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The subsea forests of the Mediterranean

The Digital Tool That Streamlines Hydrographic Information

Mapping in Paradise

Hydro INTERNATIONAL

Hydro International is an independent international magazine published 6 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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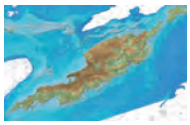

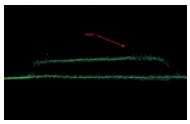

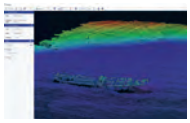

Front cover

The cover photo is a winning submission from Teledyne Marine's annual photo contest. This image shows a Workhorse Long Ranger ADCP being deployed to collect ocean current information. (Courtesy: Jarred Voorneveld, SAEON-South African Environmental Observation Network.)

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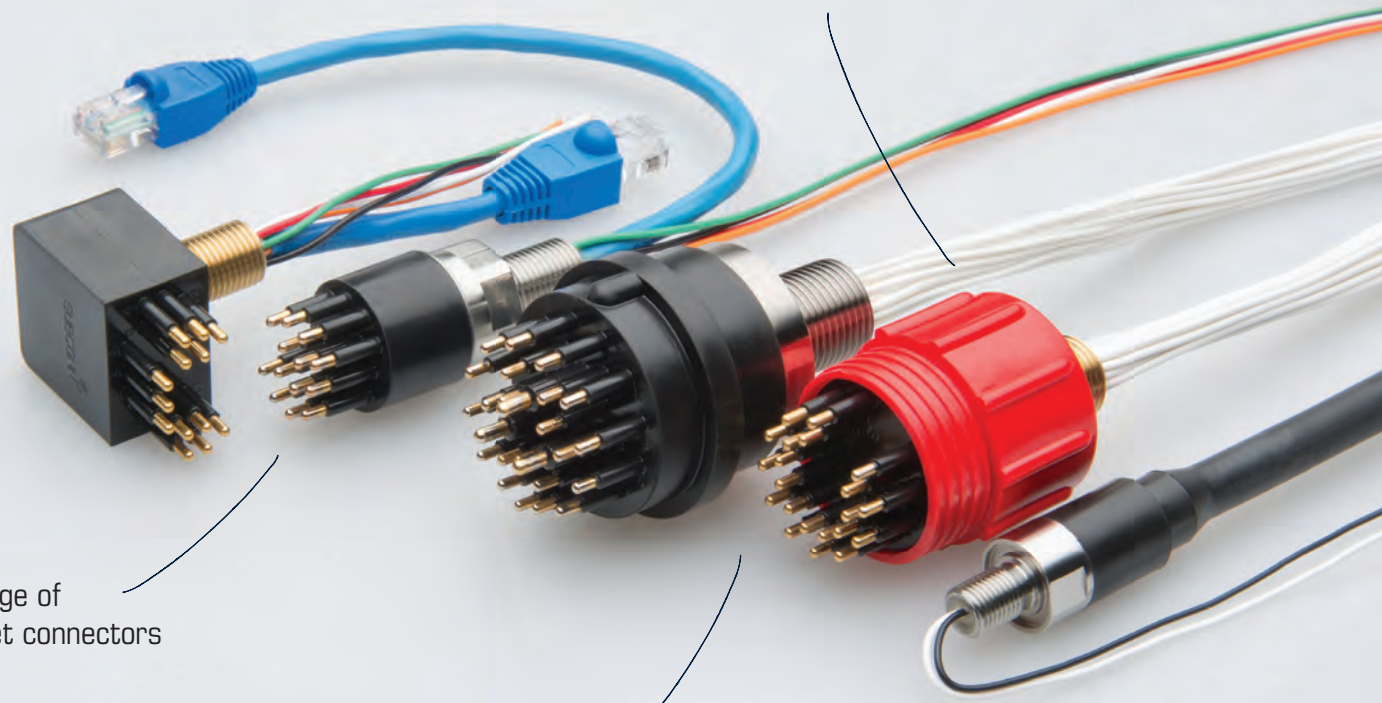

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Grand mapping coalition

▲ *Durk Haarsma.*

The need to build a grand coalition of mapping partners all over the world, from all corners and professions of the maritime community, is more urgent now than ever. During a one-day symposium - From Vision to Action hosted by the Nippon Foundation-GEBCO Seabed 2030 Project Seabed, held in London on 22 October - it was once again emphasised that the creation of a definitive global ocean floor map by 2030 would support the sustainable use of the ocean and lead to sound policy decisions regarding the seas and their coasts.

During the symposium, three new initiatives were revealed. It was announced that the project will provide vessels around the world with data-gathering equipment to enable all of them to contribute to Seabed 2030. This involves vessels that are active in the fishing, cargo and tourist industries. The project will also schedule and fund additional mapping days, extending missions in remote areas to make them even more efficient and, wherever needed, will provide multibeam echosounders to increase mapping capabilities.

Last but not least, Seabed 2030 will foster the development of innovative, scalable new solutions to increase the efficiency, safety, and cost-effectiveness of deep-sea mapping, paving the way for public participation on the largest possible scale to meet the project's goals. In this issue of Hydro International, you will find feature articles about mapping in remote areas and those closer by, in warm and cold waters, in paradise-like seas and seas which are far from paradise: readers and authors of Hydro International are often at the forefront of mapping and surveying activities, no matter where.

Rear Admiral Shepard Smith, Director of Coast Survey, National Oceanic and Atmospheric Administration (NOAA), stated in a keynote speech in London that there is no time to waste because findings in the ocean may help to solve problems in many fields, some that may not even occur to us. Smith referred to the possibility of finding new species that could help to cure illnesses, for example. He also pointed out that the discovery of ways to undo the effects of climate change or the possibilities of providing new forms of energy are examples that demonstrate the relevancy of the Seabed 2030 project and indeed the need to keep on building that grand coalition!

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So Much We Don't Know

Some weeks ago, I was in southern Portugal where I visited Cabo São Vicente, a headland in the Algarve and also the south-westernmost point of Portugal and of mainland Europe. There is a lighthouse, a restaurant and a shop where you can buy a souvenir to remind you of your visit to this remarkable point on the rocks, high above the waves of the Atlantic Ocean.

▲ *Cees van Dijk.*

While I was standing there, I looked at the horizon and thought about the seafarers in the old days who set sail, without knowing if they would ever return to their homes and families. Some of the crew members were even afraid they would fall off the Earth because they didn't believe it was round.

In Sagres, a few miles to the east, you can visit the remains of the castle of Henry the Navigator. This Portuguese prince, who lived from 1394 until 1460, was a central figure in the early days of the Portuguese Empire. In 15th-century Europe, he was the driving force behind maritime discoveries and expansion. Through his administrative direction, he is regarded as the main initiator of what came to be known as the Age of Discovery.

Henry is regarded as the patron of Portuguese exploration and he was responsible for its early development and that of maritime trade with other continents through the systematic discovery of Western Africa, the islands of the Atlantic Ocean, and the search for new shipping routes. Although Henry was the initiator of many expeditions, he didn't take part in any himself.

In those bygone days, seafarers explored many, until then unknown, coasts, and they saw people, animals, trees and landscapes they had never seen before. Now, more than five centuries later, a lot has changed for the modern explorer in the fields of safety and manoeuvrability of ships, the aids to navigation, the equipment used and the communication facilities.

In our present-day world, things are developing rapidly. Due to climate change and the melting ice, we are having to chart safe routes through Arctic waters, rising sea levels are changing coastlines and 70% of the world's oceans still need to be mapped.

I mused about all this while standing on the rocks, watching the sun disappearing behind the horizon, and listening to the roaring waves. More than five hundred years later, there is still so much we don't know.

Cees van Dijk, content manager
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A Shared Vision for Mapping the Ocean Floor

The Nippon Foundation-GEBCO Seabed 2030 Project has announced its new Director, Jamie McMichael-Phillips. Making the announcement, the Chairman of the GEBCO Guiding Committee, Vice Admiral Shin Tani, said the appointment would "propel the project into the final ten years." He also said McMichael-Phillips would be pivotal in helping the project achieve its ambition of mapping the entire ocean floor by the year 2030.

He described McMichael-Phillips as "a leader and hydrographer who had successfully made the transition from the rank of captain in Britain's Royal Navy to Head of Partnering and Engagement for the UK Hydrographic Office."

For the past five years, McMichael-Phillips had responsibility for the Asia Pacific region, based in Singapore. For nearly ten years, he has been the Chair of the Worldwide Electronic Navigational Chart Database Working Group of the International Hydrographic Organization. Shin Tani said "as an international negotiator and professional mariner, he has been involved in conflict management in one of the most difficult conflict areas in the world." He is also skilled in regional capacity building and securing valuable data that contribute to maritime economic enhancement. McMichael-Phillips will take up his responsibilities in December.

The announcement happened at the Seabed 2030 Project's Vision to Action Conference at the Royal Society, in London. The event was held to assess the progress made in the two years since the launch of the project. It brought together some of the world's leading ocean scientists and maritime organizations, including representatives from the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

Yohei Sasakawa, Chairman of the Nippon Foundation, announced several new initiatives for the project. These initiatives will focus on providing vessels around the world with data-gathering equipment – including data loggers to record bathymetric information. Seabed 2030 is a collaborative project between the Nippon Foundation, a private non-profit foundation with its headquarters in Japan, and GEBCO.

Speaking at the conference, McMichael-Phillips described the event as "an important event in the life of the project." He focused on the importance of the work of Seabed 2030, "the shape of the ocean is fundamental to how we predict climate change, tsunami modelling, ocean currents circulation, weather patterns and how we sustainably manage the oceans." He paid tribute to "the network of committed and candid people involved in the project, from generous patrons, stakeholders, eminent scientists, Nippon alumni, to philanthropists, industry and academia."

Mr McMichael-Phillips will direct an organization which is already actively gathering data from mapping initiatives around the world. The Seabed 2030 Project has divided the globe into four regions, each overseen by a regional centre. Each regional centre is feeding its data into a global centre hosted at the British Oceanographic Data Centre in Southampton, UK. In the short time that it has been operational, Seabed 2030 has already seen a doubling of the bathymetric data available – an increase equivalent to the landmass of the entire African continent.

Mr McMichael-Phillips and Vice Admiral Shin Tani.

About GEBCO
The General Bathymetric Chart of the Oceans (GEBCO) partners with the Nippon Foundation in the Seabed 2030 Project. GEBCO is a joint project of the IHO and the IOC of UNESCO – the United Nations Educational Scientific and Cultural Organization. It is the only intergovernmental organization with a mandate to map the entire ocean floor.

About The Nippon Foundation
The Nippon Foundation (founded in 1962) is a private, non-profit foundation that is jointly spearheading international efforts to map the entirety of the world's ocean floor by the end of the next decade. More than 100 organizations are now contributing to the goal of producing a complete map, which is vital to exploration.

Innovative Interceptor Tackles Plastic Garbage at its Source

Another initiative to tackle plastic garbage at its source was launched recently by The Ocean Cleanup. This Dutch non-profit organization, which is developing advanced technologies to rid the world's oceans of plastic, unveiled its invention to prevent the unrelenting flow of plastic pollution into the world's oceans. The Interceptor™, under development by the Ocean Cleanup since 2015, complements the organization's founding mission by attacking the flow of plastic garbage at its source, the world's vast network of rivers. The Ocean Cleanup aims to tackle the 1,000 most polluting rivers, responsible for about 80% of ocean plastic pollution, before the end of 2025.

The Interceptor is the first scalable solution to intercept river plastic pollution and can be deployed around the world. It is capable of extracting 50,000kg of trash per day – even reaching 100,000kg per day under optimised conditions. Four Interceptors have been built to date; two systems are already operational in Jakarta (Indonesia) and Klang (Malaysia). A third system is in Vietnam to be installed in Can Tho in the Mekong Delta, while the fourth is destined to be deployed in Santo Domingo (Dominican Republic). In addition to these locations, Thailand has signed up to deploy an Interceptor near Bangkok, and further agreements are nearing completion, including one in LA County (USA), kick-starting the scale-up.

As part of the Ocean Cleanup's research to map the problem, it was established that 1,000 of the world's 100,000 rivers (1%) are responsible for roughly 80% of the garbage entering the oceans. The Ocean Cleanup Interceptor is 100% solar-powered, with onboard lithium-ion batteries that enable it to operate day and night without any noise or exhaust fumes. The system is anchored to the riverbed to utilise the natural flow of the river to catch the plastic and is designed for 24/7 autonomous operation, removing the need for dangerous manual work. Its floating barrier that is used to direct the garbage into the system only spans part of the river; it will not interfere with other vessels and does not harm the safety, nor impede the movement of wildlife – critical requirements when operating in major rivers. An internet-connected onboard computer monitors the system's performance, energy usage, and component health.

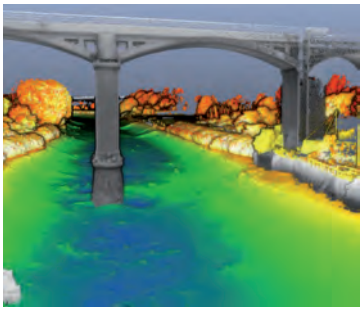
'Start of a Decade of Action and Delivery'

'Sustainable shipping for a sustainable planet' has been selected as the World Maritime theme for 2020. This will provide an opportunity to raise awareness of the United Nations' Sustainable Development Goals (SDGs), and showcase the work that the International Maritime Organization (IMO) and its Member States are undertaking to achieve the targets. The IMO Council, meeting for its 122nd session at IMO Headquarters in London, endorsed the theme, following a proposal by IMO Secretary-General Kitack Lim.

"I believe that this theme will provide flexibility to the Secretariat and the Member States in highlighting the myriad topics and challenges in meeting the 2030 Sustainable Development Agenda. At the same time, it will provide excellent opportunities to highlight the already significant contributions of shipping and the IMO to building that sustainable future," Mr. Lim said.

