Hydro INTERNATIONAL

THE GLOBAL MAGAZINE FOR HYDROGRAPHY

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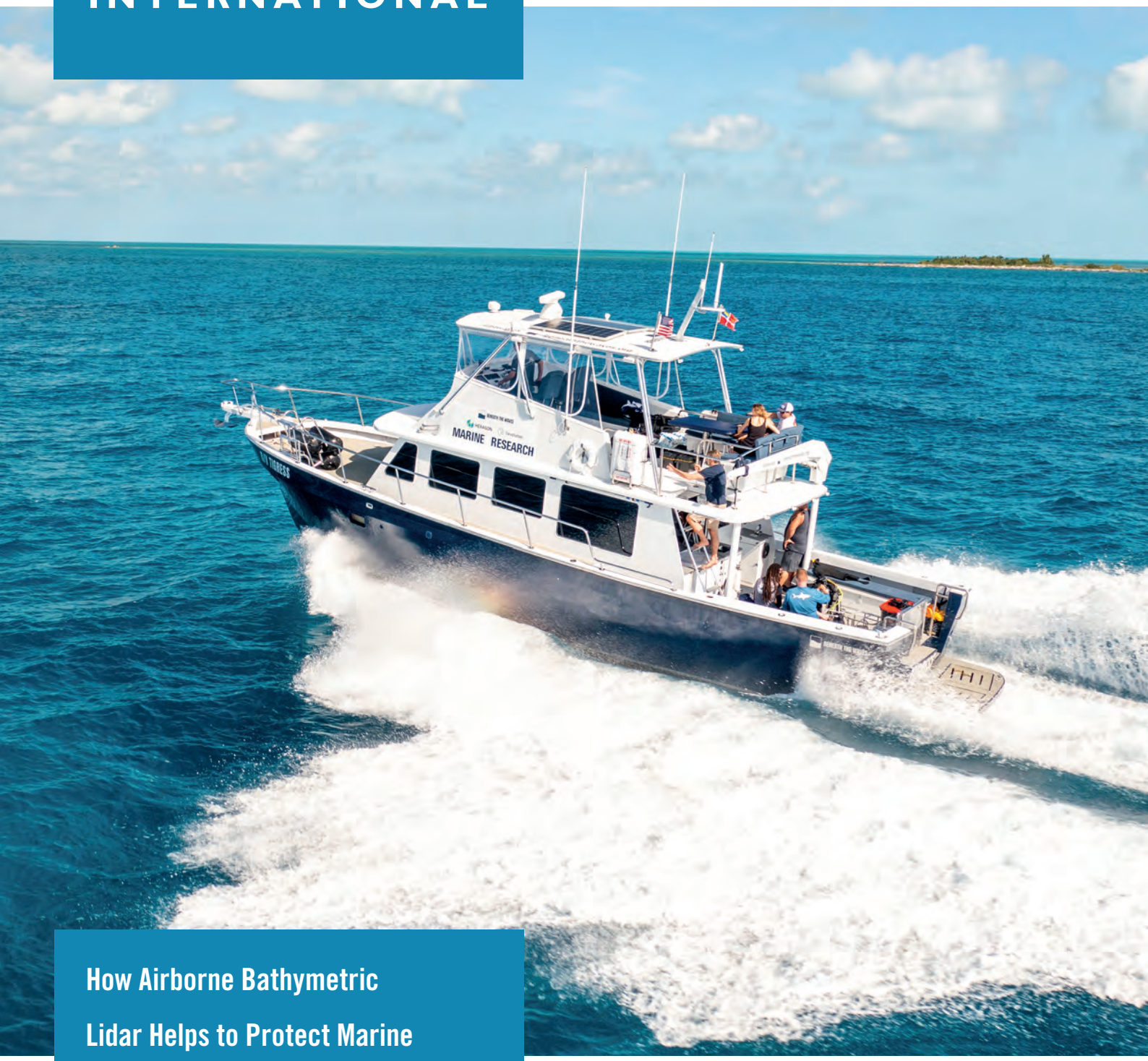
SPECIAL EDITION:
PRESTIGIOUS PROJECTS

VOLUME 26 | ISSUE 3 | 2022



How Airborne Bathymetric Lidar Helps to Protect Marine Environments

Surveying the Seabed for the Danish Energy Island

Surveying the Tonga Volcano Eruption Aftermath

A Detailed Look at the Undersea Impact

Hydro INTERNATIONAL

Hydro International is an independent international magazine published six times a year by Geomares. The magazine and related e-newsletter inform worldwide professional, industrial and governmental readers of the latest news and developments in the hydrographic, surveying, marine cartographic and geomatics world. Hydro International encompasses all aspects, activities and equipment related to the acquisition, processing, presentation, control and management of hydrographic and surveying-related activities.

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Geomares
P.O. Box 112, 8530 AC Lemmer, The Netherlands
Phone: +31 (0) 514 56 18 54
E-mail: info@geomares.nl
Website: www.geomares-marketing.com

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Cover Story

Hexagon is working with Beneath The Waves, a conservation NGO, to help protect marine environments in the Bahamas. Using bathymetric airborne Lidar solutions, researchers are able to map, study and quantify the region's endangered seagrass ecosystem. Apart from the bathymetric data the sensor collects, the initial project team had other sources of information on hand: researchers on the vessel gathered luminosity data, the divers could provide information about the seabed such as the type of vegetation and collect coring samples, and the sharks that had been equipped with cameras provided additional photo imagery.

Impact

This summer issue of *Hydro International* has a byline on the cover: it is a special edition on Prestigious Projects. In this special edition, we aim to present to our readership some of the most exciting surveying projects taking place right now.

Around 680 million people currently live in coastal areas – a figure that is expected to increase to one billion in fewer than just 30 years. If we stretch that area to 120km inland, this will be nearly half of the world population. These coastal communities face the growing threat of storm surges and tsunamis that can wash away entire neighbourhoods and endanger lives in a matter of minutes. On the other hand, coastal communities could also prosper because of the activities taking place at sea; for example, jobs in fish farming and renewable energies, such as wind farm construction, could replace work in traditional fisheries. The broader community inland will also experience the negative and positive impacts of these events at sea and in the coastal zone.

In this Prestigious Projects edition, we cover a selection of projects (it's impossible to rank or show every project going on around the globe, as there are too many that appeal to our imagination to publish in this magazine). We take a look at how some renowned parties such as NOAA and NV5 Geospatial have joined forces to create a comprehensive topobathymetric elevation model of the bay and coastline of the Morro Bay coastal estuary in California (see page 20), and we try to capture the impact of the volcano eruption in Tonga (see page 11). Another breath-taking project involves the mapping of seagrass in the Bahamas (see page 26).

It is difficult not to take pride in being part of the lively and ambitious hydrographic community that is a technological forerunner at the same time. This especially because every project, whether a survey or a research project, is adding to the impact that hydrography has on a safer, greener (or bluer if you like) and more sustainable world and its seas. This pride, however, is often reserved for those who belong to the inner circle, those in the know. Hydrographic data is often overlooked and underrated in the complete scale of projects, while it is the necessary starting point, requiring a lot of effort and knowledge to ensure the quality and authoritativeness of the data in the process of acquisition to analysis. While it sometimes feels that hydrography does not receive the recognition that it deserves, as the backbone of everything that is later built on it, it is the fate of our and a few other industries and we will have to live with it.

Our conclusion is that it is often hard to see the impact that the work of hydrographers has on a project, let alone its effect in the long term on the coastal communities and the broader communities living in the zone 120km inland from the coast. So, because these effects are so hard to measure, let's for now indulge in the projects and everything they involve: challenging circumstances far out at sea, technological developments and unexpected outcomes. Later this year, we will once again dive deep into the nitty-gritty of technology and its impact, but Prestigious Projects will do for now this summer.

Have a great read!

Durk Haarsma,
director of strategy & business development

durk.haarsma@geomares.nl

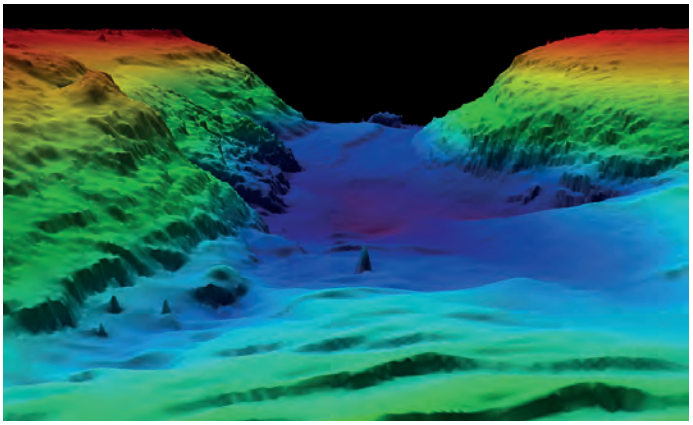
▲ *Durk Haarsma*

ADVERTISERS

NOAA Formally Joins International Effort to Map Ocean Floor

NOAA Administrator Rick Spinrad has signed a memorandum of understanding in conjunction with the United Nations Ocean Conference that formalizes U.S. participation in Seabed 2030. The memorandum also describes best practices and protocols for this type of data collection, which will help build positive collaboration between all involved countries and partners.

As of 2022, 23.4% of the ocean is mapped, reflecting an increase of 10.1 million square kilometres (almost 3.9 million square miles) of new bathymetric data from 2021. The new number represents contributions from a wide and diverse group of stakeholders, including various nations, government agencies, private companies, philanthropic partners and academic institutions.



▲ *High-resolution bathymetry mapping data collected by multibeam sonar reveals complex topographic features of the seafloor in San Francisco Bay, California. (Courtesy: NOAA)*

IHO Discusses Ocean Mapping at IOC UNESCO Executive Council Meeting

▲ *The IHO participated in the 55th meeting of the IOC UNESCO Executive Council in Paris on 13–17 June 2022.*

As part of its mission to contribute proactively to global initiatives in favour of the ocean, the IHO participated in the 55th meeting of the IOC UNESCO Executive Council in Paris on 13–17 June 2022. Discussions focused on the state of the ocean and provided insight into how the IHO could contribute to key activities such as the UN Decade, as well as provide an update on joint projects including GEBCO.

The presentation on the pilot edition of the State of the Ocean Report 2022 by Dr Vladimir Ryabinin highlighted the need for objective data that can be used as a benchmark to monitor changes in the marine environment. It states that although society is aware in principle of what is happening in the ocean and what should be done about it, the quantitative description of the ocean is incomplete and, as a result, current knowledge is insufficient to effectively inform solutions to the ocean issues that humanity is facing. To emphasize the pivotal role of data, Dr Ryabinin reminded participants of the popular saying: "One cannot manage what one cannot measure." This is an area in particular where the IHO can support global initiatives to protect the ocean. The data on the physics and features of the ocean gathered by IHO Member States can be used to target actions and increase the impact of initiatives.

Fugro and EMODnet Join Forces to Advance Ocean Sustainability in Europe

Fugro is now an associated partner of the European Marine Observation and Data Network (EMODnet), a long-term EU initiative to make diverse sources of marine data freely and uniformly available to all. Beneficiaries of this work include policymakers, scientists, private industry and the public. The Fugro-EMODnet partnership was formalized earlier this week and will focus on expanding private sector collaboration and marine data sharing in support of a sustainable blue economy.

Planned partnership activities tightly align with Fugro's industry-leading involvement in two global ocean science initiatives: The Nippon Foundation-GEBCO Seabed 2030 Project (Seabed 2030) and the United Nations Decade of Ocean Science for Sustainable Development 2021-2030 (Ocean Decade). An early output of the partnership will be the direct delivery of crowdsourced bathymetry acquired by Fugro for Seabed 2030 into the EMODnet data services.

▲ *Aerial view of the island of Capri in the Tyrrhenian Sea. Shared access to ocean science data is key to ensuring a sustainable blue economy. (Courtesy: Fugro)*

Marine Robotics Launches New Mariner X USV

Maritime Robotics recently launched a new multipurpose unmanned surface vehicle (USV) platform, the Mariner X, with a configurable design and built for high-quality data acquisition at sea. The platform wields Maritime Robotics' market-leading software and supports a wide range of sensors and other equipment of the operator's choice.

The first operator of the new Mariner X USV platform is Argeo. Named Argus, Argeo's first unmanned survey and inspection vehicle will exploit the strong demand for accurate ocean mapping, especially in the booming offshore wind market. The Argus USV will conduct advanced mapping and inspection services using robotics and autonomous ocean space technology for offshore and energy projects in water depths from 2–200 metres.

The Mariner X is a multipurpose USV platform.

