Offshore Operations in Marine GeoSciences

Acoustic seafloor mapping

Rory Quinn, University of Ulster
RJ.Quinn@ulster.ac.uk

Digital Resources for Common Module in Offshore Multidisciplinary Operations in Marine Science
1. Introduction to seafloor mapping

In the twenty-first century, acoustic (sonar) systems are routinely used for rapid, noninvasive surveys of the seafloor and subsurface. Both the Irish National Seabed Survey (INSS) and the Integrated Mapping for the Sustainable Development of Ireland’s Marine Resource (INFOMAR) mapping programmes have relied on these acoustic techniques for the last two decades, mapping the seafloor off Ireland at a resolution once thought improbable (Figure 1). Although bathymetric survey techniques have been employed in the marine sciences since at least the early part of the nineteenth century, existing bathymetric charts for most parts of the world are Victorian in vintage, compiled from lead-line soundings and sextant positioning. These charts are therefore severely outdated in terms of spatial and temporal resolution and are unsuitable for marine research and stewardship.

![Figure 1](image)

**Figure 1** The ‘real map of Ireland’ - Ireland’s designated continental shelf area superimposed on a shaded relief image of bathymetric data collected under INSS, PAD and GEBCO (Geological Survey of Ireland and the Marine Institute, 2012).

In the early part of the twentieth century, single-beam echo-sounders (SBES) replaced traditional lead-weighted lines as the primary bathymetric survey technique for civilian and military purposes (Lurton 2002). Between 1925 and 1927, the first large-scale scientific bathymetric survey was conducted by the German Atlantic Expedition on RV Meteor using SBES (Wüst and Defant 1936). In the early 1960s, side-scan sonar (SSS) was developed as a tool for regional-scale geological mapping, revolutionizing seafloor mapping in terms of spatial coverage and data resolution (Figure 2). The effectiveness of acoustic mapping evolved between the 1970s and the twenty-first century with the advent of multi-beam echo-sounders (MBES) allied to powerful and affordable desktop computing facilities (Figure 2). In addition to modern bathymetric charts providing highly accurate depth information, the results from these acoustic surveys now routinely provide details of objects on the seabed and the geological and biological components therein. Modern seabed mapping...
therefore results from the integration of many different types of information, much of which is gathered acoustically (Lurton 2002).

![Figure 2](image)

**Figure 2** Sonar surveying using a hull-mounted multi-beam echo-sounder and a towfish-mounted side-scan sonar (orange platform tethered by cable).

The major advantages of acoustic mapping systems are that they are rapid, noninvasive and capable of surveying large tracts of the seabed at very high resolution (*circa* 10cm). A full discussion of the theory behind the acquisition, processing, and interpretation of these data is beyond the scope and remit of this lecture. However, an excellent introduction to the principles and applications of underwater acoustics can be found in Lurton (2002).

This lecture outlines the most common acoustic techniques employed in seafloor mapping (single- and multi-beam echo-sounders, side-scan sonar and seismic profilers), how the data from these systems are geo-referenced using the global positioning system (GPS) and how these systems are deployed from RV Celtic Voyager.

### 2. Navigation and positioning at sea

To effectively map, interpret, integrate, and ground-truth remotely sensed acoustic data, tight navigational and positional control is essential in all phases of the investigation. To precisely locate the position of features and objects on the seabed, knowledge of the following three parameters is required: (1) the location of the survey vessel on the seafloor, knowledge of the following three parameters is required: (1) the location of the survey vessel on the sea-surface, (2) the location of the sonar platform below the sea-surface, and (3) the portion of the seafloor that is being insonified (exposed to sonar energy) at any given time. This precise positional control is achieved through a combination of position fixing (latitude, longitude and altitude above a reference datum), heading, speed, and attitude (heave, roll, pitch and yaw) information.

