (SPL) is defined as the sound intensity of a plane wave [14, 15]. Assuming a constant water impedance, sound intensity may be replaced by sound pressure, in Pascal [Pa] or micro Pascal [μPa] units. Considering the reference power pressure in water ($p_{ref}^2 = 1\mu$Pa) and the power spectrum estimates defined in (3.3), SPL in dB re $1\mu\text{Pa}^2$ is given by:

$$SPL(f) = 10log_{10}\left(\frac{P_{ss}(f)}{p_{ref}^2}\right) - S(f), \tag{3.8}$$

where $S(f)$ is the calibration factor defined in section 2. Considering the 1/3-octave band level, which is the sum of the power in all adjacent band levels and covers the entire bandwidth, the SPL can be given as:

$$SPL(m, f_{ci}) = 10log_{10}\left(\frac{1}{p_{ref}^2}\sum_{k=f_{lower}}^{k=f_{upper}}\frac{P_{ss}^{(m)}(k)}{B}\right) - S(f_{ci}), \tag{3.9}$$

where $P_{ss}^{(m)}(k)$ is the power spectrum of the m^{th} segment, f_{upper} and f_{lower} are the upper and lower bounds of each 1/3-octave band centre frequencies computed directly from the time-domain and $S(f_{ci})$ the calibration correction factor for center frequency f_{ci} as defined in section 2.

3.5 Percentile level

Percentiles are a common statistical indicator used in ocean sound to define the SPL exceeded during a specific percentage of time in the considered interval. To obtain the percentiles the SPL histogram is calculated over a given time interval taken as representative of the empirical probability density function, and then deduced the inverse distribution function between 0% and 100% which consequently returns the percentile values. This means that the N-th percentile is the value of an estimated parameter below which N % of observations fall, in a specified analysis window, or more specifically, for example, the 25^{th} percentile is the value below which 25% of the observations may be found. Typical percentiles agreed in underwater acoustics are: 5, 10, 25, 50, 75, 90 and 95. Percentile 50 is the median, that is similar to the time average, but often used since less prone to outliers.

Chapter 4

Visualization and data exchange

Data visualization and exchange heavily depend on the purpose of the experiment, data wise. Soundscaping analysis usually seek to characterize the ocean status from its sound, or more specifically, the contribution of human activity for the ocean noise component. Since ocean phenomena are not bounded by administrative or legal borders, ocean status evaluation is usually undertaken as a cooperation between several institutions and countries. Visualization and exchanging should be presented in a consistent way in order to avoid inconsistencies in the analysis of the data and to ensure that sensitive data is dully protected.

4.1 Visualization

It is relatively common to represent ocean sound along five dimensions: latitude, longitude, depth, time and frequency. However, when making experimental observations, the first three geographical dimensions are often reduced, due to the fact that the equipment's location can be considered as a single dimension, specially in cases where the measuring equipment is not moving (which is the case of an EON).

Therefore, time and frequency become the representative variables. As explained in the previous chapter, time may be represented by percentiles that is a statistical indicator of the SPL value below which a given percentage of observations in a given group (time interval) falls. On the other hand, frequency representation may be narrowband or broadband. Narrowband is normally adopted for some representative 1/3-octave sub-bands for the observation of a given phenomenon. An example could be 64 or 126 Hz normally used for shipping noise. For biological impact studies, a broadband representation is preferred, where received power is usually summed across the sub-bands. Acoustic data visualization often considers two quantities (shown as illustration in figure 4.1):

- sound pressure level (SPL) as a relative PSD spectrogram over the whole band of interest (up to the allowed maximum frequency), with an averaging time interval of 1 s
- several percentiles, calculated from a statistical analysis of SPL through time.

There are currently several tools available for performing the preliminary acoustic analysis, that can be selected depending on the purpose of the analysis, platform being used or

