Beaufort Marine Hazards

2013 Field Expedition Report

CCGS Sir Wilfrid Laurier

September 25 – October 16, 2013

Institute of Ocean Sciences Cruise 2013-22

Pacific Geoscience Centre Cruise 2013-005

Humfrey Melling – Chief Scientist

Supported by

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Monterey Bay Aquarium Research Institute (MBARI)

Oil Exploration Licence Holders - Beaufort Sea

Cover picture (courtesy of Dave Caress, MBARI)**:**

MBARI's Dorado-class AUV is lifted back onto the foredeck of CCGS Sir Wilfrid Laurier during the Leg-3 science programme. The AUV was used for high resolution mapping of seabed features using multi-beam, side-scan and bottom-penetrating sonar. Overnight mapping missions were 12-15 hours in duration, with the AUV recovered at sunrise.

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2013 Field Expedition Report[1]

Arctic Patrol Leg #3, CCGS Sir Wilfrid Laurier: Cambridge Bay to Bering Strait

September 25 – October 16, 2013

Personnel

10 scientists embarked at Cambridge Bay on September 24, via CCG crew-change flight from Victoria:

Humfrey Melling, Ron Lindsay, Jo Poole from DFO at the Institute of Ocean Sciences, Sidney BC

Peter Neelands, Greg Middleton, from the Geological Survey of Canada, Sidney BC

Charles Paull, Dale Graves, Dave Caress, Hans Thonas, from MBARI, Santa Cruz CA

Kira Aβhoff from MARUM, Bremen Germany

4 scientists embarked at Kugluktuk on September 26, via commercial carrier and Air Tindi charter flight

Scott Dallimore, from the Geological Survey of Canada, Sidney BC

Chad Kecy, Eric Martin, from MBARI, Santa Cruz CA

Timo Fleischmann from MARUM, Bremen Germany

All but Melling, Lindsay and Poole disembarked via helicopter at Deadhorse AK on October 12

Ron Lindsay disembarked at Dutch Harbor AK on October 20

Humfrey Melling and Jo Poole disembarked at Victoria on October 27

Overview

The Institute of Ocean Sciences (DFO) is engaged in long-term collaborative studies in the Pacific sector of the Arctic Ocean. The on-going focus is monitoring of the physical properties of sea ice and the upper-ocean waters. The activity addresses issues of environmental protection, environmental hazard, maritime safety, ocean variability and climate change. Our goal is to identify and describe changes in the Arctic marine environment, and subsequently to understand why changes are occurring and whether they will continue into the future.

The core programme is supplemented to a varying degree each year by activities proposed by collaborators in areas of overlapping scientific interest. Such collaborative activities increase the scientific value of the expedition, contribute to the critical mass needed to justify the effort in staging it, facilitate the efficient use of ship time and spread the logistic risk associated with inclement ice and weather over a larger funding base.

The supplementary programme for Sir Wilfrid Laurier's Leg 3 in 2013 had three components:

1. Collaboration with Natural Resources Canada and Monterey Bay Aquarium Research Institute to assess the hazard of gas hydrates to oil drilling and production on the Mackenzie shelf and slope. This study will exploit a variety of techniques to characterize the marine setting and geology of the outer shelf and slope. Geo-hazards associated with degrading permafrost, gas hydrates and terrain instability are of special interest.
2. Collaboration with USA NOAA in the maintenance of an ocean observatory on the Chukchi Plateau, now completing its tenth year. The observatory monitors sea ice thickness, ice drift, ocean current, temperature and salinity, vocalization of marine mammals and zooplankton abundance.
3. On behalf of ArcticNet (Université Laval), the task of recovering five oceanographic moorings from the Beaufort Sea was added to the programme in mid-September. The addition was occasioned the

[1] Report prepared by Humfrey Melling (DFO), Scott Dallimore (NRCan), Charlie Paull (MBARI)

cancellation of CCGS Amundsen's planned activities in the Beaufort Sea following the crash of her helicopter with three lives lost. The science schedule was extended by two days to accommodate this new activity.

The expedition was lead by Fisheries and Oceans Canada from the Institute of Ocean Sciences. It embodies the interests and collaboration of several other organizations:

- Canadian Programme of Energy Research and Development: Northern Regulatory Research Programme: Changing sea ice constraints on hydrocarbon development in Canada's Arctic (NRCan PERD B21.002)
- Canadian Programme of Energy Research and Development: Regional assessment of geo-hazards related to deep water hydrocarbon development, Beaufort Sea outer shelf/upper slope (NRCan PERD B21.003)
- Geological Survey of Canada – Pacific (Scott Dallimore): Marine geo-hazards
- Oil Exploration Licence Holders - Beaufort Sea outer shelf & slope
- Monterey Bay Aquarium Research Institute, California (Charlie Paull): Marine gas hydrates
- US Army Cold regions Research Engineering Laboratory (CRREL: Dr Jackie Richter-Menge) and US National Oceanic and Atmospheric Administration (NOAA: Drs Jim Overland, Sue Moore): Arctic ice thickness monitoring (AIM), ice-mass balance and year-round marine-mammal monitoring
- ArcticNet (Université Laval, University of Manitoba, Golder Associates: Drs Dave Barber, Phil Osborne): Ocean monitoring within Beaufort oil-lease blocks (BREA-AANDC)

Objectives

Recovery, servicing and re-deployment of internally recording instruments at ocean observatories

We planned to recover oceanographic instruments and internally recorded data from sub-surface moorings which had been operational for 1-2 years. The instruments measure ice thickness, ice ridging, ice drift, storm waves, storm surge, ocean current, temperature, salinity, ambient sound, acoustic back-scatter from plankton and sedimentation. There were 14 moorings for recovery during this leg (3 of about 700-m length; others less than 200 m) and 8 for deployment.

Geological investigation of distinctive seafloor features on the Beaufort outer shelf and slope

We planned exploration of distinctive features discovered via seabed mapping using multi-beam sonar during the last few years: slope-instability features, submarine slides, conical mounds, hollows and pits, circular expulsion features, sinuous ridges etc. Selected features were to be mapped at very high resolution using multi-beam, side-scan and nadir-pointing chirp sonar carried on an autonomous under-water vehicle (AUV). The new maps were then to guide: a) video reconnaissance and seabed sampling by tethered remote operating vehicle (ROV); b) ship-based sediment characterization by corer, cone-penetrometer and geothermal gradient probe. Plans included the use of ship-based echo sounders with chirp technology at 12 and 3.5 kHz for shallow seismic visualization. Improved geological understanding of these apparently dynamic features will advance knowledge of geological hazards to oil development in the area.

Canada's Three Oceans

Continuous measurements of surface water along the ship's path are to be supplemented by surface-to-seabed profiles at selected locations as opportunities arise. Surface water pumped from a sea bay to the main lab will be measured continuously (temperature, salinity, chlorophyll fluorescence). The CTD probe with added sensors for dissolved oxygen, light transparency and chlorophyll fluorescence will be used to measure ocean profiles, mainly at the sites of moorings. This C3O activity was initiated in the International Polar Year (2007-08). It exploits automated measurement systems on CCG icebreakers as a cost-effective means of monitoring ocean conditions in the NW Atlantic, the Arctic and the NE Pacific. Sir Wilfrid Laurier provides this information between Victoria and the south central Canadian Archipelago in July-August and along the return from the Arctic in September-October.

Ocean observatories

Observations by autonomous instruments on oceanographic moorings provide continuous year-round ocean data that complement the detailed but short-lived surveys conducted from ships. The moorings enable affordable long-term and continuous monitoring of the seas surrounding Arctic Canada.

DFO's long-term sites (ocean observatories) are on the Mackenzie shelf north of the Delta and on the Chukchi Plateau. Activity this year also included the recovery of recently established ocean observatories on the Beaufort continental slope, supported by Aboriginal Affairs and Northern Development Canada as part of the Beaufort Region Environmental Assessment (BREA). All installations enhance the multi-national Arctic Ice Monitoring Project (AIM), active under the umbrella of the Climate and Cryosphere Study and the International Arctic Ocean Observing System, sponsored by the WCRP (World Climate Research Program) and the International Arctic Science Committee (IASC).

Through careful choice of instruments for moorings we are acquiring intriguing and ecosystem-relevant views of the polar ocean at times when humans cannot be there. Upward-looking sonar at the top of each mooring measures ice thickness and topography, revealing the presence of ridges, level ice and ecologically important leads; during the summer months, the sonar activities an interleaved second mode to measure storm waves and surges (important to ocean mixing, to safety on shore and at sea). Doppler sonar positioned near the seabed measures ice drift and ocean current at all depths, revealing opening and closing of the flaw lead in winter and the upwelling of nutrient rich water into the photic zone. The strength of the echoes received by Doppler sonar reveals the ever changing distribution of zooplankton in the water column. Ambient sound recorders provide continuous recordings of sounds from marine mammals (e.g. bowhead, beluga, bearded seal, walrus), human activity (e.g. shipping, distant seismic survey) and natural processes (ice fracture, ridge building, wind waves, blowing snow, seabed gas venting). Sediment traps sample the rain of settling particles, some of which are organic material linked to biological processes and others which are terrigenous matter supplied via erosion from river banks, shorelines and the seabed. Conventional sensors for seawater temperature and salinity revealed the seasonal cycles in shelf-water properties driven by heating, cooling, freezing and weather events.

The oceanographic moorings comprising BREA's ocean observatories were all long taut-line assemblies, with in-line buoyancy and steel deadweight anchors. The instruments supported by these moorings at various depths in the water column include: Ice Profiling Sonar (IPS) at 60-m to measure ice draft, 75, 150 and 300 kHz ADCP at intermediate depths to measure ice velocity and ocean current profiles, Nortek Aquadopp DW (AQD) current meters to measure current below 500-m depth, RBR Brancker XR420 conductivity-temperature loggers, Technicap PPS 3/3-24S 24-cup sediment traps at mid-depths, between the IPS & LR-ADCP at BR-A, BR-G & BR-1 and tandem acoustic transponding releases (ORE CARTs) at the bottom of each mooring for location and recovery.

Study of geological hazards beneath the Beaufort Sea

With plans imminent for exploratory hydrocarbon drilling on the outer shelf and slope of the Beaufort Sea, it is important to identify and understand the offshore geological hazards that may constrain these plans.

The outer shelf is underlain by thick terrestrial permafrost which has been flooded by relatively warm seawater via rising sea level since the Ice Age. The permafrost layer tapers out at about 100-m depth, just past the shelf break, because deeper areas remained flooded by relatively warm seawater even during the Ice Age.

Gas hydrates are ices wherein some of the water molecules (H_2O) in the crystal have been replaced by methane (CH_4), or occasionally by ethane, propane, butane, etc. Gas hydrates are unstable at normal atmospheric pressure and temperature, decomposing spontaneously into gas and water. They are solid at higher pressure and/or lower temperature.

Gas hydrates exist beneath the Beaufort Sea in two locales: marine gas hydrates occur within sediments of the slope and basin where pressure exceeds about 27 bar (water deeper than 270 m); permafrost gas hydrates are possible within or beneath frozen sediments in water shallower than about 100 m, where the seabed was exposed to cold air when sea level was lower during the Ice Age.

Warming and possible thawing of the permafrost consequent to post-glacial flooding may have weakened surface sediment and caused the subsidence, slope failure and release of free gas that have been observed. Escaping gas may have created wide (1 km) circular features revealed on the seabed by sonar.

Field studies, including those from CCGS Sir Wilfrid Laurier in 2003, 2010 and 2012, have documented the escape of methane from the seabed of the outer shelf and slope. Gas venting has been observed from pingo-like features (PLFs) on the shelf, from an area of large landslides at top of the continental slope near 100-m depth and from conical features on the upper slope. We propose that degrading permafrost and gas hydrates liberate gas and pore water that reduce the strength of subsurface sediments, leading to seabed instability.

The permafrost and gas hydrates component of the Laurier's science programme this autumn will study methane seeps and suspected glacio-marine features on the Beaufort seabed and their relationship to sub-sea permafrost, buried gas hydrates and seabed terrain features and instability at various depths. Documentation of possible unique biological communities at vent sites and on glacial till is a valuable incidental benefit.

The tools of investigation are: multi-beam, side-scan and chirp sonar on an AUV for high resolution mapping, HD video, a manipulation arm and push-coring carousel on an ROV for seabed reconnaissance, geological characterization, push coring & sampling, drop probes for measuring geothermal heat flux and sediment strength, piston/gravity coring equipment for collecting sediment, a grab for collecting large volumes of surficial sediment, ship-mounted 3.5 and 12-kHz sonar for shallow seismic surveys

Ultimately, the project advises the oil and gas regulatory process concerning marine geological hazards for drilling and production by addressing the following concerns on the outer shelf and slope:

- What is the regional geological context of geo-hazards?
- What causes large-scale submarine landslides? What is their age?
- What causes seabed deformation on various scales? How active are the features observed?
- Where did surficial sediments originate? What is their state of consolidation and pressure? How old are they?

Completed tasks

The maps on the following two pages summarize the ship's activity within the Beaufort and Chukchi Seas. The dashed line is the ship's track; symbols mark work sites.

The following list summarizes our activities and accomplishments:

- 8 moorings comprising DFO's Beaufort long-term observatory were recovered after a year at sea, all instruments with a complete data record
- 1 mooring which is the DFO-NOAA Chukchi long-term observatory was recovered after 2 years at sea, with all expected data
- 5 moorings comprising BREA's new Beaufort observatory were recovered after a year at sea
- 8 short oceanographic moorings were deployed to sustain DFO's long-term observatories programme in the Beaufort and Chukchi Seas
- 12 CTD casts were completed, principally at sites of oceanographic moorings, measuring pressure, temperature, conductivity, dissolved oxygen, light transmission and chlorophyll fluorescence.
- Measurements of salinity, temperature and chlorophyll fluorescence in surface water drawn from a sea-bay, at 5-second intervals along the science cruise track (20 days), and continuing on to Victoria from the 75ºN on the Chukchi Plateau via Dutch Harbor AK (12 days)
- 8 missions by the AUV, completing 5 mapping surveys
- 16 successful ROV dives at 12 sites of interest, in water up to 1000 m deep

- 62 drops of the gravity corer plus geothermal sensors and 3 drops of the piston corer, at 11 sites of interest
- 42 drops of the cone penetrometer for sediment strength, at coring sites less than 500-m deep.
- Widespread operation of the ship-mounted 3.5 and 12 kHz chirp sonar for shallow seismic survey, including grid surveys at Garry Knolls and at a pingo-like feature north-west of Kopanoar.

