# Modeling Hydroacoustic Propagation for Seismic Events

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## Abstract

The goal of our research is to understand how acoustic energy from underwater earthquakes is coupled to the sound channel and how the sound is propagated from the source to the hydrophone receivers. We intend to compare results from numerical modeling of long-range acoustic propagation to hydroacoustic data. A large suite of hydroacoustic data will be assembled, in order to obtain optimal azimuthal coverage from source to receiver, as well as a wide range of source depths and source parameters. The numerical modeling will involve integrating bathymetric and sound speed databases into the models since sound propagation in the oceans is strongly dependent upon these parameters. Our object is to be able to distinguish between source effects and propagation effects.

We have conducted some simple numerical modeling experiments to compare hydroacoustic signatures for models with and without significant bathymetric interaction along the transmission path. The acoustic wavefield is computed using the parabolic equation method for a large number of frequencies within the band of interest; time domain arrivals are computed by Fourier synthesis of these calculations.

Key Words: hydroacoustic propagation, energy coupling, waveguide, parabolic equation.

## Objective

The objective of our research is to analyze hydroacoustic signals from oceanic earthquakes recorded by Navy hydrophone arrays (SOSUS) in the North Pacific and Norwegian Sea, with a view to understanding the coupling of energy to the SOFAR channel and the propagation of acoustic energy from source to receiver. The hydroacoustic signature of any underwater event depends on both the source characteristics and along path propagation effects. In order to discriminate oceanic nuclear tests from submarine earthquakes, it is important to distinguish between source signatures and propagation effects. Both the sound speed within the ocean waveguide and seafloor bathymetry, which limits the depth of the waveguide, strongly affect acoustic signatures recorded on hydrophones. We plan to integrate theoretical predictions of propagation effects with observed acoustic arrivals. Goals include (a) determining the physical mechanisms by which acoustic energy from sources with varying depths is coupled into the sound channel, (b) determining the effects of variations in bathymetry and temperature profiles along the travel path on the received signals, and (c) comparing synthetic responses to data to see if source signatures of various acoustic arrivals can be accurately modeled. This last step includes the assembly of a suite of hydroacoustic array data from a large number of underwater seismic events, in order to obtain optimal azimuthal coverage from source to receiver, as well as a wide range of source depths and source parameters. In this paper we present preliminary numerical modeling results, comparing acoustic signatures for several simple models.

## Preliminary Research Results

Advances in methods of computing the acoustic wavefield for slowly varying media make it possible to predict the acoustic signature for a given source to receiver path. We used the acoustic parabolic equation (PE) code of Collins and Westwood (1991) which gives a frequency domain solution of the acoustic wavefield along a travel path with given sound velocity profile and seafloor bathymetry. Strictly speaking, the PE method is exact only for range-independent problems, however, it is accurate for travel paths for which backscattering is negligible and the sound speed varies gradually in the horizontal direction. These assumptions are generally valid for the ocean waveguide. Energy coupling between modes is accounted for by the PE method, thus wave phenomena such as mode conversion and mode cutoff can be accurately modeled. Acoustic phase arrivals are computed by Fourier synthesis of a number of PE calculations within the frequency band of interest.

Synthetic responses were computed at a range of 100 km for a suite of models, each having a sound speed profile as shown in figure 1. For the first model, the source has a depth of 800m, equal to the sound speed minimum, and frequency range from 5-25Hz. The waveguide has a uniform thickness of 5 km. Transmission loss diagrams are shown in figure 2, indicating mode-like transmission of energy at low frequencies, and ray-like transmission at higher frequencies. The synthetic arrivals are shown for various receiver depths in figure 3.

The second model features a ridge centered at 40 km, extending to 1 km from the sea surface. In other respects, the model is exactly like the first. Transmission loss plots are shown in figure 4. Comparing this figure to figure 2, it is obvious that at low frequencies the transmission is barely

