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How to Simplify Survey Reporting

Remote, frozen, critical and changing: the Weddell Sea

Slow Recovery of Coral Reef shows Impact of Bottom Trawling

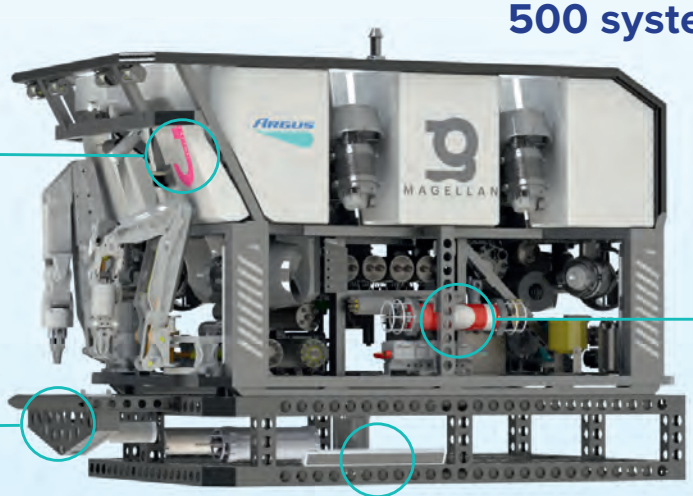
MAGELLAN

Duration at depth

Magellan, 175:56 hours continuous operational ROV dive at 5,100m.

cNode mini beacon

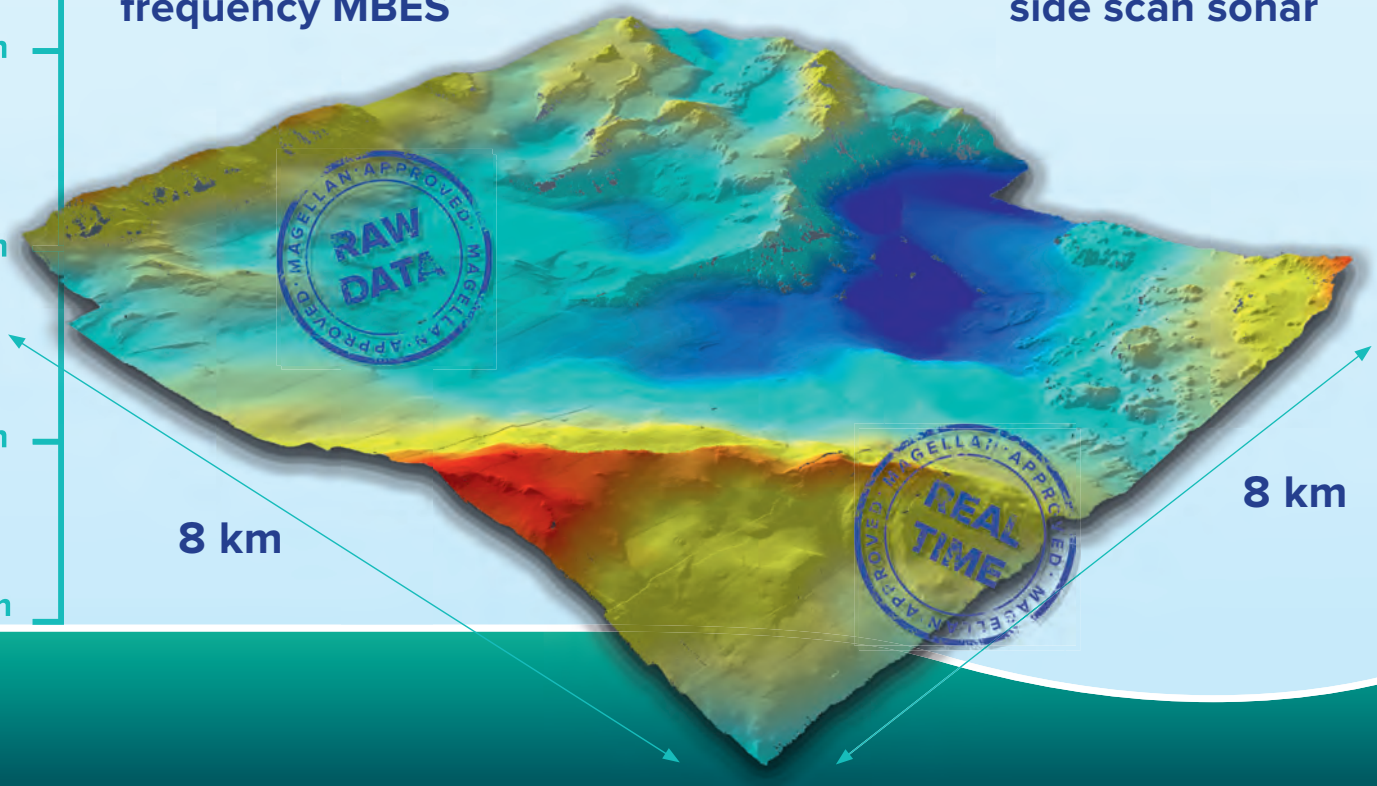
Sonardyne SPRINT-Nav 500 system



Reson T-50 dual frequency MBES

Edgetech 2205 side scan sonar

0m
1000m
2000m
3000m
4000m
5000m
6000m



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Hydro INTERNATIONAL

Hydro International is an independent international magazine published 6 times a year by Geomares. The magazine and related e-newsletter inform worldwide professional, industrial and governmental readers of the latest news and developments in the hydrographic, surveying, marine cartographic and geomatics world. Hydro International encompasses all aspects, activities and equipment related to the acquisition, processing, presentation, control and management of hydrographic and surveying-related activities.

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Front Cover

On this cover you can see a picture of the Weddell Sea in Antartica. Onboard the research icebreaker the *Polarstern*, scientists are deploying a CTD Rosette System to measure oceanographic parameters.

Inspiration

▲ *Durk Haarsma*

I've always known, from when I was a young boy, what I wanted to be: a journalist. It has never been anything else, at least not for longer than a few days. I am not sure if the television show Lou Grant triggered my wish to report on whatever happens in the world for a newspaper or a radio station, but the series about a grumpy editor at the fictional newspaper *Los Angeles Tribune* certainly fuelled my ambition. I must have been around ten or eleven years old and probably didn't understand a thing of the show, but I felt that the rush of the newsroom, the variety in topics that need to be covered and the absolute essential curiosity would fit me like a glove.

So far, my choice for a career in media, although not based in an LA newsroom, has never disappointed me. I realize that it is quite special and useful for youngsters to know what they want professionally, as it makes choices of study and college easier. However, my experience is not half as inspirational or adventurous as Dawn Wright's. Now chief scientist with Esri, she describes how she, as a little black girl growing up near the ocean on the Hawaiian Islands, was inspired by Robert Louis Stevenson's *Treasure Island* and especially by the treasure map, which played a central role in the book.

The fascination for this map shaped her choices for a career that already spans decades of mapping the seabed. It is also inspiring because Wright never let go of her aspiration, even when at some points she was one of the only women on an expedition, and often the only black woman. Supporting her persistence were role models such as cartographers Tharp and Heezen, which kept her going. Read the story of Dawn Wright on page 23 of this issue of *Hydro International*.

At the beginning of 2020, I wish a television show, a book, a map or – even better – a role model like Dawn Wright for every child, to shape their choice for a future career. In hydrography, we need plenty of new, ambitious surveying and mapping professionals to help meet the challenges of the future, so anyone who feels he or she can serve as a role model for children in their own environment should at least try. Plant the seed early on, and the industry can be sure of a lifelong dedicated influx of new hydrographers!

Durk Haarsma,
director strategy & business development
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Are Multifunctional Robots in Control?

▲ *Cees van Dijk*

I recently received a press release from a company that develops robots. Nothing special, I thought, because there are more companies doing that, but this time my attention was drawn to a special element as the robot in question turned out to be able to put another robot to work. This makes it possible, for example, to send a UAV to sea with a glider on board that can be launched remotely.

Is that special? According to a robotic expert who was interviewed in a Dutch radio programme, it is. Although we are perfectly capable of developing robots that can focus on one specific task, multifunctional robots hardly exist. For example, it is possible to make a programmable machine that delivers packages, but it is more difficult to have the same device also collect the returns from the web shop, said the specialist interviewed.

I do not doubt the authoritative knowledge of the person I heard, but he had probably not yet looked at the developments taking place in the world of hydrography and oceanography. There are already several experiments with autonomous vessels that can be used for various tasks. *Mayflower Autonomous Ship* (MAS), an autonomous vessel that follows the course of the voyage of the ship that transported the Pilgrims to the New World, will soon depart. In one of the previous editions of *Hydro International*, we described the trip of an autonomous vessel that 'sailed' through severe storms and, although badly damaged, successfully completed a heavy trip through Arctic waters. Last year, an unmanned vessel crossed Dover Strait, one of the busiest sea straits in the world. After leaving England, it passed the shipping lanes and arrived safely in Ostend, Belgium.

When asked whether we will ever see robots that can be used in a multifunctional way, the aforementioned expert answered that this will take at least another decade. When I look at the developments in the maritime sector, I think he is too pessimistic. By using artificial intelligence, self-learning robots are making a rapid and unstoppable advance.

As a result, hydrographers and oceanographers can not only do their work better, but also more safely. Regarding this development, let us remember that a robot, no matter how advanced, must always be at the service of humans. Let us bear in mind that the word 'robot', coined by the Czech writer Karel Čapek, is derived from the Czech word for 'slave'.

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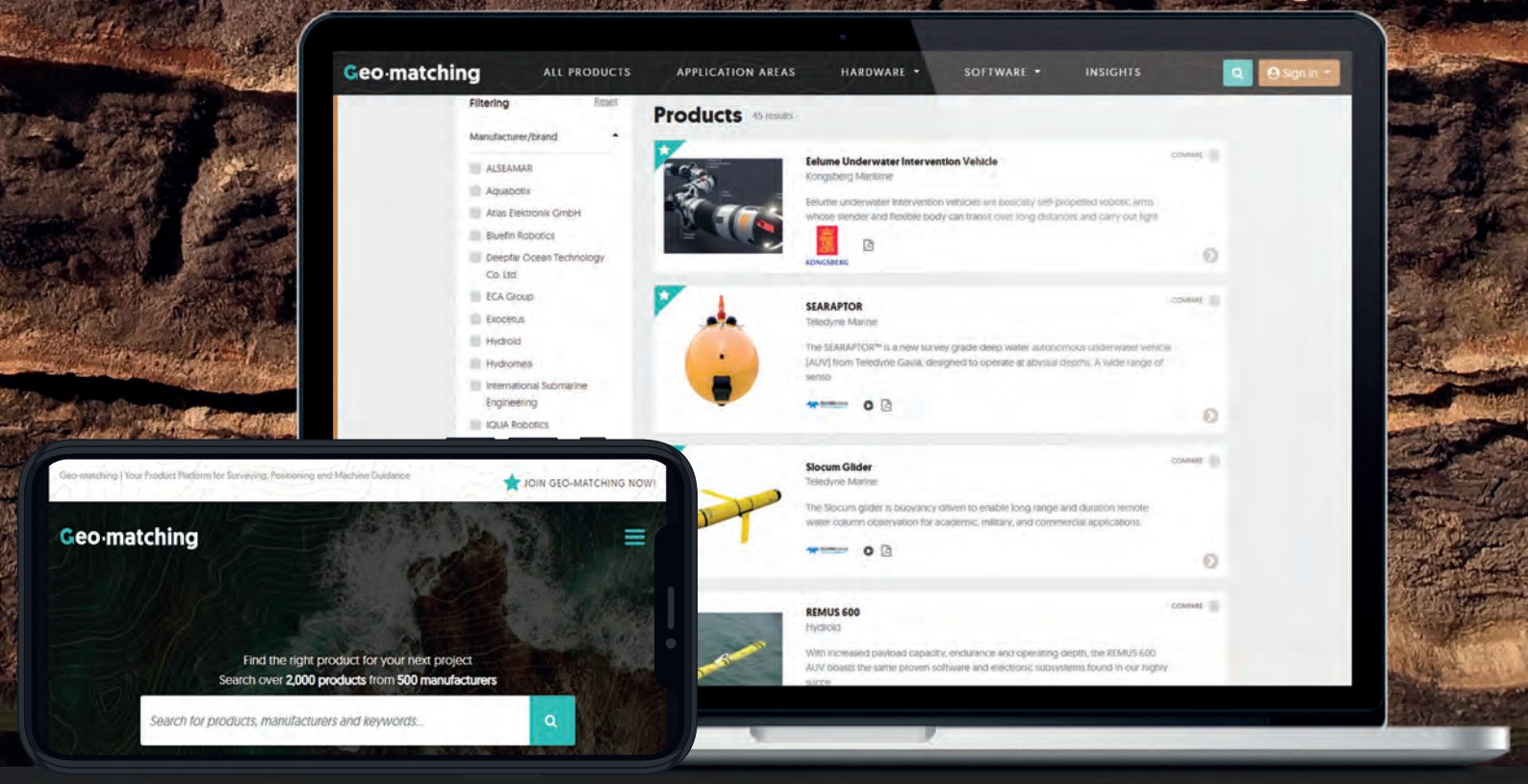

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Seabed 2030: The Data Centres

The Nippon Foundation-GEBCO Seabed 2030 Project is tackling one of the world's most exciting challenges: to map the entire ocean floor to the highest resolution possible in less than a decade. The only way they will accomplish this ambitious goal is through coordinated international effort.

