High-frequency snippet backscatter information

Introducing a promising alternative to precisely detect surficial ammunition in shallow coastal waters

An article by TINA KUNDE

Within the last years, backscatter information collected with high-frequency multibeam echo sounder systems are moving more and more to the centre of the hydrography community's attention. Not only the imagery processing possibilities for backscatter information, but also the image generating technique itself has been strongly optimised. Using snippet backscatter data, high-resolution images with a pixel size of up to 0.05 m for shallow coastal waters can be generated. Combined with the possibility of vessel-based differential global navigation satellite system (DGNSS) positioning, snippet backscatter information can be indicated as a promising prospective method for surficial ammunition detection offering a horizontal positioning accuracy of up to 0.1 m. To stay abreast of changes, this article should introduce the fundamentals of a baseline study conducted within a cruise with RV »Alkor« (AL447).

ammunition detection | Baltic Sea | DGNSS | multibeam echo sounder | snippet backscatter

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Introduction

Hydrography as a scientific discipline of geomatics has a broad range of thematic fields concerning the earth's waters. With regard to the rapid advancement in both ecology and economy, the aim of knowledge enhancement when dealing with all kind of waters is becoming increasingly important and hence the tasks covered by hydrography do. The main duties as stated by the IHO can be summarised to the assurance of the safety of navigation and the support of all marine activities assigned to different subject areas such as economic developments and the environmental protection. In particular, the economic development of renewable energies and the utilisation of water areas for offshore constructions and transoceanic cables moves to the centre of public attention.

As explained in Böttcher et al. (2011, 2015), areas used for offshore wind turbines and subsequently related cable routes need to be examined in advance to preclude the occurrence of ammunition bodies. Up to now, the detection and localisation of suspicious subsea objects is performed by using high-resolution side-scan or synthetic aperture sonars. These surveys are often supplemented by towed magnetometer systems as introduced in Frenz (2014) and Kretschmer and Jans (2016). However, both in a towed configuration or mounted on an underwater vehicle, the accurate horizontal positioning of these systems is challenging and relatively low compared to GNSS positioning. Due to the still proceeding improvements of multibeam echo sounder systems, the snippet backscatter information, which is registered simultaneously to the bathymetric depth, offers the potential to connect precise horizontal satellite positioning with ammunition detection at high survey speed in shallow coastal waters.

This article serves as an introduction to a baseline study that builds the basis for the written thesis. Conducted in collaboration with the Ministry of Energy, Agriculture, the Environment and Rural Areas (MELUR) within the scope of a research cruise with RV »Alkor« (Schneider von Deimling 2015), the acquired high-frequency multibeam snippet backscatter information were analysed due to their feasibility to detect dumped ammunition bodies of different shape and size. In addition, the attainable horizontal position accuracy using different GNSS solution states was compared to give evidence of possible accuracy increases.

Snippet backscatter theory

The signal transmitted by a multibeam echo sounder strikes the seafloor in different angles. Parts of the acoustic energy are reflected, others penetrate the seafloor where they are subject to refraction processes. The remaining part of the signal is scattered depending on consistence and morphology of the seafloor. The scattering straight towards the incident wave is named backscatter. It follows from the geometry that the backscattered signal is more extended in the outer beams of the swath than in the nadir region. The acquired and recorded time series of returned echoes per beam is called ›snippet‹ (Fig. 1). To generate a sonar image of the ensonified area, the snippet segments of all beams need to be recombined and arranged line by line along the swath. This recombination is ideally done after the evaluation of the depth measurement to ensure that the imagery data is connected to the right position, whereas only the depth values at the centre points (bottom return signal) are known; all intermediate points get an interpolated depth value. For the performance, the centre point of each beam needs to be determined and placed on the swath at the correct position. After that, the surrounding snippet intensity values within one beam are used for image formation until the intersection with the adjacent beam. As indicated in Fig. 1, the number of snippet values highly depends on the pulse length: The shorter the pulse length, the more snippets can be generated and therefore, high-resolution mosaics are possible following the range resolution formula.