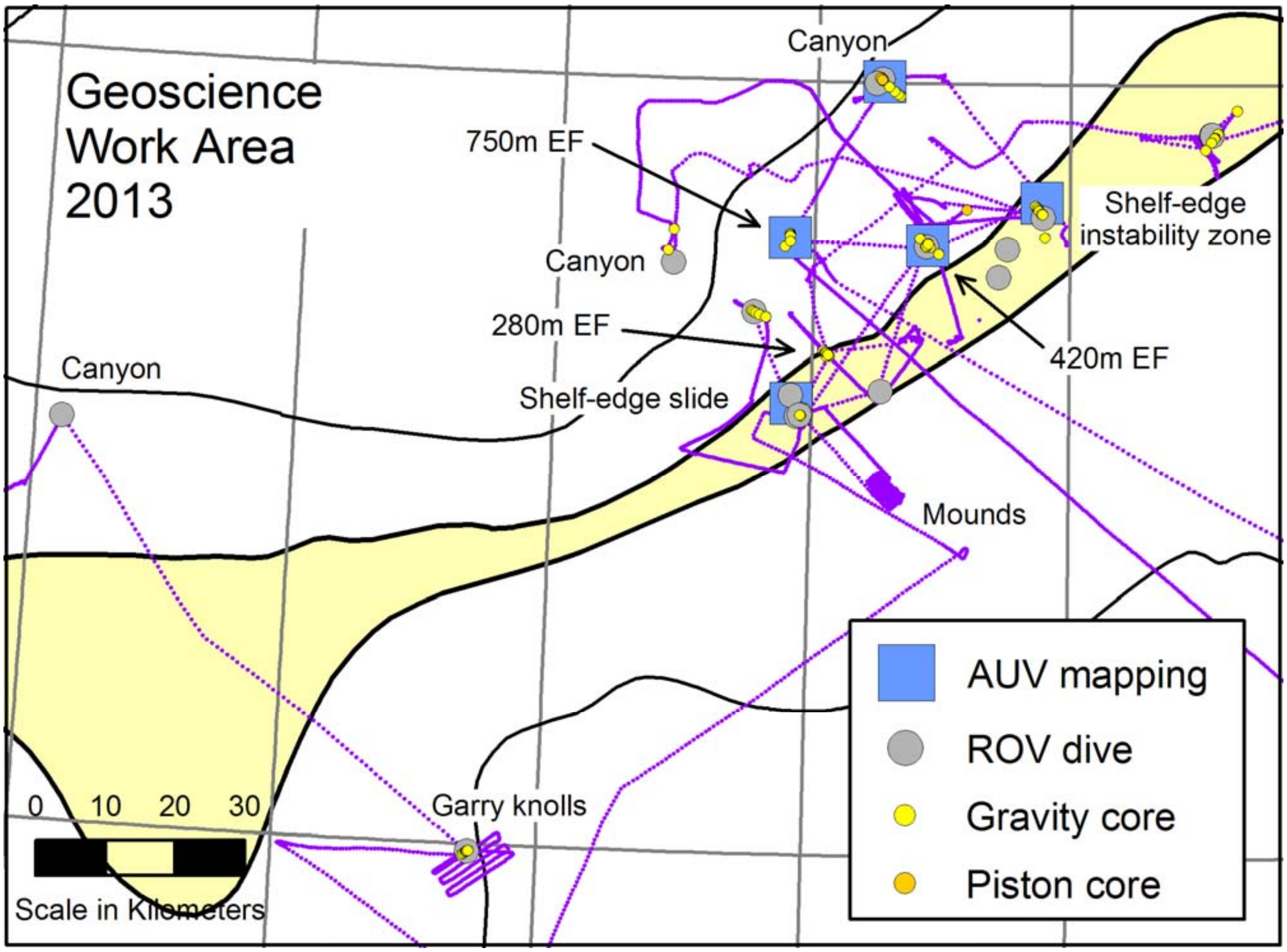
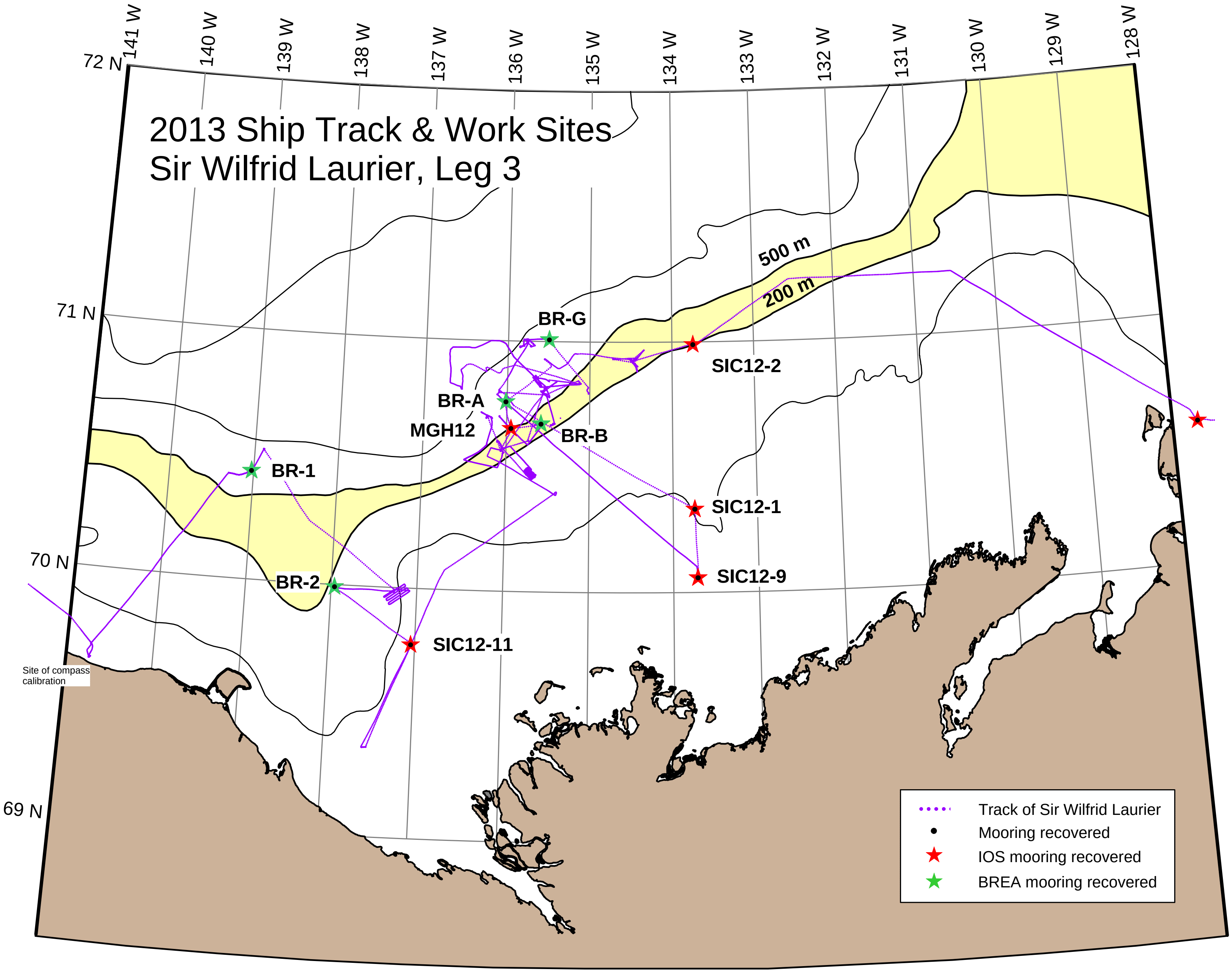


Figure 1. Geoscience work area during Leg 3 of Laurier's 2013 Arctic Patrol. The ship's track is plotted with purple dots at equal increments of time. The locations of seabed mapping by the AUV are indicated schematically using blue squares. Other symbols mark the locations of ROV dives and coring. The gravity corer was fitted with thermistors for measurement of sediment temperature. A cone penetrometer was dropped at those coring sites with water depth less than 500 m.


2013 Ship Track & Work Sites
Sir Wilfrid Laurier, Leg 3
141 W
140 W
139 W
138 W
137 W
136 W
135 W
134 W
133 W
132 W
131 W
130 W
129 W
128 W
72 N
71 N
70 N
69 N
500 m
200 m
BR-G
SIC12-2
BR-A
MGH12
BR-B
BR-1
SIC12-1
SIC12-9
BR-2
SIC12-11
Site of compass calibration
Track of Sir Wilfrid Laurier
Mooring recovered
IOS mooring recovered
BREA mooring recovered

Activities of the science programme

Observations while underway

Pumped seawater system

Continuous measurements of basic ocean properties at about 2-m depth were acquired using a thermo-salinograph with electronic sensors to measure the properties of water pumped from a sea bay. These measurements provided basic information on ocean surface waters, allowing more detailed and diverse site-specific observations to be placed in a regional context.

The sensors (Sea Bird SBE45/SBE38 for temperature, salinity and chlorophyll fluorescence) and the computers for logging data on through-flowing seawater were installed against the aft wall in the main science laboratory. The exception was a thermistor at the seawater intake to measure temperature before water was heated by contact with ship's machinery.

Water was piped to the lab via a pump in the engine room. The flow rate through the system was adjusted to about 4.8 litres per minute; slower flows do not properly flush the fluorescence sensor. The time delay between the entry of water at the sea bay and its arrival at the manifold in the science lab is critical to the accurate mapping of small ocean features. The delay was estimated in 2010 to be 30-60 seconds. The warming of water between the sea bay and the sensor in the engine room is not known; that between the engine room and the lab is about 0.25ºC.

From time to time we withdrew samples of seawater via the manifold in the science lab. These were stored and transported to IOS for salinity analysis.

Digital recording of acoustic backscatter (12 kHz)

A Knudsen 320M sounder operating at 12 kHz on loan from CHS (Andrew Leyzack) was installed on Sir Wilfrid Laurier for the Leg-3 science programme. The 1-kW rating and low frequency of this sounder provided the capability for shallow seismic penetration via Laurier's hull-mounted 12-kHz sonar transducer (Simrad Model 12-16.60: 16º beam-width). It was operated successfully in chirp mode despite the high Q (9.2) of the Simrad transducer and consequent narrow bandwidth (10%).

Knudsen SounderSuite software (v. 1.82) was used to control the sounder and record the envelope-detected echo on the computer disk drive. Tight VNC software (www.tightvnc.com) was installed on the primary computer in the rear science lab (boat deck) and a secondary computer in the foredeck "green container", enabling echogram display and control of the sounder from either work station.

There was occasional cross-talk with the 3.5 kHz seismic sonar but interference from the ship's unsynchronized 50 and 200 kHz sounders was not noticed. Ship's speed less than 7 knots gave the best results; data quality varied with sea state and ship's heading relative to the weather. The imaging of geologic sub-bottom structure by this sonar was very good in chirp mode (not good in pulse mode). We were unable to detect gas bubbles from vents at the seabed using the setup optimal for seismic.

This sounder was operated in tandem with the Knudsen Model 3260 chirp sonar (below).

Sub-bottom profiling (3.5 kHz chirp) via a ship-mounted transducer array

A Knudsen Model 3260 chirp sonar driving a ship-mounted transducer array was used this year in preference to the Huntec towed shallow seismic system used in 2012.

An array of twelve ORE 137D transducers was installed on Sir Wilfrid Laurier in 2003. The transducers were placed against the inside of the hull plating in a 4x3 arrangement, enclosed within an oil-filled compartment pressurized to 1-2 bars to inhibit cavitation (formation of bubbles) at the transducer's face during pinging The transducers (each 50 ohm) were wired in banks of 6-in-parallel wired in series, for an array impedance of 67 ohms. The beam-width of the array ranged between 55º and 30º as frequency swept from 3.5-7 kHz.

The signal cable from the array was routed via the foc'sle into the green lab container on the foredeck where the Knudsen Model 3260 deck unit and control computer were installed. Tight VNC software was installed on the primary computer and a secondary computer in the rear science lab, enabling echogram display and control of the sounder from either work station

The sub-bottom penetration of this sonar was greater than at 12 kHz but the imaging quality of sub-bottom structure was less good, perhaps because of the wider beam-width. The best data were acquired with low sea state and ship speed. Clouds of air bubbles passing under the hull at higher speed and sea state caused periodic loss of signal.

CTD and rosette casts

The CTD-rosette was deployed to measure vertical profiles of temperature and salinity (and other variables) at the site of each mooring. In situations where the delay between recovery and redeployment exceeded 12 hours, a second CTD profile was taken at the mooring site. The time required to complete a CTD cast to 1000 m was about 50 minutes, including ship positioning, rosette launch and recovery.

The CTD (Sea Bird SBE9/SBE11) and rosette sampler (24x10-litre Model 1010 Niskin bottles, General Oceanics) was operated from the boom roughly amidships on the boat deck (port side). It was lowered on steel-jacketed conducting cable by the Hawboldt winch (under manual or automatic wire-speed control). The rosette was lowered to within 5 m of the seabed (distance measured by sonar altimeter).

The CTD provided continuous profiles of temperature, salinity, dissolved oxygen, light transmission and chlorophyll fluorescence. The sampling rosette was not used to collect water samples this year.

We use the CTD profile to calculate an accurate depth profile of sound speed, essential to the accurate calibration of ice thickness derived by sonar, and for in situ calibration of CT recorders position on moorings.

Sediment from the seabed and its temperature

Samples of sediment were collected via two methods, gravity coring and piston coring. Sites for coring were selected on the bases of prior study, the new high-resolution maps from the AUV and reconnaissance dives by the ROV.

Although an IKU grab was shipped in 2013 to collect bulk samples of surficial sediment, its use was not necessary. The equipping of the ROV with a manipulator arm, collection basket and push-core device enabled it to examine and collect specific samples of interest (tube worms, shells, carbonate concretions, coarse granular material, surface sediment).

The collection of long sediment cores was variously accomplished using a short gravity corer, or using a gravity corer in tandem with a long piston corer. The gravity corer was lowered and raised using the smaller hydro-winch on the port side; it was deployed from the A-frame. With the ship's main derrick (and winch-man) not needed, the gravity corer could be used after the deck-crew's shift ended at 7 pm.

For most drops, 5 precise temperature recorders were secured to the core barrel using hose clamps. The core barrel was left embedded in the seafloor for 7 minutes to allow these sensors to reach thermal equilibrium with the sediment – keeping the watch officer busy with station keeping. The equilibrated temperatures documented site-to-site variation in seabed temperature and permit estimates of upward geothermal heat flux.

MBARI brought on board an ultra-short-baseline (USBL) track-point system for navigating the ROV at the seabed. By equipping the lower end of the coring wire with a transponder, it was possible to know the exact geographic position of the corer at depth (modified from the ship's GPS location by drift and wire dynamics). This technology allowed the precise positioning of the corer within small features of interest at the seabed. Although this capability was not implemented until near the end of the science programme, Such capability is invaluable for the geological studies of interest in the Beaufort Sea.

The piston coring apparatus (Benthos Systems, 1-tonne core head) was deployed via the derrick and the A-frame on the foredeck of Sir Wilfrid Laurier. A 50-HP work winch mounted on the port side was used to lower the apparatus on ½" steel wire to the seabed.

Because the piston corer was stowed fore-aft beside the hatch in 2012, it had to be lifted over the A-frame to be deployed. This was a potentially dangerous operation for such a heavy and cumbersome object. For 2013 brackets were welded onto the A-frame supports outboard of the A-frame, so that the core barrel could be stowed between the A-frame and the rail, with rolling against the A-frame's hydraulic rams. Since the corer need be lifted less than a metre above this stowing position to clear the rail, the safety of the deploying the piston corer was greatly improved (see picture on the preceding page).

A 10-foot workshop container on the port side of the well deck was the staging area for coring activity – storage for core liner, recently acquired cores, tools, supplies – and a work area for the chop saw, liner splitter, temperature measurements, pore-water sampling, etc. The container was equipped with hazard sensors for methane and hydrogen sulphide.

Samples of pore water were withdrawn at intervals from all collected cores using rhyzome samplers. The small holes drilled in the liner for extractions were sealed and the core sections transferred to cool storage for transport back to Victoria. Post-field phase analyses includes sedimentology (particle size, composition), chemistry of pore water and pore gas, isotopic composition of material and radiocarbon dating of macrofossils.

The gravity corer acquired shorter columns of near-surface sediment for classification and analysis. Conditions varied from relatively hard shelf sediment to soft mud in expulsion features, allowing penetration of 1-4 m.

Cores were collected in water as deep as 1000 m, requiring about 60 minutes. The time to extract a collected core and prepare the apparatus was about 15 minutes (more than 60 minutes for the piston corer).

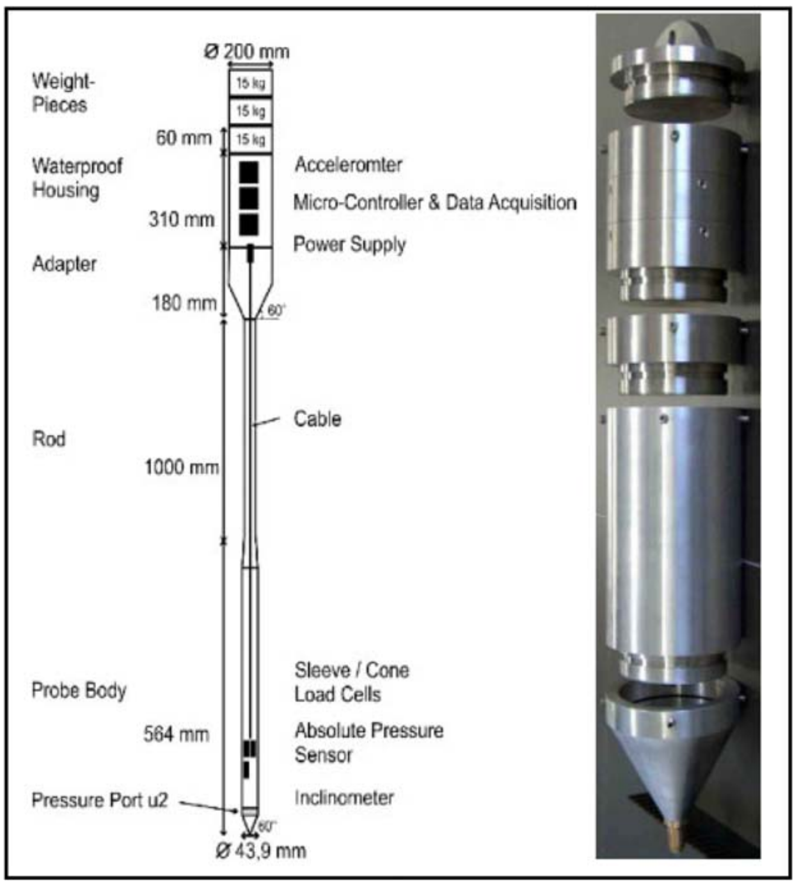


Figure 2. A cone penetrometer was used to measure the geotechnical properties (shear strength, pore pressure) of near-surface sediment.

Geotechnical properties of sediments

Geotechnical properties of the upper few metres of sediment were measured at points along transects using a cone penetrometer CPT). The CPT probe is a lowered instrument package designed to penetrate up to 6 m into the seabed while measuring the in situ strength and pore pressure of the sediment.

We used a model designed and built by Marine Geotechnics in Bremen Germany (www.rcom.marum.de). This model has 20-cm cylindrical pressure housing about a metre in length, a 0.5-6.5 m lance that enters the seabed and an overall weight between 40 and 170 kg; we used a 3-m lance. The CPT is battery powered and records data internally.

The CPT probe was deployed from the A-frame on the foredeck and raised and lowered on 5/16-inch non-conducting wire on DFO's hydro-winch. It was necessary that the lance remain embedded in the seafloor for about 2 minutes to allow equilibration of the pore pressure sensors.

Drops of the CPT probe were an after-hours activity. The operation was conducted by two science personnel with assistance of a night-watch crew member (1 at the winch, 2 at the A-frame). The removable section of the rail was not in place and persons wore safety harness.

Dives by remotely operated vehicle (ROV)

The remotely operated underwater vehicle pictured at the right was used for exploration and close video inspection of the seabed and for collection of samples – sediment using the push-core carousel, biota, shells and pebbles using the manipulator arm and collection basket. This ROV was designed and built by the Monterey Bay Aquarium Research Institute (MBARI) specifically for operations using general-purpose deck equipment likely to be found on Arctic ships of opportunity. Its attributes and dive depth (1000 m) were much improved beyond those of the Phantom ROV used from Sir Wilfrid Laurier in 2003 and 2010.