A global map showing the shape and depth of the world's ocean floor has "essential real-world applications" according to Seabed 2030 director Jamie McMichael-Phillips. Such detailed bathymetry will empower the world to use the oceans sustainably, make informed policy decisions, and better understand ocean circulation patterns and how they affect climate and weather patterns. But how is this monumental task achieved? Seabed 2030 divides the world into four regions – each overseen by a regional centre – and data is gathered from countless worldwide organizations via the regional centres and a global centre, which then collates this vital information.

The Arctic and North Pacific Oceans are covered by the regional centre based at the Center for Coastal and Ocean Mapping (CCOM) at the University of New Hampshire, USA. It is co-headed by Professor Larry Mayer, director of the School of Marine Science and Ocean Engineering and CCOM at the University of New Hampshire, and Professor Martin Jakobsson, professor of Marine Geology and Geophysics at Stockholm University. To help build the map of the Arctic and North Pacific, teams from this centre go on regular mapping expeditions carried out by Stockholm University's own research vessel, RV *Electra*. This centre is also home to The Nippon Foundation/GEBCO Postgraduate Certificate in Ocean Bathymetry – an educational programme that has, to date, trained 90 scholars from 40 countries. Last year, an alumni team of the programme won the US$4m Shell Ocean Discovery XPRIZE for technological innovation in ocean mapping.

Responsible for covering an area greater than 140 million km², and spanning the Americas in the west to Australia in the east is the Atlantic and Indian Oceans Regional Center. Based at the Lamont-Doherty Earth Observatory (LDEO), the centre is overseen by Dr Vicki Ferrini, research scientist and affiliate associate professor at CCOM. The centre has several notable national and international mapping initiatives within the region, including the Atlantic Ocean Research Alliance and the European Union's EMODNet.

The South and West Pacific Regional Center is based at the National Institute of Water and Atmospheric Research (NIWA) in New Zealand, and is headed by its Marine Data Manager Kevin Mackay. For over 50 years, NIWA has been a pioneer in seafloor landmark discovery around Aotearoa-New Zealand, including active faults and volcanoes. In just the first 18 months of activity, the centre participated in over 30 conferences, stakeholder meetings and media interviews, to promote the Seabed 2030 project and its significant aims.

The remaining division, the southern tip of Chile and Argentina through to the coast of Antarctica, falls into the remit of the Southern Ocean Regional Center, based at the Alfred Wegener Institute (AWI). A member of the Helmholtz Association (HGF), the centre focuses on polar and marine research. With its ice-covered seas, the remote Southern Ocean poses harsh working conditions but despite this, the launch of Seabed 2030 has seen the introduction of numerous new bathymetric data sets, which have greatly aided access to deep sea in this region.

The four regional centres feed their findings into the global centre, hosted at the British Oceanographic Data Centre (BODC) in Southampton, UK. Headed by Dr Helen Snaith, a senior data scientist at the BODC, the centre is responsible for creating the centralized GEBCO products, including the bathymetric grids. Established in 1989, the BODC's mission is to operate as a world-class data centre in support of marine science. It has been responsible for updating GEBCO's global bathymetric products since 1990.

The latest GEBCO grid, published last year, comprises around 32,000,000 km² of new bathymetric data, with new figures expected to be published later this year.

For more information, please visit https://seabed2030.gebco.net/

About GEBCO

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

About The Nippon Foundation

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

Peter Sparkes Appointed UK National Hydrographer

The UK Hydrographic Office (UKHO) has announced the appointment of Rear Admiral Peter Sparkes to the position of national hydrographer and deputy chief executive: a role that helps to improve the sharing, standardization and collection of marine geospatial data through international collaboration. As national hydrographer, Peter is the UK government's representative at the International Hydrographic Organization (IHO), where he works with partners to set and maintain standards that protect the safety of mariners around the world.

Peter joins the UKHO as a rear admiral in the Royal Navy. He has served previously in a wide variety of appointments, both at sea and ashore. Notably, he commanded the frigate *HMS Cumberland* on counter-piracy patrol off Somalia and the UK's Ice Patrol Ship *HMS Protector* in Antarctica. In addition to this, he commanded the 44 units (aircraft carriers, destroyers, frigates, minehunters, patrol vessels and the maritime explosive ordnance disposal teams) of the Portsmouth flotilla.

Ashore, Peter Sparkes has served in Ministry of Defence acquisition appointments and was responsible for the development and introduction into RN service of the Warship Electronic Charting Display Information System. Prior to joining UKHO, he served as the Chief of Defence Staff's liaison officer in the Pentagon, Washington DC.

Jamie McMichael-Phillips Appointed Director of the Seabed 2030 Project

Jamie McMichael-Phillips has been appointed the new director of The Nippon Foundation-GEBCO Seabed 2030 Project, which aims to map the entire ocean floor by the year 2030. McMichael-Phillips has been described as "a leader and hydrographer who successfully made the transition from the rank of captain in Britain's Royal Navy to head of partnering and engagement for the UK Hydrographic Office". As a chartered surveyor, hydrographer and mariner, he has extensive experience in strategy and policy formulation, as well as in international engagement, negotiation, leadership and mentoring – skills gained during his Royal Navy career and in civilian life.

Jamie McMichael-Phillips has managed government-to-government relationships for the exchange of geospatial data for navigational safety and for the benefit of the wider Blue Economy. He has also led outreach and capacity building for fledgeling organizations in marine data collection, assessment and cartography. Prior to his Seabed 2030 appointment, McMichael-Phillips chaired – for over nine years – the International Hydrographic Organization's Worldwide Electronic Navigational Charts (ENC) Database working group, responsible for monitoring the global footprint of electronic charts needed for safe navigation by commercial shipping.

How Scientists Use Satellite-mounted Laser to Map Global Ocean Migration

A recent study reports on the use of satellite-borne Lidar to map the daily vertical migration of zooplankton across the world's seas over the course of a decade. "Lidar allowed us to sample these migrating animals on a global scale every 16 days for 10 years. We've never had anywhere near that kind of global coverage, which enables us to look at their behaviour, distribution and abundance", said lead author Michael Behrenfeld of Oregon State University.

During World War II, naval oceanographers discovered a reflective layer that rose and fell across their sonar screens once each day. Further research revealed that it comprised swarms of fish and tiny sea creatures called zooplankton migrating towards the ocean surface as the sun set to feed under cover of darkness, then swimming back to the inky depths at dawn to escape their own predators during daylight hours. This was initially valued as a way for submarines to hide their movements.

"Combining data from ships and satellites helps to increase our quantitative understanding of the role of zooplankton in the global carbon cycle, particularly in terms of its variability in time and space. That knowledge is critically important for refining global climate models", says professor and co-author Deborah Steinberg of the Virginia Institute of Marine Science.

"I Wanna See a Kid with a NOAA Shirt"

President Trump recently declared that the United States would "act boldly" on a gigantic task: mapping a chunk of the ocean floor that is larger than the combined land area of all 50 US states. Armed with this strong backing from the White House, the National Oceanic and Atmospheric Administration (NOAA) is ready to go where no man has gone before.

The agency this year plans to accelerate exploration of the entire US Exclusive Economic Zone (EEZ), with the goal of completing the job by 2030. An official described the exploration project as challenging, but the work is already underway, with roughly 40% of the EEZ mapped in recent years. The whole zone covers more than 13,000 miles of coastline and 3.4 million square nautical miles of ocean.

Timothy Gallaudet, NOAA deputy administrator, figures there is no reason why ocean exploration cannot do for his organization what space exploration did for NASA a half-century ago. "Every time I'm on the mall I see a kid in a NASA shirt," Gallaudet said. "I wanna see a kid with a NOAA shirt, and maybe with an ROV and an AUV on it."

Volcano F is the Origin of the Floating Stones

Since August last year, a large accumulation of pumice has been drifting in the south-west Pacific towards Australia. Researchers at the GEOMAR Helmholtz Centre for Ocean Research Kiel (Germany), together with colleagues from Canada and Australia, have now identified the origin of this pumice raft: a so-far nameless underwater volcano in Tongan waters. The study has been published online in the international *Journal of Volcanology and Geothermal Research*. Some volcanic eruptions produce a very porous type of rock with a density so low that it floats – pumice. An unusually large amount of it is currently drifting in the south-west Pacific towards Australia. When it was first sighted in the waters of the island state of Tonga at the beginning of August, it formed an almost coherent layer on the ocean's surface. Various underwater volcanoes were discussed at that time as the potential source, but direct proof of the exact origin of the pumice was missing up until now. Researchers are now publishing evidence that clearly identifies the culprit: the underwater volcano just 50 kilometres north-west of the Tongan island of Vava'u. "In international scientific literature, it appears only under the number 243091, or as Volcano F", says Dr Philipp Brandl of GEOMAR, first author of the study. The team found what they were looking for on a freely accessible satellite image of the ESA satellite Copernicus Sentinel-2 taken on 6 August 2019. It shows clear traces of an active underwater eruption on the water surface. As the images were exactly georeferenced, they could be compared with corresponding bathymetric maps of the seafloor. "The eruption traces fit exactly to Volcano F", says Dr Brandl. The researchers also compared this position with information from global seismic network stations.

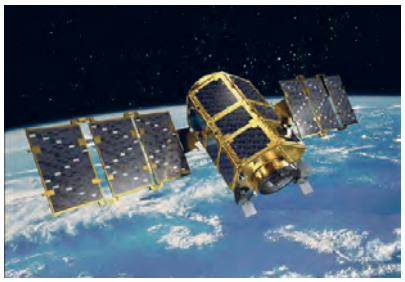
EuroSea Aims to Improve the Ocean Observation

The UK-based National Oceanography Centre (NOC) has joined an international consortium of 55 partners for the new €12.6 million, EU-funded EuroSea project. "The aim of the project is to better combine existing capacities in the European marine observing system, to fill existing gaps and to make the resulting data and information available to users more easily," says coordinator Dr Toste Tanhua from the GEOMAR Helmholtz Centre for Ocean Research Kiel. NOC's Prof. Kevin Horsburgh, Chief Scientist for International Development, is leading Work Package 5 (WP5) within the Coastal Resilience & Operational Services Demonstrator project. Prof. Horsburgh commented, "This project will boost the use of oceanographic data in decision-making and over all timescales." WP5 will provide a demonstration of the end-to-end connection from observations (including a new generation of tide gauge technologies) to their wider use, by combining observations, model data and satellite products into novel decision-making tools. The partners in the EuroSea consortium are scientific institutions and non-public partners from 13 European countries, as well as Brazil and Canada. Other partners include international institutions and networks such as the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), the European Marine Board and the European part of the Global Ocean Observing System (EuroGOOS).

Mapping the Mariana Seas Will Start This Spring

In April, a team of 60 scientists and crew from the US National Oceanic and Atmospheric Administration (NOAA) will come to the Mariana Islands aboard the NOAA ship *Rainier* to map the seafloor of the Marianas and conduct coral reef research. NOAA's Office of Coast Survey and the Office of Marine and Aviation Operations will work together to perform the ocean surveys to measure the water depths. The Mariana Islands are a crescent-shaped archipelago comprising the summits of 15 mostly dormant volcanic mountains in the western North Pacific Ocean, between the 12th and 21st parallels north and along the 145th meridian east. They lie south-south-east of Japan, west-south-west of Hawaii, north of New Guinea and east of the Philippines, demarcating the Philippine Sea's eastern limit. Detailed information on how deep the water is and the many characteristics of the seafloor would also be useful for determining fish habitats and for understanding coral reef health as well as marine geological processes. The 2020 operations will comprise two missions: coastal and habitat mapping, and the Mariana Archipelago Reef Assessment and Monitoring Program, or MARAMP.

