

## Towards a noise map model for shallow waters: analysis of propagation losses estimation

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### ABSTRACT

Propagation in shallow waters is complex and strongly dependent on many factors as the bathymetry, seabed composition and water properties among others. Because of this complexity, there is no standard method to obtain propagation losses in this kind of environments. Present contribution continues previous work in the direction of getting a method to obtain propagation losses in shallow water. Hydrophone measurements of a calibrated source emitting single tones were made near Limens beach in Pontevedra (North West Spain), a shallow water zone in Ría de Vigo (a drowned river valley). Noise measurements were accompanied with oceanographic sonde (CTD) measures, obtaining salinity, temperature and speed of sound depth profiles close to the measurement zone and also seabed information from a steel core. Same scenario was vastly simulated using dBSea, an underwater noise estimator with 3D bathymetry, in order to evaluate how important the contour variables are (bathymetry, water properties, seabed properties, etc) and how their accuracy affects to the result. Conclusions discuss software and real measurements results and how the discrepancies between them could affect the results of the simulation of a noise map of the area.

Keywords: Underwater, map, model I-INCE Classification of Subjects Number(s): 54.3

### 1. INTRODUCTION

Propagation in shallow waters is complex and strongly dependent on many factors as the bathymetry, seabed composition or water properties among others. It is known (1) that a change in the height of the receiver as low as 3-5m can produce a change in the received level of 10-20dB, this has also been measured in (2), but not much is known about how this or other variables affect the uncertainty of these pressure values.

The first source of uncertainty is the propagation model used to estimate received levels. Due to the complexity of the propagation process in shallow waters, there is no simple answer to the question of which one provides better estimations.

There are several propagation models in the literature but three of the most rated are:

- Ray Tracing
- Parabolic equation
- Normal modes

These models work from the premise of medium-high depth. With small depths, some low frequencies modes will not propagate and also cancellation of modes would occur. Propagation using these models in small depths (<40m) still needs to be improved.

In order to verify the behavior of these models in shallow waters conditions, the levels generated by a calibrated source were measured at different distances in a real, controlled scenario, and compared with the predictions given by propagation models. Underwater propagation was modeled using “dBSea” (3), an underwater noise software predictor with 3D bathymetry that works with the models mentioned before. The three different solvers of the software –Ray tracing, Parabolic equation and Normal modes– were tested against real data measurements with the aim of tuning the software in a specific shallow water scenario.

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Besides the solvers uncertainty some other variables will be tested as sources of uncertainty as the bathymetry, speed of sound depth profile, receiver depth positioning or seabed composition among others.

Next section will provide and schematic of the main objectives of the present work and section 3 will explain the methods employed to achieve these objectives. Section 4 will present the results of this contribution that will be analyzed and discussed in the final conclusions section.

## 2. OBJECTIVES

The main objective of this work is to estimate the uncertainty of the received levels given in a noise map, due to the propagation losses calculation. In order to achieve it, the following steps are taken:

- Propagation losses calculation using real data measurements in shallow water controlled area.
- Using accurate input data of bathymetry, water properties, seabed composition and receiver positioning, test dBSea models against propagation losses measurements and find the best dBSea fitting as a function of distance and frequency. Discrepancies between measurement-model will be upbounded by a maximum value.
- Evaluate how the accuracy/variability of input variables (bathymetry, water properties, seabed properties, receiver positioning) affects to the result. Several simulations varying the input variables, between physically reasonable margins, will be done, comparing these results with initial model-measurements discrepancies where accurate input variables were used.
- Use previous evaluations and results to estimate the uncertainty of the propagation losses estimation of dBSea and evaluate how it could affect the results of the simulation of a noise map of the area

## 3. METHODOLOGY

### 3.1 Propagation losses measurements

Propagation losses measurements were made near Limens beach in Pontevedra, an area placed in the middle of Ría de Vigo in the northwest of Spain. Figure 1 shows Ría de Vigo, a drowned river valley –35km long and 15km wide at it maximum with depths below 40m– where the seabed is basically composed by mud, coming from the large number of mussel farms which daily contribute to its growth. As can be seen in Figure 2, a calibrated source emitting single tones, with frequencies in 1/3 octave ranging from 125 Hz to 4000 Hz, was submerged at 1m from the surface in a 30 m depth channel.

