MAPPING SEABED FEATURES FROM MULTIBEAM ECHOSOUNDER DATA USING AUTOCORRELATION AND MULTI-SCALE WAVELET ANALYSES

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In the paper we propose the method of seabed morphological features extraction, which we have obtained from bathymetric and backscatter data, recorded by multibeam echosounder. Presented results of acoustical recognition of the southern Baltic Sea bottom are the part of measurements conducted in the band of 220 km length in the central part of Polish coastal water. The detailed analysis of seabed features were performed for area located in the vicinity of Kołobrzeg harbour. The degree of seafloor corrugation was determined by autocorrelation analysis of seafloor bathymetry. To which, we used estimation of autocorrelation length and fractal dimension, based on the shape of autocorrelation function. Moreover, the parameters of wavelet decomposition of bottom backscattering strength were the input to fuzzy logic clustering system allowing for outline of seafloor areas of similar morphological features. Both presented methods have confirmed its effectiveness in identifying morphological characteristics and types of the bottom surface.

INTRODUCTION

The use of multibeam echosounders (MBES) for bottom recognition allows for investigation of detailed seafloor geomorphologic features of extensive seafloor areas. The idea of MBES seafloor classification based on angular dependency of the backscattered intensity is known in several classification systems [e.g. 1,2,3,4]. Other, but not so popular methods utilised for research of seabed morphology (slope and roughness) are based mostly on texture analysis [e.g. 4,5]. The authors of this paper made attempt to both mentioned analyses, where the first was based on parameterization shape of bathymetric transect (wavelet, statistical and fractal parameters) in sliding windows and used parameters as the input to fuzzy logic clustering system [4]. The second system was based on parameterisation of shape of angular dependencies of backscattered signal intensities. Computed parameters were the input to the segmentation system [4]. Positive results of both mentioned procedures allowed for classification of seabed types in the Rowy polygon (southern Baltic Sea area).

Need to identify the morphological characteristics of the bottom is important in mapping of the bottom habitats and description of morphological processes, which determine the shape of the bottom surface (eg, direction and speed of bottom currents). The main idea of this paper is to find the method of fast and complex description of scales of bottom corrugations. To perform this task we examined correlation features of seabed surface, measuring the autocorrelation radii and fractal dimensions based on the autocorrelation function. Moreover, to the spatial distribution of bottom backscattering strength (BBS) we applied a segmentation algorithm based on BBS spatial wavelet decomposition and fuzzy-logic clustering algorithm. Results of seafloor segmentation and classification for both algorithms gave a good correspondence with types of the bottom and its sediments.

1. AREA AND METHOD OF ACOUSTICAL MEASUREMENT

The acoustical measurements of seafloor of the Polish Exclusive Economic Zone within the Baltic Sea were conducted on board of the rv Imor from Maritime Institute in Gdańsk. The research vessel was well equipped with instruments for seafloor research as eg. MBES, side scan sonars, subbotom profilers, cameras mounted on the ROV, sediment core and grab samplers and precise GPS navigation systems. Special interest was focused on the narrow euphotic zone of the depth up to 20m elongated parallel to the Polish cost and containing