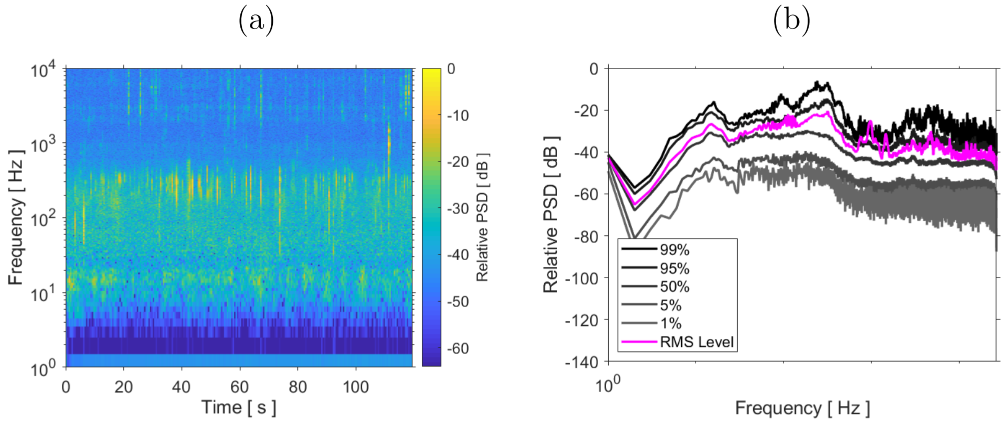

Figure 4.1: *Typical acoustic data visualization: spectrogram (a) and data percentiles across frequency (b) [source: PAMGuide[1]].*

software requirements. Table 4.1 lists a non exhaustive selection of tools drawn from the literature and from the web. Even if all the software packages of this list allow for

Table 4.1: Some available visualization tools.

Nº	Name	Platform	Available at:
1	CHORUS	MATLAB	`https://cmst.curtin.edu.au/products/` [16]
2	PAMGuard		`http://www.pamguard.org/download.php?id=108`
3	PAMGuide	MATLAB	`http://www.siplab.fct.ualg.pt/proj/jonas/pam2py.shtml`
4	PAM2Py	PYTHON	`http://www.siplab.fct.ualg.pt/proj/jonas/pam2py.shtml`
5	Triton Package	MATLAB	`http://www.cetus.ucsd.edu/technologies_triton.html`
6	Sound Ruler		`http://soundruler.sourceforge.net/main/`
7	Sound Analysis Pro		`http://soundanalysispro.com`
8	SeaPro and SeaWave		`http://www.unipv.it/cibra/seapro.html`
9	Raven Lite		`https://ravensoundsoftware.com/software/raven-lite/`
10	Bioacustics package	R	`https://cran.rproject.org/web/packages/bioacoustics/index.html`
11	Seawave package	R	`https://cran.r-project.org/web/packages/seewave/index.html`

acoustic analysis and are open-source tools, there are some notable differences. One is the coding language that varies between Matlab, Python, R and others. The other is that some of the tools, as for example CHORUS, PAMGuard and Triton, are specially designed for the analysis of large datasets. Other tools as PAMGuide or PAM2Py allow to analyse data and create an exchanging file containing the accompanying metadata that describes the data context and the data itself. Finally, Sound Analysis Pro, SeaPro and SeaWave, Raven Lite are specially designed and dedicated to biological acoustic analysis, and implement particular analysis tools for that purpose.

4.2 Data exchange

Extended soundscape analysis often requires the exchange of data between institutions / laboratories or research teams. The precautions taken above do mitigate acoustic data sensitivity and provide some degree of data reduction. The institutions owning the data may also define shareable data subsets and sharing conditions. Another important aspect when dealing with data exchange, is the metadata which is a fundamental piece of additional information for understanding the data being shared. Metadata should summarize the basic information about the data and also provide additional information for data display, tracking and comparison. Usually, this description relies on a few parameters as for example: geographical coordinates, equipment sensitivity, calibration parameters, averaging time, frequencies sampling, resolution, use restrictions, etc.

In the past, the JONAS project[1] (an INTERREG Atlantic Area funded research project) proposed an exchange data format, the so-called EDF, which is a high level group of descriptors, based on HDF5 low level format files that allows to share acoustic data in a structured and fully described form without entailing data privacy concerns. This exchanging format is included in PAMGuide and PAM2Py tools and is fully described in JONAS project "Deliverable 4.3 - Data sharing platform" [17].

Additionally, there are several low level file formats available that may be used to store the exchange data descriptors as for example Network Common Data Form (NetCDF),[2], Hierarchical Data Format version 5 (HDF5)[3], Common Separated Data (CSV)[4], ROOT[5], Zarr[6], etc. [18]

Due to the success of NetCDF file formats in the ocean exploration domain, it was recently added to PAMGuide and PAM2Py tools a new feature, specially prepared for EMSO-PT project[7] needs that allow to create exchanging acoustic files respecting the metrics described in "Deliverable 4.3 - Data sharing platform" [17] also in NetCDF file format.

