HYDRO INTERNATIONAL

Special edition:
Oceanology International 2024

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Issue 1 2024
Volume 28

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Geomares
P.O. Box 112, 8530 AC Lemmer,
The Netherlands
T: +31 (0) 514-56 18 54
F: +31 (0) 514-56 38 98
hydro-international@geomares.nl
hydro-international.com

 ISSN 1566-9076

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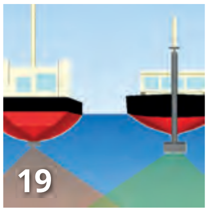
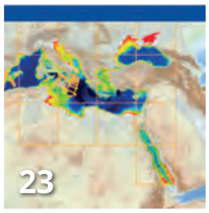
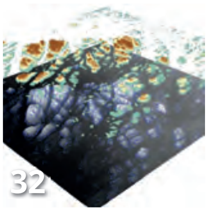






Cover Story
Global Fishing Watch uses AI and satellite imagery to map vessel traffic and offshore infrastructure to provide an unprecedented view of previously unmapped industrial use of the ocean, as seen here in the North Sea. The North Sea stands out as one of the busiest and most industrious bodies of water globally, bustling with activities integral to the energy transition. (Image courtesy: Global Fishing Watch)

Human and machine

Throughout history, tech optimists have always been opposed by tech pessimists. A clichéd example is the introduction of the steam train, allegedly lamented by tech pessimists who were afraid that cows would produce less milk when exposed to a train passing every day. And not so long ago, when Wi-Fi started to become common in households, many people would turn the signal off at night, afraid of radiation. Overly concerned or cautious behaviour when new tech enters the arena is as old as humanity, as are overly optimistic expectations about new tech that will change 'everything for the better'. Think of the pioneers of the World Wide Web, who were so certain of the good that internet would bring to individual citizens and societies as a whole. It is generally accepted now that this was all a bit too optimistic. Artificial intelligence is probably stirring discussion in society just as much as the introduction of the steam train as a means of transport did, or the internet as a source and communication tool.

In this issue of *Hydro International*, we tap into that discussion, trying to shed light on the pros and cons of the deployment of AI in hydrography. We asked Mathias Jonas, secretary-general of the IHO, to articulate his thoughts on the topic in an opinion editorial (see pages 10–11). Jonas opens his piece with the question whether human hydrographic activities will be substituted by AI. He concludes that hydrography of the future will not be feasible without the input and knowledge of expert human hydrographers.

I had the pleasure of visiting Kongsberg Discovery in Horten, Norway, late last year (see pages 52–54 for a report of my visit). Obviously, Kongsberg – like many other companies in the business – are keeping a finger on the pulse in order to follow the right strategy for the business. Kongsberg Discovery's CEO Martin Wien Fjell explained how they are closely following developments in AI, and focus areas within the company such as hydroacoustics, robotics, inertial navigation, GNSS positioning, laser and radar are benefiting already from this disruptive technology. Keeping a close watch on developments also means that Kongsberg is identifying where hurdles or overexaggerated expectations may arise. One warning for the overly optimist (or a comforting thought for the pessimist): ChatGPT will not become a hydrographer, and the human factor will remain important to ensure quality and accuracy, says Kjetil Jensen, multibeam specialist with Kongsberg Discovery.

ChatGPT agrees with both Jonas and Jensen. In a prompt to the AI machine, Jonas asked whether the tech would substitute human hydrographic activities, to which it answered 'no'. Parallel to the ever-growing role of machine learning, human input and contact are still important, as I experienced once again during my inspirational visit to the 'trendwatchers' in Horten and hope to experience much more of during Oceanology International, being held at ExCeL, London on 12–14 March. The show and conference will be a textbook example of the combination of human and machine. My colleagues and I will be there (stand S350) to meet, discuss and exchange, and we are looking forward to jointly giving substance to the human factor in hydrography, together with all of you attending the biggest event of the year!

Durk Haarsma
director strategy & business management
durk.haarsma@geomares.nl

Sonar hints at potential discovery of Amelia Earhart's long-lost plane

In the annals of aviation history, a captivating mystery endures – the perplexing vanishing act of pilot Amelia Earhart. Renowned American explorer Tony Romeo confidently claims to have identified the wreckage of the legendary aviator, placing it at a depth exceeding five kilometres on the ocean floor, nestled between Hawaii and Australia. This revelation unveils a fascinating underwater secret, strategically positioned midway between these two iconic locations. The exploration for the wreckage was markedly advanced with the crucial involvement of Kongsberg Discovery's HUGIN 6000.

A team of underwater archaeologists may be on the verge of unravelling the enigma surrounding Amelia Earhart's disappearance, as Deep Sea Vision, a private company, claims to have successfully pinpointed the wreckage of her plane. Utilizing sonar data obtained from a deep-sea drone, the flat and sandy ocean floor yielded slightly blurred but captivating sonar images, showcasing an intriguing airplane-like silhouette. This discovery marks a significant stride towards shedding light on the enduring mystery of the iconic aircraft's disappearance. Despite the lack of clarity in the image, several experts consider it intriguing enough to merit a second, more detailed examination.

▲ *Amelia Earhart is pictured standing before the Lockheed Electra, the aircraft in which she disappeared in July 1937. (Image source: NASA)*

N-Sea secures Geo Ranger for long-term subsea operations

The N-Sea Group has formalized an agreement with Geo Plus for the long-term charter of the Dutch-flagged vessel the *Geo Ranger*, a cutting-edge hybrid survey and ROV support vessel. This vessel will operate alongside the *Geo Focus*, already under the management and control of N-Sea.

▲ *According to Geo Plus, the Geo Ranger offers a seamless experience with its 'plug & go' solutions, allowing users to operate the vessel effortlessly, as if it were their own.*

Designed with meticulous attention to both crew and survey equipment, the fuel-efficient *Geo Ranger* boasts advanced on-board technology, including diverse sensors and a plug-and-play system for integrating additional project-specific customer equipment. With its emphasis on enhanced workability, durability and flexibility, the *Geo Ranger* has the potential to establish a new benchmark for survey vessels.

The *Geo Ranger* is widely regarded as the top survey vessel in its class, offering a range of features that set it apart. One key aspect is its impressive workability, capable of handling significant wave heights of up to two metres. The vessel is designed with plug-and-go solutions, ensuring a hassle-free mobilization/demobilization process and featuring quick and secure equipment installation. Moreover, the *Geo Ranger* comes standard with high-class survey equipment.

Fugro enhances fleet capabilities with two geotechnical vessels

▲ *The Fugro fleet, including the Fugro Frontier, will soon grow with two new platform supply vessels for geotechnical use. (Image courtesy: Fugro)*

Fugro has finalized an agreement to acquire two platform supply vessels, namely *Sea Goldcrest* and *Sea Gull*, to be utilized as geotechnical assets. This strategic move reflects the company's anticipation of expanding opportunities in the offshore wind sector.

The offshore wind market is set to experience robust growth, propelled by the recent commitment made at the UN Climate Summit COP28 to triple the world's renewable energy capacity by 2030, with a significant portion expected from offshore wind sources. Fugro's acquisition aligns with its strategic intent to capitalize on the unfolding opportunities in this expanding market.

Vessels are key strategic assets for maintaining Fugro's market-leading position. As communicated during the Capital Markets Day in November, part of Fugro's strategy for the coming four years is to secure long-term vessel capacity, especially for the global offshore wind market, which has a particularly large need for mapping of soil composition and its associated properties via the extraction and testing of soil samples. These activities cannot be executed with smaller and/or uncrewed platforms for the foreseeable future. The addition of these two recent vessels (built in 2019 and 2020 respectively) to its owned fleet will further strengthen Fugro's ability to address the market demands and shortage in geotechnical-capable vessels.

Teledyne Marine launches AUV service centre in Poland

Teledyne Marine announces the inauguration of a service centre for autonomous underwater vehicles (AUVs) in Poland. Established in collaboration with Enamor, this venture underscores its ambition to deliver exceptional support and services to customers in Poland and mainland Europe.

Enamor, headquartered in Gdynia, Poland, is a distinguished research and production company focusing on high-end technology projects in navigation, communication, hydrography and automation. Its partnership with Teledyne Gavia has thrived for over a decade, stemming from the initial delivery of Gavia AUVs to Polish Navy EOD divers in 2012, followed by subsequent Gavia deliveries for the Kormoran class MCMVs.

In the first half of 2023, Enamor's engineers and technicians underwent rigorous training at Teledyne Gavia to conduct AUV maintenance routines in Poland. Consequently, Enamor has officially been appointed a regional service centre for AUVs in Europe, and is well-positioned to provide quality service and support.

▲ *A new AUV service centre by Teledyne Marine is now operational in Gdynia, Poland.*

Unmanned survey captures detailed seafloor imagery in marine protected area

The National Oceanography Centre (NOC), working with the University of Southampton and the Department for Environment, Food and Rural Affairs (Defra), recently completed a Fully Autonomous Marine Protected Area Seafloor Survey. This survey will help it to understand the suitability of using autonomous underwater vehicles for UK offshore marine monitoring and establish to what extent such systems can help the UK government meet its increasing marine monitoring ambitions.

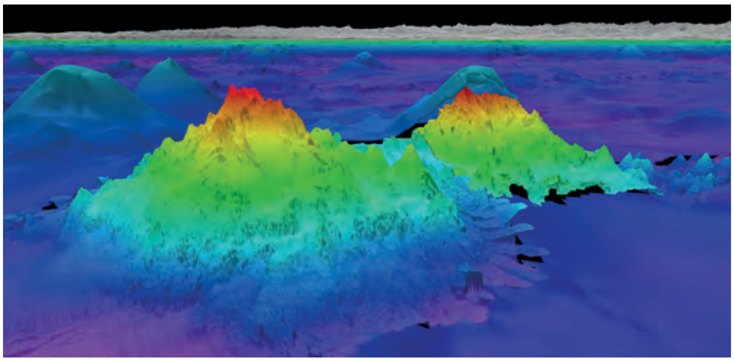
NOC conducted the fully autonomous seafloor survey of the Central Fladen Nature Conservation Marine Protected Area, which is located some 140km south-southeast of Lerwick (Shetland), using an Autosub Long Range (ALR), famously known as Boaty McBoatface, launched from shore. The ALR carried the University of Southampton's 'BioCam' instrument, a three-dimensional seafloor imaging system that comprises a stereo pair of cameras, dual LED strobes and dual line lasers. Operated together, these instruments generate georeferenced, colour-corrected conventional still images, as well as texture maps and corresponding microtopographic maps of the seafloor.

The data gathered will enable the subsequent assessment of seafloor type and condition and abundance and identity of seafloor-related fish and larger invertebrate animals, and provide evidence of human impacts on the seabed environment (physical disturbance of seabed by trawling and presence of litter, for example).

Research vessel finds four new seamounts in high seas

The crew of Schmidt Ocean Institute's research vessel *Falkor (too)* recently discovered four underwater mountains – the tallest of which exceeds 2.4km in height – during a January transit from Golfito, Costa Rica, to Valparaiso, Chile, as announced by the organization today. These new seamounts, ranging in size from approximately 1,591 metres to 2,681 metres, supplement the crew's discovery in November 2023 of an underwater mountain twice the height of the Burj Khalifa, measuring 1,600 metres, in international waters off Guatemala.

Using multibeam mapping, Schmidt Ocean Institute's marine technicians and trained hydrographic experts John Fulmer and Tomer Ketter confirmed that these seafloor features had not been previously included in any bathymetric database. The discovery of the seamounts occurred as the technicians plotted a course to examine gravity anomalies during the transit from Costa Rica to Chile. Alterations in the seafloor's topography manifest as subtle shifts on the ocean surface; a deep trench induces a slight depression, while a mountain generates an almost imperceptible bump atop the ocean. These subtle indications assist experts in making discoveries and crafting more precise maps of the seafloor.



▲ *Schmidt Ocean Institute experts recently uncovered the largest of four seamounts. This significant find occurred during a mapping transit from Costa Rica to Chile in January 2024. (Image courtesy: Schmidt Ocean Institute)*

YellowScan enters hydrography market with bathymetric UAV-Lidar solution

YellowScan, a familiar name in the mapping and land surveying realm, is making a noteworthy entrance in the hydrographic sector with the introduction of its pioneering UAV-based bathymetric Lidar solution. The YellowScan Navigator made its debut at CES 2024, marking a new step for the French company.

Since its inception in 2012, YellowScan has become a household name in the geospatial industry, pioneering innovative Lidar mapping from drones. The company has consistently delivered precise instruments that significantly enhance the day-to-day operations of numerous surveyors. It has earned a reputation for its commitment to developing outstanding products that effectively address the evolving needs of the market.

YellowScan is making a notable advancement in the hydrographic sector with the introduction of the YellowScan Navigator. This innovative solution addresses the crucial requirement of surveyors to accurately map underwater topography in rivers, ponds and coastal regions. The YellowScan Navigator is best characterized as a premium bathymetric Lidar solution specifically crafted for drone deployment. The system integrates a meticulously developed laser scanner, honed over five years and subjected to rigorous testing to ensure peak performance. According to Tristan Allouis, CTO of YellowScan, the YellowScan Navigator addresses an unmet need in the mapping market and supports society in tackling environmental challenges: "As someone who started his career working on bathymetric Lidar data, I've always pursued the vision of developing my own system. Mastering hardware design has enabled us to develop advanced processing algorithms and push the system's performance beyond state-of-the-art."

▲ *Illustrating YellowScan Navigator's mounted bathymetric Lidar on a UAV for precise hydrography data acquisition. (Image courtesy: YellowScan)*

Exail Rovins Nano integration strengthens Sapura's subsea capabilities

▲ *Sapura ROV equipped with an Exail Rovins Nano INS.*

Sapura, a pre-eminent Brazilian provider of subsea services, recently procured eight Exail Rovins Nano inertial navigation systems (INS). Integrated into Sapura's esteemed fleet of remotely operated vehicles (ROVs), the deployment of Exail INS is poised to significantly elevate the capabilities of Sapura's ROVs in the meticulous offshore installation of subsea equipment.

Ensuring highly accurate navigation down to 6,000 metres, Rovins Nano INS will help Sapura to lay flex pipes and deploy subsea hardware onto the seabed, such as templates and manifolds, rigid jumper spools and tie-in spools.

The Rovins Nano, equipped with advanced sensors such as accelerometers and gyroscopes, will function as the central component in the ROV's navigation and positioning system. It will play a vital role in precisely determining the ROV's position, orientation and velocity, which is essential for the accurate positioning and installation of subsea equipment. This integration is set to optimize Sapura's overall high operational standards such as efficiency and accuracy.

Felipe Jesus, ROV manager at Sapura, stated: "Our decision to collaborate with Exail for this upgrade was motivated by the goal to modernize our existing systems using cutting-edge technology. The precision and reliability of Exail's INS align perfectly with our commitment to excellence in subsea operations. This investment underscores our dedication to staying at the forefront of technology and delivering exceptional service to our clients."

IHO welcomes Cabo Verde as 99th Member State

The Republic of Cabo Verde, an archipelago located 500km off the west coast of Africa in the Atlantic Ocean, has taken a stride towards improving its hydrographic capacity by becoming the 99th Member State of the International Hydrographic Organization (IHO). This strategic move positions Cabo Verde at the centre of international cooperation in the area of ocean affairs, unlocking a myriad of benefits for the nation and its rich marine environment.

As a fully-fledged IHO Member State, Cabo Verde will be able to actively engage in relevant IHO Working Groups and Project Teams. This will allow it to stay abreast of advancements in nautical cartography, technology and ocean data, while also enabling its voice to be heard on matters of importance. It also gains access to the full IHO capacity-building programme, fostering the development of its hydrographic capabilities.

"There are several reasons why it is important for Cabo Verde to develop its national hydrography service: to improve the safety of navigation in the mid-Atlantic region and around the archipelago, but also to support the development of both recreational and sporting nautical tourism activities, know and identify possible living and non-living marine resources, and mitigate the effects of climate change considering that Cabo Verde is a small island state and ecologically fragile," said Dr Seidi dos Santos, president of the Board of Directors, IMP (Maritime Port Institute).

FGI harnesses Fraunhofer's Lidar tech for maritime surveys

▲ *Effective condition monitoring of underwater infrastructure, including offshore wind turbines, oil rigs, pipelines and submarine cables, is made possible through the utilization of optical sensors. (Image courtesy: Fraunhofer IPM)*

The esteemed Finnish Geospatial Research Institute (FGI) is set to utilize advanced Lidar systems developed by the Fraunhofer Institute for Physical Measurement Techniques IPM for future maritime surface surveys. Anticipating a significant advancement in data quality and field measurement efficiency, the state-run research unit is collaborating with Fraunhofer IPM on a joint project. Together, they aim to create a compact sensor platform for laser-based inspections of critical underwater infrastructures such as offshore wind turbines.

Lidar systems excel in measuring over long distances and provide precise 3D data. While laser-based systems are commonplace for geodetic measurements on land, underwater mapping and topographic measurements have traditionally relied on cameras and sonar due to light attenuation and turbidity underwater. However, Fraunhofer IPM's introduction of two Lidar systems capable of underwater 3D measurements and aerial bathymetric measurements marks a significant advancement in the field.

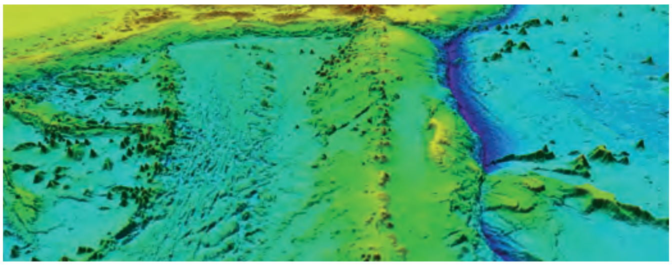
The underwater Lidar system ULi maps infrastructure underwater with millimetre precision using the pulsed time-of-flight method. The system scans statically or when in motion onboard an underwater vehicle or boat. Encased in a pressure-resistant housing, ULi can dive to depths of several hundred metres and measure objects across distances of several tens of metres. The system takes up to ten times more precise measurements than some sonar systems and generates an accurate 3D model of the object.

Seabed 2030 strengthened by ARGANS dataset contribution

ARGANS, a leading Earth observation company, has contributed a significant dataset of 8,000 square kilometres to The Nippon Foundation-GEBCO Seabed 2030 Project – the project seeking to inspire the complete mapping of the entire ocean floor by 2030. This contribution was made possible thanks to the European Space Agency (ESA), which supported projects leading to the generation of satellite-derived bathymetry.

The notable data contributed by ARGANS covers an area of 8,000 square kilometres in regions that conventional ocean vessels typically cannot reach. Using cutting-edge satellite-based remote sensing technologies, ARGANS collected high-resolution bathymetric data in these remote and challenging areas, filling critical gaps in Seabed 2030's mapping database.

Seabed 2030 is a collaborative project between The Nippon Foundation and GEBCO to inspire the complete mapping of the world's ocean by 2030 and to compile all bathymetric data into the freely available GEBCO Ocean Map – it is also a formally endorsed Decade Action of the UN Ocean Decade. GEBCO is a joint programme of the International Hydrographic Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) and is the only organization with a mandate to map the entire ocean floor.



▲ *The oceans cover over two thirds of our planet, yet we know more about the surface of Mars than that of our own seafloor. Seabed 2030 aims to fully map the global ocean floor by 2030. (Image source: Seabed 2030)*

When will human hydrographic activities be substituted by artificial intelligence?

By Mathias Jonas, Secretary-General IHO

Admittedly, the title of this column, formulated as a question, is deliberately provocative. The first reaction of those who read it and are interested in hydrography for professional reasons will probably be 'never', or 'not during my career'. Some may simply say: 'wrong question'. If you read primarily non-technically orientated media, you get the impression that this technology can provide answers to almost all questions – especially those that humanity has never asked before. This seems unlikely to me, and it is therefore worth first of all systematically discussing the possibilities and limitations of the applicability of this new technological wizardry in order to then assess its usability in hydrography. I think that both the question and the possible answers first need to be clarified as to which areas of hydrographic activities will be affected by the use of artificial intelligence.

One of the smartest conversations I have read on this topic so far was conducted by Lars Schiller, editor in chief of the German Hydrographic Society's trade journal, with Alexander Reiterer from Fraunhofer IPM. You can either download the entire interview [https://www.dhyg.de/index.php/de/hydrographische-nachrichten/hn-archiv, HN119.pdf] and have it translated by AI-driven software or follow my highly summarized interpretation here. One of Alexander Reiterer's key statements for understanding the possibilities of AI is the following:

> *AI is trained for a clear task, by humans. This is a very complex process in which algorithms are used that enable self-learning. For certain tasks, the machine is clearly superior to humans after this learning process. For example, in very lengthy and complex pattern-recognition tasks involving vast amounts of data and parameters, the capacity of an AI can be huge with the computing power available today. We cannot expand and upgrade the human brain at will. And: AI does not get tired. It can reliably complete very strenuous tasks and make logically correct decisions after hours of computing work.*

Modern hydrographic measuring systems – whether hydroacoustic systems, laser scanners or satellites – produce large quantities of high-precision measurement data with constantly increasing resolution. Today, it is often not the lack of data but the effort required to refine, normalize and convert the data into products that is the real bottleneck. Timely processing, quality assessment, visualization and ultimately interpretation require completely new methods of data analysis – precisely those that AI can offer. This is not just about the topography of the seabed, as hydrography is increasingly focusing on the construction and monitoring of industrial structures under water. There are many examples of AI applications for such purposes in the land area that can be transferred to the wet area. The maritime engineering sciences must take inspiration from the geodesists and surveyors in the land sector – and even better – work together with them. The interests of both areas meet at the coastline, whose course, which is constantly changing due to natural dynamics and human activities, should be able to be determined much more precisely from the various data sources with the help of AI methods.

