

CHARACTERIZING BIOGENOUS SEDIMENTS USING MULTIBEAM ECHOSOUNDER BACKSCATTER DATA - ESTIMATING POWER LAW PARAMETER UTILIZING VARIOUS MODELS

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ABSTRACT

In this paper, Helmholtz-Kirchhoff (H-K) roughness model is employed to characterize seafloor sediment and roughness parameters from the eastern sector of the Southern Oceans. The multibeam-Hydrosweep system's angular-backscatter data, which is operable at 15.5 kHz, is used in this study. Estimated power law parameters using H-K and composite roughness models are compared from the same areas. Interestingly, multibeam backscatter study result establishes a relationship between the power law parameters with the biogenous sediment type (calcareous/ siliceous). The combined application of the two models is found to be complementing each other for bottom roughness estimation.

INTRODUCTION

The seafloor characterizations studied so far using high frequency signal backscatter had generally been aimed at finding out relations between signal backscatter with roughness parameters from seawater to seafloor interface, and sediment volume scattering ([1], and references therein). Biogenous sediments are widespread on the seafloor. More than half of the deep ocean floor is covered with calcareous mainly consists of carbonates, and siliceous oo/c [2]. The multibeam sounding system is a current day tool for seafloor mapping [3]. Because of its multinarrow beams and wide coverage, it can also be a potential system for backscatter applications like remote seafloor characterization. In this paper, using narrow beam angular backscatter strength data of the multibeam system [multibeam - Hydrosweep system (manufactured by m/s STN Atlas Elektronik, GmbH) [4] installed onboard Research Vessel (RV) Polarstern], modeling applications are employed for Southern Ocean area data [5-7]. It is well known that the seabed roughness is a two-scale function varying from low to higher wavelengths [8]. Initiation of the seafloor roughness estimation in terms of power law parameters were made by Jackson et. al [9]. Based on this, application of the composite roughness model for multibeam backscatter data was carried out [5], and power law parameters were estimated. Two layer H-K roughness model on multibeam backscatter was applied by Talukdar et al. [10]. The advantage of using Kirchhoff approximations over earlier investigation is that, it provides accurate results, when uses them within a well-defined parameter regime. The estimated root mean square (rms) relief roughness, correlation length, and exponent values for the top-and sub surface layer of the biogenous sediments from Southern Oceans are computed (data obtained from authors on personal ground). These values are applied to determine power law parameters and presented in this paper. Fox and Hayes ([8] and references therein) had demonstrated the statistical and spectral description of the seafloor roughness in power law terms i.e., the spatial spectra of seafloor tend to follow power laws. In this paper, a comparison between the power spectral parameters obtained by following models are presented and compared for biogenous sedimented seafloor.

1. Two-layer H-K models
2. Composite roughness model using power-law parameters

The study results from three geologically important deep-sea regions of biogenous sedimentation are presented in this work. The sediment samples were also acquired from these areas. Apart from studying power law parameters from a calcareous and siliceous ooze sediments sites, one geologically mixed sediment site (calcareous and siliceous) is also presented.

MULTIBEAM BACKSCATTER DATA AND SITES

The present study has been carried out using multibeam-Hydrosweep backscatter and related core sediment sample data from a marine geological cruise [ANT XI / IV of the Research Vessel (RV) Polarstern] conducted by the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany [5-7].

Gutberlet and Schenke [4] had discussed the multibeam-Hydrosweep systems, and angular backscatter data processing techniques is given in de Moustier and Alexandrou [11] for multibeam-Sca Beam system. Sufficient acoustic pings were collected from each area when ship was stopped for sediment sampling. Backscatter and geological sample data collections are made at oceanographically important sites from Southern Oceans. Agulhas plateau area (area 'A'), Enderby abyssal plain (area 'B'), and near Prince Edward Marion Island (area 'C'). Biogenous sediments like calcareous, siliceous, and mixed calcareous and siliceous components are reported from the areas 'A', 'B', and 'C' respectively. The water depths were also found to be varying between the 2400 m (area 'A' Agulhas plateau), 5280 m (area 'B': Enderby abyssal Plain), and 4420 m (area 'C' near Prince Edward Marion Island). Top sediment grain size compositions indicate sand - silt - clay, clayey - silt, and sandy - silt for the areas of Agulhas plateau (area 'A'), Enderby abyssal plain (area 'B'), and near Prince Edward Marion Island (area 'C') respectively. The measured backscatter values are processed using the software (NRGCOR developed at Scripps Institution of Oceanography and STN Atlas Elektronik, GmbH (technical details are given in [11]). The angular values are normalized with respect to the highest backscatter strength before used curve fitting. The backscatter data collection was carried out at a station when ship was stopped for sediment core sampling, and this arrangement of data collection assured the statistical homogeneity of backscatter data.

