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Underwater Acoustic Propagation using Monterey-Miami Parabolic Equation in Shallow Water Kayeli Bay Buru Distric

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Indonesia's geographical position is an advantage compared to other countries, both in terms of geoeconomics, geopolitics and geostrategy. For this reason, it is necessary to develop and use acoustic methods to describe underwater features, carry out underwater communications or to measure oceanographic variables at sea. This research was intended to provide an analytical and visual graphical description with the aim that it can be used for various purposes both in the research, military and other marine fields, as well as to analyze the influence of sediment and different frequencies on acoustic propagation patterns in shallow waters of Kayeli Bay. This research was conducted using CTD data from Kayeli Bay, which is a body of water in Buru Regency, Maluku Province and is located between 3° 15' 55" – 3° 22' 50" S and 127° 01'35" – 127° 01' 35 "E, using the Monterey-Miami parabolic equation method using 4 types of sediment and 3 different frequencies as model input. From the results of this research it can be concluded that the propagation of sound waves in shallow seas is greatly influenced by the type of sediment and frequenty used. Changes in acoustic impedance at the bottom of the water and within the water column can significantly influence the behavior of acoustic waves in shallow water environments, and accurate acoustic impedance data are critical for effective ray tracing modelling.

Keywords: Acoustics propagation, shallow water, ray tracing, sediment, frequency

1. Introduction

Indonesia is the largest archipelagic country in the world by sea area 93,000 m^3 (Marsetio 2014). Indonesia's geographical position is an advantage compared to other countries, both in terms of geoeconomics, geopolitics and geostrategy. For this reason, it is necessary to develop and use acoustic methods to describe underwater features, carry out underwater communications or to measure oceanographic variables at sea. Acoustic propagation modeling can show the form of propagation of waves that propagate at a location so that a picture of water conditions and what phenomena occur in those waters can be known. Modeling is an efficient way to parametrically investigate and hypothesize sonar performance under various environmental conditions (Etter 2003). This study regarding sound propagation in water needs to be carried out to determine the speed characteristics and sound propagation patterns underwater based on sound speed, depth and sediment type data simulated in Matlab. This research is intended to provide an analytical and visual graphic description with the aim that it can be used for various purposes in the research, military and other maritime fields. The aim of this research was to analyze the influence of different sediments and frequencies on acoustic propagation patterns in the shallow waters of Kayeli Bay.

2. Methods

2.1 Research Location and Time

This research was carried out using CTD data with the location of Kayeli Bay, Buru Regency which was located between 3° 15' 55" – 3° 22' 50" S and 127° 01'35” – 127° 01' 35” E and data processing was carried out in March 2023-August 2023.

2.2 Underwater Propagation Model

The Monterey-Miami Parabolic Equation (MMPE) model is an underwater full-wave acoustic propagation model that uses the fractional-step Fourier march algorithm (Smith, 2000). (Ha, 2000) explained that This model was used to predict underwater sound propagation in deep and shallow water environments. Using an implementation of the Parabolic Equation/Split-Step Fourier algorithm for field functions:

$$(r+\Delta r, z) = e^{-1k_0\frac{\Delta r}{2}U_{op}(r+\Delta r,z)} \times FFT\left\{e^{-ik_0\Delta r\hat{T}_{op}(k_z)}IFFT\left[e^{-1k_0\frac{\Delta r}{2}U_{op}(r,z)}\psi(r,z)\right]\right\}$$
(1)

The environmental propagator function defined as

$$U_{op}(z) = U_1(z) + U_2(z)$$
(2)

Where $U_1(z)$ is defined environmental potential function $U_{op} = -(n-1)$ and $U_2(z)$ is a new operator that includes the effect of the density discontinuity. Within the MMPE Model, the function U_2 is approximated by

$$U_2(z) = -\frac{\varepsilon}{k_0^2}\frac{\partial^2}{\partial z^2}H(z-z_b) \quad (3)$$

Where

$$\varepsilon = \left[\frac{1-(\frac{\rho_w}{\rho_b})^{1/2}}{1+(\frac{\rho_w}{\rho_b})^{1/2}}\right] \quad (4)$$