Today, data processing in hydrography usually takes place downstream of the initial survey. AI could potentially change this if the initial pattern recognition and evaluation takes place during the ongoing measurement process, for example on an autonomously operating measuring device carrier that automatically adapts the mission sequence on this basis in a control loop, so to speak.

In my opinion, there is another future AI use case that does not directly concern the collection and processing of hydrographic information, but which will become relevant with the planned introduction of the IHO's S-100 standardization concept. The plans for a future S-100 ECDIS foresee transmitting a variety of maritime geodata on board to make navigation safer and more effective. Let's assume that all this data – electronic nautical charts, detailed bathymetry, water levels, currents and marine weather – is available on board everywhere and at all times. How can it then be analysed? Should this be simply by visualization in superimposed layers, or should intelligent AI-controlled filters identify hazards, derive route recommendations and control collision avoidance manoeuvres? And, following on from this thought, is autonomous shipping even conceivable without AI?

This issue of *Hydro International* focuses on the use of AI in hydrography and I am looking forward to learning about further fields of application for this powerful technical process that can improve our picture of undersea conditions and make them more complete, so that we can use them with caution for our purposes. To achieve this, the use of AI in our discipline must also find its way into the relevant training programmes for hydrographers because, without knowledgeable experts, hydrography will not be feasible even in a future supported by AI.

P.S.: Contrary to my usual approach, I wrote this article in my German mother tongue and had it translated by an AI-assisted online translation service. I also sent the question I asked at the beginning to ChatGPT. Here is the result:

As of my last knowledge update in January 2022, artificial intelligence (AI) has made significant advancements in various fields, including hydrography. Hydrographic activities involve the measurement and description of the physical features of bodies of water, including oceans, seas, lakes, and rivers. While AI has been employed in aspects of hydrographic data processing and analysis, the complete substitution of human hydrographic activities by AI is a complex and evolving process.

As of now, AI is often used to assist hydrographers by automating certain tasks such as data analysis, charting, and navigation. However, human expertise is still crucial for tasks that require judgment, decision-making, and the interpretation of complex situations.

The timeline for when AI might fully substitute human hydrographic activities is uncertain and depends on various factors, including technological advancements, regulatory frameworks, safety considerations, and societal acceptance. Additionally, certain tasks within hydrography may be more amenable to automation than others.

It's essential to stay updated on the latest developments in AI and hydrography to assess how the integration of AI technologies progresses over time. Keep in mind that opinions on the pace and extent of AI substitution can vary, and the information provided here is based on the state of knowledge as of January 2022.

Not bad at all. ■

▲ *Mathias Jonas, Secretary-General of the International Hydrographic Organization (IHO).*

How drones and sensor miniaturization are revolutionizing topobathymetric applications

The impact of topobathymetric technologies in hydrography

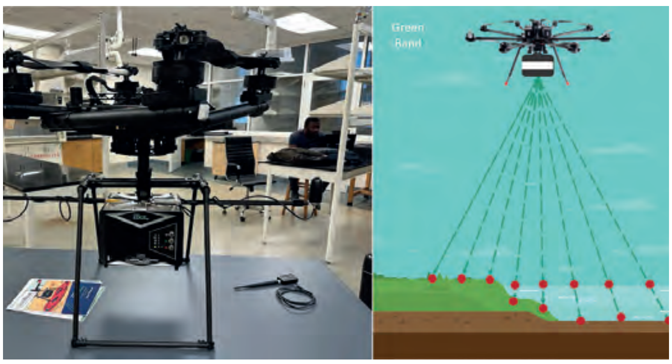
By Salman Bashit and Narcisa Pricope

In the quest to unravel the mysteries beneath our planet's water bodies, topobathymetric technologies emerge as a beacon of innovation. Among them, Lidar and sonar sensors mounted on uncrewed aerial systems (UASs) are pushing the boundaries of what is possible. Offering unprecedented precision in mapping underwater landscapes, these technologies are revolutionizing hydrography, environmental monitoring and coastal management. This article delves into the latest advancements in topobathymetric Lidar and sonar, highlighting their critical role in understanding and protecting our aquatic environments. From its origins to its future potential, we explore how Lidar technology illuminates the depths like never before.

Bathymetry, the study of underwater topography, plays a crucial role in various fields by mapping the seafloor to support navigation, scientific research and environmental management. It involves collecting data to create detailed charts used in navigation, to study seafloor profiles for biological oceanography, to assess coastal erosion and to monitor sea-level rise. This data is vital for safely managing natural hazards such as floods and river erosion, ensuring navigable waterways, and aiding in the design and maintenance of ports, harbours and urban planning. Topobathymetric data, which merges topographic and bathymetric information, further enhances our understanding of both terrestrial and aquatic environments.

Trending bathymetric surveying technologies

Numerous techniques have been used over the years to collect bathymetric data. These include hydrographic surveys, ship/boat-based sonar, airborne topobathymetric Lidar, satellite-derived bathymetry (SDB), advanced topographic laser altimeter systems (ATLAS) and, more recently, UAS bathymetric Lidar and UAS bathymetric echosounder/sonar. Moreover, marine vessels are equipped with sonar systems featuring both multibeam echosounder (MBES) and single-beam echosounder (SBES) configurations. Significantly, advancements in acoustic seabed mapping now involve the use of multifrequency multibeam sonars, allowing for the simultaneous collection of submerged bottom data at various frequencies within a singular survey. This technological capability significantly augments the precision and thorough characterization of underwater terrains, especially in deep water bodies. Moreover, autonomous underwater vehicles (AUVs), underwater remote-operated vehicles (ROVs) and unmanned surface vehicles (USVs) have also been utilized to collect bathymetric data. Sonar technologies excel in deep-water surveys due to their superior



▲ *Figure 1: UAS-mounted green band Lidar sensor. (Photo and illustration by the authors)*

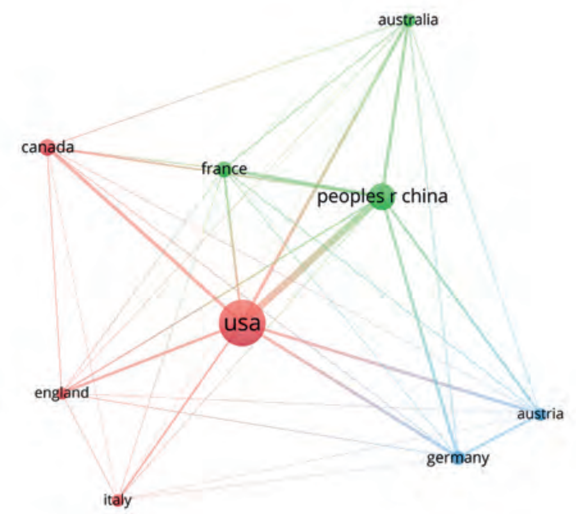
▲ *Figure 2: UAS-mounted sonar data collection using SPH Engineering's echosounder probe at the Intracoastal Waterway, Wilmington NC. (Photo by the authors)* water penetration and detailed data collection capabilities. However, options for reliable and accessible technologies in shallow-water environments are limited. Emerging technologies such as UAS-Lidar and UAS-sonar are addressing this gap, offering promising advancements for shallow-water data collection.

Pros and cons of the technologies

Various bathymetric data collection technologies offer their own set of advantages and challenges. Manual hydrographic surveys, while accurate, are labour-intensive and prone to human error, making it difficult to cover large areas effectively. Ship- or boat-based sonar, ideal for large surveys, faces limitations in shallow waters, involves high costs and requires specialized training. Airborne topobathymetric Lidar allows for quick data collection but demands clear water for effectiveness and is constrained by accessibility and cost issues, particularly in coastal area surveys. Additionally, SDB provides wider spatial coverage and is mostly suitable for coastal water but it has less depth accuracy than MBES and SBES and is highly dependent on prediction algorithms. ATLAS's nearshore bathymetric mapping with ICESat-2 shows nearly one Secchi depth mapping up to 38 metres, highlighting its potential in bathymetry surveys[1]. However, this technology requires enhancements in the geolocation capabilities of the data.

AUVs are perfectly suited for exploring challenging environments, such as deep-sea hydrothermal vents or areas beneath polar ice sheets, due to their autonomous operational capabilities. They fill the crucial gap in spatial resolution between systems that require vessels, such as multibeam echosounders and sidescan sonars, and those mounted on ROVs, enhancing overall data collection capabilities. Capable of diving up to 6,000 metres, deep-water AUVs are pivotal in scientific exploration, providing unmatched spatial resolution and navigation precision near the ocean floor, outperforming traditional surface or towed survey equipment such as sidescan sonars[2] and cameras. Although AUVs, or ROVs, provide real-time data collection, they are expensive and complex to operate.

Advances in UAS-green band Lidar and UAS-echosounder technologies are significantly enhancing shallow-water bathymetric surveying capabilities. When leveraging drone technologies, green-band Lidar offers an efficient and cost-effective means for mapping underwater landscapes, although its effectiveness is contingent on water clarity and depth penetration capabilities, which are still being optimized. Conversely, the UAS-echosounder, which is under development, promises to revolutionize underwater data collection with its lightweight design and superior water penetration abilities, potentially outperforming the UAS-green band Lidar.

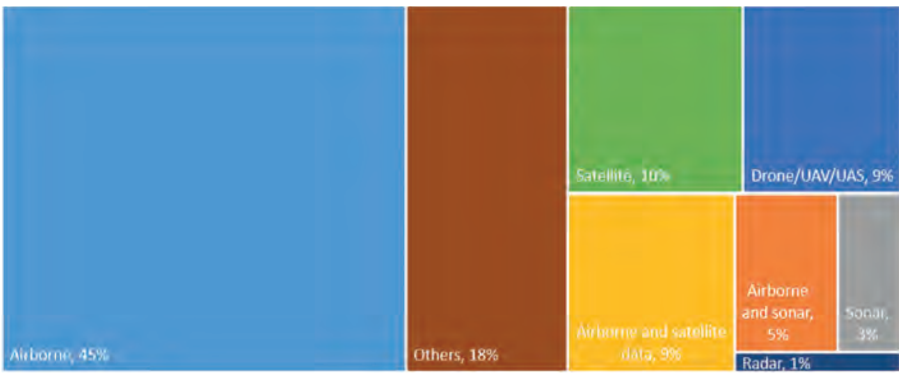


▲ *Figure 3: World countries ranked by the number of bathymetric-related publications, showing the US with the highest number of publications among the top nine countries. A larger circle represents a higher number of publications.*

Many countries, universities, governments and non-governmental organizations are actively involved in bathymetric research, as shown in Figure 3, which highlights countries where bathymetric research is being published the most, following a systematic literature review[3].

Current state of UAS bathymetric survey technologies

The CZMIL (Coastal Zone Mapping and Imaging Lidar) is a comprehensive Lidar-imagery hardware-software suite that fulfils the technical requirements of the USACE National Coastal Mapping Program (NCMP) in the United States. Its experiments showcase the capabilities of a single aircraft system equipped with a topobathymetric Lidar sensor, digital camera and hyperspectral imager[3]. The results show that the system accurately measures depths of 7–8m in murky water and up to 41m in clear water. CZMIL stands out as a leading green-band airborne Lidar system in the market. However, integrating CZMIL with UAS systems faces challenges due to the platform's weight. Despite this, there is a clear movement



▲ *Figure 4: Distribution of topobathymetric technologies based on a review of the literature (see Pricope and Bashit, 2023).*

towards making green-band Lidar technology more compact for UAS and drone applications. Some notable examples include the Mapper4000U system, TDOT GREEN, VQ-840-G, photon-counting bathymetric Lidar, the ASTRALiTe EDGE Lidar, and YellowScan's newly released Navigator Lidar sensor. Green-band Lidar is notable for its ability to collect topobathymetric data in a single scan, avoiding the need for separate data integration. Water quality has a big impact on UAS-green band Lidar, and water properties such as turbidity and clarity significantly impact how well this technique works. Remarkably, most UAS-topobathymetric Lidar systems have not been able to assess water depths deeper than 5–10m to date.

A new technology under development is the UAS-sonar/echosounding system. For example, the University of Florida has created an innovative drone-based system for underwater mapping called Bathydrone. This system features a drone connected to a small vessel equipped with a sophisticated sonar unit, capable of performing down-scan, sidescan and chirp functions. It logs GPS-referenced sonar data in real time, enhancing underwater exploration and mapping capabilities. Given that it is a lightweight surface vehicle, it has difficulty in deep-water wave environments.

SPH Engineering is developing technology that integrates an echosounder with a commercially available UAS system. The UAS-echosounder developed by SPH Engineering is recognized for its high-quality data output. However, it still requires extensive research, development and accuracy evaluation. Compared to UAS-green band Lidar, this technology boasts superior water penetration capabilities, offering a significant advantage in underwater exploration and mapping.

Pricope and Bashit[3] conducted a systematic literature review of hundreds of article and surmised that, in the realm of topobathymetric survey technologies, airborne methods lead with a 45% usage rate, while radar is the least utilized at 1%. Drones, UAVs and UASs account for 9%, highlighting the growing significance of unmanned aerial vehicles in this field. Additionally, the 'Others' category represents 18%, indicating a variety of innovative and hybrid approaches beyond the main technologies, showcasing the diversity in survey methods.

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About the authors

Salman Bashit
MD Salman Bashit, an urban planning graduate from Khulna University in Bangladesh, is currently furthering his education in Geoscience at Mississippi State University. His academic and professional journey is marked by a deep-seated interest in geoscience, with a specialization in remote sensing technologies such as Lidar and UAS-sonar.

Dr Narcisa Pricope
Narcisa Pricope is an associate vice president for research in the Office of Research and Economic Development at Mississippi State University and a professor in the Department of Geosciences. Her current focus is on developing and leading strategic initiatives to build and enhance climate resilience, develop geospatial intelligence and GeoAI programming and support faculty, students and staff in achieving their research goals and potential.

The future of topobathymetric mapping

The advent of UAS/drone-mounted echosounders and Lidar represents a significant leap in bathymetric data collection, offering unparalleled flexibility and efficiency. These technologies enable the deployment of compact yet powerful sensors for swift and precise mapping of underwater topographies, presenting a cost-effective alternative to conventional survey methods. Moreover, drones facilitate access to challenging or dangerous areas, enhancing data collection speed, accessibility and safety across aquatic environments. Importantly, the real-time data transmission feature of these tools underscores their value in modern bathymetric applications, highlighting the critical role of interdisciplinary collaboration and data sharing in advancing topobathymetric mapping efforts.

Conclusion

The exploration of bathymetric data's essential role in maritime safety, infrastructure and flood protection has spotlighted recent advancements in UAS-green band Lidar and UAS-echosounder technologies. We highlight both the advantages and challenges of current bathymetric survey methods, underlining the progress and miniaturization trends of tools such as CZMIL. Researchers worldwide working in this field envision a transformative future for UAS-mounted technologies in hydrography, poised to redefine underwater mapping with unprecedented efficiency and precision. This evolution promises a new era of enhanced marine safety and swift, accurate terrain mapping, heralding significant advancements for hydrological applications and research. ■

Oceanology International 2024: turning missions into reality

With innovation, progress and discovery at its heart, Oceanology International 2024 (Oi24) is preparing to welcome the world's largest gathering of ocean professionals to the most powerful and inspirational event in its history. Oi24 is set to be held from 12–14 March at London's ExCeL.

The three-day marine science and ocean technology exhibition and conference once again promises to deliver an unparalleled global marketplace, packed event schedule and targeted network opportunities for all those involved in exploring, protecting and sustainably operating in the world's oceans and waterways.

As the industry's foremost event, the 2024 edition of Oceanology International and its co-located event OceanICT, powered by ON&T, will provide a platform 'where missions are made possible,' according to the event organizers RX Global. It will feature an even stronger emphasis on future technology and transformational solutions, with a focus on a sustainable blue economy.

The spotlight will be on new launches on the exhibitor floor and demonstrations at the live in-water dockside location, with hundreds of exhibitors preparing to introduce products and showcase developments across the fast-paced ocean technology, science and engineering sectors.

Global ocean tech community

Featuring a compelling line-up of industry-leading speakers, the full strategic Oi conference programme will encompass a diverse range of technical sessions and ocean futures-focused content across five conference locations. World-class scientists, thought leaders and innovators in the vanguard of the global ocean tech community will bring insightful and original content.

▲ *Gathering insights and connections during a stand meeting at a previous Oceanology International event.*

Among the key contributors to the conference programme is Rick Spinrad, under secretary of commerce for oceans and atmosphere and NOAA (National Oceanic and Atmospheric Administration) administrator, who is the keynote speaker at the opening plenary of the Ocean Futures Theatre, where thought leaders will discuss meeting future ocean technology needs. Sir David King, Emeritus Professor of Chemistry, University of Cambridge, will speak at the Catch the Next Wave conference – returning for 2024 on the final day with a special edition focusing on the climate and biodiversity crisis.

David Ince, Oceanology International portfolio director, said: "At this pivotal and exciting time for the ocean technology industry, our focus is to provide an event where missions are made possible. Demand for new solutions in the blue tech and energy transition markets is exploding, so we are looking forward to delivering an inspirational Oi event in London with the power to propel the direction, progress and impact of the sector. The influence of Oceanology International is built on the scale, breadth, history and reputation of our event and I am confident that, once again, Oi will be a catalyst for ideas and innovation, with unprecedented access to comprehensive solutions, diverse content and expertise.

"As always, Oi24 provides the one occasion and one location where thousands of ocean professionals, international buyers and end users, suppliers and manufacturers can gather to do business face-to-face. For anyone looking for new solutions for their business or projects, Oi is the place to discover cutting-edge technology to ultimately drive revenues. We are committed to working hard to introduce new event services, partnerships and collaborations to enhance the experience for all participants and to deliver another packed three days of exhibition and conference activity, features, workshops and one-to-one meetings."

Gathering of all global stakeholder groups

Following its landmark return to the calendar in 2022 after a four-year hiatus due to Covid, Oi24 is perfectly placed to answer the pent-up demand for face-to-face interaction, business, networking and socializing. The event is expected to bring 7,500+ attendees and 450+ exhibitors from 80+ countries, with 100+ companies set to conduct product or service launch activity. ■

Read the full story here

Hydro International interviews Inga Lips, EuroGOOS

Observing the ocean together

By Durk Haarsma, *Hydro International*

Collaborating and coordinating are two very important tasks of EuroGOOS, the European Global Ocean Observing System, located in Brussels. The member organizations work together to share ocean observation data and develop ocean information products and services for the broad community to gain a better understanding of the ocean and its role in the Earth ecosystem. As Inga Lips, secretary general of EuroGOOS, says: "We want to unite, align and build a community."

EuroGOOS is the European component of the Global Ocean Observing System of the Intergovernmental Oceanographic Commission of UNESCO (IOC GOOS). EuroGOOS unites 46 members and collaborates with over 130 organizations that are committed to operational oceanography in all corners of the European seas, resulting in a large combined community of operators of high-frequency radars, tide gauges, FerryBoxes, fixed platforms, gliders and Argo floats (Euro-Argo), who acquire ocean data on a 24/7 basis. The EuroGOOS Secretariat, which coordinates the cooperation of the members, is based in Brussels. Inga Lips oversees the European system from the EuroGOOS office housed in the Royal Belgian Institute of Natural Sciences in the Belgian capital. A biological oceanographer who studied phytoplankton dynamics in the Baltic Sea, Inga became EuroGOOS secretary general in 2020.

In this interview, Inga shares the vision and aims of the organization with *Hydro International*. She starts by talking a litte more about the background of EuroGOOS: "We are the recognized voice of European operational oceanography, not only by the community itself but also by various partners and international institutions and by the European Commission. EuroGOOS was founded in 1994, but we got our legal status in 2013. We currently have 46 member organizations from 19 countries: a great achievement that also shows how much we are trusted in the ocean observing community in Europe."

Where do you want to take EuroGOOS?

"The idea is to try to unite all important actors who are dealing with operational oceanography so that we can align our existing strategies, build new strategies together and work towards better delivery of near real-time data for the relevant ocean services and products. It is also important to continue uniting the operational observation community more tightly with the marine environment monitoring communities. Before I started here in 2020, I hadn't been involved in EuroGOOS activities much, and I am happy with the trust given to me."

It must be a complete other world, heading up the EuroGOOS Secretariat after being a researcher?

"Yes, but I had previous experience in administrative coordination tasks, and I established and ran the marine ecology lab at the Tallinn University of Technology back in Estonia. I was engaged in the Baltic Sea Convention HELCOM activities and for some years I also coordinated the Estonian national open sea monitoring programme. I was familiar with the many platforms used in operational oceanography and collected my research data for example using FerryBox, profiling buoys and gliders. Now, of course, the scale is larger and the community is much broader, but I enjoy what I am doing, and I like the bigger challenge."

Last autumn, the tenth EuroGOOS conference was organized in Galway, Ireland. What were the main outcomes of the conference?

"We are starting to communicate better that we need a sustainable ocean observing system. Without observations, ocean services and products that are relevant to a broad range of users are not possible. Too often, people take for granted that ocean observations and related services will be made available by someone for general use. We still lack a centrally and strategically supported ocean observing system in Europe; what we have is many national systems that often only consider national priorities. So, what we really tried to emphasize at our conference was the need for long-term commitments and strategic investments at the Member State level, but also at the European level. Ocean observing is too often funded by short-term research projects, and only a very small part of operations receive long-term financial support. To change this, we need to demonstrate the value of ocean observation and operational oceanography to all stakeholders across the marine knowledge value chain."

Were there other messages?

