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Acoustic seafloor discrimination with echo shape parameters: A comparison with the ground truth

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Abstract

Features extracted from echosounder bottom returns are compared with the ground truth in a North Sea survey area. The ground truth consists of 50 grab samples for which the grain size distribution, and the gravel and shell contents were determined. Echo envelopes are analysed for two single-beam echosounders, operated at frequencies of 66 and 150 kHz. It is shown that a set of six energetic, statistical, spectral and fractal parameters carries useful information that can be exploited for seafloor characterization and classification purposes. A quantitative comparison of the individual features with the grab sample mean grain size reveals significant correlations. The echo features are also subjected to a principal component analysis in tandem with a cluster analysis. Four sediment classes with different geo-acoustic properties are examined and compared with the grab samples and existing geological information. A subtle difference between the two sounder frequencies is observed in the rendition of an isolated trench with a soft infill of clay and Holocene channel deposits. The acoustic transition from the valley to neighbouring sand and gravel fields occurs more rapidly at the lower of the two examined frequencies. A direct comparison of the acoustic sediment classes with the ground truth reveals that the main sediment types mud, sand, and gravel are more clearly separated at 150 kHz. The acoustic bottom classification scheme also appears particularly sensitive to the presence of gravel at this sounder frequency.

Keywords: Echosounder; Seafloor characterization; Shape parameters; North Sea

1. Introduction

Acoustic seafloor characterization has been long recognized as a useful tool for fast preliminary geological analysis. Acoustic methods for seabed identification and classification can be exploited in many fields, including marine geology, hydrography, marine engineering, environmental sciences, military sonar, and fisheries. The advantage over conventional bottom grabs is the nearly continuous versus sparse probing and a vast reduction in survey time and costs. Difficulties include echo to echo variations that may occur even for low sea states and homogeneous seabeds, and the need for identification of echo parameters that are best suited to discriminate between various seafloors.

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For example, the presence of current ripples can influence certain echo features, but this is undesirable when the purpose is to discriminate between sediment compositions only.

The physical mechanisms behind the process of echo formation are nontrivial and a theoretical treatment that includes specular reflection, surface backscattering and volume reverberation can be exceedingly complex, depending on the level of completeness that is pursued. Roughly speaking, bottom classification algorithms can be divided in two categories: model based and empirical. Model-based techniques attempt to characterize the seabed by translating echo signal properties directly into geological quantities via a physical model. Empirical approaches simply rely on the observation that certain features of echo signals are correlated with the sediment type. Here, the idea behind the use of a particular feature may very well be based on theoretical assumptions or expectations, but this theory is not used in the signal processing or classification. Typically, two or more features are combined by means of a cluster analysis, after which each identified cluster is associated with a particular type of sediment.

Among the reported techniques to exploit a single-beam echosounder for seafloor mapping we find approaches as diverse as the determination of the energy ratio of the first and second bottom return (Chivers et al., 1990; Dyer et al., 1997; Heald, 2001), a comparison between measured and theoretically modelled echo patterns in the time domain (Pouliquen and Lurton, 1992; Sternlicht and De Moustier, 1997) or in the frequency (wavelet) domain (Caiti and Zoppoli, 1998), and artificial neural networks (Alexandrou and Pantzartsis, 1993). Hamilton et al. (1999) compare the commercially available bottom classification systems RoxAnn and QTC.

Apart from simple echosounders, parametric sources (Caiti and Zoppoli, 1998; Gensane and Tarayre, 1992), wideband "chirp" signals (leBlanc et al., 1992; Maroni and Quinquis, 1997) and multibeam echosounders (De Moustier and Matsumoto, 1993) have been reported as potential bottom classification sonars.

In this paper three families of echo parameters are combined into an empirical seafloor characterization approach. The families are statistical moments (Van Walree et al., 2002), spectral moments (Tęgowski and Łubniewski, 2002), and fractal dimensions (Tęgowski, 2005). These approaches, and the corresponding echo shape parameters, have been relatively underexploited. The analysis is applied to echosounder data collected in the Cleaver Bank and Botney Cut areas, located in the North Sea north–west of the Netherlands (Fig. 1). The echosounder surveys were carried out specifically to collect data for the evaluation of acoustic seafloor discrimination methods. Extensive ground truth is available for an assessment of the algorithms. Between 1979 and 1991, a number of geological excursions were undertaken on the Cleaver Bank and the Botney Cut with side-scan sonar and subbottom profilers for the purpose of gravel location and extraction. Subsequent sampling programmes with Hamon grabs and a vibrocorer yielded detailed information on the seafloor surface layer. Moreover, up-to-date ground truth for the location pertinent to the present paper was established by 50 bottom grabs collected during the first echosounder survey. The two available sets of bottom reflected echosounder signals, in combination with the historical information and the actual ground truth, form an invaluable data set with opportunities to compare echo shape parameters between the two sounder frequencies on the one hand, and with the ground truthing on the other hand.

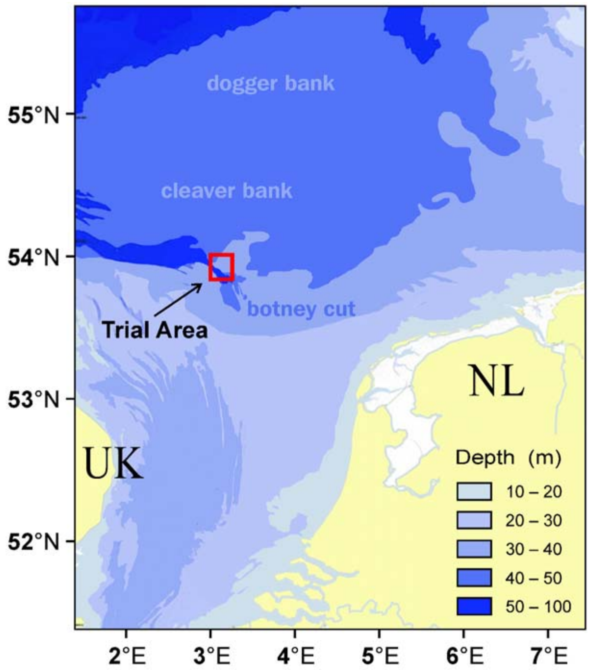

Fig. 1. Overview of the area, featuring the Cleaver Bank and the Botney Cut. The red rectangle, north–west of the Netherlands (NL), indicates the location of the acoustic surveys.