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ACOUSTIC CHARACTERIZATION OF CONTINENTAL SHELF SEAFLOOR AND BENTHIC HABITATS USING SINGLE AND MULTI-BEAM BACKSCATTER DATA

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Abstract: *Satellite based marine remote sensing is a conventional technique for oceanographic research studies. Likewise, in the future projection application of the acoustic remote sensing using high frequency single-beam echo-sounder (SBES) and multi-beam echo-sounder (MBES) sonar imagery could provide a wealth of data to facilitate ocean multidisciplinary studies including seafloor characterization and benthic habitat studies. Correspondingly, the acoustic backscatter from MBES and SBES systems operable at 95 kHz and 33/210 kHz, respectively, were used to characterize sediment texture and benthic macro-fauna along the central part of the western continental shelf of India (off Goa). Concurrent acoustical, physical, and biological parameters were measured to characterize the continental shelf seafloor. The substrate type and roughness of the seafloor were estimated using the composite roughness scattering model with the measured backscatter data. The relationships between processed acoustic backscatter strength, grain size, sediment geoacoustic inversion results and benthic macro-fauna abundance were identified from the maps generated using ArcGIS. Distinct interclass separations between the sediment provinces are evident from the spatial variability of the estimated inversion results, which simultaneously establish a strong correlation with backscatter values and biologically active faunal functional group assemblages on the seafloor. Finally, to further understand the complexity of seafloor backscattering processes, a more versatile 'multifractal' approach based technique (using SBES echo-envelope data) has been introduced. The application of multifractal technique could substantiate the hitherto applied numerical inversion based characterization of the seafloor sediments employing the backscatter data.*

Keywords: *Numerical inversion, Habitat mapping, Multifractal, Single-beam, Multi-beam*

1. INTRODUCTION

The use of high-frequency single-beam and multi-beam echo-sounders has been recognized as an effective tool to characterize the seafloor over a wide area. The acoustic backscatter data obtained from such echo-sounding systems can be matched with theoretical scattering models to interpret the information embedded in the data [1-4]. The numerical approach employed for extracting information from the data is commonly referred to as ‘inversion modeling’. The inversion modeling primarily involves physics based inversion of echo-sounding data to obtain the upper-layer seafloor roughness parameters, namely the sediment mean grain size (M_ϕ); spectral parameters at the water-seafloor interface (γ_2 , w_2); and sediment volume parameter (σ_2), that can be used to examine the fine scale seafloor processes. Interestingly, the study of the fine scale seafloor processes presents challenging task, particularly with the diversity in the benthic habitat of the area.

Studies investigating the distribution of seafloor sediments and associated benthic habitat usually involve echo-sounding systems to assess the diversity in the benthic community. In this work, an attempt has been made to understand the interaction between the seafloor sediment and benthic macro-fauna at multiple frequencies employing multi-beam echo-sounder (MBES) and dual-frequency single-beam echo-sounder (SBES) operable at 95 kHz and 33/210 kHz, respectively [5]. The information cataloged is then utilized to characterize the seafloor and related benthic habitat off Goa, central west coast of India.

The ‘power law’ behavior of SBES echo-envelope data invokes multifractal analyses in order to determine if the data follow ‘fractal’ statistics. Therefore, to further expound the complexity of seafloor backscattering processes, a more versatile ‘multifractal’ approach based technique has been initiated [6]. The ‘stochastic’ multifractal formalism introduced here allows characterization of SBES echo-envelope data with three fundamental parameters namely, degree of multifractality α , sparseness C_1 , and degree of smoothness H [7]. This method builds on the fact that layers of seafloor sediments have fractal structure, which is reflected in the shape of the acquired echo-envelope data. Besides, acoustically softer sediments are penetrated more deeply by acoustic signal and produce longer and more corrugated echoes than harder sediments. Consequently, the estimated multifractal parameters of echo-envelope, as a measure of complexity and roughness will proffer useful information for seafloor characterization.

