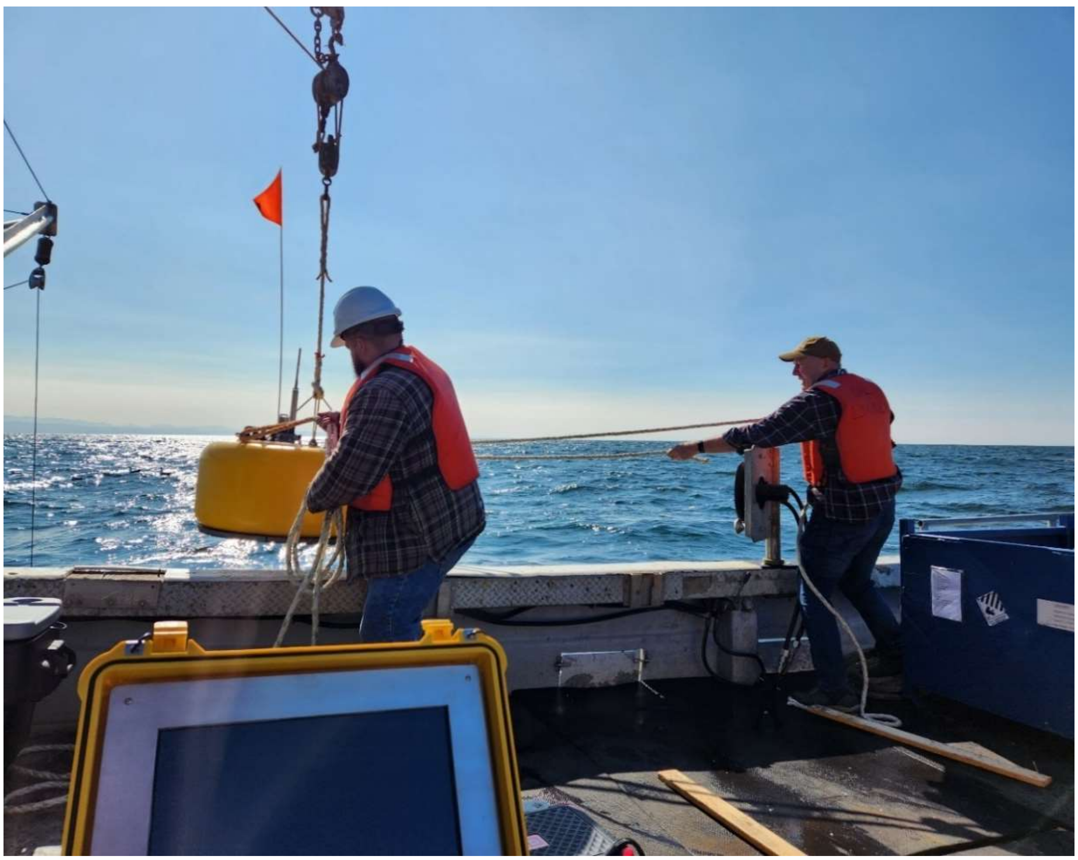
Earthquake Monitoring & Whale Tracking in the Lower St. Lawrence Seaway

OBS Deployment
NFSI-004-2023-01
FV Kalynic

September 26-29, 2023

National Facility for Seismological Investigations

Dalhousie University



Funding and Principal Investigators

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Principal Investigators and collaborators on these grants are listed below.

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Cruise Identification

This document will use the NFSI identifier for this cruise. At the time of writing, we are not aware of other identifiers having been established in collaborating organizations.

Organization	Cruise ID
NFSI	NFSI-004-2023-01

Revision History

Date	Version No.	Author(s)	Description
Feb 2024	1.0	K. Bosman, G. Cairns	Base document

Contents

Summary

In September 2023, NFSI deployed 9 Güralp Aquarius broadband ocean-bottom seismometers (OBS) in the Lower St. Lawrence Seaway. The objectives of this project are to monitor local earthquake activity for structural imaging and geohazard assessment, and simultaneously to track passing fin and blue whales to help characterize their habitat and migration behaviour. The OBS deployments were carried out from a small fishing vessel, *FV Kalynic*, in daytime operations. One of the instruments deployed had to be recovered due to a technical malfunction. The other 8 instruments are scheduled to stay on the river bottom throughout the winter, with recovery planned shortly after the ice breakup in spring 2024. This deployment was a scaled down version of the initial plan for 14 instruments, due to the passage of Hurricane Lee through the region the weekend of the planned operation, followed by unavailability of the larger vessel originally chartered for the project. The marine OBS deployments were accompanied by land installation of nodal seismometers on the adjacent banks of the St. Lawrence by other project teams. The land installations are covered in a separate report.

Cruise Participants

Science Party

Name	Affiliation	Role
Mladen Nedimović	Dalhousie University	Chief Scientist / Land Logistics
Graeme Cairns	Dalhousie University	Operations Manager / Voyage Leader (at-sea)
John Thibodeau	Dalhousie University	OBS Technician
Katherine Bosman	Dalhousie University	OBS Technician
Felix Heinzelmann	Independent	Videographer

Ship’s Crew

Name	Role
Louis Henry	Skipper
Romain	Crew

1.0 Introduction

This project was designed to simultaneously address scientific objectives that fall under two major themes:

1) Earthquake hazard assessment

The Lower St. Lawrence Seaway (LSLS) is an active earthquake zone, posing seismic risk to communities along its shorelines, including the municipalities of Matane and Baie-Comeau. To date, seismometer coverage in the region has been sparse and exclusively land-based, meaning the measurements have been too far from the primary seismogenic areas (in the center of the LSLS) to resolve small earthquakes and delineate fault structures. By deploying OBS directly above the most seismically active area of the LSLS, this project aims to greatly improve detection and location of small earthquakes, as well as resolve their more detailed characteristics. The earthquakes will be used as sources for seismic tomography with which major, potentially seismogenic faults can be identified. Finally, focal mechanism and tectonic stress analysis from these data will enhance the geological interpretation of faulting and its hazard implications, including the susceptibility to remote dynamic triggering.

2) **Endangered baleen whale monitoring**

The LSLS is critical to Canada's economy both as part of a major marine shipping corridor and as a site of intensive fishing. However, these human activities have detrimental effects on the local ecosystem, including endangered baleen whales. Understanding the migration behaviour and habitat use of whales is essential to make informed decisions on shipping and fishing regulations, to prevent harming whales through collisions or noise pollution. The OBS network aims to track fin and blue whales in the LSLS and assess their habitat use and migration behaviour, including their response to marine traffic. Based on the prevalence of their calls at onshore seismometers, on both shorelines, fin whales are expected to be abundant across the entire network. Blue whales should also be present across the entire OBS network, although observations from onshore seismometers suggest they will be most active in the eastern end, towards the Gulf of St. Lawrence.

The geographic overlap of these two societal issues in the LSLS allows this OBS deployment to target both sets of research objectives without need for any significant compromise in survey design. Furthermore, this project aims to connect the two themes by using fin and blue whale calls as seismic sources to probe shallow sediment layers for fault scarps, contributing to earthquake hazard assessment.

1.1 Operational Background

The original plan for this project called for an array of 14 Aquarius broadband ocean-bottom seismometers (OBS) to be deployed in the estuary of the St. Lawrence River between Baie-Comeau, QC in the west and Sept-Îles, QC in the east, as shown in Figure 1-1. Due to concerns about bottom-dredging fishing activities, deployment sites were limited to the deeper part of the channel and seasonally limited to the months between the end of fishing season in fall, and resumption of fishing in spring.

Deployments were to begin at the west end of the array and proceed down-river to the east. As the planned OBS stations were all within 2-3 hours transit from shore, it was decided to carry out daytime-only operations using a small vessel that would start from Matane and work its way along the south shore, overnighting in ports of convenience which would minimize transit time. This plan proved more economical than contracting a larger vessel (such as *RV Coriolis II*) able to carry out 24hr operations, even though it required a longer time. It also afforded more operational flexibility, and decoupling of the OBS operation timeframe from that for the hydrophone array deployments planned by our UQAR collaborators.

Island Venture I, owned and operated by Baker Blue Ocean based in New Harbour, NS, was contracted for the operation. The OBS equipment was to be loaded onboard at the Centre for Ocean Ventures and Entrepreneurship (COVE) in Dartmouth, NS, on September 13. The vessel would then transit through the Strait of Canso and Gulf of St. Lawrence to Matane, QC, a journey of approximately 3 days. NFSI personnel were to meet the boat in Matane on September 17 to begin operations.

In the week leading up to the scheduled loading day, however, weather forecasts warned that Hurricane Lee would sweep through the Maritimes on the weekend of September 16. The captain of *Island Venture* being uncomfortable with the idea of weathering such a powerful storm in an unfamiliar port, we postponed the operation. Loading at COVE was rescheduled to September 18th, and *Island Venture* was moved to safe mooring in Deep Cove.