SEA-KIT Unveils New H-class USV for Ocean Surveys

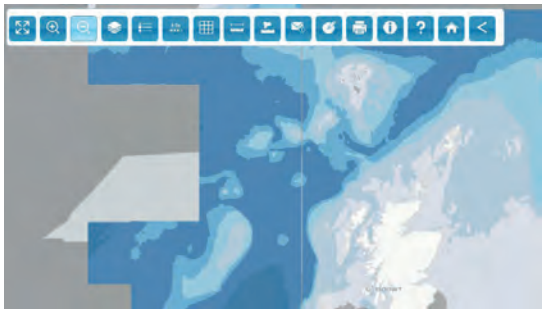
SEA-KIT International, a leading provider of low-carbon uncrewed surface vessel (USV) solutions in active operations across the globe, has revealed a new USV design that focuses on hydrography and environmental data collection.

The SEA-KIT H-class USV, with its retractable gondola and dual sensor deployment options, is a highly configurable design based on a wealth of operational data and feedback collected from the company's established X-class USVs. Several of these 12m vessels are currently operational in the Indian Ocean, North Sea, Red Sea and the Pacific.

The H-class features a composite hull for higher transit speeds, giving it greater range and endurance, as well as active stabilizers to minimize roll. The new design has 12m and 15m variants, with the 12m version transportable in a standard shipping container for rapid, low-cost deployment. Both variants can be davit launched.

SEA-KIT H-Class USV 12m and 15m variants. (Courtesy: SEA-KIT International)

Scottish Government GIS Marine Data Contract Awarded to OceanWise

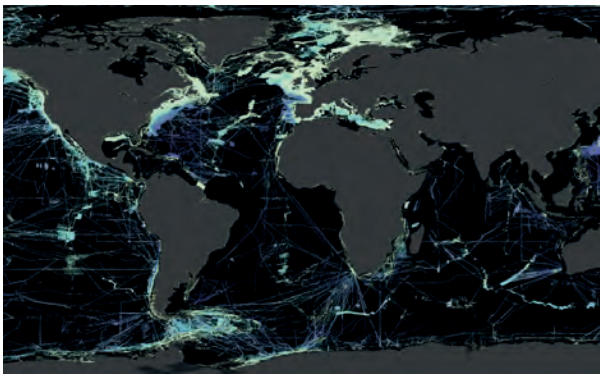


▲ *Marine Scotland Information (MSI), a web portal that provides access to descriptions and information about the Scottish marine environment.*

OceanWise, a renowned provider of marine and coastal mapping worldwide, has been awarded the framework agreement for the provision of GIS marine data to the Scottish Government until 2026.

Janet Lockey, key account manager for OceanWise, commented: "We are really pleased to be supplying our range of marine mapping data products and services to the Scottish public sector, including the Scottish Government, six public bodies and 15 local authorities. We have been working with this important customer for many years now and have built up a great relationship with those involved. We will be providing not only our flagship product 'Marine Themes Vector' but also our Marine Themes Digital Elevation Model (DEM), full range of raster charts and our Web Map Service."

New Partnership and Ambitious Expedition to Uncharted Polar Territory



▲ *The current bathymetric map of the world's ocean floor. The coloured areas show mapped areas, whereas the black parts show the massive areas that still have to be mapped. (Courtesy: The Nippon Foundation-GEBCO Seabed 2030 Project).*

The Nippon Foundation-GEBCO Seabed 2030 Project recently entered into a memorandum of understanding with the Ocean Research Project (ORP). The parties will work together to support the global effort in pursuit of mapping the world's ocean floor, especially in polar regions, through ORP's upcoming expedition, GO-MARIE.

The GO-MARIE (Glacier-Oceans Mapping & Research Interdisciplinary Effort) programme is a 2022 expedition and also the motivation for the maiden voyage of the organization's flagship, the RV Marie Tharp. A 22-metre Bruce Roberts steel schooner, the vessel is custom-built to navigate uncharted polar territory. There will be a base crew of ten, with rotating ocean science experts joining legs of the voyage.

Dubai Completes Hydrographic Data Survey of All Marine Areas

Dubai Municipality has announced the completion of a first-of-its-kind hydrographic survey of the territorial waters of the Emirate, conducted to generate comprehensive marine data in accordance with the specifications of the International Hydrographic Organization (IHO).

The results of the survey were reviewed by His Excellency Dawoud Al Hajri, Director General of Dubai Municipality. The survey is part of the Municipality's efforts to support the development of major world-class marine infrastructure projects launched by the United Arab Emirates.

Al Hajri was briefed on the advanced marine survey boat used for the project, the first vessel of its kind deployed in the country to carry out comprehensive hydrographic and geophysical surveys of deep layers of the sea floor across marine areas of Dubai. The survey covered not only Dubai's coastline and its entire territorial waters but also parts of international waters bordering it. The boat, with an operational capacity of 72 continuous sailing hours, contains integrated state-of-the-art monitoring systems.

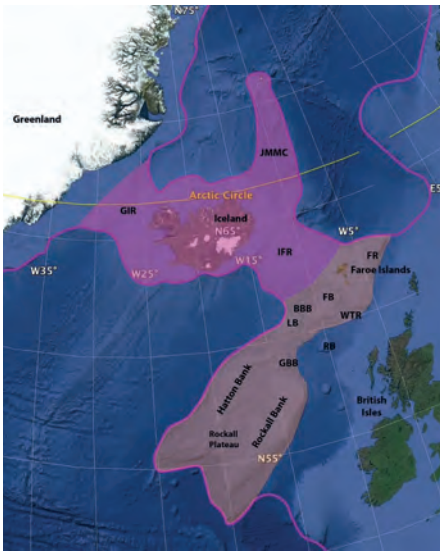
▲ *Dubai has completed a hydrographic survey of the territorial waters of the Emirate.*

The Implications of a Possible Sunken Continent in the North-east Atlantic

Is Iceland the tip of a vast, sunken continent? A new theory could revolutionize geological thinking. Academics believe that they have identified a remarkable geological secret: a sunken continent hidden under Iceland and the surrounding ocean, which they have dubbed 'Icelandia'.

An international team of geologists, led by Gillian Foulger, Emeritus Professor of Geophysics in the Department of Earth Sciences at Durham University (UK), believes the sunken continent could stretch from Greenland all the way to Europe. Professor Foulger is a world-leading geologist whose research has contributed to mapping the geological composition of the seabed in relation to continental land masses.

'Icelandia' is believed to cover an area of 600,000km^2, but when adjoining areas to the west of Britain are included in a 'Greater Icelandia', the entire area could be 1,000,000km^2 in size. If proven, this means that the giant supercontinent of Pangaea, which is thought to have broken up over 50 million years ago, has in fact not fully done so.



▲ *Bathymetric map of 'Icelandia' in the north-east Atlantic Ocean.*

New Bathymetric Lidar Sensor Boosts Performance in Hydrographic Mapping

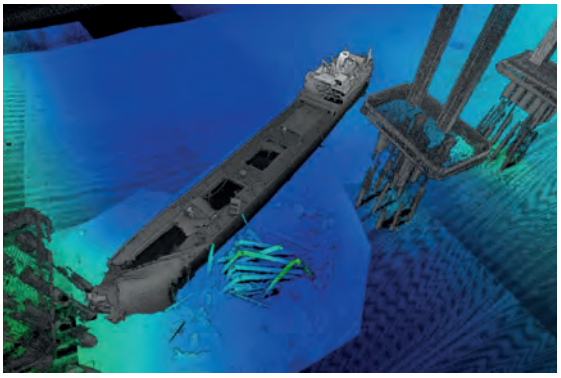
▲ *Leica Chiroptera-5 airborne bathymetric Lidar sensor.*

Leica Geosystems, part of Hexagon, has announced the introduction of Leica Chiroptera-5, the new high-performance airborne bathymetric Lidar sensor for coastal and inland water surveys. This latest mapping technology increases the depth penetration, point density and topographic sensitivity of the sensor compared to previous generations.

The new system delivers high-resolution Lidar data supporting numerous applications, such as nautical charting, coastal infrastructure planning, environmental monitoring and landslide and erosion risk assessments.

Chiroptera-5 combines airborne bathymetric and topographic Lidar sensors with a 4-band camera to collect seamless data from the seabed to land. Thanks to a higher pulse repetition frequency (PRF), the new technology increases point density by 40% compared to the previous generation system, collecting more data during every survey flight. Improved electronics and optics increase water depth penetration by 20% and double the topographic sensitivity to capture larger areas of submerged terrain and objects with greater detail. The high-performance sensor is designed to fit a stabilizing mount, enabling more efficient area coverage which decreases operational costs and the carbon footprint of mapping projects.

New Technology Lights Up Bulk Ore Carrier Wreck Location



▲ *A new view of the wreck of SS Lake Illawarra lying next to the pylons of the Tasman Bridge.*

Lying beneath the Derwent River in Hobart, Tasmania, is the wreck of SS *Lake Illawarra*. A recent survey has illuminated this site in a whole new way. SS *Lake Illawarra* was a 140-metre bulk ore carrier that struck the Tasman Bridge and sank in 1975, resulting in the tragic loss of 12 lives: seven ship crew and five motorists who were driving across the bridge.

While some may remember the tragedy and lives lost, SS *Lake Illawarra* is largely out of sight and mind for most residents of Hobart. Despite more than 70,000 vehicles crossing the bridge each day (the highest volume road section in Tasmania), most travellers wouldn't think of the wreck lying beneath the surface nearby. Until now.

CSIRO's new mapping in partnership with Jacobs has merged light and sound to produce the first ever complete map of the wreck and its position beneath the bridge. The imagery is stunning and seamlessly brings together two separate datasets to create a complete and compelling view.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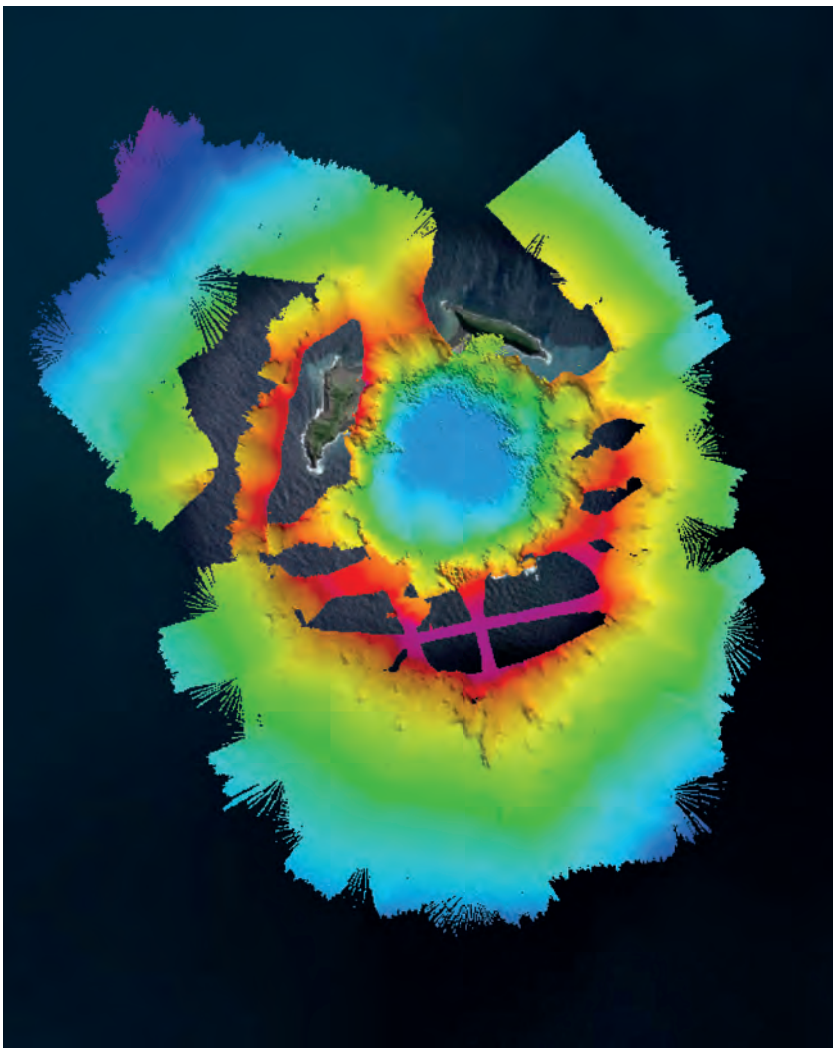
A Detailed Look at the Undersea Impact

Surveying the Tonga Volcano Eruption Aftermath

The Tonga Eruption Seabed Mapping Project (TESMaP) is a collaborative mission to discover the undersea impacts of the January 2022 eruption of the Hunga-Tonga Hunga-Ha'apai volcano. Using their collective knowledge, experience and resources, New Zealand's National Institute of Water and Atmospheric Research (NIWA) and The Nippon Foundation of Japan hope to understand what happened, how much material was displaced and what shape the volcano was left in. This information will help to improve tsunami forecasting and better predict the blast effects of subsea volcanoes, which in turn will help to protect people from similar natural disasters in the future.



