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Development and Calibration of a Sound Propagation Model for the Oregon Coast

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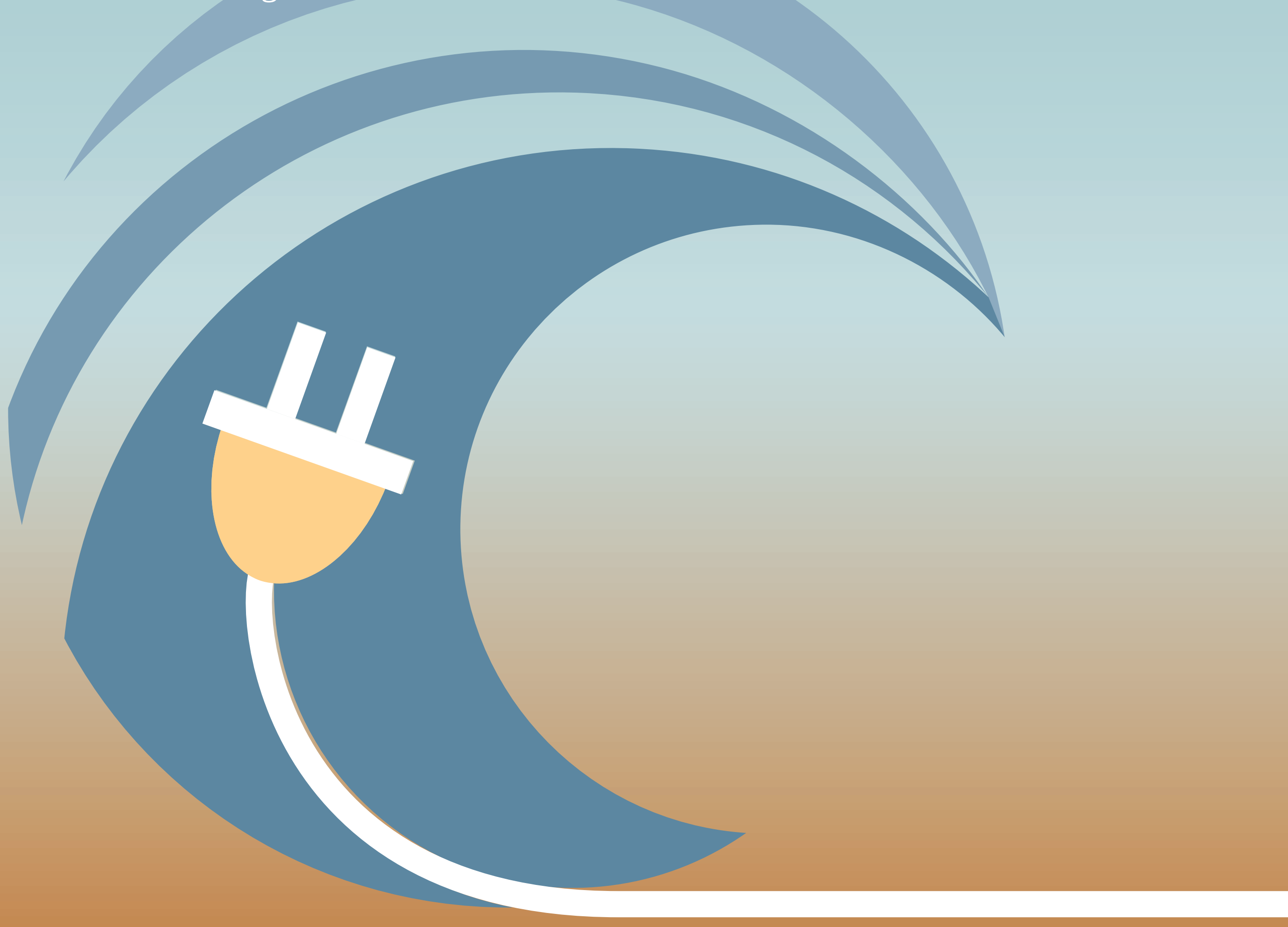

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U.S. DEPARTMENT OF ENERGY

OregonWaveEnergy TRUST

Development and Calibration of a Sound Propagation Model for the Oregon Coast

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OBJECTIVES

In this report we present results of a sound propagation modeling study off the coast of Newport, OR. Preliminary acoustic experimental data was also collected by an underwater glider equipped with a hydrophone to measure sound levels in a short transect perpendicular to the coast and away from a sound source. A propagation model was used to simulate the arrivals recorded by the glider's hydrophone and results were compared to the experimental data. Optimal experimental setup for future measurements using a glider is suggested.