For the density mixing function, a cubic spline over the finite interval $-L_p \leq \zeta \leq L_p$ is defined. Then $\bar{H}(\zeta)$ is defined by

$$\bar{H}(\zeta) = \begin{cases} 0 & , \quad \zeta \leq -L_\rho \\ \frac{2}{3}\left(1+\frac{\zeta}{L_\rho}\right)^3 & , \quad -L_\rho \leq \zeta \leq -\frac{L_\rho}{2} \\ \frac{1}{2}+\frac{\zeta}{L_\rho}-\frac{2}{3}\left(\frac{\zeta}{L_\rho}\right)^3 & , \quad -\frac{L_\rho}{2} \leq \zeta \leq -\frac{L_\rho}{2} \\ 1-\frac{2}{3}\left(1-\frac{\zeta}{L_\rho}\right)^3 & , \quad \frac{L_\rho}{2} \leq \zeta \leq L_\rho \\ 1 & , \quad \zeta \leq L_\rho \end{cases} \quad (5)$$

The first derivative of this function is

$$\acute{\bar{H}}(\zeta) = \bar{\delta}(\zeta) = \begin{cases} 0 & , \quad \zeta \leq -L_\rho \\ \frac{2}{L_\rho}\left(1+\frac{\zeta}{L_\rho}\right)^2 & , \quad -L_\rho \leq \zeta \leq -\frac{L_\rho}{2} \\ \frac{1}{L_\rho}\left[1-2\left(\frac{\zeta}{L_\rho}\right)^2\right] & , \quad -\frac{L_\rho}{2} \leq \zeta \leq -\frac{L_\rho}{2} \\ \frac{2}{L_\rho}\left(1-\frac{\zeta}{L_\rho}\right)^2 & , \quad \frac{L_\rho}{2} \leq \zeta \leq L_\rho \\ 0 & , \quad \zeta \geq L_\rho \end{cases}$$
(6)

where $\bar{\delta}(\zeta)$ is the smooth approximation to the dirac delta function the second derivative is then

$$\bar{H}''(\zeta) = \bar{\delta}'(\zeta) = \begin{cases} 0 & , \quad \zeta \leq -L_\rho \\ \frac{4}{L_\rho^2}\left(1+\frac{\zeta}{L_\rho}\right) & , \quad -L_\rho \leq \zeta \leq -\frac{L_\rho}{2} \\ -\frac{4}{L_\rho^2}\left(\frac{\zeta}{L_\rho}\right) & , \quad -\frac{L_\rho}{2} \leq \zeta \leq -\frac{L_\rho}{2} \\ -\frac{4}{L_\rho^2}\left(1-\frac{\zeta}{L_\rho}\right) & , \quad \frac{L_\rho}{2} \leq \zeta \leq L_\rho \\ 0 & , \quad \zeta \geq L_\rho \end{cases} \quad (7)$$

Equation (3) and (7) provide the necessary expression for computing potential function with a cubic spline polynomial smoothing function. The Parabolic Equation starting field in the vertical wavenumber, k_z domain, for the wide angle source is given by

$$\hat{\psi}(r=0,k_z) = -2i\sqrt{\frac{iR_0}{2\pi k_0}}\sin(k_z Z_s)\left(1-\frac{k_z^2}{k_0^2}\right)^{-1/4} e^{ik_z\frac{\Delta t}{2}}$$
(8)

2.3 Tools and Data

The tool used in this research is a laptop with the data used including: in situ CTD, bathymetry and sediment data. Data requirements for the Monterey-Miami Parabolic Equation (MMPE) method are as follows: Pefiles.inp (input file name, output method etc), Pesrc.inp (source parameter settings), Pessp.inp (sound speed profile settings), Pebath.inp setting bottom depth), Pebotpro.inp setting sediment layer properties), Pedbath.inp (setting sediment layer), Pedbotprop.inp (setting rock layer properties). The software used for this research is: ArcGis 10.5, Matlab 2020b, Microsoft Office 2016.

2.4 Research stages

The research method applied in this study follows the following research stages:

1. Collect data on temperature (T), salinity (S) and speed of sound (c) and depth (z) at the research location.
2. Determine the vertical profile of the speed of sound (c) using the MATLAB 2020 program at all research stations.
3. Setting sound speed data and environmental data with propagation distance (r) to depth (z) which are used as input in the program.
4. Verify the model results from the MMPE program.
5. Carry out the MMPE program in the research area by varying sediment types and frequency.
6. Analyze the results of the propagation model characteristics resulting from the MMPE program. The analysis was carried out mainly by determining the influence of sediment and frequency on sound wave propagation patterns.

