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Invited feature

A review of oceanographic applications of water column data from multibeam echosounders

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ABSTRACT

Multibeam echosounder systems (MBES) have long provided bathymetric data with high temporal and spatial resolution. In the last couple of decades, MBES observations of scattering in the water column have been finding increasing use in oceanographic studies. Here we review the wealth of studies using water column multibeam data to address questions in fisheries, marine mammal and zooplankton research as well as seeps and hydrothermal vents. We also summarize some of the tantalizing new oceanographic applications of water column MBES, such as kelp ecosystems, near surface bubbles, suspended sediment, mixing and internal waves, as well as the proper determination of the extent of shipwreck above the sea floor. We highlight the many advantages of using water column MBES and discuss the challenges.

Editors note

Technical advances are often the pathway to previously unattainable data, novel insights, and exploration of new questions. In the Invited Feature Article in this issue, Ross and colleagues introduce and review the multiple potential applications of water column multibeam data to address questions in fisheries, marine mammal and zooplankton research as well as in studies of seeps and hydrothermal vents. The improved resolution, and versatility of the recently available technology reviewed in this paper should be of interest to researchers in many fields in coastal and oceanographic research.

1. Introduction

The first underwater acoustic systems emerged in the early part of the 20th century, with navigation and safety to mariners driving their development. Single-beam bathymetric sounders were amongst the earlier systems developed, and are still the most common form of underwater acoustic system in use today. They are primarily used to calculate water depth beneath the hull of a vessel by measuring the two-way time travel of the emitted pulse of sound. However, these systems have also been used for a variety of applications beyond their primary hydrographic role, including military, fisheries, oceanographic, and seafloor geological and benthic habitat mapping (Lurton, 2002; Anderson et al., 2008).

The pace of development in underwater acoustic systems has accelerated over the past few decades, with rapid advancement in sonar technology stemming from improvements in geographic positioning capabilities, computer processing power, and sonar hardware and software design (Mayer, 2006; Stanton, 2012). This has been especially apparent with multibeam echo sounder (MBES) systems (Fig. 1). The first MBES systems appeared in the late 1970s (Renard and Allenou, 1979) with the early systems, such as the *SeaBeam*, limited to fairly modest angular coverage (swath widths of 45°) and forming only 16 beams (Lurton, 2002). The hydrographic community embraced these systems, which are primitive by today's standards, and they became key components in

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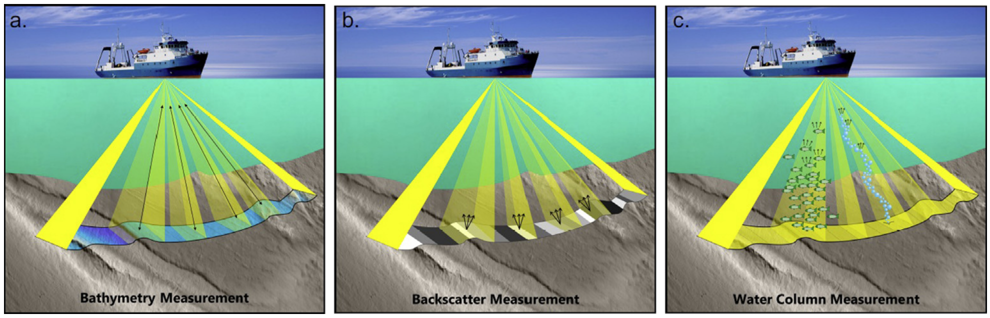

Fig. 1. Schematic diagram illustrating the different types of acoustic data that can be recorded by multibeam systems (adapted from Lurton, 2002). a) Bathymetric measurement; b) Seafloor backscatter measurement; c) Water column measurement.

bathymetric survey and hydrographic chart production. The main attraction was the large-area seafloor coverage offered by the "swath" system from a single pass of the survey platform, providing superior navigation data compared to that obtained by single-beam bathymetric sounders by reducing the risk of overlooking bathymetric shoals that may pose a risk to mariners (Fig. 1a).

Since these early MBES systems, the technology has advanced enormously. Modern systems now boast far greater angular coverage (typically 120–150°) and form hundreds of beams (Mayer, 2006; Fig. 1). Modern MBES provide data with extremely high vertical (typically <1% of water depth) and horizontal resolution (typically a small percentage of the water depth). Systems have also been developed to operate in different water depths, ranging from very shallow coastal waters to full ocean depths, with operating frequencies ranging from 12 to 500 kHz, depending on target application (Lurton, 2002).