South Korean Satellite Will Focus on Oceanography



With a focus on oceanography and the monitoring of air pollution, the 3.4-ton South Korean Chollian-2B satellite will be launched on 18 February from the Guiana Space Center using an Arianespace Ariane-5 launch vehicle. The Korean Aerospace Research Institute (KARI) has stated that this is the first time that a GEMS (Geostationary Environmental Monitoring Spectrometer) has been installed on a geostationary satellite. An additional GOCI-2 sensor to monitor the ocean environment is also aboard the satellite. The satellite will be able to capture data for more accurate weather forecasts as well as provide information to assist the nation's agencies in reducing pollution in the region. The operational lifetime expectancy of the Chollian-2B is approximately 10 years, and it was funded by the government to the tune of US$324 million.

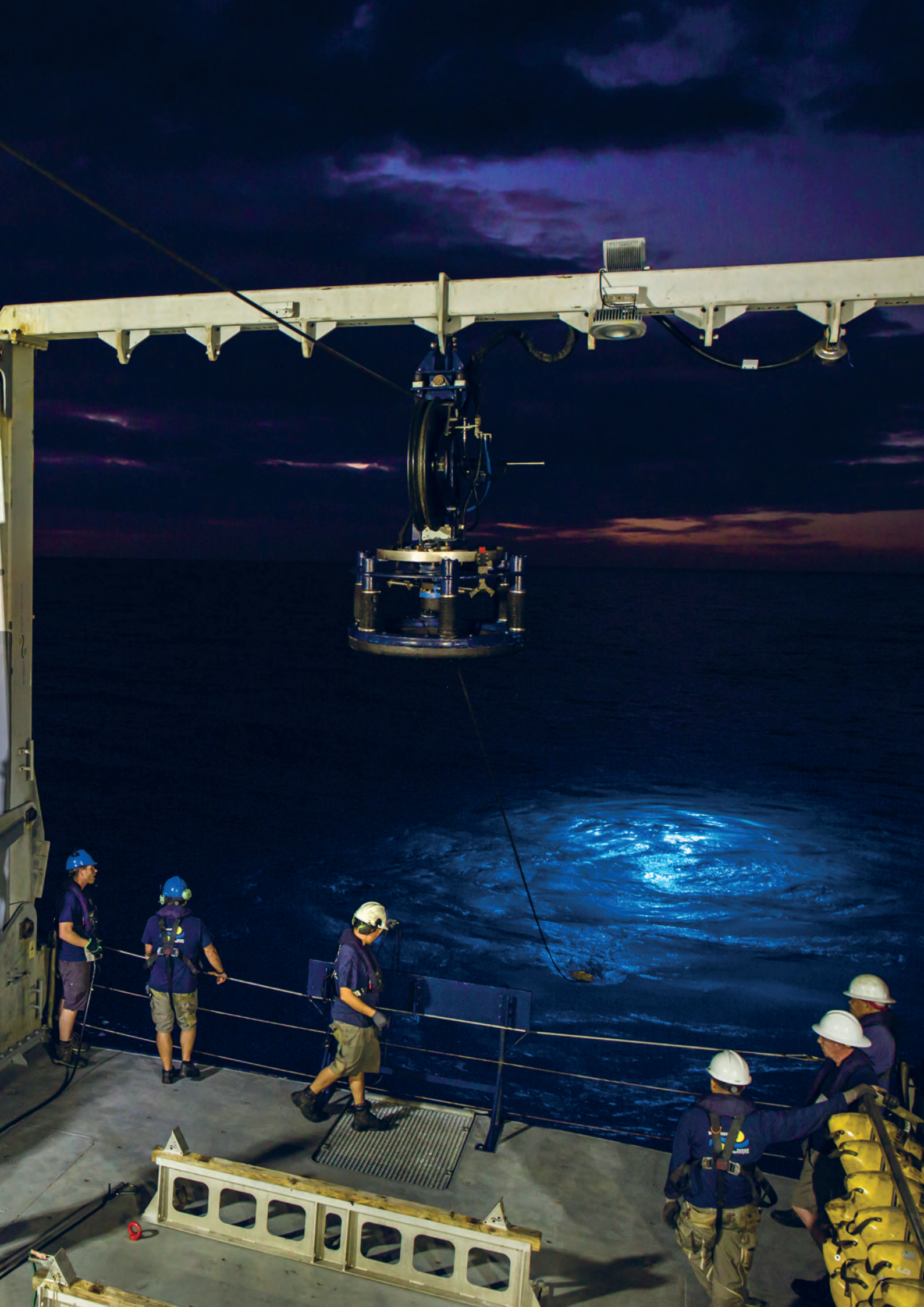
In December 2018, South Korea launched the sister satellite, Chollian-1, for EO and oceanography monitoring, which is equipped with AMI (Advanced Meteorological Imager) and KSEM (Korean Space Environment Monitor) payloads. The Cholian-2B will offer 4x sharper resolutions than the sensors already in orbit and will examine an area of 2,500 kilometres (1,553 miles) over a 10-day period.

Designing the Future Expedition

Sampling in the ocean today is mostly performed the same way it was 30 years ago, and can sometimes be inefficient and destructive to fragile organisms. Many deep-sea species remain undescribed simply because they cannot be returned to the surface in good condition for taxonomic inspection. On this expedition, teams of interdisciplinary researchers tested new technology that allows them to study species in situ, something that has never been done before. They anticipate that their work will set a new benchmark for future mid-water expeditions and pave the way for a device that combines all of their technologies into a singular solution for specimen characterization.

During their time on *Falkor*, the teams outfitted ROV SuBastian with a novel robotic encapsulation device and a near-real-time reality capture system to enable rapid characterization of deep-sea organisms. The team also hopes to develop a technological workflow for species descriptions using 3D imaging and genomic sequencing. A DeepPIV (particle image velocimeter), developed by MBARI, will be integrated into SuBastian to visualize the liquid flowing through animals such as jellyfish. This instrument consists of a laser and optics that illuminate a sheet of fluid, allowing the fluid motion to be quantified using imaging from the ROV's high-definition science camera.

Photo: Crew recovers ROV SuBastian at the end of the second day of the expedition off Oahu, Hawaii. (Image Courtesy: Logan Mock-Bunting / Schmidt Ocean Institute)



Slow Recovery of Coral Reef shows Impact of Bottom Trawling

Research Expedition to Map the Scottisch Seabed

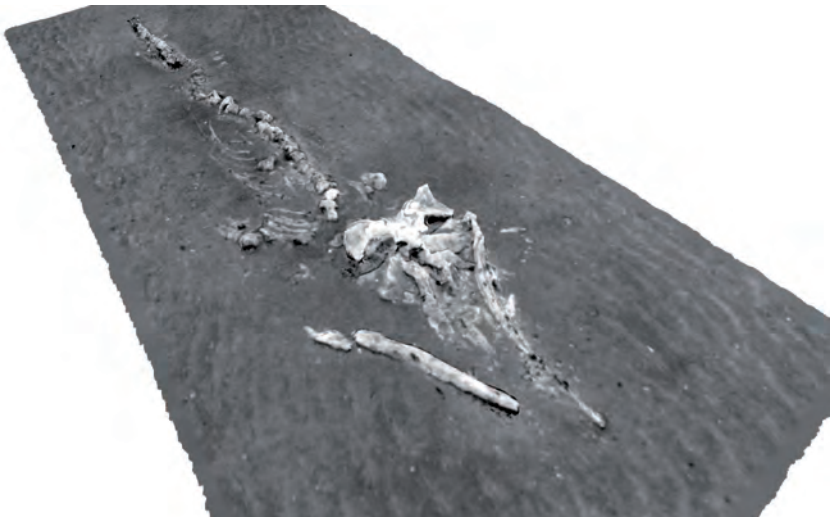
Newly developed 3D imaging technology has allowed scientists to map Darwin Mounds, a unique area of cold-water coral reefs off the coast of Scotland, to see whether it has recovered since being declared a Marine Protected Area sixteen years ago.

The images show that in areas of the Darwin Mounds that had been heavily trawled, coral growth is still very sparse, and there has been no real recolonization. However, healthy coral growth was found in parts that had only been minimally damaged by bottom trawling, indicating that marine conservation measures are most effective when they are put in place before damage occurs. The team also discovered a large amount of plastic waste snagged on the coral.

Dr Veerle Huvenne from the National Oceanography Centre (NOC), and chief scientist the expedition that made these discoveries, said, "of This proves once again that ecosystem recovery in the deep sea is very slow, and that it is better to put protective measures in place before damage occurs. However, encouragingly, settlement experiments deployed in 2011 and recovered on this expedition indicate that new coral larvae can indeed settle in the area."

HIGH-DEFINITION VIDEO DATA

These findings are the result of a three-week research expedition in the North-East Atlantic on board the Royal Research Ship *Discovery*, home port Southampton, UK. This expedition was a collaboration between the NOC, the University of Southampton, the Joint Nature Conservation Committee, the University of Edinburgh, University College Cork and the Scottish Association for Marine Science. Using the latest in marine and robotic technology, the team collected data to evaluate the status of the Darwin Mounds, a series of cold-water coral reefs lying at water depths of 1,000 metres, once heavily impacted by bottom trawling.



This expedition saw the first deployment of a newly developed 3D imaging system called BioCam, a combined stereo camera and laser scanner built by the University of Southampton under NERC's Oceanids Programme, which was used to create multi-hectare 3D visual reconstructions of the seabed. Mounted on Autosub6000, a robot sub developed and operated by the NOC, the system successfully mapped more than 50 hectares of seabed in less than 48 hours at photographic resolution.

Together with an extensive series of samples, and more than 75 hours of high-definition video data collected by the HyBIS Robotic Underwater Vehicle, the BioCam images provided evidence of healthy coral growth in locations that previously had seen only a minimal impact from bottom trawling.

COLD-WATER REEFS

Cold-water corals are coral species that can live without light, and the reefs they build are important habitats for a wide variety of deep-sea life, including commercially important fish. The Darwin Mounds have been protected from bottom contact fisheries since 2003, and were last studied in 2011, at which point they had not yet recovered from the fishing impacts.

Dr Veerle Huvenne continued, "It was very encouraging to see the recruitment of new coral polyps on the settlement experiments, although this has not yet translated into widespread new coral growth in the heavily impacted areas. We will continue to monitor the site over the coming years to learn more about how deep-sea ecosystems recover after disturbance.

"Working with the new BioCam system gave us an unprecedented insight into the spatial pattern of the coral growth. It also showed us how the marine animals are living with and around the coral, and it even provided us with unexpected discoveries, such as a complete whale skeleton that we had no idea was on the seabed in the area."

Dr Blair Thornton, co-chief scientist and leader of the BioCam team said, "The multi-hectare scale maps generated by BioCam highlight a wide range of patterns in the spatial distribution of coral and the ecology at this site. These range from the fine, metre-scale patterns seen in video surveys, to much larger patterns in the distribution of live coral over several hundreds of metres. The data will help scientists to identify these and to measure the distribution of live coral in this area."

LARGE AMOUNT OF MAN-MADE LITTER

"The fact that BioCam was able to collect data that is useful for scientific monitoring on its first deployment is a tribute to the hard work that went into preparations for this expedition from the teams at the University of Southampton, the MARS team at the NOC, local industry partners and the captain and crew of the RRS *Discovery*. We are looking forward to its next deployment." Unfortunately, the imagery also demonstrated the presence of a large amount of man-made litter. The area is characterized by strong tidal currents, and coral colonies form natural obstacles on which plastic debris can easily snag.

Hayley Hinchen from the Joint Nature Conservation Committee said, "It has been fascinating to see first-hand the coral mounds in the area, some of which are thriving and others which are struggling to recover. This survey has confirmed that, even after more than 15 years of fisheries closures, the impacts of bottom trawling are still evident, and some newer pressures seem to be growing. The level of litter that we observed across the site is quite shocking, and we still don't know how this is affecting the seabed communities we've seen over the last three weeks.

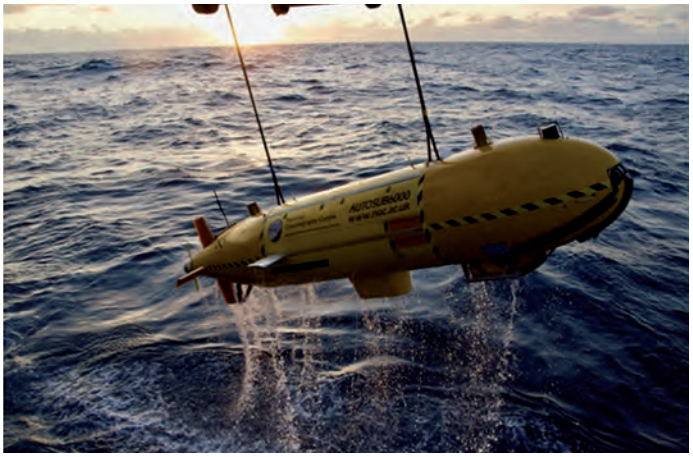
"The wealth of data collected on this expedition will allow us to assess the current status of the habitats and species in the Darwin Mounds both at the small and large scale, and to define how it has changed over time. The amazing 3D imagery from the BioCam system allows us to investigate huge areas of the seabed at millimetre-scale resolution – a tool that could really support marine monitoring and conservation efforts in the future", Hinchen adds.

