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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8493

2014 Canadian expedition to the North Pole, Arctic Ocean, expedition report

D.C. Mosher, J. Shimeld, P. Travaglini, and J. Eert

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2014 Canadian expedition to the North Pole, Arctic Ocean, expedition report

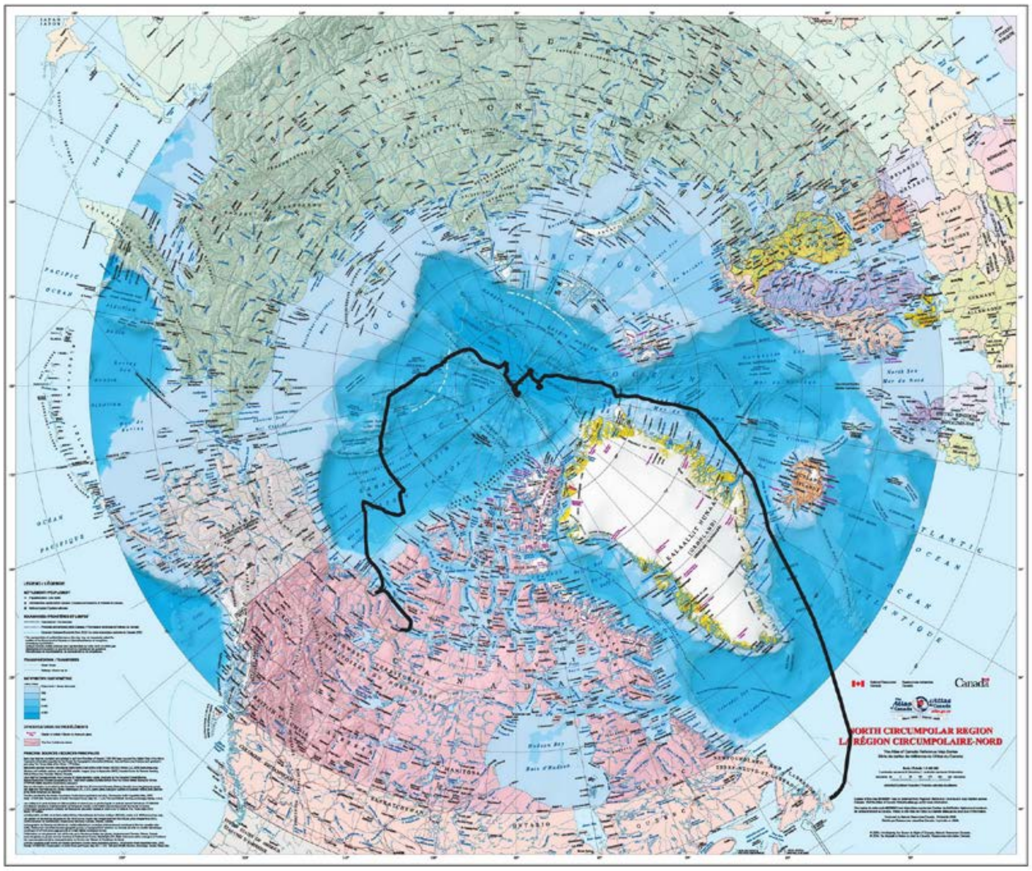
August 9 – September 17, 2014
St. John's, NL to Kugluktuk, NWT
CCGS *Louis S. St-Laurent*
and
CCGS *Terry Fox*

Captain Anthony Potts, Commanding Officer, CCGS Louis S. St-Laurent
Captain Duane Barron, Commanding Officer, CCGS Terry Fox
Dr. David C. Mosher, Chief Scientist