"The year 2020 will mark the beginning of a decade of action and delivery. It will be a decisive decade not only for the shipping industry, but for life on the planet," Mr. Lim said. He noted that September 2019 would see a gathering of Heads of State at the United Nations in New York, to take stock of how far the world has come in realising the sustainable development commitments.

Asset Inspection Survey

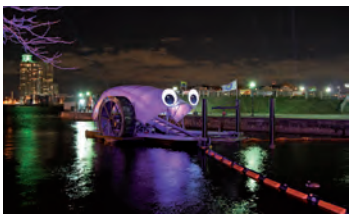


Bibby HydroMap, a UK-based company, recently completed an asset inspection survey of the Weaver Sailing Club and bridges along the River Weaver in Cheshire (UK). This was an opportunity to demonstrate its marine 3D imaging capabilities in a highly dynamic and fast-flowing environment. The River Weaver is a marine connection between a number of businesses along the river and the Manchester Ship Canal and, ultimately, the Irish Sea.

The aim of the survey was to assess the condition of the bridges which span the river, both above and below the waterline, as well as the condition of the Weaver sailing club pontoon, river embankments and riverbed in order to locate any obstructions to navigation. The purpose of the survey was to provide a baseline conditional survey of the marine assets, locate any areas of damage, identify items of debris/obstructions along the waterway and perform scour monitoring of the bridge abutments.

The survey, which was the first to use a combination of sonar and laser scanning to map the assets' integrity, identified several cases of structural damage. Damage to the underside of a road bridge was observed, which could not have been surveyed conventionally on land, and damage was also located sub-water along with the foundations of a warehouse. A number of debris items were also located along the river, including several sunken barges and an overturned car, all of which would pose risks to the navigation of the river.

Plastic Intercepted Before it Reaches the Ocean



Mr Trash Wheel is a semi-autonomous trash interceptor that is placed at the end of a river, stream or other outfall. Far too lazy to chase trash around the ocean, Mr Trash Wheel stays put and waits for the waste to flow to him, according to a description of the team behind the system. Sustainably powered and built to withstand the biggest storms, Mr Trash Wheel uses a blend of solar and hydropower to pull hundreds of tons of trash out of the water each year. Mr Trash Wheel is an initiative of the Baltimore Waterfront Partnership.

The system starts by funnelling the trash. Using containment booms, trash flowing down the river is funnelled into Mr Trash Wheel's gaping mouth. The booms have a 2-foot skirt that allows them to capture trash floating beneath the surface. Fun fact: the trash booms also help stop oil slicks from polluting the water.

The second step is rake and convey. Powered by the sun and the current of the river, Mr Trash Wheel's rake lifts litter out of the water and onto his conveyor belt. The conveyor belt moves very slowly, but is strong enough to lift anything that comes down the river including tyres, mattresses, and even trees.

Mr Trash Wheel's giant, 14-foot water wheel is the engine that powers his rakes and conveyor belt. When there's not enough water current, solar panels power pumps that pump water on to the wheel to keep it churning. Mr Trash Wheel can operate in tidal waterways, which means he keeps churning even if the river is flowing upstream.

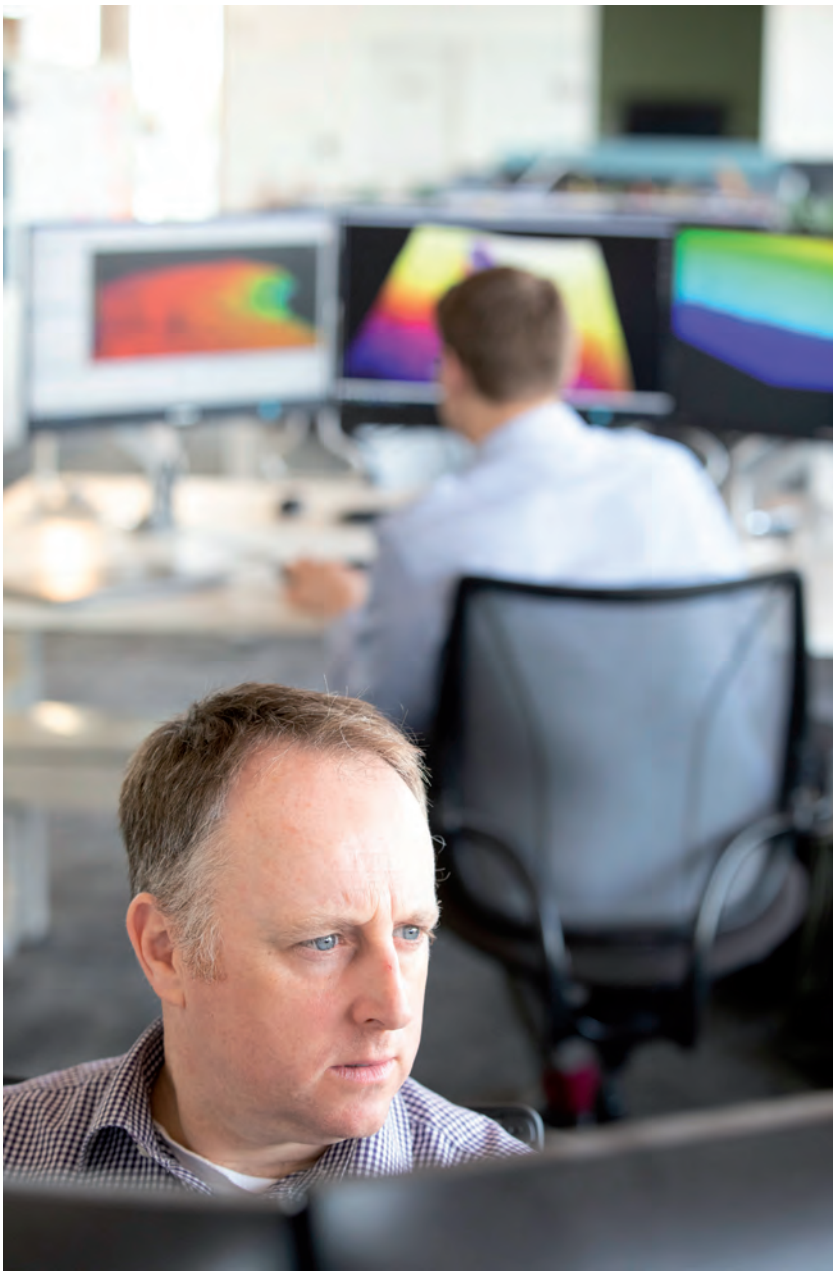
When trash reaches the top of the conveyor belt, it falls into a dumpster sitting on a separate floating barge. Once the dumpster fills, it is towed away and replaced with an empty dumpster. Ideally, the plastic Mr Trash Wheel picks up gets recycled, but current sorting technologies are unable to separate the plastics from all the other trash. For the time being, the best alternative is to incinerate the trash to create electricity.

If you lined up all the cigarette butts collected by Mr Trash Wheel, they would stretch over 150 miles. The largest amount of trash Mr Trash Wheel has ever collected in a single day weighs 38,000 lbs.

7 Questions to Phil Payne, Survey Delivery Manager, UK Hydrographic Office

'Check and double check your data before getting somebody else to check it for you'

Phil Payne, survey delivery manager of the UK Hydrographic Office talks about hydrographic programmes to support blue economic growth, intentional projects and the use of lidar for charting purposes. "There will be a continued drive towards autonomy and automated processing."



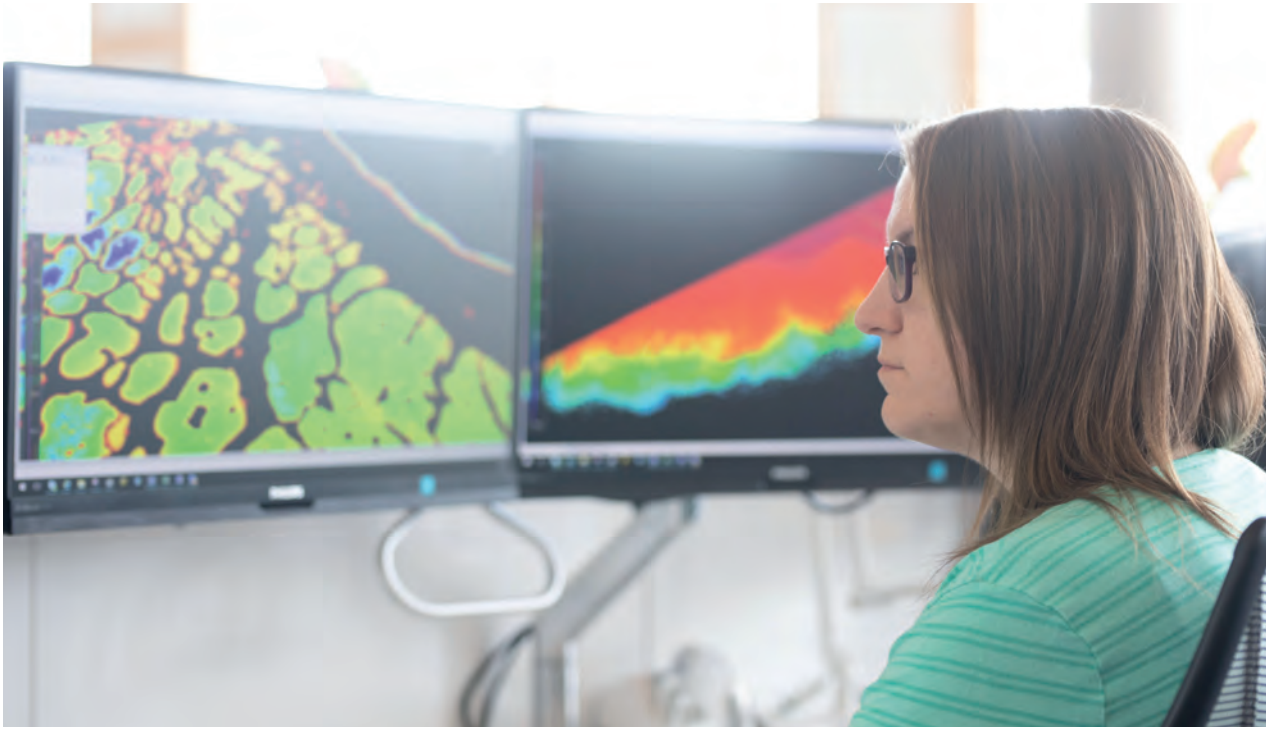
▲ *Bathymetry team at the UKHO.*

Prior to his work with the UK Hydrographic Office (UKHO), Phil Payne spent 25 years in the Royal Navy as a hydrographic and meteorology specialist. Since joining the UKHO in 2016, he has worked in a number of different roles, most recently as its Survey Delivery Manager - a role he has held since 2017.

As Survey Delivery Manager, Payne is in charge of contracting out and organising surveys around the world, which his organization undertakes as part of the UK Government's Commonwealth Marine Economies (CME) and Overseas Territories Seabed Mapping Programmes. This forms part of the work carried out by the wider Hydrographic Programmes team to support blue economic growth and help territories to fulfil their international maritime safety obligations under the Safety of Life at Sea (SOLAS) Convention.

"So far, we've covered more than 19,500km2 throughout these programmes and have conducted surveys in Commonwealth states across the Caribbean and Pacific to support sustainable economic growth and safe navigation", Payne says.

The data generated during these surveys will be used to help these small island developing states make use of their marine resources in a sustainable manner. Potential benefits for these states include expanded trade capacity and security through the accurate charting of ports and shipping lanes; the identification and assessment of suitable areas for coastal infrastructure development; disaster planning and resilience; and environmental protection through the identification of sensitive coastal and marine ecosystems.



▲ *UKHO staff analysing satellite derived bathymetry.*

Payne decided to become a hydrographic specialist when he was a Naval CCF cadet at school. "I was put forward to sit the Admiralty Interview Board (AIB), which I successfully passed. So, when I found out that I hadn't got my first-place choice for university, I decided to join the Royal Navy right there and then," he says.

When he joined, he wasn't aware of the hydrographic branch but, after a number of short stints on both small and large vessels, he came to the conclusion that he preferred the atmosphere and work ethic on board smaller ship types and began to look for a suitable career path. "This was when I discovered the hydrographic specialisation. As well as being small ship-based, I saw the value in the data we were gathering, which was useful not just for the Navy but for the wider maritime community. Four years into my career, I started my CAT B hydrographic course and never looked back."

At a recent presentation, you said the sheer size of unsurveyed areas in scope required a more expansive approach than simply resorting to ship-borne surveys. Can you explain this?
Shipborne surveys by their very nature are relatively slow to achieve the area coverage we're looking at in some overseas regions, where little modern survey work has been conducted. In areas where the waters are shallow or there are sensitive ecosystems such as corals, there's also the danger of potential groundings, resulting in significant damage to the vessel and the environment.

Why, in your opinion, has bathymetric lidar long struggled to meet the accuracy and object detection criteria required of special order or order 1A surveys under the IHO S44 Standard?
Since it was first developed, bathymetric lidar has offered several advantages over traditional boat-based echo sounder hydrography. It covers ground much quicker, does not have the same safety issues you get when using boats in shallow waters and has been able to piggyback on the work of the land lidar industry, in terms of development and software.

However, the physics involved when using light and water – specifically what happens when the light enters the water – and the ability of the systems to achieve the density required to match multibeam systems, means that the industry and hydrographic offices haven't been able to state with reasonable confidence that all relevant objects have been detected.

With this in mind, we have been pushing industry since the start of our hydrographic programmes to increase the density of the soundings of their systems, which several manufacturers have done. This is now helping us to find new ways of looking at the resultant datasets and is helping to increase our confidence with regards to object detection.

