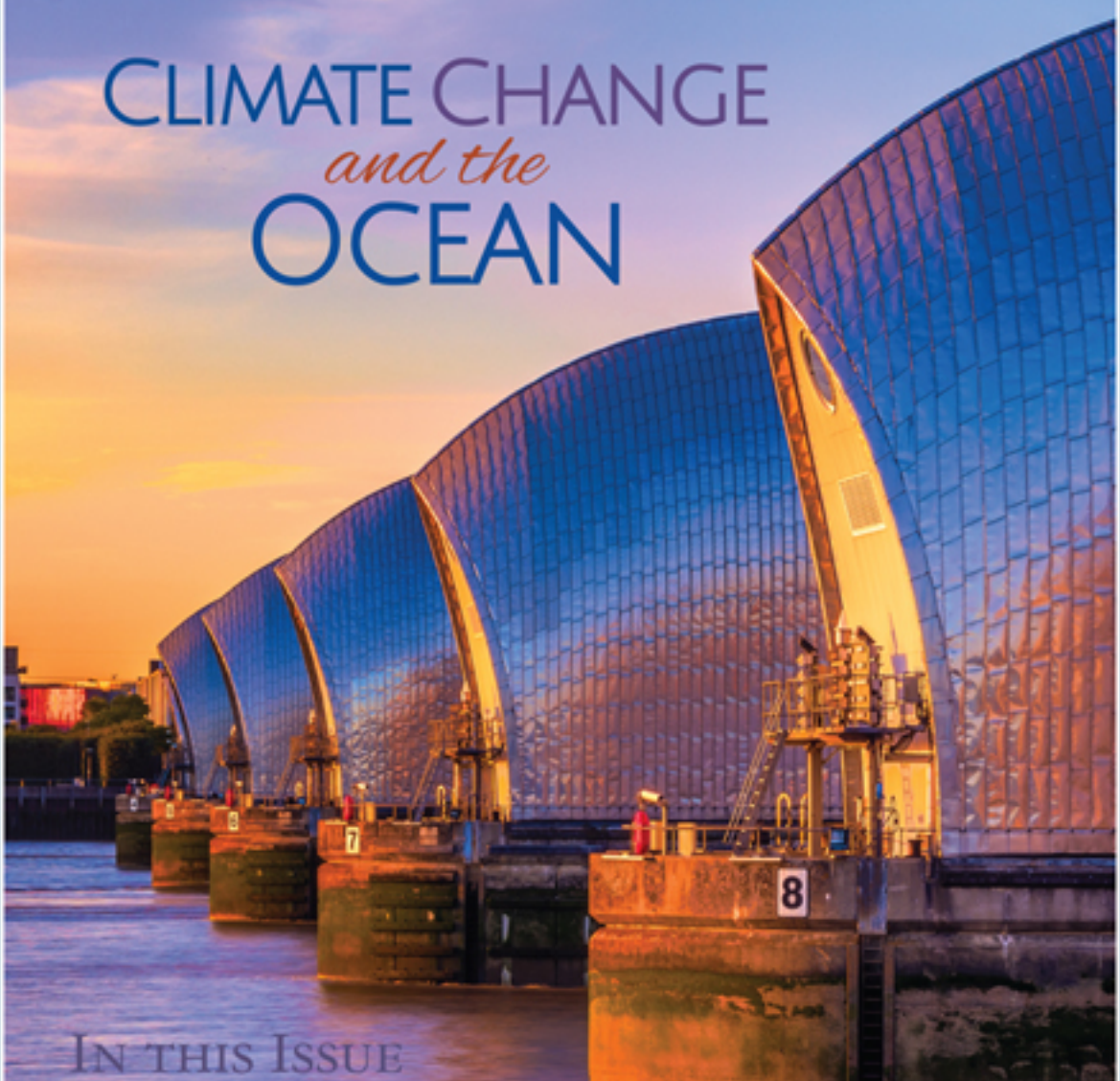
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CLIMATE CHANGE *and the* OCEAN



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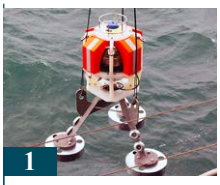
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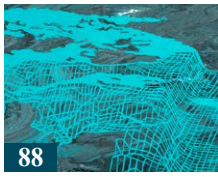
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PUBLISHER
Bill Carter
Tel. +001 (709) 778-0762
info@thejot.net

MANAGING EDITOR
Dawn Roche
Tel. +001 (709) 778-0763
info@thejot.net

GRAPHIC DESIGN/SOCIAL MEDIA
Danielle Percy
Tel. +001 (709) 778-0561
danielle.percy@mi.mun.ca

TECHNICAL CO-EDITORS

Dr. David Molyneux
Director, Ocean Engineering Research Centre
Faculty of Engineering and Applied Science
Memorial University of Newfoundland

Dr. Katleen Robert
Canada Research Chair, Ocean Mapping
School of Ocean Technology
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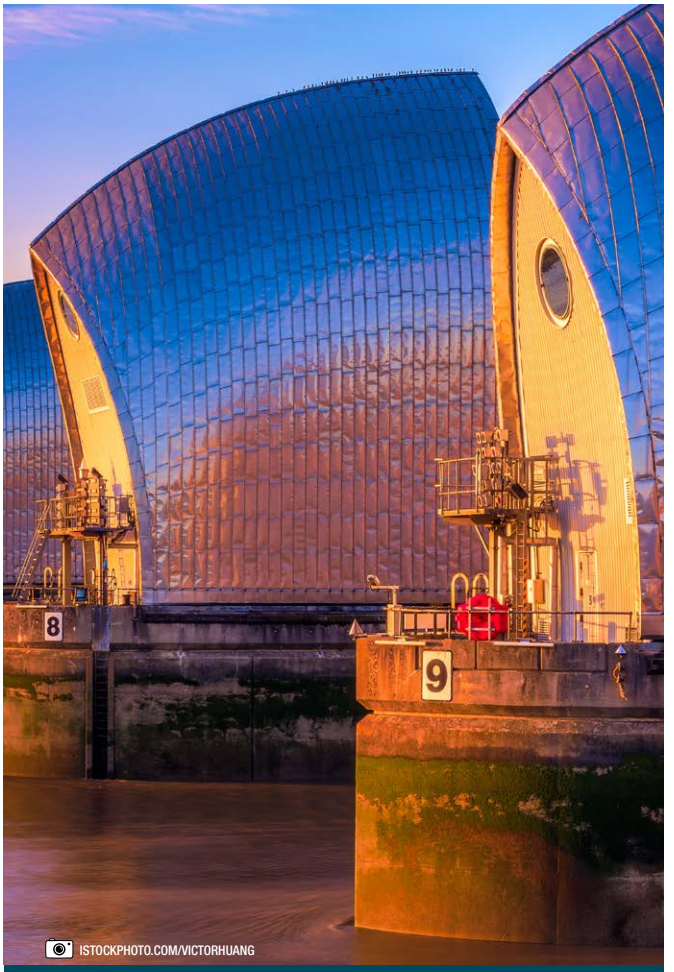
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On the Cover



The Thames Barrier is a retractable barrier system that protects central London from flooding caused by tidal surges. Comprised of 10 steel gates, it spans 520 metres across the River Thames. A flood risk management plan – Thames Estuary 2100 – outlines how to manage risk to 2100 and later. The plan is based on current climate change guidance and is adapted as needed.

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Publishing Schedule at a Glance

The JOT production team invites the submission of technical papers, essays, and short articles based on upcoming themes. **Technical papers** describe cutting edge research and present the results of new research in ocean technology, science or engineering, and are no more than 7,500 words in length. Student papers are welcome. All papers are subjected to a rigorous peer-review process. **Essays** present well-informed observations and conclusions, and identify key issues for the ocean community in a concise manner. They are written at a level that would be understandable by a non-specialist. As essays are less formal than a technical paper, they do not include abstracts, listing of references, etc. Typical essay lengths are up to 3,000 words. **Short articles** are between 400 and 800 words and focus on how a technology works, evolution or advancement of a technology as well as viewpoint/commentary pieces. Submissions and inquiries should be forwarded to info@thejot.net.

Upcoming Themes

All themes are approached from a Blue Economy perspective.

Winter 2022	Ocean technology
Spring 2023	Energy from the ocean
Summer 2023	Aquaculture
Fall 2023	Vehicles
Winter 2023	Smart ships

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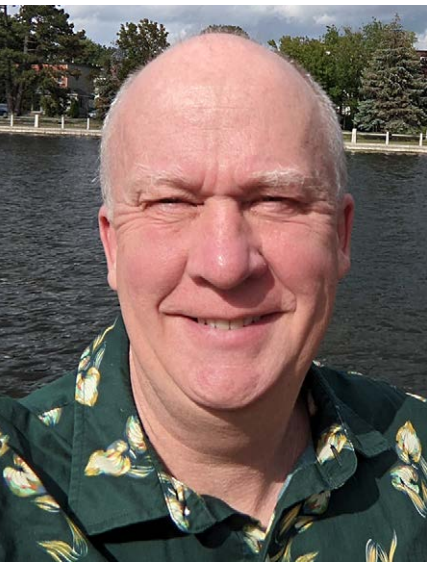
CONTACT US

The Journal of
Ocean Technology
c/o Marine Institute
P.O. Box 4920
155 Ridge Road
St. John's, NL A1C 5R3 Canada
+001 (709) 778-0763
info@thejot.net
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Guest Editor's Note



It seems that nearly every time I open a publication, including this very issue, I read a story about a place that is "surprisingly" warming faster than the global average. How can such places be so ubiquitous? Because of the ocean. On land, a basement or a cave stays cool even in mid-summer. This is because heat is trapped in the solid land surface, unable to mix downward effectively. In contrast, fluid motion at the ocean surface mixes heat downward, thereby keeping the ocean surface relatively cool. Because the planet surface is mostly ocean, pretty much all land temperatures, especially urban temperatures, are warming faster than the global average, which is itself warming much slower than it would without the benefit of heat absorption by the ocean.

In addition to retaining heat, the ocean is also effectively absorbing and storing much of our fossil fuel derived carbon dioxide emissions, thereby further mitigating greenhouse warming, albeit with unfortunate consequences, including ocean acidification. In conclusion, the ocean is providing an enormous, often unrecognized, service to society by strongly mitigating global warming, far beyond any emission reduction pledged or implemented by humans. However, we cannot blindly assume that this ocean mitigation will continue forever. Sudden and/or substantial changes can occur. For example, major changes in the ocean's role could occur if there is a release of the stored carbon in subsea clathrates or coastal permafrost. Another scenario could be a reduction in the area of coastal wetlands, which store carbon, thus resulting in the loss of a natural carbon sink, with effects akin to that of deforestation on land. Thus, monitoring and understanding the ocean's role in absorbing heat and carbon dioxide is an important component of climate change mitigation efforts.

What about adaptation? People do not live on the ocean, of course, but most of them do live close to the coast. Climate change is impacting coastal communities in many ways, though they are mostly not directly related to temperature. The most obvious concern is sea level rise. Patterns of sea level rise are not globally uniform, nor are patterns of coastal development, and local land subsidence is often larger than, and more easily influenced by human intervention than, rising seas. Coastal adaptation actions to combat sea level rise must, therefore, necessarily be locally informed, designed, and implemented. Another obvious concern, particularly in mid latitudes and small island developing states, is the increasing frequency, magnitude, and impact of tropical storms. There is sometimes a temptation to think adaptation may come in the form of off-the-shelf "projects" that can be quickly implemented by "scaling up" success stories from elsewhere. Problem solved? No, not really. Although such projects can decrease vulnerability, sustained success requires that adaptation be an

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ongoing process, with sustainable local financial and social support, continuously maintained and adapted as local needs and conditions change. A third substantial coastal climate impact, most directly apparent in Arctic regions but with global impacts, is the retreat of sea ice. The loss of a protective ice barrier and its related ecosystem, and projected rapid changes to shipping and resource extraction all mean that Arctic coastal communities will have to adapt dramatically. Briefly, although all coastal communities have climate vulnerability, building resilience is a local challenge with local solutions.

My take-home message is that global average temperature (the famous 2°C "limit") is not a useful indicator of the ocean's role in either mitigation or adaptation to climate change. In large part because of the ocean, global average temperature does not reflect real temperature rises where people live, nor does it capture the myriad real impacts of climate change. Although focusing the world's attention on global average temperature has played a role in driving intergovernmental negotiations and setting national targets, it is not enough. First and foremost, sustaining ocean health, and building resilience to climate change, must be built on local awareness and monitoring of the changing ocean and coasts coupled with local leadership and actions.

Dr. Keith Alverson is an independent consultant with a focus on the ocean, climate, and environment. He was formerly with UNESCO in France, and the United Nations Environment Programme in both Japan and Kenya.

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Reinventing Observations of the Atlantic Meridional Overturning Circulation with Fetch AZA

by Geraint West, Kristin Burmeister, and Stuart Cunningham

Sonardyne's Fetch Ambient-Zero-Ambient (AZA) being deployed during the summer 2022 OSNAP cruise from the RRS *James Cook*.

BEN MOAT

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The transport of heat and freshwater by the Atlantic Meridional Overturning Circulation (AMOC) is central to the climate of the North Atlantic and Europe. Understanding its behaviour is, therefore, critical to climate change predictions. However, until recently, it has not been possible to measure the fundamental observable of absolute pressure in the ocean economically, sustainably, and reliably. Bottom pressure recorders (BPR) utilizing a new technique known as ambient-zero-ambient (AZA) changes this. In a first of its kind deployment, researchers from the Scottish Association of Marine Science (SAMS) are deploying two of these instruments, developed by marine technology company Sonardyne, with one on each side of the Atlantic. The instruments promise to be part of a solution that optimizes how the AMOC is observed, reducing operational costs and enabling these potentially critical observations to continue for decades to come.

The AMOC is a major system of ocean currents in the Atlantic Ocean, transporting energy from the southern hemisphere to the Arctic. In general, warm water flows north away from the equator in the upper layers of the ocean to higher latitudes, where it cools and consequently sinks, before returning south. This is the overturning circulation. The AMOC, therefore, acts as a vast "conveyor belt," redistributing oceanic heat. Indeed, it transports 1.25 peta (1015) watts of energy – more than 60 times the present rate of world energy consumption – from the tropics towards the subpolar and Arctic regions. It is this circulation that keeps Northern Europe relatively mild.

This huge heat flux means that the AMOC is key to controlling the climate on interannual to decadal to multi-centennial timescales. Unfortunately, most climate models (including those used in the recent Intergovernmental Panel on Climate Change AR6 report) predict that warming at higher latitudes will reduce the efficiency of the overturning circulation, resulting in it slowing down. This has significant consequences for our weather, particularly hurricane intensity and European storminess and rainfall. The problem is that there is now lower confidence in the magnitude of the slowing and, thus, sustained observations are critical to understanding and predicting change in the AMOC.

An important step towards understanding the AMOC was taken with the establishment of the Rapid Climate Change-Meridional Overturning Circulation and Heatflux Array (RAPID-MOCHA) at 26.5°N in 2004. This consists of more than 20 instrumented moorings between West Africa and the Bahamas, with additional observations in the Florida Strait using telephone cables. Observations from RAPID-MOCHA have revealed significant variability in the AMOC, even on subannual timescales. The RAPID array blazed a trail for international cooperation and integrated basin wide measurements. The next task was to initiate observations in the subpolar gyre (SPG), so that meridional changes in the AMOC could be measured and the critical ocean-atmosphere energy exchanges quantified.

The SPG is a large system of anti-clockwise rotating currents, between 45°-65°N, which is central to the redistribution of heat and freshwater in the AMOC. At its southern and eastern edges, the SPG is flanked by the North Atlantic Current (NAC). One part of the NAC brings in warm and salty subtropical water to the subpolar North Atlantic and the Nordic Seas. As it does so, heat is released into the atmosphere, precipitation freshens the ocean, and carbon dioxide is absorbed from the atmosphere. The ocean becomes cooler, fresher, and denser. This denser water sinks and flows southward in deep western boundary currents. These flow to the South Atlantic, Indian, Pacific, and Southern oceans completing a global overturning circulation. The global overturning takes hundreds to thousands of years and sets the equilibriation time between atmosphere and ocean and is why the impacts of climate change such as sea level rise will

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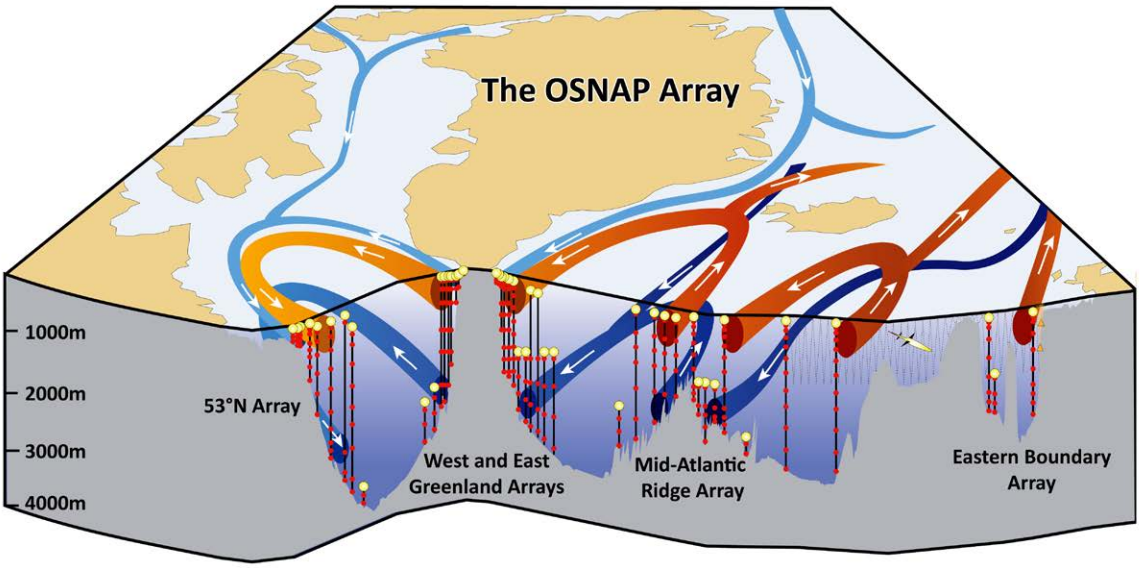


Figure 1: A schematic of the overturning in the Subpolar North Atlantic Program (OSNAP) array. Warm currents in the upper one kilometre which flow north from the Gulf Stream and North Atlantic Current are shown in red. The warm water is made colder as it flows round the subpolar gyre and in the Nordic and Labrador Seas east and west of Greenland. The cold waters in blue return southward to the global ocean at depths of one to four kilometres. This is the overturning circulation. To continuously monitor the strength and structure of all these currents, an array of moorings is continuously deployed between Newfoundland and West Greenland and East Greenland and Scotland. A mooring is a wire (black lines) from the seabed to just below the surface and is held taut and vertical by syntactic foam and glass buoyancy (yellow blobs). Instruments such as current meters and temperature and salinity sensors are fixed to the wires (red blobs). Every two years, over a period of three summer months, all the moorings are recovered during research expeditions. The data from the instruments can be downloaded for analysis. New moorings and instruments are then redeployed for another two years. In the Eastern Boundary Array, autonomous gliders (yellow vehicle with black wings) patrol regions where it is difficult to install moorings safely (mainly due to fishing). Gliders have an endurance of six to eight months. They are deployed and piloted by the Scottish Association for Marine Science.

evolve over many hundreds of years no matter how rapidly we stabilize emissions of CO_2 to the atmosphere.

Since 2014, the Overturning in the Subpolar North Atlantic Program (OSNAP), consisting of 14 partner institutions from seven countries, has been undertaking observations to better understand the AMOC and SPG circulation. Much like the RAPID-MOCHA, OSNAP comprises more than 60 moorings, as well as floats and glider transects (Figure 1). The output of these observations are monthly estimates of the subpolar AMOC strength, structure, and associated heat and fresh-water fluxes. This represents a huge international effort, which is costly to maintain. From the outset, a key objective has been to optimize OSNAP for long-term monitoring over the decades necessary to establish long-term circulation change. Consequently, one of the UK-OSNAP participants, SAMS, identified an opportunity to reduce the observational costs and increase its sustainability using a new technique allowing for long-term bottom pressure data acquisition.

Ocean pressure is important because ocean circulation at timescales longer than a few days is in geostrophic balance. The Coriolis effect of the Earth's rotating motion is in equilibrium with the pressure gradient between areas of high and low pressure (just like atmospheric weather patterns). This forces the water to flow at right angles to this gradient (the direction of flow is to the right in the northern hemisphere). Thus in the North Atlantic, higher pressure in the eastern basin relative to the western basin results in a northerly flow. Measuring the pressure gradient across these basins is fundamental to calculating net transport through the basins.

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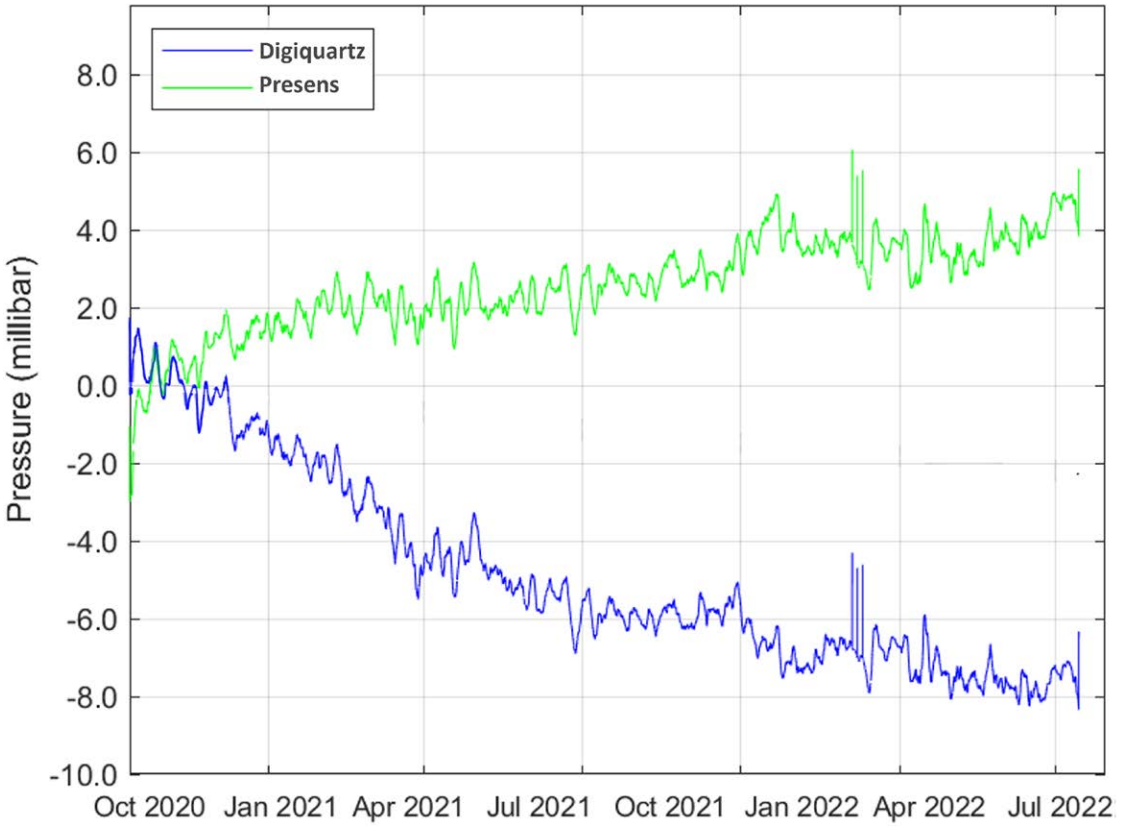


Figure 2: Eighteen months of ambient-zero-ambient (AZA) cycle data from a field deployment, showing raw Digiquartz (blue) and Presens (green) pressure data. Both display drift typical of these sensors.

The inability of available BPRs to reliably measure absolute seabed pressure over sustained periods has long been problematic for programs such as OSNAP. This is because even the best pressure sensors exhibit a time-dependent drift limiting analysis and understanding to short-term variability about a mean. This drift is caused by two mechanisms inherent in quartz pressure sensors – outgassing when the crystal is unloaded and viscoelastic creep when it is loaded (Figure 2). These effects work in opposition to each other but diminish exponentially with time. Past efforts to measure pressure have been limited to a few years, with almost no ability to tie pressure records to create records of multi-year variability. They have been put together by removing an exponential linear drift. However, the analysis of these time series is restricted to annual and shorter timescales. For a variety of climate and geophysical measurements, the need to accurately measure bottom pressure over long periods of time has led to the Ocean Observations Panel for Climate identifying ocean bottom pressure as an emerging essential ocean variable.

Solving this problem has, therefore, become a priority for scientists and engineers and several approaches have been trialled over the past 15 years. These include use of a mobile pressure recorder carried by a remotely operated vehicle (ROV) to conduct a closed loop survey on a series of concrete benchmarks, and secondly, incorporation of a deadweight tester into the BPR (often referred to as the self-calibrating pressure recorder – SCPR). In the former case, loop closure to a laboratory standard can produce accurate absolute pressure measurement; however, the procedure is obviously complex and relies on costly and repeated regular use of an ROV. In the case of the SCPR, the instrument is by nature both bulky and complex, which has restricted widespread deployment.

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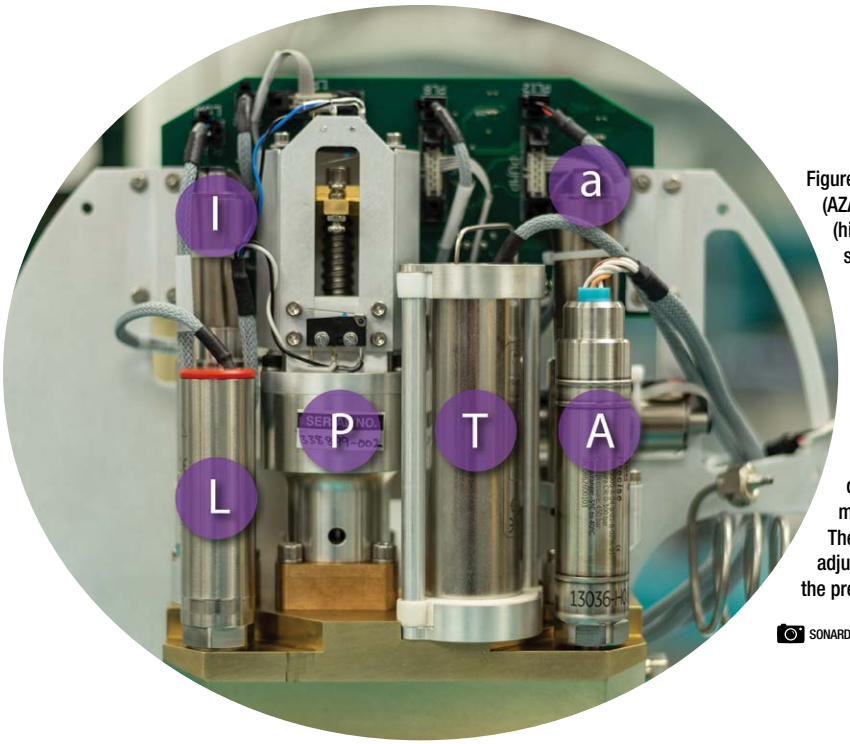


Figure 3: Sonardyne ambient-zero-ambient (AZA) mechanism, comprising (A) Ambient (high) Presens strain gauge (±0.01% full scale) – which is continuously exposed to the external ambient pressure; (L) Low (zero) 2 bar TERPS barometer (±0.01% full scale) – the reference sensor, and (T) Transfer (primary) Digiquartz pressure sensor (±0.01% full scale) – used to compare the other two sensors. In addition, there are two pressure valves, which are used to isolate the different sensors during the comparison measurement: (a) Ambient; (I) Low (zero). The mechanism also has a pressure adjustment pump (P), which is used to control the pressure inside the manifold.

SONARDYNE

For these reasons, an alternative approach, ambient-zero-ambient (AZA), is increasingly being used. AZA is based on a technique developed by the National Metrology Institute of Japan. It works on the fundamental assumption that that sensor drift is a bias and is, therefore, the same at low and high pressures. Using this assumption, a high-pressure sensor is used to measure "ambient" pressure and this is periodically compared to a high accuracy (± 0.2 mbar) low pressure "zero" reference barometer. This comparison effectively measures any drift in the high-pressure sensor, which can be subsequently removed. The benefit of this approach is that the mechanism is relatively simple in concept, robust, and does not need operator intervention. Several groups have now implemented this principle in BPR instruments, with field data suggesting that precision in AZA drift correction of one part in 10^6 is achievable. This is why SAMS concluded that the technique is mature enough for attempting measurement of the pressure gradient across the subpolar North Atlantic.

Sonardyne has been supplying technology for seabed deformation and plate tectonic monitoring to academia and industry since 2007. Both have needed centimetric measurement of bottom pressure to quantify changes in seabed elevation. Consequently, Sonardyne was one of the first companies to exploit the AZA principle in a commercial off-the-shelf instrument. Following deployment of the first two prototypes in 2017, Sonardyne has since supplied AZA instruments to academic and industry users, including more than 20 units at A/S Norske Shell's Ormen Lange gas field from 2021.

Most AZA instruments developed by other manufacturers and academic groups use a simple three-way valve to switch the instrument between external ocean pressure and internal pressure. Sonardyne chose instead to implement a system of three pressure sensors and associated valves. This more complex design reduces stress on the instrument and oil usage, which can be significant in longer duration deployments. Sonardyne's AZA mechanism, therefore, comprises the components shown in Figure 3.

In its normal operating mode, the ambient pressure valve is open and the low (zero) pressure valve is closed. This means that

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the ambient and transfer (primary) pressure sensors are both connected to the external seawater and measure the ambient pressure. When a reference measurement is initiated, the ambient pressure valve is closed and the pump piston is withdrawn, reducing the pressure in the manifold until it is near to zero. The low-pressure valve is then opened, connecting the low (zero) and transfer pressure sensors together. At this point, the transfer sensor bias can be accurately measured against the low-pressure sensor. After completing this measurement process, the low-pressure valve is closed and the pump piston is extended, which returns the manifold pressure back to ambient. Then the ambient pressure valve is opened, which re-exposes the transfer sensor to the ambient outside seawater pressure. With both ambient and transfer sensors connected to external seawater, the instrument is returned to its normal operating mode.

Sonardyne's AZA instrument is a variant of its Fetch long-life sensor logging node, which supports up to 10-year deployments. Fetch AZA runs the AZA cycle on an auto-incrementing sampling rate (although this can be altered by the user), which uses an initial interval of two days between comparison cycles, increasing by 2% for each subsequent cycle, until the interval reaches a maximum of 28 days. The purpose of this is to measure the bias more frequently while the pressure sensor is settling. In terms of actual measurement cycles, this means that the AZA instrument will undertake 77 AZA comparison measurements during year one, reducing to 19 in year three, before settling into a 28-day periodicity for the remainder of the deployment. In terms of an expected 10-year life, the total number of AZA cycles would be 217. Each cycle takes 5-10 minutes and consists of single point pressure readings from all three sensors, followed by three AZA records with pressure values recorded after a settling period and averaged over 30 seconds, and finally another set of measurements from all three sensors. By doing this, the bias of the transfer sensor relative to the reference sensor can be calculated, as well as the bias of the ambient sensor relative to the transfer sensor, to ultimately estimate the bias of the ambient sensor (Figures 4 and 5).

In common with Sonardyne's other Fetch long-life logging nodes, the AZA mechanism is housed in either a 3,000 or 7,000 metre rated glass sphere (Figure 6). A micro-electromechanical system inclinometer, high precision platinum resistance thermometer, and battery temperature sensor are fitted as standard, and a sound speed sensor can be fitted as an option. Timestamped data is logged to dual SD cards and can be accessed by Bluetooth, serial or acoustic communications links, which are also used for instrument configuration. Fetch AZA can be ROV or free-fall deployed, so an optional screw-off release and syntactic exoskeleton provides sufficient buoyancy for free-ascent to the surface for recovery.

In addition, Sonardyne's Fetch AZA has an integrated high speed acoustic modem. This enables both recovery of data and remote configuration of the instrument, using Sonardyne's Wideband 2 telemetry scheme. Typically, one year's worth of data from Fetch AZA can be harvested in about 30 minutes. This functionality is compatible with a wide range of Sonardyne topsides, ranging from ultra-short baseline systems, which also support positioning, to simple dunker systems for telemetry only. Fetch units fitted with an omni-directional transducer also support ranging between units, which can be used to provide ranging to underwater vehicles. This allows interoperability with a wide variety of platforms, including the capability to harvest data from the instruments using uncrewed surface vehicles (USV), which is now regularly done. Fetch can be configured with an internal 504 Ah battery pack, enabling deployments of up to 10 years. When a USV is used for data harvesting, this combination can achieve extremely low through-life operating costs and carbon footprint.

Although SAMS does not initially plan to use a USV for data harvesting, Fetch AZA does provide a new measurement capability

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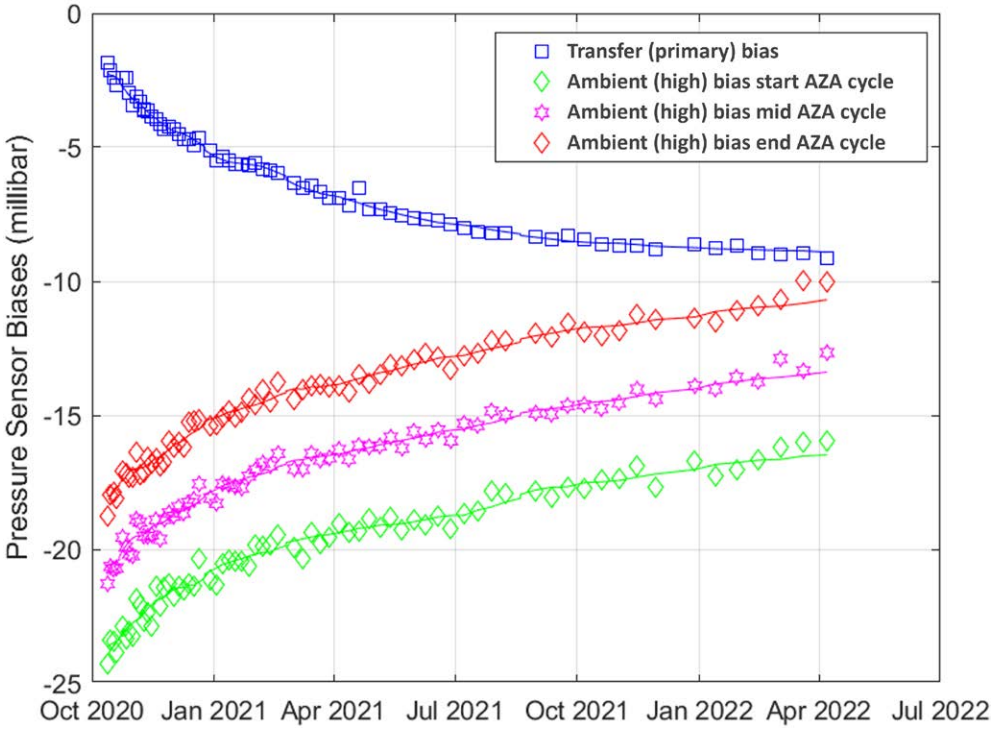


Figure 4: Eighteen months of ambient-zero-ambient (AZA) cycle data from a field deployment, showing the more frequent AZA cycles at the beginning of the deployment. The Digiquartz is the Transfer (primary) pressure sensor and the Presens is the Ambient (high) pressure sensor. Each AZA cycle measures the bias at the start (◊), m ✡-point ( ), and end (◊) of the cycle.

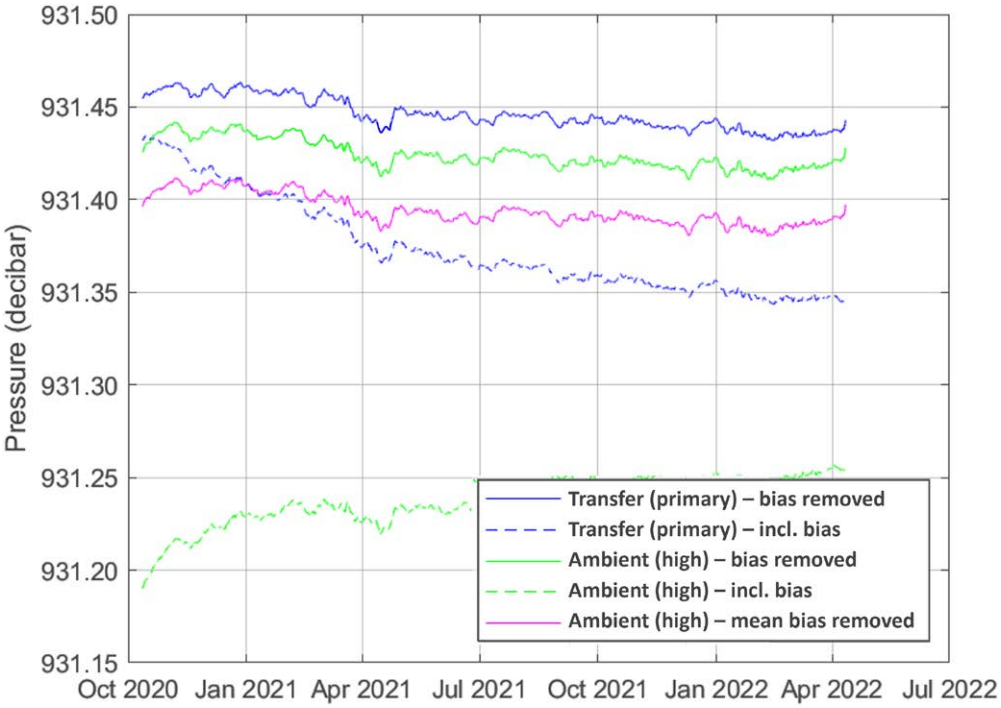


Figure 5: Eighteen months of ambient-zero-ambient (AZA) cycle data from a field deployment, showing the raw pressures (including bias) from the Digiquartz (transfer or primary) [---] and Presens (ambient or high) [---] sensors. The corresponding AZA corrected (bias removed) pressures are shown for the Digiquartz [——] and Presens [——].

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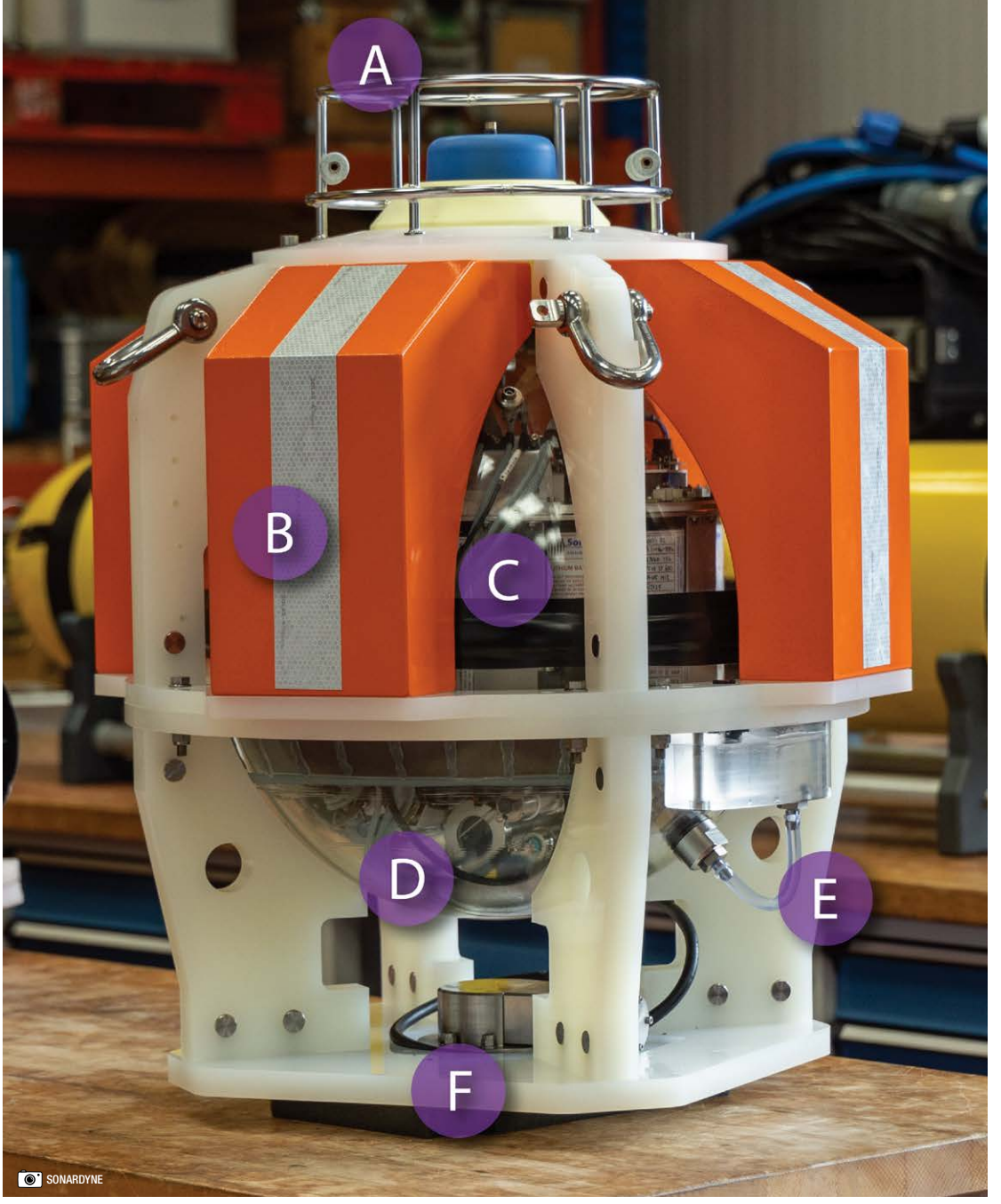


Figure 6: Sonardyne Fetch ambient-zero-ambient (AZA) comprising (A) acoustic transducer; (B) syntactic flotation "exoskeleton"; (C) LSH20 (180 Ah) or LS33600 (504 Ah) lithium battery pack; (D) AZA mechanism; (E) port to external oil reservoir; and (F) optional release.

that has the potential to drastically reduce the infrastructure requirements and, therefore, costs of OSNAP. This is because, although AZA does not measure absolute pressure, removing the drift means that bottom pressure variability over time is measurable. This summer, SAMS, together with its German partners in GEOMAR, deployed one instrument within the UK Eastern Boundary Array, in 1,800 metres water depth, off Scotland, and one in the German 53°N array, in 2,300 metres water depth, off Newfoundland (Figure 1). Data from these two instruments will produce an average reference velocity than can be combined with other data from satellites and in-situ observations. These will include data from the Gravity Recovery and Climate Experiment satellite mission, which measures the gravitational field, as well sea surface

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height anomalies from altimetry, and Argo float CTD (conductivity, temperature, depth) data to produce a distribution of ocean bottom pressure across the OSNAP area. In-situ measurements such as direct velocity measurements and CTDs on moorings will produce constraining data in the critical boundary current areas.

This new observational scheme will initially be part of the existing OSNAP arrays to 2024. The specific objective from the outset of OSNAP was to determine from the observations "the configuration of an optimally efficient long-term AMOC monitoring system in the North Atlantic subpolar gyre." The hope is that the existing moorings can be reduced in number with the BPR data providing a basin-wide integrated pressure measurement. Reducing the costs of the current program will make OSNAP much more sustainable in the longer term, enabling it to continue to underpin critical future climate change predictions. AZA is the key to realizing this change, but the technology has potential to be a game-changer elsewhere. It is already in use for seabed deformation and plate tectonic studies; however, other applications including sea level rise, tsunami detection, validation of climate model predictions, and support for satellite observations are all potential beneficiaries.