On September 15, as Nova Scotia braced for the hurricane, an unrelated medical emergency arose for the ship's crew, making them unable to proceed with the cruise. A new ship therefore had to be found very quickly if the St. Lawrence operation was to be completed before the NFSI team was scheduled to mobilize to BC for another project in early October. Pierre Cauchy, a collaborator at Université du Québec à Rimouski (UQAR), provided contact information for Pêcherie Henry, a small fishery based in Carleton-sur-Mer, QC in Chaleur Bay, that was interested in chartering their fishing vessel *Kalynic* for scientific research. There wasn't enough time for an in-person visit to inspect the boat prior to the cruise, but photos and dimensions of the deck were provided and after several calls with the captain to discuss the procedure it was estimated that, although smaller and less well equipped than *Island Venture*, *Kalynic* would be adequate for our operations. Principal Investigator Yajing Liu of McGill University managed to expedite a contract to use *Kalynic* in less than one week to allow the deployment to proceed, and it was agreed that the vessel would meet NFSI staff in Matane, QC to begin operations September 26.

As we were no longer using a local Nova Scotia vessel, the equipment needed to be mobilized by road to Gaspésie. With insufficient time to arrange commercial transport, we arranged to rent a box truck capable of transporting the OBS. A significant obstacle to this developed when we learned that due to the lithium-ion batteries in the OBS, the driver of the truck would need to be certified in Transportation of Dangerous Goods. NFSI staff quickly completed an online course to meet this requirement.

Gross vehicle weight restrictions with a Nova Scotia Class 5 driver's license limited the number of instruments we were able to transport to 9. The array design was accordingly revised for the reduced number of instruments, focusing on the west end of the original array where the river is narrow enough to obtain good spatial coverage with a small number of stations (Figure 1-2).

The plan was to meet *Kalynic* in Matane so that deployments could be carried out moving downstream, taking advantage of the current, but on the 24th the captain called in transit to say the vessel had encountered headwinds and difficult cross-seas as they rounded the Gaspé Peninsula, and had taken shelter in the small harbour of Havre des Quinze Collets in Petite-Tourelle, QC. (We later learned that a larger fishing boat sank that day due to weather conditions in the Gulf of St. Lawrence, resulting in 3 deaths[1]). It was therefore agreed that we would meet *Kalynic* in Havre des Quinze Collets and carry out the deployments east to west, moving upstream against the current, although this would slow transit times. As hotel arrangements had been made for Matane and nothing suitable was available in Sainte-Anne-des-Monts, the NFSI team would stay based in Matane, commuting by road to *Kalynic*'s location on successive days, although this was to add 2-3 hours driving to already long operational days.

1.2 Maps

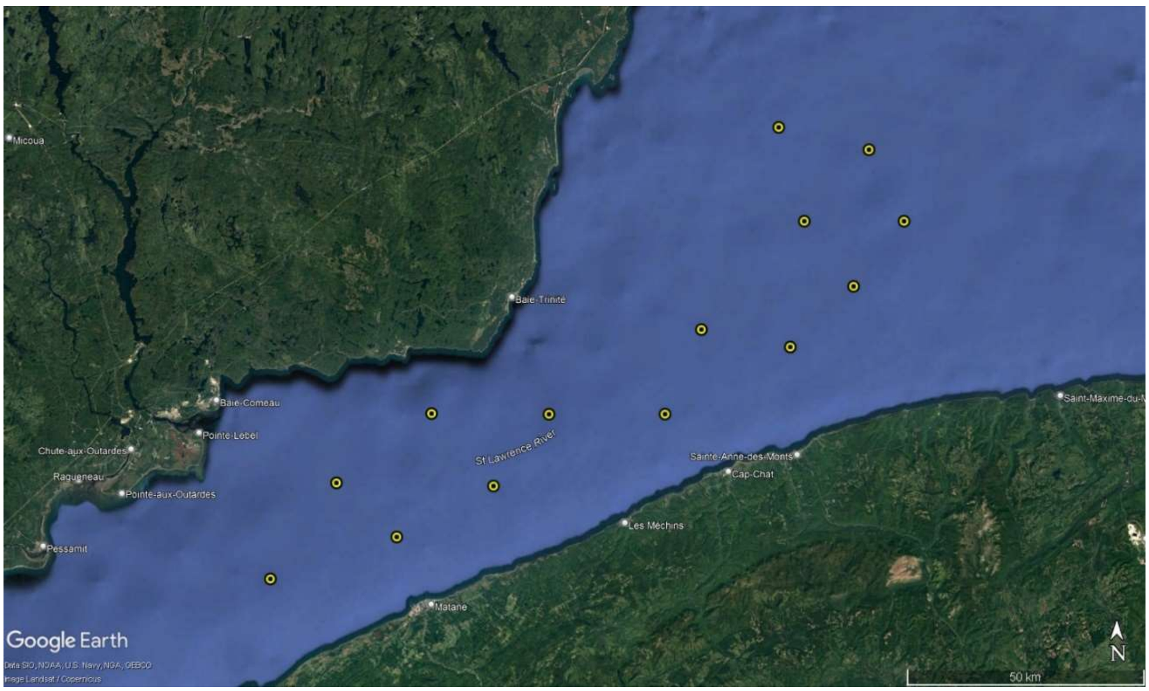


Figure 1-1: Original planned OBS array with 14 stations.

[1] https://www.cbc.ca/news/canada/montreal/fishing-boat-sinks-la-tabatiere-1.6977742

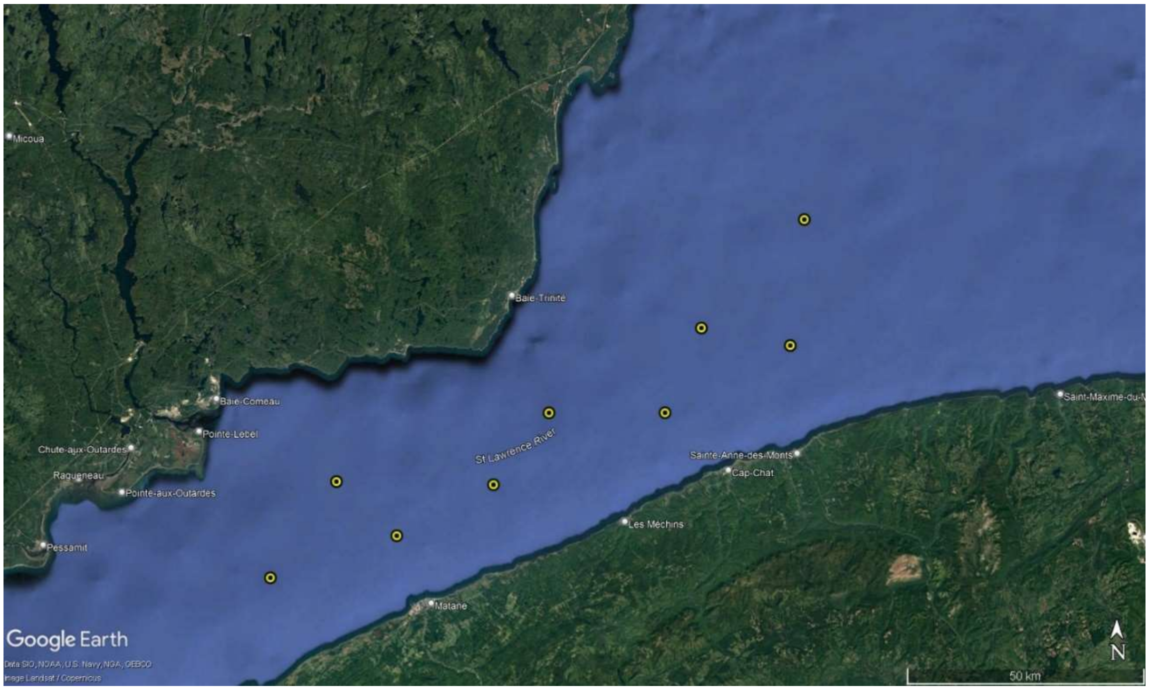


Figure 1-2: Revised deployment plan with only 9 OBS stations.

2.0 Instrument Preparation

The instruments deployed in this operation had been stored in Halifax since being received from Güralp in 2022, recording test data periodically during that time. In January 2023, the hydrophones were removed from these instruments and returned to Güralp to address a technical problem. This problem was not resolved on time to replace them in 2023. Only four hydrophones were therefore available for the project: three with reduced gain settings which Güralp had recently used for testing in the Tyrrhenian Sea, and one with a higher gain setting (known to have stability issues) that had been kept in Halifax. These sensors were installed on the instruments to be deployed at the westernmost stations (LSL01 through LSL04); all other stations were equipped with dummy plugs to seal the cable end.

In May 2023 retrofit work had been carried out in Halifax by a visiting team from Güralp, primarily to replace corrosion-prone threaded metal inserts in the buoyancy units. Drilling from this work had fouled the battery charger cap O-rings with a residue of glass and epoxy dust that needed to be cleaned. Battery charging was performed for the instruments between August 31 and September 8. Due to the uncertainty around the hurricane and feasibility of the deployment in the following weeks, however, O-ring cleaning, recovery device preparation and testing and some other tasks preferably performed before mobilization wound up being carried out in the field.