For 2012 the ROV was equipped with a Doppler-velocity log (ROWE 1.2 MHz DVL), 3-axis digital compass (PNI), high-definition video cameras (Mini Zeus HDTV) looking forward & IT1000 low light B&W camera looking aft), imaging sonar (Imagenex 881A, 675 kHz) and a gas sampling apparatus. For 2013 MBARI removed the gas sampler and added a manipulator arm (5-function ECA), collection basket, push-core carousel heat-flow probe and USBL track-point system for navigation. Also new this year was a 10-foot cargo container equipped as the ROV control centre and improved communications around Sir Wilfrid Laurier; the ROV's position relative to the ship and the ROV's camera view were made available on the bridge to facilitate ship's navigation. Video was recorded in HD-Apple Pro-Res format.

The ultra-short base-line (USBL) track-point system was deployed at a depth of about 5 m via a steel pylon secured to the port-side rail of the well deck. Hydrodynamic forces on the pylon limited its use to low ship's speed (3-4 kt). The pylon's mount included a pivot allowing it to be lifted clear of the water for transit at higher speed. At present the main derrick must be used to raise the strut. In the future we recommend installation of a winch on the rail to enable this manoeuvre without need for the crane (and the winchman).

The purpose of the dives was to examine the seabed for small-scale features of geological interest, biota and gas vents and to acquire samples (sediment, biota, pebbles) carefully selected and documented in the context

Figure 3. Electrically powered winch used to control the umbilical during dives by the ROV. The winch was mounted just forward of the hatch with a lead to a block suspended over the starboard side from the ship's derrick.

of their source. In using the ROV we are assessing its value in Arctic seabed research and building concepts for technological improvements useful in future studies.

ROV surveys were completed at 12 locations where intriguing seabed features had been identified. The imaging sonar was used to locate small-scale terrain features and textures for close examination using cameras. Once located, the ROV's cameras were used to appraise the geomorphology, sediment characteristics and biota. Sediment could be probed using the manipulator arm. The arm was also used to collect biota (tube worms), loose pebbles and cobbles. Samples were also collected using the push-core capability.

In deploying the ROV, the flexible load bearing umbilical was weighted (100 lb) to hang vertically from a block suspended over the starboard side via the main derrick. Between 10 and 30 metres of unsecured umbilical at the bottom end provided roaming freedom for the ROV. This configuration minimized the risk of entangling the umbilical in ship's equipment. The depth of the weight was controlled by the purpose built umbilical winch, with the best depth being about 10 m above the seabed. Sir Wilfrid Laurier held station while the ROV explored the seafloor within roaming distance of the weight. The ship was then be moved a few tens of metres to provide access to a new area.

Seafloor mapping by autonomous under-water vehicle (AUV)

An AUV belonging to MBARI was operated from Sir Wilfrid Laurier by MBARI's technical experts to deploy multi-beam, side-scan and sub-bottom sonar close to the seabed for terrain mapping at high (metre-scale) resolution.

The vehicle was a Dorado-class AUV built in three connected modules of 0.53 m diameter to a full length of 5.3 m and weight of 680 kg. It has 6000-m dive capability but was used this year at depths less than 1000 m, which is the rescue-depth limit of the ROV (length of the ROV umbilical). The rate of ascent and descent is 30 m/min and the endurance of the power system is 17.5 hours at the normal 3-knot cruise speed.

The AUV was secured fore-aft in a cradle on the starboard the hatch cover. Charging equipment was installed in the ROV's sea-container, with the batteries charged in situ within the AUV.

High resolution mapping was conducted along closely spaced parallel tracks at low altitude above the seabed (50-100 m). To minimize risk of damage to the AUV, surveys were planned only in areas where prior multi-beam mapping (at coarser resolution) had already been completed. Survey tracks were planned using existing topographic knowledge with waypoints programmed into the AUV before launch. The navigation plan was implemented using information from onboard the inertial (INS) & Doppler (DVL) navigation systems.

The vehicle navigates only by INS between the seas surface (where it can use GPS) and an elevation of 100 m above the seabed (where the DVL can track the seafloor). Since INS navigation errors accumulate rapidly, the AUV's position must be re-intialized once a seaflor referencehas been established. In deep water, Sir Wilfrid Laurier stayed on station, tracking the AUV relative to her position using the USBL while the AUV spiraled down. Once the DVL had contact with the seabed, the USBL- tracked position of the AUV was transmitted from the ship by acoustic telemetry via the ship's 12-kHz transducer.

Once launched, the AUV does not require attention for many hours. Its dives therefore began late in the working day, with recovery the following morning. In the interim Sir Wilfrid Laurier was free to support other activities. There was a minimum 6-hour turn-around period between missions for uploading data, charging batteries and pre-deployment system checks.

The targets of interest for high-resolution sonar mapping by the AUV includes landslides, seafloor expulsion features, surficial geology at the shelf break, mega-scale lineations and erosion canyons. In general these targets are indicative of physical processes linked to geo-hazards, such as ground-water overpressure, the upward and lateral movement of gas, fluid and sediment, terrain instability (via faulting, creep, expulsion, slides), the age and origin of sediment and the ongoing activity (or dormancy) of these processes.

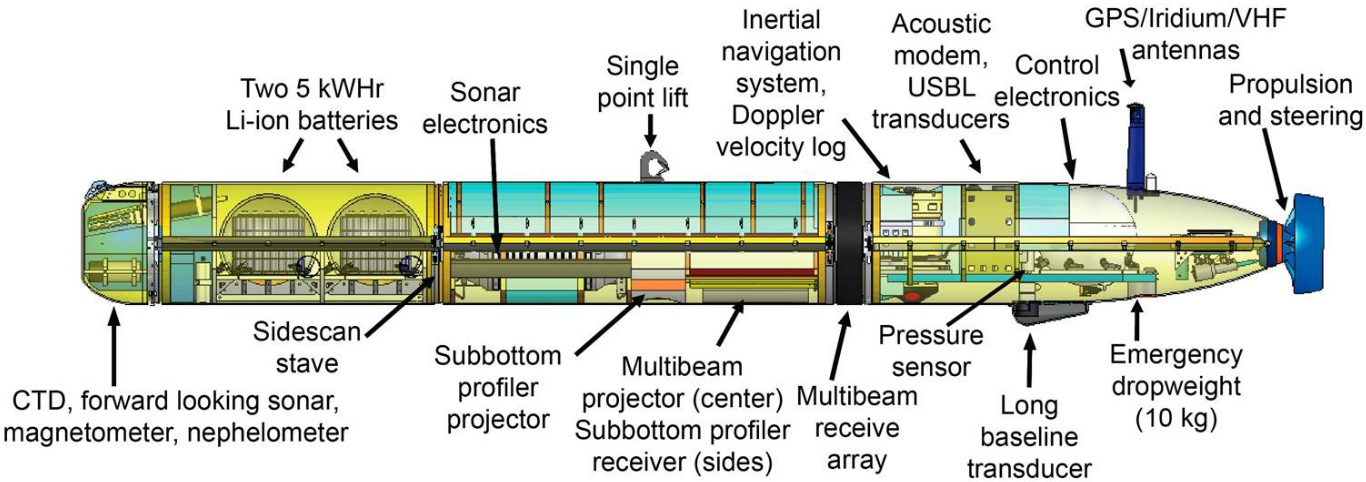


Figure 4. Sectional view of the AUV showing the modular construction. Most of the scientific payload is carried in the centre compartment.

On-shore calibration of instrument compasses

Five Work Horse ADCPs were taken ashore for calibration of their internal compasses remote from the ferro-magnetic influence of the ship. Calibrations must be done where the horizontal geomagnetic field is comparable to that at the Arctic mooring sites (6500-7500 nT); the field is too strong in Victoria (18900 nT) and too weak at Cambridge Bay (4700 nT).

The ship's helicopter was used for ship-shore transfer of the two persons and equipment needed for the task. The time required (sum of ½ hour round-trip flight time, ½ hour setup and ½ hour calibration time per ADCP) was 2-3 hours per sortie. Two sorties were required because instruments already operating at two offshore sites had not been calibrated prior to their deployment in 2012, whereas the instruments to be placed at these sites for 2013-14 needed calibration before deployment..

The first sortie was to Bernard Harbour (68°47'N 114°45'W: 5784 nT) in eastern Amundsen Gulf on September 26. The two ADCPs taken ashore were those for deployment at the CB13 (Cape Bathurst) and SIC13-9 (Amauligak) sites.

The second sortie was to Clarence Lagoon (69°37'N 140°45'W: 8758 nT) on the Yukon coast on October 11. The three ADCPs taken ashore were those recovered at the CB12 and SIC12-9 sites and that for deployment at the AIM site on the Chukchi Plateau. This sortie was combined with geological sampling of tills at the base of the permafrost bluff to the east of the lagoon.

Oceanographic moorings (DFO & collaborators)

Fourteen oceanographic moorings were recovered at twelve sites. Six moorings were short (3-m) assemblies with a single level of floatation and no lines. The remaining eight had 2-6 levels of floatation and up to 650 m of synthetic line. We use short moorings to support instruments close to the seabed and out of the reach of moving ice. In deeper water we can secure instruments on a single taller mooring, provided no component extends above 30-35 m depth. All moorings were equipped with tandem release assemblies to provide redundant capability in acoustic ranging and detachment from the anchor.

The sub-surface moorings supported electronic instruments to measure and record data on ice thickness and ridging, storm waves, sea level, ocean current, temperature, salinity, plankton density, sedimentation, turbidity, ambient sound and marine mammal calls. New data were recorded at intervals of 1 second (for ice) or 30-180 minutes (for ocean variables) for one or two years.

Eight moorings were deployed at six sites. In most cases, recovered moorings were replaced using duplicate instruments and components to minimize the ship's station time.

Recovery of moorings

The shallowest component of all moorings was submerged to at least 30-m depth because of high risk from moving ice. Moorings were recovered via acoustic activation of the electro-mechanical hook that separates the buoyant part of the mooring from a deadweight anchor, allowing the former to float to the surface. Our moorings were equipped with tandem releases for redundancy in the event of failure. In all cases this year the mooring released after the first unit was activated.

A successful recovery was contingent on the ship being able to reach the site (not always practical in heavy ice) and on having an ice-free pond over the mooring in which it can surface. The need to access particular locations and to wait for suitable ice conditions demands patience, tactical flexibility and luck.

This year we did have to pick our day for retrieving the moorings at the more northerly locations, but otherwise had no serious challenge from ice except at the AIM site on the Chukchi Plateau. Early on 14 October we encountered an almost continuous cover of grey ice about 12 miles short of the AIM mooring at 75º06'N. Conditions were worse at the mooring site with little open water, appreciable rafting and rapid re-freezing at a temperature of -11ºC. The recovery of a mooring in ice often requires that the ship find an appropriately positioned ice-free patch and drift down over the mooring with it. At the AIM site Captain Gronmyr ran Sir Wilfrid Laurier back and forth at 14 knots to break up the ice in a 500-m wide swath extending 2 km up-drift of the AIM site. In time the action of the wind on the broken ice opened several 100-m-scale patches of relatively ice-free water. Once an ice-free patch had been created, the usual drift-down approach was initiated; the mooring was released into the patch in the lee of the ship after it had drifted past. We were fortunate in being able to re-deploy in the same opening.

In contrast to 2012, we had no need to outwait in strong wind and high waves at mooring sites. In the absence of obstruction by ice or weather, almost all moorings were recovered within 30-60 minutes.

Figure 5. The AIM mooring, at sea since 2011, surfaces in the ice-free pool created jointly by Sir Wilfrid Laurier and the wind over a period of several hours. Air temperature -11°C.

Moorings recovered during Leg 3

Site	Area	Latitude			Longitude			Water depth (m)	Buoyed levels	Instruments
CB12	Franklin Bay	70	33.8101	N	127	41.5659	W	44	1	WH600, SBE37
SIC12-1	Mackenzie shelf	70	19.9470	N	133	44.5150	W	55	1	IPS
SIC12-1	Mackenzie shelf	70	19.9404	N	133	44.6384	W	55	1	ADCP, SBE37
SIC12-2	Mackenzie shelf	70	59.3421	N	133	44.6340	W	111	2	IPS, ADCP, SBE37
SIC12-9	Mackenzie shelf	70	03.5113	N	133	42.8436	W	35	1	IPS, SBE37
SIC12-9	Mackenzie shelf	70	03.5143	N	133	43.0212	W	35	1	ADCP
SIC12-11	Mackenzie shelf	69	46.4659	N	137	02.7432	W	36	1	IPS, SBE37
MGH12	Mackenzie shelf	70	39.0156	N	135	56.8047	W	283	3	AWCP, AURAL, 3x SBE37
BR-A-12	Mackenzie slope	70	45.4080	N	136	00.7980	W	661	5	IPS, 2x ADCP, 2x Technicap PPS, 4x XR420, Aquadopp
BR-B-12	Mackenzie slope	70	40.2960	N	135	35.1720	W	156	3	IPS, ADCP, 2x XR420, LISST, Aquadopp
BR-G-12	Mackenzie slope	71	00.4680	N	135	29.9100	W	702	6	IPS, 2x ADCP, 2x Technicap PPS, 4x XR420, 2x Aquadopp
BR-2-12	Mackenzie trough	69	59.4780	N	137	57.6480	W	154	2	IPS, ADCP, 2x XR420, LISST, Aquadopp
BR-1-12	Mackenzie trough	70	26.0100	N	139	01.3920	W	750	6	IPS, 2x ADCP, 2x Technicap PPS, 4x XR420, Aquadopp
AIM11-1	Chukchi plateau	75	06.0203	N	168	00.0354	W	165	4	IPS, ADCP, AURAL, 2x SBE37

Deployment of moorings

We work with two types of moorings: 1) short (3-5 m long) moorings that can be lifted completely by the crane, lowered to the surface and released to fall to the seabed; 2) longer (up to 2000 m) taut-line moorings with several levels of instrumentation and floatation, which are assembled on the deck and drawn progressively away from the ship by the FRC (fast-response craft) as components are lifted over the side. The last lift is the release assembly with deadweight anchor, which is dropped when the mooring line is straight (no loops) and no longer attached to the FRC.

The time required to deploy two short moorings was about 15-30 minutes. Longer moorings require between 30 minutes and 2 hours, depending on complexity (number of lifts) and sea state.

Preparation of moorings

The mooring team used the foredeck and the 20-foot “green container” to disassemble recovered equipment, to prepare mooring components and to stage and assemble new moorings before deployment. Preparation of the instruments for moorings was carried out in a cleaner space, a 20-foot laboratory container installed for this expedition beneath the davits on boat deck (starboard side).

Geological studies

The principal area for geological study is shown in Figure 7. Ten locations within this area were selected for study in detail, as indicated by the indicated activities: 6 locations along the edge of the continental shelf, 2 expulsion features on the continental slope and 2 canyons also on the slope. Not shown in Figure 7 are locations studied further west (see Figure 1): the Garry Knolls area on the continental shelf and another canyon downslope from Mackenzie trough. The seafloor expulsion features at 750 and 420 m depths are flat-topped mounds thought to be the consequence of upward movement of sediment, water and gas from depth. Other features appear linked to terrain failure via mechanisms not yet understood.

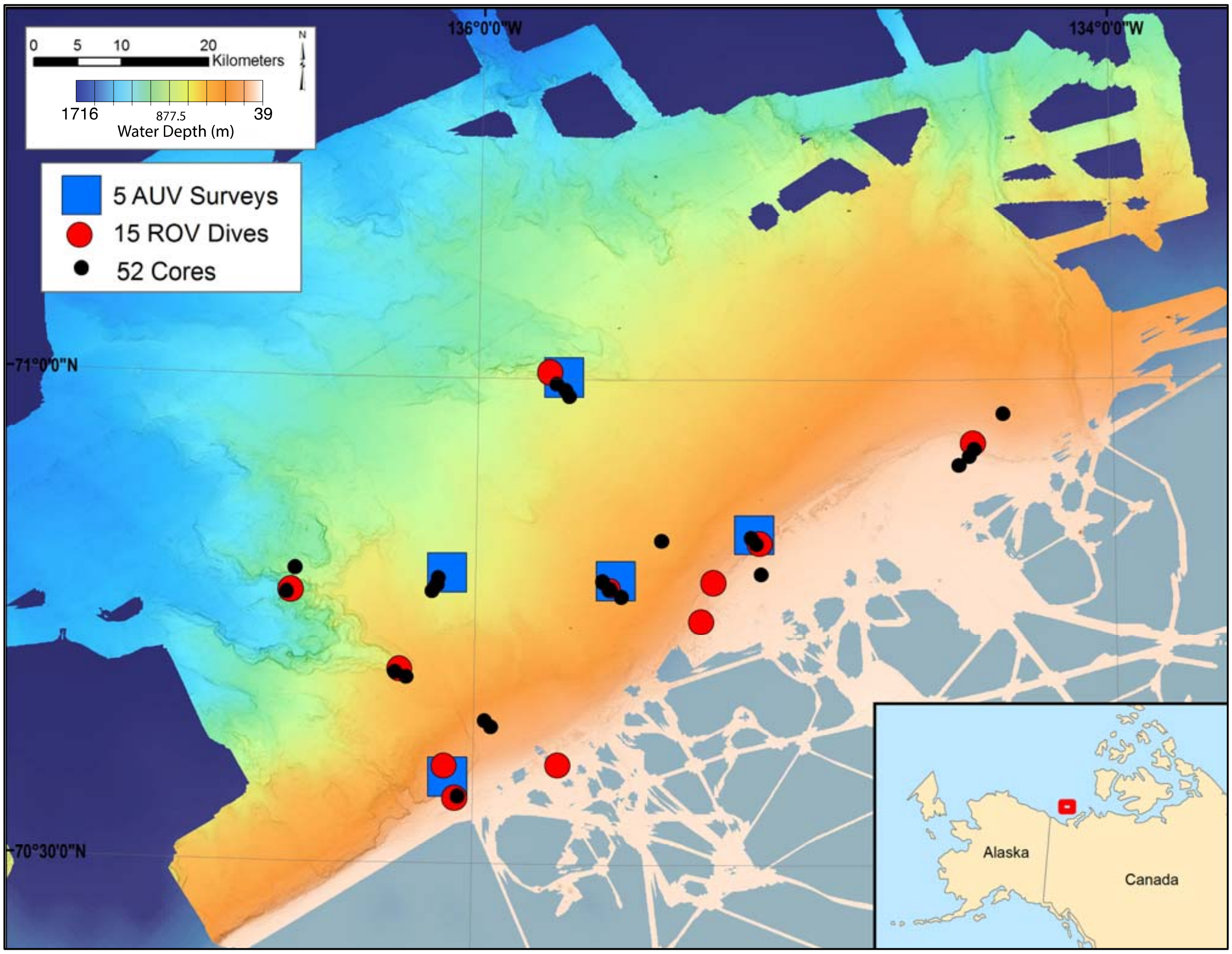


Figure 7.Locations of interest for geological study. The underlay of the figure is an image of seafloor topography acquired using multi-beam sonar. The broad “canyons” cut into the seabed on the upper slope are obvious.

