Modal Inversion SW06 Experiment

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LONG-TERM GOALS

Develop methods for rapid assessment of sediment properties relevant for acoustic propagation in a range-dependent shallow water environment

OBJECTIVES

Modal dispersion data i.e. mode arrival time as a function of frequency have been used in inversion schemes that estimate sediment properties in a range-independent environment. This method has now been extended to include range-dependent environment. Simulation studies show that range-dependent sediment properties can be extracted if modal dispersion data are obtained for multiple source/receiver locations. During the Shallow Water 2006 experiment data were collected to verify the feasibility of this approach. The inversion method based on mode dispersion data is one of the methods that can be used to estimate the sediment characteristics from modal data. The other method employs the modal eigenvalues as data. In the Shallow Water 2006 experiment effort was made to collect co-located data sets so as to perform inversions using both these techniques. The overlapping data sets will provide a direct means of comparison and validation of the two inversion approaches

APPROACH

In shallow water, the acoustic field can be represented as a sum of contributions from a set of propagating modes. It is well known that modal dispersion data contain information about the characteristics of the shallow water wave guide including the acoustic characteristics of the sediment. Inversion scheme that use the modal dispersion data for estimating sediment acoustic properties in a range independent environment has been described in the literature [1, 2]. This approach has been modified to determine the sediment properties in a range-dependent environment as outlined below.

Using perturbation analysis, the perturbation dt_n in the arrival time of mode *n* at the receiver due to perturbation in the compressional wave speed is given by

$$dt_n = \frac{\partial}{\partial\omega}\int_0^r \int_0^\infty \frac{1}{k_n(s,\omega)} \frac{\omega^2 \Delta c(s,z)}{c_b^3(s,z)\rho_b(s,z)} \left|\phi_n(s,z,\omega)\right|^2 ds dz \qquad (1)$$

where ω is the frequency of the acoustic source, $k_n(s, \omega)$ is the eigenvalue of the nth mode, $c_b(s,z)$ is the unperturbed compressional wave speed of the sediment, $\rho_b(s,z)$ is the density of the sediment, $\phi_n(s,z,\omega)$ is the mode function of the nth mode, *r* is the range to the receiver, $\Delta c(s,z)$ is the

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perturbation to the compressional wave speed and s and z represent the range and depth locations. The double integral can be changed into a double sum given below.

$$dt_n = \sum_{p=1}^{P}\sum_{q=1}^{Q} A(s_p, z_q)\Delta c(s_p, z_q) \tag{2}$$

This double sum can be reduced to a matrix equation and the equation solved to determine the quantity $\Delta c(s_p, z_q),\ p = 1,\cdots, P, q = 1,\cdots, Q$. In converting to the integral to a matrix equation we assumed the region is discretized in both range and depth. The argument s_p refers to the pth step in range and z_q refers to the qth step in depth.

It has been shown in [3] that range dependent sediment properties can be obtained when mode arrival data from multiple source/receiver combinations are available

MODAL INVERSE METHODS EXPERIMENT (MIME)

During 2006 a series of experiments were conducted in the general area of the Hudson Canyon off the coast of New Jersey. A major component of the experiment was Littoral Environment Acoustic Research (LEAR). One aspect of this initiative was Modal Inverse Methods Experiment (MIME). The objective of this part of the experiment was to validate modal inverse methods for the estimation of the sediment acoustic properties. Two approaches are available for estimating the sediment acoustic properties from modal data. In one approach the range-dependent acoustic properties are determined from the evolution of the eigenvalues of trapped modes in the shallow water waveguide. In the second approach, the mode arrival times are used estimating the range dependent sediment acoustic properties. The data for evaluating these two methods of geoacoustic inversion in a range-dependent environment were collected during the MIME part of the SW06 experiments. We now briefly describe the analysis of data and the estimation of the range-dependent sediment acoustic properties from mode dispersion data.

In order to obtain mode dispersion data broadband signals were transmitted using J-15 source. These sources have good response in the band of 50 Hz-600 Hz. Below 50 Hz the response falls off. Broadband signals (Linear frequency modulated signals) in the in band 40 Hz – 290 Hz were transmitted using the J-15 source. The signal duration was 0.5 second. The signaling scheme at each source location consisted of repeated transmission of the LFM signal. The signals were transmitted every 3 seconds and the total transmission time was approximately 12 minutes. This gave about 240 pings at each location. This scheme was adopted in the hope that considerable improvement in SNR will be obtained by summing over a number of pings.