▲ *Aerial view of the Hunga-Tonga Hunga-Ha'apai (HT-HH) volcano. (Image courtesy: SEA-KIT NIWA-Nippon Foundation TESMaP survey team)*

On 15 January 2022, a South Pacific nation with just over 104,000 residents witnessed the unexpected and unprecedented eruption of the Hunga-Tonga Hunga-Ha'apai (HT–HH) volcano. The immediate impact had catastrophic consequences for Tonga's nearby islands. The main island of Tongatapu was carpeted in toxic ash and a sonic boom travelled around the globe. The shape of the seabed greatly influenced the speed and size of the resulting tsunami; death and damage were recorded as far away as South America, and waves hit Australia, New Zealand and Japan, even touching the shores of California, Alaska and Chile. It also severed the submarine fibre-optic cables connecting Tonga with the world, leaving the country in a prolonged blackout.

In April 2022, New Zealand's National Institute of Water and Atmospheric Research (NIWA) and The Nippon Foundation of Japan announced a collaborative mission to discover the undersea impacts of the explosion, using their collective knowledge, experience and resources to build a detailed and invaluable picture of the eruption's aftermath below the ocean's surface. The Tonga Eruption Seabed Mapping Project (TESMaP) is funded by The Nippon Foundation and supported by The Nippon Foundation-GEBCO Seabed 2030 Project, which aims to map the world's entire ocean floor by 2030 and to deliver this information via GEBCO's (the General Bathymetric Chart of the Oceans) freely available definitive map..

▲ *SEA-KIT USV* Maxlimer *getting prepared for despatch to Tonga.*

▲ *USV* Maxlimer *in Tonga.*

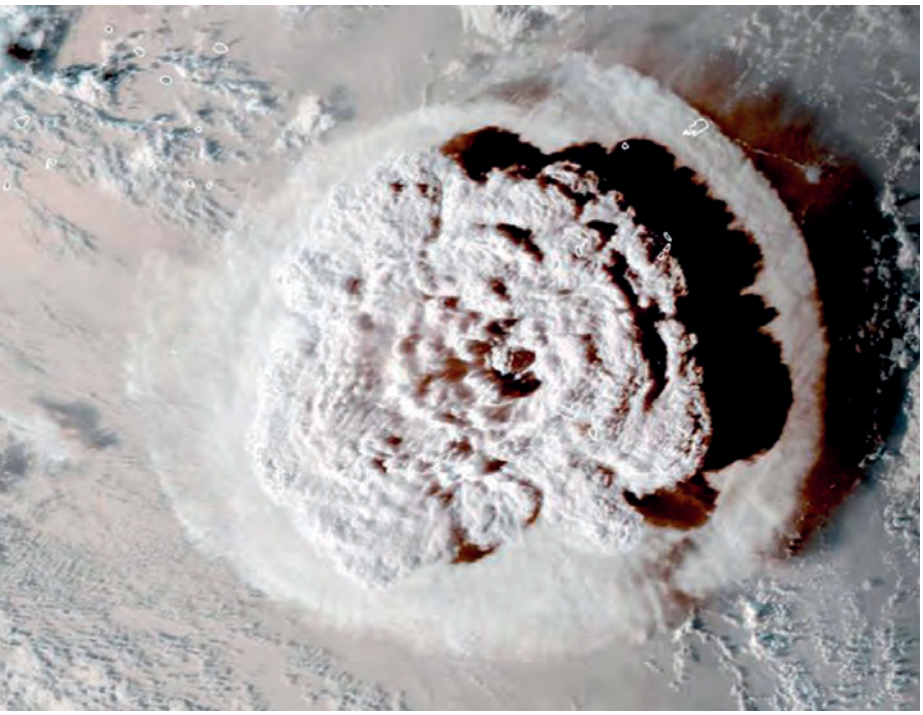
MODELLING FUTURE ERUPTIONS

Around 680 million people currently live in coastal areas, and this figure is expected to increase to one billion in less than 30 years' time. These coastal communities face the growing threat of storm surges and tsunamis that can wash away entire neighbourhoods and endanger lives in a matter of minutes. Since there are numerous similar volcanos around the globe, particularly along the Pacific Ring of Fire, the eruption of HT–HH highlights a critical risk to society, exacerbated by a lack of knowledge.

Through detailed research and surveys, expanding the collective knowledge of the undersea topography is vital to understanding what happened, how much material was displaced and what shape the volcano was left in. This information makes it possible to improve tsunami forecasting and better predict the blast effects of subsea volcanoes, which in turn will help to protect people from similar natural disasters in the future.

Phase one of TESMaP, which took place between April and May, saw NIWA scientists on board the research vessel RV *Tangaroa* survey the ocean around HT–HH, covering thousands of square kilometres and collecting video images of the eruption's impact.

Phase two, which took place between July and August, utilized SEA-KIT International's 12m uncrewed surface vessel (USV) *Maxlimer* to conduct a month of further mapping inside the caldera. This research – conducted in an area which could not be surveyed by NIWA due to safety reasons – will prove crucial to the overall findings of the project.



▲ *Explosive eruption of the Hunga Tonga-Hunga Ha'apai volcano on 15 January 2022. (Courtesy: UNICEF/NOAA)*

DISPLACED MATERIAL

Due to the sheer magnitude of the explosion, dramatic changes to the volcano were to be expected. But instead, researchers on board RV *Tangaroa* for the month-long expedition were amazed to find it still largely intact. NIWA scientists mapped a total of 22,000km^2 of the surrounding seafloor and observed changes covering an area of 8,000km^2. They recorded up to seven cubic kilometres of displaced material – enough to fill three million Olympic-sized swimming pools. Tonga's severed domestic internet cable was buried under 30m of ash and sediment, and scientists found sandy mud and deep ash ripples as far as 50km away from the volcano.

ECOSYSTEM IMPACTS

The impacts on the ecosystem were also examined. The volcano was devoid of biology, but remarkably there were features as close as 15km away that still had abundant and diverse populations of marine life. Surrounding seamounts had pockets of normal biodiversity,

such as corals, sponges, starfish and mussels, indicating the resilience of such marine ecosystems and giving scientists a baseline for monitoring recovery in the future. Preliminary water column data showed that it is still recovering, with some airborne ash yet to completely settle on the seafloor. There is also evidence to suggest the volcano may still be erupting, with a dense ash layer found in the upper water column near the site.

MAPPING THE GAPS WITH USV

As part of phase two, USV *Maxlimer* mapped the current shape of the caldera and measured environmental conditions of the water above it, all whilst being controlled remotely from SEA-KIT's base in the UK, some 16,000km away. The use of USV *Maxlimer* as a configurable platform for a range of sensors provided a unique opportunity to gather data safely and continuously from inside the caldera over a full month. During the mission, USV *Maxlimer* used just 100 litres of fuel per day, which is under 2% of the fuel consumption of a typical survey vessel. In addition to reducing the risk to people, deployment of a USV for survey inside the caldera ensures carbon emissions for the project remain low.

▲ *USV* Maxlimer *returning from HT-HH caldera in Tonga.*

This was the first time that a USV had been used for this type of mission and demonstrated how the technology is pioneering new ways of understanding our oceans. *Maxlimer*, the first SEA-KIT X-class USV, is the company's testing and development vessel. She was part of the winning Nippon Foundation-GEBCO alumni entry in 2019's Shell Ocean Discovery XPRIZE and has since achieved numerous 'firsts', including the first uncrewed offshore pipeline inspection and first international commercial uncrewed transit in 2019. The USV also completed 22 days of remote survey operations on Europe's continental margin in 2020, mapping over 1,000km^2 of ocean floor.

The mission demonstrated how technology is pioneering new ways of understanding our oceans

REAL-TIME DATA COLLECTION

Sensors on board collected bathymetric data, water column backscatter data, sound velocity, conductivity, temperature, turbidity, oxidation reduction, pressure with depth and current data, all of which will develop and support understanding of the eruption's undersea impact and ongoing activity. The USV used newly fitted winch capability for sensor dips and tows to gather water column data as far down as 300m and provide a closer look at the suspended sediment layer. This collection of oceanographic data will help to identify layers of geothermal activity as well as the change in salinity and dissolved particles, and will be used for comparison studies against samples gathered outside the caldera by RV *Tangaroa*.

Maxlimer, together with three members of the SEA-KIT team, was based in Nuku'alofa, Tonga for around 40 days. During this time, the vessel was also available for use for environmental surveys ahead of possible new cable lays to reconnect the islands, as well as for the mapping of other volcanoes in the area and generating change maps from previous eruptions. ◀

Ben Simpson is CEO of SEA-KIT International, a British company providing high-tech, uncrewed surface vessel (USV) solutions to the maritime and research industries. Simpson gained a BSc (Hons) in Maritime Studies at Southampton University before embarking on a career as captain/engineer on super yachts around the world. On his return to the UK, he held director roles at workboat builder CTruk and its sister company, CWind, before founding Hushcraft in 2015, which went on to design and build trans-ocean-capable USVs under the SEA-KIT brand. Simpson is a keen sailor and a Fellow of The Royal Institution of Naval Architects.

Jamie McMichael-Phillips is the director of The Nippon Foundation-GEBCO Seabed 2030 Project. A chartered surveyor, hydrographer and former Royal Navy officer, he has worked in a range of leadership roles, from running his own marine data gathering missions to directing defence geospatial strategy and plans for the UK. Prior to assuming his current role, for over nine years McMichael-Phillips chaired the International Hydrographic Organization's Worldwide ENC Database Working Group, responsible for monitoring the global footprint of electronic charts required for safe navigation at sea.

How Hydrography Is Crucial for Shaping the Renewable Revolution

Surveying the Seabed for the Danish Energy Island

The Danish government is building an energy island in the North Sea, 80 kilometres off the coast, with the aim of accelerating the energy transition. The ambition is that the island becomes a role model for the green transition globally. However, the plans for this enormous project will remain just that without geophysical, seismic and hydrographic surveys. A survey of the seabed, a geophysical study and object detection (i.e. UXO surveys) have produced a detailed digital map of the seabed and the geological layers beneath it. This article gives a brief overview of what is involved.

Energinet – the Danish company that will construct and operate the electrical transmission system connecting the island to neighbouring countries – is partnering with a couple of renowned players in the hydrographic surveying sector to make sure that its ambitions are founded on solid ground. MMT started pre-construction geophysical and seismic surveys in a 526km^2 area in May 2021, which will be completed in September 2022, while Fugro has been awarded a marine site characterization contract for the project.

The sea is between 25 and 50 metres deep in the survey area; a relatively shallow sea depth that makes the North Sea an excellent location for large offshore wind farms, and now also an artificial energy island. The seabed in this area is also suitable for laying foundations for the around 200 offshore wind turbines initially planned, plus the artificial island.

▲ *Location of the proposed energy island.*

THE FOUR PHASES OF THE ENERGY ISLAND LOCATION MAPPING

The work is divided in four phases. Phase 1 consists of the geophysical survey, including 2D surveys down to 100m below the seabed. Phase 2 will use remotely operated vehicles (ROVs) to carry out Unexploded Ordnance (UXO) magnetometer surveys. Phase 3 is a 3D Ultra High Resolution Seismic (UHRS) survey of the energy island locations, and Phase 4 consists of a survey and inspection to assist the Danish Navy in removing confirmed UXO.

The aim of the seabed mapping is to ensure that the North Sea energy island, the surrounding offshore wind farms and the seabed cables are constructed and laid in a manner that, while technically feasible, ensures maximum consideration of nature and the environment.

Focusing on the geophysical site survey, which included a 2D UHRS survey, Fugro aimed to exceed the client's expectations. Energinet required high specification data, but through the use of the company's dedicated survey vessels and innovative solutions, Fugro was able to deliver superior data quality. Fugro mapped the high-resolution bathymetry, static and dynamic elements of the seabed surface and the sub-surface geological soil layers to at least

100m below the seabed. For this, the *Fugro Pioneer*, a multipurpose dedicated survey vessel and a range of innovative UHR specialized survey equipment were employed. The geophysical site survey was completed in October 2021. The survey and offshore wind consultancy teams then used the acquired geodata to provide reliable site interpretation.

Fugro began the UXO survey in December 2021, and a couple of months later was surveying no fewer than 90 sites, each 150 x 50m in size. Also part of the package is a high-resolution acoustic survey of the seabed, in which the *Fugro Frontier* – a multipurpose dedicated survey vessel that can be configured to tow a variety of survey equipment – will play a pivotal role.