As the use of multi-beam sonar increases in the Arctic, evidence is emerging that ice shelves may have extended far out over the Arctic Ocean during the Ice Age. In 2010 from Sir Wilfrid Laurier we recovered a core of pebbly silty clay diamicton suggestive of glacial influence at the edge of the Mackenzie shelf. In 2012, the ROV repeatedly found such sediment (diamicton) in outcrops, where pebbles and boulders were strewn across the seabed. The first site explored by ROV in 2013 was at the shelf edge near 134°27’W, where mapped topography is suggestive of glaciation (Figure 6). The ROV’s camera revealed areas with cobbles at the sea floor and subsurface sediment with a grey hue often characteristic of glaciogenic sediment. Pebbles were collected using the ROV’s new manipulator – a first

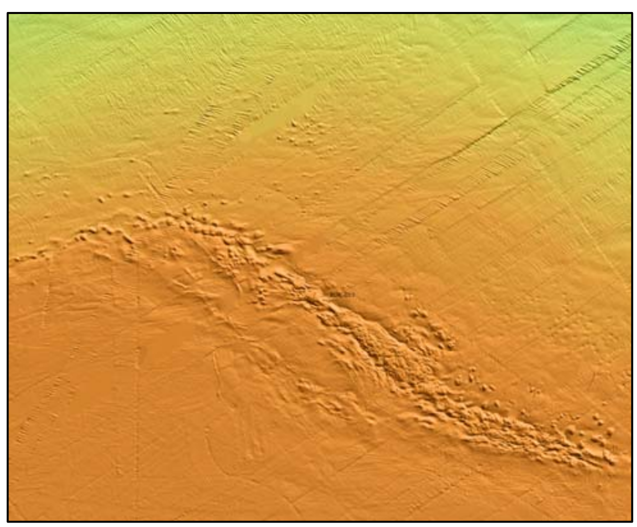


Figure 6. Shelf-edge site with distinctive topography, where diamicton was sampled using the ROV.

Similar evidence of glaciation was revealed by a subsequent dive near the shelf edge above the landslide feature 70 km to the south-west at 136°W. Our target was a curved elongate ridge feature (perhaps a glacial esker?) adjacent to a shallow moat. Scattered pebbles and cobbles were seen on the sea floor from the start of the dive, but close to the ridge the density of the cobbles increased to form a sometimes solid pavement. The cobbles were generally within a clay matrix and samples were later found to have diverse lithology; one had distinct glacial lineation.

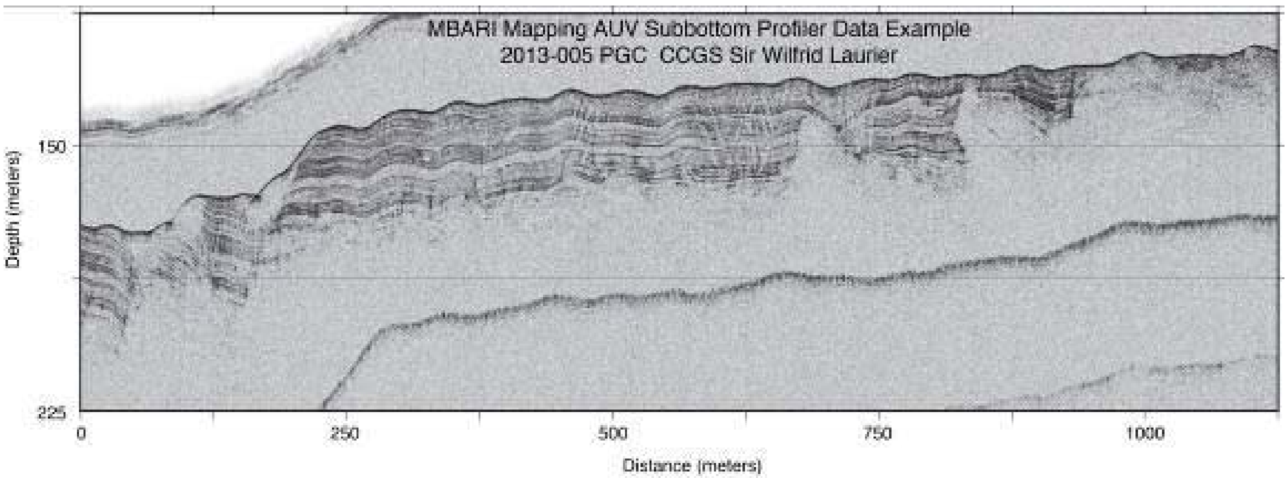


Figure 8. Shallow seismic section across the outer shelf (right) and upper slope (left) at 136°W, acquired via 3.5-kHz sonar using the MBARI AUV Laminations, terrain slips and upward intrusions of sediment can be seen.

ROV Dive 21 explored a canyon at 895-m depth near the north-east corner of the study area; prior sub-bottom profiling suggested that strata might be exposed nearby. A bright return to the scanning sonar turned out to be a mound, orange in colour, protruding from the seafloor. More orange-tinged mounds were found nearby. At the base of the canyon's sidewall small pebbles were first seen. After climbing 30 m upslope, viewing increasing density of pebbles and cobbles, we found a fresh exposure of grey clay diamicton of similar appearance to the sediments seen on the shelf edge. The remarkable aspect was that we were well past the shelf edge and in much deeper water.

Figure 9. One of several mounds with distinctive discolouration on the floor of a canyon at 895 m depth.

Station stops for sediment coring, temperature measurement and CPT drops were scheduled throughout the cruise, chiefly during evening hours. Our precise measurement of sub-bottom temperature has revealed that the sediment within sea-floor expulsion features is substantially warmer than that within the undisturbed seabed nearby, in some instances by more than 5°C. This result confirms our conjecture that ground water is rising from considerable depth within expulsion features. The CPT data have revealed that the surface sediment of expulsion features is much softer than in surrounding background areas.

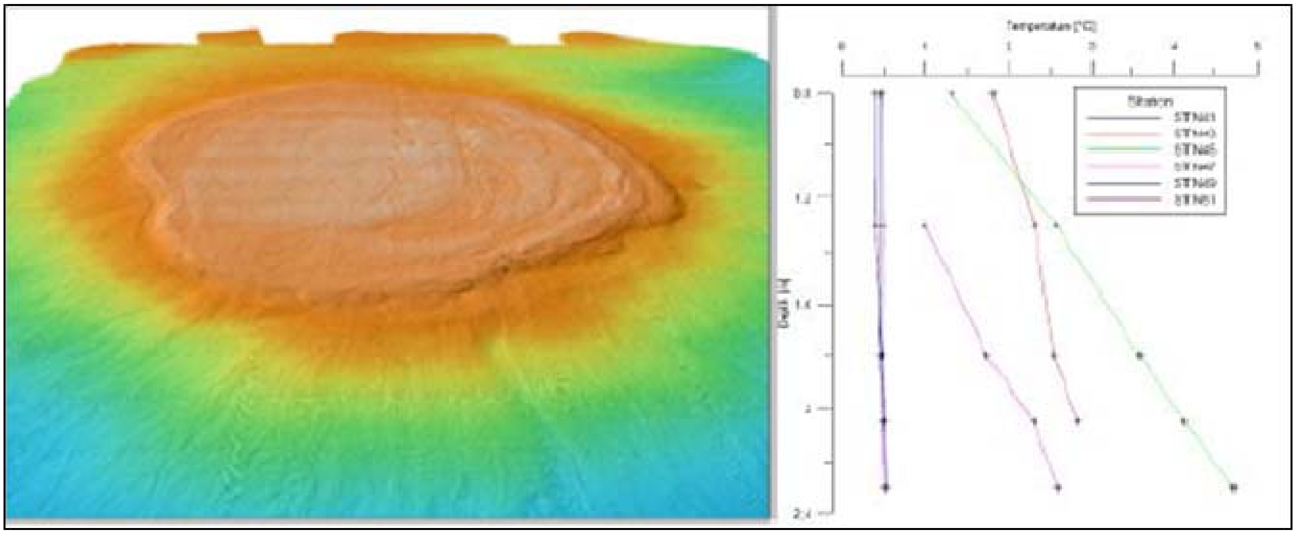


Figure 10. High resolution multi-beam image of the 420-m expulsion feature (left). Sub-surface sediment temperature at sites within the feature (right), showing the strong temperature anomalies at some locations within it.

We routinely extracted small samples of pore water from sediment cores at intervals along their length using rhysome samples. The sampled waters will be analyzed on return to the laboratory. Since the cores themselves were not removed from their plastic liners, it was difficult to make direct observations of sediment properties; again this analysis awaits return to the laboratory. However we were excited by the chance visibility (and subsequent sampling) of gas hydrate near the top of a core taken from the 420-m depth expulsion feature – sub- horizontal veins of hydrate approximately 1 mm thick.

In conventional practice, the locations at which cores are taken from the seabed are assumed to be those of the lowering point on the ship. However, ship's movement and current cause the wire to deviate from vertical, so that exact core locations are not generally known. This is undesirable when studying small features in deep water. We experimented with the USBL track-point system to pin-point sediment cores relative to features of interest. By mounting a transponder on the coring wire, the corer was positioned in the same way as the ROV. Figure 11 shows the navigation screen during one such trial.

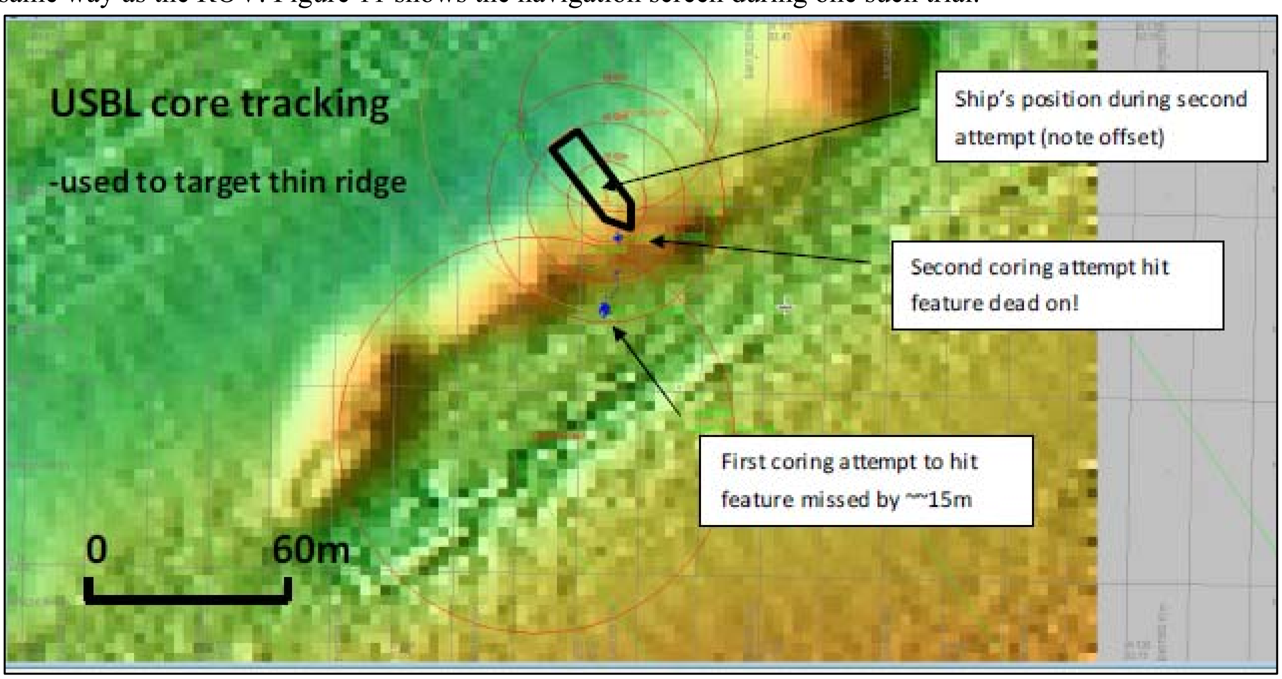


Figure 11. Navigation screen when attempting to acquire sediment from the crest of a narrow ridge on the seabed.

Garry Knolls exist in relatively shallow water on the western edge of the Mackenzie shelf. Here geo-hazards linked to terrain instability occur in association with ground ice and deep scouring caused by ridge keels in moving sea ice. Figure 12 displays the coring transect of one of the knolls, a pingo-like feature in a moat superimposed upon a multi-beam image of the seabed, showing ice scours. Cores on this feature contained ice-bonded sediment. Sediment cover in the moat was observed to be a rather featureless soft mud. Pebbles and cobbles appeared as the ROV approached the mound, and as it worked its way up the mound it was obvious that it was again climbing an exposure of diamicton with fresh faces of pebbles and cobbles (up to 50 cm) floating in a fine-grained cohesive clay matrix.

The ROV's last dive was to the headwall of a canyon near 1000-m depth at 139°W. The ROV touched down on a featureless, muddy sea floor. The geology changed with approach to the wall of the canyon; pebbles and cobbles appeared in fresh exposures of cohesive clay diamicton. At about 955m depth we encountered a cobble-rich horizon with some recently failed sediment blocks. The coarse grained cobble-rich layer ended at about 920 with the sediment then changing to a clay rich diamicton with only occasional pebbles and cobbles. The top of the canyon was at about 910 m with a muddy bottom with no apparent pebbles or cobbles.

This cruise has established that many of the extrusion features near the shelf edge are composed of fine-grained, cohesive diamicton. Our post-field research will concentrate on documenting the geotechnical properties of these sediments and investigating what pressure regime could cause the seafloor displacements we have observed. We also plan to reconcile our observations within seismo-stratigraphic framework for the area and to determine if the glacial material was carried by ice from the Canadian Shield or from the Canadian Archipelago to the east.

One component of the geology programme was initiated with the deployment of

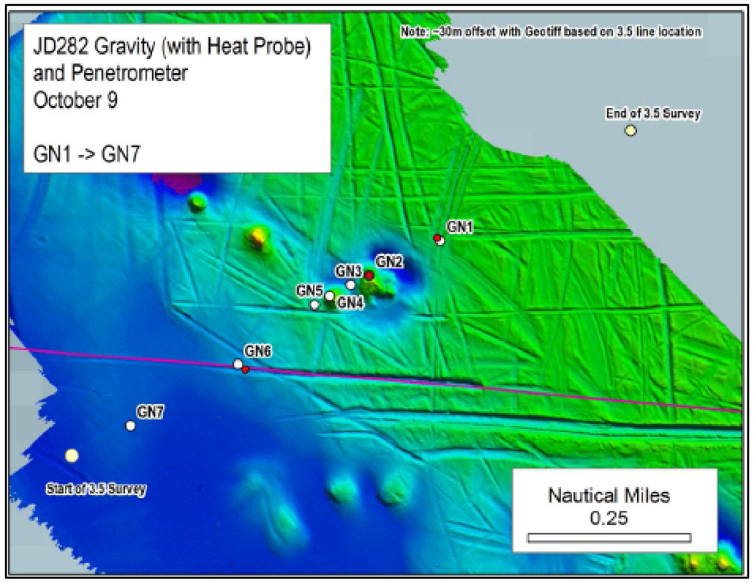


Figure 12. Locations of cores, geothermal and CPT profiling relative to mounds and ice scours within the Garry Knolls.