Precise positioning using DGNSS

The determination of the actual position of moving vehicles both on land and sea can be concluded as the main objective of tracking as a branch of navigation. For these tracking purposes, a system is needed offering full availability, reliability and usability. Therefore, GNSS became a great convenience within the scope of aids to vessel navigation. All common GNSS are using the same architecture and basic principles for localisation:

- Absolute positioning (also known as standalone GNSS) and
- DGNSS, which can be defined as an enhanced form of absolute positioning.

By using a receiver in combination with base station information, it is possible to minimise errors caused by imprecise knowledge of propagation speed and orbital data leading to an increased theoretical accuracy from metre up to millimetre scale in comparison to the absolute positioning.

For follow-up evaluation of the general accuracy of GNSS positioning, it has to be distinguished between the accuracy of the pseudorange measurement and the carrier phase accuracy. While the carrier phase evaluation for kinematic observations is quite complex, the attainable accuracy of a continuous kinematic observation can be generally stated to 1 to 2 dm. The pseudorange measurement is comprised of three main error influences:

- User range error,
- Signal dispersion (ionosphere, troposphere and multipath effects) and
- Receiver errors (noise and instrumental delays).

The inertial navigation system (INS) with its dual-antenna setup used within the presented baseline study is able to derive a position accuracy (both horizontal and vertical) of 0.5 to 4.0 m for absolute positioning and 20 to 1 cm using DGNSS.

Baseline study

The baseline study was conducted in close collaboration with the MELUR within the scope of a research cruise with RV »Alkor« (AL447) in October/November 2014. The aim of this study was the analysis of snippet backscatter information

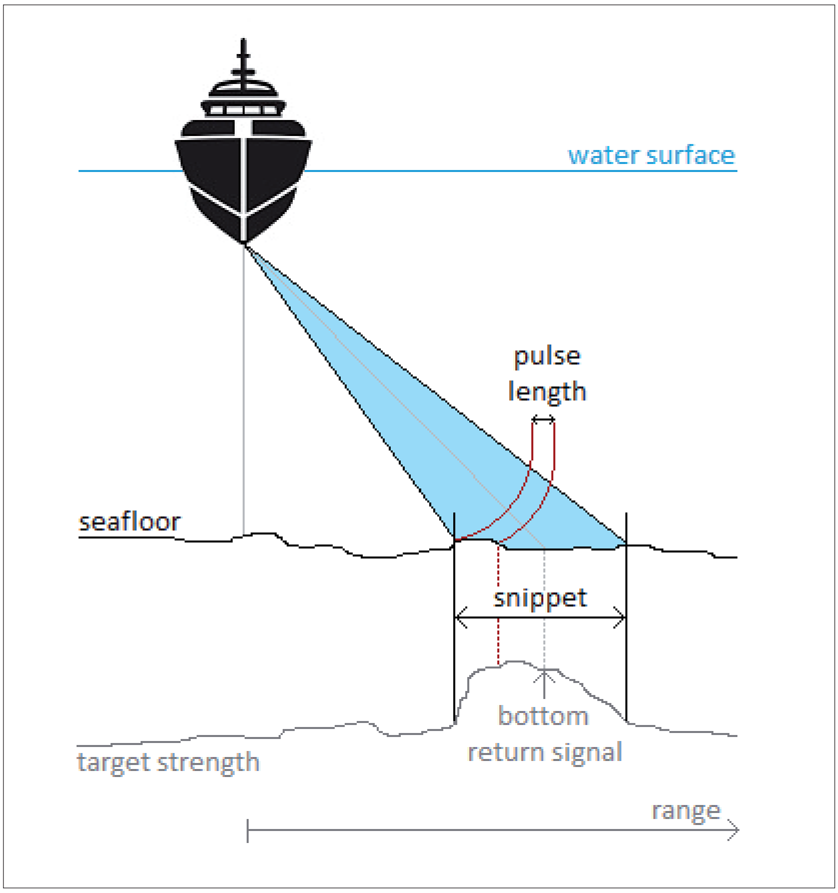
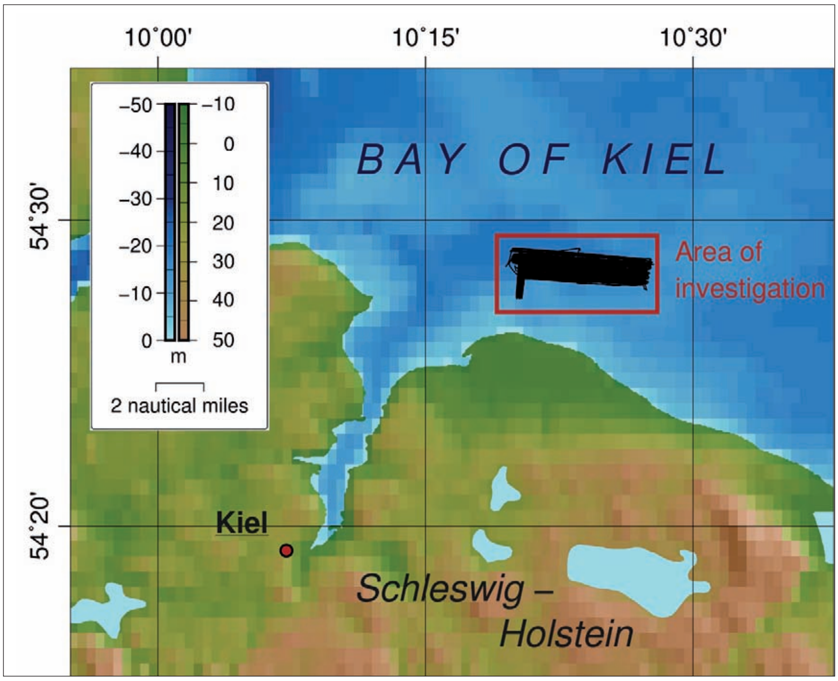


