Using Synthetic Aperture Sonar for Accurately Characterising Glacial Sediments Exposed at the Seabed

Introduction

The accurate characterisation of seabed features for the emplacement of infrastructure in a marine environment is essential for the success of projects from small scale surveys, such as an oil and gas rig site survey (IOGP, 2017) to large scale offshore wind farm surveys (Carbon Trust, 2020). The primary aim of the seabed features interpretation is to identify and characterise engineering constraints and geohazards that could impact the success of an infrastructure installation, leading to possible project delays, increasing costs and damage to assets.

Side Scan Sonar

Side scan sonar (SSS) integrated with bathymetric, magnetometer, sub-bottom profiler (SBP) and ground-truthed data are the principal datasets for interpreting seabed feature successfully (Hamouda et al, 2021). SSS has been one of the industry standard tools for interpreting seabed objects, mapping seabed morphology and asset integrity (i.e. cable/pipeline freespans). However, one of the limitations of SSS is the spreading of the beamwidth at greater ranges, leading to a loss of across-track resolution. The range of the signal transmission is inversely proportionate to frequency; with a higher emitted frequency having a shorter range (540 kHz approximately 50 m range from the port and starboard channel (Wetton et al, 2024)). Therefore, the ability to resolve seabed objects of 0.3 m in length, width and height, which is typical for offshore wind farm developers, can lead to short side scan sonar ranges (approximately <50 m) and a decrease in line spacing. If SBP data is being acquired in conjunction with SSS, then a decrease in line spacing is advantageous in providing a denser line spacing for shallow soils investigation. However, a reduction in line spacing driven by the decrease in resolution in the SSS outer ranges to achieve a 0.3 m object resolution requirement can lead to increases in vessel costs, project timeframes and an increase in carbon dioxide emissions.

Synthetic Aperture Sonar

Synthetic aperture sonar (SAS) is a form of side scan sonar that emits an acoustic signal perpendicular to the direction of travel and records the returning signal to generate an image of the seabed (Butler, 2025). The aperture refers to the sensor array length with longer apertures creating narrower beamwidths and increased ranges. The principle of SAS is to combine successive acoustic pings coherently along a known track in order to increase the apparent azimuth (across-track) resolution, with the potential to produce high-resolution images down to centimetre scale over hundreds of metres in range (Hansen, 2011). As a physical increase in the sonar array length is impractical for survey operations, this processing technique enables very high-resolution imagery of the seabed at greater ranges, reducing the resolution affects with range previously discussed with side scan sonar (Figure 1).

The advantage of using SAS over SSS is the ability to acquire very high-resolution side scan data at greater ranges (150-200 m). This enables a sparser line spacing compared to SSS and may be desirable where the seabed imagery dataset is the primary sensor for the survey design. If sub-bottom profiler data is required in conjunction with SAS data, the sparser line spacing may not provide sufficient shallow soil information from a geospatial perspective and the survey design may need to be altered.

For optimised seabed imagery from SAS datasets, platform stability is paramount (Carton et al, 2017). Variations in motion must be minimised during data acquisition and for this reason, the majority of SAS systems are deployed on remotely operated towed vehicles (ROTV) or autonomous underwater vehicles (AUV).

