# INVERTING FOR BOTTOM PARAMETERS IN SHALLOW-WATER SOFT SEDIMENT ENVIRONMENTS USING MBES BACKSCATTER STRENGTH

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***Abstract:*** *Shallow water naval operations require detailed knowledge of the environmental properties. In addition to parameters such as water depth, knowledge about the sediment properties is of high importance for a wide range of operations. In this context, the MREA BP'07 experiment was carried out in the Mediterranean Sea in 2007. Measurements employed a large set of sensors, thereby providing all information required to fully describe the environment. This paper focuses on multibeam echosounder (MBES) measurements, which were taken not only to provide information about the water depths, but also to provide the backscatter strength as a function of angle. These backscatter data are employed to infer sediment parameters. To this end, a comparison of measured and modeled backscatter strengths is conducted. Use is made of a model that accounts for both scattering at the water-sediment interface and scattering and scattering at the inhomogeneities in the sediment, i.e. volume scattering. In practice, the measured backscatter strength values are affected by the imperfect MBES calibration. This impedes a direct model-data comparison, unless the effects of miscalibration are eliminated. Therefore, a calibration curve is derived by optimizing spectral strength and volume parameter, according to known mean grain sizes at bottom grab positions. After having corrected the measured backscatter strength for these systematic effects, inversions are carried out to estimate the sediment parameters (grain size, spectral strength, and volume parameter) at various locations in the research area.*

***Keywords:*** *backscattering, seafloor classification, inversion, multibeam echosounder*

## 1. INTRODUCTION

Shallow water naval operations have become highly important for a wide range of applications, for instance mine hunting operations. Such applications require detailed knowledge about the characteristics of the underwater environment, including bottom properties.

Mainly, two types of bottom properties can be discriminated according to [1]: physical properties (e.g., grain size) and geoacoustical properties (e.g., backscatter strength). A direct measurement of the physical bottom parameters requires bottom samples. Collecting these samples is a very time consuming process. Therefore, often alternative methods are followed. They commonly employ measured geoacoustic properties, for example, obtained by a multibeam echosounder (MBES), and assign these to physical properties by, for instance, modelling [2]. Physical bottom parameters then can be inverted for by optimizing the fit between the model predictions and the measured backscatter strength. Alternatively, a relatively limited set of bottom samples can be employed to deduce the relation between measured geoacoustic properties and, e.g., mean grain size.

In this paper the measurements consist of backscatter strength as a function of angle. Backscatter models are well-proven in areas with common sediment types (e.g., sand, gravel). However, research on the backscatter modelling in areas consisting of very fine grained sediments and colloides is currently lacking.

One such site of very fine grained sediments is the shallow water region in the Mediterranean Sea, south-east of Elba Island. Data analysed in this paper are collected during the multidisciplinary MREA BP'07 experiment (as described in [3]) that was carried out in this region.

This paper is organized as follows. First, a brief description of the data, taken during the MREA BP’07 experiment, is given in section 2. Section 3 focuses on the modelling of the MBES backscatter strength measurements for inverting physical parameters of the seafloor. Thereafter, results are discussed in section 4. Finally, results are summarized and embedded in the context of the research project in section 5.

## 2. THE MREA BP’07 EXPERIMENT

In the context of the Marine Rapid Environmental Assessment (MREA) project, the MREA BP'07 experiment was carried out in the Mediterranean Sea during two weeks in the spring of 2007. The survey focussed on a shallow-water environment between 10.7° and 11.0° eastern longitude and between 42.5° and 42.8° northern latitude. For survey details we refer to [3]. A part of this area was already surveyed during former experiments, such as the Yellow Shark (YS) experiments (see [4], [5]). These experiments provide additional information for interpreting the data.

Measurements that were taken during the MREA BP’07 experiment employ a large set of sensors (e.g. multibeam and three-frequency single beam echosounders, seismic profilers, bottom grabber), thereby providing all information required to fully describe the environment. In this paper we focus on MBES data and bottom grab samples.