Fig. 1: Scheme of pulse interaction at oblique incidence and the generation of a snippet

gathered with a high-frequency multibeam echo sounder system (200 to 400 kHz) due to their usability to detect surficial objects, in this case dumped ammunition bodies of different shape and size. Additionally, the horizontal positioning accuracy of different GNSS solutions was compared to point out an accuracy improvement potential. The designated ammunition dumping site Kolberger Heide in the Bay of Kiel (Baltic Sea) and its adjacent eastern areas were chosen for data acquisition (Fig. 2). On account of the geological

Fig. 2: Area of investigation (rectangle) in the Kiel Bay. Mercator projection using the global 30 arc seconds data set GEBCO 2008. Black pattern indicates the surveyed profiles



origin and the consequences of a storm surge in 1625, this area is characterised by its shallow water depth ranging between 5 and 18 m.

Measurements and processing

The bathymetric data including the snippet backscatter information was mapped using an EM 2040C multibeam echo sounder kindly provided by Kongsberg Maritime. The system was operating with a frequency of 300 kHz, a constant pulse length of 50 µs and a maximum swath angle of 130°. For positioning, the self-calibrating multi-sensor INS F180R from Coda Octopus combining an inertial measurement unit with a NovAtel dual-antenna GNSS was used. For DGNSS evaluation, the State Bureau of Surveying and Geoinformation Schleswig-Holstein kindly provided the base station information from Kiel, Bungsberg, and Westermarkelsdorf supplied by the German satellite positioning service SAPOS with a data rate of 1 Hz. In total, 83 survey lines were sailed with an average vessel speed of four knots covering an area of 16.7 km^2. For further geological investigations, an Innomar SES-2000 standard parametric sub-bottom profiler was utilised during an additional cruise with RV »Littorina« in March 2015.

The post-processing of the bathymetric data including manual roll-pitch-yaw calibration, tide correction as well as data validation and cleaning was done using the CARIS HIPS and SIPS 8.1 software. For snippet backscatter evaluation, the QPS Fledermaus Geocoder 7.3.6 toolbox was used. To create a homogeneous and high-quality mosaic, radiometric power gain as well as angle varying gain corrections and heading spline smoothing were applied to the data. The GNSS data was post-processed using the manufacturer-specific software MOTION INSight 1.1.1 partly referring to NovAtel Waypoint GrafNav 8.3 kindly provided by Coda Octopus working with internal Kalman filtering.

