Northwest Passage Project Detailed Science Plan

1.1 Project Overview

The Northwest Passage Project (NPP) is a US National Science Foundation funded program to explore the changing Arctic through an innovative expedition that will engage diverse audiences through real time interactions from sea, a high definition 2-hour documentary, and related community events. The expedition will be conducted onboard the One Ocean *Akademik Ioffe*, which will be fully equipped with telepresence technologies for shore-based participation in the project. Undergraduate and graduate students will participate in the expedition along with scientists, historians, journalists, and a documentary film crew.

1.2 Science Overview

The science activities are motivated by the overarching goal to understand how waters of the Canadian Arctic Archipelago (CAA) have changed as a consequence of the secular warming trend over the Arctic Circle. We approach this goal using an interdisciplinary ocean-based research program to explore the changes in four (4) thematic areas:

1. Water mass properties and circulation inside the CAA. Science leads: D. Gong, Lydia Bienlien, Virginian Institute of Marine Science (VIMS).
2. Microscopic communities in transition due to a changing Arctic climate. Science leads: M. Barton, Florida International University (FIU), M. Thaler, Universite Laval (U. Laval).
3. At-sea distributions of marine birds and mammals in Canadian Arctic waters. Science leads: H. Hogan, Canadian Wildlife Service (CWS), H. Morin, University of Rhode Island, Inner Space Center (URI, ISC).
4. Greenhouse gas chemistry, and microbial activity of the melting Arctic and marginal seas. Science leads: B. Loose , Z. Kerrigan University of Rhode Island (URI), A. Bellagamba, University of Illinois at Chicago (UIC).

Motivation, description and an outline of activities in each thematic area are described below.

2.0 Sample Collection Overview

The NPP *Akademik Ioffe* expedition will transit the Northwest passage from Resolute Bay, departing August 23, 2018, traveling south and west to Cambridge Bay via Bellot Strait and then returning to Lancaster Sound and Pond Inlet before travelling down the east side of Baffin Island. The expedition will terminate in Iqaluit on September 13, 2018. The One Ocean expedition (OOE) will make 22 stops for sightseeing; a portion of these will include shore landings for debarking of participants for educational activities and videography. Science activities will be primarily ship-based and will occur continuously or on an event basis throughout the expedition. CTD rosette casts and zooplankton net tows will occur every 100 nm or approximately daily, whichever comes first. Other activities, including atmospheric sampling, flowing seawater, mammal and seabird census counts will take place throughout the expedition. There will also be an underwater glider deployment and recovery during the cruise. After Iqaluit, the ship will then transit to Halifax, Nova Scotia and while in transit onboard pumped water measurements and atmospheric measurements will continue until September 20 with a single member of the science party.

2.1 Narrative of "Typical" Daily Research Activities

A 24 hour period of science activities will unfold as follows: (1) underway atmospheric measurements, flowing seawater sampling, will be ongoing, and personnel will monitor and calibrate instrumentation as needed, (2) mammal and seabird observations will occur according to a watch schedule or time permitting from the ship's bridge while underway, (3) the shore party will debark the vessel. While the party is ashore, the vessel may reposition for (4) a CTD rosette cast, followed by (5) a zooplankton net tow. Lastly, (6) water samples will be collected and stored/filtered/analyzed, and (7) the shore party will return and the vessel will proceed to the next stop with underway sampling.

The chief scientist will post a plan of the day around 00:00 for each upcoming 24 hour period, beginning at the start of the first watch at 4am. The plan of the day will incorporate discussions with the OOE watch leader, plans for videography and telepresence, and weather forecasts for the upcoming period. Below is a list of all science activities and anticipated time involved:

Table 1: Master list of activities for during the NPP project while onboard the OOE Ioffe, based on science participant input. The "Ship Time" column indicates the number of hours the vessel would be committed by the activity; "Reps" are the number of anticipated repetitions during the cruise; and "TotalTime" is an estimate of ship time that may be consumed by each science activity. The "Source" column indicates which entity will provide the equipment for that activity.

