Master's Final Project

Master's in Industrial Engineering

An ocean sound map along the track of a journey around the globe and its applications

MEMORY

Autor: Clea Parcerisas Serrahima
Director: Michel André
Ponent: Jordi Roca
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Escola Tècnica Superior
d'Enginyeria Industrial de Barcelona

"How inappropriate to call this planet Earth when it is quite clearly Ocean."

Sir Arthur C. Clarke

Abstract

The past years have seen increasing levels of noise pollution in the oceans, which has been demonstrated to have a negative impact in marine ecosystems. This project consists in creating a World Sound Map where all the noise generated by the shipping industry (increased due to offshore industrial development) is simulated and shown in an easy-to-understand way, so the public can access this information.

This Sound Map is part of the international project led by the LAB Listen to the Deep Ocean Environment (LIDO), and it consists of an interactive Web Application where the sound pressure distribution of the noise made by the ships can be checked in the vicinity of the journey of a ship which is doing the Globe-Tour as a part of the LIDO project.

This application can be used for many things related to underwater sound: eliminating shipping noise from ocean recordings, evaluating the impact of the presence of ships in different ecosystems or comparing the locations of the ships and marine fauna in order to predict the possible harmful impact of shipping industry in marine fauna.

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1. Glossary

Acronym	*Definition*
ACI	Acoustic Complexity Index
AIS	Automatic Identification System
CLS	Market solutions enterprise
KML	Keyhole Markup Language
LAB	Laboratori d'Aplicacions Bioacustiques
MMSI	Maritime Mobile Service Identity
RL	Received Level
SEL	Sound Exposure Level
SL	Source Level
SPL	Sound Pressure Level
TL	Transmission Loss

Table 1 Glossary

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2. Preface

2.1. Origin of the project

Bioacoustics is a cross-disciplinary science which investigates sound production and reception in animals, including man, the biological acoustically-borne information transfer and its propagation in elastic media. Bioacoustics also refers to the organs of hearing and to the sound production apparatus, as well as to the physiological and neurophysiological processes by which sounds are produced, received and processed. Furthermore, bioacoustics attempts to understand the relationships between the features of the sounds produced by animals and the nature of the environment in which they are made, as well as the functions they are designed to serve. Finally, it includes the techniques associated with instrumental and biological sonar for its use in population monitoring, identification and communication encoding mechanisms which allows the assessment and control of the effects of human-made noise on animals.

The creation of the Laboratory of Applied Bio-Acoustics (LAB) is the necessary and mature response from a multi-disciplinary group of scientists to the increasing acoustic degradation of the marine habitat in the Mediterranean Sea and the North Atlantic.

The LAB has the clear objective to respond with technological solutions to the progressive deterioration of the seas, limiting the effects of anthropogenic noise and contributing to the sustainable development of human marine activities. Research outcome will answer the increasing demand from local, national and European administrations and from the society itself, by providing the necessary expertise on the control mechanisms and a better understanding of the marine noise pollution.

The LAB is leading an international program entitled "Listen to the Deep Ocean Environment (LIDO)" to apply and extend developed techniques for passive acoustic monitoring of natural, biological and artificial (anthropogenic) sounds. The present project is planned to be an extension of the LIDO project.

2.2. Motivation

The next decades will see increasing levels of offshore industrial development that will lead to increased levels of noise pollution in the oceans. These sounds may have physical, physiological and behavioral effects on marine fauna in the area of activity. Indeed, mammals, reptiles, fish and invertebrates can be affected at various levels depending on the distance to the sound source. The problem faced by the industry, and more generally by society, is that many economically important activities at sea are at risk because of a lack of information about the effects of anthropogenic (human-made) sounds on marine mammals and especially a lack of available tools to mitigate these effects. Technological developments are needed to combine the interests of the industry and the good environmental status of the oceans.

The sea environment is filled with natural sounds, although increasingly many anthropogenic sources have contributed to the general noise budget of the oceans. The extent to which sound in the sea impacts and affects marine life is a topic of considerable current interest both to the scientific community and to the public. Scientific interest arises from a need to understand more about the role of sound production and reception in the behavior, physiology, and ecology of marine organisms and how anthropogenic sound, including sound necessary to study the marine environment, can interfere with the natural use of sound by marine organisms. Public interest concerns primarily the potential effects of anthropogenic sound on marine mammals, given the broad recognition of the importance of sound in the lives of these species. For acoustical oceanographers, marine seismologists, and minerals explorers, sound is the most powerful remote-sensing tool available to determine the geological structure of the seabed and to discover oil and gas reserves deep below the seafloor.

The scientific and the public interest in the impact of human-generated ocean noise on marine animals has greatly increased. Concerns include whether human-generated sounds may interfere with the normal use of sound produced by marine animals or whether the human-generated sounds may cause the animals physical harm.

Many aquatic animals use sound for communication between members of their species. But equally important is the fact that all these species probably also use sound to learn about their environment and to survive. Therefore, there should be concern not only about the effects of anthropogenic sounds on communication but also about the impact on general extraction of information from the environment. A fundamental question is whether the impact of anthropogenic sounds on marine mammals and the marine ecosystem is sufficiently important to warrant concern by both the scientific community and the public. The data currently available suggest that such interest is indeed justified.

However, our knowledge is still quite limited, and it is therefore essential to develop a program that will help to establish a scientific base allowing to 1) automatically identify and classify non-biological and biological sounds, 2) monitor marine organisms and population dynamics, 3) assess and control the long-term effects of anthropogenic sources on marine organisms. This 3rd point of the LIDO assessments is the one concerning this project, which simulates and evaluates anthropogenic sounds and shows its impact to denounce their excess.

Personally, I decided to study engineering because I wanted to apply science to the real world. I was amazed by how, by putting some numbers together one could decide the size of a building or the shape of a bridge.

When I discovered that the world was collapsing, and the humans were destroying our planet, I realized that what I wanted to do was not only to apply science to real world but to understand it and to apply this knowledge to make it safer and greener. These thoughts brought me to research, where every day millions of researches struggle their brains to discover new things that will make a difference. In addition, and after years of studying I obtained my degree in classical music, which has always been my biggest eviction of the world. Finally, nature and animals, especially marine mammals with all their wise and their elegance have always been one of my passions. Sailing in the sea is my favorite place to be since I am a kid, and there is no better way to fall asleep than in a boat.

The combination of the three things makes the LAB (and this particular project), where it is possible to combine engineering research with marine mammals and sound, the best place to be to develop my Master Thesis and where I expect to be honored to develop the PhD.

3. Introduction

3.1. Objectives

OMExpedition is a Globe World Tour by ship. Its objective is to get recordings and samples all along the way of the ship, and many different projects are being developed from this data acquisition.

Using the ship position and the data acquired all along the journey, the LAB pretends to create a public application where everybody can access the sound pressure level distribution in an interactive and easy way, to prove and denounce the acoustic contamination of the ocean, which is demonstrated that can be harmful for lot of animal species.

The objective of the Sound Map project is to be able to know and predict the sound pressure distribution made by the shipping noise. To do so, AIS data is used to get ships' information and compute the sound they generate.

The LAB's ship records the ocean sounds at its position when the engine stops, and with these recordings the simulation can be verified by checking if the sound pressure computed by the simulation at the ships' place is the same than the one recorded with the hydrophone.

3.2. Scope

The present project pretends to create the Web Application used to show the sound pressure level distribution during the OMExpedition. To do so, a Web Server is set, and all the users' interface is designed and implemented.

To show the sound pressure level distribution, a simulation model is designed and implemented to predict the source level of each ship and its propagation. As it is a rough approximation and due to the lack of some information, several assumptions are made regarding the sound generation and propagation.

The design of the application and the implementation of the simulation have different applications that will be also studied in the present project, as the comparation with animal's distribution layers to get to know the zones that are affecting directly to animal's health.

As the noise due to the shipping will be known, it can also be used to reduce the noise of different recordings if the location of the recording is known. It is the case of the characterization of the Great Coral Reef's soundscapes, which will also be treated in this project.

4. Web Application Design

4.1. Technical specifications

4.1.1. Web Frame Work

The Frame Work for the application is FLASK, which is based in WSGI specification and the template's motor Jinja2 and has a BSD license.

FLASK is the link between the python server-side and the JavaScript client-side.

4.1.2. Data Bases

4.1.2.1. Antinea

The database used to store the data is one already existing in the LAB server.

Two different tables are used:

- Ship's table: ships information is stored.
- Ais table: ship's AIS messages
- Tracking table: the position of the ship of the OMExpedition

Parameter name	*Description*
id	Id of the entrance
mmsi	Maritime Mobile Service Identity
status	AIS status
longitude	In degrees
latitude	In degrees
speed	In knots
heading	Not used
destination	Not used
rot	Not used
course	Direction of the ship
epfd	Not used
maneuver	Not used
draught	Source depth
accuracy	Not used
dte	Not used

cs	Not used
display	Not used
dsc	Not used
band	Not used
msg22	Not used
assigned	Not used
raim	Not used
source_level_63	Not used
recv_level_63	Not used
source_level_125	Not used
recv_level_125	Not used
source_level_1000	Not used
recv_level_1000	Not used
hyd_distance	Not used
hyd_angle	Not used
second	Not used
timestamp	Unix timestamp

Table 2 Antinea.ais table

Parameter name	*Description*
mmsi	Maritime Mobile Service Identity
shipname	Name of the ship
shiptype	AIS ship type
callsign	Not used
imo	Not used
vendorid	Not used
to_starboard	Not used
to_port	Not used
to_stern	Ship lenght / 2
to_bow	Ship lenght / 2

Table 3 Antinea.ships table

Parameter name	*Description*
id	Id of the entrance
class_id	Type of data stored. Tracking is `0xE0000100`
result	Longitude
param_0	Latitude

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param_1	Not used
param_2	Not used
param_3	Not used
param_4	Not used
param_5	Not used
timestamp	Unix timestamp
run_id	Not used
segment_id	Not used

Table 4 Antinea.archived table

Connection

The connections to the data base from are executed with MySQL in the server-side by using the python tool `mysqlpy`.

4.1.2.2. Bathymetry

The bathymetry data is stored in a *.cgi file (http://topex.ucsd.edu/cgi-bin/get_data.cgi) from a public database from the University of San Diego, California.

This file is downloaded and every time that the simulation of the sound distribution of a square is ran the correspondent part is read and stored and later on interpolated.

4.1.3. Coding

To code the client-side JavaScript is chosen as the main language because all the modern web navigators interprets the JavaScript code integrated in the web pages.

AJAX and jQuery are used as complementary tools to improve user's experience.

All the code is load in one *.js file and different html templates that, using FLASK can give an interactive Web Application.

4.1.3.1. KML files

KML is a file format used to display geographic data in an Earth browser such as Google Earth. You can create KML files to pinpoint locations, add image overlays, and expose rich data in new ways. KML is an international standard maintained by the Open Geospatial Consortium, Inc. (OGC).

In this Web Application, KML is chosen as the extension to load the information to be plotted in the map.

4.2. Graphical Interface

4.2.1. Interactions

When the user enters to the home web, different actions can be performed. The main one is to move and scroll the map and zoom in and out to have a better view of the different parts of the globe.

On the main map there are some available layers that can be turned on and off:

- Layer with all the study squares: All the squares are shown, and they can be clicked to get information about the position and the date of the study square. Once a square is clicked, a button “Go to Sound Simulation” is enabled, which loads the simulation square.
- Layer with the ship’s journey: Users can approach the mouse to the journey line and they will see the information about the date and the position of the ship at the selected point.
- Layer with the Marine Regions[5]

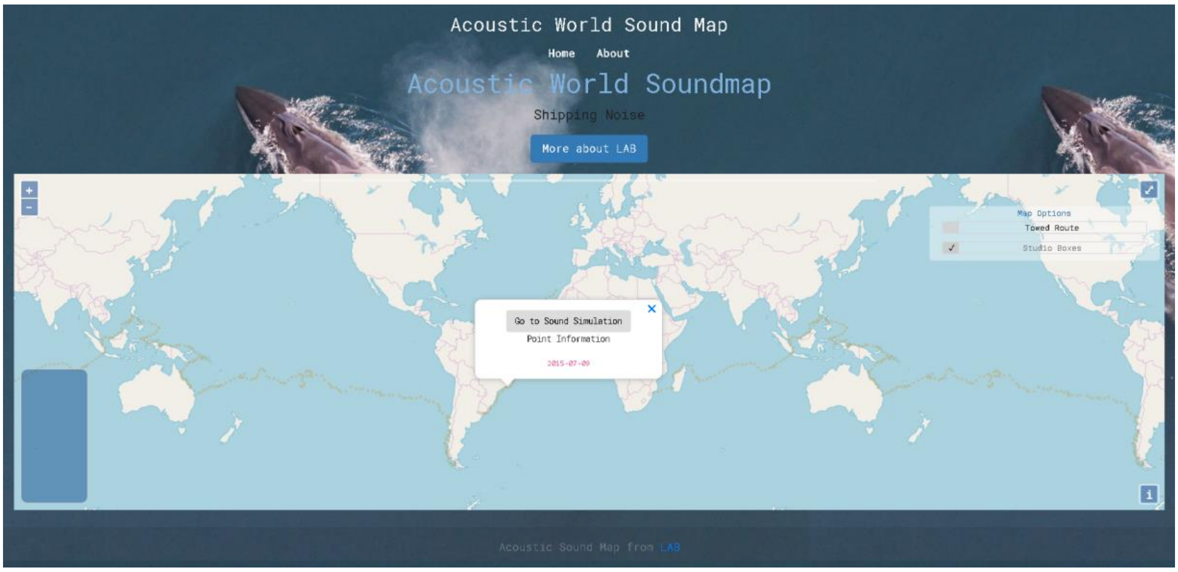

Figure 1 Capture of the World Map

One the user gets to the Sound Simulation page by clicking the “Go to Sound Simulation” button, the map zooms to the simulation square, and the first sound pressure level loads, together with all the ships (the ones moving and, thus, contributing to the sound pressure level map and the ones stopped and, thus, not contributing).