Results and interpretation

For cross-validation of suspicious backscatter anomalies, the detections were compared to German Navy data provided with kind permission of the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71). Regarding all further graphical presentations and texts, it should be mentioned in forehand that geographical coordinates are consciously waived as they represent restrictive information bound by the obligation of secrecy.

Using the documented latitude and longitude accuracy of the evaluated GNSS positioning settings, the horizontal position accuracy for the exemplary time period was determined. Fig. 3 draws a general visual comparison between the absolute GNSS and DGNSS positioning results using the SAPOS base stations over an observation period of 24 hours. The results depicted in Fig. 3 underline that the usage of the SAPOS correction service leads to a horizontal accuracy increase of nearly 87.5 % in the nearshore area. Comparing the achieved accuracies for the DGNSS positioning, it is conspicuous that there are only small differences between the different post-processing setups, which is of particular interest from an economic perspective. The only exception is the single usage of the Westermarkelsdorf base station caused by its distance to the investigated area (approximately 23.5 nm northeast). In Fig. 4, a period of three hours (6:00 a.m. to 9:00 a.m.) is shown more detailed to give an insight into the logged position data. Same as in Fig. 3, it is obvious that the DGNSS solution provides both a higher horizontal and vertical accuracy.

The complete area of investigation was analysed with a bathymetric model showing a seafloor with water depth of 5.38 m slightly falling off towards northwest down to 16.80 m. With the increasing water depth also the prevailing sediments change from coarse to a more fine grain size as documented by a snippet backscatter-derived sediment classification based on angle vs. range analysis. Therefore, also the backscatter intensities in the created mosaic switch from high to low reflectance indicated by a light respective dark colouring. The bathymetric surface and the geographical referenced snippet backscatter image were generated with a grid size of 0.4 m × 0.4 m according to the computed horizontal total propagation uncertainty, whereas the charted sediment variability uses an underlying grid size of 1.00 m × 1.00 m. For object localisation, high-resolution snippet backscatter close-up images with a mosaic pixel

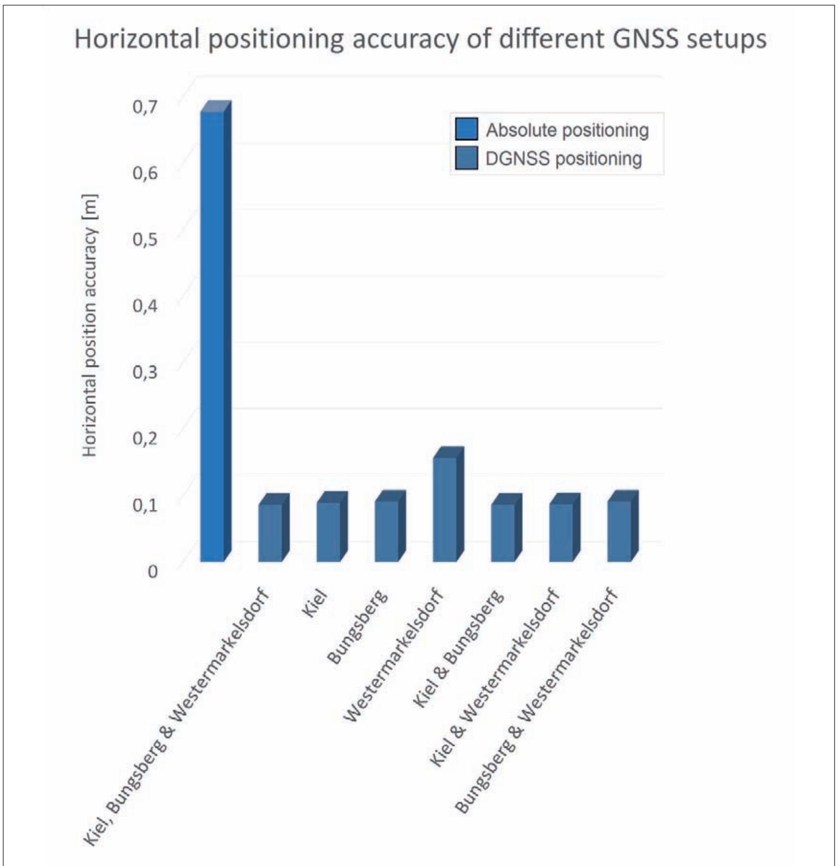


Fig. 3: Order of magnitude for achievable horizontal position accuracies. Absolute GNSS positioning and DGNSS positioning using different indicated SAPOS base stations for correction information