Acknowledgment
UK OSNAP is underpinned by National Capability funds from the Natural Environment Research Council (NERC) including the Climate Linked Atlantic Sector Science project (since 2018).



Geraint West is Sonardyne's head of science and has managed the company's relationships with the ocean science community since 2016. Previously, as director of National Marine Facilities at the UK's National Oceanography Centre, he set up its Marine Autonomous and Robotic Systems facility and commissioned the research ships, RRS *James Cook* and RRS *Discovery*. Mr. West is the current chair of the UK Society of Maritime Industries' Maritime Autonomous Systems Council.



Dr. Kristin Burmeister is a seagoing early career researcher in physical oceanography at the Scottish Association of Marine Science in Oban, UK. Her research focuses on the variability of the Atlantic Ocean on seasonal to longer time scales combining observational data with model output. Dr. Burmeister did her PhD at GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, from 2015 to 2019. Since 2019, she is involved in the iAtlantic project to assess Atlantic marine ecosystem health in time and space and in the OSNAP program to monitor the Atlantic Meridional Overturning Circulation in the subpolar North Atlantic. She attended six research cruises to maintain different mooring arrays in the Atlantic and Pacific oceans.



Prof. Stuart Cunningham is an observational physical oceanographer specializing in ocean measurements for climate studies. He began his career in 1990 with the Institute of Oceanographic Sciences, Deacon Laboratory as a research assistant in the World Ocean Circulation Experiment, then at the James Rennell Centre. From 1995-2012, he worked at the National Oceanography Centre, Southampton. He is now a professor at the Scottish Association for Marine Science and teaches with the University of the Highlands and Islands. He has led 35 research cruises as principal scientist around the world's ocean. Since the early 2000s, Prof. Cunningham has focused on purposefully designed mooring arrays. He was an originating principal investigator and led the RAPID field program for 10 years. He is now a principal investigator in the subpolar OSNAP program for observing and monitoring the Atlantic Meridional Overturning Circulation.

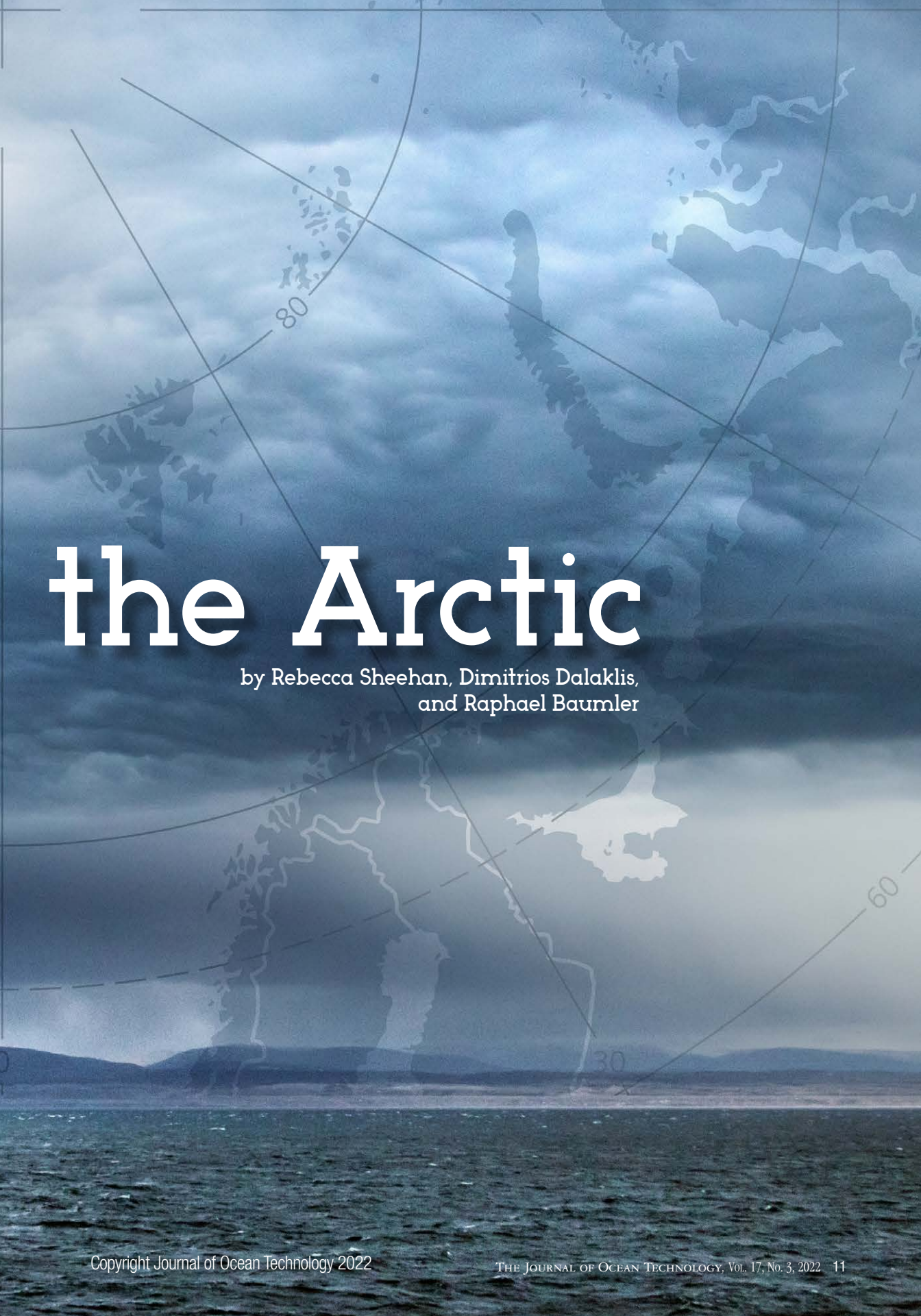
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Fisheries in



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the Arctic

by Rebecca Sheehan, Dimitrios Dalaklis, and Raphael Baumler

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Introduction

During the last couple of decades, the ability to monitor and create credible records that fully describe how the Arctic landscape is changing has progressed considerably. Multiple sources have repeatedly pointed out that the continued warming of the region's atmosphere and ocean are driving broad change to the physical environment, including diminishing sea ice coverage, declining snow cover, and melting ice sheets. With ice coverage in the Arctic Ocean following a path of continuous reduction, new opportunities for business are opening up.

For example, statistics indicate that fishing and tourism are clearly gaining momentum within the wider region under discussion. Furthermore, shipping activities in the Arctic have increased over the course of time and there is an obvious reason behind this: sea ice coverage has diminished and the length of the navigation season has grown. These changing conditions have resulted in increased attention from government, media, scientific researchers, the natural resource exploration industry, and entities engaged in tourism, fisheries, and relevant business opportunities. The message is clear: the Arctic is indeed undergoing a formative transformation.

Definition of the Arctic and Governance Regime

It should be noted that there are various different approaches towards a definition of the "Arctic" (which is also very often termed as the "High North"). The simplest description would be to define it as the areas around the Earth's North Pole; ice coverage is indeed reducing there, but these high latitudes are still dominated by the polar ice cap. Another rather straightforward definition of the Arctic could be to describe it as the area containing the Arctic Ocean as well as the respective territories with a latitude higher than the Arctic Circle (approximately 66°33'44'' N). By adopting this approach, the area within the Arctic Circle includes lands divided among eight countries: United States (Alaska), Canada, Denmark (Greenland), Iceland, Norway, Sweden, Finland, and Russia (Figure 1).

The history of the Arctic governance regime and initial efforts to protect this region can be traced back to the late 1980s. In response to forecasted threats and negative impact to its environment and Indigenous inhabitants, Finland convened a conference in Rovaniemi in 1989 to bring together all "Arctic States" to discuss the issue of environmental protection. This term is often used today to describe the Member-States of the Arctic Council (in alphabetical order): Canada, the Kingdom of Denmark (including Greenland), Finland, Iceland, Norway, Russia, Sweden, and the United States of America (U.S.).

The Arctic States again met in Rovaniemi in 1991. During this conference, the Declaration on the Protection of the Arctic Environment (the Rovaniemi Declaration) was signed, and the Arctic Environmental Protection Strategy (AEPS) was adopted. However, both the Rovaniemi Declaration and the AEPS imposed no compulsory legal mandates on Arctic States, but relied only upon their political goodwill to protect the Arctic environment. In 1996, the second meeting of AEPS was convened, in which Arctic States "fully committed to the earliest possible establishment of the Arctic Council" as a high-level interstate forum to promote cooperation/coordination, and interaction on matters related to the Arctic region. These States again met in Ottawa, Canada, approximately six months later, and signed the Declaration on the Establishment of the Arctic Council. This officially established the Arctic Council as a cooperative forum, to address issues of sustainable development and environmental protection in the Arctic.

As a strong indicator of the Arctic Council's positive influence, four internationally legally binding agreements have since been negotiated under its auspices, to include the Agreement to Prevent Unregulated Fishing in the High Seas of the Central Arctic Ocean,

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Figure 1: The Arctic Circle includes lands divided among eight countries: United States (Alaska), Canada, Denmark (Greenland), Iceland, Norway, Sweden, Finland, and Russia.

which entered into force on the June 25, 2021. The central Arctic Ocean, a high sea area that was previously accessible only by heavy icebreakers, could soon open up to commercial fishing activities. Yet, until this point of time, the level of knowledge relating to the ecosystem below the retreating sea ice cover is not sufficient and unregulated fishing could have an impact. Signatory parties have committed to not authorize any vessel flying its flag to engage in commercial fishing in the high seas portion of the central Arctic Ocean for the next 16 years. Ten parties signed the agreement: Canada, Iceland, the Kingdom of Denmark (in respect of the Faroe Islands and Greenland), Norway, the United States, and the Russian Federation, as well as China, Japan, South Korea, and the European Union.

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The goal is to ensure that adequate scientific information is available that can inform decision-making related to potential future fishing activities in an emerging ecosystem.

This agreement is an important step towards ensuring that any future fishing in the central Arctic Ocean will be carried out sustainably. It is true that, at present, no commercial fishing activities are taking place in the high seas portion of the central Arctic Ocean, an area that is roughly the size of the Mediterranean Sea. At the same time, no regional fisheries management organization or arrangement exists for this whole area either. However, due to the impacts of climate change, it cannot be excluded that commercially interesting fish stocks may occur in the future and this, in turn, will lead to fishing activities in the central Arctic Ocean in the mid- and long-term timeframe. The Agreement to Prevent Unregulated Fishing in the High Seas of the Central Arctic Ocean applies a precautionary and science-based approach to fisheries by banning unregulated fishing activities in the region of interest, while a joint scientific program is set up to improve the Parties' understanding of the ecosystems and potential fisheries. It is also interesting to note that Parties may in the future decide to commence negotiations to establish one or more regional fisheries management organizations or arrangements. This agreement will initially be in force until 2037; its validity will be automatically extended for another five years, unless one of the Parties objects.

Understanding Maritime Traffic in the Arctic

When referring to the worldwide volume of maritime traffic, the total contribution of the Arctic region was and remains rather small. But the scientifically recorded decline of ice coverage in the Arctic is facilitating a noteworthy increase of maritime traffic. This is creating, in turn, the need to capture "what exactly is happening within the Arctic Ocean." The Arctic Council's Working Group on the Protection of the Arctic Marine Environment (PAME) Arctic Ship Traffic Data (ASTD) project, launched in February 2019, was developed in response to a growing need to collect and distribute accurate, reliable, and up-to-date information on shipping activities in the Arctic. This initiative is a significant step by PAME to reduce the knowledge gap and can significantly contribute into the creation of maritime awareness, or simply put "understanding what is happening at sea."

With changes in the Arctic sea ice extent and projected changes/increase in shipping in the Arctic, the ASTD System will allow the Arctic Council to be at the forefront of monitoring trends and assessing any changes and the development of recommendations that enhance Arctic marine safety and support protection of people and the environment. This report emphasizes that the regions where there are currently high concentrations of Arctic marine activity include the North Atlantic Ocean, the Barents Sea, and along the coasts of northwest Russia. During the last two decades, significant discussion has emerged on the potential profits/financial benefits the use of the "Arctic Passages" could yield. In regard to Arctic navigation, it is necessary to highlight that the greatest interest is directed towards the Northwest Passage and the Northern Sea Route.

An Arctic with a "lesser ice" status is considered a very promising field for various economic activities, including fishing. There are approximately 214 fishing vessels registered in Northwest Russia and 3,500 registered in the Northern Norway region (with 150 of them being large trawlers and pelagic fishing vessels). Furthermore, the Icelandic fishing fleet has remained fairly constant over the last decade and consists of approximately 1,700 vessels (50 large vessels); fishing in Greenlandic waters is conducted by a limited number of shrimp trawlers and numerous small size boats (ranging between 1,500 and 2,000) (Figure 2). With ice retreating, it is plausible that commercial fishing activities will increase in specific regions of the Arctic.

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Figure 2: Fishing in Greenland waters is conducted by a limited number of shrimp trawlers and numerous small size boats, such as this fishing boat anchored in Nuuk.

There are many ways to measure the volume of shipping in a given geographic area. One way is to count the number of unique ships in the Polar Code area. The clear conclusion is that shipping in the Arctic has increased during recent years and that fishing vessels are dominant making up 41% of all ships in 2019 (Figure 3). Another way to measure the increase in Arctic shipping is by distance sailed. As with unique ships in the Polar Code area, fishing vessels remain dominant and make up 45% of the distance sailed in 2019.

Conclusion

The diminishing levels of sea ice in the Arctic can facilitate maritime activities in areas previously rather inaccessible. On the other hand, issues like uncharted areas, ice that is drifting, and harsh environmental conditions are just a few of the very dangerous safety obstacles in relation to Arctic shipping. The Arctic remains a dangerous operating environment. Provision of the necessary ice-breaking services should also be factored in this equation, since they remain a prerequisite for safe navigation. A quite simple argument is put forward: icebreakers currently are and will continue to be in the foreseeable future the main "tool" to support safe shipping activities in the Arctic.

Additionally, for both the Northwest Passage and the Northern Sea Route, the overall available response capacities are rather thin;

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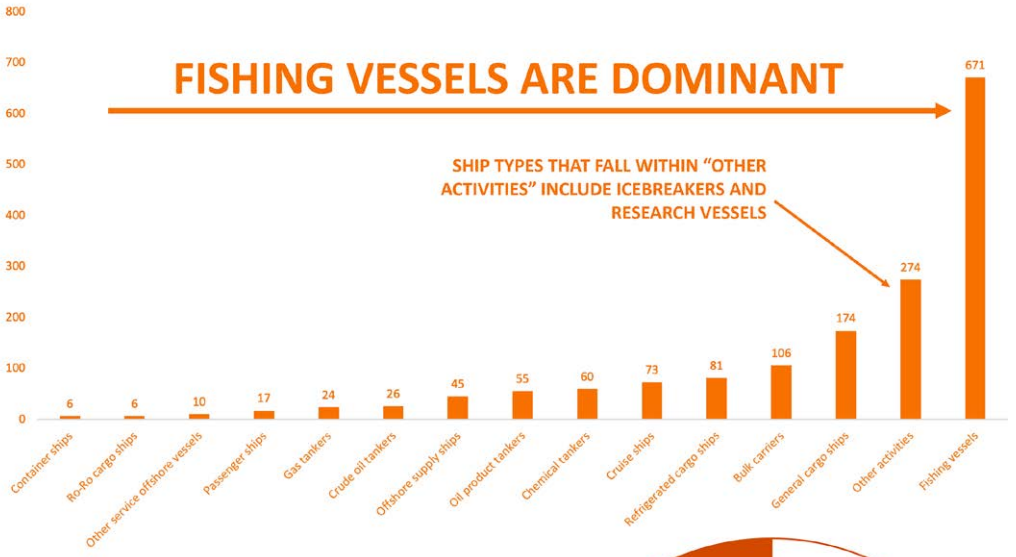
A majority of these vessels are fishing vessels

In 2019 of all ships that entered the Polar Code area

41%

were fishing vessels





The total 2013 distance sailed by all vessels was approximately *6.51 million* nautical miles.

In 2019, the total aggregated distance sailed had risen to over *10,7 million* nautical miles.

As with unique ships - fishing vessels are dominant.

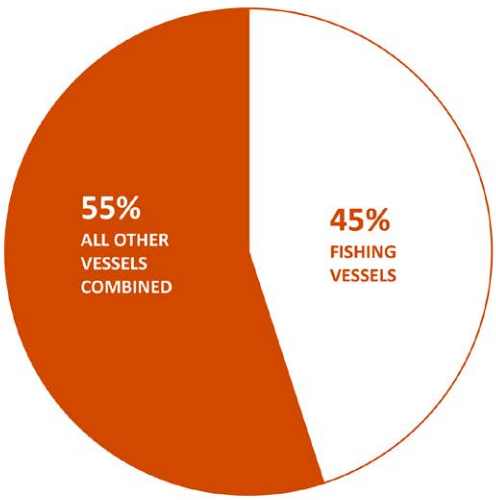


Figure 3: Shipping in the Arctic has increased during recent years with fishing vessels making up 41% of all ships in 2019. (From the Arctic Council's Working Group on the Protection of the Arctic Marine Environment (PAME) Arctic Shipping Status Report #1.)

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any expected further increase of maritime activities must be balanced with additional strengthening of emergency management capabilities. As the maritime shipping sector hastens plans to exploit the wider region and its resources and with the fishing industry eager to benefit from new opportunities, emergency preparedness systems and response capabilities available to tackle human and environmental catastrophes must be further developed. Steering towards a more positive direction for the future of the Arctic, the Arctic Council continues to mitigate the risk as the leading intergovernmental forum promoting cooperation in the Arctic.

Acknowledgement
The views herein are solely of the authors and do not represent the views of the Department of Homeland Security/U.S. Coast Guard, or any other organization with a similar scope.



Lieutenant Commander Rebecca Sheehan is currently serving as the Inspections and Investigations Branch chief at U.S. Coast Guard District Eleven in Alameda, California. Prior to assuming those duties, she joined the faculty of the World Maritime University, where she was on secondment from the U.S. Coast Guard assigned to the Maritime Safety and Environmental Administration specialization. She has 15 years of professional experience, during which time her primary mission focus has been on maritime safety and security issues, shipping inspections and compliance, and marine spatial planning. She holds a bachelor of science in operations research and computer analysis from the U.S. Coast Guard Academy and a master of public health with a concentration on emergency management from American Military University.



Professor Dimitrios Dalaklis joined the World Maritime University in the summer of 2014, upon completion of a 26 year distinguished career with the Hellenic Navy. Graduating from the Hellenic Naval Academy, his postgraduate studies took place in the Naval Postgraduate School of the United States (M.Sc. in information technology management, with distinction and M.Sc. in defence analysis). He then conducted his PhD at the University of the Aegean, Department of Shipping, Trade and Transport. He is an associate fellow of the Nautical Institute and a member of the International Association of Maritime Economists. He is the author/co-author of many articles and studies in both Greek and English languages, with a strong focus on Arctic related issues.



Professor Raphael Baumler holds a PhD in risk management and focuses his academic work on the impact of the vessel's socioeconomical environment on safety and environment. Primarily educated as a dual officer, he has worked on various types of vessels. Dr. Baumler spent 20 years in a seafaring career. He ended this occupation after six years as master on a large containership. His sea life drove him to work as staff captain on a cruise ship, and he completed various assignments as dual junior officer on board a container ship, ferry, VLCC, and supply vessel. He participates or leads International Maritime Organization (IMO) national and regional workshops on MARPOL Annex VI and Ballast Water Management Convention. He conducts various IMO projects and participates in several other research projects.

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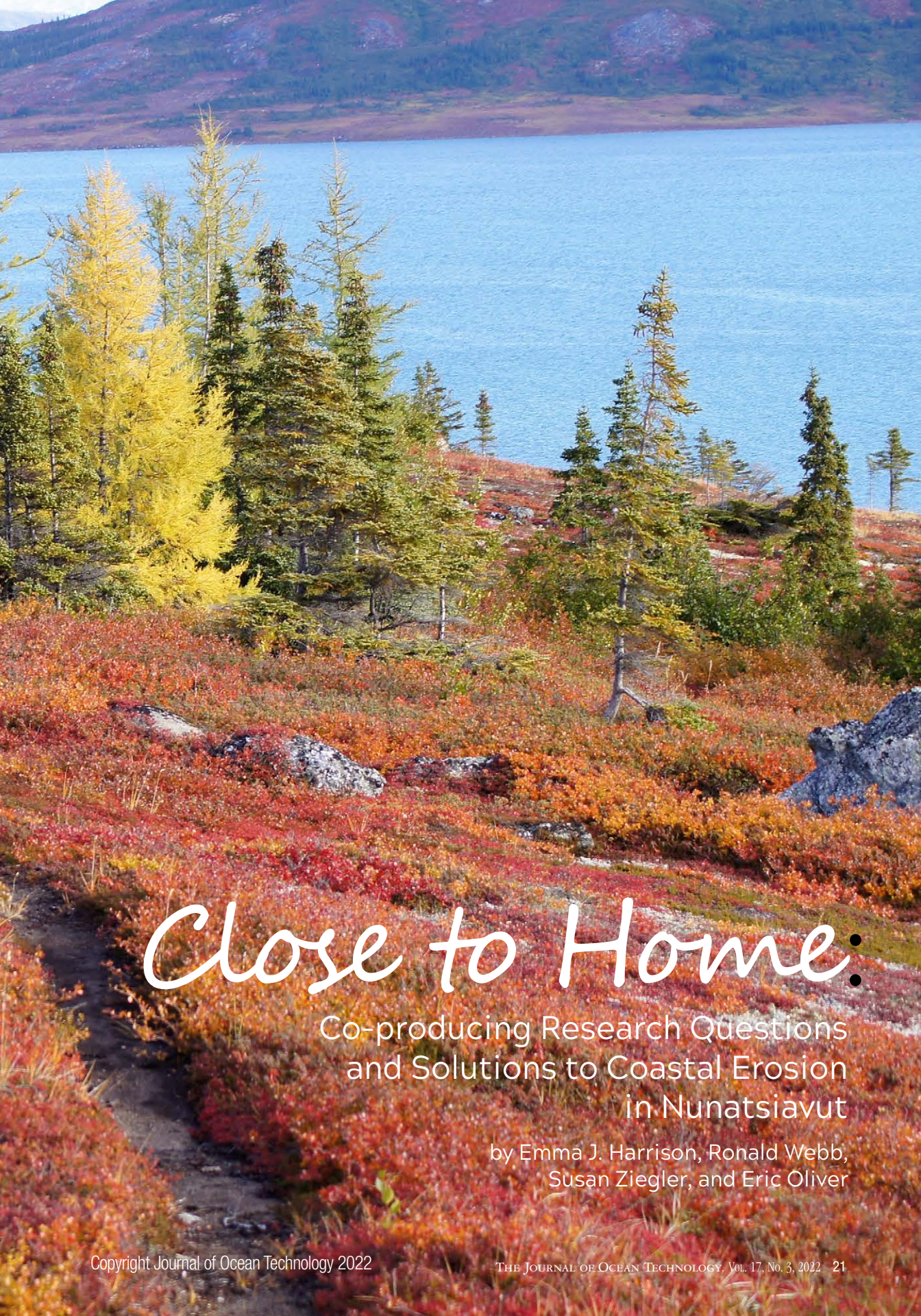



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Close to Home:

Co-producing Research Questions and Solutions to Coastal Erosion in Nunatsiavut

by Emma J. Harrison, Ronald Webb, Susan Ziegler, and Eric Oliver

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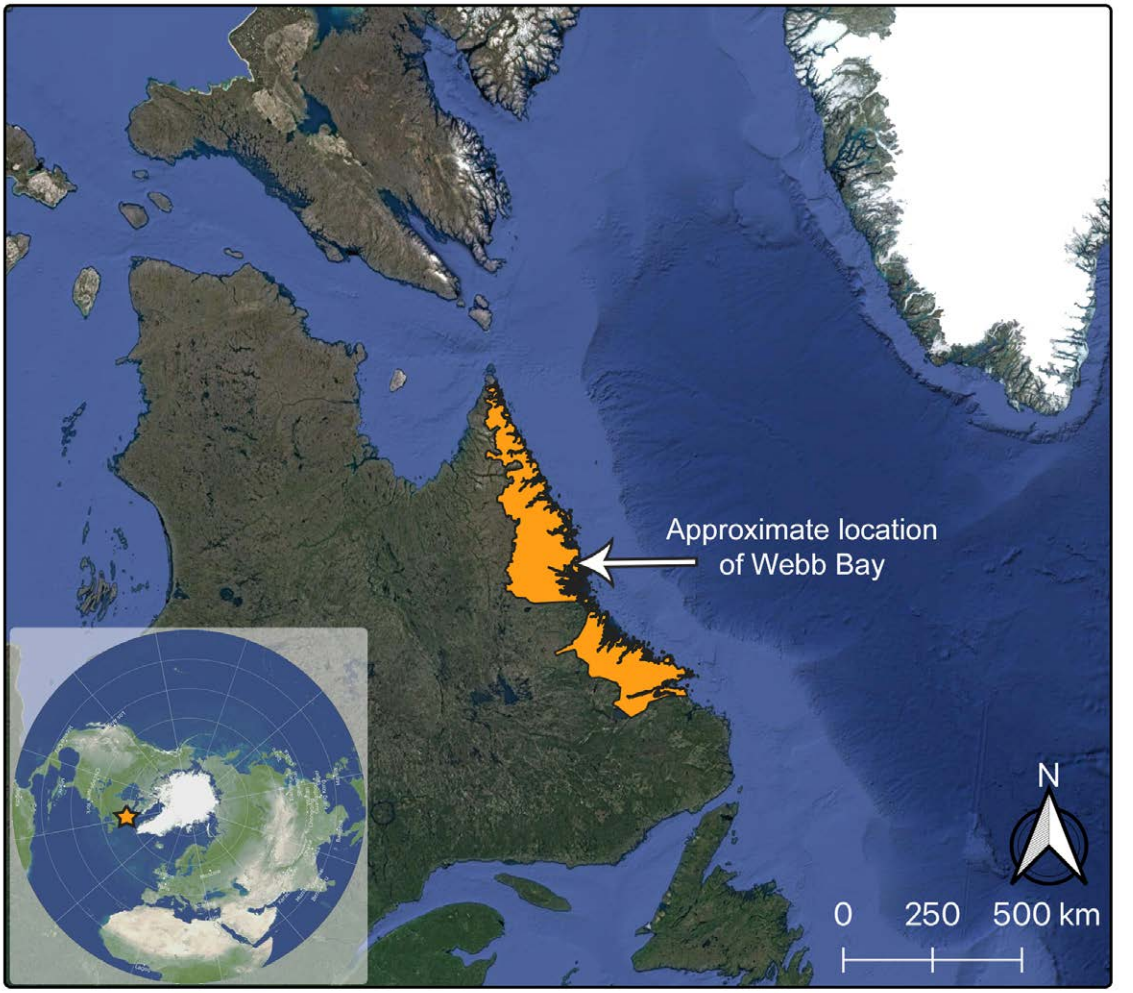


Figure 1: Nunatsiavut Land Claim area identified in orange with an arrow pointing to the approximate location of Webb Bay. Inset map showing a global polar view with a star marking the location of Nunatsiavut.

Introduction

Climate change impacts have long been considered a "wicked problem." Their causes are multiple and complex, characterized by intertwined environmental and social processes. Their solutions are sometimes intractable and often carry their own distinct harms. Situated within this precarity is an urgency to act. How can we proceed in ways that are effective and responsible? Governments, institutions, and individuals are deeply motivated towards answering this question. And yet, climate change research and funding for adaptation are part of an emerging economy that overwhelmingly benefits people from nations implicated in the climate crisis.

This contradiction represents a dynamical similarity between climate change research and colonization, called out by Inuit Tapiriit Kanatami (ITK), the national representational organization for Inuit in Canada, in the *National Inuit Strategy on Research* (2018). "Inuit in Canada are among the most studied Indigenous peoples on Earth. The primary beneficiaries of Inuit Nunangat research continue to be the researchers themselves."

Although traditional perspectives on science advocate for depersonalizing and decontextualizing research to generalize findings, climate change problematizes this paradigm in many ways, especially through

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the urgency to make research applicable to community resilience. The *National Inuit Strategy on Research* frames a directive to institutionally based researchers working in the North: regional research on the effects of climate change should be accountable to how it aids local communities in adaptive planning for the future. From a practical standpoint, this points to the need for ways in which researchers connect meaningfully with communities living on the frontlines of global change.

Here, we highlight the foundational role of Inuit knowledge, Inuit participation, and the structures of Inuit sovereignty in an ongoing research project to elucidate the linkages between climate change and accelerated rates of coastal erosion in Nunatsiavut. Nunatsiavut is an Inuit self-government region in northern Labrador and an Inuttut name meaning "our beautiful land" (Figure 1). While there is no formula for decolonizing research or co-developing projects with communities, we believe this project contains meaningful examples of a collaborative and reciprocal research praxis that can succeed because of the structures that Nunatsiavut, with its sovereignty, has created to facilitate people and place centred research.

Co-developing Research Approaches for Resilience to Climate Change on the Coast

When the first cabin went up in Webb Bay, they cut the tree trunks using a six-metre-long saw. One person would stand on scaffolding two storeys in the air holding onto one of the ends, while another person stood on the ground to work the other end. That cabin is still in excellent shape more than 140 years later, maintained by members of the Webb family. Members of the family gradually moved south to Nain where the children attended a residential school in the mid-1960s. Returning to the Bay, then and now, is a homecoming and represents continued connection to culture and the land. This year, the Webb brothers were again sawing and transporting trees to their homesites on the Bay. They laid the logs out along the beach and pounded rebar deep into the shore platform to hold them in place. Despite the better tools, it is still back-breaking work. This time, they are trying to save the homes in which they grew up.

Around five years ago, the bluff separating their cabins from the sea began to erode dramatically. According to local observations, the bluff would sometimes erode by centimetres when they were young. Now, it seems to give way by metres every storm (Figure 2). At this rate, they estimate that the first cabin will erode into the sea in a year or two. For the Webb family, who are multigenerational observers of this landscape and the natural processes that shape it, it is clear that something significant has changed in the ocean-atmosphere dynamics to make the coastline vulnerable.

This project is a research collaboration between institutionally based scientists, members of the Webb family, and Inuit researchers with the Nunatsiavut Government that aims to identify what environmental shifts are causing the rapid increase in coastal erosion. Both our objectives and our approach were co-developed. At the core of our research is a conceptual model explaining how the environmental systems in Webb Bay interact with each other, and what has changed over time. That model is derived from the intergenerational understanding and lived experience of Inuit. It includes how the dominant wind direction shifts over the seasons, which channels bring in major currents, the rivers that are important sediment sources, and the effects of sea ice formation and break-up on the land. This knowledge of how the landscape functions underpins our data collection campaign. Because this project is a collaboration between Inuit knowledge holders and scientists, we combine data and model frameworks generated from multiple ways of knowing to bear on our research questions.

Across the Arctic, coastal erosion is being accelerated by climate change. The mechanisms driving these changes are made complex by the interactions among

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A view of the beach and bluff with pallets and logs positioned to absorb wave impacts and reduce erosion near the Webb family's homes on Webb Bay.





Family cabin constructed on Webb Bay ~140 years ago (left). Mike and Joe installing logs to protect the eroding shoreline (right). All pictures credited to Susan Webb.

Figure 2: Scenes of erosion in Webb Bay.

meteorological, oceanographic, and terrestrial systems emerging at the nearshore environment of the coast. The causal drivers of heightened erosion may be unique features of high-latitude environments. Sea surface and air temperature has raised erosion rates in the Beaufort Sea by melting permafrost in ice-rich coastal bluffs; and increases in erosion rates correlated with the declining extent of sea ice. Less extensive coastal sea ice created longer tracks of open water and lengthened the fetch, or distance over which the wind blows, building larger wind swell waves with greater power to erode the coast. However, nearly all high-latitude coastal erosion studies focus within the Arctic Circle, which is subject to different weather patterns than the north coast of Labrador, which is entirely south of 60°N. These studies also tend to work with satellite-derived data products at large spatial scales while the coast of Labrador is highly variable on small scales, consisting of a complex of fiords, headlands, large bays, and offshore islands and islets. In the proposed collaborative research, we

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Figure 3: Google Earth view of Webb Bay and the surrounding land and water. Inset map showing a zoomed in view of the homesites on a Canadian topographic map.

take a targeted monitoring approach in Webb Bay over the course of a year and make comparisons with historic and modelled data in order to assess the beach and bluff stability under current, historic, and potential future geomorphic conditions.

Dynamics of Geomorphic Change in Webb Bay

Webb Bay is located ~30 km north of Nain, the largest and most northern of the five Nunatsiavut communities. The Nunatsiavut coastline is complex and rocky. It is deeply incised by fiords and shielded by hundreds of small, nearshore islands. Weather and ocean conditions can be highly variable over short distances. Webb Bay is a relatively large feature, ~16 km long and nearly 8 km across at its widest point. Two large channels connect the eastern end of the Bay with the Labrador Sea, one oriented north and the other to the south. Directly east, the Bay is blocked from offshore currents by Aulatsivik Island.

The homesite sits on a bluff above a curved, sandy beach that is inundated at high tide. A small river drains the interior periglacial lakes and bogs and forms a delta adjacent to the bluff. The coastline in the Bay is primarily rocky; the persistence of a pocket beach here likely depends on sediment supply from the river and its stabilization by the headlands of an interior embayment, which can be seen on the map in Figure 3. Beaches often form in the headlands of bays because the curvature of the shoreline offers protection from wave action.

Research has demonstrated that globally bay beaches evolve into a stable shape, conditioned to the normal wind and wave environment. Changes in the dominant swell cause a period of erosional adjustment

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while the planform curvature of the beach rotates to meet the new angle or intensity of arriving waves. One hypothesis is that a new erosive regime initiated in Webb Bay in response to changes in the wind direction and the accompanying swell. Similarly, longer duration wind events or an increase in the effective fetch length could increase the wave height and cause geomorphic adjustment of the coastline. In either case, the erosion rate would slow as the form of the beach equilibrated to the new swell state.

Alternatively, storm impacts could be driving the inflated erosion rate either through increasing storminess or via linkages modulated by the changing sea ice regime. Historically, sea ice formed in Webb Bay in early November. It fastened to the shoreline and protected the coast from the severe storms that hit northern Labrador in the wintertime. That ice is forming later now due to climate change, leaving the shore vulnerable to storm surges and large tidal swells that undercut the bluff. This mechanism would have very different implications for the probable evolution of the coastline and for the effectiveness of erosion mitigation approaches. Storms can change the coast completely within a matter of hours, limiting the usefulness of model predictions based on average conditions. However, storm-driven erosion is correlated with wave run-up, which does have the potential to be estimated through spatial analysis and climate projections.

Webb Bay is a hot spot for coastal erosion in Nunatsiavut and it is important to understand whether this site is uniquely vulnerable or a bellwether of future conditions in the region. Cabins and cultural sites are disproportionately located along the coast, and often on sections of unconsolidated sediments such as beaches and bluffs. To make a link between this case study and the regional vulnerability to coastal change, we need to parse the key drivers of the accelerated erosion rate and apply this information to predictions of future change.

Project Goals and Methods

We endeavoured to design a methodology that would achieve multiple, related outcomes that blur the lines between "basic" and "applied" science. We define our goals as:

1. Demonstrate a research praxis that empowers and respects Inuit knowledge and challenges traditional perspectives on scientific data.
2. Contribute to the growing body of knowledge on how climate change is mechanistically linked to accelerated coastal erosion in high latitude regions.
3. Link site-specific data to vulnerability at a regional scale.
4. Identify realistic and functional adaptation or mitigation approaches to deal with the specific problem of erosion in Webb Bay.
5. Develop community-based monitoring procedures and horizontal partnerships that have tangible benefits for Labrador Inuit.

We will simultaneously monitor sediment transport on the coast and littoral, or nearshore, processes in a year-long monitoring study initiating in September 2022. Data generated will be used to quantify storm surge elevation, wave height, associated wind-field intensity and orientation, and the event-scale magnitude of erosion. Event-driven erosion rates will be tracked through repeat surveys with a hand-held laser scanning device and a field of erosion pins installed along the cliff line. Moored pressure gauges in the Bay will be used to construct a record of tides, waves, and storm surges. The contribution of storm surge to sea height will be determined by deconstructing sea level measurements into constituent parts: long-term trends, tidal elevations, and the storm surge residual. We can ground truth our measurements using an established gauge site at Nain Harbour which has ~50 years of sea level data. Comparison of the 2022-2023 records between Nain Harbour and Webb Bay will be used to establish a statistical relationship between the gauge sites, allowing us to put recent Webb Bay conditions in the context of the last 50

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years. We will match the resulting record of storm surge height to wind data provided through collaboration with the Nunatsiavut Government's Archaeological Division and Oceans North, which operates a weather station in Webb Bay.

As a basis for comparison with the data generated in the yearlong monitoring study, our research will estimate historic baselines for key environmental parameters based on modelled data and observations made by the Webb family. Historic wind statistics will be computed from ERA5 which provides hourly estimates of atmospheric variables from 1950-present at high spatial resolution. Records of ice formation and irregular weather events were kept in logbooks by Joe and Ronald Webb, informing a time series of ice formation and break-up. To understand the geomorphic evolution of the coastline in relationship to offshore processes, we will model a range of wave obliquities that would have allowed the beach deposit to remain stable, given the coastal topography and bathymetry of the site. We endeavour to place boundaries on rates of coastal change averaged over long timescales, inferred with cosmogenic radionuclide dating to quantify the paleo-retreat rate of the coastal bluff and the sedimentation rate observed from nearshore submarine sediment cores. These quantities represent the magnitude of difference between present day erosion and the average erosion rate over much longer timescales.

Working with community members to identify the key dynamics at play in the local environment is a paradigm shift with powerful potential for enhanced adaptive capacity. Many northern communities are adapting to coastal change on their own with limited access to resources. Large-scale data generalizing landscape processes are less useful for predicting future changes than the detailed, place-based knowledge held by local experts. Such information is indispensable for scientific models that can support adaptive decision-making. For example, static bay beach concept is a theory from the field of coastal engineering that can be used to predict a stable beach form given information about wave direction and bathymetry. If the shifted erosion regime in Webb Bay is attributable to nearshore sediment transport processes, the predicted stable planform geometry of the beach can be modelled to estimate the magnitude and time frame of erosional adjustment. Model parameterization, and a reality-check of the model predictions, can be informed by local knowledge. The resulting information can feed directly into adaptive planning and decision-making. This and other theories can be used to model erosion mitigation measures prior to implementing them, a crucial planning step as coastal engineering often exacerbates the very problems it seeks to alleviate.

How Nunatsiavut is Moving the Needle Toward Community Relevant Research

We conclude by emphasizing that the collaboration underpinning this research cannot be ascribed solely to the individuals involved. Rather, the sovereignty structures present in Nunatsiavut make it possible to centre people and place in the research design. To do scientific work within Nunatsiavut, researchers submit an application to the Nunatsiavut Government Research Advisory Committee for review. This committee determines the project's value to Nunatsiavut, ensures that it does not replicate previous work, and determines what permits will be required. It also asks for communication strategies and training or employment opportunities that connect community members to the research. There are dozens of ways in which the Nunatsiavut Government (NG) research staff can help to improve research outcomes. In our experience, this has included making connections with researchers doing relevant work, providing accommodation in the research centre, advising on practical issues related to the region, and supporting field work.

It is hard to imagine a research project in Nunatsiavut being successful without the help of community members and the NG

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research staff. Each community has a distinct geography, ecosystem, environmental concerns, and social context. There are quirks to the availability of food, transportation, accommodation, and research support. However, the role of the ITK and NG researchers is not to ensure "successful" research outcomes as defined by investigators and funding agencies from outside the region. It is about course-correcting from the serious historic harms of colonial research.

Western academics and institutions have a long and problematic history of extractive research on Indigenous lands. ITK clearly defined this problem and its far-reaching consequences in the *National Inuit Strategy on Research*: "The relationship between Inuit and the research community is replete with examples of exploitation and racism. Research has largely functioned as a tool of colonialism, with the earliest scientific forays into Inuit Nunangat serving as precursors for the expansion of Canadian sovereignty and the dehumanization of Inuit. Early approaches to the conduct of research in Inuit Nunangat cast Inuit as either objects of study or bystanders. This legacy has had lasting impact on Inuit, and it continues to be reflected in current approaches to research governance, funding, policies, and practices." This statement reflects a perspective shared by many Indigenous communities globally.

In her 2015 memoir, *The Right to Be Cold*, Sheila Watt-Cloutier writes: "The future of Inuit is the future of the rest of the world – our home is a barometer for what is happening to our entire planet." Beyond their positionality on the frontlines of global environmental change, Inuit have positioned themselves as leaders in decolonizing research. That groundwork has produced examples of the fruitful ways in which combining knowledge approaches can bridge the gaps limiting our ability to address rapid environmental change. Even as the sovereignty of many Indigenous peoples remains unrecognized by colonial or settler governments, researchers and their affiliate institutions can shift their research modalities to affirm the autonomy and dignity of displaced, marginalized, or colonized communities. Prior decades of climate change research have made one thing very clear: new modalities are needed if we are sincere about addressing the "wicked" problems posed by climate change.



Dr. Emma Harrison is a postdoctoral fellow in the Department of Oceanography at Dalhousie University. She obtained a PhD in earth sciences from Scripps Institution of Oceanography at the University of California, San Diego, and held a previous postdoctoral appointment in geological sciences at Stanford University. Dr. Harrison is interested in decolonizing methodologies and research justice as science praxis. Her current work supports community-engaged monitoring of changes in the coastal marine environment of Nunatsiavut, in northern Labrador, as a member of a research collaboration between the Ocean Frontier Institute and the Nunatsiavut Government called Knowledge Co-Production and Transdisciplinary Approaches for Sustainable Nunatsiavut Futures. She co-founded the Center for Interdisciplinary Environmental Justice (@Decolonize4Climate), an organization that works for decolonial environmental justice and non-extractive climate change solutions. Her previous research in the field of geomorphology focused on the development of new geochemical applications to trace sediment transformation and transport in soils, hillslopes, rivers, and coasts.



Ronald Webb is an Inuk member of the Nunatsiavut community based in Nain, Nunatsiavut. Mr. Webb is well respected for maintaining traditional Inuit knowledge and values, as well as for his long history of contributions to research and community development. He currently serves on the board of the Torngat Secretariat, the organization that manages and implements the Torngat Wildlife and Plants Co-Management Boards. He was a co-owner of Sikumuit Environmental Monitors, Ltd., an Inuit business that does environmental monitoring in relation to numerous large-scale development projects in Nunatsiavut and surrounding regions. Within this organization, Mr. Webb has monitored the Voisey's Bay ship track, conducted ice and wildlife monitoring/surveying through combined Inuit and scientific approaches, conducted bear monitoring and shipping advising on the Saglek Remediation Project, conducted baseline

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environmental surveys for the Voisey's Bay Nickle Mine, and led a socio-economic monitoring program in Nain, among other activities. Prior to the Labrador Inuit Land Claims Agreement, he performed many of these duties as a member of the Labrador Inuit Association, the predecessor of the Nunatsiavut Government. He has experience as a trucker and commercial fisherman, and is a lifelong hunter and trapper. Webb Bay is his familial and ancestral home.



