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Chapter 22

# Underwater Acoustics Modeling in Finite Depth Shallow Waters

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Additional information is available at the end of the chapter

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## 1. Introduction

Ocean Acoustics is the science which studies the sound in the sea and covers not only the study of sound propagation, but also its masking by the phenomena of acoustic interference [1].

Recent developments in underwater acoustic waves modeling have been influenced by changes in global geopolitics. These changes are evidenced by strategic shifts in military priorities as well as by efforts to transfer defense technologies to non-defense applications.

Despite the restrictiveness of military security, an extensive body of relevant research accumulated in the open literature, and much of this literature addressed the development and refinement of numerical codes that modeled the ocean as an acoustic medium [2].

One of the most important properties of the oceans as far practical applications are concerned lies in their high sensitivity to the propagation of acoustic signals with frequencies in the range of 1Hz to 20kHz that, different types of electromagnetic radiation, bring together a significant amount of information on the marine environment [3]. Another reason for the practical interest in acoustic propagation in the ocean is the distance the sound can spread, reaching several hundred kilometers.

Some properties of the seabed, such as the propagation velocities and compressional attenuation, density, among others, contribute to the spread in shallow waters significantly, making it interesting to perform a quantitative estimation of their values.

Underwater acoustic models are designed to simulate in detail the acoustic wave characteristics, thus enabling the prediction of the of the relevant phenomena behaviour. However a number of limitations are inherent to these models and often have to do with the medium characteristics, e.g., depth variation, number of degrees of freedom, just to mention

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a few. Other effects such as dispersion, are influenced by a different set of conditions such as surface irregularities, presence of substances derived from natural or artificial, and others.

## 2. Shallow waters

Acoustic wave propagation in conditions differing from the ideal infinite conditions for wave propagation, normally described as shallow water environments will be discussed in the following text.

### 2.1. What is shallow water

The term “shallow waters” is used when the ocean environment model is restricted by its surface at the top and by the seabed at the bottom. An important feature of this configuration is to allow the trapping of sound energy between these two interfaces which also favours the propagation of sound over long distances.

The existing criteria for defining the regions of what is "shallow" is based not only on the properties of sound propagation in the medium, but mainly by the frequency of the sound source and the interactions of sound with the background, resulting in a ratio linking the wavelength with the dimensions of the waveguide. Moreover, according to the hypsometric criterion [2], related to the depths, we define "shallow" as the waters of the continental shelf[1]. Since the average depth of the platform along the slope is usually found to be around 200m, the regions of "shallow" are defined as having depths less than 200m.

Additionally, ocean areas beyond the continental shelf can be considered to be "shallow" when the propagation of a signal with very low frequencies is accompanied by numerous interactions with the surface and the bottom Also, in practical terms, for a given frequency, " water regions are considered to be "shallow when the "shallow boundaries and reflective effects have a majour effect on the propagation and the energy is distributed in the form of a cylindrical divergence, getting trapped between the surface and the bottom.

### 2.2. Model of a shallow-water sound channel

The shallow-water acoustic communication channel can be classified as a multipath fading channel. It generally exhibits a long multipath delay spread, which can lead to intersymbol interference (ISI) if the spread exceeds the symbol time of communication system.

The main characteristic of sound propagation in the "shallow" is the profile setting the speed of sound, which usually has a negative or approximately constant gradient along the depth. This means that the spread over long distances due almost exclusively to the interactions of sound with the bottom and surface. Because each reflection at the bottom there is a large attenuation, spread over long distances is associated with large losses of acoustic energy [2].

[1] The ocean shelf is the zone around a continent, stretching from the low-water line to depths at which there is a sharp increase in the slope of the bottom in the direction of great depths [5].

