# Range-Dependent Acoustic Propagation in Shallow Water with Elastic Bottom Effects

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## LONG-TERM GOALS

The long-range objectives of this research are to develop efficient accurate tools for quantitative forward modeling in range dependent, bottom-interacting acoustic propagation including sediment anisotropy and anelasticty.

## OBJECTIVES

The specific objectives of this research are to develop practical theoretical and software tools for employing a fully elastic version of two-way coupled modes for modeling seismo-acoustic signals in shallow water with realistic elastic bottom properties, that may extend to elastically anisotropic sediment cover.

## APPROACH

The Call for Planning Letters suggested interest in acoustic frequencies as low as 10 Hz. This frequency corresponds to a wavelength of 200 m for a sediment compressional speed of, say, 2000m/s. At such low frequencies acoustic penetration into sediments is significant. Elastic effects (shear) cannot be ignored. In addition ocean sediments are often elastically anisotropic by the very mechanisms by which they are formed. If the anisotropy is significant, horizontally polarized shear waves (SH) can be generated even from an explosion source in the water. This conversion to SH is required by the boundary condition at the interface between the water and sediments at the ocean bottom. The attenuation in near bottom ocean sediments may be very high. It may be high enough that perturbation theory is inadequate for properly describing loss in shallow water acoustic propagation. Finally there is range dependence, which can be significant in littoral regions. This project addresses two of these shallow water issues.

*Range Dependence:* We found a number of bugs in our 2-way coupled mode code. Last year we presented a preliminary figure of propagation over a 2-D seamount model. The final figure is shown below as Figure 1. The most interesting feature is the prominent interface wave. Such interface waves, called Scholte waves require the presence of elasticity. There are no elasto-dynamic interface waves in a stratified fluid medium. A stratified fluid supports hydrodynamic interface waves, known as internal waves, but not elasto-dynamic waves. We note that the figure compares favorably to a similar figure generated by Scott Frank of Marist College. We used the same geoacoustic model as Frank.

*Anisotropy:* Our local mode model incorporates anisotropy with hexagonal anisotropy, but an arbitrary symmetry axis. By incorporating this into a time domain range dependent code we will be able to trade off the effects of range dependence and anisotropy in the modeling. Much of the trade-off work has been done locally, and has appeared in JASA (Soukup et al., 2013).

**WORK COMPLETED**

In the last year we concentrated on getting our work published. “Modal investigation of elastic anisotropy in shallow-water environments: anisotropy beyond vertical transverse anisotropy," Soukup et al. appeared in a special sediment acoustics issue of the *J. Acoust. Soc. Am.* in July, 2013. It is an extensive treatment of the effects of elastic anisotropy on seismo-acoustic propagation in shallow water. A sequel to that paper, “Coupled modes, range dependence, and sediment anisotropy in shallow water acoustic propagation,” Soukup et al. was submitted to JASA and is currently in review. The work on range dependence “Elastic parabolic equation solutions for underwater acoustic problems using seismic sources,” Frank et al., also appeared in JASA in 2013. This article documents the incorporation of seismic-like sources into the PE propagation model work important for ocean acoustic signals referred to as T-phases. Finally a survey paper on ocean acoustic noise below 100 Hz is “in press” to appear in January 2014, in the *Annual Review of Marine Science*.

**RESULTS**

Figure 1. is transmission loss (TL) for a range-dependent fluid-elastic model, computed with our 2-way coupled mode code, incorporating a 1500m/s ocean layer, a 150 m layer of sediments with compressional velocity of 2400m/s, shear velocity of 1200m/s. A faster layer with compressional speed and shear speed of 3400m/s and 1700m/s, respectively, and terminated by a fast basement with a compressional and shear speed of 5000m/s and 2887m/s, respectively. We presented a preliminary figure in last year’s report. This is the final version. The range-dependence models a seamount of approximately 400m in heigth and about 20km in range extent. The seamount is 2-dimensional. The plot shows clear interface (Scholte/Stoneley) waves guided along the boundaries at shorter ranges. We are also able to compute backscattered loss, as a natural byproduct of the two-way coupled mode computations. For this model, there is essentially no backscattered energy, as we do not include a figure.

