Ramform Vanguard undertaking an integrated Ultra High Resolution 3D survey

Accelerating offshore wind development through integrated 3D surveys

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Offshore wind development is accelerating globally, driven by ambitious energy transition goals. Yet, one of the persistent bottlenecks in project timelines and budgets is site characterization. Traditional approaches are often sequential and fragmented, and struggle to keep pace with the scale and complexity of developing modern wind farms. This article explores how integrated Ultra-High Resolution 3D (UHR3D) geophysical and hydrographic surveys offer a transformative solution, enabling faster, more precise and cost-effective site characterization.

The challenge of site characterization

Before construction begins, developers must understand the seabed and subsurface conditions to design safe and cost-effective foundations. Conventional workflows typically involve multiple surveys over several years, starting with reconnaissance-level 2D seismic and hydrographic data, as well as preliminary geotechnical sampling and testing. Both geophysical and geotechnical surveys that follow are iterative as the level of commitment to developing the site grows and more detailed knowledge of the seabed and subsurface is sought.

This cyclical approach introduces delays, increases costs, and often leaves residual uncertainty in subsurface models as ultimately the subsurface is not investigated in 3D. Methods to interpolate between data points and profiles must be employed.

Why 3D UHR matters

3D seismic methods have long been a staple in hydrocarbon exploration, but their application in offshore wind is new. The shift from 2D to UHR3D seismic data enables full volumetric imaging of the shallow subsurface soil units, e.g. up to 100 m for offshore wind. This also enables improved detection of geohazards such as boulders and quantitative prediction of soil properties, including soil stiffness and strength.

The full coverage 3D data enables enhanced integration with geotechnical data and can support an optimized geotechnical sampling and testing approach that could reduce the need for dedicated deep geotechnical testing at every foundation or anchor location.

Integrated 3D survey design

Recent projects in Northern Europe designed and undertaken by TGS have proven the feasibility and benefits of a fully integrated 3D geophysical survey approach. These surveys combined UHR3D seismic acquisition using multiple sparker sources and streamer receiver arrays for 3D subsurface imaging, multibeam echo sounder (MBES) for bathymetry, side scan sonar (SSS) for seabed object mapping, sub-bottom profiler (SBP) for near-surface imaging, and magnetometer (MAG) for ferrous object detection.

All data in each of the projects were acquired simultaneously in a single-pass operation, reducing vessel time and minimizing disruption to other marine activities such as fishing.

In addition, the efficiency of the surveys minimized the risk of incurring and compounding weather standby and therefore enabled greater certainty in both the planning and execution of follow-on activities. Indeed, one survey was undertaken towards the end of the summer season for practical reasons so it was important to ensure that the line-plan and survey strategy were realistic.

Near-real-time data transfer via high-bandwidth satellite connectivity on all projects allowed for parallel data processing and interpretation to enable rapid delivery of data products and survey insights. On at least one project, the efficiency of production of survey data deliverables enabled geotechnical survey activities to continue back-to-back with the integrated geophysical survey, thereby securing full use of the data acquisition season.

Case study insights

Here we outline selected subsurface insights from one integrated UHR3D survey that TGS designed to both map and image in detail the seabed and subsurface soil units across the full site of about 100 square kilometers, as well as identify geohazards such as small, e.g. sub-meter in size, subsurface boulders. The UHR3D spatial and temporal sampling used enabled every square meter of the seabed and subsurface to be investigated with sub-meter resolution.

With the UHR3D data, we have gone beyond the usual use of seismic data in Offshore Wind, e.g. to identify major soil units and interfaces. Doing so generated new thinking on foundation placement options. For example, both qualitative and quantitative analyses of the UHR3D data have enabled subtle changes in soil stiffness to be mapped in chaotic glaciomarine sediments.

These important soil property variations closely match the limited data available from Cone Penetrometer Tests and have been classified as a distinct geotechnical soil unit.

This soil unit was not easily visible using traditional interpretative approaches. Furthermore, advanced inversion techniques (to infer soil properties quantitatively from the UHR3D data) enabled the prediction of small-strain shear modulus, an important parameter in foundation design studies, across the site. Again, the results matched well with geotechnical measurements, showing the potential for seismic data to inform foundation design parameters directly.

The integrated UHR3D survey enabled the subsurface risk to be analyzed with greater certainty and clarity. Despite the efficiency and scale of the survey imaging and interpretation workflows that isolate 'point' subsurface features such as potential boulders, based on the diffractions that are generated within the UHR3D data volume, were successful. Numerous subsurface features of about 1 m or so were identified as potential boulders.

Interestingly, an order of magnitude more such anomalies were initially found from the 2D SBP data alone and were later reclassified as iceberg scour marks when viewed in 3D. The 3D data quantified more precisely the risk of encountering boulders, e.g. by reducing the number of false positive hazard cases, thus helping to avoid unnecessary conservatism.

