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FRACTAL CHARACTERISATION OF 30 kHz ECHOES FROM SOUTHERN BALTIC BOTTOM

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The fractal dimension of 30 kHz echo envelope is used for characterise the bottom sediment type in Southern Baltic Sea. Two methods of the echo waveform fractal dimension calculation were applied: the autocorrelation function log-log slope method and the power spectrum log-log slope method. The results are presented and compared. They show that fractal dimension of echo envelope describes well the bottom sediments morphology and may be used as a significant descriptor in the remote sea bed classification procedures.

1. INTRODUCTION

The new method of the bottom sediment characterisation with the use of the echo fractal dimension was newly developed by the authors [1]. This method is based on the hypothesis, that layers of bottom sediments have fractal structure, which is transferred onto the shape of the acoustic echo. It is known that "acoustically" softer sediments are penetrated more deeply by acoustic signal and they produce longer and more corrugated echoes than harder sediments. It has been checked that fractal dimension of echo signal envelope, as a measure of its complexity and "roughness", carry useful information for sea bottom identification. The fractal dimension contains a great deal of information about the echo waveform geometrical properties and describes the vertical structure of bottom sediment layers. Therefore it may replace the number of other echo parameters in the seabed classification procedure, e.g. statistical moments. Usually, fractal dimension for envelopes of echoes from softer sediments has larger values than in the case of echoes from harder sediments.

In this paper, we present two methods of the echo envelope fractal dimension calculation compare the results obtained for the data from Pomeranian Bay.

2. CALCULATION OF THE FRACTAL DIMENSION

Fractal object is defined as a scale-invariant (self-similar) geometric set [2], what means that it can be described as a union of rescaled copies of itself. In fractal analysis, a method for measuring and comparing fractal object dimensions is needed. The methods of Euclidean geometry, for measuring length or area of 1^D and 2^D figures are not appropriate in this regard. One of the defined fractal dimensions, the so-called Hausdorff dimension [2], may be the solution to this problem. For a subset X of Euclidean space it is defined as a limit

$$D = \lim_{r \to 0} \frac{-\log N(r)}{\log r} \tag{1}$$

where $N(r)$ denotes the smallest number of open balls of radius r needed to cover subset X; an open ball $B(p, r) = \{x: \mathrm{dist}(x, p) < r\}$, where $\mathrm{dist}(x, p)$ is the distance between points x and p.

In the case of a graph of a one-variable, fractal function on a plane, the Hausdorff dimension has always value between 1 and 2 and describes the extend to which the graph resembles a smooth line ($D = 1$, the least complex shape) or an area ($D = 2$, the most complex shape) [1]. Thus the fractal dimension may be used as a measure of the complexity or "roughness" of the shape of a graph. In a case of an echo envelope, which consists of a finite number of discrete samples, the Hausdorff dimension cannot be calculated as a limit at $r \to 0$. It is estimated for some scale range $[r_1, r_2]$, within which the echo envelope is believed to have fractal properties.

We calculated the fractal dimension of bottom echo signals envelopes in time domain $y(t)$ using two indirect methods. The first method is based on the $y(t)$ autocorrelation function slope estimation in logarithmic domain. When the echo envelope $y(t)$ is assumed to be a process with fractal properties within a given range of small time lags τ, then it obeys the Lipschitz-Hölder condition [1]:

$$|y(t+\tau) - y(t)| \approx C \cdot \tau^{\alpha} \tag{2}$$

within this τ range (C is a constant). The exponent α is the Lipschitz exponent and it is related to Hausdorff dimension by

$$D = 2 - \alpha. \tag{3}$$

It can be shown that for small lags τ, the autocorrelation function $\overline{R}_{yy}(\tau)$ defined by

$$\overline{R}_{yy}(\tau) = \frac{\langle y(t) \cdot y(t+\tau) \rangle}{\langle y^2(t) \rangle} \tag{4}$$

will have the following form [1]:

$$\overline{R}_{yy}(\tau) \approx 1 - C_1 \tau^{2\alpha}. \tag{5}$$

Therefore the Lipschitz exponent α and subsequently the fractal dimension D can be calculated from the slope of a log-log plot of $\left(1 - \overline{R}_{yy}(\tau)\right)$ versus τ (for small τ) using linear regression algorithm [1].
Using the small τ condition, we selected the lag τ not greater than 6 samples.

The second method uses the slope of the power spectrum density of $y(t)$ in logarithmic domain. When the function $y(t)$ satisfies the Lipschitz-Hölder condition (2), its power spectrum density $G_y(f)$ has the form

$$G_y(f) = C_2 f^{\,p}, \tag{6}$$

where the exponent p is related to D by

$$D = (5 - p) / 2. \tag{7}$$

Similarly as in the previous method case, the fractal dimension may be calculated using the log-log plot of $G_y(f)$ versus frequency f.

3. RESULTS

The measurements of a bottom reverberation at a frequency of 30 kHz have been carried out in the Pomeranian Bay and in the other regions of Southern Baltic Sea from r/v "Oceania". In the experiments, ELAC 4700 echosounder with transducer mounted inside a towed V-fin body was used. The sounding pulses of 0.3 ms duration were emitted in 64 pulse sequences. The envelopes of bottom scattered signals were sampled at 3 to 9 kHz frequency and stored together with the information about the echosounder adjustments and ship position.