Dr. Susan Ziegler is a professor of earth sciences at Memorial University in Newfoundland and a Canada Research Chair in boreal biogeochemistry. She obtained a PhD in marine science from the University of Texas at Austin in 1998 followed by a postdoctoral fellowship at the Carnegie Institution of Washington and an assistant professorship at the University of Arkansas in biological sciences. Her research involves the use of biomarkers and stable isotopes to track elements as they cycle through aquatic and terrestrial ecosystems, in order to understand how ecosystems function and respond to environmental change. She enjoys working within those ecosystems closer to home enabling observations over time. This has led to her establishing the Newfoundland and Labrador Boreal Ecosystem Latitudinal Transect with colleagues as a research platform for investigating carbon cycling, climate change effects, ecosystem functioning, and water quality across a mesic boreal forest climate transect. Her current role as a project lead in a research collaboration between the Ocean Frontier Institute and the Nunatsiavut Government called Knowledge Co-Production and Transdisciplinary Approaches for Sustainable Nunatsiavut Futures now provides her opportunity to learn more about ecosystem understanding from those having longer and deeper experiences with the environment in the region.



Dr. Eric Oliver is an assistant professor of physical oceanography in the Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada. His research interests involve ocean and climate variability across a range of time and space scales including extreme events, the predictability of climate variations, the influence of modes of variability on the ocean, and the role of climate change on the mean state, variability, and extremes of the climate system. He is of Inuit descent with roots in Nunatsiavut (northern Labrador) and is interested in Indigenous perspectives on climate, weather, and the ocean, and understanding both Indigenous and scientific knowledge of these systems.

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Connecting Sailors and Scientists to Monitor the Pulse of the Changing Arctic

by Daniel F. Carlson, Pippa Pett, Nicolas Peissel, Charles-Olivier Bonnardeaux, and Giuseppe Suaria

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The number of sailing yachts that are venturing into Arctic waters has increased in the past decade. As a result, the sailing community has the potential to transform observational studies in the region. Long-term, cross-border engagement strategies are necessary to transition to a persistent and organized presence of sailing citizen scientists in the Arctic. In addition to tapping the well of citizen science, sailboats can provide scientists with affordable, flexible, and sustainable research platforms.

The Arctic region encloses a vast marine area that includes a quarter of the world's continental shelf and over a third of the global coastline. Despite its remote location and harsh weather conditions, the Arctic continues to capture the attention of industries, governments, and adventurers alike. Whether attracted by the vast untapped reserves of natural resources, strategic military installations, or simply the thrill of venturing into the untamed and unforgiving ice-infested fiords, more and more eyes are looking northward.

The fact that the recent surge in interest in the Arctic coincides with rapid climate change is no coincidence. Recent findings from the Arctic Monitoring and Assessment Programme show that climate warming is causing the Arctic to change at a rate that exceeds the global average by nearly a factor of four. The warming Arctic has seen subsequent reductions in the extent and thickness of sea ice. The loss of sea ice is opening up more areas for exploration. The emergence of seasonally ice-free areas has piqued the interests of multiple industries, including defence, shipping, oil and gas, mining, fisheries, and cruise ship tourism.

While reduced sea ice may present opportunities for economic development in the Arctic, these activities are not without risk. Enhanced ship traffic increases the likelihood of oil spills that, due to the remoteness, harsh weather, and lack of infrastructure, could result in an ecological disaster. Additionally, governance issues concerning natural resource ownership and extraction, as well as pollution response still remain. As a result, industrial expansion in the Arctic could pose a threat to regional and global stability.

In addition to the geo-eco-political impacts of industrial expansion in a sea ice-free Arctic, climate warming is driving rapid change in coastal systems. Permafrost thaw, sediment-laden freshwater runoff, and erosion are rapidly reshaping coastal margins. In some regions, permafrost cliffs are collapsing completely, resulting in rapid coastline retreat. The destabilization of Arctic coasts threatens current inhabitants and critical infrastructure, as well as cultural heritage that helps link Indigenous peoples to their ancestral roots.

Unfortunately, what happens in the Arctic does not simply stay in the Arctic. The Greenland Ice Sheet is losing mass at an alarming rate, threatening coastal cities and their inhabitants around the world with rising sea levels. Wildfires in temperate and boreal forests, also exacerbated by climate change, deposit ash onto the Greenland Ice Sheet, reducing its albedo and further increasing melt rates and subsequent freshwater fluxes into the ocean. Changes in the atmosphere over the Arctic also propagate to lower latitudes, driving storms, flash floods, and other weather extremes, sometimes with fatal consequences.

Mitigating the consequences of a rapidly changing Arctic requires a comprehensive scientific understanding of the atmospheric, oceanic, aquatic, terrestrial, and cryospheric systems. Furthermore, adaptation and mitigation strategies must also consider the linkages and feedbacks between the aforementioned systems, as well as teleconnections between the Arctic and lower latitudes.

While our understanding of the changing Arctic is constantly improving, the scientific community relies heavily on numerical models and remote sensing data. In-situ observations

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are essential to calibrate and validate simulations and satellite data. Additionally, detailed observation-based studies of specific processes are required to close critical knowledge gaps. Observational platforms, like scientific research vessels and land-based research stations, are limited in number and access to them is highly competitive and expensive. Therefore, despite intensive efforts by the Arctic scientific community, the observational "footprint" in the region is relatively small.

One way to increase the number and distribution of in-situ observations in the Arctic is to engage the sailing community in data collection. The number of sailboats venturing northward to places like Greenland, Iceland, Svalbard, and the Northwest Passage has increased in recent years. Sailboats are affordable, sustainable, and agile research platforms. Sailboats obviously cannot replace research vessels but they can be used to conduct detailed process studies that are difficult to conduct on board traditional research vessels. When compared to research vessels, which often plan out stations and sampling plans months before the cruise, sailboats are especially useful for adaptive studies. Their relatively small size may seem like a limitation but sailboats are highly manoeuvrable, allowing them to weave between the ice to enter areas that are usually avoided by larger research vessels. Their small size also makes them ideal for individuals and small teams of scientists.

For example, sailboats are ideal platforms for studies of iceberg drift and melt. Briefly, icebergs account for up to 50% of the mass loss from the Greenland Ice Sheet and the drift and deterioration of icebergs must be understood in order to model and predict iceberg impacts on ocean physics, biogeochemistry, and marine ecosystems. Iceberg melt studies are difficult to conduct on traditional research vessels, which typically include eight to 12 scientists with different, and often conflicting, research goals and demands on schedules and equipment. Drifting icebergs are notoriously uncooperative and may not appear as scheduled in the cruise plan.

Therefore, the sailboat *Exiles* was used to conduct an iceberg melt study in Greenland in July 2022 (Figure 1). *Exiles* sailed from Corner Brook, Newfoundland and Labrador, to southern Greenland, meeting many other Greenland-bound sailboats along the way. Once in Greenland, the deck was converted into a drone landing pad. A target iceberg was selected and drone imagery was used to produce a detailed 3D model of the iceberg sail. The sail volume can be used to estimate the mass of the entire iceberg and repeated drone surveys can be used to estimate the rate at which the iceberg is losing mass. In addition to this recent iceberg survey, sailboats have been used for hydrographic measurements in fiords around Greenland, coastal surveys of shallow macrophytes and beach-cast litter, and studies of cod recruitment, among others.

In addition to serving the needs of individual researchers, the scientific impact of Arctic sailors could be enhanced through the development of a dedicated citizen science program. Such a program would educate sailors about the needs of Arctic researchers and train them in data collection techniques and in recording relevant metadata, thereby ensuring that their observations meet FAIR (findability, accessibility, interoperability, reusability) data standards. The observational capabilities of the Arctic science community, therefore, can be enhanced by fostering engagement with the sailing community.

The development of a standardized instrument package that is tailored for use on sailboats and in Arctic conditions could ensure consistency between measurements while also simplifying training requirements for operators and data processing algorithms. Such an instrument package could, for example, include a multi-probe device to measure temperature, salinity, chlorophyll-a,

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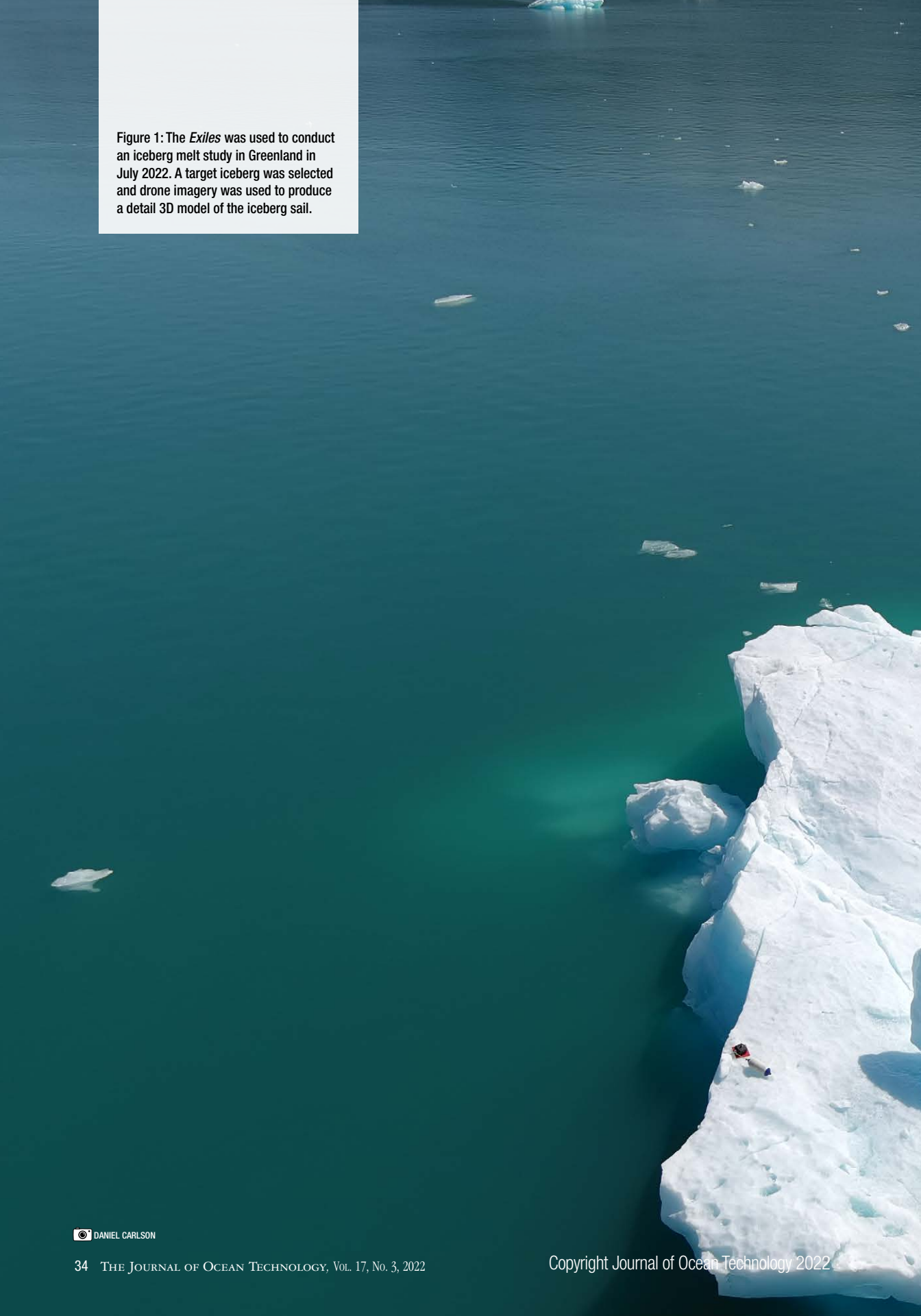


Figure 1: The *Exiles* was used to conduct an iceberg melt study in Greenland in July 2022. A target iceberg was selected and drone imagery was used to produce a detail 3D model of the iceberg sail.

DANIEL CARLSON

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turbidity, and photosynthetically active radiation in the upper 50-100 m of the water column as well as Lagrangian surface drifters, which record the movement of water parcels and buoyant objects by ocean currents. Furthermore, the Arctic sailing community could also be connected with the open source marine robotics community to drive the development of innovative and affordable unoccupied observation platforms for Polar Regions.

Developing effective strategies to adapt to climate change, especially in the rapidly changing Arctic, should make use of every possible opportunity. The sailors who decide to trade the hedonistic pleasures of sandy tropical beaches and coral reefs for the ice-infested waters of the Arctic often do so to witness and experience climate change firsthand. These sailors often reach out to scientists and/or scientific institutions, hoping to contribute to ongoing research efforts in the region. For the sailors who are able to obtain the necessary equipment and training, contributing to research gives their voyages an extra sense of purpose. Through engagement with the Arctic sailing community, we can improve our understanding of the impacts of climate change in a very complex environment while enriching stakeholders.



Dr. Daniel Carlson is an oceanographer, remote sensing specialist, sailor, and concerned citizen. He enjoys tackling important problems with new observational approaches. He has led field campaigns in Greenland, the Gulf of Mexico, and the Red Sea; and authored 29 peer-reviewed articles on a wide range of subjects, from seagrass mortality in Florida Bay to Norse archaeology in Greenland.



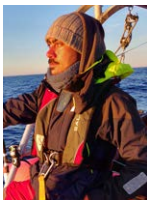
Dr. Pippa Pett trained as an internal medicine physician and intensive care doctor at Guys and St Thomas' Hospital in London, and has worked in hospitals in India, Uganda, and Tanzania, as well as a solo medic in conflict zones for Médecins Sans Frontières.



Nicolas Peissel is a humanitarian aid worker with Médecins Sans Frontières and an avid sailor. In addition to the recent scientific expeditions to western Greenland, he has captained multiple sailing vessels through the Northwest Passage. His expeditions have been recognized by influential organizations and environmental figures, including The Explorers Club, Royal Canadian Geographic Society, Climate Reality Project, and former United States Vice President – and Nobel Laureate – Al Gore.



Charles-Olivier Bonnardeaux has a life-long passion for sailing and adventure. Originally from Montreal, he now travels the world teaching sailing to at-risk youth as captain of a traditional gaff-rigged ketch for EcoMaris. He has recently participated in missions in the Canadian Arctic and Greenland.



Dr. Giuseppe Suaria is a research scientist at the Institute of Marine Sciences of the Italian Research Council in Lerici, Italy. He has been working since 2013 on the spatial and temporal patterns of abundance, distribution, composition, transport, and accumulation of anthropogenic litter in the marine environment as well as on the harmonization and inter-calibration of survey methods and sampling techniques for macro and microplastics. He has authored more than 25 international publications about plastic pollution in the marine environment and has participated in more than 25 research expeditions in Antarctica, the Arctic, the Atlantic Ocean, the Mediterranean, and the Black Sea, totalling well over 650 days of field work at sea. In 2017, he had an active role during the Antarctic Circumnavigation Expedition, being responsible for sampling microplastics during the entire voyage.

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Peer-Reviewed Papers



The Changing Iceberg Regime and Links to Past and Future Climate Change Offshore Newfoundland and Labrador

Tony King and Ian D. Turnbull

Changing Iceberg Regime



Tony King



Dr. Ian D. Turnbull

King and Turnbull explain how observed changes in iceberg characteristics are linked to changes in the air and sea surface temperature, significant wave height, and sea ice climate regime.

Who should read this paper?

People in the offshore oil and gas industry should read this paper as it has implications for future exploration and production activities in terms of reduced iceberg risk, including surface structures and subsea facilities. This work would be of particular interest to proponents of any export gas pipeline(s). The expected change in the iceberg regime will also result in reduced risk for the shipping industry. The changes to the environment that will affect the future iceberg regime will also have profound implications for the fishing and aquaculture industries, and changes shown here should be considered further in this perspective. Government initiatives regarding climate change adaptation should also consider the results shown here.

Why is it important?

This work considers the change in the iceberg regime on the Grand Banks during two periods, the 1980s and 2000-2020, in terms of iceberg groundings in the Jeanne d'Arc Basin. The change in the iceberg regime agrees well with the change estimated using a simple model with measured iceberg characteristics as inputs (size, geometry, frequency, drift). This change correlates with changes in metocean conditions during the two periods that would result in increased iceberg melting rates. These results indicate that future changes in the metocean regime, based on climate modelling, will lead to a milder iceberg regime offshore Newfoundland and Labrador, which will significantly impact a number of offshore activities and industries. This work is innovative in that it combines data and models from different sources to obtain a consistent framework for explaining observed changes in the iceberg regime and provides a basis for extrapolating these changes to the future. The results may serve to raise awareness that climate-related changes in the environment are not theoretical, but are already underway. The results can serve to benefit the ocean community by confirming the need to use the most recent data, reflecting current conditions, rather than longer time frames (i.e., 30 years or longer), and to continue the collection and analysis of data in order to best characterize the offshore environment and utilize projections to anticipate future conditions. The results of the work may be of use to the shipping, fishing, aquaculture, and offshore oil and gas industries, in terms of helping to best characterize current iceberg risk to operations, as well as future trends.

About the authors

Tony King, M.Eng., P.Eng., PMP, has over 20 years' experience in the ice engineering field and has been director of C-CORE's Ice and Ocean Engineering Group for the past 10 years. He has a background in risk analysis, probabilistic methodologies, and numerical modelling, and has performed ice risk analyses for subsea assets in most ice-prone regions of the world. He obtained both undergraduate and master degrees from Memorial University's engineering program. Dr. Ian D. Turnbull, PhD, P.Geo., PMP, is an ice researcher in the Oceans and Energy group at C-CORE. He received his PhD in geophysics from the University of Chicago in 2008, in which he researched atmospheric pressure gradient forcing on the dynamics of large, tabular Antarctic icebergs. He has expertise in physical oceanography and modelling, and he has more than 10 years of experience in offshore and metocean operations, analysis, and modelling.

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THE CHANGING ICEBERG REGIME AND LINKS TO PAST AND FUTURE CLIMATE CHANGE OFFSHORE NEWFOUNDLAND AND LABRADOR

Tony King and Ian D. Turnbull
C-CORE, St. John's, N.L., Canada; tony.king@c-core.ca; ian.turnbull@c-core.ca

ABSTRACT

Recent research on iceberg subsea risk modelling has produced strong evidence for changes in the iceberg regime in the Grand Banks region that are likely to have significant implications for development activities offshore Newfoundland and Labrador. An analysis of iceberg trajectory data from 2000 onwards [C-CORE, 2020] shows a significant decrease in iceberg grounding rates on the Grand Banks when compared to an analysis of 1980s data [Banke, 1989]. Iceberg profile data collected since 2012 shows distinct changes in the length-draft relationship when compared to data collected in the 1980s [Bruce et al., 2021]. These changes, along with analysis of other relevant parameters such as iceberg frequency, geometry, and drift speed, show that the change in iceberg grounding rates is consistent with observed changes in iceberg characteristics. In this paper, the observed changes in iceberg characteristics between the 1980s and 2000-2020 are linked to changes in the air and sea surface temperature, significant wave height, and sea ice climate regime offshore Newfoundland and Labrador over this period. Projected further changes in these variables to 2050 are explored using output from a climate model. These changes will have significant implications for iceberg risk to both subsea and surface facilities, and are likely part of an ongoing trend that will continue to decrease iceberg presence and risk in the region.

KEYWORDS

Icebergs; Iceberg deterioration; Offshore Newfoundland and Labrador; Climate change

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1. INTRODUCTION

Icebergs that occur off the coast of Newfoundland and Labrador (N.L.), Canada, originate primarily from western Greenland glaciers (Figure 1). These icebergs pose a hazard to marine activities such as fishing, shipping, and hydrocarbon exploration and production. Icebergs can contact (ground on) and scour the seabed, potentially contacting facilities such as subsea wells, flowlines, pipelines, and cables. Quantification of surface facility and subsea risk requires data such as iceberg frequency, iceberg size distribution, geometry, and drift speeds. Collection and documentation of iceberg data are required during exploration and production activities offshore N.L. A significant dataset was collected during exploration activities in the 1980s. There was very limited activity during the 1990s, but recent production activities have resulted in a rich dataset from 2000 onwards. Recent work on subsea risk modelling [C-CORE, 2020] revealed differences in the two iceberg datasets that will be described here.

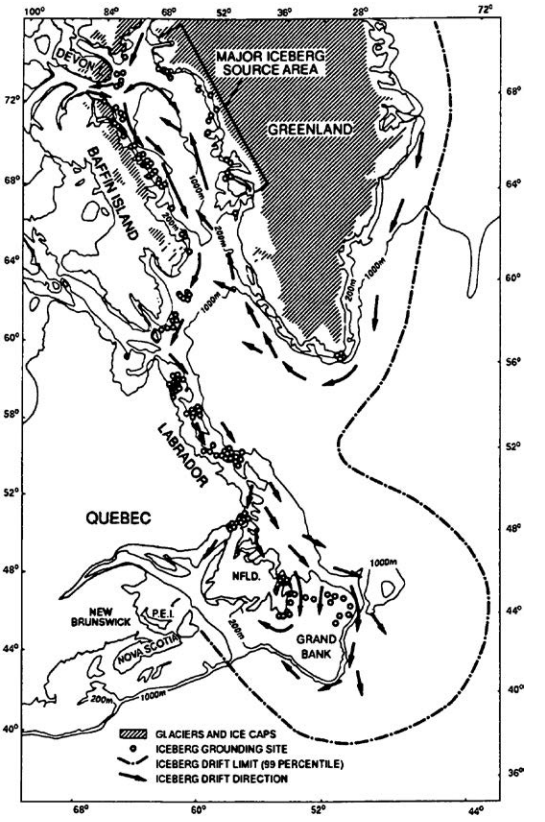


Figure 1: Iceberg source, drift pattern, and known grounding sites off Greenland and Eastern Canada [Lewis and Blasco, 1990].

The presence and nature of icebergs off Canada's east coast is primarily a function of the number and physical characteristics of icebergs calved from the source glaciers along the west coast of Greenland, as well as deterioration during the transit to offshore N.L. Fortunately, historical data regarding metocean parameters which affect iceberg deterioration (i.e., pack ice concentration, air temperature, water temperature, and sea state) are available from a variety of sources, allowing correlations to be made between changes in these parameters and observed changes in the iceberg regime. Modelled long-term projected trends in these parameters may also provide a clue to future changes in the iceberg regime. Currently, there are limited data available on the iceberg characteristics (i.e., numbers, length distribution, geometry) when they calve from the glaciers, and even less on long-term changes in these parameters. Identifying reliable sources of these data is an area of ongoing research as part of a larger effort to develop a "source-to-sink" model for projecting future trends in the iceberg regime for offshore N.L.

In this paper, changes in the iceberg regime offshore N.L. are explored between the 1980s and post-2000, in terms of an overall decrease in iceberg draft for a given waterline length. These changes are linked to changes in the

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regional climate regime in terms of the surface air and sea temperatures, sea state, and pack ice presence. Future projected regional trends in these variables are additionally explored through analysis of climate model output for 2021-2050, which suggest the changes observed in the regional iceberg regime are likely to continue and possibly amplify. The paper is organized as follows: Section 2 discusses changes in the observed iceberg waterline length to draft relationship, Section 3 discusses changes in the iceberg grounding rates observed on the Grand Banks, and Sections 4-6 discuss the changes in the iceberg waterline length, regional iceberg occurrence frequency, and iceberg drift speeds, respectively. Section 7 discusses changes in the iceberg grounding rates on the Grand Banks, Section 8 discusses changes in the regional climate and their potential links to enhanced iceberg deterioration rates, and Section 9 provides conclusions and recommendations for further work.

2. ICEBERG WATERLINE LENGTH-DRAFT RELATIONSHIP

An initial indication of changes in the iceberg regime was a shift in the iceberg waterline length-to-draft relationship. Iceberg waterline length is defined as an iceberg's maximum horizontal dimension at the waterline and draft is the distance between the waterline and deepest point on the keel. Recent field programs funded by the Hibernia Management and Development Company Ltd. have resulted in a fairly substantial dataset of iceberg profiles. An iceberg profiling field program conducted in 2012 [Younan et al., 2016] resulted in 28 high-resolution three-dimensional (3D) iceberg profiles. Analysis of these data indicated shallower drafts than observed during 1980s field programs, but there was uncertainty in the validity of this conclusion due to the limited sample size. An assessment of the usefulness of iceberg profiles for ice management applications [Bruce et al., 2016] prompted the initiation of development of the Smart Ice Management System, or SIMS [McGuire et al., 2016]. SIMS includes an iceberg profiling system comprised of multibeam and LiDAR systems to collect data on iceberg keel and sail geometry, respectively. The SIMS software cleans the data and makes corrections for iceberg drift and rotation during the profiling process, which takes approximately 15-30 minutes, depending on the iceberg size and vessel manoeuvrability. The resulting data can then be used for stability analysis and net fit (to avoid iceberg rolling or net slippage during towing, respectively), iceberg loads analysis (to assess threats to facilities), drift modelling, and subsea and facility topside risk assessments [Bruce et al., 2021]. Approximately 200 3D iceberg profiles have been collected as a result of SIMS development (including the 2012 data), the majority during the 2019 field program during which 132 icebergs were profiled. When these data are compared with data collected in the 1980s, they tend to show shallower iceberg drafts for a given waterline length (e.g., see Figure 2), supporting the initial observation using the 2012 data.

3. ICEBERG GROUNDINGS BASED ON TRAJECTORY ANALYSIS

C-CORE [2020] assessed uncertainties associated with iceberg risk analyses for subsea facilities, part of which included an analysis

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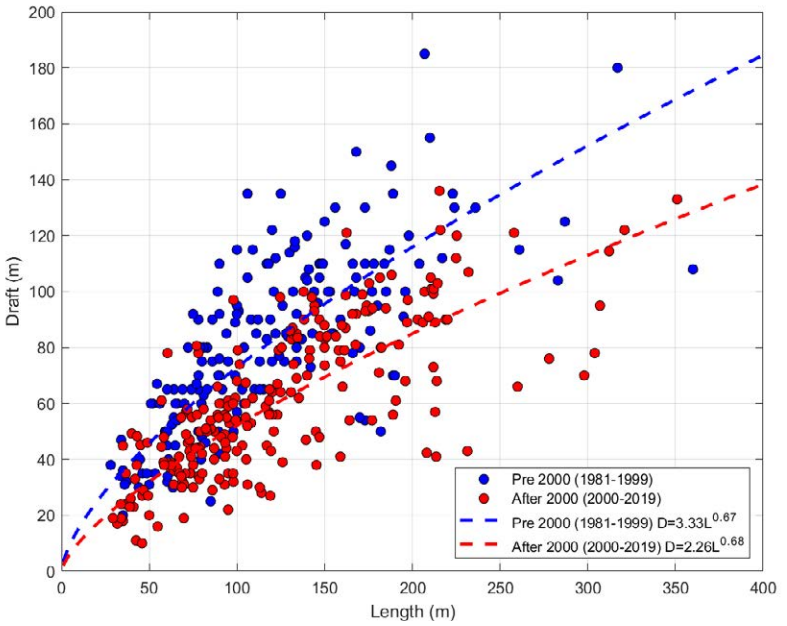


Figure 2: Comparison of iceberg waterline/draft relationships for iceberg datasets [Bruce et al., 2021].

of iceberg trajectory data. El-Tahan et al. [1985] proposed criteria for classifying iceberg grounding events based on the duration for which an iceberg is observed to be immobile. An iceberg with a period of immobility equal to or greater than 24 hours was defined as a "positive" grounding. An iceberg with a period of immobility equal to or greater than six hours and less than 24 hours was classified as a "probable" grounding. These events may be subjected to a more in-depth analysis considering factors such as the movement of other nearby icebergs, environmental forces producing low velocity, and measured draft compared to water depth, after which the grounding event may be classified as a positive grounding, a probable grounding, or no grounding. For simplicity, only positive groundings were considered in the trajectory analysis [C-CORE, 2022]. For the purpose of comparison with the 1980s trajectory dataset, this was considered sufficient, since the objective was to identify differences between the datasets, rather than to estimate grounding or scour formation rates.

Banke [1989] assessed iceberg trajectory data collected from 1983-1989 during exploration drilling on the Grand Banks and identified 44 iceberg grounding events over a seven-year period based on the criteria of one day of immobility (e.g., see Table 1). An analysis of iceberg trajectory data from 2000-2021 showed 21 iceberg grounding events over the 22-year period (e.g., see Table 2), using the same criteria and over the same approximate area (e.g., see Figure 3). This represents a factor of 6.6 decrease in the grounding rate between the two periods. This change increases to a factor of nine if only using the last 20 years of available trajectory data (2002-2021), since seven of the more recent grounding events meeting the one-day immobility criterion occurred in 2000. It is notable that the mean iceberg waterline length in 2000 was greater than following years, more in line with 1980's data [King, 2021]. Also of interest is a shift in the water depths at which the grounding events occurred, with mean water depths of 97.5 m and 87 m for the 1983-1989 and 2000-2021

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Table 1: Iceberg grounding events from Banke [1989] iceberg trajectory analysis.

Year	Number of Icebergs Tracked	Grounding Events (≥ 24 hours duration)
1983	736	10
1984	112	9
1985	234	8
1986	35	0
1987	39	2
1988	18	13
1989	Not available	2
Total	> 1,174	44

Table 2: Iceberg grounding events from analysis of Grand Banks iceberg trajectory data, 2000-2021.

Year	Number of Icebergs Tracked	Grounding Events (≥ 24 hours duration)	Year	Number of Icebergs Tracked	Grounding Events (≥ 24 hours duration)
2000	77	7	2011	0	0
2001	0	0	2012	112	0
2002	100	2	2013	0	0
2003	264	3	2014	98	3
2004	18	0	2015	212	3
2005	1	0	2016	103	0
2006	0	0	2017	91	0
2007	11	0	2018	14	0
2008	84	0	2019	113	2
2009	182	1	2020	28	0
2010	0	0	2021	0	0
Total				1,508	21

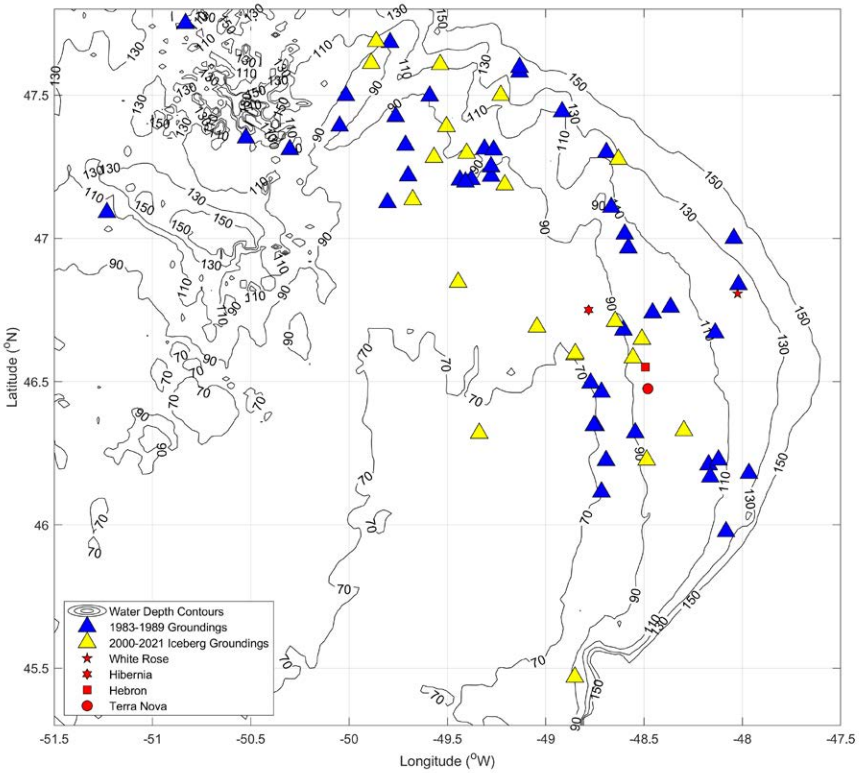


Figure 3: Iceberg grounding events identified based on one day of immobility criterion.

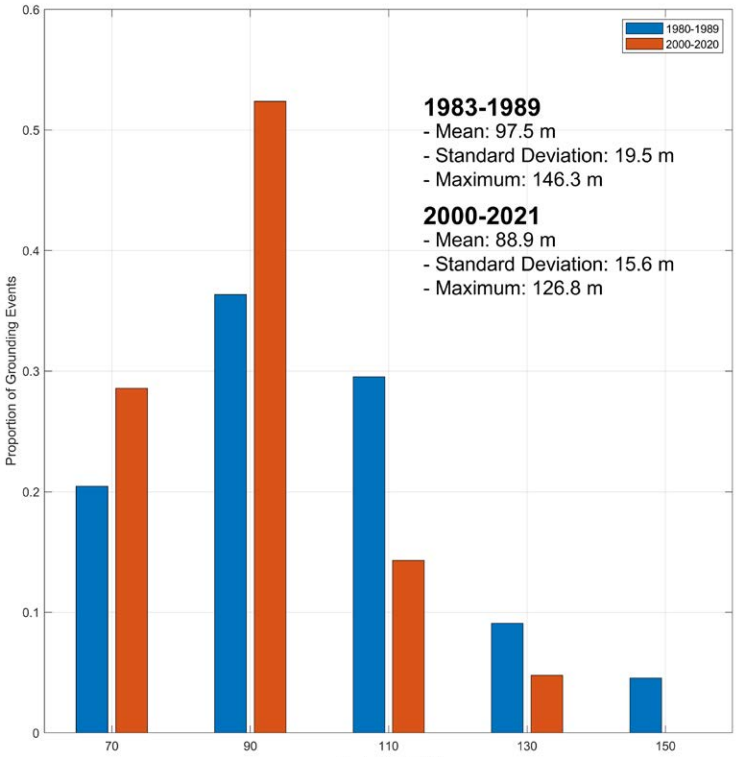


Figure 4: Water depths for iceberg grounding events meeting the one-day grounding criterion.

datasets, respectively (e.g., see Figure 4). This change is consistent with the observation of reduced iceberg drafts.

4. ICEBERG WATERLINE LENGTH

Data collected on the Grand Banks during the 1980s showed that iceberg waterline lengths during that period were well characterized by an exponential distribution with a mean of 59 m [Jordaan et al., 1995]. A more recent analysis of iceberg waterline length data collected on the Grand Banks from 2000 onwards showed that iceberg waterline lengths still followed an exponential distribution, but with a mean of just over 50 m [King, 2021]. The analysis of the more recent iceberg data excluded ice islands or the ice island fragments, defined as icebergs with a waterline length to sail height ratio greater than 15. This was deemed appropriate when considering iceberg grounding events since ice islands and ice island fragments generally have shallow drafts and are unlikely to ground on the seabed on the Grand Banks. Icebergs meeting the ice island/fragment criterion were virtually absent from the 1980s dataset (two out of 889 icebergs, or 0.2%), but more frequent from 2000 onwards (64 out of 1,116 icebergs, or 5.7%). A comparison of the two datasets is shown in Figure 5.

5. ICEBERG FREQUENCY

Iceberg frequency may be characterized using two approaches, flux and average areal density. Iceberg flux is the number of icebergs crossing or passing across or through a specified feature (e.g., a degree latitude, longitude, or a degree square) over a certain period. The average iceberg areal density is the number of icebergs that are observed

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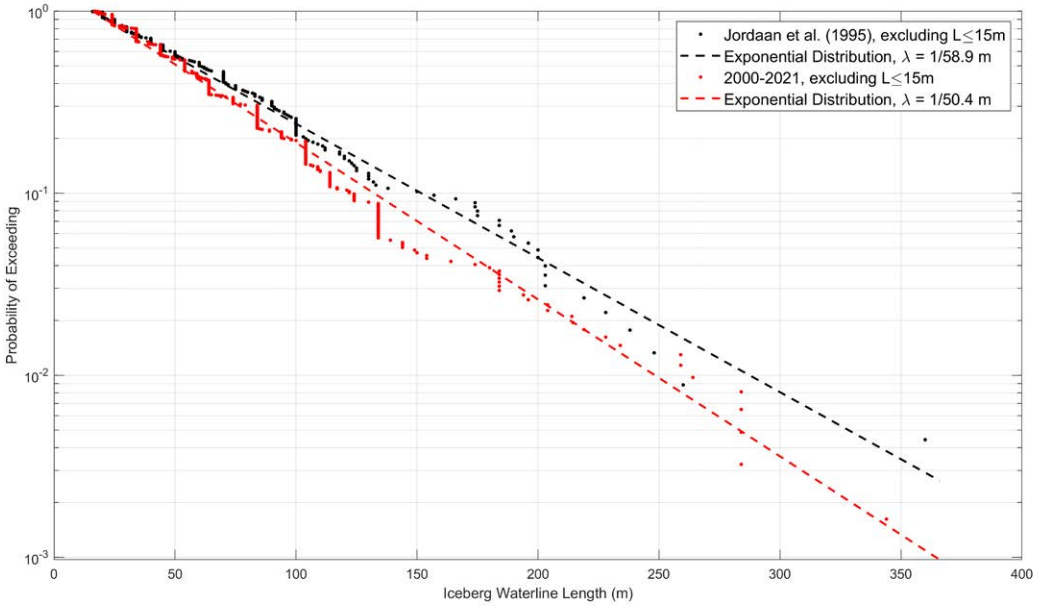


Figure 5: Iceberg waterline length distributions, pre-2000 [Jordaan et al., 1995] and 2000 onwards.

in a specified area (i.e., a degree square), averaged over an extended period.

The International Ice Patrol (IIP) has records of the annual number of icebergs crossing 48°N (just north of the Grand Banks) back to 1900. Figure 6 shows iceberg flux from 1980 onwards. The mean iceberg flux across 48°N from 1983 to 1989, corresponding to the Banke [1989] analysis, was 804 icebergs per year. The mean iceberg flux across 48°N from 2000 to 2021 was 560 icebergs per year (a reduction of 30%). Iceberg bulletins that provide the number of iceberg sightings per degree are also produced by the IIP and cover the time periods of interest. Iceberg bulletins were analyzed to calculate average iceberg areal densities in the degree square bounded by 46°N-47°N and 48°W-49°W, which encompasses all existing production facilities in the Jeanne d'Arc Basin on the Grand Banks (e.g., see Figure 3). An analysis of charts from 1982 to 1989 gives an average annual iceberg areal density of 1.73×10^{-4} km^{-2}, without applying any correction factors for misdetection of icebergs (i.e., missed icebergs) or bergy bits and growlers. An analysis of the same degree square for 2000-2021 gives an average annual iceberg areal density of 1.25×10^{-4} km^{-2} (a reduction of 27%). A more recent analysis of iceberg sighting data from aerial reconnaissance and satellite imagery [C-CORE, 2022] gives an average annual iceberg areal density of 4.9×10^{-5} km^{-2} which suggests potentially a more substantial reduction in iceberg areal density.

6. ICEBERG DRIFT SPEED

Iceberg drift speeds are calculated using data collected by industry during exploration and production activities. Calculated mean iceberg drift speeds excluded sightings when icebergs were towed or grounded (i.e., a drift speed of zero). Intervals between sightings used to calculate drift speeds were restricted to

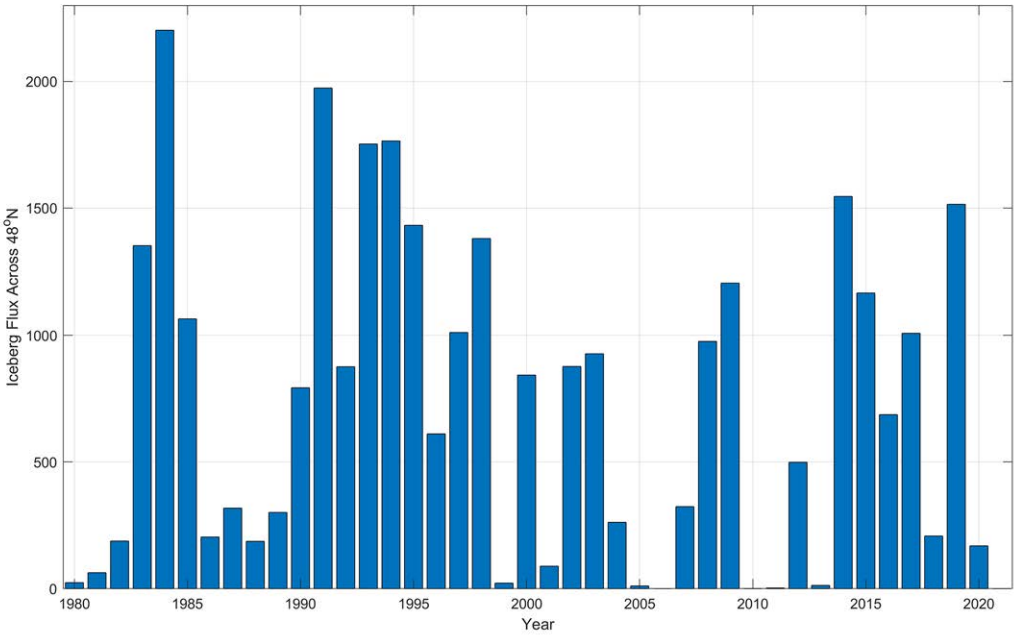


Figure 6: Iceberg flux across 48°N (International Ice Patrol).

30 minutes to 3.5 hours, and data were also restricted to those collected in the degree square bounded by 46°N-47°N and 48°W-49°W. The mean drift speed for the 1980s data was 0.35 ms^{-1} (984 data points), while the mean drift speed for data collected in 2000 and later was 0.31 ms^{-1} (5,324 data points), a reduction of 12%. The reason for this difference is unknown and still subject to investigation.

7. CALCULATED CHANGES IN ICEBERG GROUNDING RATES

Expected changes in iceberg grounding rates based on changes in iceberg parameters described previously can be estimated using a geometric iceberg grounding model presented by King et al. [2003]. Iceberg grounding rates may be estimated as follows [King, 2002; King et al., 2003]:

$$\rho_g = \frac{1}{\pi} r_d n_o S \overline{U}, \quad (1)$$

where ρ_g is the iceberg grounding rate per unit area of seabed, r_d is the proportion of iceberg keels with drafts deep enough to be within one metre of the seabed, n_o is the annual average areal density of icebergs, S is the seabed slope, and $\overline{U}$ is the mean iceberg drift speed.

The value of r_d is a function of water depth, the iceberg waterline length distribution, and the length-draft relationship. For the example given here, the midpoint of the degree square bounded by 46°N-47°N and 48°W-49°W is used, giving a water depth of 94 m. Using the iceberg waterline length distribution and length-draft relationship based on 1980s data gives a r_d value of approximately 0.0040 at 94 m water depth. Using iceberg data from 2000 onwards gives a r_d value of approximately 0.0015, which is a reduction of 63%. The reduction in r_d increases with water depth; for example, increasing to 80% at 140 m water depth.

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In order to estimate the change in grounding rates, it is only necessary to consider the changes in the various parameters using the ratio of the values from 1980s data and 2000 onwards. The seabed slope, S, is constant. The ratios for r_d, n_o, and $\overline{U}$ are 0.375, 0.72, and 0.88, respectively, which when combined give an overall reduction factor of 0.24, or a reduction by a factor of 4 in the iceberg grounding rate at the selected point. This is reasonably consistent with the observed factor of 6.6 decrease in grounding rates from the trajectory analysis, supporting the conclusion that the decrease in iceberg grounding rates is a real phenomenon, resulting from changes in iceberg characteristics. While ice management was used during both periods, improvements in ice management technology may help explain the difference between the observed and calculated reductions in iceberg grounding rates (i.e., a factor of 4 calculated versus 6.6 observed, or 9 using only the last 20 years of data).

8. OBSERVED AND PROJECTED CLIMATE CHANGES OFFSHORE NEWFOUNDLAND AND LABRADOR

In this section, it is argued that the changes observed in the offshore N.L. iceberg regime from the 1980s to the 2000-2020 period are at least partially driven by enhanced deterioration of the icebergs as they drift southward along the Labrador and Newfoundland coastlines to the Grand Banks, and these changes are likely to continue and possibly amplify into the future. The rate of an iceberg's deterioration is the sum of its deterioration rates for its freeboard and keel sections. The deterioration rate of an iceberg freeboard is a function of surface meteorological variables and wave action, while the keel deterioration rate is primarily a function of the water temperature around the keel surface area. Iceberg deterioration has been considered in previous studies through deterministic physical modelling (e.g., see Crawford et al. [2015]; and Kubat et al. [2007]), as well as probabilistic modelling (e.g., see Zeinali-Torbati et al. [2021]).