The emission frequency of the source is also a crucial parameter. As in most regions of the ocean the bottom is composed of acoustic energy absorbing material, this will become more transparent to the energy in waves of low frequencies, which reduces the energy trapped in the waveguide Thus, for the lower frequencies, greater penetration of sound in the background is observed and therefore, exhibiting a greater dependence of propagation in relation to the parameters geoacoustics. At high frequencies (> 1kHz), sensitivity to the roughness of the interfaces and the marine life is greater, resulting in a greater spread, that is, a lower penetration of the bottom and a larger volume attenuation [4]. Spread over long distances therefore occurs in the range of intermediate frequencies (100 Hz to about 1 kHz) and is strongly dependent on the depth and the mechanisms of attenuation. Figure 1 shows the attenuation of sound absorption in seawater as a function of frequency. According to [2], the dependence with frequency can be categorized into four major regions, in increasing order of frequency: absorption in the background, the boric acid relaxation, relaxation of magnesium sulfate and viscosity.

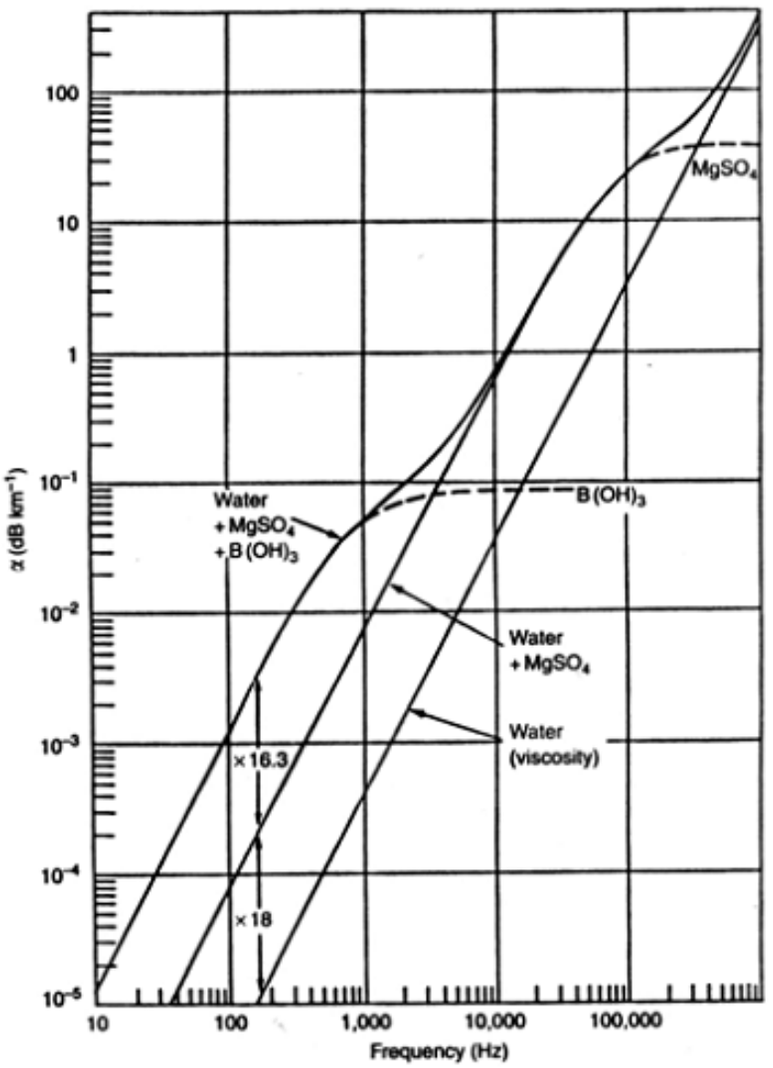



**Figure 1.** Absorption Coefficients for sea water [2].

### *2.2.1. Water layer*

In seawater, the sound speed is measured using special devices or computed from special empirical formulae, using measured values of the temperature, salinity and hydrostatic pressure.

In summer, the sound channel is mainly near the bottom, so that the propagation of sound takes place by sequential reflections of refracting rays from the bottom, causing high propagation losses.

The propagation of sound in winter, takes place either in a channel with a constant sound speed, when it is described by bottom-surface rays, or in a near-surface channel.

The propagation of low-frequency sound is most affected by random inhomogeneities with characteristic sizes ≥ 1m. Random onhomogeneities with vertical scales of 1-10 m and horizontal scales of 100-1000 m are mainly due to the fine thermohaline stricture an to internal waves [5].

