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Automatic Shipwreck Detection in Bathymetry Data

Open-source Software
and Hydrographic Survey
Data

Surveying the Arctic by Sailboat

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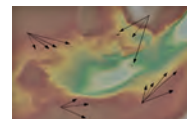
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P. 10 Automatic Shipwreck Detection in Bathymetry Data

Machine learning, AI and other computerized methods of analysing imagery have made incredible strides possible in many research areas. Algorithms have been devised to locate everything from buildings, roads and people to more specific objects like aeroplanes, ships and animals. Archaeologists, too, have begun using AI to locate ancient settlements. Recent research shows how the use of such automated methods can help reveal a seascape of human history sunk at the bottom of the ocean.



P. 14 Surveying the Arctic by Sailboat

Bathymetric soundings in the Canadian Arctic are sparse, especially in the High Arctic (>75°N), where large sections of coast and the continental shelf are completely uncharted. The lack of accurate bathymetry severely limits the accuracy of ocean circulation models and the understanding of how marine-terminating glaciers in the region will respond to a rapidly changing ocean climate.



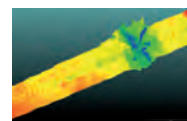
P. 18 What is GNSS Spoofing?

The survey and mapping industry has been benefiting for years from GPS/GNSS precise positioning technology. While GNSS spoofing is recognized as a real threat for unmanned aerial vehicles (UAVs or 'drones'), its influence on survey and mapping equipment is still underestimated. Reliable data capture is important across various mapping use cases, from man-based surveying and mobile mapping all the way to UAV photogrammetry.



P. 21 Open-source Software and Hydrographic Survey Data

In this present age of data collection and technological refinement, hydrographers and data processors are expected to produce high-quality deliverables with a swift turnaround. However, the cost of proprietary commercial software processing programmes has excluded many smaller contractors in the past. Such programmes incorporate finely tuned tool suites and nested algorithms that have been distilled and polished over the years. However, the financial hurdles are not as high as the passion and love that these individuals carry for this explorative industry and, thankfully, open-source resources and collective intelligence are changing the game.



P. 24 The *Titanic* Disaster and Its Aftermath

In the night of 14 April 1912, the unthinkable happened. The mightiest ship afloat, the brand-new White Star Line ship *Titanic*, was on its maiden voyage from Southampton, England, to New York. The ship was advertised as unsinkable. And, if unsinkable, why should there be adequate lifeboats for all of the passengers and crew? The *Titanic* departed from Southampton on 10 April. Less than five days later, it was at the bottom of the Atlantic Ocean. More than 1,500 people perished within three hours of striking an iceberg, which ripped the bottom out of the ship.



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Cover Story

The front cover of this edition of *Hydro International* shows a bathymetric map of offshore northern California, revealing seafloor features and submarine canyons. (Image courtesy: Jenna Hill USGS Pacific Coastal and Marine Science Center)



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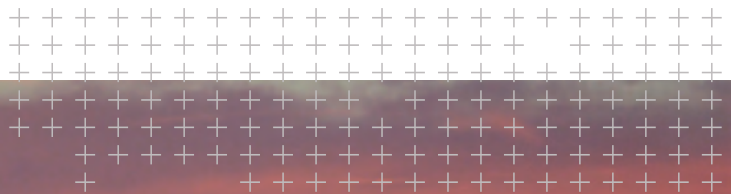
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The Democratization of Remote Sensing

It must have been more than 20 years ago that I entered into a fierce argument with a colleague. The basis of that argument was partially semantic, but also due to a fundamental issue. The terms in question were 'GIS' and 'remote sensing'. As to the former, I argued that every hydrographic package is in fact a GIS package. It may not have all the functionality, but when I started doing 'real' GIS my previous experience helped me tremendously... however, I did not win that argument (that day).

As to remote sensing, I suggested that hydrography is one of the oldest types of remote sensing in the world, and was laughed at. The reason given was that remote sensing involves planes and satellites. My counterargument was that if we look at the semantics, it is actually defined as sensing something without touching it, which is what geodesy does with angles and distances. In hydrography, the echo sounder gave us remote sensing as early as the 1920s. I didn't want to mention lead and line, but that was quite remote too of course.

Aerial photography was even earlier and can be traced back to the mid-1900s. It became fully fledged in the early 1900s, right alongside the echo sounder in hydrography. And it is not 'just' the depths; we also collect intensity information (backscatter) and process that to learn about the materials. What is the difference with a satellite observing the return strength for a part of the light spectrum? This becomes obvious when we teach students about systems such as the multibeam echo sounder, scanning profiler and Lidar. Disregarding the energy source, the acquisition and processing are very similar. So, in my book, every hydrographic surveyor is engaged in remote sensing.

However, even in hydrography we have one subject that does not require any semantic discussion at all: bathymetric Lidar. In fact, we could start a new discussion because terrestrial Lidar has gone deep as well. In the offshore world, the use of 'underwater Lidar' is increasingly customary for precise engineering surveys, replacing traditional techniques such as the scanning profiler for short distance measurements. However, that is not the Lidar I'm referring to.

Bathymetric Lidar bridges the gap between terrestrial Lidar and underwater Lidar. Just like a regular Lidar system, it uses light, and it measures depths from above the water. It is therefore the only system that penetrates the water surface to obtain measurements. Deployed

from an aircraft (helicopter, aeroplane or even a UAV), it emits a single green laser beam which, using a rotating mirror, it sweeps across a swath. Depending on the system, the first return is used to determine the water level and the deepest return the bottom, and the difference between the two gives the raw depth range. Alternatively, a separate red laser beam is used to track the water level. This data then needs to be converted to chart datum using an RTK system or tidal measurements. Sounds familiar? Yes, just like the scanning profiler...



▲ Huibert-Jan Lekkerkerk.

Bathymetric Lidar is popular in areas where the water is clear. In more turbid waters, the range is limited to a few times the 'Secchi' depth. For a long time, a dedicated aircraft was needed to conduct bathymetric Lidar. However, Lidar units have become smaller over the years. The newer models weigh less than 5kg and have their own internal battery to sustain them for up to one hour of measurements, assuming that the UAV can last that long on its own battery. Attaching the Lidar units to a UAV makes it much easier to deploy them, although the UAVs are quite large and therefore require specific licences to operate (if allowed at all in an area).

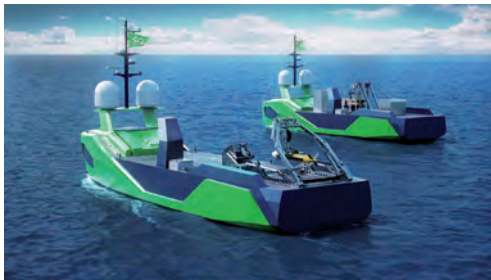
Want to reduce the cost of your surveys? Get a camera-equipped UAV and start doing photogrammetry (yes, we are going full circle here) of the water bottom. Over the past few years, camera-equipped UAVs have become much smaller and cheaper and the cameras much better. Slightly lagging behind is the processing software, which is still mainly geared towards terrestrial photogrammetry. But we are getting there. Where terrestrial Lidar is concerned, software such as OpenDroneMap means that anyone with a few hundred euros to spare can start making 3D models of their surroundings (provided there are no flight restrictions). Perhaps, in a few years, the same will be possible for our shallow (and clear) waters?

Huibert-Jan Lekkerkerk, technical editor
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Ocean Infinity Acquires MMT



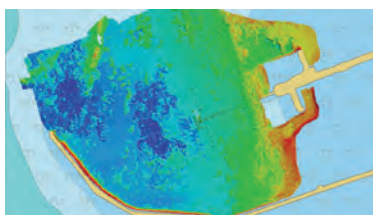
▲ Ocean Infinity recently launched its new pioneering marine robots, the Armada fleet.

Ocean Infinity and MMT have announced an acquisition that brings together MMT's deep expertise and established track record as a distinguished marine survey and data analytics

provider and Ocean Infinity's renowned robotic technology and operational expertise. The combined force will maximize the potential of Ocean Infinity's fleet of autonomous underwater vehicles (AUVs) and the soon-to-be-launched Armada fleet of uncrewed, low-emission robotic ships. The company will be premium placed to support its international clients' data acquisition requirements, working across multiple sectors including energy, subsea cables, government and defence. Following the acquisition by Ocean Infinity, MMT will continue to operate under the MMT brand. The enlarged group will have a headcount of over 300 people and will operate from an expanded geographical footprint with offices in the US, Sweden, UK, Singapore and Norway.

► <https://bit.ly/20xRhYG>

Building National Hydrographic Capabilities in Albania



▲ Digital terrain model of Romano Port, Albania.

Modern official electronic nautical charts of the entire coast and main ports of Albania have been produced and made accessible to professional shipping. The United Nations Convention for the Safety of Life at Sea (SOLAS), Chapter 5, Regulation 9, describes the

obligations for a coastal state with regards to providing hydrographic services to mariners. In order to facilitate safe and effective international (and national) transport of people and goods by sea, coastal states must map their waters and issue updated nautical charts and publications in a way that provides easy and secure access for the mariners that need them. Out of more than 150 countries with a coastline, less than half are capable of meeting international obligations for official nautical charts themselves. In many cases, a primary charting authority such as the United Kingdom or France fulfils these obligations on their behalf. Since 2014, the Norwegian Mapping Authority has been involved in supporting Albania to establish a fully operational hydrographic office.

► <https://bit.ly/3cfaTsK>

NOAA Begins Transition Exclusively to Electronic Navigational Charts



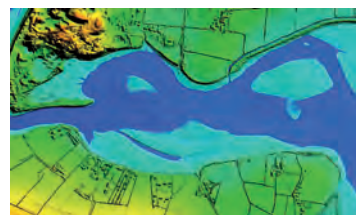
▲ The online NOAA Custom Chart tool enables users to create their own paper and PDF charts from the latest NOAA ENC data.

NOAA will begin to implement its sunset plan for paper nautical charts this month, starting with the current paper chart 18665 of Lake Tahoe. After August, NOAA's electronic navigational chart will be the only NOAA nautical chart of the area. This is the first traditional paper chart to be fully supplanted by an electronic chart as part of NOAA's Office of Coast Survey Raster

Sunset Plan, which includes a new process to notify mariners of the transition from individual paper charts to electronic charts. These charts are easier to update and maintain, keeping mariners safer with up-to-date information on marine hazards. NOAA announced the start of a five-year process to end traditional paper nautical chart production in late 2019 via a Federal Register Notice. While NOAA is sunsetting its traditional nautical chart products, it is undertaking a major effort to improve the data consistency and provide larger scale coverage within its electronic navigational chart product suite.

► <https://bit.ly/30ktRsr>

Airborne Lidar Survey to Create 3D Map of Northern Ireland's Coastline



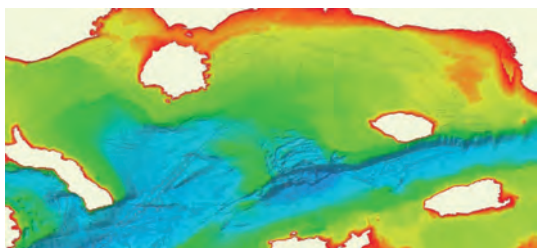
▲ Lidar imagery of the coastline south of Belfast.