8.1 Previous Studies on Iceberg Deterioration

A physical model presented in Kubat et al. [2007] considered the following five processes as the main drivers of iceberg deterioration: surface melting due to solar radiation, melting due to buoyant vertical convection, melting due to forced convection, wave erosion, and calving of overhanging slabs. Kubat et al. [2007] identified wave action as the predominant influence on iceberg deterioration, followed by water temperature. Crawford et al. [2015] presented a physical model for surface ablation of a drifting ice island in the Canadian Arctic, and considered the surface energy balance over the ice island freeboard. This research, therefore, only studied the deterioration of the iceberg freeboard, and did not consider the keel ablation. They modelled the surface ablation as a function of the radiative energy fluxes, sensible, and latent heat fluxes. The surface air temperature is a key variable in the longwave radiative and sensible heat fluxes. Crawford et al. [2015] additionally showed the skill in predicting ice island surface ablation using a simple air temperature index melt model, as a function of cumulative positive degree-days, demonstrating the significant impact of air temperature on iceberg freeboard

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deterioration rates. Zeinali-Torbati et al. [2021] identified wind speed, air temperature, water temperature, and wave energy as the main variables affecting deterioration of ice islands in their probabilistic model.

8.2 Data and Methods

Considering this research, the following four metocean variables were investigated for this study as having the most significant impact on iceberg deterioration rates: surface (2 m) air temperature, sea surface temperature (SST), sea ice concentration, and significant wave height. Although iceberg deterioration is driven more significantly by the water temperature down to the iceberg draft, subsurface water temperature data are not available for such a large region over the periods needed for this study. In addition, the depths over which subsurface water temperatures would need to be considered would be highly variable based on the draft of a given iceberg. Therefore, SST was considered in this paper, as subsurface water temperatures are highly coupled to SST through downward vertical ocean mixing and heat advection. Significant wave height was considered in this study as a proxy for sea state, as it represents the average height of the highest one-third of waves in a given wave spectrum. Sea ice concentration was considered as a key variable in iceberg deterioration because the sea ice keeps the water around the icebergs cooler and icebergs surrounded by high sea ice concentrations are protected from wave erosion. In order for waves to be generated, sea ice cover must be sufficiently low to allow wind energy to be transferred to the sea surface. Therefore, low sea ice concentrations or a lack of sea ice altogether would contribute to increased iceberg deterioration via an associated increase in wave energy.

The four variables were studied over a polygonal region of interest (ROI) offshore N.L. similar to that studied in C-CORE [2022], bounded by 44-62°N and 66-41°W (e.g., see Figure 7 through Figure 10). The ROI was divided into 0.5°×0.5° grid "cells" in which metocean variables were spatially averaged, as per C-CORE [2022]. The temporal means of each variable only over March-August (e.g., meteorological spring and summer) were considered, as this represents the main season over which icebergs drift and deteriorate along the N.L. coasts.

Past changes in these four metocean variables offshore N.L. were characterized using the ERA5 Reanalysis dataset (e.g., see Hersbach et al. [2020]), provided by the European Centre for Medium Range Weather Forecasting through the online Copernicus Climate Data Store (CDS). The ERA5 Reanalysis provides global hourly data from 1950-present at 0.25° spatial resolution for most variables, except at 0.5° for ocean wave variables. The March-August means were computed for each grid cell and each of the four variables for the two past periods studied in this paper, 1980-1989 and 2000-2020. Prior to the time-averaging, hourly ERA5 significant wave height data were assumed valid only for points at which the hourly ERA5 sea ice concentration was less than 15%, as this is considered to be a threshold at which sea spray can be generated by wind (e.g., see Jones and Andreas [2013]). If the hourly sea ice concentration was greater than or equal to 15%, the significant wave height was set to zero.

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Projections of climate change produced by climate models cover a large number of different models, each with their own built-in assumptions about global climate sensitivity to increasing anthropogenic greenhouse gas emissions. In addition, the projections from each model cover a range of potential global greenhouse gas emission scenarios into the future. Projected changes in the four selected variables were characterized using output from climate model runs of the latest Coupled Model Intercomparison Project, also from the Copernicus CDS. Means of the four variables for March-August 2021-2050, which corresponds to the next 30-year climatological baseline period, were considered. As it would be beyond the scope of this paper to consider output from all global climate models, the focus was on results from one climate model, the Canadian Earth System Model-Canadian Ocean Ecosystem (CanESM5-CanOE) model. The CanESM5-CanOE climate model has a nominal spatial resolution of 2.8° for atmospheric variables, and 1° for ocean variables. The CanESM5-CanOE climate model provides all variables at a monthly mean temporal resolution. The climate model does not provide projections of significant wave height; however, it provides future projections of wind speed. Therefore, projected monthly mean significant wave height for March-August 2021-2050 was estimated as a function of the projected monthly mean 10 m wind speed as (e.g., see Carter [1982]):

$$H_s = 0.30 \times U_{10}, \quad (2)$$

where H_s is the significant wave height (m), and U_{10} is the wind speed (ms^{-1}) at 10 m above the surface. Similar to the ERA5 data, projected significant wave heights computed for 2021-2050 were set to zero if the projected monthly mean sea ice concentration was greater than 15% in a given grid cell. Since the spatial resolution of the climate model data was coarser than the grid cell resolution at which variable spatial means were calculated, the climate model data were linearly interpolated to the grid cell resolution.

Output from the CanESM5-CanOE climate model are available for four potential future global carbon emissions scenarios, called shared socioeconomic pathway (SSP) scenarios. In each SSP scenario, global mean surface air temperature anomalies are given as relative to global mean surface atmospheric temperature over the pre-industrial era, considered 1850-1900 (e.g., see Allen et al. [2017]). The four SSP scenarios considered in the CanESM5-CanOE climate model output are (e.g., see Januta [2021]):

1. SSP1-2.6, in which the world reaches net-zero carbon emissions just after 2050, and global mean surface air temperatures are projected to stabilize around 1.8°C higher by the end of the 21st century;
2. SSP2-4.5, in which global carbon emissions remain near current levels before starting to decrease just after 2050, and global mean surface air temperatures are projected to rise 2.7°C by the end of the century;
3. SSP3-7.0, in which global carbon emissions reach approximately twice current levels by 2100, and global mean surface air temperatures are projected to rise by 3.6°C by the end of century; and

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4. SSP5-8.5, in which global carbon emissions reach approximately twice current levels by 2050, and global mean surface air temperatures are projected to rise by 4.4°C by the end of century.

It is beyond the scope of this paper to consider all four of the SSP scenarios; hence, the focus was on climate change projections from the SSP2-4.5 scenario. This scenario is currently considered the most likely, based on current trends and future projections in global carbon emissions, and stated policies on emissions reductions (e.g., see Pielke Jr. et al. [2022]).

In addition to examining the past and projected changes in the four metocean variables over the whole N.L. offshore region as outlined in C-CORE [2022], long-term trends in these variables in four selected grid cells located along the typical path of icebergs drifting south along the N.L. coast were considered. These four grid cells would typically capture different stages of an iceberg's deterioration for those icebergs that last all the way to the Grand Banks. Table 3 lists these regions, as well as their region numbers that are marked on the offshore N.L. maps shown in Figure 7 through Figure 10, and the central latitude-longitude coordinates of each grid cell. The long-term trends in each of the four variables at the four selected grid cells are examined in Figure 11 through Figure 14 by computing 10-year moving averages for the March-August 1980-2020 ERA5 data, and for the March-August 2020-2050 climate model data.

8.3 Past and Projected Spring-Summer Climate Change in the Offshore N.L. Region

Figure 7 through Figure 10 show past and projected changes in the offshore N.L. regional March-August mean surface air temperature, sea surface temperature, sea ice concentration, and significant wave height, respectively. Part (a) of each figure shows the difference between the ERA5 2000-2020 March-August mean and the ERA5 1980-1989 March-August mean of the stated variable, and part (b) shows the difference between the variable's SSP2-4.5 projected 2021-2050 March-August mean and its ERA5 2000-2020 March-August mean.

Figure 7a shows that from the 1980s to the 2000-2020 period, surface air temperatures over the offshore N.L. region mostly warmed on average for the spring-summer iceberg season. Air temperatures warmed by an average of 0.7°C over the entire outlined offshore N.L. region, with a maximum warming of nearly 1.8°C in the part of the northeastern section along the outer edge of the North Labrador Shelf (Region 1). Figure 7b shows that changes in spring-summer mean air temperatures are projected to be significantly greater for much of the offshore N.L. region for the spring-summer 2021-2050 period relative to 2000-2020, compared to the recent past changes from the 1980s to the 2000-2020

Region Number	Region	Central Latitude/Longitude
1	North Labrador Shelf	57.7°N/58.4°W
2	South Labrador Shelf	53.7°N/53.4°W
3	Orphan Basin	49.7°N/50.4°W
4	NE Grand Banks	46.7°N/48.4°W

Table 3: Numbered regions considered for climatological changes linked to enhanced iceberg deterioration.

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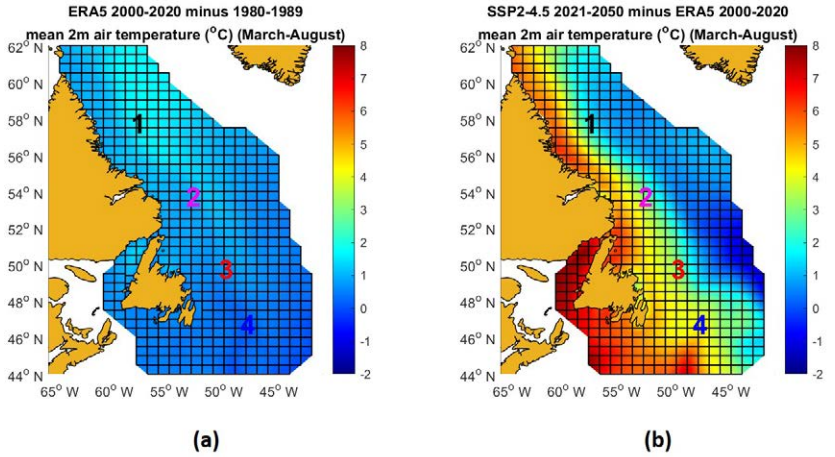


Figure 7: Changes in March-August mean 2 m air temperature offshore N.L. from 1980-1989 to 2000-2020 (a), and from 2000-2020 to (projected) 2021-2050 (b).

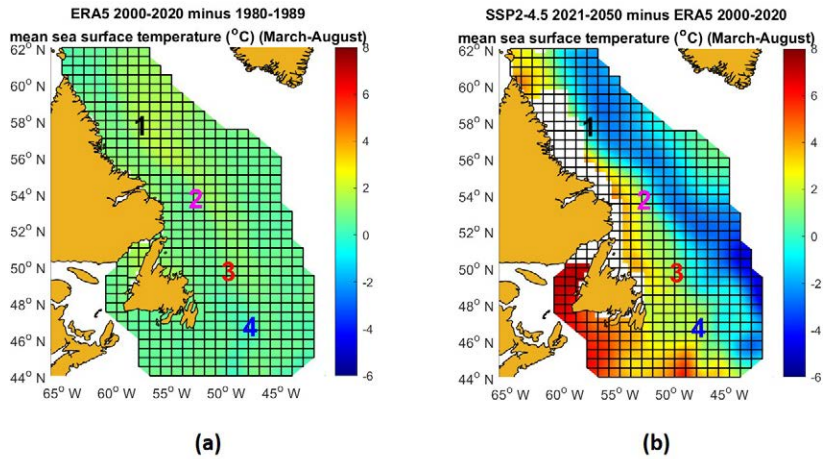


Figure 8: Changes in March-August mean SST offshore N.L. from 1980-1989 to 2000-2020 (a), and from 2000-2020 to (projected) 2021-2050 (b).

period. Average regional air temperatures are projected to rise by an additional 3.8°C for the spring-summer season for 2021-2050 relative to 2000-2020, with a warming of 4-7°C along the main iceberg drift path linking Regions 1-4. However, a sub-region of cooling air temperatures has been observed in the eastern portion of the offshore N.L. region, and the cooling in this region is projected to continue. The cooling in this area has been linked to meltwater from the Greenland ice sheet leading to a slowdown in the Atlantic Meridional Overturning Circulation (AMOC), which has decreased the influx of warm, salty water from the Gulf Stream and replaced it with cold, fresh surface water (e.g., see Rahmstorf et al. [2015]). Surface air temperatures in this region have cooled by up to 0.3°C from March-August 1980-1989 to 2000-2020 (Figure 7a), and are projected to cool by up to an additional 2°C from March-August 2000-2020 to 2021-2050 (Figure 7b). However, this region is outside the main path of drifting icebergs closer to the coast, and is, therefore, not expected to affect iceberg deterioration in the offshore N.L. region.

Figure 8a shows that from the 1980s to the 2000-2020 period, SST over the offshore N.L. region mostly warmed on average for the spring-summer iceberg season. The average spring-summer SST warming over the whole

region was nearly 0.8°C, with a maximum of 2°C in the part of the northeastern section along the outer edge of the North Labrador Shelf (Region 1). A cooling of up to 0.3°C in the SST has occurred during March-August from 1980-1989 to 2000-2020 in the eastern section of the ROI affected by the AMOC slowdown, outside the area closer to the coast where icebergs typically drift and deteriorate. Similar to projected trends in surface air temperatures, changes in spring-summer mean SSTs are projected to be significantly greater for much of the offshore N.L. region for the spring-summer 2021-2050 period relative to 2000-2020, compared to the recent past changes from the 1980s to the 2000-2020 period (Figure 8b). Average spring-summer SST warming over the whole region is projected to be nearly 1.5°C for 2021-2050 compared to 2000-2020, with up to 2-4°C SST warming along the main iceberg drift path (Regions 1-4). Sea surface cooling is projected to continue in the eastern section most affected by the AMOC slowdown. The lack of SST data immediately along the Labrador and northern Newfoundland coasts apparent in Figure 8b is due to the relatively coarse spatial resolution of the climate model output. However, the increase in SST projected further offshore can likely be extrapolated into the coastal region.

Mean spring-summer sea ice concentration decreased by up to 1-2/10th from the 1980s to 2000-2020, in regions along the Labrador and northern Newfoundland coasts where sea ice typically occurs (Regions 1-3 in Figure 9a). Further decreases in average spring-summer sea ice concentration in these regions are projected for 2021-2050 compared to 2000-2020, approximately up to 1/10th (Figure 9b). Little change in mean spring-summer sea ice concentration has been observed on the Grand Banks (Region 4) due to the fact that mean spring-summer sea ice concentration in this region is already small, and is, therefore, not projected to change significantly into the future. However, the southern marginal ice zone in the offshore N.L. region is typically in the Orphan Basin (Region 3). This region has experienced a decrease in mean spring-summer sea ice concentration of up to 1/10th (Figure 9a) and this trend is expected to continue under the SSP2-4.5 scenario with a further projected loss of up to 1/10th concentration in mean spring-summer sea ice (Figure 9b). The Orphan Basin is the last major region in which icebergs can experience deterioration before reaching the NE Grand Banks, and the past and projected loss of sea ice has led to increased area and times of open water in which higher waves can be generated and contribute to enhanced iceberg deterioration. Although climate model sea ice data are lacking directly along the Labrador coast due to the model's relatively coarse spatial resolution, it is anticipated that reductions in sea ice will continue in this region as well, leading to increased open water and wave erosion of icebergs. At the far northern end of Labrador, the climate model output shows further reductions in mean spring-summer 2021-2050 sea ice concentration of up to 3/10th relative to 2000-2020 (Figure 9b). The projected increase in sea ice in the northeastern section of the ROI is most likely incorrect, and an artifact of the climate model output starting with unrealistically high sea ice concentrations in the early part of the 2021-2050 period compared to what has already occurred by

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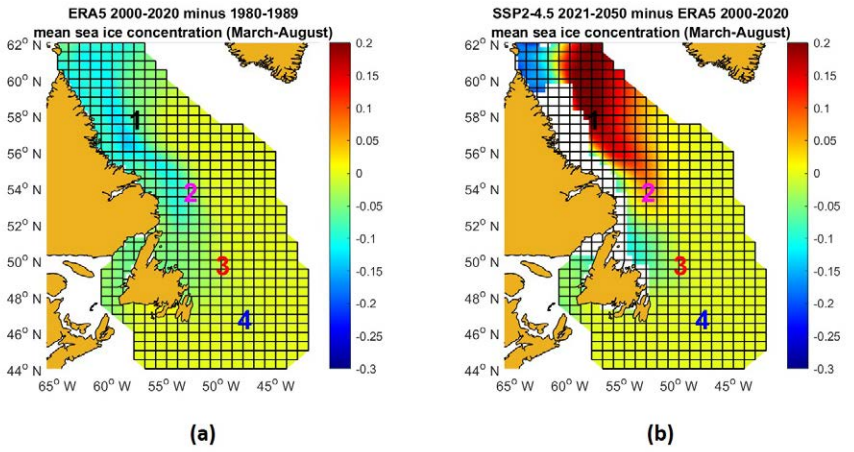


Figure 9: Changes in March-August mean sea ice concentration offshore N.L. from 1980-1989 to 2000-2020 (a), and from 2000-2020 to (projected) 2021-2050 (b).

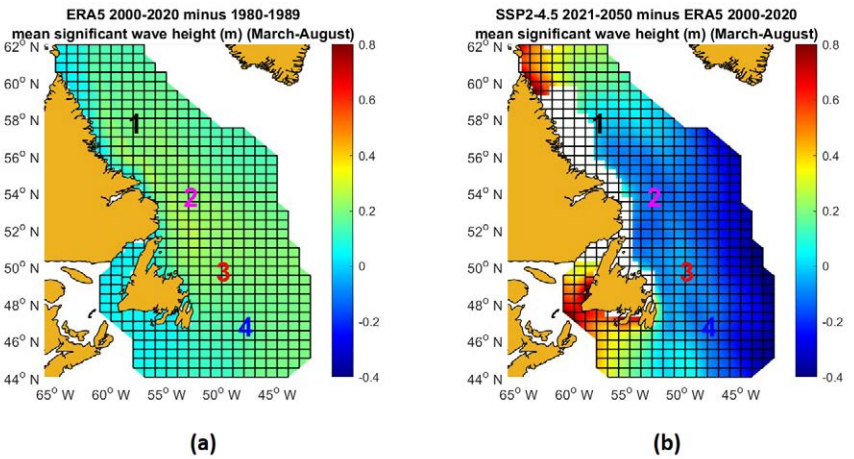


Figure 10: Changes in March-August mean significant wave height offshore N.L. from 1980-1989 to 2000-2020 (a), and from 2000-2020 to (projected) 2021-2050 (b).

2020 (e.g., see Figure 13). The unrealistically high sea ice concentrations at the beginning of the 2021-2050 period are most likely due to the model error propagation through time, as the model was initialized in 1850. Sea ice in this region is projected to decrease further into the future (e.g., see Figure 13).

Mean spring-summer significant wave height has increased in the offshore N.L. region from the 1980s to 2000-2020 by up to 0.2-0.3 m (Figure 10a), with the largest increases occurring in the Orphan Basin (Region 3). Our confidence in significant wave height projected changes for March-August 2021-2050 relative to 2000-2020 (Figure 10b) is low for the offshore N.L. region, for the following two reasons. First, there is no established clear relationship between climate change and wind speed (e.g., see Wilhelm [2022]). Second, significant wave heights derived from the climate model monthly mean wind speed data (e.g., see Equation 2) for the Labrador Shelf (Regions 1-2) are initialized unrealistically low for the early part of the 2021-2050 period, compared to recent mean spring-summer significant wave heights in this region up to 2020 (e.g., see Figure 14). However, a trend toward increasing spring-summer mean significant wave height is projected nonetheless for 2021-2050 along the Labrador Shelf, as reductions in sea ice allow

for increased wave generation. An increase of up to 0.8 m in mean spring-summer significant wave height is projected for the far northern Labrador coast for 2021-2050 relative to 2000-2020 (Figure 10b), which coincides with the reduction in mean sea ice concentration of up to 3/10th in this same region (Figure 9b). As sea ice is projected to further decrease along the Labrador coast (in the region lacking ocean climate model data) as seasonal break-up trends earlier in the season, it is expected that increased time for open water wave generation will result in enhanced iceberg deterioration, regardless of potential future trends in wind speed.

8.4 Past and Projected Spring-Summer Climate Change in Four Selected Regions

Figure 11 through Figure 14 show 10-year moving averages of 1980-2020 March-August ERA5 data and 2020-2050 March-August climate model data for surface air temperature, SST, sea ice concentration, and significant wave height, respectively, for the grid cells corresponding to the North and South Labrador Shelf, Orphan Basin, and NE Grand Banks. A moving average of 10 years was applied to all variables in order to illuminate climatic trends and smooth out higher frequency inter-annual variability.

Figure 11 shows mean spring-summer surface air temperatures for all four regions increased from the 1980s to 2000-2020, with the magnitude of the changes increasing with latitude. On the NE Grand Banks (Region 4), the mean spring-summer 2000-2020 surface air temperature was nearly 0.5°C higher than during 1980-1989, and this difference steadily increased with latitude to more than 1.7°C on the North Labrador Shelf (Region 1). The climate model projections in the four regions for March-August 2020-2050 were clearly not initialized with the observed or hindcast data used in the ERA5 dataset. However, the climate model projects continued increases in mean spring-summer surface air temperatures for all four regions up to 2050. Further increases in mean spring-summer surface air temperatures are projected at 2.4°C, 2.5°C, 3.1°C, and 3.2°C from 2021-2050 on the NE Grand Banks, Orphan Basin, and South and North Labrador Shelf, respectively.

Similar to surface air temperatures, Figure 12 shows mean spring-summer SSTs for the four regions increased from the 1980s to 2000-2020, with the magnitude of the changes increasing overall with latitude. The increase in mean spring-summer SST between these two periods was 0.5°C, 0.9°C, 0.7°C, and 1.6°C on the NE Grand Banks, Orphan Basin, and South and North Labrador Shelf, respectively. The projected increase in mean spring-summer SST from 2021-2050 is a further 2.1°C, 2.2°C, 2.4°C, and 3.5°C on the NE Grand Banks, Orphan Basin, and South and North Labrador Shelf, respectively.

As discussed in Section 8.3, Figure 13 illustrates the trends in mean spring-summer sea ice concentrations in the four regions from 1980-2020, and projected trends over 2020-2050. Mean spring-summer sea ice concentrations decreased by approximately 1/10th between the 1980s and 2000-2020 on the North and South Labrador Shelf, and mean spring-summer sea ice concentrations have historically been less in the Orphan Basin and Grand Banks during the 1980s. All four

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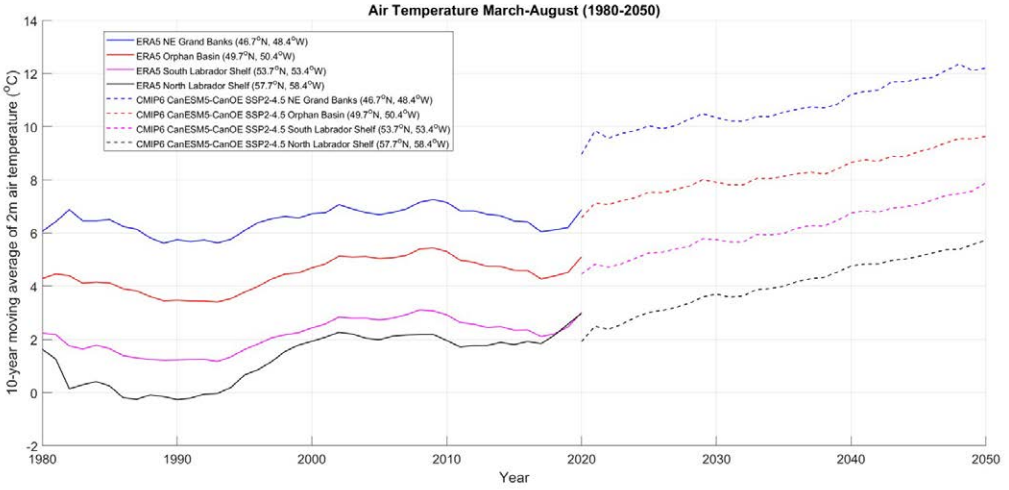


Figure 11: Changes in March-August mean 2 m air temperature in four selected regions offshore N.L. from 1980-2020, and (projected) from 2020-2050.

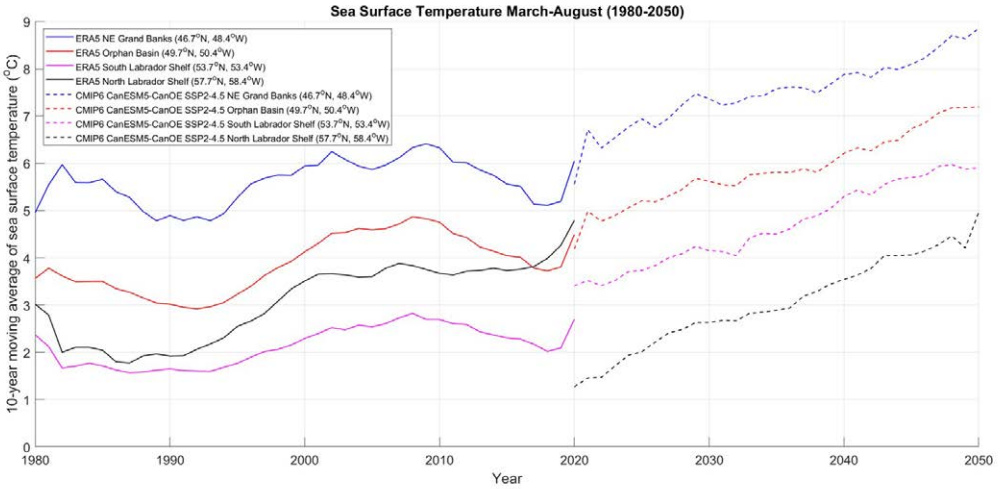


Figure 12: Changes in March-August mean SST in four selected regions offshore N.L. from 1980-2020, and (projected) from 2020-2050.

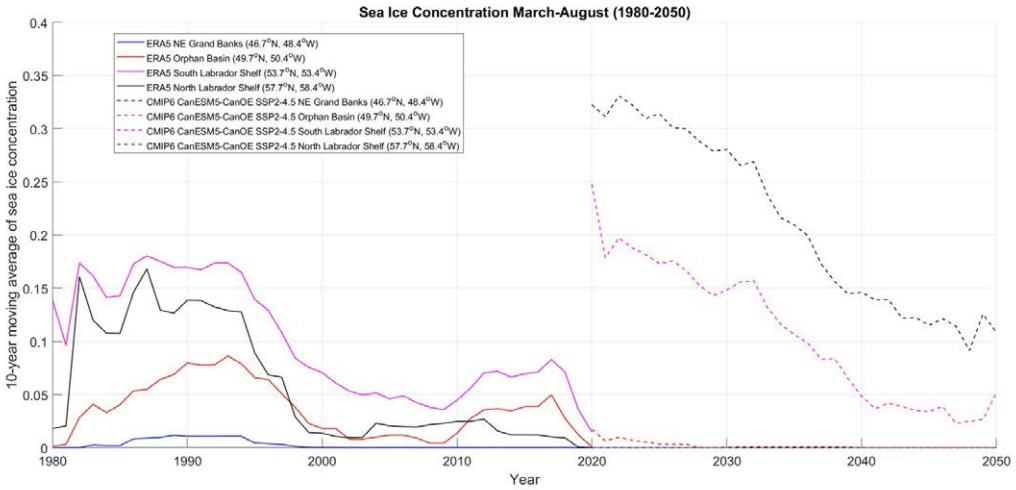


Figure 13: Changes in March-August mean sea ice concentration in four selected regions offshore N.L. from 1980-2020, and (projected) from 2020-2050.

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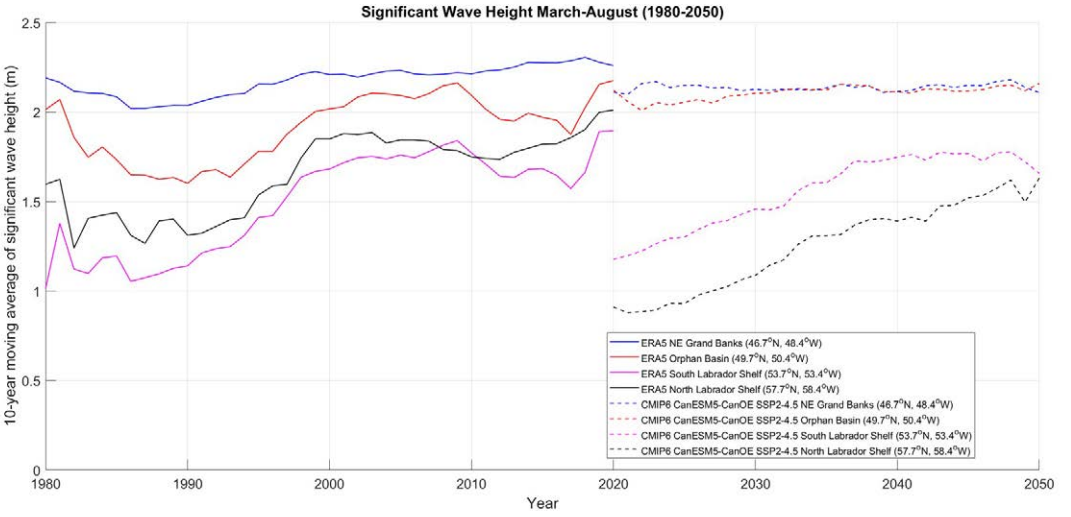


Figure 14: Changes in March-August mean significant wave height in four selected regions offshore N.L. from 1980-2020, and (projected) from 2020-2050.

regions have shown a near-total loss of mean spring-summer sea ice concentrations by 2020. Therefore, the climate model projections of sea ice loss on the Labrador Shelf already significantly diverge from what has occurred, as the mean spring-summer sea ice concentrations in this region (Regions 1-2) are initialized too high in 2020. The climate model still projects mean spring-summer sea ice concentrations in these regions of 1/10th or less, which is considered to be open water for the purposes of iceberg drift, deterioration, and wave generation. The past and projected loss of sea ice on the Labrador Shelf may significantly affect iceberg deterioration rates further upstream of the Grand Banks, as the changes in sea ice are more muted in the Orphan Basin (Region 3). Past and projected changes in mean spring-summer sea ice concentration on the Labrador Shelf are the most significant of the four regions, and this may mean these regions will play a greatly increased role in enhanced iceberg deterioration into the future.

Figure 14 shows the 10-year moving average of mean March-August significant wave height for the four regions from 1980-2020, and that of the climate model projections for the four regions for 2020-2050. Mean spring-summer significant wave height from the 1980s to 2000-2020 has increased by 0.2 m, 0.3 m, 0.6 m, and 0.4 m on the NE Grand Banks, Orphan Basin, and South and North Labrador Shelf, respectively. Projected further increases in mean spring-summer significant wave height from 2021-2050 are negligible on the NE Grand Banks, and 0.1 m, 0.5 m, and 0.8 m on the Orphan Basin, and South and North Labrador Shelf, respectively. Similar to sea ice concentration, the significant wave height data for the Labrador Shelf regions derived from the climate model output diverges significantly in the early part of 2020-2050 from the ERA5 data for 2020. The climate model underestimates the significant wave heights in these regions; however, it nonetheless projects an increase. As with the loss of sea ice, the past and projected increase in significant wave height on the Labrador Shelf may enhance iceberg deterioration rates further upstream of the Grand Banks and Orphan Basin.

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The projected changes in surface air and sea surface temperatures, sea ice concentration, and significant wave height in the four selected regions over 2021-2050 are more significant than what has already occurred between 1980-1989 and 2000-2020. The two most predominant drivers of iceberg deterioration rates, wave action and water temperature [Kubat et al., 2007], have increased in the four regions, with the most pronounced changes in the northern regions along the Labrador Shelf. The amplification of spring-summer climate change signals with increasing latitude apparent in Figure 11 through Figure 14 is consistent with the ice-albedo feedback (e.g., see NSIDC [2020]). The enhanced loss of reflective sea ice off the coast of Labrador compared to offshore Newfoundland has caused more intense increases in air temperature, SST, and further sea ice loss, as the increased open water area is able to absorb more solar radiation. Increases in significant wave height have also occurred in the Orphan Basin (Region 3) and likely contributed to enhanced iceberg deterioration upstream of the Grand Banks. The past and projected loss of sea ice in the four regions translates to increased time with open water, which increases the exposure time of icebergs to wave action and, therefore, enhances deterioration, regardless of wave heights. Increased air temperatures most likely caused increased rates of iceberg freeboard ablation, and increased sea surface temperatures are most likely linked to increased iceberg keel melt rates due to increased overall heat energy in the water column. Climate change in the ROI and enhanced iceberg deterioration rates may explain only part of the changes in the iceberg regime as outlined in this paper. Large-scale changes in the shapes and dimensions of icebergs calving at the termini of their source glaciers along the west coast of Greenland between the 1980s and 2000-2020 may be an additional factor which may be explored in future work.

9. CONCLUSIONS AND RECOMMENDATIONS

The evidence presented in this paper supports the conclusion that the iceberg regime on the Grand Banks has changed, and is likely to continue to change, resulting in lower iceberg risk to offshore activities over time. While the emphasis in the iceberg data presented here has primarily focused on iceberg grounding events, changes in the iceberg regime will also have implications for surface facilities for hydrocarbon exploration and production, as well as shipping and other offshore activities. Changes in subsea risk will be particularly relevant for any proposed gas export pipeline(s), extended tiebacks to existing facilities, and cables for facility electrification.

Iceberg and sea ice loads and risk analysis, and other loads due to metocean conditions, are usually based on historical time-series on the order of 30 years or more. Evidence presented here indicates this is not necessarily the best approach, and older data should be considered carefully in light of potential changes in the metocean regime. In the case of iceberg risk and loads, a strong case could be made that the pre-2000 iceberg data are no longer appropriate for use.

The observed changes in the offshore N.L. iceberg regime between the 1980s and

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2000-2020 are very likely linked to the increase in air and sea surface temperatures, significant wave height, and the decrease in pack ice. The changes observed in these four climate variables would enhance iceberg deterioration rates through increased melt in higher temperatures, and increased wave erosion in higher sea states and longer iceberg exposure periods in open water. Analysis of climate model output to 2050 shows that the observed trends in these variables are likely to continue, and perhaps in some cases, amplify, particularly in the more northern parts of the region.

Ongoing data collection of iceberg, pack ice, and metocean data is recommended to ensure that future load/risk assessments are based on the most relevant and current data, and that changes in the environment are detected and properly documented. Data to be collected and analyzed would be obtained using a variety of methods, including aerial and vessel reconnaissance, satellite surveillance, iceberg profiling, deployment of tracking beacons, deployment of upward-looking sonar for improved sea ice characterization, moorings for measuring currents, winds, and waves, as well as remotely operated and autonomous platforms.

Finally, it is noted that the climate changes in the immediate offshore N.L. region explored in the present work may not explain all of the observed changes in the iceberg regime. Some of the changes are likely linked to changes in the geometry of icebergs calving at the source glaciers, which is something to be further explored in future work in order to develop a more complete understanding of the entire offshore Greenland-to-Newfoundland iceberg source-to-sink process.

ACKNOWLEDGMENTS

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LODE STAR

EMMELINE BROAD

PHD STUDENT
SCHOOL OF OCEAN TECHNOLOGY
FISHERIES AND MARINE INSTITUTE
OF MEMORIAL UNIVERSITY
ST. JOHN'S, N.L., CANADA



Emmeline Broad sits next to an Umbellula seapen collected by a remotely operated vehicle on a recent expedition to the Denmark Strait.

Ocean warming threatens to alter marine ecosystem structure and diminish key ecosystem services that are vital in maintaining ocean health. Alterations in the stability of existing marine ecosystems will likely result in biodiversity loss and economic impacts associated with the instability of key Canadian fishery resources. With this looming threat, Emmeline Broad's research focuses on quantifying the role of benthic habitat in controlling shifting patterns of benthic fauna, migrating under regional changing ocean climate conditions. This research is part of a larger project called Benthic Ecosystem Mapping and Engagement (BEcoME).

Ms. Broad's research aims to evaluate the role that seabed terrain plays in defining suitable benthic habitat under present and future climate conditions (future years 2055 and 2075). This will be tested using habitat suitability models that encompass the known geographical niche of benthic marine fauna of conservation importance (e.g., cold water corals) and of commercial importance (e.g., snow crab). Projections derived from habitat suitability models are a non-invasive tool to estimate if existing spatial management policies are climate adaptive to how the marine environment may look and act in the future. Models could also indicate areas that could be future climate refuges for migrating marine fauna that may benefit from becoming spatially managed.

With a background in deep-sea benthic ecology and benthic habitat mapping, it was a natural progression in her career to research how climate change will interact with seabed habitats. Climate change is one of the most urgent and important problems in Ms. Broad's lifetime. She is compelled to contribute towards solutions that promote climate adaptive management measures of seabed habitats and provide evidence that can underpin future marine conservation policies.

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Spindrift

Q&A

Trade Winds

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Turnings

Reverberations

Homeward Bound

Parting Notes

Q&A with Paula Keener



Marine biologist with a broad background in research, science communication, ocean science education, and ocean science policy. Leadership and management positions in state and national government agencies. Established and directed an ocean exploration Education Program for the National Oceanic and Atmospheric Administration's Office of Ocean Exploration and Research. Established and directed the National Science Foundation-funded Charleston Math & Science Hub at the College of Charleston focused on systemic education reform efforts. Led development of the Marine Education Program for the South Carolina Department of Marine Resources Marine Resources Division. Co-developed the first teacher education program for the South Carolina Aquarium. Served as Adjunct Faculty at two universities and designed graduate online courses focused on national and international ocean science education, ocean exploration, and ocean literacy. Serves as member of South Carolina Department of Natural Resources, Marine Advisory Committee (Appointed), South Atlantic Fisheries Management Council Habitat and Ecosystem-based Management Advisory Panel (Appointed), and University of Charleston Graduate School Advisory Board Member and Chair.

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Where were you born? Where is home today?

I was born in Charleston, South Carolina. My home today is on a bank of the Stono River in Charleston, South Carolina, overlooking beautiful expanses of saltmarsh and oyster beds along the river.

What is your occupation?

I am a marine biologist and ocean consultant. My research focus was life history studies of commercially important fishes, specifically the serranids, or groupers and sea bass. I have spent a lot of time at sea collecting data on these and other organisms, as well as information on their habitats. I changed my focus from research to science communication and ocean literacy years ago as I became more aware of how little most people know about the ocean. This change in focus was a driver in my work with the National Oceanic and Atmospheric Administration's (NOAA's) Office of Ocean Exploration and Research, where I directed a national education program focused on educating the public about why we need to explore the ocean and how we do it with advanced technologies. After 18 years with NOAA, I retired and founded Global Ocean Visions, Inc., a small consulting company focused on ocean science research, science communication, and ocean literacy to build global capacity for informed, responsible ocean policy development. I am also working with Ocean Associates, Inc. as a program manager/senior associate. I serve on several state- and federal-level boards and committees focused on ocean research and conservation.

Why did you choose this occupation?

Growing up in Charleston in a boating family, we were often at a marina on the weekends. As a young girl and teenager, I could frequently be found hanging over docks or walking in the marsh or along the beach collecting whatever interested me. Having always been curious, I wanted to learn all that I could about the fascinating marine organisms and the diverse habitats that were home to them and me.

Where has your career taken you?

My career has taken me from over 760 metres beneath the surface of the Atlantic Ocean in the submersible Johnson Sea Link, as well as around

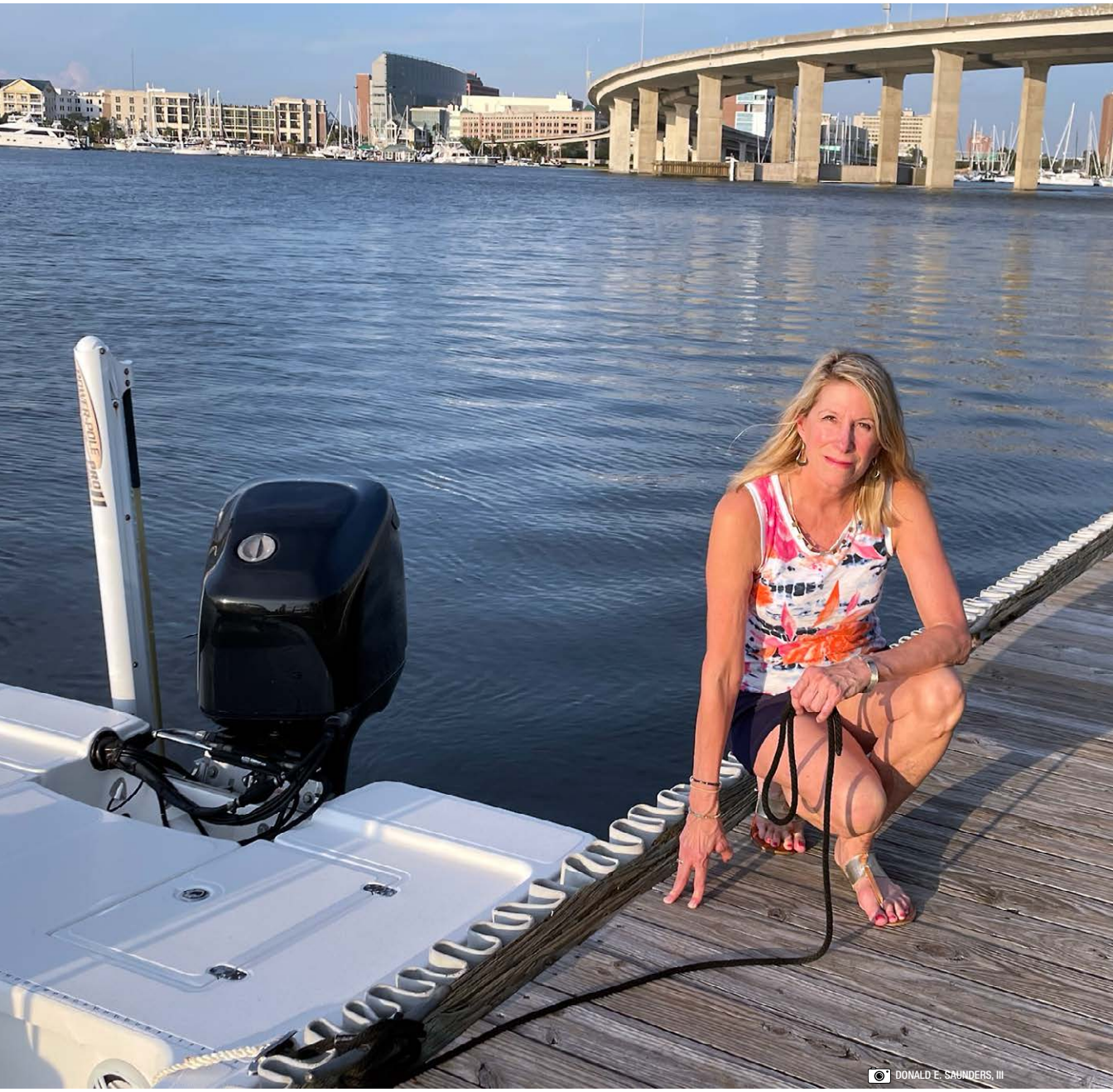

DONALD E. SAUNDERS, III

the world to 31 different countries – developed and undeveloped. I have spent many days at sea over the years, from the Atlantic Ocean to the Northeastern Lau Basin in the Pacific. I have studied and observed some of the most diverse life on the planet, from beautiful fish larvae floating in the plankton to amazing life forms surrounding deep hydrothermal vents. The best place of all is at sea.