▲ *Seawatch Wind Lidar Buoys record continuous wind measurements to support wind-resource mapping for the two energy islands.*

▲ *The multipurpose dedicated survey vessels Fugro Pioneer and Fugro Frontier are being used to complete the energy island site surveys.*

SURVEY CHALLENGES AND UNEXPECTED ISSUES

While the survey work started with very detailed project plans that attempted to mitigate as many risks as possible, there are always challenges that come up on a project of this size and duration. The three biggest challenges were related to fishing activities, pycnoclines and poor weather conditions.

One example is gill nets, which are used by fishermen but are often not picked up by sonar. The chance of the equipment getting tangled in the nets is therefore high, and can result in damage to the nets and the equipment – something all parties would like to avoid. Together with Energinet, Fugro worked to build a good relationship with the local fishing community. A fishing liaison officer was present onboard Fugro vessels and the fishing community was kept well informed of the areas being surveyed, plus a dedicated scouting vessel was employed to ensure that they did not run across any nets. If for any reason the Fugro crew came across fishing activities, the towed survey sensors were raised to ensure that they avoided the nets. While this limited any impact on fishing activities and equipment, it resulted in scans with diluted resolution and reduced coverage, and the crew had to redo the survey to ensure data quality as per client specifications.

Another challenge was the impact of pycnoclines on site investigations. A pycnocline occurs when water density increases rapidly with depth due to changes in temperature and/or salinity. As sound travels differently depending on the density of the water, this impacts the coverage of the sonar. Pycnoclines therefore cause artefacts in the data, obscuring a good image of the seafloor. To avoid this, a sound velocity check was conducted six hours prior to each survey. In addition, a moving vessel profiler was used that continuously recorded sound velocity – critical for sonars on a survey.

Finally, challenging weather conditions resulted in vessels being placed on standby. While weather is of course a factor than cannot be

▲ *Artist's impression of the North Sea energy island.*

changed, what definitely helped was being able to rely on a very accurate weather forecast model. Furthermore, Fugro's Seawatch Wind Lidar Buoys were deployed on-site to provide accurate measurements of wind profiles, waves and current profiles, which were fed into the weather model. All of this information helped to foresee potential delays and better plan the survey.

GEOPHYSICAL AND GEOTECHNICAL SURVEYS

Fugro's dedicated survey vessels arrived on-site in March 2022 to begin the geophysical and geotechnical surveys. These included ROV inspections and shallow geotechnical investigations using Fugro's innovative Blue Snake geotechnical system. The Blue Snake integrates CPT and sampling technology to enable data to be captured in a single pass with testing completed consecutively at fixed distances along the cable route. The system integrates a high-performance vibrocorer and ten-ton CPT into a single frame with a customized launch and recovery system – minimizing manual handling and improving workability in difficult weather conditions. This innovative technology optimizes data correlation, improving design and engineering for future cable installation works.

FROM DRAWING BOARD TO ENERGY ISLAND

Of course, preparing plans for such a major project is a process that gradually takes shape, from vague contours (fuelled by a clear vision) to a design that will serve as a pioneering example for the world to make the energy transition happen. COWI, the renowned Danish international consulting group, was invited to develop alternative concepts to visualize what the world's first energy island could look like. Being a project without precedent, it is no wonder that there were many questions that puzzled the COWI engineers involved. For example, should the energy island be realized in phases or in one go? What is the best way to handle the many mechanical and electrical installations that will be required? Other factors also had to be considered, such as the area requirements, the location in relation to offshore wind farms, and cable landfalls.

The island will be protected from the stormy North Sea on three sides by high sea walls, and promises to be the largest construction project in Danish history. The artificial island will serve as a hub for offshore wind farms and supply 3GW of energy, with a long-term expansion potential of 10GW. One challenge is to determine the optimal perimeter protection, as this must be high enough to keep water out while also strong enough to resist natural forces and keep maintenance requirements to a minimum.

The sketches distributed by the Danish Ministry of Energy give an idea of what the island could look like. The energy island will float but will be attached to the seabed, the depth at the intended location being well suited for this.

CONCLUSION

The boundless Danish energy ambitions provide many opportunities for the engineering sector, and certainly also for the hydrographic industry. Renewables are already an important pillar in the success of many companies in our branch, and projects such as the Danish energy island in the North Sea will only boost this. As this article outlines, such projects provide a lot of work for the recognized specialists that characterize the hydrographic field. The energy transition will require a lot more survey activities all around the world, but there is one snag: the lack of skilled personnel to conduct all the mapping and surveying projects is clearly a major concern. ◀

Denmark wants to be completely energy neutral by 2050 and in order to make sure that things keep moving, intermediate targets have been set for every five years, with emissions targets for all economic sectors. The industry has therefore invested heavily in energy-efficient technologies and renewable energy generation, supported by the government which stimulates research. The Danish energy transition generates exports and investments worth billions and lowers energy bills for consumers and companies and can count on widespread support within the country. Focusing on climate and sharing knowledge and technology with foreign countries is proving highly rewarding for Denmark. To capitalize on the tremendous market potential, the Danish government has launched an export strategy that aims to double energy technology exports to roughly USD20 billion by 2030.

Wim van Wegen is head of content at *GIM International* and *Hydro International*. He is responsible for the print and online publications of one of the world's leading geomatics and hydrography trade media brands. He is also a contributor of columns and feature articles, and often interviews renowned experts in the geospatial industry. Wim has a Bachelor's degree in European studies from NHL Stenden University of Applied Sciences in Leeuwarden, the Netherlands.

XOCEAN provides sustainable data for the development, construction, operation and maintenance of offshore wind farms.

XOCEAN – Survey Data Throughout the Offshore Wind Lifecycle

As the rapid expansion of the offshore wind industry continues worldwide, one of the challenges facing developers at each phase of an offshore wind farm's 40-year lifespan is the ongoing survey and data requirements.

Since its commercial launch in 2019, XOCEAN has completed over 65,000 operational hours of survey for world-leading energy companies and has worked on over 150 projects in 18 jurisdictions globally. In the first half of 2022 alone, XOCEAN delivered 12,000 hours of carbon-neutral uncrewed survey operations to offshore wind farms. This was done in 36 missions using multiple USVs across seven jurisdictions, supporting the development of 14.6GW of new offshore wind while increasing the number of vessels in the fleet to 23 to meet this growing demand.

OFFSHORE WIND FARM SITE INVESTIGATION SURVEY | DEVELOPMENT PHASE

XOCEAN recently completed a series of site surveys for bp's Morgan and Mona offshore wind farms, located approximately 30km off the coast in the Irish Sea. These two wind farms, which are being developed by bp and EnBW, have a combined area of approximately 800km². Once operational, they will have a generating capacity of 3GW by 2029.

XOCEAN were contracted by bp to acquire high-resolution seabed surveys in water depths ranging from 0–35m, as part of the overall geophysical site surveys required for the preconstruction phases. The high-quality data collected will give the wind farm's engineering and project teams insights to create robust designs for the sites.

With work commencing in 2021, the Morgan and Mona project took place over four phases in a two-year period covering 20,000 survey line kilometres. The XOCEAN team was able to quickly mobilize USVs to site in the Irish Sea, completing over 300 survey days. To maximize efficiency in data collection, multiple USVs were deployed to the site with up to four operating at a time.

XOCEAN delivered 70,000GB of high-quality bathymetry data, as well as recording backscatter and water column data. Drone footage of the cable landing site was captured as part of the overall scope of the project, to identify the connection points from the wind farm to the coast. XOCEAN's USVs emit just 0.1% of the CO_2 of a conventional vessel, saving 35,000kg of carbon during the project.

By utilizing XOCEAN's USV technology, the data collected will enable bp to build the most efficient offshore wind farms possible, identifying viable options for the export cable corridors with a much-reduced carbon footprint.

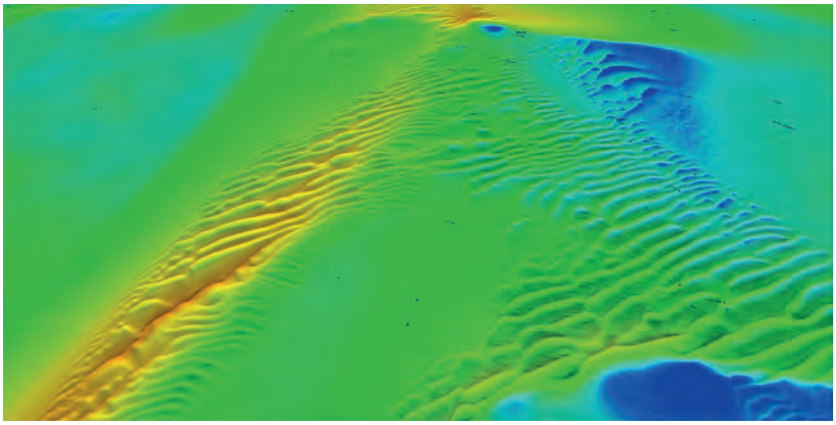
▲ *XOCEAN XO-450 operating on the Greater Gabbard Offshore Wind Farm for SSE Renewables.*

OFFSHORE WIND FARM INSPECTION SURVEY | CONSTRUCTION

XOCEAN have been engaged in ongoing seabed monitoring and construction surveys at Ørsted's Greater Changhua 1 & 2a Offshore Wind Farms, located 35–60km off the coast of Changhua County, Taiwan. At the 108.7km^2 site, where continued construction is taking place, XOCEAN has so far completed 160 seabed surveys within the wind farm in various stages of the construction, including surveys around the wind turbine generators and offshore sub-station positions in water depths ranging from 30–45m.

During the construction phase of these large offshore wind farms, an accurate and consistent view of the seabed is required, as well as insight into the integrity of the turbines and cables being installed, to allow the project and engineering teams to make informed decisions as they move through installation and development at the site.

To maximize efficiency and flexibility, mobilization on site was aided by deploying the USV from a service operations vessel (SOV) using XOCEAN's custom Launch and Recovery System (LARS).



▲ *Four XOCEAN XO-450 USVs were used to deliver 20,000km of geophysical survey for the Morgan and Mona Offshore Wind Farms.*

▲ *XOCEAN's XO-LARS (Launch & Recovery System) used in Taiwan.*

Safety during construction is a principal factor in the risk evaluation and management of an offshore wind farm. With the small size of XOCEAN's XO-450 USV, this has allowed for minimal interference as construction takes place. USV pilots monitor and have full command and control through XOCEAN's highly secure cloud-based environment, Cyberdeck.

With 26 successful missions completed over the past year, productivity has been maximized at the Greater Changhua 1 & 2a sites by utilizing XOCEAN's USV technology, whereby data collection takes place quickly and is fed back 24 hours a day, seven days a week. XOCEAN can safely deliver high-quality bathymetry data in these challenging locations.

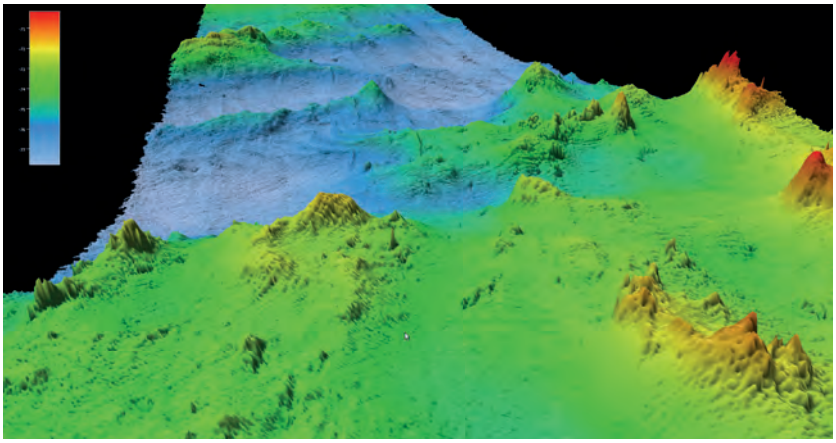
OFFSHORE WIND FARM INSPECTION SURVEY | OPERATIONS & MAINTENANCE

XOCEAN recently completed a routine operations & maintenance inspection of Equinor's Sheringham Shoal offshore wind farm on behalf of Reach Subsea, located 17–23km off Norfolk's coastline. XOCEAN was tasked with surveying 88 wind turbine foundations and two of the wind farm's 22km export route cables.