In shallow water, the field of internal waves has a number of very specifics characteristics:

- A considerable inhomogeneity and non-stationarity, due to the characteristic trains of intense soliton-like internal waves against a relatively weak background;
- Clearly expressed anisotropy, determined by the bottom relief, when waves propagate mainly in the direction towards the coast, perpendicularly to the outside edge of the shelf;
- Synchronicity of the vertical fluctuations of all fluid layers, attesting to a predominance of the first gravitational mode.

As far the fine thermohaline structure is concerned, according to [5], the ocean is a finely stratified medium, in which there exist layers with thickness from tens of centimeters to tens of meters, with comparatively homogeneous properties, separated from each other by thin boundary layers with sharp changes in the thermodynamic characteristics (the vertical gradients of the physical properties in these layers may be 10-100 times greater than their average values). Using special sound-speed meters with a large resolution, the existence of sharp fine-scale changes in the vertical dependence of the sound speed was established. Roughnesses of the water layer boundaries (roughnesses of the bottom and a disturbed surface) may also have a marked effect on the propagation of sound in shallow water. Losses on the propagation of low-frequency (up to a few kHz) sound are due to various mechanisms (absorption, scattering, geometric divergence). The absorption of sound in clear water, propagation at low frequencies, is physically mainly due to the conversion of the sound energy to heat and is the result of the chemical composition of seawater, which is a complex electrolyte. A change in sound pressure leads to a periodic change in its ionic composition, which affects the volume viscosity. The absorption relaxation mechanism in this case is well described by a formula [5], which yields the absorption coefficient β

$$\beta = \frac{0,11 f^2}{1+f^2} + \frac{44 f^2}{4100+f^2} \tag{1}$$

where the frequency is measured in kHz, and the absorption coefficient is given in dB/km. In particular, in the region of interest to us, namely approximately from 100 to 1000 Hz, the coefficient increases monotonically from $10^{-3}$ to 0,06 dB/km.

### *2.2.2. Layer of sediments*

This layer consists mainly of bottom deposits of the mud type, denser sedimentary rocks or basic rocks (granite, basalt, etc.). Its parameters, like the parameters of the other layers, depend on the geographical region.

In the layer of unconsolidated sediments, one characteristic property is the existence of abrupt random inhomogeneities. These include layered (intermittent and tapered) structures of length up to tens of kilometers, and vertical channels, associated with the venting of gases and diapers (dome-shaped folds, in which rocks with a high plasticity are extruded from below).

In the layer of semi-consolidated sediments, the speed of longitudinal waves is (2 – 3) x $10^3$ m/s, where a small positive gradient with respect to depth is possible. This layer is also absorptive and the absorption coefficients for longitudinal and transverse waves differ and are distinguished by a large spread.

In the layer of consolidated sediments basement is characterized by a high speed of both longitudinal ($c \approx (4 - 6)$ x $10^3$ m/s) and transverse ($c_s \approx (1 - 3)$ x $10^3$ m/s) waves where the attenuation coefficients are estimated as $\alpha \approx 0{,}1$ dB/(km.Hz), $\alpha_s \approx 0{,}01 - 0{,}1$ dB/(km.Hz).

In the theory of the propagation of sound sediments are seen as a two-component medium, consisting of a solid skeleton and a fluid component. These theories use a large number of parameters (porosity, average grain size, mean-square deviation from the average size, etc.), which determine the acoustic properties of a porous medium. This model allows one to consider the speed and attenuation coefficients of different types of waves. One of the most important characteristics of sediments, which can be calculated, is the frequency dependence of the attenuation coefficient of a longitudinal or transverse wave.

## 2.3. The sound field

Sound propagation in the ocean is conveniently described by the wave equation, having parameters and boundary conditions which are able to describe the ocean environment. There are essentially four types of computational models (computer solutions to the wave equation) normally used to describe sound propagation in the sea: Ray Theory, Fast Field Program (FFP), Normal Mode (NM) and Parabolic Equation (PE). All of these modes enable the ocean environment to vary with the depth. A model that also allows horizontal variations in the environment, i.e., sloping bottom or spatially variable oceanography, is termed "range dependent". For high frequencies (few kilohertz or above), ray theory, the infinite frequency approximation, is still the most practical whereas the other three model types become more and more applicable and useable below, say, a kilohertz [7].