Not surprisingly, the technology has been embraced by disciplines outside of the field of hydrographic survey. The wide-area bathymetric data coverage offered by MBES provides a means to generate digital elevation models of the seabed to reveal detailed seafloor morphology. The benefits of this application for the study of seafloor geology were quickly recognized, and MBES rapidly became a favored tool for marine geologists (Pickrill and Todd, 2003). Over the past 10–15 years, substantial research and development effort has also been focused on the extraction and processing of multibeam backscatter information from the MBES signal (Brown and Blondel, 2009). MBES backscatter is similar to sidescan sonar backscatter, and can be used to infer seafloor hardness and roughness characteristics—an extremely valuable measurement when studying seafloor surficial geology (Fig. 1b). Recent developments in data collection and processing of multibeam backscatter, combined with the availability of co-registered bathymetry, have dramatically improved the quality of the imagery. Modern MBES systems now offer backscatter data that provides as much (or more) information than is available with sidescan sonar alone (Brown and Blondel, 2009). MBES bathymetry and backscatter are now commonly used together (in combination with other geophysical survey data sets) to generate seafloor geology maps (Pickrill and Todd, 2003; Harris and Baker, 2011). Similarly, the field of benthic habitat mapping has matured over this same time frame, also driven by the availability of MBES bathymetric and backscatter data providing high-quality baseline data for many habitat mapping studies (see Brown et al., 2011; Harris and Baker, 2011).

Hydrographic, geological and benthic habitat mapping applications of single- and multibeam acoustics all rely on the collection and processing of data from the seafloor return. Seafloor mapping applications of these systems are therefore well advanced and documented in the scientific literature (Lurton, 2002; Pickrill and Todd, 2003; Anderson et al., 2008; Brown et al., 2011; Harris and Baker, 2011). However, acoustic returns may also be detected from objects in the water column (i.e. above the seafloor) that scatter the emitted sound pulse (Fig. 1c). Measurement and recording of water column returns from single-beam echosounders for numerous applications have been underway for some time: For example, the use of echosounder data in fisheries has existed since at least the 40's (Cushing, 1952; Horne, 2000); The "deep scattering layer" has been postulated to be a result of scattering from zooplankton (Moore, 1950); Acoustic scattering from suspended sediment layers had been proposed (Proni et al., 1975); and natural gas seeps had been observed (Watkins and Worzel, 1978). However, it was not until the 1990's that multibeam sonar was applied to any of these problems, and water column applications lag behind seafloor applications of MBES. This slow development was likely due to two main factors: the immense data storage requirements needed to record water column data, and the fact that even many modern multibeam sonar systems do not permit the digital logging of water column returns.

Nevertheless, MBES technology for mapping water column features is gaining momentum. Multibeam sonar offers the ability to image a synoptic slice of the water column above the seafloor, with a reasonable degree of angular resolution (e.g. Fig. 1), which makes it particularly attractive for applications where the target is either elusive or non-stationary over the necessary survey time (i.e. fisheries applications). It is not surprising, therefore, that purpose-designed fisheries multibeam systems have been developed for industry (and scientific) applications in recent years (e.g., Trenkel et al., 2008), with a growing body of scientific literature on fisheries applications of multibeam sonar generated over this time. Water-column applications in other areas such as oceanography, and geophysical/geological investigations are less numerous, but have also gained momentum within the past decade as systems and software have been developed to record and process the water column returns.

In this review paper we provide a synopsis of current and recent water column uses of multibeam echosounders. In this context, we define water column as the insonified area of the MBES swath above the seafloor return. There are currently a wide range of MBES systems in use, each designed for different applications, operating over a range of different frequencies, and using a variety of transmit/receive methods. We have limited this review to multibeam echo sounder systems operating between 12 and 500 kHz (in line with the definition of MBES systems provided by Lurton, 2002), and designed primarily for hydrographic or fisheries purposes. Very high-frequency (i.e. > 500 kHz) multibeam imaging sonar systems primarily used for object detection/avoidance are outside of the scope of this review. The review is broken down into two broad themes focused around the application of the MBES water column