The effect of source movements on shallow water bottom backscatter

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Abstract

The time-evolution model BORIS is used to study the effects of source movements on bottom backscatter. Changes in the backscattered time domain signals as functions of source depth, position and incident angles are simulated for broad band pulses both with narrow and wide beams. The results show that a change in the distance between a rough bottom and the source modifies the coherent and the non-coherent part of the pulse. A small change in horizontal position produces significant changes in the backscattered signal for both beams, while a small change to the incident angle produces significant changes in the narrow beam only.

1. Introduction

A stochastic model has been developed which enables the study of backscattered time domain signals as functions of source movements [1] [2]. In [2], examples show how the beam width and the seabed roughness affect the time-series return from the seafloor surface and from the volume. This paper continues the study of the model, and shows how the movement of the source in all three dimensions affects the time-series. When working with acoustic data from a moving source in shallow water, significant variations might be seen from one ping to another. If the causes of these variations can be understood, changes from one ping to another might be actively used in the work of characterizing the seafloor instead of being treated as "noise" in the data [3]. The ping to ping variations caused by changes in the propagation in the water columns is not included in this study.

The paper is divided into 5 sections. Section 2 gives a brief introduction to the model used, section 3 treats the effects of the source height above the bottom. In section 4 the horizontal movement of the source is treated, and the effects of roll is treated in section 5.

2. Description of the BORIS model

The model is designated BORIS which is an abbreviation for "BOttom Response from Inhomogeneities and Surface". A detailed specification of the implementation of BORIS is given in [4].

The following integral [1] forms the basis of the model:

$$\begin{aligned} p(\mathbf{P},t) &= p_s(\mathbf{P},t) + p_v(\mathbf{P},t) \\ &= \int_S dp_s(\mathbf{P},t) + \int_V dp_v(\mathbf{P},t) \end{aligned} \tag{1}$$

This integral expresses that the pressure field received at the source $\mathbf{P}$ from the seafloor is the sum of the elementary pressure fields over the seafloor surface (S) and the seafloor volume (V). For a monostatic source and receiver with directivity pattern D_i and D_r, the seafloor surface contribution is given by

$$dp_s(\mathbf{P},t) = \frac{\cos(\gamma(\mathbf{R}))}{2\pi\overline{c_0}R_0^2} p_0$$

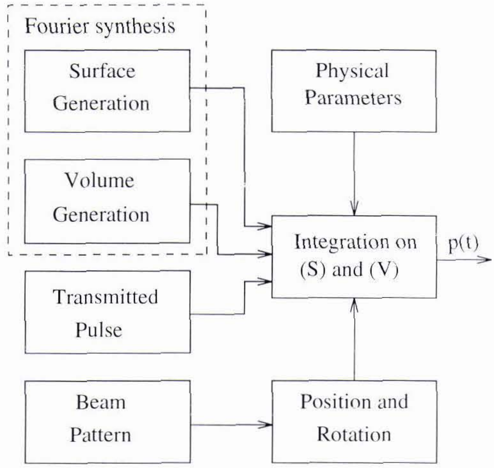


Figure 1: Simplified box diagram of the model.

$$\times \left(D_i D_r(\mathbf{R})\right) \Re_{01}(\mathbf{R}) e^{'}(t - \frac{2R_0}{\overline{c_0}}) d\mathbf{S}_\mathbf{R} \tag{2}$$

Here, $\Re_{01}$ is the local water-sediment plane wave reflection coefficient at the point $\mathbf{R}$, $\overline{c_0}$ is the average sound speed in water, $\gamma(\mathbf{R})$ is the angle between the incident direction and the vector $\mathbf{n}$ normal to the surface at $(\mathbf{R})$ and p_0 is the source level. $e^{'}(t)$ is the time derivative of the transmitted pulse $e(t)$.