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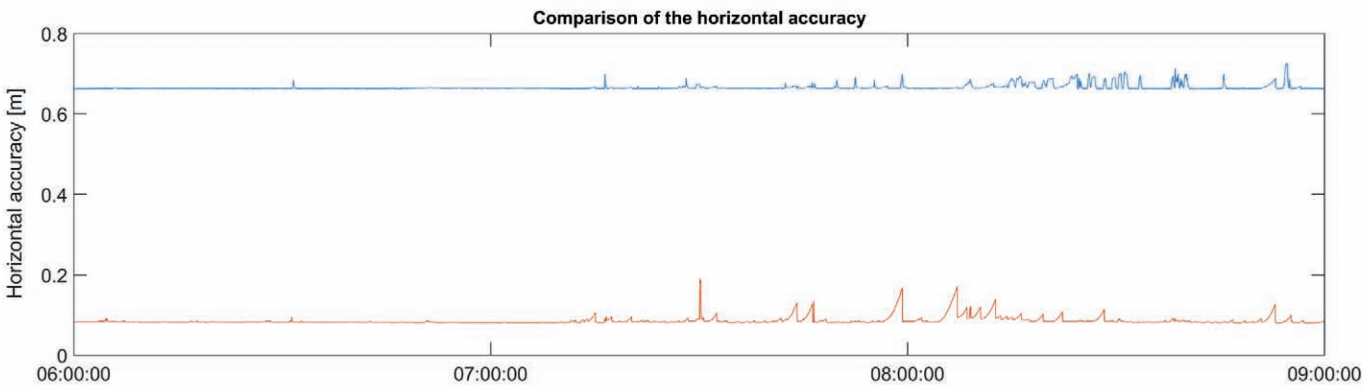

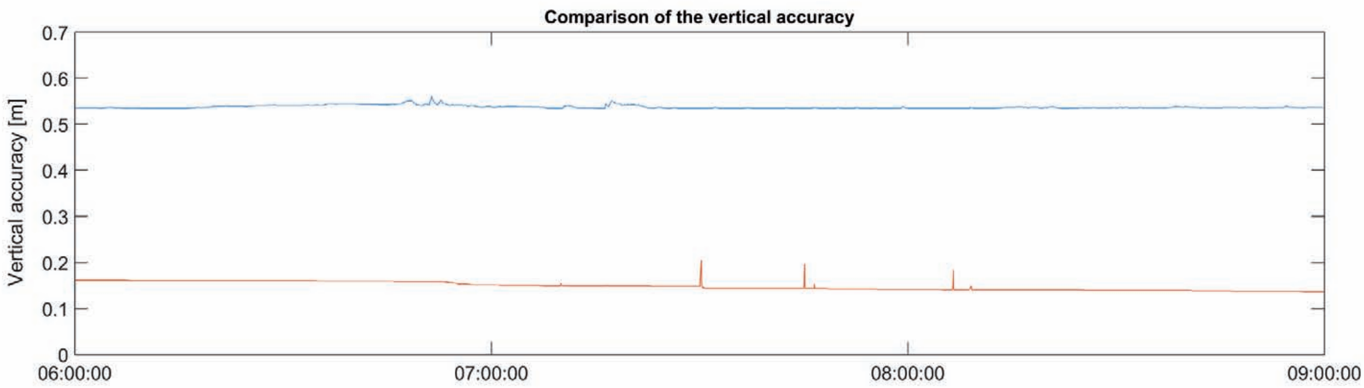

Fig. 4: Position accuracy for absolute GNSS positioning (blue) compared to DGNSS positioning using three SAPOS base stations (orange). Horizontal accuracy [m] (above) and vertical accuracy [m] (below) over a period of three hours in the morning