Description	Ship Time (hrs.)	Reps	Total Time	Source	Comment
Continuous					
Atmospheric sampling, CH_4, CO_2	0	N/A		UIC	Happens continually
ADCP TRDI 38kHz	0	N/A	0	Ioffe	This instrument is hull-mounted
Flowing seawater CH_4/CO_2	0	N/A	0	URI	Happens continually
Marine Bird abundance post breeding	0	N/A	0	CWS	Happens underway
Marine mammal surveys from the bridge	0	N/A	0	CWS	Happens underway
Echosoundings	0	N/A	0	Ioffe	Hull-mounted
Echosounding calibration	2	0	2	Ioffe	Hull-mounted
Water Column Profiles					
CTD Casts	1.5	17	25.5	Ioffe	1.5 hours per cast
LADCP	0	17	0	Ioffe	part of CTD
CH_4/N_2O bottles for P. Tortell	0	17	0	Tortell	
Profile [CH_4] in seawater measurements	0	17	0	URI	Happens underway
Preserve samples for bacteria counting	0	17	0	U. Laval	
Visible light microscopy phytoplankton/protozoa	0	17	0	U. Laval	

Nucleic Acid sampling and preservation	0	17	0	U. Laval	4 hrs per CTD cast, underway
Oxygen Isotope sampling	0	17	0	UIC	Happens underway
Plankton profiles					
Zooplankton Net tows	0.5	17	8.5	Ioffe	0.5 hours per cast
Flow cam surveys	0		0	FIU	underway
Ad Hoc or single event					
Sea ice sampling	2	4	8	URI	On opportunistic basis
Glider transit + Recovery	8	1	8	VIMS	Single instance
		Total ship time	50	hrs	2.1 days

2.2 Detailed Science Themes

Theme 1: Water mass properties and circulation inside Canadian Arctic Archipelago

Science leads: Donglai Gong (VIMS); Lydia Bienlien (VIMS)

One impact of a warming Arctic that the NPP expedition will be looking to assess is the increased freshwater storage in and export from the upper Arctic ocean. Increased melting, river discharge, as well as changing wind patterns have lead to increased freshwater accumulation in the western Arctic in recent years. However, changing coupled ice-ocean-atmosphere dynamics due to warming could result in significant export of this freshwater through the CAA. Freshwater export from the Arctic can have dramatic impacts on ocean circulation both regionally inside the CAA as well as globally when discharged to the North Atlantic Ocean near sites of deep water formation. The CAA, and particularly the Northwest Passage, is one of the principle conduits for freshwater transport from the Arctic Ocean to the North Atlantic. There are uncertainties about the property of the water masses and the magnitude of transport through the various flow pathways exiting the Arctic. Some of these potential current pathways can be observed and studied throughout the Northwest Passage along the cruise track for the NPP expedition. The following equipment will be used to study aspects of this research.

Glider: To explore this problem, the NPP will utilize a Slocum glider (**Figure 2**) to conduct a high-resolution survey in Lancaster Sound. Lancaster Sound is a critical choke point in the Northwest Passage between the Beaufort Sea and Baffin Bay. The autonomous glider will be deployed around August 24 north of Somerset Island and recovered around September 6 during the OOE return to the Lancaster Sound region.

Lowered Acoustic Doppler Current Profiler (LADCP and hull-mounted ADCP): Acoustic Doppler Current Profiler (ADCP) data will be collected continuously along transits and Lowered ADCP (LADCP) data will be collected during CTD casts.

MBES: Multibeam Echosounder bathymetric data will be collected continually along transits as well.

CTD: Conductivity, Temperature, Depth (CTD) instruments on the rosette will collect data with casts about every 100 nm or daily.

O-18: To observe the inputs of freshwater into Arctic seawater, we will measure stable isotopes of hydrogen and oxygen on seawater using laser absorption spectrometers. Freshwater runoff, precipitation-evaporation, sea-ice formation and melting ice produce water masses with unique slopes along the relationship between the stable isotopic ratio and salinity. These discrete measurements of liquid water will be taken from sample pumping, CTD casts and precipitation.

Table 2: Tentative list of cross-channel transects.

