Beyond Bathymetry: Water Column Imaging with Multibeam Echo Sounder Systems

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Echo sounder systems represent powerful tools not only to determine the seafloor depth, but also to investigate the water column. The most prominent fields of hydroacoustic water column applications include fish shoal detection and biomass assessments, target detection for military purposes, oil and gas leakage detection, and suspension matter analyses. Multibeam echo sounder systems (MBES) – so far primarily used for bathymetric measurements – are introduced in this study for demonstrating their water column analyses capabilities that become more and more available due to most recent computer power and mass storage advances. Some environmental data are presented in this study showing gas release from the seabed, fish shoals, zooplankton and oceanographic layers to highlight multibeam water column potentials. Moreover multibeam water column assessments are suggested to be valuable for the hydrographer as a supporting tool potentially useful for mitigating MBES survey related conflicts.

multibeam echo sounder systems | water column imaging | gas bubble scattering | sonar target detection

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1 Introduction

Multibeam echo sounder systems (MBES) are primarily designed for seabed depth determination. MBES send out sonar pings and apply manufacturer specific bottom detection algorithms on the received echoes to discriminate seafloor backscattering anomalies against spurious echoes. In contrast singlebeam echo sounder systems usually display and record the backscattering right underneath the vessel down to the seabed, and potentially the sub-seabed. Singlebeam echo sounders established as standard tools for remote water column investigations, e.g. for fish detection and biomass assessments, suspension matter analyses, seafloor classification, and target detection for both, environmental and military purposes. However, computer power limitations in the past hampered water column data assessments by MBES given their large number of beams. Since a couple of years ago, these limitations no longer exist and today's digital signal processing performance allows streaming, storing, and postprocessing of huge amounts of data, and therefore beamformed water column imaging (WCI) by MBES emerges as a new survey option (cf. Hughes Clarke 2006; Mayer et al. 2010).

Today, a growing interest in WCI measurements is reflected by ongoing implementation of WCI functionality into modern MBES and development of respective online and postprocessing software packages for hydrographic and fishery applications (QPS Fledermaus FMMidwater, CARIS WCI, ECHOVIEW). In this study we present datasets of water column multibeam surveys conducted with various systems and discuss WCI related assets and pitfalls.

2 Site description and motivation

One study site is located near Panarea off Italy – the smallest island of the Aeolian volcanic arc located in the southern Tyrrhenian Sea. Panarea is situated on a submarine volcano with water depth at its plateau around 20 m. Gas bubbles are reported here to be released from the seabed having a mixture of mainly carbon dioxide and traces of methane gas and the toxic gas hydrogen sulphide. Gas bubbles act as very pronounced acoustic scatterers and can thus readily be detected by sonar.

The seafloor is characterised by various ›pockmarks‹ representing several meters round shaped depressions caused by gas related explosions on the seabed. A hazardous gas eruption was discovered in 2002 and since Panarea is regularly visited to identify potential threats for the populated islands nearby. From a scientific perspective, this area is interesting to study potential environmental impact of CO_2 gas release into the ocean as a natural analogue for CO_2 capture and storage sequestration (CCS), that has been put in service offshore, e.g. in the North Sea 18 years ago (SLEIPNER field). Panarea was visited with the Italian research vessel »Urania« under the umbrella of the European joint research project ECO2 by the support of GEOMAR, R2Sonic and Embient GmbH in 2011 (today Kongsberg Maritime Embient GmbH).

The second survey area is located on the southern part of the Chatham Rise off New Zealand in water depth around 1000 m. So called gas hydrates – a solid compound of methane gas forming an ice-like hydrate under pressure – were expected in this area. Gas hydrates are considered as a massive marine energy resource investigated at GEOMAR within the joint research project SUGAR. To detect related methane gas bubble escape into the water column the 50 kHz SB3050 multibeam from our SUGAR partner L-3 ELAC Nautik GmbH was used for this cruise with RV »Sonne«.

The aim of the third study was the assessment of marine life in a survey area in the Indian Ocean by the BGR (Federal Institute for Geosciences and Natural Resources, Hannover). The hull-mounted Kongsberg EM122 12 kHz MBES of MV »Fugro Gauss« was used to collect WCI data along a total track length of 7800 km during a survey in 2012.