3. Result and Discussion

In modeling using MMPE, boundaries are used to describe the water conditions at the research location using two data collection points as the starting point and end point of the model with a distance of 2.9 km, cross-sectional depth is 33.6 m - 92.3 m, type of bottom sediment. those used in the model are sorted based on their porosity from smallest to largest, namely clay, silt, fine sand and coarse sand with a

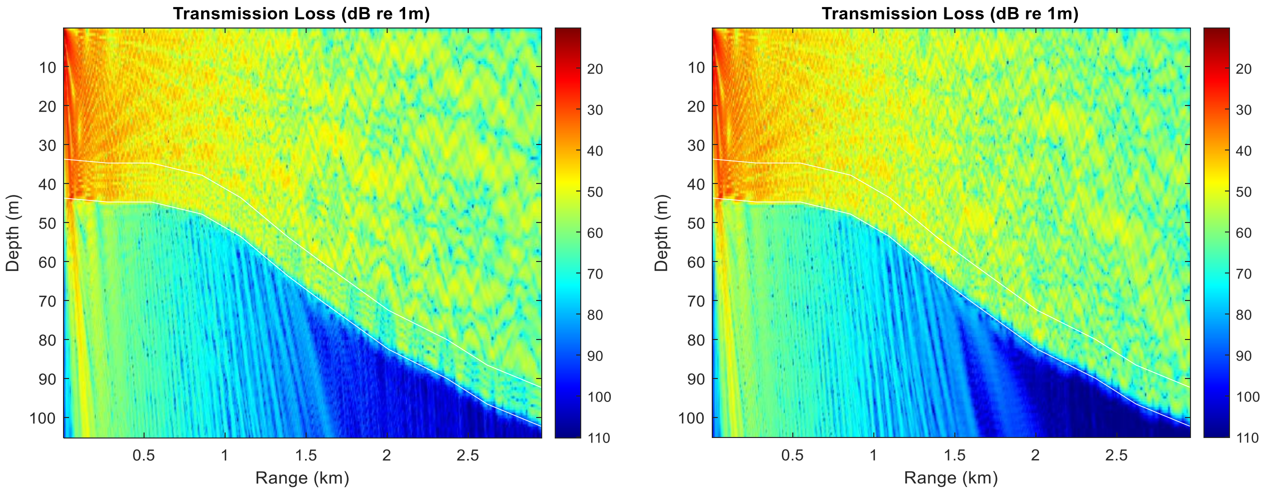

Figure 1. Acoustic propagation model using a frequency of 1000 Hz with clay (left) and silt sediment types (right)

sediment thickness of 10 m, and the type of rock used for seacrust is basalt. The source frequency used is also varied to 1000 Hz, 10 kHz and 100 kHz.

3.1 Frequency 1000 Hz

The modeling results for a frequency of 1000 Hz show that in the water column several boundary layers are formed which reflect sound waves so that several parallel propagation paths are formed. This shows that sound waves are reflected from each other by the water column based on the grazing angle using the same principle as discussed previously. The wave then experiences transmission loss, the main cause of transmission loss in shallow waters is attenuation which is influenced by frequency and propagation loss which is influenced by distance because absorption and scattering are influenced by the type of sediment in the waters (Carey, 2003). Based on the resulting model it can be said that at a frequency of 1000 Hz sound waves have good propagation capabilities in the water medium which is characterized by a relatively small transmission loss value. In addition, it can be seen that the fluctuating speed of sound with increasing depth creates boundaries in the water column which create several propagation paths. This applies to all sediment type models, but differences can be seen in the number of propagation paths formed and the distribution of transmission loss values.

