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Ammunition detection using high frequency multibeam snippet backscatter information

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ABSTRACT

The present study reports the evaluation of snippet backscatter information gathered with a high-frequency multibeam echosounder system (200–400 kHz) due to their usability to detect ammunition of different sizes in shallow coastal waters. Besides the feasibility of the snippet backscatter data, it was focused on the attainable horizontal accuracy in comparison to side-scan sonar and autonomous underwater vehicle (AUV) surveys. The data was collected in shallow coastal waters of up to 18 m water depth (Baltic Sea) close to an ammunition dumping site characterized by an almost flat seafloor covered with sand and silt sediments. The analysis of the multibeam compared to sidescan data indicates the snippet backscatter to be a promising prospective method for ammunition detection and being able to improve horizontal position accuracy of up to 0.08 m.

1. Introduction

With the end of the Second World War in 1945, European coastal waters became a large dumping ground for various warfare agents. Even designated areas were established for the disposal of the ammunition bodies, dumping processes themselves were unsupervised which in turn led to a high contamination of the shallow coastal areas both of the North and the Baltic Sea (Böttcher et al., 2011, 2015). Approximately 1.3 million tons of conventional ammunition bodies and 90 tons of chemical warfare agents have been dumped in the German North Sea, in the German Baltic Sea area it amounts to 300000 tons of conventional and 5000 tons of chemical ammunition (Böttcher et al., 2011). In contrast to landmines that are subject of intense monitoring, international discussions, and standardization (United Nations, 1997; McAslan, 1999; Harpviken et al., 2003) since decades, dumped ammunition in the sea is mostly an issue of military forces and internal research (Frenz, 2014; Kretschmer and Jans, 2016; Letts, 2016; Lopera Tellez et al., 2017). Dumped ammunition threatens safe navigation and represent a substantial environmental hazard due to their chemical, partly toxic constituents and the progressive corrosion of the outer sheath (Åkerman and Balk, 1998; Sundberg et al., 2005; Hansson et al., 2007; Beldowski et al., 2014; Böttcher et al., 2015; Baršienė et al., 2016). Corroding underwater ammunition is also highly risky for society, as wet parts of the phosphorus detonators, washed up on the beach, could be confused with amber. When drying it becomes extremely hot, causing severe burns as reported each year by several articles in the local press as well as picked up by Böttcher et al. (2011, 2015).

The increasing and rapid extension of offshore wind farms, offshore raw material exploitation, and ecological monitoring enhanced the attention on underwater ammunition. Especially during the installation of submarine power cables for offshore wind parks, dumped unexploded ordnances (UXO) became an important topic with significant economic impact. Of course, there are officially known ammunition dumping sites marked as restricted areas in nautical charts, but the fact that the corresponding documentation of the exact coordinates and locations of UXO is not available or, if any, is stored in so-called gray and sometimes even restricted literature makes it difficult to identify increased risk areas. Aggravating this situation, the ammunition bodies were even dumped outside the designated dumping sites, even though the allies had supervised the disposal activities at the end of the Second World War. Fishery activities cause further displacement of the ammunition bodies (Böttcher et al., 2011, 2015) which led to a widespread contamination of the seafloor with different types of ammunition. In addition, they might be buried into the seabed and are therefore “out of reach” for high frequency acoustic systems (Guyonic et al., 2007).

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The United Nations Mine Action Service (UNMAS) also underlined that the underwater UXO clearance requires special treatment and standards comparable to the International Mine Action Standards (IMAS) as the water body complicates the clearance operations with regard to effort, equipment, trainings, and the handling of the sensitive environment (GICHD, 2009; UNMAS, 2014). In German seas, potential underwater construction areas have to be surveyed in advance to preclude the occurrence of any UXO in accordance with the German Industrial Standard DIN 4020:2010-12 (2010).

Up to now, the state-of-the-art detection and localization of ammunition bodies is performed by using towed high resolution sidescan or synthetic aperture sonars in combination with magnetometer systems as introduced in Clem (2002), Zakharia and Dybedal (2007), Hunter et al. (2012), Frenz (2014), and Kretschmer and Jans (2016). However, those subsea systems - independent whether they were towed or mounted on an autonomous underwater vehicle (AUV) - generally suffer in navigational inaccuracy compared with direct global navigation satellite system (GNSS) positioning. A consequence, especially in turbid waters, is a significant operational slowdown of diver detection, investigation, and final clearance operation. Frequently, a time-consuming post-processing of the data to reduce time-dependent inaccuracies is still necessary to get a reliable navigation, but applicable solutions are part of an intense and ongoing research (Stutters et al., 2008). Towed systems and AUVs are operated with lower survey speeds compared to surface vessel-based surveying. As a result, a survey is more time-consuming which in turn led to exponentially increasing operational costs and therefore high financial burden. Mayer et al. (2007) as well as Wolfson et al. (2007) already investigated the possibilities of multibeam echosounder systems for the mapping of ammunition, but the improvements of multibeam echosounder systems during the last years lead to new and promising approaches. The co-registered snippet backscatter information offer the potential of object detection and precise positioning at high survey speed even in shallow water environment without using only the beams with normal incidence close to the nadir. As introduced in Kunde (2017), snippet backscatter describes a recorded time series of returned echoes for each beam which need to be recombined line by line along the swath using the bottom return signal at the center point of each beam as position reference. The snippet intensity values surrounding this bottom return signal are finally used for image formation and highly depending on the chosen pulse length. A short pulse length enables the generation of more snippets and, following the simplified range resolution formula, the generation of high-resolution backscatter mosaics for the entire swath.