3 Installation and setup

The installation of the multibeam transducers on »Urania« was realised by an ›over-the-side‹ pole mounting. A broadband R2Sonic 2024 allowed for high-range resolution using a very short pulse length of 15 µs at all operating frequencies. During the time of deployment in 2011 we worked with a prototype WCI mode not yet allowing to stream WCI data to our acquisition software QINSY. Frequencies were adjusted in 10 kHz steps on the fly to find the ideal frequency between 200-400 kHz in terms of minimal interference with other acoustic equipment used during this cruise. For deeper water surveys we also used the hull-mounted Kongsberg EM710 for bathymetric and WCI recording.

The heavyweight SB3050 transducer (200 kg) was installed via a diver on RV »Sonne« in the harbour underneath the moon pool of RV »Sonne« onto a simple adapter flange. Transducer cable plugs were waterproof sealed beforehand and were pulled through the moon pool of RV »Sonne«. Positioning underneath the moon pool guaranteed optimal performance given this ideal position in the centre of the vessel tipping axis and deep enough to avoid bow bubble wash down and respective blanking artefacts. Water column imaging and recording could be realised with ELAC's WCIViewer software run on an extra computer in parallel to the bathymetric data acquisition HYPACK workstation.

The Kongsberg EM122 on MV »Fugro Gauss« is a fixed installation. The system had already been used extensively for WCI surveys. For processing the WCI data we used QPS Fledermaus FMMidwater software.

4 Results and discussion

4.1 Data description and artefacts

MBES WCI data can be investigated in so called fan views. Fig. 1 shows typical sonar targets in a fan view superimposed with noise. It represents a ›one ping‹ record of a 160° broad fan with colour-coded backscatter intensities therein. The view corresponds to looking through the MBES fan ›from behind‹ and along the vessel's heading direction. The seafloor appears in form of a horizontal bar on the bottom of Fig. 1. From the centre of this bar a prominent half-circular feature – the smiley – arises towards the outer fan at one specific travel time instant at t_{SLB}. Smiley-like artefacts are most pronounced at t_{SLB}, and occur to a lesser degree later at t_{SL} (Fig. 1). Echoes received later than t_{SLB} principally suffer in lower signal-to-noise ratio compared to the more nadir beams at the same depth. Those smileys at t_{SLB} and later (t_{SL}) are a systematic data pattern always occurring in MBES WCI survey data due to significant seabed side-lobe echoes leaking through the beam-formed receive beam pattern of the MBES. Nevertheless, features like gas release can be detected beyond t_{SLB} (Fig. 1b).

Fig. 1a further outlines how interference from other sounders might deteriorate the quality of MBES data. At t_1 an acoustic anomaly appears over all beams either caused by a large single fish, or by a pulse transmitted by another sonar. As the interference at t_1 is visible only in the water column it does not affect any bottom detection operation performed by the MBES and therefore has no ef-