The data were collected on a vertical array. In the case of the broadband experiment, it was proposed to collect data from a broadband source whose locations were approximately along two arcs. The sets of receivers used for both the broadband experiment were an array of 48 elements (16 element vertical array and a 32 element horizontal array) and 5 single hydrophone receiver units. The broadband transmissions were made on three days (Day 216, 217 and 218). The location of the broadband transmissions and the location of the receiver units are shown in Figure 1.

The data collected during the experiment are processed to determine the modal arrival time as a function of frequency. During the field experiment, it was not possible to synchronize the transmission of the broadband signal with the start of the data acquisition system. Hence absolute mode arrival times could not be determined. However the inversion method outlined in an earlier section was modified in which the data for the inversion were the difference in the arrival time of modes.

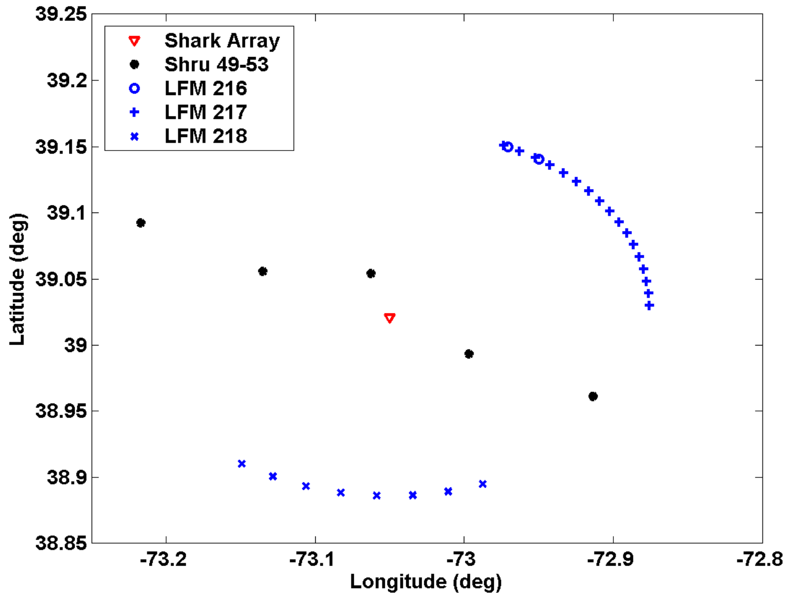

Figure 1. Location of receiver units and locations of broadband transmissions on days 216, 217 and 218.

During the course of the experiment, the sound speed structure in the water column was obtained using a CTD chain. The chain was towed by the ship that towed the source. The chain has 21 sensors distributed along the length of the chain. The elements of the chain make measurements of the temperature, conductivity and pressure every 2 seconds. The sound speed profile is computed from the values of the temperature, and conductivity at each sensor as a function of time. The sound speed profiles in the water column at different times on Day 217 are shown in Figure 2. In addition to the measuring the sound speed of the water column, the ships sub-bottom profiler was used to determine the bathymetry. The bathymetry in the area of the experiment is shown in Figure 3.

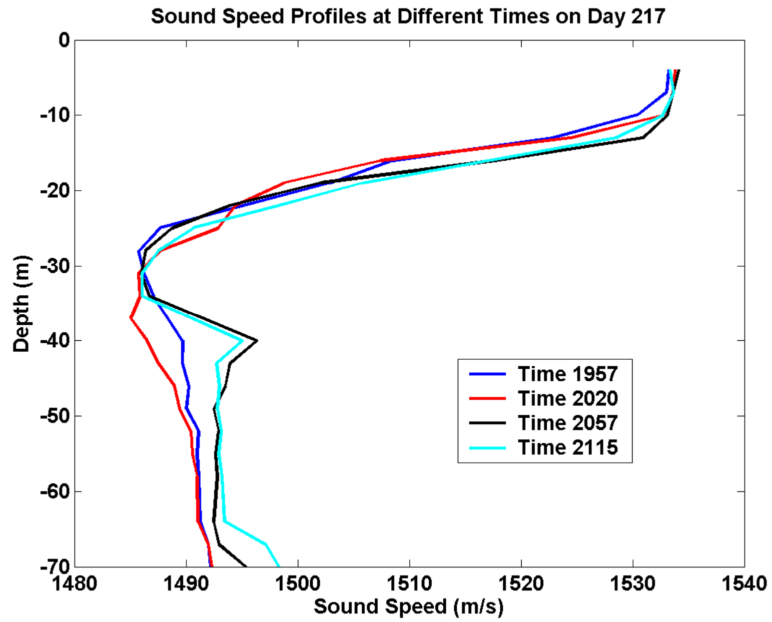

Figure 2. Sound speed profiles of the water column on day 217 taken at different times of the day.

