HIGH RESOLUTION FOCUSING ANALYSIS AND INVERSION FOR SMALL SCATTERER DETECTION

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LONG-TERM GOAL

The long-term goal of this project is to develop software to invert acoustic data from a towed source/receiver array for simultaneous velocity analysis, detection and material characterization of small scale (7 to 15 cm) scatterers in the shallow ocean and seabed sediments. Detection will be achieved by providing a reflector map of the target region. Material characterization is provided through estimates of angularly dependent reflection coefficients at the surface of the target over multiple angles; angle versus offset analysis provides a basis for characterizing the internal material parameters of the target.

SCIENTIFIC AND TECHNOLOGICAL OBJECTIVES

(i) Develop code to provide an accurate three dimensional image of small scatterers in a seabed whose propagation parameters may have lateral as well as depth-dependent variation. (ii) Such code should provide sufficiently accurate amplitude information about reflection coefficients that medium characterization aspect of the theory through estimation of its acoustic (elastic) parameters can be applied here.   (iii) Develop the necessary theory and computer code for velocity analysis for this problem under parallel support of the Mathematics Branch of ONR and other related research at the Center for Wave Phenomena.

APPROACH

Our method produces an output at each point as a sum over all source/receiver pairs in the survey. Data is accessed at the travel time consistent with propagation from source to output point to receiver in some model of background propagation. The weighting of each contribution to this sum is derived from an inversion theory that relates the peak amplitude of the output to the angularly dependent reflection coefficient for the specular source/receiver pair. A second processing algorithm, differing from the first by only one factor, allows identification of the incidence angle for that specular reflection coefficient. Processing "many" offsets provides multiple reflection-coefficient/incidence-angle pairs for each position, from which one can estimate the change in medium parameters across the reflecting surface(s). We also have a formalism that uses the disagreement between the images from the many-offset-outputs to update the background velocity; this is velocity analysis. Development of the theory and implementation of velocity analysis is being

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carried out under support of the ONR Mathematics Program and also with a visiting scholar supported by Amoco of Norway.

WORK COMPLETED

Under this research program, we first adapted our seismic inversion algorithm---designed to process single lines of data to produce two-dimensional images---to the length and time scales of the problem of interest here and we processed synthetic data for a 7.5cm radius cylindrical scatterer on a flat seabed at 10m depth. We then developed a 3D code (3DVZ) that processes towed array data to produce a reflector map of the near ocean bottom, including the small target reflectors we seek. That code allowed for only 1D variation in the background propagation speed *v(z)*. We also demonstrated through synthetic data tests that the code produces accurate amplitudes---reflection coefficients. The task of testing that code was taken up by another student. In the context of those tests, she also analyzed techniques to reduce noise in the image arising from noise in the original data. That project has been completed earlier this year.

Currently, we are developing an inversion code that will allow for 3D variation in the background propagation speed. This requires computer construction of 3D physical models and attendant visualization (done, partially supported by ONR Math), 3D ray tracing and wavefront construction (in progress, partially supported by ONR Math), and 3D generation of amplitudes for the necessary constituent Green's functions of the processing algorithm (current research).

RESULTS

The testing of 3DVZ revealed some minor bugs and limitations that have now been eliminated. That code is ready for distribution. The results of the noise analysis were surprising and contradict conventional wisdom. Processors tend to keep all of the data, process it, and then apply noise reduction techniques to the output, attempting to eliminate noise in the image. We found that this was the least desirable of three options that we tested. In the first option, the output data are smoothed with a simple Gaussian filter; this represents conventional noise reduction processing. In the second option, we deferred a differentiation operation on the input data that is part of the processing formalism. We then used a technique developed earlier under ONR Math support to apply a differentiator and smoother to the output. Differentiators in space usually have a preferred direction or lose sign information about the amplitude. . A significant feature of our technique is that it overcomes both of these shortcomings, producing a normal derivative everywhere, even though the normal directions of the reflector surfaces are not known *a priori*. In the third option, we apply the Gaussian smoothing filter directly to the input data, thereby "losing" information, according to conventional wisdom.

We found that either of the latter options provides results that are superior to the convential noise suppression techniques of the first option while preserving amplitude information for medium characterization. The accompanying figure shows output from filtered noisy data, with filters applied in the order described here; the relative quality is as described.

IMPACT/APPLICATIONS

We provide a bridge between the ocean acoustics community and the exploration geophysics community, through our oil industry consortium of thirty- four companies. The former has access to extremely sophisticated sources and receivers for data collection of the sort required to detect scatterers in shallow water. The latter has a long tradition of processing data to produce reflector maps. Our methods have made a significant contribution to the imaging and interpretation methods of that latter community.

TRANSITIONS

Our free software becomes part of a package called SU---Seismic Un*x, which is a research platform available through ftp and advertised on our web site and in a recent article in The Leading Edge, the news magazine of the Society of Exploration Geophysicists. This package has now been downloaded at more than 1300 sites in 44 countries. SU allows groups with lesser resources than ours to have access to a whole suite of programs (more than 200) that allow the user to analyze and process data sets. The application is much broader than ocean acoustics or seismic exploration: the users cover a wide spectrum of imaging and data analysis technologies. The significant codes we develop under ONR support are integrated into SU.