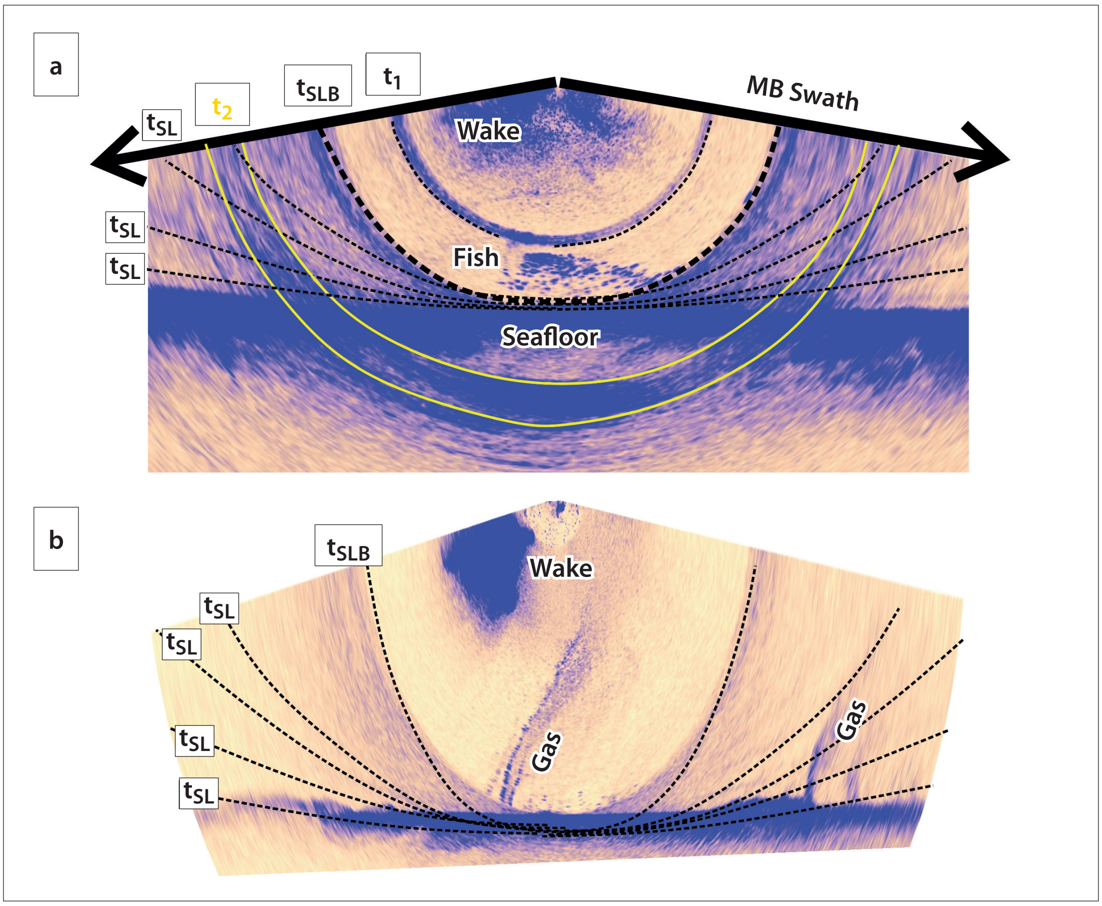

Fig. 1: MBES WCI data recorded at 24 m water depth with R2Sonic 2024 (a) at 200 kHz superimposed with noise showing side-lobe echo effects (dashed lines) from single target (t_1), from the seabed at t_{SLB} and t_{SL}, and interference from other sonars (t_2, yellow) (b) at 400 kHz without interferences but with distinct propeller bubble wash down and gas release from the seabed in the centre and outer beams

fects on the derived bathymetry. At t_2 a fuzzier noise pattern occurs most likely caused by some interference intersecting with the echo returns from the seabed. WCI data makes it obvious that this might cause problems for an MBES' bottom detector due to difficulties in discriminating seabed derived backscattering against such interfering signals.

4.2 Results from shallow water

Snapshot of the water column

WCI surveys allow for intriguing records of the water column, e.g. even singular targets like gas bubbles can be traced through the water column (Schneider von Deimling and Papenberg 2012). The fan image in Fig. 2 shows several bubble streams rising from the 24 m deep seafloor. They emerge as vertical patterns with elevated (orange) backscatter being slightly deflected by the environmental currents. High range resolution of 1.25 cm even allows for discrimination of individual scatterers/bubbles thus yielding tracking of single targets. Simultaneously, an air bubble wake pattern appears on the very top of Fig. 1 and 2 as a typical feature caused during vessel steering operations resulting in some bubble wash down through the ship's propeller.