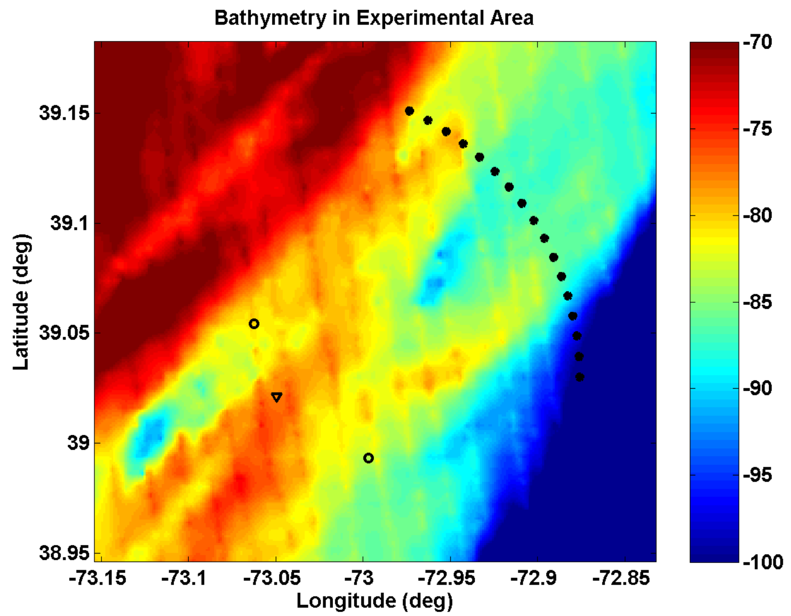

Figure 3. Bathymetry of the experimental area. The figure also shows the location of transmissions on Day 217 and the location of three receiver units (SHARK array, SHRU 51 and SHRU 53).

RESULTS

A. Estimation of arrival time differences

The first step in the estimation of the range-dependent sediment properties is the determination of the arrival times of the modes. This is done by the time-frequency analysis of the received signal. As indicated earlier broadband signals were transmitted on three days. In our analysis we have concentrated on data collected on Day 217. Though the data for Day 216 had good SNR, it was noted during the analysis that during the time of the transmissions strong internal wave activity was present in the region which affected the propagation of the modes and hence caused errors in the determination of the mode arrival structure. The data for Day 218 had low SNR and was corrupted by either transmissions during broadband transmissions.

The spectrum of the signal received at the single hydrophone receiver unit (SHRU 51) is shown in the left panel of Figure 4. The spectrum shows the multiple pings of the broadband signal. Each of these ping are then subjected to time-frequency analysis. We have adopted STFT (Short Time Fourier Transform) for performing the time-frequency analysis. The time-frequncy plot for one set of pings transmitted during Day 217 is shown in the right panel of Figure 4. The figure also indicates the arrival time at selected frequencies for modes 1, 2, and 3. Once these times are determined, the difference between arrival times of modes 1 and 2 at these frequencies are computed. Similarly the difference between the arrival time of modes 2 and 3 are determined. This is then the data used in the inversion of the sediment compressional wave speed.