2. MEASUREMENT TECHNIQUES AND METHODS

2.1 Acoustic data acquisition and sediment sampling

The bottom backscatter data was acquired over substrates ranging from clayey silt to sand in the central part of the western continental shelf of India (Fig. 1a) with calibrated SBES and MBES. The dual-frequency (33 and 210 kHz) echo-envelope data were acquired using a hull-mounted normal incidence RESON-NS 420 SBES. Meanwhile, 95 kHz MBES data were acquired using the EM1002 echo-sounding system. Sediment samples were analyzed for textural studies using a Van-Veen grab following standard protocol. The mean grain size (M_ϕ) of the sediment was calculated for each of the sampling locations. In the following text silty-sand and sand sediments will be referred to as coarse sediments ($M_\phi < 4$); and clayey-silt and silt sediments will be referred to as fine sediments ($M_\phi > 4$) for simplicity.

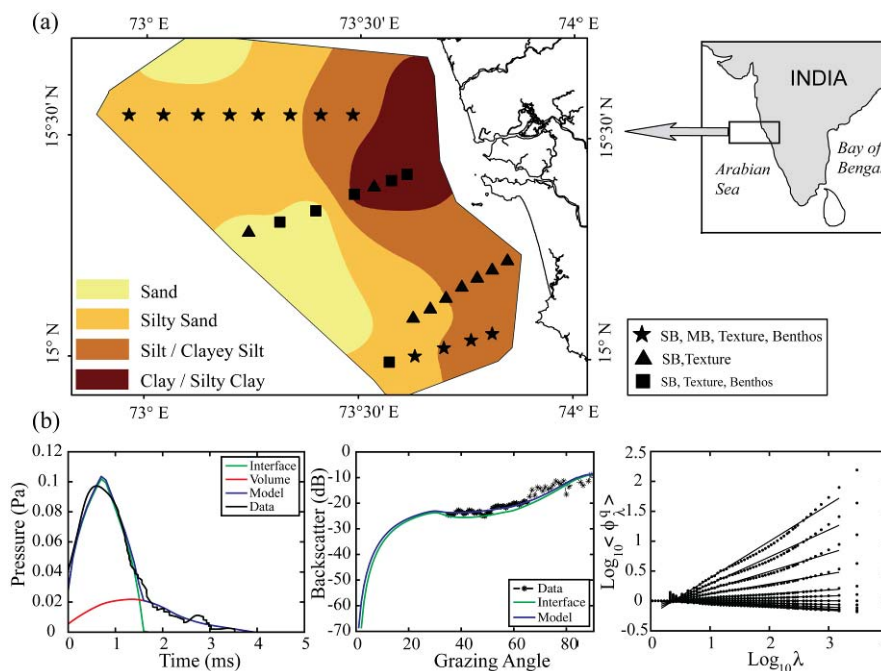


Fig. 1: (a) Shows the study area and type of data collected. Presented in (b) are the processed SBES and MBES backscatter data used to carry out the inversion modeling and multifractal analyses.

2.2 SBES echo-envelope data based sediment characterization

The shape of acquired echo-envelope depends on various factors including natural variability of the seafloor, transducer heave, and noise due to echo-sounder instability. Therefore, several post processing steps such as visual check, echo alignment and echo averaging have to be carried out before further utilization. The detailed data processing methodology has been given in Ref. [5]. Finally, prior to time dependent inversion modeling, the voltage form of data has been converted to pressure signal accounting the two-way transmission loss.

After following the post-processing steps mentioned in the preceding paragraph, the bottom geoacoustic parameters which are best suited to discriminate sediment substrates are determined by comparing the model to the average bottom echo (Fig. 1b). The temporal backscatter model developed by Sternlicht and de Moustier [2] has been employed to characterize seafloor sediments [3]. Here, the total backscatter intensity (measured at the transducer face) for a finite duration of transmitted signal is modeled by summing the intensities from the water-sediment interface and from the sediment volume inhomogeneities. The end results obtained after inversion modeling have been statistically analyzed, compared to the ground truth, and tested as new model inputs to conclude on the model-data performance fit.

2.3 MBES angular backscatter data based sediment characterization

Analogous to SBES data, the MBES data also require prior processing to eliminate the artifacts that occurred during the data acquisition. Therefore, several post processing steps such as Lambert's law removal, actual bottom slope and the insonified area corrections have

to be carried out before initiating angular backscatter inversion modeling. The detailed data processing methodology has been given in Ref. [4].