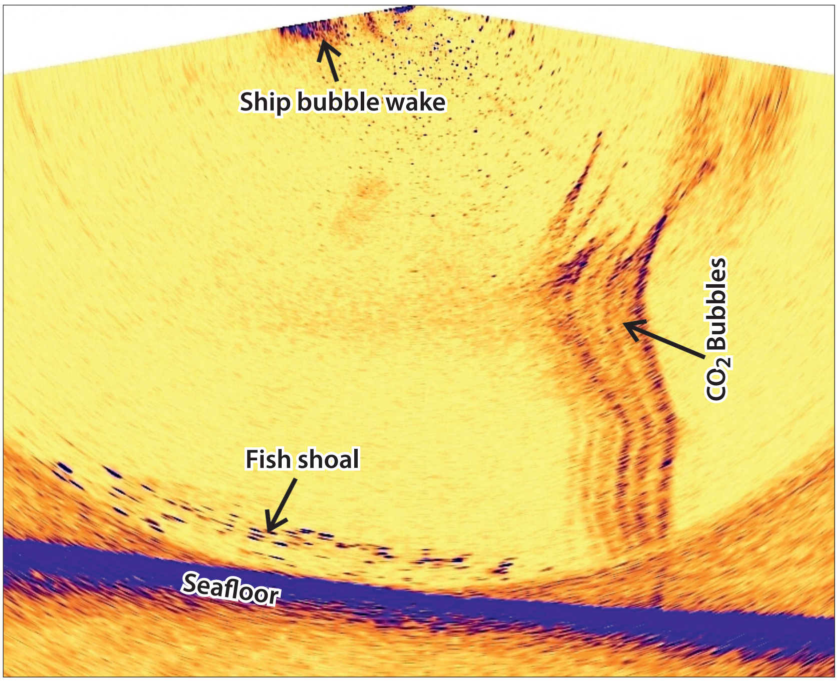

Fig. 2: Very clean water column data showing at least three natural CO_2 bubble streams released from 24 m depth, some fish close to the seabed, and bubble wash down by the vessels propeller on top

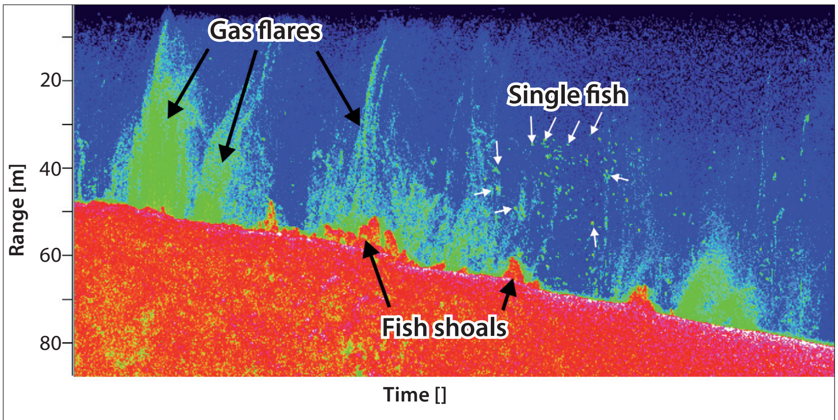

Fig. 3: Acoustic beam stack echogram showing gas release (gas flares) and fish from EM710 data

Bubble wash down may also emerge from the bow of a vessel and may cause major problems for sonar measurements due to substantial absorption of gas bubbles on sound. Therefore, bubble wash down visualisation by WCI truly provides a form of quality control on the sonar performance. Apart from gas bubbles, fish (and their gas swimbladder) are especially susceptible for acoustic detection. In Fig. 1a and 2 fish shoals emerge close to the seabed consisting of individual but strong (blue) scatterers. Their potential for causing bottom misinterpretation is considered small, however, misinterpretation by the prominent deep water scattering layer (DSL, discussed in the next chapter) caused by living animals has often caused mis-detected depths in the past.

Echograms of multibeam data

Fig. 2 only presents a snapshot of the water column. But multibeam sections spanning longer survey times can be presented in a classical echogram-like manner being ideally suited to investigate larger areas and volumes. The prototype WCI mode of the R2Sonic recorded in 2011 did not allow yet for import into QPS-FMMidwater. Therefore we used EM710 data recorded in parallel instead. Highest backscattering values were selected from all beams at respective travel times and stacked together into a single beam like echogram. Such beam stack presentations are ideally suited to give a quick overview about the most pronounced acoustic water column scatterers that occurred during a survey. Thus, hitherto unknown gas release areas could be discovered in the Panarea survey area originating from greater depths (Fig. 3).

4.3 Results from deeper water

MB WCI is not restricted to shallow water surveys. Using lower frequency MBES allows for full ocean depth WCI, however, the resolution and sensitivity decreases with range given lower sonar frequencies, geometrical spreading, acoustic absorption, and pulse stretching during the travel time of the sonar signal.