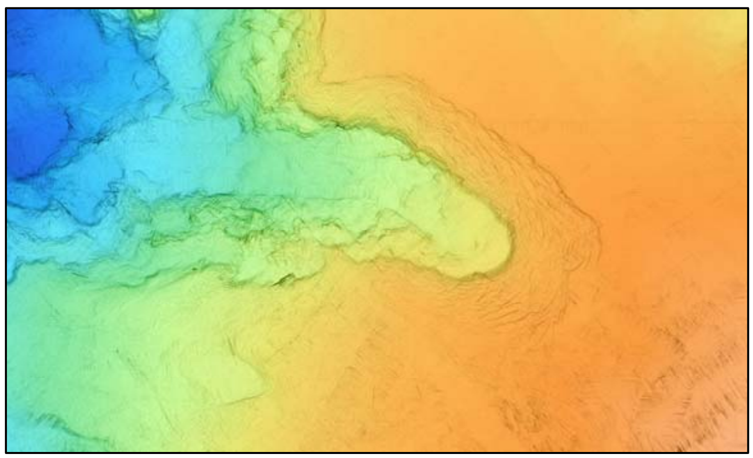
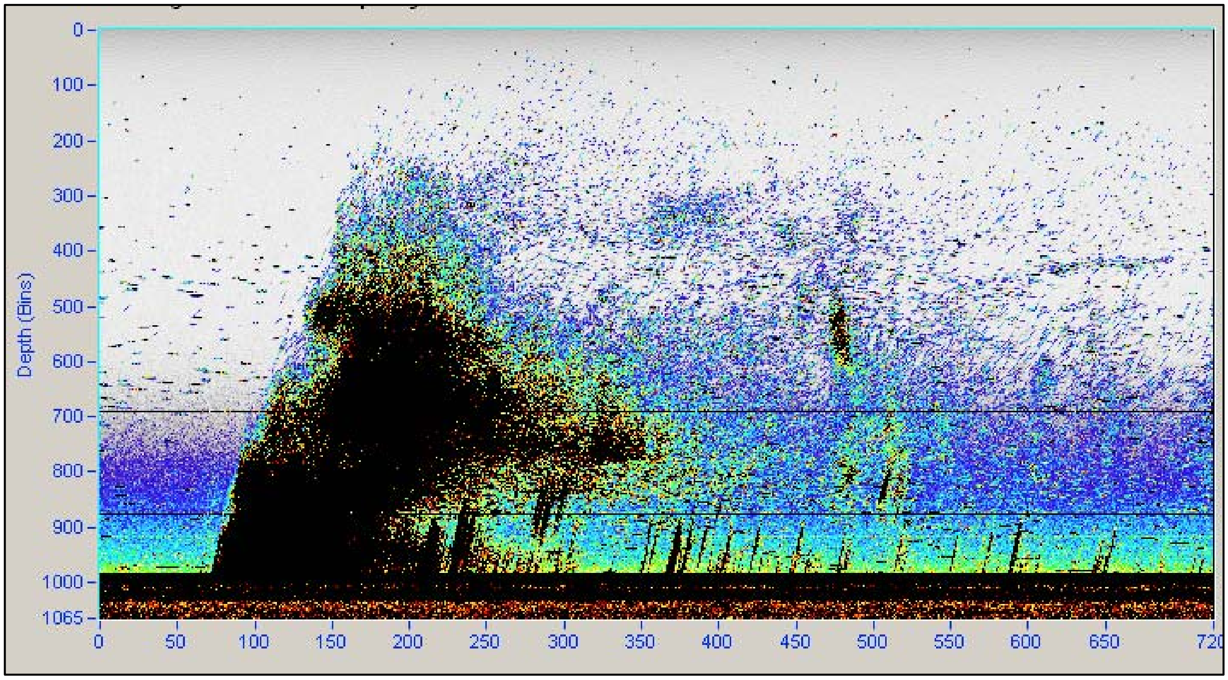


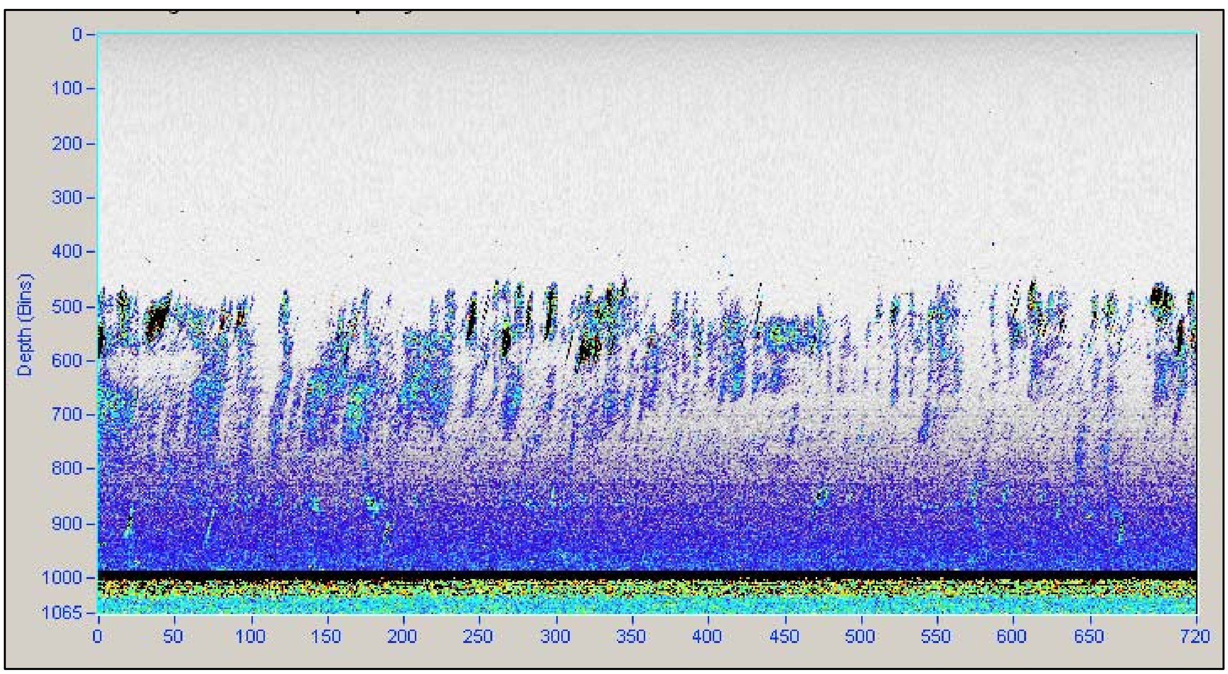
Figure 13. Canyon at the seabed near the 1000-m contour, mapped by multi-beam sonar.

Figure 14. Eroding slope of coarse bouldery diamicton at 953 m depth in a canyon.

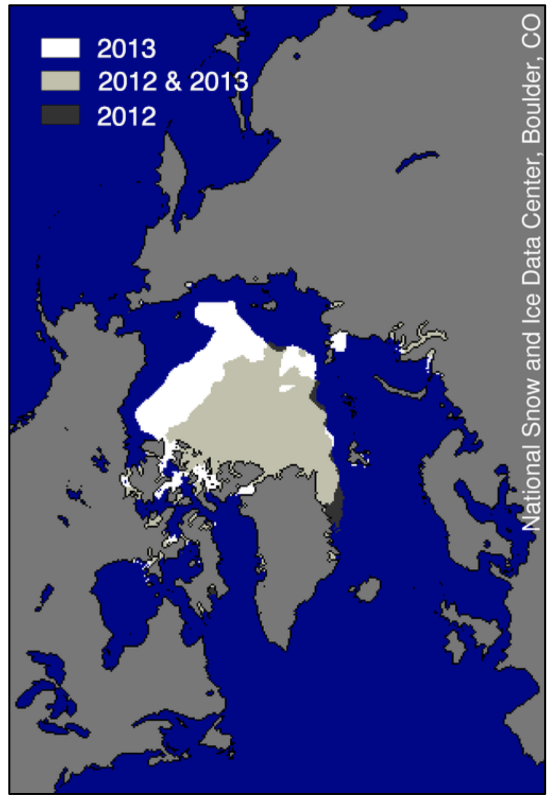
recording instruments on a submerged mooring at the Coke Cap expulsion feature (283-m isobath). The mooring carried sensors to measure temperature and salinity at 5, 12 and 32 m above the seabed, a recorder to measure ambient sound at 22-m elevation and a down-looking 200-kHz sounder at 102-m elevation. The purpose of the two acoustic devices was documentation of the gas release from the feature.

The two frames below display the strength of echoes during two one-hour intervals of the record, the top on 5 January and the bottom on 15 August 2013. The top frame shows a large release of gas from the seabed very close to the mooring; there was no gas release near the mooring for some time before the event, but bubbles were released at intervals after the bubble drifted away (black sloping echoes from targets rising within the sonar beam. The bottom frame shows no gas being released locally, but, but clouds of bubbles from elsewhere are detected drifting through the beam 25-50 m above the seabed.





Ice conditions across the Arctic, September 2013



The map at the right displays the average extent of pack ice during September 2013, measured from satellite via the thermal emission of microwaves, cloud or no cloud. Ice extent is the area within which the concentration of ice is at least 15% (http://nsidc.org/data/seaice_index/). Also shown is the ice extent one year earlier. In contrast to the last few years, the ice edge of September 2013 in the Canadian Beaufort Sea was close to its 30-year median position. At this location, it obstructed our plans from time to time. Where we did enter the ice at 75ºN on the Chukchi Plateau, the edge was well north of its 30-year median position, but well south of the edge in September during 5 of the last 6 years.

Ice extent reached its annual minimum of 5.10 million km^2 on 13 September, 50% higher than last year's minimum of 3.29 million km^2. The average extent of ice during September was 5.35 million km^2, up from 3.6 million last year.

Impact of ice and weather

For the first time in a few years, ice did have direct impact on execution of the science plan in 2013. The most dramatic consequence was the complete cover of grey ice at the AIM site, our furthest north, on 14 October. Station time there was increased 3-4 times by the need for ice management and standby for drift. Our first attempt to recover the mooring at BREA site G was blocked by ice, and BREA site 1 in the west was in and out of the ice while we worked in the area. We were threatened several times by nearby ice when working with the ROV and AUV, for fear of encroachment when the vehicles were down below. These events caused disruption of plans and lost time in reaching alternate sites.

The proximity of the ice did reduce fetches for wind and thereby sea state. On one day we took advantage of a strip of ice, finding sufficient shelter in its lee that we were able to launch the ROV. We planned the last two days of work in the Beaufort to take place on the western side of the delta, anticipating shelter from strong south-east wind forecast at that time.

Regardless, strong winds and developed seas are to be expected here at this time of year. The present methods of launch and recovery for both the ROV and AUV are limited to winds of about 20 kt and seas of about 2 m, for risk of damage to the vehicles. The operating range could likely be extended if a crane with greater outboard reach (5 m) could be installed, a better suspension for the ROV umbilical pulley designed and a launch chute for the AUV designed.

Air temperature was typically in the -4 to 0°C range for the Beaufort part of the trip, about 5ºC colder than in 2012 and close to the normal range at this time of year. Temperature at the AIM site (75ºN) on 14 October was -11ºC, causing the water in the CTD plumbing to freeze. Unfortunately the 4-kW electrical heater that we had installed rosette shelter some years ago was removed last year.

Successes

First Arctic operation of autonomous underwater vehicle (AUV) for seabed mapping – multi-beam, side-scan, sub-bottom.sonar

Discovery of unexpected and landforms and types of sediment type over a wide area along the shelf edge and continental slope, via high-resolution sonar mapping and the ROV's video and sampling.

Success in operating 3.5-kHz chirp sonar via the installed 12-element array on Sir Wilfrid Laurier – a new onboard science capability

Successful recovery of all 14 moorings on the plan including …

Retrieval of the AIM mooring through 9+ ice cover after 2 years' operation at 75.1ºN

Close to 100% reliability in data recovery from recovered instruments

Sound recordings of whales' presence in late autumn and early spring under complete ice cover on the Chukchi Plateau

First year-round sound recordings of gas release from a seabed expulsion feature

First-year round sonar record of variability in the venting of methane from a seabed expulsion feature

Setbacks

AUV damaged at launch

The AUV apparently hit the hull during its first launch, while the optimal technique was under development. Resulting damage to the tail cone, discovered at recovery, rendered the AUV incapable of steering to the survey plan; it surfaced 5 miles next day from the expected location. A spare tail cone was substituted.

Mishap with the gravity corer

The gravity corer was drawn into the block at the A-frame during the last day of coring. The instrument was not lost, but the last planned drop had to be cancelled because the wire's termination was damaged.

Freezing of the SBE9 CTD

With air temperature at -11ºC on 14 October, the CTD was discovered frozen at the time for the cast at the AIM site. The unit was thawed by disconnecting hoses and injecting warm water by syringe. On first examination of data from the cast that followed, the CTD's sensors appears not to have suffered.

Malfunctions of moored instruments

Wave-ice profiling sonar at SIC12-1: The sensitivity of the sonar degraded progressively during the deployment, causing an increasing incidence of null returns. The quality of recorded data was moderately compromised

Ambient sound recorder at AIM11-1: The battery pack was depleted after 10-months operation, as a result of misleading power-budget specifications from the manufacturer.

Issues for consideration before future applications

Deployment and recovery of the AUV and ROV

The present methods of launch and recovery for both the ROV and AUV from Sir Wilfrid Laurier are risky for the vehicles in wind above about 20 kt and seas exceeding about 2 m. The practical range of environmental conditions could likely be extended if a crane with greater outboard reach (5 m) could be installed. An improved means of suspending the pulley for the ROV's umbilical pulley and possibly a launch chute for the AUV might also be advantageous.

The recovery of the AUV could perhaps be faster if the vehicle's visibility at the surface were improved. Changing the colour of the VHF antenna shroud from black to yellow, adding marking of reflective tape to the hull and installing a brighter strobe could be worthwhile innovations.

Umbilical winch for the ROV

On return to Victoria we discovered that heads of two bolts connecting the hub flange of the winch drum to the gear shaft sheared had off at some time during the expedition. The circular holes accommodating both bolts were enlarged to an oval shape by movement and there was a pattern of wear around the washers. The hub flange appears to have developed a “slip” when the winch changed direction under load, gradually creating the oval wear pattern of all the bolt-holes.

The sheared bolts are an indication of an underlying weakness in the structure relative to the weight of the drum and umbilical. Resultant flexing causes the gear driven by the drive-belt to be canted so that the drive-belt won’t centre. It is advisable to correct this issue before the winch is used again.

Heating for the CTD-rosette shelter

The CTD froze in the rosette shelter when outside air temperature dropped to -11ºC on 14 October.

The 4-kW electrical blower heater in the CTD-rosette shelter was removed in 2012 to make room for the heat pump that cools the Electronic Equipment Room. The heat pump does not produce much heat in Arctic conditions, and what it does is blown out at 2-m height, having no impact on the cold-vulnerable CTD near deck level. The heat pump did not prevent the freezing of the CTD at -11ºC on 14 October. Fortunately this very expensive instrument package appears not to have been damaged. Can the capability to direct a warm flow of air over the CTD near deck level be restored?

Electrical winch for the pivoting strut

At present, the ship’s derrick is used to lower and raise the pivoting strut used for hydrophone deployment when underway (slow speed). Since crane use requires the winch-man and bosun, night-time operation is not practical. Lowering the strut’s pivot point from the rail to deck level, and installation of a winch further forward on the rail would enable lowering and raising of the strut without crane use.

Number of IP addresses on the ship’s LAN

With the number of computers in ship for the science activity this year (quite a few to move information and displays to various locations on the ship), we ran out of IP addresses on the LAN. Expansion of the capacity for network connections would be very useful.

Incident with the Prusik knot

A dangerous design feature was incorporated into several of the BREA moorings recovered for ArcticNet. This feature involved a short length of line on which were strung 4 heavy (20 kg) plastic Flotec buoys. The line was shackled to an instrument package at its bottom end, and ran parallel to the main mooring line for a few metres to where it was secured to it using a Prusik hitch. Since this knot was not under load, it loosened during the deployment. As the floats were lifted over the rail, the knot first held, then slipped down the main line, causing the Flotec buoys to tumble on the deck crew below.

Installation of sonar transducers

The flush hull mounting of disk-like sonar transducers on Sir Wilfrid Laurier does not provide sideways sensitivity. For applications that need sideways sensitivity, such as communication with release transponders or the AUV, it is necessary to deploy an omni-directional transducer from the foredeck (release transponders) or be more-or-less over the target (AUV). For the former the ship must be brought to a stop and the latter impedes alternate activities of the ship.

Also flush-mounted transducers are continually swept by clouds of bubbles that absorb sound and reduce effective duty cycle on echo sounders and the sub-bottom profiler.

If a gondola is planned for the installation of multi-beam sonar on Sir Wilfrid Laurier, perhaps it could be configured with space for mounted the transducers needed by other sonar systems used for science.

Also flush-mounted transducers are continually swept by clouds of bubbles that absorb sound and reduce the effective duty cycle of echo sounders and the sub-bottom profiler.

Issues surviving from earlier years

- Both the seawater pump and the seawater drain for the thermo-salinograph operation freeze up when surface water reaches freezing temperature. We did have to shut down the system for several days when in ice on this expedition, for the first time in several years. This issue has yet to be addressed.
- Better results might be obtained by cementing the engine room sea-water temperature sensor with thermal-joint compound to the inside of the hull plating. The backside of the sensor should be heavily insulated with polystyrene foam from the warmth of engine room.

