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.

OBJECTIVES

The immediate objective is to complete the development of a computer code for towed array data that back propagates the data with a wavespeed that varies in all three spatial variables. The more long-term objectives are to continue to incorporate developments in the underlying theory into the software being developed for this application. For example, the theory is currently being extended to *multi-pathing* --- the case in which the ray trajectories from a point scatterer at depth form caustics in the subsurface, leading to multiple arrivals at the same observation point on the receiver array.

APPROACH

The particular experiment that is proposed requires the acquisition of acoustic responses along a towed array (about 10m) of sonophones from a single point source. The experiment is to be repeated on a regular near-surface areal grid. Our methods are based on a high frequency asymptotic inversion technique that is called *Kirchhoff inversion.* This method back projects the observed data through integration (summation) over diffraction traveltime curves that pick out the observed data on different traces at the indicated traveltimes. The distinctive feature of our approach is that we obtain an estimate of the specular reflection coefficient and specular incidence angle from the peak amplitude(s) of the output. These estimates are model (back-projection wavespeed) consistent and require amplitude control of the source signature. On other scales, this method has achieved great success in seismic exploration, with lengths two-to-three orders of magnitude higher- and frequencies, correspondingly, two-to-three orders of magnitude lower- than those used for the experiments here.

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WORK COMPLETED

We have previously delivered software to process such data under the assumption that the shallow water and seabed environment was a medium with a wavespeed that was only depth dependence. We are currently developing software to process data under the assumption of a more general spatial dependence of the wavespeed. For this case, the first challenge was to develop forward modeling software that produced sufficiently accurate amplitudes as well as traveltimes in the forward propagating direction. An additional constraint for implementation is that the CPU time for forward modeling should be acceptable. We currently have a working code for smoothed wavespeed models.

RESULTS

The enclosed figure provides a demonstration of the current computer code. The medium consisted of a low velocity spherical inclusion in an otherwise monotonically increasing wavespeed profile. The upper left panel of the figure shows the color-coded wavespeed in both a vertical and horizontal slice through the center of the model. The upper right panel shows the geometrical optics rays in the vertical slice. The caustics and multi-pathing alluded to above are clearly visible here. The rays are color coded according to traveltime. It can be seen here that the rays that pass outside the lens penetrate deeper than the rays that pass through the sphere. The density of rays is also an indication of relative amplitude. The lower panels show the amplitude and confirm this: the left panel shows the amplitudes of the first arrivals and the right panel shows the amplitude of the most energetic arrival. The figures are seen to differ largely in the region below the on-axis point caustic. The program has been tested on much more complex models, included the DOE/SEG saltdome model and has been proven to be competitive and even more accurate than some commercially available software.

IMPACT/APPLICATION

Inversion of towed array data under the assumption of a fully inhomogeneous background wavespeed has resided in commercial processing companies servicing the oil industry and in the oil industry, itself. We know from our connections to the oil industry that the forward modeling program that we are developing is competitive with modeling programs available in the industry. Such forward modeling programs are the linchpins on which one builds a corresponding inversion code. Thus, we are developing code that will be generally available as free software through the Center for Wave Phenomena web site. We are aware of industrial codes available in the industry that have the imaging capability of the code that we are developing, but do not have the parameter estimation capability of our code.

TRANSITIONS

Our ties to the oil industry through a consortium of 36 companies provide a direct line for technology transfer and prompt and extensive testing our science and its computer implementation. We know that our methods have led to industry-standard codes for processing seismic exploration data to aid in the identification of fluid traps in the Earth. Confirmation of the efficacy of our methods comes through annual renewal by our sponsors.

RELATED PROJECTS

In this program, we assume that the background wavespeed is known. Under other ONR support, we are developing a three dimensional *migration velocity analysis* method to help determine that background wavespeed. Also, there are standard preprocessing techniques designed to reduce the size and complexity of the data as well as to carry out preliminary analysis in advance of full 3D data processing. We have found that many of those methods fall in a single category that we call data mapping. This is a technique for transforming data from an input source/receiver configuration and presumed background earth model to a different source/receiver configuration and, possibly, a different earth model. This research was initiated under the now-defunct ACTIIDOE program. It is continuing under oil industry support through our consortium project. We are developing a theory that we call *Kirchhoff data mapping* (KDM). We have a general platform for this process and have developed implementations in the following list, with applicability and limitations as further implied by the titles in the references, below.

1. Mapping of data gathered at finite, fixed offset (common offset, bistatic) between source and receiver to zero offset (monostatic) data.
2. Downward continuation of receivers (or sources).
3. Mapping of common offset data to common shot data. This output, here provides synthetic data as if the receiver array were as long as the entire survey, rather than as long as the given towed array.

Other implementations are under development at this time. At the recent (September, 1998) International Meeting of the Society of Exploration Geophysicists in New Orleans, my students and I made six presentations on KDM, of which I was sole author of two and co-author of the other four. In spite of an above average number of subn-tissions to this meeting, requiring a higher level of rejections than is usual, all six of these presentations were accepted. I view this as a measure of the high level of interest in this subject in the industry.

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Sheaffer, **S.,** and Bleistein, N., 1998, 2.5D downward continuation using data mapping theory: Center for Wave Phenomena Research Report number CWP-270, in 1998 Project Review, CWP-283.