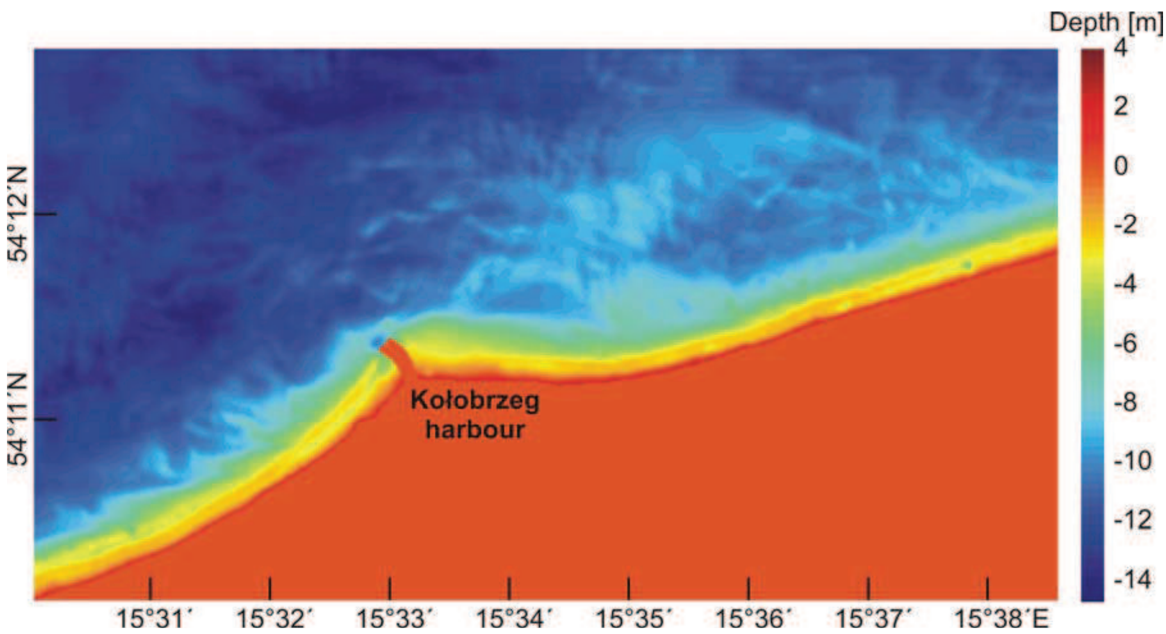

Fig.1. MBES bathymetry of investigated area - polygon located in the vicinity of the Kołobrzeg harbour

different morphological forms of the bottom. The total length of the surveyed area was about 220 km and of a width approximately 1 km. But in some particular areas, as e.g. vicinity of Kołobrzeg harbour, the measurements covered areas of larger distance than 1km from the coast (see Fig.1.). The bathymetry of surveyed area measured using MBES at a water depth of not less than 4 m and other techniques in surf zone (single beam echosounder and geodesic measurements) is presented in Fig.1. From the huge set of registered acoustical data we concentrated on MBSE bathymetric and BBS data.

The measurements were performed with multibeam echosounder Reson 8125 with working frequency of 455 kHz, range - 0,5m - 120m, no. of beams - 248, scan width - 120º and beam width - 0.5º. Due to spatial spread of investigated area, huge volume of registered bathymetric data and possibilities, as well as limitations of used computers, the spatial resolution of bathymetric 3D map was chosen on 2m by 2m, which is sufficient for investigated scales of seabed corrugations.

2. AUTOCORRELATION AND FRACTAL ANALYSIS OF SEAFLOOR CORRUGATION

The corrugation of rough surface is usually described by statistical, spectral or fractal techniques [6]. In our approach we combined statistical and fractal descriptions of bottom roughness. Efficient and reliable indicator of surface shape is the correlation length c_r, which is defined as distance over which the autocorrelation function $C(\vec{r})$ falls by 1/e. The other roughness parameter used in this analysis is fractal dimension D of the surface calculated on the base of slope of autocorrelation function.

The seafloor bathymetry map (matrix) was divided for squares of side lengths of 25 or 50 meters. For each isolated square of seafloor surface (see Fig.2.a.) was computed the autocorrelation function (Fig.2.b). The most of calculated autocorrelation functions of square areas are not isotropic, which confirms anisotropy of seabed undulations. For further analysis, we estimated the autocorrelation functions $C(\vec{r})$ and autocorrelation lengths c_r in x - horizontal and y - vertical directions for each isolated seafloor square (Fig. 2c).

Many shapes and forms in nature satisfy assumptions of the fractal geometry, that is, there are the self-similar at different scales. It has been shown that the landscape is a fractal surface [7, 8, 9]. The measure of object fractality is fractal dimension, so-called Hausdorff dimension [7, 10]. The Hausdorff dimension of a subset X of Euclidean space 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. It is practically impossible to measure fractal dimension using the above definition (1), and it is the reason for use of equivalent methods. In the case of rough bathymetric surface we used the technique based on the autocorrelation function for seabed surface bathymetric transect $f(x)$.

Theory of fractal geometry assumes, that fractal object $f(x)$ obeys Lipschitz-Holder condition:

$$\left| f(x+\varepsilon) - f(x) \right| \approx c\varepsilon^{\alpha} \tag{2}$$

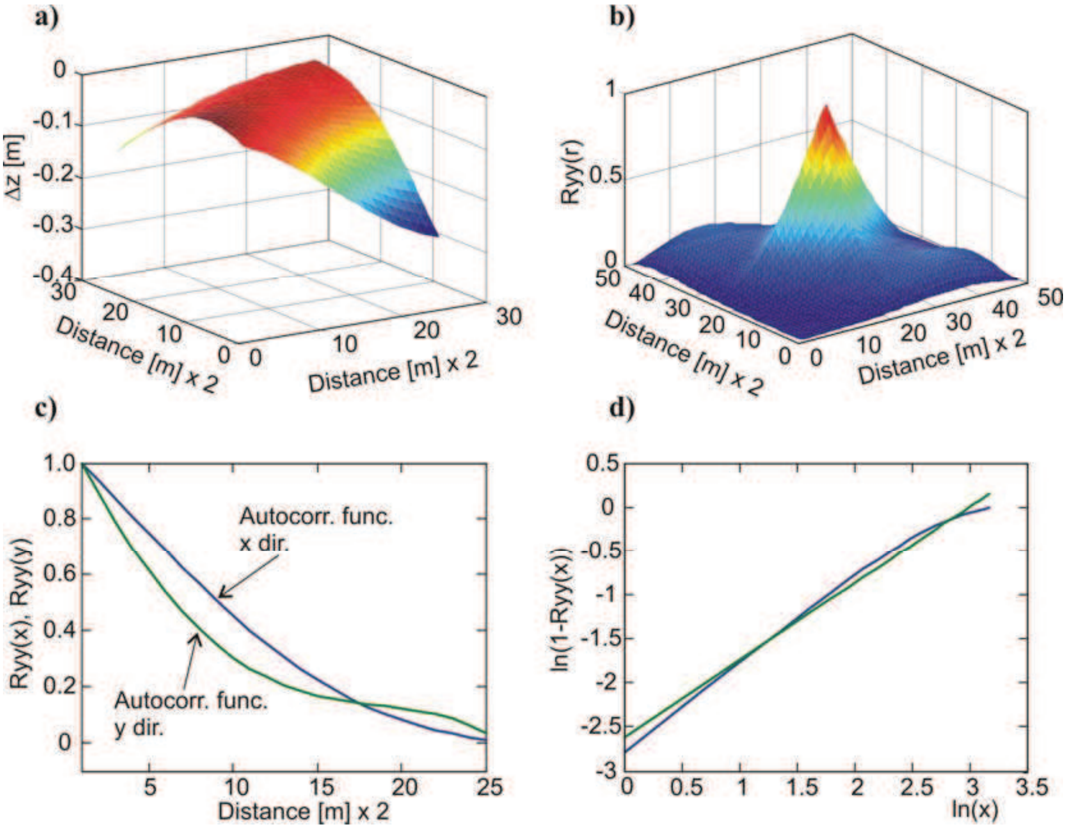

Fig.2. Example of isolated bathymetry square of size 50m by 50m a), and its autocorrelation function b), autocorrelation functions in x and y directions c), graphic method for deriving the α exponent and Hausdorff – Lipschitz dimension d)

where ε is segment of length and c is constant. In case of small length increments ε the exponent α is identified as the Lipschitz-Holder exponent [11]. The exponent α is related to the Hausdorff dimension through the formula [7]:

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

For smooth seabed the fractal dimension of surface transect is close to 1 ($\alpha \to 1$) and for corrugated surface the D is close to 2 ($\alpha \to 0$). For small segment of length ε we can write:

$$C(\varepsilon) \approx C(0) - c_1 \varepsilon^{2\alpha}, \tag{4}$$

where c_1 is a constant and $C(\varepsilon)$ is the autocorrelation function defined as:

$$C(\varepsilon) = \langle f(x) f(x+\varepsilon) \rangle. \tag{5}$$

Combination of (4) and (5) and normalisation of $C(\varepsilon)$, in logarithmic scale yields:

$$\ln\left(1 - \overline{C}(\varepsilon)\right) = 2\alpha \ln \varepsilon + c_2, \tag{6}$$

where c_2 is constant and $\overline{C}(\varepsilon)$ is normalised autocorrelation function. When applying linear regression algorithm, the Lipschitz-Holder exponent α can be calculated from the slope of a log-log plot of $1-\overline{C}(\varepsilon)$ as the function of ε [10]. The example of graphic method for deriving the α exponent is showed in Fig.2.d. Prove of seabed surface fractality is when the log plot of $1-\overline{C}(\varepsilon)$ function in relation to log plot of segment ε for a certain range fits straight line.