For the first day of operations (September 26), 4 sets of recovery beacons were prepared prior to the first deployment. The XMB-11k VHF radio beacons were programmed and assembled on the dock (Figure 2-1) while other equipment was being loaded onto the boat. Apollo Mono Iridium/GPS beacons were prepared on a small work surface available in the boat's bridge (Figure 2-2) while transiting to the first site. During transit prior to each of the two deployments on this day, all electrical connections to the Aquarius pressure case were inspected, the O-rings on the battery charger cap were cleaned and regreased with Molykote 111 compound, a dummy plug was installed in place of the hydrophone, and a set of recovery beacons and a high-visibility flag were installed.

Due to the motion of the ship and risk of splashing while underway, as well as very limited indoor workspace onboard, we decided to carry out preparations of the OBS in port for future instruments. On the morning of the second day (September 27), three OBS were prepared before leaving port. All remaining recovery beacons were also prepared at this time. The remaining OBS were prepared in the evening of September 27 after docking for the night.

Figure 2-1: Assembling XMB-11k VHF radio beacons on the pier prior to departure.

Figure 2-2: Assembling Apollo Mono Iridium/GPS beacons on the bridge of Kalynic while underway. The available workspace is quite small.

Figure 2-3: Cleaning and greasing Subconn electrical connectors on the boat's deck while underway.

3.0 Field Operations

3.1 Mobilization

Equipment and personnel were mobilized from Halifax to Gaspésie by road using rental vehicles. A 26-foot box truck with a lift gate from Penske in Dartmouth was used to transport the Aquarius OBS. Two NFSI staff members traveled in the truck: a driver certified for Road Transport of DG Materials and a passenger for safety. The space in the truck can physically accommodate more than the 14 Aquarius OBS originally allocated for this project, however NFSI staff only have Nova Scotia Class 5 driver's licenses, which allows the licensee to drive vehicles with gross weight of up to 14,000 kg. The truck weighs approximately 8,000 kg empty. Each Aquarius OBS, with ballast installed and stowed in the standard metal stillage box, weighs approximately 475 kg. Including a nominal weight for 2 people and allowing a small margin of error, this allowed a maximum of 9 OBS without spare ballasts and a pallet jack for moving them to be transported in a single trip. Due to the limited time available to complete this operation and distance from Halifax to Matane, it was not possible to make a second trip. A passenger van was used to mobilize the auxiliary equipment and remaining 3 people.

The truck and van were loaded at COVE in Dartmouth, NS on the morning of September 25, 2023, and driven directly from there to the Quality Inn hotel in Matane, QC. Total driving time was approximately 10 hours. Due to the weight of the instruments, the truck struggled to maintain highway speeds through the hilly terrain of the Cobequid Bypass and the Appalachian Mountains between Campbellton, NB and Matane, QC.

Figure 3-1: Loading Aquarius OBS in stillage boxes into 26-foot box truck using lift gate and pallet jack.

On the morning of September 26, NFSI personnel traveled from Matane to Havre des Quinze Collets in Petite-Tourelle, QC, where *Kalynic* had docked the previous evening. Most of the small ports in this area, Havre des Quinze Collets included, have knuckle cranes installed on the pier, the use of which is generally included in the docking fees. This crane was used to load all Aquarius OBS from the box truck onto the boat. Three instruments were staged out of their stillage boxes for deployment on the first day; all remaining instruments were stored in their stillages, arranged at the stern of the boat. On September 27 (day 2), three additional instruments were removed from their stillage boxes. Empty stillages were removed and stored in the box truck until demobilization. The pallet jack was loaded onto the boat and used for moving stillage boxes on deck during the final two days of deployments.

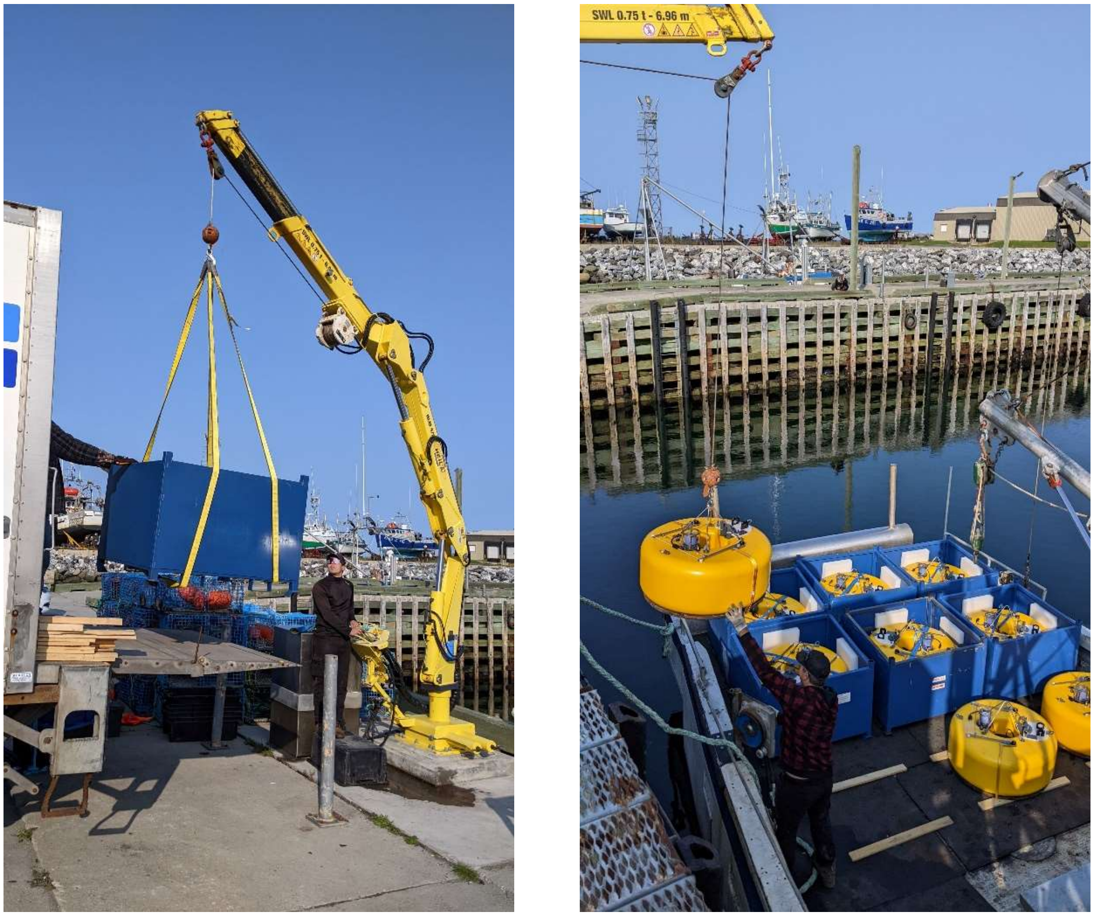


Figure 3-2: Using the knuckle crane at Havre des Quinze Collets to load Aquarius OBS and stillage boxes onto Kalynic.

3.2 Accessory Equipment Setup

Due to the small size of the vessel, all equipment was set up on deck in close proximity to the OBS instruments. *Kalynic* has a hatch near the front of the deck, which covers the entrance to the boat's hold. This provided a table-like surface to which the deck unit was secured with bungee cords. The batteries in the deck unit hold enough charge for a full day's operation and were recharged at the hotel each evening. The GPS antenna for the deck unit was mounted on a small pole at the aft port corner of the deck. Cables for the dunker and ethernet/serial connection to the OBS were run across the deck. All other tools and supplies were stored in plastic toolboxes on the deck.

For in-water acoustic communication, the omni-directional dunker was suspended over the starboard rail 5-10 meters below the water's surface and the cable held in place by hand. The dunker is a relatively lightweight piece of gear and requires no additional equipment to deploy, but layback of the cable as the ship drifted or tried to hold station in the current was a frequent problem that increases uncertainty in seafloor instrument positioning. Water depth readings were taken from the vessel's depth sounder on instrument release, and will be verified with OBS pressure readings on recovery.