Executive Summary

The 2014 Canadian Polar Expedition objectives were to map the region of the Lomonosov Ridge and Amundsen Basin to meet criteria required by Article 76 of the UN Convention on the Law of the Sea. The intent is to establish Canadian entitlement for an extended continental shelf, extending from the Canadian 200 mile exclusive economic zone within Amundsen Basin. Additional objectives included continued mapping in Canada Basin to augment existing data and support Canada's arguments for an extended continental shelf in this region. The UNCLOS objectives require the capacity to acquire multichannel seismic reflection and refraction data along positions that serve to establish sediment thicknesses (within Amundsen Basin and Canada Basin) and multibeam bathymetric and subbottom profiler data to establish foot of slope positions and the 2500 m contour (along the flank of Lomonosov Ridge and the Canadian Arctic Archipelago margin). Secondary objectives included bathymetric sounding at specific locations to validate bathymetric data acquired by other means (e.g. satellite altimetry and submarines) in order to establish baseline information such as the 2500 m contour position. Scientific objectives included gathering data to understand the tectonic relationship of Lomonosov Ridge to surrounding basins; part of the tectonic puzzle of the Arctic Basin. Additionally, data were acquired to support mapping the surficial geology of the Arctic Ocean and specifically to better understand slope sedimentary processes on both Lomonosov Ridge and the Canadian Arctic Archipelago margin. Strategic ship track lines were established to complement existing data to meet UNCLOS and scientific objectives. In addition to the geoscience program, samples and measurements were taken of Arctic Ocean water for chemical and physical oceanographic studies. The complete ship's track is shown in the figure below.

Ice conditions in the region of Lomonosov Ridge were difficult. As a result, only one partial seismic line was acquired in Amundsen Basin and three foot of the continental slope points were surveyed in the region of the North Pole. Low fuel reserves required us to abandon this region prematurely and transit to Canada Basin to continue survey work in support of the western Arctic component of the Canadian submission. In total, 746 line-km of high quality multichannel seismic reflection data were acquired, in addition to seismic refraction data recorded from 13 Sonobuoy deployments. 8355 line-km of multibeam bathymetric and coincident subbottom profiler data were acquired. The physical/ chemical oceanographic portion of the program resulted in 2 Rosette water sample stations, 2 CTD/SVP casts and 127 XCTD casts.



2014 Canadian ExpeditionTrack Plot

St. John’s to Kugluktuk
August 9 to Sept. 17, 2014

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Chapter 1
Expedition Summary

Introduction

Canada ratified Article 76 of the International Convention on the Law of the Sea (UNCLOS) in 2003. This Article specifies a mechanism for defining the continental margins beyond the 200 nautical mile (M) limit. To assert sovereign rights beyond 200 M, a coastal State has ten years to collect the appropriate information and submit a case to the United Nations Commission on the Limits of the Continental Shelf (CLCS). Canada can exercise specified sovereign rights out to a distance of 350 M or further, if Canada can claim the extension as a natural prolongation of Canadian territory. Rights include jurisdiction in matters related to environment and conservation and powers over mineral and biological resources on and below the seabed.

In order to extend boundaries beyond the 200 M limit, Canada must acquire geophysical and geological data to define the limit of Canada's continental shelf as stipulated under UNCLOS article 76.. To this end, Canada has undertaken a program of data acquisition along a number of its frontier regions. Specific to this expedition, Natural Resources Canada (NRCan) and Fisheries Ocean Canada (DFO), acting on behalf of the Government of Canada, is operating a project in the Arctic Ocean to acquire necessary marine geophysical survey data. This 2014 expedition represent the seventh Canadian ship-based survey in the Arctic and the eleventh Arctic mission, including ice camps, for this purpose.

Objectives

The 2014 Canadian Polar Expedition objectives were to map the region of the Lomonosov Ridge and Amundsen Basin to meet criteria required by article 76 of the UN Convention on the Law of the Sea. The intent is to establish Canadian entitlement to the region within Amundsen Basin around the North Pole extending from the Canadian 200 mile exclusive economic zone. Additional objectives included continued mapping in Canada Basin to augment existing data and support Canada's arguments for an extended continental shelf in this region. The UNCLOS article 76 criteria require multichannel seismic reflection and refraction data along positions that serve to establish sediment thicknesses (within Amundsen Basin and Canada Basin), and multibeam bathymetric and subbottom profiler data to establish foot of slope (FOS) positions and the 2500 m contour (along the flank of Lomonosov Ridge and the Canadian Arctic Archipelago margin). Secondary objectives included bathymetric sounding to validate bathymetric data acquired by other means (e.g. satellite altimetry and submarines) in order to establish baseline information such as the 2500 m contour position. Scientific objectives included gathering data to understand the tectonic relationship of Lomonosov Ridge to surrounding basins; part of the tectonic puzzle of the Arctic Basin. Additionally, data were acquired to support mapping the surficial geology of the Arctic Ocean and specifically to better understand slope sedimentary processes on both Lomonosov Ridge and the Canadian Arctic Archipelago margin. Strategic ship track lines were established to complement existing data to meet UNCLOS and scientific objectives. In addition to the geoscience program, samples and measurements were taken of Arctic Ocean water for chemical and physical oceanographic studies.