The ships can be clicked by the user and their information is loaded. A button is available to load the ship’s SL distribution, so the user can see how the SL is distributed relative to the azimuth angle (the course of the ship).

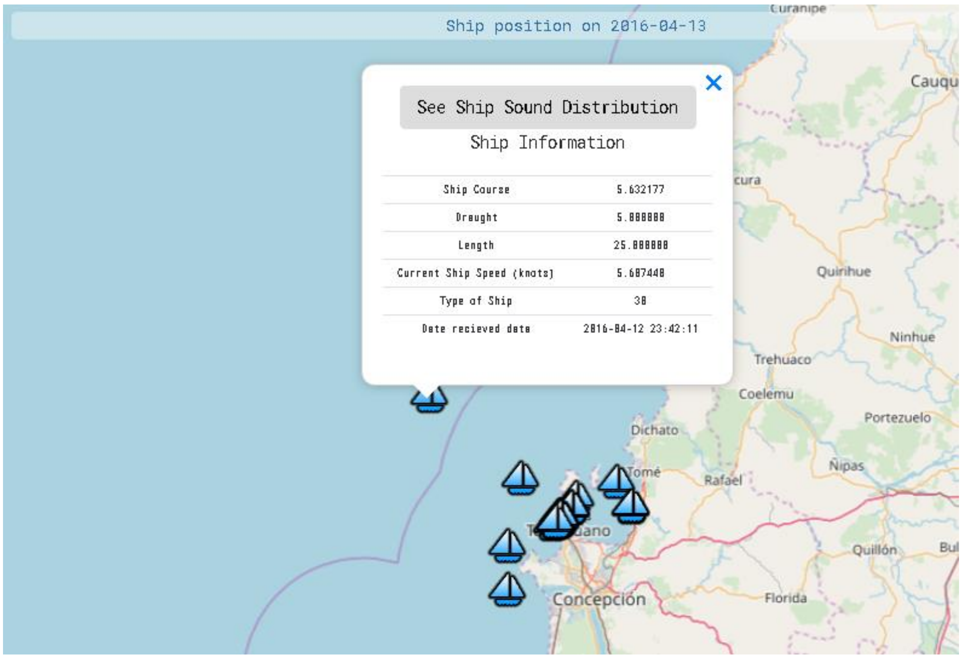

Figure 2 Ship Information When clicking

When entering to the sound simulation square, other map features are enabled:

- Simulation frequency selection: 20,63, 125 and 200 Hz
- Simulation depth selection: 10, 100, 800 and 1000 m

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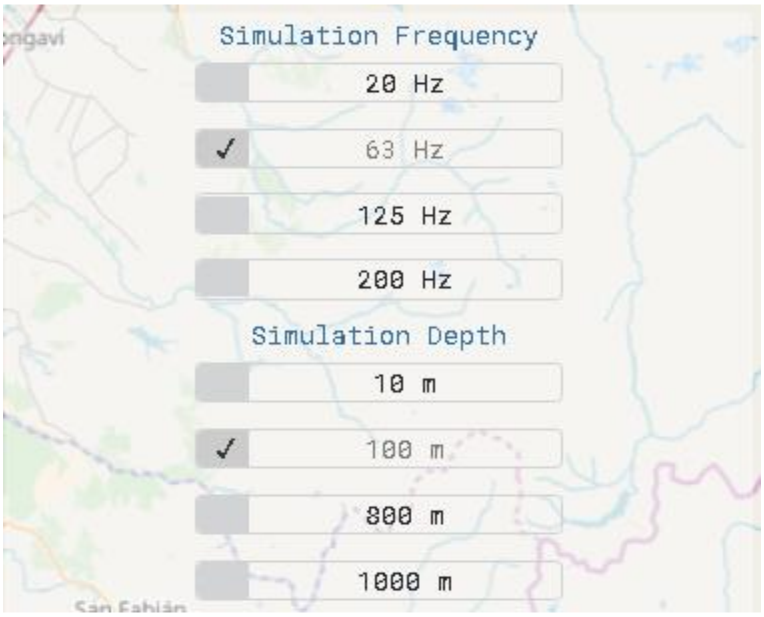


Figure 3 Frequency and Depth options

By default, the sound pressure level layer is loaded together with a small legend, but it can be disabled at any moment and other layers can be enabled:

- Marine Regions: Shows the different Marine Regions.
- Sound density (automatically disables de sound pressure distribution layer)

The time of the simulation can be changed by using a slider that loads the ships and the simulation of every 2 h, which is considered the appropriate interval time to show the changes in time staying in a realistic and coherent time-space coincidence between ships and with the AIS message interval (minimum of 30 min).

4.2.2. Aesthetic design

The design is set using Bootstrap and css styles. As the idea is to include the Sound Map to the LAB's site listentothedeep.com, the design is following the corporative style.

The main idea is to make things clear, spaced and intuitive; easy to understand. The following captures show some of the screens of the web application.

Figure 4 Aesthetic design

5. Model Simulation

5.1. Available data

Nowadays, there is a lot of available data or, at least, it can be obtained. Even so, the aim of the present project is not to get the most precise Sound Map but a rough approximation with the minimum data.

So, there is no data about the real SL of the ships and no data about the ocean parameters (weather conditions, salinity, sound speed profile, temperature ...). The available data, which is the one that is considered essential to develop the project and can be obtained at a reasonable price is resumed in the following chapters.

5.1.1. AIS data

The automatic identification system (AIS) is an automatic tracking system used on ships and by vessel traffic services (VTS). When satellites are used to detect AIS signatures, the term Satellite-AIS (S-AIS) is used.

Information provided by AIS equipment, such as unique identification, position, course, and speed, can be accessed from different satellites' DB. AIS is intended to assist a vessel's watchstanding officers and allow maritime authorities to track and monitor vessel movements. AIS integrates a standardized VHF transceiver with a positioning system such as a GPS receiver, with other electronic navigation sensors, such as a gyrocompass or rate of turn indicator.

Vessels fitted with AIS transceivers can be tracked by AIS base stations located along coast lines or, when out of range of terrestrial networks, through a growing number of satellites that are fitted with special AIS receivers which are capable of deconflicting a large number of signatures.

An AIS message contains, at least, the following information (can be more extended):

Field name	*Field value*
Latitude	Decimal latitude
Longitude	Decimal longitude
Timestamp	UNIX timestamp
Ship type	0-131 different ship types [1]
Speed	In knots
Status	0-15 different moving status[2]
Ship length	[m]
Ship width	[m]

Table 5 AIS fields

AIS data in real-time is free and available for everyone, but not historical data. Only enterprises with AIS-receivers, both terrestrial and satellites, have access to it, and it has to be purchased.

The LAB decided to purchase the historical data to CLS (a market solutions enterprise), and the AIS data from every square simulation limits during its respective time interval was obtained.

Even the data is complete, the fact that CLS has only the satellite-received AIS data makes the amount of ships per square very low compared to reality.

The data from CLS is compared to the actual traffic that can be seen in Marine Traffic (www.marinetraffic.com) to check whether if the density obtained from CLS is realistic or not.

[1] Information from Marine Traffic. https://help.marinetraffic.com/hc/en-us/articles/205579997-What-is-the-significance-of-the-AIS-SHIPTYPE-number-

[2] See Apendix 0

5.1.2. LAB's ship position

The ship records its position with its respective timestamp directly to the Antinea database.

Latitude, Longitude and timestamp of the ship during all the journey are available from the LAB's Antinea database.

5.1.3. Bathymetry

The topex bathymetry file is an accurate world bathymetry database which can be used for free for any non-profit purposes and is accessible to everyone. [1]

The resolution of the dB is one minute, and it can be interpolated to generate a softer surface.

5.2. Underwater noise transmission principles

The objective of the current project is to get an approximation of the sound pressure level, but only using the AIS data. As the information is limited, it is only possible to get a rough approximation of the sound pressure levels.

The underwater sound transmission depends on many factors as the water temperature, underwater sound speed distribution, salinity, world location, weather conditions, wind speed, bottom surface's shape etc.

Since not a lot of precision is achievable, only the main factors are considered to create the propagation model, which are the ones having an effect of the same magnitude order than the information obtained from the AIS data.

5.2.1. Fundamental sound wave concepts

The oscillation of water particles (in this case the sea), happens at a standstill, meaning that the particles move themselves in relation to a position of equilibrium, transmitting this movement to their neighboring particles. This oscillation can be slow or fast producing what we differentiate between low pitch sounds (slow oscillation) or high pitch sounds (fast oscillation). The concept of frequency is used to put values on these oscillations which establish the oscillations per second that are produced in the particles from the medium with respect to their position of equilibrium. The magnitude for measuring said oscillations is Hertz (oscillations per second).[1]

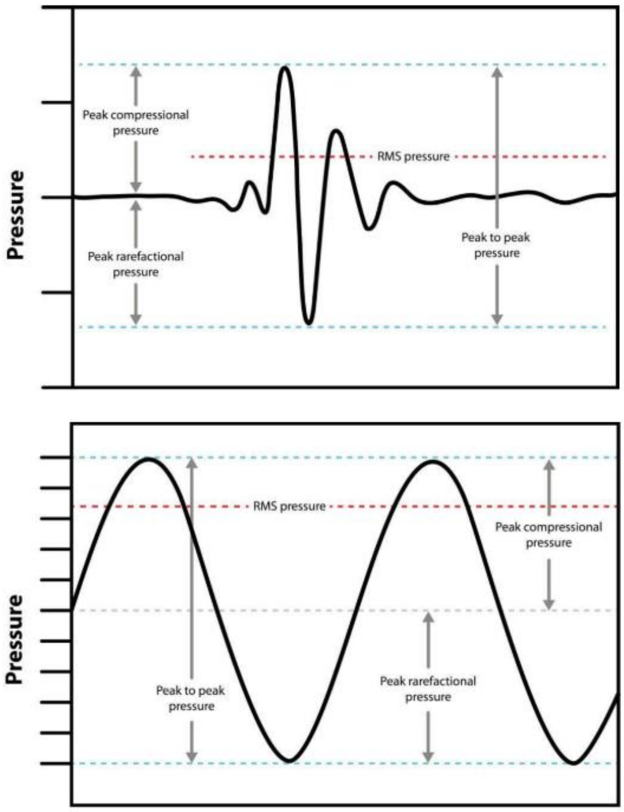


Figure 5 Some of the metrics for sound pressure illustrated for a sound pulse (upper plot) and for a periodic waveform (lower plot) [2]

A sound wave is a pressure wave propagating through a medium. The solution to the wave equation is a sinusoidal that depends on the distance from the source, the frequency of oscillation, the time and the medium characteristics. The main parameters are:

λ, wavelength. Distance between pressure peaks in [m]

c, propagation speed. Speed at which the wave reaches other points. [m/s]

f, frequency. Quantity of oscillations per unit of time. [Hz]

Which are related by the following equation:

$$\lambda = \frac{f}{c}$$

The pressure at any point in the medium can be expressed as a function of the distance, r and the time t from the source, and at each point at a distance r from the source, there is a maximum amplitude of the wave, P, which is the peak pressure.

If a static study is performed, the parameter of interest is the rms value of the pressure (and not the peak value) which is calculated as follows [3]:

$$\hat{p} = \overline{P_{RMS}} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_t}^{t_2} p(t)^2 dt}$$

A propagating sound wave carries mechanical energy with it in the form of kinetic energy of the particles in motion plus the potential energy of the stresses set up in the elastic medium. Because the wave is propagating, a certain amount of energy per second, or power, is crossing a unit area. This power per unit area, or power density, is the intensity I of the wave.

$$\hat{I} = \frac{\hat{p}^2}{\rho c}$$

Where:

ρ is the density of the medium

c is the sound speed of the medium in [m/s]

The Sound Pressure Level (SPL) is the expression of the magnitude of sound pressure in dB referred to a concrete reference magnitude. Sound Pressure values are in general far lower than those in atmospheric pressure, and this is the reason why the Decibel (dB) is the unit measure of Sound Pressure Level. It is not an absolute value but relative to a reference measure. Decibels are used since, in mammals, perception on an auditory level in pressure variations is not linear, but rather, closer to a logarithmic scale from where decibels are derived. Decibel measurements reference used is different for measurements in air and measurements in water. Any measure is useless without specifying this reference. Typical references are 20µPa in air and 1µPa in water.[1]

In the present project, from now on, the sound decibels will be relative to 1 µPa: $SPL\ [\mathrm{dB\ re\ 1\ \mu Pa}]$.