INTRODUCTION

The increase of man-made noise levels in the oceans can potentially affect marine organisms, especially marine mammals and fish for which sound plays a vital role in communication, navigation and detection of prey and predators. Sound propagates very efficiently in the ocean and can be detected over long distances from the emitting source. However, its propagation can be complex, especially in shallow coastal waters where sound interactions with the ocean surface and bottom, which can attenuate or amplify a given signal, are important. Therefore, a crucial step in assessing potential impacts of increased noise levels on the marine environment is to understand how sound propagates in a specific area. To this end, the use of modeling techniques provides an inexpensive tool to visualize and forecast possible areas of higher sound levels, and field measurements are important for validating model results.

Here we employ commonly used propagation modeling techniques to assess the potential impact that a man-made sound source could have on the marine environment in shallow coastal waters off the Oregon coast. The Oregon coast is a key location for the development of wave energy technologies with the coast of Newport acting as a test bed for research through Oregon State University (Brekken *et al*., 2009). Generation and radiation of underwater noise associated with wave energy buoys could potentially impact the marine biota, especially fish and marine mammals. For example, typical areas for development of wave energy installations, which are within 3 nm from shore, coincide with gray whale migration paths (Lagerquist and Mate, 2009). Modeling can provide information on sound levels which marine mammals and fish are exposed to in a given area of interest. This information is critical in determining potential effects of anthropogenic sound sources on marine organisms, especially species of concern along the Oregon coast such as Steller sea lions (*Eumetopias jubatus*) and migrating gray whales (*Eschrichtius robustus*).

In this work acoustic propagation software and a model of the physical environment are combined with information on source properties such as intensity levels and frequencies. A preliminary field component was carried out to validate the output of the model, consisting of calibrated measurements of the acoustic field generated by a known sound source. The development of such a model is crucial for policy makers to accurately predict the potential impacts of increasing levels of anthropogenic noise on the marine environment.

MODELING TRANSMISSION LOSS

Sound propagation modeling is an estimation tool, which is becoming a standard in noise impact assessments and that can give an indication of the rate at which sound levels can be expected to decay as a function of distance (Austin *et al*., 2009, Erbe and King, 2009). However, in order to use such tool it is first necessary to build a physical model of the area of interest. The most important information required by a physical model and used as input in most propagation models include sound speed profiles, bottom properties such as composition and layering, and bathymetry.

Austin *et al*. (2009) conducted a preliminary sound propagation modeling study for three different locations along the Oregon coast, near Oceanside on the north, near Depoe Bay on the central coast, and near Jewitt Island on the south. The propagation model they used was based on the Range-dependent Acoustic Model, also known as RAM (Collins, 1993). By assuming a flat source spectrum, they created maps of acoustic transmission loss as function of distance from the source for the three distinct locations cited above by summing the contributions of the frequencies in the 10 Hz to 2 kHz band.

Here we simulate sound propagation by using the ray-tracing model called Bellhop (Porter and Bucker, 1987). A single transect perpendicular to the coast of Newport, OR, in the E-W direction off Yaquina Head (Figure 1) was assumed for the simulations. The bathymetry of the study site was retrieved from the National Oceanic and Atmospheric Administration's National Geophysical Data Center website (NOAA – NGDC) by inputting the geographical coordinates of the desired area. The sound speed profile used in the simulations was collected by Oregon State University's Cooperative Institute for Marine Resources Studies (OSU/CIMRS) and NOAA's Northwest Fisheries Science Center (NWFSC) in April of 2009 (Figure 2). A search of geological samples from the area of interest through NOAA's NGDC Index to Marine & Lacustrine Geological Samples showed that the bottom is constituted by sand. Bottom properties of sandy silt (Hamilton, 1980) were then used as input to Bellhop with compressional sound speed of 1652 m/s, density of 1.771 g/cm^3, and compressional attenuation of 0.5 dB/m. Shear wave properties were not considered in this work.

Simulations were performed by assuming a source located at approximately 3 nm from shore, at 5 m below the sea surface, and having a source level of 170 dB. A maximum distance of 6 km from the source along with the sound speed profile measured at 5 nm from shore was also assumed. Results of calculations are shown in Figure 3 as received levels in depth and range for frequencies of 1, 2, and 3 kHz. We can observe from these results that for a shallow source a weak surface duct seems to develop for the sound speed profile collected in April. The surface duct is characterized by the energy that propagates between 0 and 10 m deep, as if it was trapped in this region. We also observe strong bottom reflections along the propagation path, which indicates the importance of the bottom characterization in the propagation modeling. Such information however, is most often lacking and approximate values are usually assumed.

