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A COMPARISON OF TIME-DOMAIN PARABOLIC EQUATION AND MEASURED OCEAN IMPULSE RESPONSES

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ABSTRACT

The time-domain parabolic equation (TDPE) model is shown to accurately model measured ocean impulse responses in a near-field shallow water ocean environment. Ocean impulse response functions are measured by cross correlating the source signature of a 20 to 150 Hz swept frequency signal with the signals received on a vertical line array. The autocorrelation of the swept signal is the input source pulse for TDPE. Ocean-bottom parameters are developed from Deep Sea Drilling Project sites near the experimental area. The capability of TDPE to model high-angle (70°–75°) multipath propagation is established. TDPE results are compared to results from the fast field algorithm, SAFARI.

INTRODUCTION

The time-domain parabolic equation (TDPE) model, developed by Collins,[1-4] is a broadband, range- dependent, acoustic propagation code. TDPE has the capability of modeling high-angle acoustic propagation and of accounting for attenuation in sediments, which are advances over an earlier time-domain formulation of PE.[5] The high-angle capability is achieved by evaluating Padé series coefficients in the PE operator instead of Taylor series coefficients, which were used in the initial formulation of PE.

In this study we test the capability of TDPE to model high-angle multipaths which interact with ocean sediments. TDPE impulse response functions are compared with ocean impulse responses measured in the Atlantic Ocean. The comparisons are done by analyzing the amplitudes, phases, and arrival times of the response multipaths.

TDPE results are also compared to results from the more established fast field program, SAFARI.[6] SAFARI is a frequency domain model, valid for all angles of propagation. The comparison to SAFARI is done to test the capability of TDPE to model high-angle multipaths.

EXPERIMENT

The experiment was conducted in the Atlantic Ocean at the southern end of the Blake Plateau, 27.5° N, 78.3° W (figure 1), in approximately 915 m of water. We consider only a near-field, range-independent portion of the test.

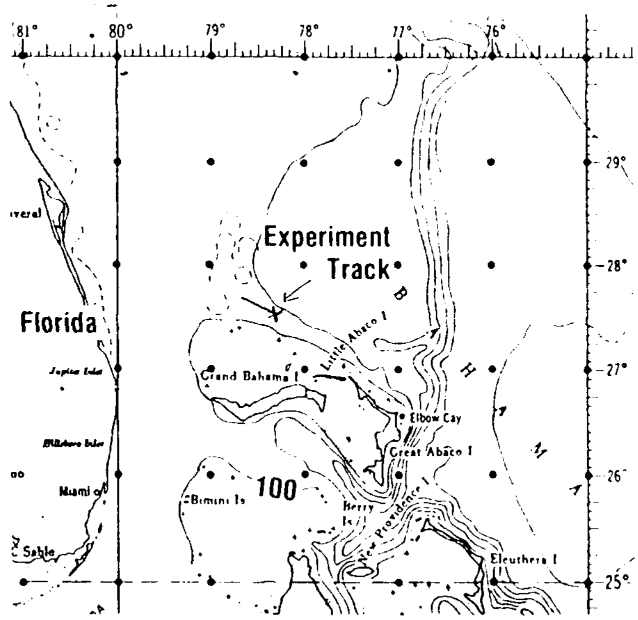

Figure 1. Experiment site in the Atlantic Ocean.

In the experiment, the source ship towed an HLF-2AH acoustic source at a depth of 96 m. While on station, a series of 20 to 150 Hz swept frequency pulses of a 20-second duration were transmitted. The signals were received on a 16-element vertical line array with 9-m hydrophone spacings (figure 2). The received signals were transmitted back to the source ship via a radio telemetry link. The range was 600 m.

Expendable bathythermographs (XBT's) were dropped to obtain water column sound speeds, and a 3.5-kHz profiler was used to determine the bathymetry profile.

For this study we consider the data received at hydrophone depths of 129 and 250 m. The ocean impulse response functions are calculated by matched filtering (i.e., cross-correlating the received time waveforms with the source signature of the swept signal). After the correlation process, the measured ocean impulse response, $\hat{g}(t)$, is given by