The wave equation for an acoustic field of angular frequency $\omega$ is

$$\nabla^2\phi(r,z)+K^2(r,z)\phi(r,z)=-\delta^2(r-r_s)\delta(z-z_s);\ K^2(r,z)=\frac{\omega^2}{c^2(r,z)}, \tag{2}$$

where the subscript "s" denotes the source coordinates. The range dependent environment manifests itself as a coefficient, $K^2(r,z)$, of the partial differential equation for the sound speed profile and the range dependent bottom type and topography appears as both coefficients (elasticity effects are an added complication) and complicated boundary conditions.

Throughout the theoretical development of these five techniques, the potential function *G* normally represents the acoustical field pressure. When this is the case, the Transmission Loss (TL) can easily be calculated as:

$$TL=10\log_{10}\left[\phi^2\right]^{-1}=20\log_{10}\left[\phi\right]. \tag{3}$$

## 3. Approximate methods in shallow-water acoustics

The various physical and mathematical models all have inherent limitations in their applicability. These limitations are usually manifested as restrictions in the frequency range or in your specification of the problem geometry. Such limitations are collectively referred to as "domains of applicability," and vary from model to model. The model selection criteria are provided to guide potential users to those models most appropriate to their needs [2].

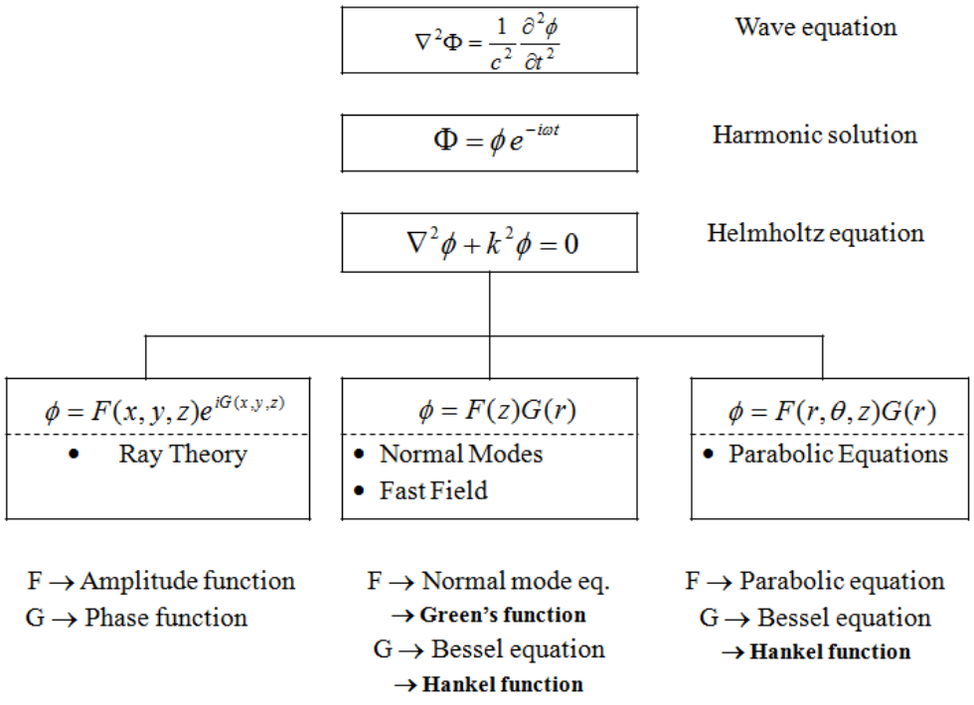



**Figure 2.** Summary relationship among theoretical approaches for propagation modeling.

A further subdivision can be made according to range-independent and range-dependent models. Range independence means that the model assumes a horizontally stratified ocean in which properties vary only as a function of depth. Range dependence indicates that some properties of the ocean medium are allowed to vary as a function of range ($r$) and azimuth ($\theta$) from the receiver, in addition on a depth ($z$) dependence. Such range-varying properties commonly include sound speed and bathymetry, although other parameters such as sea state, absorption and bottom composition may also vary. Range dependence can further be regarded as two dimensional (2D) for range and depth variations or three dimensional (3D) for range, depth and azimuthal variations [2].