The Sound Pressure Level (SPL) holds an advantage of being an objective and fairly comfortable measurement of the radiated sound but has the disadvantage of being far from representing with precision what is really perceived. It is calculated as follows:

$$SPL[dB] = 20\log\left(\frac{\hat{p}}{\widehat{p_0}}\right) = 10\log\left(\frac{\hat{p}^2}{\widehat{p_0}^2}\right) = 10\log\left(\frac{\hat{I}}{\widehat{I_0}}\right)$$

Where:

p_0 is the reference pressure

I_0 is the reference intensity

The Sound Exposure Level (SEL) is the magnitude used to compare sounds of various types or durations, SEL is defined as the level of pressure of a constant wave which, if it is maintained for one second, will generate the same acoustic energy to the receptor as the studied sound.[1]

$$SEL = 10\log\left(\frac{\int \hat{p}(t)dt}{p_0^2}\right)$$

Where $\hat{p}(t)$ is the rms pressure value, which changes with the time (as the ship moves). If the integration time is small enough to consider $q(t)$ constant during the integration period, then:

$$SEL = 10\log\left(\frac{\hat{p}\Delta t}{p_0^2}\right) = SPL + 10\log(\Delta t)$$

5.2.2. Transmission Loss due to Spreading

If no energy loss is considered, the energy of a spreading spherical wave is constant in all the spreading surface. The SPL of a point away from the source point at a distance r, and with no absorption or energy loss can be calculated as [3]:

$$SPL[dB] = 10\log\left(\frac{I_0}{r^2}\right)$$

Which can be written as well as:

$$SPL = SL - TL$$

Where SPL is the received level, TL is the transmission loss due to spreading and SL is the source level, all in dB. The source level represents the acoustic pressure at 1-unit distance from a point source, and the decibels are expressed relative to a reference pressure level, expressed as SL [dB re p_0 μPa @ 1 u].

In the present project, from now on, the SL will be computed at 1 m distance and relative to 1 μPa: SL [dB re 1 μPa @ 1 m].

$$SL = 10\log\left(\frac{I}{I_0}\right)$$

Near the source, sound can propagate uniformly in all directions. This is known as **spherical spreading**, and TL is computed as:

$$TL = 20\log\left(\frac{r}{1\ m}\right)$$

In shallow water, sound cannot propagate as a spherical wave in all directions, but only as a cylindrical wave bound by the sea floor and the sea surface. This is known as **cylindrical spreading**, and TL is computed as follows:

$$TL = 10\log\left(\frac{r}{1\ m}\right)$$

The SOFAR Channel is the abbreviation for SOund Fixing And Ranging, which is also called deep sound channel. It is a horizontal layer of water at the depth where c is minimum, which is called the channel axis, and it is about 1000 m deep at low latitude and reaches the sea surface at high latitude. It acts as a waveguide for sound, ‘trapping’ propagation paths.

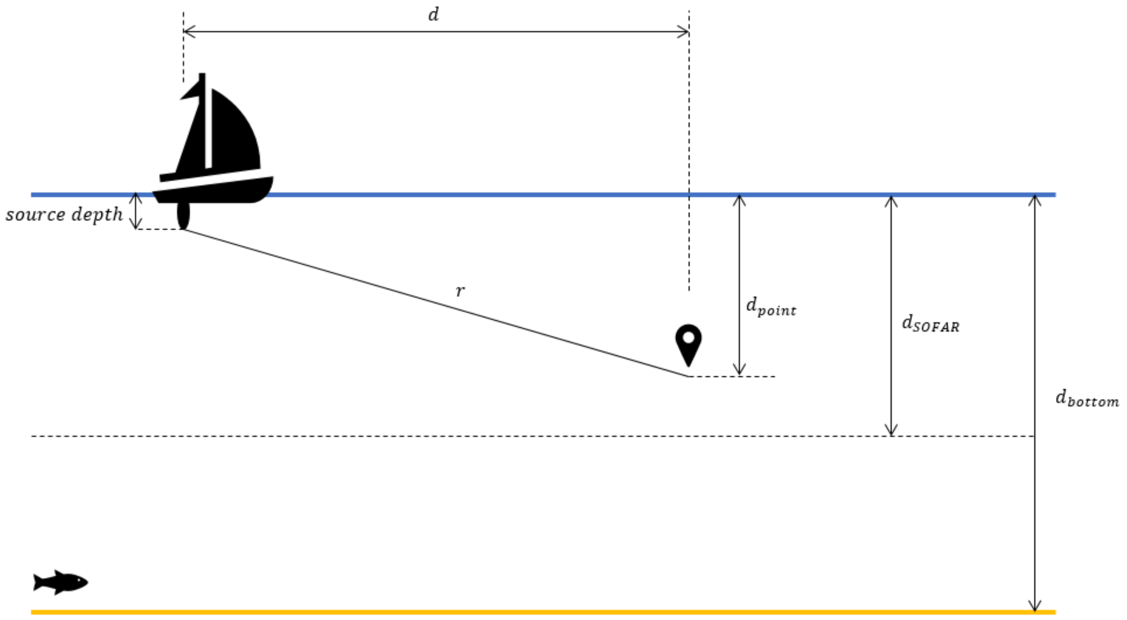


Figure 6 Spreading parameters representation

5.2.3. Transmission loss due to Absorption

Due to chemical reactions and molecular properties, a part of the energy of the pressure wave is lost. This phenomenon is called absorption and it presents a very scattered profile at low frequencies. The transmission loss due to absorption depends on many factors and has a complicated physical representation. Even so, it is mainly assumed that a good approximation is as follows:

$$TL = \alpha r$$

Where α is the absorption coefficient.

From different literature, α is considered as follows, depending on the frequency [in kHz] [3][4][5][6]:

- If $3.25 \leq f_0 \leq 7.5$

$$\alpha_f = \frac{0.1\,f^2}{1+f^2} + \frac{40\,f^2}{4100+f^2} + \frac{2.75\,f^2}{10000} + 0.003$$

$$\alpha_l = \frac{26.6\,f \cdot 1.4^{S_{med}}}{\sqrt{(1452+3.5\cdot T_{med})H}}$$

$$\alpha = \alpha_f + \alpha_l$$

- If $0.1 \leq f_0 \leq 3.25$:

$$\alpha_s = f(latitude)$$

$$\alpha = \frac{0.11\, f^K}{1 + f^2} + \alpha_s$$

- If $f_0 \leq 0.1$

$$\alpha = 0.36 f^{\frac{3}{2}}$$

5.2.4. Lloyd's effect

The Lloyd's Mirror effect is generated because the surface of the sea acts as a reflector surface. If the source is under the water surface, a ray emitted upwards reflects off the surface and experiences a 180° phase shift. The surface-reflected path interferes with the direct path at any receiver location. The surface-reflected path can be considered originating from a negative (inverted pressure) image source in air.

For horizontal propagation over long ranges, the path lengths of the direct and surface-reflected paths will be similar, and the pressures will cancel out. At close ranges, the two rays create a pattern of constructive and destructive interference.

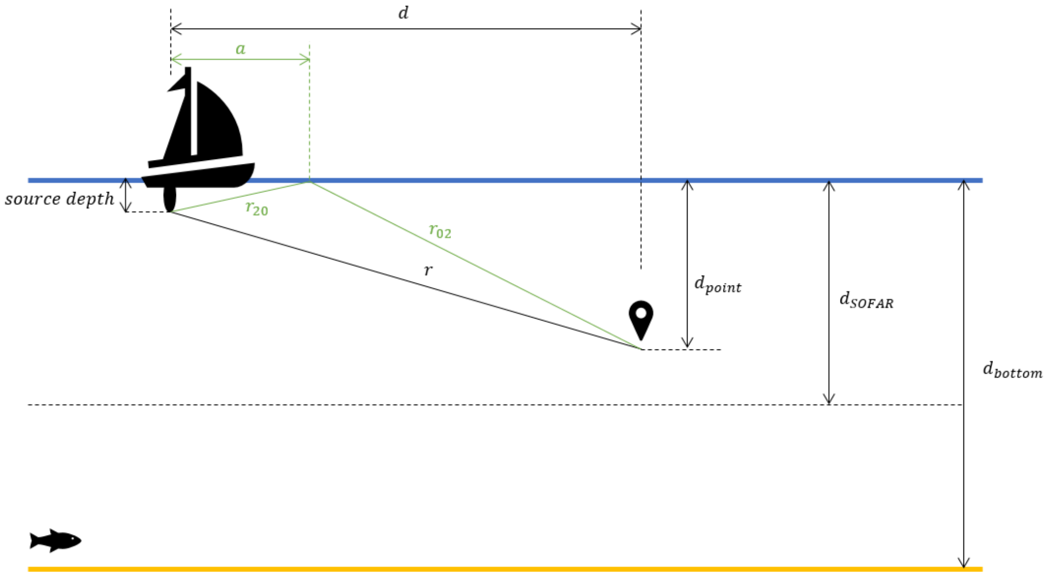


Figure 7 Lloyd's parameters representation

From the Figure 7, the following geometry relations can be extracted:

$$a = \frac{d_{source} d}{d_{point} + d_{source}}$$

$$r_2 = r_{02} + r_{20} = \sqrt{(d-a)^2 + d_{point}^2} + \sqrt{a^2 + d_{source}^2}$$

Once the geometrical parameters are set, the effect considering no loss (no spreading or absorption) calculated as [3]:

$$r_0 = \frac{4 d_{source} d_{point}}{\lambda}$$

$$P_{lloyd} = \begin{cases} 2(1-\mu)\cos\frac{r_0 \pi}{r_2}, & r \leq r_0 \\ \left(\frac{r_0 \pi}{r_2}\right)^2, & r > r_0 \end{cases}$$

The maximum constructive effect that Lloyd mirror can produce is to double the pressure peak amplitude, which is traduced in an increment of 6 dB.

The maximum destructive effect that mirror can produce is to rest all the pressure peak amplitude, which makes the pressure point at 0 dB.

5.3. Ship Noise Modeling

5.3.1. Ship Source Level

Ross' model is chosen because of its simplicity and the low amount of data needed and all available from AIS.

In the model, ship source levels are computed by defining an "average" ship as one with a speed of 12 knots and a length of 300 ft. This average ship is assigned a source level of L_{s0} dB as a function of frequency. The noise source levels of the actual ships in the model are then calculated, based on their individual speeds and lengths, by the following empirical equation based on Ross model (1987) [7].

$$Ls(f, v, l_s) = L_{s0}(f) + 60\log\left(\frac{v}{12}\right) + 20\log\left(\frac{l_s}{300}\right) + df \cdot dl + 3.0$$

Where

$$df = \begin{cases} 0.00 \leq f \leq 28.40 & df = 8.1 \\ 28.40 < f \leq 191.6 & df = 22.3 - 9.77 \cdot \log(f) \end{cases}$$

And

Ls, the source level in dB

L_{s0}, source level of the "average" ship in dB

v, ship's speed in knots

l_s, ship's longitude in feet

f, frequency in Hz

Ship Type	*Length (ft)*	*Speed (kt)*	*Ship Type ID*
Fishing Vessel	50-150	7-10	1
Merchant	275-400	10-15	2
Tanker	400-500	12-16	3
Large Tanker	500-700	15-18	4
Super Tanker	800-1200	15-22	5

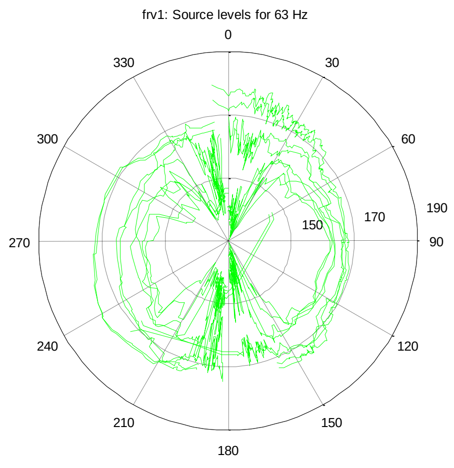
Table 6 Classification by means of length and speed limits [1]

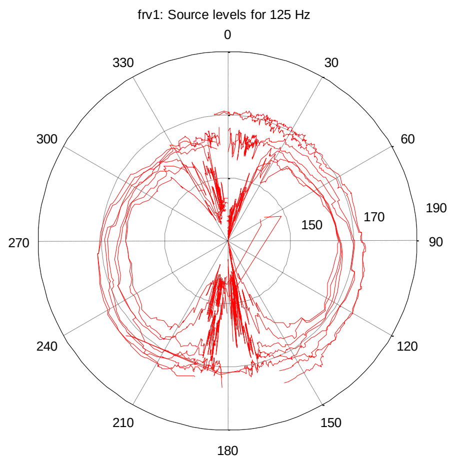
This model outputs a Source Level in [Pa], which will be used to spread the sound from the engine point.