Personnel

Scientific Personnel

2014 LSSL Expedition

1. David Mosher…Chief Scientist (GSC)
2. Paola Travaglini … Hydrographer in charge (DFO)
3. John Shimeld ….Seismic processing (GSC)
4. Des Manning … Mechanical Technical Support (GSC Chief Technician), compressor watch
5. Bob Murphy … Mechanical Support and compressor watch (GSC)
6. Patrick Meslin … Electrical (GSC) and watch keeping
7. Peter Pledge … Navigation/Networking/Engineering Support (GSC) and watch keeping
8. Walta Rainey … GIS support (GSC)
9. Kevin DesRoches … MB Acquisition and processing (GSC)
10. Borden Chapman … Technical Advisor (contract)
11. Dwight Reimer … Seismic watch keeping and EL support (contract)
12. Peter Vass …. Mechanical support tech (contract)
13. Ken Asprey … Mechanical Technical Support, compressor watch (contract)
14. Rodger Oulton … Mechanical support tech (contract), compressor watch
15. Nelson Ruben… Mammal observer and mechanical support (contract)
16. Dale Ruben…Mammal Observer (contract)
17. John Evangelatos … Watch keeping/Refraction processing
18. Kai Boggild … watch keeping (student – GSC)
19. Chris LeBlanc … MB/Bathymetry acquisition (DFO)
20. Jim Weedon … MB/bathymetry acquisition (DFO)
21. David Levy….Tech support/bathymetry acquisition (DFO)
22. Jane Eert …. Oceanographer (DFO)
23. Glenn Cooper ... Oceanographer (DFO)

CCGS Personnel

CCGSLouis S. St-Laurent

Anthony Potts, Commanding Officer
Donald Whitty, Chief Officer
Trevor Hodgson, First Officer
Kyle Hennebury, Second Officer
Baxter Stuart, Third Officer
Ron Collier, Chief Engineer
Joost Van Hardeveld, Chief Engineer
Gerald McDonald, Senior Engineer
Dylan Dominie, First Engineer
Todd White, Second Engineer
Jonathan Nowe, Third Engineer
Stuart Maclean, Fourth Engineer
Freeman Steves, VMM Engineer
Steve Tucker, Electrical Officer
Anthony Engbers, Electrical Officer
Tony Walters, Logistics Officer
Rico Amamio, Boatswain
Gary Morgan, Carpenter
Vince Mullett, Winchman
Llewellyn Oram, Leading Seaman
Paul Gillingham, Lead Seaman
Alain Monfils, Seaman
Chad Leriche, Seaman

Yuri Mikhailyuk, Seaman
Barney Noseworthy, Seaman
Craig Joe, Seaman
Keith Blake, Seaman
Kenneth Pettipas, E/R Technician
Cody Coleman, E/R Technician
Bradley Gillard, E/R Technician
Brandon Baker, E/R Mechanic
Cyril O'Brien, E/R Mechanic
Jeremy Lane, E/R Mechanic
Kody Critch, E/R Mechanic
Calvin Careen, E/R Mechanic
Bradley Keeping, E/R Mechanic
Kevin Power, Chief Cook
Sylvie Arbour, Storekeeper
David Bartlett, Storekeeper
SueAnn Pye, Second Cook
Jonathan Hoskins, Second Cook
Cheryl Benger, Second Cook
Deborah Hibbs, Steward
Justin Morash, Steward
Gregory Williams, Steward
Chad Hedderson, Steward
Kirk McNeil, Steward
Colin Lavalle, Helicopter Pilot
Paul Mosher, Helicopter Pilot
Jacques Lefort, Helicopter Engineer
Carey McGrath, Electronics Technician
Denis Lambert, Ice Observer
Claude Morency, Medical Officer
Elisabeth Paradis, Medical Officer
Tracy Clarke, Marine Architect
Jeffery Janes, Cadet – Electrical
Renee Hachey, Cadet - Engineering