MBES data were taken by a SIMRAD EM3000D that is mounted on the HNLMS Snellius, a hydrographic vessel of the Royal Netherlands Navy. This MBES operates at 300 kHz with a ping rate of 0.2 s to 0.3 s. Within an opening angle of 130° up to 245 beams are formed, dependent on the water depth. Per beam information about the depth and backscatter strength is obtained.

Depths values vary within the wide range from 0 to 130 m. Shallowest parts occur in the north-east, near to the Italian coast. From these regions on, depth increases with distance to the coast, resulting in isobaths that tend to run parallel to the coastline.

MBES backscatter strength data also tend to vary with the distance to the coast. From the shallow to the deep part, backscatter strength first decreases up to about 50 m depth, before it increases again. This behavior can be seen in the map of backscatter classes (Fig.1), as presented in [6]. The classes represent backscatter strengths at 44° beam angle, an angle that is sufficient small to obtain measurements at all present water depths, but still sufficient large to cover a large footprint area.

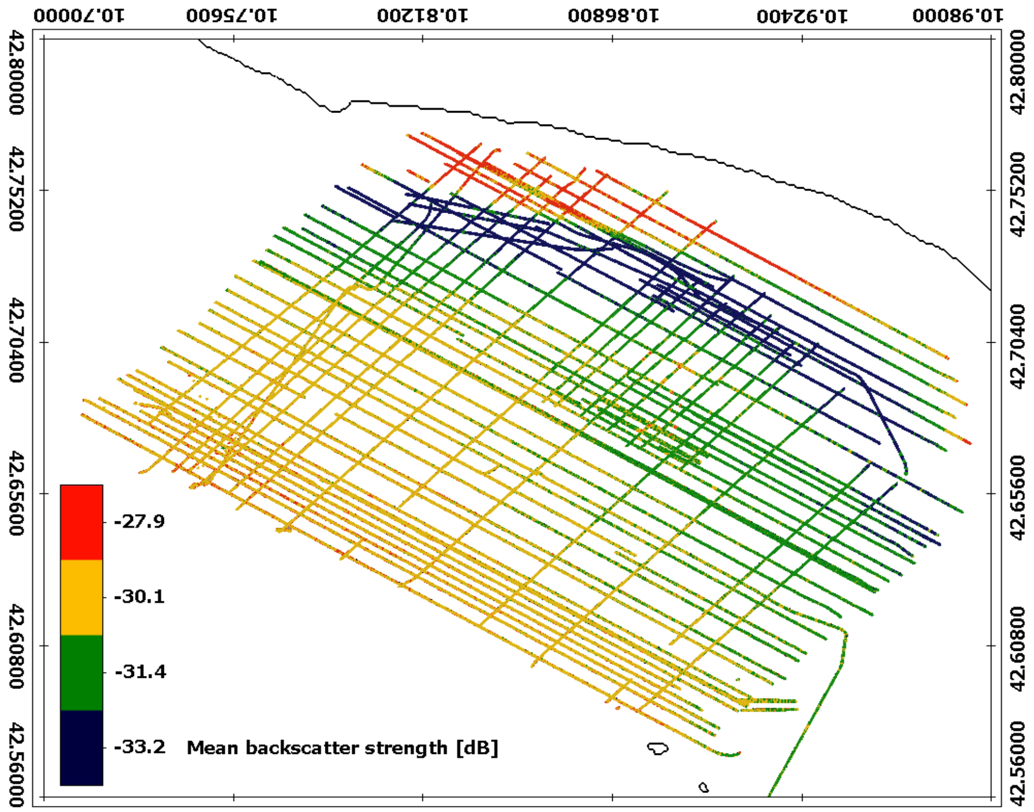


*Fig. 1: Backscatter strength classes in the MREA BP'07 area.*

Additionally, 24 bottom grabs were taken with a Hamon grabber to provide ground-truthing information. These bottom grabs were analyzed at TNO, in the Netherlands. They show the occurrence of very fine grained sediments over the entire area. Mean grain sizes $M_z$ are calculated according to [6] as the average of the three proportions $d_{16}$, $d_{50}$, and $d_{84}$. Hereby, $d_x$ denotes the grain size in $\phi$ units, at which $x$ % of the grains in the sample are smaller. A map of mean grain sizes is given in Fig. 2.