If you had to choose another career, what would it be?

I would love to own or work in a vineyard and winery. It would also be cool to be in the U.S. Navy!

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What is your personal motto?
Be kind and always remember the needs of others.

What hobbies do you enjoy?
Walking along the Stono River, crabbing, kayaking, and boating at sunset – really anything on the water. I also love cooking and listening to live music.

Where do you like to vacation?
I like to vacation in Europe and the South Pacific.

Who inspires you?
Other than my family and close friends (and watching Jacques Cousteau episodes with my father as a child), it is those with whom I have worked over the years who are immensely passionate about their work, whether ocean science research and/or policy.

What has been the highlight of your career so far?
There are so many! Having the opportunity to travel the world and meet so many amazing and diverse people along the way is probably the best. On one trip, I had the opportunity to have tea with the late Marjorie Courtenay-Latimer, who discovered that the coelacanth was not extinct as previously thought, at her home in South Africa. I also helped collect a new fish species while diving on a Smithsonian Institution-sponsored collecting trip off Belize that was named after me – *Acanthablemaria paula*. I am also an Honorary Plank Owner for the NOAA Ship *Okeanos Explorer*.

What do you like most about working in this field?
I know that what I do every day makes a little bit of a difference for our world ocean. I have always loved what I do and whether field-based or supporting research conducted by others through management/office work, it is all for the good of the ocean.

What are some of the biggest challenges your job presents?
Trying to stay on top of rapidly evolving global topics, such as plastics in the ocean and climate change. It is almost impossible given all the outlets through which information flows today, along with the volume of data collected with ever-evolving sensors and systems.

What technological advancements have you witnessed?
Wow! There are so many. Exploration technologies are ever evolving, enabling remote/autonomous exploration of the ocean and driving data assimilations that enable us to explore and understand more about out Ocean Planet. I can remember deploying an underwater camera on a hydro cable at sea and watching the imagery on a small black and white monitor in the ship's lab as we towed the camera just above the ocean floor. Today, with gliders, ROVs, and AUVs equipped with sophisticated lighting and high-definition cameras supported by telepresence capabilities, anyone anywhere can see areas of the ocean not previously seen by human eyes.

What does the future hold for this industry?
As we come to better understanding of the effects of climate change on the Ocean Planet, the need for a diverse, talented, and dedicated ocean workforce will continue to grow. This will have tremendous influence in expansion of the new Blue Economy and the technological requirements to support it at all levels.

What new technologies would you like to see?
In-situ and other sensors will continue to become evermore sophisticated and the volume of data collected will only continue to increase. Advanced technologies that support intra-sensor communications, including AI and continued automation, could provide more precise and accurate information about changes in ocean systems and processes, and enable a more holistic understanding of our Ocean Planet.

What advice do you have for those just starting their careers?
Get out to sea as often as you can. Be nimble in your thinking and take a multidisciplinary approach in how you solve problems, whether scientific and/or personal. Most importantly, love what you do.

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Support, Strengthen, and Promote

The Ocean Foundation

The Ocean Foundation (TOF) is the only community foundation for the ocean. We have over 50 projects in more than 40 countries, on six continents. Our mission is to support, strengthen, and promote those organizations dedicated to reversing the trend of destruction of ocean environments around the world.

Addressing climate change is a lens through which we view all of our work. We know that human disruption of the climate is harming the ocean. These changes in the ocean are harming humans. Yet, the ocean is our ally in fighting climate change. Therefore, we approach all these issues under the umbrella of the "ocean-climate nexus."

At the international and regional level, TOF highlights ocean acidification, warming, and deoxygenation caused by human greenhouse gas emissions, and how such emissions harm the ocean (to add to the more routine focus on what storms and sea level rise do to humans). TOF also pushes for action on enhancing the ocean's role in taking carbon out of the atmosphere.

After TOF's founding in 2003, we immediately began working on ocean acidification. In 2005, we co-organized the first marine funders meeting that focused on climate change and the ocean. We have been working on related "blue carbon" solutions since 2007. As a founding member of the Ocean & Climate Platform that same year, we encouraged the breakdown of disciplinary silos, advocating that discussions about ocean and climate be co-mingled, in recognition of the ultimate importance of the ocean to climate regulation.

TOF runs the International Ocean Acidification Initiative (IOAI), which builds the capacity of scientists, policy-makers, and communities to monitor, understand, and respond to ocean acidification both locally and collaboratively on a global scale. TOF is currently leading multi-year efforts in West Africa, the Pacific Islands, and the Caribbean. TOF hosts the Friends of the Global Ocean Acidification Observation Network (GOA-ON), a fund that supports the global effort of scientists to aggregate data about ocean chemistry at the local, regional, and national levels. In an effort to lower the cost and complexity of tools to monitor ocean chemistry, IOAI co-developed the "GOA-ON in a Box" kit of simple, accurate field and lab equipment to expand capacity globally.

TOF runs the Blue Resilience Initiative (BRI) that builds the capacity of scientists, policy-makers, and communities to enhance the roles coastal and ocean ecosystems play as natural carbon sinks, i.e., blue carbon. The goal is to promote protection and restoration as a way of recharging the ocean's capacity to absorb and store carbon, while offering coastal communities direct benefits through enhanced productivity, resilience, and other ecosystem services.

In 2012, TOF launched the first-ever Blue Carbon Offset Calculator to provide charitable carbon offsets for individual donors, foundations, corporations, and events where the funds paid for offsets support the restoration and conservation of carbon-storing coastal habitats, including seagrass meadows, mangrove forests, and saltmarshes. TOF supports such projects in the U.S., Mexico, the Dominican Republic, and Cuba. In addition, the BRI team leads efforts to transform excess sargassum into compost and biochar for use in regenerative agriculture in the Dominican

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Republic and St. Kitts & Nevis as a strategy to reduce stressors on coastal habitats and tourism, sequester and store carbon, and support greater food security.

Because island communities are disproportionately affected by the consequences spurred by human disruption of the climate, TOF has supported local work with global relevance in such communities from Alaska to Cuba to Fiji to Seychelles for the past two decades. As one example, we co-host the Climate Strong Islands Network with the Global Island Partnership, which works to promote just policies that support islands and help their communities respond to the climate crisis in an effective way.

TOF has observer status for the United Nations Framework Convention on Climate Change and we are currently developing blue bond opportunities to finance Nationally Determined Contributions. TOF staff has served on the advisory board for the Collaborative Institute for Oceans, Climate and Security. Since 2014, TOF has provided ongoing technical advice on the Global Environment Facility Blue Forests Project to provide the first global-scale assessment of the values associated with coastal carbon and ecosystem services.

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TOF maintains a curated, annotated bibliography on the ocean-climate nexus. It is consistently one of the top pages visited on our website. In addition, TOF is currently conducting research on ocean carbon dioxide removal technology science and policy. The goal of these efforts is to prevent harm in the name of urgency.

Lastly, TOF holds a leadership role in defining the sustainable blue economy. As part of this, TOF and Rockefeller have created the first ocean-centric climate solutions fund, the "Rockefeller Climate Solutions Fund." It is predicated on the knowledge that:

- The ocean can help save humankind from the consequences of climate change, but its functions are impaired by human activity.
- Ocean-positive companies will help save the ocean and restore its functions.
- We cannot solve for climate disruption without ocean-based solutions.
- The Rockefeller and TOF partnership has a decade-long track record of successful ocean-centric equity investments.

For TOF, the ocean-climate nexus will always be the lens through which we view our work to restore ocean abundance and increase equity and justice, especially for those most affected by the consequences of anthropogenic disruption of the climate.

For more information:

The Ocean Foundation

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Taking Action at the Community Level

Climate Collective



The Climate Collective project, made possible by generous donor and grant funding, coordinated by the Memorial University (MUN) Johnson Geo Centre, began in early 2021. This pilot project connects youth with opportunities to learn about climate change, to connect with Newfoundland and Labrador's (N.L.) green sector, and to access innovative hands-on learning materials. The project's overarching goal is to equip youth with the knowledge and networks needed to take climate action in their communities.

Opportunities to Learn

Climate change is one of the most quickly evolving and relevant issues of our time, and youth are interested but need access to reliable information. As the Climate Collective project was developed, it became clear that more opportunities were needed to learn about climate change, whether through innovative hands-on learning kits or various events.

Innovative Learning Kits

Since the beginning of the project, Climate Collective has aimed to collaborate with local partners to develop hands-on, innovative learning kits. Over the past year, we have commissioned or co-created kits on several topics. Through partnership with Northern-based company Pinnguaq, we have been able to offer the *Learn on the Land* kit, which allows youth to become citizen scientists by coding Microbits to monitor their environment by taking temperature, atmospheric pressure, and other measurements. We also procured Pinnguaq's *Stitches and Switches* kit, which combines traditional knowledge and beading with circuit and coding technology. This blended approach allows youth to reflect on their environment artistically while gaining an understanding of and further appreciation for Indigenous knowledge.

In partnership with SucSeed, a Newfoundland and Labrador-based company, we developed our educator garden kit, which includes an Educator All-in-One and curriculum booklet so youth can learn more about growing their food and food security.

We have also partnered with the local company Bricks 4 Biz to develop a hands-on climate change-themed curriculum for elementary students. This kit covers basic weather principles and introduces them to climate change through LEGO-based activities. This

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curriculum was piloted in the 2021-2022 school year and will be more widely available in the upcoming school year.

We are also in the process of developing an ocean-themed interactive learning kit with local partners.

Sector-developed Kits
In addition to the kits Climate Collective commissioned, a group of dedicated professionals from N.L.'s green sector came together and developed the *Currents for Change* kit to help students monitor waterway flow rates in their areas. Understanding these flow rates is important for municipalities as they plan for the future, but with limited capacity there has not been much monitoring to date. The group saw this as an opportunity to equip youth with the technology they need to become citizen scientists and help collect this important data. The dedicated volunteers of this group developed the idea for the kit and brought the project to fruition using new and existing partnerships. The first pilot of the curriculum and flow meter coding kit recently concluded, and we are excited to help our partners roll out this program to more schools in the fall of 2022.

Opportunities to Engage
Climate Collective also aims to provide youth with spaces to engage and learn about climate change. To date, Climate Collective has hosted two virtual Youth Climate Summits, *Take Action* and *Building Resilience Together*. These youth climate summits have introduced youth to local climate scientists, artists, adaptation experts, STEAM innovation, and climate action planning. Throughout the 2021-2022 school year, we held several other events, including a Green Career Event, showcasing green sector practitioners from across N.L. to give youth an idea of the green careers available in the province.

Upon realizing the lack of climate change based programming in the summer, we developed camp programming for youth aged 10-12, 13-15, and 16-18. With younger age groups, we discussed climate and weather, habitat and ecosystem change, trialled our LEGO kits, and more. With teens, in what we called "Climate Lab," we discussed local climate science and held a climate action planning workshop. We recently piloted our first Youth Climate Camps in L'Anse-au-Loup and Norris Point.

Climate Collective is excited to announce that, after multiple virtual events over the past two years, we will be hosting our first in-person Youth Climate Summit at the Geo Centre in January 2023, made possible by support from the Big Splash Fund and other donor funding. This ocean-themed summit will bring together youth and MUN researchers, non-governmental organizations, and green practitioners to explore how our ocean is changing here in N.L. It will also include a climate action planning workshop, where youth can discuss and share ideas of potential actions they could take to help their communities as they adjust to the changing ocean.

Opportunities to Act
One of the primary focuses of the Climate Collective project is to spark interest in climate action and support youth who want to take climate action in their communities. Therefore, Climate Collective aims to support by-youth-for-youth groups called "Youth Climate Action Chapters." To date, several chapters have been formed across the province. Although their action agenda is theirs to decide, Climate Collective can provide support to groups if they need them, whether through presentations, sending kit materials, or giving seed funding for projects to help them reach their goals (for example, funding to start a composting program in their school).

For more information:

CLIMATE COLLECTIVE
YOUTH · INNOVATION · EMPOWERMENT

climate.collective@mun.ca
https://www.geocentre.ca/climate-collective

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Use of Virtual Participatory Mapping Tools to Advance Local and Traditional Knowledge in Climate Change Adaptation for the Inuvialuit Settlement Region

by Sara Vanderkaden, Chris Milley, Chukita Gruben, and Jen Lam

INSIDE OUT

Arctic communities and the ecosystems upon which they depend are experiencing dramatic effects of climate change. The impacts of a changing climate have been exacerbated by increasing international attention on Arctic development as it becomes more strategically important and accessible to marine industries. Through these environmental and socio-economic changes, Arctic Indigenous peoples continue to have a close environmental connection founded on rich, intergenerational knowledge and experience with culturally important places.

Coastal restoration activities have typically focused on restoring the physical attributes of ecosystems, such as restoration of structural aspects of habitat to increase fish abundance. While physical restoration activities are important, they do not necessarily mitigate all the ecosystem issues created by a changing climate that may undermine the efficacy of restoration efforts. Social responses to climate change impacts on the environment may be more commonly addressed through social adaptation strategies. Social adaptation shifts the focus towards biophysical environmental integrity and protection of resources that people have traditionally been dependent on for health, social, and economic well-being. Understanding the relationship between people and the local environment is needed for effective physical restoration and social adaptation strategies.

The Inuvut, Inikputlu Project – meaning "Our People, Our Place" in Sallirmiutun – is advancing an approach to coastal restoration that focuses on the relationships connecting people with their environment. Through collaboration between the Inuvialuit Game Council, Joint Secretariat, NEXUS Coastal Resource Management Ltd., and Dalhousie University's Marine Affairs Program, the project team is examining how Inuvialuit have changed the way they connect with coastal places and how these relationships may be protected through community-driven adaptation and restoration efforts. The Inuvut, Inikputlu Project is based in the Inuvialuit Settlement Region (ISR), which is one of the four Inuit homelands in Canada, located in the Northwest Territories.

Understanding the nature of relationships between local communities and the environment in which they are situated helps to identify priorities for adaptive coastal restoration. As such, mapping information about the relationship between people and place is an important first step in collecting and analyzing priority activities and places for adaptive restoration activities. Participatory mapping is one way to gather this type of information.

Participatory mapping incorporates community perspectives and knowledge into

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Figure 1: Project team members piloting use of the virtual participatory mapping tool in Tuktoyaktuk.

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Figure 2: Participant using the virtual participatory mapping tool in Tuktoyaktuk.

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decision-making processes, including that of natural resource management. A variety of engagement tools have been developed to conduct virtual participatory mapping for urban planning and design processes, which integrate qualitative information.

In 2020, with the onset of the COVID-19 pandemic, the Inuvut, Inikputlu Project sought to find alternative ways to continue to advance participatory mapping processes. Accordingly, it was found that urban planning mapping software could be tailored to collect and compile information about the inter-relationships between people and place. This innovative approach was co-developed by the project team with the objective to collect socio-cultural, georeferenced information to identify adaptation priorities based on the relationships that Inuvialuit have with places of importance. During the design process, the project team tested the mapping technology using several approaches, including independent, facilitated, and group roundtable completion (see Figures 1 and 2).

It was found that one of the main benefits of this process is that data collection is not limited in geographic scope and allows survey respondents to add map features at multiple scales. Virtual mapping technologies also offer greater flexibility by allowing participants to complete the survey from multiple locations, provided they have internet access, which is becoming more accessible in northern rural areas.

This online approach also presented the opportunity for local organizations to become more directly involved in research projects through training and facilitation of online mapping surveys. This initiated a transition from "helicopter" approaches to research where external researchers travel to communities to conduct field data collection and leave with the data. The project team worked collaboratively to develop and train local project team members to engage with communities and assist with the completion of surveys. This reduces the need for carbon emitting travel and enables greater control and ownership of information by the organizations and communities.

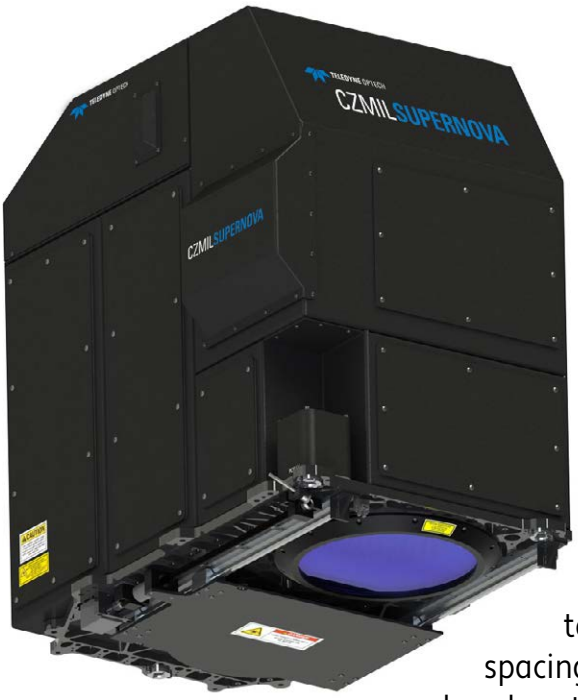
Virtual participatory mapping also offers greater flexibility in both the design and collection of data, which was necessary to accommodate public health restrictions during the COVID-19 pandemic. This flexibility ensured the online mapping survey was inclusive of community members across all age demographics and abilities to use the technology.

Despite the flexibility of virtual mapping technologies, online mapping surveys should be designed in a way that is accessible for individuals with little technical experience. Virtual participatory mapping tools must contain all the relevant information that enables participants to effectively complete the survey with high quality georeferenced data in final map products.

This innovative approach to virtual participatory mapping of the relationships between people and place has demonstrated how new information technologies can have broader cost-effective application within the ISR and across other remote and coastal communities in Canada, and internationally. In remote and Northern communities, there will likely remain a need to employ more hybrid and conventional methods to accommodate varying levels of internet connectivity and technical experience. Innovative use of urban planning tools for research on the Inuvut, Inikputlu Project enabled the Inuvialuit organizations to enhance capacity to conduct socio-cultural research.

Sara Vanderkaden, B.Sc., MMM, is a marine management consultant with NEXUS Coastal Resource Management Ltd. in Halifax, Nova Scotia. Chris Milley, B.Sc., M.Sc., MMM, is the president of NEXUS Coastal Resource Management Ltd. and an adjunct professor with the Marine Affairs Program at Dalhousie University in Halifax, Nova Scotia. Chukita Gruben works with the Tuktoyaktuk Hunter and Trapper Committee. Jen Lam, BA, MA, is the program manager with the Joint Secretariat in Inuvik, Northwest Territories.

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Optech CZMIL SuperNova topo/bathy lidar system

Teledyne Geospatial's Optech CZMIL SuperNova boasts the best depth performance and the highest green laser point density in its class. With SmartSpacing technology for even and efficient point spacing, real-time processing capability for reduced post-processing time, and configurable modes for maximizing performance in different water environments, the SuperNova provides a wide range of inputs for climate change modelling and is ideal for inland water environments, base mapping for coastal zones and shoreline. The CZMIL SuperNova's workflow is integrated with CARIS Base Editor software for seamless data processing capability and built-in AI techniques for land/water classification.

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Acoustic releases for mooring weather buoys



Weather buoy E1 off southwest England.

PLYMOUTH MARINE LABORATORY

The UK's Met Office has recently switched to using Sonardyne acoustic release transponders to secure its network of moored buoy Marine Automatic Weather Stations (MAWS) in the North Sea and Atlantic Ocean. Sonardyne's RT 6s and deck topside command units are now used to support deployment and retrieval of the MAWS buoys from their locations as far north as the Faroe-Shetland Channel and down to the southwestern approaches and the English Channel in the south.

The Met Office's MAWS buoys are a key part of its Marine Observing Network, which gathers essential observations, including wind speed, air and water temperature, and wave height and period. Because many of the buoys are moored in more harsh North Atlantic waters, they are designed to withstand extreme conditions, including significant wave heights recorded at above 18 m. They also have to be serviced every two years, requiring a safe and reliable mechanism to allow for easy release from and then redeployment to their seabed moorings.

Sonardyne's RT 6 family of release transponders operate using a secure acoustic signal from the sea surface to activate a release mechanism connected to a seabed anchor. Moored instrument strings and oceanographic buoys can then be retrieved onboard a vessel for servicing or redeployment. Each MAWS buoy is fitted with two releases; operators command and control their RT 6s using Sonardyne's Deck Topside, featuring a high brightness screen, inbuilt GPS receiver for recording deployment locations, and a battery life of eight hours. A cabled, over-the-side dunker provides the secure acoustic communication link between the surface and RT 6s.

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GREENER MARINE SHIPPING TO HELP FIGHT CLIMATE CHANGE

The carbon footprint of the global shipping community is estimated to be 2.6% of the world's annual greenhouse gas (GHG) emissions and is steadily growing due to the ever-increasing demand for ocean trade. With 90% of the world's global trade done through shipping, we need to optimize vessel efficiencies and realize the use of a full spectrum of solutions that provide opportunities to significantly reduce emissions now as we work towards longer-term, carbon neutral solutions. This includes innovative transitionary and renewable fuels, the potential of electrification, and leveraging technologies for more efficient operations.

Canada's Ocean Supercluster (OSC) and the Vancouver Maritime Centre for Climate (VMCC) are playing a critical role as catalysts in the reduction of emissions in marine shipping through a collaborative approach to problem solving and innovation. It is only through the collective efforts of industry, government, academia, and the entire ocean community that Canada will be able to mobilize and implement green technologies at the pace required to help decarbonize the marine shipping industry and make significant contribution towards our country's net-zero targets.

Ambitious but Necessary Goals

The ocean economy is responsible for generating more than one billion tonnes of carbon emissions each year. Of that, Canada's ocean industries contribute almost nine million tonnes annually of which 3.6 million tonnes come from British Columbia. More than any other segment of the ocean economy, marine shipping creates the majority of these GHGs.

The United Nations agency that regulates global rules for safe shipping and marine environmental protection, the International

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BY CANADA'S OCEAN SUPERCLUSTER AND THE VANCOUVER MARITIME CENTRE FOR CLIMATE

SHUTTERSTOCK

Maritime Organization, has committed to reducing 50% of GHG emissions in marine shipping by 2050 compared to 2008 in absolute terms. This target means no matter how much the world economy expands and trade increases, the total GHG output in marine shipping in 2050 must be half of its total output from 2008. More broadly, to limit the average global temperature increase well below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C, the Government of Canada has committed to Canada's Net Zero Emissions Accountability Act. It has also committed to an updated target under the Paris Agreement to reduce its GHG emissions by 40 to 45% below 2005 levels by 2030, of which marine shipping can play a significant role.

In anticipation of an increasing demand on the marine shipping industry to decarbonize, the VMCC developed the *Green Shipping Strategy*. Further to outlining these necessary goals, the strategy identifies implementation pathways as key indicators of success in emissions reduction in the ocean economy including end-to-end low carbon intensity alternative or renewable fuel solutions, marine electrification, port operations and infrastructure, vessel energy efficiency, and emissions abatement.

Because of the urgency of legislated emissions reduction targets, the strategy recommends that efforts should be focused on the mobilization, commercialization, and implementation of existing and emerging clean technologies and alternative fuels – noting that, in the longer term, current low-emissions solutions are not sufficient to support operational requirements and reach emissions reduction targets. As such, research and development of the next generation of technology solutions and alternative fuels will be necessary.

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Taking Action

Looking ahead, reaching longer-term GHG reduction goals will require significant global investment in research, development, and deployment of new zero-carbon technologies and systems, such as batteries, synthetic fuels produced from renewable energy sources, and other mitigating solutions. In Vancouver, and across Canada, there are a number of these critical solutions underway for the decarbonization of marine shipping in development, testing, as well as those now being integrated into operations.

Canada's Ocean Supercluster has projects in flight that have brought together partners from different ocean sectors across the country with a shared interest – to reduce emissions in marine shipping. Some of these projects include:

In Vancouver, the OSC's *Field Validation of Energy Storage System Project* is introducing Corvus Energy's novel battery-based energy storage systems suited to larger marine vessels to achieve significant greenhouse gas reductions in Canada and worldwide.

Calgary's Katal Energy and the team that makes up *Project Orca* are showing encouraging results in testing a lower-carbon transitionary fuel in marine vessels to help lower diesel dependency now with a drop in solution that requires no retrofitting.

Earlier this year, the OSC also announced its largest project to date, the *Clean Ocean Advanced Biofuels Project*. With a total value of $65 million, the Ontario-based project lead, Valent, is working with a pan-Canadian, cross-sectoral team to produce the country's first renewable diesel from abundantly available agricultural and forestry byproducts.

Atlantic Canadian projects have also placed significant focus on emissions reduction solutions in marine shipping. Projects including the Newfoundland and Labrador and Prince Edward Island led *Split PM Hybrid Propulsion Motor Project* are developing a hybrid diesel-electric system to make the hybridization of existing vessels worldwide a financially viable option.

Meanwhile in Nova Scotia, Graphite Innovation and Technologies, along with its project partners, has developed new graphene-based nanotechnology in a protective coating product for vessels. The coating is proving to reduce vessel fuel consumption, provide non-toxic protection, and reduce underwater radiant noise demonstrated through testing in both small and larger vessels, with significant global contracts secured.

Marine shipping has long had a reputation for being one of the largest emitters of greenhouse gases. With new technology and innovation, and through the work of Canada's Ocean Supercluster and the Vancouver Maritime Centre for Climate, and others, this reputation is changing. New opportunity lies ahead where solutions created for greener marine shipping are not only instrumental to meeting emissions reductions goals, but also contributes to a healthier planet, helps unlock the potential of a sustainable blue economy, and generates significant market opportunities in the process.

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Collecting to Connect

Student-built Miniboats Contributing to Ocean Science Research

by Cassandre Stymiest, Aimee Bonanno, Andrea Gingras, Sarah Nickford, Alexis Johnson, and Greg Rowe

The Educational Passages Miniboat Program offers youth from around the globe the opportunity to work together to build, deploy, and track their very own miniature sailing research vessel (Figure 1). Through this hands-on experience, students are introduced to oceanographic technology used by scientists in the field while learning about global ocean currents, wind and weather patterns, and implications of a changing climate. The program empowers people to become community scientists and global ocean stewards by introducing key topics and encouraging them to "Build, Launch, Track, Learn, Connect."

Youth take ownership and develop intrinsic value in the curriculum by building their 1.5 metre long sailboat that is tracked by a solar powered GPS unit. Its unique design has a large cargo hold that can house oceanographic systems while being a modern day message-in-a-bottle, connecting classrooms of students who build it to those who find it onshore. Available systems include an on-deck camera, air and water temperature and orientation sensors from Maker Buoy, which allow the miniboats to collect climate-relevant data as they sail. Once completed, the miniboat is launched into the ocean allowing students to get first hand data to develop analytical skills and better understand the interactions between weather and the ocean – taking what they are learning in the classroom and applying their knowledge in a hands-on experience in oceanography.

Environmental Science students at Burrillville High School (BHS) in Burrillville, Rhode Island (U.S.) built the BHS Roweboat in 2021, which provided opportunities to learn about how our ocean and atmosphere interact with each other. The *Roweboat* was first launched from a lobster boat southeast of Massachusetts near the continental shelf, and the students were able to track it with the onboard GPS (a sensor system was added later) and predict its path. While it was predicted to travel east through the Gulf Stream and to Europe, Tropical Storm Elsa (July 2021) caused the boat to travel north instead. The influence of winds, currents, and tides were also observable as it approached and landed in Nova Scotia. Utilizing the RPS-developed Path Analysis Tool, students could view modelled winds, currents, and wave heights to better understand the factors influencing the miniboat's trajectory.

After a second voyage sent the *Roweboat* to Newfoundland and Labrador, students from Fogo Island set it back to sea for a third voyage. This time a sensor system was integrated which allowed students to ask deeper science questions related to air and sea surface temperature distribution. With these additional measurements, BHS and Fogo Island students are now making connections to oceanographic research and comparing miniboat data with existing observing systems, including nearby mooring arrays that are measuring the overturning circulation in the Atlantic Ocean (Figure 2).

Miniboats, like other uncrewed surface vehicles, have a temperature sensor installed close to the sea surface (~0.5 m) which provides a unique set of data because most

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Figure 1: Students from Burrillville High School with their second miniboat in 2022, the BHS *Rowe Rlda.*

research vessels measure water temperature about 5 m below the surface. These measurements are key to understanding the true sea surface temperature and are important for studying air-sea interactions because the very upper layer of the ocean is in contact with the atmosphere. As the ocean remains severely undersampled, the deployment of miniboats is helping the global effort to increase observational coverage as the data collected by 178 miniboats to date, that have collectively travelled over 1.5 million kilometres, are now available to be added to open-source databases where researchers can use it to further their understanding of the ocean. In a recent Educational Passages

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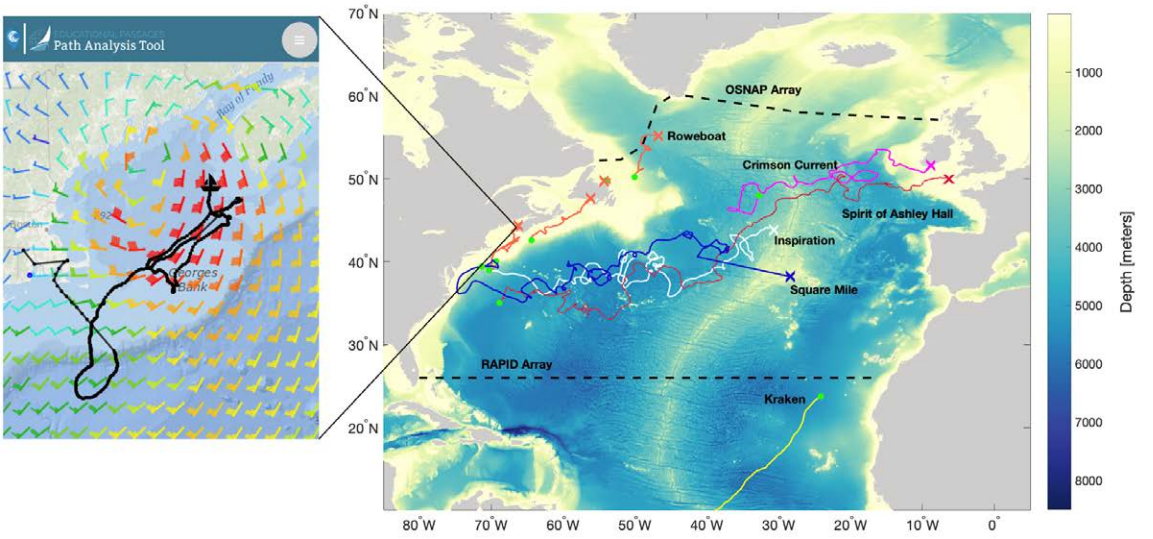


Figure 2: Map of select miniboat routes in the North Atlantic Ocean overlaid on bottom depth. Launch locations are denoted by green dots and last known or retrieval position by crosses. Dashed lines indicate the OSNAP and RAPID arrays, large scale observational efforts aimed at measuring the Atlantic Meridional Overturning Circulation. A screenshot from the Path Analysis Tool (left) shows the first deployment of *Roweboat*, during which Tropical Storm Elsa pushed the miniboat in a full counterclockwise loop just outside the Gulf of Maine before washing ashore in Nova Scotia. Miniboat *Roweboat* (orange) was deployed and recovered twice more before being deployed near the OSNAP Array.

podcast episode, Science Behind the Miniboats, ocean scientists from University of Rhode Island's Graduate School of Oceanography (URI GSO) offered a deeper dive into the importance of the miniboat data in studying climate-relevant science questions.

Through collaborations between K-12 schools, universities, and industry professionals, youth are partnered with scientists to analyze data collected by the miniboats. These partnerships also allowed for a second miniboat from BHS to be launched from URI GSO's R/V *Endeavor*. Scientists aboard the *Endeavor* met up with another uncrewed surface vehicle, called Saildrone, near the deployment area of the second miniboat (Figure 3). Similar to the miniboat deployment at the mooring array, having data collected by multiple platforms nearby provides another unique opportunity for students to compare to data from the miniboat and understand the small spatial scales of variability in the ocean. An example of how the miniboat data can be used with another platform to understand an oceanographic feature was described in the Ocean Observatories Initiative blog. The article also highlighted how sharing observations can contribute to a better understanding of our ocean with an integrated approach.

Miniboats, like the *Roweboat*, offer an opportunity for youth to collect their own oceanographic data and contribute to the larger oceanographic research community. The partnerships involved to build, teach, launch, recover, and relaunch the miniboats connect people around the world. The process provides an authentic experience that sparks curiosity, encourages teamwork, drives learning, and builds empathy. Forming connections between people and the ocean helps inspire students and their communities to take practical steps to address problems facing our ocean today in the best interest of future generations.

Cassandre Stymiest is the executive director of Educational Passages. Her key areas of interest include community science, K-12 and informal education, ocean literacy, and communication. Aimee Bonanno is an advisor with Educational Passages. Her key areas of interest include science communication, collective impact, ocean literacy, and citizen/community science. Andrea Gingras is the assistant director of public engagement at the University of Rhode Island Graduate School of Oceanography. Her key areas of interest include K-12 ocean science education and public engagement. Sarah Nickford is a PhD candidate in physical oceanography at the University of Rhode Island Graduate School of Oceanography. Alexis Johnson is a PhD candidate in physical oceanography at the University of Rhode Island Graduate School of Oceanography, studying bathymetric waves and Southern Ocean heat flux. Greg Rowe is an environmental science teacher at Burrillville High School, Rhode Island.

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Figure 3: Miniboat BHS *Rowe RIda* deployed from the R/V *Endeavor* alongside the Saildrone uncrewed surface vehicle in May 2022.

GINNY COUSENS

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Parting Notes



***Terra Nova* by Rebecca Rutstein**
18"x18", acrylic on canvas, 2016
Courtesy of the artist and Bridgette Mayer Gallery

This painting was created while the artist was on board Schmidt Ocean Institute's *R/V Falkor*, as it sailed from Vietnam to Guam in 2016. Collaborating with scientists, Ms. Rutstein set up a studio in the wet lab of the ship and created a series of paintings as an artist in residence. She integrated satellite data as well as multibeam sonar mapping data, which reveal never before seen ocean floor terrains through sound waves. The artist is interested in the intersection of art, science, and technology, and has collaborated with scientists on six expeditions at sea and two dives to the ocean floor, with more underway in 2023-24.

rebeccarutstein.com
Instagram: @rebecca.rutstein

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MATE ROV

World Championship 2022
UN Decade of the Ocean

The MATE ROV Competition uses remotely operated vehicles to inspire and challenge students to learn and creatively apply science, technology, engineering, and math to solve real-world problems and strengthen their critical thinking, collaboration, entrepreneurship, and innovation.

The Competition challenges students from around the world to engineer ROVs to complete a set of mission tasks based on real-world, workplace scenarios. The competition emphasizes and inspires a mindset of entrepreneurship and innovation by requiring students to transform their teams into "start-up" companies that respond to a request for proposals. In addition to their robots, the student teams also prepare technical reports, create a marketing (poster) display, and deliver engineering presentations.

For the 2022 competition, student teams designed and built a remotely operated vehicle and the necessary sensors and tooling to support work to combat climate change, provide clean energy, feed our growing global population, monitor ocean health, preserve our maritime history, and "deliver, together, the ocean we need for the future we want."

The JOT is pleased to once again this year publish the top honours in the Marketing Display category as designed by the teams:

In-Person

EXPLORER – WhaleTech Robotics, North Paulding High School, Dallas, G.A., U.S.A.
PIONEER – SWVCC Robotics, Southwest Virginia Community College, Cedar Bluff, V.A., U.S.A.
RANGER – Geneseas, St. Francis High School, Sacramento, C.A., U.S.A.

Telepresence

EXPLORER – Fish Logic, Macau Anglican College, Taipa, Macau
RANGER – Robocenter, The Center for Robotics Development, Vladivostok, Russia

This year, for the first time, the JOT is also publishing the top Technical Documentation Report in the Explorer category as designed by the team:

EXPLORER – Rovotics, Jesuit High School, Carmichael, C.A., U.S.A.

Congratulations to the winning teams!

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2022 MATE World Championship

WHALETECH RO

Building a brighter future with ROVs

300 N Paulding Dr, Dallas, GA 30132, USA



ABSTRACT

Our company WhaleTech is based in North Paulding Highschool, consisting of 5 members ranging from 10th to 12th grade. Our company's goal is to solve the problems of our client in the most suitable and sustainable way possible. Our client being the global community means that the problems we needed to solve are one and the same as the Earth's. Some of the concerns as set out by the MATE Foundation's request for proposals consists of the maintenance of marine renewable energies, assistance in aquaculture, and the monitoring of climate change in Antarctica. In order to fulfill these requests, WhaleTech designed and constructed the Whale 2.0, a compact and modular remotely operated vehicle (ROV), tailored specifically to the aforementioned concerns by using payloads constructed with the combined skills and qualifications of our company's members, such as a GO-BGC buoyancy en-

MISSION THEME

In 2016, the First World Ocean Assessment report was released. The report presented extensive research on not just effects of pollution and climate change in our oceans, but also the causes and symptoms of the degradation of the world's most important resource. The report made the importance of changing the way we interact with the ocean abundantly clear to the United Nations, and as a result, The UN founded the UN Decade of Ocean Science for Sustainable Development starting in 2021. This UN program set 10 goals for the participating countries, many lying heavily to the UN's previously set sustainable development goals. This is because in order to save the Earth's oceans, we need to develop more sustainable infrastructure. A few ways this can be done include marine renewable energies (MRE's) such as floating solar panels or offshore wind turbines, aquaculture, and the development of an extensive global ocean observing system.

While all three of these infrastructure improvements change the way we interact with our oceans for a more sustainable future, they aren't always as easy as traditional infrastructure, and when done wrong can be even more damaging to the environment. Unmaintained MRE's serve no purpose and unmonitored aquaculture can destroy the local ecology through disease and destruction of surrounding subsea environments. ROV's can prevent all these problems; ROV's are able to repair damages of MRE infrastructure and constantly monitor and maintain aquacultures. ROV's alongside with the additional use of additional autonomous payloads are also able to observe minute changes in the chemical and biological health of the oceans much better than any topical observations, providing new insights into how to better aid the world's ocean conservation efforts. With the assistance of ROV's, the way humans interact with the Earth's oceans radically changes for the betterment of not just the ecological health of the oceans, but the socioeconomic health of the communities that depend on them.

"The Ocean Decade - the Science We Need for the Ocean We Want." Ocean Decade, 11 May 2022.



Figure 2: Deep Trekker. "Aqua Cage Fisheries: Fish Farm Maintenance.
Phot credit: https://www.deeptrekker.com/news/aqua-cage-fisheries-using-rov

COMPANY INFORMATION





Photo Credit(Left and Right): N. Lees

Jason Lees (12th grade)	CEO, Lead Engineer, Pilot
Andy Griggs (12th grade)	Marketing Lead, Electrical Engineer, Pilot
Drew Boles (11th grade)	3D Designer, Mechanical Engineer
Tony Brozowski (11th grade)	CFO, Safety Officer, Mechanical Engineer
Graham Joonsar (10th grade)	Software Engineer

SAFETY FEATURES

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- Main power switch for emergency shut-off
- All electrical cords secured and waterproofed on frame
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SPECIAL FEATURES

- Bulgin connectors for detachable tether from onboard and surface control boxes.

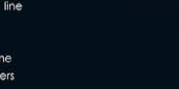
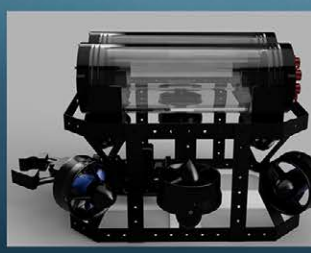


Figure: Bulgin connectors used on the onboard control boxes
Photo Credit: Andy Griggs

DESIGN RATIONALE

The ocean is the most important resource in the world, and that resource is at risk of destruction due to the unhealthy
tion and climate change of the ocean's waters to the overexploitation of its yields. Our company tasked itself to cha
through innovations in ROV's. As the ocean is vast, transportation of the ROV had to be made streamlined, which led
to be completely detached. The implication of a vast ocean is that a vast number of tasks might have to be perform
frame allowing for ample mounting space for any necessary payloads. The most important factor in mind when desig
ROV to have high maneuverability and ability to manipulate its environment. This led to the choice of six specifically
of movement to be employed by the ROV allowing for omnidirectional movement and precise environmental manip
the ROV to complete a multitude of tasks essential in changing the way humas interact with the Earth's oceans, such
ture by replacing cables and clearing them from debris with a manipulator, to the running of a systematic transect w
ing for damages in an aquaculture fish pin.

'THE WHALE 2.0'



CAMERAS

- Equipped with two Explore HD 2.0 waterproof cameras.
- Waterproof to a depth of 400 meters.
- Compact size allows for easy mounting.

Allows the pilot to see the operations of the manipulator during the tasks and for inspection of fish pen, flying the shipwreck area.



Figure: Explore HD 2.0 Camera
Photo Credit: Andy Griggs
Reference: https:/exploredeepwater.com/

MANIPULATOR

- The arm is 3D printed with a custom design
- 3 axis of movement
- Equipped with rotating claw.
- Lightweight and compact size.

Allows the ROV to replace a damaged section of inter-array cable, deploy hydrophone, remove a ghost net caught in the wind turbine, remove marine growth, deploy GO-BGC Float.



Figure: Custom built manipulator for Whale 2.0
Photo Credit: Andy Griggs

FRAME

- Lightweight modular aluminum frame
- CNC machined out of aluminum sheeting
- Dimensions: 30cm in length, 32 cm in width and 20.5 cm in height.

ELECTRONIC HOUSING

- Housed in two Blue Robotics acrylic tubes
- Sealed with O-rings and custom acrylic end pieces
- Connected and interfaced with Bulgin waterproof con nectors
- Measurements: 11.43cm in diameter and 59cm in leng
- All electrical components for thrusters, cameras, and s vos are inside the housings
- 48V conversion occurs inside the onboard control box

Reference: http://docs.bluerobotics.com/watertight-enclosures/#specifications-4-series

PAYLOADS

GO-BGC FLOAT:

- Custom built buoyancy engine
- Programmed to complete two vertical profiles of the water column
- Measures 22 cm in length and 8 cm in diameter.

Float capable of independently completing two vertical profiles when deployed in the designated area by the ROV.

AUTONOMOUS DOCKING:

- Automatically drives the robot into the "resident ROV" docking station
- Uses OpenCV to add a visual aid for the pilots in positioning the robot.

Allows the pilots to quickly return the ROV into its station for ease of access and maintenance or in case of emergency.

AUTONOMOUS TRANSECT:

- Autonomously flies along a transect line
- Uses OpenCV to determine where in the current frame of camera input the transect is and act accordingly

Autonomous program allows pilots to detect outer edge of the wreck search area.