X-shore transects	Lat1	Lon1	Lat2	Lon2
T1	74.15 N	94.00 W	74.63 N	94.00 W
T2	73.866 N	86.5 W	74.47 N	86.5 W
T3	71.93N	96.43 W	72.93 N	95.24 W
T4	69.74 N	100.72 W	69.5 N	98.7 W

Theme 2: Microscopic Communities in Transition

Science leads: Mark Barton (FIU); Mary Thaler (U. Laval)

As the waters of the Arctic warm and the sea ice cover decreases, the surface ocean ecosystem is undergoing considerable changes. Habitats are changing and moving, perhaps disappearing, and species distributions and abundance may be changing rapidly. Examination of the habitats along the NPP cruise track will have a dual approach. Zooplankton nets will be periodically towed in the upper water column (100m and less). The contents of the nets will be catalogued. The net observations will be augmented with a laboratory bench-top flow cam which can identify and quantify 'particles' from a volume of seawater. These particles can be sediments, phytoplankton, or even zooplankton. The observations can be compared to past studies and serve as a baseline in locations without previous data. Combining these approaches to an ecosystem study will make the results more robust.

FlowCam: To observe phytoplankton and zooplankton, we will conduct regular zooplankton net tows (**Figure 4**) for shipboard analysis via Flowcam. The Flowcam counts and images micrometer size particles using an imaging microscope. This provides the ability to identify and quantify 'particles' from some sampled volume. These particles can be sediments, phytoplankton, or even zooplankton. This imaging system will generate a library of images for each net tow and store them for processing later.

Conductivity, Temperature, Depth (CTD) samples: CTD rosette bottles will be sampled for bacteria, archaea, and protists to analyze via the DNA-staining dye DAPI and counting by epifluorescence microscopy. Biotic material will be filtered onto polycarbonate filters for later nucleic acids extraction. Additional science and education activities include, understanding autofluorescent pigments like chlorophyll and phycobilins, recognizing major phytoplankton groups e.g. diatoms, cryptophytes and dinoflagellates, and grid counting and calculating cell concentrations

We will re-occupy the long time series station in Lancaster Sound: Station 323: Lancaster Sound, 74.2, -79.75.

Theme 3: At-sea Distributions of Marine Birds and Mammals in Canadian Arctic Waters

Science leads: Holly Hogan (CWS); Holly Morin (URI)

Marine birds play an important role in marine ecosystems. Their abundance and distribution can be used to monitor changes and variability in marine ecosystems. We intend to characterize the distribution and abundance of marine birds (and mammals) along the survey route during the post-breeding period in late September. We plan to identify the associations between the marine bird community and the physical and biological properties of their marine environment. Changes in marine bird abundance and distribution using data collected from the same area over 30 years ago will be described.

The NPP cruise will use a standard method to perform seabird counts and contribute to the sea bird database of the Canadian Wildlife Service.

Data will be collected from the bridge using a laptop computer while ship is underway (daylight hours). We will collaborate with oceanographers to investigate bird-habitat associations (analyses likely to commence post expedition), and we will compare historical datasets to current survey data (analysis likely to commence post expedition).

Theme 4: Water Column Chemistry Affecting Greenhouse Gas Fluxes

Science leads: Brice. Loose (URI); Zak Kerrigan (URI); Anthony Bellagamba (UIC)

The concentration and isotopic composition of methane and carbon dioxide in the Arctic Ocean and atmosphere are of great interest as both are greenhouse gases and the sources and flux of both between the ocean and atmosphere are important components in the climate system. The Arctic Ocean generally absorbs carbon dioxide but ice cover limits air-sea exchange. Measuring carbon dioxide and its isotopic composition can give information about the carbon system sources and fluxes of carbon to the atmosphere. Methane – an even more potent greenhouse gas than carbon dioxide – is found throughout the Arctic circle, and the Arctic appears to be an ever growing source of methane to the atmosphere. Methane is found in land-based permafrost, and as methane ice or methane hydrate, which is distributed along the seafloor. With less sea ice cover, there can be an increased flux of methane from the ocean. However, some microbes in ocean water use methane as a food source. If microbial breakdown of methane is rapid enough, it may serve to offset the methane that escapes to the atmosphere. The estimates of this methane breakdown in Arctic water temperatures are are very few. The NPP will study this microbial breakdown of methane and the rate at which it occurs in the Northwest Passage. The following techniques will be employed during the cruise.