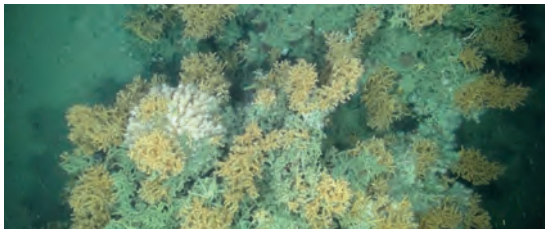
In their final blog post, two members of the expedition, Loic Van Audenhaege and Larissa Macedo, wrote, "Reef-forming cold-water corals

ABOUT THE NOC

The NOC is the UK's primary centre for providing national capability for oceanographic sciences. Our vision is to be one of the world's top three oceanographic research institutions, leading the way in the advancement of knowledge and understanding of our oceans.

The institute provides the UK with the national capability needed to be a top global player and to lead and participate in international cooperation. The NOC undertakes research in large-scale oceanography and ocean measurement technology innovation. It works with government and business to turn great science and technology into advice and applications. The NOC supports the UK science community, based in universities and smaller research institutes, with scientific facilities, research infrastructure and irreplaceable data assets – enabling the UK to harness the full power and diversity of its scientific talent in ocean science.





and many sponges require specific environmental conditions for settlement, such as the presence of a hard substrate, which remains a rare feature of the seabed. In the Darwin Mounds area, our dives allowed us to observe that sand and mud make up the primary substrate of the seafloor, except on the mounds themselves."

They continued, "Reef-forming cold-water corals cannot grow on a soft substrate. This was well-observed in our previous blog post as new cold-water corals were growing on an eight-year-old buoy, but none were observed growing on the surrounding seabed. While many organisms can sustain themselves in a soft-substrate environment, the apparent biodiversity remains low, compared to what we can see from the pictures of the coral reefs. However, it would be foolish to state that this type of habitat is not biologically interesting. Photographs have limitations in terms of showing the full variety of forms in which life can occur. For instance, as revealed by the box core operations, many tiny organisms thrive in the sediment and they may encompass an equally important part of the life at the Darwin Mounds site."

Further detailed analysis of the imagery and samples will be necessary to fully evaluate the changes in biodiversity and communities of marine animals in the area since 2011. This work is part of the CLASS programme (Climate Linked Atlantic Sector Science), which aims to increase our understanding of how the ocean will evolve under a changing climate and increased human exploitation, with the objective of supporting sustainable marine management. The BioCam project is funded by the NERC's Oceanids Programme.

ACKNOWLEDGEMENT

This article has been produced in collaboration with the NOC (UK). ◂

Highlighted Products
In each edition of *Hydro International*, we make an editorial selection of innovative products worth highlighting. Don't miss out on this unique opportunity, and send us your press releases. If you want to be sure that your new products or services are selected, please contact Feline van Hettema, our account manager.

Integrated Sub-bottom Profiler

The Innomar SES-2000 autonomous model is an unmanned surface vehicle (USV) with an integrated Innomar smart sub-bottom profiler (SBP). It acquires full-waveform data in water depths of less than 1 metre down to 100 metres. The layer resolution is better than 10cm and seabed penetration is up to 20 metres, depending on sediment type and noise level. The main applications are in inshore waters and coastal areas. Innomar's parametric SBPs are often used in shallow and extremely shallow waters with limited access for vessels. To support such surveys, German-based Innomar offers a remotely operated surface vehicle pre-configured with the Innomar SES-2000 smart SBP.

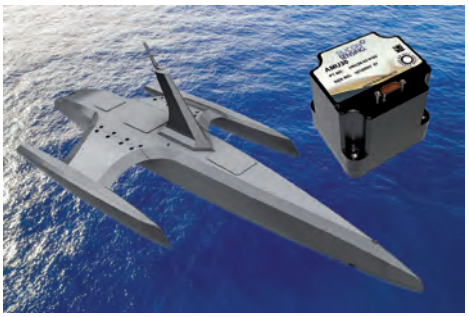
An Ocean Robot Deployed on an Ocean Robot

The Caravela AutoNaut, manufactured by UK-based firm AutoNaut, is part of an international experiment to track the formation of clouds and their role in the climate system in the Atlantic Ocean, off the coast of Barbados. The researchers will use combined AutoNaut and glider measurements to understand how the ocean temperatures affect the layer of air above, and how the winds and sunshine affect the top tens of metres of the ocean. One of the AutoNauts has been specially adapted in conjunction with the UK's University of East Anglia (UEA) to carry and release an underwater Seaglider in remote and inaccessible ocean locations.The 5m-long AutoNaut is propelled by the motion of the waves and carries a range of sensors for meteorology and/or oceanography, including atmospheric pressure, air temperature and humidity, wind speed and sea surface temperature. Furthermore, its systems and sensors are powered by solar panels and it is designed to withstand heavy seas, is self-righting and piloted using satellite communication.

UAV Smoothly Launched From Another UAV

The smooth launch and recovery of a Hugin Autonomous Underwater Vehicle (AUV) has been demonstrated using a new system from the Norwegian manufacturer H. Henriksen. Capable of being used by a wide range of small manned or unmanned auxiliary craft, the Henriksen Launch and Recovery System introduces a versatile new option for the operators of AUVs and UUVs. The lightweight Henriksen launch system can be deployed by any craft capable of supporting its weight and that of the AUV. The Hugin AUV used to test the system was 5.5-metres long and weighed 780kg, yet with the Henriksen launch system it was well within the capabilities of the RIB chosen to carry it.

Autonomous Mayflower Voyage



Two Silicon Sensing Systems ultra-precise AMU30 inertial measurement units (IMUs) will provide critical navigation data to the autopilot capability for the *Mayflower Autonomous Ship* (MAS) throughout her milestone transatlantic voyage this autumn. Setting sail this September, the 15-metre long, 5-ton MAS400 will repeat the *Mayflower's* original epic voyage made 400 years ago.

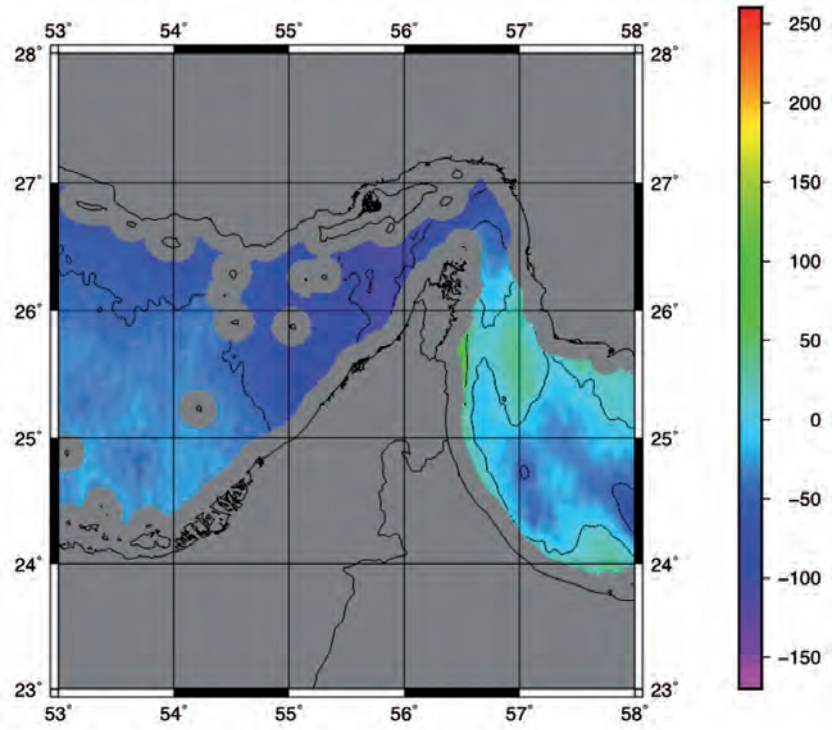
Led by marine research organization ProMare and powered by IBM, she will sail from Plymouth, England to Plymouth Massachusetts, USA. Instead of a captain and crew, she will use computer vision, machine learning, cutting-edge technologies and sensors to navigate and detect hazards. Travelling at a maximum speed of 12 knots, MAS is expected to take just 12 days to reach the coast of Massachusetts – a fraction of the 66 days of the voyage four centuries ago. Throughout the voyage, the ship will also function as a scientific laboratory. On-board sensors will transmit data for critical research programmes in areas such as maritime cybersecurity, marine mammal monitoring, ocean microplastic analysis and sea-level mapping.

Introducing State-of-the-art Geoid Modelling and Related Heights

Analysing Mean Sea Level Variations across the Strait of Hormuz

When using GNSS as a geodetic and topographic height survey technique, the GNSS-based ellipsoidal heights must be transformed into orthometric ('levelling') heights using the geoid-ellipsoid separation ('geoid heights'), but these are not accurately known in all countries. Emirates Defence Industries Company (EDIC) and Fugro recently embarked on modernizing the geodetic and hydrographic infrastructure of the Emirate of Sharjah in the United Arab Emirates (UAE). Using GNSS, levelling and gravimetry, an accurate local geoid model was developed. This allowed analysis of the fine mean sea level (MSL) variations along and between the Arabo-Persian Gulf and the Oman Sea on both sides of the Strait of Hormuz.

For demanding applications, global gravitational models (GGMs) do not suffice; hybrid gravimetric geoids, based on gravimetric geoids and GNSS-levelling benchmarks with (theoretically) known rigorous orthometric heights, are required. Nearshore, the topography of the sea surface (TSS) is computed using tide gauge observations referenced to the geoid. Offshore (in the open sea), its equivalent is the mean dynamic ocean topography (MDT), which is computed using the mean sea surface (MSS), measured primarily from satellite altimetry, referenced to the ellipsoid and the geoid. However, the MDT/TSS is reputedly unreliable nearshore. This project in the UAE researched the possible range of its inaccuracy across the Strait of Hormuz. EDIC and Fugro set up the geodetic and hydrographic baseline for the Emirate of Sharjah, including a continuously operating reference station (CORS) network, first-order geodetic control points and levelling benchmarks, radar tide gauges and associated tidal benchmarks, absolute gravity marks and a relative gravity grid, all to determine a hybrid gravimetric geoid.



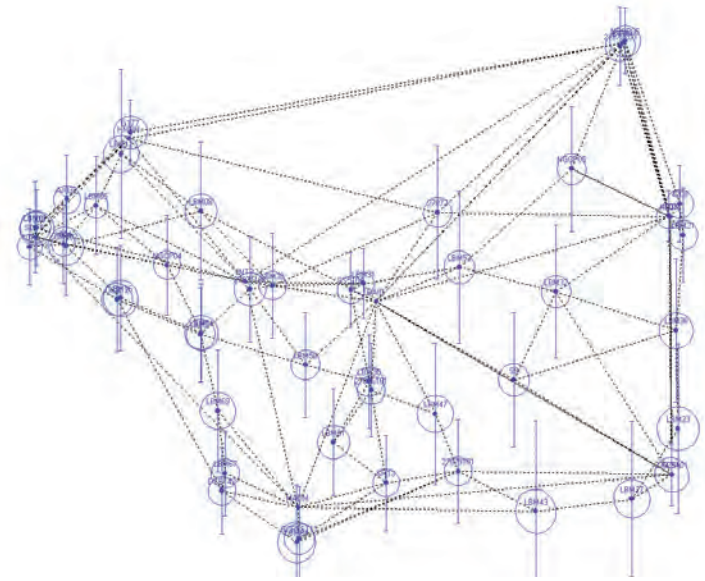
▲ *Figure 1: 15km masked satellite altimetry-derived gravity data in the study area. All values are in mGal.*

GNSS-DERIVED ELLIPSOIDAL HEIGHTS

The geodetic infrastructure consists of 31 first-order reference points, with 23 first-order geodetic control points (GCPs) complemented with eight active CORS. The geodetic GNSS survey was extended to 67 first-order levelling benchmarks (LBMs).

The data from the eight CORS was collected for 17 days. The local eight-station CORS network was tied into the International Terrestrial Reference Frame (ITRF) using 30 additional regional IGS CORS. Data processing was then performed using Gamit-Globk software from MIT and crosschecked using Bernese software (University of Bern). This step yielded uncertainties of 2mm in Easting and Northing and 5mm in Ellipsoidal height for the CORS.