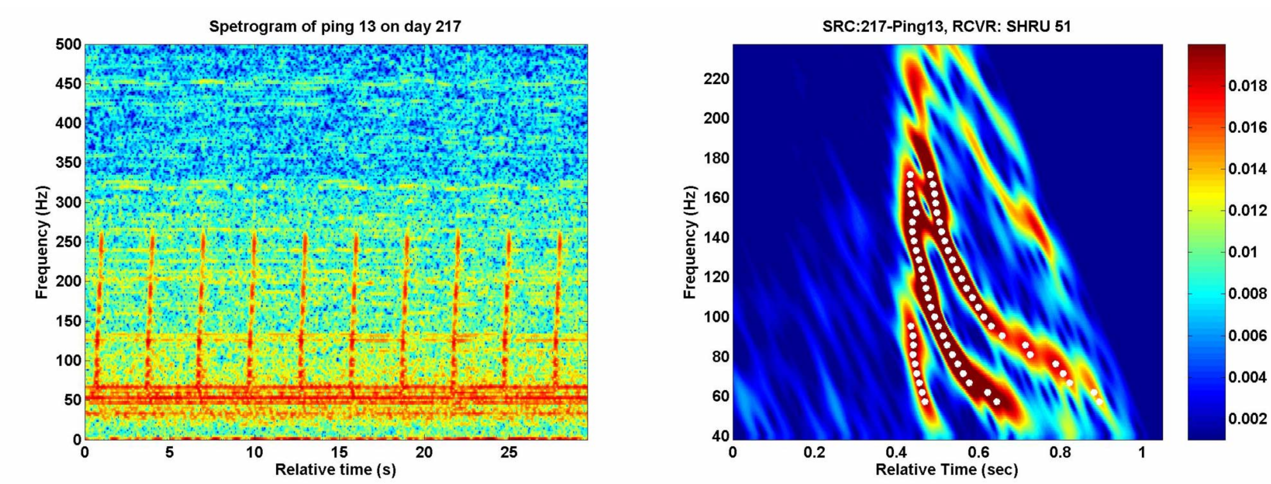

Figure 4. The left panel shows the spectrum of the received signal and the right panel the time frequency analysis of the pings.

B. Geo-acoustic Inversion

In order to determine the range-dependent compressional wave speed in the region between the source and receivers, the region was divided into six regions. Four shots locations and three receiver locations were used in the analysis giving a total of twelve source receiver combinations. The shot locations were Pings 13, 14, 15, and 16 of Day 217 and receiver locations were that of the shark array, SHRU 51 and SHRU 53. The division of the regions in to six regions together with the location of the pings and the receivers are shown in the left panel of Figure 5.

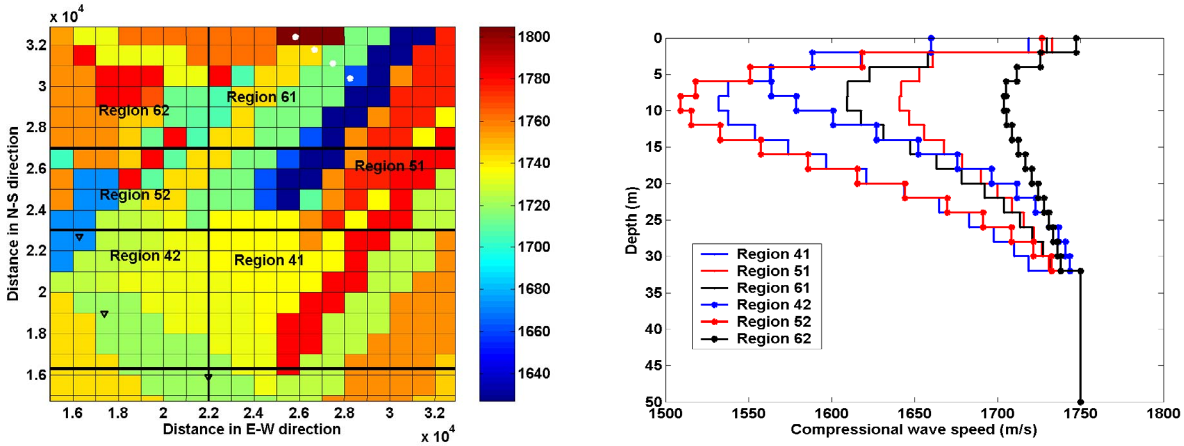

Figure 5. The left panel shows the six regions for which the compressional wave speed profiles were determined. The division into the six regions was loosely based on the surficial compressional wave speed which is also shown in the figure. The right panel shows the compressional wave speed profiles of the six regions estimated by inversion.

In performing the inversion, the sediment was assumed to be horizontally stratified. A total number of 16 layers with each layer thickness of 2 m was assumed. The only unknown was the compressional wave speed in the layer. The layers were terminated by a half space. The density in the layer was assumed to be 1.6 gm/cc and in the half space 1.8 gm/cc. The attenuation in the sediment layers were ignored. The sound speed structure in the water column was determined from the CTD chain data.