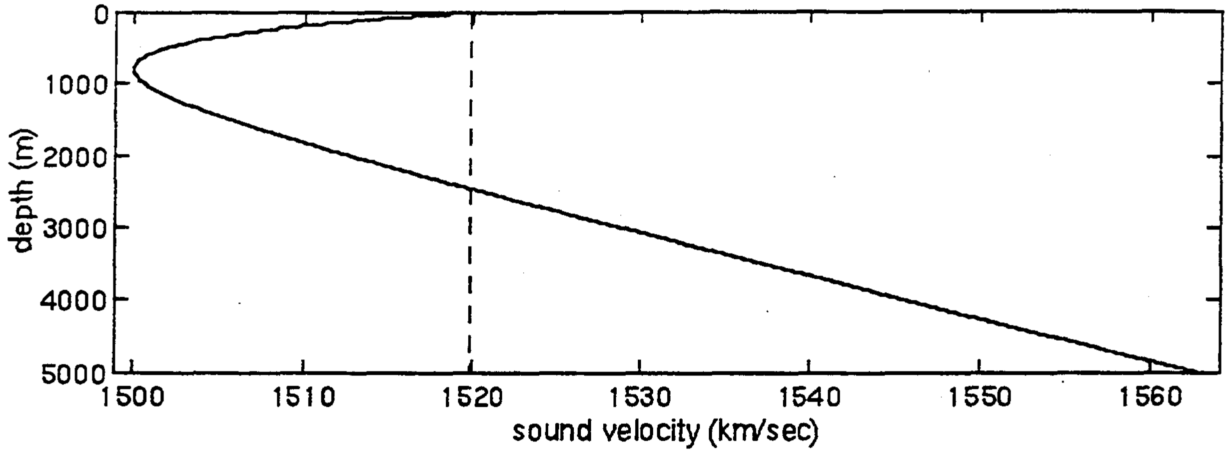


**Figure 1.** The sound speed profile used for model calculations is shown above. The critical depth, *i.e.* the depth at which the sound velocity equals the velocity at the surface, is approximately 2400m. This depth defines the lower limit of the sound channel.

affected by the ridge, while at high frequencies higher modes are stripped off by the ridge. Lower modes, corresponding to energy concentrated near the sound axis, are unaffected by the ridge at higher frequencies. The time response for a range of 100 km is shown in figure 5, for a series of receiver depths. The time duration of the acoustic phase is shorter than that for the model with no ridge, as shown in figure 3.

**Recommendations and future plans**

Computations of the time domain signatures of acoustic arrivals for simple models shows that signal duration's are dependent upon properties of the acoustic waveguide. This analysis will be extended to compare results of numerical modeling of long-range acoustic transmission to acoustic signatures seen in hydroacoustic array data and determine where greater modeling accuracy is needed. This will involve using accurate temperature profiles and bathymetric data along the source to receiver path. The bathymetric database used will be the Navy standard DBDB5, available at a grid-spacing of 5 minutes; the Levitus atlas, with a grid spacing of 1 degree, will be used to determine ocean temperature as a function of depth, location and time. These temperature data will be used to understand the effects of seasonal and annual changes in the ocean temperature on acoustic propagation.

For long-range acoustic propagation, the refraction of acoustic energy due to lateral variations in bathymetry and temperature must be taken into account. An efficient approximation to a full 3-D solution for global scale acoustic propagation is the refracted geodesic method of Heaney et al (1991), which can be used to estimate travel time and path of each mode. In this method, adiabatic mode theory (Pierce, 1965) is used to calculate horizontal phase speed for each mode as a function of latitude and longitude. Snell's law is then used to determine the horizontal path taken by each mode. Calculation of the horizontal phase speed, and thus the ray path, takes into account laterally varying bathymetry and ocean temperature. Once the travel path is determined, the parabolic equa-