The composite roughness model using the shape of the angular backscatter function developed by Jackson *et al.* [1] has been employed to characterize seafloor sediments [4]. Here, the angular scattering model combines the most dominant dimensionless scattering mechanism of the surface roughness coefficient and volume scattering coefficient as a superposition of the incoherent scatter to estimate the total seafloor backscattering strength (Fig. 1b). The end results obtained after inversion modeling have been statistically analyzed, compared to the ground truth as well as with the inversion results obtained using backscatter data at 33 and 210 kHz from the same locations.

3. RESULTS

3.1 Inversion results

The estimated M_ϕ values using three different acoustic frequencies are presented as a function of the measured M_ϕ values (Fig. 2a). On the whole, the estimated M_ϕ values agree well with the measured sediment data, having correlation coefficients of 0.97, 0.98, and 0.96 for 33, 95, and 210 kHz, respectively. The scatter diagram (Fig. 2b) between measured values of M_ϕ and estimated γ_2 delineated that higher values of γ_2 are associated with fine sediments, and in contrast lower values of γ_2 are associated with coarse sediments. The scatter diagram (Fig. 2c) between the measured values of M_ϕ and estimated w_2 revealed that the estimated values of w_2 are less than 0.001 cm^4 for fine sediments and are confined within 0.002 to 0.005 cm^4 for coarse sediments from all the three inversion results. It is observed that higher values of w_2 and lower values of γ_2 are associated with coarse sediments, while lower values of w_2 and higher values of γ_2 are the characteristics of fine sediments. In the present study, for fine sediments, the average estimates of σ_2 are found to be higher as compared to coarse sediment region. In addition to this, no definite relationship between the estimated mean values of σ_2 and the mean grain size is found in the study area (Fig. 2d) [4].

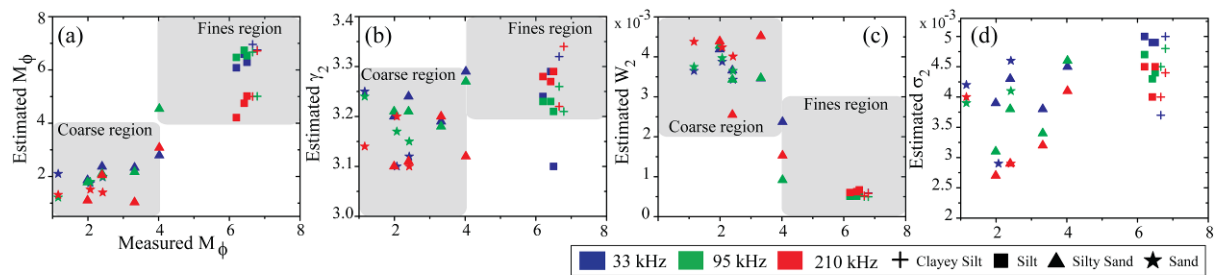


Fig. 2: The scatter plot showing multi-frequency inversion results.

3.2 Seabed habitat mapping employing SBES and MBES backscatter data

The relationships between processed acoustic backscatter strength, grain size, and benthic macro-fauna abundance were demonstrated with the application of Geographic Information System (GIS) based seafloor mapping [5]. It was evident that, for three frequencies, the backscatter intensity is directly correlated with coarse fractions (sand within the range 62 – $2000 \mu\text{m}$) and inversely correlated with finer fractions namely silt (2 – $62 \mu\text{m}$) and clay ($<2 \mu\text{m}$). Two distinct feeding groups were observed from the study area: namely, deposit feeders

(majority of polychaete worms and related soft body species like nematode, oligochaetes, nemertinea, and echurids) mainly in shallow region and filter feeders (hard body bivalves and gastropods) in deeper depths. The preferences of deposit feeders for the fine-sediment regions and filter feeders for coarse sediment regions indicate the influence of sediment texture on the feeding behavior of the organisms (Fig. 3a).

