

Modal Mapping in a Complex Shallow Water Environment

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LONG-TERM GOALS

The long-term goal of this research is to increase our understanding of shallow water acoustic propagation and its relationship to the three-dimensionally varying geoacoustic properties of the seabed.

OBJECTIVES

The scientific objectives of this research are: (1) to develop high-resolution methods for characterizing the spatial and temporal behavior of the normal mode field in shallow water; (2) to use this characterization as input data to inversion techniques for inferring the acoustic properties of the shallow water waveguide; and (3) to use this characterization to improve our ability to localize and track sources.

APPROACH

An experimental technique is being developed for mapping the wavenumber spectrum of the normal mode field as a function of position in a complex, shallow water waveguide environment whose acoustic properties vary in three spatial dimensions. By describing the spatially varying spectral content of the modal field, the method provides a direct measure of the propagation characteristics of the waveguide. The resulting modal maps can also be used as input data to inverse techniques for obtaining the acoustic properties of the waveguide. The experimental configuration consists of a stationary or moving source radiating one or more pure tones to a field of freely drifting buoys, each containing a hydrophone, GPS and acoustic navigation, and radio telemetry. In this context, two-dimensional modal maps in range *and* azimuth, as well as three-dimensional bottom inversion in range, depth, *and* azimuth, become achievable goals.

WORK COMPLETED

To date, three modal mapping experiments (MOMAX I-III) have been completed in which fixed and moving source configurations were used to transmit pure tones in the band 20 – 475 Hz to several buoys at ranges up to 20 km in a wide range of shallow water environments. MOMAX I was conducted aboard the R/V Endeavor during the period 21 March – 3 April 1997. A series of eight experiments was carried out in the East Coast STRATAFORM/SWARM area off the New Jersey coast in about 70 m of water. MOMAX II was conducted aboard the R/V Gyre during the period 5-15

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February 1999 in water depths ranging from 50 m to 150 m. A series of three experiments was carried out in the Gulf of Mexico, about 140 nmi west-northwest of Key West, FL, as part of the multi-institutional, multi-ship LWAD (Littoral Warfare Advanced Development) 99-1 Experiment. MOMAX III was conducted aboard the R/V Endeavor during the period 17-31 October 2000 in water depths ranging from 70 m to 1000 m. A series of five experiments was carried out during Leg 3 of the SWAT (Shallow Water Acoustic Technology) Experiment in the East Coast STRATAFORM/SWARM area off the New Jersey coast. The SWAT Experiment was a multi-institutional, multi-ship project that included U.S. investigators from the Naval Research Laboratory, the University of Miami, and WHOI as well as Japanese investigators from the Japan Defense Agency, OKI Electric Industry Co., and Ishikawajima-Harima Heavy Industries. In addition to the acoustic measurements, extensive environmental data were also acquired in MOMAX I-III, including: 3-6 kHz chirp sonar data; XBT, CTD, XCTD and temperature string measurements; and current, meteorological, and wave height data.

In a broader ocean acoustic context that includes both deep and shallow water, we continued the development and application of exact, analytic inverse techniques to seabed inversion problems. This work included the development of the algorithms required to use monochromatic reflection coefficient versus angle measurements as input data to the Gelfand-Levitan method.

RESULTS

During the past year, the following scientific achievements were accomplished:

Modal Mapping:

- (1) The propagation of a single normal mode was conclusively demonstrated in the 20 Hz data obtained during one of the experiments, where the water depth was comparable to the acoustic wavelength of about 75 m. This is believed to be the first at-sea measurement of single mode propagation. The lateral variation of the single modal eigenvalue, which was easily calculated by taking the range derivative of the measured phase, was then used to infer the range-dependent sound speed in the bottom.
- (2) The simple phase model previously developed, which enabled the inference of source-receiver speed from acoustic phase rate measured at a single receiver, was extended to enable the determination of source position from phase data acquired on multiple receivers. The technique was demonstrated using all three MOMAX data sets, even for cases where the precise frequency was unknown and/or variable.
- (3) Previous analysis of cross-shelf vs. along-shelf 50 Hz data was extended to include 125 Hz data. The pronounced, range-dependent behavior of the cross-shelf modal spectra, in contrast to the stable, essentially range-independent behavior of the modal spectra in the along-shelf case, were quantitatively correlated with the measured bathymetry in these two extreme cases.
- (4) The power and effectiveness of the modal mapping technique in identifying abrupt changes in seabed properties were demonstrated on synthetic data provided as part of an ONR/SPAWAR Inverse Techniques Workshop (2001). Using only continuous-wave acoustic data in the water column, our group was able to obtain the best estimate of the location and acoustic properties of an intrusion in the seabed.

Reflection Coefficient Inversion:

The improved reflection coefficient estimate obtained from a deep-water data set acquired in the Icelandic Basin in 1981 was used as input data to the exact Gelfand-Levitan inversion technique. This procedure yielded a *unique*, high-quality estimate of the sound speed profile in the seabed, thus demonstrating the successful application of an exact inversion method to ocean acoustic data for the first time.