Fig. 4 shows an echogram gathered by an ELAC SB3050. Even though we did not find gas release during this cruise the echogram nicely demonstrates the high sensitivity of MBES for imaging the biological deep scattering layer (DSL), some bottom loving fish shoals, and interference pattern from other onboard acoustic devices on RV »Sonne«.

Abundant indications of marine life were also found in the 12 kHz Kongsberg EM122 data of MV »Fugro Gauss« during the cruise in the Indian Ocean. One of the most distinct features observed is the diurnal migration of zooplankton. Apparently controlled by daylight these very small creatures agglomerate in massive layers dense and thick enough to be displayed in WCI data. At about 19:20 local time when the sun sets, an upward migration of the zooplankton is observed in the WCI data (Fig. 5), building a more than 200 m thick layer close to the surface disappearing after the succeeding sunrise. During daytime the zooplankton seems to be widely distributed in deeper regions, sometimes building clouds or swarms (Fig. 4), potentially followed by predators feeding on zooplankton, but not agglomerating to a dedicated layer.

Besides scattering layers, fish shoals and agglomerations of zooplankton, singular objects showing a very high backscatter have been observed quite frequently (Fig. 6). We assume that these data patterns represent signatures of large marine mammals. As several species of marine mammals use sound waves for communication and navigation well within the MBES' frequency range, the sequences of echoes displayed in Fig. 6 potentially might also document acoustic whistle signals generated by a marine mammal.

With MBES WCI the existence of distinct layers of water masses can be revealed as is documented in Fig. 7. The stacked echogram nicely displays a stratification of the water down to a depth of about 1500 m with prominent boundaries at about 200 m and 1100 m. Interestingly, a water sound velocity profile taken by an XBT cast in the same area during the survey documents significant changes of the sound velocity at corresponding depths which are caused by variations of the physical properties (density, temperature, salinity, conductivity) of the sea water. Consequently WCI can be used to efficiently map the boundaries of different water masses.

Low frequency MBES WCI can also provide information about the sub-seabed. Deep water multibeam surveys between 1000 and 10 000 m water depths require frequencies between 50 kHz and 12 kHz. Those frequencies certainly penetrate metres to >10 m into soft sediments with a potential strong implication on MBES bottom detection (Schneider von Deimling and Weinrebe 2013). Consultating WCI could help to better understand the recorded bathymetry and backscattering in regard to seabed penetration effects.

4.4 Other WCI possibilities

To date many shallow water systems allow for changing the transmit frequency on the fly, e.g. between 200 and 400 kHz. While doing this a visual online inspection of WCI data can help in minimizing interferences from other sonars thus optimizing measurements by adjusting the transmit frequency accordingly (Fig. 1b). Alternatively, interferences can be mitigated by synchronization of concurrent sonars, but this approach can hardly be accomplished on larger multipurpose vessels, because synchronizing several sonars would significantly slow down their ping rates.

Apart from sonar interference, MBES data corruption includes vibration and turbulence at the transducer head, propeller or other ship-self noise, and electrical noise. Partially damaged transducers, extreme settings in the water column, or marine growth on the transducer (barnacles, mussels) may also significantly reduce sonar performance. By accurate WCI analyses such shortcomings can be better identified than in ordinary bathymetric data and potentially can be mitigated to improve the overall MBES performance.

Wreck detection and related least-depth determination procedures are major tasks of hydrographic surveys because obstacles represent real threats for the shipping industry. Those anthropogenic seabed features are often characterized by an extreme shape, e.g. a vessel's mast with sudden vertical changes and thus may cause severe confusion on the bottom detection algorithm of MBES mismatching field validated data. WCI records overcome bathymetric misdetection and – if interpreted accordingly – can present a supporting tool for time consuming diver work improving wreck least-depth determination. Unfortunately we can not present such data here, but refer to previous work conducted by Hughes Clarke et al. (2006) presenting a comprehensive study about wreck visualisation and least-depth determination of the top of the mast using MBES WCI.