CCGS Terry Fox
Duane Barron, Commanding Officer
Matthew Wheaton, Chief Officer
David Critch, First Officer
Emilie Belanger, Second Officer
Morgan Biggs, Third Officer
Justin Rideout, Third Officer
Morgan Begg, Third Officer

Nigel Hawksworth, Chief Engineer
Todd Courtney, Senior Engineer
Boyd French, Senior Engineer
Kenneth Oake, First Engineer
Perry Pike, Second Engineer
Eric Naugler, Electrical Officer
Trevor Baldwin, E/R Tech
Vincent Heam, Oiler
Jeffrey Simms, Oiler
Walter Lowe, Oiler
Israel Strickland, Boatswain
Wayne Stone, Leading Seaman
David Maher, Leading Seaman
Eugene Pretty, Leading Seaman
Perry Kirby, Leading Seaman
Randell Hayes, Logistics Officer
Lori Goodyear, Clerk/Storekeeper
Nicole Sweetapple, Chief Cook
Dolores Rumbolt, Asst. Cook
John Walsh, Steward
Heidi Wells, Ships Technician
Ghislaine Telemaque, Health Officer

Navigation - Data Interfacing, Distribution and Logging

The CCGS *Louis S. St-Laurent* (LSSL) is equipped with numerous key navigational instruments. The science GPS provides positioning information for the vessel and is aided with real-time differential corrections from a Marine Star Satellite system. The heading of the vessel is provided by a permanently installed gyro. The vessel is also equipped with a speed log sensor. The information from all of these systems is sufficient for scientific survey needs.

> Bridge GPS. NMEA GGA, GLL, VTG, ZDA, RMC - 4800 Baud 8,N,1
> Bridge Gyro. NMEA HDT - 4800 Baud, 8,N,1
> Bridge Speed Log. NMEA VHW - 4800 Baud, 8,N,1

The information from all of these sensors is output via an RS232 serial feed. These feeds originate on the bridge and are combined within a serial mux. The mux feed is then distributed to various locations on the vessel. Of particular interest are the mux data drops located in the Forward Laboratory and the Seismic Laboratory.

The hull mounted Knudsen Chirp 3260 is located in the forward lab. The science mux feed was input into the Knudsen computer to provide navigation data to the headers of the SegY formatted subbottom profiler data. The data from the Knudsen 3.5 were then distributed to the Seismic Lab over the network.

> Hull Mounted Knudsen 3260 Chirp Sounder. NMEA DBT - 4800 Baud, 8,N,1

The scientific navigation system was operated from the Seismic lab. All navigation applications were run from the Regulus navigation computer. The GSCA NavNet applications were installed and provided the primary input of all bridge sensor data as well as the sounder information from the forward lab. GSCA NavNet is designed to accurately timestamp/log/distribute all navigation input onto the Local Area Network (LAN).

Regulus Computer Applications:

GSCA NavNet IO - input GGA, GLL, ZDA, VTG, RMC, DBT,

- Seismic trigger timing.

GSCA NavNet IO - ouput GGA (at 9600 baud)

- to Frydecky backup Seismic triggering system.

GSCA NavNet Survey Manager.

- Monitor all navigation data traffic.

GSCA NavNet Master Logger.

- Logging all navigation traffic.

GSCA NavNet Serial Mux.

- Redistributes navigation data via a virtual serial port to Regulus.

Regulus Survey Build 4.8.21.

- Line running display and logging for compatibility with expedition database.

All other applications/systems requiring position information were able to access the navigation data via the network using GSCA NavNet Serial Mux. It should be noted that this application was installed on the GeoEel computer as well as various ArcGIS computers located on the vessel.

Performance Comments

The navigation data were very reliable. The only navigation concerns were related to the Regulus operation in the high arctic. Regulus can only use Mercator projection. In the high arctic the distortion on the display is significant. Regulus also has issues as it approaches the dateline. Ship's gyro was unreliable at high latitudes. The navigation software application "Fugawi" handled northern latitude displays much better than Regulus or Aldebaran.