For the four types of sediment used in the model, differences in transmission loss values can be clearly seen in each image. This is caused by the difference in acoustic impedance between the media. In controlling Acoustic Impedance values, speed has a more important meaning than density (Sukmono, 2002). This is because the density of a rock has a limit where at a certain value the density of one rock will overlap with the density of other rocks. A medium that is harder and more compact (small porosity) has a higher impedance value than a medium that is not compact (large porosity) because sound waves will propagate more easily through a medium with smaller porosity (Ramdani, 2014). This impedance value will affect the reflection coefficient value. If the impedance of the sediment is greater than that of the water medium, the reflection coefficient value of the sediment will be higher, this also applies to the interface between sediment and bedrock. This reflection coefficient describes the strength and weakness of the reflection of acoustic waves from sediment and bedrock, thereby influencing the propagation pattern that is formed. The higher the reflection coefficient, the greater the acoustic wave energy that is reflected back into the medium, which causes the greater intensity of the acoustic wave in the medium where the wave propagates.

In addition, acoustic impedance gradients in shallow water cause sound waves to change direction as they move. This phenomenon is called refraction. Refraction occurs when sound waves encounter changes in the acoustic impedance of the water column or seabed. The bending of sound waves caused by refraction can have a major impact on sound propagation in shallow water. Acoustic impedance also affects the attenuation or loss of sound energy when moving through shallow water. The difference in acoustic impedance between the water and the seabed causes energy loss through scattering and absorption. This attenuation affects the range and clarity of sound transmission in shallow waters. Overall, sediments can influence the ray path of acoustic signal propagation in shallow waters by influencing seafloor characteristics, acoustic signal reflection, acoustic velocity, and the detection and acoustic characterization of seafloor sediments. Therefore, the characteristics of shallow water sediments need to be considered when simulating the propagation of acoustic signal beam paths (Liu *et al*,. 2021)

The result of this difference in impedance is what causes the differences seen in the propagation between images 1 and 2. In the water column, the transmission loss value decreases as sediment porosity increases. The color scale in the four images shows the largest horizontal transmission loss distribution value produced by the model with the clay sediment type. and the smallest in the model with coarse sand sediment type. Next, in the sediment layer in Figure 1, sound waves can be seen propagating throughout the sediment, while different

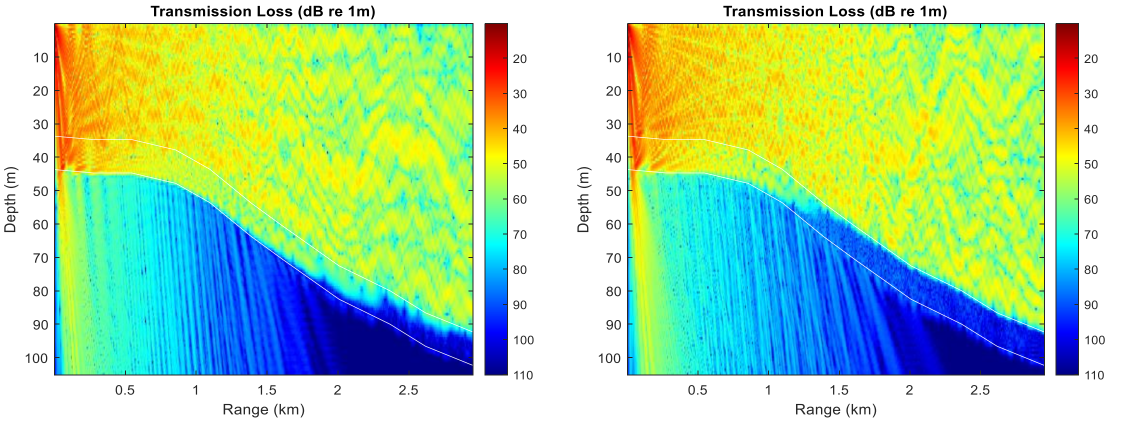

Figure 2. Acoustic propagation model using a frequency of 1000 Hz with fine sand (left) and coarse sand (right) sediment types (right)

characteristics are shown in Figure 2. In Figure 2, sound waves experience a significant increase in transmission loss values at a distance of ±2.4 km and in Figure 2, transmission loss values increase significantly. occurred at a distance of ±1.5 km. This is caused by the acoustic impedance value in fine sand and coarse sand being greater than the acoustic impedance value in clay and silt.

As previously explained, this difference in impedance value causes clay and silt sediments to absorb more sound waves and fine sand and sand sediments rough reflects more sound waves. However, due to the high acoustic impedance value in fine sand and coarse sand sediments, although there is a significant reduction in sound wave energy, sound waves can be spread throughout the sediment. Furthermore, the difference in impedance values also affects the intensity of sound waves that are reflected and absorbed by the bedrock.