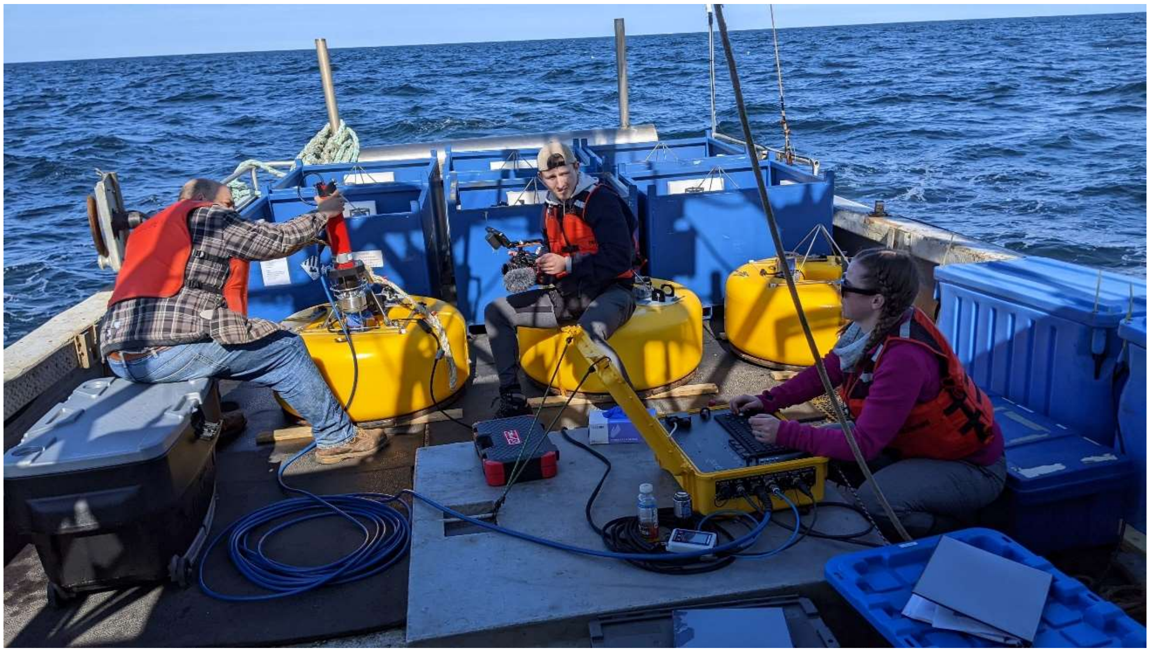


Figure 3-3: Equipment setup on aft deck of Kalynic. Deck unit is secured to hold hatch with bungee cords. The GPS antenna for the deck unit can be seen center back secured to a small pole at the stern railing. The dunker is shown being used to test acoustic communications on deck prior to deployment.

Figure 3-4: Sonardyne omni-directional dunker being deployed over the starboard rail.

3.3 OBS Release Method

Typically, a quick release mechanism (such as a Sea Catch) is used to release the OBS in the water at deployment. However, this can add significant height to the lift required to put the instrument overboard. On *Kalynic*, the available lifting equipment does not allow for this additional height. We therefore used a sacrificial rope to release the instruments, both due to height constraints and for operational simplicity. For each deployment, an eye-and-eye sling was prepared by the ship's crew by making eye-splices in both ends of a short section of rope. The finished sling was approximately 1 metre long. For some instruments, one end of the sling was secured to the lifting frame and the other looped over the winch's hook; in other cases the sling was threaded through the lifting frame and both loops placed on the winch hook. Once the OBS was lifted overboard and placed in the water, a knife was used to cut through the rope, releasing the instrument, as shown in Figure 3-5.

Figure 3-5: Sacrificial rope sling being cut with a knife during deployment of an OBS.

3.4 Cruise Narrative

Date	Event
Mon. Sept 25	07:15 ADT John and Graeme go to Penske in Dartmouth to pick up rented 26-ft box truck. Katie arrives at COVE to begin unloading OBS from containers. 08:15 John and Graeme arrive at COVE. Begin loading 9 OBS into box truck. 09:15 Mladen and Felix arrive at COVE with rental van. Load accessory equipment, tools and luggage into van. 09:45 Depart COVE. John and Katie in box truck, Mladen, Graeme and Felix in van. Van makes a few stops in North End Halifax on the way out. 11:00 Van and truck meet at Enfield Big Stop, continue on route to Matane, QC. The truck is slow on the highway due to the weight of the instruments; drops down to ~40 km/hr on some hills through Cobequid Pass. Time zone change to EDT at NB-QC border 19:15 Arrive at Quality Inn in Matane, QC. Check in, unload luggage, plan to depart at 07h00 tomorrow to head to the boat.
Tues. Sept 26	07:00 Depart hotel 08:30 Arrive at Havre des Quinze Collets in Petite-Tourelle, QC. Meet Kalynic crew, Louis and Romain. Begin loading equipment and OBS. Decided to load most OBS in stillage boxes and use the pallet jack to move them around on deck; have 3 OBS staged on deck out of stillages (empty stillages left in truck at pier). 09:00 Katie prepping some VHF beacons to cover today's deployments plus some extra (6 beacons for now). Set frequency to 154.585 MHz. 10:00 Done loading equipment. Park truck at pier for the day. NFSI personnel head to grocery store in Sainte-Anne-des-Monts to get food for the day. 10:50 Return to boat. Graeme, John, Katie and Felix board; Mladen will stay on land with the van. 11:03 Boat leaving the dock. Fairly calm seas for now. Plan to deploy at stations 8, 9 and 7 and return to Cap-Chat if possible. Expected transits between stations ~1.5 hours. 11:20 Installing GPS antenna for deck unit, secured to a short pole at port stern railing. Single 5m coax cable is not quite long enough to reach the deck unit on top of the hold hatch. 11:45 Begin prepping AQU-465F for first deployment. Need to clean battery charger cap (lots of dust still left from threaded insert replacement). Katie prepping Apollo beacons (4 for now). 12:15 On station at LSL08. Waiting for message from Apollo(s), no emails or messages on Hermes. Eventually called Steve from Xeos, turns out Hermes wasn't activated. Still not getting emails. 13:00 During testing of VHF beacon, ship's crew noted 154.585 MHz transmits in a standard distress band (had been noted by *Coriolis* crew last year also), so we absolutely should not use this unless necessary. Changing all VHF beacons to 160.725 MHz instead. Also cut down flagpole by ~1ft, was a bit too long. 13:43 Deployed AQU-465F at LSL08. Water depth 306m, expected time to seabed 6.5-7 minutes. Putting dunker over the side for in-water checks and monitoring fall progress. Move AQU-BA61 to starboard rail ready for next deployment.

	13:50 Confirmed OBS at bottom, starting location survey. First point here, then 2 other locations around the drop point. 14:15 Done location survey. Starting transit to LSL09. Waves and wind starting to pick up a bit. 14:20 Begin prepping AQU-BA61 15:32 On station at LSL09. Waves reasonably rocky, bit of a rough ride. 15:52 Deployed AQU-BA61 at LSL09. Move remaining "loose" OBS to centre of deck for stability during transit. About 3 hours from here to Cap-Chat, so not enough time for another drop today. 16:10 Acoustics are sort of working. Ranges are fine, good reception on OBS transmissions, but no status messages or OBS ID coming through. 16:25 Have sent release time reset message a few times without a successful response. Ranges still work fine. Continue with location survey for now while waiting out release timer (set for 16:45); continue sending release time reset and hope to get a response. We will have to wait at this station until at least 17:00 to make sure it doesn't surface (not sure how long burn will take on timed release). 17:10 OBS surfaces, burn would have been ~22 minutes. 17:20 OBS recovered to deck. Starting transit to shore, ETA ~3 hours to Cap-Chat. 17:30 Discovered the toilet on board is under the bench in a corner of the bridge, no privacy screen. 18:00 Decided to return to the closer Petite-Tourelle rather than Cap-Chat, due to the approaching darkness and familiarity with the former. 20:05 Arrive at Havre des Quinze Collets (Petite-Tourelle) in the dark, navigating into port by lining up pilot lights. Mladen waiting in minivan. Unload AQU-BA61 to stillage in truck; we'll troubleshoot later to figure out what went wrong (no extra ballasts here, so can't redeploy anyway). 20:30 Depart Petite-Tourelle in minivan. Take deck unit and Hermes back to hotel to charge. 22:00 Arrive at hotel in Matane. Plan to meet at 06h00 tomorrow. No dinner.
Wed. Sept 27	06:45 Depart hotel in Matane. Various discussion during the drive to Petite-Tourelle. • Due to bathroom situation on board, Katie will not be on the boat today • We should do as much prep at the dock as possible, both for limited personnel and wave/splash conditions out on the water 08:00 Arrive at Havre des Quinze Collets (Petite-Tourelle). Ship's crew shuffle OBS, have 4 out of stillages on deck (empty stillages removed to truck). Prepare remaining beacons and 4 OBS for deployments: • Grease Subconn connectors, install dummy plugs for hydrophones (high gain hydrophone on 4th OBS in line) • Clean and re-grease battery cap O-rings • Install release arm bungees and lifting frames anodes • Attach beacons and flags • Deck unit setup, start GPS syncing • Remove switch plugs from 3 OBS 10:20 Boat leaving dock. John and Graeme on board. Mladen, Katie and Felix return to hotel.