MODELS USED

We present two models, namely, the composite roughness and the two layers H-K model results to understand the backscattering processes from deep seafloor. Detailed description of the composite roughness model for high frequency bottom scattering study has been made by Jackson et al, [9]. Based on this, the application of the theory for deep seafloor quantitative backscatter model using multibeam echosounder was initiated [5-7]. In the composite roughness model, Jackson et al [9] had applied power law properties of the seafloor roughness spectrum to a H-K formulation at steep angles i.e., angles of incidences in the range 0° - 20° . The mathematical aspects of the composite roughness theory are given elsewhere. For a small-scale part of the seafloor the composite roughness model uses the Rayleigh-Rice perturbation approximation, which has been averaged over the large-scale bottom slope {equation (21) of [9]}. This has been carried out beyond the incidence angle or 20° . The model also requires the inclusion of a volume scattering term for heavily sediment seafloor. The power law parameters (γ and β) are estimated using curve fitting between the near normal incidence (up to 20° incidence angle) backscatter values.

Two-layer H-K theory is presented in detailed in the work of Talukdar et. al. [10]. Within a limited spatial dimension of footprint and a limited spectral limit using rms relief height and correlation function (Fourier transformation of the power spectrum), the roughness parameters may be determined. Basic assumptions of Gaussian roughness within a footprint have been made in this theoretical development. The developed backscattering coefficient expression is a function of the correlation length (l), rms relief roughness height (h) and an exponent value (n). Talukdar et al. [10] have used H-K roughness theory for multibeam-Sea Beam system up to 20° incidence angles. Based on the idea of incoherent addition of scattering components from the top interface (sediment-water interface) and subsurface layers for total backscattering strength computations, equation (24) of [10] is employed using Hydrosweep multibeam system's higher angular range capabilities (backscatter data up to 45° incidence angles).

Using two-layer theory, the estimated seafloor roughness parameters from the seven Southern Ocean sites are estimated very recently (data obtained from authors on personal request). Here, Power Spectral Density (PSD) functions using estimated roughness results are computed using the Wiener-Khinchin theorem in equation (17) of [10]. Employing estimated seafloor roughness values (correlation length, rms relief heights) of each backscatter data, the PSD function has been drawn with respect to the frequency (s in m^{-1}). The power law parameters, γ (spectral exponent) and β (spectral strengths) are determined employing a curve fitting between the power law expressions and spatial spectra of seafloor. The comparison between estimated power law parameters between the composite roughness and two-layer theory for biogenous sediments from three areas are presented.

STUDY RESULTS

For biogenous sediment of calcareous ooze type (area 'A': Agulhas plateau), estimated seafloor power law parameters employing composite roughness models are given in [7]. Using two-layer H-K model roughness values, power law parameters are presented in (Table 1). We have computed the PSD (Power Spectral Density) of top, subsurface layers, and entire bottom using Wiener-Khinchin theorem. The spectral transformations were obtained by employing the Fourier Transform of the spatial correlation function of the upper and lower layers. Apart from the top and subsurface layer PSD estimations, the computation of the PSD values of the entire bottom have also been carried out including the effect of attenuation coefficient and layer width (equation 1 of [10]). The fitted power law parameters for the top, subsurface and the entire bottom are presented. The estimated γ values of the power law parameters are found to be within the limits expressed in [12]. The spatial frequency (s) limit of the employed good (it is also given in the Table. Generally, the difference in the spectral parameters between the top and subsurface layers show the difference in the sediment type and roughness. According to reference [12], the spectral exponent (γ) values signify the topographic correlation parameter within the same overall variance, whereas the spectral strength (β) parameter quantifies amplitude. The availability of γ and β values for plateau features is rare. However, Berkson and Matthews (referenced in [8]) had presented γ value of the marginal plateau from the Norwegian Sea ($\gamma = 1.9$). Interestingly, the power law estimated parameters using bathymetry data are found to be in good correlation with the presently estimated power law parameters. However, computed γ using two-layer H-K theory, does not show any similarity with the multiscale based composite roughness theory ($\gamma=3.06$) [7]. Estimated γ parameter of the entire bottom is found to be equivalent to the γ value of the subsurface layers. Though, estimated/