The range-dependent inversions were performed in stages. In the first step, using data received at SHRU 51, the wave speed profile in Region 41, 51, and 61 were obtained. Then using data from SHRU 53, the profiles for Regions 52 and 62 were obtained. Finally using data from SHARK array the profile for Region 42 was determined.

The compressional wave speed profiles for the six regions are shown in the right panel of Figure 5. It is noted that the profiles have similar general structure except for the Region 62.

C. Validation of the results

As a first step in validating the results we compare in the left panel of Figure 6 the difference in mode arrival times as obtained from the experiment with the values given by the model. We note that there is general agreement between the experimental values and the model predictions. This is not surprising as the inverse method minimizes the difference between the experimentally determined mode difference times and the values predicted by the model.

The right panel of Figure 6 is taken from Reference 4 shows the general structure of compressional wave speed profile in the area of the Shallow Water Experiment 2006. This is based on core and chirp data collected by various investigators to determine the sediment characteristics in the New Jersey shelf. The compressional wave speed structure has the general character of decreasing from a high intial value to a minimum at a depth of 6 m and then increases generally with depth. The inversion results also exhibit a similar structure.

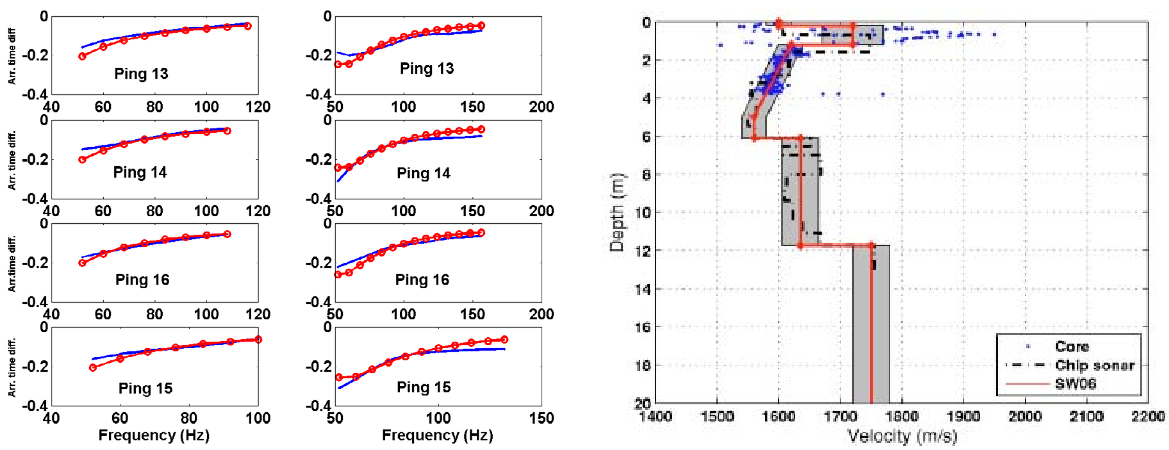

Figure 6. The left panel shows the difference in the arrival time of modes as determined from data and the values obtained using the environmental model obtained from inversion. The blue line is the experimental values and the red dots are the model predictions. This is for the transmissions to SHRU 53. Similar agreements were obtained for transmissions to SHRU 51 and SHARK. The right panel is sediment compressional wave speed obtained from core, chirp sonar and other sources of information and is from Reference 4. The feature to note is the decrease in the compressional wave speed with depth reaching the minimum around 6 m depth and then increasing with depth. These features are are also seen in the inverted profiles for different regions as shown in Figure 5.