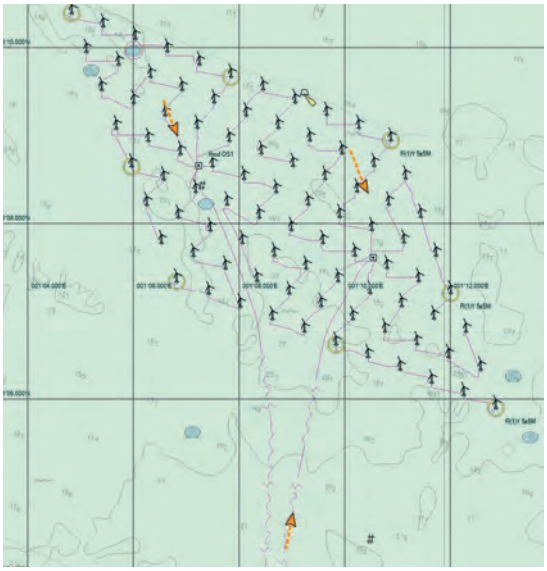
To maximize efficiency, the XOCEAN team quickly mobilized to site within 48 hours and completed the project in just nine days. Using multiple USVs allowed for swift data collection of the cable routes, whereby two USVs were deployed to inspect the foundations and inter-array cables while a third USV inspected the export cables.

While the strong tides and shallow waters of the Sheringham Shoal site may have presented challenges to a traditional vessel, the small size and weight of the USVs meant that XOCEAN could quickly mobilize to and navigate the site to acquire the data for the client.

XOCEAN efficiently and safely delivered high-quality bathymetry and backscatter data for Reach Subsea, sharing the results with Equinor in HTML format, which allowed the project teams to identify any potential changes to the seabed that would compromise the integrity of the wind farm.



▲ *Two XOCEAN XO-450 USVs were used to deliver 1,750km of geophysical survey for the third phase of Dogger Bank Wind Farm.*



▲ *Three XO-450s [orange arrows] simultaneously operating on the Sheringham Shoal Offshore Wind Farm.*

OFFSHORE WIND FARM LIFECYCLE

XOCEAN is proud of its continued partnership with SSE, having completed surveys on 16 projects with their teams over the past three years, returning to many of their offshore wind farm sites in this time. Two such projects include Dogger Bank C and Greater Gabbard, where surveys were completed at different stages of the offshore wind farms lifecycle.

OFFSHORE WIND FARM CABLE ROUTE SURVEY | DOGGER BANK C

In 2021, XOCEAN performed a geophysical scouting survey of the third phase of Dogger Bank Wind Farm's export cable route. Up to 236km offshore off the north-east coast of Yorkshire, Dogger Bank C wind farm is part of the soon-to-be largest offshore wind farm in the world, and will provide the UK with 3.6GW of power by 2026.

Dogger Bank Wind Farm is a joint venture between SSE Renewables, Equinor and Eni Plenitude. It is being built in three phases – Dogger Bank A, B and C. Fugro was contracted to undertake a variety of surveys on the array and cable route areas and engaged XOCEAN to support the acquisition of geophysical data on the cable route. Combining the data obtained from the different sensors is important to accurately determine the subsurface, and this is where XOCEAN and Fugro complement each other, working together on this project to understand the routing options for an engineering corridor for installation of the export cable route.

Efficiency was ensured by deploying two USVs to the site for swift data collection. In site conditions of up to 2.5m wave heights and water depths ranging from 18m up to 36m, XOCEAN's USVs acquired high-resolution seabed data for the project team. Using a multibeam echosounder and sub-bottom profiler to deliver over 1,750 line-kms of high-quality bathymetric and backscatter data allowed SSE to determine water depths, topography, gradients, rugosity and micro-elevation. The high-resolution sub-bottom data was used to determine the shallow subsurface soil conditions that may influence foundation and cable installation.

OFFSHORE WIND FARM INSPECTION SURVEY | GREATER GABBARD

XOCEAN has regularly returned to SSE's 140-turbine Greater Gabbard site located in the North Sea, around 20km off the coast of Suffolk. Over the past two years, SSE has engaged XOCEAN to provide routine operations & maintenance surveys of the 147km^2 wind farm.

In one such mission during this period, XOCEAN was contracted by SSE to perform inter-array cable inspection surveys to assess the depth of burial along seven cables and at two turbine locations in preparation for the arrival of a jack-up vessel. Conducting 24-hour operations in the area, XOCEAN was tasked with acquiring high-quality multibeam echosounder, sidescan sonar and sub-bottom profiler data.

XOCEAN transited to site within 12 hours, completing the survey work in just over two days. Six cable surveys and one jack-up survey were completed in the first stage of the mission along the northern area of the wind farm. A following cable survey and jack-up survey were also completed in the southern area.

XOCEAN provided SSE with over 370 survey line kms of high-quality bathymetry data in this high current environment in water depths ranging from 2 to 30m. The data collected allowed the project team to identify the state of burial or exposure of the wind farm cables, and as a result deploy sufficient protection systems to ensure the integrity and optimal operation of the cables and turbines.

CONCLUSION

Continued growth of the global ocean economy is driving the need for high-quality ocean data to enable informed decisions and support the development of offshore wind farm projects. The requirement to survey areas to modern standards is also ongoing for the creation and updating of navigational products, which support global shipping, trade and numerous other activities related to our oceans. By using USVs, we can increase the rate at which ocean data is collected, support the growth of the blue economy and conduct carbon-neutral operations to help utilize our oceans in a sustainable way. ◀

The Hydrospatial Data Collection Approach in Morro Bay

Addressing Change in Coastal Environments with Advanced Topobathymetric Elevation Modelling

Morro Bay, a shallow coastal estuary located near San Luis Obispo, California, supports an abundance of wildlife and is home to a vibrant outdoor community. However, changes such as sedimentation and a substantial loss of eelgrass have had an impact on the landscape. To better understand how the environment is changing and to gain insights into mitigation strategies, key stakeholders – including the Morro Bay National Estuary Program (NEP), the National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management (OCM) and NV5 Geospatial – have joined forces to create a comprehensive topobathymetric elevation model of the bay and coastline.

▲ *Drone photograph of the Morro Bay estuary.*

The Morro Bay coastal estuary is a natural treasure. The 2,300-acre (9.3km^2) estuary features salt marshes and mudflats and is home to more than 250 species of land, sea and shore birds and dozens of endangered species, including peregrine falcons. The estuary and the bay also attract an abundance of other wildlife – from sea otters to shellfish – as well as the aquatic vegetation that provides habitat for these species while helping to maintain the bay's water quality. Morro Bay is also home to a vibrant coastal community, where residents and visitors kayak, fish, hike, birdwatch and enjoy nature on its unspoiled beaches.

However, like many areas, Morro Bay is experiencing significant environmental change. Historical sedimentation and loss of vital eelgrass, combined with other factors, are impacting the landscape and creating a perfect storm that could forever alter the estuary's unique ecosystem. To better understand how the environment is changing and to gain insights into mitigation strategies, the Morro Bay NEP, NOAA OCM and NV5 Geospatial and its partners have joined forces. The first step is to create a comprehensive map of the bay area terrain – both above and below the water, with the goal to develop a topographic and bathymetric elevation model using state-of-the-art technology.

COMBINING LIDAR AND SONAR

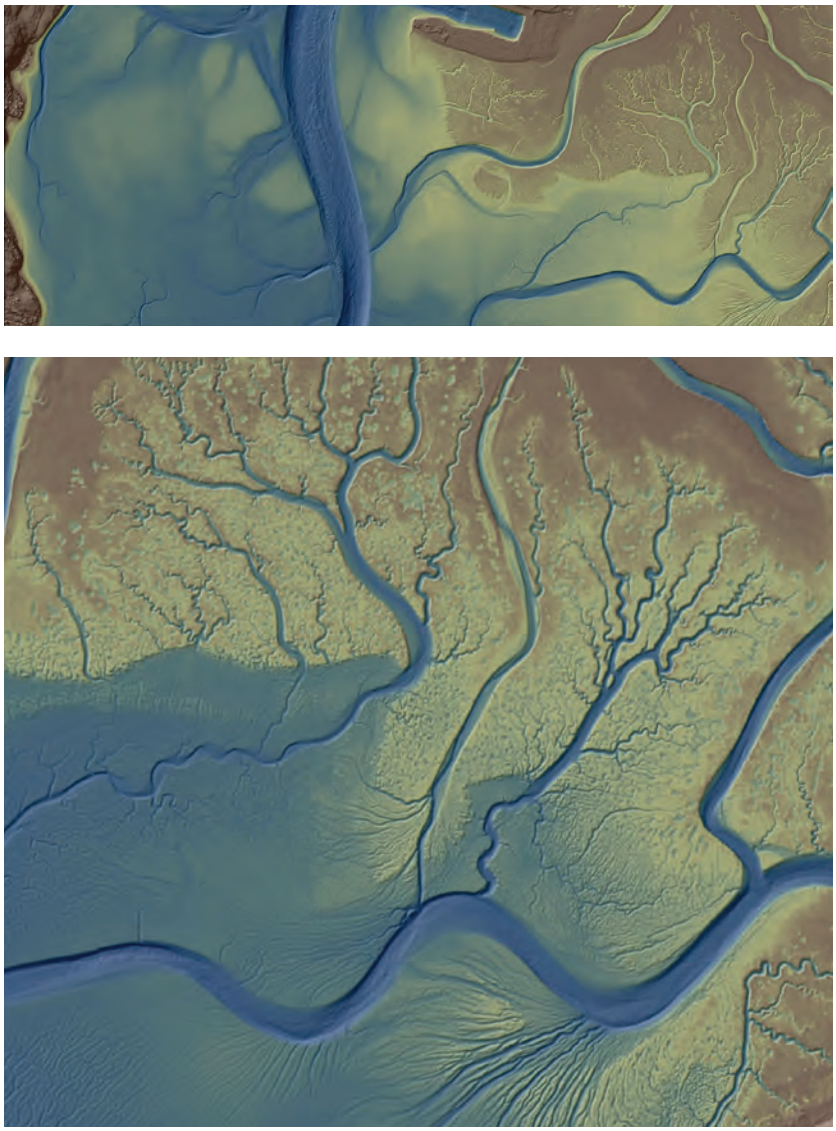
Comprising approximately 2,300 acres (9.3km^2) of shallow, semi-enclosed intertidal and subtidal habitat, the Morro Bay estuary is bordered to the west by a four-mile vegetated natural sandspit that separates Morro Bay from the Pacific Ocean. The Morro Bay watershed includes freshwater inflows delivered to the estuary via the Chorro Creek and Los Osos Creek sub-watersheds and through groundwater seepage in the Los Osos area. While areas around Chorro Creek are used in a variety of ways – from rangeland, a national forest and an ecological reserve to a National Guard Army base, the Los Osos sub-watershed also includes row crop agriculture and commercial greenhouse nurseries. Human activities in both could be impacting water quality within the Morro Bay watershed and estuary.

One of the biggest challenges faced in this area is the high volume of sediment change in the bay, which has been hastened by the loss of native eelgrass, which helps to stabilize sediments and maintain healthy oxygen levels in the water. The group wanted to examine the factors contributing to changes in the sediment movement or geomorphology. The result was a project using state-of-the-art aerial topobathymetric Lidar technology combined with vessel-based interferometric sidescan sonar and water level monitoring stations to characterize Morro Bay. The data could then help support coastal resource managers, watershed managers and other stakeholders in decision-making processes, including hydrodynamic modelling.

To start, the partners needed to understand tidal patterns and water clarity to determine the best time for data acquisition. After observing six-foot tide swings, they opted for low-tide data acquisition via an aeroplane equipped with a RIEGL 880-G2 Lidar sensor system for mapping shallow water bathymetry. The system, with a green wavelength laser that penetrates the water column, enabled them to map areas with water at depths of as much as 2.5 metres along the coasts and in marshy areas.

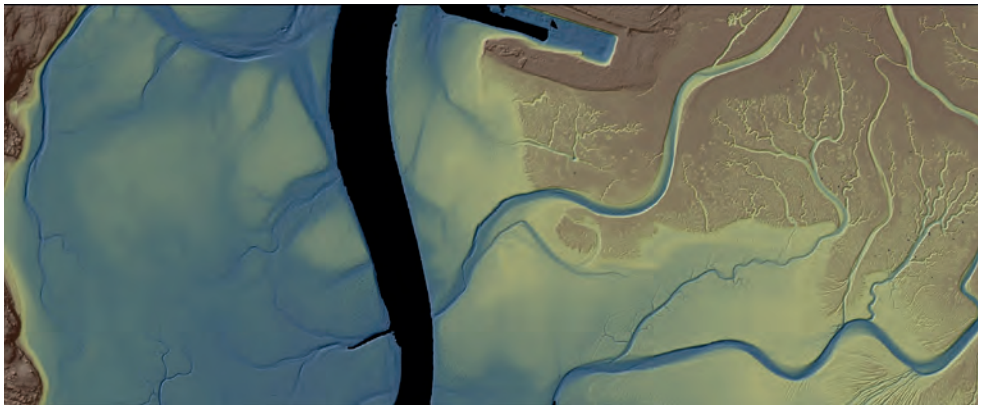
While the Lidar survey covered much of the coastline and shallow areas, there was still an area in the middle of the bay that was too deep for laser detection and was therefore left unmapped. To complete the picture, interferometric sidescan sonar technology was used over an area of more than 352 acres (1.4km^2).