The results of correlation length c_r and fractal dimension D are presented in Figures 4 and 5 which illustrate the maps of their spatial distributions. Although, in this study we did not perform detailed geomorphologic analysis of investigated area, both parameters spatial

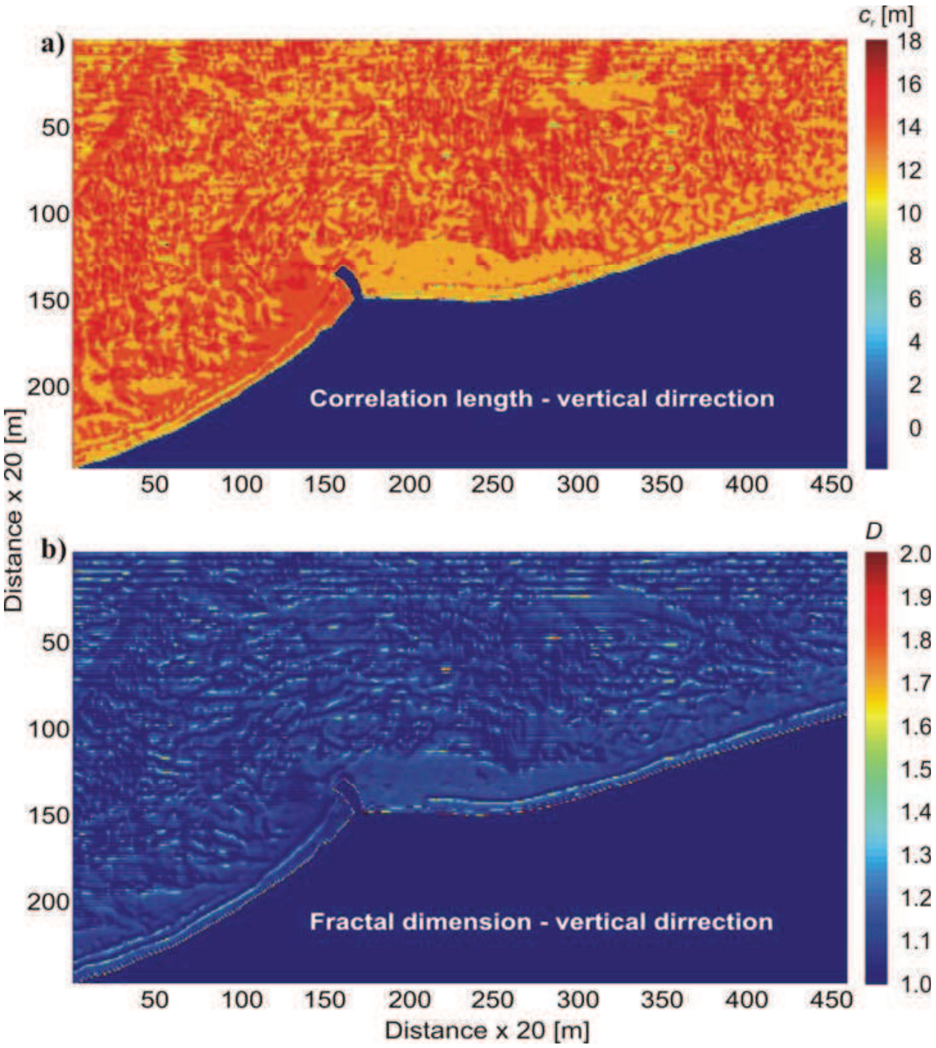

Fig.3. The spatial distributions of the correlation length c_r a) and fractal dimension D b) in the Kołobrzeg area for isolated seafloor squares of size 20m by 20m computed in vertical direction

distributions are very well correlated with geomorphologic features of the bottom. For example, in the East-North East direction from the Kołobrzeg harbour, there is the non undulated seabed, covered by sands of anthropogenic origin as a result of refulation works in this area. The values of c_r and D are different from values of parameters in area located in the West-South West direction from the harbour - the shallow seabed at a depth from 0 to 10 m with sandy waves zone. The differences in parameters measured in horizontal and vertical directions are mainly resulting from the fact that in the shallow area the majority of sandy waves and ripplemarks are parallel to the coast line. Moreover, the survey transects were conducted in West-East direction. The inaccuracy in water level estimations reflects as seafloor strips, which are well visible in fractal dimension computed for vertical direction (Fig.3.b).