Thanks to CCGS Sir Wilfrid Laurier

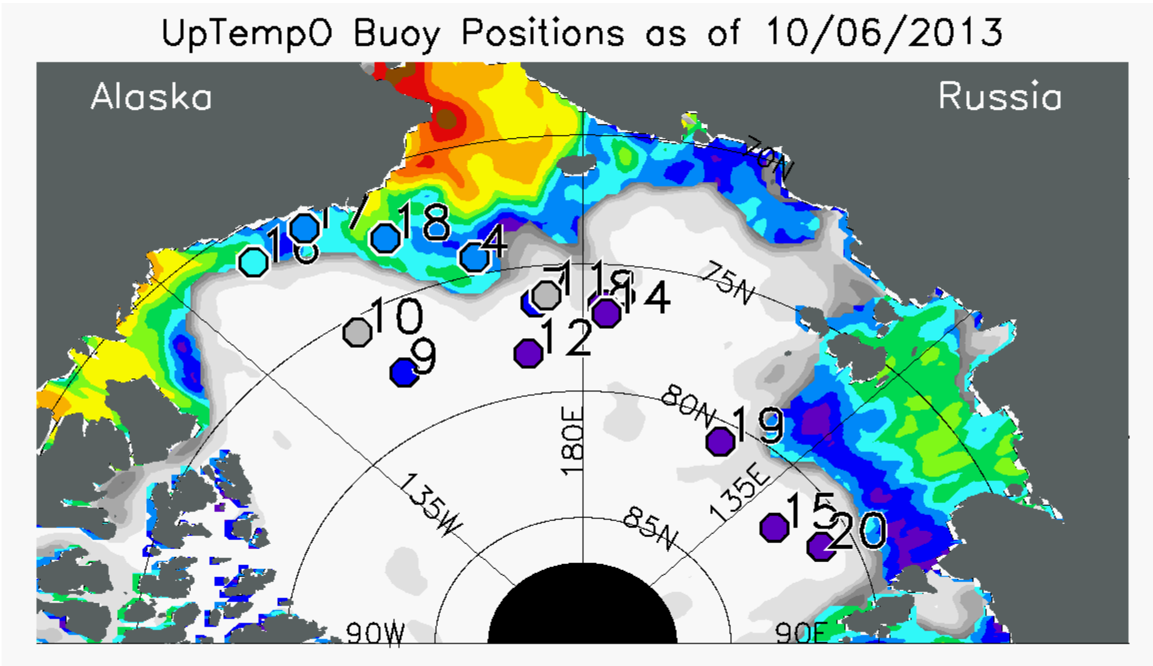
Science was successfully conducted from Sir Wilfrid Laurier amidst repeated encroachments of pack ice. The productive utilization of ship time despite adverse environmental conditions reflects the competence of ship's officers and their commitment to completion of the science work as planned.

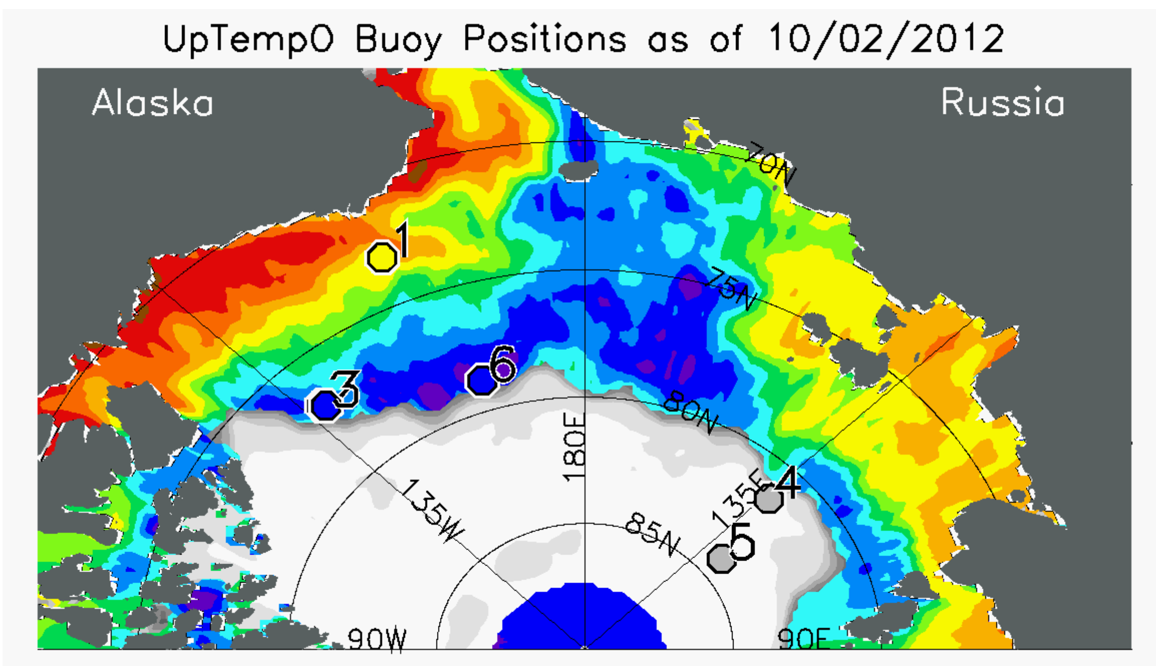
I thank Captain Victor Gronmyr and Laurier's Red Crew for their contributions to the success of our work. As usual, Sir Wilfrid Laurier has played a critical and effective role in facilitating the Arctic marine research of Fisheries and Oceans and Natural Resources Canada within a context of international collaboration.

Inter-annual variation in the marine environment

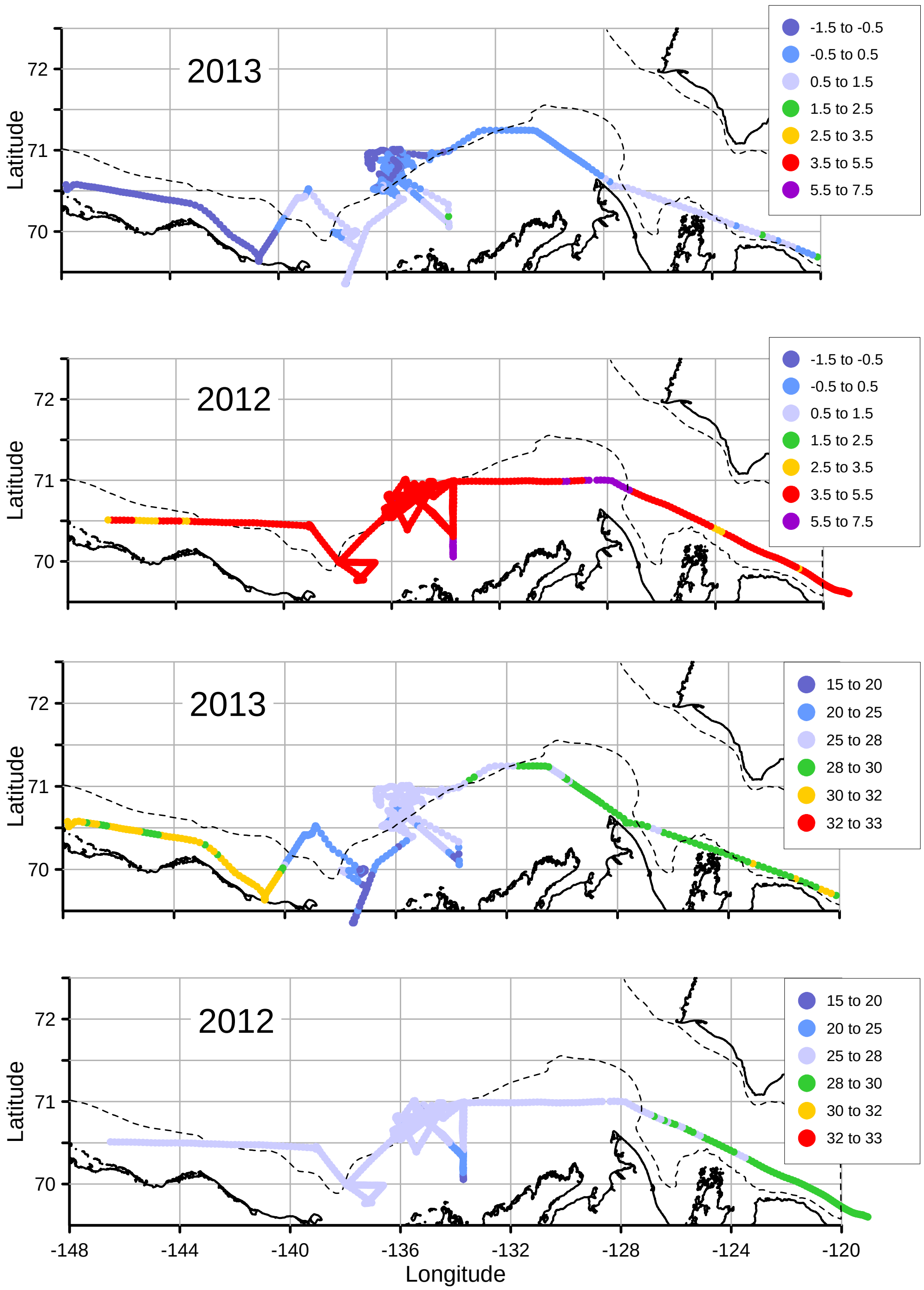
Surface temperature and salinity in the Beaufort (early October)

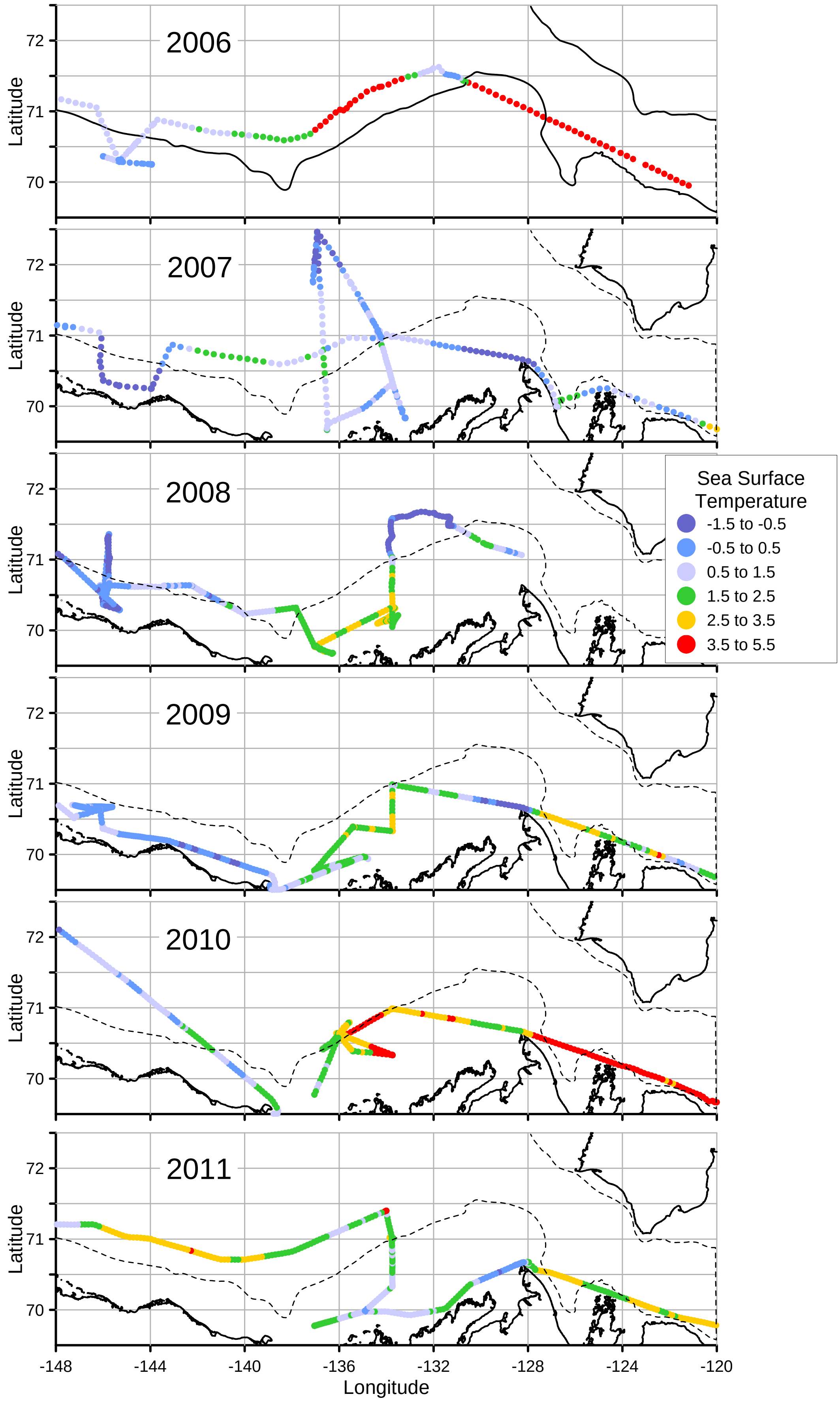
The illustrations below display Arctic sea-surface temperature in early October 2013 and 2012. Ice is shown in grey and colours change in 1°C increments from 4-5°C (red) down to 0-1°C (green) and below 0°C (blue). The information was derived from Earth satellite (http://psc.apl.washington.edu/UpTempO/Data.php). The wide band of 4-5°C water stretching from Amundsen Gulf to the Chukchi Sea obvious in 2012 was missing in 2013; conditions in 2011 were intermediate, with the entire southern Beaufort 2°C or cooler. The figures illustrate the strong influence of sea ice on nearby sea-surface temperature.

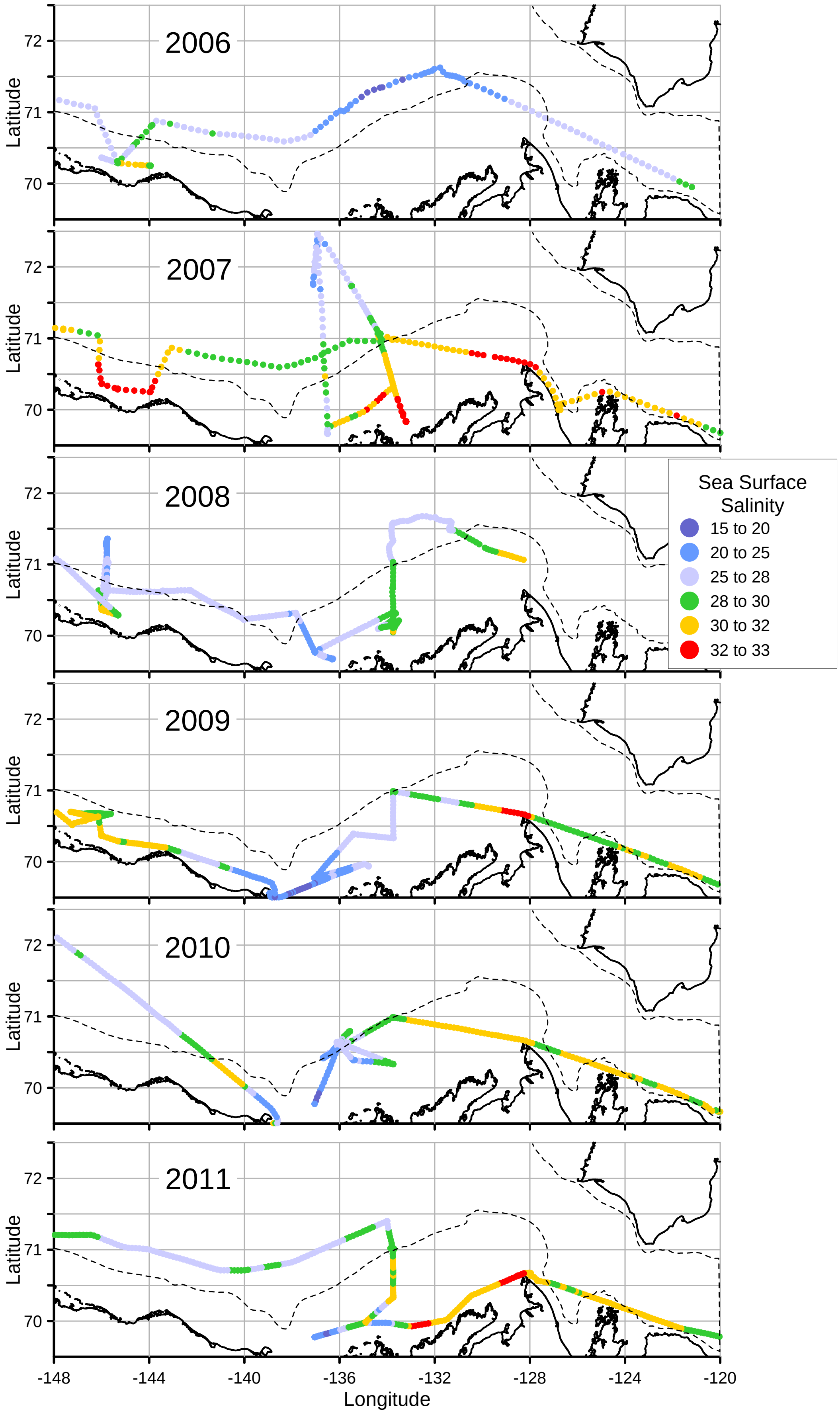




The illustrations below display the temperature (top) and salinity (bottom) of surface water during Laurier's transits in 2013 and 2012. The colour of dots indicates value according to the legend. Corresponding plots for the years 2006-2011 are shown on the pages that follow. Temperature in particular was greatly different in 2013 than in 2012.




