ONR Postdoctoral Fellowship: Investigation of Complex Range-Dependent Shallow Water Sound Transmission

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Award Number: N00014-07-1-0221

LONG-TERM GOALS

This Postdoctoral Fellowship has three main goals. The first is to quantify the water sediment interaction zone boundary condition for acoustical applications, using theory, numerical computation, experimental results, and constrained inversions. The second is to use range-dependent normal mode and parabolic equation codes along with geoacoustic profiles based on geophysical properties to develop hypotheses suitable for testing with at-sea experiments in waveguides with sandy bottoms. The third is to conduct experiments with a near bottom sound source and array to quantify the characteristics of the evanescent, compressional, shear, and slow wave fields.

OBJECTIVES

In general with a sandy bottom that has depth-dependent sound speed, attenuation, density and porosity profiles, the measured modal attenuation coefficients, and consequently the attenuation of sound in the water waveguide, will have a nonlinear frequency dependence that is less than quadratic. Numerical field calculations that use the range-depth dependencies of the bathymetry and the bottom should be capable of determining the correct intrinsic frequency dependence, when sufficient experimental sound transmission and environmental data are available.

Boston University in conjunction with the Woods Hole Oceanographic Institution has developed the low noise state-of-the-art towed array system towed behind a small autonomous vehicle (REMUS). Also, a simplification of Biot's sediment model was developed that predicts nonlinear ($n = 2$) frequency dependent attenuations. Previous results from the Nantucket Sound I experiment were consistent with the simplified Biot theory for sandy-silty sediment bottoms [1].

The first objective is to quantify the water sediment interaction zone boundary conditions using theory, numerical computation, experimental results, and constrained inversions. This includes employing multiple data sets from different experiments, using range-dependent propagation calculations, and advanced signal processing. Experimental sound transmission results from multiple shallow-water experiments (Buzzard's Bay, Nantucket Sound, the New Jersey continental shelf and the New England continental shelf) provide the experimental basis for our numerical studies to meet objectives.

The second objective of this research is, based on measurements of sound transmission from a source and array near the bottom, as well as state-of-the-art propagation codes and geoacoustic models, to quantify the properties of water/sediment interface waves, lateral waves, and direct reflected waves.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2007**	2. REPORT TYPE **Annual**	3. DATES COVERED **00-00-2007 to 00-00-2007**

4. TITLE AND SUBTITLE **ONR Postdoctoral Fellowship: Investigation Of Complex Range-Dependent Shallow Water Sound Transmission**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Boston University,Department of Aerospace and Mechanical Engineering,Boston,MA,02215**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

In the near term, the Nantucket II experiment was conducted with the source/receiver at the ocean-sediment interface. The sound transmission results will be compared against range-dependent normal mode and parabolic equation codes that have been modified to incorporate the simplified Biot theory and elastic bottoms. Synthetic aperture and other advanced signal processing techniques will be used to analyze the data to produce sound transmission results such as the horizontal wave number spectra.

APPROACH

The technical approach can be summarized as employing a balance between theory, numerical computation, and measurement to resolve extent issues concerning the water sediment boundary condition. The approach will use the state-of-the-art simplified Biot theory [2,3] and the towed array system to measure phenomena near to the water/sediment interface. Numerical calculations using coupled mode (COUPLE [4]) and parabolic equation (such as RAMS [5]) models will be used to guide experiments and eventually be benchmarked against measurements. Constrained inversion analysis will be applied to resolve geoacoustic profiles with measurement data. Advanced signal processing algorithms will be employed to determine the effects of range-dependent fluctuations on performance.

A typical experiment involved the towed-array-autonomous vehicle system and moored sound sources. The system varied depth over bottom for different experimental runs. The received pressure variations were recorded in a pod carrying data recorders. These data were merged with vehicle location data to yield the received pressure as a function of time and range. The data were processed with time frequency transforms and synthetic aperture techniques to yield the horizontal wave number spectrum to characterize interface phenomena (compressional, shear, and evanescent waves).

WORK COMPLETED

The Postdoctoral project was initiated during July 2006. The Investigator participated in both the SW06 and AWACS experiments. Initially between July and December 2006, prime activity for the Investigator was theoretical developments along with incorporation of the theory into range-dependent propagation codes. During the first year of this grant, the Investigator worked in conjunction with WHOI and BU investigations to characterize range-dependent sound transmission in the complex SW06 environment. Research calculations have been conducted to guide the analysis of measured results [6]. Analysis of experimental results pertinent to the characterization of the water sediment interaction zone have been performed.