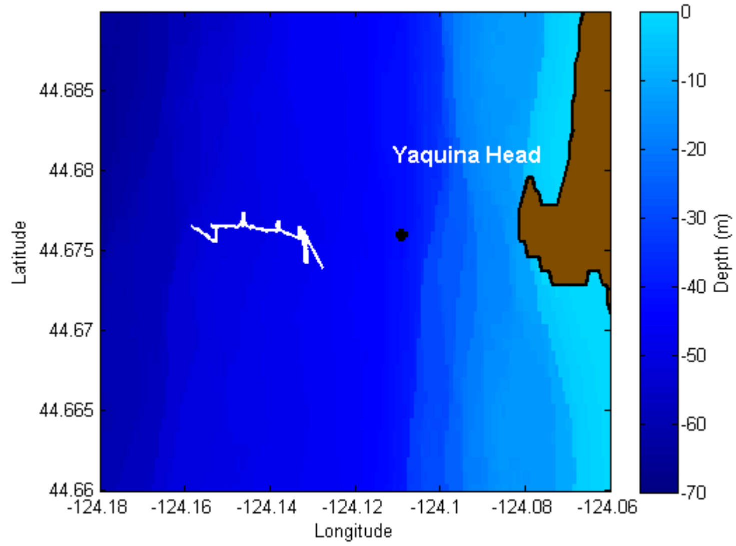


Figure 1. Bathymetry map off Yaquina Head, Newport, OR. The black star corresponds to an approximate source location used in the numerical simulations, and the white line corresponds to the glider track. (Source: NOAA – NGDC).

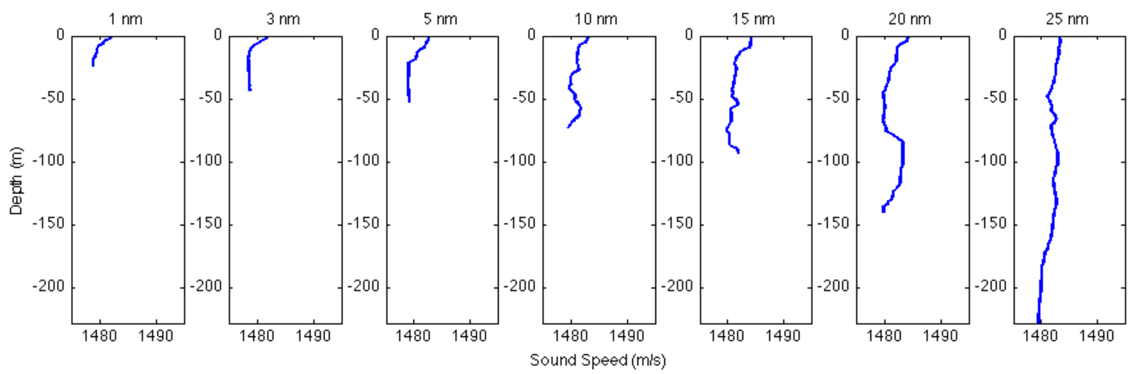


Figure 2. Sound speed profile collect off the coast of Newport, OR, by OSU/CIMRS and NOAA/NWFSC in April 2009 at increasing distances perpendicular to the coast.

