

Modal Mapping Techniques for Geoacoustic Inversion and Source Localization

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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 laterally varying, acoustic properties of the waveguide. The experimental configuration consists of a moored or towed source radiating one or more pure tones to a field of freely drifting buoys, each containing a hydrophone, GPS navigation, and radio telemetry, as shown in Fig. 1. A key component of this method is the establishment of a local differential GPS system between the source ship and each buoy, thereby enabling the determination of the positions of the buoys relative to the ship with submeter accuracy. 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. In addition, these high-resolution measurements provide new insights into source localization and tracking technique.

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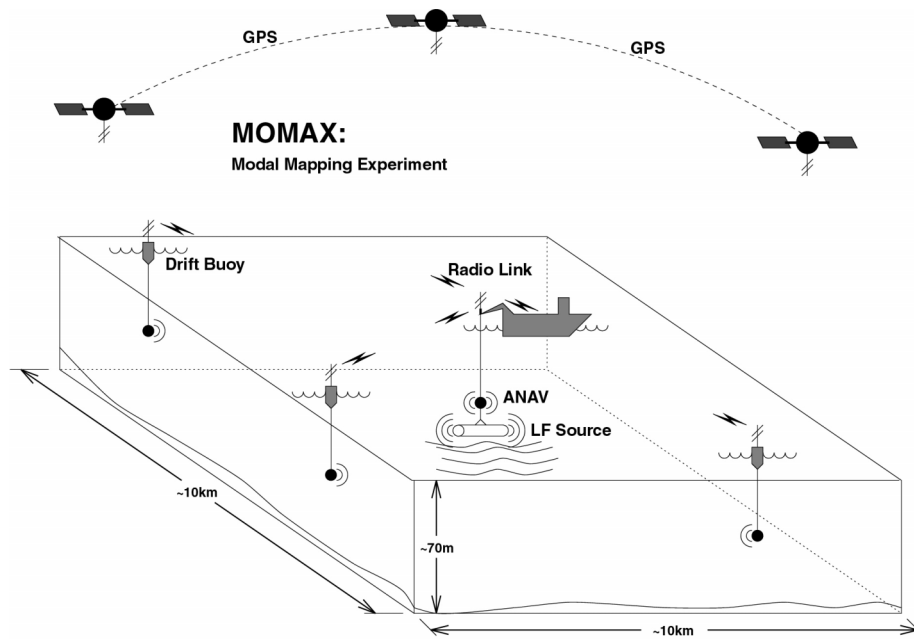


Figure 1: MOMAX experimental configuration.

WORK COMPLETED

To date, three successful Modal Mapping Experiments (MOMAX) have been completed. Two of these (MOMAX I and SWAT/MOMAX III) were conducted in the East Coast STRATAFORM/SWARM area off the New Jersey coast and one (LWAD 99-1/MOMAX II) was carried out in the Gulf of Mexico. Several drifting MOMAX buoys, each containing a hydrophone, GPS navigation, and radio telemetry, received signals out to ranges of 20 km from moored and towed sources transmitting pure tones in the frequency range 20-475 Hz. In addition to the acoustic measurements, extensive environmental data were also acquired, including: 3-6 kHz chirp sonar data; XBT, CTD, XCTD and temperature string measurements; and current, meteorological, and wave height data.

RESULTS

As an example of the modal mapping technique, we present analysis results below for Experiment 2 of SWAT/MOMAX III. Specifically, modal maps in both the spatial and horizontal wavenumber domains were generated for cross-shelf and along-shelf legs at 125 Hz.

The first step in the MOMAX processing sequence involves shifting the received acoustic signal to base band, i.e., removing the time-dependent, carrier frequency contribution to the total phase. The resulting pressure field magnitude and phase versus time data are then merged with the corresponding GPS-derived source-receiver positions versus time. This procedure enables the display of the pressure magnitude and phase as a function of two-dimensional position, as shown in Fig. 2. Here the field is plotted above the source track, which corresponds to the long L-shaped trajectory, while the receiver track corresponds to the short curved path. Both source and receiver moved in a northerly direction during the course of the experiment with source and receiver speeds of approximately 1.6 m/s (3 kt) and 0.27 m/s (0.5 kt), respectively. The source-receiver range changed from 9300 m to 3800 m during

the cross-shelf portion and increased to a maximum of 13,500 m in the along-shelf part of the experiment. The three-dimensional view displayed in Fig. 2 distorts the east-west and north-south distances, as indicated by the actual distances given along the latitude and longitude axes.