AUTONOMOUS IMAGE STITC

- Autonomously create a pho
- Uses Python and OpenCV t mitigates human error of m

Allows pilot to create photom

AUTONOMOUS MORT DETEC

- Uses a machine learning OpenCV is used to detect mo Frees users from the tedious w

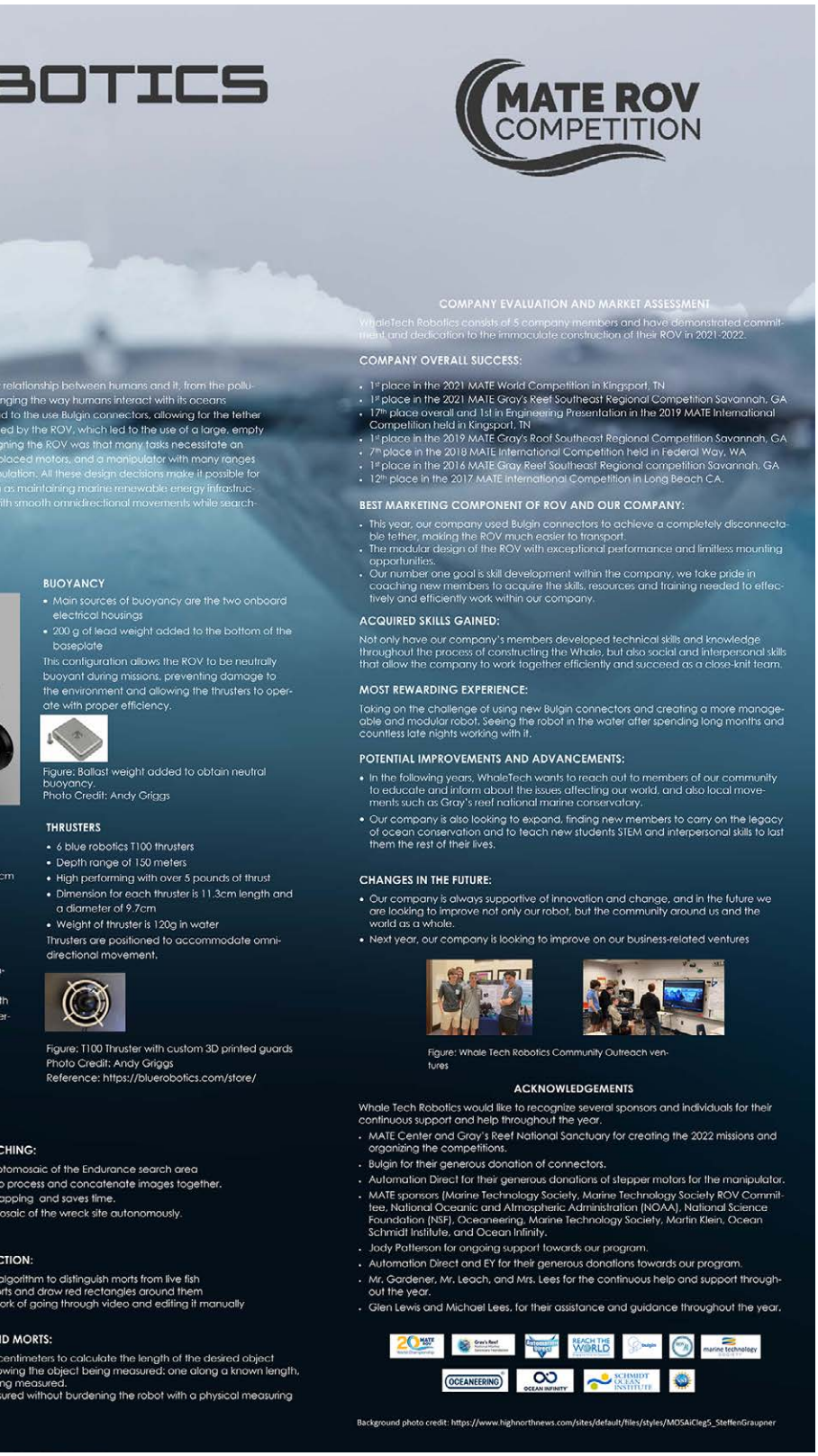
MEASURING THE WRECK AN

- Uses the ratio of pixels to Pilots draw onto an image sh and one along the length bei This allows objects to be meas implement such as a ruler.

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Marketing Display Winners

In-Person Explorer



TEAM NAME
WhaleTech Robotics
North Paulding High School
Dallas, G.A.
United States of America

TEAM MEMBERS
Andy Griggs
Drew Boles
Graham Joonsar
Jason Lees
Tony Brosowsky

INSTRUCTORS
Geoff Gardener
Nicola Lees

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2022 MATE World Championship

Southwest Virginia Community College
Inspire • Transform • Strengthen

Southwest Virginia Community Coll

Cedar Bluff, VA

Abstract

Southwest Virginia Community College Robotics, based out of Southwest Virginia Community College (SWCC) in Cedar Bluff, Virginia, consists of both freshmen and sophomores from various majors, including engineering, electrical electronics, agriculture, and mechatronics. *SeaEagle* was assembled with the unique demands of MATE'S 2022 World Competition tasks in mind, and is equipped to handle the real-world issues that these tasks represent, such as clean energy conservation and the monitoring of climate change effects upon the marine ecosystem. To accomplish these goals, the team outfitted *SeaEagle* with four motors for maximized maneuverability, four cameras for added visibility (two of which possess integrated Bluetooth and Wi-fi capabilities for added functionality), two custom-designed grippers, and an innertube which serves as supplementary buoyancy control. The team 3D-printed as many features as possible, as PLA is both plant-based and biodegradable and thus healthier for the environment than other, more common options, such as non-plant-based plastics.

Budget

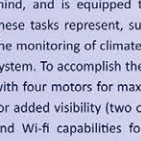


Figure 1: Excel Table of Purchases for *SeaEagle*

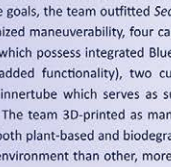


Figure 2: Pie Chart Comparing Costs of Different Elements of *SeaEagle*

Company Info



Team Photo

Photo courtesy of Brittany Hale

Mentors: Joe Godsey, Charles Bundy, Brian Hale

Members:

Sophomores: Joshua Thiel, Kevin Brooks, James Hart

Freshmen: Luke Jennelle, Elisabeth Presley

Safety Officer, Software Engineer: Luke Jennelle

CEO, Head of Engineering: Joshua Thiel

Mechanical Engineer: Anthony King

Head of Marketing: James Hart

Mechanical Engineer: Kevin Brooks

Head of Documentation: Elisabeth Presley

Design Rationale

Main Features:

- **Frame—***SeaEagle's* trapezoidal-shaped frame is constructed of 3/4 inch PVC, which was chosen for its affordability, availability, durability, and lack of hazardous sharp edges.
- **Cameras—***SeaEagle* is equipped with two analog cameras obtained from the Barracuda/Triggerfish Video System Kit, in addition to two ESP32-CAM modules. The team decided on ESP32 cameras due to their low cost and integrated Wi-fi and Bluetooth capabilities. A Raspberry Pi is used as a wireless access point for the ESP32-CAMs to connect to, so that the cameras' feed can be accessed on the Raspberry Pi from the surface using the Ethernet cable included in our tether.
- **Thrusters—***SeaEagle* utilizes four thrusters obtained from the Triggerfish/Barracuda Four Motor and Propeller Kit. Two of the four motors are placed on the ROV at a 45-degree offset to allow for maximized maneuverability, while the remaining two are mounted parallel to the frame.
- **Grippers—**The gears of the grippers were designed so that they would open and close with the lowest possible amount of resistance, while also having large enough teeth that they could be 3D-printed with sufficiently high resolution. Due to the parallelism of the arm and gear linkages, the grippers' fingers are parallel.
- **Controller(s)—**The team uses a PS3 controller to easily and efficiently control the servos used for the grippers' movement. The team opted to use a PS3 controller since there were pre-existing libraries for it.
- **Secondary Control Box—**The team also designed and 3D-printed an auxiliary control box in addition to the primary control box (Triggerfish/Barracuda Control Box Kit) which controls the thrusters **[1]**. The secondary control box has specially-designed switches for main power to each attached module such as the ESP32-CAM modules and the servos used for gripper control. There also is an LCD module that displays the status of the grippers.

Safety Features:

- **Thruster shrouds—**The PLA thruster shrouds for *SeaEagle's* four motors are designs that the team obtained from Thingiverse **[2],** and were 3D-printed on campus, using one of the 3D printers available to students.
- **Cautionary tape—**The team placed cautionary tape onto each of the thruster shrouds to inform divers and other personnel of potential safety hazards posed by the propellers.

Features' Function(s) in Efficiently Completing Competition Tasks:

- **Grippers—**Each finger has a single tooth at the tip which ensures a firm hold on objects grasped, such as ropes, pins, or litter (such as plastic drinking straws). This feature is useful for some of the subtasks of Task 1, such as ghost net removal, and would also be useful in real-world applications such as maintaining fish enclosures and wind turbines, and removing small debris from the ocean floor.
- **ESP32-CAMs—**These cameras have the ability to effortlessly network to the surface via a Raspberry Pi and Ethernet cable, and are therefore the optimal choice for the photo mosaic subtask included in Task 3. These specific cameras would also be useful in real-world applications such as mapping wreck sites, coral reefs, or other areas of interest beneath the ocean surface.



Figure 3: Completed ROV

Photo courtesy of Joe Godsey



Figure 4: Thruster Shroud

Photo courtesy of Joe Godsey



Figure 5: Innertube Buoyancy System

Photo courtesy of Joe Godsey

For many years, monitoring the rine ecosystem, bines and offsho

Southwest Virgi skills to minimi affordably as po to utilize their ir raise the standa sions made rega

With these goal the managemer

- The promotio
- The improven
- The mitigatio

Some specific t necessary to co

- Performing in
- Removing and
- Locating and

Sources:

[1] Scott Fraser, files.materovcor *Joystick-Control.* **[2]** Sthone."MA verse, https://www.thi **[3]** Moore, Stev Marine Advance Technology Edu **[4]** *Different Typ* **[5]** *ROV Demons*



Different T

MATE R COMPETI

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Marketing Display Winners

In-Person Pioneer



lege Robotics

Theme

ROVs have advanced science and aided the oceanic environment by collective health of our oceans, collecting data samples of the ma- and performing routine inspections and maintenance of wind tur- re oil and gas structures [3].

ia Community College Robotics aspires to utilize our innovation and ze and eventually eliminate ocean pollution as resourcefully and ssible. We also hope to inspire corporations and political authorities fluence, however marginal or far-reaching that influence may be, to rd for economic, social, and governance criteria that factor into deci- rding our oceans.

s in mind, the team has equipped *SeaEagle* with capabilities to aid in t of pressing real-world problems such as:

n of responsible usage of affordable and clean energy

nent of living conditions for ocean-dwelling species

n of the consequences of climate change in relation to our oceans

asks that *SeaEagle* has been furnished with the tools and systems mplete are:

spection and repairment of a fish pen

d replacing a damaged segment of underwater cable

photographing a shipwreck

Leroy van der Vegt. July 2020. Sabertooth Motor Test.

npetition.org/docs/resources/Barracuda/code/CUDA-*Arduino-ino*.

TE Compatible ROV Kort Nozzle for Bilge Pump Thruster." Thingi-

ngiverse.com/thing:2854024 (accessed March 24, 2022).

ven W., et al. Underwater Robotics: Science, Design & Fabrication. d

cation (MATE) Center, 2010.

es of ROVs. 2022.

strating Gripper Use. 2022. [5]

[4]

ROV Demonstrating Gripper Use

ypes of ROVs

Acknowledgements

E: Provided resources, funds, and support, making it pos- for the team to compete

non, Richlands: Provided pool services

ariachi: Provided team shirts

hwest Virginia Community College: Provided funds to *SeaEagle*, and covered all travel expenses

team would also like to thank our mentors, who have erously devoted much of their time, effort, energy, and ence to guiding us into the fascinating world of under- r robotics.

Southwest Virginia Community College Robotics

Saving our oceans one ROV at a time.

Company Evaluation

Overall Success:

SeaEagle is the very first ROV ever attempted by Southwest Virginia Community College Robotics, and as such, is the product of much trial and error. Many things that the team initially attempted failed, and additional solutions had to be subsequently found and implemented. It is our hope that future ROVs designed and built by the team will not be subject to the mistakes initially made during the building of *SeaEagle*, which will allow for additional time to create an even more reliable and sophisticated ROV.

Best Characteristic(s) of the Company:

- A strong focus on teamwork
- An encouraging environment in which to learn new skills
- Innovative, resourceful ideas for solutions to problems

Best Characteristic(s) of *SeaEagle:*

- Very low cost
- ESP32-CAM modules allow for many additional applications beyond what most other ROV camera systems are capable of
- Innertube for auxiliary buoyancy control

Future Improvements:

- Pneumatic/hydraulic gripper systems
- Brushless motors

Most Rewarding Part of the Experience:

The first time that we submerged the robot in a tank of water and watched it successfully respond to all of our commands via control systems

What We Would Do Differently:

- Allow more time to review and complete technical documentation
- Perform extensive calculations to assist in obtaining neutral buoyancy

How Skills and Outlook Were Strengthened:

- Learned various programming languages and platforms (Arduino, ESP32)
- Gained an increased awareness of climate change effects on our oceans

TEAM NAME
SWVCC Robotics
Southwest Virginia Community College
Cedar Bluff, V.A.
United States of America

TEAM MEMBERS
Anthony King
Elisabeth Presley
James Hart
Joshua Thiel
Kevin Brooks
Luke Jennelle

MENTORS/INSTRUCTORS
Brian Hale
Charles Bundy
Joe Godsey

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2022 MATE World Championship

ABSTRACT

Geneseas, a four-year-old company, is a team of twenty-one experienced female engineers who collaborate to meticulously develop the solution for MATE's RFP through planning, research, manufacturing, and testing. *Geneseas'* third-generation Remotely Operated Vehicle (ROV), *Beluga*, is the company's newest and most technically advanced product.

Beluga is equipped with many custom-designed tools such as a pneumatic gripper, buoyancy engine, and a digital camera system, allowing it to perform specific mission tasks in oceanic environments worldwide. *Geneseas* designed *Beluga's* gripper through careful prototyping and multiple iterative design phases using CAD. This has yielded a gripper capable of restoring and cultivating seagrass beds that absorb large amounts of carbon and more. *Beluga* also features original image recognition software that autonomously stitches together images taken of wreck sites such as the *Endurance22* wreck. These features make *Beluga* the perfect solution for achieving the UN Sustainability goals during the UN Decade of Action.

COMPANY INFO

COMPETITION TEAM MEMBERS:

Jaedyn Alford '22	Vision
Meredith Garcia- '22	Tools Lead
Lauren Jones- '22	CMO; Overall Software Lead
Emmy Asperger '23	Mechanical
Allie Dinh '23	Control Software Lead
Morgan Jones- '23	CEO; Vision Lead
Norah Zhou- '23	CFO; Electrical Lead
Alicia Del Toro '24	Electrical
Lauren Grindstaff- '24	Safety Manager; Mechnical Lead
Isa Gutierrez '24	Tools
Siena Marois '24	Software
Jianna Reyes '24	Software

CREW:
Sydney Goodall* '23; Sofia Stuck* '23; Ava Borchers* '24; Audrey Mayo* '24; Emily Murray* '24; Isabella Ramos* '25; Alyssa Renomeron* '25; Gabrielle Rosario* '25; Kinnera Tirumala* '25

*New Members -Returning MATE World Championships Competition Participants

COACHES:
Kitara Crain; Marcus Grindstaff; Maurice Vendalia



Figure 1. *Geneseas* Team Members
Photo by Mark Honbo

COMPANY EVALUATION

This year, our company successfully built an innovative and effective ROV, increased the size of our team, and enhanced our team's core capabilities. We improved our ROV by introducing new advancements such as a more compact and hydrodynamic frame design, digital cameras, and enhanced image processing capabilities. The result of this hard work is *Beluga*, our most advanced and efficient ROV yet. *Beluga* is capable of completing mission tasks ranging from repairing an inter-array power cable to ensuring the sustainability of offshore aquaculture.

Our company grew significantly this year, gaining nine new members and advancing both our team and our ROV. *Geneseas'* strongest attribute is our attention to detail and the special efforts we make to iterate multiple times with the purpose of creating effective components. Our process of prototyping, testing, revision, and re-testing integrates different subteams within our team, helping to ensure each component has been verified as high quality. This year, our team has made use of CAD software to 3-D print custom components and ensure the precision of our parts. The use of CAD has allowed our team the opportunity to create a safe, serviceable, and reliable ROV that maximizes functionality while minimizing costs.

Beluga's most innovative feature on is the new digital camera system featuring five high resolution cameras that provide consistent and reliable video feed, offering image recognition capabilities while enhancing *Beluga's* pilotability. *Beluga's* digital camera system includes an original python-developed Graphical User Interface (GUI), which allows for full software control of *Beluga's* vision and image recognition systems. The GUI displays the five cameras, providing a full underwater perspective while operating *Beluga*. This digital camera system successfully integrates both the hardware and software systems yielding an effective and reliable solution.

In the future, *Geneseas* plans to continue improving our ROVs by switching from using an Arduino to utilizing a Raspberry Pi and implementing six thrusters to improve pilotability. The most rewarding part of our experience are the opportunities we have to teach children about robotics and ecological issues. As an all-female team, we have made it a priority to reach out and inspire young girls to discover STEM. Engaging in rewarding community service experiences has strengthened our company and helped us become passionate about interacting with our community and developing solutions to environmental issues using technology.

These rewarding experiences taught us invaluable engineering and design skills and allowed us to further our knowledge of ecological issues. Our team has gained new knowledge of mechanical, electrical, and software engineering in preparation for this competition. Focusing on these core skills enabled us to build an effective ROV and taught us the importance of being meticulous while designing and engineering our products. In the future, *Geneseas* aims to continue increasing our team's size and capabilities while implementing more detailed timelines that include design reviews to enhance our team structure to ensure an efficient build process yielding a dynamic and innovative ROV.

GENESEAS

ST. FRANCIS HIGH SCHO
SACRAMENTO, CA, US

SAFETY • SERVICEABILITY • RELIABILITY

Geneseas' mission is to provides tangible solutions to real-world problem while maintaining an emphasis on safety, serviceability, and reliability for

DESIGN RATIONALE

Beluga is equipped with custom features designed to enhance the ROV by improving maneuverability, electronics capabilities, and the functionality of the camera and display system. These developments ensure safety, serviceability, and reliability, enabling *Beluga* to meet MATE's RFP and achieve the UN Sustainable Development Goals.

This year, *Geneseas* integrated a fully digital camera system, pneumatic gripper, and a vertical profiling float. This yielded the development of a versatile ROV, capable of completing all given missions. The addition of a pneumatic gripper increases *Beluga's* pilotability by providing the pilot complete control to manipulate objects and fulfill tasks such as repairing marine renewable energy technology. *Geneseas* also utilizes a custom buoyancy engine, *Olive Ridley*, capable of completing vertical profiles. *Ridley* runs in parallel to *Beluga*, working to monitor ocean conditions in Antarctic waters.

Beluga's components were engineered by *Geneseas* to ensure safety, serviceability, and reliability as *Beluga* maintains renewable energy systems, sustains offshore aquaculture, and conducts operations to combat climate change in its overarching mission to achieve the UN Sustainable Development Goals.



Figure 3. Teaching *Robotics Engineering* Course
Photo by Lauren Jones '22

Figure 6. *Beluga*
Photo by Lauren Jones '22

Figure 5. Remote Piloting System (RPS)
Photo by Lauren Jones '22

1. *Beluga* features a 180 Newton electromagnet located on the front extrusion of the ROV. The magnet is controlled by a toggle button in the RPS and allows for easy retrieval of ferrous objects. *Beluga* uses the electromagnet to release a ghost net and repair marine renewable energy systems.

2. *Beluga* utilizes four thrusters, each equipped with thruster guards and caution labels to ensure the safety of ROV operators. *Beluga* features two horizontal thrusters and two vertical thrusters which are mounted at a thirty-degree angle to direct thrust away from the lower tool deck. This arrangement maximizes power, efficiency, and maneuverability.

3. The measuring tool is used for measuring fish and the *Endurance22* wreck-site. It functions via two protruding arms that hold a metal chain in place. This metal chain has metric measurements and is viewed through *Beluga's* advanced camera system to gauge the length of the object it is next to.

4. *Beluga's* Remote Piloting System, or RPS is housed in a Dewalt box, ensuring safe and easy transportation. An accessible and serviceable bottom compartment contains all of the electronics. The RPS contains buttons for the pneumatic gripper and magnet as well as gauges that display current, pressure, and voltage. A joystick connected to the RPS controls the movement and a laptop is connected and used to view all cameras.

5. *Beluga's* pneumatic gripper system allows for the manipulation of objects upon pilot command. The gripper system features a single-action spring return piston mounted on a custom 3-D printed pivot point mount which activates a gripper claw. This enables the gripper to open and close efficiently as it functions to repair and maintain marine renewable energy systems and sustain healthy aquacultures.

6. This year, *Geneseas* switched from using 20x20 mm to 15x15 mm extruded aluminum for *Beluga's* frame which yielded a more hydrodynamic ROV. During the planning stage, *Beluga's* frame was designed completely in CAD, allowing *Geneseas* to minimize waste and achieve a versatile design featuring adjustable tool placement. The frame includes two 3-D printed polycarbonate mounts for the electronics housing and a 3-D printed handle for easy retrieval.

7. *Geneseas'* custom float, *Olive Ridley*, utilizes a buoyancy engine to complete multiple vertical profiles from water level to the bottom of the seafloor. *Ridley* features two sensors, one ultrasonic sensor and one liquid level sensor, both used to detect the float's location in the water. These sensors trigger a servo motor to either fill or expel water from an internal syringe, adjusting *Ridley's* buoyancy and causing the float to rise or sink. This enables *Ridley* to successfully complete vertical profiles and monitor conditions in Antarctic waters.

8. *Beluga* features a tether
prevent entanglement durin
two pneumatics lines which
power wires, and two CAT6
allowing for efficient set-up

9. *Beluga's* software is writ
system and a bottom-side R
that are in constant commu
sends this data to the ROV.
A testbench with identical
functionality of code. *Belu*
environments while enablir

10. After switching to digita
(GUI) in python, which allo
recognition systems. The G
underwater perspective wh
on the side of the GUI, exec

11. *Beluga* uses a python-ba
wreck site in an Adobe Pho
screenshots on a 4 by 2 gri
and autonomously opens th

12. *Beluga's* ROV electronic
6-inch Blue Robotics enclos
serviceable. A testbench re
compatibility. An Arduino-b
phases of testing, ensurin

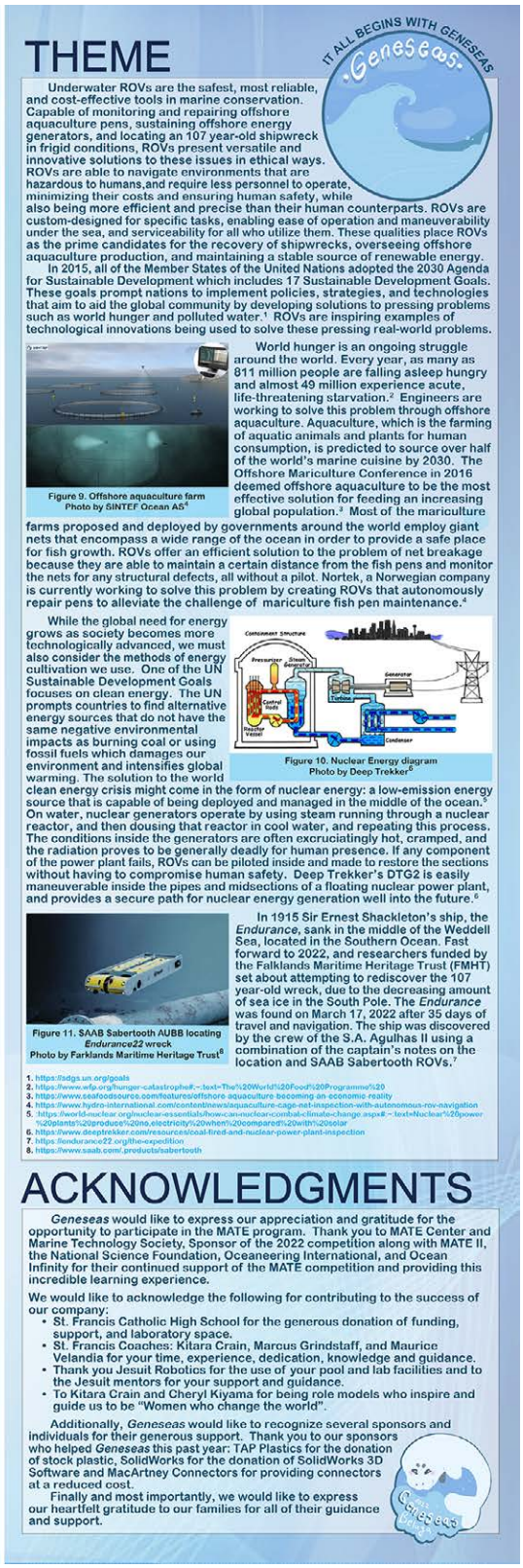
13. This year, *Geneseas* has
designing a fully digital can
four mission cameras. The
rotates to provide 180 degre
cameras provide vision of
mission tasks like inspectir
location of the *Endurance2*

14. The safety of employees
was designed with safety fea
strain relief, custom 3D print
of these features protect R
occurence of avoidable ac
respond to potential hazarc

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Marketing Display Winners





In-Person Ranger

TEAM NAME
Geneseas
St. Francis High School
Sacramento, C.A.
United States of America

TEAM MEMBERS
Alexandra Dinh
Alicia Del Toro
Alyssa Renomeron
Audrey Mayo
Ava Borchers
Emily Asperger
Emily Murray
Gabrielle Rosario
Isa Gutierrez
Isabella Ramos
Jaedyn Alford
Jianna Reyes
Kinnera Tirumala
Lauren Grindstaff
Lauren Jones
Meredith Garcia
Morgan Jones
Norah Zhou
Siena Marois
Sofia Stuck
Sydney Goodall

MENTORS
Kitara Crain
Marcus Grindstaff
Maurice Velandia

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2022 MATE World Championship

Abstract

Otodus is Fish Logic's sixth Remotely Operated Vehicle (ROV), designed on the request for proposals by MATE Center and our wider global community for an ROV to assist in marine renewable energy, offshore aquaculture and monitoring the impacts of climate change. To meet the desired functionalities, Fish Logic, a company dedicated to developing underwater ROVs, has designed Otodus with a flexible configuration. Otodus is capable of maintaining offshore wind turbines and fish aquaculture, deploying BGC Floats to monitor ocean conditions and finding the Endurance wreck.

Otodus is fully designed by the twelve dedicated members of Fish Logic. The design is an evolution of Fish Logic's previous ROV, Hydron, with the emphasis on prioritizing safety and functionality, followed by ease of use, ease of maintenance and ease of manufacture. Fish Logic has incorporated systems engineering in designing the ROV for better system integration with all aspects of the ROV validated through testing.

The majority of Otodus's structure is 3D printed, allowing the structure to take on a very unconventional form that is modular and standardized. The structure supports six brushless thrusters and tools which can be "hot swapped". Otodus was designed to meet size and weight restrictions, with the resulting ROV being a high performance, flexible, reliable, pilot optimized and mission oriented vehicle.

The development period of the Otodus encompasses 1 year with about 6830 work hours. The market value of Otodus is 35958.17 HKD.



Fig.1 Photo of Otodus (Photo by: Justin Ngo)

Company Information

MEMBERS	ROLES	YEAR
Isaac Sin Wai Teng	CEO & CTO	Grade 12
Kimi Wong Wang Hei	COO & CFO	Grade 10
Kevin Sio Ka Wuh	CMO	Grade 10
Hou Fong Chan	Head of Software	Grade 11
Ada Leong Weng Sam	Head of Fabrication	Grade 12
Chester Lo Ngou Hei	Prop Manager & Mechanical Engineer	Grade 12
Chloe Kwok Ka Kio	Head of Design & Senior Fabricator	Grade 12
Justin Ngo Ting Wei	Pilot & Mechanical Engineer	Grade 10
Julio Da Silva Nogueira Smith	Development Team Commander	Grade 12
Argus Hong Iat Hei	Development Team Pilot	Grade 9
Thomas Lei Chon Weng	Senior Mechanical Engineer	Year 1
Charles Hung Kai Tai	Safety Officer & Mechanical Engineer	Grade 10
Ryan Chan Chon In	Mechanical Engineer	Grade 12
Edward Lei Kuok Lon	Mechanical Engineer	Grade 12
Daniel Lei Man Tat	Mechanical Engineer	Grade 11
Alison Wong Sin Iok	Mechanical Engineer	Grade 11
Isla Cheong Yin Wan	Mechanical Engineer	Grade 11
Yoanna Lei Un Lam	Fabricator	Grade 10
Stephanie Ma Man Tong	Fabricator	Grade 11
Onching Lam	Graphics Designer	Grade 11

MENTORS
Mr. Andy Tsui
Mr. Ryan Ip



Fig.2 Members of Fish Logic (Photo By: Ryan Chan)
Front row: Julio, Hou Fong, Justin, Kevin, Isaac, Kimi, Thomas, Chester, Chloe, Ada
Back row: Alison, Isla, Onching, Edward, Ryan, Charles, Daniel, Argus, Stephanie, Yoanna

Company Evaluation

Fish Logic considers the past years as a success as the Otodus was developed on time, meets all expectations, and operates reliably. As a company, Fish Logic has been highly productive as all of its members were cooperative and have worked exceptionally hard throughout the whole process against all odds caused by the COVID-19 pandemic. The strength of Fish Logic lies in its ability to come up with innovative ideas, that are supported by heavy research and development investments which bring revolutionary technologies into the ROV, while being able to package them all into a well-balanced system. Otodus has a very flexible configuration making it easily optimized for specific tasks.

The current structural parts are 3D printed with integrated aluminum hexagonal rods for strength but has the drawbacks of increased weight. Fish Logic is currently experimenting on integrating carbon fiber inserts instead of aluminum rods which has the potential to lower the weight of the ROV frame by more than a third. These new parts are now being tested for its long term durability but, a more efficient manufacturing process before implementation. Participating in this competition was a great experience for the whole team. Team members had substantial gains ranging from CAD modeling and fabricating, to programing and interpersonal skills while developing the ROV. However the most rewarding part of this competition is learning how to develop systems, from design to fabrication and to operation stages. Apart from technical knowledge, the team has also gained vast experiences in working collaboratively. These skills further increased our interests in engineering and helped us prepare for our future careers.

ROV Simulator

Fish Logic has developed a ROV simulator in Unity that can simulate the drag, movement and buoyancy of the ROV with adequate accuracy that can evaluate the performance and design of the ROV. The simulator has allowed different tool layouts to be tested for an optimal layout. The pilot was able to test and propose new custom control schemes and tweak ROV speed profiles. The operations team, especially the pilot, can also run through many different scenarios in the simulated missions to gain more experience in adapting to challenges during mission runs.

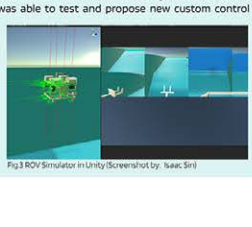


Fig.3 ROV Simulator in Unity (Screenshot by: Isaac Sin)

OTODUS

Design Rationale

Standard Mounting System (SMS)

The Standard Mounting System 5 (SMS5) is the 5th generation of mounting system developed by Fish Logic, which is integrated on all tools and attachment points used by the Otodus. The system uses a single screw to secure a bracket on a rail. This has the benefit of allowing quick relocation of tools along the rail, as well as the swift clamp-on or removal of tools and cameras. This system also allows the parts to be interchangeable, enabling the ROV configuration to be flexible and adaptable. The clamp is very secure, with its gripping force rated to be capable of resisting movement of up to 343N.

Frame Structure

Otodus' frame is a 3D printed structure made of PLA+ biodegradable plastic, strengthened by aluminium rods. Standard mounting rails have been integrated along all the straight edges of the frame, thus providing the flexibility of having tools and cameras being able to mount anywhere. All parts of the frame have a safety factor of 2, which means that the frame can handle twice the amount of stress as experienced during the operations.

Ballast Feet

Stainless steel balls are added to the bottom of the ROV in each corner. This lowers its center of gravity. With a low center of gravity and the floats on the top creating a high center of lift, the opposing forces keeps the ROV upright and stable. Additionally, the ballast feet supports the ROV when landing on a surface, allowing it to roll on the pool bed.

Electronics

All electronics are enclosed in epoxy to waterproof them, eliminating the need for a watertight canister which is prone to water leakage. Power hubs, that step down the 48V power supplied to the 12V required by the tools and thrusters, are placed near the center of the Otodus for shorter wiring to all tools and thrusters. The camera hub has an isolated step down module which prevents signal noise from the thrusters affecting the camera signals.

Magnetic Camera Mount

Magnetic camera mounts are designed to allow for the quick switching of cameras from one position to another. Neodymium magnets are placed in 3D printed enclosures that are attatched to the mount and the camera itself. The enclosure is in the shape of a cube, which prevents the camera from rotating and ensures a tight fit to eliminate unwanted vibrations. By using magnetic camera mounts, the time needed to change camera angles has been greatly reduced, from previously being 30 seconds or more to just 3 seconds.

6 Thruste

4 T100 thrusters and 2 T200 th
reliable and cost effective. In c
electronics. This is achieved by
a streamlined housing, resulti
degrees of movement which q
working around the site and r
power to weight ratio, allowin
are placed at 45 degree angles
vertical thrusters for vertical m

Standardization and Mod

Similar to most professional ROVs, standardized parts enables the tools to be in
an ROV easily adaptable to different tasks. Parts of the ROV are designed to be m
be easily serviced, where parts can be interchanged without affecting other com

Tools

Gripper

The Gripper is a general purpose claw with specialized grip surfaces for transportation of the hydrophone, removal of marine growth and collection of morts.



Fig.4 Gripper (Photo by: Justin Ngo)

Bi-Electromagnet

The Bi-Electromagnet (BEM) consists of two electromagnets that can be turned on and off individually. This is a general purpose tool used in the transportation of the repair of the fish pen netting.



Fig.5 Bi-Electromagnet (BEM) (Photo by: Justin Ngo)

BEM Latch Attachment

This attachment for the Bi-Electromagnet has a flap with a ferrous metal plate that holds the new buoyancy module and the hydrophone. They are deployed by the flap swinging open when the electromagnet is switched off.



Fig.6 BEM Latch Attachment (Photo by: Justin Ngo)

SeaLift Vertical Profiling Float

The SeaLift vertical profiling float is designed to complete 2 vertical profiles of a 2m deep pool within 2 mins. Its buoyancy engine has a DC motor that drives a piston to draw and fill an external flexible water bladder to alter the SeaLift's volume.



Fig.7 SeaLift Profiling Float (Photo by: Justin Ngo)

Seagrass Hook

This hook is mounted on the bottom rail of the ROV so that it can slip under and retrieve the seagrass.



Fig.8 Seagrass Hook (Photo by: Justin Ngo)

Cable Installer

This is an active tool mounted at bottom center of the ROV. Once the cable is installed, a linear actuator extends to attach the wet mateable connectors. A release mechanism for the cable is triggered when the actuator retracts.



Fig.9 Cable Installer (Render by: Kevin Sio)

Inter-Array Cable Carabiner

This Carabiner traps the damaged cable using a repelling magnet flap. Once attached to the damaged cable, it can be pulled to shore using a string.



Fig.10 Inter-Array Cable C (Photo by: Justin Ngo)

Buoyancy Module Carabiner

This Carabiner consists of 2 Y-shaped repelling magnet valves that clip onto the handle of the buoyancy module. When the handle is secured, the ROV can then rotate the buoyancy module and pull it away from the cable.



Fig.11 Buoyancy Module C (Photo by: Ju

Hydrophone Retriever

This cup-shaped tool traps the float of the hydrophone and picks the whole hydrophone up for retrieval.



Fig.12 Hydrophone Re (Photo by: Justi

Safety Features

Safety is the first priority of Fish Logic when designing the ROV.
To prevent accidents from occurring, a series of safety features are included:

Fuse — Fast blow fuse are used to cut the circuit when the current flow exceeds the intended limit. This avoids accidents such as electrocution.

Notification LED — Notification LEDs are present in all the electronic modules of the ROV to indicate that they are powered.

Kill Switch — A k
pow
to a

Lights — Lights are installed on to the ROV to make it more noticeable in the surroundings to avoid bumping into other ROVs, sea creatures or divers.

No Sharp Edges — There are no sharp edges on the ROV to avoid cuts on the diver, sea creatures or crew members.

Thruster Shroud — Thr
ont
bod
pro

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Marketing Display Winners



Telepresence

Explorer

TEAM NAME

Fish Logic
Macau Anglican College
Macau

TEAM MEMBERS

Ada Leong Weng Sam
Alison Wong Sin Iok
Argus Hong Iat Hei
Charles Hung Kai Tai
Chester Lo Ngou Hei
Chloe Kwok Ka Kio
Daniel Lei Man Tat
Edward Lei Kuok Lon
Hou Fong Chan
Isaac Sin Wai Teng
Isla Cheong Yin Wan
Julio Da Silva Nogueira Smith
Justin Ngo Ting Wei
Kevin Sio Ka Wun
Kimi Wong Wang Hei
Onching Lam
Ryan Chan Chon In
Stephanie Ma Man Tong
Thomas Lei Chon Weng
Yoanna Lei Un Lam

INSTRUCTORS

Andy Tsui
Ryan Ip

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2022 MATE World Championship

Theme

MATE competitions are closely related to the global environmental problems that concern the current world. The task of the participants of the competition is to build such a ROV (Remotely operated underwater vehicle), which would help to cope with them.

One of such problems is a person's need for a large amount of electricity. After all, Russia alone spent 906 TWh of electricity in 2020[1]! And every year this number is growing.The installation of offshore wind turbines can help solve this problem. Offshore wind turbines are an excellent alternative source of energy, because they are environmentally friendly. In addition, the efficiency of a wind farm is 40%[2], while, for example, for coal-fired power plants it is only 33%[3].



pic. 1 Vineyard Wind 1 offshore wind Farm under construction in U.S. federal waters in the Atlantic Ocean
The photo was taken from: https://www.atomic-energy.ru/

Underwater robots play a significant role in the installation and maintenance of offshore wind farms. First, they examine the bottom of the reservoir, look for the most suitable place to install a windmill and clean the cable installation site. Secondly, ROVs play a huge role in cable laying. They help the barges to guide the cable along the bottom and monitor the correctness of its laying.[5] Then the ROV strengthens the cable at the bottom.[6] At the end, they install it in an underwater station. ROVs also play a key role in the inspection and maintenance of the entire underwater windmill system.[7] Inspection work used to be carried out underwater with the involvement of a whole team of divers, but now it is possible to explore the depths thanks to remotely controlled underwater vehicles.[4] If any breakage is detected, the ROV helps to eliminate it. From all of the above, it can be understood that underwater vehicles greatly facilitate, reduce the cost and secure the construction of not only water wind turbines, but also other underwater projects.

Another global problem is hunger, which is exacerbated by the pandemic. According to the UN, 270.5 million people faced hunger in 2021, which is twice as much as before the outbreak of the pandemic[8]. Aquaculture makes and will continue to make a significant contribution to the global food supply, which is crucial for the "food security" of our ever-growing global population. Aquaculture also supports people and communities by providing business opportunities and jobs. According to the forecasts of the OECD and the Ministry of Food and Agriculture, aquaculture production will grow to 102-105 million tons by 2027[9]. Underwater vehicles can assist in the development of aquaculture, because they are able to inspect aquaculture pens, as well as maintain the health of the environment.[10] Thanks to the ROV's cameras, they can inspect the pens, identify damage, contamination and eliminate them with the help of special tools.[11] Thanks to special sensors, underwater vehicles can monitor the state of the water in the pen. ROVs are also able to swim inside the pen and monitor the condition of their inhabitants. All this points to the huge role of ROVs in modern aquaculture, which facilitate and secure the work in aquaculture pens.



pic. 2 Development of aquaculture in Kamchatka
The photo was taken from: https://regnum.ru/

Also, one of the most important problems is the problem of climate change, in particular, global warming, which leads to the melting of glaciers. More than 1 million tons of ice melts every day — for comparison, the iceberg that sank the Titanic is estimated at "only" 75 thousand tons. All this is fraught with hurricanes, floods, flooding of cities and countries, a sharp decline in agriculture and other economic losses[12]. Underwater vehicles can help stop or at least slow down this process, which with the help of chemical and biological sensors will monitor the circulation, chemistry, biology and the general state of the ocean. Sensors can be installed on the ROVs that will allow monitoring the state of the ocean. Underwater vehicles can also deploy, roll up and monitor entire groups of independent vehicles with sensors that allow monitoring the state of large areas of water in the ocean.



pic. 3 The consequences of record warming in Antarctica. Images from a NASA satellite.
The photo was taken from: https://earthobservatory.nasa.gov/

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ROBOCENTE

The Center for Robotics D

Vladivostok, Russia

~Save the Oc

Abstract

Our Robocenter team consists of 10 participants of grades 8-10 from different schools in Vladivostok. We represent the Cent
MATE competitions for 8 years. Our team participates in the competition in order to promote robotic creativity among childr
This year our team has designed a new ROV named "Tercel", which is radically different from last year. To create it, we distr
its creation, made a Gantt chart, used protocols and procedures, kept careful records of finances, and paid attention to secu
We have developed and manufactured special payload for our ROV:
Hooks with a grid are necessary for performance of the tasks connected with service of cable lines.
Software to perform automatic sailing and measurement tasks, as well as to facilitate the work of the pilot.
We are proud of our ROV updates this year:
We have increased the cross-section of the cable-rope, which has increased the stability of work and increased the speed of
The new frame increased the speed and maneuverability of the apparatus, reduced its weight.
The functionality of the bottom and rear cameras is now provided with one rotary.
And we express our gratitude to everyone who helped us with physical and material resources in the process of creating ROV

Design rationale

Overview of the main ROV systems
Our underwater vehicle - Tercel is designed for fast, convenient and high-quality performance of all assigned tasks. To meet the stated requirements, our ROV was equipped with the following equipment:

- Frame

To combine all the ROV components, we needed a supporting structure. Each participant offered his own frame concept. By voting, we chose the best frame from the proposed options, then we made a 3D model and cut it out on a CNC machine.

- Electronics block

To implement all the functions of our device, we use the onboard electronics module from the HighROV kit. For sealing electrical components, we used an aluminum sealed protective enclosure.

- Sensor system:
depth sensor
ammeter
IMU
- Safety
fuse
protecting shrouds on
no sharp corners

General characteristic
speed: 1m/s
weight: 9.7 kg



pic. 5 Float
Photo made by Igor Murzin

- Vertical profiling float

For data collection tasks in Antarctica, we have developed a special vertical profiling float capable



pic. 6 Rear mesh hooks
Photo made by Igor Murzin

Hooks with grid mesh

There are hooks with grid mesh on the back of our ROV. This special payload has been developed by our team for carrying out cable transfer jobs as well as removing



pic. 9 Control system.
Photo made by Igor Murzin

Ground control system

To control our ROV from land, we used surface equipment, which includes a joystick, monitor and computer



pic. 10 Camera
Photo made by Igor Murzin

Cameras

Our ROV has 2 tilt cameras that provide a viewing angle sufficient to perform all the tasks.