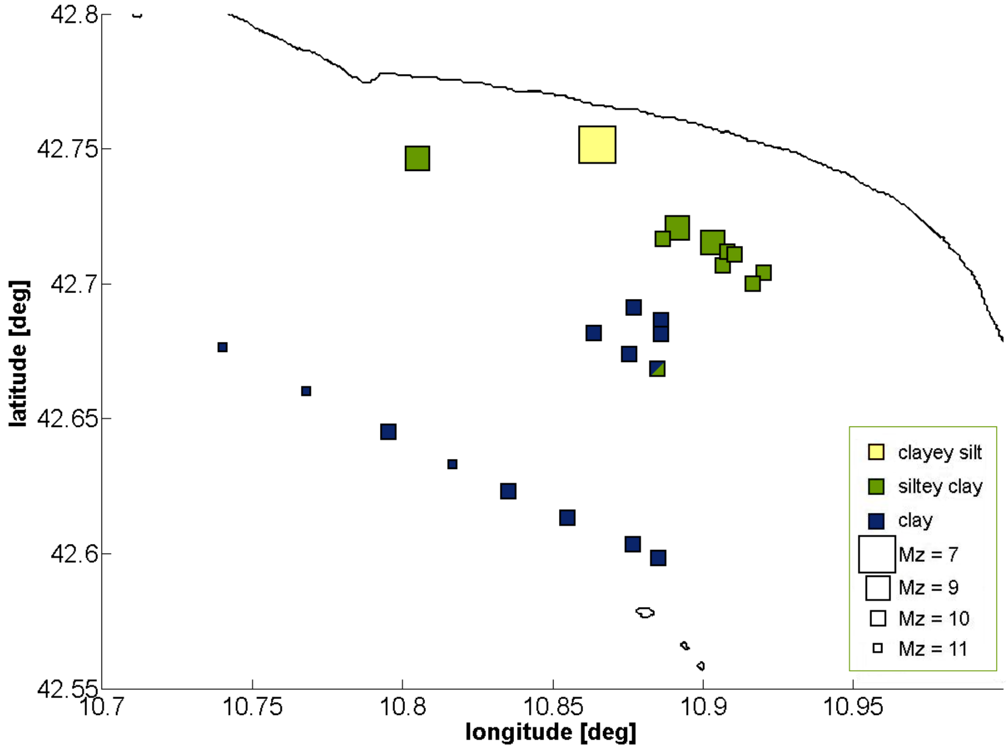


*Fig. 2: Location and classification of the bottom grab samples in the MREA BP'07 area.*

## 3. INVERSION OF SEAFLOOR PARAMETERS FROM MBES BACKSCATTER STRENGTH

The backscatter strength of an acoustic signal that is returned from the seafloor contains information about the properties (e.g., density and roughness) of the sediments. This information is expressed in the varying shape and value of the measured MBES backscatter strength curves per swathe. Therefore, MBES backscatter strength measurements can be used for assessing the sediment composition of the seafloor.

In order to link acoustic measurements to a set of related seafloor parameters, a geoacoustic model is employed according to [7].

### 3.1. The backscatter strength model

The present model [7] of the backscatter strength $BS_{mod}$ at a certain angle θ distinguishes between a contribution from a backscatter cross section that is due to interface roughness $\sigma_r$ and one that is due to volume scattering $\sigma_v$.

$$BS_{\text{mod}}(\theta) = 10\log_{10}[\sigma_r(\theta) + \sigma_v(\theta)] \tag{1}$$

Parameters that contribute to $BS_{mod}$ are listed in Table 1. While the interface roughness scattering mainly varies with the spectral strength $w_2$, the volume parameter $\sigma_2$ is the crucial parameter for the volume scattering.

| Seafloor parameter | Symbol |
|---|---|
| Sediment – water ratio of mass density | $\rho$ |
| Sediment – water ratio of sound speed | $\nu$ |
| Imaginary to real wavenumber ratio | $\delta$ |
| Sediment volume scattering cross section to attenuation coefficient ratio | $\sigma_2$ |
| Exponent of the bottom relief spectrum | $\gamma$ |
| Strength of the bottom relief spectrum | $w_2$ |