"Also very much highlighted was the importance of people. We really need to invest more in people, not only in scientists but also in

About Inga Lips
Inga Lips is secretary general of EuroGOOS. A biological oceanographer by training, she carried out research at the Estonian Marine Institute (University of Tartu) and Marine Systems Institute (Tallinn University of Technology) in Estonia. She coordinated the national open sea monitoring programme in Estonia and developed national and Baltic Sea-wide oceanographic measurement programmes. As well as chairing the Steering Group of the European Ocean Observing System (EOOS), she is a member of the scientific and technical advisory group of Euro-Argo ERIC and advisory board member of the Board of European Environmental Research Infrastructures (BEERi) and Finnish Marine Research Infrastructure (FINMARI).

computer technicians who are able to handle big data, technicians and engineers to manage and advance the technologies we are using for ocean observing. We are collecting large amounts of data which needs entirely different approaches to be fully analysed, properly stored and managed. So, this is something that really needs to be taken care of, but obviously needs more resources as well – both human and financial."

Is money always the problem? Or are there more matters to take care of?
"To be honest, we sometimes have funds. But those funds often come with short-term contracts. And, even if we know that the contract will be renewed every two years, this is not how the observing community wants to and should work – spending a lot of time applying for funding for everyday activities to serve society. Oceanographers should not have to stress so much about these repeated applications but should spend time doing their work. Just compare the observations for two interconnected systems – atmosphere and ocean. No one thinks that everyday weather measurements are to be financed through one- to four-year research studies, but this is the reality in ocean observing. Another thing is using resources more efficiently through better communication and better collaboration. If we know what others around us are doing, we can think about combining our activities. For instance, if a research vessel is going out to sea to carry out a particular job that could be combined with other tasks, people need to at least be aware of that. We are trying to facilitate a pan-European online platform through which we can inform each other about our observing plans and activities."

What is the relation between EMODnet and EuroGOOS?
"The European Marine Observation and Data Network (EMODnet) is a network of organizations supported by the European Union's integrated maritime policy that originated from the EuroGOOS community. Our member organizations contribute to the EMODnet database in all its disciplines, and many contribute to its further development. We are very much intertwined."

What do you see as the biggest challenge right now?
"As I said before, the financial sustainability of the observing system and the better communication of the value of ocean observations to the broad range of stakeholders are very important. I also think that we need to pay more attention to collaboration with industry and the private sector. The private sector is conducting an enormous amount of ocean observations, which are not always shared, so we need to find a good balance and ways to cooperate to be able to benefit from those observations. We need to offer them something, develop services and products they would need and demonstrate to them the value of sharing their data. For instance, marine or weather forecasts, which they use in their everyday activities, would be improved if they shared their data. In the end this circle will be profitable for all parties."

Is data sharing always easy?
"Not always. Industry and the private sector are making a lot of observations and are often willing to share the data, but we have to be sure about the quality of the data and educate them in quality control and compliance with other requirements. There might be issues there."

Seabed 2030 is very successful in getting industry onboard, showing the world that they are tying up with industry and

the private sector. Is that something that you look to as an example?

"Yes, we are watching examples like this closely. Seabed 2030 encourages cruise ships to deploy equipment such as echosounders or sidescanning sonar in what is called crowdsourced bathymetry. For us in ocean observing, offshore wind parks could be used as platforms for various sensors for real-time observations. And think of all the platforms that oil companies are still exploiting at sea. As oceanographers conducting our observations, we often lack an ongoing source of energy, as batteries run out very fast. The industry has a lot of platforms with enormous amounts of energy, so furthering this collaboration is certainly a good opportunity."

What can EuroGOOS do for the hydrographic industry?

"The hydrographic industry also conducts ocean observations. However, if you think that the partners gathered in EuroGOOS cover the full value chain, from observations to products and services for the public, a benefit might really be to provide the models for the hydrographic sector to understand the water movements and therefore be able to model and understand deposit or accumulation areas. Providing marine forecasts could also be beneficial, because hydrographers rely quite a lot on those forecasts and models, which is also connected to safety at sea."

And vice versa, what would your call to the hydrographic industry be to do for EuroGOOS?

"Oh, that's easy. We are so dependent on high-resolution bathymetric maps. If we don't have those, all our models to calculate currents, tides, water temperature, salinity and vertical fluxes are wrong. So, access to good bathymetric data makes us very happy. We really need very good bottom topography, because this influences how waters move and hence the movement of organisms and substances, including pollutants."

Is there anything that you've seen based on data or products that you have delivered that is so interesting, optimistic or pessimistic that you would like to share it?

"As I'm now working more from the coordination point of view and trying to find different collaboration options, I would maybe emphasize the importance of collaborations between different sectors. What is important to share as well is that we have received funding for the next four years, for which we are really happy. This funding will help us to consolidate the European marine research infrastructures through the development of federated services (including system performance monitoring and reporting, common planning of operations and traceability of data). Also, with the support of the European Commission, we are developing the common observation planning tool that I mentioned earlier, which can be used to share information between ocean observers and those planning and coordinating the observations. Through this tool, we will be able to get information for example about the deployment of different instruments in the same area at the same time, so that we can achieve good temporal and spatial coverage of observations in a specific region. And finally, something that I would really like to point out: at EuroGOOS we are facilitating different kinds of collaboration and coordination efforts, at the national but also the regional and European level. EuroGOOS is a promotor for the implementation of the European Ocean Observing System, EOOS." ■

A relevant but often overlooked aspect of uncertainty

S-44 and the systematic error

By Huibert-Jan Lekkerkerk, *Hydro International*

IHO standard S-44 is often used (or misused) to specify the quality of a hydrographic survey. While it is a useful tool, it is easy to misinterpret. One 'misuse' is to apply the IHO orders directly to non-safety of navigation, as explicitly stated in Chapter 1. Another aspect that is overlooked is the systematic error part of the uncertainty, as S-44 only states that "The equipment should be free of systematic errors which must be determined by calibration and qualification" (B.2). The systematic error is however in general not zero and very important in, for example, dredging surveys.

Systematic error and TVU/THU
S-44 and the associated survey orders define the total vertical uncertainty (TVU) or total horizontal uncertainty (THU) as a combination of errors, rather than separating them into specific errors. This seems logical for safety of navigation, as it is irrelevant which error produces the uncertainty for a shallowest depth.

On the other hand, dredging and stone placement are usually measured in terms of layer thickness or volume. For this, the standard IHO orders are not directly suitable. For example, Exclusive Order surveys in 15 metres of water depth result in a TVU of 0.19m. As the error is not specified any further, a significant part of this error could be attributed to systematic error, especially when operating a well-calibrated RTK + MBES system. For these systems, the random part of the error (precision) is probably somewhere between 0.03m and 0.10m in these conditions.

To remedy this, it is possible to specify your own 'Dredging Order' using the matrix set-up in S-44. Using the lowest values in the matrix gives a TVU of 0.06m [a = 0.05m (Bc14); b = 0.002m (Bd10)]. This might be hard to achieve concerning the random error but should help to reduce the systematic error. As an alternative, the author often uses a more detailed approach when working on dredging and stone placement projects. In the specification, the TVU for Special or Exclusive Order is stated with an additional specification, which states that the systematic error component of the TVU should not exceed x metres, where x depends on the type of project and accuracy of the volumes to be obtained.

As shown, the systematic error component of TVU (and THU) is important but still often neglected in specifications as well as most a priori tools. Theoretically, the systematic error of a well-calibrated survey vessel should be zero, but seldom is in the real world.

Error source		Type	Effect
Geodetic Parameters	Datum transformation	Geodetic	Spatio-Temporal
	Geoid-ellipsoid model	Geodetic	Spatio-Temporal
	LAT model	Geodetic	Spatio-Temporal
Tide gauge	Installation	Offset determination	Constant
	Tide model	Environmental	Spatio-Temporal
Draught	Static draught	Offset determination	Semi-constant
	Squat model	Environmental	Spatio-Temporal
GNSS	Antenna phase centre	Offset determination	Constant
	Height of base station	Offset determination	Constant
	Satellite geometry	Instrument	Spatio-Temporal
	Latency	Instrument	Spatio-Temporal
IMU (+gyro)	Alignment offset	Calibration residual	Semi-constant
	Phase centre	Offset determination	Semi-constant
	False heave / roll	Instrument	Spatio-Temporal
MBES	Alignment offset	Calibration residual	Semi-constant
	Transducer phase centre	Offset determination	Constant
	Speed of sound	Environmental	Spatio-Temporal
	Settings	Instrument	Semi-constant
	Bottom reproduction	Environmental	Spatio-temporal

▲ *Table 1: Systematic error sources in survey systems.*

Classification of systematic error
Various error sources create a small, but sometimes significant, systematic error. Depending on how we use the survey system we might be more interested in the relative systematic error or in the absolute systematic error. The absolute systematic error is the systematic offset or bias against a known true value or reference datum. A relative systematic error is the error found between two consecutive surveys of the same area with the same equipment (and settings) on the same vessel.

We also need to consider the spatio-temporal variations in some systematic errors. These are errors that may cancel out over a long time or area (and could be classified as a random error) but are to be considered systematic for the finite duration or area of the survey. The various systematic errors can be classified as:

- calibrations and offsets
- geodetic
- environmental
- instrument

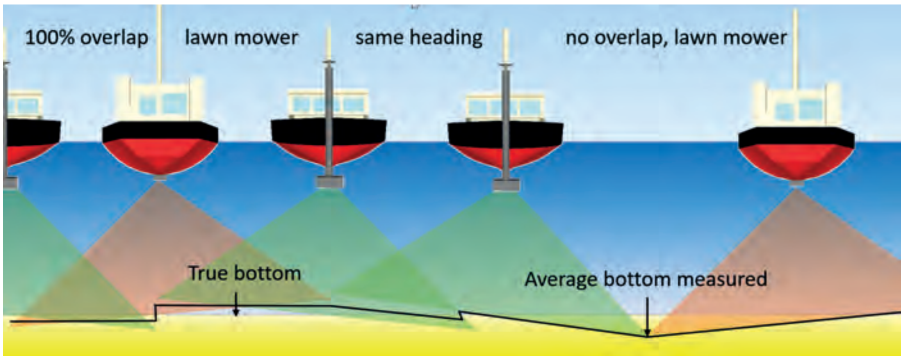
Table 1 details various errors and their type of behaviour.

Residuals from offset determinations and calibrations

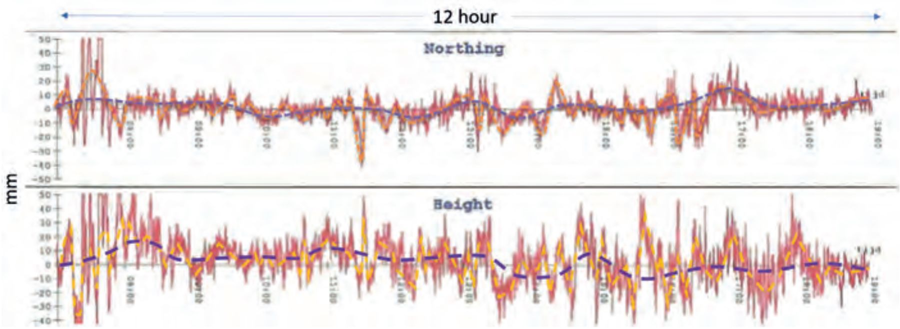
The results of dimensional control measurements or equipment calibrations are often stated with a precision. Most a priori tools (and users) will state these as a random error. This is not correct in the author's opinion. The coordinates or offsets are entered as fixed numbers and thus do not change during the survey, and are therefore systematic. With proper dimensional control and calibrations the probable error is often small but it may still be significant. If the 95% uncertainty of any node in the Vessel Reference Frame is for example 5mm, the total systematic error could be anywhere between -10mm to +10 mm with a 95% certainty. Statistically speaking, 7mm would be a reasonable approximation in this case. When using the same vessel (and settings) for in- and out-survey, the volume or layer thickness error is zero. There is therefore an effect on absolute depths.

Calibration residuals follow the same pattern. For example, a patch test yields a residual roll calibration error with an uncertainty. The number is again entered as a fixed value and does not change during the survey. This causes one side of the swath to be systematically too high and the other side systematically too low. As volumes are based on averages, the final effect depends on the amount of overlap and track heading (Figure 1). As the effect depends on how lines are sailed, there is an effect on both relative and absolute systematic error.

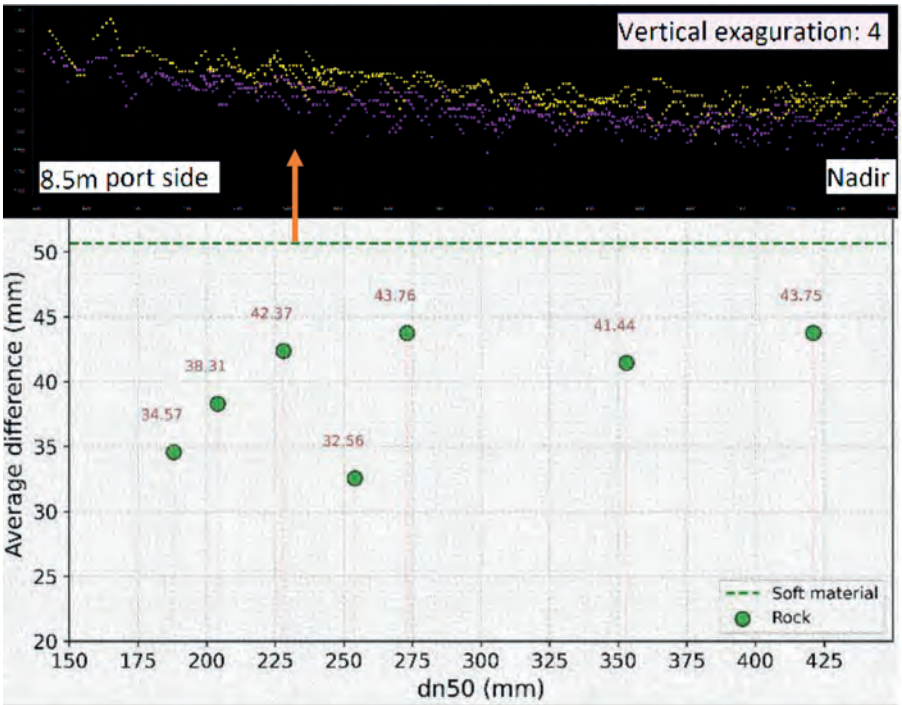
For the IMU, the effect of a residual calibration offset depends on the lever arms and vessel heading. The residual offset causes the antenna and echosounder to have an incorrect position and height. Theoretically, the effects are also dependent on the vessel motion; however, as both actual vessel motion and residuals are very small in a well-calibrated IMU, the effect on the survey results is then limited.



▲ *Figure 1: Effect of roll residual and overlap/line orientation.*



▲ *Figure 2: Temporal RTK GNSS variations in a 12-hour record. (Source: Handbook of Offshore Surveying)*



▲ *Figure 3: Results of various areas of armourstone surveyed with different pulse lengths. (Source: L. Stuurman)*

Errors in references and conversion parameters

Datum transformations are typically stated with an accuracy in the EPSG registry. Similarly, a vertical datum model such as a geoid-ellipsoid separation model or LAT model has a certain accuracy. The errors in both are probably zero on average over the entire model or transformation. However, locally they usually have a constant and possibly non-zero error. When using the same settings and software for in- and out-survey, the effect on volumes and layer thickness cancels out. Again, for absolute depths there is therefore an effect.

Environmental errors

Environmental systematic errors have causes outside of the survey set-up. A large source is the use of water-level corrections rather than GNSS heights. Tide gauges measure the tide in a specific place, but in other places the water level will be different, resulting in a systematic offset for that area. Similarly, a correction for the dynamic and static draught of the vessel will contain some element of systematic error, especially if no squat/settlement model is employed. The effects can range from almost nothing to decimetres. The use of accurate GNSS heights cancels out most of these errors.

Sound velocity is another cause of environmental systematic errors. Sound velocity changes between profiles. Even when using a moving profiler or an alert to ensure that profiles are taken regularly, there is a slowly increasing error. When using a very common check between the SV Sensor near the transducer and the corresponding value from the profile of 2m/s, the effect will increase to around 0.02m in 15 metres of water depth just before a new profile is taken. While the effect will be small for short surveys in stable water conditions, it can be significant for longer surveys or in highly dynamic waters such as estuaries.

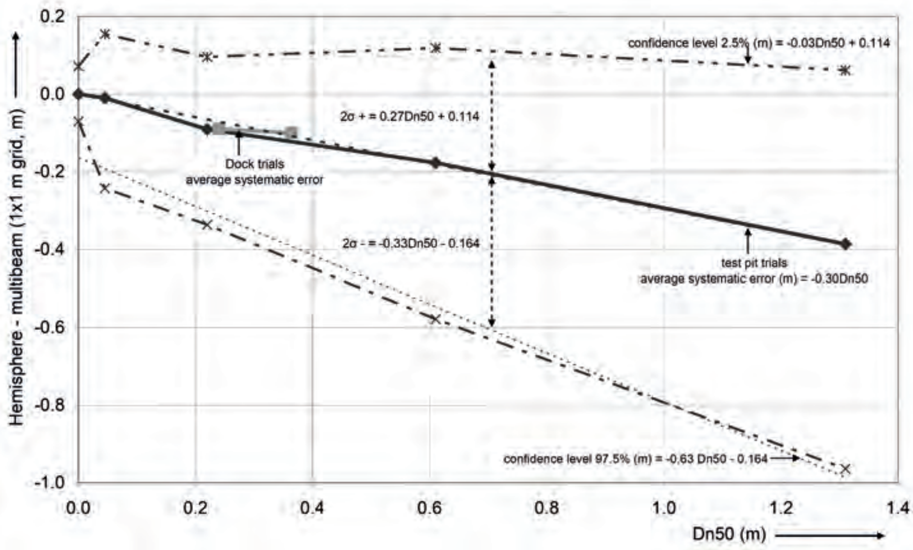
Instrument error

GNSS itself is also not free of some kinds of systematic error. Over a short time, GNSS often seems to give very stable positions. Tests have shown that over a period of 15-30 minutes there is a slowly varying height in PPP and RTK, which can have an amplitude of several millimetres up to a few centimetres (Figure 2). This is the result of satellite geometry and the changing (electronic) phase centre of the antenna. Depending on the size of the area, this results in a systematic error of a few millimetres.

The IMU is also a source of variable systematic errors due to false or induced heave, roll and pitch. These induced values will offset the measurements over a span of time lasting up to minutes after a significant change in speed or after a turn. These errors are significantly reduced for an IMU with speed and heading input. With GNSS, the effect of false or induced heave depends on the software.

About the author

Huibert-Jan Lekkerkerk is a contributing editor, freelance hydrographic consultant and author of other publications on GNSS and hydrography and principal lecturer in Hydrography at Skilltrade (Cat B) and the MIWB (Cat A).



▲ *Figure 4: Systematic difference between spherical foot staff and MBES for different armourstone sizes. (Source: Construction and survey accuracies for rock works)*

Finally, the echosounder settings can have a significant effect. A significant error can be caused by using different frequencies over a soft bottom. Tests have furthermore shown that longer pulse lengths can lead to a deeper bottom (Figure 3). Finally, the levels as obtained with a multibeam over armourstone differ from those obtained with the common reference above water (spherical foot staff), leading to differences in obtained levels, layer thickness and volume of centimetres to decimetres depending on the size of the armourstone (Figure 4).

Conclusion

As shown, there are many errors that do not cancel out. A posteriori checks on dredging works by the author have shown the relative residual systematic error to be anywhere between roughly 0.01 and 0.05 metres. The absolute systematic error may be much higher but is harder to establish. It was also shown that it is very hard to work these systematic errors into an a priori computation, as results also depend on the environment. Maximum values could be established for the main components by considering a worst-case scenario. It is recommended to specify the maximum allowed systematic error on dredging and construction projects separate from the TVU and to require a procedure to test these before the survey commences.

Finally, the recommendation of performing the in- and out-survey on dredging and construction projects with the same vessel and same settings is repeated here. This will still give a systematic error but should reduce the error in obtained layer thickness and volume. There will however still be an effect on absolute depths. ■

A portrait of EMODnet

Meet the European Marine Observation and Data Network

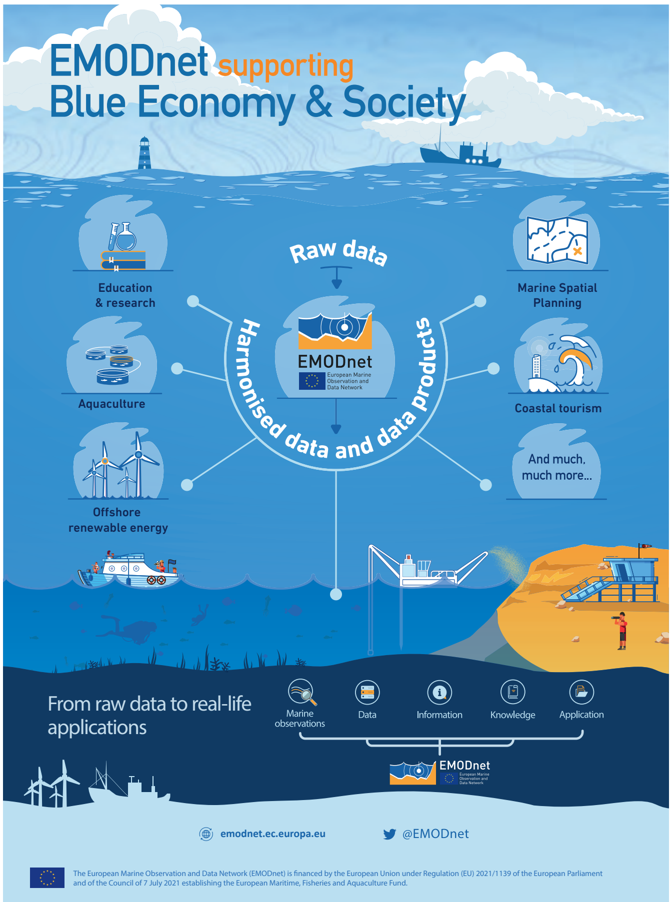
By Frédérique Coumans, *Hydro International*

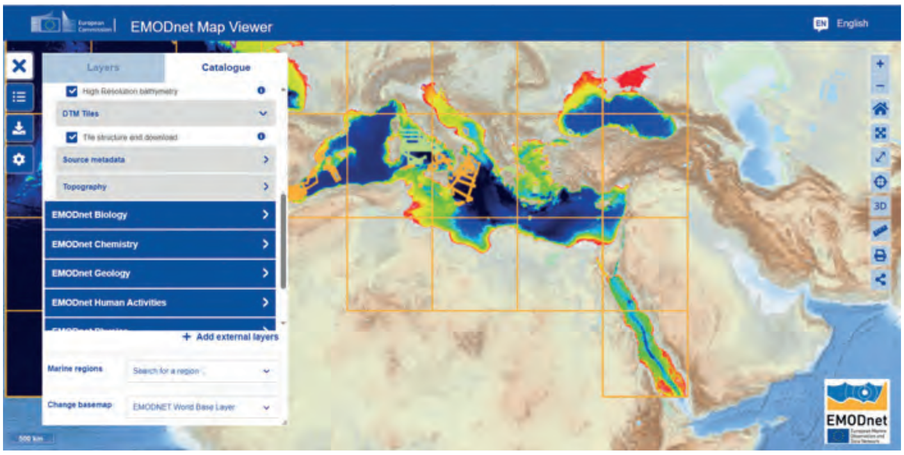
Is climate change affecting fish populations in this part of the ocean? Are we seeing more vessel activity than usual? What is the best location in this area to develop a wind energy park with the least damage to the seabed? The data needed to help answer these and hundreds of other marine-related questions can be found for free through the European Marine Observation and Data Network portal, EMODnet.