5.3.2. Ship SL distribution

Regarding directionality, the inclination angle and the azimuth is considered, as the intensity of the sound propagation is not the same depending on the direction relative to the ship's speed.

Literature is taken into account [8] to model a rough directivity parameter, which is usually considered to be different depending on the ship's type, but considering the lack of information, all the ships are considered to have the same distribution pattern with a gaussian deviation.





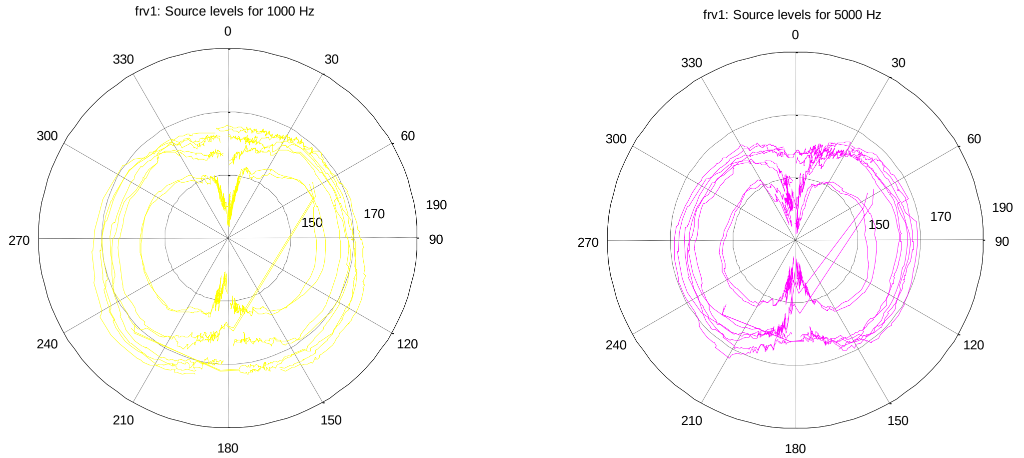


Figure 8 Source Level distributions at 63, 125, 1000 and 5000 Hz [1]

From the literature [1], an angle of 15º is considered as the zone of less propagation, and after applying the gaussian deviation of 1 dB, the following distribution is obtained:

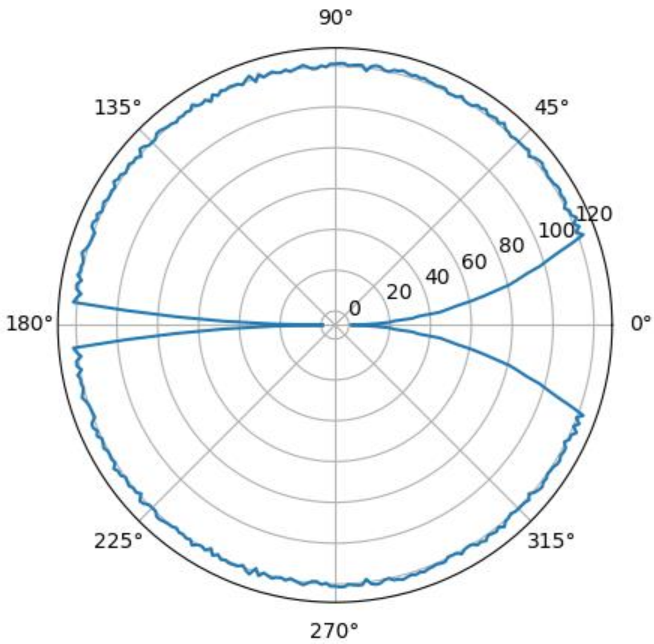


Figure 9 Ship SL distribution example

5.4. Simulation

5.4.1. Assumptions

Modeling the sound propagation in the ocean is a complex procedure because there is a lot of missing data. There are different model approximations that take into account different aspects of the sea status as wind speed and (related to it) the waves height, as well as the sound speed profile, the temperature, the salinity and the density, among others.

The source level of the ships can't be precisely defined because there are no available recordings of all the ships that will be modeled. For this, only an approximation of the ships' source level can be extracted from literature regarding its length, speed and draught.

Since the SL determination is a rough approximation, it makes no sense using a very precise sound propagation model. For this reason, the following assumptions are applied to the model:

Regarding sound propagation

1. The Earth is not flat

The Earth is not a flat surface, but to work with distances and calculate them easily some approximations have to be made.

In the present project, Mercator projection is assumed, as it is one of he most common ones in our country.

The Mercator projection is a cylindrical map projection presented in 1569. It is the standard map projection for nautical navigation because of its ability to represent lines of constant course as straight segments that conserve the angles with the meridians. Although the linear scale is equal in all directions around any point, thus preserving the angles and the shapes of small objects, the Mercator projection distorts the size of objects as the latitude increases, where the scale becomes infinite.

The radius of the Earth of Mercator's projection is considered constant, as the Earth is treated as a perfect sphere. In the present project $R_{Earth} = 6371.0\ km$ is assumed.

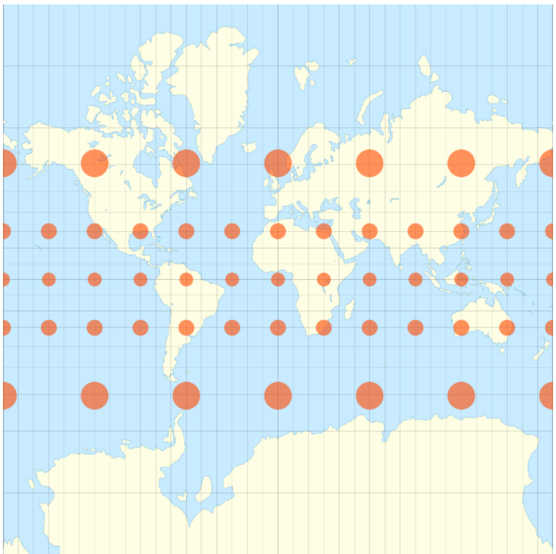


Figure 10 Mercator Projection deformation

The corners of the square of study of a position $(lat, long)$ are then calculated as follows:

$$dlat = \frac{d_{square}}{R_{Earth}}$$

$$dlong = \frac{dlat}{\cos(lat)}$$

Where:

$dlat$ is the increment of latitude in rad

$dlong$ is the increment of longitude in rad

2. Sound speed constant

The sound speed depends on may factors, as depth, location, salinity, temperature... Many literature present different sound speed profiles depending on these factors, but as no data about the ocean parameters is available and considering that the precision it can give is greater than the one achieved with the sound simulation, sound speed is considered constant at every location, depth and temperature.

$$c = 1524 \frac{m}{s}$$

3. Spreading law considered to be perfect [3]

Spherical spreading when $r < depth$ or $r < H$ and cylindrical spreading otherwise, as seen in previous chapters (see **Error! Reference source not found.Error! Reference source not found.**).

The SOFAR channel depth (d_{SOFAR}) is considered constant in all the locations and with a depth equal $H = 50\ m$.

$$d_{SOFAR} = 350\sqrt{H}$$

This assumption can only be made if the respective depths of the bottom and the channel are considered constant and flat.

4. Depth approximation

The database of bathymetry has as a much lower resolution than the simulations computed, which makes the data discontinuous. To solve this inconvenience, the data of the bathymetry is interpolated using the `bisplrep` function from the python `scipy` package.

Anyway, at each simulated point the bottom surface is considered constant and flat.
The interpolation can be seen in the following image:

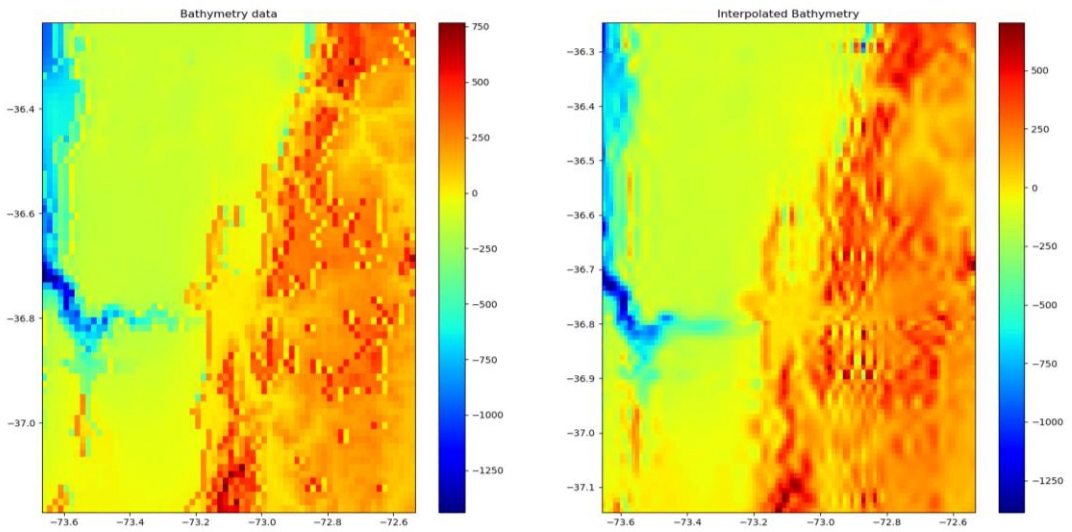


Figure 11 Bathymetry interpolation

5. Ship as a point

Even the main sound source of a ship is its engine, the vibration produced by the engine propagates all along the mass of the ship, producing different sound sources.

For the simulation, each ship is considered a single point, with all its sound source concentrated at the point, and the intern ship sound propagation has not been considered.

6. μ parameter of reflection

The sea surface is not a perfect mirror ($\mu = 1$) and it depends on wind speed and the waves height (which are related), but the data of the sea surface state is not available.

To consider the real error, μ is chosen as:

$$\mu = 1 - \ gauss\ (0{,}0.2)$$

7. Lloyd effect at near field and far field.[3]

For the simulation, it is assumed that if (see 5.2.4):

- $r \geq 7r_0$ (Far field)
- $r < 2\sqrt{d_{source}d_{bottom}}$ (Near field)

no Lloyd effect is relevant (Far field). [3]

8. Assumed frequency ranges to be constant and depend only on the latitude. [4][5]

For the calculation of α_l (see 5.2.3), state of the sea, water temperature and SOFAR depth are needed. As this data is not available for each point, mean values are considered.

$$S_{med} = 2\ (low\ waves)$$

$$T_{med} = 17.0\ [°C]$$

$$H_{med} = 50\ m$$

9. α_s depending only on the world zone

The parameter α_s depends on many different factors, as the salinity and the temperature of the ocean water. As this data is not available in the current project and to make it possible to calculate, α_s is assumed constant in different zones of the world where it is more similar [4][5][6].

Thanks to this assumption, α_s can be computed only depending only on the latitude and longitude of the point.

Absorption, α_s, depends only on frequency and zone of the world (it affects only frequencies from 0.1 to 3.25 kHz).

The values chosen are the ones computed at K = 0.5 [6].

Zone	*Latitude boundaries in [min]*	α_S
Polar	-80 to -60	4.2
Subpolar	-60 to -50 and 60 to 80	1.8
Moderate (A, B, C)	-50 to -25 and 25 to 60	1.23
Tropical	-25 to 25	0.3

Table 7 Classification by means of length and speed limits[6]

10. Doppler effect.

The real frequency SL of the front points is not the same for the point that see the ship approaching or going away from them because of the relative speed. Because of that, the frequency at the source level point is computed using the following:

$$f_{point} = \frac{f_0}{1 + \frac{\Delta v}{c}}$$

Where

f_0 , the frequency at the source point in Hz

$f_{receiver}$, frequency at the calculated point in Hz

$\Delta v = v_r - v_S$ speed of the receptor respect to the source. Positive when receptor and source are approaching and negative otherwise in m/s

11. The ship is moving, and the sound speed is not infinity.

To compute the real position of the ship when the sound was generated, ships' speed and course are considered constant, and the speed of the sound on the water as well.