*Table 1: Seafloor parameters.*

The interface roughness cross section differs according to changes both in sediment softness and angle. Therefore, a set of three approximations is applied, which all cover a certain angular range and sediment type: 1) the Kirchhoff approximation for smooth and moderate rough bottoms at grazing angles between 40° and 90°; 2) the composite roughness approximation for smooth and moderate rough bottoms at grazing angles below 40°; and 3) the large-roughness approximation for gravel and rock bottoms. The last approximation, however, does not contribute to the model used here, since only soft sediments are present in the MREA BP'07 area. All contributions are a function of the roughness spectrum. Hereto, [7] uses the following isotropic relief spectrum $W_2(K) = (h_0K)^{-\gamma} w_2$, with $K$ denoting the wave number of the bottom relief and $h_0$ a reference length of 1 cm.

The sediment volume scattering cross section is calculated from Eq. 2 by applying corrections for slope effects and shadowing. Hereby, $R(\theta)$ denotes the amplitude refraction coefficient at grazing angle $\theta$. Furthermore, $P(\theta)$ is calculated according to $P(\theta) = [\kappa^2-\cos^2(\theta)]^{1/2}$ with $\kappa = (1+i\delta)/\nu$ and $\mathrm{Im}\{P(\theta)\}$ is its imaginary part.

$$\sigma_{pv}(\theta) = \frac{5\delta\sigma_2 \left|1 - R^2(\theta)\right|^2 \sin^2(\theta)}{\nu \ln 10 \left|P(\theta)\right|^2 \mathrm{Im}\{P(\theta)\}} \qquad (2)$$

### 3.2. Calibration

Before employing a comparison between model and measurements for the purpose of inverting bottom parameters, calibration has to be applied. The calibration of the measured backscatter strength data is necessary, since these data show systematic effects over the entire angle range. In order to eliminate these systematic effects, a calibration curve is derived and is added to the MBES backscatter strength measurements $BS_{meas}$.

To this end, backscatter measurements are selected from regions in which sufficient groundtruthing information is available. These are regions in which bottom grabs are taken. Around each grab position a sequence of 100 pings is selected. The average of these pings is then employed in an optimization step. In this step the mismatch between the model and each of the averaged measurements is minimized with regard to the spectral strength $w_2$ and the volume parameter $\sigma_2$. The other model parameters of $BS_{mod}$, thereby, are adapted to the measured mean grain size $M_z$ at the current bottom grab position.

The resulting calibration curve should reflect systematic effects only and should therefore be independent of the area, i.e. bottom type.

For the reason of reliability, only grabs with a mean grain size of $M_z$ = 9ϕ or less are considered for calibration purposes. This restriction is made, since the model was basically introduced for an $M_z$-range of -1 to 9 ϕ. For the MREA BP'07 experiment this leads to a selection of four bottom grab positions (see Fig. 2).

In the case no systematic effects are present the difference between the optimal model, including the optimized parameters $w_2$ and $\sigma_2$ as well as the measured $M_z$ value, and the measurements should be zero. From Fig. 3 it can be seen that this is not the case. At all four considered grab positions the difference curves (thin, colored lines) are shifted from zero and vary strongly, but in a comparable way. Therefore, the calibration curve $C$ is taken as the average of these difference curves (thick, black line). The calibration curve itself is independent of grain size.

