CONFERENCE & EXHIBITION
NEAR SURFACE
GEOSCIENCE'17

EAGE

Tu 23 A12

Multi-frequency Seafloor Characterization Using Seismic Sources of Opportunity

M.N. Banda* (University of Bath/Seiche Ltd), Ph. Blondel (University of Bath), M. Burnett (Seiche Ltd), R. Wyatt (Seiche Ltd)

Summary

The low frequencies used in seismic surveys mean that seafloor characterization is limited horizontally and vertically. It is possible to use multiple reflections from the seabed to hydrophones on Seismic Support Vessels to measure scattering strengths and geoacoustic properties of seabed areas far from the seismic survey. This can be done by combining lower frequencies (directed toward the seabed and with repeatable beam patterns because of sensor design), providing potential sub-surface penetration and higher frequencies (emitted in all directions, with high inter-pulse variability), directly related to surface properties (slopes, roughness, seabed type). This is demonstrated with results from a shallow-water survey, in which the useful frequency range extends from 100 Hz to 20 kHz. Seismic pulses are used as sources of opportunity, and multiple scattering contributions are corrected for variations in propagation ranges and sizes of scattering patches (related to pulse durations). Twelfth-octave frequency bands give highly accurate information of seabed properties, which can be compared to models or previous measurements. The energy distribution of all measurements can be divided into three equally contributing frequency bands, and their RGB representation enables rapid assessment of seabed properties, identifying geomorphological changes and small-scale topography variations.

Introduction

Marine seismic surveying is routinely employed to identify sub-surface reservoirs (e.g. oil and gas), subsea mineral deposits (e.g. hydrothermal systems), geo-hazards (e.g. pockmark fields, tsunami-generating areas), and large geodynamic structures (e.g. mid-ocean ridge magma chambers, subduction zones). The main survey vessel tows one or several seismic sources, emitting high-amplitude broadband sounds, typically below 300 Hz and is directed toward the seabed (e.g. Telford et al., 1990). Acoustic receivers (streamers) are towed further back, capturing reflections from layers and discontinuities at sizeable depths below the seabed, and over areas modulated by the geometry of the streamers. Seismic Support Vessels (SSVs), also known as “chase” vessels, move around the survey lines (Figure 1), notifying other vessels of the seismic operation and ensuring overall safety.

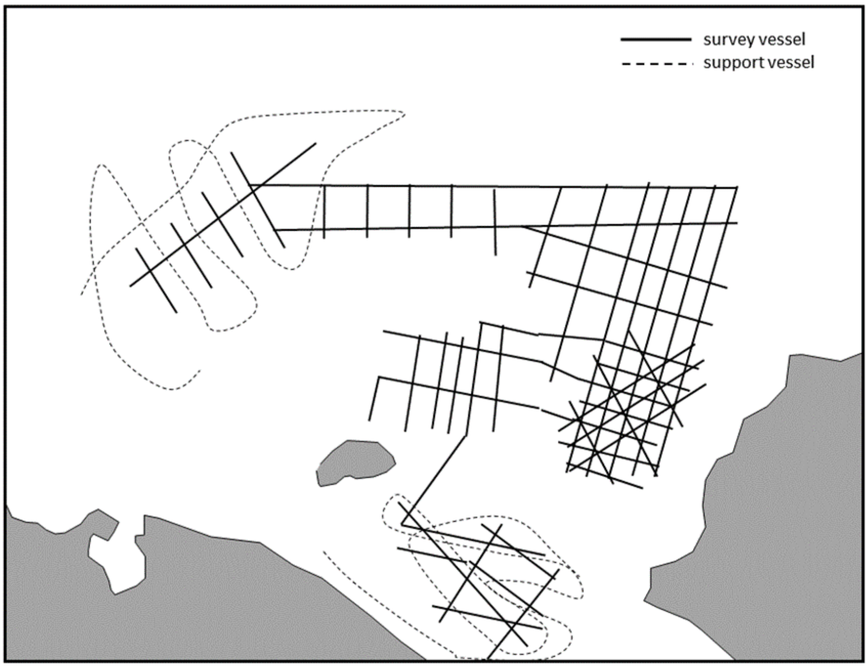

Figure 1 *Concept figure showing a typical seismic survey in a near-shore environment. The survey vessel covers ground over areas of interest (e.g. exploration block), with tracklines often in excess of thousands of kilometres. The support vessel(s) cover larger areas in a non-systematic way (for clarity, only a few tracklines are shown here).*

As seismic surveying increasingly moves to shallower areas and complex environments, it becomes more important to get better information about the sub-seabed, for example to position offshore infrastructure or to understand sediment movements between nearby shores and the exploration/exploitation areas. However, traditional seismic analyses focus on the lower frequencies (< 300 Hz), restricting the vertical and horizontal resolutions of measurements close to the seabed. The emphasis on sub-surface structures also generally means that the seabed is not seen as a processing priority by surveyors. Geophysical profiling by SSVs is generally limited to specific frequencies, to avoid interference with the seismic surveying, and to areas immediately below the SSVs. It is however possible to make use of existing data, combining receivers already used for other purposes with multistatic geometries to measure seabed reflections from further afield, and at higher resolutions (i.e., employing the broadband energy emitted the seismic sources).