### 3.1. Ray-theory models

Ray-theoretical models, a geometrical approximation, calculate TL on the basis of ray tracing. Ray theory starts with the Helmholtz equation. The solution for $\phi$ is assumed to be the product of a pressure amplitude function $A = A(x,y,z)$ and a phase function $P = S(x,y,z)$: $\phi = Ae^{iS}$, where the exponential term allows for rapid variations as a function of range and $A(x,y,z)$ is a more slowly varying "envelope" which incorporates both geometrical spreading and loss mechanisms. Substituting this solution into the Equation (2) and separating real and imaginary terms yields:

$$\frac{1}{A}\nabla^2 A - \left[\nabla S\right]^2 + K^2 = 0 \tag{4}$$

and

$$2\left[\nabla A \cdot \nabla S\right] + A\nabla^2 S = 0. \tag{5}$$

Equation 4 contains the real terms and defines the geometry of the rays. Equation 5, also known as the transport equation, contains the imaginary terms and determines the wave amplitudes. The separation of functions is performed under the assumption that the amplitude varies more slowly with position than does the phase (geometrical acoustics approximation). The geometrical acoustics approximation is a condition in which the fractional change in the sound-speed gradient over a wavelength is small compared to the gradient $c/\lambda$, where $c$ is the speed of sound and $\lambda$ is the acoustic wavelength [2]. Specifically

$$\frac{1}{A}\nabla^2 A << K^2. \tag{6}$$

In other words, the sound speed must not change much over one wavelength. Under this approximation, Equation 4 reduces to

$$\left[\nabla S\right]^2 = K^2. \tag{7}$$

Equation 7 is referred to as the eikonal equation. Surfaces of constant phase ($S$ = constant) are the wavefronts, and the normal to these wavefronts are the rays. Eikonal refers to the acoustic path length as a function of the path endpoints. Such rays are referred to as eigenrays when the endpoints are the source and receiver positions. Differential ray equations can then be derived from the eikonal equation.

The ray trajectories are perpendicular to surfaces of constant phase, $S$, and may be expressed mathematically as follow:

$$\frac{d}{dl}\left[K\frac{dR}{dl}\right] = \nabla K, \tag{8}$$

where $l$ is the arc length along the direction of the ray and $R$ is the displacement vector. One can determine that the direction of average flux (energy) follows that the trajectories and the amplitude of the field at any point can be obtained from the density of rays. Once $S$ is obtained, the Equation 5 yields the amplitude. We mention here, also, that "corrected" ray theory assumes that $A$ can be expanded in powers of inverse frequency-the leading term is the infinite-frequency result with the additional terms being frequency corrections [7].

The ray theory method is computationally rapid, extends to range dependent problems and the ray traces give a very physical picture of the acoustic paths. It is helpful in describing how noise redistributes itself when propagating long distances over paths that include shallow and deep environments and/or mid latitude to Polar Regions. The disadvantage of ray theory is that it does not include diffraction and such effects that describe the low frequency dependence ("degree of trapping") of ducted propagation.

### 3.2. Fast Field Program (FFP)

In the underwater acoustics, fast-field theory is also referred to as "wavenumber integration." Range independent wave theory solves the wave equation exactly when the ocean environment does not change in range. One of the possible derivations of the solution technique is to Fourier decompose the acoustic field an infinite set of horizontal waves,

$$\phi(r,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty} d^2k g(k,z,z_s)e^{ik(r-r_s)}. \tag{9}$$

and from Equation 2, the depth dependent Green's function, $g(k, z, z_s)$, satisfies

$$\frac{d^2g}{dz^2} + \left(K^2(z) - k^2\right)g = -\frac{1}{2\pi}\delta\left(z - z_s\right). \tag{10}$$