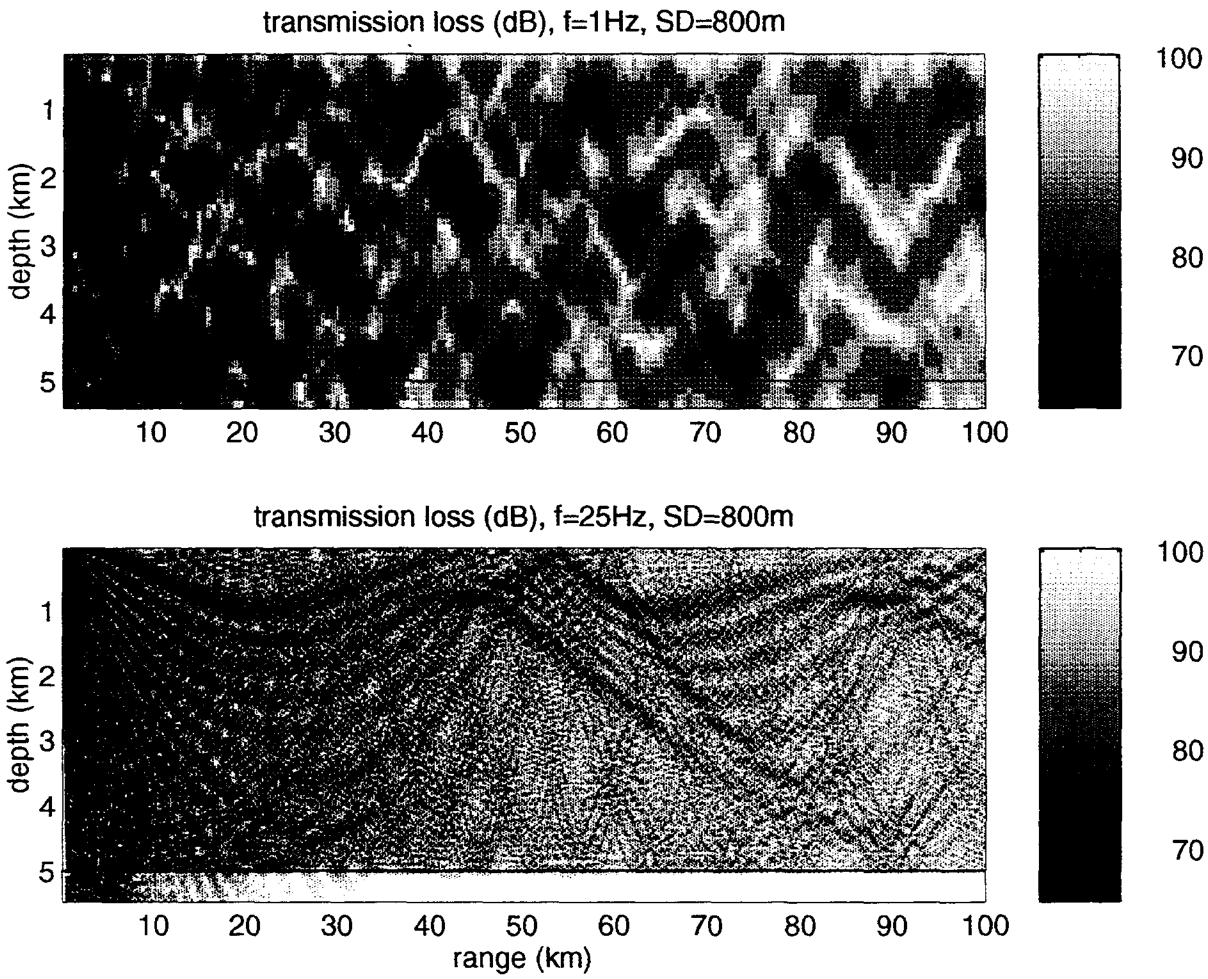


**Figure 2.** Transmission loss plots for a uniform waveguide with velocity profile as shown in figure 1. The source depth is 800m.