In addition to participating in the SW06 and AWACS field tests, three noise characterization experiments were performed in Buzzard’s Bay during January, March and May of 2007. Also, an experiment, The Nantucket Sound II experiment, was conducted to measure the evanescent acoustic field at the water-sediment boundary interface. Supporting environmental measurements were made for each experiment, where data collected, in addition to acoustic measurements made with the towed hydrophone array system and the autonomous vehicle that included position, water depth, conductivity, and temperature.

RESULTS

Sediment attenuation has an important effect in many underwater acoustics problems, in particular those of shallow waters. Results have shown that the accurate calculation of the acoustic field in a shallow-water waveguide with sandy sediment bottom requires a nonlinear frequency-dependent compressional wave attenuation in the upper layer of sediment. Careful examination of experimental data, summarized in [7] and [8], show that the accurate calculation of shallow-water sound transmission between 100 Hz and 1 kHz in a waveguide with sandy-silty bottom requires a nonlinear frequency-dependent attenuation, $n = 1.8 \pm 0.2$, in the near-water sediment layer. However, the simplified theory of Biot predicts a quadratic (nonlinear) frequency dependence, $n = 2$. Though both theory and experiment show nonlinear frequency dependence, there is a difference between theory and experiment.

A recent paper discusses calculations used to explain the less than quadratic frequency dependence of compressional wave attenuation [9]. To quantify the attenuation properties of shallow-water waveguides, various physical mechanisms were considered as possible influences on propagation. In particular, the influence of sound speed and attenuation gradients and effects due to elasticity were discussed. It was determined that effects due to shear can result in greater effective attenuation than is expected from a quadratic frequency exponent. For shear wave speeds of approximately 300 m/s, these effects are in general agreement with less than quadratic expected values.

To better quantify the effects that shear has on shallow-water sound propgation, an experiment, Nantucket Sound II, was conducted during August of 2007. The experiment involved a bottom mounted source and a near-bottom array system towed behind a small autonomous vehicle. The goal of the experiment was to measure water-sediment interface wave phenomena. Prior to the experiment calculations were performed using parabolic equation and wavenumber integration codes to estimate horizontal wavenumbers near to the ocean sediment interface. Calculations were performed to aid in experimental design, and a sample wavenumber spectrum obtained from an elastic parabolic equation calculation, for a shear wave speed of 300 m/s, is presented in Fig. 1. This calculation produced a simulated pressure field that was transformed to the horizontal wavenumber spectrum, the basic concept was to calculate what was measured. Modal peaks can been seen at approximately 1.1 m^{-1} and a shear peak can be seen at approximately 6.1 m^{-1}. This broad peak covers the range of speeds from shear to the Scholte wave. Equivalent calculations performed with a fast field code yield results that showed this peak to be closer to the Scholte wave speed.

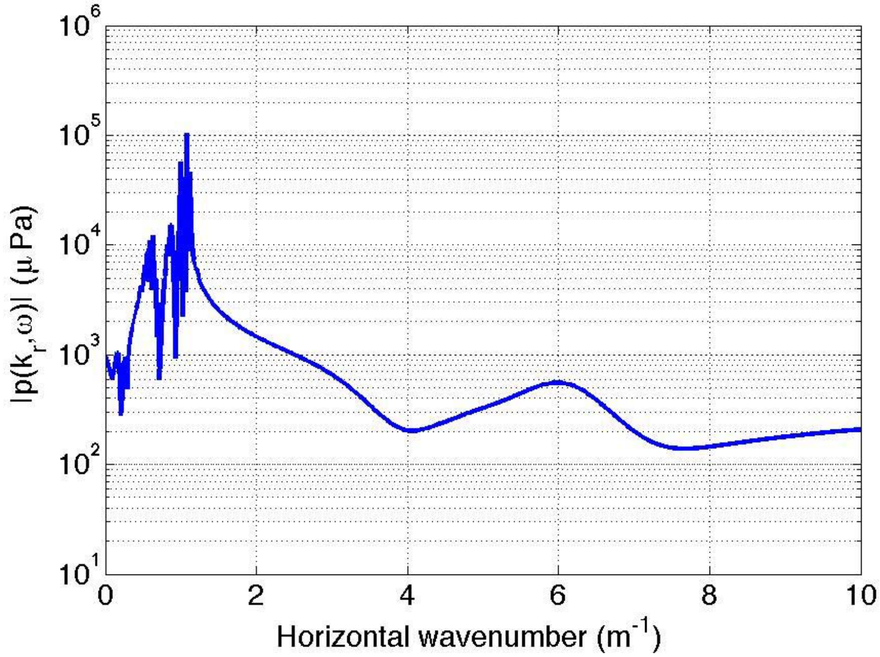

Figure 1. Magnitude plot of the horizontal wavenumber spectrum from elastic parabolic equation calculations. The frequency is 275 Hz and the shear sound speed is 300 m/s.