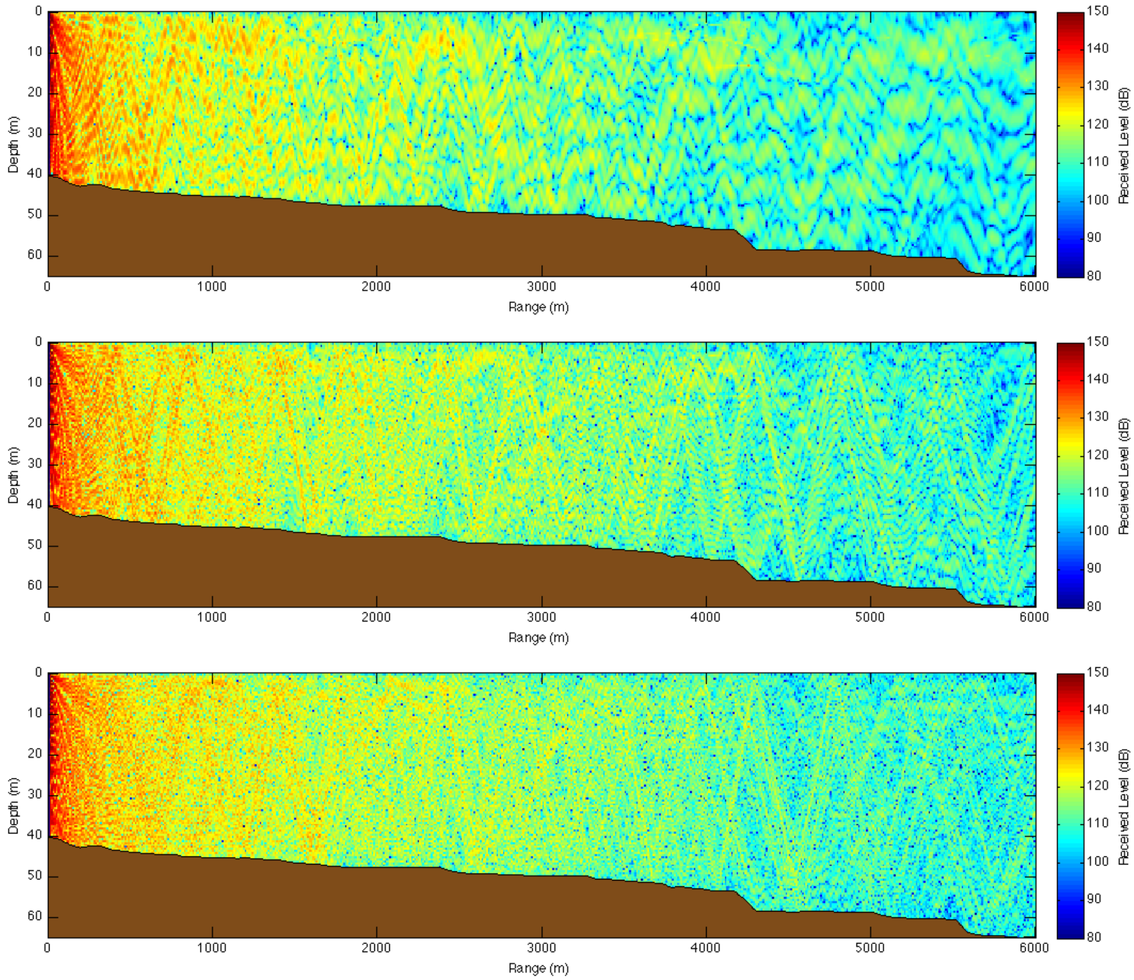


Figure 3. Received levels as function of range and depth assuming a source at 5 m deep, with source level of 170 dB and frequencies of 1(top), 2 (middle), and 3 (bottom) kHz.

SOUND PROPAGATION EXPERIMENT

In measuring underwater noise generated by natural or man-made sources, many factors must be taken into account, including frequency, bandwidth, duration, intensity, and source-receiver geometry. The complicated oceanography and natural random fluctuations in the water column structure observed in shallow waters also play a major role in sound propagation. Therefore a single noise measurement is not sufficient to make an accurate characterization of exposure levels.

In order to quantify sound propagation effects, a preliminary field component was carried out to measure sound levels emitted from a calibrated sound source. The experiment took place on April 19, 2011, off of Yaquina Head, Newport, OR (Figure 1).

The acoustic source used in the experiment was a Lubell LL916C Underwater Speaker manufactured by Lubell Labs of Columbus Ohio. Sound source level (SL) was below 170 dB re 1 μPa at 1 m, in accordance to the permitting issued. The source was programmed to transmit an upsweep pulse (Figure 4) of frequency content from 1 to 3 kHz and 8 s in duration, every 20 s. The source was deployed from a small boat at a depth of approximately 5 m from the sea surface, and at approximately 3 nm from the shore where water depths are approximately 40 to 50 m. The coordinates of the boat, and hence of the source, were recorded by a hand-held GPS. While Figure 1 shows an approximate location of the transmitting source used in the experiment, when plotting the GSP coordinates of the skiff from which the sound source was suspended (Figure 5) we observe that in fact it drifted quite a lot during the experiment forcing the boat to constantly reposition itself.

A Webb Research Corporation Slocum Glider (Figure 6) was used to record sound pressure levels of the emitted signal along a single transect perpendicular to the coast, and up to 3 km away from the source location (Figure 1). The glider was programmed to move through the water column in a saw-tooth pattern in order to sample as much of the environment along its track as possible. Data was recorded continuously for about 4:30 hours, from 11:30 am to 4 pm at a sampling rate of 120 kHz. The analysis of the recorded data is presented in the next section.