$$\hat{g}(t) = g(t) * a(t)\,, \qquad (1)$$

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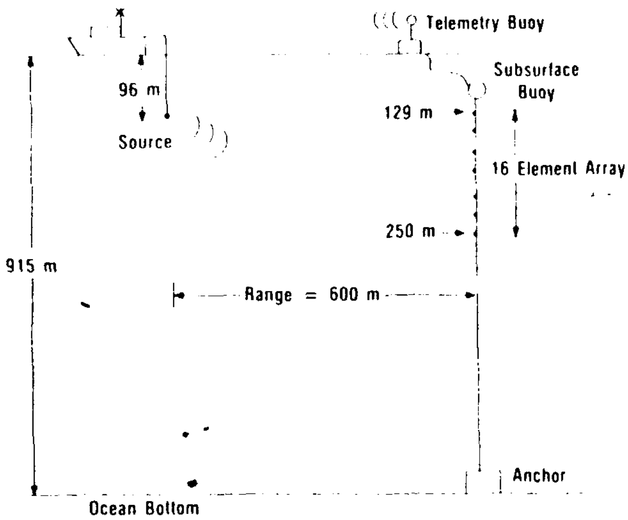

Figure 2. Experiment Setup.

where a(t) is the autocorrelation of the 20 to 150 Hz FM sweep and g(t) represents the broadband ocean impulse response. (The asterisk denotes convolution.) The broadband response, g(t), is bandlimited and shaped by a(t). The source autocorrelation, a(t), is shown in figure 3.

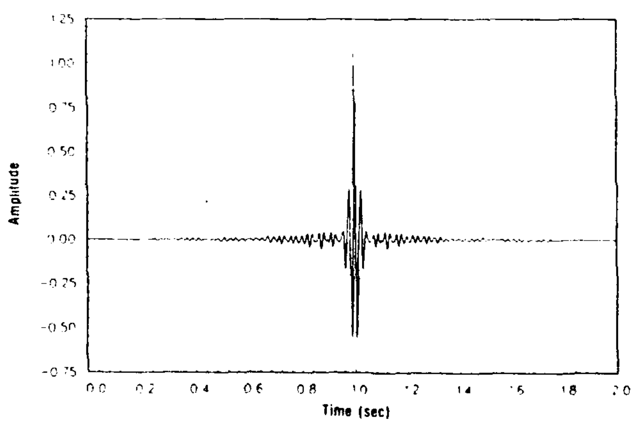

Figure 3. Autocorrelation of transmitted HLF-2AH source, also used as the input source pulse for TDPE and SAFARI.

MODEL PARAMETERS

Environmental parameters input to TDPE consist of water column and sediment sound speeds, densities, and attenuations. The profiles used are shown in figures 4a, b, and c. The water column sound speeds are computed from XBT data. Sediment sound speeds and densities are extrapolated from data gathered at Deep Sea Drilling Project (DSDP) sites conducted near the experimental site.

The ocean sediment in this area is characterized by a highly reflective layer at 160 to 170 m below the ocean bottom.