The UK Government and UKHO have for many years had little reason to investigate the use of lidar for charting purposes. How come?
The UKHO did put considerable effort into looking into lidar when it was in its infancy and did conduct some initial survey work under the Civil Hydrographic Programme (CHP). The CHP, run by the Maritime and Coastguard Agency (MCA) and supported by the UKHO, mainly looks to provide surveys around UK waters for Safety of Life at Sea (SOLAS) purposes, where the detection of significant objects is important. So, when initial work showed the object detection issues mentioned earlier, it was decided to discontinue commissioning lidar surveys for this programme. However, we do continue to accept lidar data from other sources outside of the CHP, which we assess to determine whether it can be used for charting.

Lidar technology has developed since these initial trials and we have had considerable success in using it during our work with the CME programme. While our lidar specification allows for Order 1B lidar surveys, in terms of object detection it does require increased density in line with our equivalent acoustic surveys in shoal waters. It is under these

conditions that we commissioned five individual lidar surveys, including two in Turks and Caicos Islands and Belize. These two projects covered 7,395km2 and 2,575km2 respectively using a specifically modified light aircraft fitted with state-of-the-art lidar sensors to accurately measure the depth of the water.

Where previous surveys had to make repeated flights over a body of water, the new sensors have around ten times the point density, allowing the surveyors to meet the UK Hydrographic Lidar Specification density requirement in a single flight. Taken alongside the technology's decreased size and power consumption, this means smaller aircraft can be used for a shorter period, which considerably reduces the environmental impact of the surveys and makes them more cost effective. This has led to an estimated overall reduction of around 80% in the surveys' carbon footprint compared to the larger aircraft that have previously been used for such surveys.

We've also been able to use satellite derived bathymetry (SDB) to great effect when scoping out regions where we may look to survey at a later date. For example, the UKHO recently completed an SDB data handover to the Kiribati Government for more than 2,500km of the island chain, including depths and seabed classification to help them monitor sea level rise and erosion, as well as develop plans to support safe navigation.

The UN lists Kiribati as one of several island groups most likely to be inundated by the sea in the 21st century because of global warming, with low-lying parts of the island chain extremely vulnerable to the effects of tsunamis, tidal surges and sea-level rise. In addition to this, Kiribati has a lack of up-to-date seabed mapping data, threatening the safety of ships at sea and increasing the risk of damage being caused to their marine environment.

What developments in the hydrographic and oceanographic world do you expect in the near future?
At the UKHO, we continue to work with the industry to find ways of leveraging lidar technology and SDB to our best advantage and incorporating these into our global surveying work.

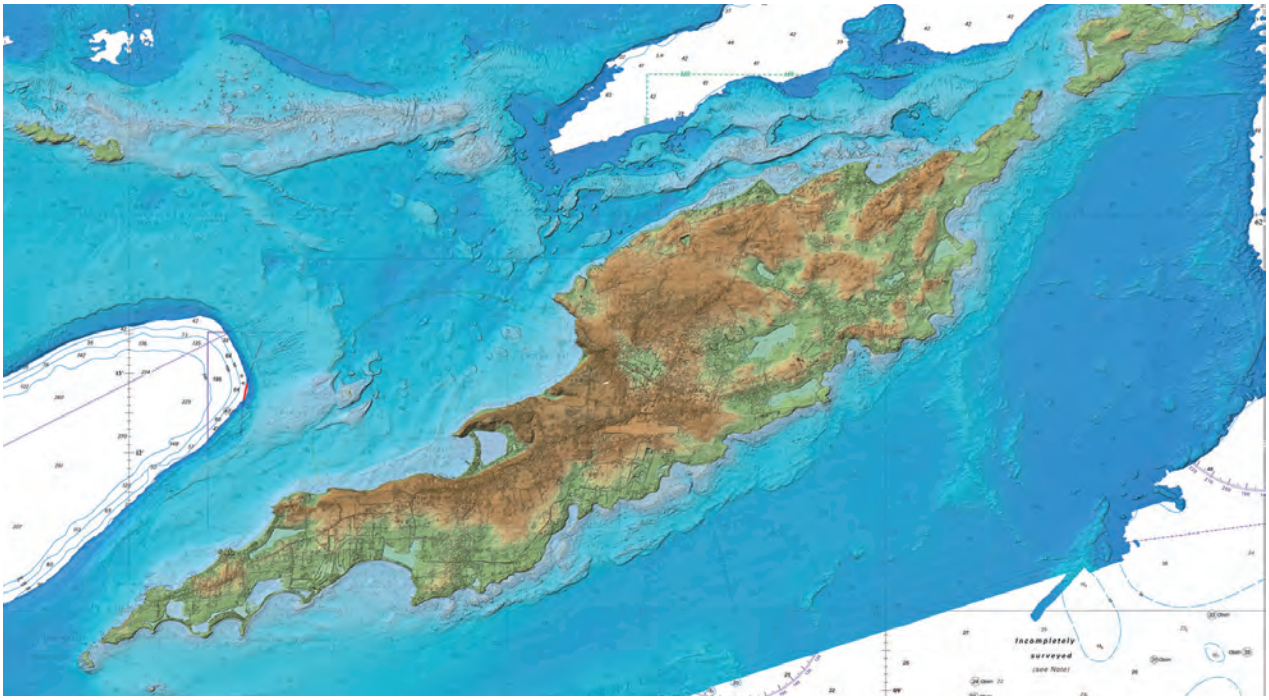
There's also a continued drive towards autonomy and automated processing, which in time, will potentially reduce data collection costs and the environmental impact of larger manned platforms.

This is a trend I expect to see much more of in the future, as it will allow staff to concentrate on the interpretation of the data, while outsourcing some of the surveying work to technology.

What challenges do you encounter during acquisition, validation and onward charting?
With acquisition, it's the real-world factors that get in the way of theory and planning. For example, I was surveying in the British Virgin Islands back in 2016 when Hurricane Irma hit. Our boat was thrown about 200m and damaged beyond immediate repair, so all of our original survey plans were out the window. Instead, we managed to get use of another boat with a single-beam echo sounder, which we used to survey key areas around the islands. This crucial work helped the local government to open up ferry jetties and quays to allow maritime traffic to start moving again.

For validation, our main issues are system compatibility. The industry is moving forward at such a pace that we often find it difficult to get

▲ *Using new sensors with around ten times the point density.*



▲ *Lidar captured in Anguilla as part of the Commonwealth Marine Economies Programme.*

datasets to even open fully before we can start to validate them. While we can control surveys specified by ourselves or our colleagues at the MCA, we receive lots of data from other sources that may be provided in a whole raft of different formats – creating this validation issue.

When it comes to onward charting, the cartographers prefer a modern 1A survey that we have been able to fully validate, as this allows it to be dropped into the current chart easily. Where we have less confidence in the data, we have to expend a lot of time and effort in making sure that the best picture of the seabed is given on the chart, while retaining older shoal soundings that are important for the safety of navigation. This explains our drive to get lidar surveys up to a 1A standard.

How do you compare the object detection capabilities of both shallow and deep lidar systems in relation to more traditional multibeam echo sounders?

The most effective way to compare them is to have overlapping data. With limited budgets and so much unsurveyed water, repeating areas using multiple technologies is not always desirable. However, we have managed to get a few datasets where we have both multibeam and lidar in areas where there are lots of obstructions and small objects – these are ideal for checking out the relative capabilities of these systems.

What is your advice for young people who are thinking of a hydrographic or oceanographic career?

My main piece of advice would be to get ready for a thoroughly rewarding and diverse career path. Work hard at getting the basics right and all these paths will open up to you. And as my Cat A Course teacher once told me, "when it comes to data, check it and then check it again before getting somebody else to check it for you!" ◀

Overseas Territories Seabed Mapping Programme

The Overseas Territories Seabed Mapping Programme is funded by the UK Government's Conflict, Stability and Security Fund (CSSF). It is co-ordinated by the Foreign and Commonwealth Office as part of the UK's commitment to support Overseas Territories.

Commonwealth Marine Economies Programme

Funded by the UK Government's Conflict, Stability and Security Fund (CSSF) and led by the Foreign and Commonwealth Office, the CME Programme is supporting 17 Commonwealth Small Island Developing States (SIDS) in the Caribbean and Pacific in identifying the potential of, and developing their marine economies in a sustainable, resilient and integrated way. The Programme promotes growth, innovation, jobs and investment whilst safeguarding healthy seas and ecosystems. In partnership with the SIDS governments, the Programme will develop and implement national Maritime Economy Plans to ensure it leaves a lasting legacy.

About the UK Hydrographic Office (UKHO)

The UKHO is a leading centre for hydrography, providing marine geospatial data to inform maritime decisions. It works with a wide range of data suppliers and partners to support maritime navigation, safety, security and marine development around the UK and worldwide.

It makes location-based information available through ADMIRALTY Maritime Data Solutions, its world-leading range of charts, publications and custom data sets. Its use of marine data and technology, combined with its expertise, ensures it continues to innovate and provide a wider range of solutions.

It sources, processes and provides access to location-based information, ranging from seabed to surface. This enables its partner organizations to make critical maritime decisions – informing the sustainable use and management of the marine environment and supporting the development of the blue economy.

iXblue Echoes 10000 sub-bottom imager for object detection

To meet the various needs of the sub-bottom profiling market, iXblue has conceived a complete range of sub-bottom profilers: the Echoes Series. Developed over the past 30 years in close collaboration with the French Navy and several international oceanographic research institute laboratories, including the French Research Institute IFREMER, iXblue's product quality and technology expertise come from extensive practice and the cumulative return on experience, coupled with constant innovation and evolution. A recent mission to Scotland emphasises the object detection performance of Echoes 10000 in shallow waters.

Sub-bottom profiler (SBP) data acquisition and analysis of the seafloor, lakes, fluvial or any other waterways from natural and anthropic origins can provide crucial information for underwater studies. SBPs are used to identify and characterise the sediment layers below the seabed. The obtained data provides structural information on sediment layers, such as their thickness, slope or level. Fields of application such as subsea construction inspection, biomass monitoring, resource control, pollution tracking, geo-archaeology or sedimentology are increasing and represent a growing market share that needs to be explored. It can be used to detect and map buried objects (cables, pipelines etc), gas fronts or wrecks. Together with Delph Seismic software, 3D observation and characterisation of sedimentary architecture and buried objects allow any offshore constructor to identify areas to be secured or exploited. Back in December 2018, iXblue's Sonar Systems Division and the University of St Andrews conducted up to 11kms of near-surface geophysical investigation in shallow water environments (< 25 m) along Scotland's shorelines, using the Echoes 10000 (10 kHz). High-resolution seismic profiles showed individual and parabolic reflective objects that corresponded to decimetric rocks visible in sediment cores. This unique performance was due to the in-house design of efficient CHIRP technology with large transducer beams (around 20°), resulting in an impressive signal continuity and the identification of buried objects. This key performance brings new insights into the 3D mapping of individual boulder clearance for shallow marine environments (< 150 m).

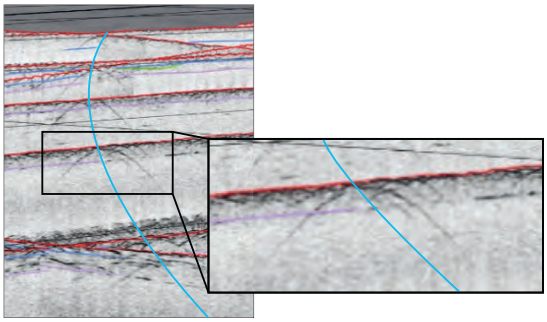
HIGH PERFORMANCE OF ECHOES SERIES THANKS TO COMPLETE VERTICAL INTEGRATION

Today, sub-bottom profilers use a broadband frequency shifting from low to high frequencies, providing a wide range of penetration, resolution and directivity for the first 200m of sediments. These acoustic signals use frequency (FM) and amplitude (AM) modulation over a defined duration. This signal is commonly called a "CHIRP" (Compressed High Intensity Radar Pulse). SBPs transmit this signal in water and listen to the reflected signal from the bottom and sediment layers. The received acoustic signal is digitized and then deconvoluted. This technique provides penetration that is comparable to low-frequency systems with a resolution of high-frequency systems. In addition, the correlation of the received data with the transmitted CHIRP signal performs a strong noise filtering to yield an additional gain in the signal to noise ratio.