The volume contribution is given by

$$\begin{aligned} dp_v(\mathbf{P}, t) &= \frac{-n_1^2(\mathbf{R}^{'})}{2\pi R_0^2 \overline{c_0}^2} \mu(\mathbf{R}^{'}) p_0 \\ \times &\quad D_i(\mathbf{R}) D_r(\mathbf{R}) \Im_{01}(\mathbf{R}) \Im_{10}(\mathbf{R}) \\ \times &\quad \left(\frac{1}{\pi} \frac{\frac{\alpha R_1}{2\pi}}{(\frac{\alpha R_1}{2\pi})^2 + t^2} * e^{"}(t - 2(\frac{\overline{n_1} R_1 + R_0}{\overline{c_0}})) \right) \\ \times &\quad d\mathbf{V}_\mathbf{R} \end{aligned} \tag{3}$$

In this expression, $\overline{n_1}$ is the average refractive index in the first few metres of the bottom, n_1 is the local refractive index at location $\mathbf{R}^{'}$ and R_1 is the distance of penetration into the sediment. α is the attenuation coefficient, $\Im_{01}(\mathbf{R})$ and $\Im_{10}(\mathbf{R})$ are the plane wave transmission coefficients. The double time derivative of the transmitted pulse $e(t)$ is denoted by $e^{"}(t)$.

These equations give the sound pressure level for a given time t at position $\mathbf{P}$ by integration over the surface (S) and the volume (V). The local incident angle $\gamma(\mathbf{R})$, the local reflection coefficient $\Re_{01}(\mathbf{R})$ and the local degree of inhomogeneities in the volume $\mu(\mathbf{R}^{'})$ are assumed to be known. Instead of using average quantities for these parameters, a different approach has been taken. Before the calculations are carried out for the integral over S, one realization of the seafloor surface and volume is calculated based on a statistical set of parameters. The calculations are based on the Fourier synthesis method. For the surface, a filtered power law spectrum is used to calculate the height field, while for the volume part an exponential correlation function has been used to generate the inhomogeneity field. The model includes 3D rotation and position matrices for the source and receiver which allows for variations of position, heave, pitch and roll.

It is important to notice that the model has a stochastic nature, and that the result from one run to another will be different even with the same input parameters. This is because there is an infinite number of realizations of the seafloor for a fixed set of statistical parameters. However, the same realization might be used in several runs by controlling the random generator used in the model. A simplified block diagram of the model is shown in Fig. 1

3. Effect of the source height above the bottom

With a directive beam and a rough bottom, the shape of the returned signal is expected to change as a function of depth due either to the change in the size of the insonified surface or change in the surface aspect ratio. As demonstrated in [2], even for a perfectly flat surface, the shape of the signal depends on the insonified area if the beam is directive. For a rough surface, a larger insonified area will include more surface scatter with the effect of prolonging the tail of the surface contribution signal. To illustrate these effects, the BORIS model was run at varying depths over a soft, rough surface. The transmitted pulse was a Ricker pulse centered at 8 kHz. For the transducer, two different Gaussian beam patterns of amplitude *versus* angles were used at 3° and 15° respectively for the half beam width measured at -3 dB. The receiving beam pattern was omni directional. The other parameters used in the model are shown in Table 1. The surface and volume were unchanged for all runs in order to compare directly the results, i.e. the same realization of the surface and volume have been used.

Table 1: Model parameter settings.

Parameters	Values
Surface increment dp_s (m)	0.03
Volume increment dp_v (m)	0.03
Depth H (m)	10.0 (5-20)
Sound speed, c_1 (m/s)	1550
Density ρ_1 (g/cm^3)	1.4
Surf. rms rough. σ_h (m)	0.02 (0.01)
Surf. pow. e-p. ν	2.0
LP cutoff K_{lp} (rad/m)	30
HP cutoff K_{hp} (rad/m)	1
Volume inhomog. μ	0.03
Volume Hor. Cor. l_h (m)	0.3
Volume Ver. Cor. l_v (m)	0.02
Attenuation α (dB/m/kHz)	0.5

