Inversions for Geoacoustic and Geometric Parameters Using a Full-wave, Range-dependent Forward Modeling Technique

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Inversion of acoustic field data using a range-dependent, full-wave forward modeling technique and matched-field processing (MFP) is considered. Data examined were collected as part of the Matched Field (MF) tomography component of the Haro Strait PRIMER Experiment of June/July 1996[1]. Solutions to a discrete forward model parameter vector, $\mathbf{m} = m_j$ for $j = 1..., M$, are sought where each element of $\mathbf{m}$ is bounded and is either a geoacoustic or a geometric parameter. Assuming a bottom consisting of two homogeneous layers, parameters of interest are source depth, sediment compressional sound speed, sediment density, basement compressional sound speed, and basement density. Multiple iterations of the forward model seek to minimize the discrepancy between discrete sampling of synthetic, $q(\mathbf{m}, t)$, and measured, $p(t+\tau)$, waveforms through an objective function, $E(\mathbf{m})$ where

$$E(\mathbf{m}) = 1 - \frac{\sum_{i=1}^{N} max_{\tau_i} \int q_i(\mathbf{m}, t) p_i(t + \tau_i) dt}{\left(\sum_{i=1}^{N} \int q_i^2(\mathbf{m}, t) dt\right)^{1/2} \left(\sum_{i=1}^{N} \int p_i^2(t) dt\right)^{1/2}}.$$

With absolute travel time being difficult to measure, relative, discrete time histories of s and q are compared by finding the offset, τ, which gives the smallest E. The use of broadband, range-dependent forward models has long been considered computationally inefficient in inversion methods where thousands of runs must be done to accurately sample the parameter space.

Two trends have expedited this process to the point where inversions can be accomplished for $j \sim 5 - 10$ in a reasonable amount of time. Synthetic waveforms are constructed using broadband split-step (FFT) parabolic equation runs and the c_o insensitive propagator which gives full second-order accuracy [4,5]. These simulations are computationally intensive as the sampling in depth and range must be fine enough to account for wide-angle propagation and the number of individual frequency runs must be large enough to accurately match the experimental source shape. Advancements in computer processing speed and memory size are rapidly occuring. For example, two thousand forward simulations in the Haro Strait environment takes two to three days on a 128 Mhz processor but can now be done overnight on a 512 Mhz processor. The second improvement involves the efficiency of inversion techniques. The latest hybrid inversion techniques combining global and local inversion techniques dramatically reduce computation time[3]. The simplex simulated annealing method of Fallat and Dosso[3] is used in this study.

The use of full-wave, range-dependent modeling is examined for two reasons. First, inverting real data to converge on a unique solution for $\mathbf{m}$ is inherently difficult due to noise, receiver array location uncertainty, and model simplifications in approximating the natural environment. The more data used during the inversion, the more accurate the estimation of $\mathbf{m}$. Therefore, we examine broadband MFP where simulations are done for many frequencies and the simulated wavefield is matched to the entire receiver array domain in relative travel time and depth. Comparisons are made to previous studies such as Chapman et. al. [2] for evidence of a decrease in ambiguity manifested by a reduction in the number of local minima in $E(\mathbf{m})$ and a decrease in sensitivity to correlation between parameters. Second, full-wave, range-dependent modeling allows for inversion studies in more complex environments where bathymetry or range-dependent water sound speed structure are observed. The complex bathymetry of the Haro Strait environment conducted just off of Stuart Island in Washington State is ideal. The MF tomography component of the experiment involved a grid network of light bulb sources with center frequency of 600 Hz and an overlapping grid network of vertical arrays such that each transmission was roughly 0.5 to 3.0 km.

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