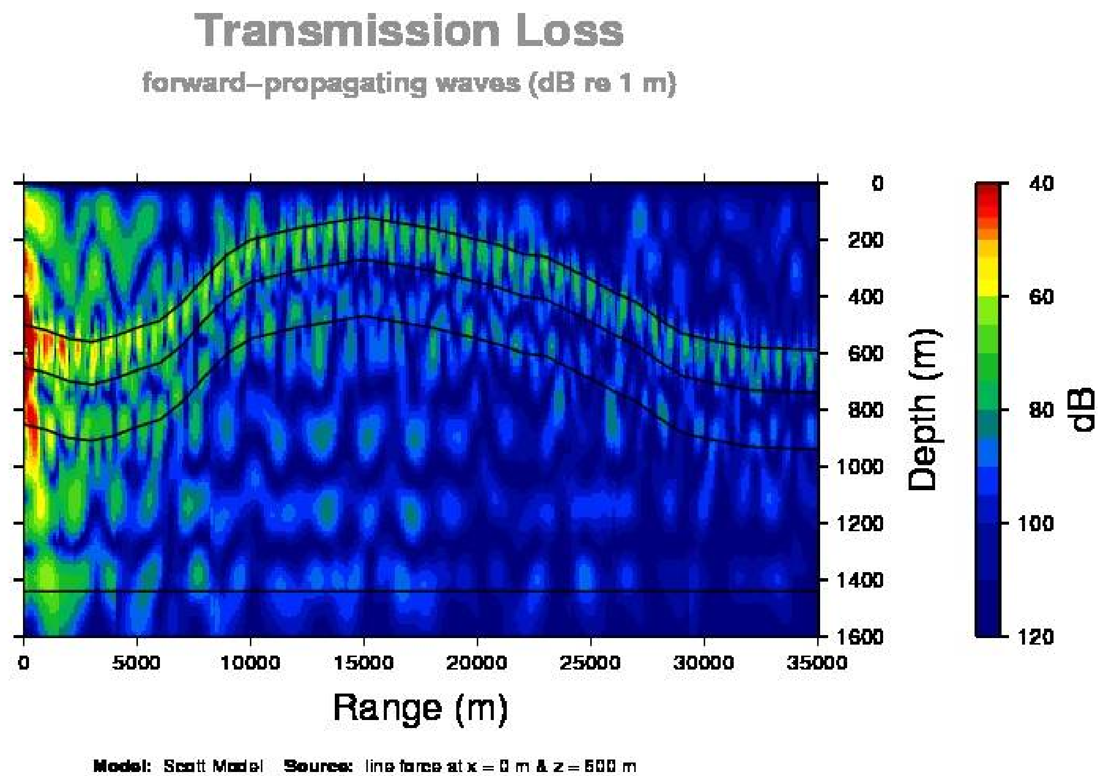


***Figure 1. Transmission loss (TL) for a range-dependent fluid-elastic model, incorporating a 1500m/s ocean layer, a 150 m layer of sediments with compressional velocity of 2400m/s, shear velocity of 1200m/s. A faster layer with compressional speed and shear speed of 3400m/s and 1700m/s, respectively, and terminated by a fast basement with a compressional and shear speed of 5000m/s and 2887m/s, respectively. The range-dependence models a seamount of approximately 400m in heighth and about 20km in range extent. The seamount is 2-dimensional. This is a final version of last year's preliminary plot, which, shows clear interface (Scholte/Stoneley) waves guided along the boundaries at shorter ranges.***

Figure 2. illustrates a main point of our work on the effects of sediment anisotropy on the seismo-acoustic modes of a shallow water environment with realistic levels of shear wave anisotropy (about 12%). Figures 2a and 2b illustrate that the horizontally polarized shear waves (SH) shown in Figure 2b are decoupled from the vertically polarized shear waves (SV) and the compressional (P) waves when the symmetry axis of the medium is vertical. Figures 2c and 2d illustrate what happens when the symmetry axis is rotated away from the vertical. SH is required to be excited by the satisfaction of the boundary conditions. The relative amplitudes are what would be expected for an in-water explosion. The excitation of the SH cannot be avoided.