Figure 3 shows the time-domain signal returned from the surface as a function of depth and time. Plots a) and b) shows the results from the runs using narrow and wider beams respectively. No volume contribution is included in this figure, and the delays due to the water column have been removed in order to aligned the pulses in time. At 5 m, the narrow beam is insonifying a disc with diameter 0.52 m, the wider beam is insonifying an area with diameter 2.67 m. For the narrow beams, little energy is seen in the tail, and the first part of the return has a shape which tends towards the derivative of the transmitted pulse [2]. For the wider beam, scattering from the surface is evident in the tail. As the depth is increasing for the narrow beam, little energy is seen in the tail, and the first reflection resembles the transmitted pulse. It is interesting to observe the effect of roughness on the time domain signal. For the deeper runs, the surface features appear closer to the first part of the reflection. This can be explained by the simple geometric fact that the difference in time between the center of the beam and a distinct feature will decrease with depth increased (Fig. 2).

Figure 4 shows both volume and surface contribution. The volume contribution can now be seen for the narrow beam, while for the wider beam the scattering from the volume becomes mixed with the scattering from the surface. The contribution from the volume *versus* the contribution from the surface scatter will depend mainly on the volume and surface description parameters.

4. Effect of horizontal movements of the source

For a rough bottom, a horizontal translation of the source will change the insonified area of the bottom, and the time domain signal is expected to be affected. The change will depend on bottom parameters, beam pattern and transmitted pulse. Typically, a rougher bottom gives more changes than a smoother bottom. To study this effect, the BORIS model was run at a height of 10 m above the bottom, and the source was translated horizontally in steps of 0.1 m. The statistical realization of the bottom was unchanged during the runs. Figure 5 shows the time domain signals of the total scattering from a bottom with rms roughness 1 cm. The other parameters are unchanged (Tab. 1). A small change in the position changes the time-domain signal for the narrow and the wider beam. For the narrow beam, little energy is seen in the tail, and only small changes are seen in the first part of the signal. For the wider beam, the variations are greater, and the tails of the signals undergo a significant change. Figure 6 shows the same simulations with rms roughness of the bottom increased to 2 cm. Due to the limited insonified area, the scattering from the surface is still low for the narrow beam, but the changes seen in the first

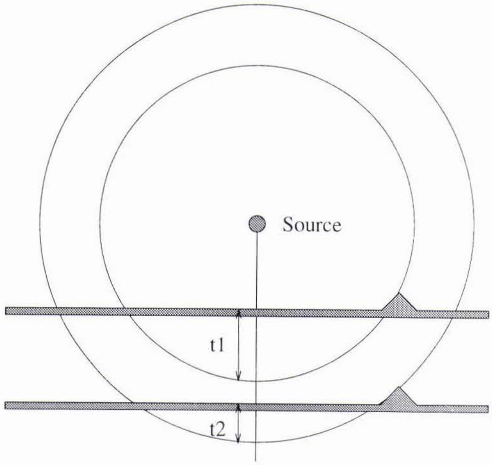


Figure 2: A distinct feature at the bottom will appear closer to the normal incident reflection if the depth is increasing.

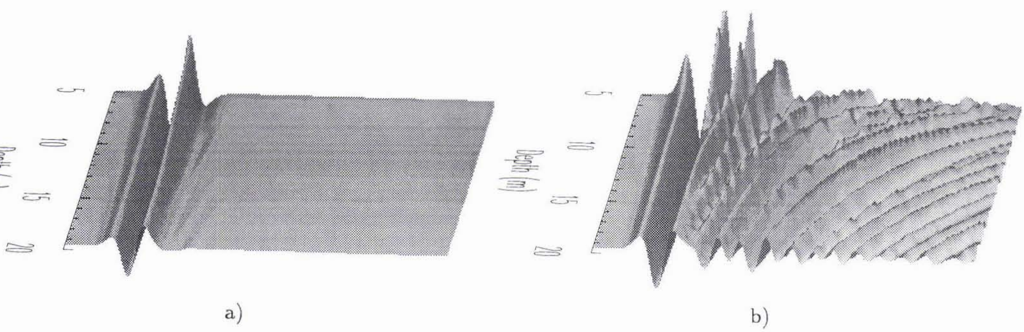


Figure 3: The pulse as function of depth and time including the surface return only. a) narrow beam, b) wide beam.