of the subsurface layer and entire bottom are same (low), but due to moderate strength (β) value of the entire bottom is seen. However, estimated β values using composite roughness theory and two layer H-K theory are same. In general, higher PSD values for a top/total layer towards the higher spatial frequency end reflect the possible presence of either small-scale roughness (microtopographic features) and/or volume roughness (sediment inhomogeneity). We have presented PSD values varying from 0.1 (m^{-1}) to 2.0 (m^{-1}). In order to study seafloor small-scale features (microtopography volume inhomogeneity), the chosen spatial frequency ranges are adequate. However, while comparing the presently studied PSD values with the dataset of Talukdar et. al [10], the scattering is equally dominant for both the top and subsurface layer of Agulhas plateau (area 'A') Evidence of sediment volume inhomogeneity (the composite roughness model), though insignificant, is observed in this area, which could be due to the unconsolidated top layer of foraminifera and nanofossil sediment than the other consolidated foraminiferal sediments. The East Equator Pacific foraminiferal sediments are more consolidated than the other regions of calcareous deepsea sediments like Agulhas plateau. The plateau is mostly capped by the unconsolidated calcareous sediment (referenced in [5]).

Biogenous silicious ooze sediment from area 'B' (Enderby abyssal plain) indicate distinct difference in the spectral exponent (γ) and spectral strengths (β) values (Table 1) between the top and subsurface power spectral parameters (two-layer H-K). The plotted PSD values for top and subsurface layers do not reveal, any difference up to the spatial frequency of 0.40 (m^{-1}) (Figure: 1). Beyond the spatial frequency of 0.40 (m^{-1}), a significant rise in the PSD value of subsurface layer is observed. Though detailed information regarding the geology of this area is not available, but our study shows two distinct sedimentary layers especially towards the higher spectral frequency-end. The top layer is significantly smoother than the subsurface layer (the computed γ values of the top and subsurface layer). A comparison with the estimated power law parameters using the models such as the composite roughness and presently employed two-layer H-K using spherical wave approximations provides some interesting insights with respect to the biogenous sediment types. Using composite roughness model for area 'B' (Enderby abyssal plain), γ values (~ 3.68) are comparable with the estimated γ value of -3.30 for total layer) of two layer H-K. with significant difference in β values. However, these siliceous sediment areas consist of low volume roughness parameters (insignificant volume inhomogeneity) suggesting moderate signal penetration depth. For mixed biogenous sediment of calcareous and siliceous type near Prince Edward Marion Island (area 'C'), it is difficult to predict the presence of any small-scale features or volume roughness from the drawn PSD functions. However, from composite roughness results, the sediment volume inhomogeneity parameter has been estimated to be moderate. The estimated γ values of the power spectral parameters for top and subsurface layers are almost similar (two layer H-K). There is no significant difference in the sediment composition within the layer. Though, exact spectral component (γ) values from this type of area is not available, however, the values presented by Berkson and Matthews (referenced in [8]) from basalt-sediment interface reveal equivalent result. A difference in the spectral strength (β) values between the layers is seen which may support the fact that the roughness estimated among the layers is different. Except for β values, the γ values are the same for the top, subsurface, and the entire bottom. Throughout the spatial frequency range, a constant difference in the PSD values between the top and subsurface layers, and entire bottom are seen i.e., the overall roughness is dominant throughout the spatial frequencies varying from the lower to higher frequencies (Figure: 1). Except the level (PSD) differences, the spectral characteristics are same for the top, subsurface and entire bottom. However, the given spectral exponent value is not matching with the

composite roughness model result [5]. A moderate value of the volume roughness parameter from the composite roughness model signifies comparable sediment inhomogeneity in these areas than the siliceous sediment areas. In the mixed areas of calcareous and siliceous sediment, volume inhomogeneities are found to be moderate for area 'C' (Near Prince Edward Marion Island).

Table I.: Estimated power law parameters of the seafloor:

Areas:	'A' Aggulhas plateau	'E' Enderby abyssal plain	'C' near Prince Edward Marion Ist.
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Composite Roughness Power Spectral Parameters:

' γ '	3.06	3.68	3.04
' β '	0.00009	0.00002	0.0002
' $\sigma, /a_b$ '	0.001	0.00017	0.0013

Power law parameters Using Two -Layer H-K Roughness Model:

Top layer:			
' γ '	= -2.0	= 2.6	= 1.9
' β '	= 0.00003	= 0.00009	= 0.00009
for - $s >$ -	0.2 $s >$ 1.0	0.3 $s >$ 1.8	1. $s >$ 0.8
Subsurface layer:			
' γ '	= 15	= 16	= 2.0
' β '	= -0.00006	= 0.00018	= 0.00014
for - $s >$ -	0.4 $s >$ 1.0	0.3 $s >$ 2.0	0.5 $s >$ 2.0
Total:			
' γ '	= 15	= 3.3	= 2.0
' β '	= 0.00009	= 0.00004	= 0.0002
for - $s >$ -	0.1 $s >$ 1.0	0.4 $s >$ 2.0	0.2 $s >$ 2.0

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