With these two constant velocities and assumptions, ships' position when the sound was generated can be calculated, assuming the sound travelled distance is r_{t-1}.

$$d_{travelled} = v_{ship}\Delta t$$

$$r_{t-1} = \sqrt{\left(x_{0_t} - x_{0_{t-1}}\right)^2 + \left(y_{0_t} - y_{0_{t-1}}\right)^2}$$
$$= \sqrt{\left(x_{0_t} - x_{0_t} d\, cos(\alpha)\right)^2 + \left(y_{0_t} - y_{0_t} d\, sin(\alpha)\right)^2}$$

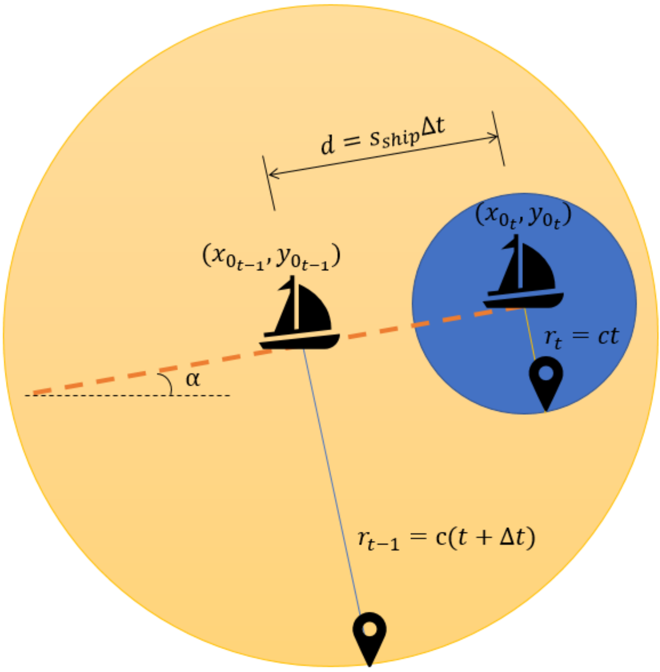


Figure 12 Ship speed effect

12. AIS minimum frequency and ships' interpolation

The AIS messages sent by the ships have a minimum interval time of 30 minutes. This is an important factor to consider for SEL calculation because it requires the position of the ships at every consecutive interval of time. If the interval is of 30 minutes (minimum AIS frequency of messages) the position of a ship travelling at 12 knots (average speed) can change around 11 km, which is an 11% of the length of the simulation square (100 km).

To do so and not miss the ships in the simulation square, an interpolation is performed, and the ship is considered to go in a straight line between two consecutive positions or, in case there is no other known position, it is just considered to maintain a constant direction and speed.

It is considered that the minimum integration interval for the SEL calculation is the one covering a maximum of the 5% of the simulation square, which for a ship travelling at the average speed would be around 15 minutes.

To simplify the calculation of the interpolation, only data from the same day is considered, even if there is an AIS message from the last hours of the day before which is not included at the beginning due to lack of AIS data.

The simulation interval of the Web Application is 2 hours, which is enough to cover the AIS frequency and be accurate. Even so, there are some ships that stop their AIS-satellite communication for any reason, and they will not be shown in the sound pressure map.

Related to ships' source level:

1. Directionality distribution equal for all the ships types and situations

The directionality pattern distribution is inferred from an intern study about ships' sound distribution, and one simple model is chosen, trying to approximate it to all the measurements done.

2. SL using Ross' model

The source level of the ships is modeled using Ross' model, which considers the speed and the length of the ship.

There are more accurate and modern models, but a lot more data is needed, which makes them not valid for the project purposes.

3. Deviation of the SL distribution

The deviation of the source level of the ships is set to 1 dB, considering it a good enough approximation extracted from the literature.

4. Directivity of the ship

Directivity modeled as a constant distribution of SL except the front and back zones, 15º, as seen in Figure 9.

5.4.2. Coding

To program the simulation, python is chosen as the coding language do to its versatility and its facility to integrate the simulation in the Web Application.[3]

Different classes and modules are set following the following scheme:

- `/data`
- `/static`
  - `/css`
  - `/img`
  - `/js`
  - `/kml`
- `/templates`
- `/venv`
- `DB.py`
- `ais.py`
- `duration.py`
- `get_kml.py`
- `map.py`
- `noise_map.py`
- `noise_simulation.py`
- `plot_sound.py`
- `ship.py`

Which contains:

- `/data`: JSON files to load the AIS data of the different ships position and information
- `/static`
  - /css: styles of the web application
  - /img: Images to load in the web application
  - /js: JavaScript coding for the user's interaction
  - /kml: kml static layers. A cache is done the first time someone access in one day, so it is already loaded the rest of the day
- `/templates`: basic html static code

[3] Appendix B contains the code and the github repository url to clone it.

- `/venv`: virtual environment to control all the different packages versions
- `DB.py`: Connections with the ANTINEA database
- `ais.py`: load the AIS data to the database (it is delivered as a *.csv file)
- `get_kml.py`: get the KML file for a specific situation
- `map.py`: route control of the web application. Serve the correct templates at each action and load the required data
- `noise_map.py`: Create a noise map with all the information required and the sound pressure level simulation in a matrix
- `noise_simulation.py`: start a whole sound simulation
- `ship.py`: ship class retains all the ship information in an organized manner. Also calculates the SL of each ship depending on its specifications.

5.4.2.1. Python packages

Basemaps

The matplotlib basemap toolkit is a library for plotting 2D data on maps in Python. It is similar in functionality to the matlab mapping toolbox, the IDL mapping facilities, GrADS, or the Generic Mapping Tools. PyNGL and CDAT are other libraries that provide similar capabilities in Python.

Basemap does not do any plotting on its own but provides the facilities to transform coordinates to one of 25 different map projections (using the PROJ.4 C library). Matplotlib is then used to plot contours, images, vectors, lines or points in the transformed coordinates. Shoreline, river and political boundary datasets (from Generic Mapping Tools) are provided, along with methods for plotting them. The GEOS library is used internally to clip the coastline and political boundary features to the desired map projection region.

5.4.3. Simulation procedure

To start the simulation, a frequency and a depth of simulation are chosen, together with the ship's position and the time, and a resolution is set.

The ship tracking is obtained from the *Antinea.acheived* table and discretized in different days, where each day is considered as one independent simulation square.

As the AIS data is expensive and its price depends on the covered surface, it is checked that the different square surfaces do not overlap, so if the ship stays more than one day in a point, only one square is considered for all the days.

Once the simulation center point (ship position) with the correspondent timestamp is loaded, the AIS data matching the simulation square surface and the simulation time is called from the *Antinea.ais* table together with the ships' information from *Antinea.ships* and the bathymetry of the square surface is loaded and interpolated from the *topex* file.

Known the position and the speed of the ships and its type the source level (SL) generated by the ship at 1 m of the engine can be modeled, and each ship sound simulation is added to the map by:

1. Decide if the ship is moving or not, and if it is using its engine. If it is not moving and/or not using its engine, it is not considered.
2. Compute ship's SL distribution considering Doppler's effect (different frequency frontwards than backwards)
3. Compute the sound pressure level (RL) that the ship generates at each point (discretization points are computed depending on the chosen resolution) and summing the RL of all the ships.

To compute the sound pressure of each point (x, y) of the simulation relative to one ship with its SL distribution the following calculations are made:

1) Get the depth of the point. If it is greater than the simulation depth

2) Calculate angle formed between the ship position and the point

$$angle = (\alpha + \beta) \text{ (see Figure 13)}$$

3) Calculate if there is land in between (also considering ocean points that are above source depth). If there is, this SL will not affect this point, so the sound pressure level to add is 0 Pa.

Figure 13 Ship course

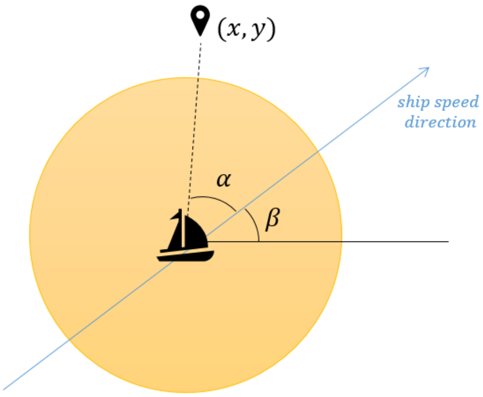


Figure 13 Ship course

4) Calculate the angle formed between the ship course and the point $\alpha = angle - \beta$

5) Compute the position of the ship when the sound was produced (x_0, y_0) (see Figure 12). Incremental time between two consecutive time computations is considered 1 second

6) Calculate geometric parameters r

7) Calculate Lloyd parameters. $r_2 = r_{02} + r_{20}$ (see Figure 7)

8) Calculate if the point is backwards or frontwards related to the ship direction and apply Doppler effect to calculate the frequency that generated

9) Get the SL of the ship at the current frequency at the angle α computed (see Figure 9)

10) Compute the absorption parameter α_{total} depending on the frequency (see 5.2.3)

11) Calculate Lloyd's effect and apply transmission and absorption losses to the effect.

12) Calculate transmission and absorption losses depending on if it is considered all spherical or cylindrical spreading [3][9]:

$$sr = \min(d_{SOFAR}, d_{bottom})$$

$$TL = \begin{cases} 20\,log(r) + \alpha_{total} r, & spherical, r < sr \\ 10 log(r) + \alpha_{total} r + 20.9 + 5 log(sr), & cylindrical, r \geq sr \end{cases}$$

13) Calculate the resultant SPL

$$SPL = SL + LL - TL$$

Where LL = Lloyd effect (constructive adds, destructive rests).

Once all the points are computed, the resultant SPL of each point is then converted to Pa and added to the other ships SPL in Pa in the map point.

Finally, a map layer can be plotted to show the total sound pressure distribution in the selected region using `Basemaps` and `matplotlib`.

To calculate the SEL distribution, the SPL distribution is computed every Δt and all the SPL distributions are added as:

$$SEL_{map} = \sum (SPL_{map} + 10 \log \Delta t)$$

Where Δt is considered to be 15 min.

5.5. Sound Simulation Results

5.5.1. Density comparison with other data sources

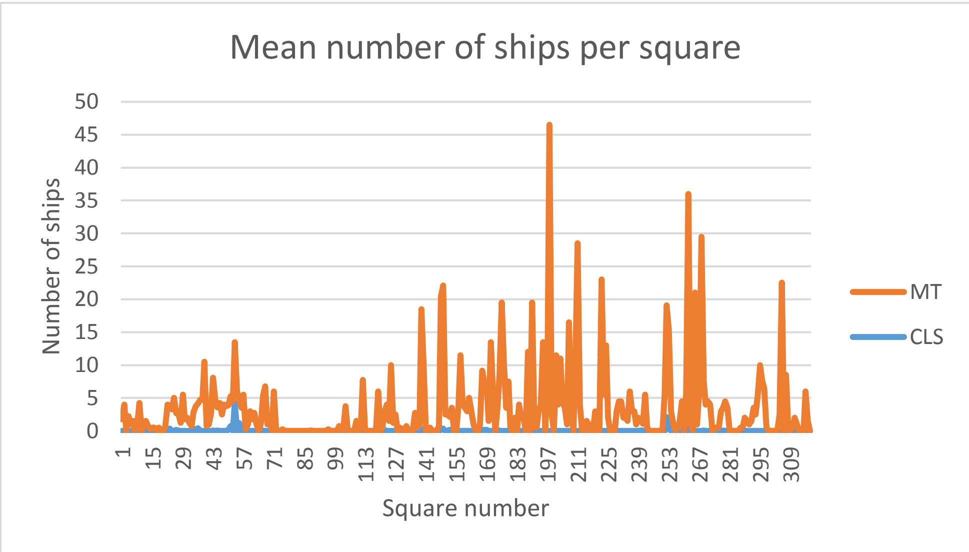


Figure 14 Density of ships per square comparison

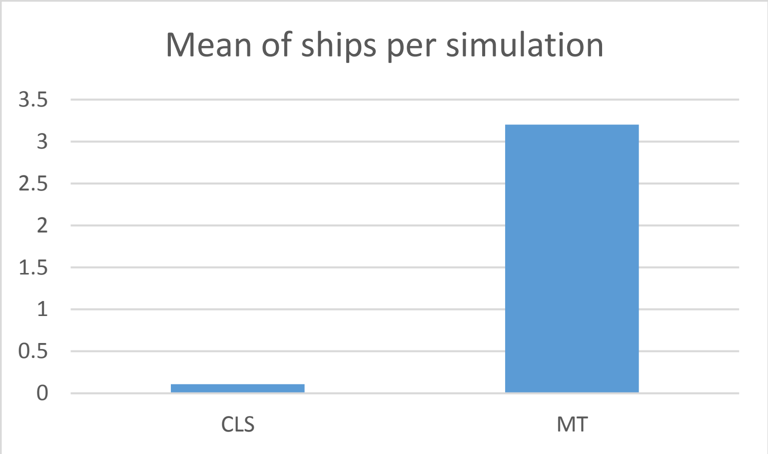


Figure 15 Mean number of ships per simulation comparison

The data obtained from CLS is not representative and though cannot be used for the purpose of the project. CLS only gets the 3% of the messages compared to Marine Traffic, which is not representative and though cannot be considered as a valid data set.

The difference of reached data is because CLS does not have terrestrial AIS receivers, and only has satellites. The data obtained is, then, representative of the satellite coverage of AIS messages.

This is the reason why most of the square simulations of the Web Applications are empty. In 7 Future work further details of the necessary steps to solve this issue.

5.5.2. Sound Pressure Level Map (SPL)

The implemented simulation gives an output of all the SPL at each point for a given frequency and depth, as expected.