2006
2007
2008
2009
2010
2011
Latitude
72
71
70
Longitude
-148
-144
-140
-136
-132
-128
-124
-120
Sea Surface Temperature
-1.5 to -0.5
-0.5 to 0.5
0.5 to 1.5
1.5 to 2.5
2.5 to 3.5
3.5 to 5.5


2006
2007
2008
2009
2010
2011
72
71
70
Latitude
-148
-144
-140
-136
-132
-128
-124
-120
Longitude
Sea Surface Salinity
15 to 20
20 to 25
25 to 28
28 to 30
30 to 32
32 to 33

Surface conditions in 2012 were the warmest for in October during the 7-year period of routine observation (2006-1012) and the second freshest after 2006. In contrast to other years in the sequence, there was little evidence in 2012 of salinity decrease with increasing distance from the coast. Salinity was higher in Amundsen Gulf, as is typical of most years (except 2006).

The surface salinity typically decreases with distance from the coast, implying that fresh water from the Mackenzie River has during the last 6 summers generally been transported northward to accumulate in the Canada Basin. There also appears to be a westward component to this transport, since the surface waters of the basin north of Alaska are typically fresher than those in the basin within the Canadian sector.

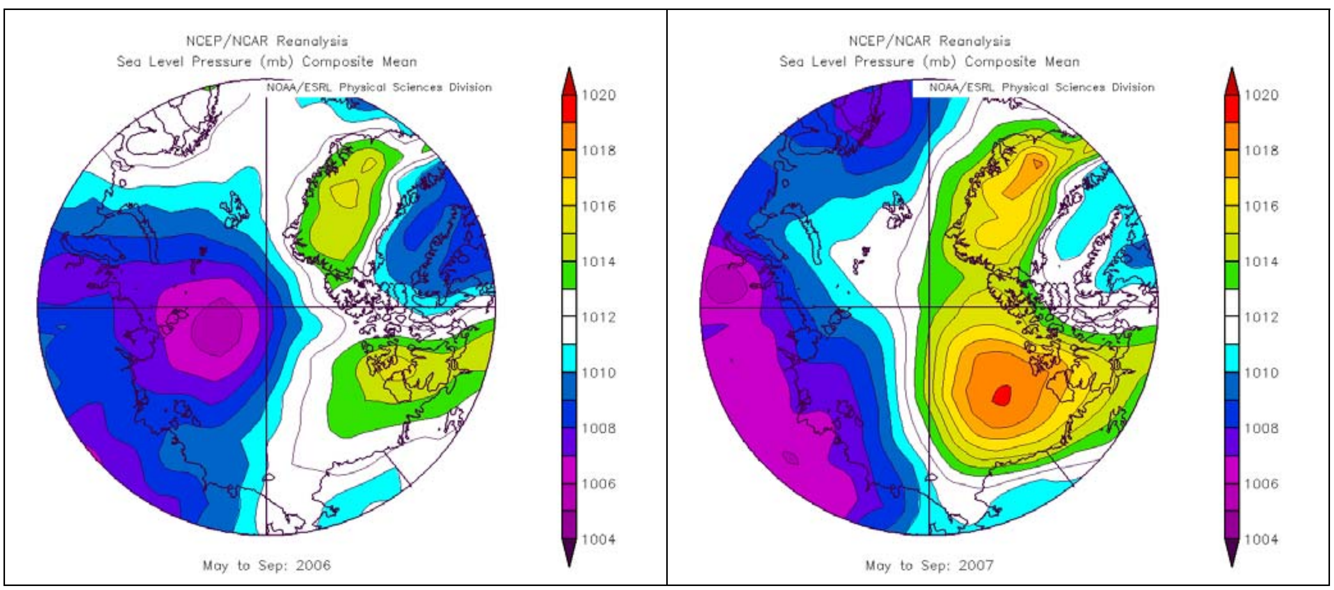
Meteorological insights

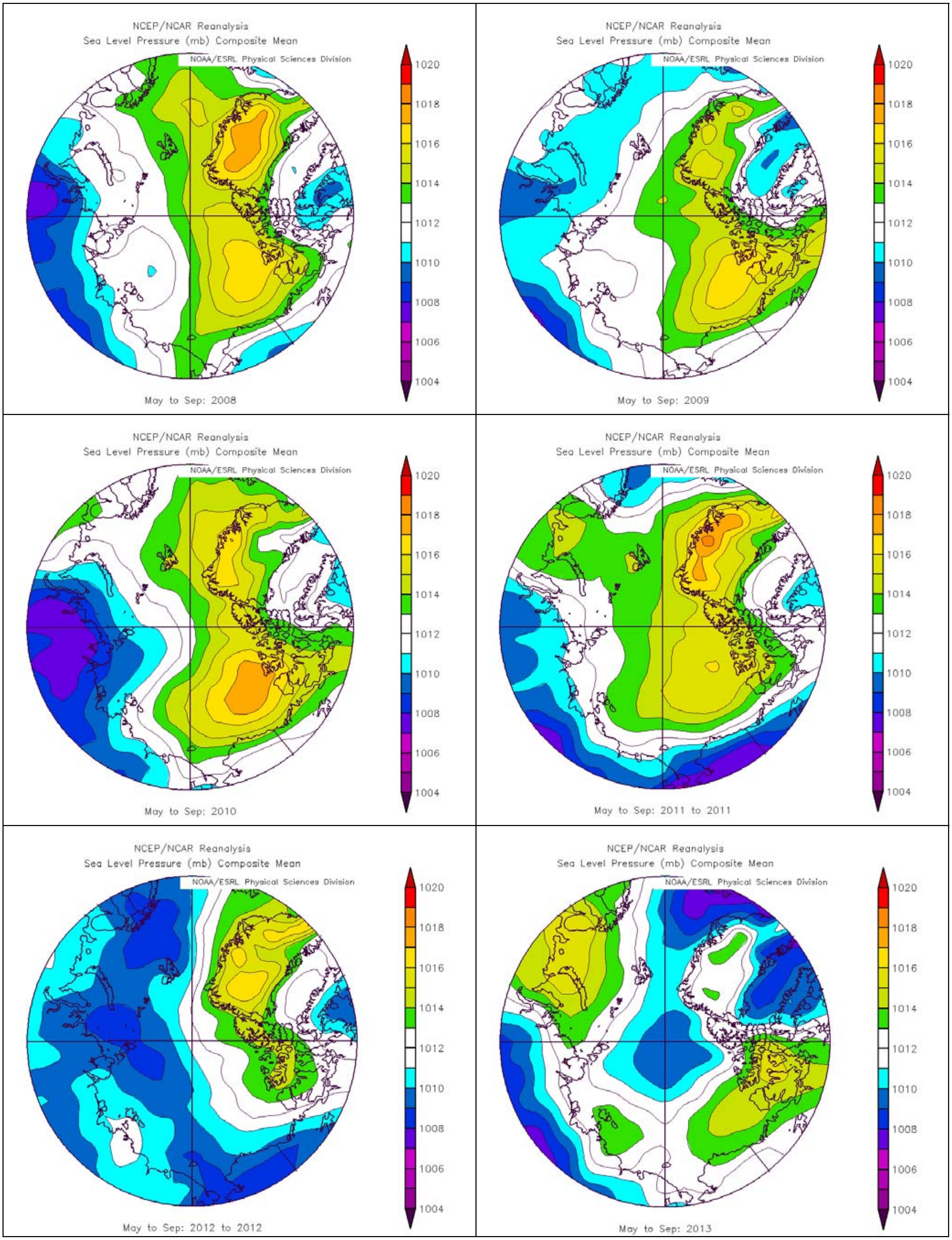
Contoured plots in Figure 10 show the pattern of average air pressure at sea level during the months of May through September for 2006 through 2013, and the 30-year average over these months at the lower right [data from the NCEP re-analysis project]. These SLP patterns determine the wind patterns during each summer and the effect that they have on ice movement. On average (lower right), a weak cell of high pressure dominates the Beaufort Sea in summer. Winds blow clockwise around this cell, giving easterlies across the Beaufort to Wrangel Island, and southerly winds (white band) across the central Arctic from Siberia towards the Canadian Archipelago which drive the trans-polar drift of sea ice. This pattern of wind generates high ice pressure along the western side of the Canadian Archipelago.

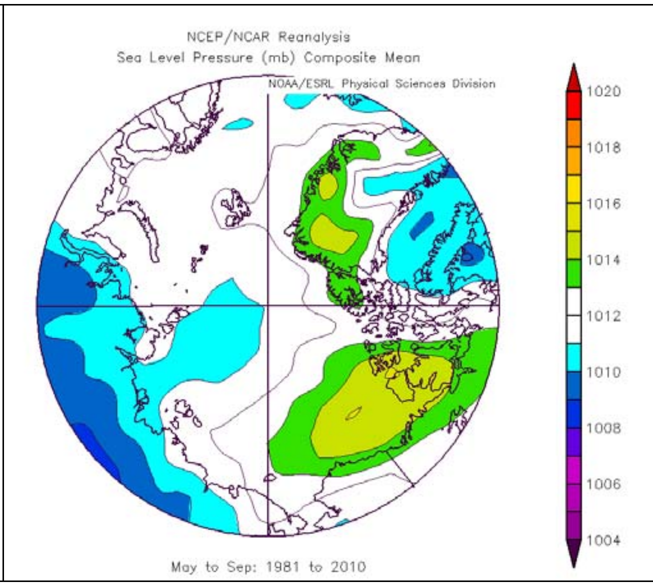
Recent anomalies in atmospheric pressure and winds are important factors underlying present ice and ocean conditions in the southern Beaufort Sea. Each of the seven summers has been different. Until 2013, the pattern in 2009 was most similar to the long-term average, although the anti-cyclone in the Beaufort and the winds driven by it were much stronger.

The pattern in 2013 was very similar to the long-term average – an elongated cell of high pressure stretching across the southern Canadian Archipelago and the southern Beaufort towards Wrangel Island. The central pressure was 1014 mb in contrast to 1020 in 2007; the south-north extent of the anti-cyclone was relatively small, so that wind along its northern flank was directed towards the Canadian Archipelago, not towards Fram Strait as was the case in all other years shown. Sea ice was less likely to be forced out of the Arctic this summer.

Figure 15 Contoured plots of air pressure at sea level averaged over the months of May through September, individually for 2006 through 2012, and then as an average over 30 years (lower right). Data from the NCEP re-analysis project http://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl




NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Mean
NOAA/ESRL Physical Sciences Division
May to Sep: 2008
NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Mean
NOAA/ESRL Physical Sciences Division
May to Sep: 2009
NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Mean
NOAA/ESRL Physical Sciences Division
May to Sep: 2010
NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Mean
NOAA/ESRL Physical Sciences Division
May to Sep: 2011 to 2011
NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Mean
NOAA/ESRL Physical Sciences Division
May to Sep: 2012 to 2012
NCEP/NCAR Reanalysis
Sea Level Pressure (mb) Composite Mean
NOAA/ESRL Physical Sciences Division
May to Sep: 2013
1020
1018
1016
1014
1012
1010
1008
1006
1004



Narrative

Date	Day	Activity
24-Sep	Tue	10 team members travel from Victoria to Cambridge Bay via CCG charter flight. 4 members travel via commercial carrier from Yellowknife. This flight does not land at Cambridge Bay because of a mechanical problem. Sir Wilfrid Laurier remains in Cambridge Bay overnight on hope of loading these travellers tomorrow.
25-Sep	Wed	Cloud & fog in Cambridge Bay preclude arrival of personnel from Yellowknife. Travellers charter a small aircraft (4 people, 900 lb of cargo) & fly to Kugluktuk. Laurier departs Cambridge Bay at 0730 bound for Kugluktuk.
26-Sep	Thu	Laurier arrives at Kugluktuk at 0800 in fine weather. Travellers & cargo are loaded via helicopter by 0900. Laurier continues westward. 1500: Melling & Poole travel ashore via helicopter at Bernard Harbour to calibrate ADCP compasses
27-Sep	Fri	1800: Recover CB12 mooring near Cape Bathurst in heavy fog. Deploy replacement. CTD
28-Sep	Sat	Overnight transit slowed by fog. 1000: Recover SIC12-2 mooring at shelf edge. Deploy replacement. No CTD here - leaking touch-switch connector. 1600: Launch AUV for dive #1 at shelf edge 15 mi west of SIC12-2. Launch ROV for dive #1, nearby ... aborted at 70-m depth after total system failure - leak. Evening: Complete transect of 6 CPT/core-geoT sites across shelf edge.
29-Sep	Sun	0930: Recover AUV (90 min operation). 1045: Launch ROV for dive #2 at shelf edge 70 56.162'N 134 26.725'W; recovered 12:20. 1415: AUV dive plan abandoned in presence of ice. 17:30: Recover BREA mooring BR-A-12 (70 min operation). Evening: Complete transect of 6 CPT/core-geoT drops at Coke Cap exlusion feature.
30-Sep	Mon	Overnight transit to BREA site BR-B. 0700: Recover BR-B mooring (60 min operation). 0930: Recover IOS mooring at MGH12-1 (45 min operation). 1215: Launch AUV for dive #2, survey of landslip feature. 1340: Launch ROV for dive #3 at head of landslip 70 42.028'N 136 13.951'W; recovered 1740 (4 hours). Evening: Complete transect of 4 CPT/core-geoT drops across the 'NE' landslip.

01-Oct	Tue	0540: AUV surfaces before dawn. AUV on deck at 0840. 0900: Launch ROV for dive #4 at arcuate feature on the shelf-edge bulge (105 min operation). 1215: Launch ROV for dive #5 at EF420 expulsion feature(165 min operation). 1545: Launch AUV for dive #3, 14h survey of EF420. Monitor dive until 1645. 1730: Piston core downslope of EF420 (90 min operation).
02-Oct	Wed	0700: At shelf edge south of EF420, awaiting AUV in heavy fog. 0800: Close-in on & recover AUV (30 min operatiopn). 0930: Launch ROV for dive #6 at the W end of the shelf-edge bulge (120 min operation). 1230: Launch ROV for dive #7 several miles further east on the shelf-edge bulge (150 min operation). 1500: Transit through heavy fog to AUV launch location. 1540: Launch AUV for dive #4 mapping at shelf-edge area near BR-G (15 hours). 1730: Launch ROV for dive #8 at the shelf edge near BR-G (90 min operation). Evening: Complete transect of CPT/core-geoT drops across Coke Cap.
03-Oct	Thu	0730: At AUV recovery location - send command to abort the mission & recover AUV (100 min operation). 1015: Recover BREA mooring at site BR-G (35 min operation). 1200: Launch ROV for dive #9 at 'W' landslip 71 00.292'N 135 44.902'W, 900 m (500 min operation); water seeps with biological aggregations & glacial till found here. 1805: Launch AUV for dive #5 mapping 'NE' landslide valley (14.5 hours). Evening: 5 core-geoT sites in this area (too deep for CPT) starting 1800. 1930: At AUV launch point for dive #6, 70 47.07'N 136 07.05'W. AUV. 2040 on bottom. 2100: Transit overnight to SIC12-9 mooring site.
04-Oct	Fri	0700: At AUV recovery location near landslip 'W'. 0800: Establish communication with AUV. Tranmsit mission-abort signal & recover AUV (30 min operation). 0900; Launch ROV for dive #10 on SW side of landslip 'NE'. Up once to permit ship's manoeuvring in ice. Back down. Up at noon in fog. 1310: Start piston coring at landslip 'NE'. 1600: 2nd core on board. 1600: Transit to 760m expulsion feature. 1930: Launch AUV for dive #6 on 760m expulsion feature. Evening: Core-geoT dropsover landslip 'NE' (too deep for CPT).
05-Oct	Sat	0630: Standing by for daylight at SIC12-9. CTD profile. 0805: Start recovery of 2 moorings (10 min operation). 0830: Start deployment of 2 moorings (15 min operation). 0850: Transit to site SIC12-1 (18 mi). 1030: Recover & deploy 2 moorings, complete CTD (45 min operation). 1115: Full speed to AUV pick-up point. 1505: AUV in sight. 1520: AUV on board. 1525: Transit to EF720. Complete 3 CPT/core-geoT drops at EF720. 1920: Launch AUV for dive #7 at 420m expulsion feature, 70 47.24'N 135 31.91'W Evening: Complete 6 CPT, core-geoT sites across EF420 (MS01 … MS06).
06-Oct	Sun	0440: AUV surfaces in darkness. Wind SE 20 kt with developing sea. Recover AUV in rough water (30 min operation, at some risk to AUV). 0945: At ROV dive site, but sea conditions to rough to dive. Transit NE, then N, then W, then S to the shelter of an ice strip "C Cod" (5.5 hours) 1550: Launch ROV for dive #11 at the shelf edge near BR-G (90 min operation). No AUV survey because of concern about nearby ice & water depth exceeding 1000 m (rescue constraint). Evening: Complete core-geoT sites across landslip 'W'
07-Oct	Mon	0700: Standby at EF420 for coring. Wind E 15-20 kt. Morning coring/geoT of EF420, using USBL tracking system for accurate knowledge of drop sites. 1300: Launch ROV for dive #12 at EF420 (180 min operation) 1630: Transit to AUV launch point near landslip 1800: Launch AUV for dive #8 over landslip Overnight: Shallow seismic run to PLF (42 m) north of Kopanoar, grid survy of this feature.