Despite challenges posed by naturally moving sand, maintenance dredging activities and areas of thick healthy eelgrass that were hard to penetrate with Lidar and sonar, the project showcased the strength of these complementary technologies. The combination of Lidar and sonar enabled the partners to create a high-resolution seamless elevation model for the whole bay, depicting both land and sea.



▲ *Fully integrated bathymetric elevation model for Morro Bay (Lidar combined with sonar).*

The resulting integrated elevation model of Morro Bay offers a detailed look at the geography. The data collected exceeds the vertical accuracy of Quality Level 2b (~30cm) specified in the NOAA National Coastal Mapping Strategy 1.0, Coastal Lidar Elevation for a 3D Nation. The topographic Lidar achieved less than 5cm vertical accuracy at the 95% confidence level and bathymetric Lidar achieved 10cm accuracy (95% confidence level) against shallow water survey checkpoints. Additionally, the bathymetric Lidar was able to cover the nearshore gaps that are traditionally left unmapped by sonar systems (due to shallow depths), as well as other shallow areas typical of estuarine environments and embayments.



▲ *Topobathymetric Lidar coverage for Morro Bay – black area indicates where sonar data is necessary to complete the bathymetric elevation model.*

UNEARTHING VALUABLE INSIGHTS FOR REVITALIZATION EFFORTS

The data collected across Morro Bay offers valuable scientific insights into geomorphic changes in the area. With the 2019 topobathymetric elevation model serving as a baseline, a variety of stakeholders have been able to leverage the survey data to help understand sediment transport, aid restoration efforts, make changes to improve water quality and generally support improvements in coastal resilience.

Perhaps one of the most prominent research projects to leverage the survey data is that concerning the study and reintroduction of the eelgrass habitat in Morro Bay. Loss of seagrass is a significant issue worldwide, with climate change adversely impacting its habitats. Morro Bay has had a long history of healthy eelgrass growth, but 2007 marked the start of a massive decline, with eelgrass beds decreasing from 350 acres (1.4km^2) to just 15 acres (0.06km^2) in only five years – more than a 95% decline.

This dramatic change is a major concern since eelgrass serves many functions in the environment, including being a direct food source for the migratory black brant goose. Through photosynthesis, eelgrass provides oxygen in the water, and its roots hold the bay sediment in place, improving water clarity and preventing erosion. The plant's floating structures also dampen wave action, keeping the water clearer to let light in, and serve as a canopy beneath which wildlife can remain safe from predators.

Researchers at California Polytechnic State University-San Luis Obispo and their partners identified a relationship between the bay's eelgrass collapse and widespread erosion. Their study showed that places that lost eelgrass during the major decline experienced substantial erosion, while places that maintained eelgrass did not. This followed up on an earlier study that showed that the water quality conditions where eelgrass died out – mostly in the southern and back part of the bay – were defined by higher temperatures and salinity, lower oxygen levels and higher turbidity, limiting light penetration. These areas also experienced limited flushing, with water being trapped for longer than in areas where eelgrass remained healthy. However, at the mouth of the bay where there was strong oceanic tidal influence, waters were cooler, clearer and more oxygenated, which are conditions conducive to eelgrass health.

Leveraging findings from the Cal Poly study and the combination of Lidar and sonar data collected during elevation modelling, the Morro Bay NEP has been able to pinpoint sites that offer optimal depths and other conditions where they are currently conducting eelgrass restoration efforts. Additionally, data collected by ongoing water quality monitoring stations in the bay (such as the work conducted by the Central and Northern California Ocean Observing System) provides continued information about factors such as the bay's hydrodynamics, sedimentation and water quality, which influence resilience and habitat conditions.

These studies of the topobathymetric data and water levels have helped researchers to successfully restore eelgrass beds, inform bay area adaptation strategies, and serve as a prototype that could influence global seagrass conservation strategies. However, the geographic data and elevation modelling may ultimately have an even greater impact. The data collection approach in Morro Bay could serve as a model for others to better understand factors that impact coastal resilience and provide the insights necessary to foster a healthy natural ecosystem and ensure that our coastlines, estuaries and bays remain national treasures. ◀

Steve Raber is senior programme manager for NV5 Geospatial, where he is responsible for business development within the federal-civil government sector and the management of several large contracts, from his office in Colorado Springs, Colorado. Steve's broad geospatial background includes employment with both the federal government and private industry, emphasizing the use of remote sensing and GIS in natural resource management applications.

Ann Kitajima has been with the Morro Bay NEP for 20 years, serving first as the monitoring programme manager and more recently as assistant director. She manages programme grants and develops monitoring strategy. She holds a Master's degree in Environmental Engineering from University of California, Irvine and has a nearly 30-year career in the environmental non-profit and consulting fields.

Carolyn Geraghty is the restoration programme manager for the Morro Bay NEP, where she develops and oversees watershed and estuarine restoration projects and conservation efforts. She has a Master's degree in Environmental Planning from UC Berkeley focusing on watershed science and a BSc in Biology and Environmental Studies, and has been working in the environmental field for over 15 years.

A Visit to the iXblue 2022 Users Conference

The Promise of Autonomous Marine Operations

The transition to autonomous marine operations is a promising process that is in full swing, and the advantages of carrying out hydrographic or oceanographic tasks autonomously weigh heavily against traditional methods. Global climate change and carbon footprint reduction triggered the development of the autonomous technologies, and the transition towards them continues to help deal with these global challenges. However, the process towards the increased use of these new technologies also needs to be supported both business-wise and policy-wise, as all too often surveying companies find the business case hard to make, even though the pros are quite clear. Regulations also need to be put in place to avoid a Wild West hunt to the bottom of the ocean.

▲ *The iXcampus in Saint-Germain-en-Laye, Ile-de-France, houses the headquarters of the iXblue company.*

At the iXblue Users Conference, hosted at the iXcampus in Saint-Germain-en-Laye, Ile-de-France, France on 23 June 2022, many of these pros were highlighted by the speakers of the day. They included Dr Mathias Jonas, Secretary-General of the International Hydrographic Organization (IHO), Rear Admiral (ret) Tim Gallaudet of Ocean STL Consulting, Dr Anna Lim from Argeo and Hendrik de Beuf from DEME, and many more. This well-organized conference shed light on the future of autonomous operations in which iXblue's Drix USV is playing a leading role.

INFLUENCING THE AGENDA

The conference was opened by Dr Mathias Jonas. In his opening address, Jonas acknowledged that autonomous technology is heavily influencing the agenda of the IHO. Not only does the transition to autonomous marine operations make it possible to generate more renewable energy, for example by making it easier to monitor offshore wind farms, but it is also improving safety at sea. For instance, the use of uncrewed vessels removes the need to send crews out to dangerous places. Another advantage, and a growing market for autonomous surveying in any form, is a sustainable food supply. Aquafarming, for instance, is growing fast, already providing half of the fish consumed in the world. This means that less of a drain is being made on natural resources, leading to a better climate. Furthermore, wherever there is pollution, and everybody knows there is a lot, autonomous monitoring is being called into play, with the measurement of microplastics in the water column serving as a striking example.

All of the above are examples of improving things that we do already. With autonomous technologies, operators can get to remote places more easily or speed up the work that needs to be done without putting crews in harm's way. However, it was the things we are not yet doing, the glimpses into the future, that made delegates at the iXblue Users Conference sit up in their seats. After all, possible solutions to the crisis that the world is now in always appeal to an audience whose green hearts beat for the blue world.

SOLUTION

The Norwegian company Argeo is continuously increasing efficiency and data quality, while at the same time reducing CO_2 emissions from operations involving infrastructure, offshore wind, oil & gas and deep-sea minerals. Dr Anna Lim from Argeo addressed the subject of deep-sea minerals.

In 2023, the International Seabed Authority will decide on the rules, regulations and procedures to guide the exploitation of deep-sea minerals in waters outside the EEZ. Expectations are high, as many minerals and rare metals are now being appropriated by the global economy in large and unsustainable quantities. This is simply because they are in devices that almost everybody uses every day, such as lithium in batteries and phones and even rarer minerals that are used in the same devices in smaller quantities. These come from places on Earth that are hard to reach, which often puts a strain on geopolitical relationships. While deep-sea mining is not allowed at present, deep-sea minerals could make for an alternative source of critical metals.

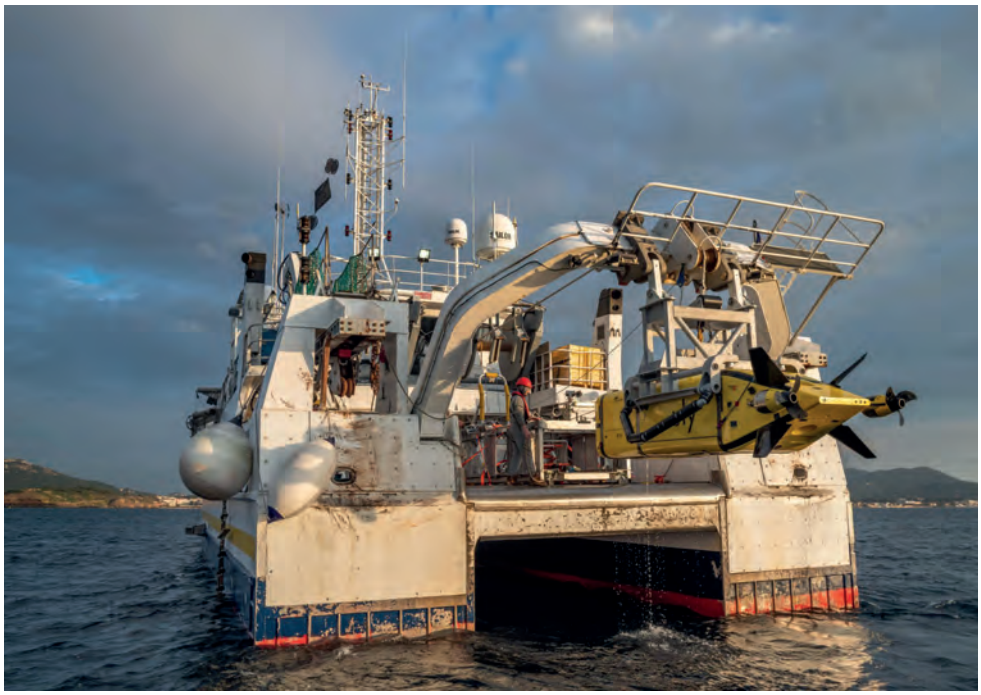
Scientists have high expectations of the seafloor massive sulphides, polymetallic nodules and crusts that are found along mid-ocean ridges, on volcanic seamounts or in the abyssal plains of the world's oceans. Harvesting these

▲ *Presentation at the iXblue Users Conference 2022 on the renewal of the French hydrographic and oceanographic fleet (CHOF).*

deep-sea minerals, which contain critical metals such as manganese, cobalt and nickel, could solve the exhausting and devastating hunt for the same metals and minerals on land. However, this is no easy task, as most of them are found at great depths of more than five to six kilometres. Furthermore, to find them we still have to survey millions of square kilometres of seabed to be able to harvest as efficiently and sustainably as possible. This is where AUVs come in, as they provide an efficient way to cover large seafloor areas with the highest possible resolution multiphysics data, meaning that they are best suited to carrying out the mineral exploitation and mapping surveys.

According to Dr Lim, it is important to base future decisions on factual knowledge that in turn relies on data from exploration surveys. The key principle for any deep-ocean exploration survey can be formulated as multi-dimensional data-driven efficiency, where each survey must provide relevant data of high quality at an optimal areal coverage rate, and with a minimum impact on the environment. Such a systematic approach will rely heavily on autonomous underwater technology.

Hendrik de Beuf, chief surveyor with DEME, a Belgian company specialized in dredging, marine engineering and environmental remediation, took up where Dr Anna Lim left off. DEME clearly intends to combat the global threats of a rising sea level, growing world population and increased scarcity of natural resources. According to the DEME vision, the search for minerals needs to be carried out as cleanly and sustainably as possible. In one area assigned for exploration, DEME has already tested the harvesting of nodules using an autonomous underwater vehicle, and with promising results. It goes without saying that DEME is eagerly awaiting updated policy in this new field.