[1] https://www.jonasproject.eu
[2] https://www.unidata.ucar.edu/software/netcdf/
[3] https://www.hdfgroup.org/solutions/hdf5/
[4] https://datahub.io/docs/data-packages/csv
[5] https://root.cern/
[6] https://zarr.readthedocs.io/en/stable/
[7] https://www.ccmar.ualg.pt/page/emso-pt

Chapter 5

Simulated test case

This section presents an illustrative example of how the proposed calibration and processing steps could be applied to an acoustic data set acquired on a hypothetical CAM-ring EON. Since the EON and CAM-ring currently do not exist, this is a simulated exercise. This simulation has the following advantages: 1) it sets the stage for a full simulation of an extended area covering several EONs in various locations (deep water, shallow water, landing area in islands, etc), 2) it may be used to place upper bounds on performance of ocean sound analysis and modelling tools, and 3) it allows to determine the optimal performance for the detection of sound sources (*e.g.*, marine mammals). In that respect it may be a valuable tool for system deployment planning and for the development of data analysis tools.

This exercise is based on the scenarios presented in deliverable "D4.1 - Environmental and system scenario description" [2], complemented with actual AIS data from 2019, for simulating the received signal at an EON due to shipping. The stage was set in the northwest coast of Portugal, near the cable departure point at Figueira da Foz. Thus, this example covers the stages from the modeling of the received signal at the EON till the data file creation used to for data exchange (Figure 5.1), which contains averaged levels, statistics and the corresponding metadata.

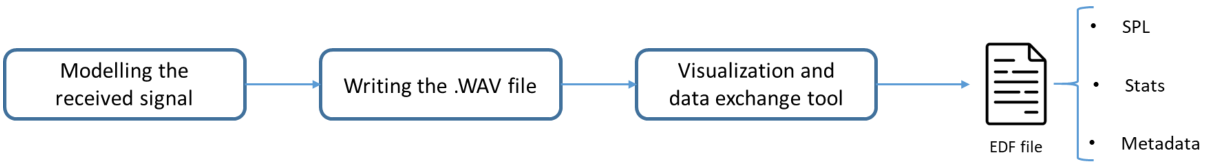

Figure 5.1: *Simulated test case stages from the modeling of the signal received at the EON till the creation of the exchange data file.*

5.1 Description of the region of interest

The target region between Nazaré and Aveiro, extending offshore to -11 degrees longitude west, is shown in Figure 5.2. The bathymetry, represented as contour white lines in this figure, shows an extended platform of approximately 100 km from the shoreline and then to the west quickly reaching depths of 3000 m and more. Color code shows the cumulative number of AIS (Exact Earth)[1] vessel contacts, during the first week of July 2019. The black dashed square is the area of dedicated analysis. In this area it is possible to observe