Bluesky International will use aircraft-mounted Lidar sensors to create a highly detailed 3D map of the whole of the Northern Ireland coastline. The Bluesky data will form part of the wider Northern Ireland 3D Coastal Survey; extending into the marine environment with a satellite-derived bathymetric survey and a pilot bathymetric

Lidar survey. In combination, these surveys will inform the development of future coastal management policies. Working on behalf of the Department of Agriculture, Environment and Rural Affairs (DAERA), the Lidar survey will be used to create the first-ever complete baseline, which it is hoped will underpin recording of coastal change and help to identify the rate at which the coastline is changing as a result of climate change. In addition to the Lidar data, Bluesky will simultaneously capture highly detailed aerial photography which will be processed to produce a fully orthorectified, ten-centimetre-resolution database.

► <https://bit.ly/3sWeD9u>

Upgraded Version of EMODnet Bathymetry Digital Terrain Model Launched



▲ EMODnet Bathymetry Digital Terrain Model.

sustainable ocean governance and blue economy activities. This new EMODnet Bathymetry product benefited from significant developments and expert inputs in 2020, including new data gathering, reprocessed data, thorough selection of the best data source and use of innovative bathymetric sensors (such as satellite-derived bathymetry). It allows users to visualize bathymetric features with greater detail, in addition to providing a powerful 3D visualization functionality covering all European seas, into the Arctic and Barents Sea, and greater accuracy along European coastlines, thanks to the integration of both in-water and satellite datasets. It is available free of charge for viewing and downloading and for sharing by OGC web services from the EMODnet Bathymetry portal.

► <https://bit.ly/3sZW016>



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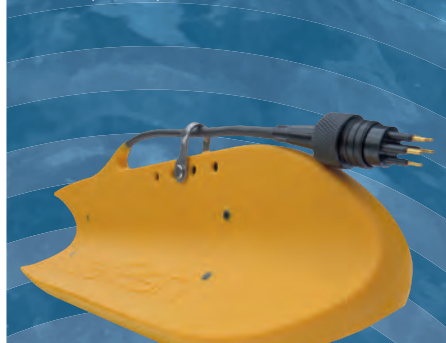
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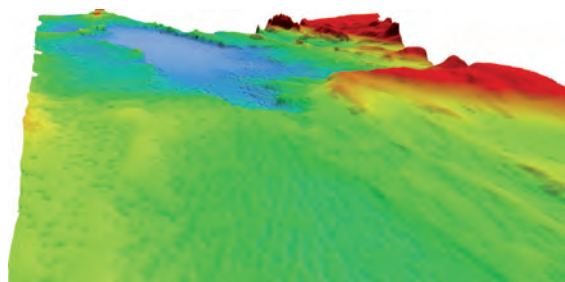


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Remote-controlled USV Survey of Lake Superior Seabed



▲ Sample bathymetry data captured during the Lake Superior seabed survey.

In a substantial move forward for the Canadian marine industry, two XOCEAN Uncrewed Surface Vessels (USVs), remotely controlled via satellite, took to Lake Superior this winter to conduct pioneering survey work for the Canadian Hydrographic Service (CHS) in partnership with IIC Technologies. The project marks the first time that USV technology has been used to gather bathymetry data in inland waters in Canada. CHS contracted IIC Technologies to acquire a high-resolution seabed survey in water depths up to 200m, of over 800km² off Thunder Bay, Ontario, using USV technology. IIC partnered with XOCEAN, who provided and remotely operated their XO-450 USVs from XOCEAN's Control Centres in the UK and Ireland, while IIC provided the party chief, shore-based data processing and logistical support. The uncrewed vessels are around the size of an average car (4.5m) and half the weight (750kg) and are remotely monitored and controlled 24/7 via a satellite connection by a team that can be located anywhere in the world. XOCEAN's USVs offer significant benefits, including increased safety with operators remaining onshore, survey efficiency due to multiple-day mission 24/7 operations, drastically reduced local resourcing requirements and carbon-neutral operations, which together lead to significant economic savings.

► <https://bit.ly/3ru4Zul>

The project marks the first time that USV technology has been used to gather bathymetry data in inland

EU and China Enter Marine Data Partnership



▲ Xiang Wenxi (NMDIS) and Jan-Bart Calewaert (EMODnet) signing the EU-China MoU.

This month, EU-China collaborations on marine data and knowledge sharing have taken a new step forward with the signing of a Memorandum of Understanding (MoU) between the European Marine Observation and Data Network (EMODnet) and the National Marine Data and Information Service (NMDIS) of China. The

agreement consolidates the operational, technical and scientific collaboration which is already well underway, by providing a clear framework to advance the joint efforts through the EMOD-PACE and CEMDNET projects on three specific areas of collaboration: (i) the sharing of available in situ, earth observation and modelled marine data, (ii) the exchange of knowledge and best practices related to marine data and information product R&D and associated technology, and (iii) the development and implementation of common work plans between NMDIS and EMODnet in relation to ocean reanalysis, seabed habitat mapping, ecological vulnerability and coastal zone adaptation.

► <https://bit.ly/3vcx0mf>

GeoAcoustics Returns to Independent Ownership



▲ GeoAcoustics GeoPulse sub-bottom profiler.

GeoAcoustics has returned to independent ownership following divestment from the Norwegian multinational Kongsberg Maritime AS. Kongsberg originally acquired the company in 2008 and it has been a part of the

Sensors & Robotics business area. Based in Great Yarmouth in the United Kingdom, GeoAcoustics has been manufacturing marine survey equipment for more than 42 years, and it is a world-leading manufacturer of sonar survey systems for engineering, geophysics and naval survey applications. Principle product lines are swath bathymetry systems for shallow waters, side-scan sonars and sub-bottom profilers. GeoAcoustics' general manager Dr Richard Dowdeswell commented: "This is an exciting chapter in the history of GeoAcoustics and we are looking forward to expanding our global reach through the introduction of new channel partners as well as bringing new products to market".

► <https://bit.ly/20f8PIk>

Kongsberg Maritime to Launch Next-generation HUGIN Endurance AUV



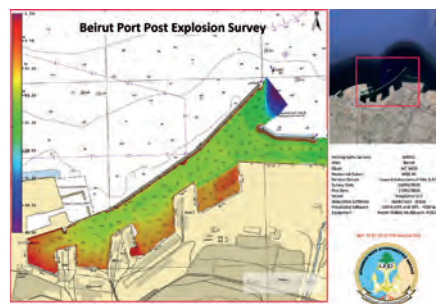
▲ Kongsberg Maritime's new HUGIN Endurance AUV can map up to 1,100 square kilometres on a single mission.

Kongsberg Maritime has announced the next generation of its advanced HUGIN Autonomous Underwater Vehicle (AUV). Named HUGIN Endurance, the new AUV boosts operational duration to approximately 15 days, enabling

extended survey and inspection missions far from shore. This longevity allows HUGIN Endurance to undertake extensive missions without the support of a mother ship. Shore-to-shore operations offer the opportunity to reduce the carbon footprint for commercial activities and yet retain unrivalled data resolution and accuracy. With this in mind, Kongsberg has added its Maritime Broadband Radio (MBR) communications system to HUGIN Endurance's payload, allowing it to surface and share large quantities of data swiftly with any suitably equipped installation, such as another vessel, a shore station or a wind turbine fitted with an MBR antenna.

► <https://bit.ly/3efRhHT>

Lebanon Newest Member of IHO



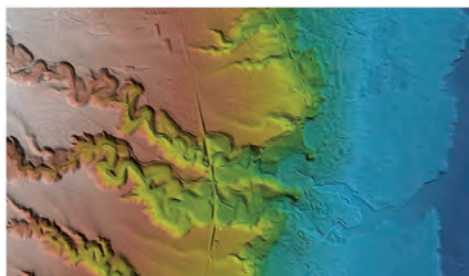
▲ Lebanon's recently established hydrographic office resurveyed Beirut port following the explosion in August 2020. (Courtesy: Lebanese Navy Hydrographic Service)

Lebanon has joined the International Hydrographic Organization. By becoming its 94th Member State, Lebanon will benefit from the organization's resources and expertise in order to improve safety of navigation and contribute to the development of its maritime activities. Beirut harbour is very important for this coastal state, as a strategic gateway for trade and the provision

of goods. After the explosion which rocked the capital on 4 August 2020, the seabed around the port was altered. A team of Lebanese hydrographers resurveyed the port to reopen and enable ships carrying supplies and materials for reconstruction to safely enter.

► <https://bit.ly/3bsrcDH>

USGS Selects Woolpert for Topographic Lidar Task Order in Hawaii



▲ This topo-bathy Lidar image was collected by Woolpert over Kauai, Hawaii. (Image courtesy: USGS)

The US Geological Survey has awarded Woolpert a task order under its Geospatial Product and Service Contract 3 to acquire Quality Level 1 topographic Lidar data in Hawaii. The task order applies to Oahu, the four islands in Maui County and

portions of the Big Island of Hawaii. It is funded by the USGS, with interagency cooperation from the National Oceanic and Atmospheric Administration's Office for Coastal Management. The Natural Resources Conservation Service, the Federal Emergency Management Agency and the State of Hawaii, Office of Planning, also contributed to the task order and will be end users of the data. This is Woolpert's third task order to collect QL1 Lidar data in Hawaii as part of the GPSC 3 contract. The firm has acquired a combination of approximately 6,600 square miles of topographic and 125 square miles of bathymetric Lidar data encompassing the state's eight main islands as part of a systematic plan to produce Hawaii's first statewide, high-resolution elevation dataset.

► <https://bit.ly/3sWoiNe>

Valeport Introduces New SWiFT CTD Profiler



▲ Valeport SWiFT CTD.

Designed with the intention of a seamless workflow, the new SWiFT CTD is the next generation of Valeport's popular SWiFT profiler range and delivers enhanced accuracy and versatility for

those requiring CTD measurements. The SWiFT CTD profiler from Valeport, a leading oceanographic and hydrographic instrumentation manufacturer, provides survey-grade sensor technology coupled with the convenience of Bluetooth connectivity, a rechargeable battery and an integral GPS module to geolocate each profile. Using Valeport's leading high-accuracy sensor technology to combine sensors for multiple profiles in a single drop, the SWiFT CTD features a new fast response temperature probe and operates down to 500m as standard, delivering directly measured conductivity, temperature and depth.

► <https://bit.ly/3quVfPc>

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Hydrological Algorithms Help to Uncover Sunken History

Automatic Shipwreck Detection in Bathymetry Data

Archaeologists have long been interested in shipwrecks. These sites can tell us about ancient transportation and trading routes, technological innovations and cultural exchanges over thousands of years. Documenting shipwrecks can be a difficult task, however. With breakthroughs in remote sensing technology (specifically sonar and radar), researchers have been able to acquire highly resolved maps of ocean floors. Consequently, we can also locate cultural objects – like shipwrecks – sitting on the bottom of oceans, lakes and other bodies of water.

Machine learning, AI and other computerized methods of analysing imagery have made incredible strides possible in many research areas. Algorithms have been devised to locate everything from buildings, roads and people to more specific objects like aeroplanes, ships and animals. Archaeologists, too, have begun using AI to locate ancient settlements. Recent

research shows how the use of such automated methods can help reveal a seascape of human history sunk at the bottom of the ocean.