▲ *Figure 2a: CORS network.*



▲ *Figure 2b: First-order and LBM subset geodetic network.*

The first-order GCPs were observed using geodetic GNSS. A final least squares adjustment was constrained to the eight initially computed CORS coordinates, which provided uncertainties of 5mm in Easting and Northing and 15mm in Ellipsoidal height for the GCPs. Transformation of the geographical GCP coordinates to the UAE local coordinate reference system (epoch 2000.0) was performed using the ITRF2014 and GEODVEL tectonic plate motion models (MORVEL56 was tested but not used).

ACCURATE GRAVITY GRID

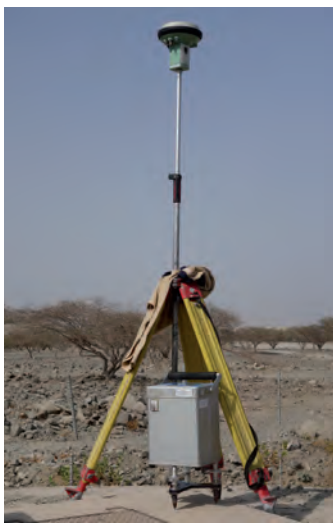
To determine the gravity derived geoid, relative gravity data was measured at a 2km grid spacing in the Sharjah Emirate and at a 5km spacing in the surrounding emirates to complement the existing gravity database (terrestrial and coastal airborne gravity data). Measurements were carried out according to state-of-the-art methodologies. Three absolute stations were established for tying-in the relative measurements to the International Gravity Standardization Network (IGSN71), scaling the network and limiting the error propagation. Processing of the absolute measurements was performed by the University of Montpellier with Micro-g Lacoste g9 software with a final 5μGal uncertainty. The relative gravity measurements were reduced to second-order free-air anomalies. The final least squares adjustment was constrained to the absolute stations values, providing grid point uncertainties of 32μGal.

ACCURATE MEAN SEA LEVELS

The nearshore water level was observed for two years using radar level tide gauges installed at four coastal tidal stations (Figure 4). Harmonic analysis to determine the 37 main tidal constituents was performed using a least square adjustment. Statistical analysis of the differences between the observed and the predicted tides validated the computation process. With the complete datasets, the differences between the yearly harmonic components averaged over two years allowed estimating mean sea level (MSL) and lowest astronomical tide (LAT) uncertainties

▲ *Figure 3a: FG5 absolute gravimeter.*

▲ *Figure 3b and c: CG6 measurements of vertical gradient.*



▲ *Figure 3d: Combined GNSS and relative gravimetry.*

with an uncertainty of between 2 and 4cm depending on the station.

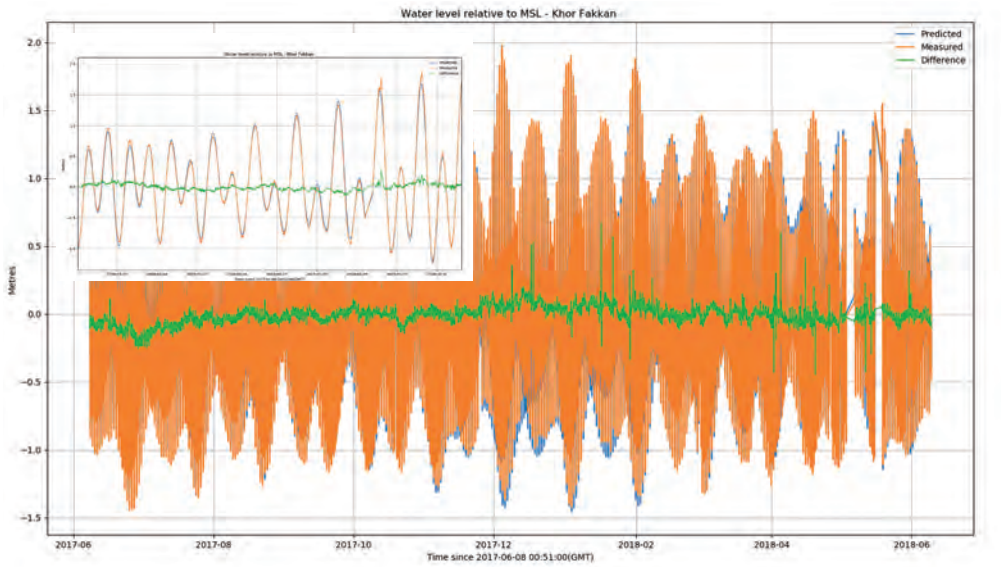
ACCURATE RIGOROUS ORTHOMETRIC HEIGHTS

A 400km first-order, first-class levelling network made of three loops with 67 levelling benchmarks was established and observed forward and backward to define the vertical datum (Figure 5). Both loops closed to within 1 to 3mm√Km with the difference between forward and backward runs within 4 to 9mm. Gravity observations were carried out at each levelling benchmark. The levelling network was least squares adjusted in geopotential numbers to account for gravity variations along the levelling paths. Helmert orthometric heights were computed approximating integral mean value of gravity with Poincaré-Prey reduction. The difference between geometric heights (stand-alone levelling without accounting for local gravity variations) and the gravity-reduced Helmert orthometric heights was 7.1cm at the extreme of the network. Finally, rigorous orthometric height corrections (terrain, density and geoid effects) were applied using the method by the University of New Brunswick (UNB). Depending on the benchmarks, these rigorous corrections ranged up to 1.5cm – which is quite significant, considering the challenging level of accuracy required for reliably tying the four tide gauges with each other and achieving an accurate hybrid gravimetric geoid in the Al-Hajar mountain range.

ACCURATE GRAVIMETRIC AND HYBRID GRAVIMETRIC GEOID MODELS

A gravimetric geoid was computed for the entire Sharjah Emirate using Stokes-Helmert approach implemented in UNB/Fugro's SHGeo package. With this method, the topographic masses are numerically condensed into a layer of infinitesimal thickness on the geoid prior to implementing a Stokes integration. The latest release (2019) of the software takes into account the topographic masses' lateral density variations for maximal accuracy.

The process started with the compilation and assessment of all newly acquired and existing datasets available for the region (UAE and neighbouring countries), and included land, airborne (including lines flown nearshore), shipborne and satellite altimetry-derived marine gravity. A least square downward continuation was computed on the entire datasets to detect outliers. The optimal combined/satellite-only reference fields over the area of interest (AOI) were found to be the GECO/GOCO05s models.



▲ *Figure 4a and b: Observed and predicted water level over first year and enlargement – Khor-Fakkan.*

The SRTM-1" DTM was used to compute the topographical effect. The 3-space/no-topography method was implemented due to its capability to recover short wavelengths of smooth input data when adding condensed effect after downward continuation.

The accuracy of the gravimetric geoid was evaluated using the 67 levelling benchmarks. The residual standard deviation was 3.9cm, showing a remarkable improvement with respect to the global GECO gravity model for which this value was only 11.1cm. The gravimetric geoid was then fitted onto the benchmarks by least squares collocation. In addition to making the geoid consistent with the vertical datum realization, such a fitting is essential whenever there are areas with strong gravity anomalies where gravity data is scarce, inaccurate or just not publicly available (typically beyond the borders, in this case in Oman), which prevent capturing some medium to long wavelengths of the gravity field in the AOI. The hybrid gravimetric geoid was evaluated implementing blind tests, giving an accuracy of better than 2.5cm (pessimistic estimation).

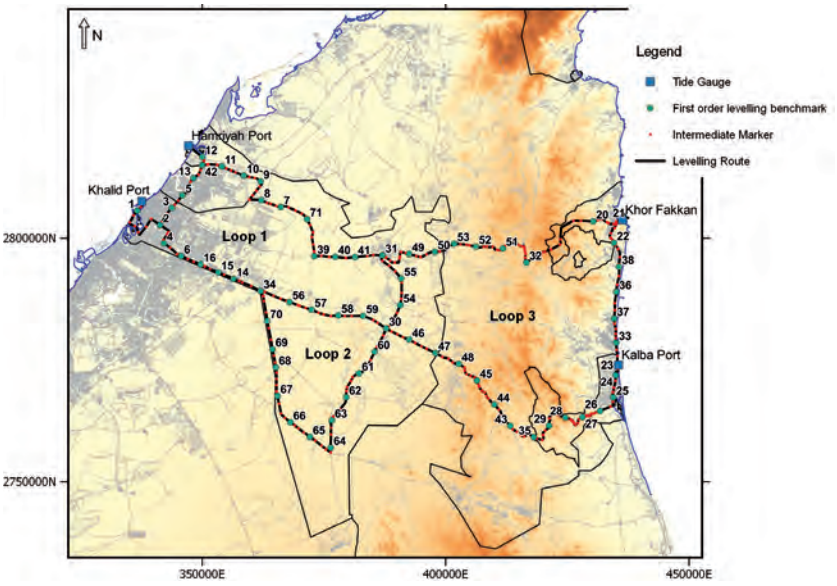
STUDYING MSL DIFFERENCES ALONG ARABO-PERSIAN GULF AND OMAN SEA

Once the levelling network was shifted onto the Al-Hamriyyah MSL (Gulf), comparisons yielded differences of -13.0cm at Khalid (Gulf), and -0.063cm at Khor-Fakkan and -0.001m at Kalba, (both in Oman Sea). According to literature, the MSS varies significantly in the Gulf and the Oman Sea (exceeding 15m, mostly due to geoid variations), but the four tide gauges of interest happen to be in areas where TSS should be quite similar in height.

At local scale, MDT models agree as to the TSS along the Gulf coastline, very slightly decreasing westward. This trend is confirmed by the measured variation of the MSL between Al-Hamriyyah and Khalid (-13.0cm), whose uncertainty due to some possible – albeit limited – local effect was estimated below 2cm. The MSL gradient along the Oman Sea coastline looks more questionable; the TSS is slightly but clearly decreasing northward (-0.062cm from Kalba to Khor-Fakkan, with the uncertainty estimated to be below 3cm), but this trend cannot be ascertained by any model due to the variability of the TSS slope magnitude and direction in the Oman sea. Likewise, between the Gulf and the Oman Sea, whereas the TSS appears in the same range in the AOI (virtually the same MSL at Al-Hamriyyah and Kalba), no model seems capable of ascertaining the extent to which they are the same. Indeed, when compared to the

Geoid model	Mean residual [m]	Residual standard deviation [m]	Minimum residual [m]	Maximum residual [m]
Best fitted GGM (GECO)	+0.081	0.111	-0.164	+0.450
Raw gravimetric geoid	+0.981	0.039	-0.095	+0.064
Hybrid gravimetric geoid	0.000	0.010	-0.026	+0.019

▲ *Table 1: Geoid model evaluation using 67 GNSS-levelling benchmarks.*



▲ *Figure 5: First-order levelling network and tide gauge locations (four).*

TSS resulting from the study's tidal measurements and the rigorous orthometric heights, the latest MDT publicly available (CNES-CLS18 MDT, based on GOCO05s GGM, consistent with this geoid at low degree/order) showed TSS slope biases of 2 to 7mm/km in both seas and virtually no difference in the SST shift between the two seas (Figure 7).