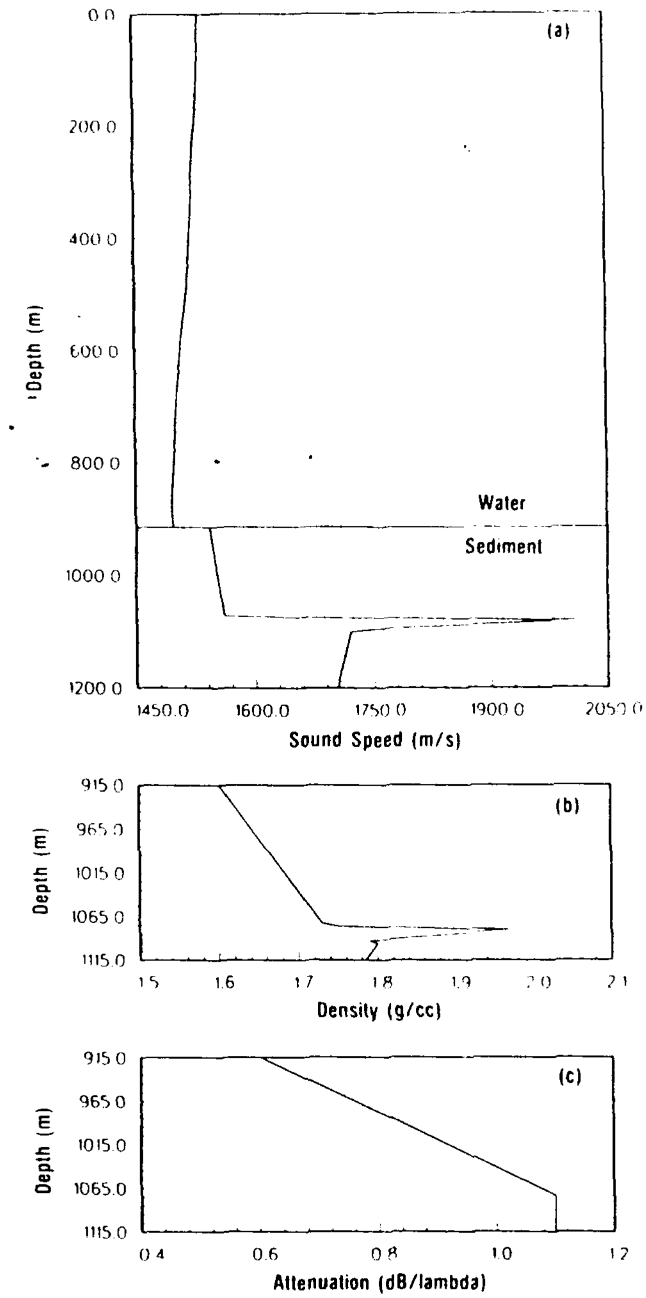

Figure 4. Environmental parameters input to TDPE.
(a) Sound Speed Profile,
(b) Sediment Density Profile, and
(c) Sediment Attenuation Profile.

This feature of the sediment layering offers an excellent test of TDPE's capability to handle high angles and subbottom layering with abrupt impedance changes. The density and sound speed of the subbottom layer is chosen to approximate the same acoustic impedance of the layer in the DSDP data. The DSDP data show a higher sound speed and a lower density than used in the model. This is done to reduce the computational intensiveness of the model run.

The source pulse propagated in TDPE is the autocorrelation of the 20 to 150 Hz FM sweep shown in figure 3. The TDPE model simulates the matched filter result of equation 1.

The environmental parameters and source pulse input to SAFARI are the same as those used for TDPE, although the manner in which TDPE and SAFARI account for layering of the environment is different. TDPE interpolates between environmental inputs, sampling at each depth increment. SAFARI treats environmental layering in a step-like manner.

RESULTS

The TDPE contour, figure 5, shows the acoustic pressure field in depth and relative arrival time at a range of 600 m. The pressures along the time axis describe the time waveform arrival structure at a particular depth. The wavefront arrivals are labeled D (direct path), S (surface reflected), B (bottom reflected), SB (surface-bottom reflected), BS (bottom-surface reflected), and SBS (surface-bottom-surface reflected). The arrival DR is the direct arrival refracted through the bottom and reflected off the subbottom layer and transmitted back into the water column. SR is the surface reflected arrival refracted through the bottom.

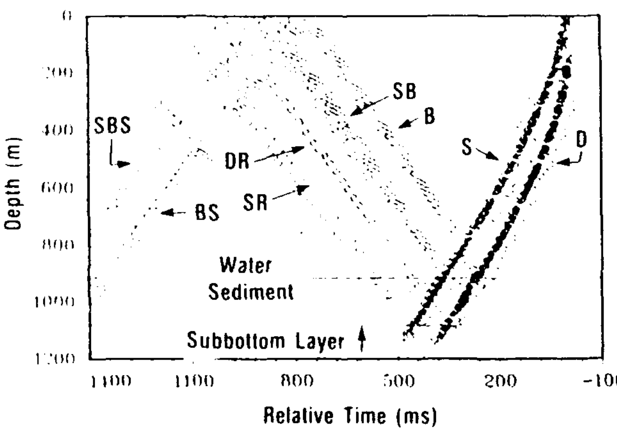

Figure 5. TDPE contour of acoustic pressure.

Impulse responses of measured data and TDPE results are shown in figures 6a and b. Responses are normalized to have a maximum amplitude of one. The D and S arrivals agree with the measured data with only a slight difference in amplitude and phase. The S arrivals at the 129- and 250-m receiver depths have propagation angles of 20° and 30°, respectively. The high-angle multipaths after 0.9 s are windowed, renormalized, and displayed in figures 6c and d. These multipaths have propagation angles of 68° to 75°. At the 250-m depth, the amplitudes and phases of the B and SB arrivals agree with the measured data. DR agrees in amplitude. The BS and SBS events have the correct amplitude, the offset in arrival time being due to a mismatch in environmental parameters. The two later