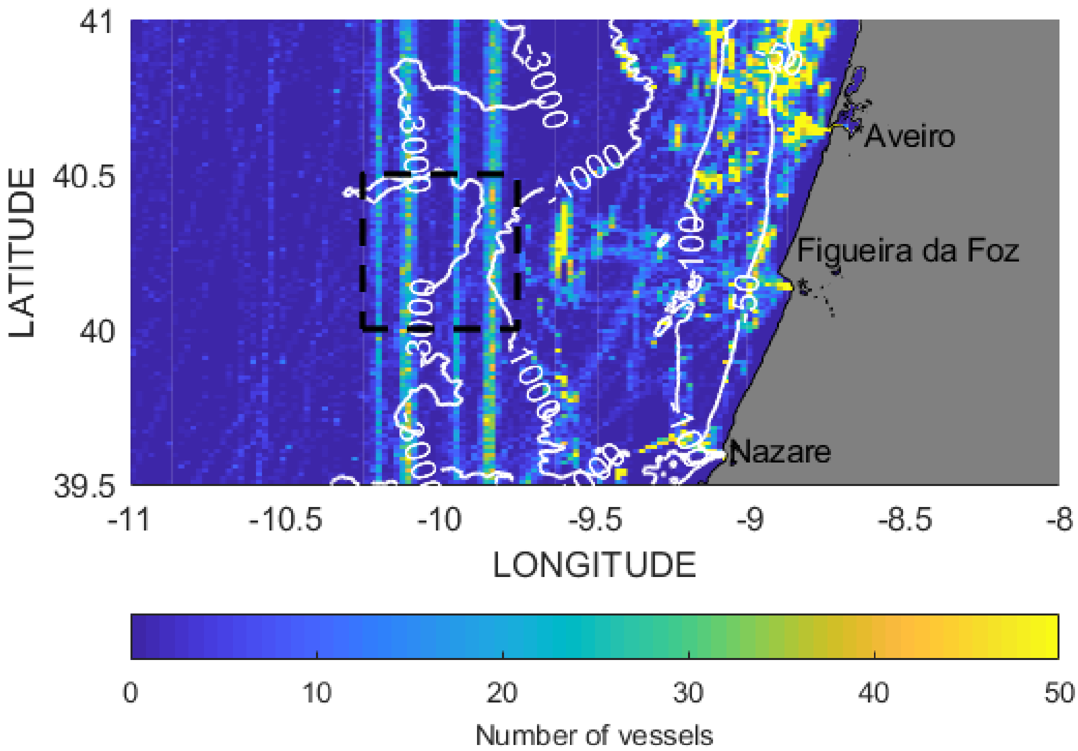

Figure 5.2: *cumulative AIS distribution in the first week of July 2019 and bathymetry at the starting point at Figueira da Foz. The black dashed square shows the target area analysed (longitude -10.25 to -9.75 and latitude 40 to 40.5).*

the two high density shipping lanes, the Traffic Separation System (TSS), resulting from the high ship density north and south bound sailing from/to the strait of Gibraltar to/from the north of Europe. These traffic lanes are in fact very clear which makes it an interesting test case from the point of view of shipping noise analysis and soundscaping. Based on the AIS, this region of the Atlantic North is populated with a panoply of vessel categories as for example tankers, cargos, fishing vessels, sailing vessels, etc, being the tankers and the cargo the most abundant. High density of ships can also be found offshore Aveiro and approaching the ports of Figueira da Foz and Nazaré, which are believed to be due to fishing vessels. In order to reduce the computational complexity, the modelling stage will only consider the area delimited by the dashed black square [-10.25- -9.75W, 40-40.5N] as depicted in Figure 5.2. This makes it possible to simulate the signal received by the EON due to the intense traffic lanes in this specific area.

[1] `https://insights.spire.com`

5.2 Modeling the received signal

Acoustic propagation modeling was based on scenario 3 described in chapter 4.3 of deliverable D4.1 [2]. The scenario meant to represent a range independent deep water case study (water depth between 3000 and 5000 m), with a double minimum sound speed profile reaching the critical depth, as shown in Figure 5.3.

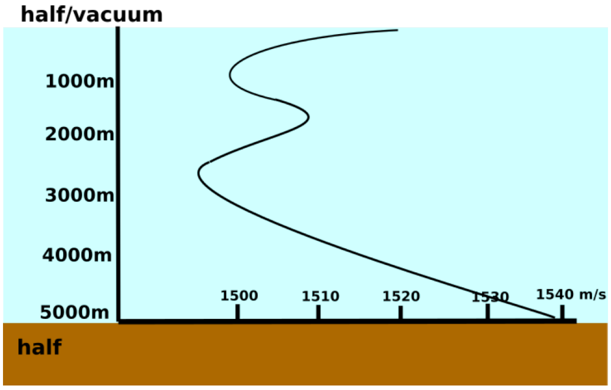

Figure 5.3: *Range independent scenario for the abyssal plain between Portugal and Azores (extracted from [2])*

Modeling the signal received at the EON involves several steps that are sketched in the diagram of Figure 5.4. The first stage concerns the definition of the region of interest and

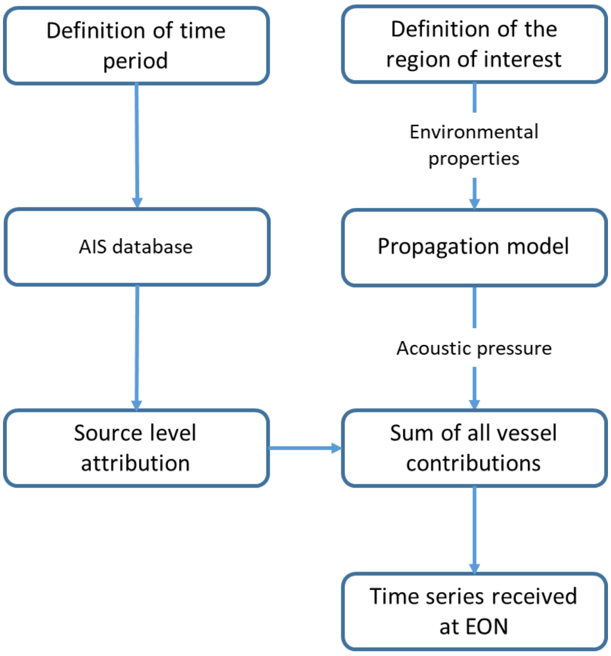

Figure 5.4: *Modeling the received signal time series.*

period of time. At this stage, the first week of July 2019 and the area corresponding to the black dashed square as shown in Figure 5.2 [-10.25; -9.75W, 40.0-40.5N] were selected.

