Improving seabed classification through the use of multiple acoustic frequencies

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Abstract

Existing acoustic technologies used for seabed mapping typically use only one acoustic frequency. There is a growing interest in the scientific community to combine various acoustic frequencies to improve the accuracy of seabed habitat maps produced using these technologies, as it is typically done in satellite remote sensing. Classifying and mapping seabed sediment types can be achieved using acoustic echo sounders as different sediment types absorb, reflect or scatter varying amounts of acoustic energy, which allow them to be differentiated. Such maps can indirectly be used to delineate the distribution of marine benthic habitats of demersal (bottom dwelling) fish species as these habitats are believed to be primarily determined by substrate type. Using multiple frequencies should improve seabed sediment classification, and therefore seabed habitat maps, because backscatter intensity, a measure of the intensity of acoustic energy scattered back towards the source, varies with frequency. Hence, the use of multiple frequencies is expected to add information, as lower acoustic frequencies penetrate the seafloor deeper and higher frequencies will detect smaller spatial features. This research investigates the benefit of combining multiple acoustic frequencies from a single beam echo sounder to directly improve the mapping of seabed sediments, and indirectly improve seabed habitat maps. Raw acoustic data from 38 kHz and 120 kHz frequencies have been processed to extract backscatter strength data from the returned acoustic energy received by the transducer. These processed data have then been used to derive information about seafloor sediment characteristics. GIS techniques were used to classify the backscatter data and the resulting classes are compared to existing interpreted surficial geological classes of the area. This paper presents preliminary results of the classification done using the two frequencies, compares it to the individual classifications performed by each frequency, and relates it to interpreted surficial geological classes.

Background and Relevance

Mapping of the seafloor is almost entirely performed using acoustic systems, as optical systems are limited by the fact that light does not propagate in waters deeper than 10-50 meters, depending on water clarity (Guenther *et al.*, 2000). Sound is emitted at a given frequency, propagates through the water column, interacts with the seafloor or other objects (e.g. fish, vegetation), and part of it (i.e. the backscatter) is returned to and recorded by the transceiver.

Most systems used today for seabed mapping make use of only one acoustic frequency (Kostylev *et al.*, 2001, Anderson *et al.*, 2002, Courtney *et al.*, 2005). The frequency selected depends on the application and the water depth. Backscatter data are used to map and classify seabed types based on the theory that different sediment types reflect and absorb varying amounts of acoustic energy. This theory is based on models which quantify the relationship between sediment types and backscatter intensity, based on certain frequencies and geophysical parameters (APL94, 1994). Some researchers have explored the use of multiple acoustic frequencies for applications such as mapping corals (Fossa *et al.*, 2005), detecting fish (Korneliussen and Ona, 2002), and differentiating limestone reef and sediment flat mesohabitats (Kloser *et al.*, 2002).

However, the utility of combining multiple acoustic frequencies to acquire information about seafloor sediment characteristics remains largely unexplored. The combination of multiple frequencies is expected to provide more information about sediment structure and surficial geological classes. This assumption is based on the theory of the physical response of acoustic energy from different sediment types. Hence, combining multiple frequencies should improve sediment classification because both surface and volume backscatter vary with frequency (Anderson *et al.*, 2008). An object must be larger than the acoustic wavelength to be detected. Therefore, higher frequencies will detect smaller features while lower frequencies will penetrate the seafloor deeper (Anderson, 2007). Hence, lower frequencies should detect seafloor features that higher frequencies should not and *vice versa*. Varying amounts of surface and volume backscatter are primarily a result of two geophysical properties, grain size and porosity, which allow normal incidence echo sounders to differentiate between sediment types (Anderson, 2007). The use of multiple frequencies should be most effective when the seabed sediment distribution is heterogeneous, as a mixture of sediments should best be detected with more than one frequency. Finally, this potential for improvements in sediment classification can indirectly improve efforts to define the distribution of marine benthic habitats of demersal (bottom dwelling) fish species as these habitats are believed to be primarily determined by substrate type (Kostylev *et al.*, 2001).

The main objective of this study is to determine if and how the combination of multiple frequencies will directly improve seabed sediment classification, as well to indirectly improve seabed habitat maps. A secondary objective is to determine which sediment types are best detected by one frequency, or the other, or the combination of the two frequencies.

The International Council for the Exploration of the Sea (ICES) has recently listed the use of multiple acoustic frequencies as one of the main future issues for acoustic seabed classification (Anderson *et al.*, 2008). Furthermore, investigating the usefulness of combining multiple acoustic frequencies to improve seabed classification is important and necessary research for fisheries science and marine geology.

Methods and Data

Data were collected on ship surveys conducted by the Department of Fisheries and Oceans Canada (DFO) on the Scotian Shelf, in the North Atlantic Ocean, in September 2002 and October 2003. The study area is composed of two 100 km^2 study sites on Western Bank, which each have a 5km^2 detailed study site within its boundaries. The detailed study sites have higher resolution data from the normal incidence echo sounder, as well as interpreted surficial geological classes. Data were collected using a

BioSonics DTX normal incidence echo sounder system at both 38 kHz and 120 kHz frequencies.

The current geological setting of Western bank has been shaped by events following the last glaciation. Marine transgressions have placed pre-existing glacial deposits of well-rounded gravels and fine to coarse-grained sands into the area. This process has replaced fine-grained silts and clays which have been deposited into deeper water. There are presence of boulders, and the sediments are generally reworked by waves and currents moving from the northeast to southwest (Courtney *et al.*, 2005). Recent sonar surveys have revealed that the seabed contains evidence of glacial processes, as evident by moraines, and fluvial erosion and there is a high degree of sediment patchiness and small scale roughness. There is a full range of sediment bedforms which include ripples, megaripples, sand ribbons, and ridges (Anderson & Gordon, 2007, p.14).

