# PARAMETERS OF ECHO SIGNALS ORIGINATED FROM A GAS SEEPAGE SITE IN THE SOUTHERN BALTIC SEA

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*Gaseous shallow sediment has been recognized in several areas of the Southern Baltic Sea. The most commonly observed manifestation of the gas in the bottom top layer is an acoustic blanking or shadowing resulting from significant attenuation and scattering of acoustic signals in the regions of gas bubble occurrence at the bottom. The main goal of this publication was to examine whether known methods of acoustic echo parameterization generally used to determine the fraction of the surface deposits would be sufficient in determining the extent of the occurrence of gas saturated sediments and areas with periodic gaseous outflows. To this end, a set of an acoustic echo signals recorded in gas seepage regions by using four different frequencies (12, 70, 120 and 200 kHz) was analyzed. To determine the acoustic features of gaseous sediments, based on the shape of the echo envelope, a few statistical parameters, as well as the parameters resulting from a wavelet transform, were calculated. A comparison of the results allowed for a relatively accurate separation of pockmark areas.*

## INTRODUCTION

The presence of gas in shallow marine sediments has been discovered in many oceanic regions around the world. So far in the area of the Baltic Sea, all undertaken attempts were primarily performed in order to detect and determine the distribution of commercially available gas reservoirs located at depths below 1km under the surface of the bottom. To a much lesser extent, the conducted studies were concentrated on shallow layers of sediment. The presence of gas in these layers can have a significant impact on the ecosystem of the Baltic Sea, as well as on human activities associated with the seabed, so it is important to determine the areas of its occurrence.

So far, observations of gas bubbles at the top bottom layer of the Southern Baltic Sea have mostly been carried out in the Eckernförde Bay region [1, 2], in the Russian Exclusive Economic Zone of the Baltic Sea [3] and in the region of the Danish straits [4]. Previous research carried out in the Polish Exclusive Economic Zone of the Baltic Sea were conducted mainly by the Polish Geological Institute in western and central parts of the area (geogenic contamination analysis), but the applied methodology only to limited extent allows us to draw conclusions about the presence of gas in the upper layer of sediment [5]. A few trials were conducted in order to observe acoustically any manifestations of the presence of gas bubbles in the sediments of the Bay of Gdansk [6,7], and in the Bay of Puck [8] in the areas with a high occurrence of organic carbon groundwater discharges [9]. and high sedimentation rates [10]

In 2008-2011, a series of acoustic and geochemical measurements were conducted in order to determine the potential areas of methane gas bubble occurrence at the bottom top layer of the Southern Baltic Sea [11]. In the years 2008-2014, we conducted a number of hydroacoustic investigations in order to identify the forms of gas appearance in Southern Baltic surface sediments as well as its distribution. To this end, a number of diverse acoustic echo-sounders emitting various frequencies were simultaneously used. For rapid recognition of diverse forms of sediment, we tested a method of parameterization of acoustic echo signals described in this publication.

## 1. STUDY AREA

The main study area is situated in the Bay of Gdańsk, a region under a strong anthropogenic influence. Hydrological conditions in this area are significantly influenced by Vistula river discharge [12]. In the lower waters, common anaerobic conditions are often caused by the seasonal thermocline situation and the permanent pycnocline from just few to several meters above the bottom. In this region we can observe excessively high contemporary sedimentation rates of matter rich in organic content (the range in some regions being even over 2mm per year), caused by increased eutrophication [13]. All of these factors lead to the formation of free gas in sediments during the process of the anaerobic decomposition of organic matter.

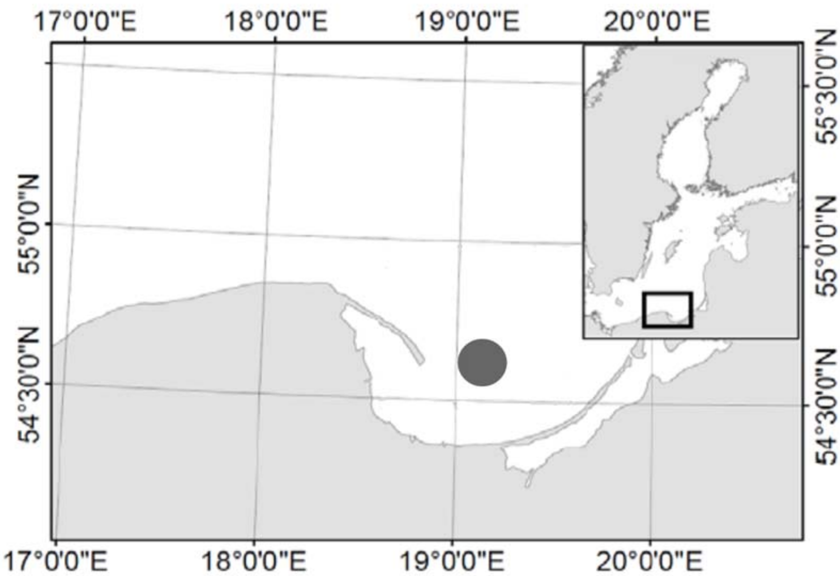


Fig. 1. Location of the experiment.