The minimum requirement for accurate navigation of a survey vessel is the Global Positioning System (GPS). Using the calculated distance and orbital position of satellites (a minimum of three is required for accuracy), the GPS receiver determines a position fix in degrees of latitude and longitude, conventionally to the WGS84 datum (World Geodetic System of 1984, the default datum for GPS units). This position can in turn be translated into any global or local metric coordinate system (e.g., UTM). Accuracy of GPS varies with satellite constellation geometry and receiver type, but an accuracy of ±5 m with an update rate of once per second (1 Hz) is now common.
To reduce positional errors to an acceptable level for high-resolution surveys (±1 m), differential GPS (DGPS) employs a land-based station to calculate the error in positioning and transmit the error to the shipboard receiver. Corrected data from the shipboard GPS unit is output to software packages for survey navigation and logging. Furthermore, for quantitative analysis of the seafloor and/or subsurface, it is essential to relate depth data to a static horizon, and therefore it is necessary to remove the effects of tidal variation over the survey period. Tidal corrections are achieved with reference to either a static tidal gauge or to modeled tidal predictions. For high-accuracy surveys the tidal curve should be recorded continuously at a site in close proximity (±1 km) to the survey site. Recently the technology of DGPS has been superseded by Real Time Kinematic (RTK) systems that use the characteristics of the signal carrying the GPS data from satellite to the receiver, to give \( x, y, \) and \( z \) values to an accuracy of ±1 cm. RTK-GPS also negates the requirement to set up a tide gauge, as tidal corrections can be derived from the \( z \)-component of the signal.

In some applications, the sonar platform is towed by the ship (often referred to as the towfish, see Figure 2), and its position determined in one of two ways—either by manual calculation or by using acoustic tracking techniques. ‘Layback’ is the term used to define the horizontal distance between the towfish and the GPS antenna mounted on the survey vessel. It is important to remember that the sonar data is generated not at the survey vessel, but at the towfish. The layback correction can be calculated manually using Pythagoras’ theorem, where the length of cable deployed corresponds to the hypotenuse and the depth of the towfish equates to one leg of the right-angled triangle. Alternatively, an acoustic beacon (transponder), operating at a set frequency, is attached to the towfish and interrogated by a ship-mounted hydrophone to accurately determine the position of the towed array. In the majority of applications, the sonar platform is attached directly to the hull of the ship, i.e. it is hull-mounted. The echo-sounders and seismic profiler employed on RV Celtic Voyager are hull-mounted systems.

Which portion of the seafloor is being insonified at any given time is addressed by measuring the motion of the ship or sonar platform using an Inertial Measurement Unit (IMU) or Motion Referencing Unit (MRU). This system uses a combination of accelerometers and angular rate sensors (gyroscopes) to track vessel movement, detecting the current acceleration and rate of change in attitude. These corrections are applied to remotely sensed data to correct for the effects of pitch, roll, and yaw on the survey vessel and/or towfish. In practice, as IMUs are expensive to purchase and/or hire and their mobilization is time-consuming, they are usually only used for MBES surveys, where these corrections are essential for high-quality data.

### 3. Brief introduction to ocean acoustics

In order to effectively interpret acoustic data, it is essential to understand how these data are generated. Sonar systems function by transmitting acoustic pulses toward the seafloor and waiting for the returned energy to be received and processed by onboard computers. Once an acoustic pulse is transmitted by a survey instrument, it is at the mercy of the medium through which it propagates (the water column and sediment pile) and is no longer in the control of the surveyor or survey instrumentation. The interaction of the acoustic pulse with the water column, seafloor, and subsurface is not always straightforward and can influence the resulting acoustic data in many ways. In order to correctly interpret acoustic remote-sensing data, it is therefore essential to have some appreciation of underwater acoustics. Two factors must be considered: (1) interactions of the acoustic pulse with the water column, the seafloor, and the subsurface, and (2) mechanisms whereby the transmitted energy is returned to the instrument.
Figure 3 Variation in sound velocity as a function of depth.

Sound is used to measure physical properties of the seafloor, the depth of the ocean, ocean temperature, and ocean currents, by transmitting an acoustic pulse into the water column and measuring the time taken for the pulse to travel back to the instrument. Sound velocity in water (Figure 3) is dependent on temperature, salinity, and pressure. A typical value of sound velocity in saline water is $1,480 \text{ ms}^{-1}$. The value for freshwater is lower, as freshwater is less dense than saline water. Velocity depends primarily on temperature, less on pressure, and very little on salinity. All of the acoustic techniques described in this chapter are founded on the same basic principles of seismic reflection: each technique measures the time taken for an acoustic pulse to be transmitted from the survey instrument, travel through the water column (or sediment), reflect (or scatter) from a boundary, and travel back to the instrument.