BATHYMETRY AND SHIPWRECK ARCHAEOLOGY

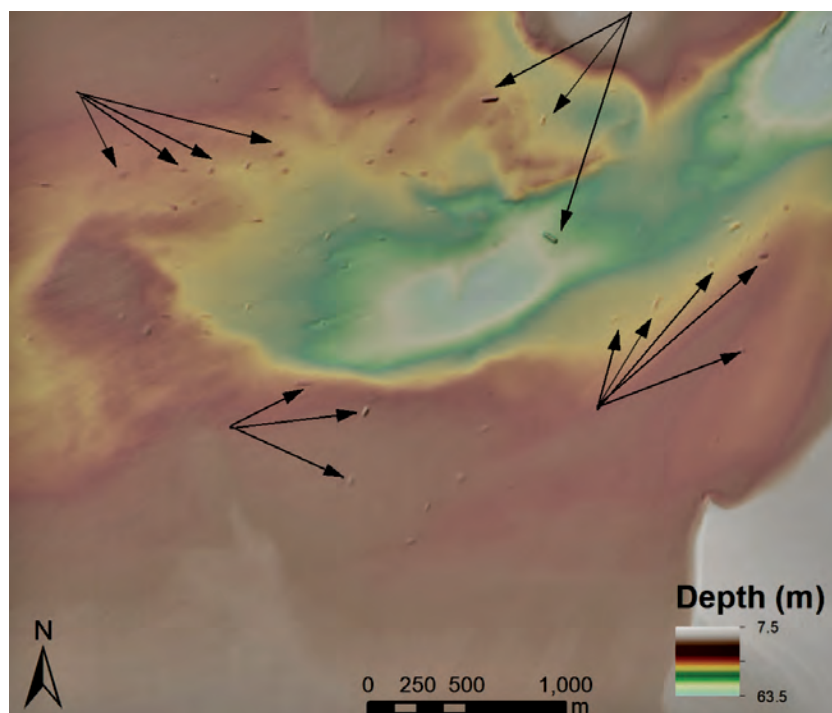
Researchers have used bathymetric datasets to locate everything from ancient Roman and

Greek vessels to World War II aircraft carriers. Technical studies of specific bathymetric data types have shown that shipwrecks can be identified in high-resolution imagery, but smaller or highly damaged wrecks are not as easy to locate. While most shipwreck archaeology has used bathymetric datasets produced by sonar and radar instruments, which are collected from boats or submerged vessels, some researchers have utilized bathymetric datasets collected from the air, specifically Lidar.

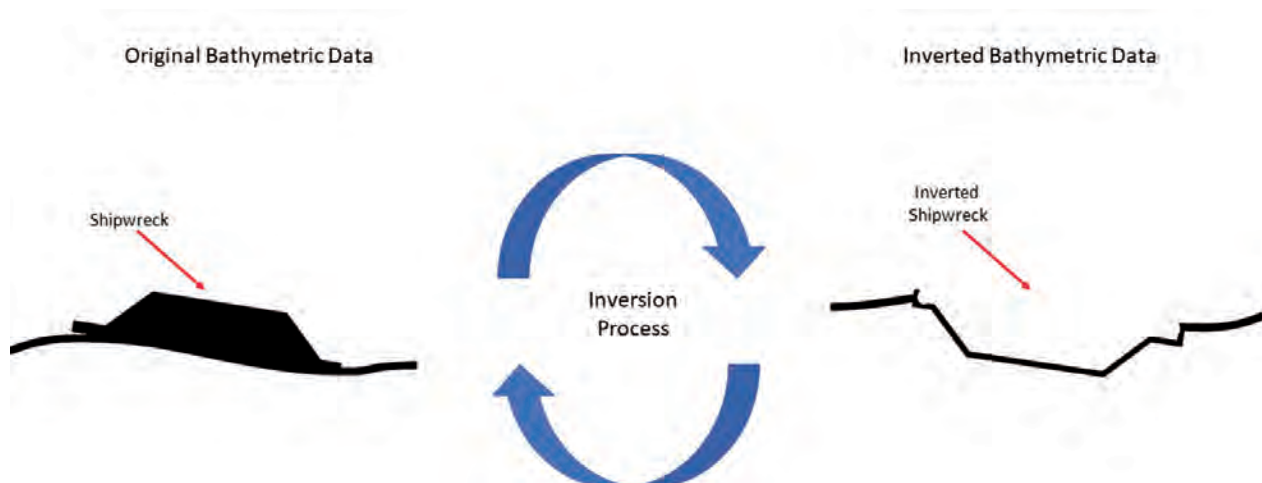
Lidar (light detection and ranging) data, collected using pulses of light to record 3D surfaces, has made headlines within archaeology for its ability to detect cities hidden under jungle and forest canopies. However, there are actually two kinds of Lidar data: topographic Lidar (which is used to locate features on land), and bathymetric Lidar (which can penetrate water and map shallow ocean floors). Archaeologists have used bathymetric Lidar to detect shipwrecks in shallow waters around the world. One limitation of Lidar, however, is that the water must be calm and clear for proper data collection.

THE 'BIG DATA' PROBLEM AND UNDERWATER ARCHAEOLOGY

The use of 3D data like bathymetry and topography has improved researchers' ability to detect objects in image datasets. Shipwrecks, which appear as mounds at the ocean's bottom, can therefore be identified based on their depth compared to the surrounding ocean floor.



▲ Figure 1: Shipwrecks visible in bathymetric data from the National Oceanic and Atmospheric Administration in the United States. Arrows highlight some of the larger visible shipwrecks. (Credit: Dylan Davis, Danielle Buffa & Amy Wroblewski (2020). Source: <https://doi.org/10.3390/heritage3020022>.)



▲ Figure 2: Illustration of how inverting bathymetric data works for detecting shipwrecks. The original dataset is flipped so that a mounded wreck becomes a hollow depression. The algorithm can then ‘fill’ that depression to detect a shipwreck as if it was a sinkhole or topographic depression. (Credit: Dylan Davis.)

However, the ocean is vast, and recording shipwrecks and other features by hand is extremely time-consuming and expensive. To this end, there are many different methods that can be used to automatically extract information from images.

The use of AI and machine learning methods have become increasingly popular as they can be extremely precise, but these methods are also very complicated and require high levels of processing power to implement. There are also other methods of pattern recognition that use a variety of object characteristics to create expectations for a computer to locate new objects. These can include colour, shape, texture, size and height, to name just a few.

Generally speaking, the greater the number of characteristics considered in a detection algorithm or model, the more accurate the detection becomes. This is particularly true if the features of interest are complex and highly variable. Different methods have had varying levels of success in detecting a range of feature types. Within archaeology, for example, automated techniques have successfully located urban complexes in Central America, Native American constructions in the United States, and tens of thousands of archaeological burial mounds and tombs across Europe and parts of Asia. Among marine archaeologists, however, these methods have not yet been extensively adopted.

For automated methods like machine learning and AI to work, image data must be at a fine enough resolution to detect patterns related to the target of interest. For example, to locate a

sunken cruise liner, your data resolution can be lower than if you are looking for a canoe or kayak. For a cruise liner, your data resolution can be lower because the object is large and easy to spot, even if the imagery is not highly detailed. In contrast, something small, like a canoe or kayak, needs finely grained data to keep it from blending into the noise of coarser-grained datasets. In several countries around the world, including the United States and the United Kingdom, high-resolution

to 50m of water. To use these methods to locate ‘mounded’ features, you just need to invert the bathymetric data to turn ‘mounds’ into ‘sinks’ (Figure 2). In this way, shipwrecks become sinkholes that the algorithm can identify (Figure 3).

Using this inversed sinkhole method, shipwrecks can be systematically identified in vast bathymetric datasets. Because the method is reproducible, researchers can use it on any

Generally speaking, the greater the number of characteristics considered in a detection algorithm or model, the more accurate the detection becomes

bathymetric data (like sonar, radar and Lidar) is widely available. This data can allow researchers to develop automated methods for locating shipwrecks, many of which can have historical or archaeological significance (Figure 1).

SINKHOLE ALGORITHMS AND SHIPWRECK DETECTION

Because intact shipwrecks show up as mounds or lumps on the ocean floor, one particularly simple way to try and automate their detection is to use sinkhole extraction algorithms. These methods were originally developed by hydrographers to locate watersheds, sinkholes and other concave topographic features. In some of our recent research, we used a sinkhole extraction algorithm developed by geographers to detect shipwrecks located in up

dataset from any location and different researchers will produce identical results. This also helps to make research more reliable by limiting potential errors introduced by individual analysts. Especially considering the vastness of submerged areas around the world, a time-effective, reproducible method is important for underwater investigations. This is especially relevant for underwater archaeological work because submerged cultural heritage must be recorded before it is destroyed by natural and human events.

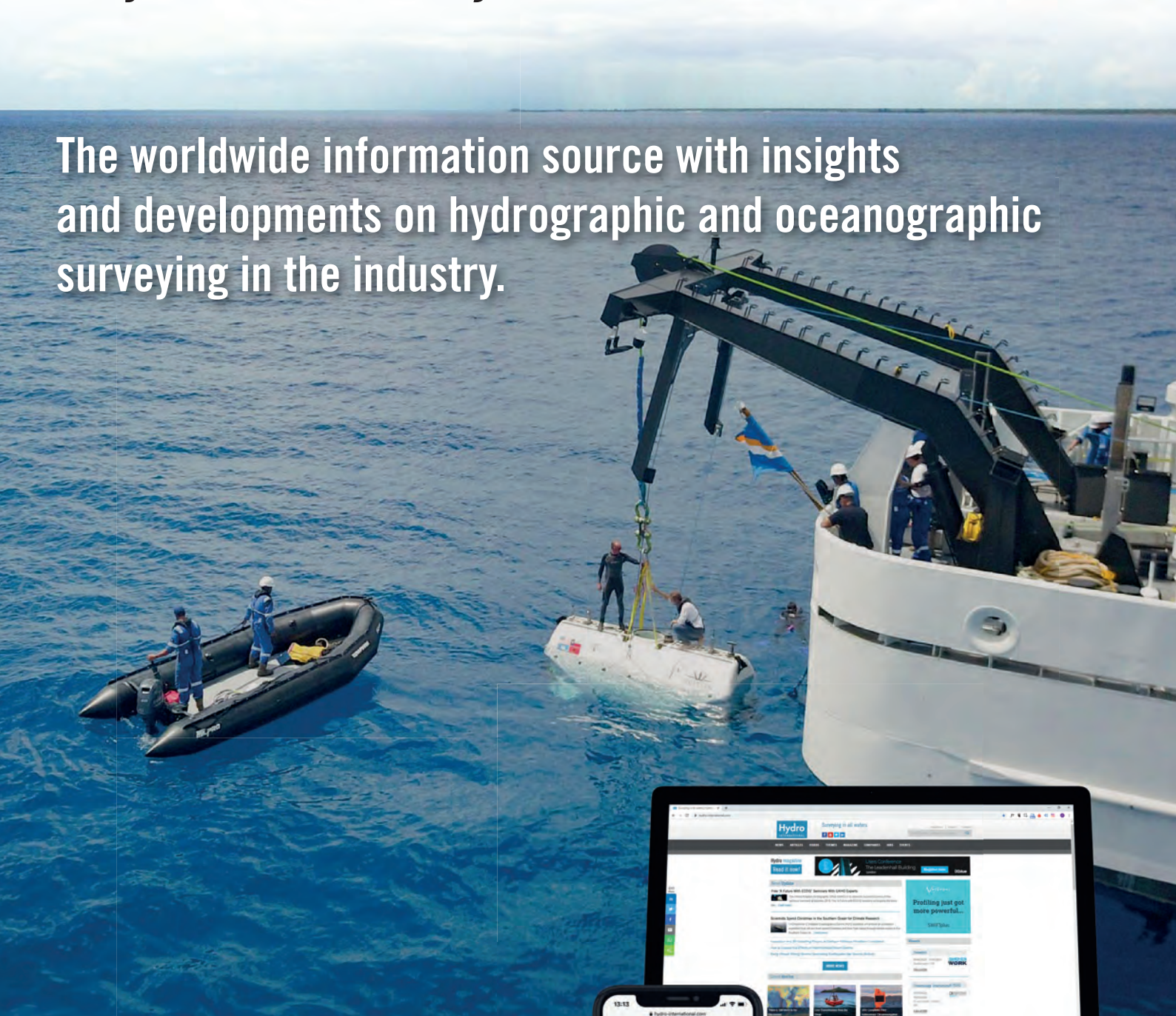
HOW USEFUL ARE AUTOMATED METHODS?