Here we present a baseline study conducted in collaboration with the Ministry of Energy, Agriculture, the Environment, Nature and Digitalization (MELUND) within the scope of a research cruise with RV ALKOR (Schneider von Deimling, 2015). The aim of this study is to analyze the high frequency multibeam snippet backscatter information due to their feasibility to detect objects of different sizes in the Baltic Sea (Germany) as a first step of detailed object analysis. In addition, the attainable horizontal positioning accuracy using differential GNSS (DGNSS) solutions supported by land based reference stations was compared to give evidence of possible accuracy increases particularly with regard to future monitoring strategies.

2. Regional setting

A moving Weichselian glacier formed the Baltic Sea 20,000 years BP (Lemke, 1998). The deep subsoil of the Baltic Sea basin consists of terrigeneous sedimentary rocks, granites, and gneisses and is therefore more similar to the land surface than to the oceanic seafloor (Niedermeyer et al., 2011; Lemke, 1998). The prevailing seafloor sediments in our working area in the Western Baltic Sea mostly consist of sand and silt.

The study area is located near the Kiel Fjord (Fig. 1). It is characterized by shallow water depth ranging from 5 m down to 17 m and by a recent seafloor of not even 400 years formed during a storm surge event in February 1625 (NABU Schleswig-Holstein, 2017). The designated ammunition dumping site Kolberger Heide, located 4.5 km off the coast, and its adjacent eastern areas were surveyed (Fig. 1).

3. Measurements and processing

The data were acquired in October and November 2014 using the medium sized German research vessel ALKOR as described in Schneider von Deimling (2015). Bathymetric data and backscatter information were mapped by means of a Kongsberg Maritime EM 2040C multibeam echosounder mounted in the moonpool. The system operates with a frequency between 200 and 400 kHz and a maximum swath angle of 130°. Therefore, it allows a theoretical coverage of 4.3 times the actual water depth. The transmitted swath consists of up to 400 beams (1.3° × 1.3°). An equidistant spacing was chosen to ensure a uniform sampling in across-track direction. To guarantee the best possible comparability of backscatter intensities with sidescan sonar data already recorded by the German Navy, a constant pulse length of 50 μs at 300 kHz was used. Conductivity, temperature, and depth profiles were frequently taken for sound velocity and beam propagation corrections. With the applied pulse length of 50 μs and an average sound velocity of 1490 m/s, the Kongsberg Maritime EM 2040C comes with a range resolution of 0.04 m. Bearing and dynamics of the vessel as well as the geographical position were recorded with the inertial navigation system Coda Octopus F180R. This system combines an inertial measurement unit with a dual-antenna GNSS manufactured by NovAtel. The GNSS antennas had a baseline length of two meters and were mounted on the railings of the observation deck to achieve optimal satellite reception. In total, 83 survey lines were sailed with an average vessel speed of four knots, covering an area of 16.7 km^2. The comparatively low survey speed during the multibeam echosounder survey lies in the fact that it was conducted as a multi-purpose survey. Water column imaging was performed in parallel and therefore, the noise provoked by the vessel should be maintained as low as possible. For further geological investigations, the sub-seafloor structure was recorded using an Innomar SES-2000 standard parametric sub-bottom profiler during a cruise in March 2015 with RV LITTORINA. The SES transmitted two primary frequencies of 96 kHz and 104 kHz and recorded the parametric difference frequency of 8 kHz.

For cross-validation of suspicious dumped object backscatter anomalies in our multibeam data, we compared our detections with the German Navy Tactical Map (provided with kind permission of the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research, WTD71, near Kiel). The WTD71 data were gathered during several survey campaigns using a Kongsberg Maritime HUGIN 1000MR AUV equipped with the sophisticated Kongsberg Maritime HISAS 1030 synthetic aperture sonar (Kretschmer and Jans, 2016). The stored information includes besides a sonar image also the description of position, dimensions, and type of the UXO.

The bathymetric data were processed using the CARIS HIPS and SIPS software solution in version 8.1 before further analyses took place. The processing included the manual roll-pitch-yaw-calibration of the vessel motion, tide correction using data of the tide gauge station at Kiel Lighthouse, manual validation of navigation and attitude information, and the manual removal of obvious data outliers. It should be mentioned that the tidal range is considerably < 1 m in the study area as it is more dominated by internal standing waves. The usage of the GNSS tide for depth computation was deliberately avoided as the multibeam data did not provide a fixed RTK-GNSS-solution.

Backscatter anomalies detected and captured during the data acquisition were evaluated with particular attention to be able to compare the picked locations of the suspicious objects to the German Navy Tactical Map information after transforming the Cartesian into geographic coordinates using the QPS Fledermaus Geocoder 7.3.6 toolbox.