Seawater sampling: $^{13}CH4$ (carbon-13 methane), and $^{13}CO2$ (carbon-13 carbon dioxide) will be continuously sampled using a Picarrro Laser spectroscoper and membrane contactor attached to the flowing seawater system. The same instrument will be used to analyze discrete profiles of $^{13}CH4$ and $^{13}CO2$ concentration collected using the CTD rosette. To measure methane in seawater, water will be continuously pumped into the wet lab aboard the *Ioffe* to be analyzed by infrared spectroscopy (**Figure 3**). This will provide a continuous record of surface methane concentrations and serve to illuminate interesting features that emerge as the ship transits. Students will collect ice core samples to look for methane trapped in sea ice and they will repeat bacterial methane oxidation experiments to compare with the abnormally large values observed by Kitidis et al. (2010).

Methane oxidation rate measurements: Shipboard incubations will be used to measure the rate of methane oxidation following the procedure of Uhlig & Loose (2017). Gas-tight foil bags will evacuated and filled with seawater, then spiked with an isotopically-labeled methane gas standard and allowed to equilibrate with the seawater. Incubation bags will be sampled every 12-24 hours to determine the time rate of change of methane in the incubation chamber.

Atmospheric gas sampling: Two laser absorption spectrometers to analyze (1) the stable isotopic ratio ($^{2}H/^{1}H$ and $^{18}O/^{16}O$) of seawater and water vapor and (2) the stable isotopic ratios (^{13}C) of CO_2 and CH_4. These analyzers are small, approximately the size of a desktop computer, and designed to make continuous measurements in field settings. They can be operated remotely and log continually during the course of the cruise. The work proposed here will support the science mission by using water isotopes along with salinity to differentiate water masses. Freshwater runoff, precipitation-evaporation, sea-ice formation, and melting ice produce water masses with unique slopes along the relationship between the stable isotopic ratio and salinity. The carbon isotope values will be used to fingerprint changes in the methane production pathways as oxidation generates a distinct fractionation signature.

2.3 Open Data Policy

We will disseminate scientific data and results through the NPP website. All processed measurements will be stored in the NSF-supported Arctic Data Portal (https://arcticdata.io) and all appropriate Canadian and Inuit science databases such as the Canadian Wildlife Service sea bird database.

2.4 References

Kitidis, V., Upstill-Goddard, R. C., & Anderson, L. G. (2010). Methane and nitrous oxide in surface water along the North-West Passage, Arctic Ocean. *Marine Chemistry*, *121*(1–4), 80–86. https://doi.org/10.1016/j.marchem.2010.03.006

Uhlig, C., & Loose, B. (2017). Using stable isotopes and gas concentrations for independent constraints on microbial methane oxidation at Arctic Ocean temperatures. *Limnology and Oceanography: Methods*, *15*(8), 737–751. https://doi.org/10.1002/lom3.10199

Appendix I: Figures

Figure 1: Proposed cruise track for the 2018 NPP cruise. The red line represents the cruise track, circles are locations of land excursions for filming and tourism, light blue lines are the proposed transect locations, and the light blue region in Lancaster Sound in the operational area of the glider.