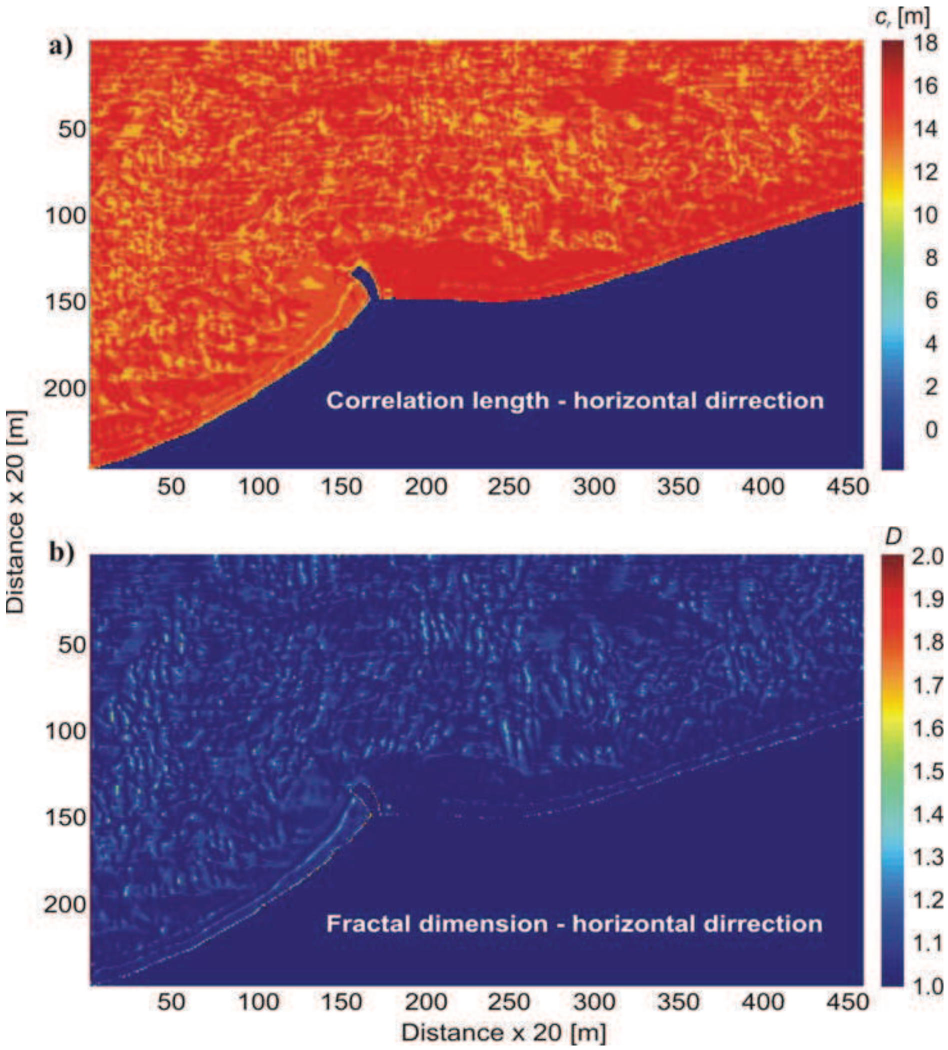

Fig.4. The spatial distributions of the correlation length c_r a) and fractal dimension D b) in the Kołobrzeg area for isolated seafloor squares of size 20m by 20m computed in horizontal direction

3. WAVELET DECOMPOSITION OF BACKSCATTERING STRENGTH DATA

The other approach to geomorphologic features extraction from the MBES recordings is the analysis of BBS data. Fig.5.a presents the map of spatial distribution of BBS values (relative, not scaled). The narrow horizontal strips reflect strong angular dependency of BBS. We have used the method based on discrete wavelet analysis of echo signals [12] for distinguishing the seabed types correlated with energy backscattered from the bottom. The method relies on multilevel wavelet decomposition of the bottom backscatter imagery into approximation and detail imageries (horizontal, vertical and diagonal). The decomposed signal S (imagery) can be described as the sum of decomposed elements as follows:

$$S = \left(D_1^H, D_1^V, D_1^D\right) + \ldots + \left(D_{N-1}^H, D_{N-1}^V, D_{N-1}^D\right) + \left(A_N, D_N^H, D_N^V, D_N^D\right), \tag{7}$$

where D_N^H, D_N^V, D_N^D are horizontal, vertical and diagonal details and A_N is approximation of N-th level. In presented analysis, the biorthogonal wavelets (bior.3.6) were used. Chosen decomposition elements were the input to fuzzy c-means (FCM) data clustering algorithm [13] producing segmented maps of the bottom. The result of above procedure for 4 clusters is