Wang, L., and Bleistein, N., 1998, 3D multi-valued traveltime and amplitude maps: Center for Wave Phenomena Research Report number CWP-278, in 1998 Project Review, CWP-283.

The following are presentations made at the 68 th International Meeting of the Society of Exploration Geophysicists, New Orleans, September 1998. All appear in the Expanded Abstracts on the indicated pages.

N. Bleistein, True amplitude 3D constant background DMO - an implementation of data mapping: 1760-1763.

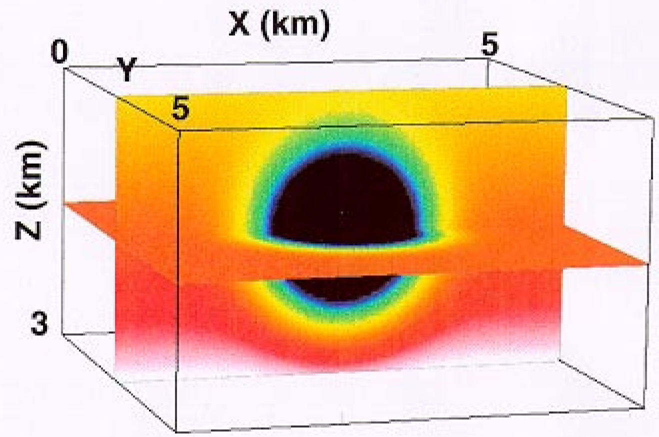
N. Bleistein, 2.5D data mappings: 1353-1356.

N. Bleistein and H. Jaramillo, A platform for data mapping in scalar models of data acquisition: 1588-1591.

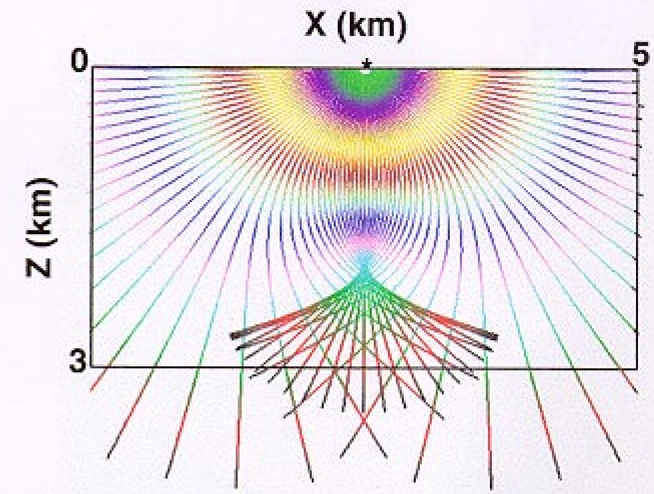
H. Jaramillo and N. Bleistein, Seismic data mapping: 1991-1994.

S. Sheaffer and N. Bleistein, 2.5D downward continuation using data mapping theory: 1554-1557.

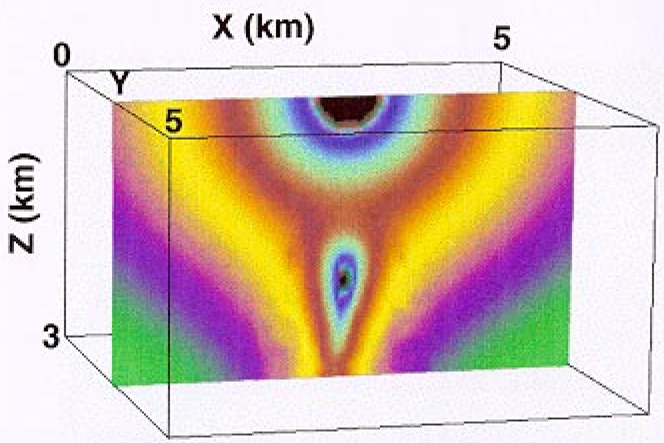
L. Wang and N. Bleistein, 3D multi-valued traveltime and amplitude maps: 1879-1882.



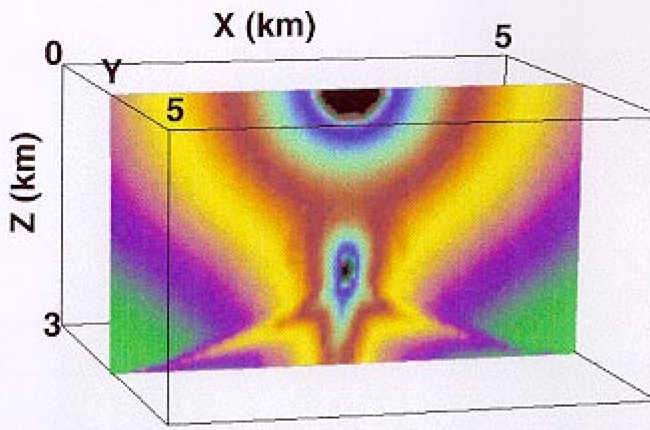
(a) Lens model.



(b) Rays in lens model.



(c) Amplitude of first arrivals.



(d) Amplitude of most energetic arrivals.