The bathymetry of the area of interest was obtained from the GEBCO[2] database [19] that showed that the area surrounding the EON location at -10 degrees longitude west and 40.25 latitude north, is in its majority deep water (>3000 m depth) on the northwest and between 500 to 2500 m on the southeast. The EON receiver was deliberately placed in between the TSS tracks.

Water column physical properties, temperature and salinity, were obtained through the Copernicus - CMEMS database[3] and used to calculate the sound speed profile (SSP) through the McKenzie 9-term equation [20]. In this scenario, bottom properties are assumed to play a minimal role on acoustic propagation therefore, a generic bottom composed of one sand sediment layer over a rocky sub-bottom according to the model proposed by Soares *et al.* [21] and detailed in Table 5.1, was used. The acoustic field was

Table 5.1: Assumed seabed parameters (adapted from [21]).

Model Parameter (units)	**Value**
Sediment speed (m/s)	1650
Sediment density (g/cm^3)	1.9
Sediment attenuation (dB/λ)	0.8
Sediment thickness (m)	10
Sub-bottom speed (m/s)	1800
Sub-bottom density (g/cm^3)	2.8
Sub-bottom attenuation (dB/λ)	0.2

simulated taking into account actual ship positions (based on AIS information) and the receiver hypothetical location of the EON, in the middle of the TSS tracks. The receiver was considered at the bottom and the sources at a mean depth of 7 m, as suggested in Scrimger *et al.* [22]. The AIS data of the target area was obtained through the exactEarth [4] database for the first week of July 2019 with a temporal resolution of 1 second. The source level of each vessel type was estimated taking as reference the source levels determined by McKenna *et al.* [23]. Since there are vessel categories on the AIS list that are not reported on McKenna's list, approximate source levels were drawn from McKenna's list for all AIS vessels in the area. In particular, it was decided to assign a source level of 1% of the cargo source level to sailing vessels, 90% to fishing vessels and 80% to the passenger vessels. The Kraken normal mode model [24, 25] was used to calculate the acoustic field at the 1/3-octave (10 base) band center frequencies between 20 and 1000 Hz. The contributions of all ships in the considered area were coherently summed in the frequency domain and the time series obtained at the EON was obtained through Fourier synthesis.

5.3 Modeling results

This section presents the results obtained during the signal modeling process and exchange data visualization. For illustration, the transmission loss (TL) is shown in Figure 5.5 for 20 Hz (a) and 1000 Hz (b). The TL results at 20 Hz show a minimal excitation of the few

[2] `https://www.gebco.net/`
[3] `https://marine.copernicus.eu/`
[4] now acquired by Spire Global `https://spire.com/maritime/`

modes at the chosen source depth (7 m), resulting in a relatively low energy contribution throughout the range - depth plane. With increasing frequency modal depth sampling also increases and bottom ensonification clearly takes the usual pattern of convergence zones common in deep water.

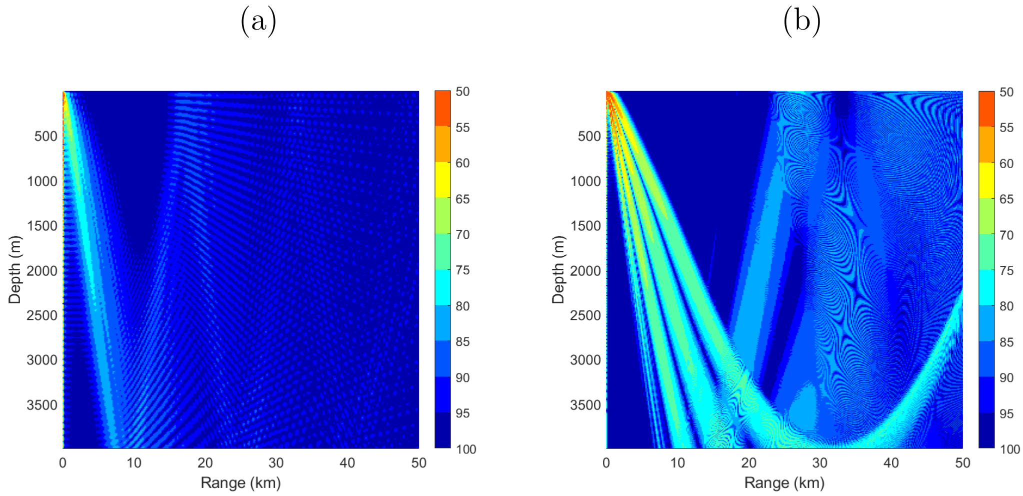

Figure 5.5: Transmission loss at 20 Hz (a) and at 1000 Hz (b).