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Marketing Display Winners



TEAM NAME
Robocenter
The Center for Robotics Development
Vladivostok, Russia

TEAM MEMBERS
Abramova Maria
Alexander Katolik
Bondarenko Igor
Chalyy Svyatoslav
Grishchenko Andrey
Murzin Igor
Tikhon Ipatov
Timur Mangliev
Zakhar Nikolayev

MENTORS
Alexander Omelyanenko
Vadim Sorin

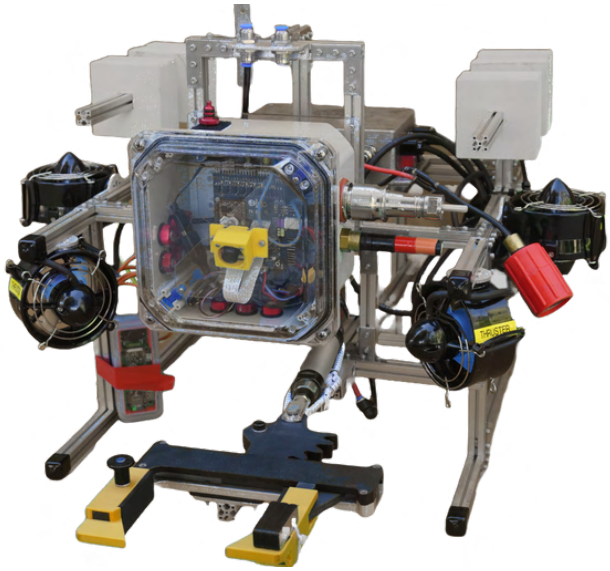
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TECH REPORT

JESUIT ROBOTICS

MATE 2022

Explorer Class



MANATEE

TEAM MEMBERS

Freshmen:
‘25 Mark Weden*, Mechanical
‘25 Ethan Bullard*, Mechanical
'25 Douglas Crone*, Electronics

Sophomores:
‘24 James Randall, Software
‘24 Jonah Reynolds, Safety Officer
‘24 Adon Sharp, Software
‘24 Alex Bertran*, Software
‘24 Nathan Peterson*, Software

Juniors:
‘23 Daniel Kriefels, Mechanical
‘23 Timothy Monroe, Mechanical
‘23 Michael Solis, Electronics

Seniors:
'22 Charlie Diaz, CEO
‘22 Nick Venegas, Electronics
‘22 Taylor Vicente, Compliance Officer

*New Members

COACHES AND MENTORS

Jay Isaacs
Cheryl Kiyama
Steve Kiyama
Marcus Grindstaff
Michael Sharp
Andrew Grindstaff

ROVOTICS

Jesuit High School
1200 Jacob Lane
Carmichael, CA USA

INTRODUCTION

ABSTRACT

Rovotics is a fourteen-person company with years of collective experience designing, manufacturing, and operating robotic solutions to ecological problems in aquatic settings. *Manatee* is Rovotics' newest and most advanced Remotely Operated Vehicle (ROV) and is designed to operate in a multitude of underwater environments. The ROV is fully equipped with tools to maintain offshore wind farms, inspect aquaculture pens, monitor the health of the ocean, and ensure a healthy environment for sea life.

Manatee is the product of months of planning, prototyping, and testing to meet quality and safety standards. With features such as a modular frame, expandable electronics, and an extensible software platform, *Manatee* is built to adapt to emerging global environmental challenges. This technical document describes the design and development process of our ROV and how *Manatee* addresses the myriad of challenges and tasks it will face.

JESUIT HIGH SCHOOL



Figure 1. Rovotics team members

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- National Science Foundation - Their funding of the MATE competition
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- Oceaneering International - Their support of the MATE competition
- Jesuit High School - Generous donation of funding and pool time
- Jay Isaacs, Head Coach - His time, creativity, knowledge, and guidance for the past seventeen years
- Steve Kiyama, Assistant Coach - His time, experience, and guidance for the team
- Cheryl Kiyama, Program Director - Her time, experience, and management of the team
- Bulgin - Their generous donation of connectors
- MacArtney Connectors - Providing connectors at a reduced rate
- GitHub - Providing complimentary private code repositories
- Fusion 360 - Providing CAD software
- SolidWorks - Providing CAD software
- TAP Plastics - Donation of stock plastic
- Mentors - Marcus Grindstaff, Michael Sharp, Andrew Grindstaff
- Adobe Systems - for providing student discounted software license
- Our Families - Their continued support and encouragement

DESIGN RATIONALE

DESIGN EVOLUTION

Manatee is Rovotics' third generation of our core ROV system, based on a previous ROV design. The reuse of core systems provided the means for Rovotics to rapidly design, prototype, and manufacture *Manatee's* mechanical frame, electronics, and control software in a predictable amount of time, allowing for an earlier development schedule with a more reliable ROV platform earlier in the season.

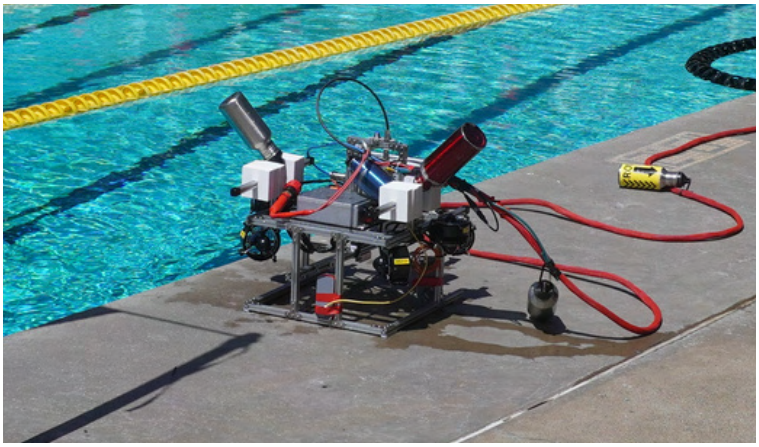


Figure 2. Manatee ROV on Deck

This early standardized platform allowed Rovotics to iterate quickly and efficiently on tools in the design process.

Rovotics first made the switch to commercial off-the-shelf (COTS) components in our 2018 first generation ROV design. A strong focus on standardization allowed Rovotics to quickly replace damaged components with reduced lead times. Use of commercially available parts allowed Rovotics to train newer members more easily, because custom parts require specialized knowledge to create and maintain, and frequently this knowledge was lost with graduating members. Standardization permitted Rovotics to allocate more resources towards developing new functionality which necessitated custom hardware and software innovation, like with our digital cameras, which are now more leak resistant due to improvements in housing construction. *Manatee's* frame design allows for standardized parts to be detached and replaced quickly.

The decision on the standardization tradeoff was made to ensure that both customers and Rovotics employees can be confident that our technology will be forwards compatible with future Rovotics innovations. Advancements used in previous ROVs are able to be reused this year, which provides cost benefits. Rovotics' introduced several innovations with standardization in mind, including a new Raspberry Pi Hat designed with standard I^2C support to easily upgrade ROV functionality; a standard tool mounting interface to quickly swap different tools to service many different tasks; a standard SW test bench to quickly optimize SW updates with limited ROV downtime.

With safety as a top priority, Rovotics' standardization ensures that proven safety systems from previous ROVs have been maintained in Manatee. Its mechanical design implements safety elements such as thruster guards and a smaller, lighter Topside Control Unit to protect the deck crew from injury.

DESIGN AND MANUFACTURING PROCESS

Rovotics decided to design a new ROV that would leverage much of its previous core ROV system. Mechanical designs of the frame and electronics housings were to be largely based on proven designs.

Rovotics' modular frame and rectangular electronics housings proved to be improvements over previous cylindrical housing designs. The *Manatee's* design process began with an interdepartmental team of mechanical, electrical, and software engineers to discuss which aspects of the new ROV should remain the same as the previous design, and which aspects could be improved. A decision matrix was applied to the design process. Factors, such as current usability, product or material availability, cost, and suitability for future use were evaluated. It was found that the existing

Main Electronics Housing (MEH) was too large to manage the buoyancy of our ROV, and the extra space that was allocated for electronics was not needed. The mechanical department analyzed commercial, off-the-shelf, and waterproof housing solutions to meet the requirements. The result was the purchase and modification of a smaller rectangular waterproof housing. The housing chosen is a variation on a prior MEH design, but is smaller so it will allow for the easier distribution of buoyancy on the ROV.



Figure 3. Tool Integration to Modular Frame

The ease of design, manufacturing, and modification of previous ROVs' aluminum extrusion frame proved to be useful during development and operation. Application of the design matrix verified the use of an extrusion frame design which remains a significant advantage. As a result, the *Manatee's* aluminum extrusion frame is an optimized version from a prior design. Initial frame design work was done on Fusion 360, Rovotics's Computer-Aided Design (CAD) platform of choice. After the initial design was complete, revisions were made during meetings in which the optimization of costs, tool placement, and the reduction of size and weight were discussed. Upon the completion of design revisions, parts for the frame were purchased and the final product was fabricated.

TROUBLESHOOTING AND TESTING TECHNIQUES

For the past several ROV iterations, Rovotics has implemented multiple dedicated test environments utilized to test and troubleshoot problems using a Root Cause Analysis, or RCA method. Parallel test environments allow each department to complete software and electronics tools or field testing before integrating with the *Manatee* Production ROV. Rovotics' testing approach serves to reduce the downtime of *Manatee*, as well as diminish the risks posed when integrating new features.

The electronics and software departments use a simulation test environment to test new components and code respectively. These test environments are designed to simulate the functionality and conditions faced by the production ROV, *Manatee*. For example, thruster test code used on the test platform allowed the crew to verify motor control and operation prior to integration of the code onto the production ROV.

Before Rovotics implements a new software feature onto the ROV, it is tested on one of Rovotics' three software test benches (Figure 4). These test benches are outfitted with adequate hardware to simulate both the environments of topside and bottomside, ensuring that untested code doesn't make it into the Rovotics GitHub or the ROV. During the 2021-2022 season, Rovotics used these test benches to ensure the safety of all of its software, including new programs like its depth hold.

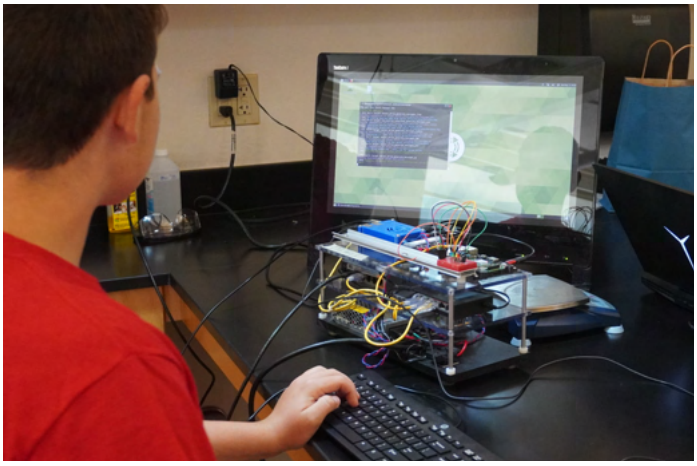


Figure 4. Software Engineer at Testbench

Rovotics was able to test depth hold on a test bench by creating a simulation environment for rapidly changing the pressure using a pump. This allowed Rovotics to see how the software responded to rapid changes in pressure. The software test benches each contain a drop-in replica of both ROV's core electronics control system, which allows for testing MEH electronics components in the software test environments.

The electronics team's test environment is a repurposed production robot from a previous competition, allowing the electronics and mechanical departments to test new designs and components in a similar environment to that of *Manatee*. This ROV test environment contains the same electronics as the *Manatee* production ROV and is similar in construction and design, allowing this test system to be used for water trial runs.

For testing of tools, the repurposed old ROV allowed testing to occur with minimized risk to the production ROV. The mechanical department developed and tested prototypes of tool designs using the integration test environment. Each tool undergoes an extensive design review process that ensures each tool is ready for testing. Once necessary tool modifications and software and electronics testing were completed, the team integrated the mission tool onto *Manatee*.

Using dedicated test environments made it easier to troubleshoot issues encountered with the Production ROV and allowed each department to continuously develop in parallel with minimal downtime, unlike prior years of sharing a single test and development environment across the teams. This practice saved the company many hours of troubleshooting time while enabling more time for parallel tool development.

MECHANICAL SYSTEMS

FRAME

Rovotics' modular frame system is made out of beams of 15 x 15 mm extruded aluminum with T slots. Previous ROVs used custom frames with higher manufacturing costs and lacked the flexibility afforded by a modular frame. Rovotics originally moved to use aluminum extrusion because of its low cost, ease of manufacturing, and ability to be rapidly modified. Still, the 20 x 20 mm aluminum extrusion used on a prior ROV's design proved to be very heavy. Rovotics switched to 15 x15 mm aluminum extrusion, (Figure 6) providing a lighter frame build and more responsive ROV. Extrusion and a wide assortment of fastening solutions are readily available from many online suppliers, supporting easy standardization.

Manufacturing extrusion frames consists of cutting the extrusion to length and fastening extrusion segments together using brackets, screws, and sliding nuts. Modification of the frame is identical to the manufacturing process and is, therefore, just as quick and easy.

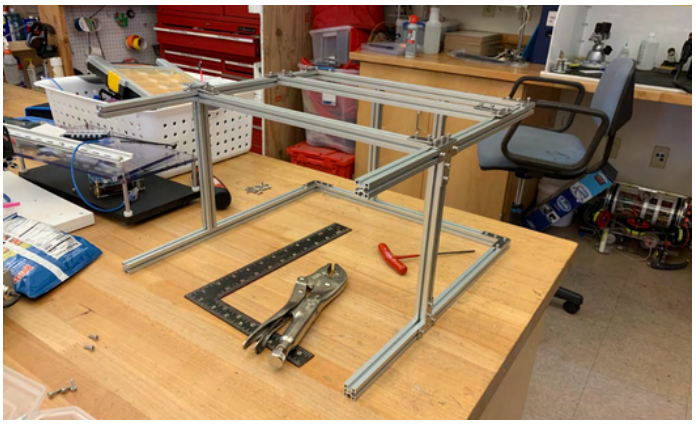


Figure 5. Manatee Extruded Aluminum Frame

During our design revision discussions, the design requirement for *Manatee's* frame specified a sizable rectangular prism providing ample interior space for tools. The frame's revised design used less extrusion than our previous ROV design, which further decreased the cost and weight while increasing the tool mounting area.

The MEH and Power Systems Enclosure (PSE) are mounted to the top frame (Figure 6), which accounts for most of the buoyant force. Placing this buoyancy source at the top of the ROV contributes to its stability. The mechanical design team chose the MEH and PSE because of their off-the-shelf availability and short lead time. These housings also utilize more secure face seals as opposed to the bayonet seals used on previous tube-style housings. The PSE is a cast aluminum box chosen for its high thermal conductivity. This thermal conductivity is used to cool both the Electronic Speed Controllers (ESC) and voltage converters. Horizontal thrusters are mounted on the corners of the frame at 45° for vector drive, and two vertical thrusters are mounted on either side of the ROV. The center of mass is aligned with the center of thrust to maximize ROV stability.

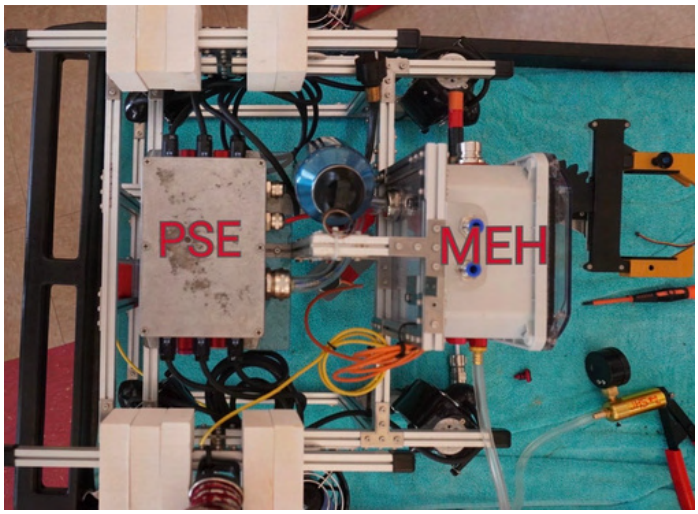


Figure 6. Manatee Top View

TOPSIDE CONTROL UNIT

One of Rovotics' significant investments in the *Manatee* ROV is a new TCU that integrates all on-deck devices to improve portability and reduce setup time (Figure 7).

The large size and significant weight of the previous TCU made it cumbersome to use and was a potential safety hazard. The new design is smaller and lighter allowing one person to safely handle it. The new TCU includes all of the previous capabilities of the last TCU as well as some new features such as multiple pneumatic switches and an internal pneumatic regulator to simplify the setup process.



Figure 7. TCU with Joystick and Peripherals

The TCU was designed to fit in a Pelican iM2700 Storm case that allows easy transportation, setup, and protection due to its durable and mobile design. 6.35 mm (1/4 inch) piece of ABS plastic is mounted to the TCU to serve as the control panel for the TCU. The control panel has an ammeter, pressure gauge, two voltmeters, and two pneumatic switches. Consolidating all meters and controllers allows for a more simplistic use of the TCU.

ELECTRONICS HOUSINGS

Both *Manatee's* Main Electronics Housing (MEH) and Power Supply Enclosure (PSE) are rectangular, off-the-shelf housings. In previous years, Rovotics used cylindrical housings to contain our ROV's core electronics. Though these designs performed well, Rovotics determined that commercially available parts

were easier to replace, quicker to obtain, and more aligned with our standardization goals. As our electronics suite expanded to accommodate new features such as digital cameras, it was deemed necessary that our housings expand as well.

By dividing the electronics architecture into two waterproof housings, the PSE and the MEH, *Manatee* can retain the operating and servicing advantages of utilizing a clear plastic housing while simultaneously reducing thermal expansion caused by high energy components.

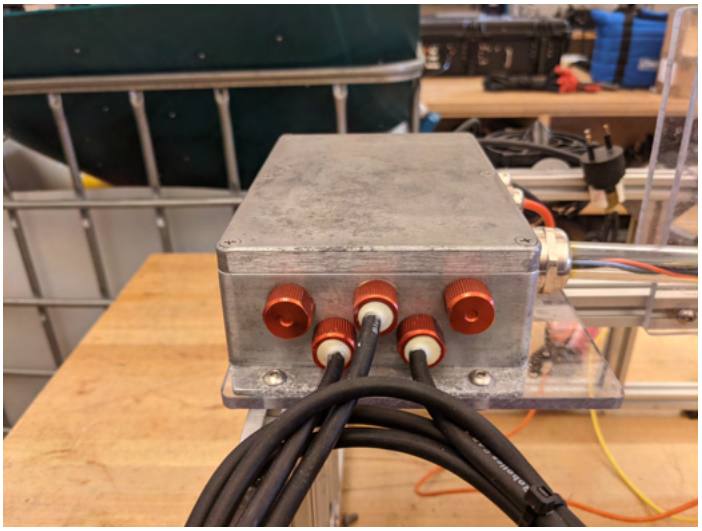


Figure 9. Power Supply Enclosure (PSE)

The PSE houses *Manatee's* ESCs and voltage converters. To dissipate heat generated by the ESCs and the voltage converters, the PSE is manufactured out of aluminum which, when submerged in water, doubles as a heat sink.

The voltage converters, which are responsible for generating the majority of heat in the system, were aligned on the aluminum walls of the PSE to maximize thermal transfer to the water. The utilization of an aluminum PSE has brought average voltage converter operating temperatures down from 80° C in our cylindrical housings to 35° C.

The polycarbonate MEH contains the core ROV computational systems.

The MEH has a clear lid to allow for a 110° Field of View (FOV) digital camera which is used as our primary navigation camera. The clear lid also allows for visual inspection of the interior of the housing, which is valuable for operations and servicing. A modular sliding shelf system provides easy access to service internal components.

The clear and flexible Power and Communications Tube joins the PSE and MEH. This tube allows the PSE to provide power to the MEH electronics, and the MEH to provide the ESCs information from topside. This tube is especially beneficial for maintenance as it allows vacuum testing both housings simultaneously which reduces the complexity and improves the reliability of the test.

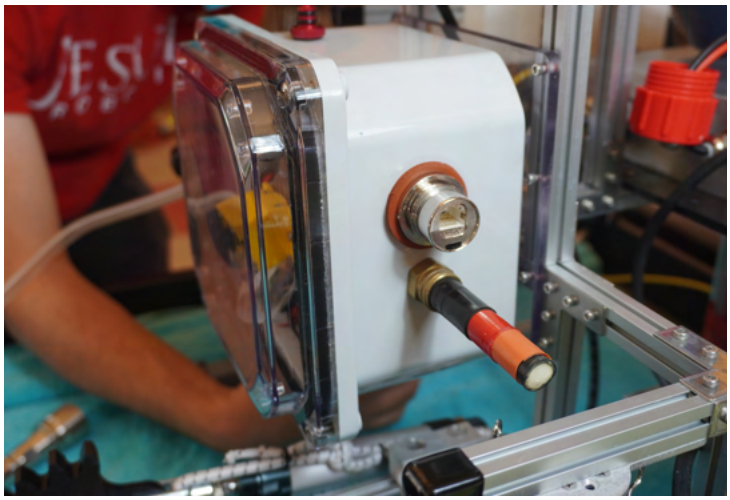


Figure 8. Main Electronics Housing (MEH)

PROPULSION

Manatee is equipped with six T100 Blue Robotics thrusters. The T100 thrusters were chosen for their low weight, affordability, and proven reliability on previous Rovotics' designs. A previous ROV design used four T100 thrusters and two T200 thrusters; however, the additional cost was not justified by the little benefit provided. Additionally, the standardization in thrusters eliminates the costs of having two different types of backup thrusters. To achieve stable vector control, four T100 thrusters are mounted at 45° angles at the corners of the ROV, allowing all

thrusters to contribute to the total propulsion in the cardinal directions and minimize flow interference with accessories in the center of the vehicle. The T100 thrusters operate at a maximum power of 150W each, manageable within *Manatee's* power budget. For the safety of personnel and equipment, low resistance thruster guards (Figure 10) are mounted on both sides of the thrusters to prevent foreign objects from entering the thrusters, increasing safety for the deck crew and reliability of the thrusters.

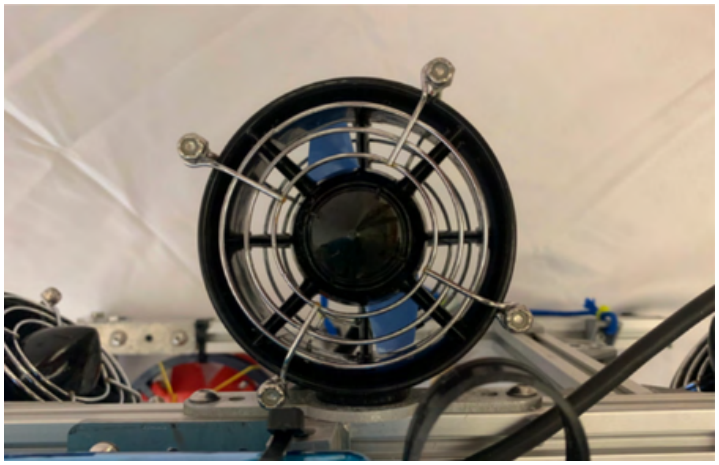


Figure 10. Manatee's T100 Thruster Guards

BUOYANCY

Manatee, along with its components and tether, has a maximum displacement of 7650 cm3. It possesses three main buoyancy components: *Manatee's* Main Electronics Housing (MEH), Power Systems Enclosure (PSE), and Manually Adjustable Buoyancy System (MABS), seen in Figure 12.



Figure 11. Rovotics Employees in Lab

At over 4360 cm3, the two electronics housings are *Manatee's* largest displacement components and serve as the primary driver for the ROV's buoyancy. These two electronic housings are joined with a single piece of aluminum extrusion allowing for adjustment of the ROV's center of buoyancy. Our MABS utilizes syntactic foam disks which will remain buoyant for depths up to 300 meters, allowing *Manatee* to reach the target depth of any MATE mission with ease. The MABS allows for buoyancy to be adjusted by inserting or removing foam disks, allowing the deck crew to quickly adapt to any mission's needs.

Rovotics maintains a spreadsheet to record the displacements and densities of each part of the ROV. Using Archimedes' Principle, this data was used to calculate *Manatee's* weight in both air and water. Once the majority of the ROV was manufactured and assembled, the actual and calculated values were compared to allow for fine-tuning using our MABS.

Manatee's tether achieves a slight positive buoyancy by using rigid, lightweight aluminum water bottles interspaced along its length. The tether's positive buoyancy ensures that it does not interfere with the ROV during operations while not being so buoyant that it impedes ROV movement.

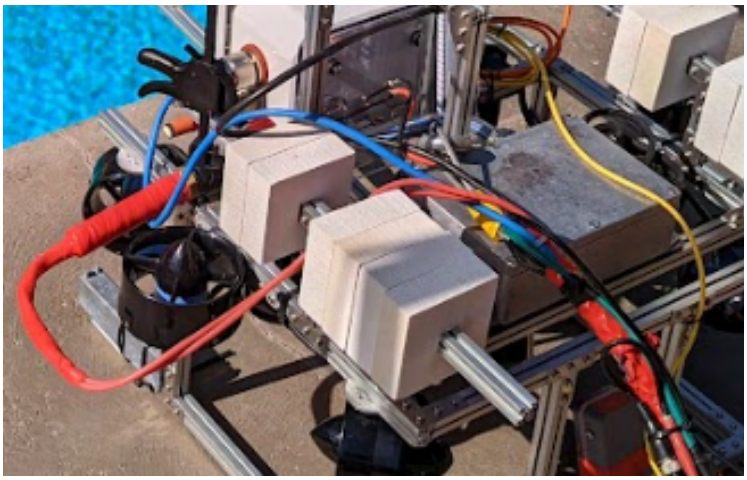


Figure 12. Manually Adjustable Buoyancy (MABS)

PNEUMATICS

Manatee's pneumatic system is a simple, lightweight, single-line system that receives air from the MATE supplied connection and is regulated to 2.76 Bar (40 psi) by an adjustable pressure regulator. *Manatee* has two pneumatic grippers, each controlled by two-way, three position solenoid valves which are located in the TCU and are activated by co-pilot controlled switches.

Manatee's dual grippers are the only pneumatic tools in the ROV system. Each gripper is extended by the activation of a pneumatic piston and returns to the retracted position by an elastic cord. By utilizing an elastic return, Rovotics eliminated the need for a return air line on the tether, improving tether flexibility and reducing weight. Components in the system are rated for 8.5 bar (120 psi) or greater to meet the MATE safety requirement. The entire system is also protected by a pressure relief valve located ahead of the pressure regulator.

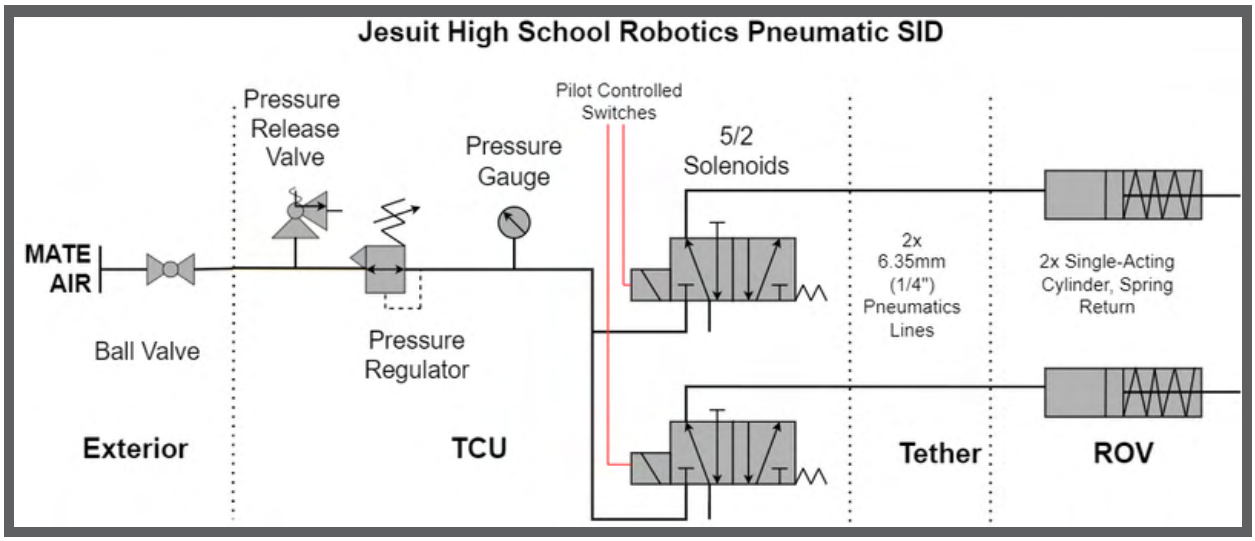


Figure 13. Pneumatics SID

ELECTRICAL SYSTEMS

TOPSIDE ELECTRONICS

The TCU's bottom compartment (Figure 15) was designed with a liftable lid to easily service the most critical components, such as the powerful Intel NUC, a single board computer (SBC), housed in the bottom compartment. Wiring channels also ensure an organized and modular construction. The internal Intel NUC serves as the main computer for the topside control system.

The Intel NUC communicates to all subsystems through a routed Transmission Control Protocol (TCP) / User Datagram Protocol (UDP) IP communication. Both the router and an ethernet switch are contained within the TCU. The keyboard, mouse, joystick, and throttle connect to the Intel NUC through a USB hub integrated into the TCU. A single 533 mm (21 inch)monitor is mounted on to the lid of the case and is connected directly to the TCU. The Intel NUC has more processing power and RAM allowing it to drive the monitors and run the pilot and co-pilot systems effectively.

A second monitor is also connected to the TCU to assist the co-pilot. A highly visible main shut-off power switch has also been implemented as a safety feature to enable the quick shut down of the ROV. The back of the TCU contains USB and Ethernet connections and bulkhead connectors for pneumatics. To prevent connection errors, two different format high-current Anderson Powerpole connectors are used as separate connection points for both the 48V MATE supplied power and the 48V power feed to the ROV.

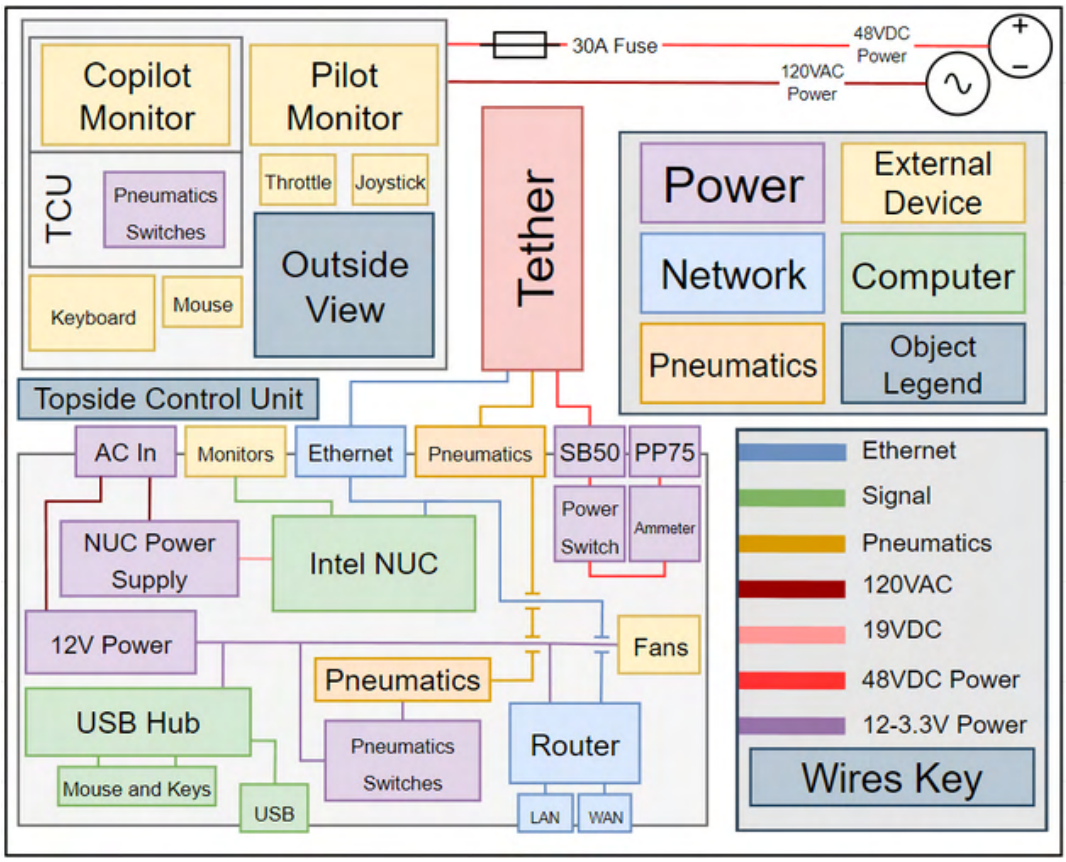


Figure 14. TCU SID

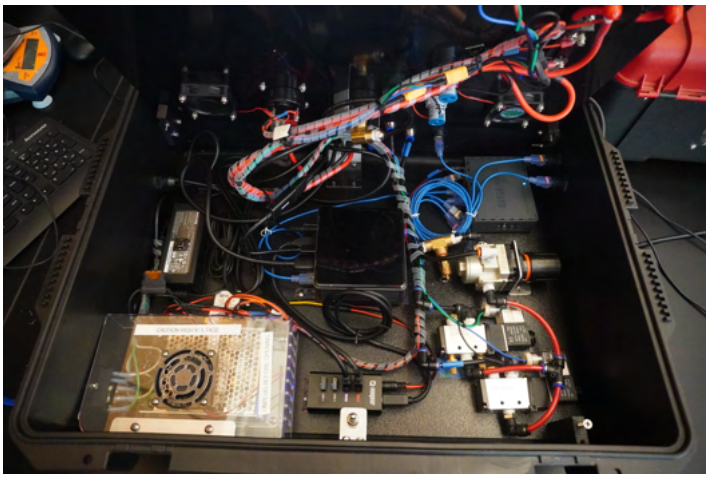


Figure 15. TCU Interior

BOTTOMSIDE ELECTRONICS

The bottomside (ROV) electronics system was designed around the principles of serviceability and standardization. The ROV electronics are contained in the Power Systems Enclosure (Figure 16) and the Main Electronics Housing. The PSE contains two 600W DSQ0150 48V to 12V voltage converters, a custom power Printed Circuit Board Assembly (PCBA), six Blue Robotics Electronic Speed Controllers (ESC), and an Arduino Nano. The control signals for the thrusters are sent to the PSE using a simple USB connection between the Arduino Nano in the PSE and the main Raspberry Pi computer in the MEH. The serial communication received by the Arduino is then converted to Pulse Width Modulation (PWM) signals sent to the Blue Robotics ESCs. The Arduino Nano is programmed with a watchdog timer to default the thrusters to zero thrust in the event that the main Raspberry Pi (RPi) crashes or communication is lost. Each thruster is connected directly to the PSE with a Blue Robotics 6mm penetrator. The two Murata DSQ0150s convert 48V from the tether to 12V for a total of 1200 watts available for ROV power.

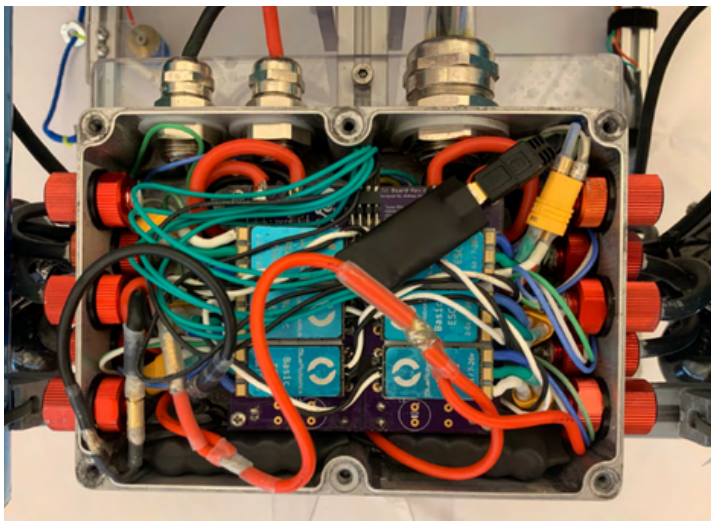


Figure 16. Interior of Power Supply Enclosure

The DSQ0150's were chosen for their nominal power, efficiency, reliability, and performance characteristics along with their array of safety features including overcurrent, overvoltage, undervoltage shutdown, and short circuit protection. The DSQs are placed on a power board that Rovotics designed to tightly integrate all high power components into a small aluminum enclosure. With this power conversion board comes a secondary "sister" board, which carries all Blue Robotics ESC's. These are supplied with 12v from the DSQ's and control the Blue Robotics T100 thrusters. Both boards are interconnected to allow sharing of power and communications signals, effectively creating a power distribution and control stack. This power stack is isolated in an off the shelf all aluminum housing. All high current electronics are connected directly to the aluminum enclosure with thermally conductive tape. This keeps all high power electronics cool by transferring all heat generated through the enclosure into the aquatic environment.

The Main Electronics Housing (Figure 17) contains Manatee ' main computer, a Raspberry Pi 3B+, a custom Raspberry Pi HAT, and a 5 port ethernet switch.

The RPi 3B+ is outfitted with a custom RPi HAT (Figure 18) to streamline environmental sensing, device control, and to provide power. Off the shelf RPi HATs were initially considered, but a lack of basic functionality and high costs led to the development of Rovotics custom solution. To reduce costs and build times, off the shelf I^2C breakout boards are used to expand its sensing capabilities. Breakout boards can be placed on the RPi HAT where they are provided with power and a connection to the I^2C bus. This eases serviceability of the electronics system by allowing vital components to be replaced or removed if needed.

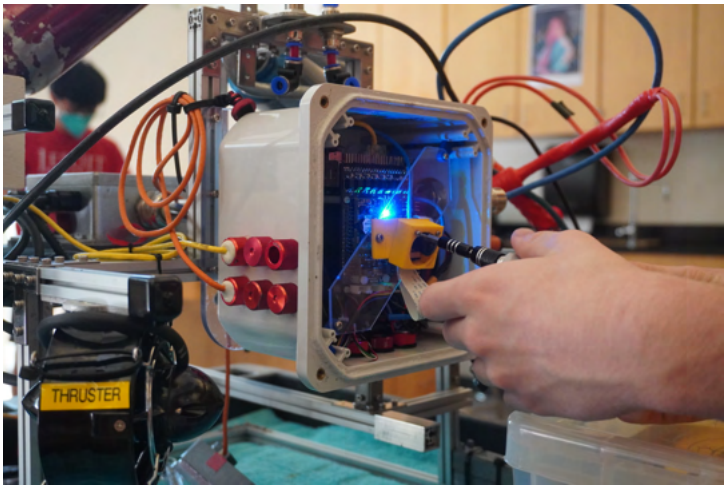


Figure 17. Interior of Main Electronics Housing

The RPi HAT contains a 9-axis inertial measurement unit (IMU) (1) and a humidity, pressure, and temperature sensor (2). A I^2C isolator is included to allow safe communication with the DSQ (3). To expand the pi's limited control capabilities, a ATSAMD09 breakout board provides additional PWM control, analog to digital (ADC) converters, and the ability to drive NeoPixels (4). Many I C Grove connectors are present on the HAT to allow for simple expansion to new capabilities (5). Six 2A relays (6) and two 4.5A relays (7), as well as two 1.7A (2.5A peak) directional motor drivers (8) are included to allow for electromagnet, laser, and motor control among other things. Power connections and individual indicator LED's for the relays and drivers, as well as the ability to switch them between 5v and 12v, are built into the HAT significantly simplifying wiring and use.

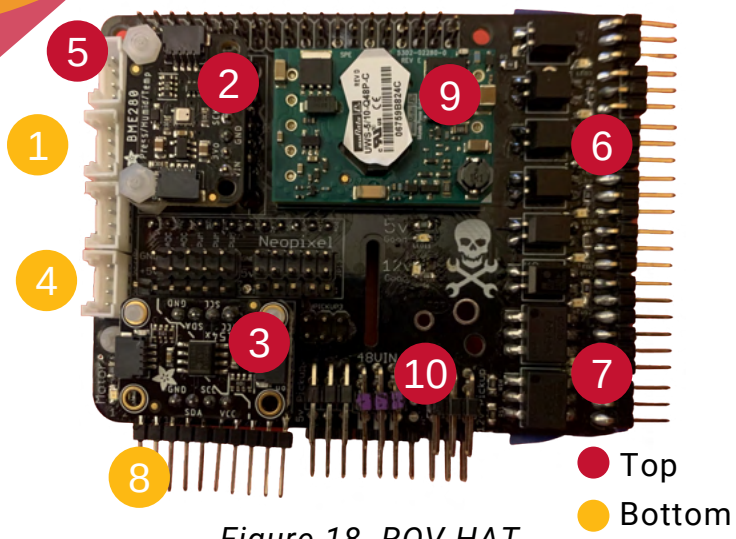


Figure 18. ROV HAT

A five port ethernet switch connects the Raspberry Pi 3B+ and any additional cameras or equipment to the TCU and each other. The switch was chosen for its incredible balance of performance, compact size, and low cost. In the event that more cameras or ports are needed to connect to the TCU, a secondary ethernet switch can be added to expand capabilities without changing the electronics system's size.

To provide 5V for the control electronics, a Murata UWS-5/10-Q48 voltage converter (9) located on the RPi HAT takes 18V-75V and converts it to 5V for use by the electronics. This wide voltage input range allows the core control electronics to remain powered in the event of large drops in voltage. The UWS regulator has additional safety features, including input undervoltage lockout and over temperature shutdown. In the case of a short circuit, onboard indicator lights will pulse to show current limiting via the “hiccup” auto restart technique. Converted 5V power is connected to power pickups to allow 5V power to be easily accessed. 12V is additionally brought in from the DSQ converters and distributed amongst power pickups (10). All power inputs to the HAT and power pickups are designed to be reversible or polarized. 12V and 5V pickups are separated and clearly labeled to further prevent incorrect connections.

TETHER

Manatees’ reliable, manageable, and lightweight (3.6 kg) tether (Figure 19) is designed to transport necessary signals, power, and pneumatics 15.5 meters from the TCU to the ROV. A high-visibility, durable and flexible, braided polyester sheathing that protects the lines housed within. The braided polyester allows for stretch or controlled “give” of the tether, helping to ease sudden jerks or sharp motions, and preventing unwanted stress on connections. Adjustable flotation devices are used to keep the tether held in the optimal position for operations, preventing the tether from becoming an obstacle to the ROV, preventing interference damage. *Manatee's* tether has sturdy strain relief at both the TCU and at the ROV. The ROV can be lifted by its tether without damaging connections.

Two 12 AWG (American Wire Gauge) insulated silicon power lines supply 48V to the ROV. They were chosen for the excellent balance of flexibility and low resistance. The calculated resistance of the power cable is 0.3 ohms, meaning that at the maximum possible 30 A current draw, the voltage will drop 9V across the tether (30 A * 0.3 ohms = 9V). This gives our ROV a minimum operating voltage of approximately 39V, which is above the programmable 34V input cut-off voltage of the DC-DC voltage converters. A gigabit Category 6 Ethernet (CAT6) cable (T-568B termination) is used as a network line to *Manatee’s* Raspberry Pi computer. In order to accommodate *Manatee’s* pneumatic systems, two 98 durometer ¼” OD, ⅛” ID (6.35 mm od, 3.175 mm id) polyurethane pneumatic tubes are used to create two open-loop systems. The tubing diameter was chosen to balance safety and airflow based on the pressure drop at the expected depth of 6 meters and requirements of the tools developed for the RFP. The tubing chosen exceeds the safety requirement of 3 times the operating pressure of 40 psi (topside) at 180 psi (23° C). The relative pressure drop of the ROV at the maximum operating depth of 7m is 10.0 psi (0.687 bar).

Given this, the expected relative pressure of the pneumatic lines at the ROV is at least 30 psi (207 kPa). All pneumatic tools are designed to operate safely and effectively at the minimum and maximum pressure.