The sonar transmits a fixed amount of energy into the water in the form of the acoustic pulse. As the pulse wavefront spreads in a spherical pattern, the intensity of the pulse falls with increasing distance (or range) from the source. The energy returning to the sonar is also affected by spherical spreading. As the acoustic pulse propagates through the water column and subsurface, some of the energy is simply absorbed by the medium due to frictional effects. In general terms, the higher the frequency of the transmitted pulse, the higher the absorption rate. Absorption is also stronger in saline water than in freshwater.

The transmitted acoustic pulse may be deflected as it propagates through the water column and subsurface. For example, it may encounter air bubbles, fish, suspended sediment, rough seafloors, subsurface targets, and so on. In each scenario, a proportion of the sound is scattered and reflected in various directions, including back toward the survey instrument. It is important to understand the differences between reflected energy and scattered energy. In general terms, echo-sounders and sub-bottom profilers rely on specular reflection, and side-scan sonar relies on scattered (diffuse) energy, to produce acoustic images of the seafloor and subsurface.

When the transmitted pulse reaches an obstacle in the water column, at the seafloor or in the subsurface, some portion of the acoustic pulse is reflected from the interface. The orientation of the reflecting medium with respect to the incident ray (measured as the angle of incidence, or grazing angle) is the most important factor in determining whether the reflected energy travels toward or away from the survey instrument.

As seismic reflection techniques (echo-sounders and sub-bottom profilers) rely on specular reflection, these sources conventionally transmit the acoustic pulse vertically downward and rely on the acoustic pulse being reflected vertically upward. The relative proportion of
energy transmitted to each of these rays is determined by the contrast in acoustic impedance \((Z)\) across the boundary, where acoustic impedance is equal to the velocity \((V)\) of the medium multiplied by density \((\rho)\):

\[
Z = \rho V. \quad \text{Eq 1}
\]

The strength of the reflection from the boundary between two materials (a measure of the proportion of energy returned toward the survey instrument) is governed by the reflection coefficient \((K_R)\), where

\[
K_R = \frac{Z_2 - Z_1}{Z_2 + Z_1}. \quad \text{Eq 2}
\]

The polarity of the reflection coefficient is dependent on whether there is an increase (positive reflection) or decrease (negative reflection) in the acoustic impedance across the interface. In normal subsurface geological situations, values of \(K_R\) fall into the range of \(\pm 0.1\) (Anstey 1981), with the majority of energy being transmitted.

Seismic reflection surveys account for more than 90% of the money spent worldwide on applied geophysics (Milsom 1996). The majority of these surveys are conducted by and for the hydrocarbon exploration industry in the search for oil and gas reserves. However, in the marine environment, seismic reflection techniques are employed in the form of bathymetric surveys and sub-bottom profiling surveys and, in a looser framework, in side-scan sonar surveys.

In side-scan sonar systems, the transducers transmit the acoustic pulse out to the side of the system, inclined at an angle toward the seafloor. The majority of the incident energy in this case is reflected away from the actual source. However, as the seafloor (and objects lying upon it) contain an inherent roughness, a proportion of the incident pulse is scattered by the roughness of the medium, and some of this scattered energy is “backscattered” (or diffused) toward the side-scan instrument. This backscattered sound is also known as reverberation. The intensity of the backscattered signal is a direct function of bottom roughness and angle of incidence. The rougher the bottom, the stronger the reverberation. However, roughness is a relative term and is dependent on the frequency (and, more importantly, the inherent wavelength) of the acoustic pulse.

To date, we have spoken in terms of time (or travel time), that is, the time taken for a pulse to be transmitted toward the seafloor and returned to the survey instrument. However, all measurement of depth or distance in marine acoustics depends on the conversion of time to depth and an assumption regarding the velocity of sound through sediment or water. The time taken for the acoustic wave to travel from the transducer to the reflecting boundary and back again is known as the two-way-travel-time \((twt)\), which is related to depth \((d)\) by the following equation:

\[
d = \frac{V \times twt}{2}. \quad \text{Eq 3}
\]