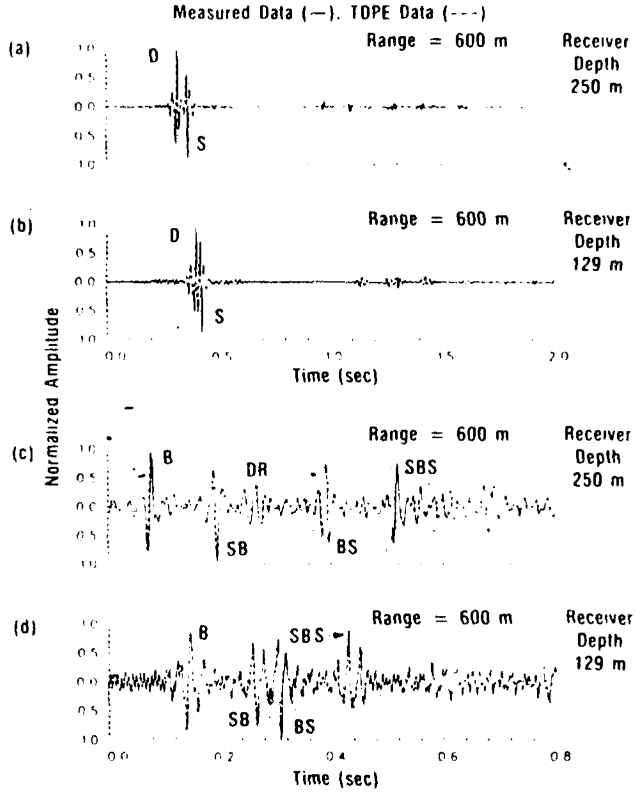

Figure 6. Overlay of measured data and TDPE result (a, b, c, and d).

arrivals have propagation angles greater than 75°. The B arrival at the 129-m receiver depth agrees with the measured data. There is agreement in amplitude for the SB and BS arrivals, although there is some phase distortion possibly due to interaction with the DR arrival. The SBS arrival has some phase distortion.

SAFARI impulse responses and the measured responses are shown in figures 7a, b, c, and d. D and S arrivals agree with the measured data at both receiver depths. There is little difference between the TDPE and SAFARI result for these arrivals. At the 250-m depth, the amplitudes of the B and SB arrivals compare favorably with the measured data, although the TDPE result has better phase agreement. At the 129-m depth, the amplitudes of the B, SB, BS, and SBS arrivals agree with the measured data. The phase of the B arrival is better for the TDPE result, and the SAFARI result agrees better for the SB and BS arrivals. The agreement of the SAFARI SBS arrival is better than the TDPE result.

CONCLUSIONS

TDPE accurately models high-angle acoustic pulse propagation in the ocean environment studied here. Amplitudes and phases of the TDPE impulse responses agreed with the measured impulse responses. The differences between the modeled and measured responses

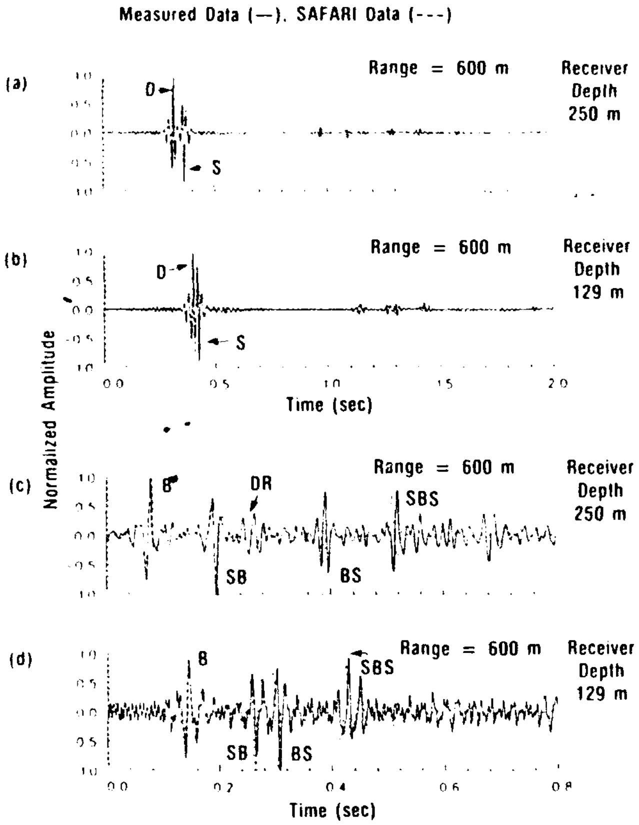

Figure 7. Overlay of measured data and SAFARI result (a, b, c, and d).

are attributed to inaccuracies in the environmental parameters input to the model. The comparison of TDPE and SAFARI shows that TDPE handles the high-angle multipaths as does the more established SAFARI code.

ACKNOWLEDGMENTS

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