Today fishery surveys increasingly take advantage of multibeam. Fish abundance is closely linked to the respective seabed habitat (reefs, seamounts, valleys, etc.) that can be thoroughly assessed by MBES. Therefore the fishery industry makes use of large MBES WCI coverage, although, calibrated backscattering strength needed for quantitative fish stock assessments, that have been established with singlebeam system in the

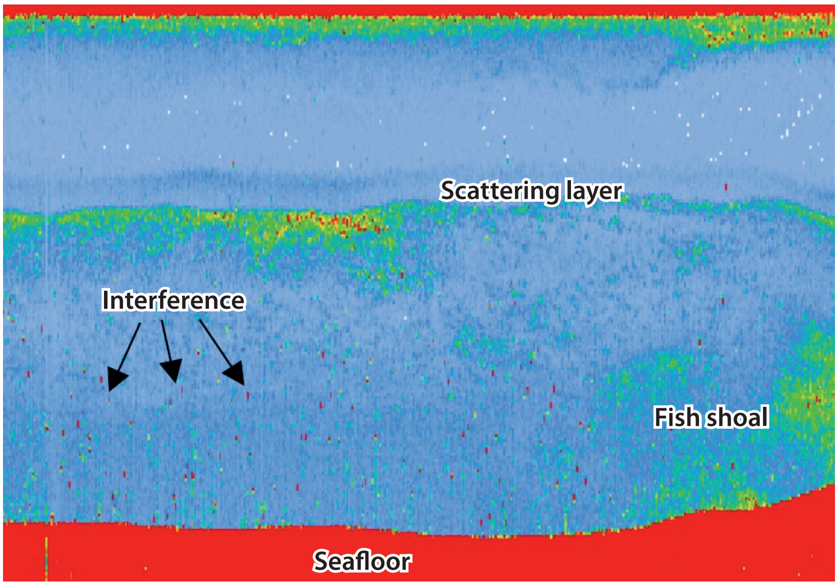

Fig. 4: Beam stack echogram presentation of ELAC SB3050 50 kHz WCI data recorded off New Zealand, 670 m water depth. Short pulses of interfering sonar pulses are indicated by arrows

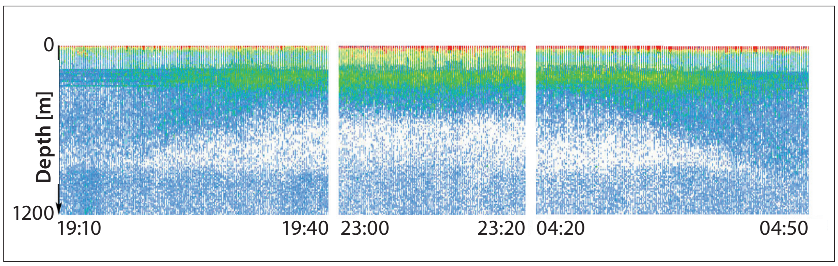

Fig. 5: Beam stack echogram presentation of Kongsberg EM122 12 kHz WCI data recorded in the Indian Ocean. With decreasing daylight zooplankton is migrating upwards agglomerating and building a thick and dense layer close to the surface disappearing in the next morning after sunrise

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fisheries community, are not yet available for MBES (except Kongsberg ME70).

5 Recommendations

Maximum data rates of modern MBES with WCI achieve up to 70 MB per second resulting in 42 terabytes for one week with continuous storage. Such data rates and amounts are challenging to handle on a short and long term and backup of WCI survey data before disembarking a vessel after the cruise becomes virtually impossible. Data reduction techniques are available already highly reducing the amount of data while still preserving the most important information. However, the postprocessing of WCI data – not yet available on all MBES processing software packages – has to be considered in a developer's stage at the moment and handling such large datasets is generally painful.

Another limitation arises during data acquisition: the sonar settings (e.g. transmit power, pulse length, receiver gain) may either be optimized for bathymetric or water column measurements and in some cases only a compromise in between the two is feasible. Nevertheless, we could acquire very valuable results for both, bathymetry and WCI at the same time.

The big advantage of MBES over singlebeam systems is based on their large coverage. But regarding WCI data, inherent artefacts on the outer beams significantly deteriorate the water column backscatter quality beyond t_{SLB} as shown in Fig. 1. Therefore, undisturbed WCI echoes are only available until the first seafloor return was received usually corresponding to the centre beam depth. Nevertheless, WCI data beyond this critical range can be evaluated with reduced quality (Fig. 1b).