Navigation - Display and Line Running

Regulus II Survey is primarily used for line running operations and data logging. During line running operations, the system has limitations associated with working in the high arctic regions. Specifically, all navigation is projected using Mercator projection. This results in distortions at the pole. The display will also have erratic artifacts when navigating near the data line. When in these operational areas, the vessel switched to Fugawi which is able to use a polar stereographic projection. During these times, Regulus was simply being used as a navigation logging system as the display was unreliable. In order to assess line running from the Seismic lab during these times, a separate computer running Arc (polar stereographic projection) with a GPS input was used.

Navigation - ShapeFiles/Ship Track Lines

Regulus II navigation files were converted using GSCA Navigation tool developed for ArcGIS 9.3 by Paul Fraser. The tool converts the navigation E files to A files then interpolates the A file to 10 second increments. The interpolated A files are then converted to Arc point and line shape files within ArcMap. This conversion tool is very useful to have during surveys as it allows visualization of the navigation files in ArcGIS.

The GSCA Navigation tool is only available for use in ArcGIS 9.3. For that reason, a laptop with the older version of ArcGIS was brought for processing navigation files. This tool must be recreated for use in ArcGIS 10.1 as NRCan has now migrated to this version of the GIS software.

Networking

The LSSL is internally networked via fibre optics. The vessel has two separate distinct networks; one for the ship and one for science purposes. It should be noted that the network is designed specifically to keep science and ship's networks separate with NO EXCEPTIONS.

The science network comprised a mix of computers with operating systems ranging from Windows XP to Windows 7 and Ubuntu. The network workgroup was CCGLSL. The network was primarily used to transfer files from computer to computer as well as a backbone for transferring real time navigation data using GSCA NavNet. Ultra VNC was used to operate several computers remotely. Namely, the Hurricane Compressor computers (HC1,HC2), the WinRadio Computer located in the Radio Room and the Knudsen 3260 located in the forward lab. All computers on the network were allowed to use dynamic IP addresses. In addition, the Symmetricom NTP server was installed on the network with a static IP. Several networked printers were also installed in the Boardroom.

SonoBuoy/WinRadio setup

SonoBuoy signals were acquired using one of two Yagi antennas mounted on the mast of the Louis S. St. Laurent. The antenna cables were run to an AB antenna switch located in the crow's nest. The antenna signal cable was then run from the AB switch, down the mast and into the Radio Room to a WinRadio receiver (WR-G39WSB). The WinRadio was configured and running on a computer in the Radio room called ***WinRadio***. The WinRadio computer was also running a copy of the *GSCA Antenna Switch* application. This application communicates with the *WinRadio* computer using RS232 and powers the AB switch relay through a GSCA custom microcontroller board called the "**Gizmo v1.0**". Using this application, it is easy to switch between forward and aft looking Yagi antennas. The *WinRadio computer* was controlled from the Seismic lab using UltraVNC. The seismic watch keeper was then able to control and monitor the WinRadio computer while using the SonoBuoys. Signals from WinRadio (SonoBuoy in operation) were then run over a length of RG-6 from the radio room to the seismic lab. Data logging of the sonobuoy received signals was accomplished using the GSCA Portable Digitizer.

Performance Comments
The system performed well, but there is room for improvement. Reconfiguring the system such that a forward and aft sonobuoy can be logged simultaneously would be beneficial. One must be careful with the selection of sonobuoy channels. Several have a background noise (84, 85). Channel 86 appears optimum from a range standpoint. All channels are adversely affected by VHF radio communications on channel 19. There are also intermittent broadband noise bursts which appear on some records, the source of which was never determined. The manufacturer of the sonobuoy should be consulted regarding this noise.

General Recommendations (for subsequent years)

- Buy Fugawi, for exclusive navigation use.

- Buy Global Mapper, for exclusive navigation use.
- Put together a real NavNet Server system in the forward lab. Digi multiport USB to serial converter (minimum 8 ports).
- Interface the POS/MV output into NavNet as well (full real time positional/heading redundancy).
- Separate computer with multiple screens/display adapters for VNC viewing.
- Improve WinRadio setup so that it can log a forward as well as aft sonobuoy at the same time.
- Obtain a small hand held radio which can be tuned to sonobuoy frequencies. To be used when deploying sonobuoys from a helicopter to confirm that the sonobuoy is transmitting.
- NAS. For science data backup. Mirrored RAID.
- Upgrade the Gizmo board for better installation mounting.
- Investigate moving the 3.5 Hull Mount Knudsen array to the UNUSED 12k Hz bay.
- Investigate Sonobuoy noise bursts with Ultra Electronics input.
- Digital Datalink transmitter/receiver (fibre optic) for triggers? Knudsen trigger synching and SonoBuoy triggers.
- Upgrade computers in the Seismic lab (they are ancient).

