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Propagation of Sound from an Explosive Source Placed in a Shallow-Water Wedge or Deep Water near the Ocean Bottom

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INTRODUCTION AND MAIN RESULTS

The predictions made in this poster about impulsive-like signals from in-water explosions are based on a theoretical analysis of acoustical signals from the explosive point source placed in two benchmark models: the wedge of fluid and the half-space of fluid, each over an elastic solid bottom. When frequency-dependent attenuation in the bottom is accounted for, the Scholte-wave phase might dominate in the signals received at great distances in each model.

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Introduction

The predictions made in this poster about sound propagation situations referred to in the title are based on a theoretical analysis of the acoustical signals from the explosive point source of a wide spectral range, placed in the two benchmark models: the wedge of fluid (Fig. 1) and the half-space of fluid (Fig. 2), each over an elastic solid bottom, where the shear-wave speed is less than the speed of sound in the fluid. In the wedge, the propagation proceeds by repeated reflections; whereas, in the half-space, via a single bottom reflection. Using a semi-analytical generalized-ray method, the received

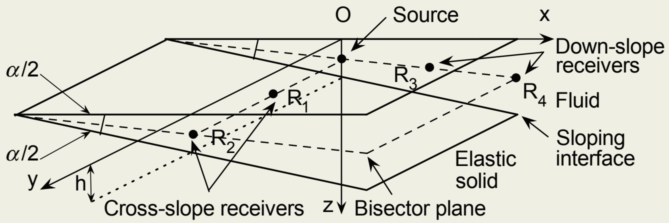

FIG. 1. Cartoon (not to scale) of a three-dimensional (3-D) benchmark model of the fluid wedge of apex angle $\alpha = 3$ deg over an elastic solid (sandstone) bottom, used to explain cross- and down-slope long-range acoustical propagation of explosive sound in the coastal wedge. A point source is placed below the origin O of a Cartesian coordinate system (x, y, z) at the bisector plane of the wedge, where the depth of the fluid is h = 200 m. Four receivers R_1, R_2, R_3, R_4 are also placed at the bisector plane of the wedge; R_1 and R_2 cross-slope off the source at ranges of $r_1 = 20$ km and $r_2 = 40$ km; R_3 and R_4 down-slope off the source at ranges of $r_3 = 20$ km and $r_4 = 40$ km. The geoacoustic properties of the fluid (water) are: $\rho = 1$ g/cm^3; $c = 1500$ m/s; $\alpha_P = 0$ dB/λ. Those of the elastic solid (sandstone) are: $\rho_2 = 2.2$ g/cm^3; $c_P = 2670$ m/s; $\alpha_P = 0.1$ dB/λ; $\alpha_{Refr} = \alpha_P$ dB/λ; $c_S = 1090$ m/s, $c_S < c$; $\alpha_S = 0.2$ dB/λ; $\alpha_{Sch} = 1.1\alpha_S$ dB/λ.

Introduction (cont.)

signals have been evaluated exactly, each in the form of a time-series of the acoustic pressure exhibiting three distinct phases: the phase of the critically refracted (lateral) waves, the phase of the source signal and the regularly reflected waves, and the phase of the Scholte waves. When frequency-dependent attenuation in the bottom is accounted for, the Scholte-wave phase is attenuated the least and may dominate over the other two phases at long ranges (Figs. 3-7). It might dominate the propagation in the SOFAR channel, upon entering from the coastal wedge or deep water.

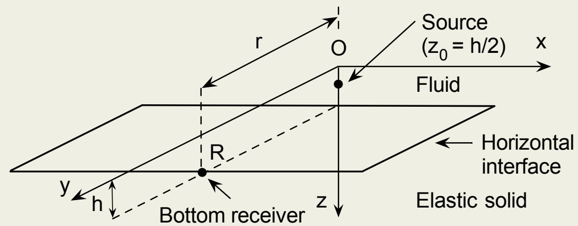

FIG. 2. Cartoon (not to scale) of a three-dimensional (3-D) benchmark model of the fluid half-space over a semi-infinite elastic solid (sandstone) bottom, used to explain long-range acoustical propagation of explosive sound along a flat bottom of the deep ocean. The origin O of a Cartesian coordinate system (x, y, z) is placed above a horizontal fluid-solid interface at a height of h = 200 m, and a point source is placed at a height of h/2 = 100 m, thus the depth of the source (relative to the origin O) is then $z_0 = 100$ m. A bottom receiver R is placed in the source medium (fluid) at the interface at a range of r = 40 km. The geoacoustic properties of the fluid (water) are: $\rho = 1$ g/cm^3; $c = 1500$ m/s; $\alpha_P = 0$ dB/λ. Those of the elastic solid (sandstone) are: $\rho_2 = 2.2$ g/cm^3; $c_P = 2670$ m/s; $\alpha_P = 0.1$ dB/λ; $\alpha_{Refr} = \alpha_P$ dB/λ; $c_S = 1090$ m/s, $c_S < c$; $\alpha_S = 0.2$ dB/λ; $\alpha_{Sch} = 1.1\alpha_S$ dB/λ.