\(V\) is highly variable for different sediment types. As noted above, \(V\) for salt water is approximately \(1,480\) \(\text{ms}^{-1}\). \(V\) varies between different sediment types and rocks. In general, hard rigid materials (rock, metal, wood) have relatively high compressional wave velocities, while soft plastic materials such as unconsolidated sediment have low compressional wave velocities. Furthermore, the general empirical rule applies that the compressional wave velocity increases in step with density in similar material types. For example, sediment generally becomes denser with depth of burial, hence their compressional wave velocity also increases with depth. In some shallow penetration applications, no differentiation is made between the velocity of sound in the water column and in the sediment pile. Instead, a constant value of \(1,500\) \(\text{ms}^{-1}\) is used for \(V\). This is usually the same value used in side-scan sonar and bathymetric surveys.
The majority of users and manufacturers of acoustic instruments state that the resolution of acoustic systems is principally dependent on the frequency of the acoustic waves employed. This rule of thumb is misleading. It is naive to assume that higher-frequency acoustic systems always acquire higher-resolution acoustic data. In fact, the resolution and detection capability of acoustic instrumentation and resultant data is a complex issue, dependent on pulse lengths, beam angles, pulse rates, speed over ground, sample frequencies, and display mechanisms, to name a few (Quinn et al. 2005). It is therefore imperative that users of these data have some appreciation of underwater acoustics in order to carry out accurate and realistic interpretations. Some processed images derived from acoustic remote-sensing surveys are now of sufficient detail that they are interpretable by almost anyone, sometimes without much prior experience in remote-sensing interpretation. These types of images prove enormously beneficial in convincing resource managers and government bodies of the worth of this approach.

4. Profiling methods

4.1 Single-beam echo-sounders (SBES)

An essential component of all marine studies is the production of a detailed bathymetric (depth) chart, with bathymetric maps often forming the baseline data set for the investigation. Inexpensive SBES are commonplace, with many vessels equipped to conduct relatively unsophisticated but effective low-resolution bathymetric surveys. More sophisticated MBES are becoming increasingly common in investigations (see below), although cost remains a prohibitive factor for some.

![Koden echo-sounder display. Note the steep gradient of the seafloor (in red) and the shoal of fish in the water column located between 20 and 40 m.](image)

SBES measures depth by multiplying half the time from the signal's outgoing pulse to its return by the speed of sound in the water (Eq 3). For precise applications of echosounding, such as hydrography, the speed of sound must also be measured accurately, typically by deploying a sound velocity profiler (SVP). Since the traditional pre-SI unit of water depth was the fathom, some people call SBESs ‘fathometers’ (particularly common in the USA). Fishers often refer to SBES as ‘fish-finders’ as echo-sounders also produce a return from swim bladders, so can be used to locate fish in the water column (Figure 4).

Conventional echo-sounder systems consist of single hull-mounted or pole-mounted transducers that act as both an acoustic transmitter and receiver (transceiver). These systems transmit a single- or dual-frequency pulse, typically within the 50–300 kHz bandwidth. The frequency-dependent, vertical resolution of these systems can be as great as a few centimeters. Echo-sounders produce an acoustic pulse with a 30–45° cone angle, oriented vertically downward, concentrating the acoustic energy in a small circular area of the seabed (the radius of this circle is dependent on the water depth). The horizontal
resolution of these systems is controlled by a combination of source frequency, cone angle, and water depth. For example, a 200 kHz echo-sounder with a 50° cone angle has a horizontal resolution of 0.14 m in a water depth of 20 m.

One major disadvantage of SBES systems is that the density of the survey grid controls the effective horizontal resolution of the survey. In a tidal environment, the maximum survey grid density achievable is on the order of 5 m. Therefore, the highest possible horizontal resolution for the bathymetric survey is ±5 m. Bathymetric data is conventionally represented as profiles, two-dimensional contour plots, or three-dimensional digital elevation models (DEMs). Regional-scale SBES surveys are conventionally designed with survey lines oriented perpendicular to the coast, as bathymetric variation is usually at a maximum in this direction. Site-specific SBES surveys are conventionally designed with survey lines oriented on a grid. RV Celtic Voyager is equipped two single-beam echo sounders - Kongsberg Simrad EK500 and EA600 operating at user-selectable frequencies of 12, 38 and 200 kHz.

4.2 Sub-bottom (seismic) profilers (SBP)

Knowledge of the strata underlying the seabed is fundamental to many marine geological, engineering, biological and archaeological studies. Seismic profilers employ acoustic sources with lower frequencies than SBESs – these sources therefore penetrate the seabed, and reflect off boundaries, layers or objects in the subsurface (Figure 5), and are detected by an acoustic receiver (or hydrophone) that is usually mounted in close proximity to the source. Reflections occur from boundaries or layers where there are differences in density and/or sound velocity across a boundary, that is, where an acoustic impedance contrast exists. Seismic profilers generate a data set that can be processed to give a cross section in the direction of movement of the boat in two-way travel time (Figure 6). With additional knowledge of the speed of sound through the sediments (obtained from in situ measurements of core material or by comparison with empirically derived values), the time section can be converted to a depth section.