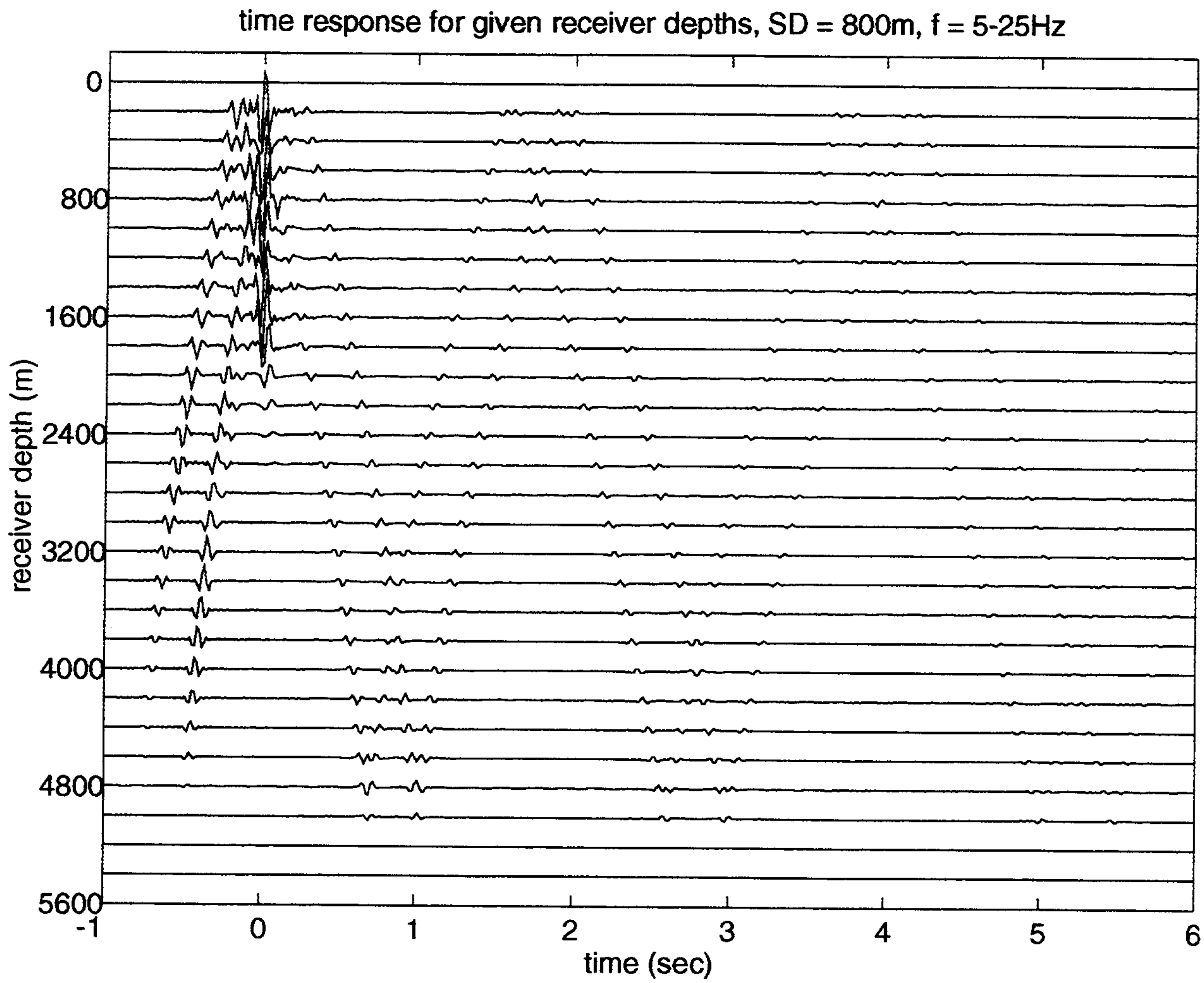


**Figure 3.** Acoustic signatures at various receiver depths. Times given are reduced times, *i.e.* relative to r/1.5 km/sec.