Fig. 1 and 2 present the spatial distribution of the echo envelope fractal dimension values obtained using two method for the Pomeranian Bay. Fig. 1 shows the fractal dimension D_a calculation results of the autocorrelation function slope method while Fig 2. presents the D_p calculation results of the power spectrum slope method.

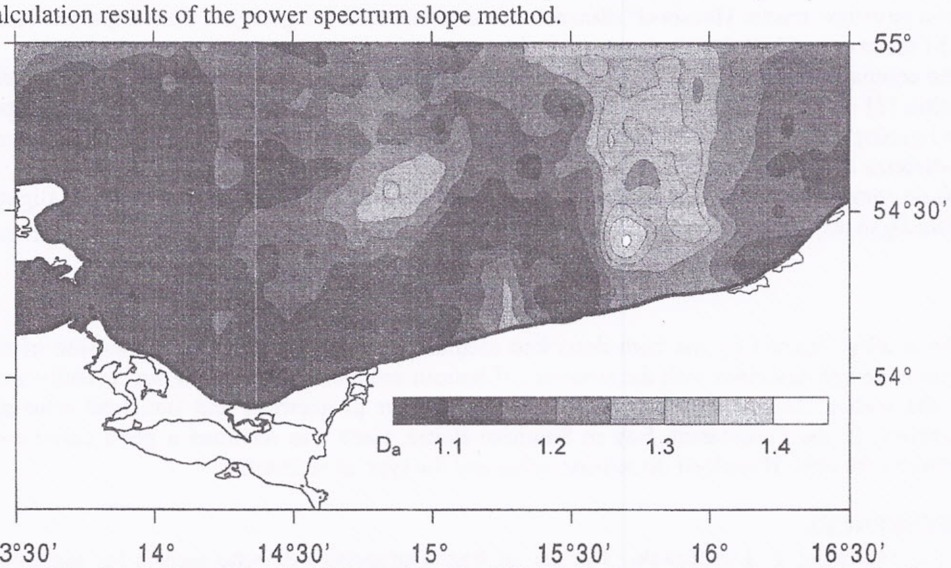

Fig. 1. The distribution of the fractal dimension D_a of 30 kHz bottom echo envelope within the Pomeranian Bay, obtained by the autocorrelation function log-log slope method

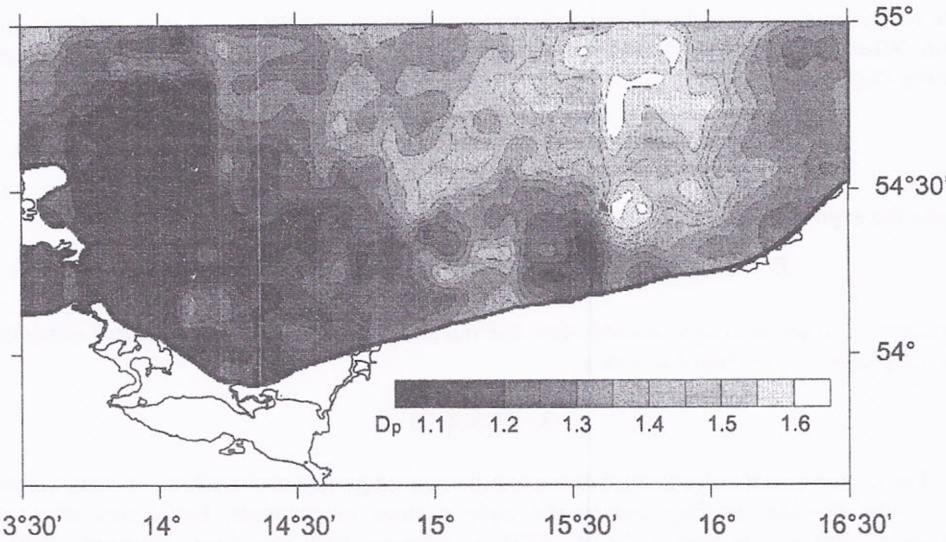

Fig. 2. The distribution of the fractal dimension D_p of 30 kHz bottom echo envelope within the Pomeranian Bay, obtained by the power spectrum log-log slope method

It can be seen that for strongly layered sediments the fractal dimension of echo envelope has the highest value, while for more homogeneous sediments, e.g. acoustically hard sands, this parameter has lower value. In the Southern Baltic Sea, the obtained averaged value of the echo envelope fractal Hausdorff dimension was about 1.28 for gravel, 1.40 for grained sand, 1.51 for clay and 1.66 for mud.

The comparison between this distribution and a map of bottom surface sediments in Southern Baltic [3] shows a good correlation between the echo fractal dimension and sediment types and geological forms. For instance, the fractal dimension has greater values for more layered sediments in areas of Baltic deeps and smaller values for shallow water sands.

While comparing the results obtained by the both methods, it is visible that D_a differs slightly from D_p in absolute values, but the trends are similar in the both cases.

4. CONCLUSION

The results obtained by the both described methods show, that the fractal dimension of the echo envelope describes well the structure of bottom sediments and may be successfully used in the seabed classification procedure, instead of other geometrical and statistical echo parameters. In the Pomeranian Bay in Southern Baltic, there was obtained a good correlation between the echo Hausdorff dimension value and the type of sediment.

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