Assuming azimuthal symmetry, we can integrate Equation 9 over the angular variable to Hankel functions and their asymptotic form reduces Equation 9 to (for simplicity, we take $r_s = 0$)

$$\phi(r,z) = \frac{e^{-i\pi/4}}{(2\pi r)^{1/2}} \int_{-\infty}^{\infty} dk (k)^{1/2} g(k,z,z_s) e^{ikr}. \tag{11}$$

Note that the factor $r^{-1/2}$ arises from cylindrical spreading. We now discretize the above integral and transform to a form amenable to the FFT technique by setting $k_m = k_0 + m\Delta k$; $r_n = r_0 + n\Delta r$ where $n, m = 0, 1, \ldots, N-1$. The additional condition $\Delta r \Delta k = 2\pi/N$ and $N$ is an integral power of two. The discretization scheme limits the solution to outgoing waves and Equation 10 becomes

$$\begin{aligned} \phi(r_n,z) &= \frac{\Delta k e^{i(k_0 r_n - \pi/4)}}{(2\pi r)^{1/2}} \sum_{m=0}^{N-1} X_m e^{2\pi i m n/N}, \\ X_m &= (k_m)^{1/2} g(k_m,z,z_s) e^{i m r_0 \Delta k}. \end{aligned} \tag{12}$$

The above equation is now easily evaluated using the FFT algorithm with the bulk of the effort going into evaluating $g$ by solving Equation 10. Although the method is labeled "fast field" it is fairly slow because of the time required to calculate the $g$'s. However, it has advantages when one wishes to calculate the "near field" region or to include shear wave effects in elastic media. Because of this latter capability, it can be used as the propagation component of a description of (micro) seismic noise. The FFP method is often used as a benchmark for others less exact techniques. One such technique, not applicable to the near field but exact for a large class of range independent far-field problems is the computationally faster normal mode method [7].

### 3.3. Normal Mode Model (NM)

Normal-mode solutions are derived from an integral representation of the wave equation. In order to obtain practical solutions, however, cylindrical symmetry is assumed in a stratified medium (i.e. the environment changes as a function of depth only). The solution for the potential function $\phi$ can be written in cylindrical coordinates as the product of a depth function $F(z)$ and a range function $S(r)$:

$$\phi(z, r) = F(z) \cdot S(r). \tag{13}$$

Next, a separation of variables is performed using $\xi^2$ as the separation constant. The two resulting equations are:

$$\frac{d^2F}{dz^2} + (k^2 - \xi^2)F = 0 \tag{14}$$

$$\frac{d^2S}{dr^2} + \frac{1}{r}\frac{dS}{dr} + \xi^2 S = 0 \tag{15}$$

Equation 14 is the depth equation, better known as the normal mode equation, which describes the standing wave portion of the solution. Equation 15 is the range equation, which describes the traveling wave portion of the solution. Thus, each normal mode can be viewed as traveling wave in the horizontal *(r)* direction and as a standing wave in the depth *(z)* direction [2].

The normal-mode Equation 14 poses an eigenvalue problem. Its solution is known as the Green's function. The range Equation 15 is the zero-order Bessel equation. Its solution can be written in terms of a zero-order Hankel function $\left(H_0^{(1)}\right)$. The full solution for $\phi$ can be expressed by an infinite integral, assuming a monochromatic (single-frequency) point source:

$$\phi = \int_{-\infty}^{\infty} G(z, z_0; \xi) \cdot H_0^{(1)}(\xi r) \cdot \xi \, d\xi \tag{16}$$

where *G* is the Green's function, $H_0^{(1)}$ a zero-order Hankel function of the first kind and $z_0$ the source depth. Note that $\phi$ is a function of the source depth $(z_0)$ and the receiver *(z)*. To obtain what is known as the normal-mode solution to the wave equation, the Green's function is expanded in terms of normalized mode functions.

The advantages of the Normal Modes procedure are: that once value problem is solved one has the solution for all source and receiver configurations, and, that is easily extended to moderate range dependent conditions using the adiabatic approximation.

