Modelling of acoustic wave backscattering on rough seabed – comparison of different approaches

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Introduction

The underwater acoustic methods of seafloor characterisation have achieved special attention during last decades due to being more simple, fast, versatile and cost effective in comparison with alternative methods, e.g. using geological cores or video cameras. For development of reliable and efficient acoustic methods of seabed identification and classification, the theoretical modelling of acoustic scattering on water-bottom interface and within insonified sediment volume is necessary. It allows prediction which features of bottom echo and in what manner should be used to characterise the seabed properties with best potential generalisation abilities and sufficient level of accuracy.

The paper presents the results of modelling of echosounder signal backscattering on rough seabed surface. Two different approaches were used, viz. the direct acoustic echo pressure modelling and concurrently, the incoherent signal intensity modelling. Also, the different statistical descriptions of seabed roughness were applied, e.g. Gaussian form or power law form of the surface spatial power spectrum. The comparison of several cases was made and the dependence of the simulation results on different initial parameters, describing both the environment properties and used underwater acoustic system settings, was also investigated.

Modelling Procedures

Seabed Surface Modelling

In the presented modelling, only the surface scattering on seabed was considered. This may be a good approximation of the reality for signal frequencies of hundreds kHz and higher.

The seabed surface $f(x, y)$ was modelled taking into account only its small scale roughness of rms height h not greater than 0.2 m and of correlation length L not greater than 1 m. In larger scale, the seabed surface was assumed to be flat.

The surface roughness was modelled using the 2-dimensional inverse Fourier transform, assuming two concurrent forms of the amplitude spectrum of its spatial variability (and random, uniformly distributed phase spectrum):

1. The form providing the Gaussian form of the isotropic spatial correlation function of the surface height, assumed in work [4]:

$$C(r) = A\exp\left[-\left(\frac{r}{L}\right)^2\right], \qquad \text{eq. 1}$$

where r - distance between two surface points in horizontal direction, A - a constant, L - correlation length.

2. The form providing the power law form of surface power spectrum, also assuming isotropy of the surface, used in [1]:

$$W(\mathbf{K}) = \beta K^{-\gamma}, \qquad \text{eq. 2}$$

where $\mathbf{K}$ is 2-dimensional spatial wave number, β is the coefficient related to surface rms height and γ is the exponent related to surface fractal dimension, describing the surface roughness.

Echo Pressure Modelling

The method of the modelling of seabed surface backscattering described in this section is based on the deterministic approach and it allows for exact calculation of a single echo signal in pressure domain $p(t)$ from a given bottom surface $z = f(x, y)$, assuming the depth H, transmitted pulse shape $p_s(t)$ and other parameters of experiment, without any assumptions concerning the statistical properties of the surface.

The modelling of acoustic wave scattering is based on the BORIS model [5]. Assuming that the source transmits a signal $p_{tr}(t) = p_0 s(t)$ downwards to the seabed, the pressure-time dependence of the echo $p(t)$ from scattering surface is:

$$p(t) = A\iint_S \frac{\cos[\gamma(\mathbf{R})]b^2(\mathbf{R})}{R^2} s'\left(t - \frac{2R}{c_0}\right)ds \qquad \text{eq. 3}$$

where $A = p_0\Re_r/(2\pi c_0)$, p_0 - transmitted wave amplitude, $\Re_r$ - plane wave reflection coefficient for water-bottom interface, c_0 - sound speed in water, R - vector from the transducer to surface element ds, γ - incident angle, b - beampattern value for element ds, assumed to be the same for transmitting and receiving, $s'(t)$ - first time derivative of transmitted signal $s(t)$.

Echo Intensity Modelling

The concurrent method of sea bottom echo modelling is based on statistical approach to seabed surface small scale roughness [6]. It is characterised by much smaller computational complexity than previous method.

Instead using the exact function describing the surface roughness, some statistical assumptions are made with respect to it, which are expressed by the scattering coefficient s_s. Therefore, if the transmitted signal is narrow band and the domination of incoherent scattering may be assumed, the calculations can be performed in the echo intensity or echo squared envelope domain [6].

In such a case, the backscattered echo intensity $I(t)$ is:

$$I(t) = \iint_S \frac{s_s[\gamma(\mathbf{R})]B^2(\mathbf{R})}{R^4} I_0\left(t - \frac{2R}{c_0}\right)ds \qquad \text{eq. 4}$$

where $I_0(t)$ - transmitted pulse intensity, proportional to its squared envelope, $B^2 = |b|^4$ - two-way beampattern value, $s_s(\gamma)$ - the surface backscattering coefficient, which is related to the surface roughness statistical properties.