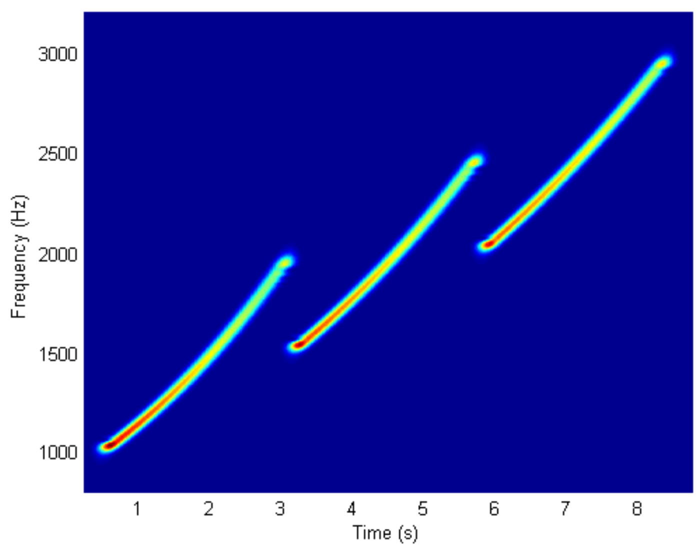


Figure 4. Spectrogram of the source signal

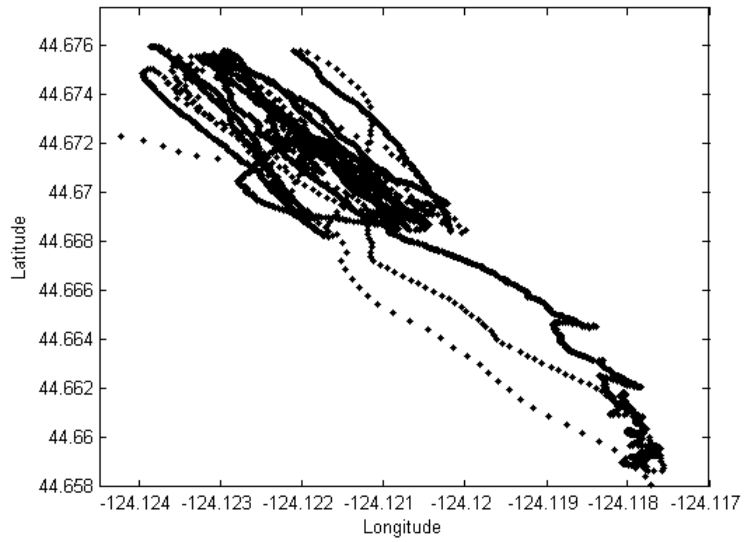


Figure 5. GPS location of the small boat from which the sound source was deployed, indicating its drift and constant repositioning.

Figure 6. Webb Research Corporation Slocum Glider, owned by the Northwest Electromagnetics and Acoustics Research (NEAR) Lab, and used in the field experiment.

GLIDER DATA ANALYSIS

The glider depth profile while recording data is shown as the blue curve in Figure 7 for the last hour of the experiment. At the inflection points of each dive, the ballast pump goes on to change the buoyancy of the glider, causing the instrument to dive or ascend. Activity of the ballast pump causes acoustic noise, which is observed in the acoustic recordings (red line) and can be discarded from the analysis.

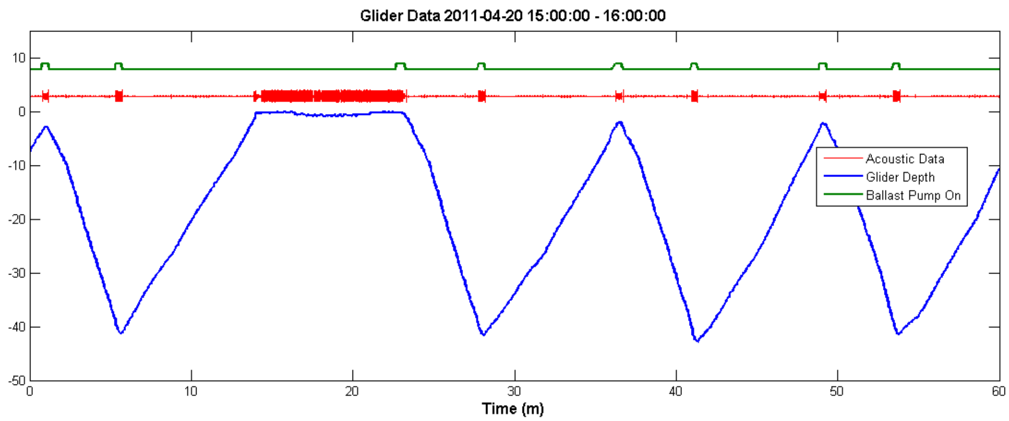


Figure 7. Raw received data on the glider (red) for one hour of recording. The saw-tooth glider track (blue) and the ballast pump data (green) is also shown, matching the featured observed in the acoustic data.

For this preliminary experiment we looked at the data from one yo, or dive cycle (Figure 6), of approximately 13 minutes in duration, which started at 12:56:18 pm when the glider was located at 1.16 km from the source boat. The maximum distance reached by the glider at the end of this yo was 1.54 km. The raw data recorded by the glider during this single yo is presented in Figure 9. Note the very noisy portions of the data between 200 and 300 s and just after 700 s, which correspond to turning points when the glider is changing its orientation.