EMODnet is a data service that aims to help realize the EU's integrated maritime policy and is funded by the EU Directorate-General for Maritime Affairs and Fisheries. The more than 120 member organizations are experts in marine data. They collectively assemble and harmonize data collected from diverse sources into interoperable data layers and geodata products. Kate Larkin, head of the EMODnet Secretariat, based in Ostend at the Belgium coast, is certain: "Data services like EMODnet add value to ocean observations, converting individual datasets into easy to find and use products. The open and free access to high-resolution baseline data, integrated data and information saves stakeholders a lot of money. The trusted, continent-wide data products also open up new opportunities for innovation and growth." The European Commission has calculated that open access to marine data via EMODnet and other services saves one billion euros a year.

Pan-European data and maps

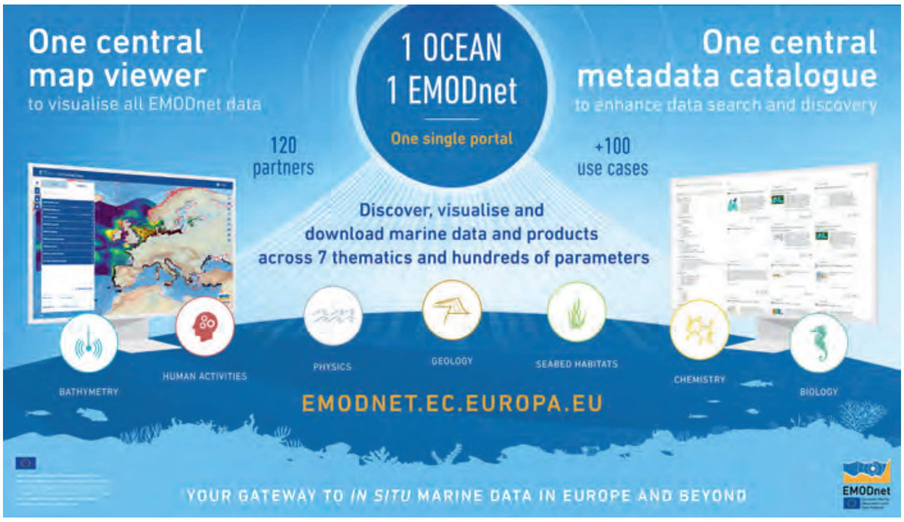
Before EMODnet, which started in 2009, European ocean observation data was largely distributed in disparate organizations. This data was often closed to the wider user community and, even if it was openly available, it was not very user-friendly. EMODnet changed this, providing data about the marine environment (bathymetry, biology, chemistry, geology, seabed habitats and physics) and related human activities (offshore platform sitings, vessel density and maritime spatial planning). Larkin says: "EMODnet is unique in offering both marine environmental data and data/information on human activities at sea. Both are essential to monitor the environmental status of our oceans and to assess humanity's impact on them." For each theme, EMODnet has created a gateway to a range of data archives that are managed by local, national, regional and international organizations. Through these gateways, users have access to standardized observations, data quality indicators and processed data products. "We also create and make available pan-European multi-resolution maps of seas and oceans, spanning all seven disciplinary themes," continues Larkin. "Based on the philosophy 'collect once, use many times', we provide high added value whereby a user, such as an offshore renewable energy operator, no longer has to start from scratch collecting marine environmental survey data in the planning stages of a new installation." One of the products that such an energy company can use is the Bathymetry digital terrain model. This has recently been further enhanced in the new unified EMODnet Portal, where a user can access not only the full pan-European DTM, but can also download high-resolution datasets for their region of interest in an easy-to-use common map viewer.





▲ *Bathymetry Digital Terrain Model.*


▲ *Kate Larkin, head of the EMODnet Secretariat.*



Understanding environmental processes

Another clear use case relates to storm surges, which pose a huge risk to coastal communities, human life and property. EMODnet Bathymetry, including the digital terrain model, has been used by several EU Member States to deliver more accurate storm surge models. The EMODnet's Central Map Viewer offers countless possibilities to combine multidisciplinary data from many themes. Kate Larkin elaborates: "For example, seeing areas of highest vessel activity and comparing this with a map of the most vulnerable seabed habitats, can help marine managers to more accurately identify potential no-boating zones, allowing marine life to restore and recover. It also empowers coastal tourism operators towards more sustainable approaches. Such easy and free data combinations are a game-changer for assessing human impact and driving evidence-based, sustainable marine management." To be clear: EMODnet does not conduct its own analyses or impact assessments, but provides the data that enables users to do so in an effective and efficient way. Larkin explains: "We stimulate organizations to use our data resources to build new applications."

Expanded geographical scope

The core mandate for EMODnet is delivering high-resolution multi-parametric maps and data services for European seas. However, partnerships have expanded the geographical scope. The platform provides a multitude of resources covering, among others, the Atlantic, Arctic and Mediterranean areas. There are several collaborations in the US, including with the National Oceanic and Atmospheric Administration (NOAA). EMODnet was one of the first European initiatives to collaborate with NOAA on free and open source ERDDAP services that give users a simple, consistent way to download subsets of maritime datasets. Dialogue is also ongoing with the US and Canadian Integrated Ocean Observing System to achieve a better interoperability of regional data services. There is also a partnership with China, says Larkin: "Two projects so far, funded by the EU and China respectively, have leveraged sharing of best practices and marine data to ensure more accessible and usable marine knowledge for all. About 20 European partner organizations took part."

On the theme of bathymetry, EMODnet actively contributes to the Seabed 2030 initiative to produce a global seabed map by 2030. On the theme of biology, EMODnet has worldwide coverage of many biodiversity parameters, thanks to a collaboration with EurOBIS, part of the international Ocean Biodiversity Information system of UNESCO. And on the theme of geology, a collaboration with Mexico and other partners in the Caribbean Sea now offers various products for this region, and the same is being set up for the Caspian Sea.

Open access

As they are funded by the European Union, the data products are fully open access and free to use by all (Creative Commons 4.0). However, in some cases the underlying data is subject to a specific data policy, restricting it to open source. Larkin explains: "We have the philosophy of making data as open as possible and as closed as necessary. This means that users can still benefit from all data shared with EMODnet since all data is accompanied by metadata that describes the data collection and attributes ownership to the data originator. Then, if a particular dataset requires permission to access, the user can contact the data originator to request this." Kate Larkin, her Secretariat team and in fact the whole network have many ongoing dialogues with stakeholders to promote data sharing – including with the private sector – to further fill gaps in geographical coverage, parameter and resolution. "We are strengthening collaboration with all sectors of the blue economy, from offshore renewables to aquaculture and the shipping industry," continues Larkin. "This often engages our Data Ingestion service, which specifically helps organizations to curate data into FAIR data: Findable, Accessible, Interoperable and Reusable. One such example is a collaboration with the UK Crown Estate and the UK Marine Environmental Data and Information Network to make marine environmental data, collected under licence by British offshore renewable energy operators, available via EMODnet."

Win-win for the private sector

It is not just public marine and maritime organizations who can apply to participate in the no-fee partner network; the private sector can also use the services and join open events free of charge. Examples are Open Sea Lab Hackathons and other more sector-specific dialogues and events. Larkin: "The private sector can also share data with EMODnet, which is a win-win, not only because the company can get free support for data curation. Since the data can now be integrated into pan-European and increasingly global layers, it has more impact, with our services being accessed by more than 200,000 users per year. In addition, our full offer is linked to international ocean data and metadata catalogues that serve even larger user bases, such as GEOSS for earth observation data and OBIS, the clearing-house on marine biodiversity data." Connecting best practices used for data and metadata is also important for the full marine knowledge value chain. Larkin concludes: "It is one of our priorities this year to provide guidance to ocean observation and data collection efforts to collect a rich description of metadata alongside the data. It will make the data better available for ingestion to EMODnet and to the wider European and global community." ■

For more information: https://emodnet.ec.europa.eu/en.

About the author

Frédérique Coumans is a contributing editor to *GIM International* and *Hydro International.* For more than 25 years, she has covered all aspects of spatial data infrastructures as editor-in-chief of various magazines on GIS, data mining and the use of GIS in business. She lives near Brussels, Belgium.

From historical struggles to present-day advances in navigation

The evolution of Dutch hydrography

By Wim van Wegen, head of content, *Hydro International*

Given the Netherlands' geographical location, it is unsurprising to find it has a long tradition of hydrography. The lowland, often below sea level, forms a delta where major rivers from Central Europe flow into the North and Wadden Seas. While the Dutch have a centuries-long history of pioneering in hydrography, the establishment of a national hydrographic service occurred relatively recently, in 1877. This article delves into the history of Dutch hydrography, highlighting the eternal struggle of the Dutch against water and the impact of this on the development of hydrographic expertise in the country, and zooming in on today's innovative hydrographic sector.

The Netherlands is situated at the confluence of the Rhine, Meuse, Scheldt and Ems rivers, which flow directly or indirectly into the North Sea. The country also has an intertidal zone in the south-eastern part of the North Sea, known as the Wadden Sea. The geographical location of the Netherlands poses a significant challenge for engineers. In essence, storms can drive North Sea water towards the coast while rivers are also attempting to discharge excess water, exerting considerable pressure on river dikes. Such circumstances highlight the vulnerability of the Netherlands and the crucial importance of effective water management in the country.

Besides its geographical location, another cornerstone of Dutch hydrographic expertise stems from its maritime legacy. As a longstanding maritime powerhouse, the Netherlands has relied on shipping for many centuries, which has fostered safety and prosperity. Since its establishment in 1877, the Hydrography Department of the Royal Netherlands Navy has been entrusted with various hydrographic, meteorological and navigational responsibilities, including the production of nautical charts, descriptions, guides and announcements for seafarers. Throughout history, the Navy has diligently protected Dutch maritime territories, coastal regions, ports and shipping lanes, inherently integrating hydrographic tasks into its broader maritime security mandate.

▲ *The Netherlands is located in a delta where the rivers Rhine, Meuse, Scheldt and Eems drain into the North Sea. (Image courtesy: Shutterstock)*

Dutch hydrographic pioneers

The prominent role of the Dutch in 16th-century European trade necessitated advances in navigational instruments beyond what was available. Notably, Lucas Janszoon Waghenaer (1533–1606) and Aelbert Heyen (ca. 1550–ca. 1613) made significant contributions in this regard. Waghenaer in particular is hailed as a pioneering figure in the establishment of safer sea routes along the European coasts. His work, *Spieghel der Zeevaerdt*, published in 1584 and in English under the name *The Mariner's Mirror*, marked a significant leap forward in maritime cartography. This groundbreaking sea atlas included charts, sailing directions, coastal views and navigational tables covering the European coasts from Gibraltar to North Cape, revolutionizing maritime navigation. Waghenaer's extensive collection of maps was largely standardized in scale and employed consistent symbols for landmarks, beacons and small villages, delineating shoals with dots encircled by double dotted lines and utilizing hatching to denote coastlines.

Other advances in the 16th century laid the foundation for the hydrographic profession. In 1533, the cartographer Gemma Frisius proposed using triangulation to accurately

▲ *Thanks to its exquisite typography, Blaeu's Atlas Maior swiftly gained recognition as a status symbol among the affluent in the 17th century, solidifying its position as one of the era's most coveted treasures.*

▲ *As shown in a comparison between a map from 1300 and one from today, the geography of the Netherlands has undergone significant changes due to land reclamation efforts, resulting in considerable expansion over the centuries. (Image source: Earth Magazine)*

position distant locations for map-making. One of his notable students, Gerardus Mercator, later gained global recognition for his cylindrical projection system, ensuring angular fidelity on nautical charts for the first time. Mercator's most renowned achievement was the development of the 1569 world map using this projection, which depicted sailing courses of constant bearing, known as rhumb lines, as straight lines. This pioneering system continues to be employed on modern nautical charts. Willebrord Snel van Royen, better known as Snellius, was another brilliant mind of his time. His expertise spanned geodesy, navigation, hydrography and astronomy. Born in 1580 and living until 1626, he gained renown for his precise measurement of the distance between the Dutch towns of Alkmaar and Bergen op Zoom using triangulation. Snellius is widely regarded as one of the pioneers of geodesy.

Atlas Maior

In 1635, Joan Blaeu, a distinguished publisher from Amsterdam, released the two-volume *Atlas Novus*. This monumental work cemented Blaeu's status as the official cartographer of the Dutch East India Company. Known for his deep interest in hydrography, Joan Blaeu played a significant role in the development of maritime cartography. The *Atlas Novus* became increasingly comprehensive in subsequent editions. Eventually, in 1662, the monumental *Atlas Maior* was published. Spanning 11 volumes and featuring 600 maps, the *Atlas Maior* was widely considered a masterpiece of the Golden Age of Dutch cartography, comprehensively compiled as a multi-part world atlas. This achievement solidified Blaeu's status as a pre-eminent cartographer and publisher of his time.

While widely recognized for his expertise, Blaeu also occasionally caused frustration. This sentiment prompted the Zeeland chamber of the Dutch East India Company to commission its own cartographers from 1669 onward. Among the grievances were complaints about the high prices charged by Joan Blaeu for his manuscript maps, prompting the Zeelanders to establish their own hydrographic survey and mapping service.

Several other Dutch cartographers have significantly contributed to the enhancement of maps and hydrographic knowledge. Noteworthy among them are Johannes van Keulen and his lineage, esteemed for their production of sea atlases in the 17th century, along with Jodocus Hondius, who played a pivotal role in the English edition of Waghenaer's *Spiegel der Zeevaerd*.

Hydrography after Napoleon

After the Napoleonic era, often referred to as the French era in the Netherlands, Europe experienced significant geopolitical change. The Congress of Vienna, convened from September 1814 to June 1815, marked a crucial turning point for the continent. Initially, the Netherlands merged with Belgium to form the Kingdom of the Netherlands. However, from 1830 onward, both nations pursued separate paths. The Netherlands, once a dominant force during the Golden Age, found itself in a period of stagnation, prompting a need for reinvention. A similar trend can be observed in its pursuits in hydrography.

As early as 1787, the government had initiated scientific planning for hydrographic research. However, following the establishment of the Kingdom of the Netherlands in 1815, the systematic exploration of Dutch coastal waters and estuaries commenced, extending until 1874. Throughout this era, the government made a concentrated effort to formalize and organize hydrographic research.

Between 1815 and 1825, extensive exploration and mapping projects were conducted in the estuaries of Zeeland province and other Dutch coastal regions. This effort later expanded to include other areas. Notably, a comprehensive survey of the Zuiderzee, a North Sea inlet, was carried out from 1844 to 1845, resulting in the detailed mapping of crucial waterways.

In 1815, Minister of the Navy J.C. van der Hoop recognized the need for updated coastal observations due to complaints about outdated maps. Introducing innovative techniques, precise mapping was achieved through advanced triangulation methods along the coastline. The resulting hydrographic map of the Netherlands set the standard throughout the 19th century. Based on the publication of foreign maps depicting the coastal waters of the Netherlands, alongside Dutch hydrographic mapping activities, it became evident that the country was reclaiming its prominence in this domain.

▲ *Cornelis Lely is revered for his visionary contributions and pioneering work in Dutch hydraulic engineering.*

▲ *Built in 1910 at the Fijenoord naval yard in Rotterdam, the Hydrograaf originally served as a steamship dedicated to surveying for the Hydrographic Service. Its primary task involved the sounding and mapping of waterways during the survey season, which spanned April to October. Notably, the Hydrograaf gained the affectionate title of 'the queen's ship', as it was frequently utilized by Wilhelmina for official visits to the West Frisian Islands throughout the 1920s and 1930s.*

1874 to 1980, an era marked by the institutionalization and internationalization of hydrographic research, began with the establishment of hydrography as a department within the Navy in 1877. The core objective of the Navy's hydrographic service was precision through meticulous measurement. Each endeavour entailed measuring ocean depths while simultaneously pinpointing the precise geographical coordinates of surveyed points. This meticulous process relied on specialized instruments such as sounding devices, sextants and time meters. Furthermore, the strategic placement of beacons was executed with precision, with their geographic coordinates established accurately before deployment as reference points for measurement.

Initially, the three focus areas were Dutch coastal waters and maritime areas and coastal waters in the East and West Indies. The recording and mapping of coastal waters and estuaries in the Netherlands were largely completed in the first half of the 19th century. Notably, Dutch survey vessels were continuously active in the colonial waters of the vast area now known as Indonesia from 1858 until their activities were interrupted by the war with Japan in 1942.

Game-changing events

Two flood disasters in the 20th century starkly illustrated the dire consequences of the neglected maintenance of dikes and waterworks in the Netherlands. These events spurred the implementation of the Zuiderzee Works and the Delta Works, monumental endeavours aimed at safeguarding the Netherlands against future water-related catastrophes. Today, these projects remain among the most remarkable feats in the field of civil engineering worldwide.

Zuiderzee Works

Initial plans for the Zuiderzee Works date back to 1850, but it was not until the devastating flood of 1916 that the Zuiderzee Act of 1918 was passed, kickstarting the realization of engineer Cornelis Lely's vision. Lely, who also served as Minister of Water Management, meticulously conducted numerous studies on water depth and soil composition prior to formulating his plan. His visionary approach was ahead of its time, setting a new standard in engineering.

In essence, the Zuiderzee Works entailed Lely's proposal to block off the Zuiderzee – an inland sea or, more accurately, a North Sea inlet – from the ocean with a dam. This would transform the inland sea into a vast freshwater lake, with portions of it reclaimed for land. Engineers initially greeted Lely's ambitious plans with considerable scepticism, questioning their technical feasibility and debating their utility and necessity, though attitudes shifted following the 1916 flood. Despite these challenges, Cornelis Lely persisted, buoyed by the support of the Zuiderzee Association and an unwavering determination. This association appointed engineer Cornelis Lely as a key adviser, who wrote a series of highly valuable technical papers. He possessed broad knowledge and a sharp understanding of hydraulic engineering works, and the present project closely aligns with his proposals.

Cornelis Lely began preparations for the Zuiderzee Works as early as the summer of 1887, focusing on terrain research, soil drilling and soundings in the Zuiderzee. These early explorations were conducted aboard a sailing ship, primarily targeting the northern region of the Zuiderzee floor. Using a simple dipstick, Lely drilled into the seabed to assess soil types based on the sound and depth of penetration as he sought to identify the most suitable areas for reclamation. He meticulously preserved soil samples, which he later brought along on subsequent tours of the Zuiderzee.

A significant challenge emerged during the intense preparations for the implementation of the Zuiderzee Works around 1921. This was a lack of sufficient tidal information, particularly in the northern part of the Zuiderzee, for which urgent measurements were required. However, the absence of suitable self-registering tide gauges for open sea conditions posed a problem. To address this, the Zuiderzee Association innovatively developed solutions using existing components. Despite these efforts, only a limited amount of reliable data was collected that could be used as input for the model calculations.

Delta Works

Another remarkable Dutch engineer who undoubtedly equalled Lely in merit was Johan van Veen. However, it is striking that the preface to his biography begins with the poignant statement: "Before you is a captivating biography of one of the greatest Dutchmen of all time: Johan van Veen. […] Yet, despite his accomplishments, most Dutch people remain unfamiliar with his name."

On 1 February 1953, over 150 breaches occurred in the dikes across the Netherlands as the North Sea unleashed its fury. Johan van Veen had been sounding the alarm about this impending disaster for years, but his concerns about the state of the Dutch dikes went largely ignored. Although he held the position of chief engineer at Rijkswaterstaat, he was subordinate to two superiors and his innovative approach to assessing the condition of the dikes left his bosses sceptical and unsure. This poses important questions about the effectiveness of our current methods and the need to heed expert advice in safeguarding against potential risks and challenges.

Johan van Veen rightfully earns the distinguished title of 'architect of the Delta Works'. He was a self-taught pioneer who was far ahead of his time, recognizing the threat of sea-level rise as early as the 1930s, based on his observation of storm surge levels and the height of average tidal rises. Prior to the invention of computers, calculating tides was a time-consuming process that required manual labour. To expedite the process, hydraulic engineers sought more efficient and reliable alternatives. Johan van Veen played a pivotal role in this development by introducing the electric-hydraulic analogue for tidal calculations. He further refined his method during World War II and experimented using copper wires, capacitors and other instruments. These experiments resulted in the Deltar, one of the first Dutch computers, which provided unprecedented speed and power for calculating the hydrological effects of the closure of the Dutch delta area.