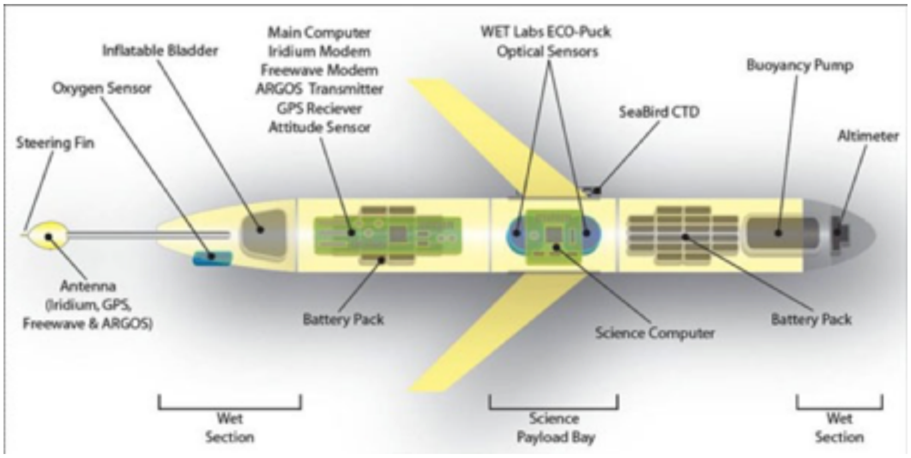

Figure 2. Slocum Glider, similar to the one to be used in during the NPP. Image source: http://auvac.org/configurations/view/49.

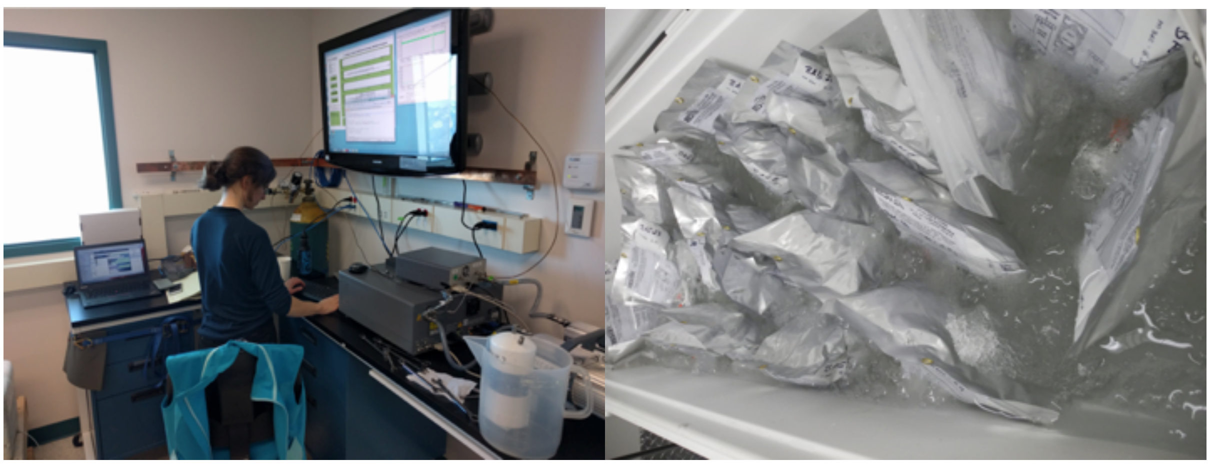

Figure 3. (Left panel) Ship or lab-board analysis of methane and carbon dioxide. (Right panel) Incubators in an ice-water bath for analysis of methane oxidation.

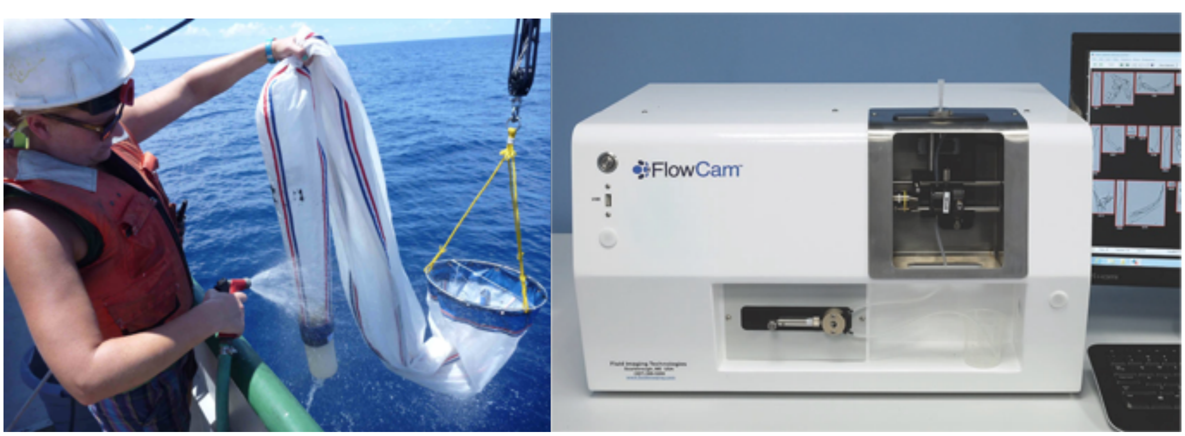

Figure 4. (Left panel) Plankton net tows are used to capture small particles in the water column. (Right panel) An imaging microscope known as the FlowCam™ is used to identify and count these particles.