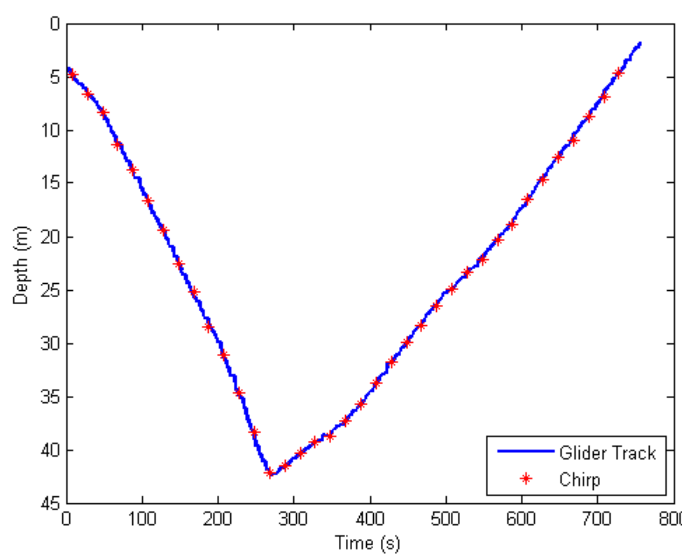


Figure 8. Glider yo with start time at 12:56:18 pm from which data was analyzed. Times when the source transmitted the chirp signal are superimposed with a red star.

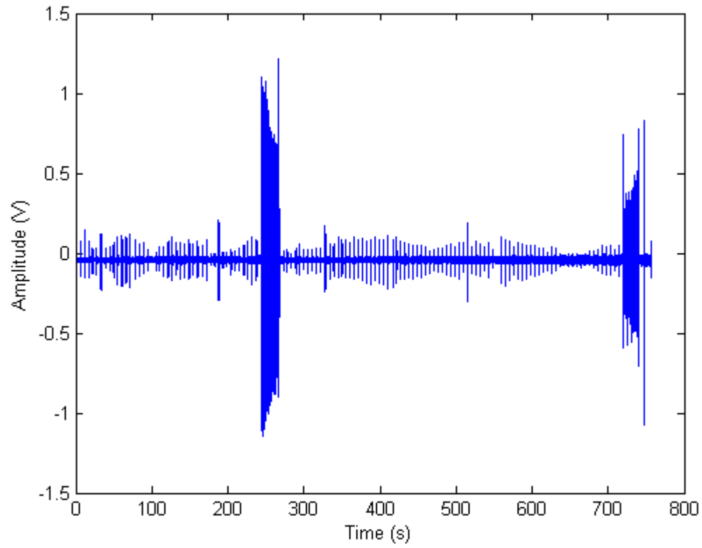


Figure 9. Acoustic raw data recorded by the glider during the dive profile of Figure 8.

In order to observe the desired signal, in this case the upsweep chirp transmitted by the source, in the recorded data we matched filter the source signal with the raw data. The resulting envelope of the signal is plotted in Figure 10. The times when the source transmitted the chirp signal are also indicated in the same plot by red stars.

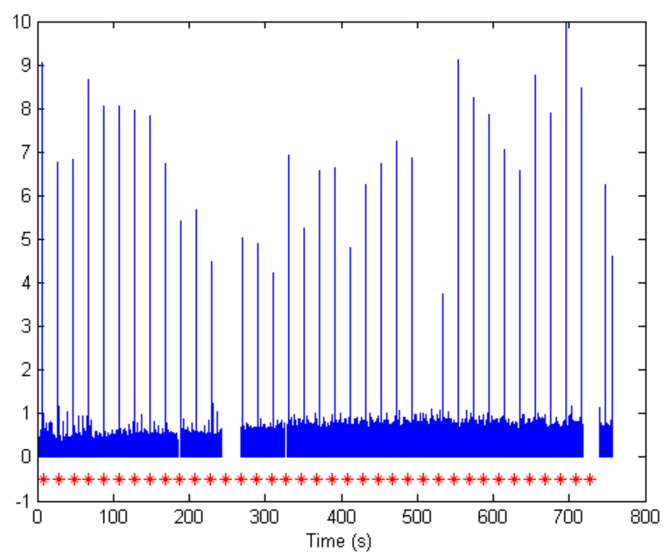


Figure 10. Received signal matched filtered with the source signal. Red stars correspond to times when the source transmitted the chirp signal. Blank gaps correspond to times when the glider was maneuvering and/or the ballast pump was on.

COMPARISON OF DATA AND SIMULATION

In order to perform a proper comparison of received sound pressure levels with simulations, the source location should be known and ideally fixed at a constant depth. In the preliminary experiment carried not only the receiver (glider) was moving, but also the source was constantly drifting in both range and depth from the target location due to strong winds and currents. Such conditions compromised the quality of the data collected and making it difficult to perform a proper comparison and validation of the propagation modeling.