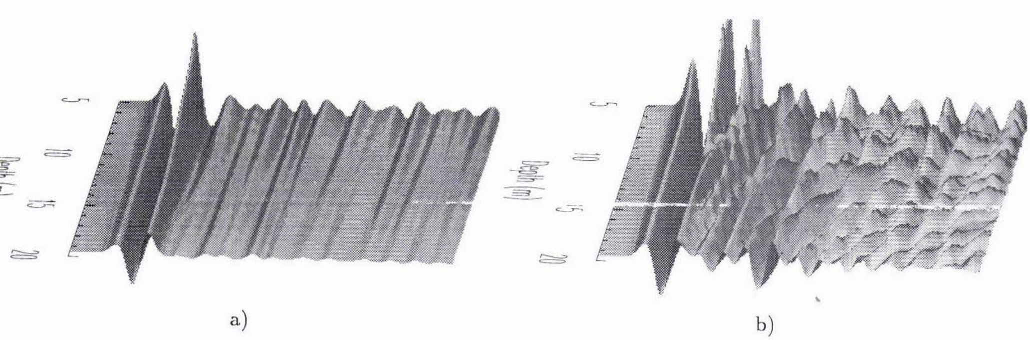
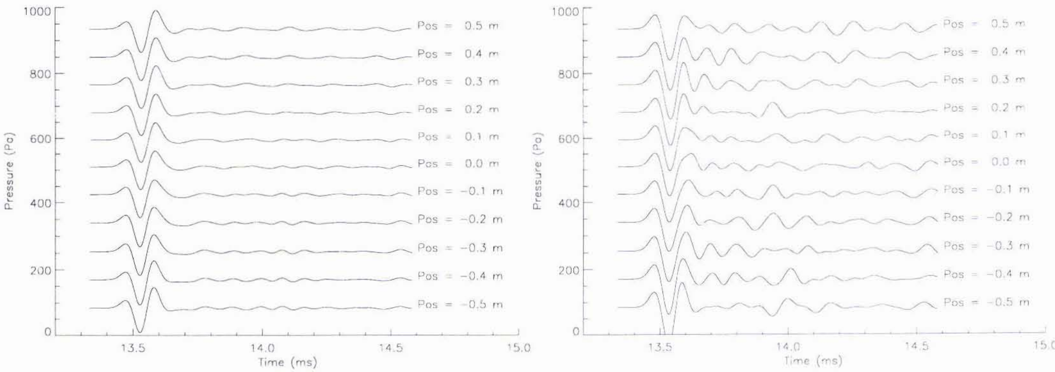
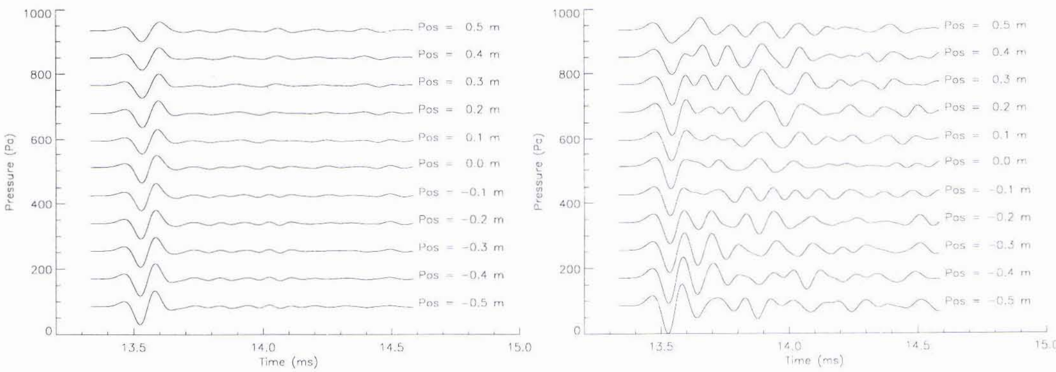


Figure 4: The pulse as function of depth and time including both the surface and volume return. a) narrow beam, b) wide beam.



a) b)

Figure 5: The return as function of position. The rms roughness is 1 cm. a) narrow beam, b) wide beam.



a) b)

Figure 6: The return as function of position. The rms roughness is 2 cm. a) narrow beam, b) wide beam.

part of the signals are stronger than for the bottom with rms roughness equal to 1 cm. For the wider beam, the energy in the tail is generally increased due to the increased surface scatter with respect to the rms roughness of 1 cm and the variations from one position to the next are more significant.