The slope inaccuracy was anticipated while analysing estimated errors from satellite altimetry at the geoid computation stage (Figure 6). All data within 15km of the shoreline was masked out. This represented an acceptable compromise for keeping as much data as possible while using data with errors similar to those of marine ship-track gravity (3.5 to 5mGal). Whereas this choice resulted in typical errors of between 0.5 and 5mGal, one may notice that they reach almost 12mGal offshore Khor-Fakkan (and 7mGal offshore Kalba), and much higher nearshore. All studies agree that extracting accurate MSL from satellite altimetry in coastal areas is hardly feasible due to amongst other things corrupted waveforms and errors in most of the corrections. However, this geoid study suggests that the resulting inaccuracy depends on the area and can be anticipated using the error model provided with the satellite data. In any case, a network of tide gauges remains the only way to accurately measure coastal MSL variations. Although slightly underestimating TSS slopes in these coastal areas, CNES-CLS18 MDT has proved fairly accurate in the AOI, certainly due to its related MSS relying on Jason-1/2 and Cryosat-2 and its inclusion of data from the Drifters surface velocity program (SVP) in the Oman Sea. Once shifted onto a reference MSL

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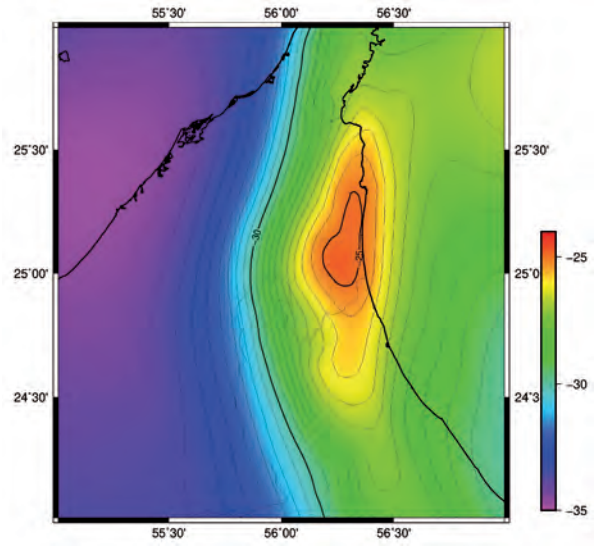
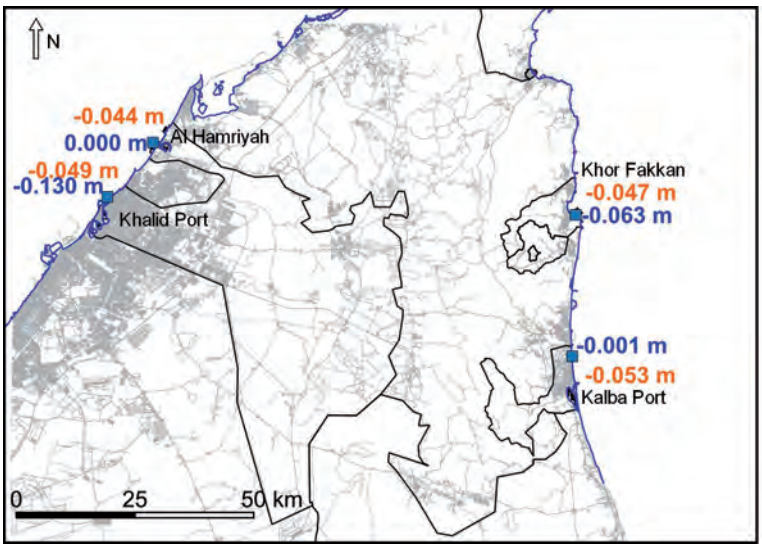


▲ *Figure 6: Emirate of Sharjah's gravimetric geoid. Values are in m.*



▲ *Figure 7: Comparison between Sharjah hydrographic levels/geoid 2019 TSS (in orange font) and CNES-CLS18MDT interpolated and shifted to minimize the differences to the four tide gauges (in blue font).*

ABOUT THE AUTHORS

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at a reference port, the model can be used to estimate the MSL in first approximation up to a few dozen kilometres from the reference port. Even better, the model can be calibrated using two tide gauges in each sea and the SST extrapolated much further if the TSS slope is somewhat regular.

CONCLUSION

The combination of state-of-the-art GNSS data for 17-day observation sessions, water level data from four tide gauges over a two-year observation period, precise geodetic levelling, and absolute and precise relative gravimetry allows the computation of rigorous orthometric heights and a high-accuracy hybrid gravimetric geoid. This has given the Emirate of Sharjah a reliable geodetic and hydrographic infrastructure whose robustness has allowed refining of the TSS slopes nearshore along the Gulf and the Oman Sea as well as the TSS difference between both seas. The latter is hard to accurately measure from satellite altimetry alone. This study also suggests that gravity-estimated errors from satellite altimetry can be an indicator of the need for increased coastal water level measurements. ◀

"Tharp Helped Keep Me Going"

How a Treasure Map Led Her to the Bottom of the Sea

"It wasn't always easy being a black woman in my early days as an oceanographer," says Dawn Wright, chief scientist at a worldwide operating company specialized in mapping and spatial analytics software. But a fictional pirate and a pioneering ocean explorer helped her chart her course.

"I grew up in the Hawaiian Islands, so the ocean has always been a sacred place to me. My summers included many hours spent in the waves, and ample time for reading. The book that captured my imagination above all others was Robert Louis Stevenson's *Treasure Island*. One of the central anchors of the story is Captain Flint's treasure map. The irony is that, as you read the book, or watch the Disney movie, the details of the map are never revealed. It is just the notion of the map's existence, and what it could lead to, that drives Long John Silver and others to the point of obsession."

MYSTERIOUS MAP

"I fancied myself one of the characters in the story, fascinated by the idea of a pirate's life, with liberty, equality and fraternity held high. At the beach, I followed imaginary clues and dug for loot in the sands. And I pored over the last page of my leather-bound copy, where a colourful rendition of the mysterious map was included on the inside of the back cover.

"I had no idea at the time as a child what cartography was, but that map fascinated me to no end: the shapes of the landforms, the colours, the arrow pointing north. Not only was I set on a permanent heading towards a love of pirates and pirate lore, I also wanted to know how to better decipher maps, and how to make them myself. I wondered, why did most maps only show the top of the ocean? What is beneath

the surface, and how in the world do you make a map of that?

"Those questions ended up launching my career of making real treasure maps of the ocean floor. I studied geology at college, then oceanography at Texas A&M. It was there that I would find another map to my future: the 1977 World Ocean Floor Panorama by Marie Tharp and Bruce Heezen, which adorns the walls of many great institutions of oceanography around the world. It was the first in history to hint at the full scope of what lies beneath the blue."

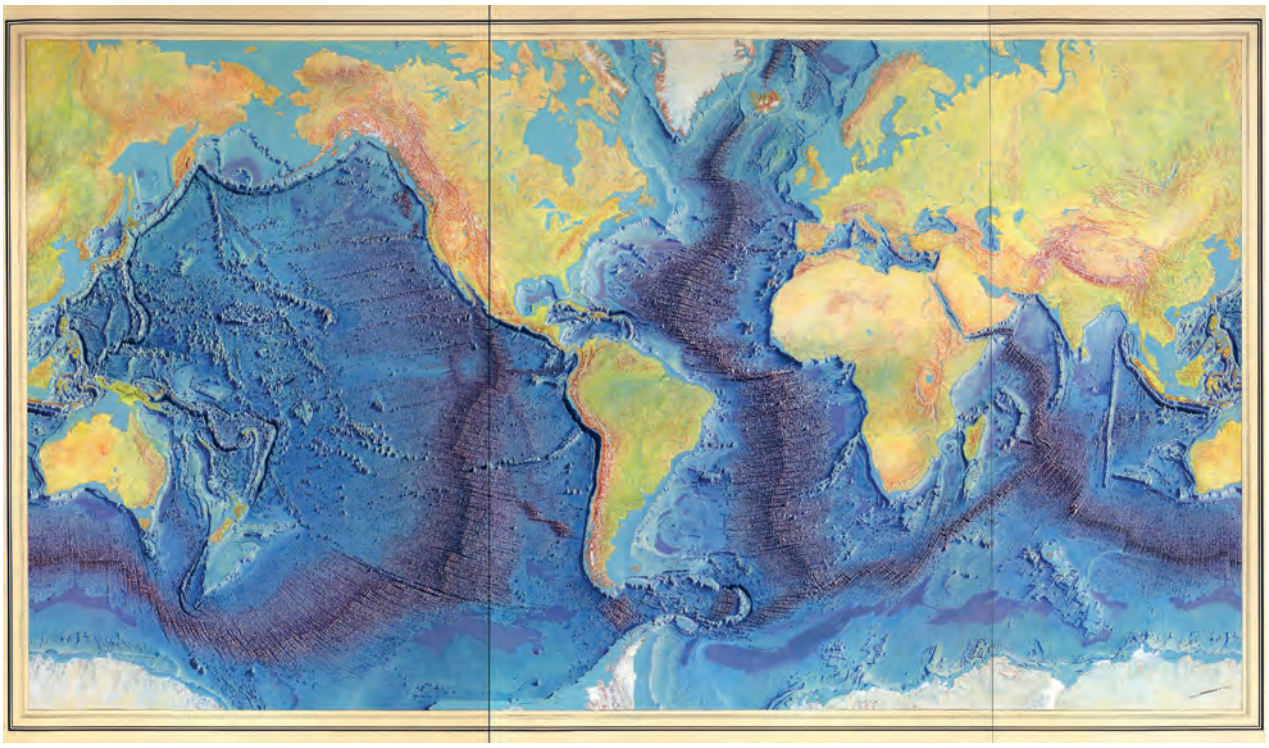
MARINE CARTOGRAPHY

"I fell more deeply in love with this document once I learned the backstory of one of its creators. As a researcher at Columbia University working in the 1950s and 1960s, Marie Tharp began the world's first systematic, comprehensive attempt to map the entire ocean floor. During the process of translating millions of ocean-sounding records into a single drawing, she discovered a rift valley that informed the theory of plate tectonics. Her contributions were for years left out of historical accounts in favour of her male peers, but now Tharp is hailed as the inventor of 'marine cartography'. And even though the data upon which her work was based were sparse and far less accurate than what we work from today, the map is still unmatched in its beauty, elegance, and insight.

"Like Flint's treasure map, Tharp's panorama still invites wondering minds to seek further discoveries in the world it depicts. It helped inspire me to specialize in the study of the shape of the ocean floor and the geological processes at play. To write my thesis, I travelled along the Tonga Trench in the Western Pacific Ocean, using a sonar 'sounding' system to gather yet more detailed swaths of seafloor data."

SCIENTIFIC DRILLING VESSEL

"And it stayed with me as my career took off. Though I hoped to continue mapping unexplored parts of the seafloor after obtaining my Master's degree, my first post, in 1986, was as a laboratory technician aboard the scientific drilling vessel *JOIDES Resolution*. This type of vessel does not have sonar mapping equipment; instead, it can lower miles of drill pipe through the entire depth of the ocean to the seafloor, recovering cores that reveal rich paleo-oceanographic history. I sailed on ten of these expeditions, logging nearly six months per year at sea. Though I loved the work, the 12-hour days could be arduous: I was usually one of a handful of women on a ship of 100 people, and always the only black woman. Women were expected to deal with the close quarters and heavy equipment, just as the men were.



"On the toughest days, Tharp helped keep me going. One of my favourite expeditions was to a famous place boldly depicted in another of her stunning panoramas: the Eastern Indian Ocean. In preparation for the expedition, I had discovered her Indian Ocean panorama, produced in 1967 for *National Geographic*. Tharp was with me on board, too, in a way: because our ship was outfitted to drill beneath the seafloor, not to map the highs and lows of the seafloor with sonar technology, it was important to have her map on hand to help me understand the features that we were drilling into.

"When we crossed the equator, it triggered a special ceremony – the line-crossing ritual, which was based on US Navy tradition. During these rites, 'pollywogs' – those who had never crossed the equator at sea before – have to be deemed worthy of entering the ranks of 'shellbacks', or those who had already crossed the equator on prior expeditions, and who are given all sorts of fantastical names. I was over the moon when given the role of one such shellback, Davey Jones, during the festivities on one of those trips. Flint's map in *Treasure Island* danced somewhere in the back of my mind."

MAPPING EXPEDITIONS

"As my career progressed, I went on to lead my own seafloor mapping expeditions. Now I work for Esri, a private mapping, GIS and geospatial data science company. One of the joys there has been teaming up with kindred spirits who are just as curious about what's beneath all the blue that most other maps show. Mindful of the high visual standards that Tharp established with her panoramas, we've built an entire ocean basemap with carefully chosen colours, saturation and shading, legible labels, and a clear hierarchy of information and coordinates. It's become a platform upon which other scientists can layer their own discoveries.

"But unlike the maps of Tharp's time, we can instantly add high-resolution bathymetric data, thanks especially to a global initiative to create a super-detailed map of the entire ocean floor, known as Seabed 2030. Despite all the seminal studies and maps in science, the technology should not cause us to forget the early struggles, triumphs and innovations of the seafloor mapping community – Tharp in particular. And, perhaps, the ocean-braving pirates who first inspired at least one of us." ◂

What are the attractive aspects of our profession, why did you choose employment in this industry, what do you see as the most important challenges? These and many other questions often dominate the personal meetings between colleagues. That's exactly what we would like to highlight. If you want to contribute to this new section in *Hydro International*, please contact Cees van Dijk, content manager (cees.van.dijk@geomares.nl).