Wedge of Fluid over Elastic Bottom

Cross-Slope Acoustical Propagation
Receiver R_1 at a Range of r_1 = 20 km (Fig. 1.)

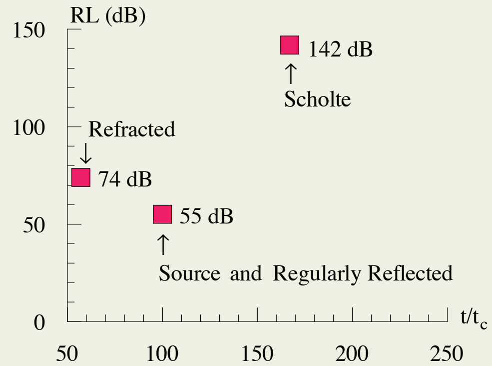

FIG. 3. Received levels (RLs) of the three phases [attenuated critically refracted (lateral), unattenuated source signal and regularly reflected, and attenuated Scholte], recorded in order of their arrivals at the receiver placed at the bisector plane cross-slope off the source at a normalized range of r/h = 100 (in Fig. 1, the receiver R_1 at a range of $r_1 = 20$ km); due to a Gaussian-weighted source signal with a center frequency of $c_f = 3$ Hz, a bandwidth of $w = 0.5$ Hz, and a source-pressure level of 171 dB re 1 μPa at 1 m; (RL = received level; $t_c = h/c$; t = time; h = depth of the fluid at the source location; c = compression wave speed in the fluid).

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P1.3-244

Wedge of Fluid over Elastic Bottom (cont.)

Cross-Slope Acoustical Propagation
Receiver R_2 at a Range of r_2 = 40 km (Fig. 1)

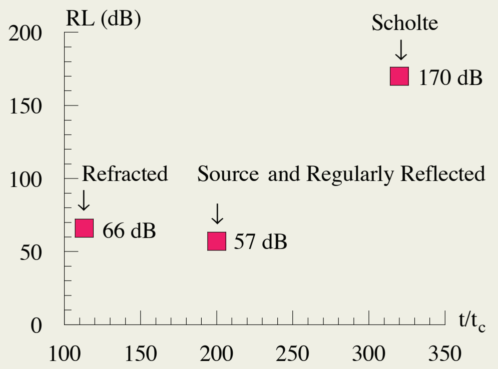

FIG. 4. Received levels (RLs) of the three phases [attenuated critically refracted (lateral), unattenuated source signal and regularly reflected, and attenuated Scholte], recorded in order of their arrivals at the receiver placed at the bisector plane cross-slope off the source at a normalized range of r/h = 200 (in Fig. 1, the receiver R_2 at a range of r_2 = 40 km); due to a Gaussian-weighted source signal with a center frequency of c_f = 3 Hz, a bandwidth of w = 0.5 Hz, and a source-pressure level of 171 dB re 1 μPa at 1 m; (RL = received level; ; $t_c = h/c$; t = time; h = depth of the fluid at the source location; c = compression wave speed in the fluid).

Wedge of Fluid over Elastic Bottom (cont.)

Down-Slope Acoustical Propagation
Receiver R_3 at a Range of r_3 = 20 km (Fig. 1)

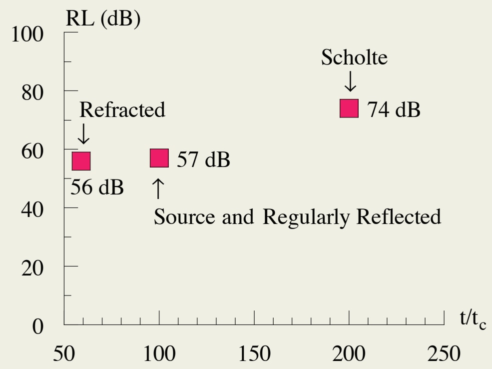

FIG. 5. Received levels (RLs) of the three phases [attenuated critically refracted (lateral), unattenuated source signal and regularly reflected, and attenuated Scholte], recorded in order of their arrivals at the receiver placed at the bisector plane down-slope off the source at a normalized range of r/h = 100 (in Fig. 1, the receiver R_3 at a range of r_3 = 20 km); due to a Gaussian-weighted source signal with a center frequency of c_f = 3 Hz, a bandwidth of w = 0.5 Hz, and a source-pressure level of 171 dB re 1 μPa at 1 m; (RL = received level; $t_c = h/c$; t = time; h = depth of the fluid at the source location; c = compression wave speed in the fluid).