From these simulations, the narrow beam appears to be less influenced by small changes in the position than the wider beam. Consequently, if the variations from one position to the other are used to extract seafloor roughness parameters, a wider beam might be a better choice. For impedance estimation, the narrow beam seems to be the better choice as in this case, the variations from one position to another are less dependent on the roughness. As the surface contribution is almost negligible in the tail, the narrow beams may be easier to use for volume contribution studies.

5. Effect of small changes in roll/pitch

For a typical situation with a hull mounted or a towed sonar, the source will be exposed to variations in pitch and roll. An interesting simulation can be performed looking at the time domain signal as function of variation in the incident angle. As the source used in the simulations has a symmetric beam pattern around the mean direction, only the effect in one dimension (roll) is studied. In Fig. 7 the roll of the source is simulated for angles between $-5°$ and $5°$. The rms roughness is 2 cm, the depth is 10 m, and the other parameters are unchanged. The source is at position 0, so that the results with Roll $= 0°$ equal the result for Pos $= 0$ m in Fig. 6. For the narrow beams the roll has a significant influence on the time domain signal. The shape of the first reflection changes and for an increase in the roll, the level decreases strongly because the source is not at normal incidence. As expected, the

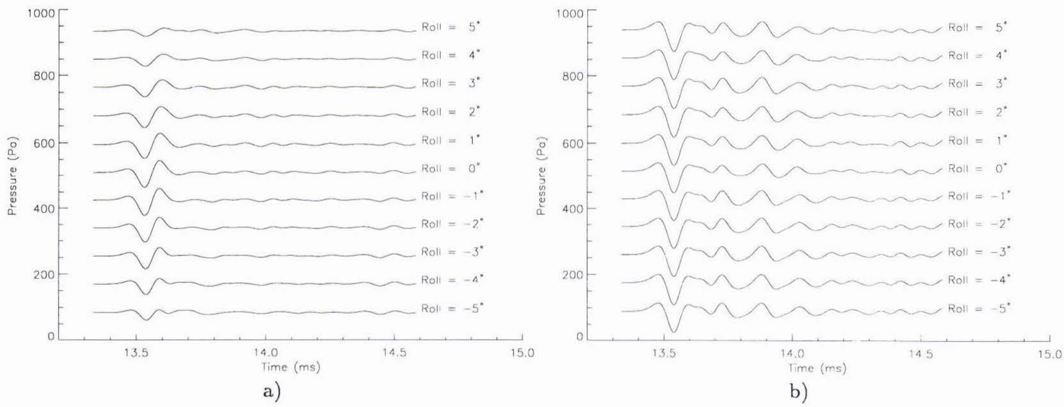


Figure 7: The return as function of roll (incident angle). a) narrow beam, b) wide beam.

change is much less marked for the wider beam, and the signal is almost constant from -5° to 5°.

6. Summary

The effects of source movements on backscattered time domain signals have been studied using model simulations. The simulations were carried out using a broad band Ricker pulse and two different beams of 3° and 15° respectively. The source height above the bottom varied from 5 to 20 m. The results showed that the signal changes notably over the depth range studied for both the narrow and the wider beam. Further simulations were conducted by moving the source horizontally over a rough bottom. Even for small variations in the position, the time-domain signal changed significantly, and the changes appeared to be higher for the wider beam. A simulation to study the effect of varying the incident angles showed that the narrow beam was more affected by the change than the wider beam. The continuation of this work will be focused on verifying the results with recorded data.

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