	11:50 Mladen, Katie and Felix arrive at hotel. Mladen attempt to extend our stay an extra night; not possible as the hotel is fully booked for the weekend (event). Booked at Riôtel (nearby) for Thursday night instead. 12:45 Fixed Apollo email forwarder, had been set to only send alarm messages. 13:10 Arrive on station at LSL07 13:13 Deployed AQU-F561 at LSL07 13:23 Confirmed OBS at bottom, starting location survey. 13:44 Done location survey. Location fix is not great due to strong current (~1.1 kts) causing boat to drift and dunker layback. 13:50 Starting transit to LSL06. Likely we will only get 2 deployments done today, so a 4th boat day will be necessary. 15:00 Mladen and Katie to Riôtel to extend stay to Saturday, then pick up some lunch. 15:15 On station at LSL06, activating beacons 15:20 Deployed AQU-195D at LSL06 15:28 Confirmed OBS at bottom, starting location survey. 15:48 Done location survey 15:53 Starting transit to Les Méchins, ETA 17:45 17:10 Mladen and Katie depart hotel, heading to Les Méchins 17:50 Mladen and Katie arrive at Les Méchins as boat is docking. 18:10 Mladen, John and Louis depart for Petite-Tourelle to collect trucks. Graeme and Katie prep remaining 3 OBS for deployment: • Clean and re-grease battery cap O-rings • Attach release arm bungees and lifting frame anodes • Connect hydrophones (low and mid gain) and secure in brackets • Attach recovery beacons and flags • No new instruments turned on, leave for the morning to save battery. AQU-555C still running from yesterday 19:50 Depart Les Méchins 20:30 Arrive at hotel. Plan to arrive at Les Méchins for 06h30 tomorrow, leave hotel ~05h45
Thurs. Sept 28	05:55 John moving box truck from Quality Inn Matane to Riôtel (we will be switching hotels today). 06:00 Remaining personnel leave Quality Inn to meet John 06:20 All personnel leave Riôtel in van, heading to Les Méchins 06:50 Arrive at Les Méchins 07:00 John and Graeme on boat, pulling away from the pier. Turn on 3 Apollos immediately to ensure we get messages before deployment. 07:10 Mladen, Katie and Felix leave Les Méchins. Mladen calling rental agency to extend van rental to Saturday. 07:55 Arrive at hotel. We have not received any messages from Apollos yet today; Katie troubleshooting. 08:05 Call Xeos support line, no one picking up. Got through to Xeos reception, Steve not in until 10am ADT today, left a message for him to call back when he arrives. 08:10 John checking Bluetooth with Apollos. Don't appear in list of available devices initially (expected, they've been on long enough that antenna should have switched over to GPS). Turning off and back on they do show up, all looks good.

	09:17 Backlog of messages comes through (XeosOnline and email) all at once, going back to 11:05 UTC (07:05 local time, just after being powered on). 09:23 Deployed AQU-555C at LSL05 09:30 Call from Geoff at Xeos. They've been working on a problem with XeosOnline this morning, seems to be fixed on their end now. 09:31 Confirmed OBS at bottom, starting location survey. 09:53 Done location survey, starting transit to LSL04 11:20 Arrive on station at LSL04 11:23 Deployed AQU-D85B at LSL04 11:32 Confirmed OBS at bottom, starting location survey. 11:53 Done location survey, starting transit to LSL02. ETA 14:20. Expecting a 4th drop today is likely at current pace, turning on next Apollo beacon. 12:00 Mladen, Katie and Felix check out of Quality Inn 12:20 Mladen, Katie and Felix arrive at Riôtel. 1 room is available for early check-in, but others expected not until 16:30. 14:19 Deployed AQU-4D5C at LSL02 14:27 Confirmed OBS at bottom, starting location survey 14:45 Done location survey, starting transit to LSL03 16:13 Deployed AQU-1A62 at LSL03 16:21 Confirmed OBS at bottom, starting location survey 16:47 Done location survey, starting transit to Matane. ETA 18:00 17:30 Mladen, Katie and Felix leave hotel. Stop at Canadian Tire to pick up a lock for the box truck. 17:50 Van arrives at Matane pier. Boat arriving a few minutes later. 18:10 Van leaving pier, all NFSI personnel plus Louis 18:15 Van drops off personnel at hotel, Mladen and Louis continue to Les Méchins to collect Louis's truck. 19:30 Mladen returns to hotel. All head out for dinner.
Fri. Sept 29	06:20 Van leaves hotel (Mladen, Graeme, John, Felix). Only 1 station remaining to deploy today. 06:40 First message received from Apollo beacon. 09:10 On station at LSL01. Deployed AQU-0E62 09:20 Confirmed OBS at bottom, starting location survey. 09:42 Done location survey, starting transit back to Matane. ETA 12:00 11:55 Boat docked at Matane pier. Starting to unload equipment and empty stillages. Mladen and John head to hotel to collect box truck and Katie. 12:25 Mladen, John and Katie return to Matane pier. Most equipment already unloaded, dunker rinsed with fresh water. A few other things also need rinsing, then loading everything into box truck. 13:00 Kalynic leaving Matane for return transit to Carleton-sur-Mer. 13:15 Van and truck leave Matane pier, head back to hotel. 14:00 Katie in truck at hotel, collecting log files from deck unit, other tidying of equipment to prep for travel back to Halifax. Start transcribing log sheets and other metadata. 15:20 Katie and John looking at AQU-BA61 for troubleshooting. While waiting for some steps, re-arrange equipment in stillages to minimize how much needs to be taken to Dal vs COVE.

<table>
<tr><td></td><td>Try acoustic comms in air. Same behaviour as in the water, MDFT commands respond with a short transmission with no data.
Check serial console during acoustics, power consumption. Wait for write cycle to see what happens.
Undeploy instrument, then redeploy and try acoustics again. Everything working normally after redeploy…
17:40 Tidying up equipment, head out for dinner.</td></tr>
<tr><td>Sat. Sept 30</td><td>07:12 Leaving hotel for travel back to Halifax. John and Graeme in box truck, Mladen, Katie and Felix in van.

Time zone change to ADT at QC-NB border

16:15 Drop off Felix at AirBNB in Dartmouth
16:40 Van arrives at Mladen’s house. Katie picked up to head home.
17:00 Truck drops off Graeme at home. John taking the truck home overnight, will return to COVE/Dal tomorrow to unload.</td></tr>
</table>

3.5 Station Notes

The location of station LSL09 was adjusted prior to leaving the dock on September 26. The original location was deemed to be too far from other stations for reasonable transit times, so it was moved closer to stations LSL08 and LSL07 to balance operational concerns with array coverage. Unfortunately, the new planned location was not recorded, leading to a very large distance between "planned" and actual drop locations in the table below. Actual drop locations are taken from the Boat Tracker log of *Discovery* running on the deck unit, and water depths were obtained from the ship's depth sounder.

Table 3-1: Planned locations and actual OBS drop locations for all stations. The planned location for LSL09 was changed due to long transit time to the original planned drop location.

Station	Launch Time (UTC)	Planned Location		Actual Drop Location			Distance from Planned (km)
		Latitude	Longitude	Latitude	Longitude	Water Depth (m)	
LSL01	2023-09-29 13:10	48.8896	-67.9774	48.8873	-67.9731	314	0.405
LSL02	2023-09-28 18:19	49.0711	-67.7918	49.0701	-67.7888	269	0.245
LSL03	2023-09-28 20:13	48.9712	-67.6182	48.9709	-67.6235	301	0.388
LSL04	2023-09-28 15:23	49.0679	-67.3435	49.0741	-67.3388	323	0.770
LSL05	2023-09-28 13:23	49.2023	-67.1859	49.2137	-67.1987	325	1.572
LSL06	2023-09-27 19:20	49.2028	-66.8545	49.2025	-66.8536	316	0.073
LSL07	2023-09-27 17:13	49.3605	-66.7498	49.3563	-66.7488	298	0.473
LSL08	2023-09-26 17:44	49.3272	-66.495	49.323	-66.4892	306	0.628
LSL09	2023-09-26 19:52	49.5621	-66.4522	49.4459	-66.6253	280	17.975

Seafloor locations were surveyed for all stations using the dunker for a standard 3-point ranging triangulation. Range data were processed using a 3rd party triangulation code package called ob_inst_survey[2], assuming a constant sound velocity of 1500 m/s. Standard errors for all surveys range from 2.5 to 5.0 meters, with a median of 3.6 meters. Survey resolution is limited by the precision of the surface GPS coordinates (0.0001 degrees) and the two-way traveltime measurement (10 ms). Bearings of drift measurements are given in degrees clockwise from North.

[2] Code originally developed by Neville Palmer of GNS Science (New Zealand), modified by NFSI staff. Github repository: https://github.com/nfsi-canada/ob_inst_survey

Table 3-2: OBS drop locations and surveyed seafloor locations.

Station	Drop Location		Surveyed Seafloor Location			Horizontal Drift	
	Latitude	Longitude	Latitude	Longitude	Depth (m)	Distance (m)	Bearing (°)
LSL01	48.8873	-67.9731	48.88748	-67.97293	302.3	23.7	30.9
LSL02	49.0701	-67.7888	49.07008	-67.78943	263.2	46.2	267.7
LSL03	48.9709	-67.6235	48.97202	-67.62263	294.3	139.3	27.0
LSL04	49.0741	-67.3388	49.07362	-67.34102	313.4	170.2	251.6
LSL05	49.2137	-67.1987	49.21267	-67.19813	321.6	122.0	160.3
LSL06	49.2025	-66.8536	49.20290	-66.85277	311.6	75.1	53.7
LSL07	49.3563	-66.7488	49.35603	-66.74908	294.4	36.1	214.7
LSL08	49.323	-66.4892	49.32293	-66.48913	307.2	8.8	146.9
LSL09	49.4459	-66.6253	49.44580	-66.62455	273.2	55.3	101.6

Horizontal drift patterns are quite variable for these stations but tend to be oriented NE-SW along the river, suggesting drift is dominated by tidal currents. The descent pattern of the instrument design is unknown at this time and may also be a significant factor in drift direction and magnitude.