## 2. MEASUREMENTS

Acoustic observations were carried out in order to identify a different form of shallow gas saturated sediments and manifestations of gas presence in lower waters. To this end, a number of research cruises were carried out from 2008 to 2014. Diverse acoustic signals of various frequencies and beamwidths transmitted by a number of types of acoustic equipment were used. Receiving comprehensive results and a more accurate bottom diagnosis of gaseous methane presence at the bottom surface layer was possible through the simultaneous application set of an echosounder not previously used in these kinds of investigation.

As the principle tool used during data collection, an Odom MK III echosounder mounted in the hull of the ship working at two frequencies (12 kHz and 200 kHz) was employed. The especially low frequency allowed for observations of the sediment layer even just a few meters under the bottom surface. In gas bubble outflow regions, a Simrad EK60 echosounder operating on three frequencies (70, 120 and 200 kHz) was used during the ship's drift. Transducers of the Simrad EK60 echosounder were mounted close to each other in a metal cover and towed alongside the ship at a depth of about 3 meters below the sea surface.

In order to explain in a detailed applied methodology, a representative set was chosen from the collected data. The acoustic observations discussed in this article were carried out during the movement of the vessel at the designated transect (Odom MKIII 12 kHz data) and during the vessel's drift around the selected gas seepage region (Simrad EK60 echo-sounder). The consisted data set includes echo signals recorded in the area of gas saturated sediments and gas outflows from the methane pockmark, as well as signals recorded in regions of the distribution of sediment, without significant amounts of free gas between solid particles. We only used data which has been verified based on geochemical analysis.

## 3. ANALYSIS OF RECORDED DATA

While performing acoustic imagining, various features of shallow gas saturated sediments such as gas charged layers, acoustic turbidity, discontinuities in the stratification of gaseous sediments and gaseous pockmarks were all observed. The shape of the echo envelope is directly related to the bottom's physical properties. A parametric analysis of acoustic echo was performed based on a volume backscattering strength ($Sv$) in order to determine the range of the occurrence of gaseous sediments and all types of inhomogeneities associated with the gas bubble displacement between solid particles.

To better explain the parameterization procedure, in this paper we have used the sample data set corresponding to the gaseous pockmark area in the Bay of Gdansk region.

As a first step, both the data from the Odom MKIII echosounder as well as data from the EK60 multi frequency echosounder was analyzed to remove the signal recorded with a significant tilt of echo-sounders caused by waving. The statistical envelope parameters were calculated based on the linear form of the $Sv$ (expressed on a logarithmic scale). The TVG function was established in the form of $20\log_{10} R$ (where $R$ expresses the distance between the transducers and the specified part of the bottom.

Based on the transformed echo envelope, the statistical zero ($n=0$) order moment, the second ($n=2$) order moment and the third ($n=3$) order moment characterizing the variability of the shape of the echo envelope was calculated thus:

$$\Lambda_{X\,n} = 2\int_{0}^{\infty} t^{n} X(t)dt \tag{1}$$

Where *t* expressed the reaching time of the selected echo fragment from the bottom to the transmitter, and *X(t)* represents the transformed echo envelope.

In the next step the second and third order moments were used to calculate the skewness of the echo envelope describing the asymmetry of the envelope based on the formula:

$$X_{SK} = \frac{\Lambda_{X\,3}}{\sqrt{\Lambda_{X\,2}^{3}}} \tag{2}$$

A separate group of parameters used previously by other authors to determine surface sediment fractions [14] had factors calculated based on a wavelet analysis. In the first step, the wavelet transform coefficient describing the degree of the correlation between the wavelet and the analyzed part of the signal was calculated according to the formula:

$$C(a,b) = \int_{-\infty}^{+\infty} X(t)\psi(a,b,t)dt \tag{3}$$

where $\psi(a,b,t)$ describes a wavelet function (in this publication the *Haar wavelet*). In the next step, the wavelet is shifted to the right by the value of the parameter *b* and again another wavelet transform coefficient is calculated. This step is repeated with the entire signal coverage and calculation wavelet transform coefficient for each step. Sequentially, the scale factor *a* is increased, which results in a wavelet stretch and the whole procedure is repeated. In the next step, the basis of the wavelet transform coefficient, and the wavelet decomposition energy parameters are calculated according to the formula:

$$E_{wav.j} = \int_{0}^{b_{\max}} C^{2}(a,b)db \tag{4}$$

As the last parameter, the entropy of wavelet signal decomposition was calculated:

$$ent_{wav} = \sum_{j=1}^{7} E_{wav.j} \ln E_{jwav} \tag{5}$$

## 4. RESULTS AND DISCUSSION

Applying four different frequencies during the research allowed us to precise the observation of the pockmark structure. In regions with a high gas concentration it is possible to observe such an effect as acoustic blanking and shadowing connected with a rapid absorption of the signal in the sediment. In the figure (Fig 2.), it is possible to notice significant differences between the shape of the echo envelope registered in the gas free muddy sediment (column A.) and the part of sediment containing gas bubbles (column B.). In any considered case (70, 120 and 200 kHz) it was possible to observe a much higher amplitude of the reflected echo and a significant attenuation of the signal in the area defined as a gas crater, a ranging average in the first 50cm of the sediment -15,2 dB/m for 70 kHz, -27,9 dB/m for 120 kHz and -43,3 dB/m for 200 kHz.

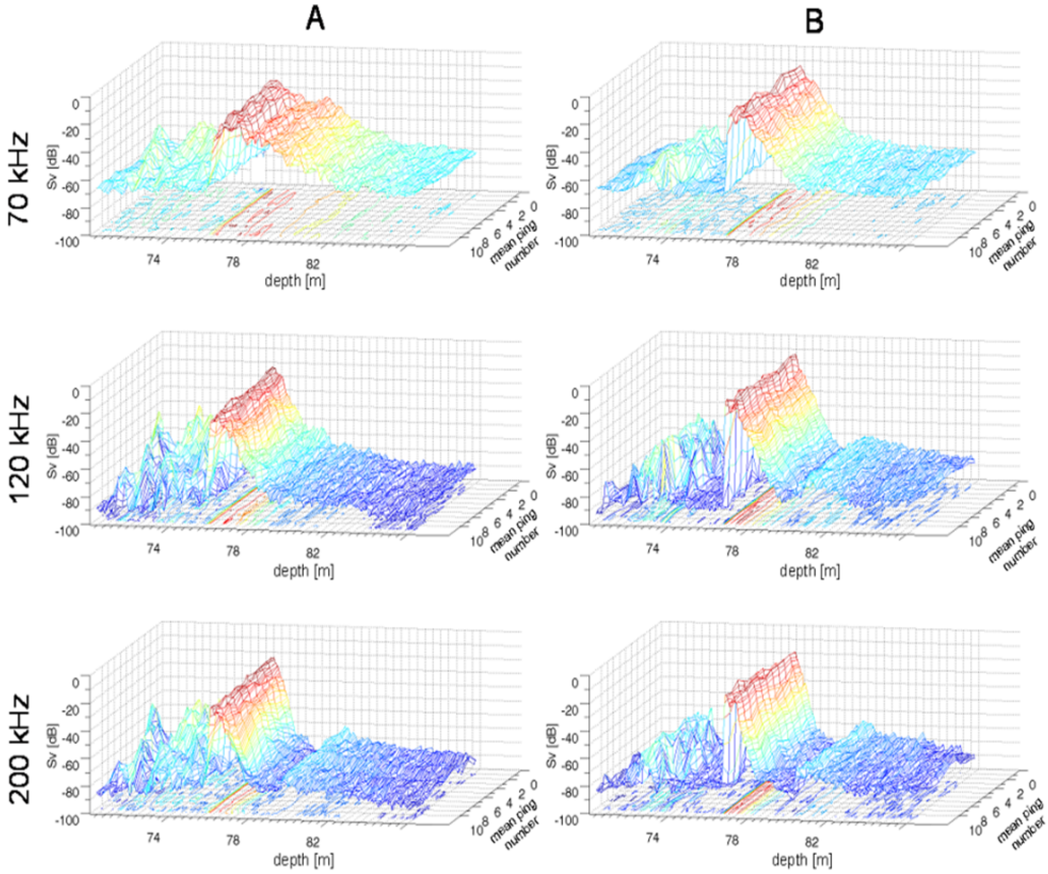


Fig. 2. Examples of the echo envelopes obtained as a mean value from the packet of 10 consecutive pings for the various transmitted frequencies (70, 120, 200 kHz), for the gaseous pockmark area (A) and for the muddy sediment region without gas bubbles (B).