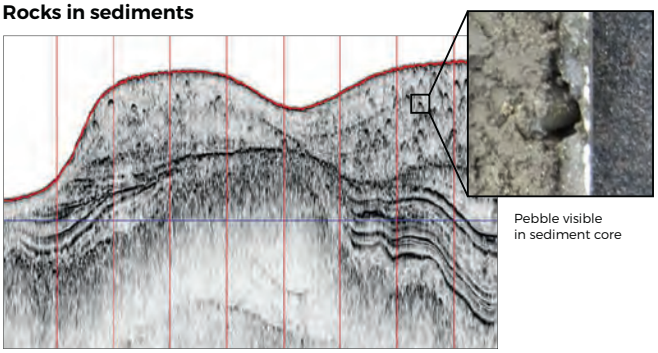
iXblue know-how in sub-bottom profiling is built from a custom piezo-electric transducer design activity in the 150Hz to 400kHz range. These high-power and wide

OBJECT DETECTION

Pipelines

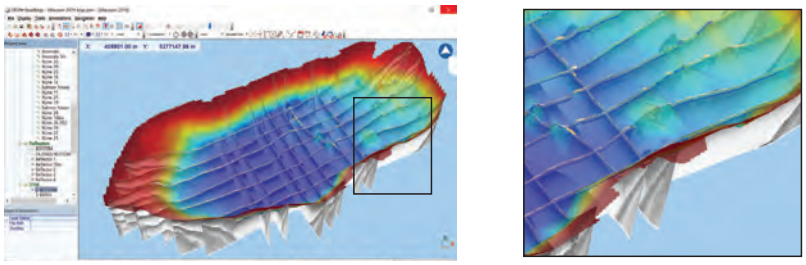


Rocks in sediments

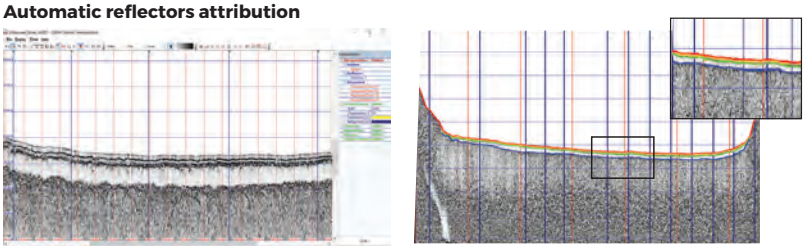


▲ *Fig 1: 15° to 20° aperture with CW short signal at 10 Hz makes pipes ring louder, and clearly identify it even in a rocky environment. Similarly, on the second profile, an embedded rock 5cms in diameter can be detected in sandy sediment.*

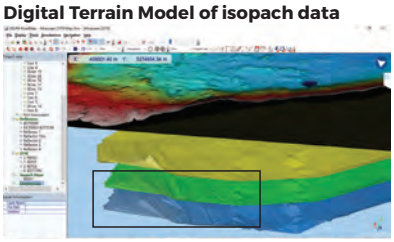
Bathymetry derived from seismic data



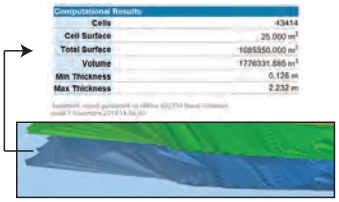
Automatic reflectors attribution



Digital Terrain Model of isopach data



Delph Sediments volume calculation



▲ *Case study: Delph Software processes for 3D calculation of sediment volume (example from a lake).*

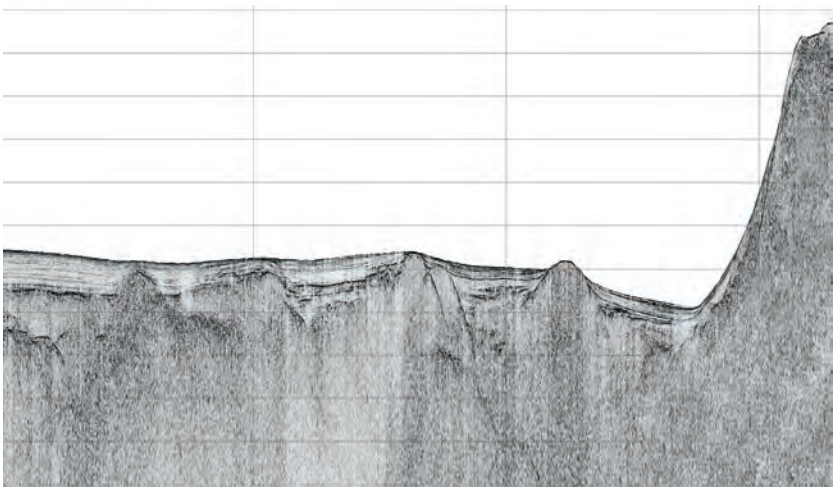
bandwidth devices were especially suited to the development of a complete range of controlled pulse sub-bottom profiler projectors. Enhanced by in-house designed low distortion and high efficiency power amplifiers, all components are manufactured internally. This mastering of the acquisition chain ensures that the acoustic signal transmitted is very close to the theoretical CHIRP waveform, thus ensuring the highest degree of resolution and quality resulting from the signal processing.

UNIQUE FEATURES

Echoes transducers' wide aperture is a key factor in object detection and in obtaining maximum penetration whatever the seabed topography (Figure 1).

PENETRATION AND SIGNAL TO NOISE RATIO

On the following profile, anyone could appreciate the image texture in such chaotic and mountainous subsea environments (Figure 2).



▲ *Fig 2: Estuary survey from shallow to down slopes with efficient bottom tracking (Canada).*

DELPH SOFTWARE SUITE

A complete software suite for efficient data processing

iXblue is also developing an open software suite for acquiring, processing and mapping all kinds of hydrographic and geophysical data. The Delph Software Suite naturally brings out the best in the Echoes sub-bottom profiler's data with possible improvements to the CHIRP processing and complete 3D geo-referencing of survey data both in real-time and offline.

Delph Interpretation is a complete software suite, including applications and tools which address the requirements for the processing and interpretation of geophysical datasets with optimized quality control. The software includes dedicated sensor modules (Delph Sonar / seismic / Mag) that are all linked to a mapping interface (Delph RoadMap) offering 3D visualization and quick access to raw and processed data.

An innovative approach to workflows on geophysical data offers flexibility and extreme efficiency in the management of large volumes of data and multi-sensor surveys. Users have a global multi-sensor display of sonar, bathymetry, seismic, magnetometer, geotechnical and cartographic data, while still retaining the maximum level of detail for analysing records. Batch data processing and production tools allow users to maximize the time being used for Q.C. and interpretation by eliminating the tedious and repetitive tasks. For example, the calculation of the volume of sediments can be easily extracted from the software.

COVERING THE FULL SPECTRUM OF APPLICATIONS

The Echoes Series can be pole, hull-mounted or integrated on Unmanned Surface Vessels (USV) and are therefore easily operated and mobilised from vessels of opportunity, covering a full spectrum of applications, from shallow to deep water: tomography, physical oceanography, seafloor mapping, oceanographic survey, industrial survey, geotechnical survey, marine archaeology, broadband projectors and deep ocean operations.

WHAT'S NEXT?

There is more innovation and integration to come: as iXblue focuses on autonomous surveying, the company is actively working on better, more efficient, compact and adapted solutions, together with leading industry companies and partners, with the aim of reducing survey costs, while improving data resolution and coverage rate. ◀

Two Similar Projects in Different Parts of the World

Mapping Underwater Terrain with Bathymetric Lidar

High-resolution bathymetric surveys support aquaculture research and increase navigational safety. In a case study, Tim Webster reports how this is done at Cape John Peninsula in Canada. In the second one, Carol Lockhart describes the project in the Kingdom of Tonga, a Polynesian archipelago comprising 169 islands that stretches across approximately 800 kilometres in the South Pacific Ocean.

Measuring water depth for nautical purposes dates back to ancient civilisations. As technology has evolved through the centuries, besides ship-based echo-sounding, remote monitoring and mapping of water bodies has become increasingly available via LiDAR bathymetric surveys conducted by airborne systems.

New coastal survey sensors combining topographic and bathymetric LiDAR are designed to offer more accurate data for environmental monitoring, research and surveying both below and above sea level. Bathymetric surveys allow professionals to measure water depth, map the underwater terrain, classify submerged vegetation and habitat as well as study marine ecology, water quality, contaminant spills and hydrodynamics. The following two case studies describe instances of how bathymetric and topographic LiDAR systems allowed researchers from the Nova Scotia Community College, led by Dr. Tim Webster, to map Cape John peninsula in Canada and how Carol Lockhart from Geomatics Data Solutions (now Woolpert, Inc.) captured a 633-square-kilometre area over the South Pacific Ocean.

MAPPING CAPE JOHN PENINSULA

Mapping shallow water and coastal areas using traditional aerial photography or boat-based echo sounder methods can be costly, time consuming and challenging due to water clarity and unforeseen weather conditions. To overcome these challenges and increase productivity and data accuracy, the research team from the Nova Scotia Community College decided to use the Leica Chiroptera 4X bathymetric and topographic LiDAR for its geomatics research to survey the coastal zone of Cape John peninsula in Canada.

The purpose of the geomatics research was twofold. First, the team mapped the benthic habitat and the existing aquaculture in the bay, including the mapping of the shellfish infrastructure and the buoys to estimate how much biomass is being grown.

The second goal of the research was to develop a hydrodynamic model to help the lease of new oyster farms and propose the appropriate locations around the bay, without damaging the sensitive Zostera marina or so-called eelgrass. The eelgrass beds are important for sediment deposition and nursery grounds for many species of fish and shellfish; thus it is used as an ecosystem health indicator by Fisheries and Oceans Canada (DFO).

The team carried out similar research in the Maritime Canada region in 2014 on how to optimise data collection and post-processing of

▲ *Fig 1: Bora Bora. (Courtesy: Jules Silver)*

▲ *Fig 2: The landscape of Nova Scotia.*

shallow water topographic-bathymetric LiDAR survey using the Leica Chiroptera II. This time, the researchers had the chance to deploy the new Chiroptera 4X and compare the captured data with results from 2014. To quantify the improvement of the point cloud density and target identification of the new Chiroptera 4X, the team compared the captured data of three surveying instruments: Chiroptera II, Chiroptera 4X and a multibeam echo sounder.

This geomatics experiment involved the target surveying of four one-cubic-metre cubes at different water depths to determine the level of detail and data provided by the three different sensors.

Flying the Chiroptera 4X over the bay, the research team collected information on the surveying targets and compared the captured data of the terrain and seabed from 2014 with the data from this experiment carried out in 2018. Using the four cubes and other flat targets captured with the three different survey methods, researchers compared point cloud density, orthophoto mosaics, Digital Elevation Model and LiDAR amplitude.

The analysis of the captured data was completed using the discrete points derived from the waveform data in Leica LiDAR Survey Studio post-processing software for point cloud generation and cleaning of raw LiDAR data. Taking advantage of the Chiroptera 4X's near-infrared laser for topographic data collection, combined with a green laser for bathymetric data collection, the research team precisely captured underwater features and generated virtual reality elevation models to study the benthic habitat. Additionally, researchers proposed sustainable locations for oyster farming without damaging the eelgrass habitat.

SAFE PASSAGE THROUGH PACIFIC WATERS

The Pacific is an extremely culturally diverse region, as exemplified by the more than 1,000 languages spoken and, yet, what connects them is the water. The ocean and coastal seas have long been integral to the Pacific way of life. The economy, transportation and culture of those sharing the Pacific waters is based on the naval and marine infrastructure and ecosystem this ocean provides. Even though marine navigation plays a key role in the archipelago, the South Pacific is inadequately charted.

Shallow water depth range data is critical for safe marine navigation and for the construction of harbours, pipelines and any other infrastructure in the coastal area or shallow offshore zones. Without precise information on water depth and the exact location of underwater features and submarine canyons, economic and sustainable development is negatively impacted.

iXBlue together with project partners Geomatics Data Solutions (now Woolpert, Inc.) and EOMAP Australia were requested to map the Tongan archipelago and surrounding areas to provide the 3D water depth information and improve the nautical chart of the region.

The project was part of the Pacific Regional Navigation Initiative (PRNI), an overarching programme geared towards the safe and reliable passage through the Pacific Ocean while protecting the environment and allowing Pacific island economies to develop. The project was sponsored by the New Zealand Ministry of Foreign Affairs and Trade (MFAT) in partnership with Land Information New Zealand (LINZ).

The Kingdom of Tonga, a Polynesian archipelago comprising 169 islands, stretches across approximately 800 kilometres in the South Pacific Ocean. In Tonga, agriculture, fishing and forestry provide the most employment. For this reason, detailed data on both land and shallow water features can support the sustainable development of the island group.

Considering the relatively large area in need of high-resolution survey and charting, LINZ required a smart solution to bring the most out of the tight budget. iXBlue, together with EOMAP Australia and Geomatics Data Solutions, applied a multi-sensor approach to collect topographic and bathymetric data, including Satellite-Derived Bathymetry (SDB), Airborne Laser Bathymetry (ABL), Multibeam Echosounder (MBES) and tide gauge install and datum computations.

SDB surveys are very effective tools in mapping large areas to the visible water depth. However, to capture high-resolution data on land and under water the Chiroptera 4X ALB was used. The Chiroptera 4X was installed in a Cessna 441 to acquire data for Tonga and Niue, including Beveridge Reef, covering approximately a 633-square-kilometre area. Geomatics Data Solutions experts collected both high-resolution bathymetric and topographic data on- and offshore and compared the results of the Chiroptera 4X to SDB.

Besides the bathymetric data of the seafloor, one of the unexpected benefits Geomatics Data Solutions gained from using Chiroptera 4X was the improved penetration of the denser bathymetric laser data on land, providing full coverage even on dense vegetation where the topo laser did not penetrate.

Local stakeholders will receive full imagery and the topo-bathy dataset, so they can also benefit from the high-resolution data provided with the new Chiroptera 4X, and can use the data for other purposes in addition to improving the nautical charts. The combined use of different surveying equipment provided complete knowledge of all navigational-significant features and additional topographic information of the islands.

▲ *Fig 3: The Coastline with lighthouse in Nova Scotia.*

▲ *Fig 4: The blue waters of French Polynesia. (Courtesy: Julius Silver)*

SURVEYING COAST AND LAND SEAMLESSLY

Responding to the growing need for collecting high accuracy data for environmental monitoring and surveying of shallow water regions, innovative, high-resolution technology was developed to allow professionals to survey and map above and below sea level with survey depths down to 25 m.

Thanks to the 4X technology of the newly-released Chiroptera, experts surveyed at four times the sounding density than was previously possible. ◀

Tim Webster has been a research scientist with NSCC's Applied Research Group since 2000. He has an MSc from Acadia University and a PhD from Dalhousie University.

Carol Lockhart is a Project Manager and a Hydrographer. She has been surveying for over 20 years and was the owner of Geomatics Data Solutions (GDS), a marine and terrestrial survey data firm, until it was acquired by Woolpert.