A short 4 s long time series signal received at the EON is shown in the spectrogram of Figure 5.6, where frequency lines are clearly visible with the expected pattern of higher levels in the mid-frequency range and lower levels at both the lower and upper end of the frequency band. The lower levels at low frequency is possibly due to the source depth excitation of the few modes as already noticed in figure 5.5 (a), while at 1000 Hz it might be due to the lower source levels of the ships contributing to the field at that frequency. The simulated time series was written into a .WAV file and used as input to

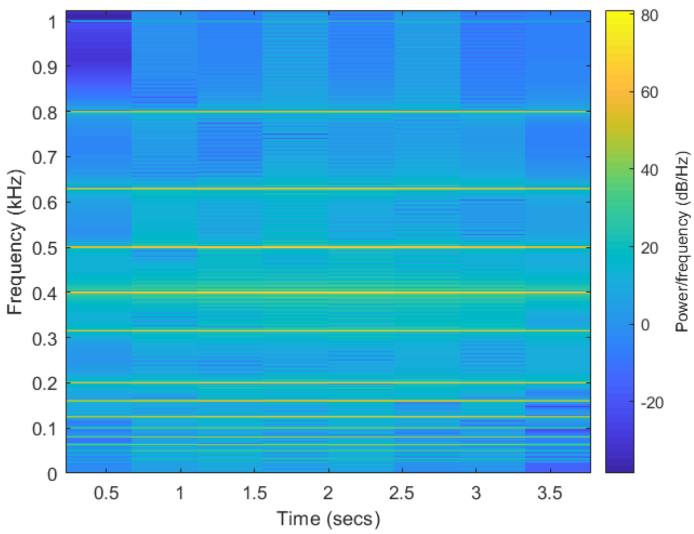

Figure 5.6: *Spectrogram of the simulated signal at the EON for a time duration of 4s.*

the visualization/ exchange tool according to the sequence presented in Figure 5.1. In this case the PAMGuide tool was used since it allows to write the averaged levels in a specific format that best favours data exchange. The results obtained with PAMGuide are presented in Figure 5.7, detailing the spectrogram and some of the percentiles.

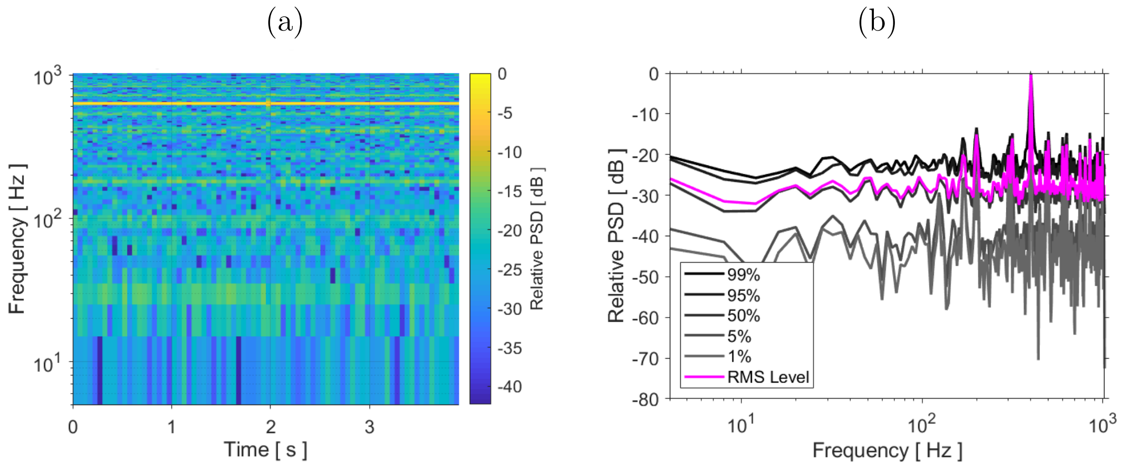

Figure 5.7: PAMGuide visual output: spectrogram (a) and percentiles (b).

Figure 5.7 shows relatively low noise level, being the highest levels exceeded in 5% of the time.