Seismic Reflection and Refraction

The LSSL acquired multichannel seismic reflection and sonobuoy refraction data. The four major equipment categories for seismic data acquisition are:

- Tow sled and G-gun equipment;
- Compressor and air distribution system;
- GeoEel streamer system;
- Sonobuoy system;

The seismic source was an 1150 in^3 pneumatically charged array (Fig. 1.1) of three Sercel G-guns. A square wave trigger signal was supplied to the firing system hardware by a FEI-Zyfer GPStarplus Clock model 565, based on GPS time (typically about 15 seconds). Gun firing and synchronization was controlled by a RealTime Systems LongShot fire controller, which sent a voltage to the gun solenoid to trigger firing. There was an approximate 54.8 ms delay between trigger and fire point.

Pressurized air for the pneumatic G-guns was supplied by one of two Hurricane compressors, model 6T-276-44SB/2500. These are air cooled, containerized compressor systems. Each compressor was capable of developing a total air volume of 600 SCFM @ 2500 PSI. The seismic system was operated at 1950 PSI and one compressor could easily supply sufficient volume of air under appropriate pressure. Both compressors were used during the mission with no significant issues. Compressor #1 had freezing in the air vent piping which damaged the piping and heat wrap wiring.

The compressors are housed in two oversize containers mounted port and starboard on the aft-quarter of the LSSL. These containers were modified in 2014 to allow for greater air flow for cooling. The ends were vented and the roof was made detachable. This modification proved to be successful and no cooling fan issues were noted.

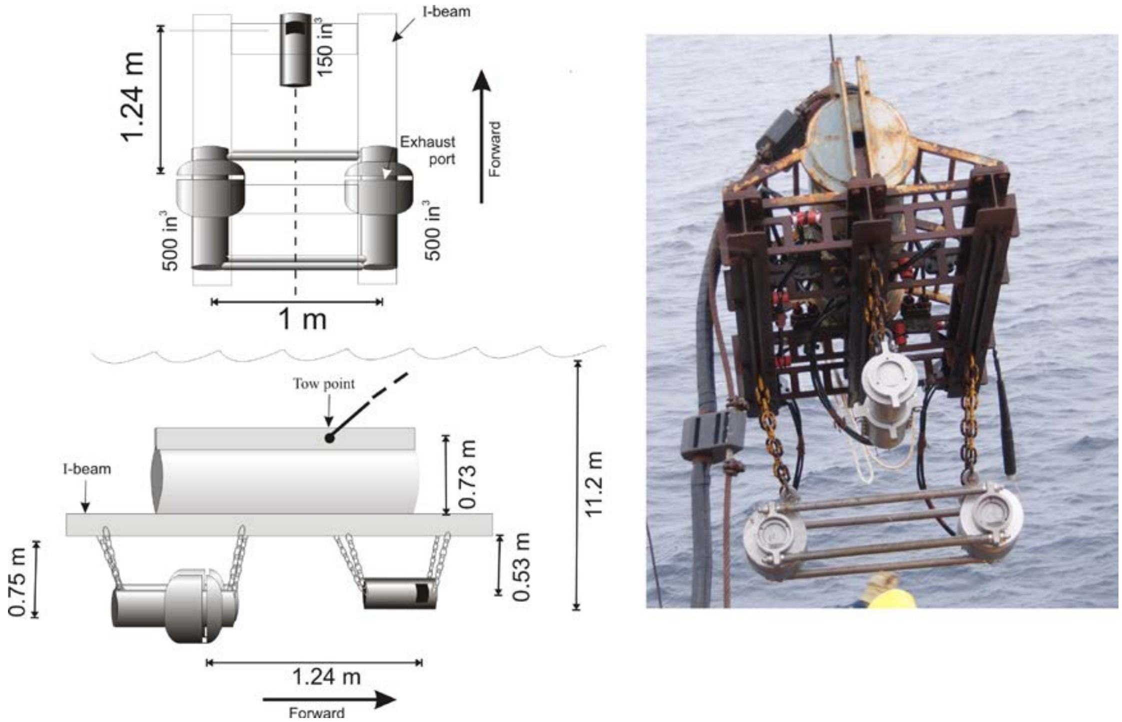


Figure 1.1. G-gun array design and photo of it being deployed.