Appendix II: Research Sonar on the URI Northwest Passage Project

1. Introduction

As part of the proposed University of Rhode Island Northwest Passage Project (NPP) expedition aboard the *Akademik Ioffe*, the science team will utilize two sonar systems: A TRDI Acoustic Doppler Current Profiler (ADCP) operating at 38kHz and a Lowered Acoustic Doppler Current Profiler (LADCP) operating at 300kHz. The TRDI 38kHz ADCP is mounted on the hull of the *Akademik Ioffe* and the 300kHz LACDP is mounted on the water sampling rosette. Both the TRDI 38kHz ADCP and the 300kHz LACDP will be used to measure ocean currents.

The NPP expedition is aware of concerns about the potential for research acoustic sources to have a behavioral impact on marine organisms, particularly marine mammals. The LADCP 300kHz sonar operates at a frequency that is outside the detection limit of all the Arctic marine mammal species, the intensity decreases very rapidly with distance from the instrument, and it will only be used at 17 water sampling stations as described in the science summary. However, the operating frequencies of the 38kHz ADCP sonar can be detected by some marine mammals (such as narwhals and belugas) and operates at an intensity where an animal in the vicinity of the vessel could hear the signal.

There are several procedures that can be used to reduce or eliminate any impact on marine organisms that may exist from the use of the sonar.

- First, the sonar can be run intermittently, with a focus on the times when it would be most important to collect acoustic data.
- Second, it may be possible to run the 38kHz in a reduced power mode. Running in a low power mode would reduce the distance from the ship that the sound from the instrument could be perceived by any animals.
- Finally, the sonar can be turned off and not used in areas or situations where it is deemed that the sonar may pose an unacceptable risk of impact.

2. Proposed Operating Procedures

The proposed standard procedure for the NPP 2018 expedition will be to have the hull mounted 38kHz sonar operating when the ship is underway, except under these conditions:

1) Sonar operation will cease when marine mammals are detected within 500m of the ship.
2) The sonar will be off when within 5 km of any Nunavut community.
3) East and South of Bylot Island, the sonar will only be used when greater than 5km from land and will not be used in any harbor, bay, fjord, or channel.
4) Out of respect for concerns about the sonar in regard to a group of narwhals that moves between the Arctic Bay and Pond Inlet areas, the sonar will be off while in Navy Board Inlet, Eclipse Sound, and Pond Inlet.
5) When in restricted waters of the Bylot Island Migratory Bird Sanctuaries or Parks Canada Waters, the sonar will be off.

The science party is eager to have input on how the sonar should be operated by those with local knowledge. NPP is particularly interested in areas where the local communities would find the science results useful and where there are areas of additional concerns about the sonar and where the sonar should not be used, or used in a mitigation mode. NPP looks forward to input from the communities of Nunavut.

3. Acoustic Source Details.

TRDI Acoustic Doppler Current Profiler (ADCP) operating at 38kHz
Center frequency is 38.4kHz with a +/-3dB bandwidth of 37.2-39.6kHz
Source level of the instrument at 1 meter is 227dB re 1 micro-Pascal.
The acoustic pressure at 182 meters directly in line with the instrument (below the ship) is 180 dB re 1 micro-Pascal.
The acoustic pressure 20 degrees off the main beam of the instrument at 22 meters is 180dB re 1 micro-Pascal.
This instrument produces sound at a frequency that marine mammals are able to detect it. However, the sound intensity is focused downward, below the ship, and decreases to 180dB at 182meters below the ship. More importantly, the sound radiating away from the ship horizontally, in the surface layer, decreases to 180dB at 22 meters and will continue to decrease with distance from the ship due to spreading and absorption. At these levels, marine mammals, such as narwhals, will be able to detect the sound from the instrument if they are close to the ship. The sound will not be particularly “loud” for the marine mammals, as narwhals are known to echolocate with source levels at 1 meter up to 218dB re 1 micro-Pascal. However, the marine mammals may find the sound unusual and could react to it by temporarily changing their behavior (such as by moving away from the sound source). The methodologies proposed for this expedition include common mitigation measures and should minimize any potential disruption.