The Deltar, which stands for Delta Tide Analogue Calculator, was used in the design and execution of the Delta Works from 1960 to 1984. Johan van Veen built the initial prototypes of the Deltar between 1944 and 1946, and his work was continued by J.C. Schönfeld and C.M. Verhagen after his death in 1959. It is highly likely that without the rapid tidal calculations provided by the Deltar, the Delta Works could not have been carried out as quickly as they were after the February disaster of 1953.

The stature of Johan van Veen can perhaps best be illustrated by the fact that his work is still used as lecture material. One such example is the Scheldt study, conducted in 1944–1945, which is a comprehensive examination of various factors that include changes in river channels and depths, the deepening of the river mouth, and the impact of land reclamation on the river's flow. Additionally, the study explores the interaction between the river and storm surges. While the research had been forgotten for many years, it resurfaced in the 1990s when the Dutch Ministry of Infrastructure and Water Management's subsidiary Rijkswaterstaat began a study of the Scheldt estuary. Strikingly, the approach to the two studies was highly similar, despite the half-century gap between them. This is further evidence of Johan van Veen's forward-thinking and innovative approach.

Modern Dutch hydrography

In the era following World War II, hydrography in the Netherlands burgeoned into a profession of paramount importance. This ascent paralleled the growing economic significance of the maritime sector, underscored by the Netherlands' prominent position as a global leader in hydraulic engineering. Notably, the international acclaim garnered by Dutch hydraulic engineering received an immense boost from the monumental Delta Works project.

▲ *Pictured here: In 1953, Johan van Veen unveiled the Delta Plan, the blueprint for the Delta Works, solidifying his legacy as the visionary father behind its inception and development. (Image source: Rijkswaterstaat)*

▲ *Van Oord is one of the Dutch companies renowned worldwide for its expertise in flood protection and hydraulic engineering. (Image courtesy: Van Oord)*

▲ *Ocean Technology, the hydrography course at the Maritime Institute Willem Barentsz, is the sole programme in the Netherlands certified at the highest international hydrographic level (Category A). (Image courtesy: NHL Stenden)*

At the forefront of this renaissance were esteemed Dutch companies such as Arcadis, Boskalis, Royal HaskoningDHV and Van Oord – renowned worldwide for their expertise in flood protection and hydraulic engineering. Their pioneering contributions have not only solidified the Netherlands' reputation as a hub of maritime innovation but have also propelled the nation onto the global stage as a trail-blazer in water management solutions.

In the post-World War II era, the role of the Hydrographic Service of the Royal Netherlands Navy has assumed newfound significance. Tasked with the crucial responsibility of mapping the ever-evolving contours of the ocean depths, the service plays a vital role in ensuring the safety and efficiency of maritime navigation. Moreover, its contributions extend beyond mere cartography, encompassing a broader mandate of environmental stewardship and sustainable development in the maritime domain.

The Dutch hydrographic standards are based on the S-44 standards set forth by the International Hydrographic Organization (IHO), with additional specifications tailored to the unique conditions found in the Netherlands. These stricter requirements particularly focus on coastal defence, morphological research, environmental considerations and the management and maintenance of inland waterways. As one of the founding countries of the IHO, the Netherlands has played a pivotal role in shaping its development.

Education in a transforming hydrographic sector

The success of Dutch maritime engineering relies heavily on the expertise of skilled hydrographers. In 2002, the hydrography course at the Amsterdam University of Applied Sciences was discontinued. NHL Stenden University of Applied Sciences subsequently took over the programme, relocating it to the Maritime Institute Willem Barentsz (MIWB) on the island of Terschelling, one of the West Frisian Islands. Renowned for its exceptional facilities, MIWB boasts modern measuring equipment, simulators and training vessels tailored for comprehensive practical training. A key promotional point of the institute emphasizes the promising career prospects facilitated by the scarcity of skilled professionals in the field – a challenge not only internationally but also within the Netherlands' maritime sector. After all, the work of hydrographers holds immense significance, directly impacting dredging operations and offshore activities, thereby influencing their feasibility and success.

The programme has been rebranded as Ocean Technology, and is the only programme in the Netherlands certified at the highest international hydrographic standard (Cat A). Students receive exceptional instruction in their chosen field, cementing the programme's reputation. For instance, students engage in depth measurements at sea and the highly accurate mapping of seabed structures as hydrographers. Their responsibilities encompass project preparation, installation of equipment aboard measuring vessels, data collection and subsequent analysis and synthesis of data into maps and reports.

As the venue for hydrographic training shifted in the Netherlands, so too did the backdrop against which significant innovations in the field emerged. The oil and gas boom in the North Sea gave rise to a new nautical branch: civil hydrography. This development brought forth heightened demands for accuracy, reliability and speed in data processing, leading to the introduction of precise surface and underwater navigation systems. Dutch companies have played a pivotal role in driving advancements in data automation and processing, with a strong emphasis on quality assurance – a sentiment echoed by Prof. J.A. Spaans, a key figure in shaping the hydrography curriculum in Amsterdam.

Hydrography is currently undergoing significant transformation and facing challenges, a trend mirrored not only in the Netherlands but also in other regions with robust hydrographic sectors. Particularly vital in mapping the seabed for wind turbine installation and maintenance, hydrography's future is intertwined with sustainable energy transitions and technological advancements.

The field is evolving alongside cutting-edge technologies, with vessels equipped with advanced hydrographic instruments enhancing data collection efficiency and map production. This translates to expedited and more precise navigation, crucial for both maritime shipping and submarine infrastructure development. Proof of this evolution can be seen in the increasing adoption of autonomous hydrographic platforms.

The rapid integration of advanced technologies within the hydrographic sector promises to revolutionize data collection and map production, catalysing innovation. This transformative landscape inevitably influences hydrographic education, prompting the Maritime Institute Willem Barentsz to align its training closely with industry demands.

Today's hydrographic sector

The Netherlands has a robust international presence in hydrography, marine geophysics and oceanography. This prominence is fuelled by collaborative efforts among Dutch companies who pool resources to deliver a diverse array of ocean-related services and products. Leveraging their collective expertise, these companies offer comprehensive solutions to global demands in oceanographic monitoring, surveying and forecasting. The Netherlands' prowess in this domain is often showcased at prominent events such as Oceanology International and Ocean Business, where the Dutch pavilion serves as a testament to its collective capabilities. While Fugro enjoys widespread recognition worldwide, other Dutch companies such as Geo Plus and Braveheart have also earned international acclaim for their esteemed hydrographic surveying, inshore, nearshore and offshore support and crew tendering services.

Numerous esteemed Dutch companies excel in hydrography, marine geophysics and offshore precise positioning. Deep BV is a prime illustration, providing bespoke services tailored to offshore, coastal zones, seaports and inshore waterways. But the Netherlands is also known for companies that develop highly innovative hardware and software solutions for capturing and processing hydrospatial data.

Demcon Unmanned Systems is an excellent example of the transformative shifts in modern hydrography. At the forefront of electric autonomous unmanned vessels, Demcon is committed to ensuring safer, sustainable, efficient and cost-effective maritime operations. The company manufactures autonomous uncrewed survey vessels (USVs) that not only redefine safety standards but also pave the way for eco-responsible practices in the industry.

Of course, Fugro is also known for its contributions to a new generation of USVs in the Netherlands. Designed for hydrographic and geophysical surveys, offshore asset inspections and construction support services, these vessels signify a shift towards remote and autonomous mapping. The importance of this transition is highlighted by Fugro's acquisition of SEA-KIT International, an innovative developer of USVs recognized for its low carbon emission maritime operations and research.

Software providers such as QPS play a vital role in the maritime industry, offering advanced solutions in geomatics software and services. Their comprehensive offerings cover the entire workflow, serving both surveyors and pilots. Similarly, BeamworX, a prominent software engineering and consultancy company, focuses on the hydrographic surveying and offshore market. Specializing in the acquisition, processing and integration of single and multibeam echosounder data, BeamworX contributes significantly to technological advancements in this field.

About the author

Wim van Wegen is head of content at *GIM International* and *Hydro International*. In his role, he is responsible for the print and online publications of one of the world's leading geomatics and hydrography trade media brands. He is also a contributor of columns and feature articles, and often interviews renowned experts in the geospatial industry.

Across generations, the Netherlands has harboured a profound connection to maritime pursuits, its heritage deeply rooted in the sea. Over centuries, the Dutch hydrographic sector and associated fields have meticulously refined their skills in offshore operations, acquiring an unparalleled understanding of the nuanced conditions above and below the sea surface that significantly influences project outcomes. This extensive experience has established the Netherlands as a premier global centre for pioneering offshore wind businesses, maritime enterprises and esteemed research institutes, renowned for their remarkable achievements and groundbreaking innovations worldwide.

However, with this esteemed position comes a profound responsibility to safeguard this reputation for future generations. The Netherlands remains committed to upholding the highest standards of maritime excellence, ensuring sustainable practices and continued innovation to preserve its legacy as a leader in the maritime industry. ■

Bibliography

The bibliography, containing the sources consulted for this article, can be accessed through the online version of this article published on www.hydro-international.com.

▲ *Demcon Unmanned Systems specializes in designing USVs tailored to accommodate a wide variety of payload capacities. (Image courtesy: Demcon Unmanned Systems)*

▲ *The Braveheart Spirit, a vessel in Braveheart Marine's fleet, is equipped with state-of-the-art hydrographic survey technology, making it ideal for long-term projects in remote offshore locations. (Image courtesy: Braveheart Marine)*

Mapping the seabed using high-res bathymetry data and semi-automated methods

Hidden landscapes: the mapping of Ireland's shelf geomorphology

By Riccardo Arosio, Andrew J. Wheeler, Fabio Sacchetti and Aaron Lim

The Marine Geoscience Research Group at University College Cork, under the aegis of the Irish Marine Institute, has published the first high-resolution geomorphological map of most of the Irish continental shelf: the Irish Shelf Seabed Geomorphology Map (ISSGM v2023). This colossal mapping exercise took advantage of the vast INFOMAR multibeam echosounder dataset and used a protocol of semi-automated mapping techniques to accurately and rapidly extract seabed features. The map is an important digital reference for policymakers, marine industries (e.g. offshore renewables, fisheries and aquaculture) and future marine scientists.

For the past 25 years, Irish government-funded initiatives have carried out extensive seabed mapping campaigns, beginning with the Irish National Seabed Survey (INSS, 1999–2005) and continuing as the Integrated Mapping for the Sustainable Development of Ireland's Marine Resource (INFOMAR) programme (2006–2026), funded by the Department of Environment, Climate and Communications. To date, open source multibeam echosounder (MBES) data has been collected in ~91% of Ireland's territorial waters (~880,000km^2). The INFOMAR datasets have served many purposes, such as UNCLOS claims, compliance with SOLAS regulations, shipwreck investigations and local spatial planning, to name a few. But as the country increasingly looks towards the sea for its energy and resource needs, a holistic, accurate and detailed geomorphological map of the continental shelf, providing the users with easily accessible and understandable information about the nature and processes acting at the seabed, becomes indispensable.

To meet this challenge, the UCC group spent two years: (1) compiling and critically reviewing the scattered scientific knowledge of the geomorphology of the Irish continental shelf; (2) developing an effective and accurate mapping protocol to delineate and characterize landforms for a very large-scale dataset; (3) generating and adopting an internationally standardized classification

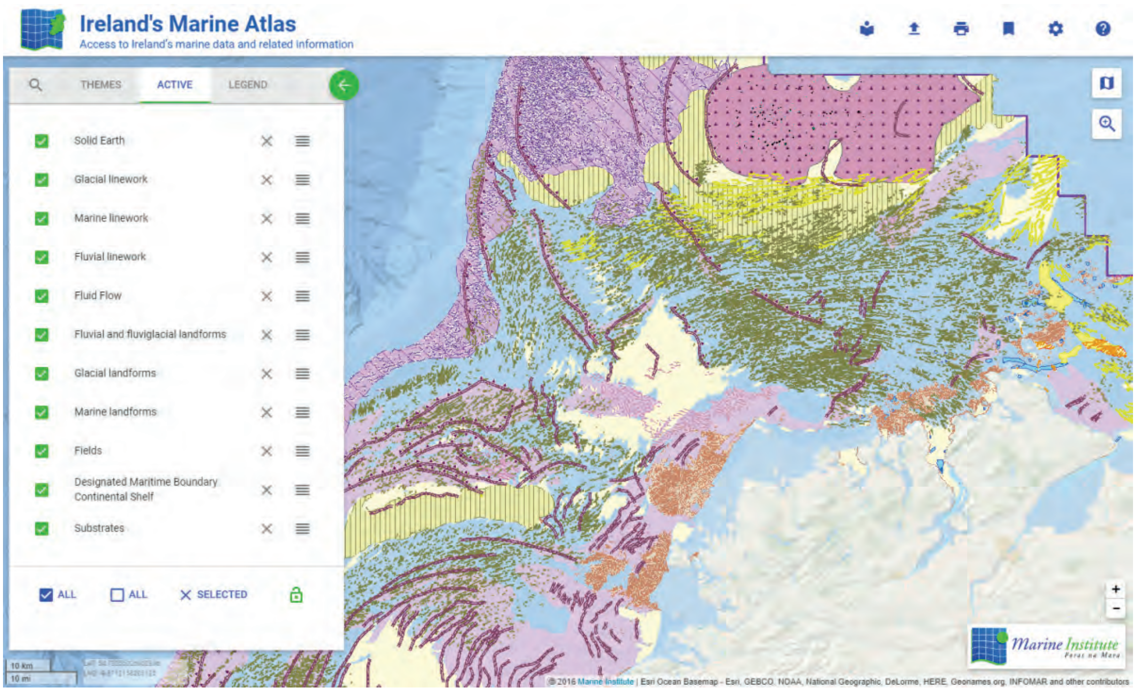


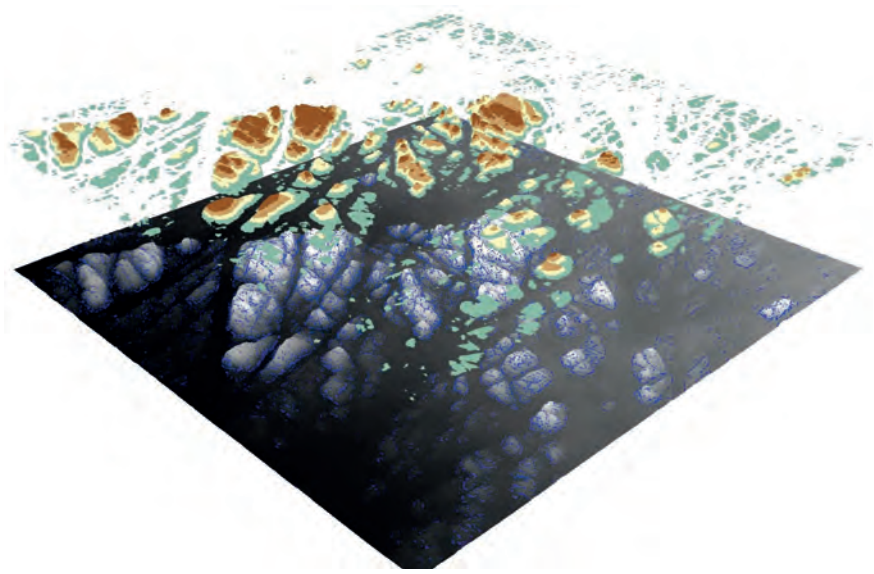
Figure 1: The Irish Shelf Seabed Geomorphological Map (ISSGM) version 2023 as it appears online, in Ireland's Marine Atlas.

system that can be easily compared to other maps; and (4) building an interactive GIS database to disseminate the map and scientific knowledge to stakeholders and the general public. The final product is the Irish Shelf Seabed Geomorphology Map (ISSGM) version 2023 (Figure 1).

Manual or automated – a balancing act

Manually digitizing thousands of geomorphological features in approximately 110,000km² of up to 5m-resolution digital elevation model (DEM) bathymetry is not something that can be done even in a very long PhD project. It should not be surprising then that the task of mapping the shelf geomorphology around Ireland made the employment of semi-automated techniques indispensable. Machine learning (ML) is now commonly adopted in computer vision to rapidly classify images with outstanding results, identifying people or objects as trees, animals and so on. ML techniques, as convolutional neural networks, have also been trialled on DEMs with the purpose of mapping geomorphology; however, the results are still unsatisfactory (Arosio et al., 2023a) and certainly insufficient for the level of detail that the UCC group and Marine Institute required.

Less sophisticated, but still very efficient, are the mathematical – or better geomorphometrical – operations on DEMs that allow a relatively rapid and consistent extraction of seabed features. These methodologies cover the bulk of the work undertaken for this project, and they mostly belong to a type of technique called 'residual relief' separation. The separation aims essentially to 'peel' away landforms of interest from the bathymetry surface using filtering techniques (Figure 2) similar to those used in image correction and noise removal. More technically, the regional relief (i.e. the broadscale undulation of the terrain) is first approximated by a modified median filter using a circular focal neighbourhood tailored to the wavelength of the landforms of interest. The filtered surface thus obtained is then subtracted from the original DEM to leave a 'residual' layer containing the landforms. The residual relief raster can also be locally normalized to allow for amplitude variations in the features across the area. In this way, provided the right filter thresholds are used, thousands of landforms can be rapidly delineated with minimal manual intervention.



▲ *Figure 2: An example of bedrock outcrops (in colour) 'filtered out' of a DEM (black and white bottom layer).*

In many places, the seabed is too complex for filtering to provide a satisfactory result. MBES artefacts, palimpsests and heavily altered features hinder the identification of thresholds that can separate the 'wheat from the chaff', and in other cases the relevant features are so subtle or fragmented that it is impossible to isolate them using geomorphometry. As a result, manual delineation or correction was, in many occasions, unavoidable.

Not only semantics: an international classification system

Maps of seabed geomorphology provide foundational information for a broad range of marine applications, and to be most effective, geomorphic characterization of the seabed requires standardized and interjurisdictional terminology that can be understood both regionally and internationally. For this reason, the creation of the Irish map proceeded alongside an ongoing collaboration between geoscience agencies in the United Kingdom (BGS), Norway (NGU), Ireland (UCC and GSI) and Australia (GA). The collaboration focused on developing a new standardized approach to meet this need, leading to the creation of the 'MIM-GA two-steps classification system' (Nanson et al., 2023).

Following this concept, seafloor geomorphology in the ISSGM is considered in two parts: (1) the shape (or morphology) of the seafloor and (2) the geomorphology of those shapes. The first classification covers basic morphological definitions that describe seabed features by their shape (e.g. ridges, mounds, depressions, etc.). Seabed morphology is used as the baseline for benthic habitat mapping and monitoring, linking seabed morphological classes with substrate composition to benthic and pelagic species distribution, and is an essential asset for marine spatial planning. The second classification covers morphogenetic definitions that provide a geological interpretation of the features identified (e.g. drumlins, coral mounds, pockmarks, etc.). Alternative interpretations of seafloor geomorphology can have considerable impacts on marine industries. It is very important then to separate geometric classification of seafloor morphology from subsurface interpretations that can involve significantly more uncertainty.

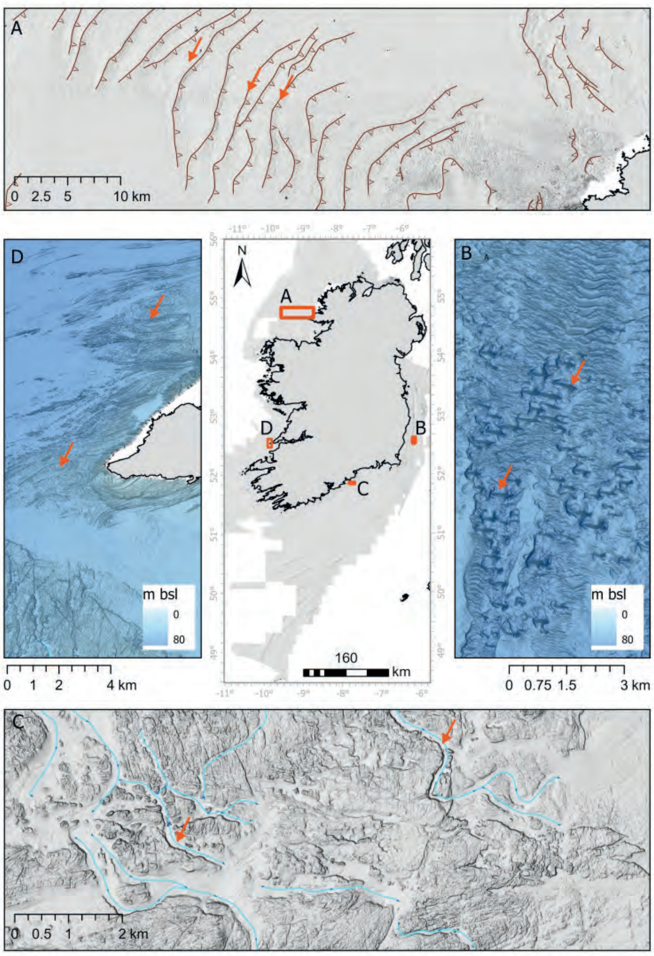
The MIM-GA classification has attracted the attention of many institutions around the world and the GEBCO Sub-Committee on Undersea Feature Names (SCUFN). More information can be found in Nanson et al. (2023).

A map and a database

In its complete form, the ISSGM (v2023) includes 35 different landform units and four substrate types generally mapped at 20m/pixel resolution, with a few exceptions where a higher resolution (10m or 5m) was utilized if geological interest counterbalanced time, effort and hindrance caused by artefacts. Together with the contents of the paper published with the ISSGM (Arosio et al., 2023b), the map illustrates the variety of landforms and processes active on the Irish continental shelf, including new and all previously mapped units. Additionally, this work has revealed places where ground-truthing is lacking or completely absent but of potential geological interest, and identified landforms whose interpretation remains ambiguous, indicating avenues for potential future work.