Seismic acquisition required a watch keeper in the seismic lab and another in the compressor container at all times. The seismic lab watch keepers (Reimer, Meslin, Pledge and DesRoches) were responsible for data acquisition/recording, watching over-the-side equipment, gun firing and log keeping. As well, a remote screen permitted monitoring compressor pressures and alerts as well as communicating with the compressor watch-stander. Compressor watch keeping (Asprey, Murphy and Oulton) were required to watch over the compressor for any failures for emergency shut down and provide general maintenance that might be required during operations. During much of the program, the ambient air temperature was below zero degrees Celsius, and with the high air flow rate through the enclosure, the working environment within the compressor container was uncomfortable.

Seismic Reflection

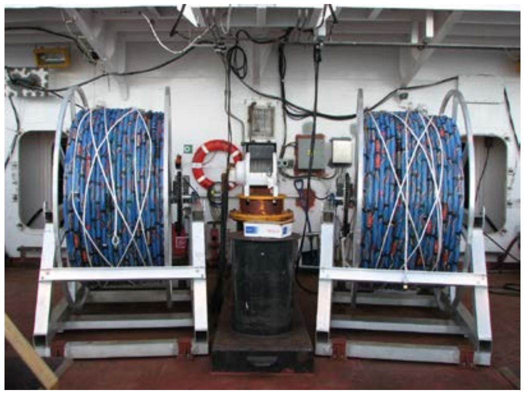


Figure 1.2. Two Geometrics GeoEEL Streamers on the quarter deck of the LSSL.

Seismic reflection signals were received on a 16-channel Geometrics GeoEel digital streamer system (Fig. 1.2). The streamer was towed from the aft end of the G-gun tow sled at a depth of 11.2 m. Two active 150 foot streamer sections were included in the overall streamer configuration. Total streamer length was approximately 300 m. See Figure 1.3 for the towing geometries. Two identical streamer systems were assembled for the 2014 program and were deployed and recovered by hand. In the past, it was found the winches were too slow to deploy and recover the streamer and the streamer would pinch in the ice. It was found more effective to deploy and recover by hand. The float section of each streamer frequently failed at the forward connector, possibly due to continuous flexing during towing operation. A Sonardyne acoustic release was employed this year on the streamer. Weights were attached to the release at the end of the streamer, allowing the streamer to sink vertically on deployment. When released, the weights would fall and the streamer would float to horizontal position once the ship was underway. This system proved extremely effective at eliminating streamer pinching in the ice.