08-Oct	Tue	0800: Lauch ROV for dive #12 on a shelf-edge moraine (70 34.17'N 136 02.38'W) 1000: Launch ROV for dive #13 on the upper part of the landslip 1220: Recover AUV 1300: Launch ROV for dive #14, collecting rocks at 70 34.10'N 136 02.66'W 1430: Retrieve ROV. Strat coring in somae area. 1615: Halt to coring in building wind (25G30) & seas - bowthruster overheating. Overnight run via Kopanoar PLF to SIC12-11, operating chirp sub-bottom sonar.
09-Oct	Wed	0730: Recover, refurbish & deploy 1 mooring, complete CTD (3-hour operation). 1030: Transit to BR-2. 1300: Recover 1 mooring, complete CTD (1-hour operation). 1400: Slow-speed transit east along 70N to Garry Knolls, running seismic. 1630: Cancel planned dive on a depression within the PLF corrider - too much swell. Evening: Coring & CPT across ROV dive target. Standby overnight
10-Oct	Thu	0740: Launch ROV for dive #15 in PLF corrider 69 59.429N 137 15.488'W 0915: Transit to Chevron lease block. 1235: Launch ROV for dive #16 on a valley at 1000m depth 70 31.3633n 138 53.7468W (4-h operation). 1630: Transit to BR-1. 1730: Recover ArcticNet mooring at BR-1. Complete CTD. Overnight transit to Clarence Lagoon.
11-Oct	Fri	1000: Offshore Clarence Lagoon. Science teams ashore by helicopter for calibration of compasses & for collection of geological samples (3 h operation). 1300: Transit WNW
12-Oct	Sat	1000: Anchored NE of Cross Island. Start transfer of geological team to Deadhorse via helicopter - 4 flights (3.5-h operation). 1355: Anchor up. Laurier transiting WNW towards AIM site (14 kt, 2 engines 'til nightfall)
13-Oct	Sun	0700: Laurier at 72 12'N north of Point Barrow, 11 kt on 300T, on route to AIM site
14-Oct	Mon	1000: In ice at AIM site, checking drift 1100: Start ice management updrift of AIM. 1320: Positioned to work the AIM site (90 min operation, recover, deploy, CTD). 1500: Southbound for Bering Strait.
15-Oct	Tue	0700: Position 72 13'N 166 54'W. 11.6 kt with a following sea.
16-Oct	Wed	0700: 67 26'N 168 47'W 1600: Bering Strait 1745: Reached site of AOOS wave buoy, but wind (25 kt) and sea (2 m) too difficult to attempt its recovery
17-Oct	Thu	0700: 62 02'N 168 15'W
18-Oct	Fri	0700: Wind S 35 kt. Ship slowed to 4 kt. 190 miles to Dutch Harbor
19-Oct	Sat	1100: Anchored in Dutch Harbor. Wind SE 35 kt, too strong to approach fuel dock
20-Oct	Sun	Take on 500 T fuel 2130: Laurier leaves the fueling dock
27-Oct	Sun	0630: Laurier off Albert head 48 23.1'N 123 27.1'W

Appendix 1: Locations of moorings: Beaufort & Chukchi Seas 2013-14

Site	Area	Latitude			Longitude			Water depth (m)	Buoyed levels	Instruments
CB13	**Franklin Bay**	70	33.7550	N	127	41.6790	W	38	1	WH600, SBE37
SIC13-1	**Mackenzie shelf**	70	20.0300	N	133	44.3660	W	55	1	IPS
SIC13-1	**Mackenzie shelf**	70	20.0400	N	133	44.4500	W	55	1	ADCP, SBE37
SIC13-2	**Mackenzie shelf**	70	59.3570	N	133	44.6490	W	111	2	IPS, ADCP, SBE37
SIC13-9	**Mackenzie shelf**	70	03.5400	N	133	42.9160	W	35	1	IPS, SBE37
SIC13-9	**Mackenzie shelf**	70	03.5080	N	133	42.9320	W	35	1	ADCP
SIC13-11	**Mackenzie shelf**	69	46.4690	N	137	02.7700	W	36	1	IPS, SBE37
AIM13-1	**Chukchi plateau**	75	05.2953	N	168	01.3589	W	163	4	IPS, ADCP, AURAL, 2x SBE37

Appendix 2: Locations of CTD/rosette profiles: Sep-Oct 2013

Conseq No	Station	Latitude		Longitude		Depth, m	Date time utc
2013-22-0001	CB13	70	33.70	127	41.69	38.9	28-Sep-2013 00:56
2013-22-0002	AUV-DP1	70	55.40	134	29.53	91.6	28-Sep-2013 21:55
2013-22-0003	BR-A	70	44.57	136	01.68	614.8	30-Sep-2013 01:59
2013-22-0004	BR-B	70	40.11	135	34.43	138.0	30-Sep-2013 14:16
2013-22-0005	MGH12	70	38.78	135	57.30	280.2	30-Sep-2013 17:01
2013-22-0006	BR-G	71	00.61	135	31.30	719.2	03-Oct-2013 18:31
2013-22-0007	SIC13-9	70	03.51	133	42.82	32.6	05-Oct-2013 14:29
2013-22-0008	SIC13-1	70	19.93	133	44.50	54.8	05-Oct-2013 17:15
2013-22-0009	SIC13-11	69	46.45	137	03.15	34.5	09-Oct-2013 14:36
2013-22-0010	BR-2	69	59.22	137	57.40	154.4	09-Oct-2013 19:51
2013-22-0011	BR-1	70	25.89	139	02.03	759.9	11-Oct-2013 01:51
2013-22-0012	AIM13-1	75	04.57	168	01.83	163.1	14-Oct-2013 22:13

Appendix 3: Locations of geoscience stations (PGC Cruise 2013-005)

StnNum	Latitude			Longitude			ExtNum	Type
STN002	70	56.15940	N	134	26.75370	W	MBARI MINIROV D13	ROV
STN003	70	58.05816	N	134	20.59662	W	GC01	Gravity and Heat Probe
STN004	70	58.06182	N	134	20.61858	W	NULL	FreeFallPenetrometer
STN005	70	56.31222	N	134	25.17582	W	GC02	Gravity and Heat Probe
STN006	70	56.29122	N	134	25.14864	W	NULL	FreeFallPenetrometer
STN007	70	56.00280	N	134	25.84170	W	GC03	Gravity and Heat Probe
STN008	70	56.00556	N	134	25.79226	W	NULL	FreeFallPenetrometer
STN009	70	55.92900	N	134	26.01198	W	GC04	Gravity and Heat Probe
STN010	70	55.92684	N	134	26.04216	W	NULL	FreeFallPenetrometer
STN011	70	55.64532	N	134	26.74440	W	GC05	Gravity and Heat Probe
STN012	70	55.64988	N	134	26.73342	W	NULL	FreeFallPenetrometer
STN013	70	55.04016	N	134	28.09752	W	GC06	Gravity and Heat Probe
STN014	70	55.03284	N	134	28.14330	W	NULL	FreeFallPenetrometer
STN016	70	56.16996	N	134	26.65230	W	MBARI MINIROV D14	ROV
STN017	70	38.69766	N	135	56.12622	W	GC07	Gravity and Heat Probe
STN018	70	38.69754	N	135	56.12664	W	NULL	FreeFallPenetrometer
STN019	70	38.77002	N	135	56.35998	W	GC08	Gravity and Heat Probe
STN020	70	38.77002	N	135	56.38002	W	NULL	FreeFallPenetrometer
STN021	70	38.87874	N	135	56.65164	W	GC09	Gravity and Heat Probe
STN022	70	38.87622	N	135	56.64930	W	NULL	FreeFallPenetrometer
STN023	70	38.95002	N	135	56.94000	W	GC10	Gravity and Heat Probe
STN024	70	38.95002	N	135	56.94000	W	NULL	FreeFallPenetrometer
STN025	70	38.99184	N	135	57.04998	W	GC11	Gravity and Heat Probe
STN026	70	38.98998	N	135	57.04998	W	NULL	FreeFallPenetrometer
STN027	70	39.13140	N	135	57.47322	W	GC12	Gravity and Heat Probe
STN028	70	39.13998	N	135	57.46002	W	NULL	FreeFallPenetrometer
STN030	70	42.00828	N	136	13.96902	W	MBARI MINIROV D15	ROV
STN031	70	42.09000	N	136	14.45010	W	GC13	Gravity and Heat Probe
STN032	70	42.03000	N	136	14.01000	W	GC14	Gravity and Heat Probe
STN033	70	41.93550	N	136	13.46568	W	GC15	Gravity and Heat Probe
STN034	70	41.80200	N	136	12.60000	W	GC16	Gravity and Heat Probe
STN035	70	41.64000	N	136	11.19000	W	GC17	Gravity and Heat Probe
STN037	70	34.02288	N	136	03.44556	W	MBARI MINIROV D16	ROV
STN038	70	36.09180	N	135	43.95450	W	MBARI MINIROV D17	ROV
STN040	70	50.26140	N	135	24.36432	W	PC01	PistonCore
STN041	70	47.98002	N	135	35.38002	W	NULL	Gravity and Heat Probe
STN042	70	47.97780	N	135	35.36292	W	NULL	FreeFallPenetrometer
STN043	70	47.62068	N	135	33.50622	W	NULL	Gravity and Heat Probe
STN044	70	47.62002	N	135	34.12002	W	NULL	FreeFallPenetrometer
STN045	70	47.52000	N	135	33.64998	W	NULL	Gravity and Heat Probe
STN046	70	47.51310	N	135	33.63150	W	NULL	FreeFallPenetrometer
STN047	70	47.40402	N	135	33.39000	W	NULL	Gravity and Heat Probe
STN048	70	47.42340	N	135	33.32340	W	NULL	FreeFallPenetrometer
STN049	70	47.30832	N	135	32.91120	W	NULL	Gravity and Heat Probe
STN050	70	47.31132	N	135	32.88486	W	NULL	FreeFallPenetrometer
STN051	70	46.78002	N	135	30.85998	W	NULL	Gravity and Heat Probe
STN052	70	46.75998	N	135	30.88002	W	NULL	FreeFallPenetrometer
STN053	70	45.02646	N	135	16.73832	W	MBARI MINIROV D18	ROV
STN054	70	47.21820	N	135	14.82180	W	MBARI MINIROV D19	ROV
STN055	70	49.72950	N	135	06.41100	W	MBARI MINIROV D20	ROV
STN056	70	38.69760	N	135	56.88000	W	NULL	Gravity and Heat Probe
STN057	70	39.01254	N	135	56.95170	W	NULL	FreeFallPenetrometer
STN058	70	39.00654	N	135	57.02064	W	NULL	Gravity and Heat Probe
STN059	70	38.99508	N	135	57.05010	W	NULL	FreeFallPenetrometer
STN060	70	38.97006	N	135	56.94420	W	NULL	Gravity and Heat Probe

StnNum		Latitude			Longitude		ExtNum	Type
STN061	70	38.97522	N	135	56.94732	W	NULL	FreeFallPenetrometer
STN062	70	38.89938	N	135	56.64120	W	NULL	Gravity and Heat Probe
STN063	70	38.89788	N	135	56.64210	W	NULL	FreeFallPenetrometer
STN064	70	38.81004	N	135	56.35944	W	NULL	Gravity and Heat Probe
STN065	70	38.81580	N	135	56.33436	W	NULL	FreeFallPenetrometer
STN066	71	00.30108	N	135	44.85888	W	MBARI MINIROV D21	ROV
STN067	70	59.00142	N	135	40.55772	W	GC18	Gravity and Heat Probe
STN068	70	59.13792	N	135	41.09052	W	GC19	Gravity and Heat Probe
STN069	70	59.35998	N	135	41.89716	W	GC20	Gravity and Heat Probe
STN070	70	59.72100	N	135	43.18338	W	GC21	Gravity and Heat Probe
STN071	71	00.20952	N	135	44.98728	W	GC22	Gravity and Heat Probe
STN072	70	59.96568	N	135	46.24662	W	MBARI MINIROV D22	ROV
STN073	71	00.38610	N	135	45.34824	W	PC02	PistonCore
STN074	71	00.23742	N	135	44.96880	W	PC03	PistonCore
STN075	70	48.19836	N	136	05.93130	W	GC23	Gravity and Heat Probe
STN076	70	48.17730	N	135	05.91528	W	GC24	Gravity and Heat Probe
STN077	70	47.15868	N	136	07.05132	W	GC25	Gravity and Heat Probe
STN078	70	48.09330	N	136	05.90244	W	GC26	Gravity and Heat Probe
STN079	70	48.02136	N	136	05.89590	W	GC27	Gravity and Heat Probe
STN080	70	47.60688	N	136	05.82528	W	GC28	Gravity and Heat Probe
STN081	70	50.62560	N	135	08.30814	W	GC29	Gravity and Heat Probe
STN082	70	50.63040	N	135	08.31030	W	NULL	FreeFallPenetrometer
STN083	70	50.47086	N	135	07.84440	W	GC30	Gravity and Heat Probe
STN084	70	50.46462	N	135	07.86672	W	NULL	FreeFallPenetrometer
STN085	70	50.35548	N	135	07.57206	W	GC31	Gravity and Heat Probe
STN086	70	50.34882	N	135	07.59468	W	NULL	FreeFallPenetrometer
STN087	70	50.25012	N	135	07.36812	W	GC32	Gravity and Heat Probe
STN088	70	50.24826	N	135	07.35504	W	NULL	FreeFallPenetrometer
STN089	70	50.04864	N	135	06.84054	W	GC33	Gravity and Heat Probe
STN090	70	50.04924	N	135	06.82902	W	NULL	FreeFallPenetrometer
STN091	70	49.97526	N	135	06.52878	W	GC34	Gravity and Heat Probe
STN092	70	49.97178	N	135	06.52908	W	NULL	FreeFallPenetrometer
STN093	70	45.68400	N	136	33.15006	W	MBARI MINIROV D23	ROV
STN094	70	46.62576	N	136	34.49646	W	GC35	Gravity and Heat Probe
STN095	70	48.29094	N	136	33.27288	W	GC36	Gravity and Heat Probe
STN096	70	47.47896	N	135	33.84498	W	GC37	Gravity and Heat Probe
STN097	70	47.37300	N	135	33.85392	W	GC38	Gravity and Heat Probe
STN098	70	47.37162	N	135	33.86808	W	NULL	FreeFallPenetrometer
STN099	70	47.34174	N	135	33.94614	W	GC39	Gravity and Heat Probe
STN100	70	47.34030	N	135	33.95670	W	NULL	FreeFallPenetrometer
STN101	70	47.41938	N	135	33.63894	W	GC40	Gravity and Heat Probe
STN102	70	47.42220	N	135	33.62970	W	NULL	FreeFallPenetrometer
STN103	70	47.41908	N	135	33.73278	W	GC41	Gravity and Heat Probe
STN104	70	47.42256	N	135	33.73848	W	NULL	FreeFallPenetrometer
STN105	70	47.54424	N	135	33.39246	W	GC42	Gravity and Heat Probe
STN106	70	47.54946	N	135	33.37842	W	NULL	FreeFallPenetrometer
STN107	70	47.36574	N	135	33.85044	W	MBARI MINIROV D24	ROV
STN108	70	34.16808	N	136	02.38716	W	MBARI MINIROV D25	ROV
STN109	70	35.66856	N	136	04.93986	W	MBARI MINIROV D26	ROV
STN110	70	34.10130	N	136	02.65548	W	MBARI MINIROV D27	ROV
STN111	70	34.09116	N	136	02.50200	W	GC43	Gravity and Heat Probe
STN112	70	34.08966	N	136	02.49936	W	NULL	FreeFallPenetrometer
STN113	70	34.12272	N	136	02.57706	W	GC44	Gravity and Heat Probe
STN114	70	34.13226	N	136	02.57430	W	NULL	FreeFallPenetrometer
STN115	70	34.14120	N	136	02.56890	W	GC45	Gravity and Heat Probe
STN116	70	34.14024	N	136	02.56248	W	NULL	FreeFallPenetrometer
STN117	69	59.18754	N	137	16.48446	W	GC46	Gravity and Heat Probe
STN118	69	59.19318	N	137	16.50396	W	NULL	FreeFallPenetrometer
STN119	69	59.28906	N	137	16.03620	W	GC47	Gravity and Heat Probe

StnNum	Latitude			Longitude			ExtNum	Type
STN120	69	59.28738	N	137	16.03236	W	NULL	FreeFallPenetrometer
STN121	69	59.39286	N	137	15.71100	W	GC48	Gravity and Heat Probe
STN122	69	59.38854	N	137	15.72096	W	NULL	FreeFallPenetrometer
STN123	69	59.40306	N	137	15.65556	W	GC49	Gravity and Heat Probe
STN124	69	59.40288	N	137	15.65034	W	NULL	FreeFallPenetrometer
STN125	69	59.42628	N	137	15.55614	W	GC50	Gravity and Heat Probe
STN126	69	59.42070	N	137	15.56100	W	NULL	FreeFallPenetrometer
STN127	69	59.43612	N	137	15.48444	W	GC51	Gravity and Heat Probe
STN128	69	59.44134	N	137	15.48120	W	NULL	FreeFallPenetrometer
STN129	69	59.49660	N	137	15.16518	W	GC52	Gravity and Heat Probe
STN130	69	59.43060	N	137	15.45378	W	MBARI MINIROV D28	ROV
STN131	70	31.37190	N	138	53.90778	W	MBARI MINIROV D29	ROV
	70	35.01600	N	136	04.66200	W	Seabed survey	AUV
	70	47.47200	N	135	33.52800	W	Seabed survey	AUV
	70	50.89800	N	135	06.71400	W	Seabed survey	AUV
	71	00.11400	N	135	44.35800	W	Seabed survey	AUV
	70	47.88000	N	136	05.83200	W	Seabed survey	AUV