RELATED PROJECTS

The Center for Wave Phenomena Consortium Project. 35 oil companies and related service companies, supporting research in seismic data processing, imaging and inversion.

ONR Mathematics Branch. The Application of Inverse Methods to the Ocean Environment.

ACTI: The Advanced Compuational Initiative Program of DOE. One project with Los Alamos National Laboratory and one project with Lawrence Livermore National Laboratory. (This PI is a co-PI on the former project.) The main thrust of these projects is data processing and imaging in anisotropic elastic media. The subject of my work in the first project is *data mapping*, tranforming data gathered in one source/receiver configuration and transforming it to data that might have been received in a different source/receiver configuration. This is a method to analyze and reduce the enormous size of seismic data sets while retaining important amplitude information of the original.
The Center for Wave Phenomena consists of five faculty members, two in Math, Martin de Hoop and me, three in Geophysics, Kenneth L. Larner (Cecil and Ida Greene Professor), John Scales, Ilya Tsvankin, with 16 graduate students (on average) and four staff. The funding level is over $1.8million per year, with additional funding coming in the form of

grants from the oil industry, the Gas Research Institute and the Society of Exploration Geophysicists.

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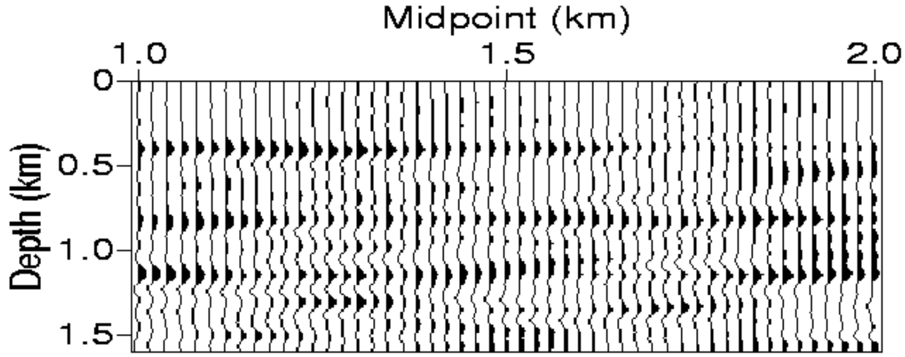
Web site: http://www.cwp.mines.edu. Papers, paper lists, instructions for accessing free software, free lecture notes, information about the Center for Wave Phenomena. This site averages 10,000 hits per week from people outside of CWP. The related site for Samizdat Press (lecture notes) experiences an additional 10,000 hits per week. Statistics available at the sites.



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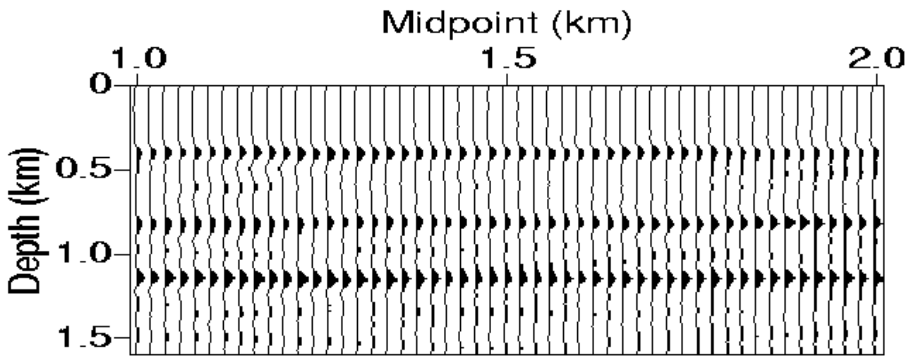

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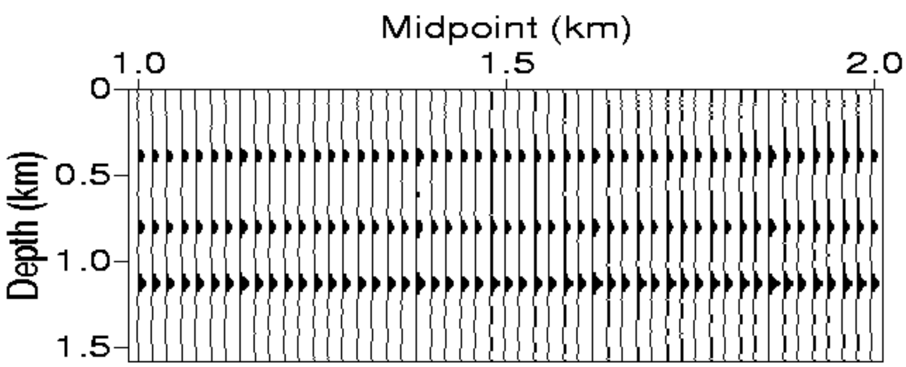

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