Because of their complexity and often imperfect results, some may wonder if using these methods is worth it. After all, if you can scan

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through data and pick out shipwrecks perfectly in a couple of hours, why take all that time to train a model? Without a doubt, for researchers focusing on a limited study area, automation may not represent great use of their limited

shipwrecks exponentially faster than human analysis (requiring only about 3 minutes to detect over 200 shipwreck sites). When doing this by hand, it took us nearly 10 hours to record that many shipwrecks. So, even though

undertaking, and one which computer automation is well suited to assist in. For those interested in using automated methods for shipwreck (or other object) detection, there are many tools available within GIS systems (including open source platforms like QGIS, WhiteBox GAT and SAGA, among others), as well as some online tutorials using ArcGIS Pro and deep learning. ◀

The method could locate shipwrecks exponentially faster than human analysis (3 minutes to detect over 200 shipwreck sites)

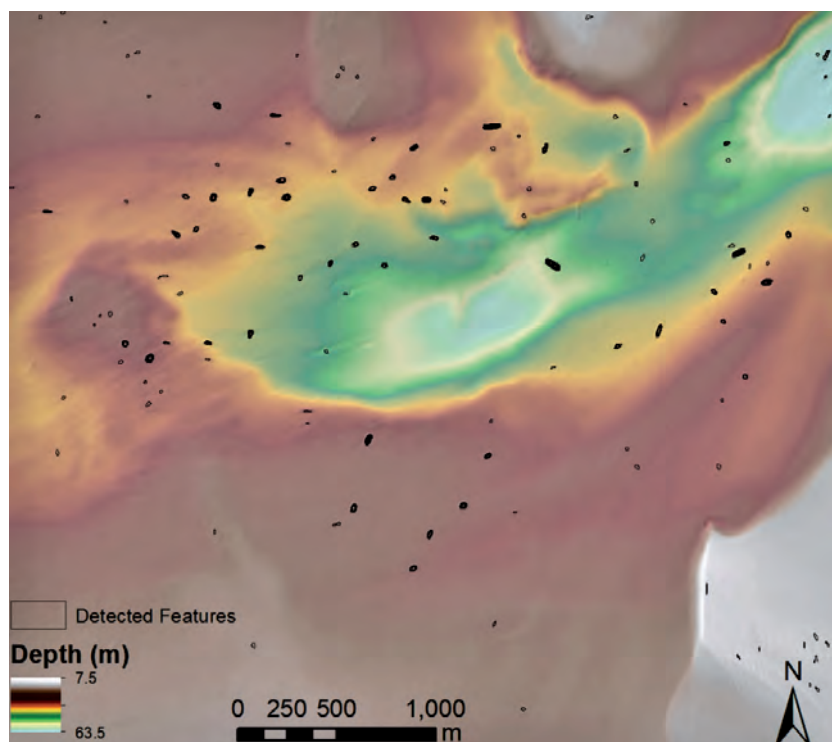
time. However, if the scale of a research project is larger – perhaps ocean-wide, or regional covering thousands of miles of coastline and open water – then the speed at which automated methods can conduct a preliminary evaluation of the data makes them worth the effort.

In an automated study of shipwreck detection conducted in the United States, we found that a sinkhole extraction algorithm could detect approximately 75% of known shipwrecks within the study region. Certainly imperfect, but a pretty good initial attempt. What was more impressive was that the method could locate

the algorithm may have missed some shipwrecks, it saved us hours of time, and this is just for a small study area of about 20km².

CONCLUSION

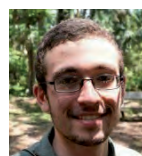
Recent research has demonstrated the potential for the automated detection of shipwrecks using mathematical models. This work promises to rapidly expand the capacity of researchers to investigate the ocean floor for remnants of human history. The archaeological record is fragile and, once lost, this information can never be recovered. For submerged capsules of human history, improving our ability to detect and monitor these sites is an important



▲ Figure 3: Example of detected shipwreck locations in the United States using sinkhole extraction algorithms. Credit: Dylan Davis, Danielle Buffa & Amy Wroblewski (2020). (Source: <https://doi.org/10.3390/heritage3020022>.)

Further Reading

1. Davis, D. S., Buffa, D. C., & Wroblewski, A. C. (2020). Assessing the utility of open-access bathymetric data for shipwreck detection in the United States. *Heritage*, 3(2), 364-383. <https://doi.org/10.3390/heritage3020022>
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Dylan Davis is a PhD candidate in the Department of Anthropology at The Pennsylvania State University, USA. He earned his MA and BS in Anthropology and BA in Geography from Binghamton



from the University of Sheffield, UK, and her BA in Anthropology from the University of Maryland, USA.

Dani Buffa is a dual-title PhD student in the Anthropology and Climate Science programmes at The Pennsylvania State University, USA. She earned her MSc in Osteoarchaeology



in humans within ecological networks and is working in both Australia and the United States to examine these dynamics.

Amy Wroblewski is a third-year graduate student in the Ecology programme at The Pennsylvania State University working in the Human Environmental Dynamics (HENdY) lab. She is interested

Bathymetric Mapping of the High Arctic for Ocean Modelling and Charting

Surveying the Arctic by Sailboat

Bathymetric soundings in the Canadian Arctic are sparse, especially in the High Arctic ($>75^{\circ}\text{N}$), where large sections of coast and the continental shelf are completely uncharted. The lack of accurate bathymetry severely limits the accuracy of ocean circulation models and the understanding of how marine-terminating glaciers in the region will respond to a rapidly changing ocean climate.

The Canadian High Arctic is undergoing some of the most rapid climate forcing on the planet, with regional air temperatures increasing at twice the global average. Accelerated melting of the extensive ice fields and glaciers of the Canadian Arctic Archipelago (CAA) has led it to be the largest contributor to global sea-level rise outside of Greenland and Antarctica. Climate forcing by atmospheric warming, however, is only one part of the equation. Glacier mass loss by calving of icebergs and submarine melting driven by warm ocean water is another key factor, yet these glacier-ocean interactions remain largely unstudied in the CAA.

Marine-terminating glaciers also change ocean properties by reducing water temperatures and releasing fresh water into the ocean, altering ocean stratification and circulation. Understanding these feedback mechanisms is critical to the prediction of future glacial contributions to sea-level rise and the ocean's response to climate forcing. However, the accuracy of predictions is fundamentally limited by knowledge of the geometry of the problem.

GEOMETRICAL CONSTRAINTS

The geometrical constraints on glacier-ocean interactions are numerous:

- 1) the height and topography of the submerged portion of the glacier face determine the area subject to submarine melting;
- 2) the depth of the seabed at the glacier grounding line defines the depth of freshwater discharge into a fjord and buoyancy-driven fjord circulation as well as the properties of ocean water in contact with the ice (water temperatures generally increase with depth in the Arctic);
- 3) the bathymetry of the receiving fjord influences the vertical distribution of water masses that can propagate to the glacier termini through the presence of sills and shoals; and
- 4) the topography of the continental shelf determines regional ocean circulation patterns and the properties of ambient waters present at fjord mouths via deep troughs that cut across the continental shelf.

At present, most fjords and vast sections of the continental shelf in the CAA remain uncharted,

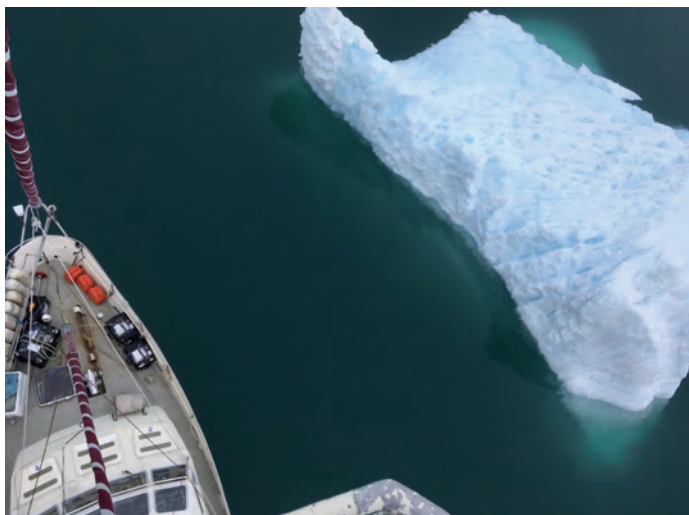
owing largely to the region's harsh climate and inaccessible ice-covered seas. Therefore, existing bathymetric grids of the CAA underlying state-of-the-art ocean circulation models are based on interpolations between very sparse soundings. The models then fail to capture the complexities of seabed topography and its influence on ocean circulation, water mass transformation and glacier-ocean interactions. There is a strong need to develop new cost-effective mapping programmes in the High Arctic to improve data coverage, particularly in the shallow uncharted nearshore areas that larger vessels with deep draft are unable to access safely.

INNOVATIVE RESEARCH PROGRAMME

In 2019, the Canadian Glacier-Ocean-Iceberg Dynamics in a Changing Canadian Arctic (GO-Ice) project began with the goal of better understanding glacier-ocean interactions in the CAA. A key objective of the project is to survey previously uncharted coastal regions, particularly the glacial fjords and coastline of south-east Ellesmere Island and north-east



▲ Photo 1: A marine-terminating glacier on Ellesmere Island in the Canadian High Arctic (G. Joyal).



▲ Photo 2: The SY *Vagabond* surveys iceberg waters in the Canadian High Arctic (A. Hamilton).



▲ Photo 3: Pole-mounted Sonic 2026 installed on the polar sailboat *Vagabond* for surveying the uncharted waters of the Canadian High Arctic (E. Brossier). (Inset) Map of the 2019 and 2020 cruises showing multibeam surveys in red.

Devon Island (Nunavut, Canada), where numerous marine-terminating glaciers drain into northern Baffin Bay and Jones Sound. To accomplish this objective, the research team partnered with a crew of experienced Arctic sailors aboard the 47-foot (15.3-metre) polar sailing yacht the *Vagabond*. The team has spent two seasons conducting oceanographic research and hydrographic surveys in the CAA from this novel platform, with the surveys serving the dual purposes of improving ocean model bathymetry and providing valuable data to the Canadian Hydrographic Service (CHS) to update nautical charts. The project has developed as a transdisciplinary collaboration between academics, industrial partners, government and northern communities, and aims to contribute to the Seabed 2030 project to see the global ocean fully mapped by 2030.

Given the remoteness of the area and the unknown seabed topography, the research team chose to utilize a portable, low-power multibeam echo sounder with a large dynamic range, the Sonic 2026, generously provided in-kind by industrial partner R2Sonic Inc (Texas, USA). Using this Sonic 2026, the *Vagabond* mapped more than 3,500km² of previously uncharted waters during the 2019 and 2020 cruises, in depths ranging from 5m to 750m, including mapping the vertical walls of marine-terminating glaciers. Surveying in this remote polar environment presents numerous challenges: a robust pole-mounted system had to be fabricated to withstand operation in ice-covered seas; static and dynamic calibration of all sensors had to occur at sea (there are no dry docks in the Canadian Arctic); navigation data required careful post-processing because satellite coverage is poor

at these high latitudes; numerous sound velocity profiles were required for refraction corrections due to highly stratified waters near glacial meltwater plumes; and the vessel had to safely navigate in uncharted and iceberg-strewn waters.

