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: As mentioned above, range dependence can be quite significant in littoral regions. There are currently available excellent codes for computing bottom interacting acoustic signals in shallow water for 1-D. Henrik Schmidt's OASES program, a direct descendent of the original SAFARI, has solved the 1-D problem for isotropic elastic bottoms. OASES is efficient, can accept

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arbitrary layered bottoms, and, very importantly, is numerically utterly stable. The currently available is version is 1-D. 2-D models do exist. William Siegmann and colleagues have produced a very fine parabolic equation model for propagation in range dependent media and even includes transverse isotropy. I and my past students (see References) have derived and coded a range dependent elastic model based on coupled modes. This incorporates arbitrary range dependence, and includes both forward and backwards propagation. The backwards propagation is not an approximation, a point it is important to emphasize. We generate the set of local modes, and solve a matrix Riccati equation over the range dependent section to arrive at the forward and backwards propagating fields. Currently the code must be run in a very hands-on batch mode. We are converting our current very hands-on code into a more generally useful tool. We are also working closely with both Scott Frank of Marist College, and Jon Collis of the Colorado School of Mines, who are former Ph.D. students of Siegmann's and experts in the elastic PE.

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 been submitted to JASA. However we have not incorporated this into the time domain propagation results. This is planned for the future.

WORK COMPLETED

This project is a new-start for FY11, and we have just begun converting our code. We have submitted a paper on the anisotropy trade-offs to JASA (Soukup, Odom, and Park).

Working with both Scott Frank and Jon Collis, we have agreed on a common environmental model to employ with both the coupled mode and PE computations.

RESULTS

Figure 1. is a preliminary ocean, bottom and sub-bottom morel with a 600m thick 1500m/s constant sound speed water column, 35m of soft sediments with very low shear speed, a thicker layer with a shear speed of 1450m/s, terminated by a hard basement with a 5000m/s compressional speed and 2887 m/s shear speed. There is a sediment layer with a shear speed of 1450m/s. As this is less than the 15m/s compressional speed of the water column, energy may couple very efficiently to the sediment shear waves as seen in Figures 2 and 3.

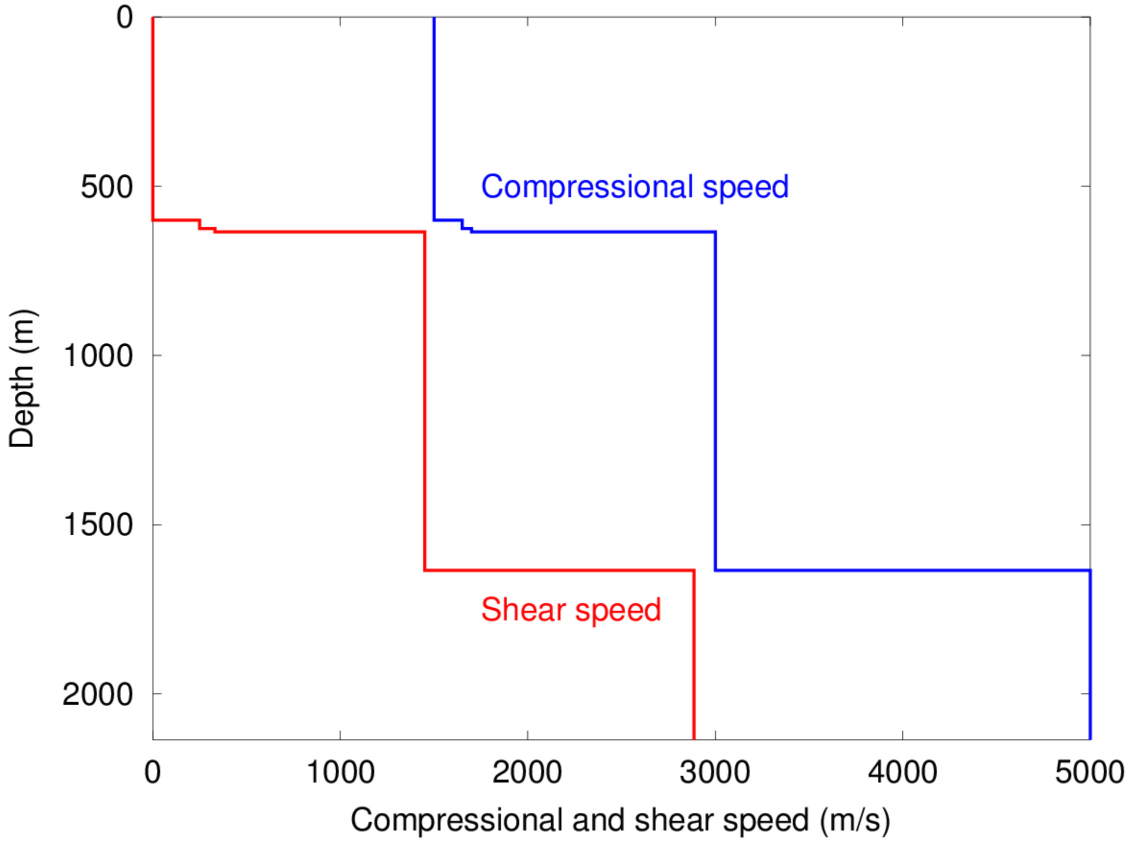

Figure 1. A preliminary ocean,bottom sub-bottom model. The compressional speed is in blue and the shear speed is in red. The water column is a 150m/s constant sound speed layer. There are 35 meters comprising two layers of very soft shear speeds of 250m/s and 331m/s. The next layer has a shear speed of 1450m/s, which is lower than the 1500m/s water layer. Because the shear speed is lower than the 1500m/s water column sound speed, energy can be trapped in this layer, as is seen in Figures 2-5.