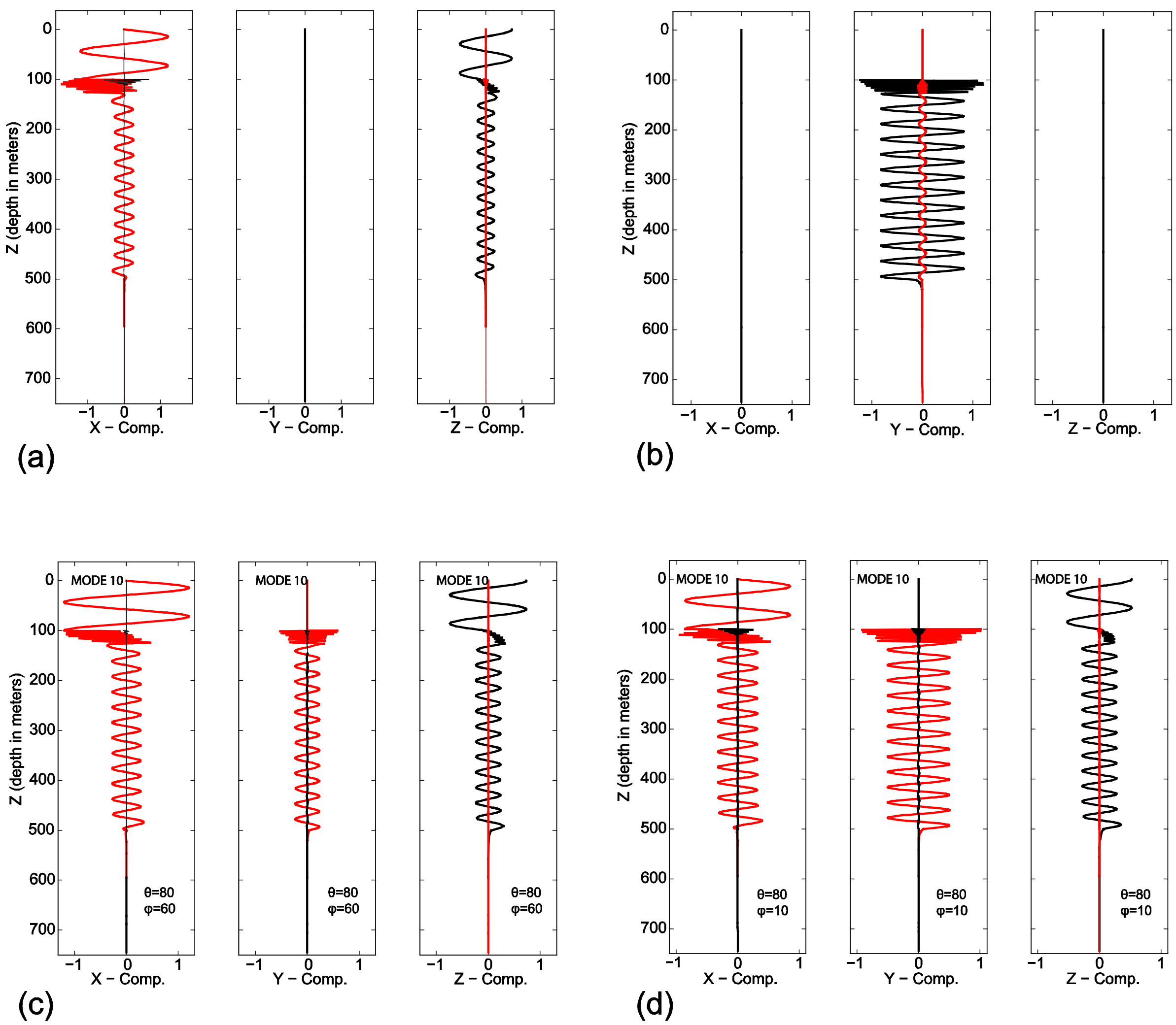


***Figure 2. Modes of a seismo-acoustic wave in a shallow water model with a vertical anisotropic symmetry axis (Figures 2a and 2b) for which the horizontally polarized shear waves (SH) propagate completely independently of the compressional an vertically polarized shear waves (P-SV), and for a model for which the anisotroic symmetry axis is tilted away from the vertical, and P-SV and SH are strongly coupled together. Excitation of the SH cannot be avoided for an anisotropic medium with a tilted symmetry axis (Figures 2c and 2d).***

## IMPACT/APPLICATIONS

This work will lead to a practical method to investigate seismo-acoustic propagation in shallow-water environments, and allow us to compare and contrast various environmental effects on the seismo-acoustic wave-field.

## RELATED PROJECTS

Our research is directly related to other programs studying effects of propagation at low frequency bottom-interacting sound.

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