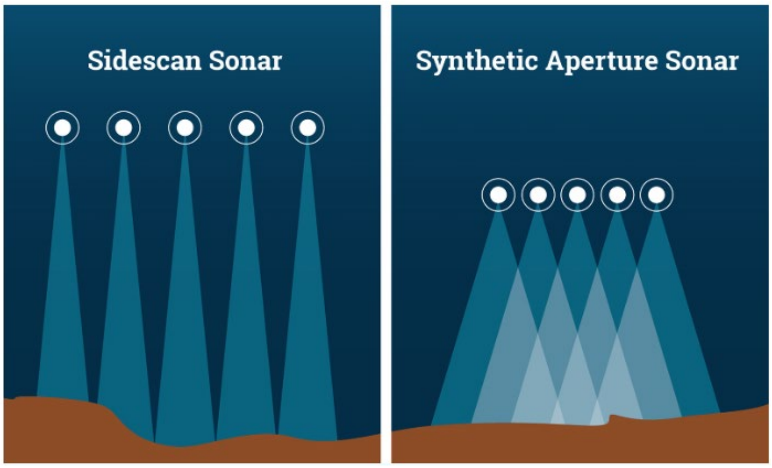


Figure 1 *A comparison between SSS and SAS data acquisition. The main difference is each ping during SSS data acquisition covers a certain part of the seabed, whereas for SAS data acquisition, subsequent pings overlaps the same part of the seabed, with the seabed imagery produced through post-processing (image courtesy of NOAA Ocean Exploration).*

Case Study: Caledonia Offshore Wind Farm

Kraken Robotics carried out a trial programme acquiring SAS data using the KatFish ROTV at the Caledonia Offshore Wind Farm (OWF). The Caledonia OWF is located along the easter edge of the Moray Firth within the United Kingdom Continental Shelf (UKCS), 40 km south-east of Wick, Scotland and covers an area of approximately 429 km² (Figure 2). The western boundary of the proposed wind farm is adjacent to the existing Moray East OWF. The area surveyed by Kraken Robotics was the fixed foundation site, negating the floating foundation site further to the south. The aim of the trial was to compare previously acquired SSS data with SAS data to assess the difference in data resolution.

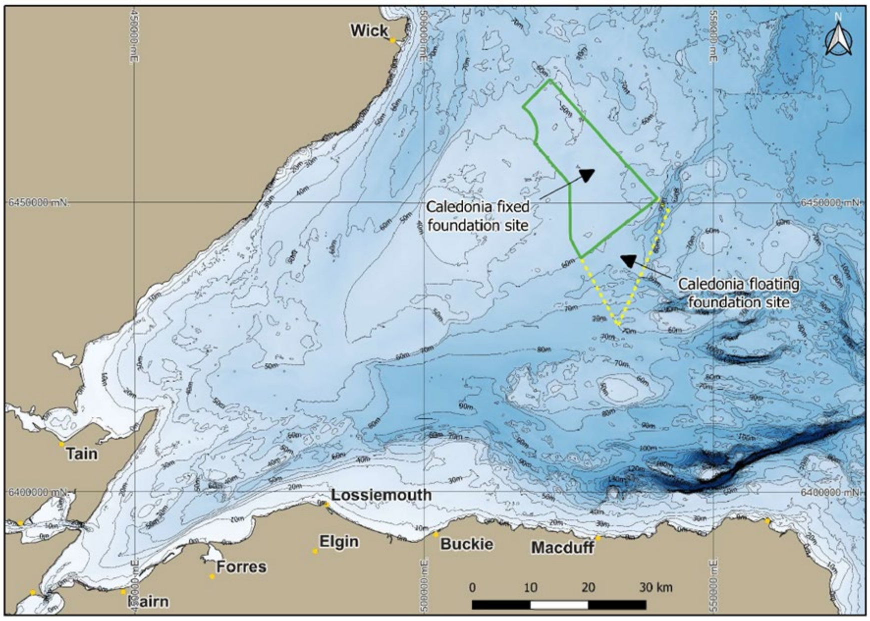
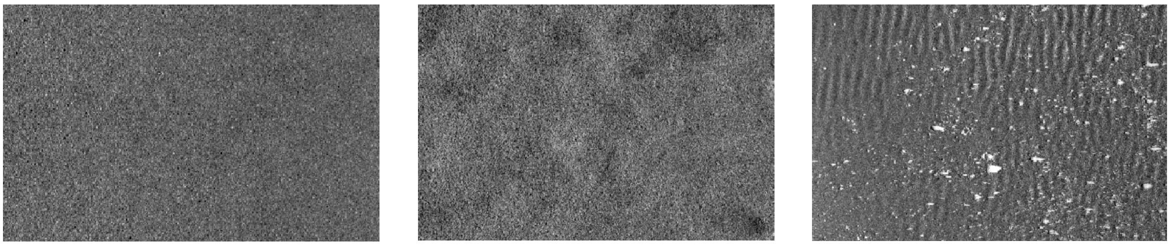