For illustration purposes, Figure 11 (a) shows the received sound pressure level (dB) in the 5 kHz frequency recorded along the glider path. The recorded pressure levels can then be used to construct Figure 11 (b) by performing interpolation in range and depth. In particular, Figure 11 (b) shows the interpolated result at 750 Hz. It is worth noting that the more times the glide goes back and forth along a given path the better the quality of the interpolated field. In the experiment the glider

Modeling for both frequencies shown in Figure 11 were also performed and the results are shown in Figure 12 (a) and (b). Calculations were performed assuming a source level of 145 dB. Results were plotted for ranges between 500 and 2750 m to try to best match the data presented.

It is hard to make any comparisons, even if only quantitative in nature, between data and simulation for the two frequencies presented. Knowledge of source levels, better environmental characterization at the time the data was collected, and having a fixed source at all times are important factors that need to be taken into account when performing such model validations. A statistical analysis of the field, that is, comparison of mean and standard deviations of received pressure levels at various locations with simulated data (Jagannathan *et al.*, 2012), or comparison of arrival times would be more appropriate given the availability of good quality data.

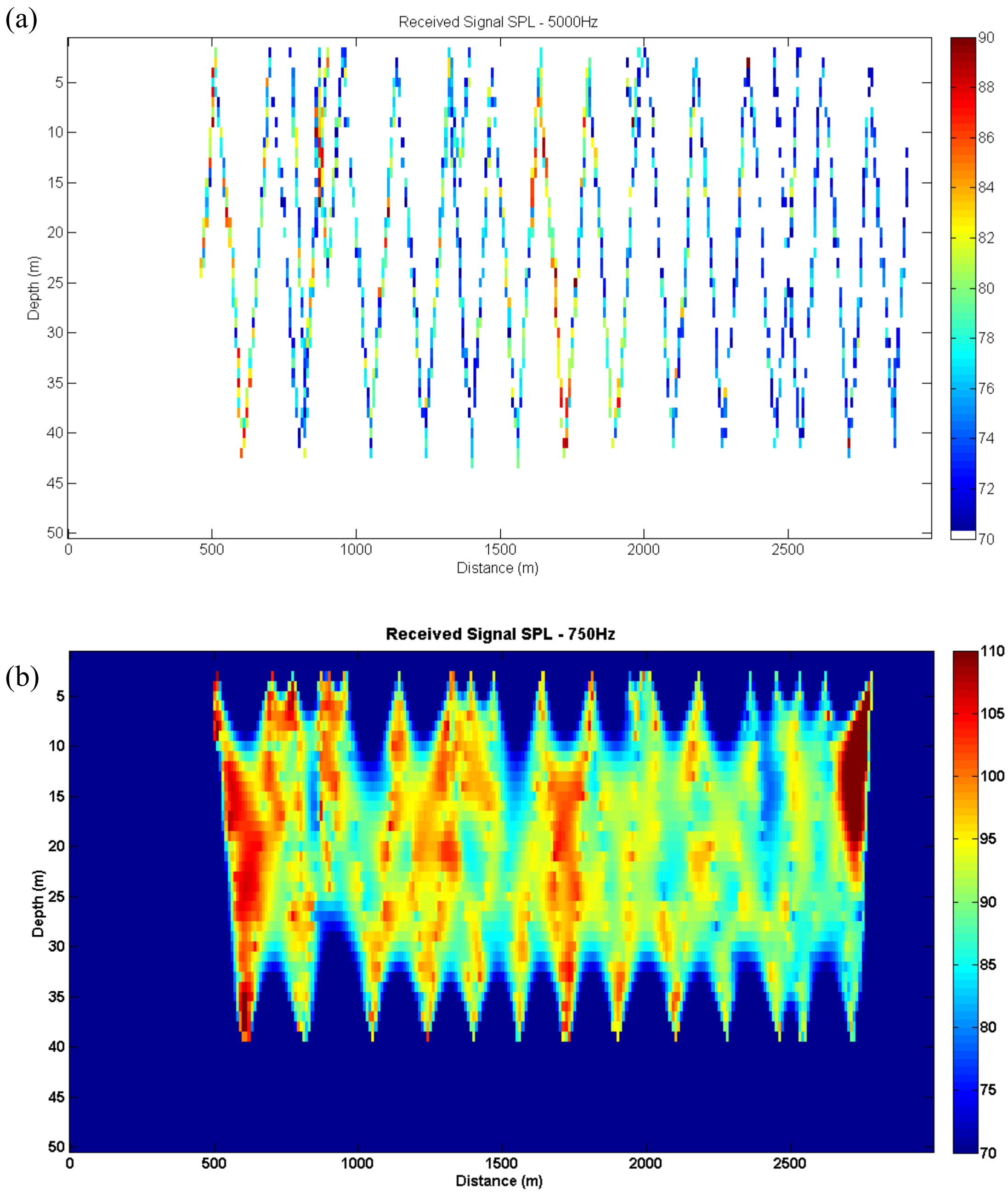
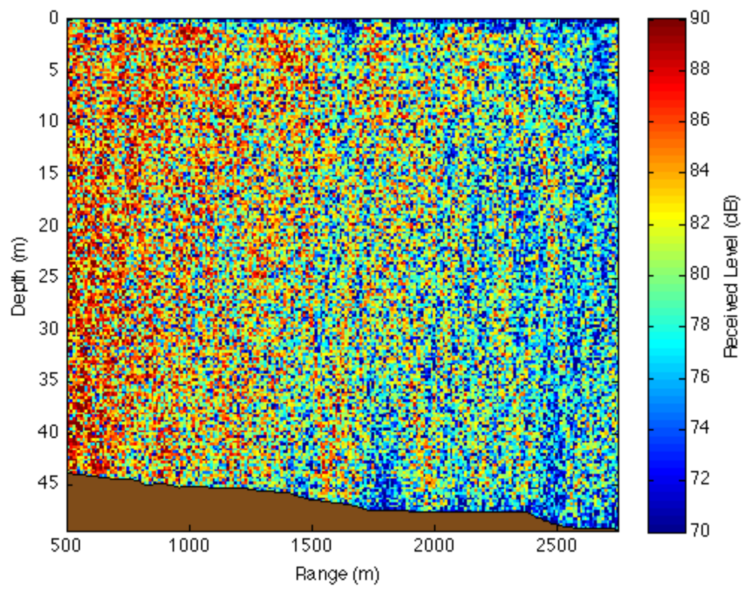