GLACIAL GEOMORPHOLOGY

The multibeam survey has shown impressive early results. In an unnamed bay on south-east Ellesmere Island, the terminus of a glacier and adjacent seabed topography was mapped. The data show a vertical ice face that is grounded between 40m and 100m below sea level, punctuated by a large subglacial channel where fresh meltwater is discharged into the fjord at depth. The seabed in front of the terminus shows high relief: a submerged esker (winding ridge of glacially deposited sediment) rises 60m above the surrounding seafloor, and recessional moraines (narrow ridges parallel to the ice face) and iceberg scours mark the bed. This snapshot provides a remarkable window into the complex geometry of the glacier-ocean intersection that greatly informs our understanding of the physical processes at work in driving patterns of glacial retreat. A repeat survey planned in 2021 will reveal even further insight into the dynamic nature of this complex system.

CHART PRODUCTION AND UPDATES

The utility of the survey goes beyond glacier-ocean research and numerical modelling. The cruise track is planned in collaboration with the CHS in order to map high-priority uncharted waters at IHO standards, such as those in active shipping lanes. This collaboration is crucial to ensure safe navigation in the ecologically sensitive High Arctic,



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especially as marine traffic is increasing as sea ice cover retreats. Northern communities in the CAA are extremely dependent on annual resupply by ship, so our efforts help, in a small part, to ensure the safe passage of critical goods to these remote communities.

CONCLUSIONS

Surveying polar regions is challenging and expensive. However, the need to map the Arctic is critical, given the rapid changes occurring in the polar regions and their global impacts. By collaborating across various sectors of marine-stakeholder communities, the *Vagabond* research cruises have demonstrated how hydrographic-

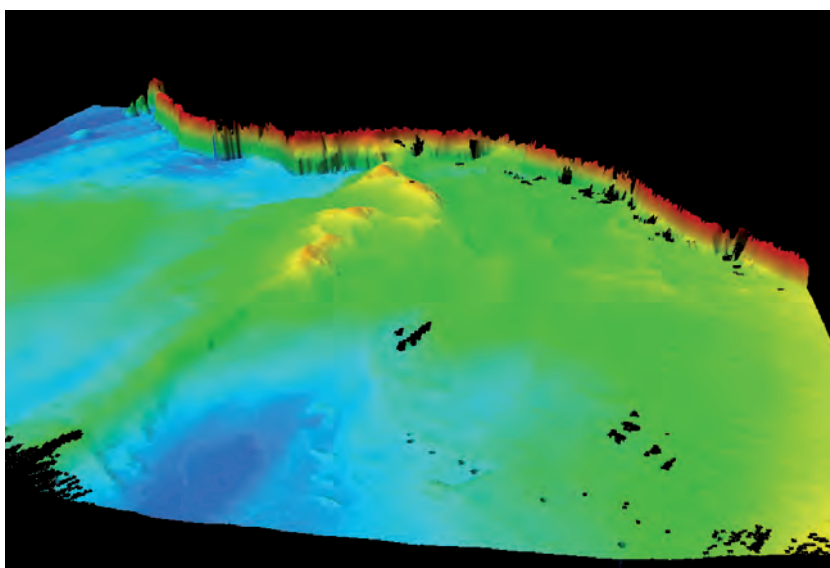
quality multibeam data can be collected in remote areas at relatively low cost through trusted crowdsourced partners. The survey products benefit basic climate research, improve the capacity of federal hydrographic programmes to map territorial waters, and contribute to the world's efforts to completely map the ocean floor.

Seemingly lofty goals perhaps, so why not aim for a more sustainable world at the same time, and do it all from a sailboat?*

**The authors readily acknowledge that the vast majority of surveying during the Vagabond cruises was done under engine power; however, a few surveys were conducted under sail alone.*

ACKNOWLEDGEMENTS

The authors are indebted to support from each of the following individuals and organizations: the SY *Vagabond* crew Eric, France, Léonie and Aurore; Jimmy Qaapik; George Schlagintweit (CHS); Luke Copland (UOttawa); Paul Myers (UALberta); Maya Bhatia (UALberta); Jochen Halfar (UToronto); the community of Grise Fiord, Nunavut; the community of Arctic Bay, Nunavut; R2Sonic Inc.; QPS; the Polar Continental Shelf Project; National Science and Engineering Research Council of Canada; ArcticNet, a Network of Centres of Excellence of Canada; and the Canadian Hydrographic Service. ◀



▲ Photo 4: High-resolution multibeam data of a glacial fjord on Ellesmere Island, Canada, showing the vertical glacier wall and the complex seabed near the terminus. Improved underwater topography such as this vastly enhances efforts to accurately model glacier-ocean interactions.



▲ Photo 5: Surveying the remote coasts of the Canadian High Arctic is a significant logistical challenge, but the data acquired by the SY *Vagabond* benefits fundamental research and federal charting agencies (G. Joyal).

About the GO-Ice project

Glacier-Ocean-Iceberg Dynamics in a Changing Canadian Arctic is a collaborative research project led by Dr Luke Copland at the University of Ottawa and supported by ArcticNet, a Network of Centres of Excellence of Canada, to investigate the state of glaciers and oceans in the Canadian High Arctic. It aims to provide the most up-to-date monitoring of changes in glacier mass balance and ocean circulation, to better understand the atmospheric and oceanic drivers of glacier change and the impact of meltwater and a warming Arctic on ocean circulation. An interdisciplinary team of researchers utilizes an array of methodologies to address these questions, ranging from extensive field programmes at various sites across the High Arctic, to analysis of remote sensing data, numerical modelling and partnership with northern communities.



Andrew K. Hamilton is a postdoctoral fellow at the University of Alberta studying glacier-ocean interactions in the Canadian Arctic. He holds a PhD in environmental fluid mechanics from the University of British Columbia, has been conducting glacier-ocean field work in the High Arctic for 14 years, and is lead scientist on the GO-Ice *Vagabond* research cruise.
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Gabriel Joyal is a geomatics researcher at the Centre de géomatique du Québec, a college R&D and technology transfer centre. He holds an MSc in physical geography from Université Laval. He has been working in the Canadian Arctic for over seven years, mapping lake and sea beds as part of various research programmes including Cape Bounty Arctic Watershed Observatory (2013), ArcticNet CCGS Amundsen cruises (2014–2018) and GO-Ice (2019–2020).
✉ gabriel.joyal@csgq.qc.ca

How Spoofing Affects Survey and Mapping

What is GNSS Spoofing?

With spoofing attacks on the rise, survey-grade GNSS receivers need to be protected by interference mitigation technology utilizing the latest security techniques to ensure reliable positioning.

The survey and mapping industry has been benefiting for years from GPS/GNSS precise positioning technology. While GNSS spoofing is recognized as a real threat for unmanned aerial vehicles (UAVs or 'drones'), its influence on survey and mapping equipment is still underestimated. Reliable data capture is important across various mapping use cases, from man-based surveying and mobile mapping all the way to UAV photogrammetry. Ensuring dependable positioning requires the use of robust equipment, designed in such a way that alleviates all possible vulnerabilities. The use of GNSS receivers which are robust against jamming and spoofing is key to trustworthy data capture anytime, anywhere.

GPS/GNSS SPOOFING VS JAMMING

Both jamming and spoofing are a type of GNSS radio interference that happens when weak GNSS signals are overpowered by stronger radio signals on the same frequency. Jamming is a kind of 'white noise' interference, causing loss of accuracy and potentially loss of positioning. This type of interference can come from adjacent electronic devices or external sources such as radio amateurs in the area. Spoofing is an

intelligent form of interference which fools the user into thinking that he/she is in a false location. During a spoofing attack, a radio transmitter located nearby sends fake GPS signals into the target receiver. For example, even a cheap software-defined radio (SDR) can make a smartphone believe it's on Mount Everest (see Figure 1)!

GNSS users are experiencing ever-more cases of jamming, and spoofing events are on the rise too – especially in recent years since it has become easier and more affordable to create malicious spoofing systems. There are plenty of examples, from Finland – which experienced a week-long spoofing attack in 2019 – to China where multiple vessels have been the target of a spoofing attack. Hence, jamming and spoofing protection is no longer a 'nice to have' feature but a critical component of a GNSS receiver.

SPOOFING INCIDENTS ARE ON THE RISE

C4ADS, an NGO conducting data-driven analysis of conflict and security matters, concluded that Russia has been extensively using spoofing to divert aerial drones from entering airspace in the

vicinity of governmental figures, airports and ports. And some of the most enthusiastic spoofers are fans of the augmented reality mobile game 'Pokémon Go', who use SDRs to spoof their GPS position and catch elusive Pokémon without having to leave their rooms.

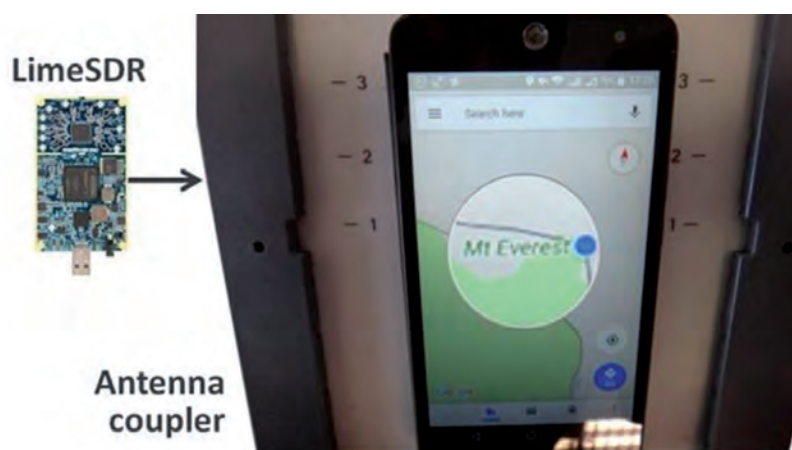
Such attacks usually target a specific receiver. However, the spoofing transmission will actually affect all GPS receivers in the vicinity. For example, an SDR can affect all GPS receivers within a 1km radius of the spoofing source, and the signal can be amplified for further propagation. This means that survey or mapping jobs in densely populated areas are at a higher risk of such 'indirect' spoofing attacks.

HOW TO SPOOF-PROOF A RECEIVER

A spoofer can either rebroadcast GNSS signals recorded at another place and time, or generate and transmit modified satellite signals. Therefore, to combat spoofing, GNSS receivers need to be able to distinguish spoofed signals from authentic signals. Once a satellite signal is flagged as spoofed, it can be excluded from positioning calculations.

There are various levels of spoofing protection that a receiver can offer. Using the analogy of a home intrusion detection system, it can be based on a simple entry alarm system or a more complex movement detection system. For added security, the home owner could decide to install video image recognition, breaking-glass sound detection or a combination of the above. An unprotected GNSS receiver is like a house with an unlocked door; it is vulnerable to even the simplest forms of spoofing. Secured receivers, on the other hand, can detect spoofing by looking for signal anomalies or by using signals designed to prevent spoofing, such as Galileo OSNMA and E6 or the GPS military code.

▲ Figure 1: Even a cheap SDR can overpower GNSS signals and spoof a single-frequency smartphone GPS into believing it is on Mount Everest.