A variety of seismic sources are available for marine applications, including water guns (20-1500 Hz), air guns (100-1500 Hz), sparkers (50-4000 Hz), boomers (300-3000 Hz), pingers (c. 3500 Hz) and chirp systems (500 Hz - 12 kHz). The greatest resolution of near surface structure is generally obtained from the higher frequency sources such as the Chirp systems, while the lower frequency tend to better characterize structure at depth (for example locating oil or gas reservoirs).

The seismic system mounted on the hull of RV Celtic Voyager is a pinger, which transmits short pulses of a single frequency (3.5 kHz, for example), which gives a vertical resolution of 0.3–0.5 m and penetration of 10–50 m. Transmission of the pulse and reception of the returning echoes are conducted within a single set of transceivers, optimizing the system’s horizontal resolution. Similar to SBES surveys, regional-scale seismic surveys are conventionally designed with track lines oriented perpendicular to shore, as stratigraphic variation is usually highest in this direction.
Figure 5 An illustration adapted from an educational website on petroleum illustrates the basic application of seismic data acquisition in a marine setting.

Figure 6 Seismic-reflection profile acquired by the USGS showing three small channels cut into glacial-marine sediment. The transgressive unconformity (red line) is eroded into the upper surface of fluvial deposits and locally overlain by a sheet of sandy marine sediment generally less than 1 m thick.
5. Swath methods

5.1 Side-scan sonar

Side-scan sonar is a method of seabed imaging using narrow beams of acoustic energy transmitted out either side (port and starboard, Figure 7) of the towfish and across the seabed (Fish and Carr 1990). Sound, backscattered from the seafloor and from submerged objects, is processed to provide laterally undistorted acoustic images of the seafloor in real time (Figure 8). The swath-width of side-scan sonars (i.e. the area of the seafloor surveyed in a single pass) is user-controlled, generally 10 times the water depth. Up to the early part of the twenty-first century, side-scan sonar was regarded as the workhorse of offshore survey, featuring heavily in all offshore investigations. However, side-scan sonar is now slowly being replaced by the multi-beam echo-sounder as the instrument of choice as multi-beam systems allow the user to collect high-resolution backscatter data in addition to bathymetric data.

As with most acoustic instruments, side-scan systems are available in a variety of types, depth ratings, and operating frequencies. Standard systems are portable and suitable for deployment from inshore survey vessels, employing one of two industry-standard frequencies for imaging: 100 kHz and 500 kHz. In general terms, a 100 kHz operating frequency is chosen for regional surveys with swath widths in excess of 100 m per channel. Frequencies of 500 kHz are generally used where a higher resolution is required, such as for detailed shipwreck surveys.

![Figure 7 Towfish-mounted side-scan sonar, insonifying large tracts of the seafloor (Kleinsonar.com).](image)

Material properties of the substrate determine the acoustic response of the seafloor (Quinn et al. 2005), and the data generated during side-scan sonar surveys. All materials have an inherent roughness — for example, coarse-grained material scatters more energy than fine-grained material due to the rougher interface presented to the acoustic pulse. Therefore, rock, gravel, wood, and metals scatter more energy than finer-grained sediments and will therefore be recorded as darker elements on the sonar record. Reflector shape, including seafloor gradient, also influences reflectivity and backscattering.

The majority of side-scan investigations follow a predetermined survey pattern, with lane spacing less than the swath width of the sonar, allowing for overlap between successive survey lines. This overlap allows for deviation off the survey line and also compensates for loss of resolution with range. Although data in the past was conventionally displayed on
Figure 8 Side-scan sonar record of shipwrecks imaged on a mixed rock and sand substrate (Delph Sonar). The black area at the centre of the sonograph represents the water column.

Figure 9 Side-scan sonar mosaic (comprising in excess of 50 individual side-scan lines) collected over a heterogeneous seafloor at Petit Bios Pass by the USGS.

thermal film, modern systems allow for digital acquisition and geo-rectification. Individual geo-rectified side-scan lines are routinely compiled into sonar mosaics to provide large-area acoustic images at the original resolution (Figure 9).
5.2 Multi-beam echo-sounders (MBES)

Multi-beam echo-sounders are a direct development of the SBES, but instead of estimating the depth of a single point on the seafloor directly beneath the transceiver, they estimate the depths of tens or hundreds of points within a swath orthogonal to the transceiver, ensuring high-density, high-resolution coverage (Figure 10). MBES systems are therefore used to increase bottom coverage, with each of the narrow beams producing data at a resolution equivalent to that of a narrow SBES. MBES systems are usually mounted on the hull or on a remotely operated vehicle (ROV) but can be mounted on a towfish if required.