▲ *Ifremer, the French Research Institute for Ocean Science, has equipped its Ulyx AUV with a synthetic aperture sonar from iXblue.*

HURDLES

However promising this all may sound, there are still some hurdles to be overcome before the field can make full use of the advantages of autonomous marine operations. A few of these are technological by nature of course, but I'll leave those to the technicians at fine companies like iXblue, where many engineers are working hard to develop autonomous marine operations into a mature industry. Here, I would like to focus on policy and business.

The first hurdle to overcome concerns regulations. To avoid the autonomous realm of the oceans becoming a Wild West for deep-sea mining and renewable energy, we need to agree on regulations that address issues such as safety, privacy and exploration rights, especially in areas outside the EEZ. Rear Admiral Tim Gallaudet, who headed up NOAA before his retirement, warned the audience at the iXblue Users Conference of situations where there are no rules and where people do whatever they can to get to the bottom as quickly as possible, using means that have not been designed to meet criteria for clean energy, sustainability and efficiency. Gallaudet advocates more regulation, for example in partnership with the American federal government.

Another challenge that needs to be overcome in the near future is that of the gap between the workforce and the deployment and use of autonomous and uncrewed vehicles. At the moment, the workforce has not been sufficiently trained and there is insufficient capacity to bridge the gap quickly, with the result that we cannot make optimal use of autonomous technology. This point needs to be considered by naval and maritime colleges as well as educators from the private sector.

The last point is the business case for autonomous surveying. The margin between revenue and costs, interest and depreciation is often still very thin. For rental companies, upfront investments are so high that any downtime, whether when carrying out a surveying job at sea or simply in the harbour, is too much. More work in the future will not be the problem, so an AUV or USV left on the ship or on the quay will probably occur less and less frequently. Another part of the solution, besides the full-time deployment of the vehicles, is a good and decent price. Too often, governments contract out work at the lowest price. Governments at all levels are still the biggest clients in many of the projects that involve AUVs and USVs, and they should take the lead in setting an example in doing business. If sustainability is an argument for deploying new technology, it should also be an argument for hiring surveying companies!

The iXblue Users Conference in Saint-Germain-en-Laye shed light on the future of autonomous maritime operations. iXblue brought together a crowd of enthusiastic and passionate 'tech for a better blue environment' believers who work both for iXblue and their clients from all over the globe with a bunch of high-level influencers, in a beautiful environment. While it is of course impossible to cover all the presentations in this report, keep track of *Hydro International* and we'll keep you up to date. The main takeaway for now is that, although some hurdles still need to be overcome, technical, business-wise and policy-wise, the future of autonomous maritime operations is bright and promising! ◀

Discovered by Tiger Sharks, Validated by Technology

How Airborne Bathymetric Lidar Helps to Protect Marine Environments

Hexagon is working with Beneath The Waves, a conservation NGO, to help protect marine environments in the Bahamas. Using bathymetric airborne Lidar solutions, researchers are able to map, study and quantify the region's endangered seagrass ecosystem. This process can determine the extent, composition and condition volume of seagrass, allowing the team of researchers to plan conservation of the ecosystem as a 'blue carbon' habitat. This project will potentially launch one of the world's most impactful nature-based mitigation efforts while protecting biodiversity in the Caribbean islands.

R-evolution, Hexagon's sustainability business venture, is leading the way in accelerating the transition to a sustainable global economy by identifying and attracting capital to finance business opportunities that benefit the environment and society. For one project, R-evolution takes advantage of cutting-edge airborne bathymetric solutions from Leica Geosystems, part of Hexagon, to promote decarbonization, the protection of coastal ecosystems and the preservation of biodiversity.

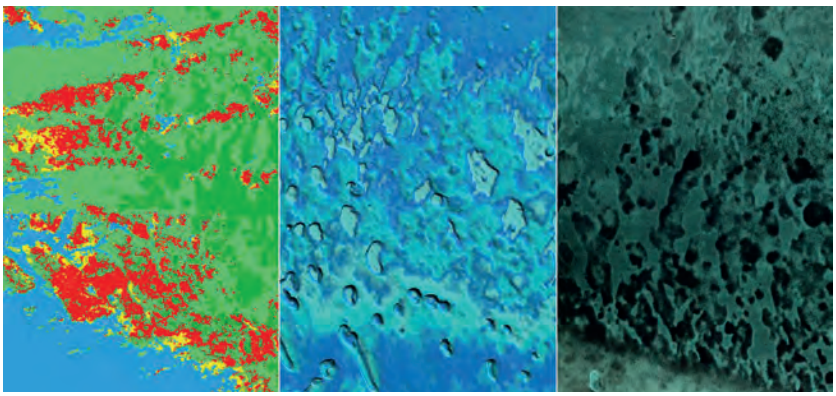
The world has seen an exponential increase in carbon emissions, resulting in drastic changes to the climate and threatening life on Earth. Carbon sinks are one powerful resource nature has at its disposal for keeping carbon dioxide levels at bay. For too long, however, the carbon discussion has centred around land-based carbon sinks, such as forests, while neglecting the biggest and most global storage depot on Earth: the ocean.

BLUE CARBON HABITATS

'Blue carbon' ecosystems refer to coastal and marine vegetated habitats – such as seagrass meadows, salt marshes and mangrove forests – that sequester and store carbon from the atmosphere and ocean. Seagrass, in particular, captures carbon dioxide more efficiently than land-based forests do. Moreover, since most carbon is stored in soil and sediments, it can remain there for millennia if left undisturbed. Nevertheless, despite their crucial role in mitigating climate change, seagrass meadows remain among the least recognized and least protected ecological habitats. The lack of data on the distribution of seagrass meadows poses a significant obstacle to conservation and restoration efforts.

SHARK STUDY REVEALS UNEXPECTED INSIGHTS

In the Bahamas, home to a large seagrass ecosystem and also a designated shark sanctuary, scientists were studying sharks' movements on behalf of the conservation NGO called Beneath The Waves. Their research unexpectedly revealed that tiger



▲ *Airborne survey results including radiometric normalized sea-bed image (left), sea-bed digital elevation model (middle) and machine learning generated sea-bed classification raster (right).*

▲ *Leica Chiroptera-5 bathymetric Lidar system.*

▲ *R-evolution and Beneath The Waves management in front of survey aircraft.*

▲ *Seabed sediment coring for analysis of carbon content.*

sharks spend a large portion of their life patrolling and foraging dense seagrass meadows. Using this insight, the organization leveraged a combination of sensor-tagged sharks, satellite data, marine vessel surveys and scuba divers to further investigate and map the extensive seagrass meadows of the Caribbean. This mapping project was an essential first step in learning more about the little-known ocean habitat. However, to protect and restore the blue carbon sinks, the conservancy's findings needed to be validated with high-positional accuracy and datasets that can provide efficient, year-on-year change detection and monitoring.

Mapping large areas with vessels, divers and sharks is such a long and resource-heavy process that it is not an option for large-scale projects. To map, study and quantify the threatened seagrass meadows of the Caribbean islands at scale, Beneath The Waves teamed up with R-evolution. This sustainability business venture leverages airborne bathymetric Lidar technologies from Leica Geosystems, part of Hexagon, to capture details about the vital habitat, including its extent and composition. Bathymetric surveying supports environmental monitoring by mapping and classifying submerged vegetation and habitat to assess aquacultures and study marine ecology and hydrodynamics.

THE BENEFITS OF AIRBORNE SURVEYS

Airborne surveys could improve the efficiency, resolution and accuracy of the mapping process, covering the same area in just a few days and thus offering a more time-efficient and cost-effective solution. Because it is easily repeatable, it also forms an excellent basis for year-on-year change detection and monitoring. In addition, Lidar point clouds provide 3D elevation and land classification information with higher positional accuracy and spatial resolutions compared to the data quality generated with, for example, satellite imagery. Airborne bathymetry systems are optimized for shallow-water data collection, so they are ideal for mapping seagrass which grows primarily in water depths of 30 metres or less.

Collecting high-quality bathymetric data with the Leica Chiroptera airborne Lidar sensor was routine for the team at Hexagon, but it was key to leverage that data to generate the insights required for this project. A development team had been researching ways to automate the processing of the acquired data. Apart from the bathymetric data the sensor collects, the initial project team had other sources of information on hand: researchers on the vessel gathered luminosity data, the divers could provide information about the seabed such as the type of vegetation and collect coring samples, and the sharks that had been equipped with cameras provided additional photo imagery.

LOSS COMPENSATION AND NORMALIZATION

After the data capture, the bathymetric Lidar full-waveform information fused with image radiometric information from the Chiroptera sensor systems was compensated for losses in the atmosphere, water surface and water volume and thereafter normalized with the measured depth. The result was a high-resolution, consistent seabed dataset that included both radiometric and spatial information of the vegetation. By feeding this data into deep-learning artificial intelligence (AI) classification algorithms, the team were able to identify different seabed types, vegetation species and density. The sediment core samples provided information about the amount of carbon each vegetation type stores. By combining this information, they could map the carbon captured by the seabed automatically and at scale.
In December 2021, the team used the Chiroptera 4X to map the area. Leica Geosystems has since introduced the high-performance airborne sensor Leica Chiroptera-5, which offers a 40% higher point density, a 20% increase in water depth penetration and improved topographic sensitivity compared to previous generations so that future surveys of this and other regions will generate even more detailed hydrographic maps at even faster speed.

The preliminary results look very promising, and the team hopes that the accuracy and resolution of the bathymetric Lidar will provide an invaluable new data source for seabed carbon mapping. Combining the marine expertise of Beneath The Waves with the innovation and technological know-how of Hexagon, the collaborative project expects to yield groundbreaking results for blue carbon conservation and to potentially launch one of the world's most impactful nature-based mitigation efforts. This offers an opportunity to protect biodiversity in the marine habitats of the Caribbean islands and generate new value streams simultaneously. ◀

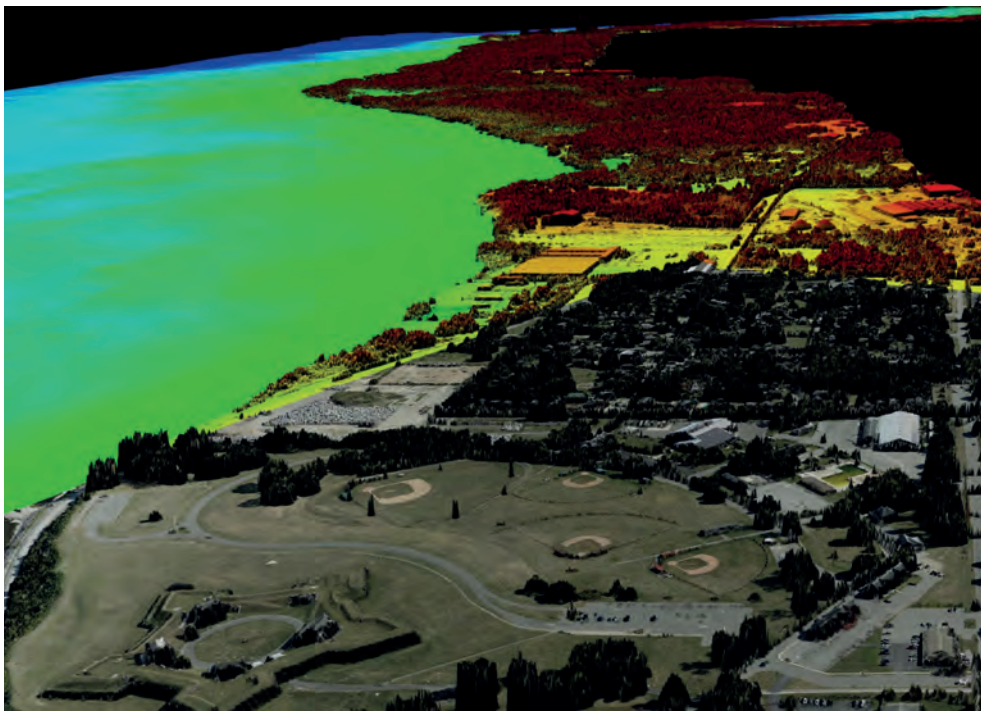
A Bathymetric Lidar Programme Can Cost Less per Square Kilometre than Acoustic Methods – Provided You Think Big Enough

Think Big for Coastal Mapping

▲ *CZMIL Supernova installed in a Cessna 208B Caravan aircraft.*

Think big for coastal mapping" is the foremost advice that Don Ventura of Teledyne Geospatial would impress upon agencies interested in bathymetric Lidar. "It's a matter of efficiency of scale. Airborne bathymetric Lidar can actually be more efficient and cost less per square kilometre than acoustic methods in nearshore, optically-suitable waters. Data collection with airborne bathymetric Lidar is 20-30 times faster than with a survey vessel using acoustic technologies. It is not unreasonable to expect to survey 50-100 square kilometres per day, whereas covering a similar area by boat could take considerably longer.