Reviewing remote sensing image classification techniques

Mapping the Subsea Forests of the Mediterranean

The distribution of Posidonia oceanica seagrass meadows has been mapped by a combination of remote sensing techniques, Geographical Information Systems (GIS) and sonar data. A fundamental, but challenging, part of this methodology is the remote sensing image classification. This article presents a review of different image classification techniques to optimise the final maps, so that effective action can be taken to conserve seagrass meadows.

▲ *Spatial data collection with sonar equipment installed on the boat. (Courtesy: Anne van der Heijden)*

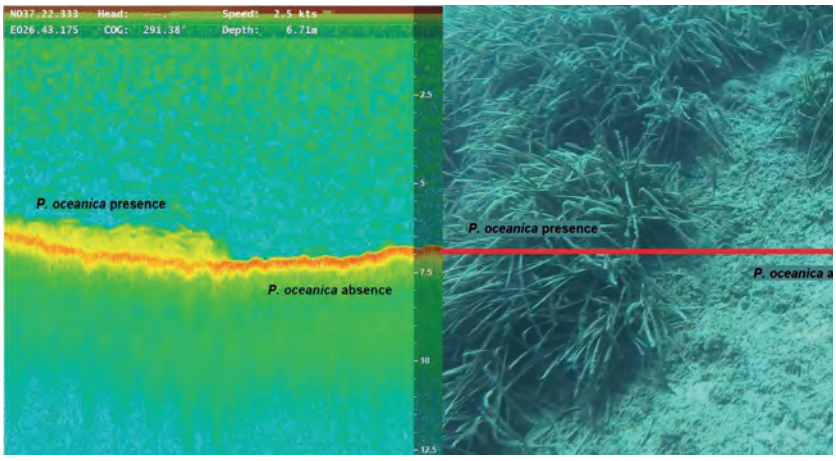
The degradation of P. oceanica seagrass meadows is a major concern as these marine ecosystems play a fundamental role in the health and productivity of many Mediterranean marine habitats. Seagrass monitoring and mapping are fundamental tools for measuring the status and trends of meadows and their environmental condition (Topouzelis et al., 2018). The Greek Non-Governmental Organization Archipelagos Institute of Marine Conservation, operating from the islands of Samos and Lipsi, focuses on the collection of spatial data around the Greek coast to generate more accurate habitat distribution maps of P. oceanica, so that these highly valuable ecosystems can be monitored and protected. Archipelagos conducts marine research with multiple research vessels, including the 22-metre long Aegean Explorer. This vessel is equipped with an array of scientific instruments, including single and multibeam sonar, a structure scanner, a biomass scanner and an underwater camera capable of reaching depths of 300 metres.

MAPPING SEAGRASS DISTRIBUTION

The distribution of P. oceanica is mapped by means of remote sensing techniques, GIS and sonar measurements in the field. The input for the remote sensing methodology is Sentinel-2A satellite imagery. The satellite image is preprocessed to deal with necessary corrections to interferences that determine the light in the atmosphere and water, before deriving any quantitative information on the aquatic habitats that focus on seagrass (Traganos and Reinartz, 2018). The main steps here are atmospheric correction, sun glint removal and water column correction.

During the field operations, ground truth data about the seagrass meadows was collected. A DownScan sonar was installed on a research vessel and at the rear of a kayak to obtain information about the seafloor. The sonar transducer emits ultra-sound waves to the seafloor from which bottom morphology is derived. When P. oceanica is present it appears on the sonar output as a fuzziness above the seafloor. Waypoints are set for P. oceanica (P) or no P. oceanica (NP), which are used as training data during the image classification process and accuracy data during the accuracy assessment.

▲ *Archipelagos' research vessel 'Aegean Explorer'. (Courtesy: Nicola Mayrhofer)*



▲ *Fig 1: DownScan sonar output (left) and corresponding seagrass patch captured by underwater camera (right).*

CLASSIFYING SEAGRASS PRESENCE OR ABSENCE

After the correction of the satellite image, the pixels were classified to indicate P. oceanica presence or absence. Essential in most aquatic remote sensing studies is the process of identifying distinctive cover or substrate types in the study area on a satellite image and assigning them to the proper classes, which is defined as remote sensing image classification. In this methodology, supervised image classification is applied, in which the classification is performed with ground truth data. Four supervised image classifiers are reviewed: Maximum Likelihood Classifier (MLC), Radial Support Vector Machine (SVM), Linear SVM and Random Forest (RF). Each of these techniques is built on its own mathematical function. The choice of a technique can be based on different criteria, such as image resolution, spatial scale and the ground truth data set. The techniques are reviewed on their accuracy percentage and Kappa Index. These parameters are derived by means of the accuracy waypoints and a Confusion Matrix (Cohen, 1960).

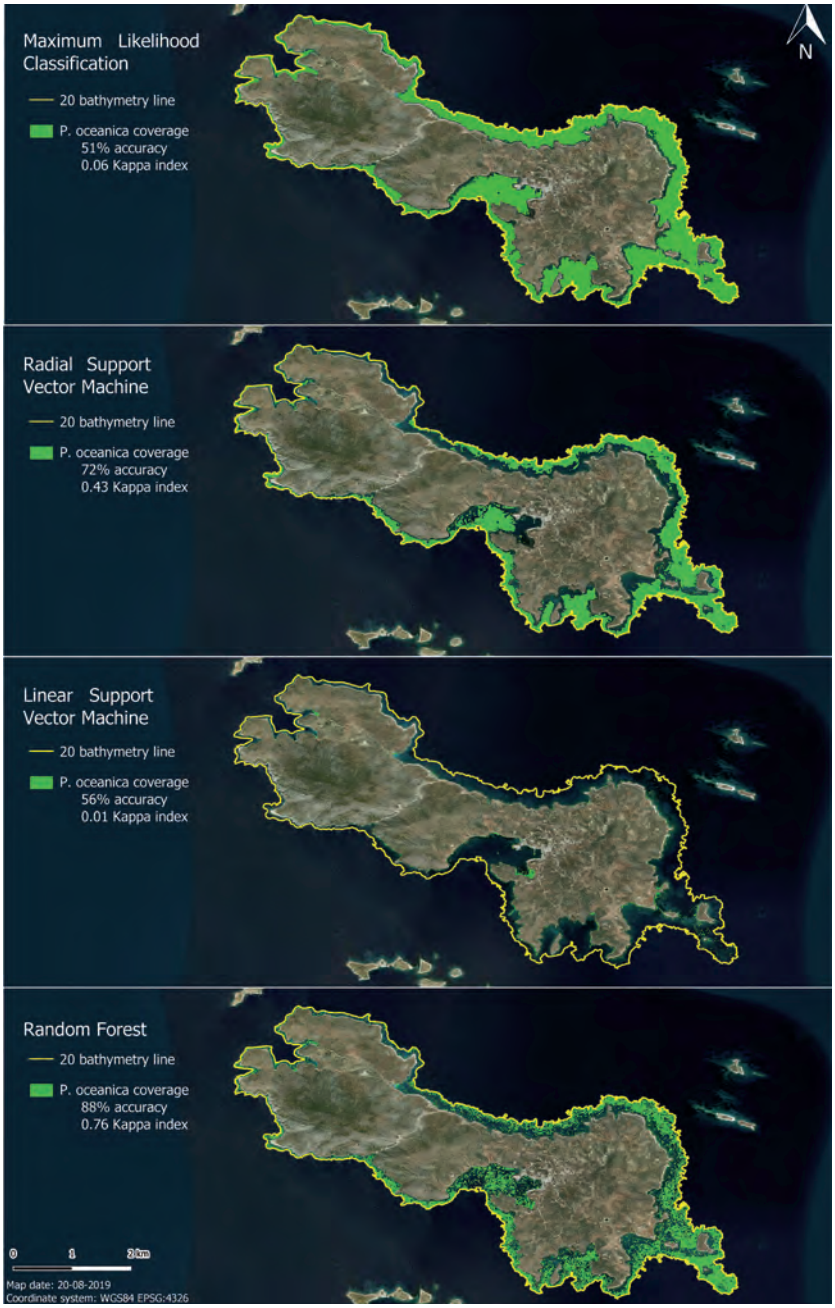
COMPARING IMAGE CLASSIFIERS

The four image classification techniques were performed for six different islands in the Southeast Aegean Sea, at three different spatial scales and with different waypoint densities to optimally explore the function and performance of the techniques. Figure 2 indicates the seagrass distribution around the island of Lipsi, modelled by the four classifiers. Due to the limitations of satellite imagery, the distribution is modelled to a bathymetry of 20 metres. The maps show significant differences in seagrass distribution modelled by the four techniques.

RF and Radial SVM resulted in the most accurate maps (respectively 88% and 72%) for this study, even when the waypoint density was reduced. It is evident that the seagrass pixels classified by RF are more randomly distributed than with Radial SVM, which clearly shows the function of these two techniques. MLC seems to overestimate the P. oceanica coverage, as more than 50% of the NP points are modelled as P pixels. Linear SVM makes an extreme underestimation as 98% of the P points are modelled as NP pixels.

CONCLUDING REMARKS

The modelling of P. oceanica coverage around islands in the Southeast Aegean Sea resulted in highly accurate outputs modelled by RF and Radial SVM. The review has shown that each image classification technique consists of its own function and therefore delivers distinguishing outputs. The choice of a



▲ *Fig 2: P. oceanica distribution around the coast of the island of Lipsi.*

▲ *Fig 5: Kayak-based data collection with a DownScan sonar. (Courtesy: Anne van der Heijden)*

classification technique depends on different criteria, including spatial scale, image resolution and the ground truth data set. Simultaneously, the choice of a classification technique also strongly depends on the purpose and use of the final maps. For example, Archipelagos is committed to conserving the seagrass by presenting the maps to the government, local communities, ports and fishermen to achieve legislation, protection and awareness. In this case, a classifier that slightly overestimates is more likely to be selected than one that strongly underestimates. These classification purposes and applications should be kept in mind when investigating the techniques and the motives for selecting one. Because of these motivations, further contributions and efforts are required to investigate the assessment and applications of remote sensing image classification techniques. ◀

Acknowledgements
I would like to thank Thodoris Tsimpidis and Anastasia Miliou (Directors of Archipelagos Institute of Marine Conservation) for the opportunities and resources they gave me both on- and offshore during my research internship. Due to their love of the ocean and their commitment to marine research, they are a source of inspiration.

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Inge van den Meiracker is a MSc graduate student in Geographical Information Management and Applications (GIMA). During her six-month research internship at Archipelagos, she focused on using GIS and remote sensing as a solution for effective marine conservation strategies.
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Unlocking the secrets of the sea

Exploring the Origin of Indian Ocean Geoid Low

A dedicated research team of geoscientists at the National Centre for Polar and Ocean Research in India leads a unique mission to explore the origin of the Indian Ocean Geoid Low and reveal its long hidden secrets.

A massive dent in Earth's geoid covers a large area south of the Indian peninsula, in the middle of the Indian Ocean. This 106-metre anomaly has an unusually weak gravitational potential and is in fact the largest equipotential gravitational field distortion in the world. This gravity low indicates that less of Earth's mass is concentrated in this area than is typical of other areas. Extreme geoid anomalies such as the Indian Ocean Geoid Low (IOGL) are fascinating because they signify a major shift in subsurface geodynamic conditions in the region. (1)

MULTIPLE THEORIES, BUT THE MYSTERY REMAINS

For decades, scientists have wondered about the IOGL phenomenon, and several have conducted research and developed hypotheses that suggest possible sources of this anomalous geoidal low. Multiple theories have been proposed. Lower mantle convection may have contributed, or perhaps it emerged from hot buoyant material from the deep mantle beneath the African continent. Prevailing theories are based on seismological investigations and viscoelastic modelling and, considering the range of theories and the nature of the IOGL, the cause may be a response to an extended mass anomaly with multiple sources. Despite the lack of consensus on the exact cause, all studies indicate that the IOGL is a deep-seated earth structure. Seismic velocity models derived from long-term seismological observations captured in the IOGL region could provide critical clues, illuminating multiple wavelength sources of the IOGL and hopefully resolving this scientific mystery once and for all. (2, 3 and 4)

A MISSION TO EXPLORE ORIGIN OF INDIAN OCEAN GEOID LOW

A dedicated research team of geoscientists at the National Centre for Polar and Ocean Research (NCPOR) in India is leading an extensive long-term deployment of broadband Ocean Bottom Seismometers (OBSs) in the IOGL region to find out possible geodynamic causes behind this enigma. This mission is unique and the first of its kind, directly addressing the lack of seismological data from the IOGL region. The objective is to capture data that will resolve this long-standing scientific secret. The team would particularly like to find out what the relationship is between the deep mantle structures and the IOGL. Exactly what caused the IOGL? And what makes it different from other geoid anomalies around the globe? The research team, funded by the Ministry of Earth Science in India, is determined to address these questions.

This multi-institutional project, Exploring the Origin of IOGL, is one of the thrust initiatives of the Ministry of Earth Sciences in India. The research team also acknowledges support received from national and international research collaborators towards this endeavour, in particular, from the SK-348 &360

expedition teams and the USGS. This work will integrate and build upon numerical modelling, based on global seismic tomographic results relating to mantle geodynamics below the Indian Ocean and earthquake ray path models. (5)

As the first step, a detailed marine geophysical reconnaissance study of the area was conducted. This study covered a series of transects across the IOGL area, from Chagos-Laccadive Ridge in the west through the southern part of India and Sri Lanka, and across the Bay of Bengal to the western offshore region of the Andaman-Nicobar Islands. Following this detailed mapping, a fleet of 17 OBSs were deployed in May 2018. They were all retrieved over a year later in August 2019, then deployed again for one further year. The Ocean-Bottom Seismometers (OBSs) manufactured by German marine engineering company Umwelt- und Meerestechnik Kiel (known as K.U.M.) were selected for this marine mission, supported by Samhitha Marine Private Ltd (marine and oceanography solution provider in India).