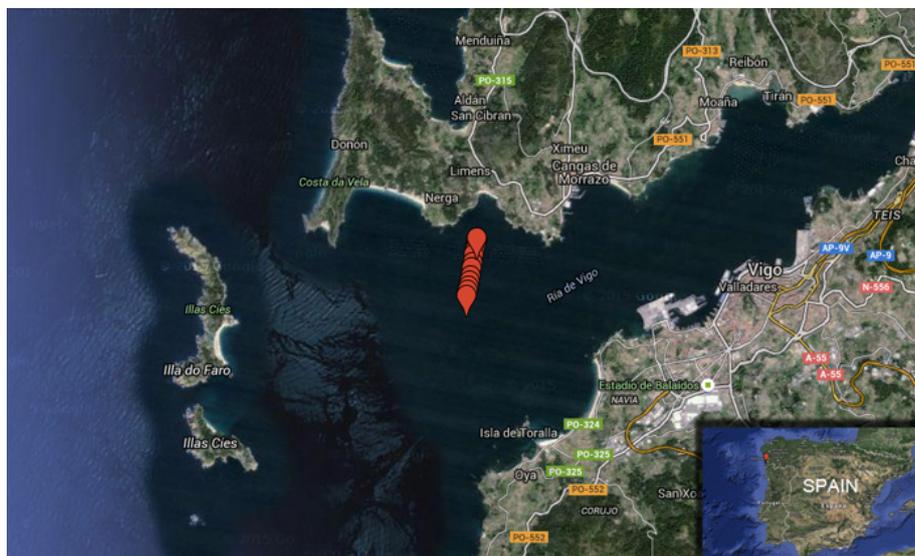


Figure 1 – Measurements locations inside Ría de Vigo, NW of Spain

A line of 14 measurement points –red dots in Figure 1– was established from the source location, close to the coast, till the middle of the estuary, with depth varying from 30 to 36 meters and distance from 10m to 1600m. Two hydrophones with different gains were placed on each measurement position at 5m from the seafloor.

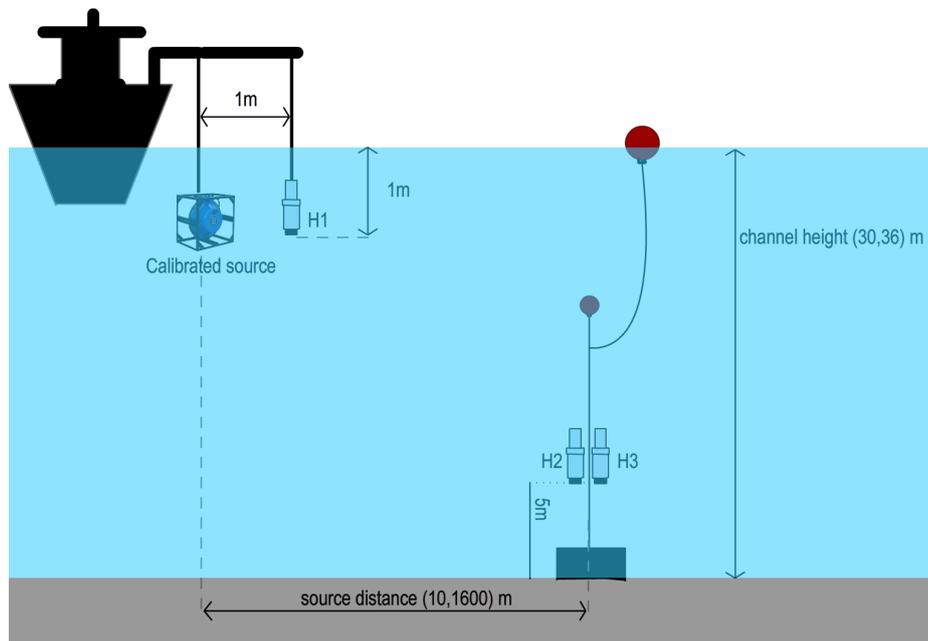


Figure 2 – Propagation Losses setup example for one of the 14 measurement points. Source distance varies from 10 to 1600m and channel height from 30 to 36 m

Noise measurements were accompanied with oceanographic probe (CTD) trials, obtaining salinity, temperature and speed of sound depth profiles close to the measurement zone. Seabed information from a steel core barrel used to characterize the seafloor at this particular area, showed composition and width of each substrate, essentially clay, silt, gravel and different types of sand as can be seen in Figure 3. Ray tracing 3D bathymetry of the zone was also available kindly provided by (4).

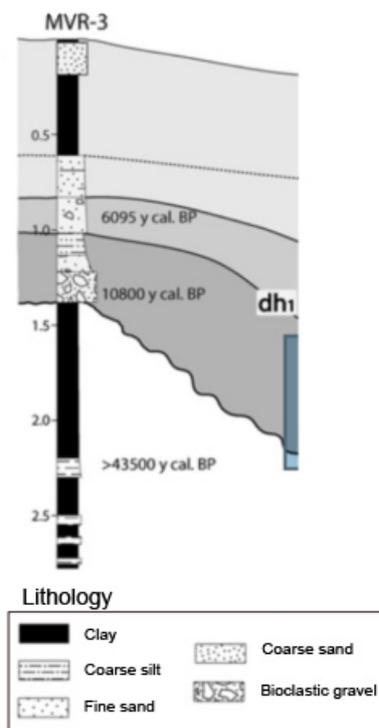


Figure 3 – Seabed layers composition obtained from the steel core barrel (5)