This particular study area on the Scotian shelf was chosen for a number of reasons. First of all, there has been a lot of work done in this area by DFO and therefore the area is generally well known. It hence lends itself well for testing a new method for seafloor mapping where ground truthing is important. Previous work has included geological and habitat mapping using sidescan, multibeam, and single beam sonar systems (Anderson *et al.*, 2005, Courtney *et al.*, 2005). There also has been a lot of ground truthing done through the use of video transects and underwater photography. Finally, there exist multiple frequency normal incidence echo sounder data of the study area which is required for this project.

Acoustic data from the surveys were processed in order to compensate for radiometric and geometric biases (i.e. remove the effects induced by the sonar system and the transducer's varying range, or distance, from the seafloor) so that meaningful backscatter data can be extracted. Raster surfaces of both depth and backscatter intensity were interpolated from these data. Surfaces for each frequency were then classified, using both supervised and unsupervised classification techniques, in order to delineate different seafloor types or surficial geological classes. Following this step, another classified map of seafloor types was created using the combination of the two acoustic frequencies (38 kHz and 120 kHz). The combined frequency classes were compared to the classes derived from each individual frequency. Then, the classification results were compared to existing interpreted surficial geological classes of the detailed study areas in order to examine and quantify the differences and similarities between the single frequency and multi-frequency results.

Results

This paper presents preliminary results of this research project. It highlights the different classifications of seafloor types based on acoustic backscatter from two frequencies individually and then from the combination of both frequencies. It looks at the similarities and differences of each classification in relation to the different surficial geological classes and will come with recommendations regarding the best frequency to use for detecting specific types of sediments.

Conclusions

This research demonstrates how backscatter information obtained from multiple acoustic frequencies, as opposed to one, provides further insight into the physical characteristics of seafloor sediments. This was achieved using normal incidence echo sounder data from two frequencies using specific classification algorithms in order to effectively delineate seabed sediment classes. An important result is that improved classification of seafloor types based on the combination of acoustic backscatter from several frequencies can be achieved. Such an approach is expected to be very useful to marine habitat mapping, fisheries and resource management, and geological studies. This research can be expanded to examine the effectiveness of such methods in a different study area with varying physical characteristics. It would also be interesting to incorporate multibeam data. Such a dataset would provide higher frequency data with wider spatial coverage and should add useful information about the study area and therefore impact the results of the classification.

References

APL94-Applied Physics Laboratory. (1994). High frequency ocean environmental acoustic model handbook APL-UW TR 9407. *Applied Physics Laboratory Technical Report* (University of Washington).

Anderson, J.T., Gregory, R., & Collins, W. (2002). Acoustic classification of marine habitats in coastal Newfoundland. *ICES Journal of Marine Science, 59,* 156-167.

Anderson, J.T., Simon, E., Gordon, D., & Hurley, P. (2005). Linking fisheries to benthic habitats at multiple scales: Eastern Scotian Shelf Haddock. *American Fisheries Society Symposium, 41*, 251-264.

Anderson, J.T. (2007). Acoustic seabed classification of marine physical and biological landscapes. In *ICES Cooperative Research Report No. 286,* (pp.1-6).

Anderson, J.T., Van Holliday, D., Kloser, R., Reid, D.G., Simard, Y. (2008). Acoustic seabed classification: current practice and future directions. *ICES Journal of Marine Science, 65,* 1004-1011.

Courtney, R., Anderson, J.T., Lang, C., & Fader, G. (2005). Comparative seabed classification using sidescan and normal incidence sonar data at selected study sites on the Scotian shelf, Canada. *Proceedings of the International Conference "Underwater Acoustic Measurements: Technologies & Results"*. Crete, Greece.

Fader, G.B.J. (2007). Report of the spatial utilization of benthic habitats by demersal fish on the Scotian shelf synthesis meeting 2007. In *Canadian Technical Report of Fisheries and Aquatic Sciences 2770,* (pp. 14-16).

Fossa, J., Lindberg, B., Christensen, O., Lundalv, T., Svellingen, I., Mortensen, P., & Alvsvag, J. (2005). Mapping of Lophelia reefs in Norway: experiences and survey methods. In A. Freiwald & J.M. Roberts (Eds), *Cold-water Corals and Ecosystems* (pp. 337-370). Berlin – Heidelberg, Germany: Springer-Verlag.

Guenther, G.C., Cunningham, A.G., LaRocque, P.E., & Reid, D.J. (2000). Meeting the accuracy challenge in airborne Lidar bathymetry. *Proceedings of EARSeL-SIG-Workshop LIDAR, No. 1.* Dresden, Germany.

Kloser, R., Keith, G., Ryan, T., Williams, A., & Penrose, J. (2002). Seabed biotope characterisation in deep water – initial evaluation of single and multi-beam acoustics. In A. Stepnowski (Ed.), *Proceedings of the sixth European conference on underwater acoustics* (pp. 81-88). Gdansk, Poland.

Korneliussen, R., & Ona, E. (2002). An operational system for processing and visualizing multi-frequency acoustic data. *ICES Journal of Marine Science, 159,* 293-313.

Kostylev, V., Todd, B., Fader, G., Courtney, R., Cameron, G., & Pickrill, R. (2001). Benthic habitat mapping on the Scotian Shelf based on multibeam bathymetry, surficial geology and sea floor photographs. *Marine Ecology Progress Series, 219,* 121-137.