The NAMMU are sophisticated, next-generation broadband OBS systems that are easy to deploy on the ocean floor, developed for deep-sea data-capture operations in depths of up to 6,000m. These devices contain a range of technical features including GPS, broadband triaxial seismometer, four-component sensors (one vertical; two horizontal and a hydrophone), plus a digitizer with a dynamic range of more than 142 decibel and a frequency range of up to 120 seconds. These NAMMU collect data at 100 samples per second and are self-installing on the sea floor. These devices can collect data for up to three years (configuration and battery dependent) in a single deployment, although for this particular project, the data is retrieved at the end of each year. To do so, another marine expedition sails out to retrieve the OBSs, sending an acoustic signal to each device. The OBS then detaches from its anchor and rises slowly to the ocean surface, enabling straightforward recovery and data collection. (6)

IMPACT, OUTCOMES AND FUTURE PLANS

Seismological data captured by the OBSs in this mission will contribute to confirming or rejecting various hypotheses about the cause of the IOGL, resolving long-standing global debate. This data is also likely to advance the work of other researchers, including those working in solid earth science and those focused on deep-ocean wave dynamics. The team looks forward to sharing detailed findings with the global scientific community in the future. ◂

Further Reading

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About the NCPOR

The NCPOR is India's leading research and development institution responsible for the country's research activities in both the polar and Southern Ocean domains. The research team comprises several experts including NCPOR Director, Dr. M. Ravichandran, along with Dr. Dhananjai Kumar Pandey, Lachit Singh Ningthoujam, the Chief Scientist on this mission, Sanjay Singh Negi and Amit Kumar of the NCPOR's Geosciences Division, and Padma Rao B and C P Dubey of the National Centre for Earth Science Studies (NCESS).

Insights from the first commercial use of Fugro RAMMS

This is How Airborne Multibeam Lidar Coastal Mapping in Paradise is Done

The Rapid Airborne Multibeam Mapping System, RAMMS, was developed over a period of three years before it was officially launched in the summer of 2018. Senior hydrographer Richard Goosen describes how Fugro used the system for coastal and nearshore mapping at the paradise Turks and Caicos Islands.

In July 2018, Fugro embarked on a large-scale project to map the Turks and Caicos Islands for the United Kingdom Hydrographic Office (UKHO). This landmark effort called for integrated, high-resolution bathymetric, topographic and orthoimage datasets to support nautical chart updates and coastal zone management activities. To achieve the sizeable bathymetric portion of the survey, Fugro debuted a new airborne lidar system known as RAMMS: Rapid Airborne Multibeam Mapping System.

A NEW ANSWER TO AN OLD PROBLEM

When it comes to shallow water, airborne lidar bathymetry (ALB) has long been proven to be a fast, safe and cost-effective method for accurately defining nearshore water depths. Traditionally, ALB systems have been specialised to deliver either high point densities or good depth penetration, but not usually both, due to sensor design limitations. As such, 'high-resolution' systems are typically used in areas shallower than 15m, and 'deepwater' systems are used in areas down to 50m (water clarity permitting). While it is possible to merge datasets acquired by high-resolution and deepwater systems, doing so is time-, cost- and resource-intensive.

In recent years, international hydrographic agencies have challenged contractors to improve the efficiency and quality of ALB data acquisition and deliverables. Specifically, they have pressed for a solution that would support inshore nautical charting standards.

▲ *RAMMS data overlaid on orthoimagery in coral-rich area.*

Fugro accepted this challenge, identifying and leveraging decades of shallow-water mine detection technology developed by Areté Associates, then refining it to meet hydrographic surveying needs. The system, known as RAMMS (Rapid Airborne Multibeam Mapping System), was developed over a period of three years before it was officially launched in the summer of 2018.

SYSTEM DEVELOPMENT

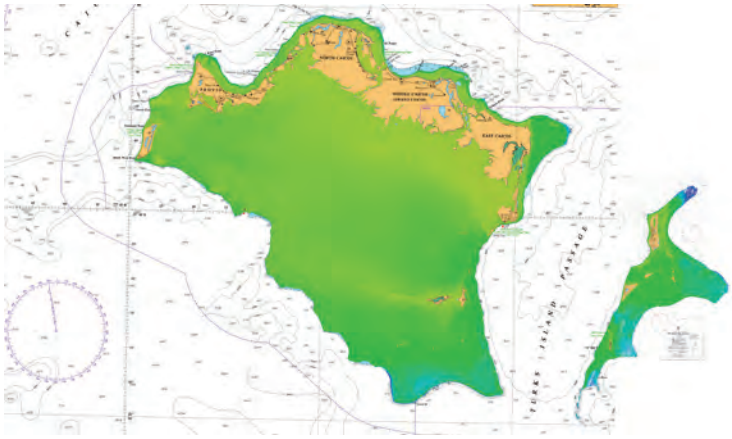
RAMMS is based on third-generation lidar technology and differs from conventional ALB sensors in the way energy is transmitted and received from the sensor. Traditional scanning systems use a pulsing laser that transmits discrete beams of laser light, which are then directed to the seafloor in a 'pseudo swath' using scanning or rotating mirrors. In contrast, RAMMS is a solid-state pushbroom system with no moving parts. Instead, it transmits a single diffuse pulse of laser light that generates a 'true swath' of energy approximately equal in width to the flying height of the aircraft. The returning signal is then focused into a streak tube receiver where it is beam-formed into a maximum of 900 individual slices (beams) comprising the full waveform.

This swath-coverage methodology closely parallels the workings of vessel-based multibeam echosounder systems and produces data of a similar quality. RAMMS delivers 24,000 range observations per second while achieving 3-Secchi disk depth penetration, making it possible to meet International Hydrographic Organization (IHO) Order 1 survey standards. This lightweight system can also be combined with other remote sensing technologies to address a wide range of bathymetric, topographic and imagery needs from a single airborne mission.

After testing RAMMS on land, off the California coast and at an established lidar-testing facility in Fort Lauderdale, Florida, Fugro performed a proof-of-concept project in Belize. The RAMMS data acquisition tied in with a multibeam echosounder survey that was already underway for the UKHO and provided favourable results. With that, RAMMS was ready for commercialisation.

MAPPING IN PARADISE

In July 2018, the UKHO awarded Fugro a contract to survey 7400km2 of the Turks and Caicos Islands in support of the Foreign and Commonwealth Office's Overseas Territory Programme. The project called for full bathymetric, topographic and orthoimagery data, collected to IHO Order 1b specification. With sparse existing survey coverage and shallow water depths (0m at shoreline to 40m at the reef edge), ALB was deemed the most cost-effective option for acquiring the project's bathymetry data. Fugro proposed using RAMMS and was subsequently awarded the contract by the UKHO. To capitalise on the system's availability in the region, the UKHO awarded Fugro a second shallow water survey comprising 2500km2 off the northern coast of Belize. This add-on work was performed immediately after completion of the primary Turks and Caicos mission in support of the UK's Commonwealth Marine Economies Programme.

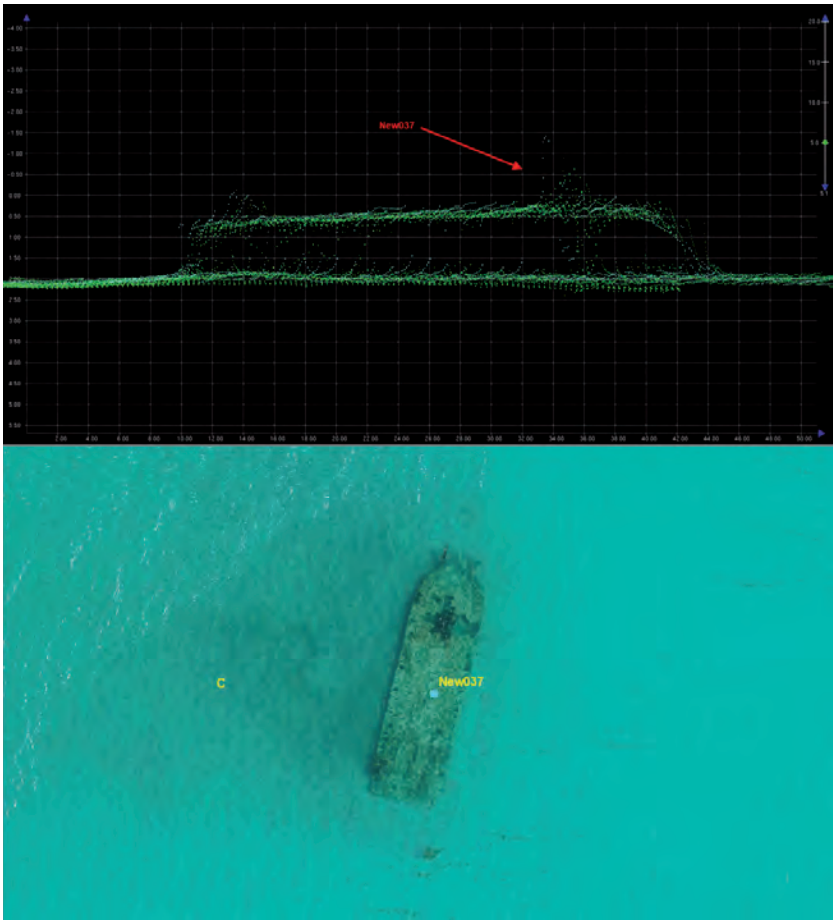


▲ *Turks and Caicos RAMMS coverage.*

▲ *ALB was deemed the most cost-effective option for acquiring bathymetry data.*

As is expected for any new technology, challenges arose during this first large-scale deployment of RAMMS, with data management chief among them. Since RAMMS records the full waveform for each pulse, raw data capture is very large. Additionally, the high-resolution orthoimagery coverage meant that each 4- to 5-hour collection flight resulted in approximately 1TB of preprocessed data. Raw data deliverables for Turks and Caicos alone totalled more than 82TB! Due to limited local infrastructure, the data could not be uploaded to Fugro's Houston data centre via a data link but had to be shipped by hard drive instead.

The project's large size and diverse survey area also tested the system. The Turks and Caicos project required long flight lines, introducing several processing challenges which impacted the ability to create LAS files in the field. Staff also needed to update the field-processing



▲ *One of 84 new wrecks discovered during the two surveys.*

module several times during the project to account for the dynamic environment that spanned the shallow, extremely reflective bank, its topography, and a very steep drop-off along the edge of the barrier reef that surrounds almost the entire island chain. The nature of the software meant that each time a significant update was applied, all the data had to be reprocessed to ensure data cohesion. Similarly, new data artefacts were discovered that had not been encountered during development, requiring some lines to be reflown to fill unexpected data gaps.

These issues aside, by the time the Turks and Caicos part of the deployment had been completed, the system workflow, software and processing routines had been refined back to the original design intention, which was to achieve initial LAS upload to the data centre in a 1:1 (flight time to processing) timeframe.

REMARKABLE ACHIEVEMENTS

In addition to achieving over 10,000km2 of bathymetric data coverage, Fugro was able to contribute to the navigational safety of both regions by identifying 84 new shipwrecks, defining the coral reef and delineating the land-water interface. Delivered data will significantly improve navigation in the region,

▲ *Modelling the potential impact of rising sea-levels.*

enabling the update of existing navigation products and the production of new, larger-scale navigation products. The interface between bathymetric and topographic data will also enable modelling of the potential impact of rising sea levels.

One of the benefits of the RAMMS pushbroom sensor is the across-track density that is achieved. At 325m above ground level, a 33cm sounding interval is achieved on each pulse, which easily exceeds the two soundings per 2km2 bin requirement for the survey. It was also hoped that the deployment would achieve nine pings per 2km2 bin over most of the area, and this was achieved for more than 95% of the survey site; only sections of deeper water, breaking waves, and poor water clarity were the exception.

Object detection probabilities for RAMMS are still being analysed over a variety of environments. However, for this project, the system repeatedly demonstrated the ability to not only detect but also delineate 2m objects. Where the seabed is highly reflective, it is possible that small objects may be lost in the overly strong return. Additional processing may be required in these circumstances to ensure effective object detection.

Given the region's excellent water clarity, water penetration met expectations, achieving depths in excess of 40m. The extremely steep slope at the edge of the bank was delineated around the entire island chain.

The huge quantity of geodata gathered by RAMMS during both phases of the project was also used for a highly detailed seabed classification product produced by Fugro's GeoConsulting group, using innovative automated geoprocessing techniques. The approach used a variety of GIS products derived from the RAMMS digital terrain model and a normalised intensity mosaic to identify areas of specific morphology and texture, requiring much less manual mapping than traditionally used.

▲ *More than 20,000 km2 of data is acquired.*

BUILDING ON SUCCESS

The UKHO project provided the perfect opportunity for Fugro to commercially launch the RAMMS system. The good water clarity and relatively favourable conditions enabled Fugro to focus on producing great data in the absence of complications presented by more challenging areas. As a result and aided by constructive feedback from the UKHO, Fugro now has a more refined processing software and a more streamlined workflow that is already showing benefits on more rapid project turnaround.