The parameterization of acoustic signals allowed us to observe significant differences between the echo scattered from the muddy sediments without gas (or an inappreciable amount of gas bubbles), gas saturated sediment without gas bubble outflows (for 70,120,200 kHz) and sediments with visible gas bubble outflow (for 12 kHz). Especially the parameters obtained based on wavelet transform seems to be very sensitive to signal penetration depth into the bottom, which is often strongly associated with the presence of trapped gas bubbles between solid particles (Fig 3). In the gaseous pockmark regions (Fig. 3, column A), wavelet parameters achieve much higher relative values than for the adjacent area (Fig. 3, column B) where the content of gas bubbles in sediment is minor or nil.

Large contrasts in the values of the wavelet decomposition energy parameters (especially the fourth, fifth and sixth) allow for the automatic separation of sediments with different properties (due to the presence of gas at the bottom). These changes are also able to be observed based on the entropy of the wavelet signal decomposition parameter, Fig. 4 and Fig. 5.

In the case of echo signals recorded using a 12 kHz echo-sounder it is also possible to observe significant changes in three others parameters: the zero order moment, the second order moment and the skewness (Fig.4). These differences in the parameters calculated for an echo at a different part of the bottom are less visible but also significant in the case of other frequencies (70, 120 and 200 kHz). The skewness parameter seems to be especially useful in the process of the gaseous sediment characteristic and the separation of specific regions (Fig. 5). It should be noted that the echo signal obtained from the Odom MKIII echo-sounder was recorded during gas bubble outflow from sediments, while the echo signal obtained from the EK60 echosounder was recorded in the same region but in over a period when no outflowing bubbles were observed. Lower dynamics in parameter variation may be thus caused by a lesser content of gas bubbles in the boundary layer between water and sediment in this period, which both directly influence the signal penetration depth into the bottom and thus affect the shape of the echo.

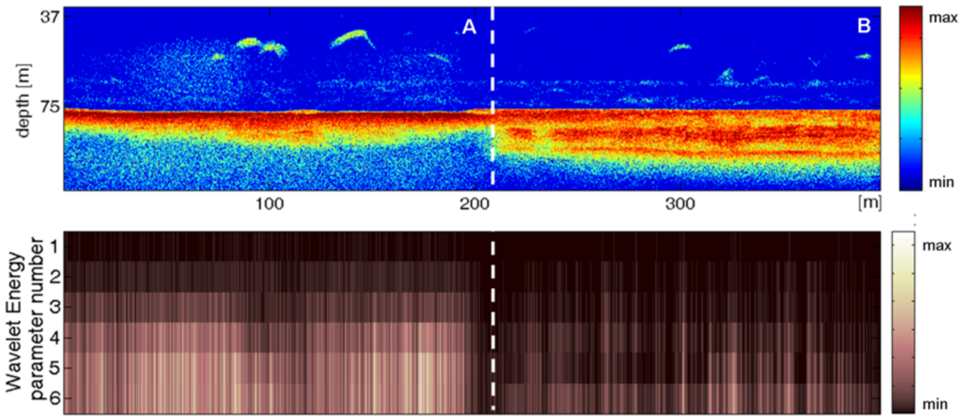


Fig. 3. Top panel echogram (obtained from 12 kHz echosounder) shows the border between the gas pocket with visible gas bubble outflows (left side) and the part of muddy sediment without gas bubbles or with a minor amount of gas (right side). The lower panel presents the variability of the six first wavelet decomposition energy parameters.