TRDI Lowered Doppler Current Profiler (LADCP) operating at 300kHz
Center frequency is 307.2kHz with a +/-3dB bandwidth of 268.8-345.6kHz.
Source level of the instrument at 1 meter is 215dB re 1 micro-Pascal.
The acoustic pressure at 40 meters directly in line with the instrument (directly below the rosette) is 180 dB re 1 micro-Pascal.
The acoustic pressure 20 degrees off the main beam of the instrument at 1.8 meters is 180dB re 1 micro-Pascal.
This instrument is only used when the CTD/water sampling rosette is deployed (approximately once per day). The operational frequency of this instrument is outside the hearing range of fish and marine mammals. The signal from this instrument will rapidly decrease with distance from the instrument due to spreading and absorption. There is no known impacts from this instrument on any marine creatures.

Appendix II: Description of the Slocum Glider

A Slocum Glider is a type of Autonomous Underwater Vehicle or AUV. AUVs operate independent of ships based on programed instructions they are given. The Slocum Glider to be used on the URI Northwest Passage Project 2018 can communicate with land based researchers though a satellite link. The data from the glider can be downloaded and new instructions can be uploaded.

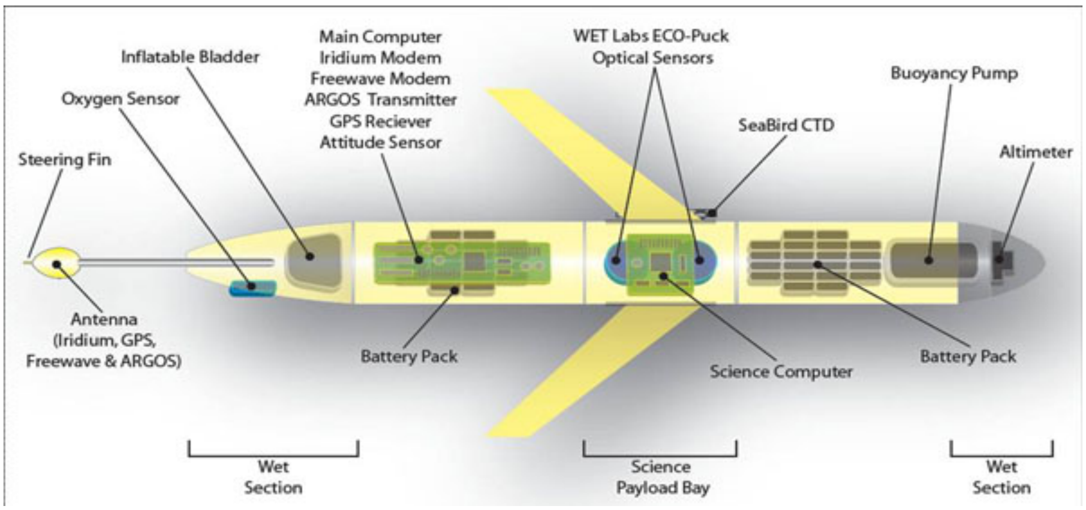

Figure 1. Diagram of a Slocum Glider showing the parts.

A Slocum Glider operates by making small changes to its buoyancy which allows it to move up and down in the water column to create a profile of the water column. An idealized illustration of the path a Slocum Glider takes in show in Figure 2.