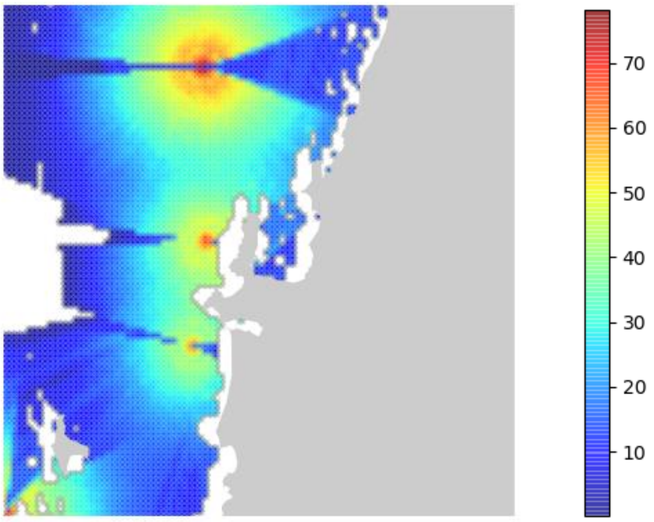


Figure 16 Simulation results of one square at f = 100 Hz and depth = 2 m in dB re 1 µPa

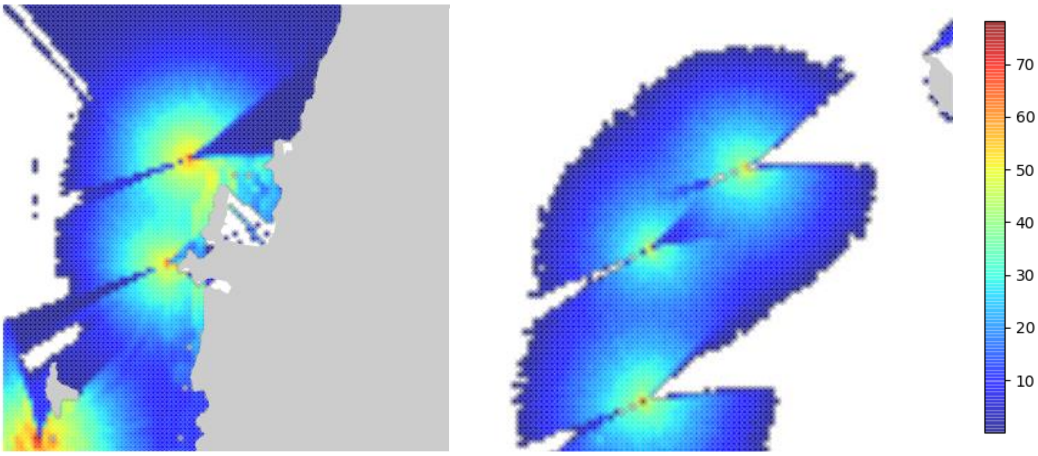


Figure 17 Sound Pressure simualtion in dB re 1 µPa

The white parts of the Figure 16 are parts that have less than 2 m of depth (2 m is the depth simulation).

5.5.3. Sound Exposure Level Map (SEL)

The resulting SEL maps are obtained as expected.

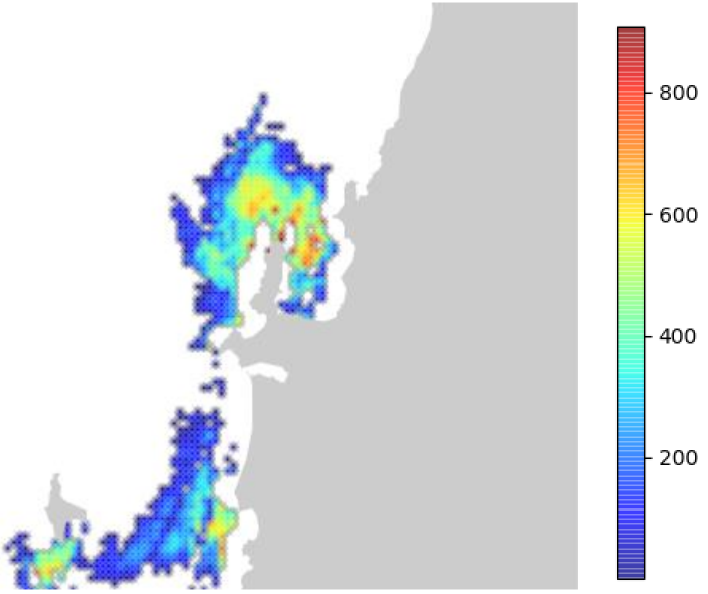


Figure 18 SEL simulation in dB re 1 µPa²

6. Applications

6.1. Underwater soundscapes characterization

One of the applications of the World Sound Map is to provide the shipping noise intensity to extract the shipping noise from any ocean recording, making it easier to work with the recordings and to recognize biological sounds.

One example of this application would be the LAB's project of the Great Coral Reef soundscape characterization.

The aim of this project is to model the health of the Coral Reef from a recording. This can be a good option to study the status of the coral reefs without being invasive and with an easy and cheap way of extracting the data.

To do so, different parameters are calculated to study its relationship with the health of the Coral reef, and then a model is built by considering only the relevant parameters.

Even more, these recordings can be added to the World Sound Map, so the users can listen to the Coral Reefs sounds with and without the shipping noise by enabling or disabling it with an interaction button.

6.1.1. Great Coral Reef soundscape characterization

As the OMExpedition stopped at the Australian Great Coral Reefs, the recordings are available at the LAB, which makes it a good opportunity to apply the shipping noise extraction.

The recorded Reefs are resumed on the following table, with the respective position of the ship.

Coral Reef Name	*Latitude*	*Longitude*
Muller	-21,2797	151,5295
Muller	-21,2783	151,5323
Swain	-21,3428	151,2807
Ellison	-17,7043	146,4088
Adelaide	-17,6832	146,4497
Potter	-17,6732	146,553
Sudbury	-17,009	146,2247
Theford	-16,805	146,1743

Upolu	-16,5197	146,002
Hastings	-16,6665	145,9322
Pickersgill	-15,8495	145,558
Vicki Harriot	-15,493	145,6227
Ribbon	-15,376	145,7753
Pasco	-15,04	145,5297

Table 1 Recording positions and correspondent reef name

Sounds can be made by three different types of sources:

- Biophonies
- Anthropophonies
- Geophonies

The biophonies represent the diversity of the reef, which is expected that has a positive correlation with the reefs' health.

Due the fact that it is demonstrated that shipping noise has a negative impact in a lot of marine animals, it is expected that anthropogenic noise has a negative correlation with the reefs' health.

No studies have been made about the impact of geophonies in animals' life.

6.1.2. Modelling

To create the model, several parameters extracted from literature are considered.

The different frequency bands considered are 62.5, 125, 250, 500, 1000, 2000, 4000, 8000, 16000, 32000 and 64000 Hz, chosen because of their usual use in underwater sound analysis.

6.1.2.1. Computed parameters

<u>Acoustic Complexity Index</u>

The ACI is computed using an automatic procedure to calculate the difference in amplitude (I) between adjacent temporal steps (k) using the following formula [10][11]:

$$ACI_{ij} = \frac{\sum_{k=1}^{n} |I_k - I_{k+1}|}{\sum_{k=1}^{n} I_k}$$

where n is the number of temporal steps (k), i is a frequency bin and j is the interval of time considered. The sum of all the frequency bins (i) and temporal intervals (j) is calculated for every recorded file.

It is proved that the biological sounds have a greater ACI than the anthropogenic sounds due to their nature. It is used as an indicator to compute the biological activity. [11]

The decided acoustic time window to compute the ACI is 10 seconds. Results of Paco's Reefs are shown in the next Figure.

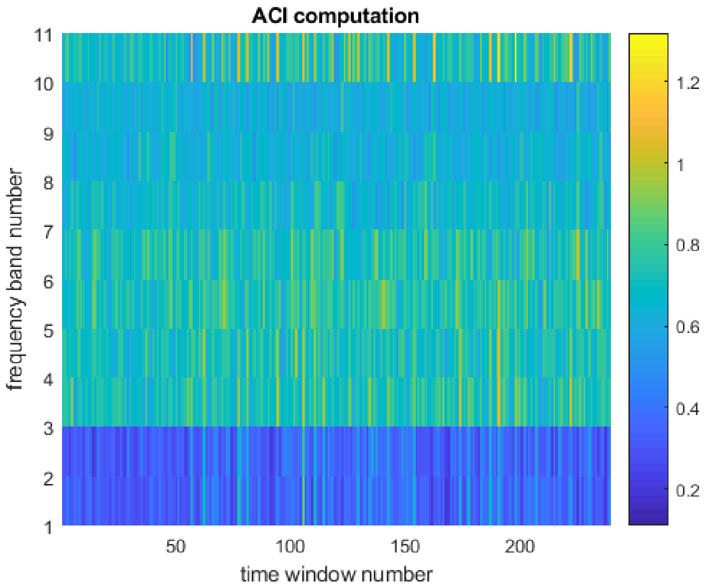


Figure 19 Aci computation of Pasco's Reef.

Frequency bands [62.5, 125, 250, 500, 1000, 2000, 4000, 8000, 16000, 32000, 64000] Hz

As it is expected, the lower frequency bands have a much lower ACI than the higher ones.This is because shipping noise is mainly arround 100 Hz, while fish and srimps vocalizations are from 250 Hz until 4.000 Hz.

<u>Sound pressure</u>

Sound pressure in total and separated by different sources.

To compute the sound pressure and the power:

- Total mean sound pressure
- Mean sound pressure per band
- Mean Ship Noise intensity (extracted directly from the recoding or from the Sound World Map)

As the sound pressure is relative to the distance of the source, the parameter used to create the model is the normalized pressure, which is the sound pressure per band divided by the total mean sound pressure.

The ship noise intensity is also normalized.

Figure 20 shows the pressure of each frequency band for one of the Reefs. Then the mean of each band and the total power mean are calculated, and they are normalized.

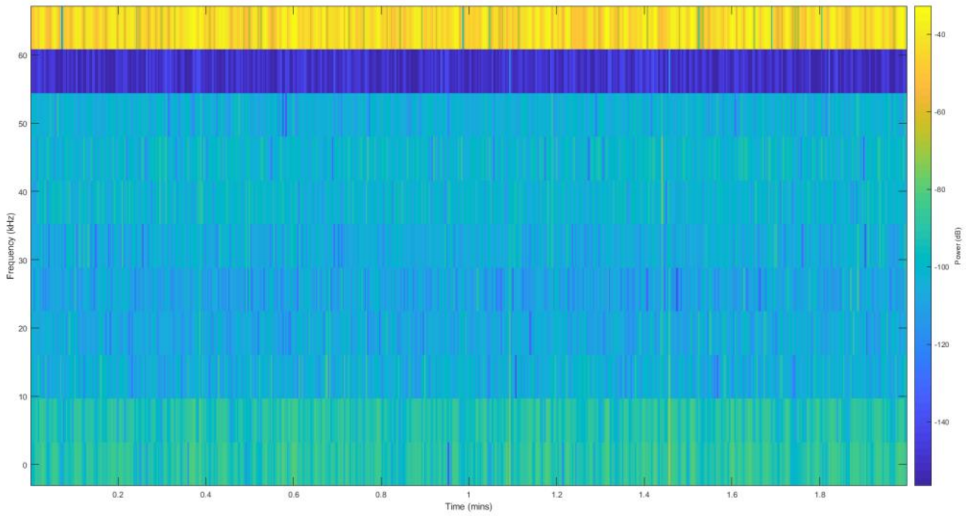


Figure 20 Spectrogram of a stract of the Pasco Reef recording. [dB are calculated with air pressure reference]

As the shipping noise cannot be extracted from the sound pressure map simulation because of the lack of AIS data, it is extracted by calculating if there is a constant and loud (higher than the mean) sound with a low AIS around 100 Hz. To create the model, the power of the shipping noise is taken as one of the features.

