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Subject: Progress Report ONR No: N00014-94-1-0201
         Jan. 1, 1994 - Oct. 31, 1994

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Date: Nov. 9, 1994

The following topics were studied in detail during the report period:

1) Combined volume and surface scattering in a channel, using a modal formulation.

2) Two-way formulation to account for backscattering in a channel.

3) Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel.

4) The effect of random fluctuations on the two-frequency coherence function in a shallow channel.

5) Approximate eigenfunctions and eigenvalues for linear sound-speed profiles.

These topics are discussed in the following sections.

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1. Combined volume and surface scattering in a channel using a
   modal formulation.

   In the next month, a paper will be submitted to JASA on this
subject. The abstract of the paper is:

Combined volume and surface scattering in a
channel using a modal formulation

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In previous work, a modal approach was used to study random
volume scattering in a shallow channel (M.J. Beran and S.
Frankenthal, J. Acoust. Soc. Am., 91, 3203-3211, 1992). Here, we
shall show how the effects of a rough channel surface may be
included in the formulation. To include the effects of the rough
surface, the modes are taken to be dependent on the range and
transverse coordinates in addition to the depth coordinate. The
propagation is studied in terms of the ensemble-averaged two-
point coherence function and the equation governing the coherence
function is derived. The general method for volume scattering is
given in detail in the above reference. Here it is shown how the
surface scattering terms may be treated in this approach.

The two-point coherence function is expressed as the sum
over both self-modal and cross-modal coherence functions. The
difference between the self-modal coherence functions and the
cross-modal coherence functions is discussed. A numerical example
is given using typical shallow-water parameters.

A draft of the paper is now available on request. The paper is
being edited for its final form.

2. Two-way formulation to account for backscattering in a channel.

In the analysis performed on the combined volume and surface scattering, it was found that the addition of the surface scattering caused the conservation of energy to be violated. It was found that the violation occurred because backscattering was not properly taken into account. A proper formulation was developed based on an analysis given in the book by C.A. Boyles, (Acoustic Waveguides, Applications to Ocean Science, Interscience, John Wiley and sons, 1984). However, in the paper mentioned in Sec. 1, the backscattering was taken to be small. In this work we are developing a coherence formulation in which the backscattering may be more significant. At the same time we are attempting to generalize the method to account for large transverse scattering.

3. Data analysis to determine vertical and horizontal correlation lengths of the random index-of-refraction fluctuations in a channel.

In order to properly determine the volume scattering in a channel, it is necessary to know both the characteristic horizontal and vertical correlation lengths associated with the index-of-refraction fluctuations. Unfortunately, we could not find suitable experimental data in the literature. The situation is quite different from the deep ocean where there is considerable information available on internal waves.

Mr. Thomas Barnard, the Ph.D student, has, however, obtained SWELLEX-2 vertical-array thermistor data with the help of scientists at NRL. From this data he has obtained characteristic vertical scales for day-time and night-time observations. He also found results that are sometimes dependent upon the averaging times. In addition, Mr. Barnard expects to obtain data from Dr. Paulson of Oregon State University which will allow him to estimate characteristic horizontal scales. Data processing is still progressing and we hope to be able to present results at the May ASA meeting in Washington, DC.

4. The effect of random fluctuations on the two-frequency
   coherence function in a shallow channel.

The two-frequency coherence function may be used to
calculate scattering of transient acoustic fields. A paper on
this subject is in the final stages of preparation but
calculations are still required to give numerical results.
The calculations should be completed in about six months. A
preliminary abstract of the work to be included in the paper is
given here:

The effect of random fluctuations on the two-frequency
coherence function in a shallow channel

Abstract

We consider here the effect of random sound-speed
fluctuations on the two-frequency coherence function for acoustic
propagation in a shallow channel. The approach we use is a direct
generalization of the modal approach used in a previous paper on
volume scattering with a single frequency[1]. The two-frequency
coherence function allows us to study the effect of volume
fluctuations on the propagation of transient acoustic signals in
a shallow channel.

The governing two-frequency coherence equations are derived.
It is shown that, in the modal formulation we use for the spatial
decomposition, the two frequencies behave as two extra modal
parameters. Conditions are given under which the equations are
valid. From the equations, characteristic length scales are found
which give the propagation distance over which the two-frequency
coherence functions decay significantly from their initial
values. A numerical example, using typical shallow water
parameters, is presented. Finally it is shown how to use the two-
frequency results to estimate the distortion of transient
acoustic signals propagating in a shallow channel.

5. Approximate eigenfunctions and eigenvalues for linear
   sound-speed profiles.

In the paper in Sec. 1, numerical calculations were included
for a constant sound-speed profile. The same calculations should
be done for a linear sound-speed profile. Although a general
solution for the vertical mode wave equation has been found for
linear sound-speed profile, the properties of the Bessel
functions of pure imaginary order in the solution are poorly
understood. We require accurate approximations to match the

boundary conditions. Mr. Barnard has been studying this problem and obtained suitable approximations. In the course of his analysis he has also shown how to obtain approximate solutions for a piecewise-linear profile. In the coming months Mr. Barnard's approximate solutions will be used to calculate the scattering coefficients used in the coherence equations.