### 3.4. Parabolic Equation Model (PE)

The parabolic approximation method was successfully applied to microwave waveguides, laser beam propagating, plasma physics, seismic wave propagation and underwater acoustic propagation.

The PE is derived by assuming that energy propagates at speeds close to a reference speed – either the shear speed or the compressional speed, as appropriate [2].

The PE method factors an operator to obtain an outgoing wave equation that can be solved efficiently as an initial-value problem in range. This factorization is exact when the environment is range independent. Range-dependent media can be approximated as a sequence of range-independent regions from which backscattered energy is neglected. Transmitted fields can then be generated using energy-conservation an single-scattering corrections [2].

The basic acoustic equation for acoustic propagation can be rewritten as:

$$\nabla^2 \phi + k_0^2 n^2 \phi = 0 \tag{17}$$

where $k_0$ is the reference wavenumber ($\omega/c_0$), $\omega(=2\pi f)$ the source frequency, $c_0$ the reference sound speed, $c(r, \theta, z)$ the sound speed in range ($r$), azimuthal angle ($\theta$) and depth ($z$), $n$ the refraction index ($c_0/c$), $\phi$ the velocity potential and $\nabla^2$ the Laplacian operator.

Equation 17 can be rewritten in cylindrical coordinates as:

$$\frac{\partial^2\phi}{\partial r^2}+\frac{1}{r}\frac{\partial\phi}{\partial r}+\frac{\partial^2\phi}{\partial z^2}+k_0^2n^2\phi=0 \tag{18}$$

where azimuthal coupling has been neglected, but the index of refraction retains a dependence on azimuth. Further, assume a solution of the form:

$$\phi=\Psi(r,z)\cdot S(r) \tag{19}$$

and obtain:

$$\Psi\left[\frac{\partial^2 S}{\partial r^2}+\frac{1}{r}\frac{\partial S}{\partial r}\right]+S\left[\frac{\partial^2\Psi}{\partial r^2}+\frac{\partial^2\Psi}{\partial z^2}+\left(\frac{1}{r}+\frac{2}{S}\frac{\partial S}{\partial r}\right)\frac{\partial\Psi}{\partial r}+k_0^2\Psi\right]=0 \tag{20}$$

Using $k_0^2$ as a separation constant, separate Equation 20 into two differential equations as follows:

$$\left[\frac{\partial^2 S}{\partial r^2}+\frac{1}{r}\frac{\partial S}{\partial r}\right]=-Sk_0^2 \tag{21}$$

and

$$\left[\frac{\partial^2\Psi}{\partial r^2}+\frac{\partial^2\Psi}{\partial z^2}+\left(\frac{1}{r}+\frac{2}{S}\frac{\partial S}{\partial r}\right)\frac{\partial\Psi}{\partial r}+k_0^2n^2\Psi\right]=\Psi k_0^2 \tag{22}$$

Rearrange terms and obtain:

$$\frac{\partial^2 S}{\partial r^2}+\frac{1}{r}\frac{\partial S}{\partial r}+k_0^2S=0 \tag{23}$$

which is the zero-order Bessel equation, and:

$$\frac{\partial^2\Psi}{\partial r^2}+\frac{\partial^2\Psi}{\partial z^2}+\left(\frac{1}{r}+\frac{2}{S}\frac{\partial S}{\partial r}\right)\frac{\partial\Psi}{\partial r}+k_0^2n^2\Psi-k_0^2\Psi=0. \tag{24}$$

The solution of the Bessel equation 24 for outgoing waves is given by the zero-order Hankel function of the first kind:

$$S=H_0^{(1)}\left(k_0r\right) \tag{25}$$

For $k_0r \gg 1$ (far-field approximation):

$$S \approx \sqrt{\frac{2}{\pi k_0 r}} e^{i(k_0 r - \pi/4)} \tag{26}$$

which the asymptotic expansion for large arguments. The equation for $\Psi(r,z)$ (Equation 24) can be simplified to:

$$\frac{\partial^2 \Psi}{\partial r^2} + \frac{\partial^2 \Psi}{\partial z^2} + 2ik_0 \frac{\partial \Psi}{\partial r} + k_0^2 (n^2 - 1)\Psi = 0. \tag{27}$$