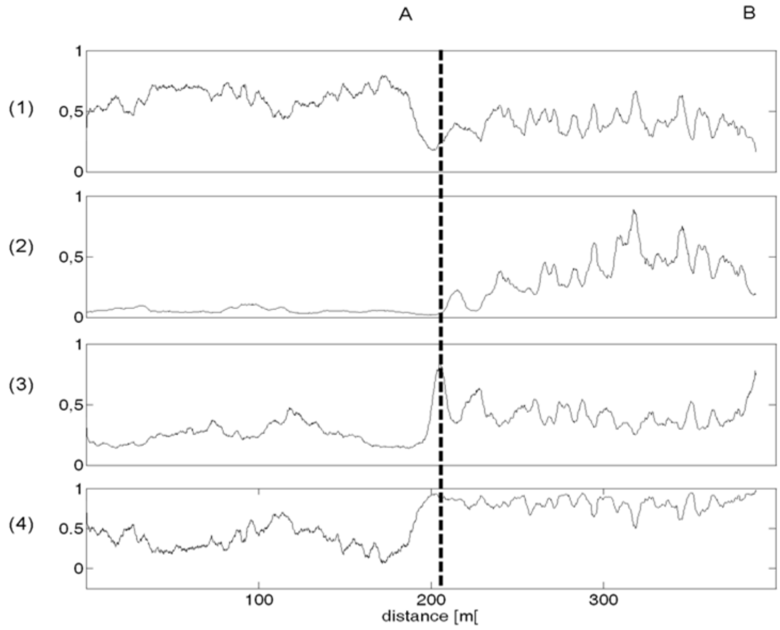


Fig. 4. Example of the variability of the four parameters calculated for the part of the bottom presented on the echogram on Fig. 2. In the (1) panel – zero order moment, panel (2) – second order moment, panel (3) – skewness, panel (4) – entropy of wavelet signal decomposition. All parameter values were normalized for the whole observed area.

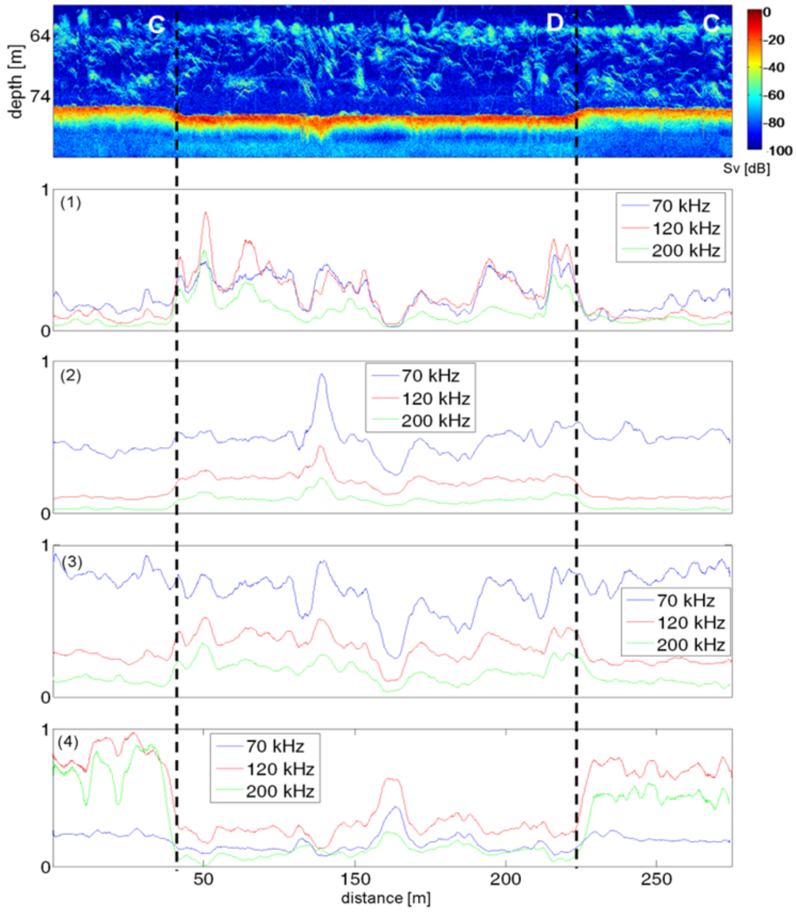


Fig. 5. The top panel presents an echogram (obtained from the 120 kHz echosounder) for the gaseous pockmark region (column D) and muddy sediments (columns C).The four consecutive panels show the variability of the parameters for 70, 120, 200 kHz: (1) - wavelet signal decomposition entropy, (2)-second order moment, (3) - zero order moment and (4) - skewness. All parameter values were normalized.

## 5. SUMMARY

However, methods of acoustic signal parameterization are not a very new tool in the process of sediment characteristics (especially in terms of the grain size of the sediments), usage the specific parameters presented in this publication to determine the extent of gaseous deposit occurrence in the Polish Exclusive Economic Zone of the Baltic Sea is a relatively novel approach.

Described in this publication, the parameterization method of the acoustic echo envelope show high sensitivity to changes in the signal associated with the occurrence of gas in the sediments. The presented examples clearly demonstrate that a significant amount of gas bubbles in sediments is one of the main factors that have an influence on the acoustic properties of the sea bottom and also affect the shape of the echo envelope. Differences in the length of the scattered signals are particularly noticeable in the case of gas saturated muddy sediments and sediments with similar grain sizes containing no bubbles. This features allow us to treat the calculated parameter as an indicator which can be used in the next step as an input data set for a various classification of algorithms which will allow to isolate gaseous sediment zones.

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