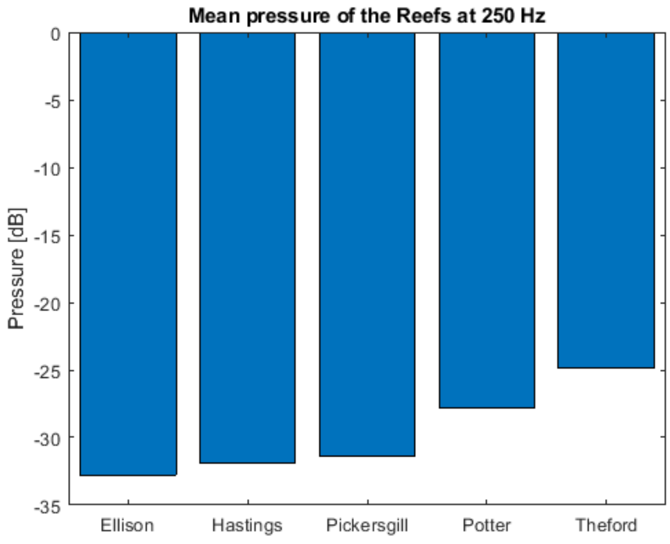


Figure 21 Mean pressure of the reefs at 250 Hz (fishing vocalization)

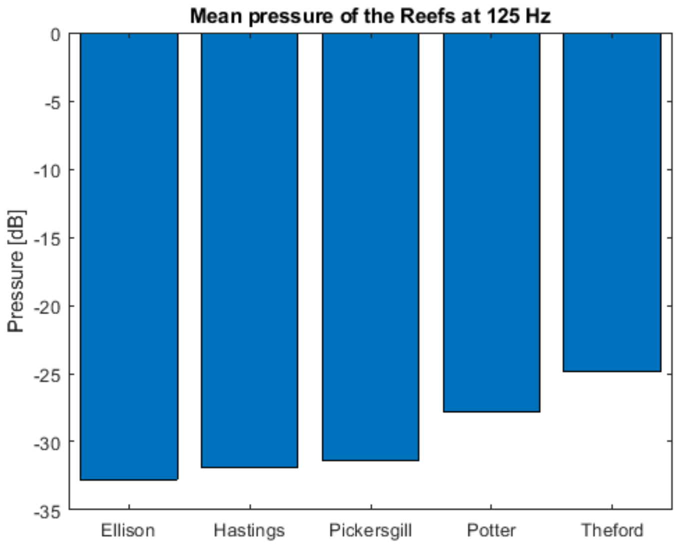


Figure 22 Mean pressure of the reefs at 125 Hz (shipping noise)

<u>Count of life diversity</u>

Number of animal’s detection.

An intern software of the LAB is used to classify different fish sounds. To use this classifier which automatically counts the number of fishing sounds that appear in each recording, it is first necessary to create and train the classifier.

To do so, sounds of different fish species are identified in the recordings by a manual inspection and added to a data base which is later used to train the classifier.

Following images show the spectrograms of some animal's sounds.

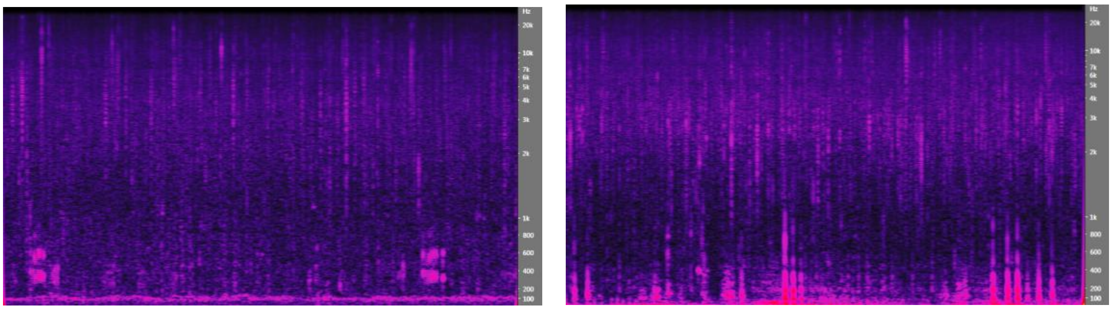


Figure 23 Spectrogram of Croaker sound and Bar Jack sound

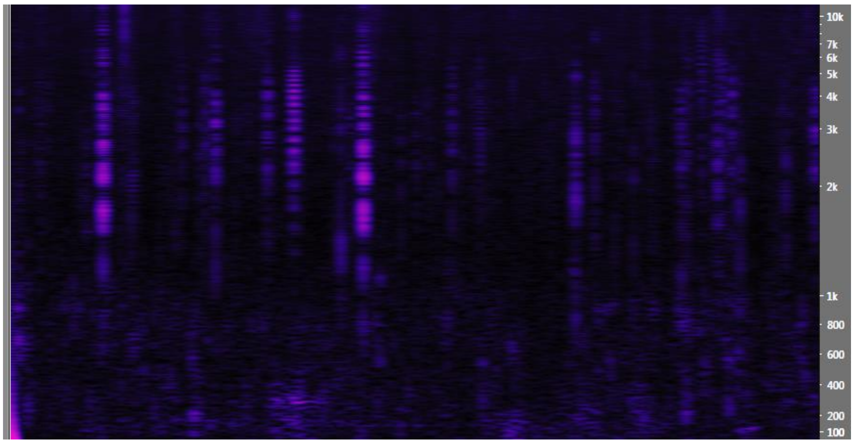


Figure 24 Spectrogram of Snapping Shrimps sound

Before adding them to the database, it is necessary to create the labels in the same database and define the highest and the lowest frequency of each sound.

Class label	*Label*	*Typical frequency [kHz]*		*Scientific Name*
		lowest	highest	
s000066	croaker sound	0,4	5	Sciaenidae, Micropogonias undulatus
s000067	barred grunt	0,05	5	Haemulidae conodon nobilis
s000068	bar jack	0,01	5	Carangoides ruber

Table 8 Label parameters of the database

After the manual labeling, the classifiers are created automatically. Following images show the acquired confidence interval.

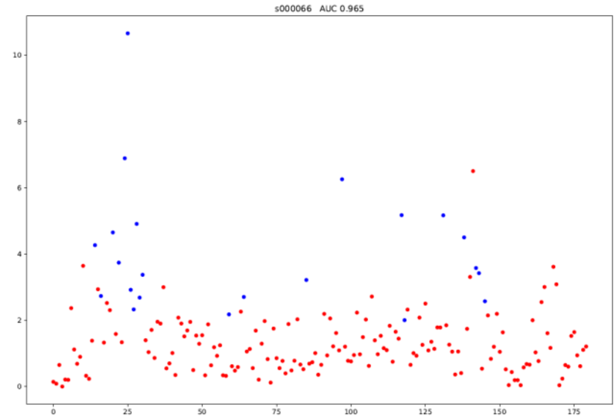


Figure 25 IC of the croacker classifier

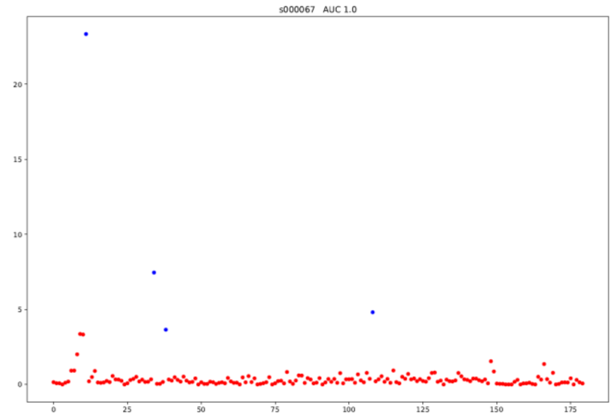


Figure 26 IC of the Barred Grunt classifier

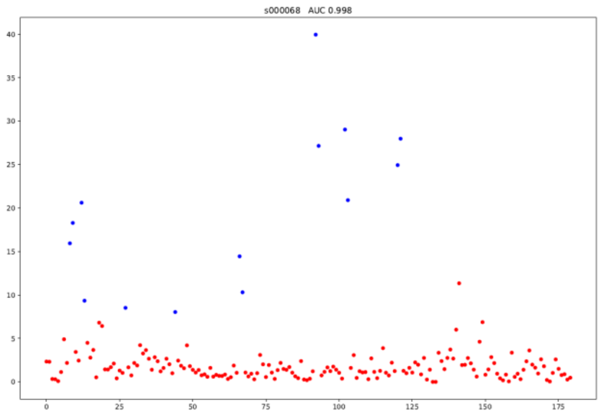


Figure 27 IC of the Bar Jack classifier

The resume is the following:

Classifier	*AUC*

Croacker	0.965
Barred Grunt	1.0
Bar Jack	0.998

Table 9 AUC resume of the trained classifiers

6.1.2.2. Model adjustment

Regression

The data available about Coral Reef's health is incomplete, which makes the regression not valid. Table 10 shows the available and the lacking data.

Coral Reef Name	*% Cover hard coral average Manta tows*	*% Cover hard coral record part*	*Crown-of-thorns starfish/tow*
Muller			
Swain			
Ellison	10-20%	0-10%	0
Adelaide			
Potter	30-40%	0-10%	0,09
Sudbury			
Thetford	20-30%	0-10%	0
Upolu			
Hastings	5-10%	5-10%	0
Pickersgill	10-20%	0-10%	0,53
Vicki Harriot			
Ribbon 5			
Pasco	NA	NA	0,1

Table 10 Available data about Coral Reef's health

Regression is computed by assigning the health index, which is considered to be the mean of the percentage of cover hard coral average Manta tows, to the 5 Reefs with available data.

Table 11 Resumes the health index obtained.

Coral Reef Name	*% Cover hard coral average Manta tows*	*Health index*
Ellison	10-20%	0,15
Potter	30-40%	3,5
Thetford	20-30%	2,5
Hastings	5-10%	0,075
Pickersgill	10-20%	0,15

Table 11 Health index

To optimize the model computation only the relevant factors are selected by running the `fsrnca` (Feature selection using neighborhood component analysis for regression) MATLAB function with the optimized lambda value (the one that minimized the loss values).[4]

After the study, and choosing a tolerance of 0.01, the only relevant parameters is the pressure level at 125 Hz, which is the shipping noise band.

The regression equation is:

$$Health\ idx = 0.03831p - 5.2223$$

Where p is the mean pressure value of the 125 Hz frequency band in dB.

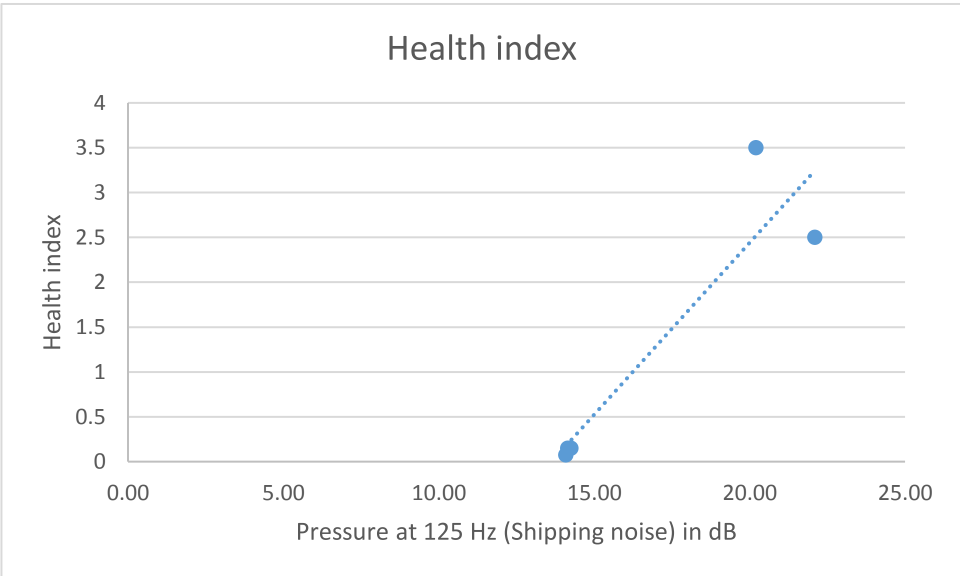


Figure 28 Regression of the health index realted to the shipping noise

[4] In Appendix B the github url to access the code

6.1.2.3. Validation

There is a lack of data of the health of the Coral Reefs (see 6.1.2.2 Model adjustment), which has made validation not representative. Validation is not performed but in 7.1.2 Coral Reef Data future possible steps are explained.

Even if the regression is not representative (there is only 5 data points and validation cannot be performed), it can be seen a clear tendency of the relation between the shipping noise and the health index of the coral reef.

6.2. Animal's distribution comparison

There is a growing consensus about the potential impact of man-made sound on marine fauna. The conscious awareness of this issue has been reinforced by a series of strandings coinciding with the exposure to man-made sound sources. Anthropogenic originated sound can affect cetaceans in different ways, and these effects can be on an individual or group level. The question of how and why man-made sound affects marine mammals is controversial and research into this area will be continued in the future.

Functional groups according to auditory characteristics	*Estimated Bandwidth*	*Genus represented*
Low frequency	7Hz to 22 kHz	Baleana, Caperea, Eschrichtius, Megaptera, Balaenptera (13 species/subspecies)

Mid frequency	150 Hz to 160 kHz	Steno, Sousa, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcaella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon (57 species/subspecies)
High Frequency	200 Hz to 180 kHz	Phocoena, Neophocaena, Phocoenoides, Plaanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus (20 species/subspecies)

Table 12 Functional groups according to the auditory characteristics of cetaceans, the estimated bandwidth and the genus that represents each group [1]

The LAB has a database where each cetaceans species is related to the Marine Regions where it can be found.

When one square sound simulation is loaded, it is computed which Marine Region it belongs to, and the database is consulted to get all the animals that have a presence in there plots a list of them. Like this, the user can see which marine species are in the zone and can deduce if there is a danger for them or not.

The KML layer which specifies the Marine regions is from Marine Regions[5], and can be clicked on it to load a list of all the species that can be found in the marine region.