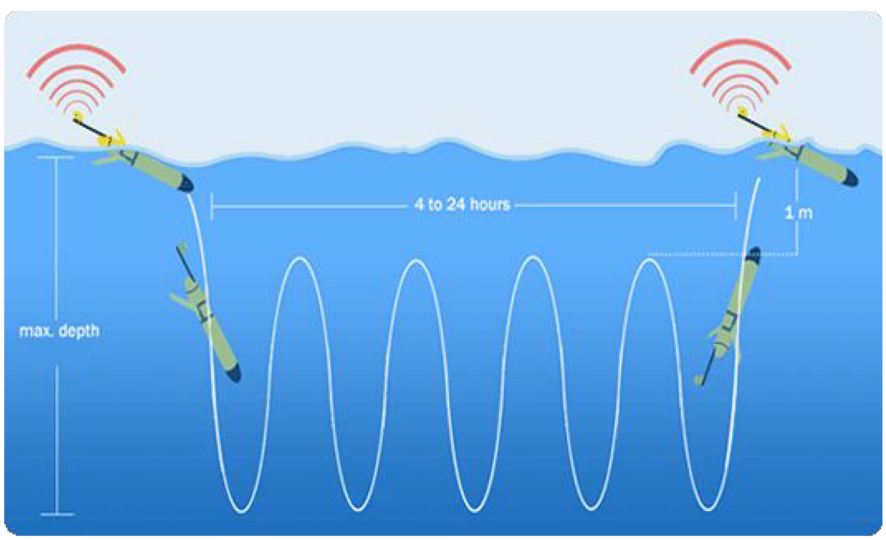

Figure 2. Illustration of the operation of a Slocum Glider.

To make a Slocum Glider work, a pump transfers seawater in and out of a holding chamber, which results in a change to the vehicle's density; this leads to a sequence of sinking and rising, which is translated into a forward motion by the attached wings. The average horizontal speed is

20–40 cm/s and vertical motion is 10–20 cm/s. Dive depth can be regulated by a pressure sensor. Forward and backward shifting of the battery packs controls dive angle; a rudder in the tail fin controls the yaw. When at the surface for communication, an air bladder at the tail is filled for additional buoyancy. The glider is about 2.4 meters long with a 0.45 meter diameter and weights about 90 kilograms. The glider is painted yellow with a black nosecone. For the NPP expedition, the glider will be equipped with conductivity meter (to measure salinity), a temperature sensor, a pressure sensor (for depth), a dissolved oxygen sensor, and 3-channel fluorometer (to measure Chlorophyll-a, CDOM, and optical backscattering).

The glider makes a minimum of noise underwater, with the greatest noise happening for short periods when the pumps are operating. Typical sound levels are 35 to 45 dB re 1μPa at 1m and while pumping sound levels range from 45 to 85 dB re 1μPa at 1m. At 100m from the glider the maximum sound levels will be 65 dB re 1μPa. These are very low underwater sound levels and as such the gliders are considered good platforms for passive acoustic listening. For example, they are being used as a monitoring tool by the U.S. National Oceanic and Atmospheric Administration (NOAA) to monitor endangered North Atlantic right whales as well as fin, sei, and humpback whales. Marine mammals do not seem to be disturbed by the gliders or to disturb the gliders.

For the 2018 NPP expedition, the glider will be deployed around August 24 north of Somerset Island and will be recovered around September 6, when the ship returns to the area. The glider will operate within the Lancaster Sound area. Once the glider is deployed, the ship does not need to stay near the glider. The glider will be untethered and can operate on its own for multiple weeks. To pilot the glider, the science team will be in daily communication with the glider pilot at the Virginia Institute of Marine Science. Data will also be downloaded to the ship on a daily basis.

Figure 3. Dr. Donglai Gong with a glider before deployment (with no side fins attached).

The glider's mission is to conduct repeated cross strait transects to monitor water masses, freshwater transport, boundary currents on the two sides of Lancaster Strait, and eddies inside the strait. This across-strait survey pattern would complement the ship's along-strait survey and a more comprehensive view of the oceanographic conditions in Lancaster Strait during the period of the cruise.

While Dr. Gong has operated Slocum gliders in the Arctic before, primarily in the Beaufort Sea area, and others have operated them around the Arctic, we are unaware of any Slocum Gliders used in the Nunavut Territory. Other types of gliders/autonomous underwater vehicles have been used extensively in the Arctic: around Alaska, around Greenland, around Svalbard, and around Ellesmere Island.