Further assume that:

$$\frac{\partial^2 \Psi}{\partial r^2} << 2k_0 \frac{\partial \Psi}{\partial r} \tag{28}$$

which is the paraxial approximation. Then, Equation 27 reduces to:

$$\frac{\partial^2 \Psi}{\partial z^2} + 2ik_0 \frac{\partial \Psi}{\partial r} + k_0^2 (n^2 - 1)\Psi = 0. \tag{29}$$

which is the parabolic wave equation. In this equation, $n$ depends on depth ($z$), range ($r$) and azimuth ($\theta$). This equation can be numerically solved by "marching solutions" when the initial field is known [2]. The computational advantage of the parabolic approximation lies in the fact that a parabolic differential equation can be marched in the range dimension whereas the elliptic reduced wave equation must be numerically solved in the entire range-depth region simultaneously Typically, a Gaussian field or a normal-mode solution is used to generate the initial solution.

## 4. Final considerations

A brief description of underwater acoustic propagation models for the "shallow environment has been considered. The choice of appropriate model depends on the simplifications needed for the environment in question. All the discussed models are well known and have been successfully developed by several authors for a variety of conditions.

The application of underwater acoustics is mostly sensor-based, including ocean sampling networks, environmental monitoring, undersea explorations, disaster prevention, assisted navigation, speech transmission between divers, distributed tactical surveillance, and mine reconnaissance.

Acoustical transmission is more flexible than others approaches, as it can be deployed in a wide variety of configurations, including networks consisting of both mobile and stationary nodes. It is not, however, free of complexity, In fact, certain aspects of underwater acoustic communications are more difficult than those RF terrestrial networks, especially high propagation delay. In general, underwater acoustic communications are influenced by

transmission loss, bubbles, stratification, multipath propagation, Doppler spread, noise, and high propagation delay.

Transmission loss describes the weakening intensity of sound over a distance and is comprised of losses from both spreading and attenuation. Spreading loss is a geometrical effect that represents the weakening of sound as the wave moves outward from the source. It can be further classified as spherical spreading, cylindrical spreading, or a variant with properties somewhere between the two. Attenuation loss encompasses the effects of absorption, scattering, and leakage out of a sound channel. Absorption, a true loss of acoustic energy that results from the conversion of that energy into heat, accounts for the majority of attenuation. Bubbles produced by breaking waves at the surface can influence the propagation of high frequency signals. No bubble-induced losses were discovered for waves produced with wind speeds of 6 m/s or less [6].

The propagation of sound waves in the ocean is a somewhat complex process, particularly when there are multiple interactions with the seabed, which is often difficult to model. The theory of wave propagation is physical basis for the study of underwater acoustics and descriptive, and this we considered that the proper domain of the theory in simple environments is essential for proper understanding in solving problems realistic sound propagation in shallow water.

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## 5. References

[1] Maia, L. P., Acoustic inversion and passive source location in shallow waters Master Thesis, Ocean Engineering. COPPE/UFRJ, Brazil, 2010. *(in Portuguese).*
[2] Etter, P. C., Underwater Acoustic Modeling and Simulation, Spon Press, 2003.
[3] Rodríguez, O. C., Submarine Acoustic Propagation Models: Comparison with the results of the with the analytical solution of the 3 layer problem. Signal processimg laboratory, Universidade do Algarve, Portugal, 1995 (*in Portuguese).*
[4] Xavier, B. C., Shallow Water Acoustic Propagation Models, MSc Dissertation, Ocean Engineering, COPPE/UFRJ, Brazil, (2005). *(in Portuguese).*
[5] Katsnelson, B. G. and Petnikov, V.G., Shallow water acoustics, Springer-Praxis books in geophysical sciences, 2002.

[6] Borowski, B. S., Doctoral Dissertation of Faculty of the Stevens Institute of Technology, 2010.
[7] Kerman, B. R., Sea Surface Sound, 253-272, Kluwer Academic Publishers, 1988.

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