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Seabed Discrimination with Downward and Forward-Looking Sonars

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Summary

An area of about 100 square nautical miles in the North Sea has been surveyed with an echo sounder and a forward-looking sonar, operated at 150 kHz and 100 kHz respectively. The signals reflected and scattered off the sea floor were analysed in the laboratory to determine the echo energy and echo shape parameters. As it appears, clustering occurs when features are plotted against one another, where each cluster in parameter space corresponds to a distinct sediment type. It is shown that the echo sounder discriminates between mud, sand and gravel, whereas the forward-looking sonar also distinguishes intermediate sediment classes. Finally the results are compared with a historical geological map and with 50 grab samples collected during the sea trials.

1. Introduction

Acoustic seabed classification is becoming increasingly important. The advantage over conventional bottom grabs is the continuous versus sparse probing, and a vast reduction in survey time and costs. In the past decade classification algorithms have been developed for echo sounder signals. The approaches are various. The energy of the first and second bottom returns may be used [1], a principal component analysis may be applied to the first echo [2] or, for instance, the echo signal is treated as a distribution from which statistical moments are calculated [3]. We will follow the last approach.

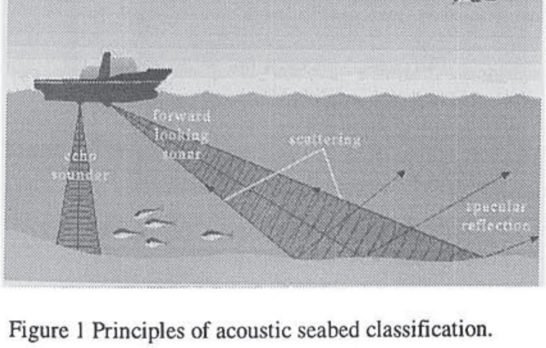

Figure 1 Principles of acoustic seabed classification.

In this paper we show that acoustic seabed classification is also possible with oblique sonars. Results of a direct comparison between an echo sounder and a forward-looking sonar suggest that the latter offers better discrimination. The prospect of seafloor characterization with multiple beams is appealing as a broad strip of the seafloor could be mapped with a single sailed track. Fig. 1 illustrates the principles of acoustic seabed classification with an echo sounder and a forward-looking sonar. In general echo signals are shaped by specular reflection at the water-sediment interface and backscattering from individual grains and bottom irregularities. Owing to its finite beamwidth an echo sounder echo receives contributions from both mechanisms, while oblique sonars completely depend on backscattering. Both the amplitude (energy) and shape of the received echoes can be used to differentiate between the various seafloors.

2. The sea trials

Echo sounder signals (150 kHz, beamwidth 17.5°) were recorded on the North Sea during sea experiments in October 2000. A track with ten longitudinal legs was sailed, covering an area of roughly 10 × 10 nautical miles. Fig. 2 shows a geological map of the trials area [4], together with

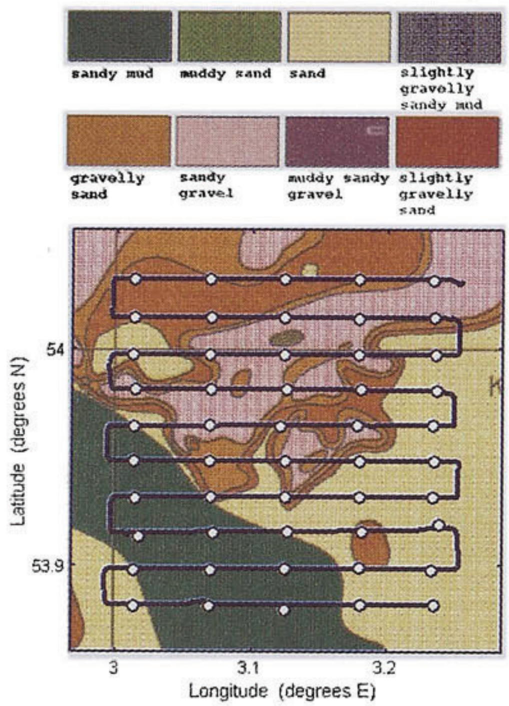

Figure 2. Geological map of the trials area and legend of Folk classes.

the sailed tracks and a legend of sediment classes according to Folk [5]. Fig. 2 also shows the positions of 50 bottom grabs which were collected and analysed by NITG-TNO. The contents of the grabs are presented in Fig. 3 via their Folk classes,

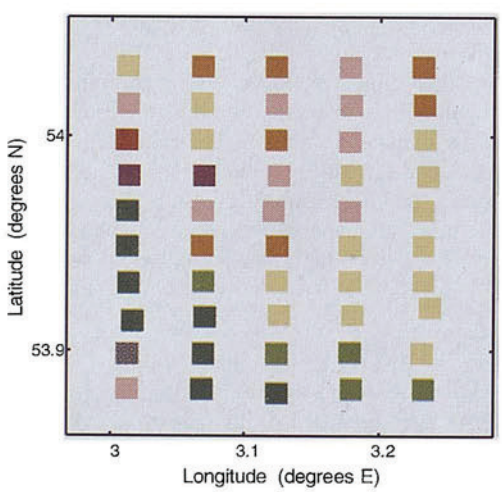

Figure 3 Ground-truth results for the grab samples. The colours correspond to the legend in Fig. 1.

which were determined by the respective mud, sand, and gravel percentages. Up-to-date grab samples are important because seabeds change in the course of time.