size of 0.05 m × 0.05 m were generated during the post-processing. Fig. 5 gives an insight showing two of the detected objects and their appearance within the snippet backscatter. The subfigures indicated as (a) show the German Navy sonar image used for validation and comparison. In the centre, indicated as (b), a screenshot taken during the data acquisition – and therefore not geographically referenced but orientated with respect to the appropriate bearing – is shown. Subfigures indicated with (c) show the processed and geographically referenced snippet backscatter mosaic. Comparing images (b) and (c), the post-processed mosaic remains below the expectations, but nevertheless, the detection of surficial objects is technically feasible. In total, 20 objects of different shape and size were examined more closely. Due to the fact that all objects are located in a similar environment and water depth, an assessment of the data sensitivity is only possible in theory.

In addition to the image-based object analysis, the horizontal object position was determined and compared with the official data. All objects show a significant difference in the horizontal position compared to the reference information. On the one hand, this can be seen in the fact that it is not ascertainable where the reference position was picked, on the other hand also the usage of different positioning solutions must be taken into account when regarding the partly considerable high differences.

Discussion

As mentioned, the snippet backscatter images can be seen as an alternative technique to monitor dumped surficial ammunition bodies in a shallow water environment. In contrast to deep-towed sonar systems (both side-scan and synthetic aperture sonar) or systems mounted on an autonomous underwater vehicle, the vessel-based multibeam can be supplemented with a high-precision GNSS. Quantitative sediment transport processes can be measured, monitored and predictively modelled using the versatile multibeam data. Furthermore, this may help to identify possibly hazardous areas and can give information about the surrounding habitat to evaluate a possible toxic contamination.

Compared to applied side-scan sonar systems, the coverage of the multibeam echo sounder can be stated as the most influencing limitation factor. However, the detection of dumped objects is only possible up to a certain water depth as the footprint of the swath was stretched and, consequently, the transmitted pulses are distributed