Old questions and new mysteries

A description of all the findings would be too long for this article, but a quick 'tour' can give an idea of the breadth of information contained in the map. The shelf can be nominally separated into four regions which, while they share a common shallow marine nature, show unique traits and geomorphological characteristics. Starting from the north-west Irish shelf, we find a diverse association of glacial landforms including large recessional moraines (Figure 3A), iceberg plough marks and drumlins. This is the Irish seabed region where glacigenic forms have been best and most extensively preserved, permitting detailed studies on the extent and retreat rate of the last ice sheet in the area. The western Irish Sea seabed shows the most complex geomorphology, with at least half the area of the central and southern section of the region covered by large units and fields of dunes, mainly transverse and trochoidal (Figure 3B). These unusually high and still puzzling trochoidal dunes are the features that have received most attention in past studies. They are associated with linear or channel-like depressions, from which they obtain abundant scoured mobile sediment that permits their subsistence. In the Celtic Sea, the most striking morphology is the palaeochannels, a dense network of buried to semi-buried fluvioglacial features that may be linked to the demise of the great ice sheet at the end of the last Ice Age (Figure 3C). Further investigations in the shallow seismic stratigraphy are required to confirm the interpretations, which would improve the understanding of the distribution and structural control of Pleistocene palaeodrainage in the region. Reaching finally the



▲ *Figure 3: Examples of landforms from the four nominal regions on the Irish shelf. A) Recessional moraines forming a retreating pattern offshore Donegal. B) Trochoidal dunes in the Irish Sea. C) Sinuous palaeochannels winding on bedrock. D) 'Eye-shaped' fold structures in bedrock offshore Loop Head.*

About the authors

Riccardo Arosio is a marine geologist and postdoctoral researcher at University College Cork in the Marine Geosciences Research Group. Riccardo's research focuses on the use of geomorphometry and machine learning to characterize the geology and geomorphology of the seabed.

Andrew Wheeler is Professor of Geology and head of Geology at University College Cork. As a marine geologist, he works on both shallow- and deep-water systems with interests in seabed mapping, benthic boundary layer processes and Pleistocene seabed developmental histories.

Fabio Sacchetti is a project manager, senior hydrographer and team leader for INFOMAR, the Irish National Mapping Programme. Fabio also coordinates various research projects focused on marine remote sensing, sedimentology, geomorphology, underwater archaeology, offshore glacial processes and underwater acoustics.

Aaron Lim is a lecturer in Coastal Geomorphology and director of the MSc in Coastal and Marine Management at University College Cork. Aaron's research interests include applied seafloor mapping, seabed processes and submarine photogrammetry.

Acknowledgements
The authors would like to thank the hard work of the captains and crews of the Irish research vessels that assisted in the collection of the Irish National Seabed Survey and INFOMAR datasets. This project was funded by the Irish Marine Institute's research [grant number PDOC 19/08/03]. The map contains Irish Public Sector Data (Marine Institute & Geological Survey Ireland) licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

south-west, about 30% of the mapped seabed is covered either by bedrock outcrops or by bedrock only thinly covered by superficial sediment, making it the rockiest seabed region around the coast of Ireland. The most extensive outcrop is the Waulsortian platform offshore north Kerry, whose massive limestone beds appear to be affected by relict karstic processes. However, the most stunning bedrock structures crop out south of the mouth of the Shannon and north of Loop Head (Figure 3D).

Conclusion
As Ireland enters a new era of development for blue growth, offshore renewable energy and climate action, the Irish Shelf Seabed Geomorphological Map (ISSGM) version 2023 will hopefully be instrumental to many, providing a lucid and complete geomorphological database including a systematic review of previous research findings, easily accessible and ready to use. The ISSGM is available online on the Irish Marine Atlas (https://atlas.marine.ie) under the Geology Theme. ■

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▲ *Cliffs overlook the entrance to the cove along the Irish Sea. (Image courtesy: Shutterstock)*

Shaping naval strategies worldwide

Fast-tracking the evolution of unmanned maritime systems

By Captain George Galdorisi (USN, retired)

In an era of great power competition, unmanned maritime systems (UMSs) have begun to take centre stage and are now on an accelerated development path for reasons that are clear. Like their air and ground counterparts, these unmanned maritime systems are valued because of their ability to reduce the risk to human life in high threat areas, to deliver persistent surveillance over areas of interest, and to provide options to war fighters that derive from the inherent advantages of unmanned technologies.

The past year may well be remembered as a high-water mark for the insertion of UMSs into a number of international exercises, experiments and demonstrations that have, literally, spanned the globe. Over the course of these events, unmanned maritime systems have performed an increasingly ambitious and complex series of missions, giving great confidence to those nations and navies who see them as an important part of their fleets.

While it will take years to unpack all the lessons learned from the ongoing war in Ukraine, one mission that has surfaced during this conflict that connects maritime warfare and unmanned surface vehicles is the use of USVs armed with explosives to attack naval vessels. This is a tactic and concept of operations that has been discussed in numerous professional articles and even war-gamed, but until now has been hypothetical.

▲ *T38 Devil Ray (foreground) operating with U.S. Coast Guard Cutter.*

Today it is real. As described in reports of Ukraine's attacks on Russian naval vessels in the Black Sea, armed USVs have been used with deadly effect. Here is how one naval analyst described the momentous impact of using armed USVs to attack naval vessels and what that means for the future of maritime warfare:

> Ukraine's attack on Sevastopol on 29 October 2022 will go down in history as the first major example of what many believe is a new era of drone warfare. The Russian Navy Black Sea Fleet found itself defending against both surface and aerial drones. Seven uncrewed surface vessels (USVs) were involved, along with nine uncrewed air vehicles (UAVs).
>
> USVs have evolved quickly over the past few years, but only now have they truly gone to war. The surface drones approached the port in the early morning. They raced toward their targets, piloted remotely from hundreds of miles away using onboard electro-optical devices. On their bows, impact fuses would detonate the warheads. Future wars may see increased use of weaponized surface drones.

Accelerating unmanned maritime systems development – Middle East efforts
To be clear, the advantages of accelerating the development of unmanned maritime systems have not been restricted to the United States. The U.S. Navy is not the only navy keenly interested in unmanned surface vehicles, and the following events show the keen interest of the navies of many nations in finding new missions for these UMSs.

International Maritime Exercise (IMX), held under the auspices of U.S. Naval Forces Central Command, Commander Task Force 59 in the Arabian Gulf, focused on the integration of manned and unmanned vessels and included operations with several regional partners. Navies and coastguards of the nations and navies involved in IMX worked to fully explore the capabilities of unmanned systems such as the Saildrone, the MARTAC MANTAS and Devil Ray, and many other USVs from participating nations. This is the first time that so many nations participated in an event of this type.

In the run-up to IMX, the Commander of U.S. Naval Forces Central Command, U.S. 5th Fleet, Vice Admiral Brad Cooper, noted: "The Navy has been working with manufacturers to test new technologies, including firms such as Saildrone and MARTAC under a contractor-owned, contractor-operated model."

What is noteworthy about CTF-59 operations in the Arabian Gulf is the fact that IMX was not a 'one-off'. Rather, manned-unmanned integration operations in the Arabian Gulf continue. The U.S. Navy now has 20 USVs in or near the waters of the Arabian Gulf. Indeed, the United States and its allies want a force of 100 unmanned surface vessels patrolling waters from the Red Sea to the Arabian Gulf by the end of this year.

▲ *T38 Devil Ray – shoreline operations.*

▲ *T38 Devil Ray during Australian operation Autonomous Warrior.*

One U.S. USV company, Maritime Tactical Systems Inc. (MARTAC), was a primary participant in IMX. Its unmanned surface vehicles, MANTAS and Devil Ray, were mainstays of this exercise. Here is how one defence analyst captured the essence of MARTAC's participation in this major exercise:

> MARTAC has a strong presence in 5th Fleet operating with Task Force 59, a Middle East-based taskforce working on the development of unmanned systems. Typical missions for MARTAC include intelligence, surveillance and reconnaissance, port and harbour security and sensing capabilities, in addition to classified missions.

Accelerating unmanned maritime systems development – Asia-Pacific efforts
In another international exercise focused on missions for unmanned maritime systems, the Australian Defence Force (ADF) hosted Exercise Autonomous Warrior (AW). Nations participating in this Royal Australian Navy-led exercise included Australia, New Zealand, the United Kingdom and the United States, and featured a total of 30 autonomous systems. The unmanned surface vehicles that were part of this two-week exercise were the Saildrone, MANTAS and Devil Ray featured in IMX, the Atlas Elektronik ARCIMS, the Elbit Systems Australia SEAGULL and the Ocius Bluebottle.

Another exercise, the bi-annual Rim of the Pacific (RIMPAC) exercise (the world's largest international maritime exercise) was especially noteworthy as the U.S. Navy inserted four unmanned surface vehicles in this major international exercise. RIMPAC gave the event's 26 participating nations an opportunity to see these USVs in action.

The U.S. Third Fleet Commander, Vice Admiral Michael Boyle, the commander of RIMPAC, put special emphasis on the unmanned vehicles participating in RIMPAC, as well as manned-unmanned integration:

> What's also new in this RIMPAC is a lot more integration of unmanned systems – on the surface, in the air and under the surface. The four unmanned surface vehicles that the Navy brought to the exercise carried

▲ *T38 Devil Ray (foreground) and Saildrone USV (background) night operations during International Maritime Exercise Arabian Gulf.*

specialized payloads for anti-submarine warfare, intelligence, surveillance and reconnaissance, domain awareness and communications capability.

One of the important lessons learned regarding the operations of unmanned surface vessels during RIMPAC was what was important to the sailors operating these four USVs. One official from the Navy's programme office for unmanned maritime systems noted that:

Digital Horizon brought together new, emerging unmanned technologies and combined them with data analytics and AI to enhance maritime security and strengthen deterrence

"One of the biggest pieces of feedback we're getting is that they're [sailors operating these USVs during RIMPAC] talking about payloads, they're talking about capabilities. They're not talking about the autonomy. They're not worried that [the USV] is going to ever run into something."

Accelerating unmanned maritime systems development – European/MENA efforts

On the other side of the world, NATO exercises REPMUS, and the follow-on Dynamic Messenger, provided an opportunity for NATO nations to evaluate unmanned systems and their ability to coordinate on, above and under the sea. Led by Portugal and conducted near the Troia Peninsula, these exercises focused on the integration of 120 autonomous assets into a single network. Several NATO commands – NATO's Allied Command Transformation, NATO's Allied Maritime Command, the NATO Centre of Excellence and the NATO Centre for Maritime Research and Experimentation – were part of these exercises. This enabled partner nations to learn best practices regarding how to shepherd unmanned systems into their respective navies.

Soon after these exercises, the U.S. Navy-led exercise Digital Horizon, a three-week event in the Middle East, focused on employing artificial intelligence and 15 different unmanned systems (12 USVs and 3 UAVs), many of which were operated in the region for the first time. The exercise, meant to be a continuation of IMX but on a significantly larger scale, was hosted by Task Force 59 and built on the work done during IMX. Indeed, Digital Horizon was the largest international unmanned exercise ever held.

Digital Horizon brought together new, emerging unmanned technologies and combined them with data analytics and artificial intelligence to enhance regional maritime security and strengthen deterrence. The exercise featured 17 companies that collectively brought 15 different types of unmanned systems, ten of which operated with U.S. 5th Fleet for the first time. As Captain Michael Brasseur, commodore of Task Force 59, noted, one of the objectives of Digital Horizon was to use unmanned maritime vehicles to conduct intelligence surveillance and reconnaissance missions, including identifying objects in the water and spotting suspicious behaviour.

Impact on future naval operations

From the perspective of the U.S. Navy, these exercises and initiatives are important and represent a significant course change as the Navy works to convince Congress that its plans for unmanned systems are sound. Secretary of the Navy, the Honorable Carlos Del Toro, noted the Navy's new 'show, don't tell' philosophy built on an ongoing series of exercises, experiments and demonstrations, further indicating that he believes that the Navy is: "On the same page as Congress."

About the author

Captain George Galdorisi (USN, retired) is a career naval aviator whose 30 years of active-duty service included four command tours and five years as a carrier strike group chief of staff. He began his writing career in 1978 with an article in U.S. Naval Institute *Proceedings*. He is the author of 15 books, including four *New York Times* bestsellers. Note that the views presented in this article are those of the author and do not reflect the views of the Department of the Navy or the Department of Defense.

Looking ahead to this year and beyond, world navies are keen to bring both commercial off-the-shelf (COTS) unmanned maritime systems, as well as other USVs in various stages of development, to exercises, experiments and demonstrations. This will enable them to not only demonstrate their own capabilities, but to also learn best practices by observing the operations of unmanned maritime systems of other nations. These efforts are certain to accelerate the development of these USVs and, for the U.S. Navy, hasten the goal of a 500-ship Navy that is envisioned to have 350 crewed ships and 150 unmanned vessels.

Surveying for a CATZOC A1 navigable bottom in the presence of fluid mud

Mapping through fluid mud

By Dr Pawel Pocwiardowski, NORBIT

The presence of suspended sediments in water bodies presents significant challenges for the dredging industry. Existing methods to determine nautical depths are intrusive single point methods relying on in situ density or shear strength measurements[1,3] or low-frequency single-beam echosounder recordings[1,2]. The use of single-beam echosounders is however systemically problematic as they are not practical in satisfying the CATZOC A1 coverages required for contemporary electronic navigational charting.

Here the author describes a method to obtain ZOC category A1 for areas exhibiting suspended mud using multibeam echosounders operating at an ultra-wide frequency range of 80–400kHz. This method reaches the nautical bottom as well as single-beam systems and generates high-resolution full search bathymetric maps.

Problem definition

The acoustic methods used in various studies have shown how different frequencies penetrate different mud layers[2]. As can be seen, typical multibeam frequencies higher than 200kHz propagate through the water column until meeting the fluid mud layer. In some cases, high-frequency signals punch randomly through the fluid mud so that the resulting data is broken up between the upper and lower layers of the floor, interfering with the operation of sonar systems conducting bathymetric surveys. The problem is illustrated in Figure 2.

The task is therefore to provide a solution capable of detecting each layer separately and reaching the navigable bottom for wide swath area coverage.

LMD method – how to map through fluid mud

NORBIT previously introduced ultrawide-band frequency modulated operation – often called multispectral backscatter (MSB) – which makes it possible to derive properties of the signal at the low end and high end of the spectrum simultaneously. The extension of that technique into layered media detection (LMD) utilizes FM signals extending from 80kHz to 400kHz and facilitates additional determination of bathymetry from the stratified sea bottom by exploiting the different penetration depths of different frequency bands. At the same time, high-resolution bathymetry maps are obtained by employing proven beamforming and a new LMD technique that utilizes the specially designed ultra-wide FM signal to its full potential in characterizing the layered seabed for detailed seabed analysis.

The method proposed involves the clear identification of both layers, avoiding the typical problems with narrow-band high-frequency sonars. It operates by using two concurrent detection processes within the same broadband signal, each at different frequency bands to identify separate layers. Different frequency bands penetrate different depths in the layered media. High-frequency bands are more effective at detecting suspended sediments near the surface of the top layer, while lower frequency bands can penetrate through to the deeper layers, efficiently characterizing each stratum of the seabed (see Fig. 3).

The high-frequency part of the signal, identifying the top layer (compare Fig. 1), guides the detection process for the subsequent lower frequency end of the wide-band signal. The entire signal processing occurs simultaneously in the sonar hardware, requiring no manual intervention, and is seamlessly integrated into real-time operation.

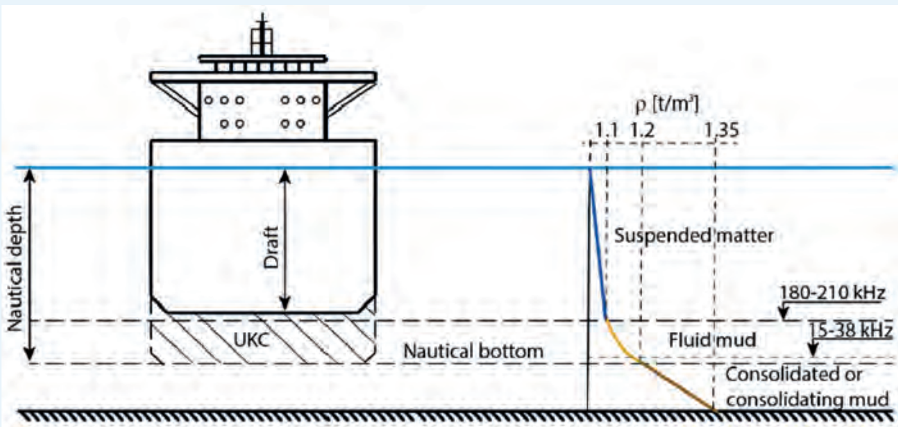


Figure 1: Navigable bottom and fluid mud layers (adapted from Ref. 2).

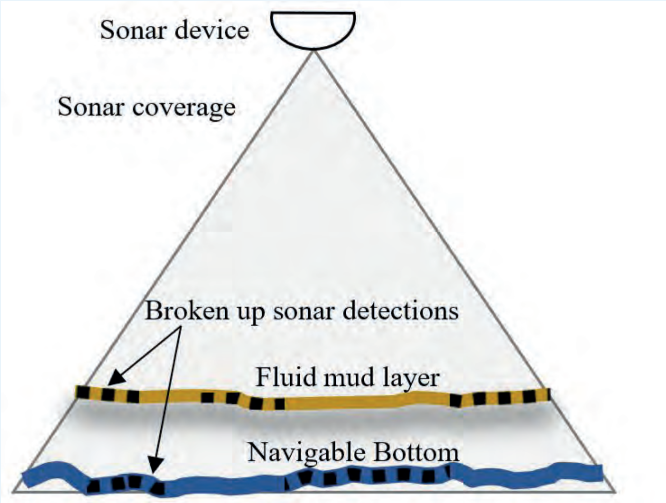


Figure 2: Fluid mud layer problem showing typical detections alternating between layers.

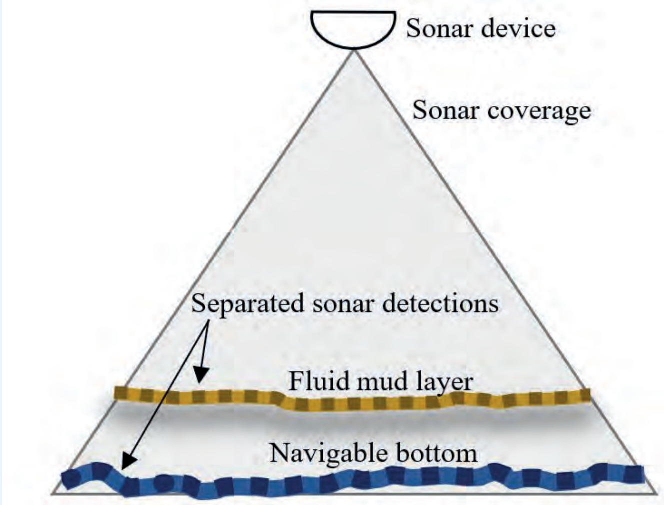


Figure 3: Layered media detection (LMD) method showing two separately detected layers.

Using lower frequencies inherently reduces the system's resolution, necessitating a careful balance in selection of the frequency and the physical size of the system. Frequencies between 80kHz and 120kHz have proven to be a good compromise for the lower end of the acoustic spectrum, providing adequate penetration without significantly compromising acoustic resolution. This is especially suitable for dredging operations with system apertures around 0.5m producing an angular resolution in the order of 2 x 2 degrees.

LMD in action

Implementation of the LMD method into bathymetric systems is only possible for highly advanced sonar platforms. These highly advanced devices are capable of volumetric signal processing and operate with ultra-wide broadband signals produced by the newest achievements in acoustic transducer technologies. The LMD technology was developed by NORBIT in its powerful WINGHEAD sonar platform called i87S. The sonar is capable of projecting high-power FM signals with an ultra-wide bandwidth (80–400kHz), enabling operation of the LMD method.

The above method was deployed and tested in several places in USA ports and harbours. One survey was carried out in the vicinity of Kings Island in the Savannah District in the USA. This area was chosen as it is known to contain fluid muds. The NORBIT i87S system was installed on the survey vessel along with the RheoTune sampler and a 28kHz single-beam echosounder for comparison.

The system was configured to output both frequency bands at the same time to show how a typical survey with high-frequency multibeam sonar would compare to the LMD sonar. The left-hand side of Figure 5 shows the surface obtained from the 370kHz-band processing and the right-hand side of the figure shows the processing result of the 80kHz band. As can be seen, the high-frequency image shows the top of the fluid mud broken up, with some gaps sporadically punching through the top of the mud. The data has been cleaned and gaps interpolated to show the entire area. Here, it would not be possible to see a navigable bottom as most of the sound is reflected from the top surface and cannot penetrate to the lower layer. On the right-hand side, the low frequency spectrum shows what lies underneath the fluid mud. It shows an average of six feet penetration and dredge marks in the deeper sections, now fully covered by mud and inaccessible to a typical multibeam sonar.