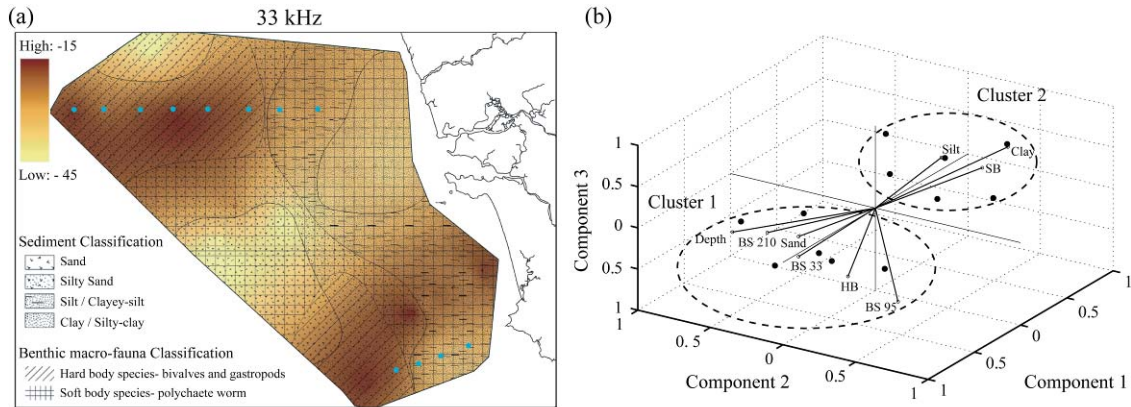


Fig. 3: GIS based classification representing the backscatter-animal-sediment interrelationship at 33 kHz. Panel (b) represents PCA clustering.

Two distinct clusters with high and low backscatter intensity values of the three frequencies were distinguished from the study area. Sediments from high backscatter locations are mainly coarse ($M_\phi < 4$) in nature, dominated by sand content with prominent occupancy of hard body benthos. Whereas, sediments from low backscatter locations are mainly fine ($M_\phi > 4$) in nature, dominated by high percentage content of both silt and clay with substantial occupancy of soft body organisms (Fig. 3b).

3.3 Multifractal analyses of echo-envelope data

The corresponding multifractal parameters α , C_1 and H were determined using SBES echo-envelope data. Our analyses show no significant variation in α and H , whereas C_1 , which represents the sparseness of the data, varies with respect to the mean grain size of the area (Fig. 4). It is observed that the relatively higher values of w_2 and C_1 are associated with coarse sediments, while the lower values of w_2 and C_1 are the characteristics of fine sediments.

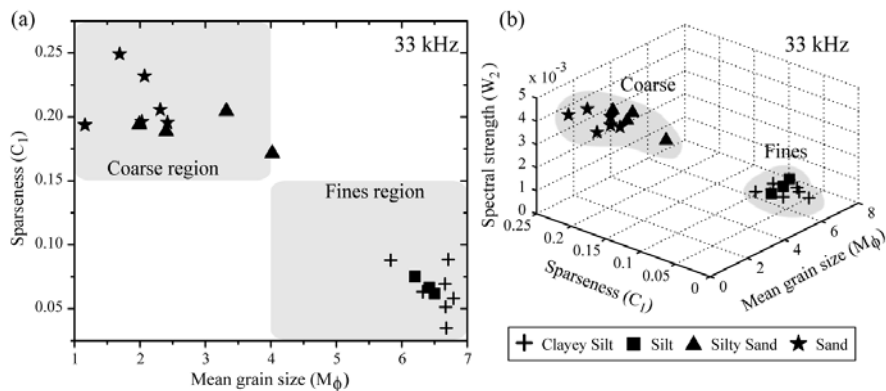


Fig. 4: Scatter plot showing clustering among M_ϕ , C_1 and w_2 . Regions comprising of coarse and fine sediments are clearly demarcated.

4. CONCLUDING REMARKS

The geoacoustic inversion results obtained using MBES and SBES data provide important information that can be utilized for acoustic seafloor characterization. The other objective of the benthic habitat mapping exercise has further demonstrated a relationship between acoustic backscatter, sediment texture and benthic habitat attributes exist in the study area. The ‘stochastic’ multifractal formalism introduced here allows characterization of SBES echo-envelope data signifying the fractal structure of bottom sediments. The derived multifractal parameters are a good descriptor of a bottom type in the investigated area and substantiate the hitherto applied numerical inversion based sediment characterization.

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