3.2 Frequency 10 kHz

There is modeling using a frequency of 10 kHz which shows an increase in transmission loss values in all models when compared to the 1000 Hz model.

Attenuation in water increases with frequency. High frequency sound waves experience greater absorption and scattering, resulting in higher transmission loss in shallow waters. In figure 3, some sound waves are propagated on the surface duct, in this surface duct the sound waves will be refracted or reflected, and some will be transmitted to the bottom of the water where they will then be refracted, reflected in the sediment itself, and also reflected back into the water column.

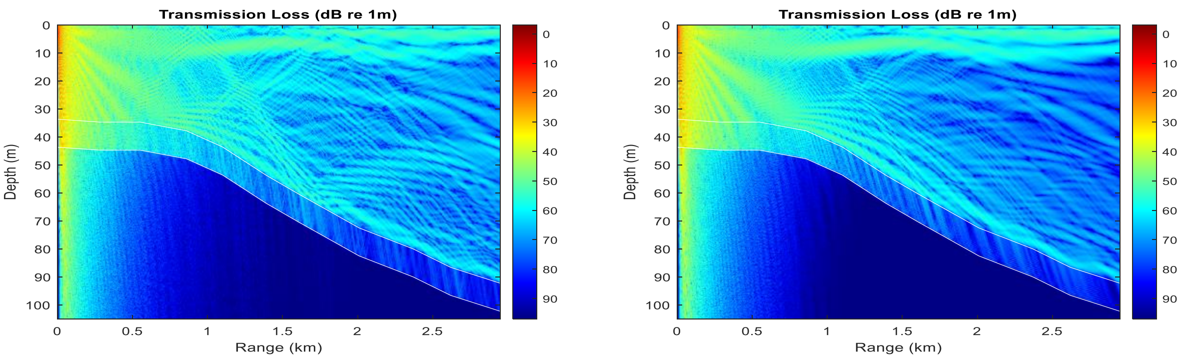

Figure 3. Acoustic propagation model using a frequency of 10 kHz with clay (left) and silt sediment types (right)

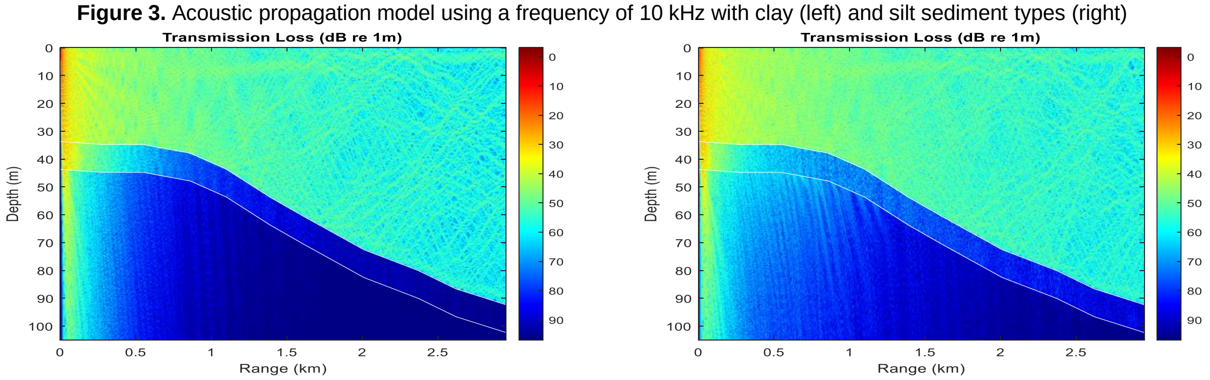

Figure 4. Acoustic propagation model using a frequency of 10 kHz with fine sand (left) and coarse sand sediment types (right)

The model in Figure 3 with clay and silt sediment types has a higher attenuation value compared to Figure 4 which has fine sand and coarse sand sediment types, and also has a thinner propagation path, besides that the sound waves propagating in the sediment also show clearly intensity of sound waves absorbed by sediment. This confirms the previous explanation that clay and silt sediment types have a tendency to absorb sound while fine sand and coarse sand sediments tend to reflect sound due to the different acoustic impedance values of each sediment. The results of this study are in accordance with previous researchers (Manik, 2016). In Figure 4, waves can propagate to all parts of the rock, although with a decreasing intensity. In the model with coarse sand sediment type, even though the intensity of the reflected waves is high, sound waves are well propagated throughout the sediment and bedrock, this is due to the high acoustic impedance value of coarse sand so that sound waves in the sediment can propagate throughout all parts of the sediment.