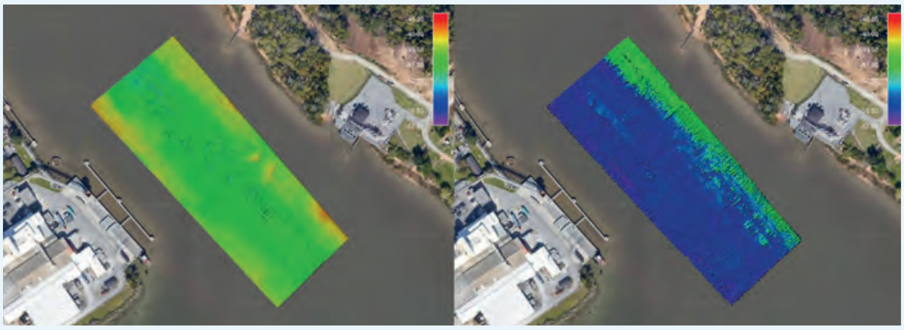
Another nearby area in the Turning Basin (Fig. 6) was also surveyed with the LMD method and the sonar was also configured to output data from both the low- and high-frequency band for comparison. Similarly to the previous case, the high-frequency band data shows the top of the fluid mud surface. This data is broken up due to alternating detections between the upper and lower layers and indicates typical data obtained with a standard high-frequency multibeam sonar. What lies – on average ten feet – below that blanket is the navigable bottom shown in the right-hand side of Figure 6. Some deeper areas (up to 15ft) are also visible, most likely resulting from dredge activity and other morphological features normally impossible to visualize using single-beam echosounders due to the low sampling density and low resolution.

Validation

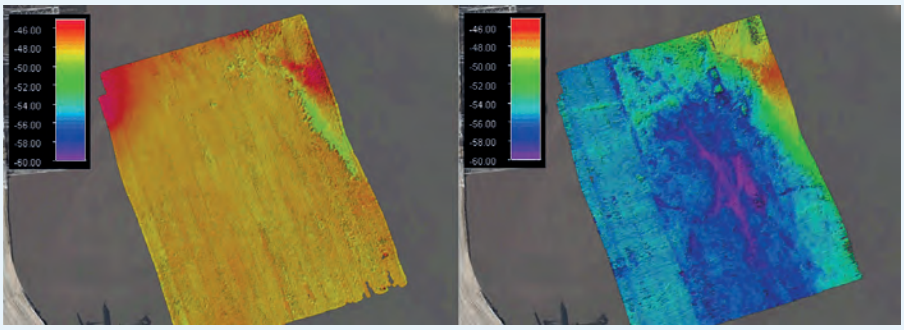
The data obtained with the LMD method was validated against the proven 28kHz single-beam echosounder survey and showed a good match under the presence of fluid mud in the location described above.

Figure 4: NORBIT WINGHEAD i87S used for suspended mud survey.

The agreement of the 80kHz band of the i87S with the 28kHz single-beam echosounder shows that fluid mud penetration can be obtained using a powerful multibeam system where the detection process of the low-frequency band is guided by concurrent processing of the high-frequency band. This cooperation between high and lower frequency bands makes it possible to successfully and robustly discriminate between the layered sea bottom, even with the swath bathymetry systems covering large areas during the survey.



▲ *Figure 5: Resulting surface in Kings Island, 370kHz on the left and 80kHz on the right. The colour scale is the same. The difference between the blue and green colour is six feet.*



▲ *Figure 6: Resulting surface in Turning Basin, 370kHz on the left and 80kHz on the right. The depth colour scale is the same. The difference between the blue and orange colour is ten feet.*

About the author

Dr Pawel Pocwiardowski has worked at NORBIT since 2013 as product director for Sonar Systems. He has over 20 years of experience working with multibeam systems and underwater acoustics. His main interest is the design of the sonar systems and solutions and facilitating the growing needs of the remote sensing markets.

Conclusion

A novel approach for mapping of the navigable bottom under fluid mud conditions was implemented in the NORBIT i87S sonar system using the layered media detection method. This was achieved due to the concurrent processing of the low- and high-frequency band of the ultra-wide FM modulated signal produced by a powerful multibeam sonar. The mutual interaction between the concurrent processing of these two bands in this method efficiently discriminates between the stratified seabed and detects the navigable bottom without the destructive interaction of the suspended layers.

Despite the unique processing power and modern capabilities, the sonar size and weight have been minimized and it is possible to install and operate the system by a single person as a portable installation.

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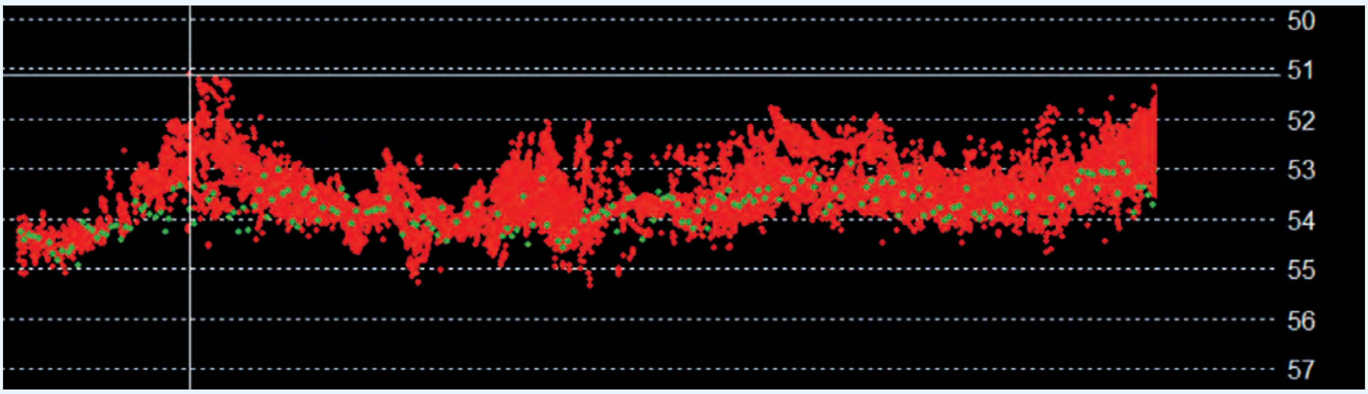


▲ *Figure 7: Comparison of LMD: Red – LMD from i87S, Green – 28kHz single-beam echosounder. Vertical scale is in feet.*

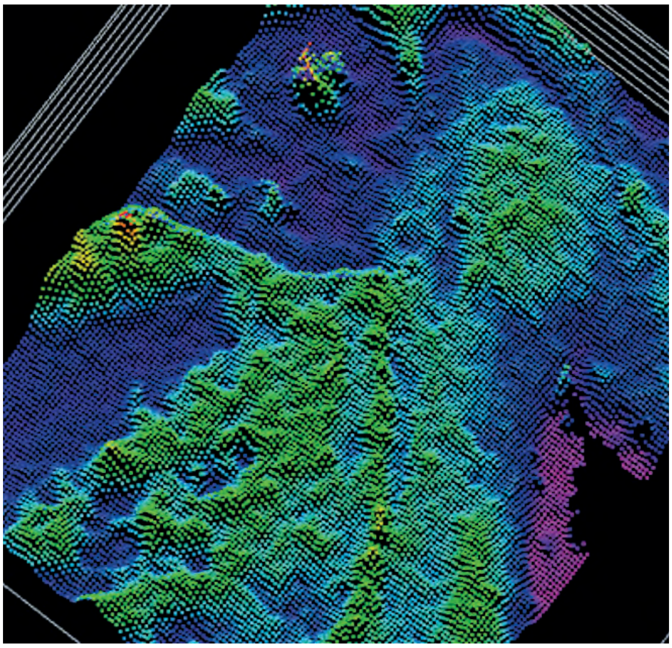
An efficient method for mapping water properties

The role of satellite-based mapping in hydrography

By Rachel Bobich and Corey Goodrich

By harnessing capabilities of advanced satellite technology and ever-evolving data analysis, satellite-based mapping (including satellite-derived bathymetry, SDB) offers an efficient, extensible and cost-effective method for mapping water properties, underwater topography and other elements of coastal zones and inland waters. This discussion prioritizes two critical applications of satellite-derived mapping – environmental monitoring and hydrographic planning – to demonstrate the flexibility of the technology and outline two distinct uses that may be relevant to a stakeholder's needs in the maritime industry.

By harnessing capabilities of advanced satellite technology and ever-evolving data analysis, satellite-based mapping (including satellite-derived bathymetry, SDB) offers an efficient, extensible and cost-effective method for mapping water properties, underwater topography and other elements of coastal zones and inland waters. This discussion prioritizes two critical applications of satellite-derived mapping – environmental monitoring and hydrographic planning – to demonstrate the flexibility of the technology and outline two distinct uses that may be relevant to a stakeholder's needs in the maritime industry.



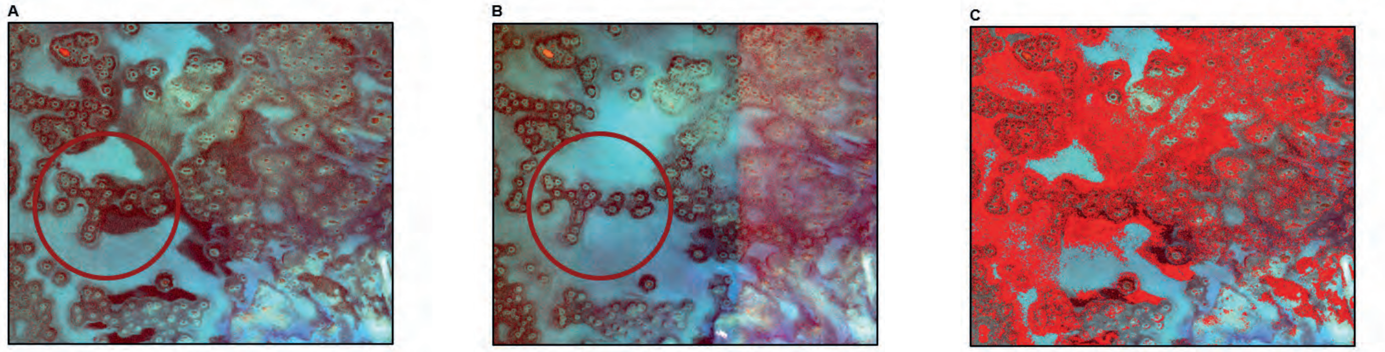
▲ *Figure 1: Seagrass beds shown in 3D at 30cm resolution over a small subset of the larger Grand Bahama AOI.*

Most effective in nearshore and navigational area limit line (NALL) environments, satellite-based technology has been deployed in difficult-to-navigate or remote territories where data gaps persist and/or no environmental footprint is permitted. Strengths of the technology include the near-global ability to map large shallow-water areas, repeatedly if warranted, to provide modern hydrographic information at a fraction of the cost of a traditional airborne or shipborne survey without mobilization of equipment or personnel. Satellite-derived mapping is stated to provide results out to 30 metres depth in optically clear waters.

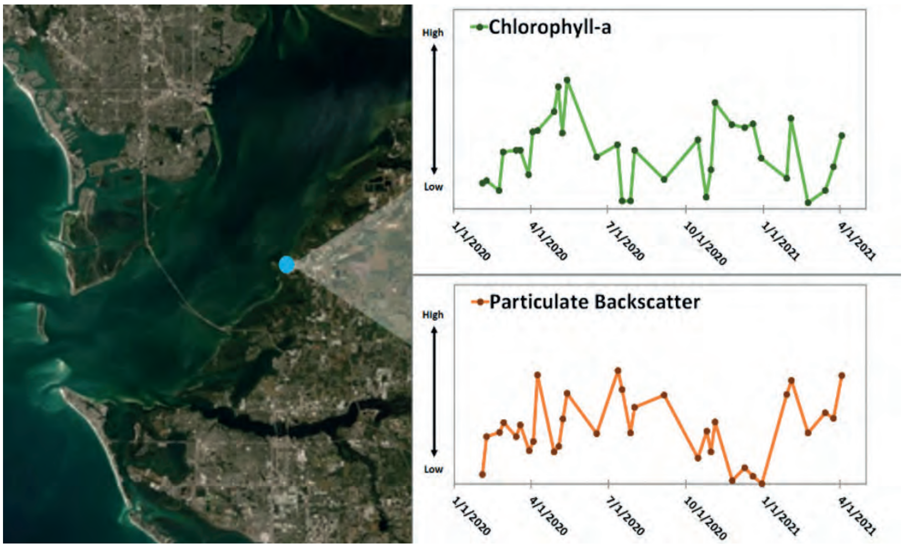
Satellite-based mapping and analysis hold immense promise for government hydrographers, intelligence agencies and organizations worldwide engaged in maritime navigational safety, updating bathymetric information, environmental conservation and coastal development planning. The diverse real-world implementations of SDB, from environmental monitoring to geospatial intelligence and including potential future applications, underscore its growing importance in a world that increasingly values modern, comprehensive bathymetric information.

Use case: environmental monitoring

Ecological observation and studies have become a well-established attribute of satellite-derived bathymetry's ever-evolving science. As a crucial component of global marine ecosystem health, seagrass beds provide a multitude of ecosystem and nursery ground benefits. These include sediment bed stabilization, erosion prevention and the reduction of wave action during storms, carbon sequestration, water quality improvements through absorption, and biodiversity support (Coffer et al., 2023). Leveraging both hyperspectral and multispectral satellite-derived bathymetry workflows for the habitat observation and monitoring of this invaluable resource has proven to be quick and cost-effective.



▲ *Figure 2: **A:** True colour composite image of seagrass beds and healthy coral reefs from 2010. **B:** True colour composite image of same area showing loss of seagrass beds and healthy coral. **C:** Image showing areas of seagrass loss from 2010 to 2021 in red.*



▲ *Figure 3: A rise in chlorophyll concentrations compared to overall particulate backscatter may indicate measurable algal blooms.*

▲ *Figure 4: (Left) SDB is used in the field to improve survey safety and efficiency. (Right) Joint Hydro Survey team: Jamaica's National Land Agency, Jamaica Defense Force and TCarta collaborated to fuse SDB, MBES and drone technology in surveying Port Antonio, Jamaica.*

A seagrass bed analysis shown in Beneath the Waves highlights where TCarta provided environmental mapping services to identify seagrass extent and loss in three AOIs across the Greater Bahama Bank. Utilizing Maxar's satellite imagery, detailed classifications of this area near the Ragged Islands in the Southern Bahamas were able to shed light on the density and quantity of vegetation present. One analysis performed at 30cm resolution with a calculation of the surface roughness of seagrass beds and another at 1.24m resolution using the differences in spectral response at differing depths were employed. To properly assess the surface roughness of seagrass beds versus coral reefs, 3D point cloud visualizations of the bathymetry were made. As seen in Figure 2, SDB of a seagrass bed shows the shape and density of seagrass beds compared to sand, rubble and coral reefs.

The introduction of surface roughness influenced by bathymetric ground-truth data allows this workflow to be trained to detect different densities and depths of seagrass. The Bahamas, with varying but known seafloor types and morphologies, allows for a quick classification without excess in situ data or other inputs to better train the model. This workflow seamlessly and economically detects habitat change and overall health of these cooperative submerged marine flowering plants.

Limitations may include sensor capture type and temporal influences such as weather, season, wave action, sea surface light refraction and false (deeper than actual bathymetric depth) returns due to a low albedo effect. However, these limitations are easy to leverage as training for future analyses due to the known benthic classifications and environmental conditions found in the area.

Another use case of TCarta's environmental impact monitoring was leveraged by Sentinel-2 20m-resolution images collected from 8–13 April 2021 over the Piney Point discharge site in Port Manatee, Florida. The analysis indicated a slight increase in relative chlorophyll-a concentrations over previously derived measurements from January 2020, while particulate backscatter concentrations remained consistent with previous measurements. The increase in chlorophyll indicated that wastewater was at high enough concentrations to be measurable via satellite in Tampa Bay and/

or the nutrient-laden wastewater had triggered an algal bloom. Using satellite-derived bathymetry, limitations of measuring such suspended sediments or nutrient blooms of microscopic algae give way to hurdles of accuracy regarding depth or quantifying density or amounts due to turbidity and a low albedo effect. After all, the darker the plume or submerged object is, the more light it will absorb.

Use case: hydrographic survey planning

Satellite-derived mapping technologies have long been promoted as an advanced reconnaissance tool and complementary technology to traditional hydrographic survey methods. Since a considerable amount of human and capital resources are required to execute a successful and accurate topobathy Lidar survey, single-beam sonar survey (SBES) or multibeam sonar survey (MBES), SDB and satellite-derived water quality can be deployed to improve the efficiency and effectiveness of hydrographic surveys.

Marine survey planning

In the planning stages of a shipborne survey, SDB has been used to plan more efficient survey track lines and avoid shallow, nearshore areas and hazards. It has also been used to pre-identify relevant ATONs (aids to navigation) and DTONs (dangers to navigation) required in surveys such as federal maritime charting surveys.

Airborne survey planning

In the case of planning an airborne Lidar survey (topobathy), SDB has been used to provide a generalized summary of depths within a project area, paving the way for planning and conducting feasibility studies for traditional bathymetric surveys to be undertaken, especially where inadequate chart data exists.

Collaborations bring together desk-based surveyors with hydrographic field surveyors

Beyond bathymetry, or depth information, advanced processing of satellite imagery can provide historical and modern water quality information that is relevant to planning survey priorities, including site selection and prioritization. Additionally, water quality information can be used to understand or document survey results. In a project delivered to Dewberry, survey planners and programme managers used TCarta's Water Quality Dashboard to make flight decisions and plan resources and stage logistics (https://lidarmag.com/2023/12/31/mapping-florida-waters/).

In both marine and airborne surveys, SDB has proven useful post-survey for filling in data gaps, such as holidays or gaps between survey lines with respect to defined coverage, as well as confirming or fully mapping NALL-designated areas or gaps in depths to the zero-depth contour. The technological integration of SDB with traditional survey methods helps to leverage the strengths of each technology while mitigating the weaknesses. Often, these collaborations bring together 'desk-top' surveyors with hydrographic field surveyors, where both backgrounds are highly valued and impact on project success and efficacy.

Conclusion

Satellite-based observation methods are non-destructive and do not increase the carbon footprint compared to traditional in situ survey methods. From 13 July 1972 onward, satellites have traversed the globe, providing valuable insight into what is going on above and below the surface of our waters. This massive (and ever-growing) amount of data, spanning over 50 years, can be used to effectively map and monitor the health and biodiversity of various marine ecosystems, as well as to increase the safety and efficacy of traditional bathymetric surveys. ■

About the authors

Rachel Bobich is a hydrographer and the proprietor of RMB GEO, a marine and data science firm. She specializes in hydrospatial mapping techniques such as topobathy Lidar and satellite-derived bathymetry, alongside multibeam acquisition and processing. Her career spans roles in government agencies and private organizations, including the NGA's GEOINT division programme and previous work as GIS manager for the Department of Natural Resources, Marine Resource Division in South Carolina.

Corey Goodrich is a majority owner and managing partner of TCarta, a small Denver, CO-based business specializing in satellite-based innovative technologies for improved modelling and understanding of shallow-water and coastal environments. Corey's primary assignments as managing partner include financial operations, business opportunity and proposal development, internal management and academic partnerships. Corey is serving her second term as trustee on the National Board of The Hydrographic Society of America.

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OceanICT: pioneering the frontier of data and connectivity showcase

The co-located expo within Oceanology International 2024 has been expanded to bring together the most influential AI, communications, satellite, IT and IoT stakeholders. OceanICT, an event focused on marine information and communication technology, returns for a higher-profile third edition this year, as demand rises for new data and connectivity solutions to facilitate a smarter, more sustainable ocean.

As a co-located event within Oceanology International 2024 in London, the unique OceanICT expo is positioned to offer ICT stakeholders the 'greatest stage' to showcase technologies, congregate and collaborate, according to Oi24 organizers. Around 30 specialist exhibitors will take the opportunity to introduce their new ICT innovations and breakthroughs when the largest concentration of global ocean technologists gathers over three days from 12–14 March.

First launched at Oi in 2018, OceanICT is this year powered by ON&T and has been expanded to meet growing demand for heightened connectivity and interoperability across the blue economy with the amount of data acquired within the ocean space continuing to increase.

Connect the dots

As coastal, offshore and ocean industries look for solutions to help facilitate efficient ocean data collection, transfer, storage and analytics to future-proof long-term exploration efforts and development plans, there is more focus on the search for cutting-edge AI, communications, satellite, IT and IoT solutions for measuring, monitoring, protecting and operating in the world's oceans.

▲ *OceanICT is a premier event for marine information and communication technology.*

David Ince, Oceanology International portfolio director, said: "The need for a dedicated marine event to serve the ICT market is vital as the blue economy transitions towards a more sustainable future. At Oi24, we are accommodating the transformation in the use of technology with a unique space within the event. Our aim with OceanICT is to 'connect the dots', providing the greatest stage for AI, communications, satellite, IT and IoT solutions providers to meet and collaborate with key marine and ocean data end users from around the world.

"OceanICT capitalizes on being a part of Oceanology International, the world's largest, most influential gathering of industry, government and academic professionals from marine science and ocean technology. By bringing together the leading organizations providing solutions for communications, data storage, networking and more, Ocean ICT adds a new dimension to Oceanology International's already diverse approach. OceanICT is an unmissable opportunity to meet face-to-face with the market and interact with the latest technology first hand."

OceanICT exhibitors at Oi24 include CSignum, ET Works, the European Space Agency, MSM Ocean, MicroStep-MIS, Seafloor Systems, Seequent and the title partner ON&T.

Grant Day, European Space Agency, said: "As an exhibitor at OceanICT, my primary objective with ESA Space Solutions is to speak to as many companies as possible who are looking to do innovative things with R&D in marine space, particularly any solutions that involve satellites, so things like communication, navigation, earth observation or space weather. ESA Space Solutions offers a great deal of support – more than just the funding – and OceanICT is an interesting space where companies are likely to be doing things that we are keen to speak to them about and help with the development process." ■

More information about OceanICT is available here.

Deciphering global heat patterns

How rising ocean temperatures are influencing our weather

By Joël Hirschi, National Oceanography Centre, UK

Globally, surface air and ocean temperatures have warmed by about 1°C since 1900. More than 90% of the additional heat contained in the climate system (atmosphere, ocean, land) due to global warming is stored in the ocean, so what do these increased ocean temperatures mean for our weather?