Pressure measurements were made as the vehicle and array proceeded along a straight-line constant-depth path that had a closest point of approach of 46 m and an extreme range of 500 m.. The merged data files were post processed to first yield $P(r,t)$, then $P(r,\omega)$, and with a synthetic Hankel transform, $P(k,\omega)$. Horizontal wavenumber estimates, $P(k,\omega)\cdot P(k,\omega)^{\bullet}$, were found to show modal wavenumber peaks as well as an additional peak that is consistent with an interface wave. Figure 2 gives a plot of the magnitude of the pressure transform magnitude, $|P(k,\omega)|$,as a function of horizontal wavenumber. Several wavenumber peaks are combined in a single peak at or below the water wavenumber and represent the trapped modes in the waveguide. Another peak occurs at approximately 6.95 m^{-1} that would imply a shear wave speed of 284 m/s (assuming that the shear wave speed is 0.875 times that of the interface wave speed). This shear wave speed is consistent with the value required in numerical calculations to explain the less than quadratic frequency dependence.

Although interface waves have been measured with bottom mounted sensors at the lower frequencies, this measurement is distinguished by the fact that it was measured with an array system in the water column.

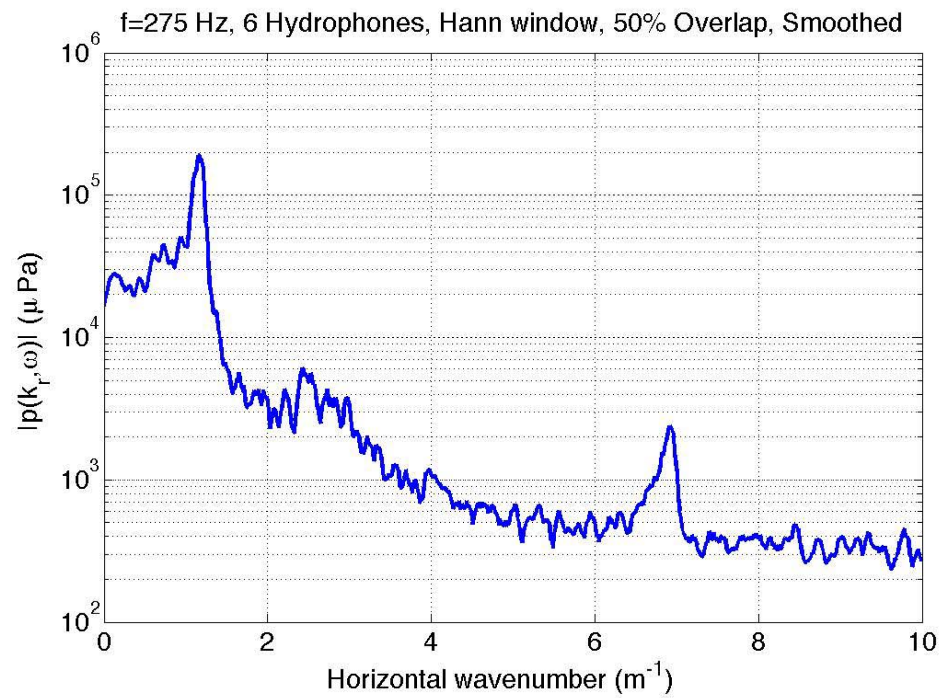

Figure 2. Magnitude plot of the experimentally measured pressure as a function of horizontal wavenumber. The plot, for 275 Hz, was produced using the linearly averaged output from six hydrophones. A modal wavenumber peak can be seen at approximately 1.1 m^{-1}. A second peak at about 6.95 m^{-1} is consistent with the measurement of a water-sediment interface wave. The interface wave peak indicates a shear wave speed of 284 m/s.

IMPACT/APPLICATIONS

Numerical studies show that the observed less than quadratic frequency dependence can be explained by shear wave leakage and subsequently accounted for in standard underwater acoustic propagation models. The horizontal wavenumber measurement technique represents a new method for shear wave speed measurement in shallow water.

RELATED PROJECTS

Initially the Postdoctoral work was under the ONR Multiphase Media Investigation at Boston University. This current effort is directly related to the Multiphase Media Investigation. The ONR Postdoctoral Grant to Boston University has Professors William Carey and Allan Pierce as advisors. The Investigator also holds a position as a Guest Investigator at WHOI under the advisement of Dr. James Lynch.

The Investigator has participated in both the SW06 and AWACS experiments. The Investigator has worked in conjunction with designated ONR Principals at BU, WHOI, and Rensselaer Polytechnic Institute. The Postdoctoral research activities have been partially funded by the ONR Ocean Acoustics Program by grants at WHOI and BU.

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PUBLICATIONS

- Published [refereed]: [10]
- Accepted [refereed]: [11]
- Proceedings [non-refereed]: [6], [9]