### 3.2 dBSea simulations

The test scenario was vastly simulated in dBSea using accurate input variables: 3d bathymetry of the area, water properties from the CTD probe, exact receiver depth positioning and seabed composition from the steel core barrel. All algorithms (normal modes, parabolic equation and ray tracing) were tested and analysed to determine the best propagation model as a function of distance and frequency, and the accuracy of the best fitting choice determined. The best fitting between measurements and simulations was obtained using the solvers model that minimized the error for each distance and frequency band. Parabolic equation had the better performance at low frequencies and ray tracing at highs, normal modes didn't work well in such low depths (<40m).

Once the best fitting between the actual data and the software simulations was obtained using all the accurate input data available, simulations varying input data variables were made. These simulations serve to estimate the uncertainty of the model output as a function of the changes in the input variables, and compare them with the accuracy of the model supposing a perfect knowledge of the input data. The changes in the input variables are introduced to analyse the effect to lack of accurate information, or temporal or spatial variability.

#### 3.2.1 Experiments description

The main input variables to dBSea and the different variations tested can be summarized in Table 1.

Table 1 – dBSea input variables vs tested variations

Variable	Variations
Bathymetry	3 different sizes maps of the same area
Speed of sound depth profile	Actual   Constant
Receiver depth positioning	Actual   Max. level of the water column
Seabed composition	Actual(15 layers)   5 layers   Default

In a preliminary study of the variables –using best fitting model and all the accurate input data available– three different bathymetries of the same area, but with different sizes/zooms were tested, and three different versions of dBSea. This preliminary study served to fix these two non environmental variables to the values that best fit the measurements with the simulations. As a result of this study, the base software configuration resulted to be: dBSea version 1.3.6, best fitting solvers model, and the bathymetry with the biggest zoom (the smallest represented size).

Starting from the preliminary study configuration, simulations varying the rest of the inputs variables where done:

- Constant and actual (CTD measured) speed of sound profile.
- Depending on the height of the receiver two different levels were obtained: the level at the actual deep of the hydrophone (Hactual) and the maximum received level in the water column (Hmax).
- Seafloor composition had three variations: 1m layer of sand (default); 15 layers of 5 types of materials, obtained at the measurement area, as described by Figure 3; and a 5 layers simplification of the steel core barrel data where all the materials of the same type were compressed in just one layer, obtaining a 5 layers configuration (clay, coarse silt, fine sand, coarse sand and bioclastic gravel).

## 4. RESULTS

As a result of the preliminary study it was found that the best fitting result between the simulation and the measurements was obtained using the following configuration:

- dBSea version 1.3.6
- The bathymetry with the biggest zoom
- 5 layers seabed composition, actual speed of sound depth profile and actual receiver depth positioning

It was found that the error increase of using the bathymetry with the smallest zoom was 0.58 dB and the maximum deviation between dBSea versions was 0.23 dB.

The closest measurement positions –at 11 and 38 m from the source– returned values that deviated more than 15 dB from the average so it was decided to remove them from the results.

Figure 4 shows the evolution of the error with the distance for the best result; for each distance all errors across frequency have been averaged. Figure 5 shows the evolution of the error with distance; for each frequency, errors at all distances have been averaged.



Figure 4 – Error evolution with distance for the best propagation model configuration

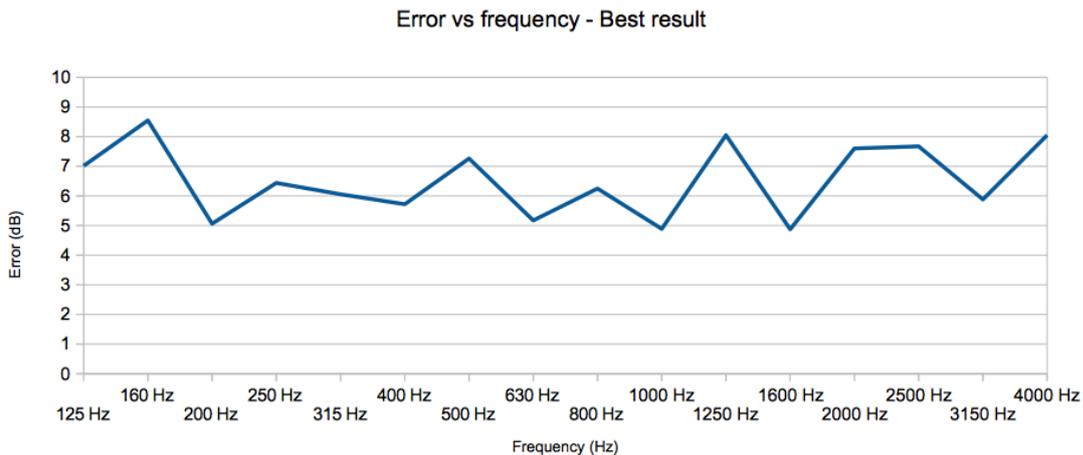


Figure 5 – Error evolution with frequency for the best propagation model configuration