In the year since this first commercial project, Fugro has acquired more than 20,000km2 of data across the Americas. Most of this work has been completed with much smaller aircraft than would be possible using traditional ALB systems, which has reduced fuel usage and improved sustainability. Looking ahead, Fugro aims to further enhance the system by finalising Uncrewed Aerial Vehicle (UAV) deployment capabilities and enabling remote monitoring of the system, using Fugro's Office Assisted Remote Services (OARS®). ◀

More information
Learn more about Fugro RAMMS: www.fugro.com/ramms

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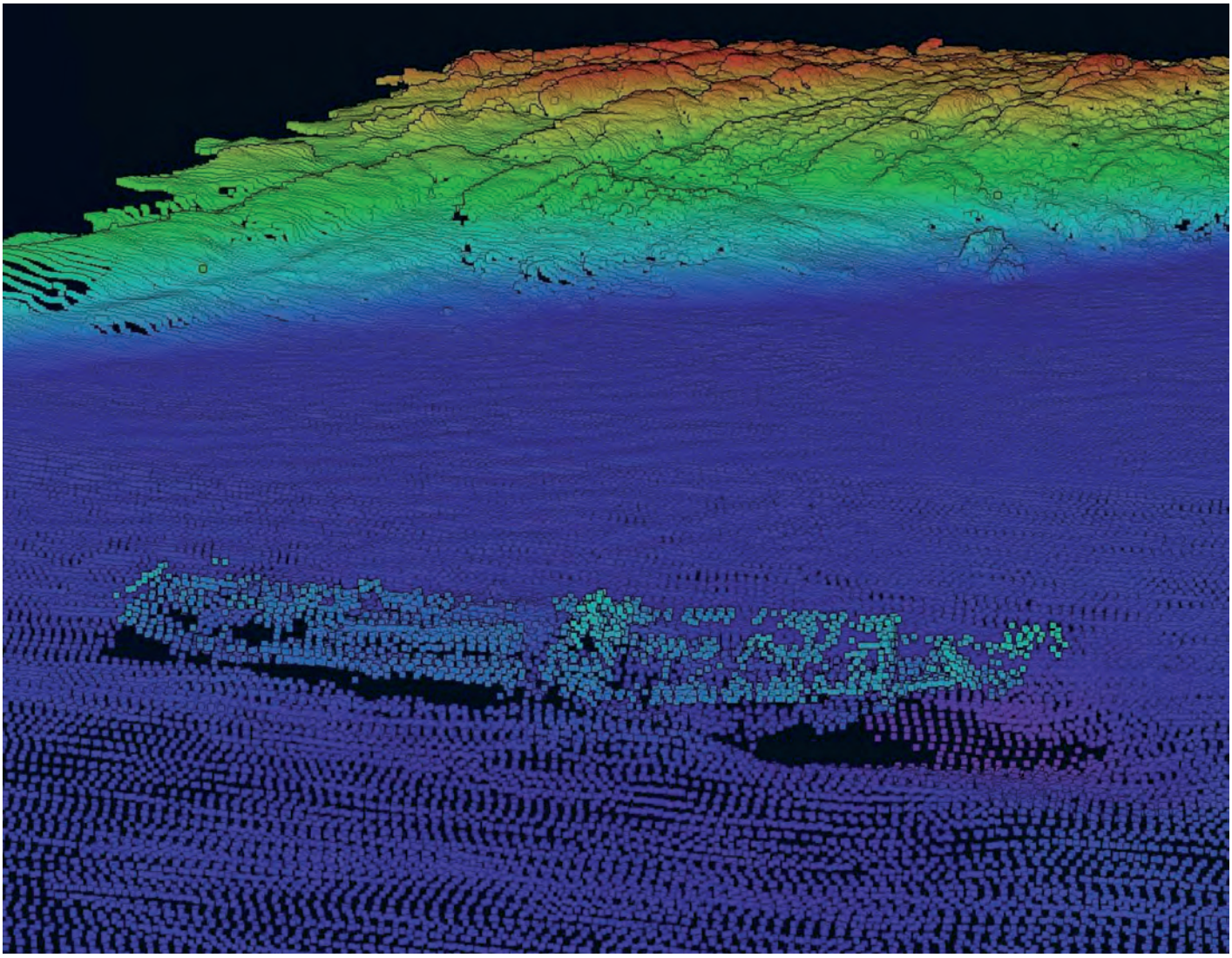
Navigate Hydrographic – the Nautical SmartChart

Hydrographic data delivery and charting for the future

Here is a question – what is the core role of a hydrographer? To map the seafloor? Provide a precise position on the water? Some may believe it is to play with lots of expensive toys on boats, while colleagues are stuck in the office. While all those answers may be correct, I am asking about the core role of a hydrographer. I would suggest that it is collecting data to provide information that companies, clients and consultants rely on to make educated and accurate decisions. This is where our value as a professional service is demonstrated. However, here is another question - how do we present that information and more to the point, could it be better?



▲ *Fig 1: Navigate makes 3D visualisation easy to allow better understanding of a hydrographer's work. (Courtesy: Sam Houston)*

CURRENT HYDROGRAPHIC DELIVERY METHODS

Hydrographers have a variety of options to present their collected information, each with their own pros and cons. The traditional nautical chart is the most familiar way of presenting hydrographic information and importantly maintains the integrity of the data. But ultimately nautical charts present 3D information in a 2D format, and this process will always bring with it some limitations.

GIS-type software is increasingly commonplace in the spatial industry because it offers benefits in data management and flexibility. While these factors alone make it a fantastic format for spatial professionals, often these individuals are not the end-users. The decision-makers, such as harbour masters and engineers, are often time-poor and hesitant about the software learning curve. Not to mention the cost barrier– most GIS software isn't cheap, and the dedicated bathymetry add-ons even more so.

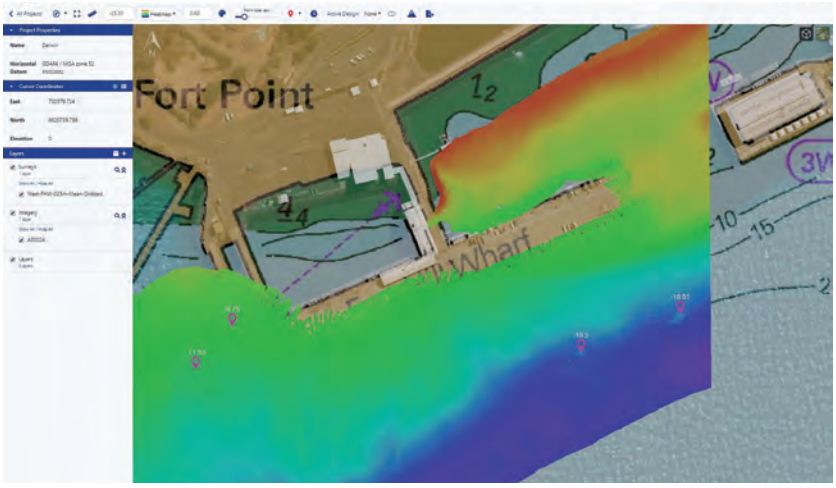
Hydrographic visualisation packages, and there are many products out there, are also used. However, when they are not feature-rich (i.e. expensive and complicated), they tend to be a freewaretype viewer that doesn't offer a lot more than simply looking at a surface or point cloud. This means they tend to be used in conjunction with another form of delivery, such as a nautical chart.

THE FUTURE OF DATA DELIVERY WITH NAVIGATE

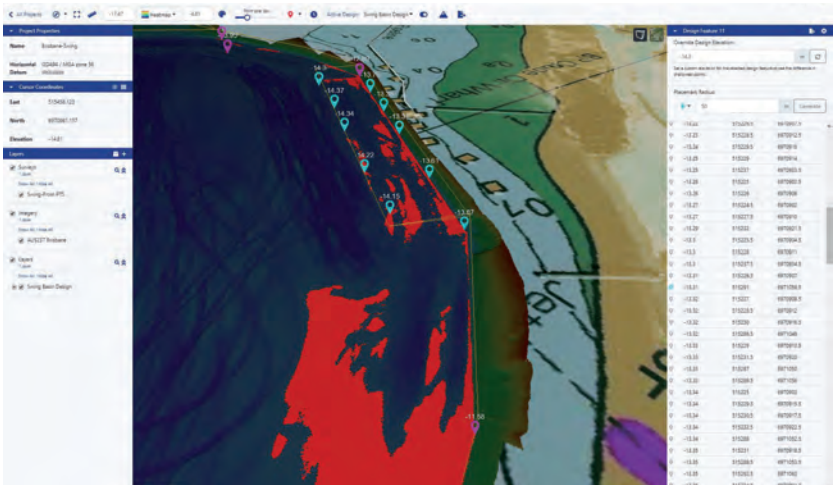
You're on a survey project, and the client requires survey data fast and often to monitor progress. You spend a large portion of your time creating paper charts, only for them to be printed, looked at for five minutes and then cast aside at the next survey update. Sound familiar? With the high cost of labour for something so inflexible and inefficient, why is the paper chart still the default mode of delivery? The reason is that available alternatives don't provide the same level of information and aren't as easy to interpret as a chart. And despite the cost of labour to produce, viewing paper charts is free, so any replacement costs need to be justified by the productivity gained. You could also send out 'raw' data, but how do you as the surveyor maintain the data integrity, or attach metadata? Considering the level of responsibility the surveyor has, one can imagine why a pdf is often preferred to a points file.

The future of data delivery comes down to presenting critical information with improved flexibility. For a hydrographer in a port – the main information being conveyed is about the navigable areas being safe for shipping. The harbour master or dredging manager will want to answer questions such as what berths have silted up, what the minimum depth is, or whether that sandbank has grown since the last survey. Not only that, but they want to know now, not in a few days when you have finally managed to format the data for the chart, QC'd the title block, soundings and contour generation, and printed them out to take upstairs.

All these reasons led to the creation of Navigate Hydrographic – the Nautical SmartChart. Navigate has been developed for an ever-modernising industry where the demand for quality results are required almost real-time. Navigate will increase speed of data turnaround, ease of use and interpretation, and ultimately increasing the value of the hydrographer's work to his or her business and client.



▲ *Fig 2: More than just a visualisation tool, Navigate takes the benefits of a hydrographic chart and brings them onto a modern platform. (Courtesy: Darwin Port)*



▲ *Fig 3: Design Analysis is one of the key features of Navigate. (Courtesy: Port of Brisbane)*

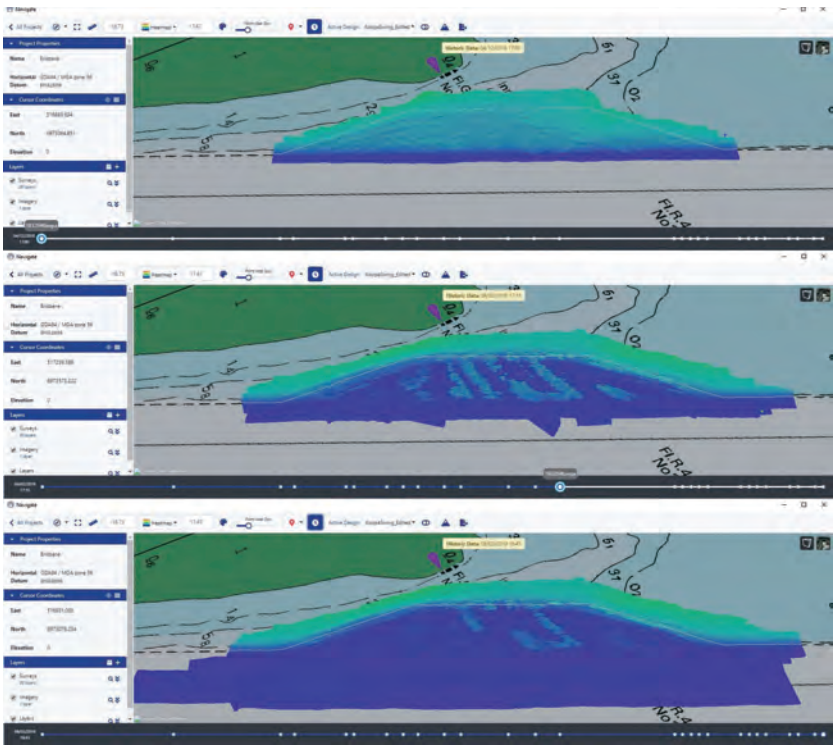
WHAT MAKES A SMARTCHART?

Navigate aims to take the idea of 3D bathymetry to the next level by not just providing raw data but delivering packaged and customisable information to clients. This information can be shared and accessed easily from anywhere around the world. However, Navigate has numerous features which make it truly smart:

- Being Approachable. When the layman thinks of spatial software, what immediately comes to mind? Google Earth. And everyone can use Google Earth. Navigate offers a modern style of

UI experience, making it easy to learn and master for non-spatial professionals.

- Metadata Management. Everything we do requires metadata, but how best to visualise this? Creating a sounding in Navigate not only flags a depth but presents the when, who, what and how the survey data was collected.
- Easy data compilation. Because Navigate attaches metadata to every data source, it can easily and automatically compile multiple surveys without input from the surveyor. Old data will be hidden by new, but never deleted. It makes it easy to visualise when a survey was carried out to see where old data needs updating. It also means that your client will always be working with the latest dataset.
- Visualisation of Navigable Depth. Minimum navigable depth is the number one question in a port. Navigate not only allows instant assessment of what the depth is but where the depth is.
- Smart Soundings. Soundings on a chart play an important role in presenting an important depth. However, charts with hundreds of soundings all over a page are an inefficient means of presenting this information. Navigate takes soundings to the next level, and makes their role, and their creation smart. This means only the relevant soundings are presented when required. Create soundings in specific areas at different resolutions and share these easily.
- Design Analysis. Ports have complicated channel designs. Berths, reaches, channels, swing basins - they all have different declared depths. Colouring data by one elevation doesn't work when the design changes. Navigate makes it super easy to see what is above each different design depth, and if necessary, make changes to the design on the fly.
- Timeline – the fourth dimension. Hydrography is as much a study of when as what depth. Navigate has the unique ability to offer true 4D data visualisation – use the time slider to see your seafloor change with each subsequent survey. If the user wants to see how the seafloor looked at each stage of construction or dredging, or pre and post-flood, Navigate can show this easily.
- Adaptability. These days, final survey deliverables are more than just bathymetry. What about backscatter? Side scan imagery? Or sun shaded models? All of these can easily be part of a Navigate project.
- Flexibility. Cope with varying resolutions. Raster based software makes it difficult to bring multiple resolutions together. Navigate allows you to have a gridded dataset in the same project as the entire sounding density survey of a seafloor feature and view them simultaneously.
- Context. Context is important to clients. Not everyone can look at a point cloud and know exactly where they are relative to everything else. That's why Navigate comes built-in with web mapping services automatically to assist the visualisation of data. All of this data is available in both 2D and 3D.
- Secure. Navigate allows compressed data to be packaged with the important metadata in a read-only format. So, as a surveyor, you can be sure the data you send isn't being tampered with, and what you prepare is what is seen by the end-user.
- Sharing. Navigate allows simple data sharing all over the world. Data is packaged, compressed and easily transferable to clients, and there is no need to configure format, datum or anything else when it is imported. Easily share read-only datasets to your client and know it will compile and update their projects correctly.



