Long Range Sediment Tomography

James H. Miller
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02881
Phone (401) 874-6540 fax (401) 874-6837 email miller@uri.edu

Gopu R. Potty
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02881
Phone (401) 874-6540 fax (401) 874-6837 email potty@uri.edu

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LONG-TERM GOALS

Our long-term objective is to develop an inversion scheme for the estimation of acoustic properties of sediments in shallow water at long range using broadband explosive sources.

OBJECTIVES

- Analysis of the shot data collected during the ASIAEX experiment in the East China Sea (ECS) in 2001 for inversions of bottom properties. Validate the inversion with other measurements in the region including gravity cores, chirp sonar, etc.
- Quantify the resolution and accuracy of the inversions.
- Investigate the potential of this method for other shallow water areas as a rapid environmental assessment tool. Optimum source frequencies and ranges will be studied using synthetic test cases.
- Develop advanced signal processing techniques which will enhance our ability to identify and extract modal arrival times. These techniques include matching pursuit algorithms and time-frequency-space-mode processing of vertical line array data.
- Develop efficient methods to integrate geophysical data into geoacoustic models. This effort will also be pursued simultaneously through another ONR sponsored study (ESME program).

APPROACH

Studies to develop a sediment tomography technique using broadband sources started with the Shelfbreak Primer Experiment of 1996- 1997. An inversion scheme was developed using the explosive data collected on vertical line arrays over distances of approximately 40 km. This inversion scheme was based on matching the arrival times of individual modes. Advanced time frequency analysis techniques and global search algorithms aided in developing a robust technique for long-range sediment tomography. The successful implementation of this technique is documented in a number of publications (Potty et al.[1,2,3]).

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The sediment tomography technique estimates the compressional wave speeds as a function of depth in a range independent, single source-single receiver scenario. Using multiple sources and using adiabatic approximation it is also possible to estimate the compressional wave speed as a function of range. Our goal is to develop this technique into a robust 3-D sediment mapping tool. In addition to the compressional wave speed we have been able to estimate the compressional attenuation also using spectral ratios measured from the time frequency scalograms (Potty et al.[2]).

Using the insight gained from the Primer experience we applied this technique in a different environment as part of the ASIAEX experiment. The East China Sea (ECS) test site was different from the Primer site (New England Bight) in terms of the type of sediments and their spatial distribution. Additionally we had to deal with lower signal to noise ratios due to a lower charge weight. On the whole the ECS experiment offered a different kind of challenge compared to the Primer experiment. We were able to collect good quality data which has been analyzed and inverted. Most of the data we have analyzed were collected on the APL- URI data acquisition system and the results are being documented. As an improvement to our traditional tomography technique Lazauski[4] utilized data in the neighborhood of the Airy phase and noticed that the Airy phase arrivals are very sensitive to sediment properties. The ASIAEX data analysis is ongoing and we are now concentrating on attenuation inversions.

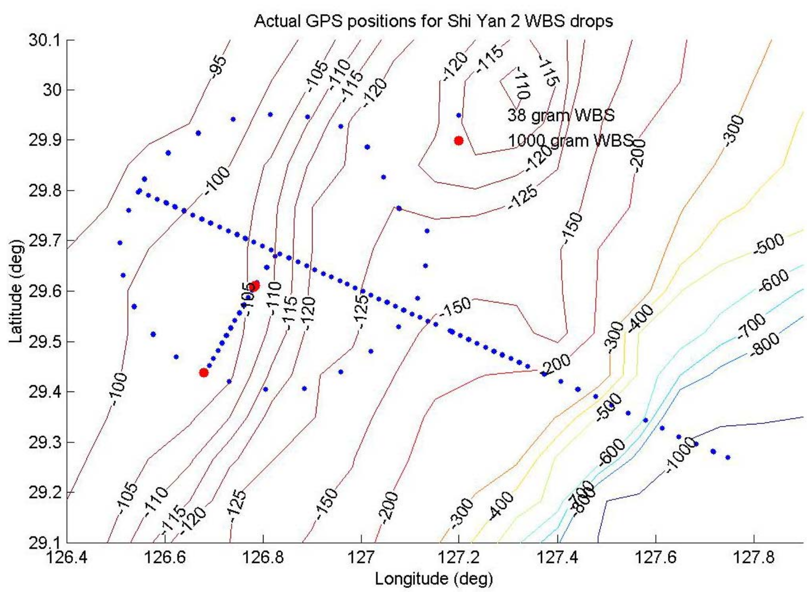

Figure 1. Locations of the WBS deployments. The bathymetry at the location is also shown. The VLA was deployed from R/V Melville which was stationed at the center of the circular pattern of WBS deployment. (Miller et al.[5])

WORK COMPLETED

The design and implementation of the experiment has been successfully completed in May-June 2001. The APL/UW vertical line array, consisting of 16 hydrophones and the URI data acquisition system were used to acquire the data. The VLA was deployed from R/V Melville and the explosives were deployed from the Chinese research vessel Shi Yan 2. Over 200 shots of weights 38 g and 1000 g were deployed for reverberation and propagation studies. The locations of these shots were recorded using a handheld GPS. The recorded locations of the SUS charges are shown in Figure 1. These shots were set to explode at a depth of 50 m but we expect some variation in the source depths.