Anthropogenic features on the seabed like wrecks or offshore constructions facilities with their inherently steep slopes often cause bottom detection failure. WCI by MBES could be used for 3D assessments and least-depth determinations. At the moment, the WCI processing – at least for some data formats – is still restricted because ray path corrections for the water column velocity changes cannot be corrected yet, but this presents a straight forward task to be solved in the near future. Moreover, multipath effects are likely to occur and have to be considered while surveying extreme morphologies.

6 Conclusions

Water column imaging sonar systems have been established as valuable tools for the fishery industry and obstacle avoidance applications for decades. Many new systems entered the market in the past years especially for 3D near range applications, e.g. including harbour and construction facilities investigations, scour monitoring, intruder warning systems, and ship hull inspections. Modern multibeam sonar systems also offer water column imaging having gained significance in fisheries and natural and anthropogenic oil and gas leakage related research. Apart from such tasks, water column imaging by MBES has attracted only little attention to the hydrographic community so far. One reason might be that water column data storage and postprocessing workflows are computational expensive. But real-time observation using WCI during the measurement in the field is straightforward to use and does not produce extra costs (for some systems) and represents a viable quality control tool for hydroacoustic surveys. WCI data inspection can certainly identify particular data corruptions, and, if mitigated, can thus improve the bathymetric measurements. Further, the evaluation of WCI contributes to a better environmental understanding and interpretation of hydroacoustic survey data.

Beyond using MBES WCI as a quality control tool, many new fields of applications emerge in water column investigations like fish stock assessment and mapping of anthropogenic »extreme« features on the seabed where bottom detection usually fails. ⚓

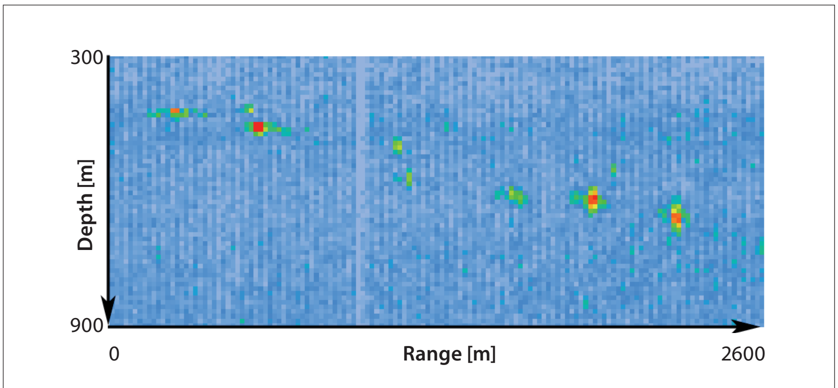

Fig. 6: Beam stack echogram presentation of Kongsberg EM122 12 kHz WCI data recorded in the Indian Ocean. Objects with high reflectivity probably represent signatures of marine mammals

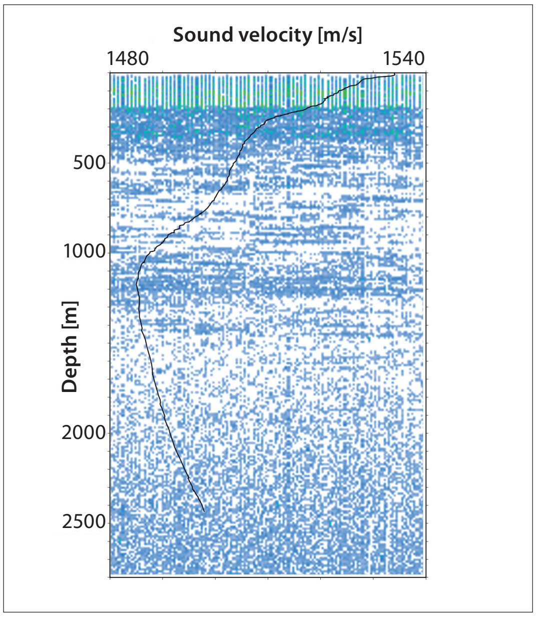

Fig. 7: Beam stack echogram presentation of Kongsberg EM122 12 kHz WCI data recorded in the Indian Ocean. A water sound velocity profile taken by an XBT cast in the same area is plotted on top of the WCI data. Layer boundaries in the WCI data correlate with changes of the water sound velocity