The spatial modal map shown in Fig. 2 provides an interesting view into the nature of modal propagation in this case. The interference pattern evident in the magnitude suggests that the field is composed of several coherently interacting modes, and that the modal composition differs in the cross-shelf and along-shelf directions. On the other hand, the phase displays a remarkably stable and regular behavior, a feature that is exploited in dealing with the source localization and tracking problem.

The modal behavior suggested by this spatial modal map is further elucidated by an examination of the spectral content of the field in the horizontal wavenumber domain. The wavenumber spectrum is obtained by applying an asymptotic Hankel transform to the measured pressure field as a function of source-receiver range. This process is equivalent to beam forming the complex pressure data obtained on the MOMAX synthetic aperture horizontal arrays. By implementing this operation over a succession of sub-apertures in range, the evolving spectral content of the modal field can be determined. Specifically, peaks in the modal spectrum appear at horizontal wavenumbers corresponding to the modal eigenvalues for the waveguide.

The procedure described above was applied to the 125 Hz data shown in Fig. 2 using an autoregressive (AR) spectral estimation technique. The resulting spectrograms for the cross-shelf and along-shelf sections of data are shown in Figs. 3 and 4, respectively. The behavior of the modal spectra is distinctly different in the two cases. In the cross-shelf case, there appear to be two dominant modes, with an increasing eigenvalue for the higher mode as a function of range and water depth at the source. The latter dependence on bathymetry is to be expected, at least for simple geoacoustic models of the seabed. On the other hand, the along-shelf spectrum appears to contain four dominant modes that are relatively stable with changing range. This behavior is consistent with the relatively constant water depth throughout this leg. The along-shelf spectrum exhibits a blurry character in the 8-9.5 km range that also appears in the cross-shelf spectrum in the 6-7.5 km range. This behavior may be due to an abrupt range-dependent feature in the bottom. Similar effects have been demonstrated on synthetic data for a hypothetical intrusion in the seabed with geoacoustic properties that are distinctly different from the surrounding media. On the other hand, lateral variability in the water column, due perhaps to the passage of an internal wave packet through the experimental area, is also under investigation as a possible explanation for the blurriness of the spectra.