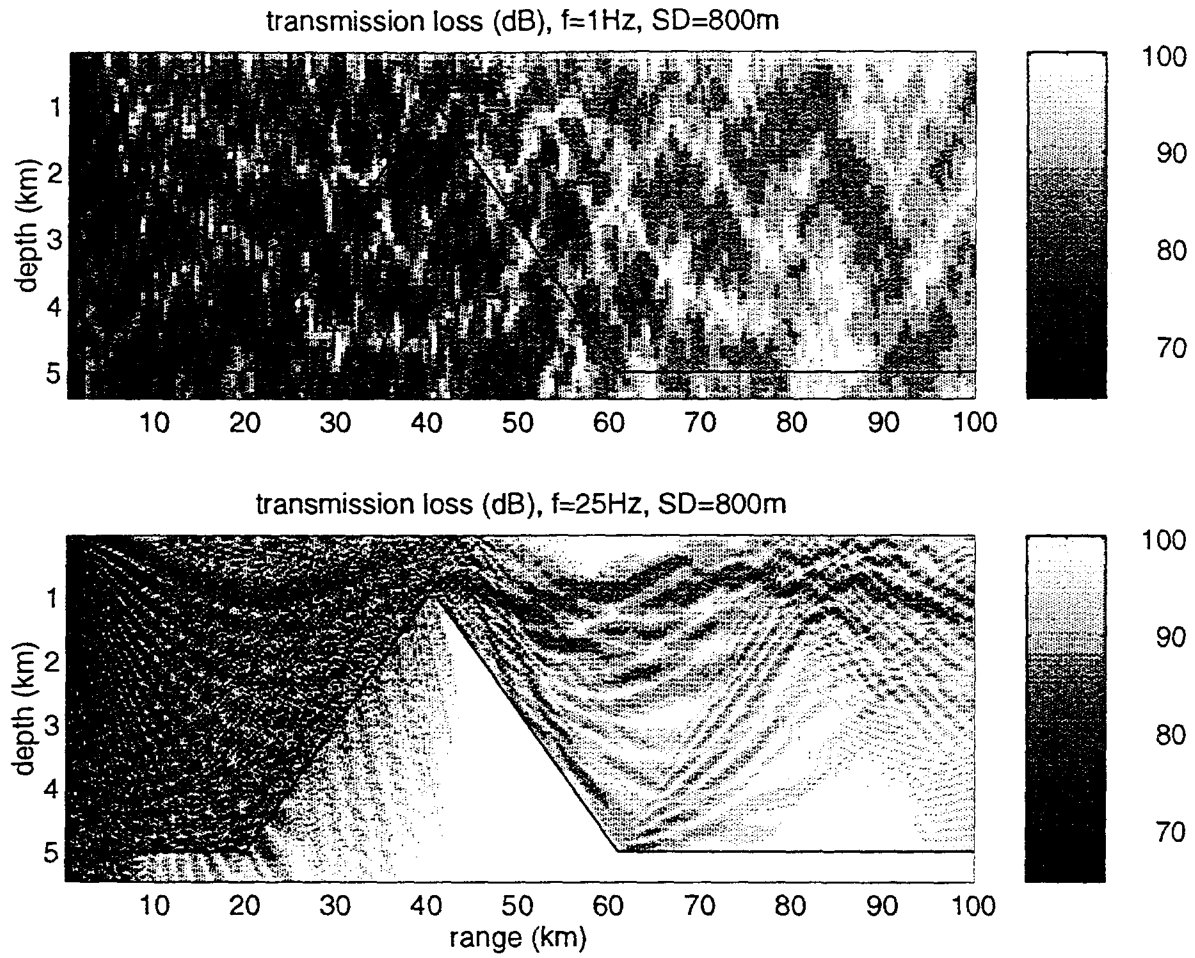


**Figure 4.** Transmission loss plots for ridge model.

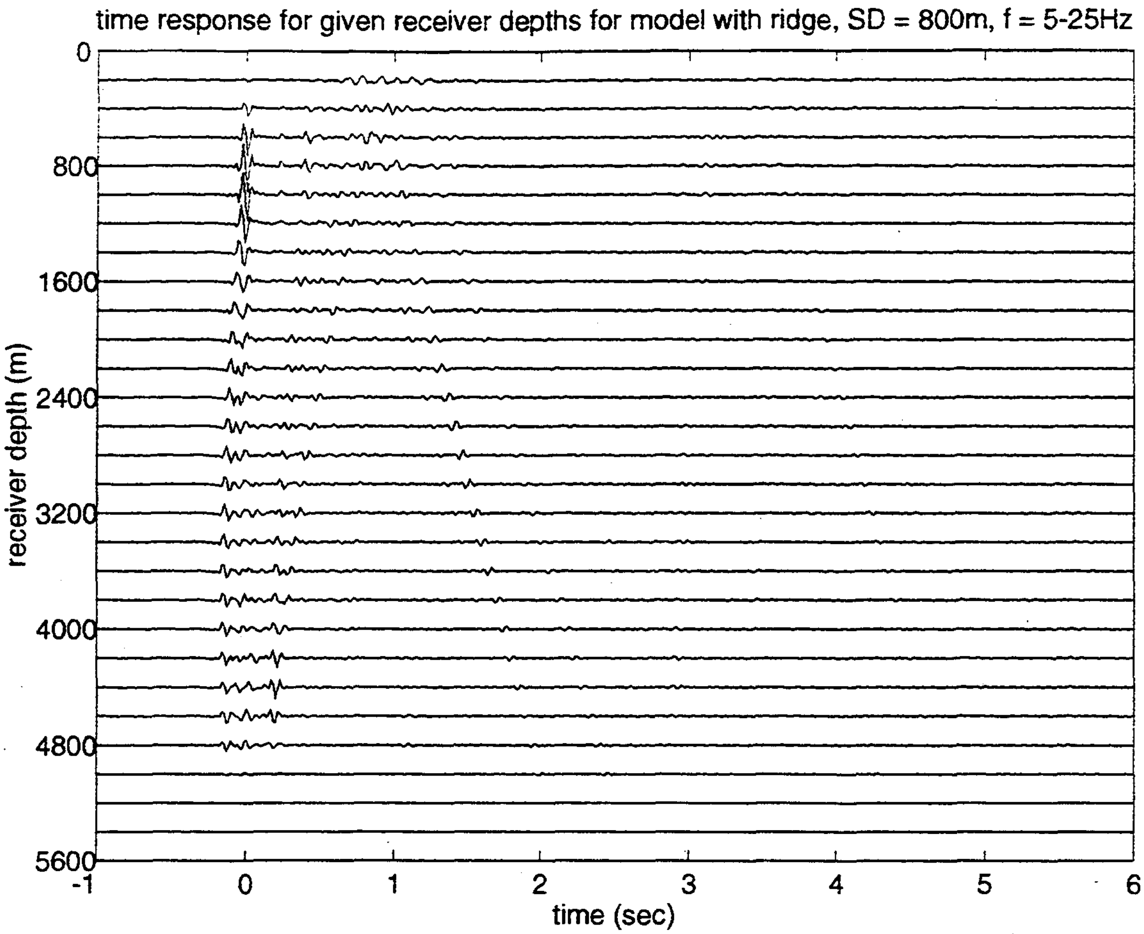


**Figure 5**. Time domain response for model with ridge extending to near the sound axis.

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