In the same area a survey with a forward-looking sonar (100 kHz, horizontal beamwidth 1.5°, vertical beamwidth 11°, and a grazing angle of 30°) was conducted in May 2001. Five of the legs sailed during the first sea trials were repeated, c.f. Fig. 5.

The bathymetry of the trials area varies. Sand and gravel grounds are found between 30 and 40 m, the mud is situated at depths up to 60 m. It is therefore of importance to remove the influence of depth on the echo features in the signal processing stage.

3. Processing and feature extraction

The received echo signals were digitally filtered to remove noise outside the frequency band of the sonars. The effects of water-depth dependent propagation losses were removed by corrections for spherical wavefront spreading and absorption losses according to Francois and Garrison [6].

Each signal is cropped to a section of N samples around the echo. The intensity I_n of a sample is proportional to the square of the amplitude s_n, and the total energy in each echo trace is given by

$$E = \sum_{n=1}^{N} I_n \, . \qquad (1)$$

The echo energy is an important parameter because it relates directly to the hardness (normal incidence) and roughness (oblique incidence) of the seabed. Additional shape parameters are the timespread

$$T = \left[\frac{1}{E} \sum_{n=1}^{N} I_n (t_n - t_0)^2 \right]^{1/2} \qquad (2)$$

and skewness

$$S = \frac{1}{T^3 E} \sum_{n=1}^{N} I_n (t_n - t_0)^3 \qquad (3)$$

of the echo, where the average arrival time or echo centre of gravity t_0 reads

$$t_0 = \frac{1}{E} \sum_{n=1}^{N} t_n I_n \, . \qquad (4)$$

The timespread is a measure of the echo width and the skewness a measure of the echo asymmetry.

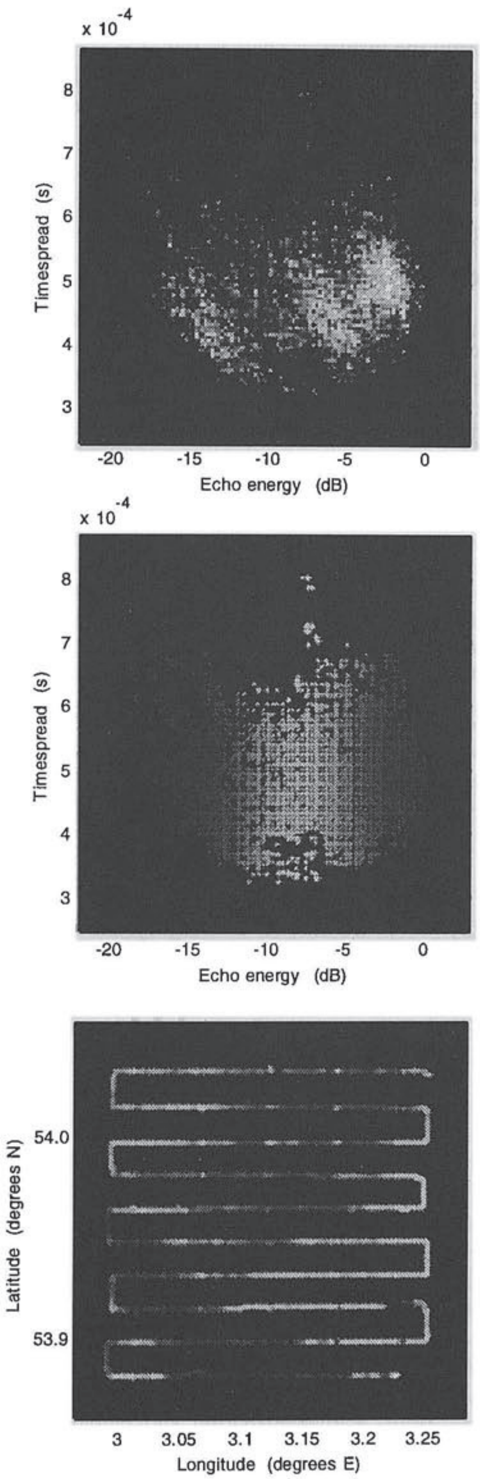

Figure 4. Timespread *T'* vs. energy for the echo sounder. The colours are chosen to reflect the map in Fig. 1.