Method

Passive Acoustic Monitoring (PAM) ensures compliance of seismic source levels with environmental regulations. It relies on towed hydrophone arrays, point measurements by the support vessel(s), drift buoys (Heath and Wyatt, 2014) and, in emerging applications, Autonomous Surface Vehicles. These hydrophones are much further from the survey lines, and seismic pulses will be received after propagation over multiple paths, especially in shallow water or with complex seabed topography (Figure 2). Single or multiple reflections from the seabed and/or the sea surface will result in a series of pulses at hydrophones, with different received amplitudes related to attenuation and to the acoustic scattering properties of the surfaces. Sea surface reflections are expected to be homogeneous, at least at the frequencies used, and like multiple seabed-sea surface reflections they can be identified from the times of arrival at the receivers and can be discarded. The remaining seabed reflections will vary with the acoustic properties of the surface and sub-surface. Their amplitudes will vary with the angle of incidence of the source (seismic) to the seabed, its angle of scattering from the seabed to the receiver, and the azimuthal angle for out-of-plane returns. Multistatic scattering models (e.g. Jackson and Richardson, 2007) or field and laboratory experiments (e.g. Blondel and Pace, 2009) can then be used to match these returns to specific seabed types.

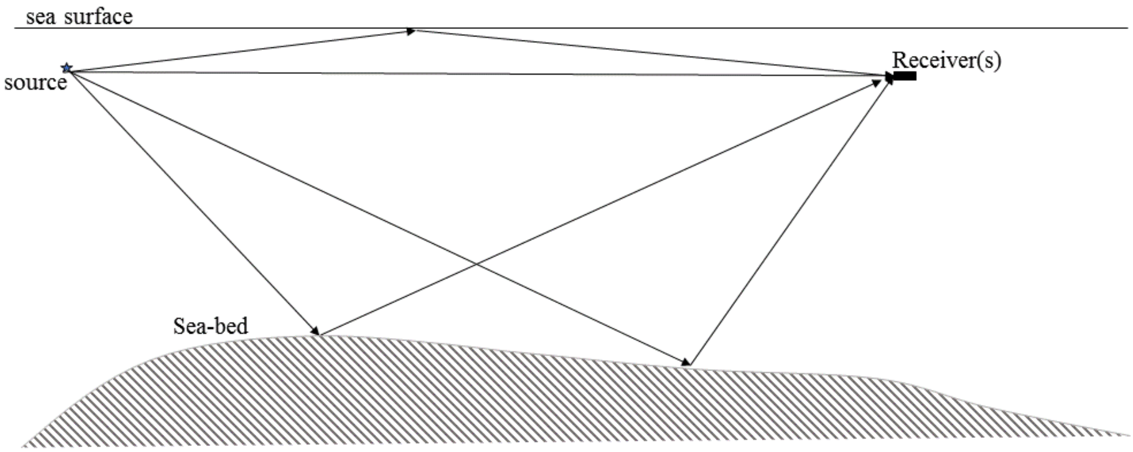

Figure 2 *Multi-path propagation will be particularly important in shallow water or at large ranges.*

By making use of frequencies beyond those traditionally used in seismic processing, it should also be possible to achieve higher spatial resolutions. Seismic pulses are spaced several seconds apart (generally between 10 to 20 s), enabling good propagation over sizeable ranges. They are also temporally small, enabling good spatial resolution of the survey regions depending on the frequencies used in post-processing and analysis. Depending on source array design, the number of sources and their relative geometries, seismic sources are known to emit sound at frequencies up to 20 kHz (e.g. Tashmukhambetov et al., 2008; Guan et al., 2015; Banda and Blondel, 2016). The large range of frequencies occurring induces other challenges in interpreting reflections of seismic airguns, used as sources of opportunities. At extreme ends of the frequency bands, for example frequencies lower than 100 Hz vs. frequencies higher than 20 kHz, different modes of propagation and interaction with the seabed will prevail (e.g. Lurton, 2010). Because seismic sources are designed to be most efficient at low frequencies, their acoustic characteristics at higher frequencies might vary with time, the location of individual sources in the array, and environmental conditions such as wave motion and tide. At these higher frequencies, these sources can no longer be considered to radiate energy as monopoles (McCauley et al., 2003) and they present different frequency-dependent directivity patterns (Hovem et al., 2012). It will therefore be important to match direct arrivals of individual seismic pulses with their seabed reflections to assess the relative importance of these effects.