[5] http://www.marineregions.org/downloads.php

7. Future work

7.1. Improvements

7.1.1. AIS DATA

7.1.1.1. With the already existing program

One of the most relevant things to have good results is the available data. If the data is not representative of the reality the results will not be relevant. It is the case with CLS data, which doesn't have a coverage good enough to get all the ships (or most of them) at a square at a certain interval of time.

In the future work, a better coverage data source should be purchased, such as Marine Traffic to run the Web Application.

Another improvement which can solve one part of the lack of data is the interpolation. In the future, ship position interpolation will be added to the Web Application so the position of all the ships on the map will be known at any time.

To simplify the calculation of the SEL, data from previous days is not considered for the interpolation in the present project. Even so, this would be an improvement which will be implemented in the next version of the Web Application and will be also used for the sound pressure map when needed.

Once the data is available, it will be possible to do the validation of the simulation, which has not been possible to make because of the lack of data.

To validate the simulation, all the available recordings from the ship will be processed and the shipping noise intensity will be detected. A MATLAB algorithm is developed for this purpose, where the ACI of each band is computed and, considering that the shipping noise is a constant noise at low frequencies (from 50 to 200 Hz), it is extracted, and its intensity is calculated.

Once all the recordings are processed, the validation of the model will be performed by analyzing the error between the simulation noise intensity at the ship's position and the extracted intensity noise from the recording.

7.1.1.2. Real time simulation extended to all the World

To increment the information that the users receive, the application will proceed to simulate the entire world shipping noise. This simulation will need a lot of computational memory and a lot of time, so it will not be possible to actualize it in a small interval of time.

To do so, real-time data will be needed, which can be purchased at Marine Traffic for example. It can be actualized once every two hours (and give the server enough time to execute the simulation) or once per day, depending on the budget.

Historical data will be stored and the users will be able to consult the shipping noise distribution of previous dates (starting from the first purchase day). Daily sound density maps can be computed and they will be accessible to the users.

To add this features the following steps must be done:

- Get one powerful server to run the simulations
- Implement the API to get the whole world AIS data
- Create a script to store the historical AIS data to the DB
- Create a script to automatically create daily sound density maps
- As the algorithm is only prepared to compute a square of 100 x 100 km, it is necessary to add to the code an order to stop computing points once the sound pressure level is negligible to reduce time-consuming.
- Actualize the Web Application with the necessary features to make it understandable and intuitive.

7.1.2. Coral Reef Data

The available data of the Coral Reefs health is not enough to validate the model obtained. A health clear index is needed to perform the modeling.

The following steps would be to obtain the health index data from all the recording points surroundings. They have been asked to the scientific team of the University of Queensland of Australia, who were taking samples and performing analysis at the same points where the recordings were made.

Once this data is obtained the validation can be done and the model can be built.

7.1.3. Animal’s distribution “acoustic-danger” zones

To improve user’s experience, the Animals’ distribution can be automatically compared with the sound density levels.

To do so, every time that a square is loaded (or the whole world, in the case that the work described in 7.1.1.2 is implemented), all the zones that overlap with the sound density simulation have to check all the marine animal species that can have a presence there.

Once the marine animal species are known, their intensity limit per frequency has to be checked and then compared to the maximum sound density level of the simulation.

These two things compared can compute the “acoustic-danger” zones, which will be the zones susceptible to provoke harm to the specified animals.

If more specific KML layers are available as, for example, an individual KML layer for each animal species, the user experience can be incremented, as the user will be able to check the status of each animal species individually.

Even more, specifications and characteristics of each animal species can be loaded at the Web Application itself, direct from the World Sound Map, and all the “acoustic-danger” zones can be seen for each species individually.

7.2. Simulation and modeling

If, as expected, the anthropogenic noise has a negative impact in the coral reefs, it can be extrapolated to other marine ecosystems.

As a PhD, a predictor of different ecosystems’ health depending on its soundscape can be made. If the noise is a main factor of the marine ecosystems health, then the World Sound Map can be used as a predictor to locate all the potentially “in danger” zones.

To do so, the model should be applied to all the highest sound pressure level points and the health could be predicted.

8. Planification

8.1. Scheduling

The current project is divided in three main parts:

1. Design and implementation of the sound simulation
2. Design and implementation of the Web Application
3. Design and implementation of the different applications

The main tasks are divided in subtasks.

Task 1: Design and implementation of the sound simulation

Task 1.1: Read literature about shipping noise and sound propagation modeling and compare it with the available data. Analyze the best approach achievable and decide assumptions. Purchase the decided data if necessary and upload it to the LAB's database. (Both for the source level and the sound propagation models).

Task 1.2: Design and implement the code for the simulation. First code the ship source level model and then the sound propagation. Run it and compare the results with literature.

Task 1.3: Validate the results

Task 2: Design and implementation of the Web Application

Task 2.1 Decide the best technologies to use: Web frame work, coding languages, packages and tools.

Task 2.2: Design and implement the Web Application front-end

Task 2.3: Design and implement the Web Application back-end

Task 2.4: Unify with work done at task 1.

Task 3: Design and implement the applications of the project

Task 3.1: Decide important parameters for the coral reef modeling. Code to extract and compute them. Model the Coral Reef and validate it.

Task 3.2: Add the Animal's comparison tool to the Web Application

The project of the Sound Map is not finished with the current project, and it is scheduled to continue. The future work proposed is also scheduled:

Future Work:

Task F.1: Get better AIS data and test it. Validate the simulation model.

Task F.2: Get Coral Reefs' health data and validate the model. Extend it to other models.

Task F.3: Open the Sound Map to real-time data

Task F.4: Adding other functionalities to the Application (animal's comparison, density profile etc.) and implement the system to LIDO. Install the application at the LAB's server.

PhD: Design and develop a model to relate the soundscape recordings with the health of the ecosystems.

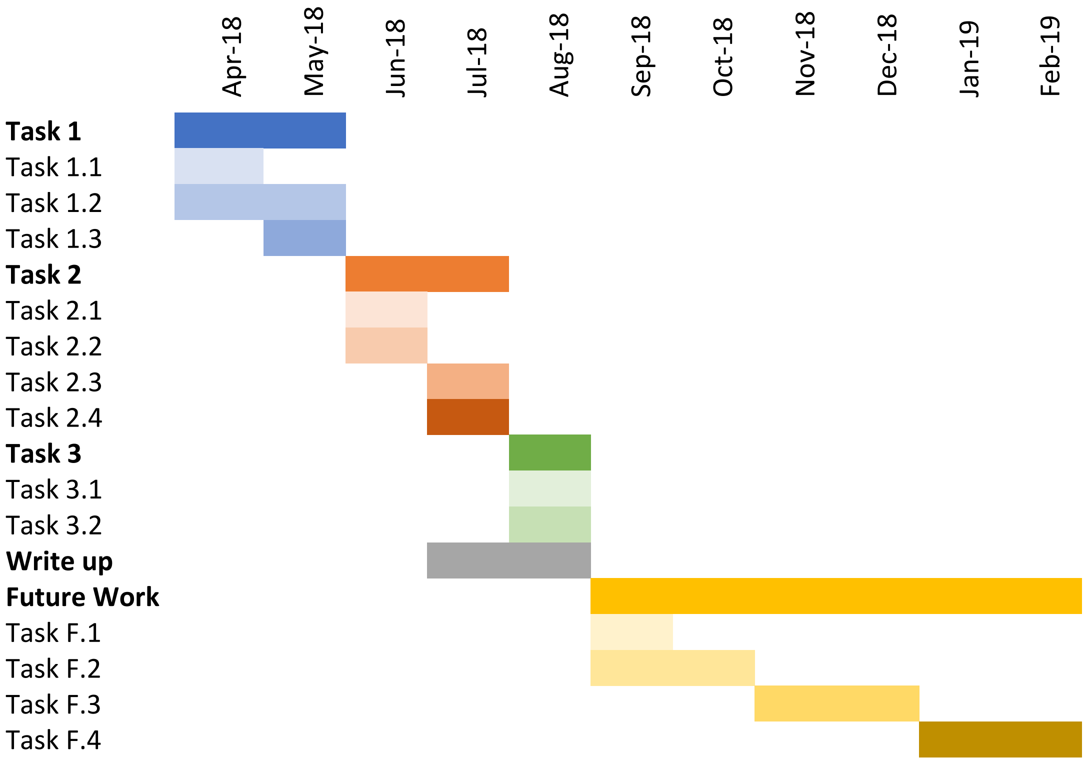


Table 13 Project's scheduling

8.2. Budget

8.2.1. Project realization and execution

The present project has been realized and executed thanks to the LAB. The final expenses are resumed in the following table:

Concept	*Quantity*	*Unit price*	*Price*
CLS data	1	2.000 €	2.000 €
LAB server	1	0 €	0 €
engineer	600h	10 €	6.000 €
TOTAL			8.000 €

Table 14 Project realization and execution's Budget

8.2.2. Future work execution

The LAB is already developing some of the future work points. The expected expenses are resumed in the following table:

Concept	*Quantity*	*Unit price*	*Price*
AIS historical data[6]	10 (1,000,000 each)	1.969 €	19.690 €
AIS API[6]	1	40.000 €	40.000 €
LAB server	1	500 €	500 €
Engineer (future work)	600h	10 €	6.000 €
TOTAL			66.190 €

Table 15 Future Work realization and execution's Budget

6 From Marine Traffic

8.3. Environmental Impact

The project denounces the acoustic contamination of the ocean, which has a harmful impact on marine animals and ecosystems. Proving it with real data measurements can have a great impact, even more if it is an information which is available to everyone.

The public awareness of the acoustic pollution problem can make a change in people's behavior, which can be traduced

Even the results of the project can have a big positive impact, the realization of the project itself has different minor negative impacts:

- To get the AIS data a Satellite working network is used
- To get the sound recordings during the Globe Tour a ship is used to go from one recording point to the other. Even if the ship is a sailing ship, which has negligible acoustic impact, it has to use the engine when there is no wind, which contributes to the acoustic pollution and the global warming, as well as the reduction of finite resources as petrol.
- To permit worldwide access to the Sound Map, worldwide internet connection is needed.
- To work on the project, some facilities are required:
    - The LAB, as any building, has a landscape and environmental impact
    - The computer to work with, which has a finite life and will be turned into waste in less than 5 years.
    - Internet connection
    - An active server

Even so, the negative impact that the project has is minor compared to the positive impact that it can achieve.

Conclusions

The objectives of the project are achieved in a satisfactory manner. Even so, and due to the lack of data, some of the results are not as expected or they cannot be validated. As this is an important aspect to consider the reliability of the results, it will be performed again in the near future to finish the project with better data sources.

The code for the sound pressure level simulation has been designed and implemented, with satisfactory results. Some techniques have been used to compensate the little regularity of the AIS messages received by satellites. The fact that the data purchased at CLS doesn't have a realistic ship's density has made the validation not relevant, as the results would differ a lot depending on the data of each square. Even so, in future work different solutions are presented to solve the issue. They will be applied to finish the project at the LAB.

The Web Application has been created and designed and works as expected. Some proposals to improve the Web Application are explained, and the desired functionalities will be implemented in a near future to improve its functionality before submitting the Web Application to the public.

Regarding the applications of the project, they have been correctly applied and used, and it has been proved their relationship with the main part of the project. There is also a lack of data in the health index of the coral reefs which affects in the reliability of the model, but the results are coherent and they point out that there can be established a relationship between marine ecosystems health and its soundscape analysis, and prove that shipping noise has a direct relation with the bad status of a coral reef.

About the comparison with animal's distribution, the main objective to relate animals' distribution and the shipping noise has been satisfactorily achieved, but many improvements can be made once the discrepancies about the effects of the sound exposure on marine animals are solved

The project achieves its main objective of analyzing the acoustic contamination of the oceans due to human activity with the objective to be able to prove its negative impact in the marine ecosystems, and it can have a big impact in the public awareness of the problem once it is opened to the public. The future work proposed points out the project's multiple applications in different fields, which also have a lot of potential to present solutions to the destruction of the ocean environment.

It is expected that the information provided on the Web Application contributes to the development of new marine regulations about human-made underwater acoustic sounds, which can have a great impact in the health of the marine ecosystems of our planet.

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Appendix A. AIS Data

A.1 AIS status

Status	*Description*
0	Under way using engine
1	At anchor
2	Not under command
3	Restricted maneuverability
4	Constrained by her draught
5	Moored
6	Aground
7	Engaged in Fishing
8	Under way sailing
9	Reserved for future amendment of Navigational Status for HSC
10	Reserved for future amendment of Navigational Status for WIG
11	Reserved for future use
12	Reserved for future use
13	Reserved for future use
14	Reserved for future use
15	Not defined (default)

Appendix B. Code

All the code mentioned and executed in this project can be dowloaded from the following github repositories:

Sound simulation and Web Application code

git clone https://cparcerisas@bitbucket.org/cparcerisas/sound-map.git

Coral Reef model code:

git clone https://cparcerisas@bitbucket.org/cparcerisas/coral-reef.git