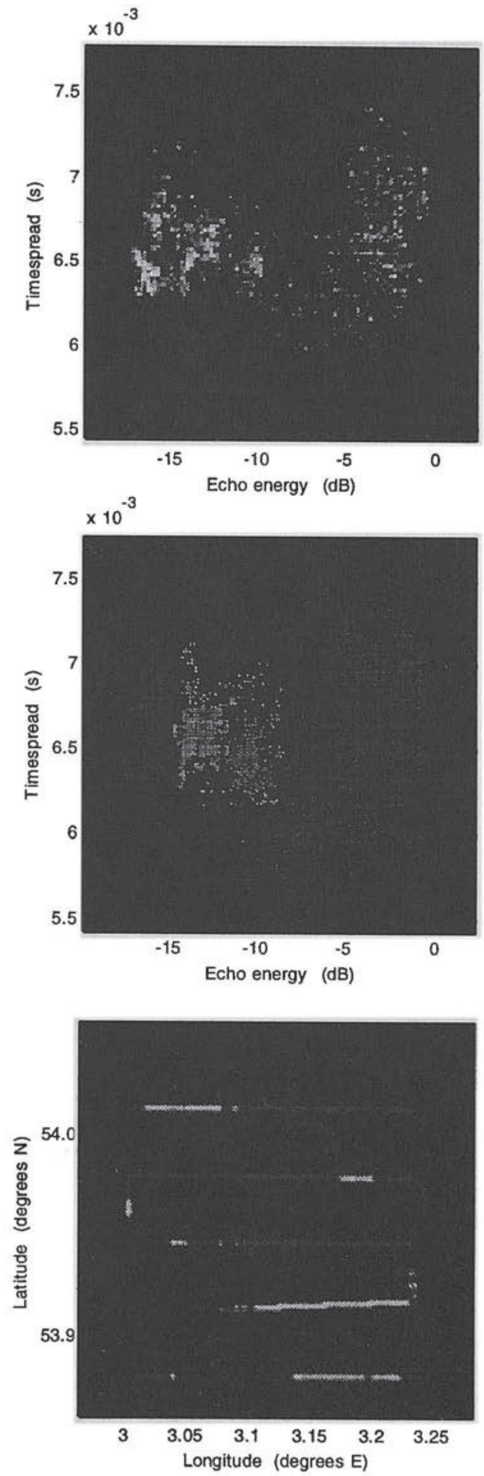

Figure 5. Timespread *T'* vs. energy for the forward looking sonar. Five sediment classes are distinguished.

Since T and S are normalized by the factor $(1/E)$ they are shape parameters, independent of the echo energy. Higher-order moments such as the kurtosis were tried out but observed to add no further discrimination. After T and S are calculated with Eq. 2 and Eq. 3, the timespread T is additionally corrected for a depth-dependent sonar footprint size, yielding T' as used in Fig. 4 and Fig. 5.

3. Results and discussion

Scatter plots are obtained when two features are plotted against each other (top graphs of Fig. 4 & Fig. 5). A software tool was developed that divides feature space into bins, the colour of which is a measure for the number of echoes falling within the bin. The tool further allows for continuous colouring along one dimension (Fig. 4) or a manual selection of clusters (Fig. 5). The middle graphs show the colour assignment in parameter space, the bottom graphs present the sailed tracks in the same colours, i.e. each echo on the track is represented by the corresponding colour in the middle graph.

For the echosounder, a plot of timespread versus energy reveals three clusters (Fig. 4). Since the colouring is along the abscissa, the "classification" results in the bottom graph of Fig. 4 are in fact solely based on energy. This graph strongly correlates with the historical geological map of Fig. 1 and also with the ground truth in Fig. 2. The seabed reflectivity increases with an increasing average grain size from mud via sand to gravel. A plot of skewness versus energy (not included in this paper) gives rise to similar clustering, albeit with slightly less discrimination between sand and gravel.

Results for the forward-looking sonar are found in Fig. 5, again with timespread versus energy. At least five different classes are distinguished. A striking difference with the echo sounder plot is observed for the area around 3.2 degrees East and 53.95 degrees North, the purple area in Fig. 5. At a 30° grazing angle the backscatter intensity apparently is as low as for the mud (dark green). It was verified that this remarkable result is not due to a decline in the sonar source power or other equipment settings during the experiments. Clearly the use of timespread in addition to the echo energy has revealed a sediment type that differs from the mud (dark green) or the sand (yellow). A plot of skewness versus energy for the forward-looking sonar (not included in this paper) distinguishes the same, basically five clusters.

The main deviation of the ground truth in Fig. 3 from the historical chart in Fig. 2 is the presence of gravel in the lower left-hand corner of the map. The ground truth provides supporting evidence for the acoustic results as both Fig. 4 and Fig. 5 claim that the lower left-hand corner is the same class as the gravel grounds in the upper half.

4. Conclusion

We have shown that seafloor characterization can be achieved with both an echo sounder and a forward-looking sonar and that the latter offers a more refined discrimination between sediments. The authors intend to elaborate further on the subject matter in future papers.

Acknowledgements

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