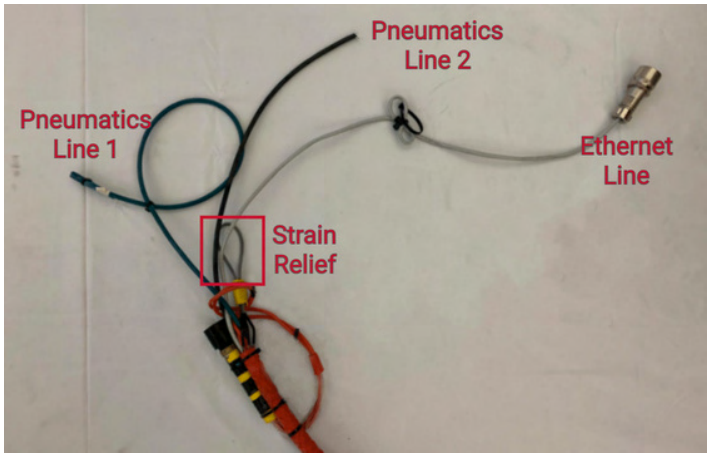


Figure 19. Tether Connections to ROV

Tether management is handled by the tether manager, who is responsible for the proper deployment, tensioning, and stowing of the ROV's tether. At the beginning of a mission, the tether manager calls for all non-essential personnel to leave the deck (side of the pool). The tether manager then removes the tether from its carry bag, uncoils the tether, and lays it out on the deck with one end facing the TCU and the other end facing the ROV. The tether is connected to the TCU first, beginning with the strain relief connection, followed by the power, ethernet, and finally, the pneumatics line. The tether is then connected to the ROV, proceeding in the same order as the TCU connection. When the ROV is deployed, two deck crew members lower the ROV into the water using strain relief and hardpoints on the ROV. While in maneuvers, the tether manager has constant contact with the tether and ensures a proper amount of slack is provided so as not to inhibit ROV movement. Upon the completion of the mission and the shut down of the ROV, the tether manager disconnects the tether from the ROV, disconnecting the strain relief last, and then disconnects the tether from the TCU, again, disconnecting the strain relief last. Once the tether has been completely disconnected, the tether manager coils the tether and places it back in the carry bag. The tether manager coils the tether by alternating the winding of every other loop in an over-hand under-hand manner, which prevents damage to the tether seen in continuous winding and helps with storage.

SUBMERSIBLE CONNECTORS

Manatee uses a Bulgin 6000 series ethernet connector, Blue Robotics cable penetrators (Figure 20), SubConn wet-mateable electrical connectors, and McMaster-Carr cable glands. Blue Robotics WetLink cable penetrators are used for the connections between PSE and the thrusters, making a waterproof and modular seal without the using epoxy pitted penetrators.

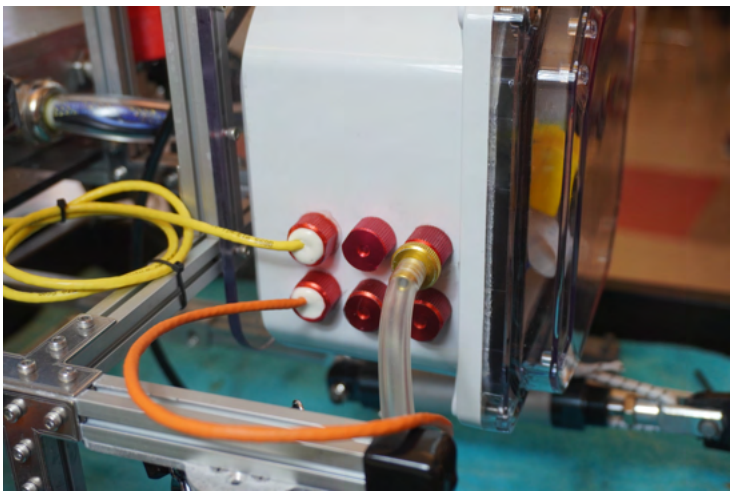


Figure 20. Blue Robotics Penetrators

Connections between the MEH and PSE make use of a custom connector named "the Tube". The Tube is a waterproof conduit enabling multiple wires to pass through it. The Tube also allows for connection flexibility as additional wiring can be passed through the Tube without changing the design. The tether's power connection utilizes SubConn connectors, chosen for their durability and reliability. With the new MEH design, Rovotics can use more reliable Blue Robotics connectors for tools. The balance of modularity and reliability helps to minimize ROV downtime.

Device	Quantity	Voltage	Max Power Each	Total Power
T100 Thruster	6	12V	150W	900W
Blue Robotics ESC	6	12V	6W	36W
Raspberry Pi and Pi Hat	1	5V	8W	8W
Cameras	3	5V	3W	9W
Ethernet Switch	1	5V	4W	4W
DSQ0150 Voltage Converter	2	48V	18W	36W
Lasers	2	5V	0.25W	0.5W
Tether Max Power Loss	1	7.3V	170.5W	179W
Total Power Consumption				1172.5W

Figure 21. Rovotics Power Budget

SOFTWARE SYSTEMS

SOFTWARE INFRASTRUCTURE

Manatee' ROV software system integrates the functions of command and control, ROV telemetry, digital imaging, graphical interface (GUI) displays, and managing input from keyboard and joysticks. The software consists of two primary subsystems: Topside and Bottomside. The Topside provides the user interface and pilot controls, and communicates to the Bottomside through the TCU. Bottomside receives the command and control data for ROV thrusters and tools from Topside and sends back sensor and camera information.

Rovotics architecture is based on the open-source Robot Operating System (ROS) framework. We chose this software architecture because it has a modular system organized around easily maintained nodes, or subsystem programs, that control core features such as thrusters, input, sensors, or individual tools. Each node is connected over a network, which means new features and subsystems can be quickly added without risk to critical ROV infrastructure. Control signals such as joystick and pilot features are broadcast through the network and received by nodes on devices in the ROS framework requesting the information, such as our original vector drive algorithm, which handles the translation of joystick input to thruster data.

TOPSIDE

The Topside Control Unit (TCU) contains an Intel NUC which communicates to the Bottomside. The TCU software prints telemetry data to the display screens, uses OpenCV to display live camera views (Figure 22), controls the ROV through two joysticks and a keyboard, and makes changes and adjustments to settings through a ROS GUI. Topside is manned by a pilot, and a co-pilot. The co-pilot uses Rovotics' custom GUI to enable or disable thrusters, initiate software tasks, and switch camera feeds for the pilot. Topside also includes a laptop for operational calculations such as the GO-BGC surface calculator, and the fish biomass calculator, allowing for a more streamlined Topside operation where tasks can be done in parallel, alongside operation of the ROV.



Figure 22. Topside Camera Feed

BOTTOMSIDE

Manatee' Bottomside main subsystem is a Raspberry Pi 3B+ which receives command and control instruction from the Topside. The Raspberry Pi manages hardware interfaces for ROV functions, such as thruster control, and communicates vital sensor and telemetry data through ROS to the TCU for display. For thruster control, the Raspberry Pi communicates serially to an Arduino Nano that generates PWM signals to control six electronic speed controllers (ESC). The Nano was chosen for its hardware timers dedicated to PWM and communication processes, ensuring fail-safe operation disabling all thrusters in the event of a communications failure.

CODE MANAGEMENT

To ensure efficient development across multiple software developers, Rovotics utilizes GitHub (Figure 23), a Version Control System (VCS), to manage parallel software development. Using a VCS, Rovotics monitors the changes to software and manages multiple software versions. GitHub is a well-supported and highly-adopted distributed VCS

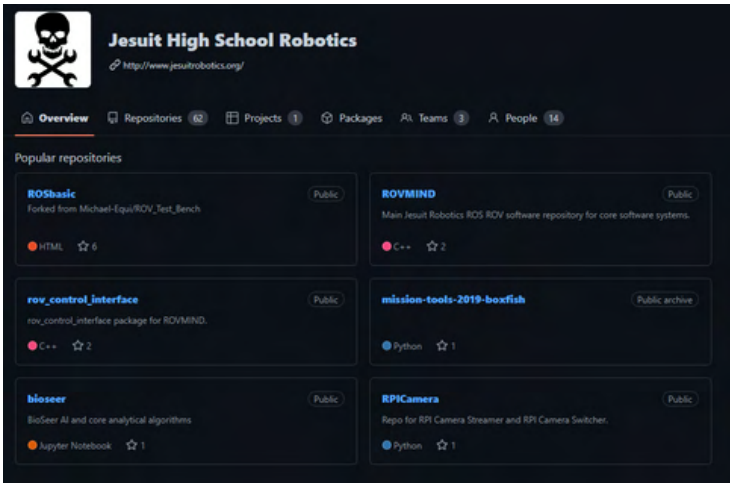


Figure 23. Rovotics GitHub

that provides each developer with a remote and local copy of the code repository.

GitHub also enables software branching and merging, which is of paramount importance when multiple team members work on different areas of the software environment. In the event that problems arise, GitHub allows for rollback of previous, functioning versions. Rovotics has readily available documentation for the process of pushing to GitHub, including instructions for creating new releases of software and use of our cloning shell scripts. This documentation is available to all team members, as is all of the Rovotics code, so that future Rovotics members will be able to quickly understand and maintain the software environment.

TOOLS

FLOAT

Rovotics' float, Vampire Squid (Figure 24), is used in task 3.1 to complete two vertical profiles of the underwater environment. Vampire Squid is driven by an electric motor-powered buoyancy engine powered by four AA batteries. Vampire Squid's buoyancy engine consists of an electric motor attached to a lead screw which actuates the plunger of a 150 ml syringe. The syringe's tip is open to the environment, allowing it to intake or eject sea water to alter the float's displacement. Vampire Squid has an overall length of 76.5 cm and a diameter of 13 cm.

Vampire Squid is activated when placed within the jaws of *Manatee's* front-facing horizontal gripper. An internal Hall-effect sensor detects magnets embedded in *Manatee's* gripper, priming the float for deployment. Once released from *Manatee*, Vampire Squid intakes seawater and begins its descent.

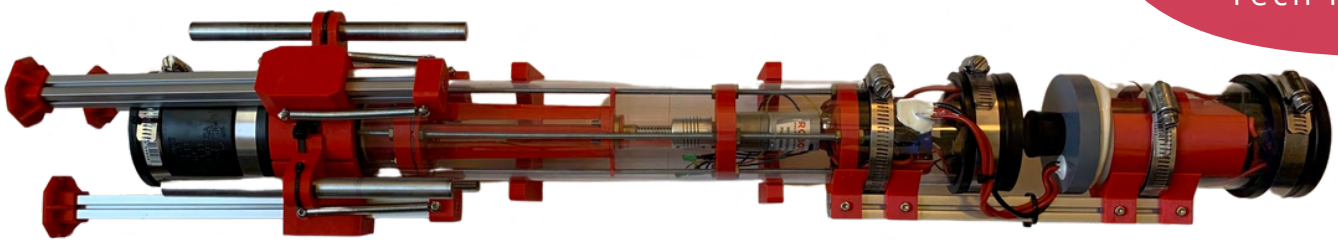


Figure 24. Vampire Squid

GRIPPER

Manatee is equipped with two identical pneumatic parallel grippers (Figure. 24). *Manatee's* parallel grippers allow it to complete a wide variety of tasks from deploying a float to repairing an inter-array cable. *Manatee's* grippers belong to Rovotics' first series of standardized grippers, the Large Parallel Gripper series, or LPG. The LPG series is built around a 50 cm length of 15mm x15mm aluminum extrusion and is attached to *Manatee* with a standardized mounting solution that can be easily attached to any ROV.

Manatee's grippers belong to Rovotics' first series of standardized grippers, the Large Parallel Gripper series, or LPG.

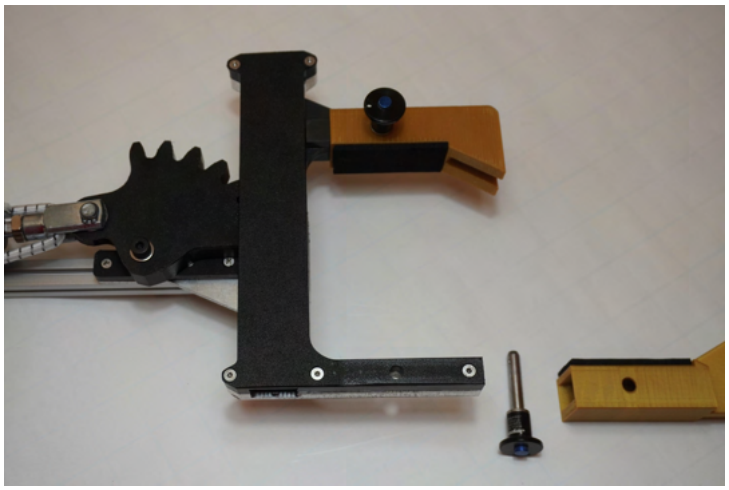


Figure 25. Gripper

The LPG series is built around a [insert length] cm length of 15mm x15mm aluminum extrusion and is attached to *Manatee* with a standardized mounting solution that can be easily attached to any ROV. Each LPG is manufactured out of a combination of milled aluminum, HDPE, and PVC, offering the best balance between cost, weight, and durability. The fingers of the LPG are rectangular and each have a 6.35 mm (1/4 inch) hole drilled through the middle of them for quick release pins, allowing the characteristics of the LPG to be quickly altered, making the LPG Rovotics' most versatile gripper yet.

MEASURING SYSTEM

To measure objects in the water accurately and efficiently, the ROV is supplied with two pairs of laser diodes positioned 5 centimeters apart, with a third laser diode 10 centimeters away.The laser diodes provide a pair of calibrated reference lines for the software tools to calculate the measurement of the object. For objects closer to the camera, the laser diodes 5 centimeters apart are used, while the laser diodes 15 centimeters apart are used for larger objects that may be further away. Using the calibrated reference lines, a team member can plot points on the two lasers and the two ends of the object to calculate the length of the object.

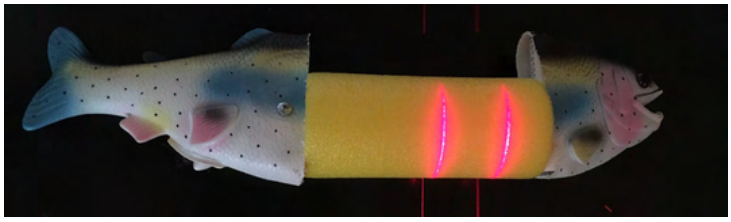


Figure 26. Laser Projected on Fish

DEPTH HOLD

Rovotics implemented its new depth hold feature this year. The purpose of this feature is to maintain *Manatee's* depth autonomously so that the pilot can have better lateral motion control when using a gripper. This allows for tasks that require

manipulation of objects to be completed with more precision. The Depth Hold feature takes input from *Manatee's* depth sensor, and runs a PID (Proportional Integral Derivative) loop based on this input. The PID loop provides an effort value for *Manatee's* vertical thrusters, and adjusts this effort value based on the resulting changes in depth, thus allowing the ROV to learn from previous attempts to stabilize depth. The PID loop has been specially tuned to *Manatee*, to ensure that it is as efficient as possible in maintaining depth. To keep simplicity, thruster effort values are interpreted by the same program that interprets joystick signals, so that the ROS infrastructure required for control of the thrusters can be kept as simple as possible.

VISION SYSTEM

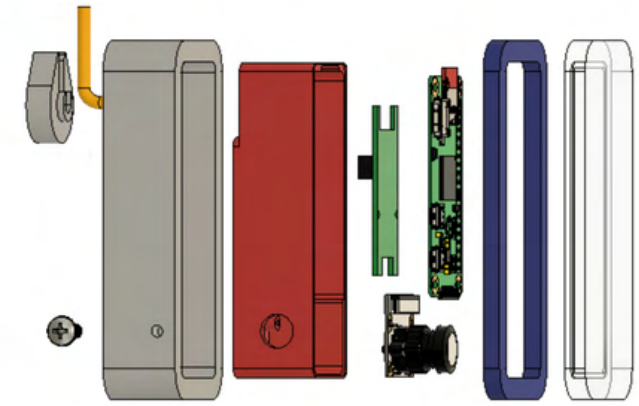


Figure 27. Exploded Camera CAD

Manatee's completely digital vision system is equipped with up to 6 external digital ethernet cameras in addition to the navigation camera. The cameras each have a Raspberry Pi Zero powered through a custom Ethernet switch designed to provide power to the camera modules using unused wires in the ethernet cable. The cameras are custom made from Commercial Off the Shelf (COTS) and custom manufactured parts with the software, electronics, and housing (Figure 27) all designed, built, and tested in-house.



Figure 28. Digital Camera

Manatee's digital cameras are housed in a PVC housing covered with a polycarbonate lens, which are sealed together with silicone (Figure 28).Cameras are mounted to the ROV's frame fixed or telescoping mounts, the latter of which allows cameras to be rapidly repositioned during tool exchanges. There are three main cameras, the navigation camera in the MEH, and two tool cameras.

SAFETY

COMPANY SAFETY PHILOSOPHY

Employee safety is Rovotics' highest priority. Employees are committed to meeting or exceeding all safety guidelines published by MATE and have a proven track record of consistently meeting MATE's safety requirements.

Adherence to the company's safety policies and training procedures allows employees to prevent accidents and injuries. All employees must take safety training to operate equipment used in the design and manufacture of the ROV. Example equipment includes standard machining tools and soldering stations. Rovotics also requires that all employees wear safety glasses (Figure 29) when working in or near conditions that can result in eye injuries.

Additional safety training for deck crew employees is required to operate the ROV during missions and ensures adherence to the operations and safety checklist.



Figure 29. Employee Observing Safety Protocols

TRAINING

Peer-to-peer training encompasses all aspects of operations at Rovotics, including tool and machinery training, pilot and deck crew training, and sales presentation training.

When learning to operate tools such as soldering irons or mills, new employees first observe experienced employees using the tools. Experienced employees supervise and mentor new employees (Figure 30) as they learn to use the equipment. After new employees consistently demonstrate safe operating practices, they can work independently.

Before competing, Rovotics completes a minimum of forty hours of underwater run practice to ensure safe and efficient ROV product demonstrations. This comprehensive training trains the pilot, co-pilot, and deck crew personnel on routine safety protocols, and allows them to become familiar with the operation and performance of the ROV, so product demonstrations can be completed rapidly and effectively. In preparation for our sales presentation, every team member shares key learnings and compiles facts and details about the ROV and our company.



Figure 30. Senior Member Instructing Trainee

The entire company rehearses for a minimum of fifty hours together, about three weeks before meeting customers. This preparation and training ensures each employee is prepared to communicate all aspects of product information fluently and clearly to our customers.

SAFETY FEATURES

At the start of each year, Rovotics reviews MATE safety requirements and applies them to the design, manufacture, and operation of our ROV. An operational safety checklist (Appendix 1) ensures that MATE's safety requirements are addressed at all ROV development and operation stages. *Manatee* has numerous safety features. O-ring face seals and epoxy potting are waterproofing techniques used to ensure all electronics remain dry, protecting personnel and equipment from electrical hazards.

A leak detector monitored by the software detects moisture and humidity in the electronics housing. If a leak occurs, the ROV status indicator notifies the pilot, and *Manatee* is shut down. After shut down, *Manatee* can be safely brought back to the surface by the deck crew.

The secure strain relief on both the ROV and the TCU ensures the safety of all electrical connectors. For easy visual inspection of the electronics, the MEH enclosure includes a clear lid. Thruster guards were mounted to protect debris from entering the thruster, and rubber end caps were added to provide smooth corners on the top frame.

The TCU incorporates digital displays for the crew to quickly determine if power delivery to the ROV is outside of safe operating values. A microcontroller monitors and displays current and voltage information to the pilot and co-pilot, allowing for quick shut-down in the event of any anomalies. CPU temperatures on the Raspberry Pi are also monitored. If values outside of safe operating ranges are detected, a power switch on the TCU (Figure 31) can immediately cut the ROV's power.



Figure 31. ROV Shutoff Switch

OPERATIONAL AND SAFETY CHECKLISTS

Safety protocols documented in Rovotics' Operational and Safety Checklists (Appendix 1) are closely followed throughout ROV operations.

Employees also adhere to an operational Job Safety Analysis (JSA) for ROV launch, recovery, and waterside safety. To make this information readily available, Rovotics has attached all relevant checklists to our TCU. This allows the TCU to be operated without a high degree of software knowledge.

LAB PROTOCOLS

To ensure a safe work environment, specific safety protocols are implemented while working in the lab. Rovotics uses JSA forms for employees to create and review before performing risky operations. With *Manatee's* new laser tool, Rovotics' ROV DECK AND WATER SAFETY JSA now includes the proper use of protective eye wear during pre-launch and ROV retrieval.

Experienced employees provide training to new employees on electrical safety, laser safety, hazardous materials handling, housekeeping, tool safety, and injury prevention such as back strain. Material Safety Data Sheets (MSDS) are available for products used in the Rovotics's production process.

Rovotics' lab facility features a chemical vent hood (Figure 32) so that electronics soldering can be performed without fume exposure. The work area maintains a negative pressure relative to the room, and fumes are carried up to a roof-mounted vent.



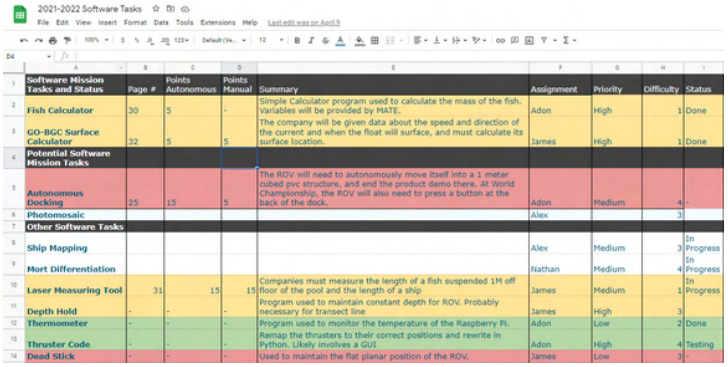
Figure 32. Chemical Vent Hood

TEAM WORK

PROJECT MANAGEMENT

Rovotics holds weekly virtual meetings to discuss company-wide project scheduling and departmental progress updates. These weekly meetings allow departments to explain progress made during the previous week to the whole team, as well as present plans for the next week.

Rovotics' Project Schedules are created in Google Sheets and made accessible to employees to use from a shared Google Drive. The CEO creates schedules for all aspects of the company, from software (Figure 33), electronics, and mechanical ROV development to technical documentation. Department leads assist the CEO in making these schedules, providing knowledge from their respective departments to set realistic goals and deadlines for the team to achieve. Then using feedback from the team, the CEO manages the team's schedule and discusses due dates and any assistance needed during weekly status and planning meetings.



Software Mission Tasks and Status	Page #	Points Autonomous	Points Manual	Summary	Assignment	Priority	Difficulty	Status
Fish Calculator	30	5	-	Simple Calculator program used to calculate the mass of the fish. Variables will be provided by MATE.	Adon	High	1	Done
GO-BGC Surface Calculator	32	5	5	The company will be given data about the speed and direction of the current and when the float will surface, and must calculate its surface location.	James	High	1	Done
Potential Software Mission Tasks								
Autonomous Docking	25	15	5	The ROV will need to autonomously move itself into a 1 meter cubed pvc structure, and end the product demo there. At World Championship, the ROV will also need to press a button at the back of the dock.	Adon	Medium	4	-
Photomosaic					Alex		3	
Other Software Tasks								
Ship Mapping					Alex	Medium	3	In Progress
Mort Differentiation					Nathan	Medium	4	In Progress
Laser Measuring Tool	31	15	15	Companies must measure the length of a fish suspended 1M off floor of the pool and the length of a ship	James	Medium	1	In Progress
Depth Hold	-	-	-	Program used to maintain constant depth for ROV. Probably necessary for transect line	James	High	3	
Thermometer	-	-	-	Program used to monitor the temperature of the Raspberry Pi.	Adon	Low	2	Done
Thruster Code	-	-	-	Remap the thrusters to their correct positions and rewrite in Python. Likely involves a GUI	Adon	High	4	Testing
Dead Stick	-	-	-	Used to maintain the flat planar position of the ROV.	James	Low	3	-

Figure 33. Software Project Manager

Throughout the development, the CEO is responsible for monitoring company progress, assessing whether ROV development is on track, and collaborating with department leads to stay on schedule. Departmental updates allow the CEO to adjust project schedules and department assignments based on each Department's progress. After updates are shared, the CEO and Department Leads collaborate on necessary schedule changes to keep the tasks on track and to set goals for the upcoming week.

COMPANY ORGANIZATION

Rovotics is organized into three key departments: Mechanical, Electrical, and Software. Each department has a department lead who manages the assignments and task priorities for employees within their department. The CEO, who is also the Mechanical department lead, works closely with the assigned Software and Electronics department leads to maintain project schedules, discuss feedback on task completion, and ensure collaboration across the departments. Department goals & individual employee work assignments are then determined and assigned by each department lead (reference page 1 to see member roles and responsibilities).

Rovotics encourages cross-training to allow employees to broaden their skills in other departments. By developing knowledge in other areas, employees gain a big-picture perspective, allowing them to provide greater value to the company. Additionally, senior employees in each department are tasked with training junior employees throughout the development process.

COLLABORATIVE WORKSPACE

To ensure sharing valuable knowledge and many years of corporate memory, Rovotics uses a widely available cloud storage system, Google Drive, to manage company files. Utilizing Google Drive, employees can collaboratively edit files with real-time access to the most current version of a document. In addition, the shared document repository continues to ensure a variety of company information, including training, past design proposals, and company operational processes, are available to all employees. Like Google Drive's documentation repository, Rovotics' mechanical department uses a cloud-based Autodesk Fusion 360 project to collaborate on designs and assembly drawings.

A shared Fusion 360 project ensured design progress and easier collaboration in a team-based or even remote work environment. This allows other employees to review and revise designs collaboratively across different devices and locations.

Rovotics selected Zoom as the video and collaboration platform for our virtual meetings and Discord for instant messaging.

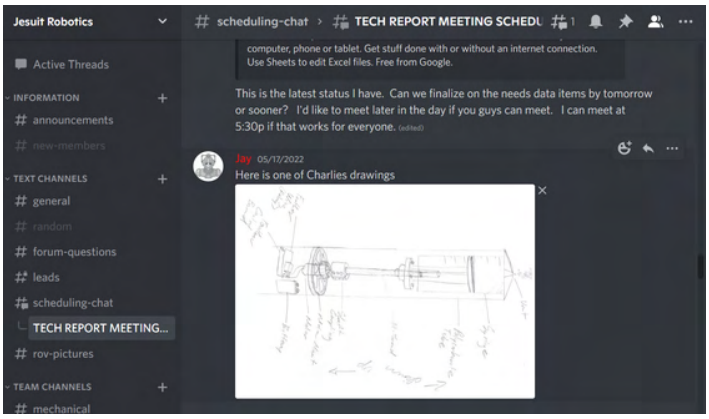


Figure 34. Rovotics Discord

Zoom makes it easy to schedule and hold video meetings with employees, making it easy to demo tool prototypes, share department updates, and review project schedules. In addition, GitHub is also used to maintain Rovotics' code, and software team members regularly use GitHub's suite of software tools to collaborate on software projects. The use of Discord's role functionality makes it easy to send messages to certain teams and keep track of plans. However, for real-time, instant messaging communication, employees communicate using Discord (Figure 34) to discuss development problems and share solutions and ideas.

BUDGET AND PROJECT COSTING

Rovotics prepares a budget with estimated expenses at the beginning of each season based on the prior year's actual costs. This year, the company's projected budget was much easier to forecast since *Manatee* is based on a previous ROV design. Using a standard ROV design allowed the company to focus on cost estimates for ROV enhancements and new tools. In addition, employee transportation and competition meal expenses are estimated but listed separately since Rovotics employees are responsible for these costs.

Income was estimated based on funding from Jesuit High School and donations. To ensure adherence to a projected budget, the company submitted purchase requests for review and approval by coaches, and receipts for purchases were tracked in a project costing sheet that was reviewed monthly. The 2021-2022 Budget and Project Costing report is shown in Figure 35.

2021-2022 Project Summary	Item Description	Amount
Income Source		
School Funding	Jesuit School Funding	$ 16,425.00
Donations	MATE Competition Awards	$ 700.00
Available Income		**$ 17,125.00**
Project Cost Summary		
Available Income	School funding & Donations	$ 17,125.00
Actual Project Cost	Production ROV, R&D, Operations Expenses	$ 16,004.13
Project Balance	Budget available for next year	**$ 1,120.87**
Employee Paid Expenses		
Competition Meals	Donations collected for competition meals;14 people	$ 2,590.00
Transporation & hotel subsidy	Donations for car rental, gas, & lodging	$ 4,200.00
Total Employee Paid Expenses		**$ 6,790.00**

	Item Description	Type	Budget	Project Cost	Variance
Production ROV Expenses					
Frame & Housing & Bouyancy	Polycase Housings, 15x15 extrusion, foam	Purchased	$ 475.00	$ 489.38	$ (14.37)
Thrusters	(6) T100 Blue Robotics thrusters & ESCs	Purchased	$ 1,100.00	$ 1,076.63	$ 23.38
TCU	Case, Monitors, Electronics, Pneumatics, NUC	Purchased	$ 2,000.00	$ 1,894.15	$ 105.85
Tether & Connectors	subcon, CAT5e wire, strain relief, sheathing	Purchased	$ 400.00	$ 260.31	$ 139.69
Electronics & Connectors	Si wire, connectors, HAT PCB, DSQs, controllers	Purchased	$ 1,000.00	$ 1,354.36	$ (354.36)
Pneumatics	Valves, fittings, tubing, gauges	Purchased	$ 95.00	$ 85.16	$ 9.84
Mission Tools	gripper, float, ROV cameras, lasers,	Purchased	$ 500.00	$ 468.00	$ 32.00
Pilot Controls	Joystick	Re-used	$ 40.00	$ 32.46	$ 7.54
Raw materials	Plastics, metals, hardware, 3D filament, consumables	Purchased	$ 1,200.00	$ 1,500.00	$ (300.00)
Total Production ROV Expenses			**$ 6,810.00**	**$ 7,160.44**	**$ (350.44)**
R&D Expenses					
3 SW Test Benches	Test Bench materials	Purchased	$ 600.00	$ 815.63	$ (215.63)
Total R&D Expenses			**$ 600.00**	**$ 815.63**	**$ (215.63)**
Operations Expenses					
Lodging	7 hotel rooms for team/2 per room	Purchased	$ 7,000.00	$ 6,615.00	$ 385.00
Mission Props	MATE mission props	Purchased	$ 500.00	$ 324.00	$ 176.00
MATE Entry Fee	MATE entry fee	Purchased	$ 400.00	$ 400.00	$ -
Power Fluid Quiz Fee	MATE power fluid quiz	Purchased	$ 25.00	$ 25.00	$ -
Lab Supplies	Lab Supplies: Consumables, plastic, glue, hand tools	Purchased	$ 400.00	$ 413.39	$ (13.39)
Printing	Report, display, brochure printing	Purchased	$ 300.00	$ 250.67	$ 49.33
Total Operations Expenses			**$ 8,625.00**	**$ 8,028.05**	**$ 596.95**
Total Project Variance			**$ 16,035.00**	**$ 16,004.13**	**$ 30.87**

Figure 35. Budget and Project Costing

CONCLUSION

CHALLENGES

Rovotics faced difficulties with personnel, work environments, supply chain issues and design with manufacture in mind.

Scheduling needed meetings outside of regular LAB hours proved to be a challenge. It became difficult to share and hand off tasks between employees. This issue affected early revisions of the technical report. Rovotics addressed this by creating a tech report task force. A small group of employees integrated and authored the final report with the rest of the employees dedicated to providing feedback.

Work environment challenges impacted Rovotics ability to keep the project on schedule, such as the difficulty of developing software remotely for the ROV to keep SW projects on schedule. Rovotics addressed this by setting up virtual machines that simulated the ROV's Topside and Bottom side. Additionally, supply shortages became particularly difficult this year because of the focus on using COTS parts, especially microcontrollers and electronic components. Materials took significantly longer to arrive, resulting in schedule delays and frequent replanning of build activities. Rovotics took additional steps to plan purchases earlier and purchased extras to minimize the impact of delays and shortages during the season.

This season Rovotics encountered technical challenges as we worked to improve our digital camera system. The primary concern with our digital cameras was the cameras' waterproof housings, which proved unreliable and difficult to manufacture. Rovotics designed a whole new housing, enabling us to manufacture ten digital cameras reliably, doubling the number of working cameras from last season. Rovotics' approach to the improved camera housing design was the product of several iterations of design reviews, prototyping, and testing in and out of the water that ultimately allowed us to mass produce our final revision of the new housing with a high level of repeatability and precision.

LESSONS LEARNED AND SKILLS GAINED

Rovotics' greatest lesson learned this year came from redesigning its second-generation-digital camera housing. Last season we made the incorrect assumption that the camera housing needed to be disassembled to update the software. Once we confirmed that the camera software could be updated remotely, a difficult to manufacture o-ring sealed housing was replaced with a low-cost permanently sealed housing. The new camera housing is simple to manufacture, reliable, and compact. We learned that a thorough, disciplined review of requirements is needed before starting our design process. This would have allowed us to eliminate the o-ring problem sooner.

Additionally, the second-generation camera housing also taught Rovotics the importance of having well-documented assembly instructions. To effectively manufacture cameras in quantity, critical steps needed to be carefully documented. Once assembly instructions were tested and verified, this also allowed several Rovotics engineers to manufacture cameras at once.

FUTURE IMPROVEMENTS

A primary goal of Rovotics is to create a software environment that allows for easier completion of autonomous tasks that involve piloting the ROV. The software team has elected to name this Autonomous Infrastructure. Rovotics' goal with this software tool is to allow for autonomous tasks to be completed easily and to lessen the amount of development time. This would streamline the process of completing autonomous tasks and save Rovotics time and resources.

Rovotics aims to have documentation that is accessible to both senior employees and recruits, so a goal next year is to consolidate all documentation into one location. The end result of this process will be a place where documentation pertaining to all departments and marketing will be easily accessible by all employees.

APPENDICES & REFERENCES

APPENDIX 1: OPERATIONS AND SAFETY CHECKLISTS

Pre-Power Procedure (Pilots & Deck Crew)

- ☐ Area clear and safe (no tripping hazards, items in the way)
- ☐ Verify power switches and circuit breakers on TCU are off
- ☐ Tether flaked out on the deck and free from damage
- ☐ Tether connected to TCU and secured
- ☐ Tether connected and secured to ROV
- ☐ Tether strain relief connected to ROV
- ☐ Verify the electronics housing sealed
- ☐ Visually inspect electronics for damaged wires, loose connections
- ☐ Fasteners are tight on the electronics housing
- ☐ Thrusters free from obstructions
- ☐ Power source connected to TCU
- ☐ Vacuum test electronics housing (see vacuum test procedure)
- ☐ Verify vacuum check port is securely capped

Vacuum Test Procedure (Deck Crew)

- ☐ Verify MEH housing fasteners are secure and visually inspect front cover seal.
- ☐ Verify PSE screws are secure.
- ☐ Verify screw caps on all cameras are secure
- ☐ Connect vacuum hand pump to ROV electronics housing
- ☐ Pump electronics housing to -35 kPa (vacuum), this is 10 inches of Hg on the gage.
- ☐ Verify electronics chamber holds -35 kPa (vacuum) for 5 minutes
- ☐ Remove vacuum pump and securely cap vacuum check port
- ☐ Stow vacuum hand pump back in case

Power Up Procedure (Pilots & Deck Crew)

- ☐ Verify TCU receiving 48V nominal
- ☐ Control computers up and running
- ☐ Ensure deck crew members are attentive
- ☐ Call out, "Power On"
- ☐ Power on TCU
- ☐ Call out, "performing thruster test"
- ☐ Perform thruster test/verify thrusters are working properly (joystick movements correspond with thruster activity)
- ☐ Switch between each camera to verify video feeds and proper camera positioning.
- ☐ Test any electrical or pneumatic tools that require pilot control

Launch Procedure (Pilots & Deck Crew)

- ☐ Place ROV in water
- ☐ Visually check for bubbles
- ☐ If there are bubbles from the electronic housings, remove ROV from water immediately and call out "electronics leak". Proceed with Leak Detection Protocol
- ☐ The deck crew calls out "Ready to Launch"
- ☐ Deck crew members handling ROV call out "Hands Off!"
- ☐ Co-pilot calls out "Thrusters Engaged" and pilot begins mission

ROV Retrieval (Pilots & Deck Crew)

- ☐ Pilot calls "ROV Surfacing"
- ☐ The deck crew calls out "ROV Surfaced. Disable thrusters"
- ☐ Co-Pilot disables thrusters and calls out "Thrusters disabled"
- ☐ The deck crew calls "Hands On", and removes ROV from the water
- ☐ After securing the ROV on deck, the deck crew calls out "ROV Secured on Deck"
- ☐ Co-Pilot powers down TCU if the team is demobilizing from deck.

Leak Detection Protocol (Pilots & Deck Crew)

- ☐ Power down system and remove ROV from water if running a mission. Recover ROV by pulling to the surface using the tether if required.
- ☐ Visually Inspect to determine source of leak. Do not disassemble any part of the ROV until the leak is located.
- ☐ Install pressure testing equipment and use soapy water to verify the leak source.
- ☐ Create a plan to repair the leak and check all systems for damage and proper operation.
- ☐ Document the cause of the leak and implement corrective action or design changes as required

Loss of Communication (Pilots & Deck Crew)

- ☐ Cycle power on TCU to reboot ROV
- ☐ If no communications, power down ROV, retrieve via tether
- ☐ If communication restored, confirm there are no leaks, resume operations
- ☐ If communication is not restored, begin troubleshooting procedures, Isolate the issue. Is there a hardware or software cause? Proceed to analyze/ isolate cause
- ☐ Document the cause of the failure and implement corrective action or repair as required

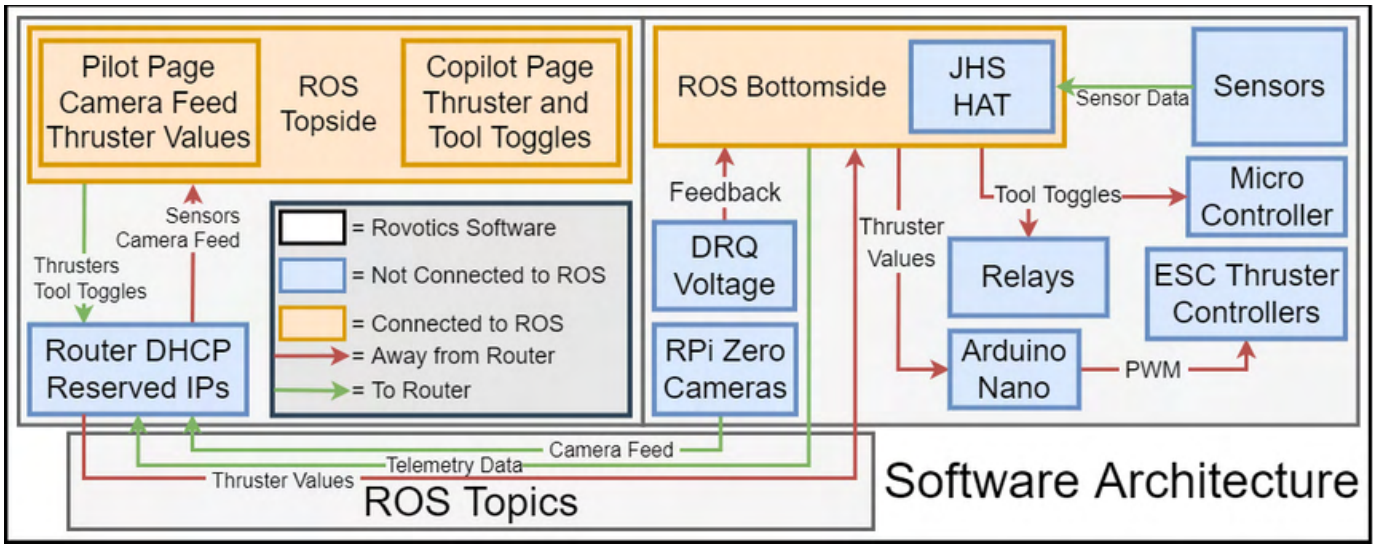
Pit Maintenance (All Team Members)

- ☐ Pit is organized and free of garbage.
- ☐ Verify all tools and cables are neatly stored and there are no trip hazards.
- ☐ Check electrical cords and correct any possible electrical hazards
- ☐ Clean Thrusters with Deionized Water
- ☐ Inspect Tether Power and Network Connectors
- ☐ Check supplies and organize a shopping list if anything is needed for repair or upkeep.
- ☐ Verify TCU, ROV and tether are clean, dry and properly stored. Protective caps for electrical connectors should be in place
- ☐ ROV, TCU and tether have been readied for use on the next mission run

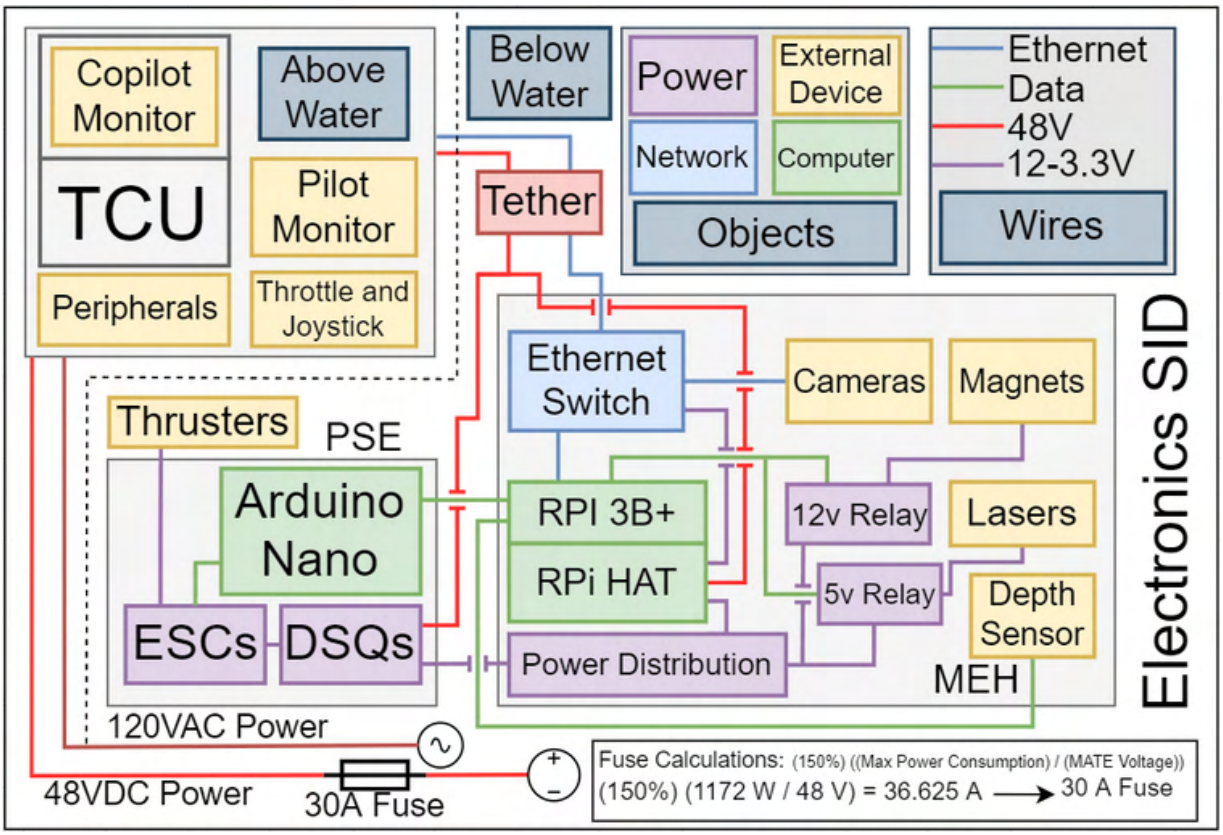
Inspect and Test Pneumatics (Pilots & Deck Crew)

- ☐ Verify all pneumatics lines are properly connected to the air source, TCU, and ROV
- ☐ Verify that the compressor is switched on
- ☐ Activate pneumatics system and open main valve
- ☐ Verify there are no leaks and pneumatic lines are securely connected while under pressure
- ☐ Test tools and adjust pressure regulator to 2.75 Bar (40PSI)

APPENDIX 2: SOFTWARE ARCHITECTURE DIAGRAM



APPENDIX 3: ROV SID



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c/o Marine Institute
P.O. Box 4920
St. John's, Newfoundland and Labrador
Canada A1C 5R3

Tel. +001 (709) 778-0763
Fax +001 (709) 778-0793

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