3.3 Frequency 100 kHz

Due to the use of a very high frequency, namely 100 kHz, this results in a quite significant increase in the transmission loss value in the modeling results. This shows that sound frequency also influences propagation conditions in the water column. In some cases, lower frequencies can produce better propagation conditions, reducing transmission loss at he selected receiver (Peter, 2004). In Figure 5, it can be seen that the sound waves emitted are predominantly divided into two. Waves with a small grazing angle are reflected by the water column and propagated in the surface duct, whereas waves with a larger grazing angle are transmitted to the bottom of the water. Apart from that, it can be seen that sound waves cannot propagate throughout the water column as a result of the large energy loss. large due to the high frequency and absorption carried out by sediment.

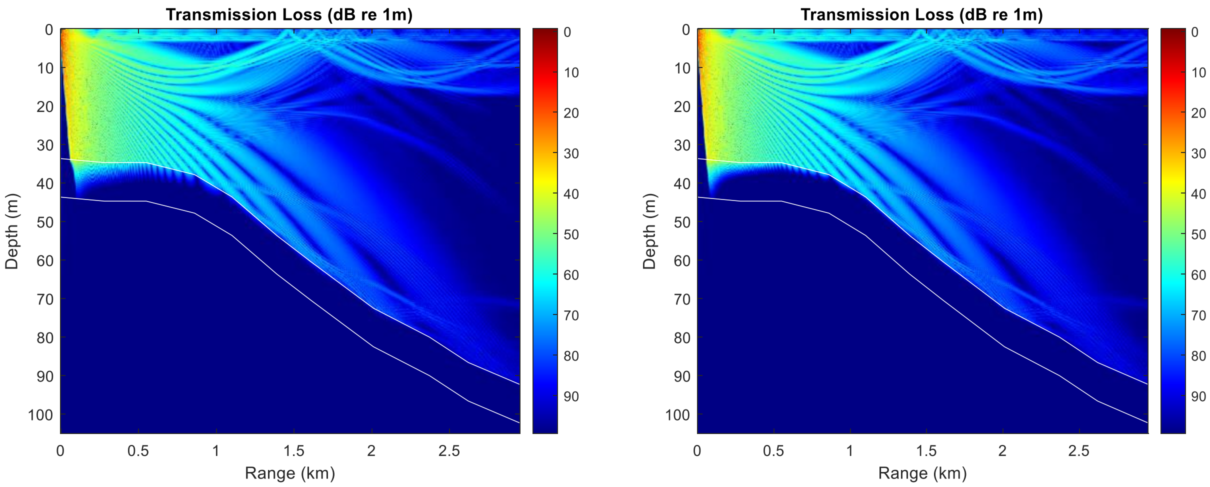

Figure 5. Acoustic propagation model using a frequency of 10 kHz with clay (left) and silt sediment types (right)