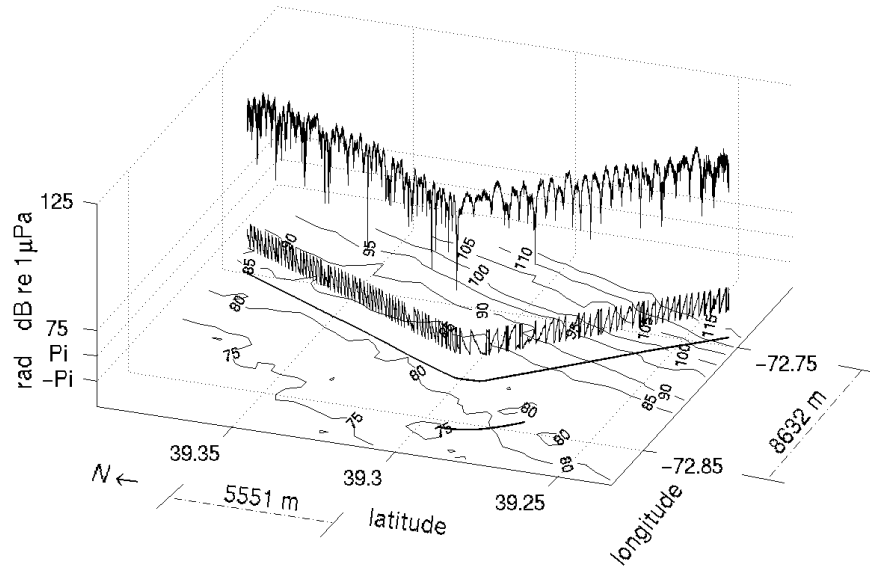


Figure 2: 125 Hz pressure magnitude (dB re 1 microPascal) and phase (rad) versus latitude and longitude (decimal degrees) for SWAT/MOMAX III Experiment 2. For visualization purposes, the measured phase has been reduced by the amount kr , where $k=0.476 \text{ m}^{-1}$ and r is source-receiver range. The long L-shaped track and the short curved path correspond to the source and receiver trajectories, respectively. Also shown is the water depth (m).

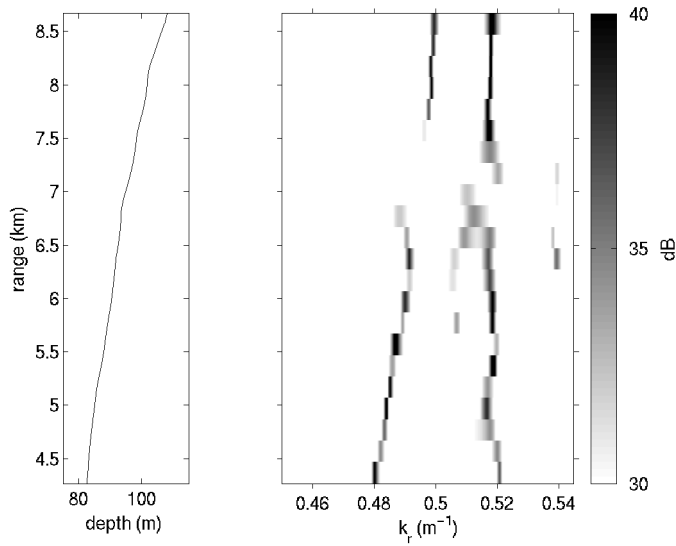


Figure 3: Horizontal wavenumber spectrogram for the southern (cross-shelf) portion of the source track shown in Fig. 2. An AR spectral estimator of order 166 was applied to a 1000 m sliding window in range with 800 m overlap between adjacent windows. The gray scale is proportional to the intensity (dB) of the corresponding spectral component. Also shown is the water depth at the source location versus source-receiver range to the center of the sliding window.

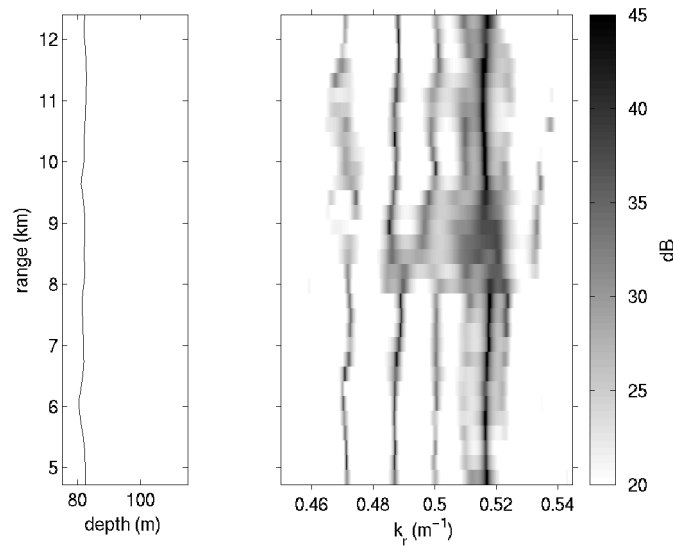


Figure 4: *Horizontal wavenumber spectrogram for the northern (along-shelf) portion of the source track shown in Fig 2. An AR spectral estimator of order 320 was applied to a 1920 m sliding window in range with 1680 m overlap between adjacent windows. The gray scale is proportional to the intensity (dB) of the corresponding spectral component. Also shown is the water depth at the source location versus source-receiver range to the center of the sliding window.*

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.

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