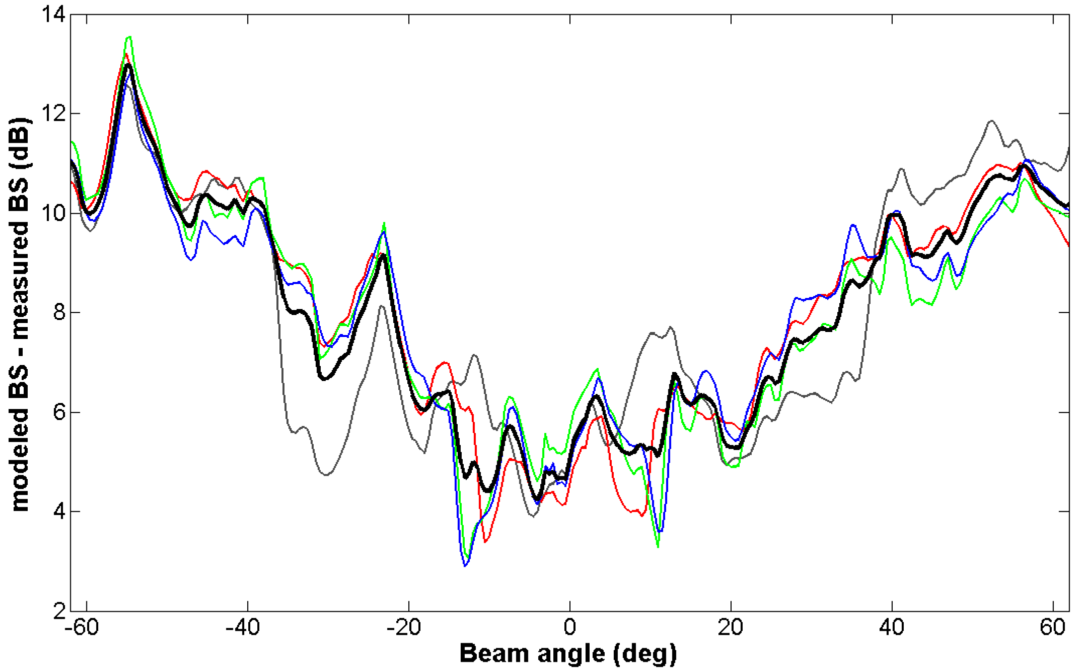


*Fig. 3: Differences between modelled and measured backscatter strengths at bottom grab positions for $M_z$ = 7$\phi$ (thin, gray line) and $M_z$ = 9$\phi$ (thin, colored lines). The calibration curve (thick, black line) is taken as the average of these curves.*

### 3.3. Inversion

Estimating seafloor properties by inversion is conducted for three parameters, which are assumed to vary strongly with seafloor type. These parameters are the mean grain size $M_z$, a scaling factor $w$ for the spectral strength $w_2$, and the volume parameter $\sigma_2$. These parameters are known to show strong variations (see [7]). Consequently, actual values might deviate significantly from default values. For the remaining parameters empirical relations, expressing them as a function of mean grain size, are employed.

A maximum agreement between the calibrated measurements $BS_{meas}+C$ and the model $BS_{mod}$ at interpolated angular positions $k$ is obtained by optimization. Hereto, the following energy function $E$ is minimized:

$$E = \sqrt{\frac{\sum_k (BS_{\mathrm{mod},k} - (BS_{meas,k} + C))^2}{\sum_k (BS_{meas,k} + C)^2}} . \tag{3}$$

## 4. RESULTS

Inversion of the three parameters, mean grain size, spectral strength, and volume parameter, has been conducted by employing the model of backscatter strength values as described in section 3. Hereto, several regions in the MREA BP'07 research area have been selected based on the classification of the backscatter strength at a beam angle of 44° (Fig. 1) and the mean grain size distribution of the bottom grabs (Fig. 2).

Figure 4 shows the map of the inverted volume parameter $\sigma_2$. Patches of comparable $\sigma_2$ values persist throughout the entire area. They tend to follow the pattern of the bottom grab samples and the backscatter strength classes. Overall, $\sigma_2$ values are slightly higher than expected. The default value for $\sigma_2$ in the model is 0.002 for fine grained sediments [7] such as in the experimental area. Extreme high volume parameters occur in the shallowest parts close to the Italian coast. Such high values might result from the occurrence of gas deposits in the sediments as observed on seismic profiles [3].