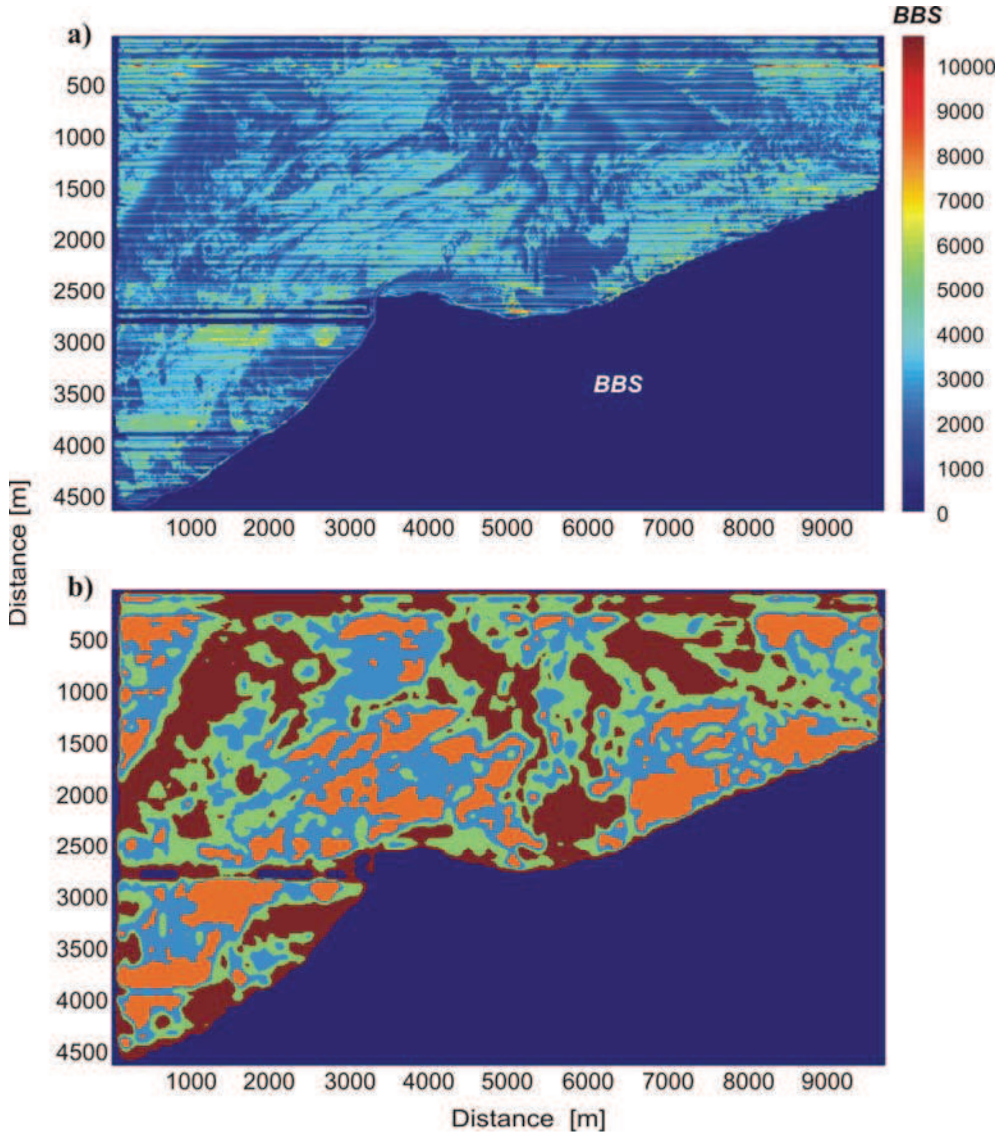

Fig.5. The map of bottom backscattering strength a) and result of segmentation of BBS spatial distribution for 4 clusters using wavelet decomposition parameters as the input to FCM clustering method b)

shown in Fig.5.b., where colour patches mark the areas of similar reflection properties. It should be noted, that received spatial distribution of seabed backscattered features is different from maps of characteristics resulted from seafloor roughness (Figs. 3 and 4) because both methods indicate different morphologic features of sea bottom.

4. CONCLUSIONS

The statistical and fractal parametric approach has been applied to analyse the bathymetric data collected in vicinity of Kołobrzeg harbour. The tested autocorrelation length and Hausdorff dimension are significantly differentiating factors for seabed shape discrimination between the different degrees of its corrugation. Additionally, the parameters of wavelet decomposition of bottom backscattering strength used for seabed classification system permit for outline of seafloor areas of similar morphological and sedimentological features. Comparative analyse of results of both results is very helpful for determination of seabed geomorphologic characteristics.

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