In this work, two concurrent forms of $s_s(\gamma)$ were considered: the form used in [6] for the case of Gaussian surface and the form introduced in [1] for power law surface.

Sample results

The numerical simulations of echo pressure $p(t)$ and concurrently of echo intensity $I(t)$ were performed for the same assumed statistics of bottom surface. The narrow band transmitted signal was used. The transmitted pulse envelope was assumed to be initially rectangular, deformed due to bandpass filtering in the transducer. For comparison of echoes obtained using $p(t)$ and $I(t)$ modelling, the squared envelope $|p_e(t)|^2$ and its average waveform was calculated for the narrow band signal $p(t)$. At the present stage of the research, the shapes of simulated signals rather than their absolute values were compared.

The sample results are presented in Fig. 1 (see the figure caption for details). It is quite visible that the shapes of echoes obtained by $I(t)$ modelling and by averaging the results of $p(t)$ modelling are quite similar. In case of shorter pulses, it is shown that the echo duration predicted by theory of intensity modelling is shorter than for one obtained by averaging for 100 realisations of surface roughness.

Conclusions

The general conclusions regarding the analysis of simulation results, also those not included in the scope of these 2 pages, may be summarised as follows.

- The obtained results are in general in line with expectations from theory and the simulated pressure echo waveforms are also similar to some extend to real acquired echoes.
- The comparison of shapes of modelled echo envelopes in pressure domain and in intensity domain shows that those two approaches are in an agreement.
- In both cases, for properly defined the experiment conditions, the simulated echo properties show sensitivity to bottom properties i.e. surface roughness.
- Echo pressure modelling leads to more accurate investigation of seabed backscattering than intensity modelling, as it was also concluded in [2] and [3].

Very important step in further research will be to perform the detailed comparison of the simulation results with the real data acquired in sites of known seabed properties, what may constitute the foundations for more reliable seafloor characterisation methods.

References

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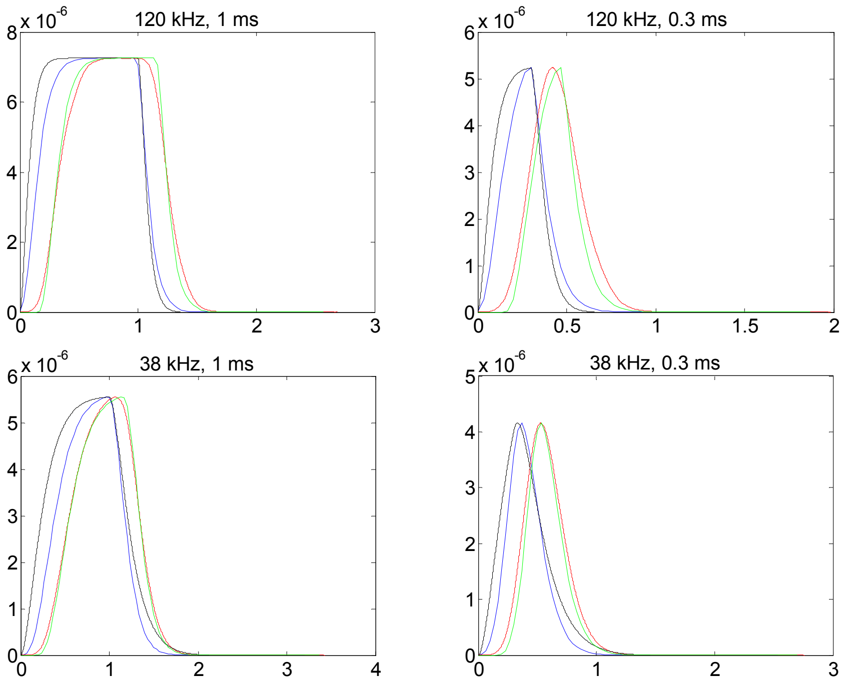

Fig. 1: Comparison of simulated echo squared envelopes for Gaussian seabed surface: red - averaged using *p*(*t*) for 100 realisations of surface roughness; blue - obtained by *I*(*t*) modelling; green – blue shifted in time to compare with red; black – transmitted pulse. The used parameters were: *h* = 0.04 m, *L* = 0.25 m, bottom depth 20 m, pulse duration 1 ms or 0.3 ms, transducer 3 dB beamwidth 6°, operating frequency 38 or 120 kHz. All signals are normalised to maximum value of the signal plotted in red.