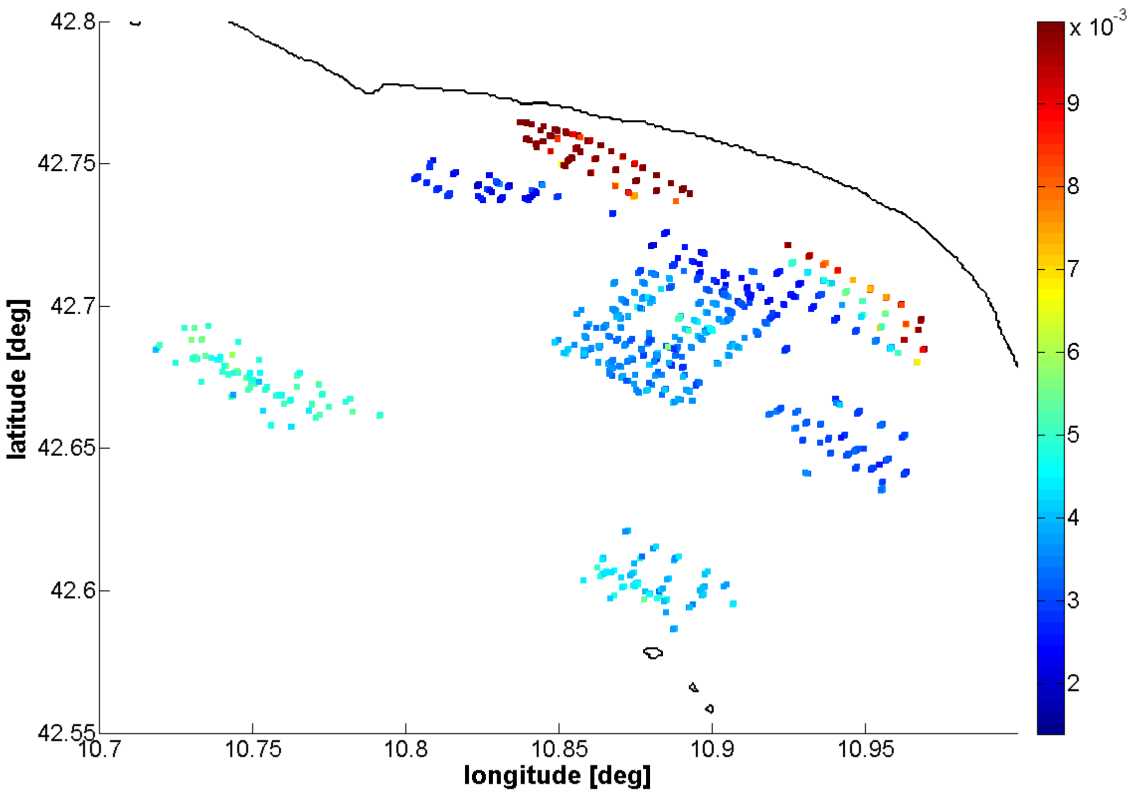


*Fig. 4: Inverted volume parameter at several spots in the MREA BP'07 area.*

However, the two other parameters $M_z$ and $w_2$ (not shown here) do not show such clearly separable patches as the volume parameter does. The inverted mean grain size is scattered throughout the entire area, thereby underestimating the actual mean grain size values of the slightly coarser sediments and overestimating the actual mean grain size values of the softest sediments. The inverted spectral strength appears to be less scattered, but shows values at the outer search boundary for almost each measurement taken in regions that feature very soft sediments ($M_z$ = 9ϕ or less). Only in the shallowest part, where sediments with mean grain sizes of 7 to 9ϕ occur, two patches of different $w_2$ values are distinguishable. Research on these parameters is ongoing.

## 5. CONCLUSION

Three bottom parameters mean grain size $M_z$, spectral strength $w_2$, and volume parameter $\sigma_2$ have been inverted for, using a model that accounts both for the interface roughness scattering and the volume scattering of the seafloor sediments. Thereby, valuable results are obtained for $\sigma_2$, which match the pattern of backscatter strength classes. The range of applicability of the model can therefore be extended to grains even smaller than $M_z$ = 9ϕ, at least when considering the inversion of the volume parameter.

Neither $M_z$ nor $w_2$ can be inverted reasonably for the MREA BP’07 soft sediment environment. These model parameters seem not be suited to properly describe (resolve) small differences in the backscatter properties of such fine grains. From this we can conclude that volume scattering plays a dominant role in interpreting the backscatter strengths in soft sediments.

Additional research has to be carried out with regard to the search boundaries of the spectral strength in order to make the model capable to discriminate between the softest sediments. Furthermore, fine grained regions might also be considered for groundtruthing.

## 6. ACKNOWLEDGEMENTS

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