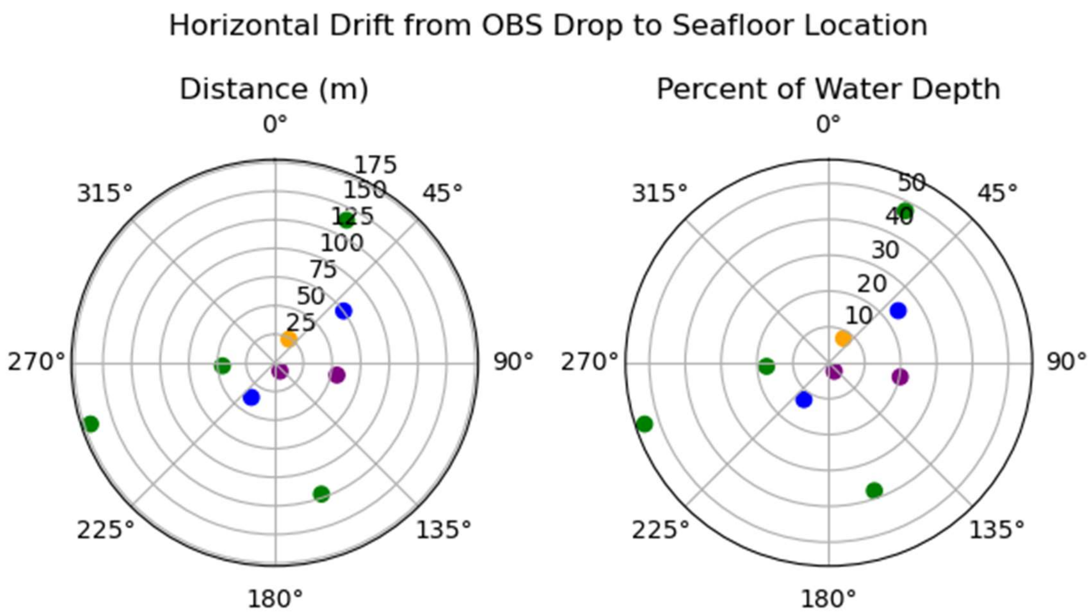


Figure 3-6: Horizontal drift measurements for all stations surveyed, coloured by deployment date. Purple – Sept 26, blue – Sept 27, green – Sept 28, orange – Sept 29.

Instrument AQU-BA61 was deployed at station LSL09 but experienced communication problems once in the water, sending no response to status message requests although it had performed normally in acoustic checks on deck before being put in a software deployed state. Acoustic ranging for the location survey was working normally, so a seafloor location was obtained. As the communication problem prevented us from resetting the backup release timer, however, the instrument surfaced automatically about 1.5 hours after deployment and was recovered. Without spare ballasts, the instrument could not be redeployed. It was offloaded in port for troubleshooting later and station LSL09 had to be dropped from the array. All remaining instruments were checked for the same problem by repeating final acoustic checks on deck after putting the Aquarius into its deployed state. No other instrument showed the same behaviour during this operation.

All instruments are fitted with an Apollo Mono Iridium GPS beacon and an XMB-11k VHF radio beacon. GPS position messages can be viewed through the XeosOnline portal or using the Hermes handheld receiver, and are forwarded to an email alert list of key personnel. All VHF beacons are set to a frequency of 160.725 MHz. The table below lists the instrument serial numbers, acoustic modem information and Apollo Mono GPS beacon serial numbers for all stations which remained on the seafloor.

Table 3-3: List of OBS serial numbers, acoustic modem address and UID, and Apollo beacon serial number for all stations which remained on the seabed (excludes LSL09).

Station	Serial Number	Modem Address	Modem UID	Apollo Mono S/N
LSL01	AQU-0E62	5702	U006AE7	541
LSL02	AQU-4D5C	6009	U007466	535
LSL03	AQU-1A62	5903	U00730D	534
LSL04	AQU-D85B	6110	U007464	538
LSL05	AQU-555C	5810	U007462	532
LSL06	AQU-195D	5803	U00730F	537
LSL07	AQU-F561	6013	U00730C	531
LSL08	AQU-465F	5309	U00746B	528

Four broadband hydrophones (High Tech model HTI-04-PCA/ULF) were available for use in this deployment, with three different gain settings. These were installed on the westernmost stations, as listed in the table below.

Table 4: Hydrophone serial numbers and gain settings, as installed at stations LSL01 through LSL04. All hydrophones are model HTI-04-PCA/ULF manufactured by High Tech Inc.

Station	Hydrophone S/N	Hydrophone Sensitivity (dB re 1 V/µPa)
LSL01	1235127	-190 (low)
LSL02	1235126	-174 (mid)
LSL03	1235075	-146 (high)
LSL04	1235125	-174 (mid)

3.6 Vessel Track

GPS coordinates of the ship track were recorded using the Boat Tracker function in *Discovery* software running on the deck unit. Coordinates are obtained from the Time Machine in the deck unit, connected to a standard GPS antenna mounted on the ship's railing. The following figure shows the track recorded for each day's operations. Some days the tracker was started or stopped during the initial or final transit of the day, respectively, rather than in port; track lines have been extended to the relevant pier in these cases for illustrative purposes.

Operations began from Petite-Tourelle near the east end of the array on September 26, deploying at LSL08 and LSL09 in moderately choppy seas, with subsequent recovery at LSL09 due to instrument malfunction. The boat returned to Petite-Tourelle for the first night. September 27 we proceeded from Petite-Tourelle to deployments at LSL07 and LSL06, and docked at Les Méchins for the night. September 28 we set out for deployments at LSL05, LSL04, LSL02 and LSL03, docking in Matane for the final night. September 29 we deployed at LSL01 and then returned to Matane for demobilization.

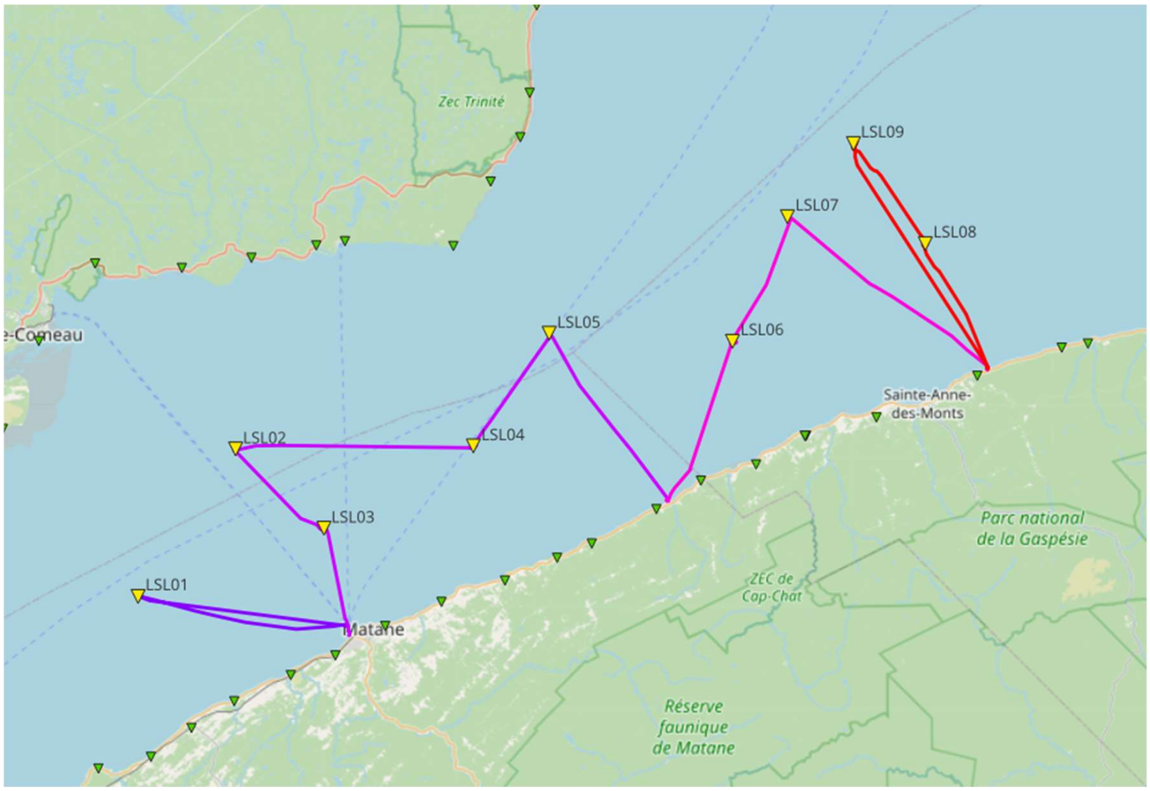


Figure 3-7: Boat track for September 26-29, 2023. Tracks are coloured sequentially by date, red (Sept 26) through purple (Sept 29).

3.7 Demobilization

The vessel returned to the pier in Matane just before noon on September 29 after completing the final deployment. NFSI equipment and stillage boxes were removed from the boat using the knuckle crane located at the dock. The dunker and cables were rinsed with fresh water before being packed for transport. Toolboxes and accessory equipment were loaded into empty stillage boxes, and all stillages and the pallet jack were loaded into the box truck and secured. Without the OBS instruments, the weight limit of the truck was no longer a concern.