Figure 2 *Location of the Caledonia OWF. The green polygon represents the fixed foundation site where SAS data was acquired survey and the yellow dashed polygon represents the floating foundation site, where SAS data was not acquired.*

The SAS data acquired had a resolution of 3 by 3.33 cm using a range of 150 m for the port and starboard channels and the aim was to interpret all objects that contained a length, width or height 0.3 m or larger. Large scale seabed features such as bedforms, wrecks, oil and gas wells, seabed sediments changes were also included in the seabed features interpretation.

Interpretation Methodology

Where the Caledonia OWF is located within the Moray Firth, a significant number of boulders were expected, which was confirmed by previous geophysical surveys over the area. The previous seabed features interpretation using side scan sonar and other geophysical datasets interpreted the boulder fields as polygon areas, with objects 1.0 m or larger within the boulders fields interpreted as an individual boulder. The following seabed sediment types were expected within the Caledonia OWF area, as presented in Figure 3:



Holocene Sediments (Holocene Sand) | Holocene overlying Glaciomarine Sediments (Sands and Clays) | Glaciomarine Sediments (Sands and Clays)

Figure 3 *Highlighting the three predominant seabed sediments within the areas surveyed with SAS in the Caledonia OWF. The Glaciomarine sediments contain a significant number of boulders and cobbles. All seabed sediment description were provided by client supplied information.*

As the SAS data acquired had a high resolution of 3 cm by 3.33 cm, numerous boulders and items of debris were resolved. It was decided that using polygons to interpret boulder fields was not adequate use of the SAS data and instead it was decided all boulders 0.3 m or greater in size in one dimension were to be interpreted, to take full advantage of the SAS data and provide further information to the ground model. Due to the significant number of boulders expected, manual interpretation involving numerous Geophysicists interpreting each boulder was not feasible due to significant timeframes. Therefore, Kraken Robotics decided to use an AI solution to interpret all seabed objects. Hidrocibalae were contracted to provide their AI solution to interpret all objects 0.3 m or greater in length, width and height.

Results

Within the areas surveyed by SAS, approximately 78,000 boulders were interpreted. It should be noted that the SAS data acquired covered an area of 19 km² and the reduction in the amount of data acquired was due to weather constraints. The majority of the objects interpreted were boulders with approximately 400 objects interpreted to be debris, located primarily around wreck sites (Figure 4). The vast quantity of boulders occurred where the glaciomarine sediments were observed to outcrop at the seabed and within these areas, objects smaller than 0.3 m (cobbles) were also observed.

The seabed features interpretation deliverables were in a GIS compatible format, however for visualisation purposes, as all boulders were interpreted, a boulder density map was produced that allowed the end user to have a high level overview of where boulders may present infrastructure installation issues for wind turbine generator (WTG) locations, offshore substation platforms and inter array cables (IAC). Items of debris were presented separately and not included in the density map.

Conclusions

The SAS data acquired within the Caledonia OWF provided 3 cm by 3.33 cm high resolution imagery of the seabed to a range of 150 m on both the port and starboard channels. The high-quality imagery allowed boulders and cobbles associated with glacial sediments to be clearly resolved. Interpreting all boulders 0.3 m or greater in size provided the end user a greater understanding of this particular engineering constraint