Wedge of Fluid over Elastic Bottom (cont.)

Down-Slope Acoustical Propagation
Receiver R_4 at a Range of r_4 = 40 km (Fig. 1)

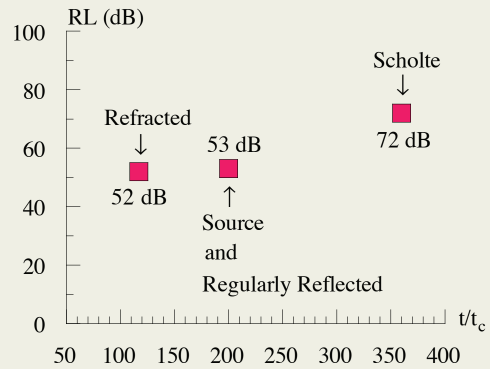

FIG. 6. Received levels (RLs) of the three phases [attenuated critically refracted (lateral), unattenuated source signal and regularly reflected, and attenuated Scholte], recorded in order of their arrivals at the receiver placed at the bisector plane down-slope off the source at a normalized range of r/h = 200 (in Fig. 1, the receiver R_4 at a range of r_4 = 40 km); due to a Gaussian-weighted source signal with a center frequency of c_f = 3 Hz, a bandwidth of w = 0.5 Hz, and a source-pressure level of 171 dB re 1 μPa at 1 m; (RL = received level; $t_c = h/c$; t = time; h = depth of the fluid at the source location; c = compression wave speed in the fluid).

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Half-Space of Fluid over Flat Elastic Bottom

Acoustical Propagation along Flat Elastic Bottom
Receiver R at a Range of r = 40 km (Fig. 2)

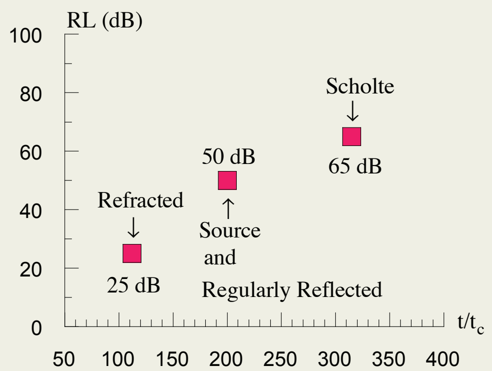

FIG. 7. Received levels (RLs) of the three phases [attenuated critically refracted (lateral), unattenuated source signal and regularly reflected, and attenuated Scholte], recorded in order of their arrivals at the bottom receiver placed in the source medium (fluid) at the interface at a normalized range of r/h = 200 (in Fig. 2, the receiver R at a range of r = 40 km); due to a Gaussian-weighted source signal with a center frequency of c_f = 3 Hz, a bandwidth of w = 0.5 Hz, and a source-pressure level of 171 dB re 1 μPa at 1 m; (RL = received level; t_c = h/c; t = time; h = characteristic depth; c = compression wave speed in the fluid).

Conclusions

Two propagation models were applied to predict the received levels (RLs) of the impulsive-like sounds from an in-water explosive source of a wide spectral range, including very low frequencies (like those of 3 Hz) that may propagate in the two modeled environments over large distances, up to several tens of kilometers, without significant losses.

The modeling approach was based on a generalized-ray technique, evaluating at long ranges the received signal exactly, in the form of a time-series of the pressure, including the three phases: critically refracted (lateral) waves, source signal and regularly reflected waves, and Scholte waves.

Accounting for frequency-dependent attenuation in the models' elastic bottoms, it was shown through Figs. 3-7 that the RLs of the Scholte-wave phases were the highest, thus clearly dominated over those of the other two phases at long ranges.

Conclusions (cont.)

Figures 3 and 4 showed the RLs of the signals received cross-slope off the source; notably, Fig. 4 showed that the RL of the Scholte-wave phase at a range of 40 km was nearly equal to that of a Gaussian-weighted source signal with a center frequency of c_f = 3 Hz, a bandwidth of w = 0.5 Hz, and a source-pressure level of 171 dB re 1 μPa at 1 m.

Figures 5 and 6 showed the RLs of the signals received down-slope off the source, which decreased slightly with increasing range. Notably, in Fig. 6 the depth of the receiver R_4 is 1147 m, which might be close to the depth of the SOFAR channel axis; thus, the signal incoming at the receiver R_4 might then enter the channel, where the propagation might be dominated by the Scholte-wave phase.

Figure 7 showed the RLs of the signal that propagated over a range of 40 km along the elastic (ocean) bottom. The signal may also enter the SOFAR channel, but from below.

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