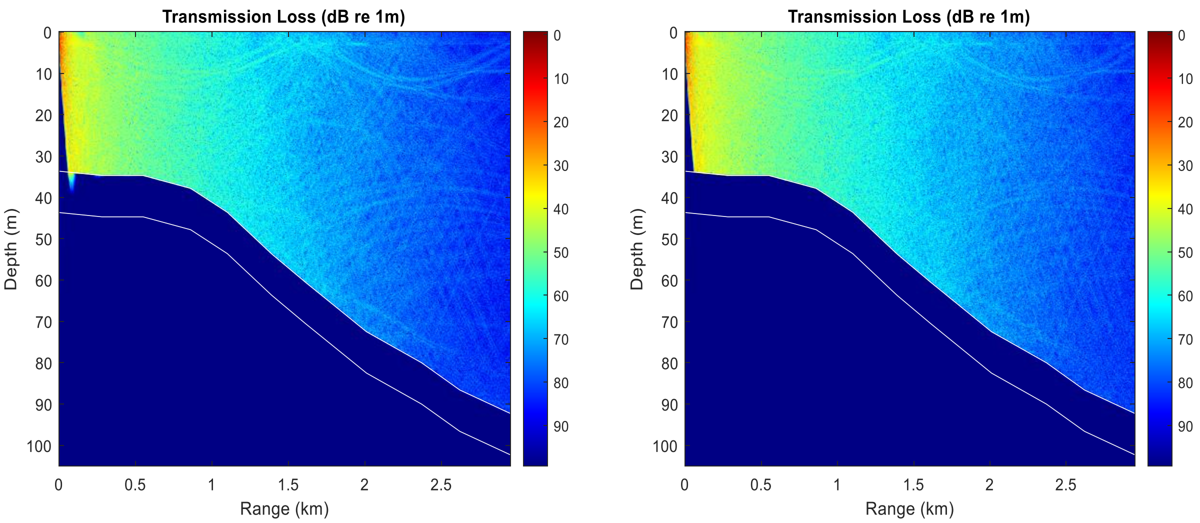

Figure 6. Acoustic propagation model using a frequency of 100 kHz with fine sand (left) and coarse sand sediment types (right)

A different thing happens in Figure 6 where, even with a significant reduction in sound wave energy, the sound waves can still be reflected into all parts of the water column. This is influenced by differences in the intensity of sound waves absorbed by the sediment. In Figure 7, the model with the clay sediment type shows that sound waves are still able to penetrate the sediment, this intensity continues to decrease for the silt and fine sand sediment types, but in the coarse sand sediment type the sound waves are completely reflected by the sediment. The difference in propagation patterns in Figures 5 and 6 occurs because the energy loss that occurs in models with clay and silt sediment types is greater because the absorption factor that occurs in the sediment is greater when compared to models with fine sand and coarse sand sediment types. The results of this research are in accordance with previous researchers (Manik and Apdillah, 2020). In the four models, it can be seen that only a small amount of sound wave intensity can propagate through the sediment layer, then the sound wave cannot propagate further into the underlying bedrock layer.

4. Conclusion

Based on the modeling carried out, it can be concluded that the propagation of sound waves in shallow seas is greatly influenced by the type of sediment used. Acoustic impedance influences shallow waters through phenomena such as reflection, refraction, bottom-water interactions, and models. Changes in acoustic impedance at the bottom of the water and within the water column can significantly influence the behavior of acoustic waves in shallow water environments. Accurate acoustic impedance data is critical for effective ray tracing modeling. Frequency influences wave propagation, the higher the frequency used, the shallower the wave propagation.

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7. References

Carey William M. Doutt James, Evans Richard, Dillman Lynne. 2003. Shallow-Water Sound Transmission Measurements Taken On The New Jersey Continental Shelf. SACLANTCEN CP-42

Etter P.C. 2003. Underwater Acoustic Modelling and Simulation. London. CRC Press

Ha Yonghoon. 2000. Java-based implementation of Monterey-Miami Parabolic Equation (MMPE) model with enhanced visualization and improved method of environmental definition. (thesis).

Liu Dai, Li Zhenglin, Wang Guangxu, Liu Yunfeng. 2021. Sound Propagation with Undulating Bottom in Shallow Water. Journal Of Marine Science And Engineering Volume 9(9).

Marsetio. 2014. Sea Power Indonesia. Universitas Pertahanan.

Manik H.M. 2016. Acoustical Measurement and Biot Model for Coral Reef Detection and Quantification. Advance in Acoustics and Vibration 2016(17), 1-11

Manik H.M, & Apdillah Dony. 2020. Remote Sensing of Seagrass and Seabed using Acoustic Technology in Bintan Seawater, Indonesia. Pertanika Journal of Sciense & Technology. Vol 28(2), 421-439

Peter L. Nielsen, Finn B. Jensen. 2004. Prediction of low-frequency acoustic propagation in shallow water.

Ramdhani Haqqu. 2014. Deteksi Dan Karakterisasi Akustik Sedimen Dasar Laut Dengan Teknologi Seismik Dangkal Di Bangka Belitung. (thesis)

Smith, Kevin B. 2001. Shallow Water Acoustic Predictions Using A Split-Step Fourier Parabolic Equation Model. Journal of Computational Acoustics, Vol. 9(1), 243–285 @ IMACS

Sukmono, S. (2000). Seismic Inversion for Reservoir Characterization. Dept. of Geophysical Engineering. ITB.