Another advantage of thinking big is added flexibility: surveyors can adjust operations to current environmental conditions, especially with a much faster aircraft platform. If local conditions prove unsuitable, and with all survey plans loaded into the system, it's possible to switch to another area entirely, which might be a couple of hundred kilometres away. This dramatically increases the likelihood of coming back with a dataset you can use every time you take off.



▲ *Composite oblique imagery illustrating seamless topo-bathy Lidar and imagery data from the CZMIL Supernova system.*

CZMIL SUPERNOVA: A NEXT-GENERATION BATHYMETRIC LIDAR SYSTEM

Teledyne Geospatial is a pacesetter in hardware and data processing software for airborne bathymetric Lidar. In June 2021, it launched its ground-breaking CZMIL Supernova system, or Coastal Zone Mapping and Imaging Lidar. The CZMIL Supernova is ideally suited for a number of different environments such as open coastlines, complex nearshore bathymetry and topography, offshore reefs of various descriptions and other shallow-water aquatic environments including inland waterways. With the most powerful green laser available on the commercial market, it offers maximal depth penetration (4.4 / Kd for the 'deep channel' receiver and 2.9 /Kd for the 'shallow channel' receivers). According to Ventura, one substantial benefit of such a powerful bathymetric Lidar system is how much more reliable the system performs in less-than-optimal conditions. "People are now understanding the value of having a system capable of not only greater depth penetration compared to other systems on the market but also the ability to combat turbidity in waters where it would otherwise prove difficult to obtain consistent survey coverage using other topo-bathy Lidars", says Ventura.

Next to superior coverage in turbid waters, the CZMIL Supernova has up to three times the point density of its predecessor. Its full waveform capture of land and water opens the door to other uses of the data beyond elevation and depth, such as object detection, water clarity assessments, reflectance imagery of the sea or lakebed, orthomosaics, DEMs/DTMs, etc. This means that once the cartographers have satisfied their requirements, a range of other marine users can also benefit from the Lidar data.

EXPANDING APPLICATIONS OF TOPO-BATHY LIDAR

"Through experience and wider stakeholder outreach, more opportunities are appearing", says Ventura. "The market is still relatively young because many agencies that typically aren't mapping as their principal activity could still benefit from access to bathy Lidar data." Their main responsibility might be coastal zone management or resiliency, for example. Key phrases you hear today – protecting and understanding the environment, change detection, sea level rise, flood inundation modelling – all require shallow water data and details on the land-sea interface.

Many national hydrographic agencies are now incorporating specific passages about bathymetric Lidar in their tenders, according to Ventura. "We're seeing the inboard edge of the area of interest being drawn on land because they know the systems can collect topographic as well as bathymetric data. That's something we are keen to encourage.

Ventura also notes that the industry in the past has been guilty of not promoting the base products that can be generated from a survey other than the point cloud. "With topo-bathy Lidar, you also have full waveform returns from the seabed. That means, similar to multibeam backscatter or sidescan interferometry, you can generate reflectance imagery and identify the nature and form of the seabed as it changes." From

CZMIL SUPERNOVA
Technical Specifications

GENERAL SPECIFICATIONS	
Operating altitude	400 meters to 800 meters AGL
Aircraft speed	120 - 140 kts
Digital cameras	Phase One iXM-RS150F
Positioning & GPS/GNSS	Applanix POS AV™ 610 with PPRTX subscription
LIDAR HYDROGRAPHIC MODE	
Shallow channels measurement rate	Up to 210,000 Hz
Shallow channels maximum depth	$2.9/K_d$ (bottom reflectivity ≥ 15%)
Shallow channel depth accuracy*	$\sqrt{(0.25^2+(0.0075d)^2}$ m, 2σ
Shallow channel horizontal accuracy*	(0.40 + 0.075d) m, 2σ
Deep channel measurement rate	Up to 30,000 Hz
Deep channel maximum depth	$4.4/K_d$ (bottom reflectivity ≥ 15%)
Deep channel depth accuracy*	$\sqrt{(0.3^2+(0.013d)^2}$ m, 2σ
Deep channel horizontal accuracy*	(2.0 + 0.075d) m, 2σ
Scan angle	20° circular
Swath width	72% of operating altitude (291 m at 400 m AGL)
Laser classification	Class 4 laser product: IEC 60825-1 Ed. 3.0 2014
LIDAR TOPOGRAPHIC MODE	
Measurement rate	Up to 240,000 Hz
Horizontal accuracy	±0.40 m, 2σ
Vertical accuracy	±10 cm, 2σ
PHYSICAL	
Power requirements	85 A for Lidar/camera @ 28 VDC
Operating temperature	0°C to 40°C
Storage temperature	-20°C to +60°C
Humidity	0-95% non-condensing
Sensor head	89 W x 60 D x 90 H cm; 164 kg (361 lbs)
Control & operations rack	59 W x 56.5 D x 106 H cm; 106 kg (234 lbs)

* Data accuracy specifications are for data acquired at 400 m AGL.

In the above table, d is the depth in meters and K_d (m^{-1}) is the water diffuse attenuation coefficient (a measure of water turbidity). Maximum depth specification is valid for K_d in the interval 0.08 – 0.4 m^{-1}.

▲ *General specifications of CZMIL Supernova.*

there, Ventura says, you can ground-truth the generated imagery and then create seabed classification maps and such.

CZMIL Supernova incorporates a high-resolution PhaseOne camera that can be used for Lidar data QA and creating mosaic imagery. So, in addition to the Lidar data, these systems provide excellent RGB and sometimes multispectral imagery for the survey area. "It's all done at the same time, georectified, orthorectified, and at centimetric resolution." CZMIL Supernova's optional hyperspectral camera, the ITRES CASI 1500, allows the surveyor to also collect hyperspectral imagery in the survey area.

INDUSTRY FORERUNNERS

One company with a head start in the use of the CZMIL Supernova is Terratec, a leading Norwegian mapping company. Terratec was the first private service provider to acquire the CZMIL Supernova. It has deployed the system on a range of projects, including marine coastal zone base maps and mapping Scandinavia's arctic lakes. In 2022, they added surveys around the Baltic region and Eire's west coast and continue to explore other international opportunities.

In July 2022, Terratec mobilized the CZMIL Supernova in Catalonia, Spain, to survey approximately 300 square km of the Mediterranean coast. The aim is to update the coastline to get a better indication of local changes and sea level rise. As is often the case, there is a need to fill the existing data gap between where traditional hydrographic surveying ends and terrestrial mapping begins. Topo-bathy Lidar is an ideal tool for this. Other regions where topo-bathy Lidar has or is being utilized, with new projects expected, include the Caribbean, Pacific island and archipelagic states, Middle East region (especially the Red Sea area), South America, Australasia, and other Mediterranean countries.

FLEXIBILITY TO OVERCOME ENVIRONMENTAL CHALLENGES

Each different environment brings particular challenges and opportunities, impacting the feasibility and planning of bathymetric Lidar work. Tidal and water turbidity variations are major factors that planners can play with to their advantage. To maximize the coverage of bathymetric Lidar, surveyors can use tactics such as leveraging big tidal ranges and conducting surveys at low water or, conversely, following a period of neap tides when there tends to be less sediment transport.

"We have new clients using their systems in different environments: freshwater lakes in Sweden, inland waterways in Florida, the open-ocean west coast of Ireland, and now also in the Mediterranean", says Ventura. This is in addition to other well-established programmes in Australia, the United States and Canada. "We always go on about the depth capability of these systems, but really, the focus today is very much on the coastline. I see Lidar as another tool in the box: it is an augmentation to the arsenal of tools available to the modern hydrographic surveyor and something that should be contemplated, especially for surveys where some of the areas are traditionally difficult'. That might mean they are hazardous for manned vessels, very shallow, or very dynamic tidally, where you're restricted a lot of the time by literally the amount of water that you've got."

A major focus is to tie the bathymetric data with changes on land and in the nearshore area. Topo-bathy Lidar can give surveyors that seamless join that has long eluded geographers. "It's a zipper between the two big datasets, the hydro and the topo", says Ventura. ◀

ABOUT

Teledyne Geospatial is part of **Teledyne Imaging**, a group of leading-edge technology companies united under the Teledyne umbrella. Teledyne Geospatial is made up of **Teledyne Optech** and **Teledyne Caris**. Don Ventura is the product manager for bathymetric Lidar.

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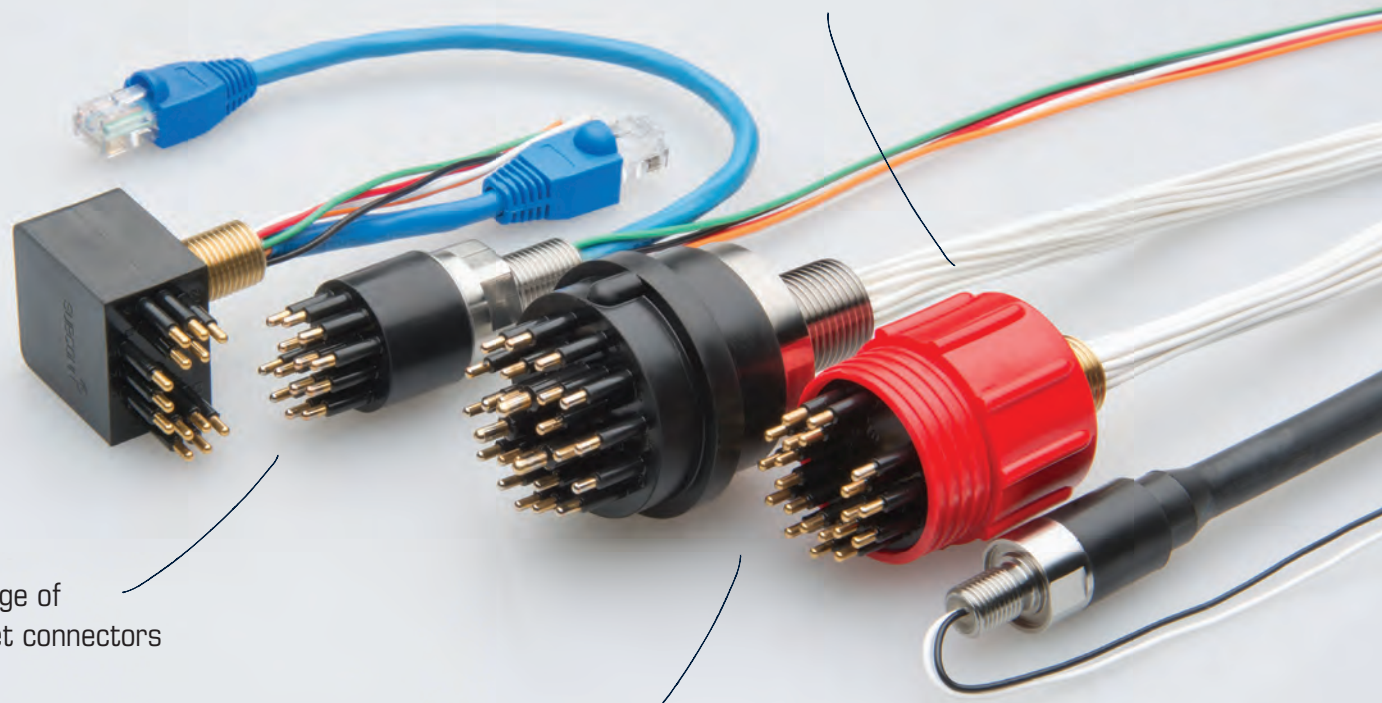

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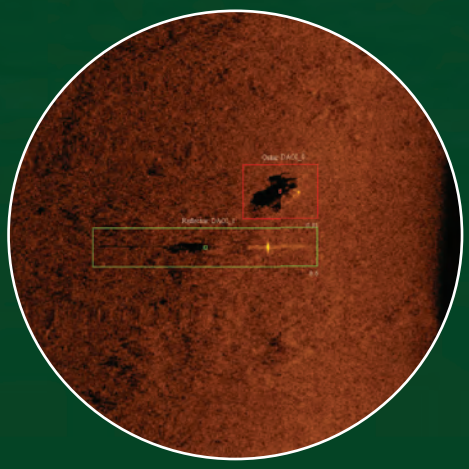

OBJECT RECOGNITION

- objects of interest are detected and highlighted live during the mission
- AI-based system as an extra module that runs directly onboard the vehicle and analyses raw data

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