Figure 11. Received sound pressure level in dB recorded by the glider along its path. (a) True recorded levels at 5 kHz; (b) Interpolated levels along the saw-tooth path at 750 Hz.

(a)



(b)

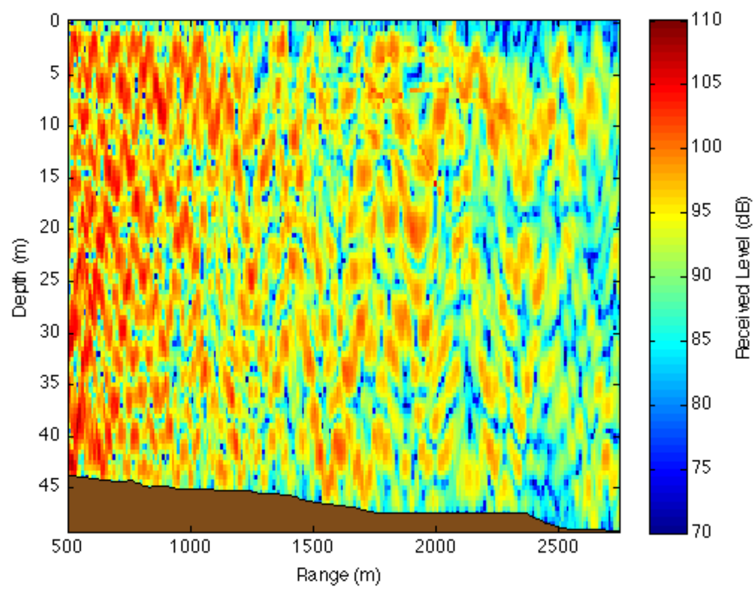


Figure 12. Simulated sound pressure field assuming source levels of (a) 130 dB and (b) 145 dB. The choice of source level was made so that levels would be comparable to those of Figure 11.

CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

The acoustic signature of wave energy harvesting devices is not yet known, nor is the impact that the deployment of many devices could cause in a given area. A combination of modeling and field measurements using an underwater glider, for example, could assist wave energy developers in coastal areas in obtaining a better understanding of sound propagation in the local environment and hence a better assessment of the noise levels affecting local marine organisms.

In the preliminary experiment for acoustic data collection using an underwater glider, two important factors hindered the quality of the collected data. They were the drifting of the sound source during transmission, and the lack of a proper source characterization to obtain the source level information necessary for estimation of zones of noise impact.

The available sound source that was used in the preliminary experiment had to be suspended from a small boat, which drifted considerably from the originally planned source position due to strong winds and currents at the day of the experiment. This is confirmed from the GPS locations plotted on Figure 5. Ideally, the sound source should be fixed, moored to the seafloor to avoid great dislocations as occurred in this experiment. It is also desirable to use a source that can be placed in different depths in the water column. The Lubell LL916C Underwater Speaker has a maximum operating depth of approximately 5 meters and hence had to be deployed and left suspended from a small boat. Because of the small depth of operation and also the strong winds it was also hard to maintain the source at a constant depth. Knowledge of the source level, measured *in situ*, is also very important if a model validation is to be conducted. Unfortunately such source characterization could not be performed and an estimated source level was assumed for the simulations.

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DISCLAIMER

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