Time and cost benefits

By front-loading a comprehensive and integrated 3D survey, developers can avoid multiple geophysical campaigns, accelerate geotechnical planning, reduce over-engineering through better subsurface understanding, and shorten overall project timelines, potentially enabling earlier power generation.

A comparative analysis shows that while upfront costs may be higher, cumulative site characterization costs can be significantly lower, especially when the geotechnical scope is optimized.

Conclusion

For design engineers and developers, the availability of UHR3D seismic data opens new possibilities. These include micro-siting of turbines based on detailed soil variability, tailored foundation designs that reflect actual subsurface conditions, improved risk management, reduced contingency requirements and enhanced collaboration between geophysical and geotechnical teams.

Allan McKay

Integrated UHR3D surveys are a paradigm shift in offshore wind site characterization. By combining multiple sensor technologies in a single, efficient campaign, developers gain a holistic view of the seabed and subsurface, enabling smarter, faster, and more cost-effective decisions. As offshore wind scales up, this approach will be essential to meet the industry's evolving demands.

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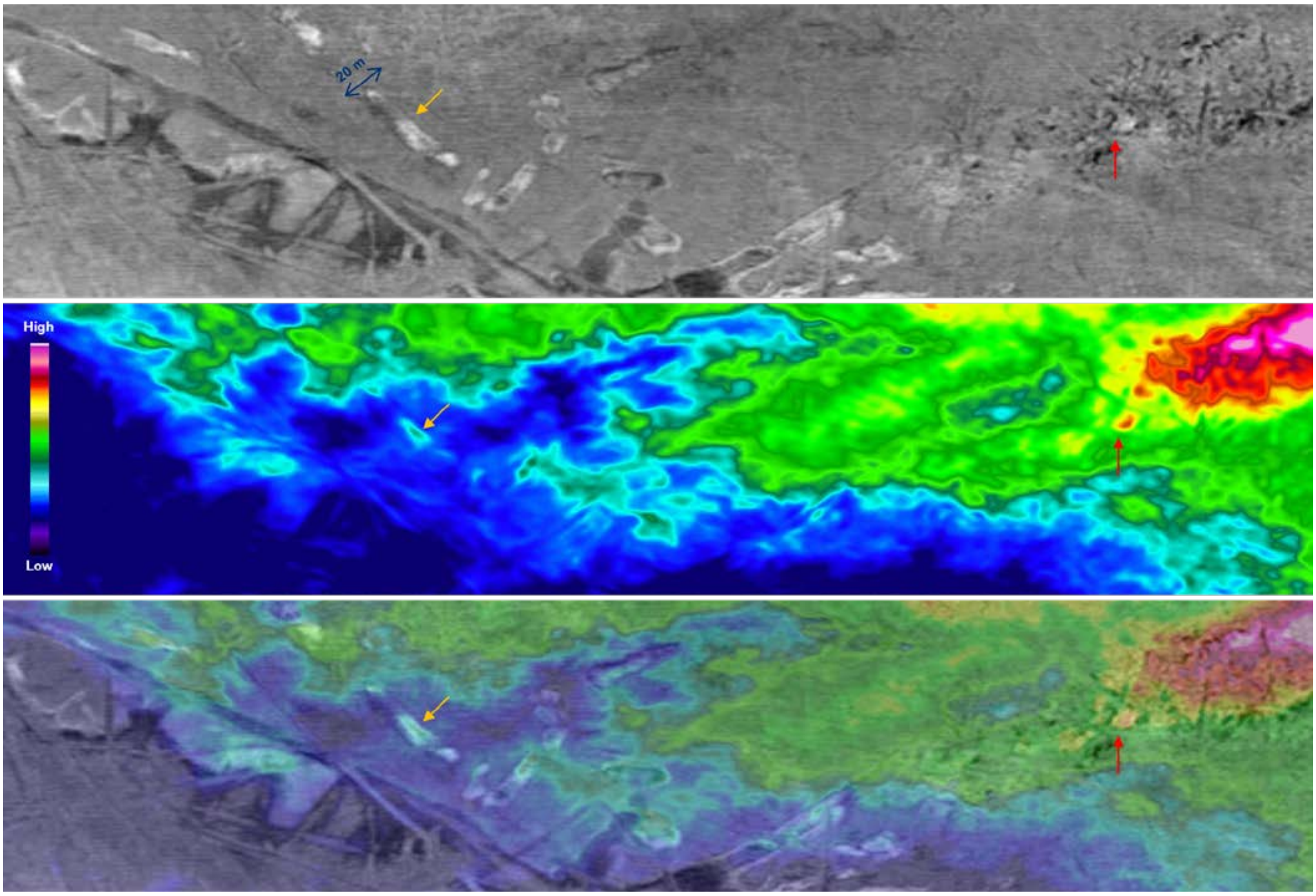

Depth slice through an UHR3D seismic image of the subsurface (top) together with (middle) an indication of soil property variation linked to stiffness (in this case seismic propagation velocity determined via an advanced imaging technique called Full Waveform Inversion) with a composite image of both (bottom)