Dawn Wright joined Esri as chief scientist in October 2011. Previously, she spent 17 years at Oregon State University as a professor of geography and oceanography, where she maintains an affiliated faculty appointment (her article was first published on www.citylab.com).
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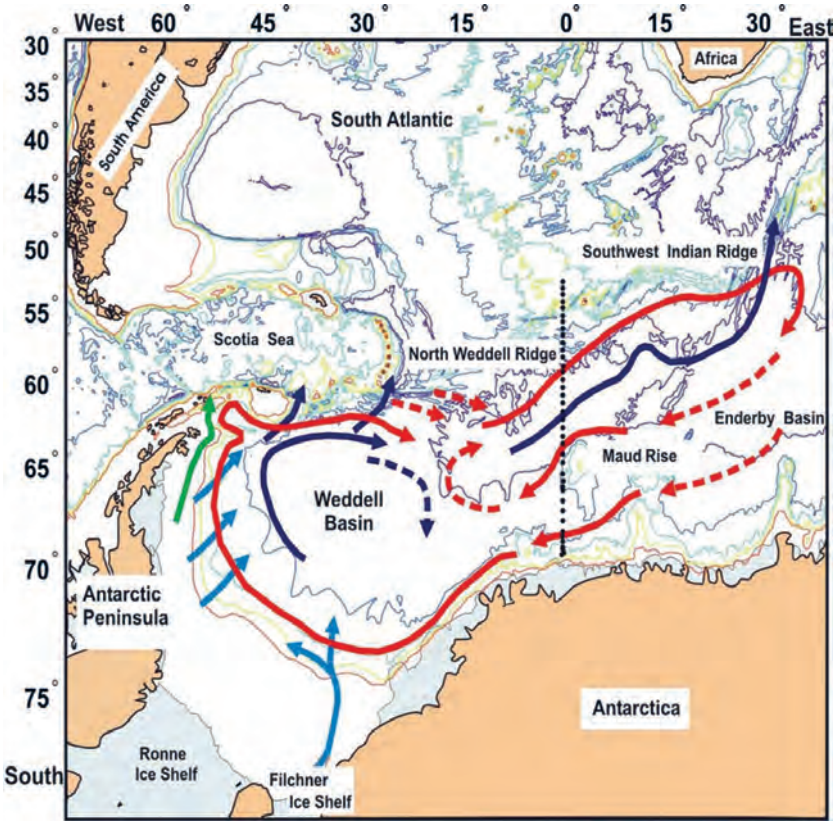
Scientific Challenges in a Crucial Region for Planet Earth

Remote, Frozen, Critical and Changing: the Weddell Sea

Located in the Atlantic sector of the Southern Ocean, the Weddell Sea generates extremely dense bottom water that spreads into all the world's ocean basins, transporting oxygen, CO_2 and other solutes. Everything that is added here is transferred into the abyssal oceans, including anthropogenic CO_2. However, changes are taking place in the Weddell region that will have an impact on other oceans and on the global climate.

The Weddell Sea (Figure 1) is a huge embayment between the Antarctic Peninsula and the Antarctic continent, situated at the southern edge of the Atlantic Ocean. The boundary of the Weddell Sea to the south is formed by the Filchner-Ronne Ice Shelf, the greatest floating ice volume on Earth. It is a remote, relatively inaccessible part of the Southern Ocean – the huge sea expanse that surrounds the continent of Antarctica (Figure 2). The water circulation in the Weddell Sea is characterized by an elongated gyre (a kind of huge eddy), the Weddell Gyre, which extends beyond the Weddell Sea towards the north and the east. The vigorous water transport of the Weddell Gyre is driven by the strong westerly winds in the north and easterly winds in the south, both of which are due to typically stable weather patterns in this region.



▲ *Figure 1: Map of the Weddell Sea and environs. (Courtesy: AWI, Bremerhaven)*

Some of the strongest winds and the highest waves in the world occur here: the roaring forties and furious fifties are well known. In austral winter, almost the whole of the Weddell region is covered by sea ice, while in summer the ice cover almost entirely retreats, except for perennial ice fields in the west. Since sea ice is one of the main factors to influence processes and elemental cycles in the ocean, it is evident that the region is subjected to extremely high seasonality. Tabular icebergs of several hundred metres in thickness occur, following the circulation of the gyre.

WATER MASS FORMATION

In this frosty region in the far south, the seawater closest to the sea surface gets as cold as it can in winter, reaching freezing point at about -1.9°C. At the same time, the excess salt left over from extensive sea-ice formation is released into the cold seawater that stays behind. In some areas, dubbed coastal polynyas (open water within the ice coverage), this process occurs at a very high rate, producing extremely dense seawater, among the densest on Earth. The dense water is transformed (by mixing with other local waters) into a water mass called Antarctic Bottom Water, filling the deepest parts of the Weddell Sea that may reach depths of over 5,000 metres. The formation process involves surface waters and

thus all the chemical and biological species present, and dissolved gases in this surface water are transferred into the Antarctic Bottom Water. This bottom water therefore contains abundant oxygen and CO_2 (including anthropogenic CO_2). These processes occur predominantly in winter, making it hard to observe them in this inaccessible region (Vernet et al., 2019).

CONNECTIVITY WITH OTHER OCEANS

The Weddell Sea is not just a remote corner of the oceanic realm, where nothing worthwhile happens. Instead, it is one of the world's major drivers of processes and chemical cycles in all oceans, and highly relevant to the global climate. The locally-produced Antarctic Bottom Water leaves the Weddell region towards the north, replenishing the layers of bottom and deep water in all the major oceans. This means that, in many places in the oceans, the water close to the sea floor is derived (at least in part) from this relatively small region, the Weddell Sea. By way of the Antarctic Bottom Water, the Weddell Sea (and some other maritime regions around Antarctica) therefore ventilate the abyssal oceans (i.e. supply oxygen), but also transfer (anthropogenic) CO_2, nutrients and other chemicals. The Weddell Gyre itself is influenced by remote atmospheric conditions and climate modes. For example, the Southern Annular Mode, a belt of westerly winds moving north and south and a major climate driver, appears to enhance upwelling of deeper water into the surface layer. Also, the El Niño phenomenon in the equatorial Pacific seems to exert remote control on the Weddell Gyre, with a spin-up of the gyre transport, followed by a weakening of the transport.

CHANGES IN THE WEDDELL REGION

Although its relative inaccessibility means that the Weddell Sea is undersampled compared to other oceanic regions, we do have some data that is suitable for analysing decadal trends in physical and chemical variables and parameters. We need to continue these observations of the changing sea before imminent changes accelerate in the near or further future. We know, for example, that the very dense bottom waters of the region are becoming warmer and decreasing in surface area. At the same time, ventilation of the waters formed in the Weddell Sea is decreasing, meaning that less oxygen is transferred into the other oceans. The atmospheric forcing in the southern hemisphere is also changing, partly due to the ozone hole, and this has an impact on the Weddell Gyre, with more upwelling of deep water into the surface layer, where the nutrient and CO_2 concentrations increase.

Because of the uptake of man-made CO_2, the local ocean is becoming more acidic, which may have a detrimental influence on the ecosystem. As to the biology of the region, the abundance of Antarctic krill is decreasing, whereas its competitor, salps, is expanding its territory to the south. Finally, changes in the ice coverage have been observed by satellite observations, though quite different from those

▲ *Figure 2: Ice coverage in the Southern Ocean. (Courtesy: AWI, Bremerhaven)*

▲ *Figure 3: Moorings with instruments and an AUV used by the Alfred Wegener Institute. (Courtesy: AWI, Bremerhaven/ FRAM/Sabine Lüdeling)*

taking place in the Arctic. The changes in ice cover will feedback on many other processes and cycles, such as albedo and heat exchanges, gas exchange between the ocean and the atmosphere, and the ecosystem, which is closely intertwined with the water and the ice.

OBSERVING AN INACCESSIBLE REGION

Traditional observations from ships are still the backbone of our knowledge and should continue. They are arduous and expensive, but necessary. However, our lack of knowledge of wintertime processes will hardly be addressed in this way as ships do not often visit the region in the winter. New methods for observation are however being developed, such as biogeochemical Argo floats, which float around the gyre at a depth of about 1,000m and measure vertical profiles of temperature, salinity, oxygen, nitrate and other parameters every ten days, and transfer the data to a satellite. Software is now available that lets the floats stay under the ice and only send their data if there is water above them. Seals are also being used as platforms for instruments, and generally stay in the region all year.

Temperature and salinity data are also collected and transmitted by satellite to the lab. For whale and other mammal research in the Weddell Sea, passive hydro-acoustic instruments are used, which provide information on the abundance and routes of these animals. These instruments can be moored and therefore present all year. Finally, the use of Autonomous Underwater Vehicles (AUV) has recently become more common. AUVs enable a suite of measurements to be carried out in sea areas that are inaccessible to ships, such as under the ice shelves of the Weddell Sea.

Particularly valuable datasets can be collected using stationary moorings that collect data and samples for one or two years, overcoming the limited seasonality of ship-based measurements (Figure 3). However, these moorings still need to be collected to read out the data, collect samples and service the equipment. As some of the important climate cycles driven by the Southern Ocean are decadal, long-term commitment is essential if we want to obtain reliable observations of a changing ocean. For the Arctic Ocean, a network of state-of-the-art observatories called FRAM has been installed by the German Helmholtz foundation. This type of coordinated observations would be particularly helpful for polar systems like the Weddell Sea.

CONTINUOUS OBSERVATIONS ARE A PRIORITY

Research in the remote Antarctic is international, with strong cooperation among many countries and institutes. Reliable and robust technology is key to the observation of the changing Weddell Sea, an important region for the Earth's climate. Deploying instruments and producing regular time series requires a considerable commitment from universities and research institutions. However, if we want to keep track of the effects of climate change in such dynamic regions with an impact far beyond their own boundaries, continuous observations must be made a priority. ◂

Dr Mario Hoppema is a senior chemical oceanographer/biogeochemist based at the Alfred Wegener Institute in Bremerhaven, Germany. He received his training in the Netherlands. His working area has for many years been the Antarctic and Southern Ocean, in particular its carbon cycle; he has been on several expeditions with the ice breaking German research vessel *Polarstern* (Polar Star).
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Dr Walter Geibert is a geoscientist who uses natural radioactivity to study the timescales of chemical, physical and biological processes in the ocean. He studied in Trier and Bremen, followed by positions as a researcher at the University of Edinburgh, the Scottish Association for Marine Science in Oban, and the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany, where he is now a senior scientist.
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Prof. Maria Vernet is a senior researcher/phytoplankton ecologist at Scripps Institution of Oceanography. Dr Vernet has conducted research in the Arctic since 1987 and in Antarctica since 1988 and has taken part in many expeditions. She was part of the team to study the effect of ultraviolet radiation on marine phytoplankton after the discovery of the Antarctic ozone hole in 1985.
✉ mvernet@ucsd.edu

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Magellan, 175:56 Hours Continuous Operational ROV Dive at 5,100m

Duration at Depth

A few operators have developed systems capable of 'bouncing' to 6,000m depths, but no one has amassed the experience and technical capability of operating on a continuous basis, day in day out, at these depths. Until now.

The abyssopelagic zone, at 3,000–6,000 metres depth, covers 83% of the ocean floor. Until recently, the demanding conditions and pressures at these depths have prevented companies from conducting routine operations in the deepest reaches of this zone. The vast majority of commercial systems have a maximum design depth of 4,000 metres, with almost no operators actually operating the systems at their design limits.

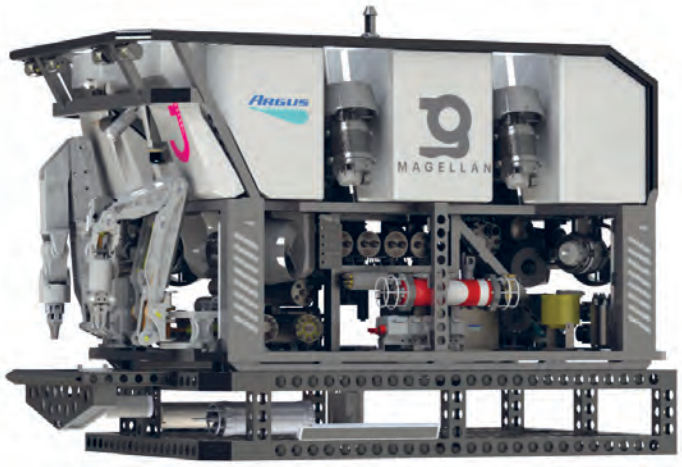
The discovery of deep ocean mineral deposits has created a demand for companies and systems capable of performing commercially viable operations between 4,000 and 6,000 metres.

The independent ultra-deepwater company, Magellan Ltd, was formed with the goal of developing systems and techniques capable of conducting routine operations at the extreme limits of the abyssopelagic zone.

During the past 30 months, Magellan has been quietly developing the systems and experience to successfully operate dual ROV systems at these depths. System reliability has been proven with over 10,800 hours of operations at depths greater than 5,000 metres. Paradoxically, it has been found that the majority of system failures occurred during transits through the water column, driving the goal of extended mission time at depth. A programme of continuous improvement and risk mitigation has subsequently culminated in steadily increasing reliability and extended dive times.

"Magellan's Argus Worker ROV systems have now proven their capability to operate at these extreme depths (5,000–6,000m) reliably, with extended mission times during continuous operations", says Doug Scott, offshore manager onboard the *MV Freja*.

"Building on the experience gained in combined MBES, SSS, Visual ROV surveys for the traditional oil and gas market, Magellan has brought together an experienced multidisciplinary team with



experience in deepwater operations to drive our push into the ultra-deep regions."