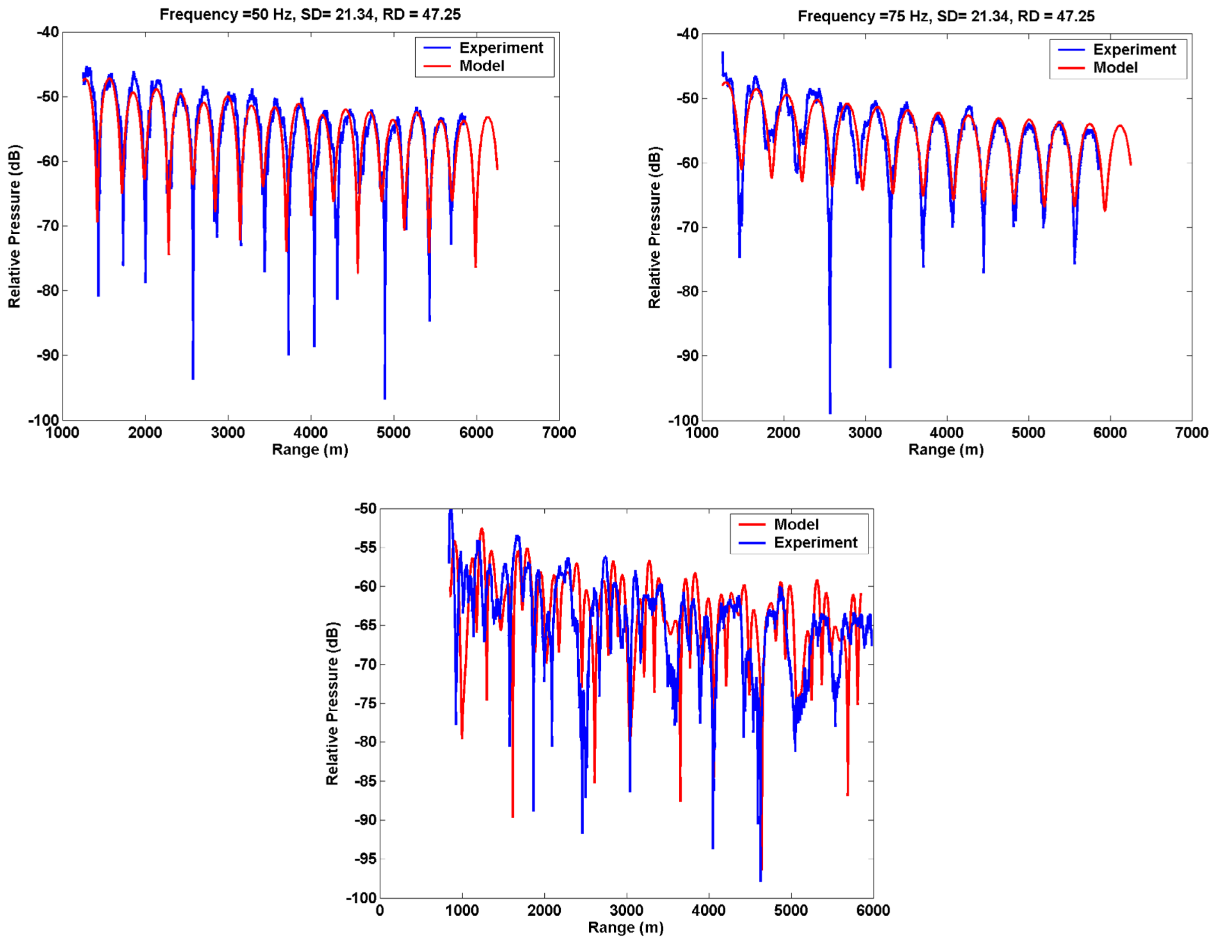

Figure 7. The top left panel shows the pressure field determined during the narrow bansd experiment and the field predicted by the model using the compressional wave speed profile for region 42. This is for 50 Hz data. Similar comparison is done for 75 Hz data (top right panel) and 125 Hz data (bottom middle panel).

During the MIME experiment narrowband experiment was also conducted. In this part of the experiment the acoustic pressure field was measured as a function of range on a number of tracks. These measurements were made in a number of frequencies. One of the tracks of this experiment was in Region 42 of Figure 5. We therefore investigate the ability of the model obtained for Region 42 to predict the field measured during the narrow band experiment. The comparisons are shown in Figure 7 which shows good agreement at frequencies 50 Hz and 75 Hz. At 125 Hz the agreement is not quite so good. This is because the inversions used only data from modes 1, 2, and 3. Data from higher order modes could not be used as they decay faster with range. At higher frequencies the lower modes decay rapidly with depth into the sediment and therefore do not contribute towards estimation of the sediment properties.

IMPACT/APPLICATIONS

The data collected during this experiment will enable validation of the proposed method for estimating range-dependent sediment compressional wave speed from modal dispersion data. Using a distributed set of receivers and a moving broadband source it will be possible to estimate the compressional wave speed profiles over a wide area. This will therefore be a useful tool for rapid environment assessment.

RELATED PROJECTS

A number of investigators were involved in the SW06 experiment. The analysis of their data will also lead to estimation of sediment properties. A direct comparison between the different inversion methods can therefore be done. Extensive environmental measurements taken during the experiment will help in assessing the impact of variability in water column characteristics.

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