Figure 2. shows the first and second acoustic mode. Note that there is weak coupling of energy into the horizontal components of the modes in the very soft and harder sediments. Also note that it is the displacement components (black for vertical, red for horizontal), which are plotted, rather than the pressure. The mode amplitudes do decay exponentially in the hard basement. This is not shown in the plots.

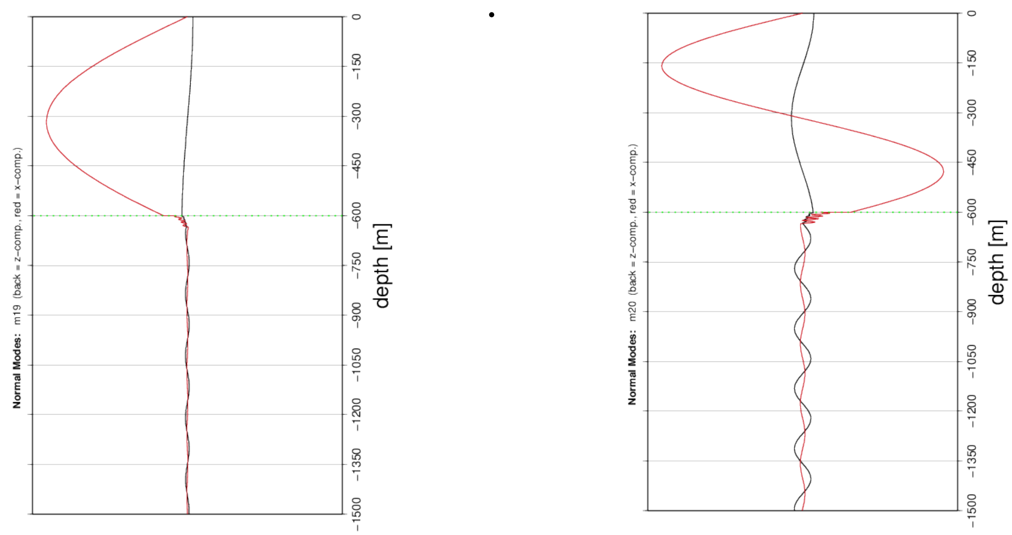

Figure 2. On the left is acoustic mode 1, and on the right is acoustic mode 2. The vertical (black) and horizontal (red) displacement components are shown. The penetration into the bottom is readily apparent.

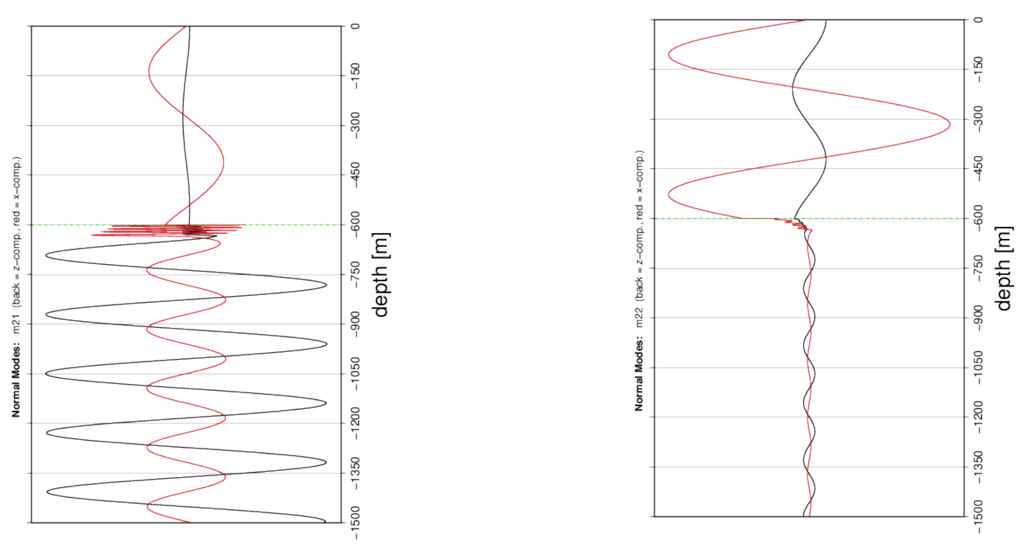

Figure 3. The figure on the left is striking in the relative amount of modal energy in the bottom, which is clearly greater than the relative amount of energy in the water. On the left is the next higher acoustic mode. The point is that when the elastic bottom properties are taken into account they can have a significant effect on the wave field.

The most striking feature of Figure 3. is the relative amplitude of the water column and sediment components of the energy in the leftmost figure. The reason for this is a shear wave resonance in the sediments, and would not appear in an all-fluid model supporting only compressional acoustic waves. Such shear wave resonances will produce what are effectively “holes” in the acoustic spectrum as measured by a receiver in the water column. This is purely an elastic effect and will not be seen in a fluid-only model. The plots are particle displacement amplitudes, rather than pressure. This is typical representation for elastic waves

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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