Two types of swath systems are commonly employed for bathymetric mapping—multibeam echo-sounders and interferometric sonars (also termed bathymetric side-scan sonar). Each of these systems has its own advantages and disadvantages. To put it simply, MBES systems offer higher-resolution bathymetric data with low-order backscatter data as a by-product, whereas interferometric systems offer lower-order bathymetric data and true side-scan. The more sophisticated MBES can simultaneously acquire depth and backscatter data for each point insonified on the seafloor (Figure 11). These data can then be used to derive charts of the seafloor showing relief and backscatter intensity, which can in turn be used to produce geological maps when ground-truthed using direct (grabs, cores) or indirect (video, stills) sampling methods. Despite their complexity and relative expense, MBES now dominate seafloor mapping.
JIBS MBES data - (A) 1m-resolution bathymetry and (B) backscatter data acquired over the dispersed remains of the armoured cruiser HMS Drake (torpedoed in 1917) and steam trawler Ella Hewett (collided with remains of HMS Drake in 1962). Note the importance of the backscatter data in providing a clearer image of the wreck remains and the bedforms (eg. to the SW) in addition to giving information on sediment types (dark areas = gravel; light areas = sand).

MBES have many uses and are designed to operate in various water depths. System choice therefore depends on the water depth range to be surveyed. MBES systems are grouped into three main categories (Lurton 2002). Deepwater systems are designed for regional survey and operate in the frequency range of 12 kHz (deep ocean mapping) to 30 kHz (continental shelf investigations). The large size and weight of these MBES transceivers limits their installation to deep-sea vessels. Shallow-water systems typically operate at 100–200 kHz and are designed for hydrographic survey of the continental shelves. High-definition systems, operating between 300 and 500 kHz, are used for high-definition work and object detection. Their small size and weight makes them ideal for small-vessel deployment and for mounting on ROVs. RV Celtic Voyager is equipped with two MBES systems – a Kongsberg Simrad EM1002 (95 kHz) for deeper water work and EM3002 (295 kHz) for shallower water, higher-resolution survey.

6. Data acquisition, processing and interpretation

The quality of remotely sensed data is affected by many factors, including vessel and towfish instability, positioning accuracy, weather, boat heave, and water column noise. To aid data interpretation, detailed and time-stamped (always use GPS time) field notes should be logged during survey. As the person interpreting the data has often not been involved in the data acquisition phase, comprehensive survey logs can be of great benefit to the interpreter. Simple things like “start of line” (SOL) and “end of line” (EOL) marks should be recorded both on the data and in a field log to facilitate data processing. Due to the large
volume of data acquired in acoustic remote sensing surveys, systems of file naming should be logical and consistent. Files should be numbered sequentially to avoid ambiguity.

To the surveyor, ‘signal’ is the portion of data that is required, and ‘noise’ describes anything else that is recorded but is considered to contain no useful information. Good-quality data has a high signal-to-noise ratio (SNR). Because of this, much of the surveyors’ efforts are dedicated to the need to improve the SNR of data. In the marine environment, noise is caused by such phenomena as vessel engine noise, wake from passing vessels, sea-surface chop, and in extreme cases by marine life. Survey procedures should be adapted to ensure that the best possible data is acquired. For example, a pulsing echo-sounder may cause regular interference on side-scan data. The easiest way of eliminating this interference is to turn off the echo-sounder. However, in shallow-water applications, the skipper may require a depth readout, so the echo-sounder cannot be switched off. In this case, interference may be limited by increasing the distance between the echo-sounder transducer and the side-scan towfish by towing on a longer cable length (Fish and Carr 1990).

The results from geophysical surveys can be presented in many formats, depending on data type and audience. The results of surveys along single traverses can be presented in profile form, where the horizontal scale is distance and the vertical scale is the quantity being measured: for example, the results of a single bathymetric transect would plot distance against depth. The results along grid-type surveys can be contoured and presented as two-dimensional or three-dimensional plots and surfaces: for instance, the results of a bathymetric survey could be contoured to provide a bathymetric chart of the area. The results of side-scan sonar surveys are usually presented as either acoustic snapshots (image data) or mosaics of the seafloor. Whatever method is used, it is important to present data in such a way that the target audience is addressed and data attributes are clear. Data should be presented to inform, not to impress.