NFSI technicians performed troubleshooting for AQU-BA61 which was deployed and recovered at station LSL09 later the same afternoon. Testing indicated the data acquisition system was functioning normally, but the acoustic modem was unable to wake up the main computer to retrieve status information. After undeploying the instrument and then putting it back into its deployed state, acoustic communication in air functioned normally with successful status messages. We are following up with the manufacturer about this behaviour, but it is possible to detect the communication issue on deck and appears to be possible to fix by rebooting the instrument. An additional test has been added to our deck procedure to address this issue.

3.8 Operational Summary

Vessel	Kalynic
Mobilization start date	Sept 25, 2023
Cruise start date	Sept 26, 2023
Cruise end date	Sept 29, 2023
Demobilization end date	Sept 30, 2023
Onboarding port	Petite-Tourelle, QC
Overnight ports	Sept 26 – Petite-Tourelle, QC Sept 27 – Les Méchins, QC Sept 28 – Matane, QC
Offboarding port	Matane, QC
OBS deployed	9
OBS positioned	9
OBS recovered	1
VHF beacon frequency	160.725 MHz
Long-term backup release date	September 1, 2024

4.0 Discussion

While only 8 instruments were successfully deployed on this cruise rather than the 14 originally planned, this outcome must be weighed relative to the adversities that arose in the preceding weeks, which came close to forcing cancellation of the deployments altogether.

Many aspects of this operation were also new to NFSI, differing significantly from cruises on large research vessels for deep water offshore projects that we more commonly undertake. This presented challenges, but also valuable learning opportunities such as how to deploy from a small fishing vessel, mobilizing from small generally unattended fishing ports in Gaspésie, deployment in an estuary environment with tidal currents, marine operation coordination with land support, and dealing with regulations around transport of dangerous goods by road. Although requiring operational resourcefulness and adaptability from both NFSI staff and *Kalynic's* crew, these challenges proved manageable. They led to changes in our pre-deployment instrument preparation and testing procedures which have benefitted subsequent operations, and instilled confidence in our ability to carry out this sort of operation going forward.

Other than the reduced number of instruments, the main shortcoming at a technical level was the lack of hydrophones on half of the instruments, inappropriate gain settings on the hydrophones that were available, and unavailability of a faster (1kHz) logging rate on the hydrophone channel which had been promised by Güralp many months before but didn't materialize. This will unfortunately compromise the whale tracking objective of the deployment, but will not impact earthquake detection. We are working with Güralp to get a new generation of hydrophones as well as firmware modifications to address these issues.

The instruments deployed are scheduled to remain on the seafloor collecting data until ice breakup in the spring of 2024, with recovery planned in early May.

5.0 Lessons Learned & Best Practices

Following each of its field operations, NFSI reviews its performance to identify problems, lessons learned and areas for improvement for future operations. Key points identified from the NFSI-004-2023-01 cruise were as follows:

1. Weather concerns during the height of the North Atlantic hurricane season (August to October): Nova Scotia commonly experiences significant impacts from major hurricanes in the North Atlantic in late summer and early fall. Hurricane Lee passed through Nova Scotia and Gaspésie the weekend we were scheduled to start operations. We were already aware of this issue following the impact of Hurricane Fiona on a 2022 mobilization. Large-scale climate modeling by experts in the field suggests the Atlantic hurricane season will include more and stronger storms compared to historical averages. For future projects, September operations in Atlantic Canada should be treated as high risk for weather-related delays and include appropriate contingency plans.

2. Weight limit for road transport of Aquarius BOBS: A standard Nova Scotia Class 5 driver's license allows the licensee to operate a vehicle with gross vehicle weight of up to 14,000 kg. Most trucks capable of carrying a significant number of OBS weigh greater than 8,000 kg when empty, and the vehicle weight is not always provided prior to collecting a rented truck. As each OBS in its stillage box with ballast installed weighs 475 kg, this limited the number of instruments we were able to transport in a single load to 9. For deployment of more instruments, other options such as mobilization by sea direct from Halifax (as was the original plan for this project) or commercial transport are preferable.

3. Operating hours for daytime-only field work: Small boat operations need to be carefully planned to maximize use of available daylight and allow a minimum of 8 hours rest in port overnight (plus transit time between the dock and hotel). Due to the last-minute change of port of embarkation, the first two days of this cruise we did not leave port until after 10 AM after a relatively long commute from the hotel (~1.5 hours) and time spent at the dock loading equipment onto the boat (day 1) and performing splash-sensitive preparatory tasks for the instruments to be deployed that day (day 2). This limited the number of instruments that could be deployed on each of those days. As wind and wave conditions were also much calmer in the early morning and evening, but were often challenging in mid-day, the later starts also increased transit times. Planning for future daytime-only operations will include consideration for these tasks.

4. Land support for daytime-only field work: It was very helpful to have a person on land during this operation, especially when we were required to switch hotels partway through the cruise. The

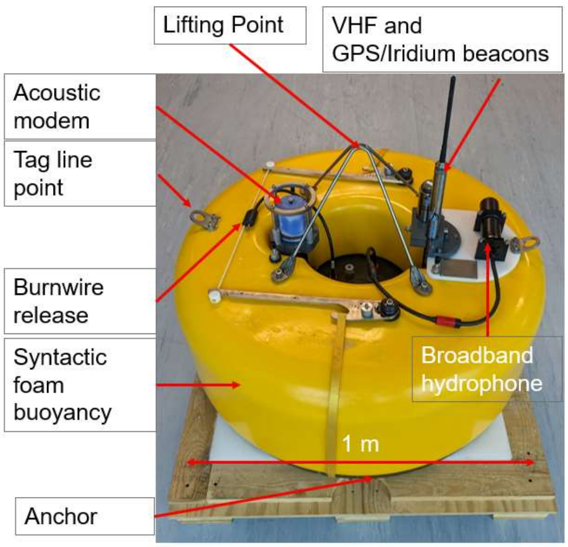
shore person was also able to meet the boat at the various ports of opportunity each evening, allowing for much greater flexibility than we otherwise would have had.

5. OBS preparation is best performed in port to the extent possible. This includes cleaning and greasing O-rings and external electrical connections, and assembling and testing recovery beacons. These tasks demand a clean environment and attention to detail. They are difficult to perform on the deck of a small vessel while underway, due to the motion of the boat and risk of splashes on sensitive electronic components. Final steps involving connectors to the pressure case will generally need to be performed on deck at sea, but these should be minimized and carried out in a sheltered environment to the extent possible. Preference order for possible work locations:
    a. In port prior to departure
    b. Inside the boat's cabin (or dry lab space when available on larger ships)
    c. A sheltered location on deck during calm weather or while the boat is near-stationary
    d. Wherever available space and operational constraints allow, taking appropriate precautions to prevent water ingress
6. Apollo Iridium GPS beacons should be tested well in advance of planned deployments to verify Iridium subscription activation for the beacons and Hermes handheld receiver as well as the function of the XeosOnline portal. On two occasions we were forced to hold station waiting to receive confirmation that the beacon installed on the OBS was indeed working. On the day of deployment, beacons should be activated several hours in advance to ensure they have time to connect to the satellite network, as this can be quite variable.
7. An acoustic communication bug was discovered which prevented the modem from communicating with the main computer board of the Aquarius on one occasion. This can prevent us from receiving status information from the instrument or resetting the backup release timer. Acoustic ranging works normally in this situation, and the acoustic burn command should work. Undeploying and redeploying the instrument appears to reset the link between the modem and the main board.
    a. This appears to be a random occurrence with low probability but has a high impact when it does occur.
    b. Pre-deployment procedures have been modified to detect this problem by repeating final acoustic checks after putting the instrument into a software deployed state.

Appendix A: Equipment Specifications

Aquarius Broadband Ocean Bottom Seismometers

The NFSI Aquarius Ocean Bottom Seismometers (OBS) are broadband devices made by Güralp Systems Ltd. The instruments are typically deployed in free fall mode, released from a surface vessel to sink to the seafloor under the weight of their detachable ballast, and return to the surface for recovery under their own buoyancy when the ballast is released via acoustic command.