▲ *Fig 4: Our unique Timeline allows for true 4D analysis – see the seafloor change through time. (Courtesy: Port of Brisbane)*

CONCLUSION

There will always be a place for the traditional nautical paper chart in the hydrographic community, particularly for seafarer applications. But sometimes the humble nautical chart isn't enough to answer all the questions your client asks. Navigate is the software solution that incorporates the benefits of a nautical chart with the features of 3D and 4D software visualisation. It not only makes data look smart but be smart. ◀

More Information

Navigate is available for a free 30-day trial and can be licensed either on a month by month plan for flexibility and casual use, or on an annual subscription licence. Prices and further information can be found on our website: www.navigatehydro.com

Dylan Colson is an Australasian Certified Professional Hydrographic Surveyor at Level 1. With over ten years' experience in the industry, working mainly in the ports and dredging sectors, Dylan has seen first-hand how information communication is key to demonstrating the value of hydrography.

A Radical Update Was Needed

Danish Hydrographic Office Turns to GIS For Automated Maritime Charting

Denmark has challenging seascapes to map and chart. It has a rich history of nautical charting that dates back to the seventeenth century, and many of its navigational products for Greenland were created in the 1960s. When GPS started to gain prominence, a radical update was needed.

Apart from its 42-mile land border with Germany, the peninsular country of Denmark, with its scores of bays, straits, and fjords, is surrounded almost entirely by the North and Baltic Seas. Denmark is also composed of more than 400 islands, including the Faroe Islands, located in the Atlantic Ocean between the United Kingdom and Iceland. And then there's the Danish territory of Greenland, an 836,000-square-mile Arctic island whose mountains descend precipitously to the sea and whose glaciers release icebergs into labyrinthine straits and fjords.

Denmark has a rich history of nautical charting that dates back to the seventeenth century, and many of its navigational products for Greenland were created in the 1960s. The information on those charts was good and sufficient for traditional navigation, but when GPS started to gain prominence in shipping in the 1990s and early 2000s, hydrographic offices around the world had to start producing Electronic Navigational Charts (ENCs). But Denmark's existing data—especially farther north, around Greenland—did not line up with GPS points or new high-quality multibeam sonar readings. So the hydrographic office at the Danish Geodata Agency (known by its Danish acronym GST) needed to take a different approach.

The Danish Geodata Agency (GST) is building an enterprise-wide geodatabase for all its nautical data, which will make it easier to create paper and electronic charts, like this one of Greenland's west coast. (©Danish Geodata Agency—320-0208). "Though the charts were accurate for the time, we had to georectify old data with new data to produce an update," said Rune Carbuhn Andersen, head of the Arctic Division at the Danish Hydrographic Office.

But the division kept all its nautical data in separate files, and that was difficult to update. Within a few years, the Greenland group at GST turned to Esri to get help with creating a central, enterprise-wide geodatabase for all the data portrayed on both its paper and electronic charts.

"The way Esri was thinking—of data and a database structure and, eventually, potential automation—that was, in a sense, unique," said Andersen.

For Greenland, the group implemented what is now called ArcGIS for Maritime: Charting, a complete system for managing and producing maritime data and products. Maritime: Charting stores all the data in Esri's Nautical Information System (NIS), an enterprise geodatabase, which makes it easier to create data products and incorporate automation.

Development took a few years, in part because so much decades-old data needed to be cleaned and classified and in part because of substantial internal reorganization at the Danish Hydrographic Office. But the division's close collaboration with Esri paid off magnificently.

▲ *Harbour on the Danish Coast. (Courtesy: Dirk Schmidt, Pixabay)*

▲ *Hills and Danish Coast.*

"At the end of last year, the Danish Hydrographic Office produced two charts for Greenland that were 70% automated," said Rafael Ponce, executive consultant for maritime services at Esri. "It was a huge improvement."

The data modernisation project for Greenland was so successful in general that when GST needed a next-generation chart production system for all Danish waters, the choice fell again on Maritime: Charting. In February, the agency partnered with Esri and its official distributor in Denmark, Geoinfo A/S, to implement this project, which focuses on both paper and electronic charting.
"By the end of the current project, we expect to have a complete Nautical Information System for all three regions—Greenland, Denmark, and the Faroe Islands," said Ponce.

GUY NOLL, MARITIME GIS CONSULTANT, ESRI

Having readily accessible data on the world's oceans, in a system that enables this information to be used to create a range of map products, is important not only for navigation but also for understanding the 71% of the globe that isn't land. The blue economy—a reference to all economic activity that stems from or affects oceans and other waterways—generates an estimated $2.5 trillion each year and is anticipated to grow at twice the rate of the rest of the global economy by 2030.
"We're trying to help people understand their world; make good decisions from the best available data; and, where possible, identify where we need more data," said Guy Noll, Esri's maritime GIS consultant. Which is why Esri is working closely with other hydrographic offices—including the National Oceanic and Atmospheric Administration's (NOAA) Office of Coast Survey and the Lithuanian Transport Safety Administration's (LTSA) Hydrography Division, among others—to modernise their maritime mapping systems.

"The Esri platform enables the foundational technology needed to develop a marine spatial data infrastructure (MSDI) from which new products and services can be created, transforming traditional hydrographic offices into true geospatial agencies," said Ponce.

UPDATED PROCESSES FOR GREENLAND INSPIRE MODERNISED METHODS IN DENMARK

For much of GST's recent history, its hydrographic office was divided into regions: Danish waters and the Faroe Islands, with Greenland on its own. Each division did its own maritime charting and hydrographic mapping without much overlap.

It was during this period that the Greenland group began updating the island's coastline maps and conflating all its old maritime charts to keep up with the fast pace of modern technology. But data for Greenland was lacking, according to Andersen, and the group was starting from scratch in creating electronic charts, said Ponce. So the team had to establish all new data cataloguing routines and come up with its own schemas. Additionally, going from a file-based cartographic production environment to a database-driven environment was challenging.

AN UPGRADE IN MARITIME CAPABILITIES IN LITHUANIA

Lithuania's hydrographic office was Esri's first international maritime user. The office, which is part of the Lithuanian Transport Safety Administration (LTSA), was an early adopter of Esri's original nautical chart production system and used it for years.

In April, LTSA renewed its partnership with Esri; Hnit-Baltic, Esri's official distributor in Lithuania; and Quality Position Services (QPS), a subsidiary of Saab, to modernise its nautical charting and bathymetry capabilities. The hydrographic office will implement a new seabed database and nautical cartography system, as well as upgrade the automation of its ENCs and paper charts.
LTSA will also use Esri's data management capabilities to share hydrographic information across industry sectors to spur maritime-related economic growth. This will be helpful in approaching the blue economy.

"Because the hydrographic office belongs to LTSA, and LTSA uses Esri technology for other transportation needs, such as roads and highways, the platform can cover multiple domains in Lithuania," said Esri's Rafael Ponce. "Exchanging information from land to sea will be much easier, seamless, and invaluable."

"Sometimes the data was 50, 60, or more years old, coming from different sources—in some cases, it was local data. There were also sparse bathymetries, or water depth measurements," said Ponce. "Before creating the central database, the NIS, a lot of work had to be done to just clean and classify the legacy data, which was at different levels of certainty as to how accurate it was, to make it all suitable for producing navigational products."

This instilled a kind of intelligence in the process, said Andersen, because his team now does quality control on the data as it is being created. At the same time, the group is putting everything into the S-57 data model; originally a

▲ *Iceberg flow in the landscape of Greenland.*

▲ *Hills and ice in Greenland.*

data exchange standard from the International Hydrographic Organization (IHO) aimed at ensuring that all data in ENCs are properly attributed and encoded to be read by Electronic Chart Display and Information Systems (ECDIS). It is essentially obligatory to use this data model, so updating old products in S-57 will be an ongoing challenge for GST and system suppliers like Esri for years to come as they begin to also implement the new S-100 and S-101 data models currently being developed. And while GST is still devoted to making paper charts, given that they are used widely by professional mariners, the agency is focused on making ENCs. More importantly, it is operating in an ENC-first manner, which reflects where maritime mapping is headed. "With GST's data organized around the S-57 standard, the agency can extract a lot of information from it using a combination of geoprocessing tools and Python scripts to automate more and more of the processes associated with making paper charts," explained Ponce.

Now, the system that was created for Greenland is going to be expanded to Danish waters and the Faroe Islands. But the implementation will be different. "Danish waters already have a full catalogue of ENCs, but those ENCs have been maintained as independent files," said Ponce. "With the new system, GST is going to produce those in a central database. The improvement will be in streamlining production, bringing all that information into the NIS to create data products more easily and automatically. This will result in GST being able to update its products more frequently."

This could be decisive for Denmark in gaining a foothold in the blue economy. As ocean-based activities—from shipping, tourism, and fishing to offshore mining and renewable energy production—move farther north, being able to produce a variety of maritime mapping products, quickly, will be key. "Hydrographic offices around the world are facing new challenges in the twenty-first century, and Esri tools are helping them evolve and address those challenges in a better way," said Ponce.

NOAA'S COAST SURVEY CHANGES FOCUS TO MANAGING DATA ITSELF

NOAA's Coast Survey, which delivers navigational products and services for the United States' 3.4 million square nautical miles of exclusive economic zones and 95,000 miles of coastline, was the first hydrographic office to turn to Esri for nautical charting. In 2007, Coast Survey's Marine Chart Division (MCD) began using ArcGIS technology to manage its hydrographic data and facilitate the production of ENCs and paper charts. By 2014, the organization was changing its focus from making cartographic representations of its data to managing the data itself.

With the Products on Demand functionality in ArcGIS for Maritime: Server, users can create a paper chart, like this one of Charleston Harbour in South Carolina, from Coast Survey's electronic chart database.

"As Coast Survey matured as a GIS organization, staff realised that their workflow wasn't very efficient," said Noll. "Esri evolved with the organization and gave it new tools, including Products on Demand in ArcGIS for Maritime: Server, plus Python-scripted geoprocessing tools that allowed it to automate certain parts of its production."

"It's still an iterative process," said John E. Nyberg, chief of MCD, "but we do have all our data in a database now, and we've moved to an ENC-first approach."

Unlike at GST, however, Coast Survey is edging away from paper charts—encouraging mariners to use them more as backups—and more towards ENC-first. This is an important shift, given that, as Nyberg puts it, Coast Survey's charting dataset is a foundational base map for the blue economy.

"As the blue economy grows, there's a need for everything within it to be working from a common framework, using common data content," said Noll. "That's what Coast Survey and other hydrographic offices like it maintain." Thus, commercial ships with ever-improving navigational systems can exploit this data. Recreational boaters, of which there are many in the United States, can use Coast Survey's ENCs directly or through partner providers. And all users—from professional mariners to anglers in tiny johnboats—can get up-to-date, high-resolution charts. "We've moved away from the notion that ENCs and paper charts have to be equal," said Nyberg. According to Noll, the fact that Coast Survey has gone ENC-first opens the door to a broader production paradigm.

"Because Coast Survey is focusing most of its effort on the data accuracy and quality of the database, and then relying on ArcGIS tools to flag and create new products—soon, automatically—that means it can update its ENCs every week," he said. Nyberg hopes that Coast Survey will eventually update its ENCs more often, potentially even as the data is added to the database. ◀

▲ *Resund Bridge to Copenhagen.*

▲ *Qaarsut in Northwestern Greenland. (Courtesy: Greenland Tourism)*

▲ *Tasiilaq. (Courtesy: Wikimedia)*

S2C TECHNOLOGY: COMMUNICATION AND TRACKING COMBINED

- time, space and cost-saving solutions
- low power consumption for autonomous operations
- advanced data delivery algorithms, addressing and networking, remotely configurable settings
- extendable platform with multiple configuration options: power-saving Wake Up module, acoustic releaser, additional sensors, custom solutions, OEM versions available

USBL POSITIONING SYSTEMS

simultaneous positioning and communication - no need to switch between positioning mode and modem mode

- flexible SiNAPS positioning software
- reliable data transmissions
- range: up to 8000 m
- accuracy: up to 0.04 degrees

LBL POSITIONING SYSTEMS

highly accurate, precise and stable performance, simultaneous positioning and data transmissions

- flexible SiNAPS positioning software
- reliable data transmissions
- range: up to 8000 m
- accuracy: better than 0.01 m

UNDERWATER ACOUSTIC MODEMS

reliable data transmissions even in adverse conditions, customizable R-series modems, light and compact M-series "mini" modems, the HS high-speed modems, special editions for developers, S2C communication and positioning emulator - remote access or standalone device

- range: up to 8000 m
- depth: up to 6000 m
- data rate: up to 62.5 kbps

NEW!
ULTRA-COMPACT "TINY" MODEMS

S2C M (left) and the new S2C T "tiny" modem - 20% smaller and lighter

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