Chapter 6

Wet demonstrator

The K2D consortium is actively planning to deploy a three node wet demonstrator for testing the AUV docking capabilities, acoustic communications and soundscaping, in the area of the Setúbal plateau near the town of Sesimbra. This region is a key spot for marine biodiversity, specially for cetaceans. However this part of the Portuguese coast is also extremely busy in terms of ship traffic and fishing vessels. These factors promote the development of new and more adequate management policies to preserve/protect/monitor marine life in the area. Considering the purpose of the K2D project, Sesimbra offers good conditions to implement underwater equipment due to : a) the existence of a land station between Forte São Teodósio and Naval Club, and b) the bathymetry of the area which extends to 100-200 m depth relatively close to the coast.

6.1 Environmental description

The bathymetry of the area was obtained from GEBCO[1] database and presents a relatively large platform within the 200 m bathymetric line, almost parallel to the coast (Figure 6.1a). This regions offers an interesting feature to the south: the underwater Canyon of Setúbal which favors a number of natural phenomena with an important impact on fisheries and consequently an important spot for cetaceans feeding, specially dolphins. The water column temperature and salinity[2] variation with depth contribute to an interesting estimated sound speed profile that registers a minima approximately at 200 m depth as shown in Figure 6.1(b). It is possible to note that the largest variation takes place in the upper part of the water column, say between the 200 and 300 m depth. This SSP is similar to the one presented and described in scenario 2 of D4.1 - Environmental and system scenario description [2].

The acoustic bottom properties become relevant for sound propagation in shallow waters, however they are relatively difficult to obtain. Fortunately, there were a number sea trials conducted in the area, more precisely, offshore in the continental platform between Sesimbra and the Canyon of Setúbal, that allowed for bottom properties estimation. In this area, the bottom coverage is muddy sand either fine, changing to medium or large grain either mixed or not with biological remains, shells, etc, and its geo-acoustic properties are listed in table 6.1.

[1] `https://www.gebco.net/`

[2] extracted from Copernicus - CMEMS `https://marine.copernicus.eu/`

(a) (b)

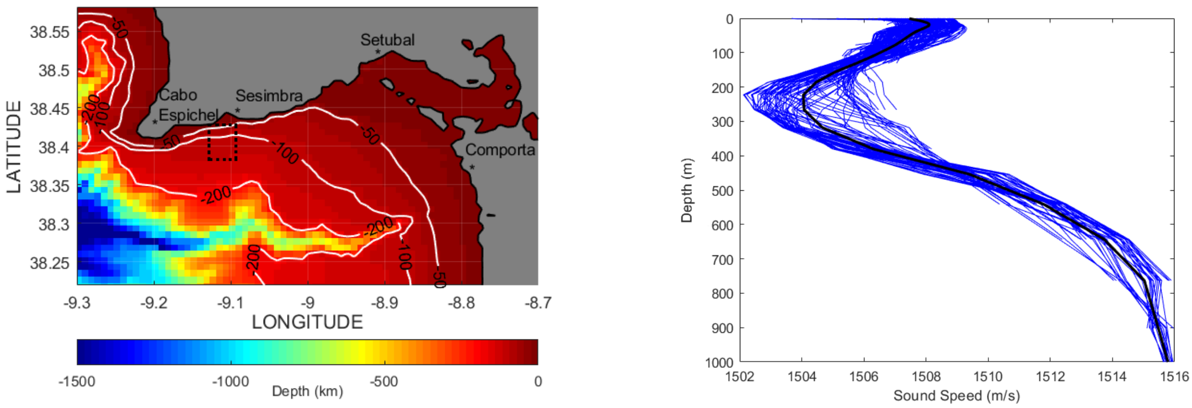

Figure 6.1: Bathymetry of the area for the deployment of the wet demonstrator, marked by the black rectangle (a) and sound speed profiles' variation for the month of July 2019 with mean sound speed profile (thick black line) (b).

Table 6.1: Assumed seabed parameters (adapted from [26]).

Model Parameter (units)	Value
Sediment speed (m/s)	1600
Sediment density (g/cm^3)	1.9
Sediment attenuation (dB/λ)	0.8
Sediment thickness (m)	2-4
Bottom speed (m/s)	1800
Bottom density (g/cm^3)	1.9
Bottom attenuation (dB/λ)	0.8