Acoustic arrivals on the vertical line array from all the shots have been identified and extracted. The time-frequency analysis of these signals using wavelet-based method has been completed. The dispersion of the modal arrivals can be observed from these time-frequency scalograms. The arrival times corresponding to various modes form the basis for our inversion scheme. We are also exploring various methods to efficiently and accurately extract the modal arrival times from the time-frequency diagrams using image processing techniques.

Another short cruise aboard the Taiwanese research vessel OR2 with Korean and URI scientists was conducted in August, 2001. Cores were taken at selected locations during this cruise to augment the sediment property information. This core data will provide sediment compressional speeds and attenuation for comparison and validation of the inversions.

RESULTS

Inversion for compressional wave speed is carried out with two different objectives. In the first approach acoustic signals from a single charge is used to invert for a depth dependent compressional wave speed profile assuming range dependence. In the second approach we treat only the compressional wave speed in the surface layer as unknown. The mean compressional wave speed of sediment below the first layer obtained from the first approach is used for the second layer. But in this approach we look for surficial sediment speeds at a number of locations using a few adjacent charges. Potty and Miller[3] has discussed this approach. This inversion approach produces a map of surface sediment compressional wave speed whereas the first approach produces a sediment compressional wave speed profile.

The arrival times obtained from the time-frequency diagrams were used as data for the inversion scheme. The sediment model for the inversion of depth dependent compressional wave speed consists of three layers of sediment and a basement. The compressional wave speed in these layers and layer thicknesses are the primary unknowns in the inversions. In the first layer the compressional wave speeds at the top and bottom are considered unknowns. In addition the water depth, EOF coefficients and range are also considered as unknowns.
The sediment tomography technique using the hybrid approach inverts for the compressional wave speed profile (left panel in Figure 2). The compressional wave speed increases from 1590 m/s to 1660 m/s in the top layer which is approximately 1-2 m thick. The second layer is nearly 2 m thick having a higher compressional speed of approximately 1660 m/s. The compressional wave speed reduces to 1620 m/s in the next layer which is 20 m thick. In the basement the compressional wave speed in approximately 1670 m/s. The *a posteriori* analysis provides the standard deviations as shown in the right panel of Figure 3. Note that the standard deviation is comparatively high (40 m/s) in the depth range 0- 2 m. It reduces to 5 m/s for the next 25 m. The standard deviation is 15 m/s in the basement layer. Based on this we expect maximum improvement in the top 5 m when the local method is applied to the GA inversion. Gravity and piston core data along the propagation path show good agreement with the inversion (right panel in Figure 2). The compressional wave speeds are in the range 1600 m/s to 1675 m/s in the top 1 m of the sediment.

The surficial sediments at the experimental location show some spatial variability. Sediments in the south-east side of the experimental area have a higher compressional wave speed whereas in the north-west side they are slower. This was previously observed by Niino and Emery[6]. The gravity core data also show a similar trend (Miller et al.[5]). We have carried out inversions using WBS signals from charges in the north-east half of the circle. The bathymetry in this area in gently sloping compared to the lower half. The compressional wave speeds obtained from the inversions were used to represent the compressional wave speed contours as shown in the right panel in Figure 4. The inversion values are higher than the gravity core values. But the spatial variation of compressional wave speed values shows the same trend as gravity core data and historic sediment data by Niino and Emery[6].

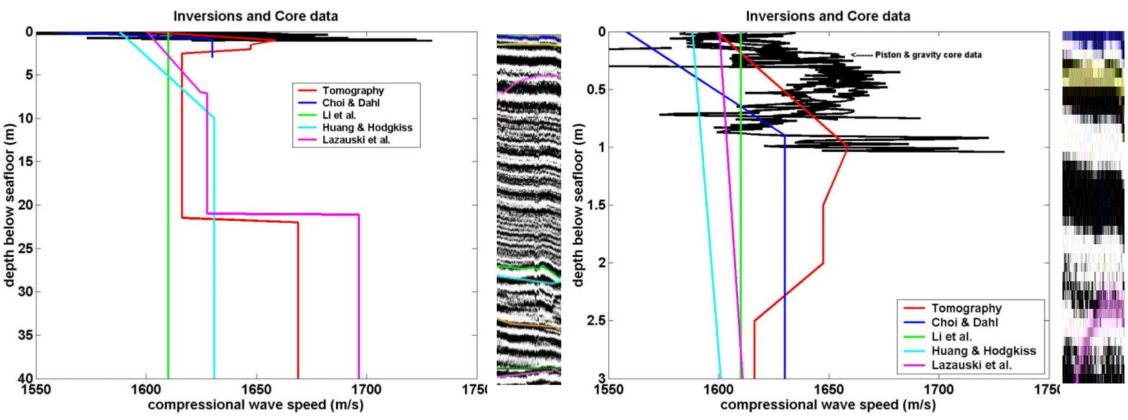

Figure 2. Compressional wave speeds obtained using the hybrid method for the top 40 m and 3 m of the sediment are shown in the left and right panels respectively. The tomography inversions are compared with other inversions. The seismic profiles are also shown along with the inversions. (Miller et al.[5])