The only satisfactory method presently available for quantifying marine acoustic data is to physically ground-truth anomalies and ambiguous targets, either through diver, drop-down video, or ROV investigations (see accompanying lecture notes).

7. Applications of acoustic techniques

Acoustic instruments are now standard in marine investigations where knowledge of properties of and processes in the water column, seafloor and sub-surface are required. Navies, exploration companies, government organisations, research institutions, engineering companies, fisheries scientists, marine ecologists, geologists, oceanographers and archaeologists all use these techniques to acquire non-invasive high-resolution high-volume data sets. For example, acoustics can help to quantify sediment budgets, provide information on hydrodynamics, investigate specific habitats, quantify seabed movement, detect hydrocarbons, map the geology of an area and play a role in recording the distribution and state of small objects/features on the seafloor. Furthermore, repeat (time-lapse) sonar surveys have proven effective in quantifying change in a variety of studies.

Marine archaeologists use the techniques to locate and identify shipwrecks (Figure 12) and investigate submerged archaeological landscapes (Figure 13). In fact, much of the recent renewed interest in the archaeology of submerged coastlines stems from the increased resolving capability of acoustic methods and their role in locating, mapping, and reconstructing these environments (Figure 13). Perhaps some of the most exciting developments in this area of research in recent years are being realized through the provision of high-resolution MBES data sets acquired over large geographic areas.
Figure 12 Multi-beam echo-sounder data of (a) HMS Royal Oak and (b) the SS Richard Montgomery (bottom) wreck sites. HMS Royal Oak was anchored at Scapa Flow in Orkney, Scotland when she became the first of five Royal Navy battleships and battle cruisers sunk in World War II. She was torpedoed at anchor by the German submarine U-47 on 14 October 1939. SS Richard Montgomery was an American Liberty ship built during World War II, and subsequently wrecked in the Thames Estuary (UK) in 1944 with around 1,500 tons of explosives on board. The explosives continue to be a hazard to the area. Data acquired by ADUS for Salvage and Marine Operations, UK Ministry of Defence.
Figure 13 Palaeogeographic reconstruction of the Bann Estuary at 12,000 BP when the relative sea level was at -14.0m. The reconstruction is based on JIBS 1m multibeam bathymetry, 10m resolution terrestrial DEM and interpreted seismic profiles.

Marine biologists use MBES data to map biomass in the water column (Figure 14) and to create habitat maps of the seafloor (Figure 15), where acoustics are used as physical proxies for specific biological habitats. Knowledge of the distribution and extent of marine habitats serves to establish sensible approaches to conservation needs and to facilitate better management of the marine environment through an understanding of how particular human activities are undertaken in relation to marine habitats (JNCC).

Figure 14 Images of a fish school of *Sardinella aurita* from a multibeam sonar. Arrows indicate vessel route. a) 3D reconstruction of the school (volume 2260 m$^3$, surface area 5796 m$^2$, overall length 41.6 m, width 16.7 m, height 14.9 m). Multibeam sonar receiving beams are shown at the front of the vessel. Remaining panels show cross-sections of density in fish from: b) horizontal plane; c) vertical plane alongships; d) vertical plane athwartships. Red cross-hairs indicate location of the other two cross-sections. Image from Gerlotto et al., 2003.
8. Acoustic instrumentation on RV Celtic Voyager

The onboard acoustic instrumentation on RV Celtic Voyager (Figure 16) includes an acoustic doppler current profiler (RDI, BV ADCP38, 38 kHz), two hull-mounted multi-beam echo sounders (Kongsberg Simrad EM1002 and EM3002), two single-beam echo sounders (Kongsberg Simrad EK500 and EA600: 12, 38, 200 kHz), a hull-mounted pinger seismic profiler (SES Probe 5000, 2x2 array, CODA DA200 acquisition) and a sound velocity profiler (AML SVPlus/+ smart SV+T). Navigation and positioning is supplied by a Trimble NT Differential dGPS.
Onboard acoustic instrumentation on RV Celtic Voyager includes two MBES systems (EM1002 and EM3002) and a seismic profiler (pinger).

References