Advanced interference mitigation technologies, such as the Septentrio AIM+, use sophisticated



▲ Figure 2: GNSS spoofing could be used to manipulate movement of aerial drones.

signal-processing algorithms to mitigate jamming and flag spoofing. For spoofing detection, AIM+ checks for various anomalies in the GNSS signal, such as unusually high signal power. It also works together with RAIM+ integrity algorithms to ensure range (distance to satellite) validity by comparing range information from various satellites. AIM+ won't even be fooled by an advanced GNSS signal generator, Spirent GSS9000. Even with realistic power levels and actual navigation data within the signal, it can still identify it as a 'non-authentic' signal. Other advanced anti-spoofing techniques such as using a dual-polarized antenna are currently being researched.

SATELLITE NAVIGATION DATA AUTHENTICATION

Various countries are investing in spoofing resilience by building security directly into their GNSS satellites. With Open Service Navigation

Message Authentication (OSNMA), the European Galileo is the first satellite system to introduce an anti-spoofing service directly on a civil GNSS signal.

OSNMA is a free service on the Galileo E1 frequency that enables authentication of the navigation data on Galileo. Such navigation data carries information about satellite location and, if altered, will result in wrong receiver positioning computation. As a close partner of ESA, the European GNSS manufacturer Septentrio has been contributing to the design and testing of the Galileo system since its inception. Today, as the OSNMA system is entering its testing phase, Septentrio receivers have successfully been used to test the OSNMA signals. The US GPS system is also experimenting with satellite based anti-spoofing for civil users with its recent authentication system called Chimera.

ADVANCED INTERFERENCE MITIGATION TECHNOLOGY

OSNMA is a part of the puzzle comprising the AIM+ interference defence system. The anti-jamming component suppresses the widest variety of interferers, from simple, continuous narrow-band signals to the most complex, wideband and pulsed transmissions. The anti-spoofing component consists of signal anomaly detection, OSNMA, RAIM+ as well as other algorithms.

FUTURE-PROOF GNSS RECEIVERS

Interference mitigation technology such as AIM+ protects accurate positioning today. To ensure the best protection for tomorrow too, GNSS manufacturers are offering future-proof technology which allows users to take advantage of new GNSS security services like OSNMA and Chimera as soon as they become available. Utilizing future-proof GNSS receivers in survey, mapping and UAV equipment enables integrators to reduce their time to market with resilient products. Secured GNSS means trustworthy precise positioning and peace of mind for everyone who relies on this technology. ◀

Further Reading

<https://www.septentrio.com/en/advanced-interference-monitoring-mitigation-aim>

<https://septentrio-my.sharepoint.com/:b:/p/marketing/EU99N82bWyZPsvd4Dp9g5lwBEwqQLgeT8i7wtW64TEk-tw?e=S0fGFD>

<https://www.nbcnews.com/news/vladimir-putin/russia-spoofing-gps-vast-scale-stop-drones-approaching-putin-report-n987376>



▲ Figure 3: European Galileo satellites provide an open authentication service on the E1 signal and a commercial authentication service on the E6 signal. (Image courtesy: European Space Agency)



Gustavo Lopez is senior market access manager at Septentrio. With over 18 years of experience working with GNSS technology, he is a senior expert with in-depth knowledge of various GNSS applications and use cases. He is at the forefront of the latest developments in geodetic-grade positioning solutions for various markets including survey, mapping and UAV.



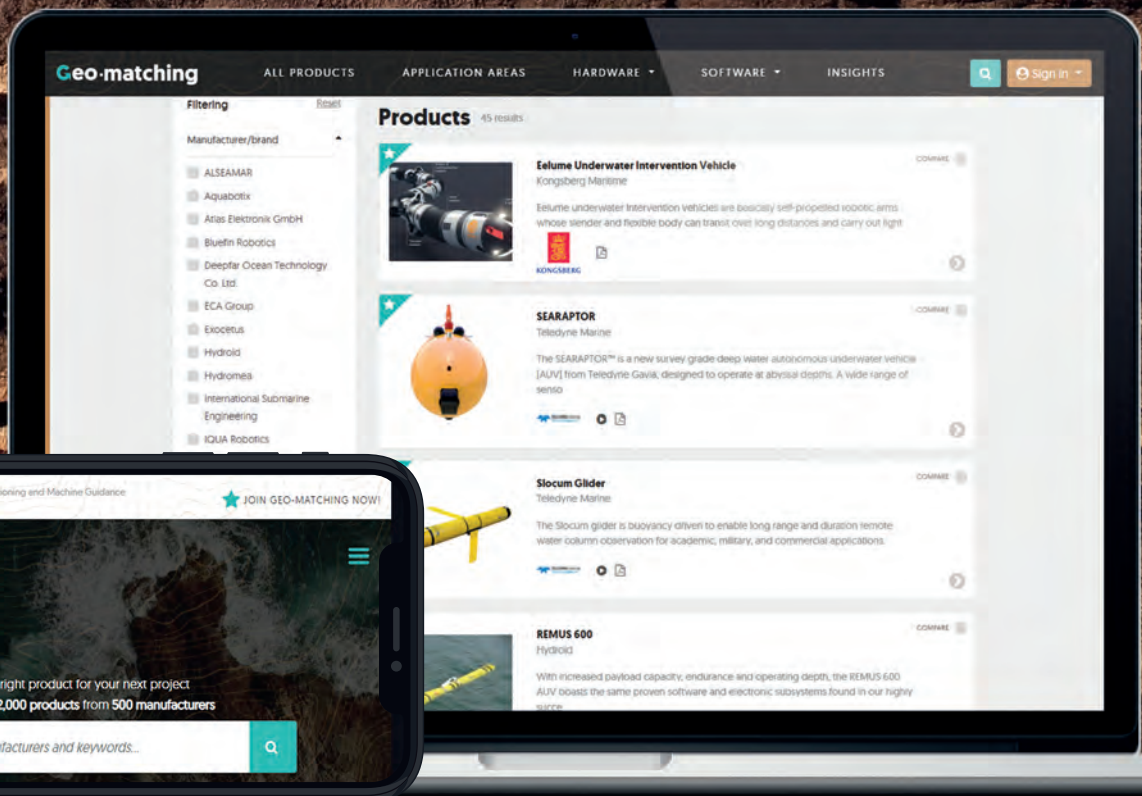
Maria Simsky is a technical writer in marketing and communication at Septentrio. She has an engineering background with in-depth experience of GNSS technologies and software. She is inspired by cutting-edge technology that helps to make the world a better place.

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Open-source Software and Hydrographic Survey Data

In this present age of data collection and technological refinement, hydrographers and data processors are expected to produce high-quality deliverables with a swift turnaround. However, the cost of proprietary commercial software processing programmes has excluded many smaller contractors in the past. Such programmes incorporate finely tuned tool suites and nested algorithms that have been distilled and polished over the years. However, the financial hurdles are not as high as the passion and love that these individuals carry for this explorative industry and, thankfully, open-source resources and collective intelligence are changing the game.

Very often, clients provide large datasets with requests for end product fly throughs or refined visualizations of smoothed and processed bathymetry, along with short deadlines and restricted budgets. Open-source software suites such as CloudCompare and the plug-in extension Cloth Simulation Filter (CSF) help to fulfil such expectations. This gives smaller firms the ability to process data in a similar way to that of the powerhouses in the industry, with their unrestricted budgets.

FILE FORMATS

Originally designed to perform swift cloud and mesh comparisons on large datasets, CloudCompare currently exists as an open-source 3D point cloud editing and processing

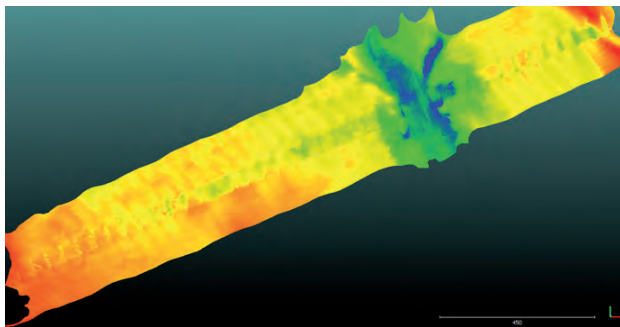
software. It boasts a suite of tools for extraction, analysis and end product creation. With a multitude of users, an active forum (GitHub), online tutorials and plenty of documentation, navigation is effortless. Integrating this tool into an already existing workflow is simple, since it can ingest and export a heap of file formats with drag and drop functionality. Examples are .csv, .ascii, .pts, .txt, .vtk, .dxf, .las, .laz, raster grids, Esri's .shp, image files, and so on. The programme saves each project and associated files in a proprietary file format of a .bin file. It is a best use case for visualizing scenes, creating aesthetically pleasing presentations, and for quick fixes to an already existing workflow when it comes to bathymetric processing. The cross-section functionality after running the

point cloud through another useful tool for insight.

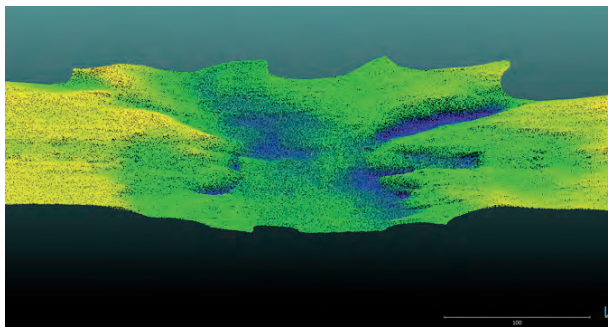
CSF, a plug-in designed by Wuming Zhang et al. from Beijing Normal University, China, quickly extracts ground points from a point cloud. Originally used for separating ground and non-ground measurements from Lidar (light detection and ranging), this tool can be just as applicable for quick seafloor extraction analysis and visualizations.

POINT CLOUD EXTRACTION

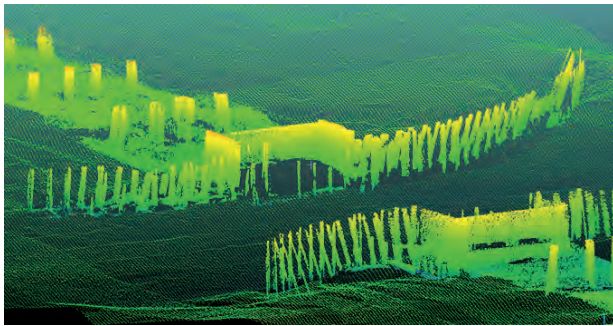
The plug-in is based on cloth simulation and modelling and is derived from a 3D computer graphics algorithm used to simulate cloth in computer programmes. The point cloud is



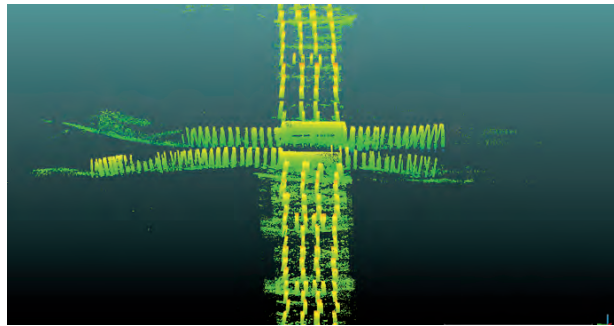
▲ Dataset from the Fort Pierce Inlet, 2019. Delivered as one large point cloud to process, it was originally two merged point clouds from both a multibeam survey and Teledyne BlueView laser scan of the pilings and bridge structure.



▲ Fort Pierce Inlet, Florida. Inlet Mouth. View into the West.



▲ Full dataset, view into the North.