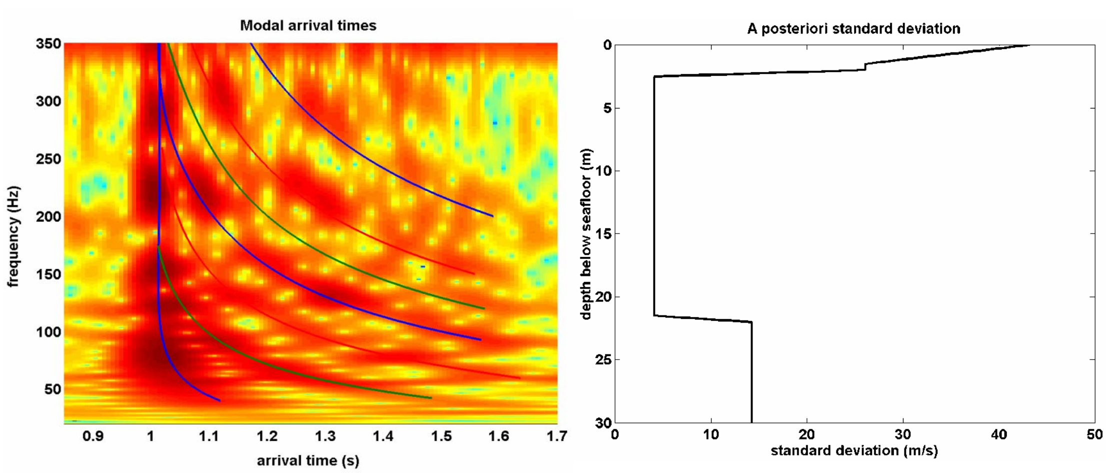

Figure 3. Modal arrival times for modes 1 to 6 and mode 8. The continuous lines are the theoretical curves computed using normal mode theory. The right panel shows the standard deviation calculated from the a posteriori analysis. (Potty et al.[8])

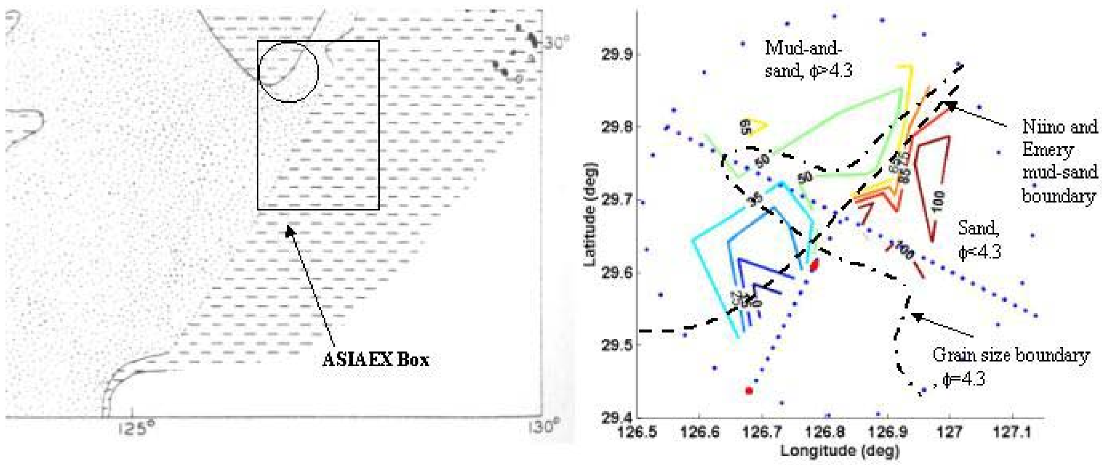

Figure 4. Compressional wave speeds of surface sediments obtained from the tomographic inversions. Contour lines and labels correspond to speeds above 1600 m/s. The values show spatial variations similar to the grain size analysis of the cores. The dashed line indicates the Niino and Emery mud-sand boundary (left panel). The dashed-dot line indicates the general boundary between sediments with grain sizes less than and greater than 4.3. (Miller et al.[5]).

IMPACT/APPLICATIONS

This inversion scheme using explosive sources is suitable for rapid estimation of acoustic properties of sediments in shallow water. This method is cost effective as a single sonobuoy and air-deployed explosives can provide the data. Using multiple sources and receivers sediment properties would allow an area to be mapped.

TRANSITIONS

The sediment parameters obtained by this inversion can be used for the forward modeling efforts at East China Sea. Our technique is suitable for forward force deployment when rapid assessment of environmental characteristics is necessary. In addition to naval air ASW applications using sonobuoys and SUS charges, this technique would be compatible with Navy special operations involving autonomous vehicles. In that scenario, the vehicle could drop a small timed charge and receive the acoustic signals at a distance. This would allow the sediment properties to be estimated in the area.

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