SHALLOW WATER ACOUSTIC SCATTERING, DIFFUSION, AND LEAKY MODES
and
STUDENT SUPPORT

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Award # N00014-03-1-0378
Student Support
Award #: N00014-02-1-0393

LONG TERM GOALS

The long-term goal of this research is to improve our ability to model and predict VLF acoustic propagation in shallow water with particular emphasis on the range dependence of the medium and the geoacoustic properties of the bottom, and to quantify the various factors affecting the overall acoustic energy budget in shallow water propagation.

OBJECTIVES

Our scientific objectives are to incorporate the effects of sediment anisotropy, strong sediment attenuation, and the effects of both deterministic and stochastic medium properties into a local coupled mode propagation model, and to develop accurate theory and robust numerical algorithms for the shallow water propagation problem.

APPROACH

We are using an approach based on coupled local modes to carry out a systematic study of the effects of scattering, normal dispersion, anisotropy and intrinsic attenuation on a propagating shallow water acoustic signal with strong bottom interaction. The coupled mode theory is developed from the first order equations of motion for the stress and displacement rather than from the second order equations for a velocity or displacement potential. The later approach introduces coupling coefficients depending on the second-order derivatives with respect to the range coordinate of the local mode functions. These second-order coupling coefficients are an artifact of the formulation, and not present in the coupled mode theory based on the first order equations of motion.

WORK COMPLETED

We continue to progress towards understanding the effects of sediment anisotropy and scattering on mode coupling in a range dependent, shallow water waveguide. The modes in a purely fluid waveguide

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Shallow Water Acoustic Scattering, Diffusion, And Leaky Modes and Student Support**	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) **Applied Physics Laboratory,,College of Ocean and Fisheries Sciences,,University of Washington,1013 N.E. 40th Street, ,**	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

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)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

are intrinsically ordered by the number of zero crossings in the vertical direction. The number of zero crossings also correlates directly phase velocity. Modes with larger numbers of zero crossings have a higher phase velocity. In a waveguide with an elastic bottom, the presence of shear complicates the mode ordering. The number of zero crossings may not indicate the mode order. However, the modes can still be ordered by phase velocity. In a shallow water waveguide with an isotropic or transversely isotropic bottom, SH is decoupled from the P-SV motion, and the SH component does not participate at all in the propagation of the water borne acoustic modes. However, in a waveguide with a more generally anisotropic bottom, the P-SV modes and the SH modes are no longer independent, and there can be significant energy in the quasi-SH, which must be taken into account even for the water-borne acoustic modes, if they have any significant bottom interaction. In this past year we have derived and coded a perturbation theory for modal scattering by volume heterogeneities. The heterogeneities themselves may be elastically anisotropic. The theoretical model assumes weak scattering, and employs the Born approximation. The modal scattering depends on the volume coupling terms in the mode-mode coupling matrix. The evaluation of these terms requires a numerical integration over depth of products of the local eigenfunctions and the heterogeneity terms. The results, presented at the Acoustical Society Meeting in April of this year in Nashville, Tennessee (Soukup & Odom, 2003), are discussed in the next section.

RESULTS

Figure 1 shows the scattering matrix and the modes into which the energy was scattered by the volume heterogeneities. The model is a 100m plane water layer underlain by plane anisotropic sediments. The anisotropy is characterized by five elastic moduli, and is mathematically equivalent to a crystal with hexagonal symmetry. Of course the sediments are not a single crystal, but transversely isotropic media are mathematically equivalent to hexagonally symmetric crystals, and also require five elastic moduli for their characterization. The frequency is 50 Hz. The scatterers for this example are confined to the sediment layers. The results represent scattering from volume perturbations to density and to the five elastic moduli required to characterize the anisotropy. From the color pattern of the scattering matrix, it is apparent that higher order modes are somewhat more efficiently scattered by volume heterogeneities than the lower order modes. (Blue corresponds to weak scattering by volume heterogeneities.) This is not surprising as lower order modes average over a greater depth, and so are less affected by localized heterogeneities. We use the mode ordering scheme described above, whereby modes are ordered by increasing phase velocity, with the result that quasi-SH modes are interspersed with quasi-P-SV modes. Because the bottom sediments are anisotropic, quasi-SH modes may have non-zero particle motion in the sagittal (x-z) plane.