6.2 Anthropogenic noise prediction

The main contribution to anthropogenic background noise in this area is related with ships passing offshore in their route between the north of Europe and the Strait of Gibraltar, the so-called TSS shipping lanes. Figure 6.2 shows the cumulative AIS distribution during the month of July 2019 based on ExactHearth data base (a) and the predicted shipping noise pressure level (b). Figure 6.2(a) shows that vessels coming along the coast from the North, circumvent the Espichel Cape, and cross off Sesimbra towards the port of Setúbal. However, when passing in front of Sesimbra, at least some vessels tend to move to deeper waters in order to avoid the protected area marked in Figure 6.2(a). Ships above a certain tonnages are forbidden to navigate in this protected area, where fishing and anchoring is also forbidden. As in the case presented in section 5.2 there is a wide variety of vessel categories with different source levels that contribute to the local soundscape. Figure 6.2(b) shows the predicted noise map (mean values) for the month of July 2019. In this case, one can note the loudest levels reaching 135 - 140 dB in various coastal areas, as for example near Cabo Espichel and entering in the Peninsula of Setúbal, that closely match

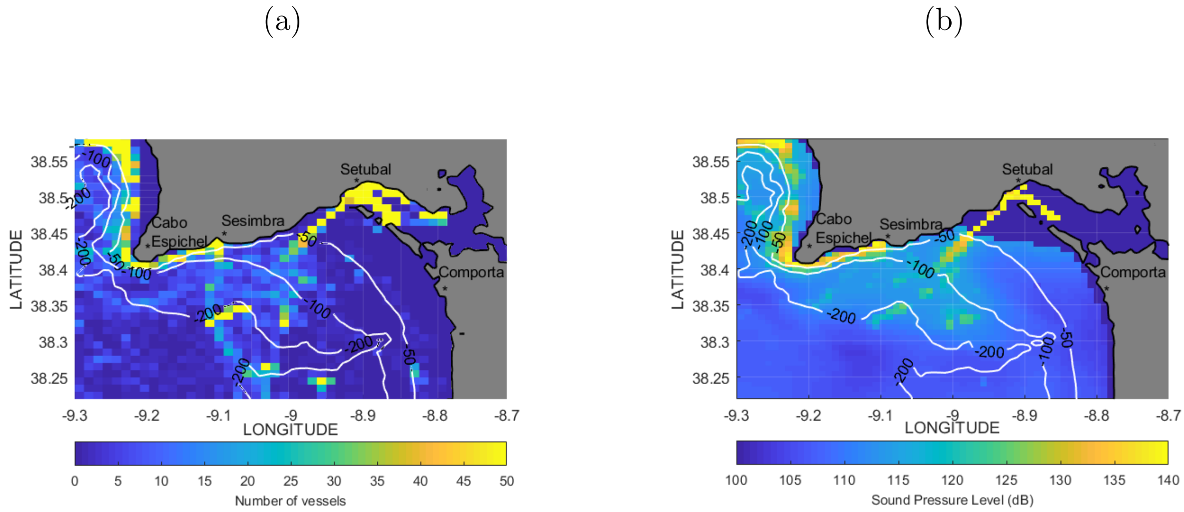

Figure 6.2: Cumulative AIS distribution during the month of July 2019 (a) and mean predicted shipping noise pressure level (dB re 1μPa^2)(b).

the vessel distribution presented in 6.2(a). It is interesting to see that the canyon works as a natural sound barrier largely attenuating the propagation of higher levels produced in the coastal areas towards the south.

Chapter 7

Conclusions

Acoustic data recording requires special attention in order to allow for future comparisons between data collected at different locations along the CAM-ring cable, and with that collected at other observatories. This report, describes some the key steps involved in the acquisition, processing and exchanging of soundscape acoustic data, and provides recommendations that should be taken into account once the data collection by cable installed EONs will become a reality.

Furthermore, this report makes also a series of recommendations regarding strategies for data management and exchange, which is a fundamental issue taking into account the security sensitivity of acoustic data on one hand, and the need for multi-team international collaboration on ocean sound data analysis, on the other hand.

As a proof of concept, an hypothetical cable layout was used to simulate the signal received by an Environmental Observation Node (EON) due to the ships passing by a region near the cable departure point, in deep water, to the west of the town of Figueira da Foz. Since the simulation developed in this study was based on real AIS and environmental column data, the results obtained may offer a good insight into what might be the actual shipping noise field as recorded near the bottom along the cable trajectory. A similar simulation was performed for a shallow water area in the Setúbal plateau near the town of Sesimbra where the wet demonstrator is scheduled to be deployed. This numerical simulation, allowed to have a clear picture of the typical sound levels of the area during the month of July grounded on real ship traffic measurements. In practice, this simulation tool will help to support the decisions to be made during the cable repeater development process, and for the strategy of mosaicking of the sound data pieces into the overall ocean sound model picture.

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