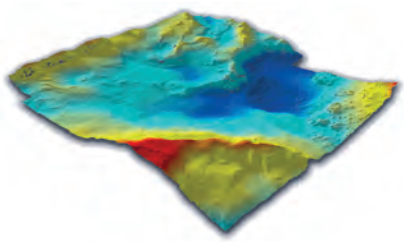
ULTRA-DEEPWATER MBES SURVEY

This extended mission time has been exemplified by the recent 200kHz Multibeam survey of a topographically challenging site at 5,100 metres depth. The site survey was completed in a single operational dive of 175:56 hours with real-time display of acquired data.

Blending the real-time data acquisition of deep-tow systems with the ability of AUVs to operate in challenging regions, these systems open up new possibilities in ultra-deepwater search and survey.

EQUIPMENT

Subsea positioning of the ROV system is achieved using a USBL-aided Sonardyne SPRINT-Nav 500 system. The vessel's HIPAP 500 system has been complimented by the addition of Kongsberg cNode MiniS transponders providing good tracking to full depth. The Sonardyne system combines a solid-state dual Attitude Heading Reference System (AHRS) and Inertial Navigation System (INS), a Syrinx Doppler Velocity Log (DVL) and a high accuracy pressure sensor in a single housing.



A Teledyne RESON SeaBat T50-S Integrated Dual Head multibeam system (200kHz and 400kHz capability) typically provides 600m swath coverage at 125m altitude, with the real-time PDS display allowing the ROV pilots to correct altitude and tracking thereby ensuring full coverage through topographically challenging areas on the first pass.

Optional equipment such as an EdgeTech 2205 Side Scan Sonar (75–1,600kHz dual frequency system) can be fully integrated into the package, bringing deep-tow swath coverage to ROV operations.

"Combining the low frequency, 75kHz coverage of the side scan sonar's Full Spectrum CHIRP processing with the higher resolution 400kHz coverage of the RESON T-50 Multibeam on the ROV allows rapid confirmation of targets as the search area is covered", says Richard Parkinson.

PHILOSOPHY

Applying and building on Magellan's philosophy of providing what is needed rather than what would be nice to have, each project is analysed and planned to deliver the needed results with the best efficiencies and lowest costs.

WHERE DO WE GO FROM HERE...?

Magellan continues to build its experience in ultra-deepwater operations on its own or sister company projects, as well as performing on-demand search and survey work scopes for companies requiring ultra-deepwater operations.

"With dual 6,000m Argus electric ROVs and a 6,000m 50-tonne active heave compensated winch, permanently mobilized on the Danish-flagged *MV Freja*, Magellan has a cost-effective, versatile platform capable of rapid response to ultra-deepwater search, identification and recovery projects worldwide", says Richard Parkinson, Magellan founder and director. ◀

MAGELLAN

Doug Scott has been involved with ROVs from the infancy of the industry in the early 80s. He witnessed first-hand the development of the industry as technology became both more reliable and sophisticated with increasing operating depths. Building on his involvement with early ROV-mounted MBES systems and subsequent IRM campaigns, he naturally evolved into ultra-deepwater (6,000m) with Swire Seabed during their push into ultra-deepwater. For the past two years, he has been bringing his extensive ultra-deepwater and commercial experience to Magellan operations. www.deepwaterspecialists.com.

How to Simplify Survey Reporting

Digital Tool to Streamline Hydrographic Information and Make Reporting Easy

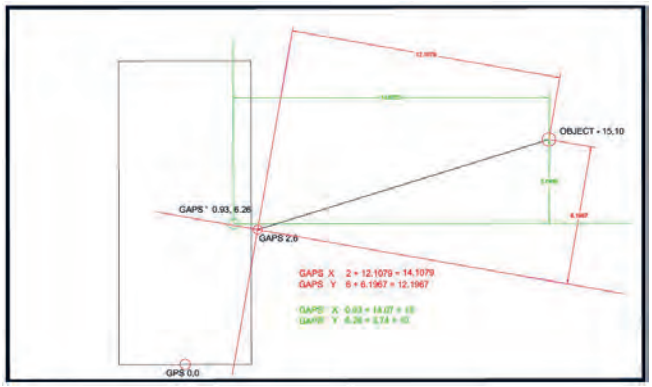
Wouldn't it be great to work on a hydrographic project without spending a lot of time looking for all the elements needed for a professional report? This was what Sanyal Sunil had in mind when he developed SURge, a digital tool to simplify survey reporting.

Hydrographic survey reporting has always been a headache for surveyors in the field, as they have to spend a lot of time formatting the reports, finding the correct logos and diagrams, displaying observations schematically, and carrying out irrelevant calculations, all of which have to be neatly represented in the report but have nothing to do with the operational part of the job. Considering the usual cramped and hectic working environment on board survey vessels, these long and tedious reporting exercises distract and exhaust the surveyor.

Being an active surveyor, I came across this situation a number of times. This made me think about developing a consolidated software platform for survey reporting, in which you just have to input the parameters in a graphic user interface and select the observation data files to produce a well-manicured survey report. The idea seemed unprecedented and novel. A report generator programme to help us with all the reporting we have to carry out during the calibration and field phases of survey – positioning system calibration, heading sensor calibration, transit fixes, rig positioning reports …. The list of reports we produce is endless and the effort we put into preparing them could be diverted into the operational part of our job, if we had such a utility.

IDEA GAINING SHAPE

I began to work on this idea during my free offshore days and, after almost two years and a lot of trial and error, I have managed to present a decent product. Input and feedback from my colleagues encouraged me to move ahead,



▲ *Figure 1*

finally consolidating all the required reports into this single platform, enabling a centralized monitoring for the reporting formats and allowing periodic updating if required.

'SURge', as I call it, is a single platform solution for all the hydrographic survey reports during the calibration and field phases of a survey and is presently only used by the survey division of the National Petroleum Construction Company, Abu Dhabi, where I am presently employed as a hydrographic surveyor.

WHERE IT REALLY MATTERS

Of late, there has been a great deal of discussion about the 'calibration free' (as claimed by the manufacturer) underwater positioning Ultra Short Base Line equipment (USBL). If we inspect their claim in detail, we can conclude that their claim is legitimate, but also misleading to some extent.

Is it really calibration free? Let me illustrate with an incident that happened in one of the ROV positioning jobs I had. A pipeline inspection was in progress using an observation-class ROV with eventing and CP survey. The ROV was positioned using the above-mentioned 'calibration free' USBL. During the course of the survey, the DP vessel on which the ROV was mobilized had to turn around by 180 degrees due to operational constraints, keeping the ROV above the pipeline being inspected. As the vessel turned, the ROV began to shift its position on the survey screen and when the turn had been completed, the ROV was almost 0.4 metres away from where it had been before the turn. Note that, on the ground, the ROV was sitting idle above the pipeline.

This made the survey team on board recalculate the offsets, which were confirmed. So, where was the error? How can a USBL system provide a wrong coordinate for the beacon, when the positional input is correct and the system is 'calibration free' for all the other freedom of movements? The answer lies in the heading information provided by the USBL system.

EQUIPMENT CALIBRATION

It is true that if the equipment is used as a stand-alone system with the low-quality GPS receiver provided, placed exactly above the USBL head, then the equipment does not require calibration as it is receiving an absolute position. By making use of its inbuilt heading and altitude sensors, it then correctly calculates the position of the underwater unit.

But sadly, this will not be the case most of the time, when the USBL has to be used with a combination of different sensors combined on a referential frame of the survey vessel. For this purpose, the USBL head has to be mounted on a frame and placed in a suitable location on the survey vessel's coordinate frame, and has to be positioned using this frame.

The USBL head mounted in this way may have a mounting angle error, which means that the heading sensor that is used by the USBL system to calculate the underwater positions may not be aligned with the heading sensor that is used by the survey vessel to calculate the relative positions of the various equipment, including the USBL head.

REFERENTIAL COORDINATES

The mounting angle error can be easily identified by comparing the vessel heading and the USBL heading and has to be corrected if the USBL is using positional input from the vessel's referential frame. But at this point, I have seen people ignore this factor, simply quoting the 'calibration free' tagline provided by the manufacturer and therefore inducing an error in the data. They simply measure the X and Y coordinates of the USBL head with respect to the positional sensor and enter these into the USBL system (surprisingly, the manufacturer has kept the abnormal coordinate

convention for the lever arms), ignoring the fact that the USBL system has its own referential coordinates and the system may end up providing incorrect coordinates for underwater units if the GPS antenna coordinates have not been recalculated according to the USBL lever arm frame.

The manufacturer has not made any provision for entering a correction value for the heading, probably because it will diminish their claim that their equipment does not require calibration. It has tried to get around the problem with a relatively new term – 'the lever arm correction' – for which the relative position of the USBL head with respect to the GPS unit has to be recalculated, according to the lever arms of the USBL system.

SCENARIO EXAMPLE

Let me illustrate the scenario with an example. In Figure 1, the GPS positioned at the vessel reference point (the small circle on the lower edge) has an absolute coordinate value of (0,0). The USBL head is measured as two metres to starboard and six metres to bow (2,6): if the lever arm correction is not calculated and applied, the USBL coordinates will remain (2,6). Now consider that the angular difference between the vessel's gyro and the USBL gyro is 10° (USBL gyro high), which can be the result of a mounting angle (10° is slightly exaggerated to prove the point).

Now, we have an underwater object with the absolute coordinates (15,10). If we take a fix using the beacon, the USBL will provide the values (14.1079,12.1967), by calculating the position in its own coordinate frame.

If we have calculated the lever arm corrections exactly, that is we have recalculated the position of RP with respect to the USBL head in its coordinate frame (shown in red), we will get (0.93,6.26) as the USBL head coordinates instead of (2,6). This will result in the USBL system correctly calculating the coordinates of the underwater object in position (15,10). The problem in this scenario is that the values 0.93 and 6.26 are hypothetical values and cannot be physically measured on board. The values have to be derived.

CALIBRATION TIME

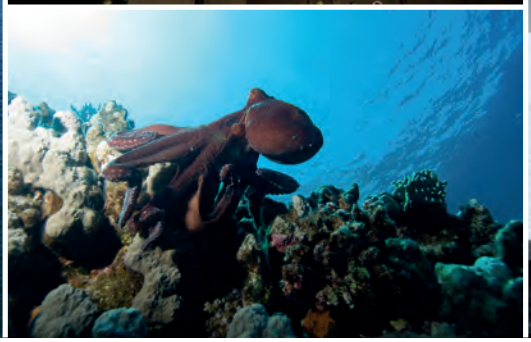
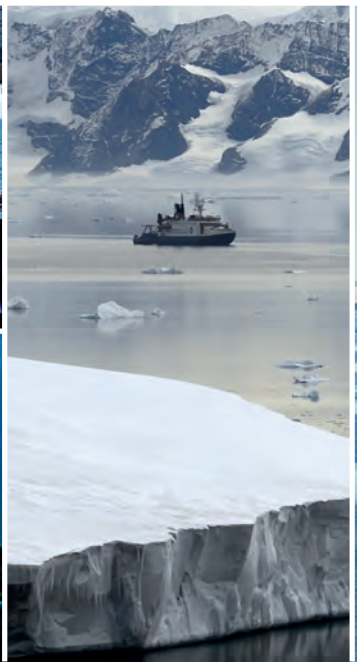
But how? If you have a good command of AutoCAD, you can draw the offsets in CAD and rotate the whole figure according to the heading correction, keeping the USBL head as centre and aligning it with the referential frame of the USBL. But that exercise is going to consume a large part of your calibration time (also considering the time required to open an AutoCAD programme). So, we came up with a utility in SURge to calculate the lever arm coordinates for the USBL, where you just have to enter the measured coordinates of the GPS and USBL unit and the angular difference of the unit with respect to the vessel. The utility will provide the coordinates to be entered.

The lack of a common performance guideline for standard survey reporting has always been of concern to hydrographic surveyors in the field and, as a result, the surveyor has to produce reports according to the client's whims. The consolidation of survey reports into a single platform and standardization with a universal identity with a suitable prefix abbreviation for each report would bring a seamless survey reporting scenario into play. Governing bodies like the International Hydrographic Organization and IMCA could effectively implement this. ◂

Sanyal Sunil (1977) joined the Indian Navy and specialized in hydrographic surveying. He gained his sea legs in the Indian Navy's Hydrographic Department, nurtured his interest in geography, and graduated. He has a postgraduate degree in GIS and Remote Sensing. He has worked in the field of hydrographic surveying since 1996 and witnessed the shift in perspective from the analogue era to present-day digital technology. He ventured into commercial hydrographic surveys after retiring from the navy in 2011 and founded Team SURge with three other navy colleagues.
✉ sanjasmal@gmail.com

PRODUCTS FOR POSSIBILITIES

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