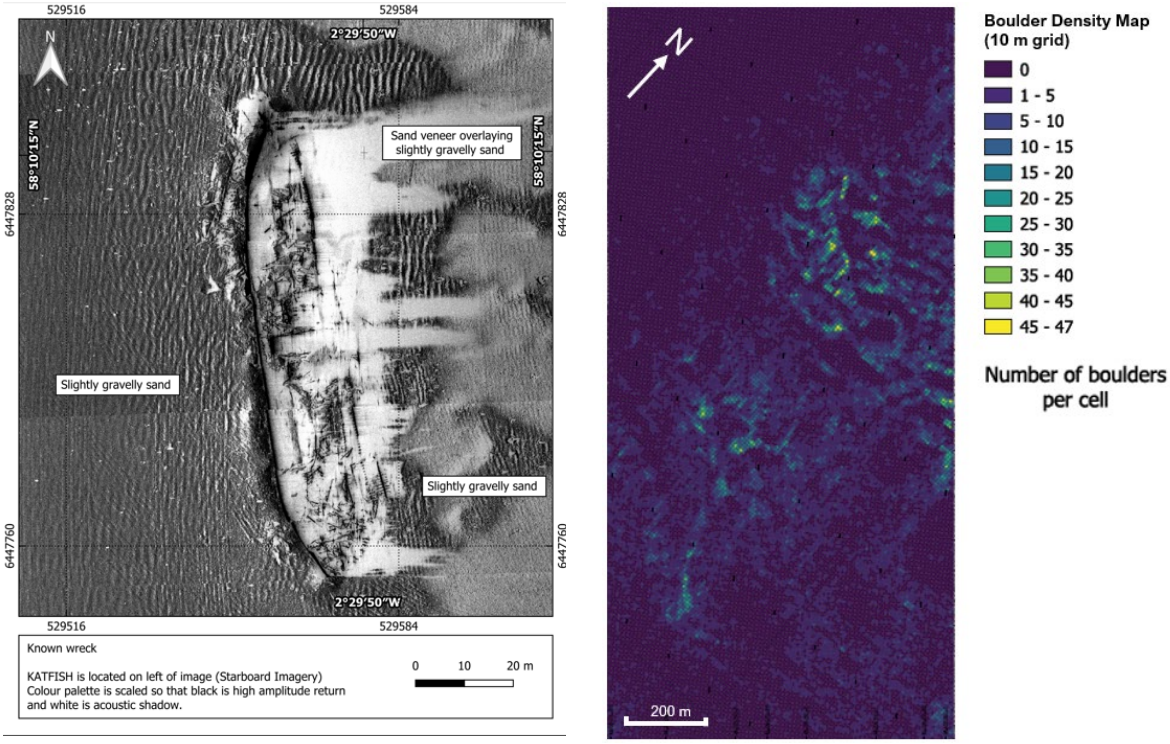


Figure 4 *Left: A SAS data example of a known wreck surrounded by items of debris and possible boulders. Right: A sample of the boulder density map with a 10 m grid.*

Acknowledgements

I would like to thank Ocean Winds for allowing this data to be presented and to Hidrocibalae for their support through this project. A special mention to the Kraken Robotics offshore and processing/reporting teams that acquired the SAS data and produced the interpretation and deliverables.

References

Butler, C., McCarthy, M. [2025] Object Identification Using High Resolution SAS Imagery. EAGE Near Surface Geoscience 2025, 1st Conference on UXO and Object Detection.

Carbon Trust [2020] Guidance for geophysical surveying for UXO and boulders supporting cable installation: Offshore Wind Accelerator, OWA-C.

Carton, G., DuVal, C., Trembanis, A., Edwards, M., Rognstad, M., Briggs, C., Shjegstad, S. [2017] Munitions and Explosives of Concern Survey Methodology and In-field Testing for Wind Energy Areas on the Atlantic Outer Continental Shelf. BOEM. Contract No.: M16PC00001.

Hamouda, A., Nassar, M. and El-Gharabawy, S. [2021] Distinguish seabed objects utilizing different marine acoustic techniques, National Institute of Oceanography and Fisheries (NIOF), Egypt.

Hansen, R.E. [2011] Introduction to Synthetic Aperture Sonar, Sonar Systems, ISBN: 978-953-345-3

IOGP [2017] Guidelines for the conduct of offshore drilling hazard site surveys, Report No. 373-17-1.

NOAA Ocean Exploration, Synthetic Aperture Sonar (SAS).

Wetton, M.J., Vaughan, D.P., Dyer, N. [2024] Seabed and sub-seabed boulders as an engineering hazard in the marine environment; method of detection and quantification. Proceedings of the XYIII ECSMGE 2024, Pages 3440-3445