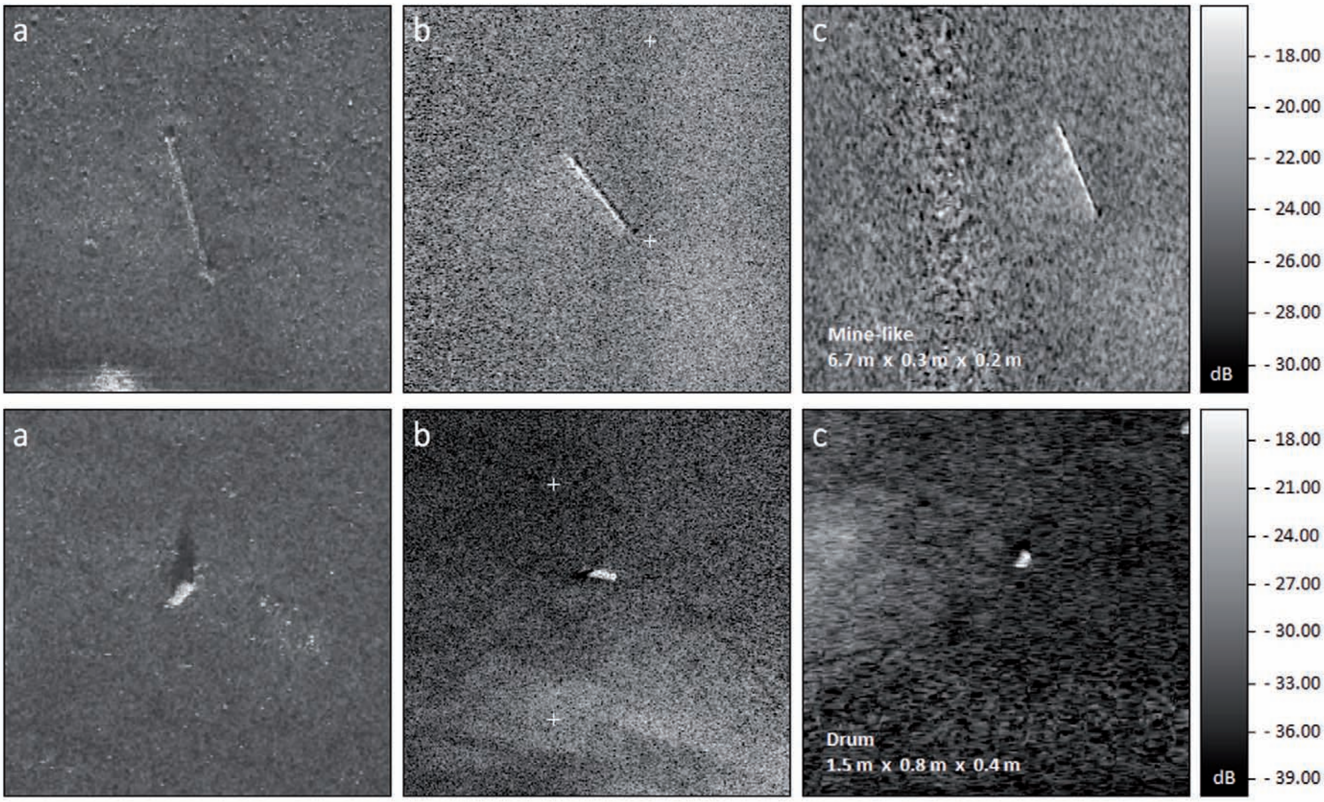

Fig. 5: Detected ammunition bodies on the seafloor. Side-scan sonar images taken from a database provided by the German Navy (left), screenshot of multibeam snippet backscatter information during data acquisition (centre), and post-processed snippet backscatter mosaic with a pixel size of 0.05 m × 0.05 m (right). Dark colours represent low, light colours high backscatter intensities given in dB

over a wider range leading to resolution decrease. With both system approaches, a detection of buried ammunition bodies is not feasible, but the usage of low-frequency acoustic or sonar systems is already an object of research as also mentioned by Kretschmer and Jans (2016). Anyhow, for a reliable detection of ammunition bodies, the survey should always be conducted using different systems to confirm the findings and to justifiable preclude potential hazards.

Conclusion

The central issue addressed by the study was the feasibility of snippet backscatter information collected with a vessel-based high-frequency multibeam echo sounder to detect ammunition bodies of different sizes dumped in shallow coastal waters. By means of the analysis of GNSS information, a possibility to improve the current lack of horizontal position accuracy should be pointed out. Based on the evaluation of 20 randomly selected objects, it can be established that the snippet backscatter information gathered with the EM 2040C multibeam echo sounder are suitable for the detection of surficial objects. For verification, imagery as well as position data provided by the German Navy was used. The vessel-based GNSS offers a significant increase of the horizontal position accuracy from 0.64 m up to 0.08 m compared to the absolute positioning. The combination of precise positioning and feasible snippet backscatter information enables a long-term monitoring strategy using a vessel equipped with GNSS and a high-frequency multibeam echo sounder as a platform.

With regard to the post-processed snippet backscatter images, especially its resolution, further improvements are preferable. Compared to the online data, it is obvious that the post-processed images did not represent the normal case. Nevertheless, high-frequency multibeam snippet backscatter offer a promising alternative at least from both economic and scientific perspective.

Already focused by the body of experts, the assessment of future sedimentation processes provides a framework for further investigations regarding the monitoring of ammunition body burification caused by sediment transport. The successfully demonstrated positioning improvements obtained by post-processing the data with SAPOS corrections could serve in the future to quantitatively evaluate possible sedimentation dynamics. 18 month after the AL447 research cruise, the cooperative project UDEMM (project period: March 2016 to February 2019) is focused on the implementation of an environmental monitoring of ammunition delaboration procedures. Using acoustic, visual, and chemical studies, future-oriented methods, techniques, and strategies for the mentioned environmental monitoring should be developed to ensure a long-term benefit for both the environmental and the economic point of view. ⚓

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