On the right hand side of Figure 1 are the scattered modes. Because the scatterers may be elastically anisotropic, this figure represents a snapshot along a single azimuth, in this case 0°, i.e. in the forward direction. Because we have ordered the modes by phase velocity, there is no distinction made between quasi-SH and quasi-P-SV modes. Volume scatterers efficiently couple energy between the quasi-SH and quasi-P-SV modes. It is important to note that if the bottom sediments are anisotropic, the quasi-SH waves have particle motion in all three orthogonal coordinate directions. Ignoring the quasi-SH for bottom interacting sound over an anisotropic bottom, will lead to errors of interpretation.. For example, attenuation will be underestimated.

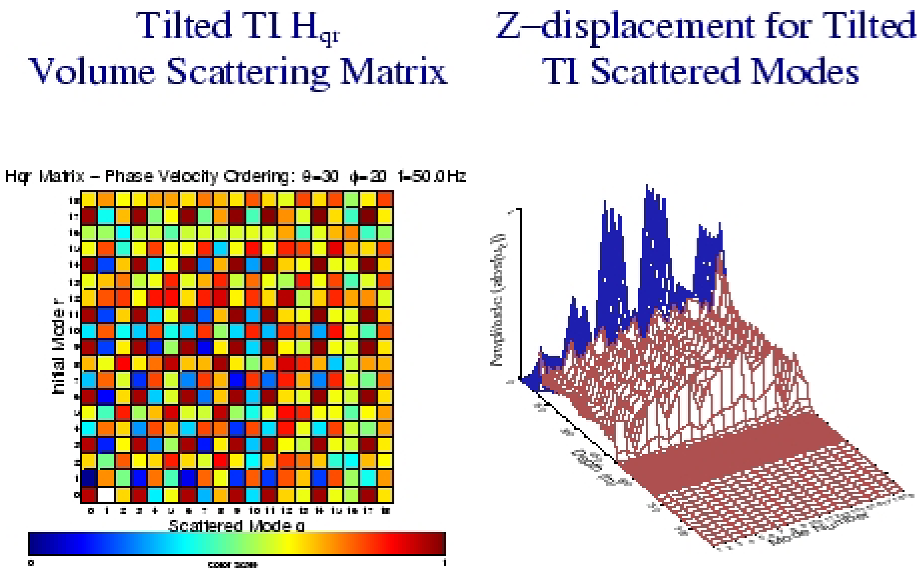

Figure 1. This figure shows a scattering matrix (left) for a fluid-elastic medium with anisotropic bottom sediments, and the modes excited by volume heterogeneity scattering(right). The model is a 100m water layer over anisotropic sediments. The frequency is 50 Hz. The modes are ordered by increasing phase velocity. This means that quasi-SH and quasi P-SV modes are interspersed. It is important to remember that quasi-SH modes can have non-zero particle motion in the fluid layer. Blue indicates weaker mode coupling resulting from volume scattering. The number of blue squares in the matrix are an indication that lower order modes are more weakly affected (scattered) by volume heterogeneities than higher order modes.

IMPACT/APPLICATIONS

Highlighting the importance of volume scattering and sediment anisotropy in mode coupling and signal loss is an important step in the understanding of acoustic propagation in complicated heterogeneous waveguides. This research is directly applicable to predicting the effect of a complicated shallow water environment on the acoustic field. Elastic anisotropy is an almost ubiquitous property of marine sediments. At high frequencies in the kilohertz range, it will not be important, but at lower frequencies, it can have a significant impact on signal attenuation and propagation.

An important application to another field of the theoretical results we have derived is the generation of oceanic T-waves. The modal scattering theory of Park and Odom (1999) was used to show that modal scattering from a sloping bottom or seabed roughness can excite the low order acoustic modes known to carry the T-waves (Park et al., 2001). This application was funded under the National Ocean Partnership Program (NOPP).

TRANSITIONS

Modal methods for modeling in random range dependent shallow water waveguides should provide important constraints on the most significant waveguide properties affecting propagation at low frequencies.

RELATED PROJECTS

Our research is directly related to other programs studying surface, volume and bottom interaction effects, including 6.2 and 6.3 efforts to quantify bottom backscatter and bottom loss effects in littoral regions.

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