Applications

The approach outlined above has been tested with two typical surveys taken from a larger portfolio and carried out in the last 5 years; one was a shallow-water survey with a series of fixed sources of increasing volumes and the other was a deep-water survey with a single, towed source. The shallow-water survey was made in an oceanic channel less than 25 m deep, with decreasing bathymetry from a large river mouth to the continental shelf. The source location was fixed and six drifting buoys, with two hydrophones at different depths, were deployed at different ranges over 4 days. Their tracks followed approximately straight lines with the tide, and acoustic sampling was conducted at 88.2 kHz. The surveyed area was approximately circular and 13.5 km in diameter. Three different sources were tested, with working volumes ranging from a single 10 cubic inch source, to an (approximately) 700 cubic inch array, leading to the acquisition of reflections from close to 795 seismic pulses (repetition rates of 10 – 20 seconds). Figure 3 (left) shows the frequency content of seismic signals, consistently higher than the background levels between 100 Hz and 20 kHz. The deep-water survey was made at depths larger than 1,500 m. A single source, approximately 4,500 cubic inches, was towed behind a primary vessel. The support PAM vessel closely followed it, sampling acoustic measurements at 500 kHz. The resulting signal-to-noise comparison (Figure 3, right) shows the useable frequency range can be conservatively defined as between 500 Hz and 5 kHz. This is significantly different from the shallow-water survey, although it still demonstrates the presence of high frequencies, and their potential for higher spatial resolutions.

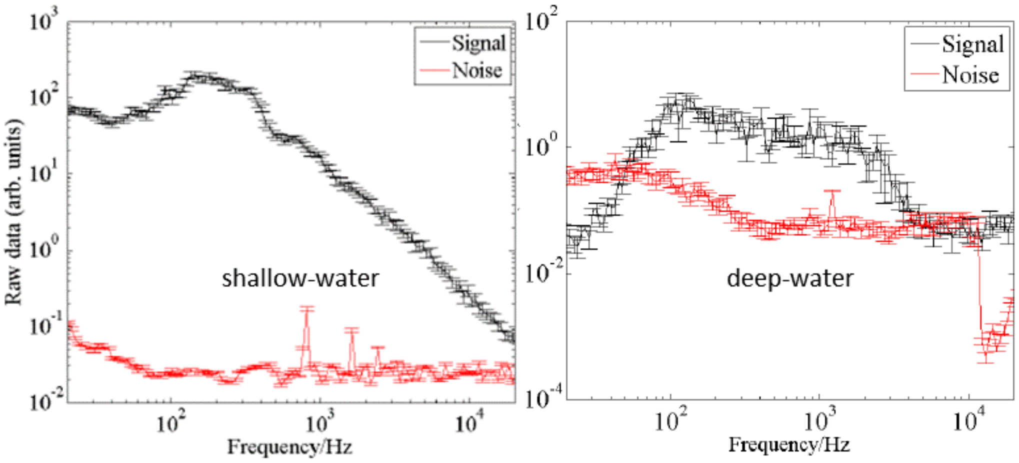

Figure 3 *Frequency contents of seismic signals and background noise in two different surveys.*

Individual seabed reflections need to be corrected for the ranges between the source of opportunity (seismic airgun) and the seabed, then between the seabed and the receiver. Standard attenuation coefficients (e.g. Lurton, 2010) are applied to account for spreading and absorption in seawater. The duration of each pulse is measured for each direct arrival and used to correct for differences in scattering patches on the seabed (corresponding to annuli of different diameters and thicknesses depending on pulse durations). These scattering strengths are therefore comparable for each seabed reflection. It is possible to compare these results from a narrow frequency band with measurements from other sonar tools (e.g. 7 kHz sub-bottom profiler or 10 kHz sonar), identifying the exact geoacoustic characteristics of each ensonified patch of seabed. Lower frequencies will experience some degree of penetration into the seabed (volume scattering), whereas higher frequencies will be directly related to the surface (slope, roughness and material). It is therefore possible to make informed comparisons with values expected from models (e.g. Jackson and Richardson, 2007) or measurements (e.g. Blondel and Pace, 2009).