IMPACT/APPLICATIONS

The experimental configuration consisting of a CW source and freely drifting buoys will provide a simple way to characterize a shallow water area and may be useful in survey operations. In addition, the planar, synthetic receiving array may offer an effective new technique for localizing and tracking CW sources in shallow water.

TRANSITIONS

The synthetic aperture technique and Hankel transform inversion methodology which underlies the modal mapping method has been implemented in the ACT II experiment, sponsored by DARPA and ONR. This approach has also been adopted by several research groups internationally, including the Japanese groups involved in SWAT.

RELATED PROJECTS

MOMAX I and III were conducted in the same area off the New Jersey coast where the ONR-sponsored STRATAFORM, SWARM, Geoclutter, and Boundary Characterization experiments were carried out. The extensive geophysical, seismic, acoustic, and oceanographic data obtained in these experiments are being used to ground truth the MOMAX measurements.

The LWAD 99-1 Project included a broad range of underwater acoustic and environmental measurements, in addition to MOMAX II. The results from these other experiments are being used to assist in the interpretation of the MOMAX II data.

REFERENCES

G.V. Frisk, "A Review of Modal Inversion Methods for Inferring Geoacoustic Properties in Shallow Water," *invited paper* in Full Field Inversion Methods in Ocean and Seismo-Acoustics, edited by O. Diachok, A. Caiti, P. Gerstoft, and H. Schmidt (Kluwer, Netherlands, 1995).

K. Ohta and G.V. Frisk, "Modal Evolution and Inversion for Seabed Geoacoustic Properties in Weakly Range-Dependent, Shallow-Water Waveguides," *IEEE J. Oceanic Engineering Special Issue on Shallow-Water Acoustics II*, **22**, 501-521 (1997).

J.A. Douff, G.V. Frisk, and H. Martell, "Determination of Distance Between a Moving Ship and Drifting Buoys to Centimeter-Level Accuracy at Sea Using L1 Phase Receivers and Differential Moving-Base Kinematic Processing," in *Proceedings of the Institute of Navigation GPS-98 Conference*, Nashville, Tennessee, 6 pages (15-18 September 1998).

J.A. Doult, G.V. Frisk, and H. Martell, "Using GPS at Sea to Determine the Range Between a Moving Ship and a Drifting Buoy to Centimeter-Level Accuracy," in *Proceedings of the Oceans '98 Conference*, Nice, France, 4 pages (28 September – 1 October 1998).

G.V. Frisk and K.M. Becker, "Modal Evolution and Inversion in Laterally Varying, Shallow-Water Waveguides," in *Proceedings of the International Conference on Acoustics, Noise and Vibration*, Montreal, Quebec, Canada, 5 pages (8-12 August 2000).

G.V. Frisk, K.M. Becker, and J.A. Doult, "Modal Mapping in Shallow Water Using Synthetic Aperture Horizontal Arrays," *invited paper* in *Proceedings of the Oceans 2000 MTS/IEEE Conference and Exhibition*, Providence, RI, 4 pages (11-14 September 2000).

G.V. Frisk, "The Relationship Between Low-Frequency Phase Rate and Source-Receiver Motion in Shallow Water: Theory and Experiment," *invited paper* in *Proceedings of the 17th International Congress on Acoustics*, Rome, Italy, 2 pages (2-7 September 2001).

PUBLICATIONS

L.L. Souza, G.V. Frisk, and K.M. Becker, "Application of the Gelfand-Levitan Method to the Estimation of the Seabed Sound Speed Profile," in *Proceedings of the V Encontro de Tecnologia em Acustica Submarina (V Underwater Acoustics Meeting)*, Rio de Janeiro, Brazil, 6 pages (21-23 November 2001).

G.V. Frisk, "Underwater Sound," *invited paper* in McGraw-Hill Yearbook of Science and Technology 2002, edited by M.D. Licker, 403-406 (McGraw-Hill, New York, 2001).

K.M. Becker and G.V. Frisk, "A Study on the Effects of Sound Speed Fluctuations Due to Internal Waves in Shallow Water on Horizontal Wavenumber Estimation," in *Proceedings of the Conference on the Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance (Lerici, Italy, 16-20 September 2002)*, edited by N.G. Pace and F.B. Jensen, 385-392 (Kluwer, Netherlands, 2002).

D.K. Wilson, G.V. Frisk, T.E. Lindstrom, and C.J. Sellers, "Measurement and Prediction of Ultra-Low Frequency Ocean Ambient Noise Off the Eastern U.S. Coast," under revision for publication in *J. Acoust. Soc. Am.*

K.M. Becker, S.D. Rajan, and G.V. Frisk, "Application of Modal Inverse Techniques to the ONR/SPAWAR Inverse Techniques Workshop Data," *invited paper* submitted to *IEEE J. Oceanic Engineering Special Issue on Geoacoustic Inversion in Range-Dependent Shallow-Water Environments*.

G. Frisk (Chair), J. Merrill (Study Director), D. Bradley, J. Caldwell, G. D'Spain, J. Gordon, M. Hastings, D. Ketten, J. Miller, D. Nelson, A. Popper, D. Wartzok [National Academy of Sciences/National Research Council Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals], Ocean Noise and Marine Mammals, submitted for external review, 212 pages (National Academy Press, Washington, DC, 2002).