The best result gives an estimation error of 6,68 dB with respect to the measures with a maximum error deviation with frequency of 1.86 dB at 160Hz and maximum error deviation with distance of 1.92 dB at 1194m. Average errors and maximum deviations from the average with frequency and distance will be notated from here on as follows:

$$\text{Error\_best} = +6.68 [1.86@160\text{Hz}, 1.92@1196\text{m}] \text{ dB}$$

Table 2 shows the increase in average and maximum errors in propagation losses estimation, when input variables deviate from actual ones:

- Receiver height positioning: actual deep of the hydrophone (Hactual) or maximum received level of the water column (Hmax).
- Speed of sound depth profile: actual (c\_actual) or constant (c\_constant).
- Seabed composition: actual/15 layers (s\_actual), 5 layers simplification (s\_5) or default (s\_default).

Table 2 – Increases in best estimation error due to changes in model variables. Increments due to changes in a single variable are shown first in bold, then 2 variables increments, and 3 variables increments at the end.

Variable(s) changed	Error increase (dB)
<b>s_actual</b>	<b>+0.37</b> [3.22@250Hz, 2.20@1194m]
<b>s_default</b>	<b>+0.58</b> [3.01@4000Hz, 2.69@1194m]
<b>c_constant</b>	<b>+0.50</b> [4.51@4000Hz, 3.03@1194m]
<b>Hmax</b>	<b>+0.98</b> [3.72@2500Hz, 2.98@670m]
s_default+c_constant	+0.75 [18.02@4000Hz, 8.74@321m]
s_actual+c_constant	+0.21 [4.30@4000Hz, 2.87@1194m]
Hmax+s_actual	+1.53 [3.76@2500Hz, 4.83@1194m]
Hmax+s_default	+2.05 [4.5@4000Hz, 6.31@449m]
Hmax+c_constant	+1.38 [4.64@2500Hz, 4.24@670m]
Hmax+s_default+c_constant	+1.38 [3.62@2500Hz, 3.42@1194m]
Hmax+s_15+c_lineal	+1.28 [4.33@2500Hz, 4.51@449m]

## 5. CONCLUSIONS

This document describes measurements made inside Ría the Vigo and how to use these measurements to adjust the simulation software dBSea using accurate input data of bathymetry, water properties, seabed composition and receiver positioning.

During the first part of the investigation we get a solvers combination that best fit the measurements and, once done, some non environmental variables such as the dBSea version, the size of the bathymetry were fixed. The differences between different dBSea versions are not quite important (below 0.3 dB) and they have to do with minor changes on the algorithms.

Differences between bathymetries zoom, around 0.5 dB, can be related to the number of cells that the dBSea use to solve a bathymetry. If this number is fixed, a change in the size of the map can cause that each cells vary their content and therefore the result. Results pointed that a larger number of cells per distance improves the model fitting but more tests need to be done.

The best result obtained gave an error in the propagation losses simulation of 6.68 dB above the real measurements, with a maximum frequency deviation of 1.86 dB at 160Hz and maximum distance deviation of 1.92 dB at 1194m. This result implies that the error of a simulation with exact input data (except for the seabed composition, that performs better when simplified to 5 layers) will be unbounded by 8.6 dB in average.

The best result was obtained using accurate input data for the speed of sound depth profile, the exact positioning of the receiver and information about the seabed composition. The results pointed that the 5 layers compressed version of the seabed works better than the 15 layers actual one. This has to do with dBSea seabed attenuation calculation method that works with each layer independently, so in the light of the results, is better to have all layers of the same material compressed in one than too many interleaved layers.

The effect on the error of the environment input variables has been also evaluated obtaining differences less than 2 dB above the best result, giving an overall error of 10.6 dB in average. Results also showed that single variable contribution cannot be added to obtain multiple variable contributions, that is to say, effects of individual variables do not add up linearly. The most impacting elements seem to be using the default seabed instead of a five-layers description of it, and retaining the maximum level in the water column, instead of the one at the precise height of the receiver.

In the light of our results, if the propagation solver is carefully chosen, it seems possible to build noise maps in shallow waters with almost no environmental information, besides bathymetry. The

effect of this lack of knowledge on the uncertainty of the results due to propagation will not exceed 10 dB in average, which is the expected variability with depth of received levels.

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