For rapid analysis, relative energy contributions in 1/12th octave bands are divided into three equal partitions, and was assigned to primary colours Red, Green and Blue. Figure 4 illustrates this technique with the shallow-water survey. Seabed reflections cover the frequency range from 500 Hz to 20 kHz, and are divided into equally important contributions <1.4 kHz, 1.4–4.2 kHz and >4.2 kHz. The representation of each seabed contribution as an RGB triplet, with linearly scaled intensities, shows the general properties of the seabed and any outlier. Here, the blue patches in the SW and centre (more reflections above 4.2 kHz, but still some significant contributions in the other bands) are consistent with coastal sediments coming from the river delta. Pink patches in the NW are compatible with the change in slope and muddy sediments becoming prevalent. Detailed analyses of the exact frequency content (by 1/12th octave bands) can then lead to more detailed interpretations of the local geoacoustics.

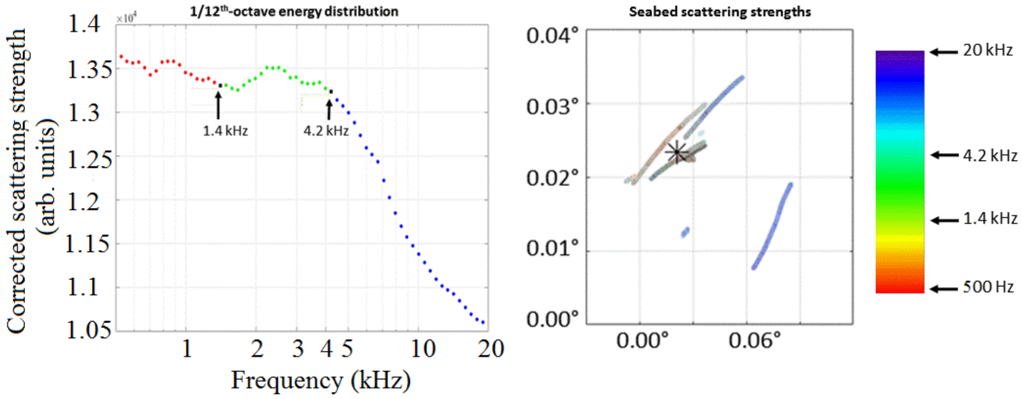

Figure 4 *Three frequency bands (left) can be used to summarize seabed reflectivity (right).*

Conclusions

Seismic airguns can be used as sources of opportunity to characterize seabed properties with high spectral and spatial resolutions, using hydrophones on Seismic Support Vessels. Denser tracks increase seabed coverage and frequency-dependent propagation enables large characterisation ranges.

Acknowledgments

This work is supported by Innovate UK (Knowledge Transfer Partnership grant # KTP009670). The cooperative spirit of the partners whose data is presented here is gratefully acknowledged.

References

Banda, N. and Blondel, Ph. [2016] Identifying mid-water targets using the higher frequencies emitted by seismic sources of opportunity. *IEEE Oceans'16*, Conference Proceedings.

Blondel, Ph. and Pace, N.G. [2009] Bistatic sonars: sea trials, laboratory experiments and future surveys. *Archives of Acoustics*, **34**(1), 3-17.

Guan, S., Vignola, J., Judge, J. and Turo, D. [2015] Airgun inter-pulse noise field during a seismic survey in an Arctic ultra shallow marine environment. *J. Acoust. Soc. Am.*, **138**(6), 3447–3457.

Heath, B. and Wyatt, R. [2014] Sound Source Verification to assess marine mammal impact. *Sea Technology* **55**(12), 47-50

Hovem, J.M., Tronstad, T. V., Karlsen, H. E. and Lokkeborg S. [2012] Modeling Propagation of Seismic Airgun Sounds and the Effects on Fish Behavior. *IEEE J. Ocean. Eng.*, **37**(4), 576–588.

Jackson, D.R. and Richardson, M. [2007] *High-Frequency Seafloor Acoustics*, Springer, Berlin.

Lurton, X. [2010] *Introduction to underwater acoustics: principles and applications*. Springer, Berlin.

McCauley, R., Duncan, A., Penrose, J. and McCabe K. (2003) Marine seismic surveys: Analysis and propagation of air-gun signals. *Centre for Marine Science & Technology (COE).*

Tashmukhambetov, A. M., Ioup, G. E., Ioup, J. W., Sidorovskaia, N. A., and Newcomb, J. J. (2008) Three-dimensional seismic array characterization study: experiment and modeling. *J. Acoust. Soc. Am.*, **123**(6), 4094–108.

Telford, W.A., Geldart, L.P. and Sheriff, RE (1990) *Applied Geophysics*, 2^{nd} *ed.* Cambridge University Press, Cambridge.