Instrument weight 240kg + 90kg anchor
Sink rate ~0.6 m/s; Rise rate ~1.5 m/s

Specification	Number	Research Impact
Number of units	120+1	High resolution and coverage
Max deployment (months)	18	Allows long-term deployments needed for earthquake monitoring
Clock drift (us/day)	<30	Precise time-keeping over long deployments
Seismometer bandwidth	120s – 100Hz	Joint use for earthquake process and structure imaging studies
Dynamic range	24-bit	Able to record broad range of signal amplitudes
Hydrophone bandwidth	100s – 8kHz	Acoustic monitoring of microseismics and seafloor compliance
Communication	Acoustic Modem	Allows real time data to surface from SF instruments
Buyancy	Syntactic foam	Unsinkable once anchor is released

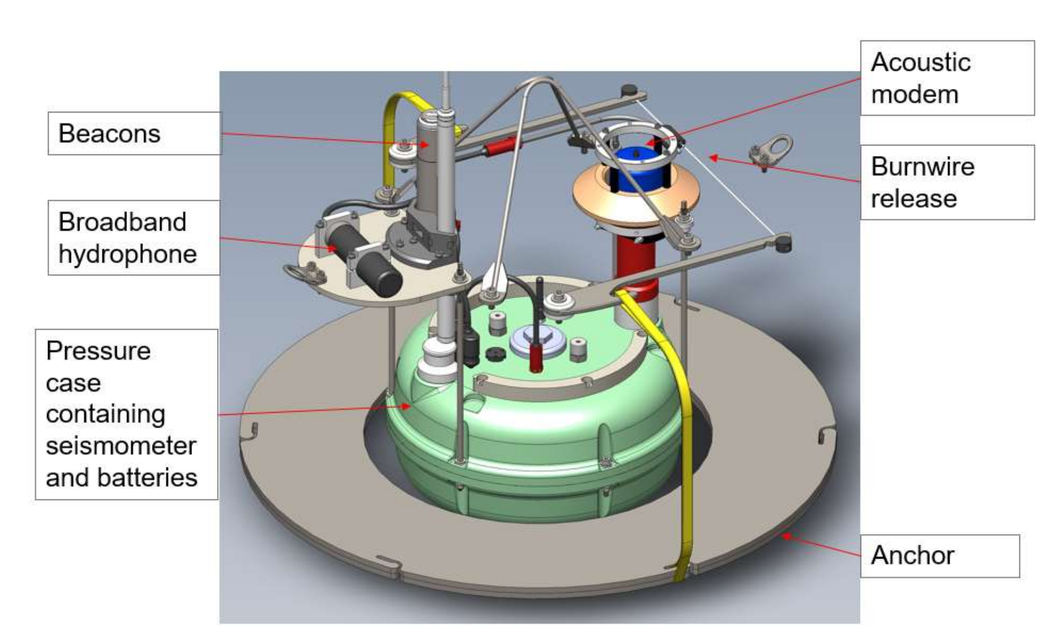


Table A-1: Güralp Aquarius OBS specifications, reflecting NFSI customizations.

Feature	Specification
Seismic sensor	• Broadband triaxial force-feedback sensor • Flat response from 120 s to 100 Hz • Nominal velocity response 2000 V/ms^{-1} • Tilt tolerance +/- 90 deg.
Absolute Pressure Gage	• Keller PA-10L. Accuracy 0.25%
Hydrophone	• High Tech HTI-04-PCA/ULF • Passband 100 s to 8 kHz; • Sensitivities for LSL devices (all dB re 1V/µPa): -146dB (1 sensor), -174dB (2 sensors), -190dB (1 sensor).
Additional Channels & State of Health	• 3-comp digital compass composed of MEMS accelerometer and magnetometer • Temperature, humidity & supply voltage sensors
Data Logger	• Güralp Ultra-Low Power Digitizer board with Certimus computer.
Data Storage & Recording formats	• 128 GB dual redundant flash cards • Data stored in miniSEED format • Metadata stored in dataless SEED, RESP and StationXML format
ADC & Sample Rates	• 24-bit low-power 4 channel delta-sigma • Sample rate typically 250 Hz for seismic channels and 5 Hz for auxiliary sensors
Clock	• Double compensated microprocessor controlled TCXO • Locked to GPS time before each deployment • Uncorrected drift typically < 1 ms/day • Linear drift correction applied post-deployment
Power	• Lithium-Ion battery packs made up of 468 LG INR 18650 MJ1 cells • Total energy of 5954 Wh provides nominal autonomy of 15-18 months on seafloor, depending on application • Charge time approx. 1 hr/month of deployment
Acoustic Communication	• Sonardyne 6G LMF omnidirectional transceiver used for communication and positioning instruments on the seafloor • Used with surface transponder or USBL systems • Communication rates up to 9000 bps
Release Mechanism	• Burnwire triggered by acoustic command, timed release or critical battery level trigger
Recovery Tracking Beacons	• Xeos Apollo Mono Iridium GPS LED Flasher beacon • Xeos XMB-11K VHF beacon
Instrumentation Pressure Case	• 7000 series rolled aluminium, anodized • Pressure rated to 6000 m • Weight: 89 kg in air; 44.6 kg in seawater
Syntactic Foam Flotation	• Weight: 150 kg in air; 86 kg uplift in seawater
Ballast	• 10 mm + 15 mm steel plates • Weight: 89 kg in air, 77.4 kg in seawater
Full Instrument Weight/Buoyancy	• Air weight 239 kg instrument + 89 kg ballast = 328 kg • In-water weight: 44.6 + 77.4 – 86 = 36 kg

	• Buoyancy without ballast: 86 – 44.6 = 41.4 kg
Full Dimensions with Flotation and Ballast	• 1000 mm diameter cylinder • Height to top of buoyancy 459 mm • Height to top of lifting bar 725 mm
Sink/Rise Rate	• Sink rate 0.6 m/s, Ascent rate 1.5 m/s

Recovery Devices

The NFSI Aquarius OBS are equipped with recovery beacons made by Xeos Technologies Inc. These beacons are surface activated and autonomous, providing a margin of safety should the OBS batteries become depleted or the software malfunction. Two types of recovery beacons are used: an XMB-11K VHF beacon and an Apollo Mono Iridium GPS/LED Flasher beacon.

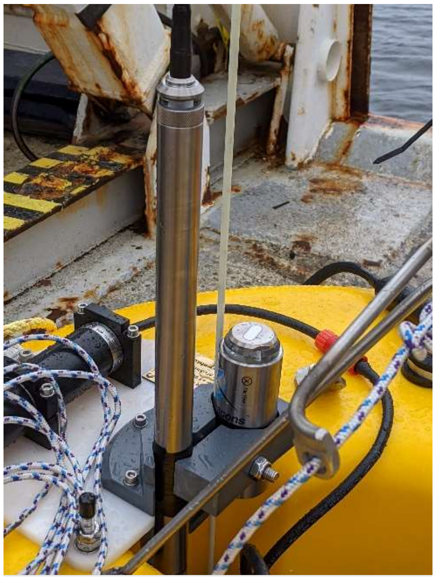


Figure A-1: Recovery devices mounted on OBS. XMB-11k VHF beacon on left, Apollo Mono GPS/LED/Iridium beacon on right.

The XMB-11K emits a VHF radio signal that can be located using a receiver equipped with a directional Yagi antenna to ranges of up to 12 km for a duration of typically 5 days (dependent on pulse length and repetition frequency) after surfacing. There are four preset selectable frequencies for the XMB-11K: 154.585 MHz, 159.480 MHz, 160.725 MHz and 160.785 MHz.

The Apollo Mono transmits its GPS position via Iridium satellite and has an LED flasher to visually locate the instrument at night. For the first hour after surfacing, the Apollo will send positional updates every 10 minutes and activate its flasher, then switch to hourly updates. Instrument positions can be tracked via an online map or with a handheld Xeos Hermes receiver. Positional update frequency and LED activation can be reconfigured remotely through the Iridium link to extend battery life. The Apollo is powered by primary lithium batteries. Communication longevity will depend on update frequency and sea conditions, but with daily updates for a drifting instrument will be more than 1 year.

Positioning System

A Sonardyne Omnidirectional Modem 6 Mini-Dunker LMF LBL and Telemetry Transceiver System Type 8244-3155 was used to communicate with the Aquarius instruments and triangulate their position on the seafloor during the NFSI-004-2023-01 deployments.

The Dunker is operated by lowering it over the side on the end of a cable. It works as an acoustic modem for communication between an Aquarius Deck Unit and instruments on the seafloor or in the water column. By measuring acoustic travel time, it can also provide range measurements to a seafloor instrument, but not direction. Ranging is used to position instruments with acoustic triangulation by moving the ship to measurement points overhead that provide geometric constraint.

Table A-2: Sonardyne Modem 6 Mini-Dunker Type 8244-3155 Telemetry Transceiver System Specifications

Feature[1]	
Transceiver depth rating	3,000 m
Operating Frequencies	LMF (14-19 kHz)
Transducer Beam Shape	Omni-directional
Transmit Source Level (dB re 1 μPa @ 1 m)	187-190 dB
Tone Equivalent Energy (TEE)	193-196 dB
Range Precision	Better than 15 mm

As listed on Sonardyne datasheet

Appendix B: Vessel Technical Specifications

Vessel Name: Kalynic; Official Number: 814715
Owner: Les Pêcheries L. Henry Inc., 1641 Boulevard Perron, Carleton-sur-Mer, QC G0C 1J0

<u>General Operation</u> Vessel Class: Fishing Year Built: 1991 Port of Registry: Gaspé Home Region: Eastern Region Home Port: Carleton-sur-Mer, QC	<u>Specifications</u> Length (m): 10.79 Breadth (m): 4.97 Draft (m): 1.92 Gross Tonnage (t): 29.80 Net Tonnage (t): 13.96
<u>Crewing Regime</u> Crew: 2	Propulsion Power (HP): 250 Maximum Speed (kts): 8