▲ Pilings, view into the North. Post CSF application. Non-ground points.

inverted and a rigid cloth is laid on the inverted surface. During the simulation, cloth is modelled as a grid that consists of particles with mass and interconnections, called a Mass-Spring Model. By analysing the interactions between the cloth nodes and the corresponding points, the locations of the cloth nodes can be determined to generate an approximation of the ground surface. The ground points are then extracted from the point cloud by comparing the original points and the generated surface [1].

This filtering method only requires a few easy-to-set integer and Boolean parameters, and takes less than a couple of minutes to process. The accuracy stands up to other toolsets and it has the functionality found in proprietary commercial software. Benchmark datasets provided by ISPRS (International Society for Photogrammetry and Remote Sensing) working Group III/3 were used to validate the filtering method, and the experimental results yielded an average total error of 4.58%, which is comparable with most state-of-the-art filtering algorithms [2].

CLASSIFYING POINT CLOUDS

Parameters in the selection dialogue are split into general parameters and advanced parameters. General parameters allow the user to specify whether the scene is relatively flat, contains associated relief, or is steeply sloping, which determines the rigidity of the cloth. Note that, for steep slopes, this algorithm may yield relatively large errors as the simulated cloth is above the steep slopes and does not fit with such ground measurements well due to internal constraints among particles. This problem can be solved by selecting the option for steep slopes. If there are no steep slopes in the scene, this can be ignored.

Advanced parameter settings contain three constraints to assist with the level of detail and refinement.

The integers shown when the filter dialogue is selected are standard and should be appropriate for most datasets. Cloth resolution is the grid size of cloth used to cover the terrain. The bigger the cloth resolution integer set, the coarser the DTM (Digital Terrain Model) that is produced will be. Max. iterations refers to the maximum iteration times of terrain simulation. Classification threshold refers to a threshold to classify the point clouds into ground and non-ground parts, based on the distances between points and the simulated terrain.

OPEN-SOURCE AND MACHINE LEARNING

This dataset is from the Fort Pierce Inlet in 2019. Delivered as one large point cloud to process, it was originally two merged point clouds from a multibeam survey and a Teledyne BlueView laser scan of the pilings and bridge structure. Since the separate bare earth and structure files were not provided, the CSF was ideal for this dataset. The client was concerned about scour around the pilings, and desired to see a quick visualization of the depth. As the point cloud is inverted during extraction, the depth of the scour could be shown in detail.

The extraction or refinement of coral heads and boulder piles within the scour needed to be manually performed with CloudCompare's segmentation tool or a separate tool process as the surface is produced from inversion. Retaining the same coordinate and height values, despite the various tool processing techniques applied, is a bonus for data integrity. Another benefit of the CSF algorithm is that the simulated cloth can be directly treated as the final generated DTM for some circumstances, which avoids the interpolation of ground points, and can also recover areas of missing data [2]. The user can additionally check a box for a separate meshed (Delaunay Triangulation 2.5D XY plane) surface export once the filter has extracted the ground points.

The use of insightful and synergistic programmes such as CloudCompare, open-source softwares, machine learning and automation will continue to gain traction as collaborative atmospheres continue to grow and influence niche industries such as hydrographic ventures. This allows for ease and interoperability in future scientific communities. ◀

Acknowledgment

Cloud Compare, created by Daniel Girardeau-Montaut.
<https://www.danielgm.net/cc/>

Citations

- 1: [http://www.cloudcompare.org/doc/wiki/index.php?title=CSF_\(plugin\)](http://www.cloudcompare.org/doc/wiki/index.php?title=CSF_(plugin))
- 2: Zhang W, Qi J, Wan P, Wang H, Xie D, Wang X, Yan G. An Easy-to-Use Airborne Lidar Data Filtering Method used to test this method. Guangjian Yan helped to review this manuscript and give much advice.



Rachel Bobich, owner of RMB GEO, is an independent contractor in the marine and geospatial data industries. She specializes in multibeam acquisition and processing, satellite imagery analysis and open-source tool suites. Her career has taken her into the GEOINT division programme with the NGA, and she was previously GIS manager for the Department of Natural Resources, Marine Resource Division in South Carolina. She has worked closely with government agencies and private organizations such as NOAA and Mote Marine Laboratories. Navigating new solutions to existing workflows and optimizing organization and collaboration are her core values.

IHO & GEBCO: Providing Valuable Data to Care for Our Oceans

When people think of depth data, the first things that usually jump to mind are maps and navigation, even though the implications for this work actually extend well beyond these areas. The shape and texture of the seabed are important for a wide range of ocean processes, and can influence climate, pollution, biodiversity, and so on. The International Hydrographic Organization (IHO), one of the General Bathymetric Chart of the Oceans (GEBCO) project's parent organizations, celebrates its 100th anniversary on 21 June 2021, and we felt it would be a good opportunity to look at why depth data matters.

Detailed bathymetry is the information that helps us to determine what the seabed looks like. Just as above water there are mountains, hills and valleys, the same is true underwater. The shape and texture of the seabed can influence tides and currents, which guide the movement of pollutants in the oceans and seas, as well as determining the speed of tremor and tsunami wave propagation. The seabed provides habitats for marine species and plays a role in spawning areas; information which is useful for initiatives aimed at protecting biodiversity. The seabed also plays a role in ocean circulation, which in turn has an impact on the climate and the atmosphere. IHO Member States and other GEBCO partners are collecting depth data, which is becoming increasingly accurate thanks to progress in technology, and which can be used, for example, to refine and improve the accuracy of climate change impact models. A complete picture of the seabed can help ensure that initiatives for the sustainable use of the oceans are targeted and effective.

Participants in GEBCO merge all of this information, which is relevant for all ocean stakeholders and can contribute to the development of the blue economy. Knowledge of the seabed, together with other hydrographic data obtained during sea surveys, is the basis of all marine activities and has a wide variety of applications.

Information related to the topography of the seabed or the strength and regularity of currents can be used by operators to develop marine renewable energy projects, while industries like fishing and aquaculture can benefit from information on environmental factors like temperature, salinity and currents – information that is recorded in detailed digital charts.

GEBCO is an IHO & Intergovernmental Oceanographic Commission of UNESCO joint project to collect bathymetric data and map the oceans. It was launched by Prince Albert I of Monaco in 1903, and some of the initial data was collected during his research expeditions.

The IHO, an intergovernmental organization, was created in 1921 and works with its 94 Member States to increase knowledge of the ocean. It works to ensure that all of the world's seas, oceans and navigable waters are surveyed and charted, and it coordinates the activities of national hydrographic offices and promotes uniformity in nautical charts and documents. It also issues survey best practices, provides guidelines to maximize the use of hydrographic survey data, and develops hydrographic capabilities in Member States.

Hydrography focuses on the physical features of oceans, such as the shape of the seabed,

depth, temperature, currents and sea level. There is a lot of overlap with disciplines such as oceanography, and much of the information collected is relevant to the larger discussions currently taking place on increased knowledge and protection of the ocean, such as the UN Decade of Ocean Science for Sustainable Development and the Sustainable Development Goals. ◀

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.

Understanding the Unthinkable

The *Titanic* Disaster and Its Aftermath

In the night of 14 April 1912, the unthinkable happened. The mightiest ship afloat, the brand-new White Star Line ship *Titanic*, was on its maiden voyage from Southampton, England, to New York. The ship was advertised as unsinkable. And, if unsinkable, why should there be adequate lifeboats for all of the passengers and crew? The ship departed from Southampton on 10 April. Less than five days later, it was at the bottom of the Atlantic Ocean. More than 1,500 people perished within three hours of striking an iceberg, which ripped the bottom out of the ship.

How this happened is a story told many times. Human hubris, unswerving trust in the infallibility of technology, and the commercial impetus of fast Atlantic passages all contributed to the loss of the ship and the accompanying loss of life. Even as the ship was settling in the waters of an icy North Atlantic, some survivors reported that there was a belief among many passengers that the ship was the safer place to be; accordingly, not all the lifeboats were filled to capacity.

This accident shocked the international community. The British and American

governments investigated the accident – the British determined: “That the loss of said ship was due to collision with an iceberg, brought about by the excessive speed at which the ship was being navigated.” Certainly, that was the major factor. However, like many accidents, there were a number of contributing causes. These included: watertight bulkheads that were improperly designed; an insufficient number of lifeboats and life rafts; apparent lack of concern by the captain about reports of ice prior to collision with the iceberg; little training of crew in emergency procedures including lowering of lifeboats; no radio watches on nearby ships

which could have assisted in lifesaving efforts; and, remarkably, not even binoculars for the ship’s lookouts.

Both the British and American governments arrived at similar conclusions and recommendations following the loss of the *Titanic*. The chief recommendation was that all ships be equipped with sufficient lifeboats for passengers and crew, that all ocean-going ships maintain 24-hour radio-telegraph watches, and that bulkheads be designed such that flooding of any two adjacent compartments would not result in sinking of a vessel. These recommendations and others were adopted by the first International Convention for the Safety of Life at Sea (SOLAS) at a conference held in London in 1914.

DEVELOPMENT OF SEAFLOOR MAPPING TECHNOLOGIES

Commercial concerns saw an opportunity in the *Titanic* disaster and began searching for a means to determine the presence of icebergs and other unseen or submerged obstructions forward of moving vessels. European and North American inventors joined the race. In 1912, Reginald Fessenden, a Canadian inventor and radio pioneer, joined Submarine Signal Company, a forerunner of today’s Raytheon, and began work on an electro-acoustic oscillator similar to a modern transducer. This oscillator was originally designed for both ship-to-ship communication and to receive reflected sound from an underwater object. In late April 1914,



▲ Length of steamship *Titanic* compared with highest buildings.

Fessenden tested this device off the Grand Banks on the US Revenue Cutter *Miami* and succeeded in reflecting sound off an iceberg at a range of approximately two miles and hearing the return echo. A second echo was heard that was determined to be from the bottom.

Submarine warfare during World War I accelerated research into the field of acoustics. By the end of the war, the use of acoustics for both detection of objects in the water and measuring depth had been proven. In 1922, the USS *Stewart*, equipped with a Hayes Sonic Depth Finder that utilized a Fessenden oscillator, ran a line of soundings across the Atlantic Ocean taking over 900 individual soundings. The profile obtained from these soundings was published in the first issue of the International Hydrographic Review. Piano-wire sounding systems became obsolete overnight. Although leadline sounding continued for a number of years in shallow water, acoustic sounding systems replaced the leadline for most purposes within two decades.

World War II further accelerated the development of directional sonar systems (called Asdic in England). Although meant originally for the detection of submarines, these systems ultimately developed into modern side-scan sonar systems. Underwater photography equipment and magnetic anomaly detection (MAD) instruments were in their infancy during this period. MAD systems were proved effective in detecting submarines. An early use by hydrographers of the complementary use of sonar, underwater photography and MAD gear was in the charting of ships torpedoed off the United States East Coast. This was done by Coast and Geodetic Survey (C&GS) officers working off the Coast Guard buoy tender *Gentian* in 1944.

Following the war, there were further advances, including the development of an early side-scan sonar system called Shadowgraph in 1954 by German scientist Julius Hagemann, who was working at the United States Navy Mine Defense Laboratory. This system remained classified for many years, but civil use of side-scan began developing shortly after this advance. In the commercial sector, Harold Edgerton of the Massachusetts Institute of Technology (MIT) and Martin Klein, also of MIT, were early pioneers. Edgerton turned a bottom-penetration sonar on its side in 1963 and imaged a sunken lightship from a C&GS vessel. Edgerton was a founder of EG&G and discovered the Civil War



▲ *Painting of the Titanic sinking by the bow, with people rowing a lifeboat in the foreground and other people in the water. Icebergs are visible in the background. (Engraving by Willy Stöwer: Der Untergang der Titanic)*

era USS *Monitor* off Cape Hatteras with an EG&G commercial side-scan system. Martin Klein began his career with EG&G but left to found Klein Associates, a name synonymous with side-scan technology.