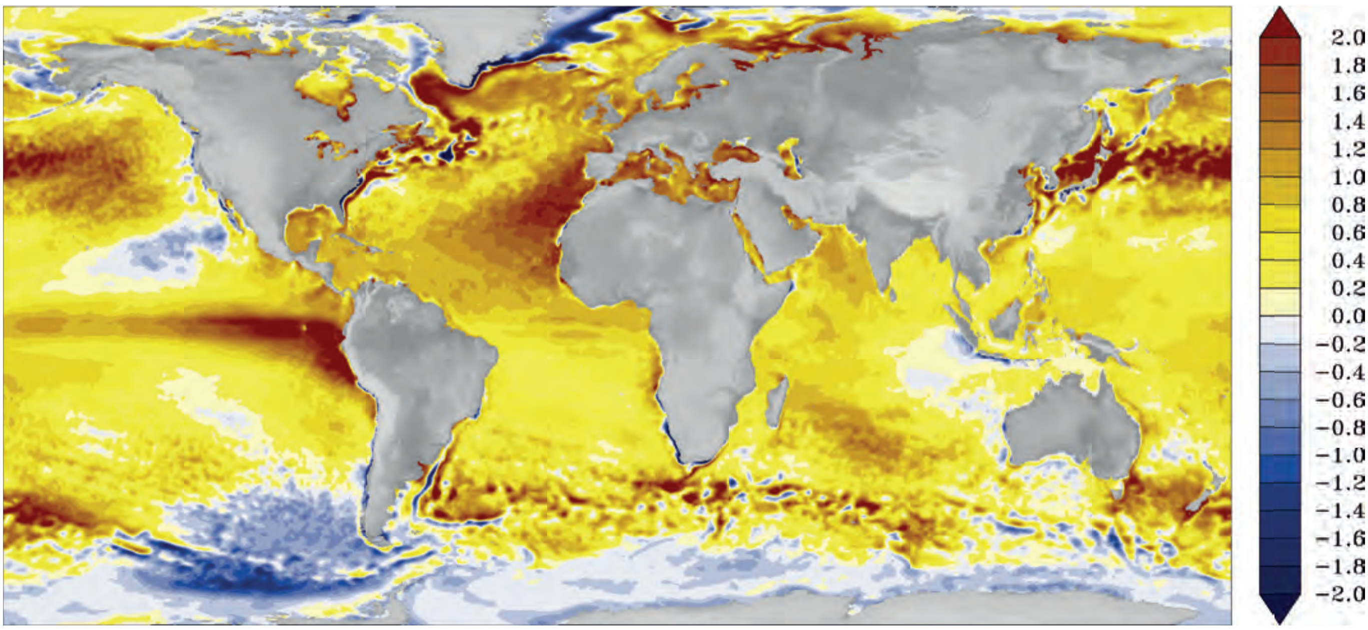
Background

The ocean stores significantly more heat than the atmosphere: the top few metres of the ocean contain more thermal energy than the entire atmosphere. There is a continuous exchange of heat between the ocean and atmosphere and the weather we experience is intrinsically linked to the heat contained in the ocean.

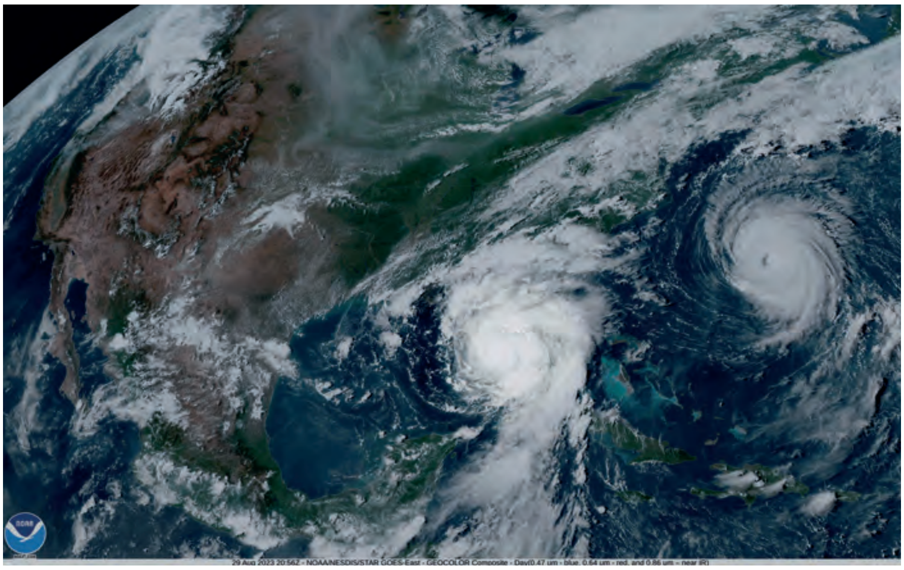
As atmospheric winds flow over the ocean, they typically pick up moisture and either gain or release heat. At mid-latitudes, and depending on the season, maritime air masses are usually either comparatively mild and humid (winter) or cool and humid (summer). Regions such as western Europe or the north-western US and western Canada experience maritime climates. These are characterized by reduced seasonal temperature extremes compared to locations at similar latitudes in the interior and along the east coasts of the continents as the prevalent westerly winds either come from the ocean (west coasts) or the interior of the continents (east coasts).

Oceans are heating up

Global sea surface temperatures (SSTs) reached their highest level on record in 2023. These temperatures made headlines in July and August, when average SSTs reached almost 21°C. A remarkable feature is that these temperatures were observed in early August, whereas



▲ *Sea surface temperature anomalies in degrees Celsius for 2023. The anomalies are with respect to the 1991 to 2020 period. (Observational data (DOISST) taken from: Huang, B., C. Liu, V. Banzon, E. Freeman, G. Graham, B. Hankins, T. Smith, and H.-M. Zhang, 2020: Improvements of the Daily Optimum Interpolation Sea Surface Temperature (DOISST) Version 2.1, Journal of Climate, 34, 2923-2939. doi: 10.1175/JCLI-D-20-0166.1)*



▲ *Hurricane Idalia approaching the western coast of Florida while Hurricane Franklin churned in the Atlantic Ocean at 5:01 p.m. EDT on August 29, 2023. (Credit: NOAA Satellites)*

records set in previous years occurred in March, when average SSTs normally reach their highest values.

From May 2023 onwards, global SSTs moved into unchartered territory and, compared to 2016 when the last SST record was set, SST values have consistently exceeded anything we previously observed. Currently, global SSTs continue to be the highest ever recorded for the time of year and are on track for new record highs in February and March 2024.

A defining ocean feature of 2023 was the development of a marked El Niño event as well as a series of 'marine heatwaves'. In the North Atlantic, unusually high ocean temperatures developed from April onwards, culminating in the first marine heatwave around the UK and Ireland in June. Later in the summer, exceptionally warm temperatures occurred in the Mediterranean Sea as well as off Newfoundland off the east coast of Canada. We also saw abnormally high ocean temperatures developing in the north-west Pacific.

From May/June onwards, El Niño became the dominant feature with a warm SST anomaly developing in the equatorial Pacific. El Niño events push the global surface ocean temperature and surface atmosphere temperatures (SATs) higher. For example, this happened in previous El Niño years in 2016 and 1998, which both held the record for highest global SSTs and SATs. The record temperatures observed in 2023 and now in 2024 should not come as a surprise, in particular on the back of the rapidly warming climate we are witnessing.

Tropics and subtropics

The link between ocean temperatures and weather systems is perhaps most clearly seen in tropical cyclones (TCs). TCs can develop into the most powerful storms, reaching wind speeds in excess of 300km/h (186mph). TCs with wind speeds of more than 119km/h (74mph) are called hurricanes, typhoons and cyclones. TCs are the costliest weather-related disasters. Since 1980, global TC damage has exceeded one trillion US$. Damage linked to single storms regularly exceeds US$100bn (£78.6bn) in cost.

A key criterion for TCs to develop into powerful storms is for SSTs to reach at least 26.5°C. In the global oceans, this temperature threshold is exceeded throughout the year in the equatorial western Pacific, around Indonesia and in the eastern Indian Ocean. In the Atlantic and eastern Pacific, SSTs of 26.5°C or more are reached or exceeded during parts of the year, from June to October in the northern hemisphere and from December to April in the southern hemisphere.

It is the regions where 26.5°C is only reached during part of the year and/or at new locations where historically this threshold was not reached at all that we expect the largest changes in TC activity in a warming climate. Higher SSTs could increase the length of the TC season and TCs may start occurring in regions where they usually do not form. In the north Atlantic, several TCs have been observed in November and December in recent years. Regions that are not normally prone to major TC damage have increasingly experienced favourable TC conditions south of the equator in the Atlantic and Indian Oceans. This has led to several damaging TCs affecting south-east African nations such as Madagascar and Mozambique in recent years.

Predicting how rising ocean temperatures will affect TCs globally as the climate continues to warm is complex. The combined changes in the ocean and atmospheric circulation in a warmer climate could be both favourable and unfavourable to the formation of either a higher number of or more powerful TCs.

Very warm SSTs are favourable for TCs, but a windy background in the atmosphere disrupts their formation. This is especially true when wind speed and direction vary with height in the atmosphere in the TC formation regions. In a warming climate, higher SSTs are a certainty in most regions; however, our understanding of how atmospheric winds and their vertical shear will change in the future is harder to predict. The current consensus is that the number of TCs in the west Pacific, the most prolific TC region, will not increase. An increase in TC activity is expected in the Atlantic – something that has been observed in recent decades. It is too early to say whether the increase we observe in the Atlantic is part of a long-term trend or of a longer-term cycle. However, indications are that a larger fraction of TCs could turn into powerful, destructive storms with increased rainfall intensity as warmer air can hold more humidity than colder air. Observations also show that, for the Atlantic region, the intensity of TC rainfall has been increasing – most clearly after TCs have made landfall.

Subtropics to mid-latitudes

The rising ocean temperatures of recent years coincide with TC-like storms developing outside the tropics. For example, SSTs in the Mediterranean Sea were exceptionally high in 2023, and in the autumn we saw the development of powerful storms referred to as 'Medicanes'.

In September 2023, Medicane Daniel dumped many inches of rain (locally up to 39 inches) over parts of Greece and then later on over Libya – leading to the catastrophic dam collapse and the tragic consequences of the resulting flood. At the time when storm Daniel formed, the surface waters of the Mediterranean Sea exceeded 26.5°C and Daniel fed on these high ocean temperatures, gaining power as it moved from Greece to Libya.

How warmer ocean temperatures impact weather systems at mid- to high latitudes is a topic of ongoing research. As for TCs, a warmer ocean means that there is more energy available for weather systems, with the potential for stronger winds and increased rainfall intensity. The spatial patterns of SST change are key to understanding how weather responds to a warmer ocean. In the northern hemisphere, SSTs have increased at most locations – from the tropics to high latitudes. A notable exception is found in the north-east Atlantic, where a region between Ireland and Greenland has warmed more slowly than the surrounding areas. Studies have suggested that this 'warming hole' in the north Atlantic affects atmospheric circulation patterns over the north Atlantic region, potentially impacting the atmospheric jet stream which is the key driver for mid-latitude weather systems.

Extreme weather events such as mid-latitude heatwaves, cold spells and floods are directly linked to the jet stream, a ribbon of fast-flowing air (up to 300 km/h) at an altitude of about 10km in the atmosphere. The jet stream is typically not a coherent 'river' that circumnavigates the globe, but breaks into a series of seemingly disconnected meanders. These meanders are associated with high- and low-pressure areas. Sometimes the jet stream can be 'stuck' in a given position for days or weeks. It is then that some of the most extreme weather events occur as the standing atmospheric wave means that high- or low-pressure areas are locked over the same areas for prolonged periods. This is conducive to the build-up of extreme temperatures and was often the cause of the heatwaves we have experienced in recent years. A standing atmospheric wave can also continuously steer moisture-laden air towards a particular region, resulting in extreme rainfall and flooding.

Understanding what causes the jet stream to become stuck and how the frequency of such blocking events could change in the coming decades as our climate warms further can only be understood when considering the complex interplay between ocean and atmosphere, while SSTs are central to the communication between the two systems.

Mid- to high latitudes

At high latitudes, warming SSTs go hand in hand with the observed reduction in sea-ice cover. Arctic sea-ice reduction is probably the most dramatic manifestation of climate change. The high latitudes are where the effects of global warming are most clearly seen and the warming signal in the Arctic is larger than anywhere else on the planet.

Vast areas that used to be covered by sea-ice for most of the year have now become largely ice-free. During the winter season, this means that the atmosphere is in contact with open water more often, resulting in a vigorous exchange of heat and moisture. In winter, over the regions where open water replaced sea-ice, we have observed the strongest warming signals and increases in surface air temperature: as much as 10°C–20°C during the winter months.

Advances in sensor and computer technology

How the frequency and strength of extreme weather events will change in response to global warming can only be understood by improving our knowledge about how the components of the climate system – the atmosphere, the ocean, ice sheets, glaciers and sea-ice – and land interact.

▲ *When observed from space, as exemplified by this view from the Moon, the Earth appears predominantly blue. This enduring azure coloration, consistent for over 4 billion years, is attributable to the vast expanses of liquid water adorning its surface.*

The ocean covers 70% of the globe and its surface is by far the largest interface between these systems. The last few decades saw enormous strides towards simulating the complexity of the climate system on supercomputers. Climate models are powerful and versatile tools to study climate, climate change and its impacts and to test possible mitigation strategies. However, despite this progress, key processes are still missing. Observational data against which models can be benchmarked becomes increasingly sparse as soon as one moves beneath the ocean surface. This limits our knowledge of the workings of one of the main communication channels – the ocean-atmosphere – within the climate system.

In the rapidly changing environment we are in, it is more important than ever to observe our world and to accurately document its changes in as close to real time as possible. New sensors, automated observing platforms and other emerging technologies offer the prospect of having a 3D view of the ocean in almost real time. Advanced computer modelling techniques, machine learning and increasing computing power will provide us with the ability to monitor our oceans, detect early warning signals for major changes, inform solutions and ultimately contribute towards keeping our seas healthy for the benefit of us all.

Conclusion

The escalating warmth of our oceans, housing the majority of additional heat within our climate system, signifies a profound shift in environmental dynamics. This surge in thermal energy amplifies the intensity and frequency of extreme weather events, from the strengthening of tropical cyclones to the genesis of potent mid-latitude storms. As we confront the accelerating pace of climate change, understanding the intricate interplay between oceanic heat and atmospheric dynamics becomes paramount. Leveraging advanced technologies, such as automated observing platforms and cutting-edge computer modelling, offers a beacon of hope in our quest to monitor, predict and mitigate the impacts of these changes, safeguarding the resilience of our planet for generations to come. ■

About the author

Dr Joël Hirschi is the associate head of marine systems modelling at the National Oceanography Centre in Southampton, UK. His role involves studying ocean models and the effect of warming seas on weather patterns and how it influences extreme weather events such as hurricanes, tropical cyclones and marine heatwaves.

Hydro International visits Kongsberg Discovery

Strategizing and trend watching in Horten

By Durk Haarsma, *Hydro International*

Visiting Kongsberg Discovery in Horten, right on the Oslo Fjord in Norway, is a treat. Not only because the company is one of the leading forces in worldwide hydrography and oceanography, but also because it is doing its utmost best to make its guest feel welcome at its headquarters, offices and production facilities. The cold wind sweeping over the fjord in early winter cannot spoil the joy of diving into the companies' strategy behind the name change that took place last year, but also the strategy that will take Kongsberg Discovery further this year. It goes without saying that conversations in a company like this are very much about the trends and developments taking place in the wider world that impact on hydrography.

A few facts

Kongsberg Discovery, the business department that was established last year, has more than 1,000 employees working in Horten, Trondheim and Oslo in Norway and in Spain, the UK, the US, Canada, Singapore and Malaysia. The biggest office outside Norway is in Valencia, Spain, which is responsible for the sales and service of Kongsberg products for the Mediterranean basin. Turning over close to three billion euros in 2022, Kongsberg serves the entire ocean space, working in offshore installations, naval, research and science, underwater and infrastructure surveillance, deep-sea exploration, submarine and subsea installations with USVs and AUVs and communication technology. Kongsberg has become a household name for hydrography over the last few decades, and Kongsberg Discovery has expanded across hydroacoustics, robotics, inertial navigation, GNSS positioning, laser and radar. Upcoming disruptive technologies such as quantum, artificial intelligence and machine learning are being introduced into all the aforementioned. *Hydro International* spoke to Kongsberg Discovery's CEO, Martin Wien Fjell, and multibeam specialist Kjetil Jensen, both of whom took ample time to talk about strategy, trends in hydrography and many other topics.

Trending areas according to Martin Wien Fjell

The CEO of Kongsberg Discovery, Martin Wien Fjell, explains why the company was split off as a separate business area to focus on activities to solve problems in climate, food, energy and security: "Over 70% of our Earth is covered by oceans. Obviously, those oceans control weather and temperature and distribute heat around the globe, while also holding the answer to the most significant challenges we currently face." Kongsberg began with hydroacoustics in defence and anti-submarine warfare and identification, moving on to the fisheries sector with echosounders and sonars. Currently, Kongsberg hardware and software is used to identify 80% of the biomass in the oceans and is therefore instrumental in setting the fish quota for the European Union for instance: "We are well positioned to continue being part of the solution to the growing need for sustainable food." Renewable energy is another growth sector,

▲ *Martin Wien Fjell holds the position of president at Kongsberg Discovery.*

▲ *A glimpse into the premises of Kongsberg Discovery, situated in Horten.*

Acknowledgment

We extend our sincere appreciation to Sigurd Fjerdingen, vice president products, Uncrewed Platforms, for organizing the tour and visit. Mr Fjerdingen oversees operations at the production facility situated on the Oslo fjord, in close proximity to the Kongsberg office. It is here that all the latest trends and strategies are implemented, particularly in the production of AUVs and USVs such as the Hugin which are custom-built within the facility. Crucial testing procedures occur on the fjord itself, conveniently located just a stone's throw away from the production facility.

On multibeam, the role of the surveyor and growing business

Multibeam specialist Kjetil Jensen joined the conversation to update us on the latest developments and trends: "Smaller, more compact and integrated systems are a major trend, but of course we can't pack high-quality multibeam into an object the size of a penny. We are therefore aiming to make it as small as possible while maintaining quality. While reducing size will have consequences for performance, many of our customers don't need the very best performance for very shallow water surveys. So, smaller units that are easier to use and set up is one trend. While some people relish being able to dive into sub menus and adjust the exact pulse lengths, frequencies and penetration of each ping, most customers want something that is simple to set up and will work off the bat.

"Another trend is removing the human component from the process as much as possible. We're seeing this for larger ocean-going surveys, but also for a lot of the smaller USVs for basins and harbours. Customer feedback shows us that we are at the forefront of the market with a lot of remote capability, both with our own acquisition software, Seabed Information System (SIS), and remote quality assurance in Blue Insight. That's good, because the lack of qualified hydrographers available means that customers are looking for technology solutions and moving towards remote operations with land-based experts conducting the quality assurance. So, although traditional methods may be changing, there is still a need for experts. You can't just send a USV over the horizon for two months and expect it to come back without ever checking in and seeing whether or not the data is okay. We still need that human interference every now and then, unless ChatGPT becomes a hydrographer, which I doubt. Automation decreases the total workload by offloading a lot of the menial tasks, but the amount of work, the seabed mapping, that needs to be done is increasing."

As Jensen explains, another specific trend for remote operations is USVs for deep-water seabed mapping. Kongsberg is seeing lots of initiatives to map the seabed, for example for Seabed 2030, and a lot of initiatives taken by countries to explore their EEZ. For instance, Norway recently opened up parts of the EEZ for deep-sea mining exploration, providing permits for companies to survey for minerals in a limited area. In the words of the Norwegian energy minister Terje Aasland: "There is a need to gather more knowledge and investigate whether it is possible to proceed with extraction in a responsible and sustainable way." The global climate crisis is therefore going to have an impact on the amount of work out there, while work continues in looking for oil and pipeline inspections.

▲ *Kjetil Jensen, an expert in multibeam technology, is responsible for Kongsberg Discovery's ocean mapping business unit.*

not only in Norway but in many other places around the world. Wien Fjell: "A lot of that energy will come from offshore. That is leading to debates between fishermen and those planning and building installations for renewable energy at sea, debates that are often not fact-based. In reality, we don't know what the effects – positive or negative – of offshore wind farms on the ecosystem or fisheries will be." Kongsberg aims to support this debate by providing the necessary facts. These facts, delivered through the monitoring of thousands of square kilometres of sea, are brought into the discussion by research institutions working together with Kongsberg. Another pillar for Kongsberg Discovery is security. According to Wien Fjell, the ocean is the last place where you can hide: "Whatever you do in the ocean, it's really hard to find. At Kongsberg, we have the technology to identify threats hiding out in the ocean. Our AUV range has been monitoring pipelines now for 15 to 20 years, and the need for the monitoring of pipelines and other critical infrastructure is increasing quickly."

These three trending areas are the focus of Kongsberg Discovery, whose establishment as a separate entity was driven by growth through specialization. Based on these trends, the company believes it is in the race for sound growth in the coming years. Asked whether there are any technology developments that they think will help them to get that growth going at the level they want and which technology is the most promising, Wien Fjell answers: "We follow some of the trends in computer processing and quantum physics, and AI is also clearly part of the technology roadmap. For example, AI can be added into drone radars, which are being developed to identify different types of flying objects and are used in the surveillance of offshore wind parks. Distinguishing between different types of birds is one of the features that is really interesting. Can you imagine being able to identify an endangered bird species, such as a sea eagle, and to turn off the relevant turbines?" Asked for any developments that might challenge that growth, Wien Fjell replies: "Geopolitics. Recent developments between Europe, the United States and China will have an effect on global companies. Increasing interest rates and therefore potential declines in the global economy might also have an influence. Those effects might be felt through new regulations or trade patterns. We need to build a robust company that can manage those challenges to ensure that we can withstand the adverse effects of geopolitics and the potential downsides in the economy." ■