Advances in depth measurement technology paralleled the development of side-scan technology. In April 1961, engineers at General Instruments Corporation developed a proposal for BOMAS, Bottom Mapping Sonar. Quoting from the proposal: "BOMAS derives bottom

(Sonar Array Sounding System). By the late 1970s, the technology had migrated to the civil community and has since displaced single beam sounding systems as the standard seafloor mapping tool.

FINDING TITANIC AND THE AFTER-MATH OF THE DISCOVERY

In the immediate aftermath of the sinking, proposals to locate the sunken *Titanic* were discussed and ultimately dismissed because the wreck lay well beyond the limits of technology at

In the early morning hours of 1 September, the unmistakable form of a boiler made it clear that *Titanic's* final resting place had been found

profile information from the intersection of the ocean bottom with a vertical plane perpendicular to the heading of a ship. The sonar data is processed automatically and in real time to provide a depth contour strip map.... A sonar intensity map can be provided simultaneously...." Multi-beam sounding with its attendant bottom reflectivity mapping capability was born. Two years later, the first prototype multi-beam system was installed on the USS *Compass Island* and subsequent units installed on Navy survey ships. In the meantime, the acronym had changed to SASS

that time. Through the decades, the development of subsea technology finally provided the means to locate the wreck and subsequently to not only investigate it using remote technology, but also to dive to the wreck and conduct a series of investigations that included surveys of the interior of the ship.

In July 1985, the final search began, with Ifremer deploying their newly developed side-scan sonar SAR vehicle on a mission led by Jean-Louis Michel on the research vessel *Le Suroit*. That survey covered 70% of a 150

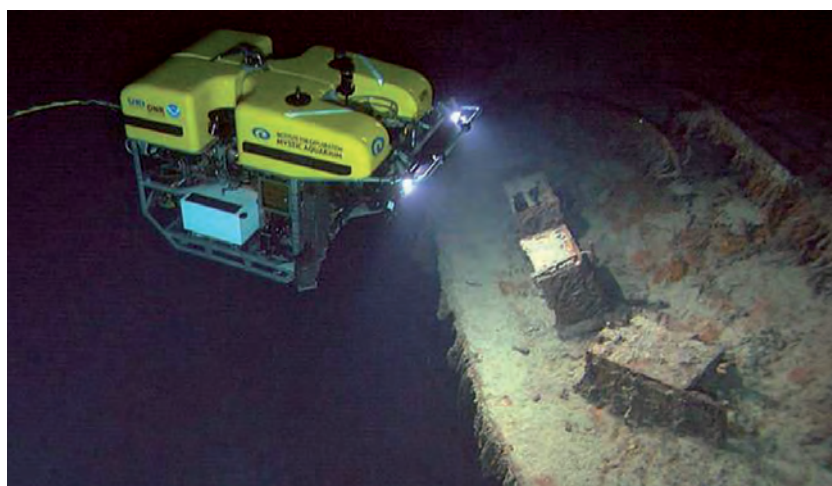
square nautical mile survey box without locating the *Titanic*. Picking up the search in August, the WHOI team, led by Robert Ballard aboard the research vessel *Knorr*, utilized the towed vehicle Argo with a 100kHz side-scan sonar and three low-light black and white video cameras. Ballard's team relied on the optical system to locate the *Titanic*, and in the early morning hours of 1 September, the unmistakable form of a boiler made it clear that the search was over. *Titanic*'s final resting place had been found.

Since the discovery in 1985, a series of expeditions have visited the *Titanic* with a variety of goals. Ballard and Woods Hole returned to the wreck in July 1986 on the WHOI research

vessel *Atlantis II*, with the submersible Alvin and the ROV Jason Jr. The 1986 expedition photographed and filmed the wreck, focusing on the largely intact bow section. Working from the data collected from the 1985 Argo survey as well as 1986 data, WHOI's William Lange and others assembled a preliminary site map of the *Titanic* wreck site that delineated the site from the bow to the stern section and plotted a wide range of features scattered on the seabed. A private venture funded and led by RMS Titanic, Inc., the salvor-in-possession of the wreck (RMST), and technically supported by Ifremer, returned to the wreck in July 1987 and made 32 dives to recover some 1,800 artifacts from the seabed, the first of a series of recovery dives

made by RMST until 2004, which ultimately salvaged nearly 5,000 artifacts.

Dives made by documentary film crews and James Cameron (whose first dives were in 1995), working with the P.P. Shirsov Institute, captured dramatic images of the wreck as well as additional technical information and a more detailed view of aspects of the wreck site, using Mir submersibles. In particular, Cameron's extensive documentation and penetration of the interior of the bow with small ROVs known as 'bots' provided incredible insights into the ongoing processes of environmental change and preservation inside the ship, as well as evidence of what had occurred during the sinking of the *Titanic*. Cameron's work has arguably done more to share the *Titanic* as a wreck site with a greater audience than anything else.



▲ The ROV Hercules exploring the bow of the *Titanic*, 2004. (Courtesy: Institute for Exploration/University of Rhode Island/NOAA)



▲ This composite image, released by RMS Titanic, Inc., and made from sonar and more than 100,000 photos taken in 2010 by unmanned, underwater robots, shows a small portion of a comprehensive map of the 3-by-5-mile debris field surrounding the bow of the *Titanic* on the bottom of the North Atlantic Ocean. (Courtesy: AP Photo/RMS Titanic, Inc.)

The scientific products of the various expeditions include a detailed analysis of the microbiological corrosion of the ship's steel (led by Roy Cullimore), geological studies of the sediments and current studies (by the Shirsov Institute), a detailed sonar survey of the bow where the *Titanic* struck the iceberg, photomosaics of the bow section, and forensic studies of the ship's sinking sequence and break-up. In addition, RMS Titanic, Inc. commissioned the creation of an 'archaeological GIS' map delineating where the 5,000 artifacts had been recovered from between 1987 and 2004. That GIS, which is being completed by RMST under contract by the Center for Maritime & Underwater Resource Management of Michigan, a private non-profit, is reported to be nearly complete.

The National Oceanic & Atmospheric Administration's Office of Ocean Exploration conducted two missions to the *Titanic* in 2003 and 2004. As the nation's ocean agency, NOAA has an interest in the scientific and cultural aspects of the *Titanic*. NOAA's focus is to build a baseline of scientific information from which we can measure the processes and deterioration of the *Titanic*, and apply that knowledge to many other deepwater shipwrecks and submerged cultural resources. The 2003 mission, with the Shirsov Institute, had several key goals, the first being to catalogue any anthropogenic activities currently impacting the wreck site, or evidence of such activity since its discovery in 1985. Digital imagery was obtained and a deck-view mosaic of the bow section was created. Additionally, ongoing bacteriological analysis

was conducted as well as basic oceanographic research.

THE 2004 MISSION, CONDUCTED ONBOARD THE NOAA RESEARCH VESSEL

Ronald H. Brown, working with Robert Ballard of the University of Rhode Island and the Institute of Archaeological Oceanography, utilized an ROV to continue the assessment of the wreck's ongoing environmental changes and the bacteriological work of Roy Cullimore. One other key achievement of the 2004 mission was the completion of a topographic map of Titanic Canyon and the surrounding area, including the wreck of the *Titanic*, with a Seabeam 2112 multi-beam sonar system. The digital terrain

approximately ten square nautical mile survey zone around the wreck site, with a series of closer, higher resolution surveys of the area delineated in the 1986 WHOI map of the site and even closer surveys of key features and areas of the site. That project was successful in generating the mapping data as well as comprehensive visual coverage of the wreck, including detailed photomosaics of a number of features in the artifact scatter, which included sections of the ship's hull, machinery and equipment and other artifacts.

What is clear from this brief overview is that the last few decades have witnessed a revolutionary expansion of humanity's capacity to not only locate deep-sea shipwrecks, but increasingly to

The original version of this article appeared in a previous issue of Hydro International several years ago.

More Information

- Robert D. Ballard and Michael Sweeney, *Return to Titanic: A New Look at the World's Most Famous Lost Ship*. National Geographic Society, Washington, D.C. 2004.
- Robert D. Ballard, ed. *Archaeological Oceanography*. Princeton University Press, Princeton & Oxford, 2008.

In many ways, the *Titanic* and the surrounding area are likely to be the best-studied section of the deep ocean floor

model of this large area of seabed places the *Titanic* within a larger geological and geographical context.

NOAA also participated, as did Woods Hole, the National Park Service, the Institute of Nautical Archaeology, the Waitt Institute and contracted partners such as Phoenix International, Ltd., in RMS *Titanic*, Inc.'s last (to date) expedition to the wreck in August 2010. This mission, with a non-recovery scientific focus, focused on William Lange's and the WHOI Advanced Imaging and Visualization Laboratory's work to create a detailed 2D and 3D visual mosaic of the site. To do so, it made a detailed survey using the Waitt Institute's REMUS 6000 autonomous underwater vehicles of an

capture imagery and data that essentially 'virtually raises' these wrecks for ongoing research as well as public education. In many ways, the *Titanic* and the surrounding area are likely to be the best-studied section of the deep ocean floor. That status has come because of the iconic nature of the wreck and the potential for profit from the opportunity to connect to this ship and its tragic loss either through a tour of the recovered artifacts or a virtual tour on film or in a photograph. At the same time, measurable and important science has been conducted, and in that, a way forward for not only this site but others has been demonstrated, especially in the adaptation and adoption of technology to access and learn from sites once thought unreachable. ◀

Albert E. 'Skip' Theberge graduated from the Colorado School of Mines in 1969 as a geological engineer and entered ESSA Corps, a descendant organization of the commissioned service of the United States Coast and Geodetic Survey. In 1970, this became NOAA Corps with the formation of the National Oceanic and Atmospheric Administration (NOAA) within the US Department of Commerce. He retired from NOAA Corps in late 1995. Since retiring from NOAA Corps, he has been affiliated with the NOAA Central Library where he is acting head of reference. In that capacity, he has built the NOAA Photo Library and NOAA History websites. He has written over 100 articles on the history of hydrography, oceanography and geodetic surveying over the past 20 years. Among awards he has received are the United States Department of Commerce Gold Medal and the NOAA Distinguished Career Award.

James Delgado is among the world's leading experts in maritime archaeology and cultural heritage. Dr Delgado serves as senior vice president of SEARCH, the largest cultural resource management company in the United States. Prior to joining SEARCH, Dr Delgado served as the director of Maritime Heritage in the Office of National Marine Sanctuaries for NOAA for seven years. Previously, he served a four-year term as president and CEO of the Institute of Nautical Archaeology, the world's leading scientific and educational organization dedicated to the understanding of humanity's seafaring history through the excavation and scientific study of shipwrecks. Delgado is lecturer at the Archaeological Institute of America.

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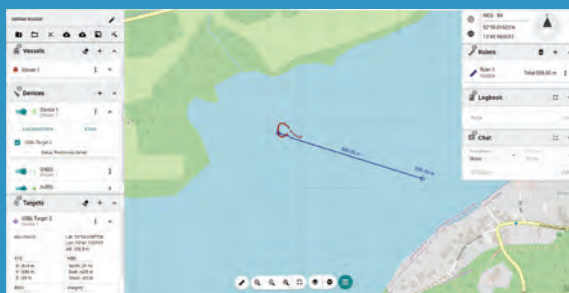
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