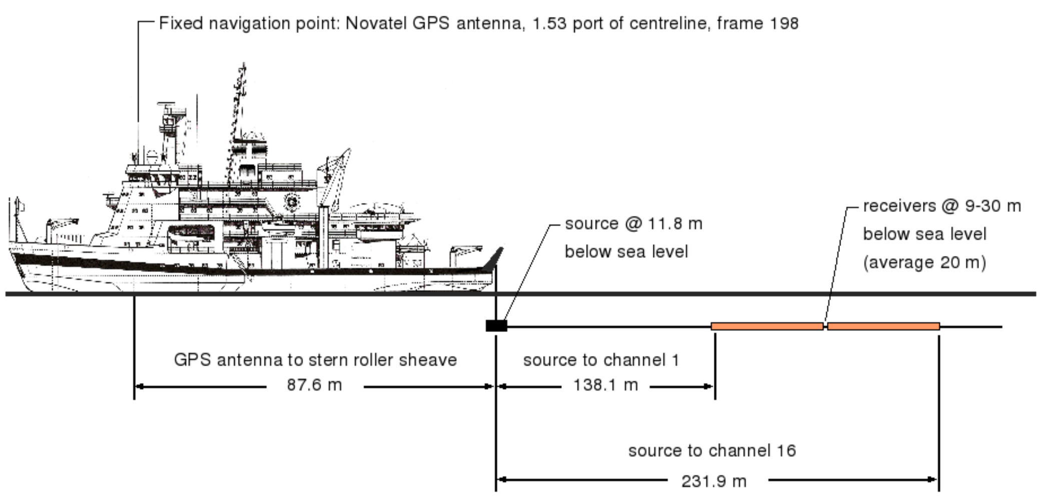


Figure 1.3. Geometric arrangement of the seismic reflection equipment

The active elements in the GeoEel streamer were Benthos Geopoint hydrophones. There were eight groups of four Geopoint hydrophone cartridges in each active section. Thus, with two active sections, this streamer had a total of 16 active channels, each with four Geopoint cartridges. Seismic signals received by the hydrophone elements in the streamer were digitized by 24 bit A/D modules which form part of the streamer system. Digitized seismic signals were sent up the cable as USP data packets to the recording system. A Geometrics software program called Stratavisor provided streamer control, logging and display of the data. Stratavisor version 5.30 was implemented for most of the 2014 program. Flooding and damage in the section couples and repeaters in the streamer caused issues that appeared to be software related. With this digital streamer, it is difficult to troubleshoot between software and hardware issues as there are no diagnostics in the software. All section couples required significant attention during streamer assembly and maintenance.

Included in the Stratavisor software was a streamer depth monitoring option. Depth sensors were fitted inside the forward end of each active section. The active section tow depth was displayed on the Stratavisor monitoring software. These sensors did not work and when they appeared to work, displayed erroneous values. Wooden floats were added to cover the A/D and repeater modules (Fig. 1.4). These floats added significant buoyancy to the streamer and helped immensely in maintaining appropriate tow depths.

Seismic reflection data tracks for all UNCLOS ECS surveys from 2007 to 2014 are shown in Figure 1.5. The 2014 data are shown in red. These seismic reflection data were post-processed using Claritas seismic processing software (see Chapter 3). Original SEG-D files were assembled into line segments and converted to SEG-Y format. Brute stacks were generated at sea and printed for QC. Data quality was excellent for the most part. Heavy ice conditions requiring extra propeller revolutions created most of the noise apparent on seismic data. Final post-processing was also completed at sea and included bandpass filtering (2/5/160/240), debias, trace binning, F-K filtering, trace editing based on signal to noise conditions, minimum phase conversion and source signature and gapped deconvolution, CMP Sort and stack, poststack filtering, FK filtering for multiple attenuation, F-X running mix coherency filter, despike, 5 trace mix, Stolt migration at water velocity (1480 m/s), SVD coherency filter and muting to water bottom. See Figure 1.6 for a comparison of brute stack and processing seismic results and the Chapter on Seismic processing by Shimeld for the full reflection report.

Figure 1.4. Cedar float that attaches over the repeater and A/D units.

Reflection Results

Twelve seismic reflection lines totalling 746 km were acquired (Figure 1.5; Table 1.1). Data were generally of high quality (Fig. 1.6). Data degradation occurred principally in heavy ice conditions. In Amundsen Basin, the CCGS *Terry Fox* (Fox) was unable to break ice ahead of the CCGS *Louis S. St-Laurent* (LSSL). The Fox was too light and could not break a track wide enough for the LSSL to follow while towing seismic equipment. Early attempts with this configuration resulted in irregular line patterns and narrow tracks. As a result, the LSSL would use too many revs on its propellers, causing damage to the hydrophone streamer. A resolution to this issue required the LSSL to break ice ahead for a number of km, then return, then deploy seismics and then follow the Fox up the already broken track. Even with this solution, the Fox would have to frequently return to assist the Louis and line patterns were rarely straight. Frequent flooding of the streamer – generally at the connector where the streamer attaches to the sled, was encountered.

With the purpose of establishing 1% sediment thickness points in Amundsen Basin, the sediment thickness map of Dossing et al. (2014) was used to guide locations of seismic lines. The first attempt was to run a line (Line 1401) orthogonal to LR from the base of Gakkel Ridge towards the Lomonosov Ridge starting at about 87° 24'N and 19° 22'E on the morning of August 21. By early evening, the streamer had failed and the gear was recovered after completing about 31 km of data in a rather irregular line pattern. The streamer was twisted around the gun sled. The line was continued with multibeam and chirp only but we were soon unable to make further progress towards the north. Turning back along our old track, we tried deploying the seismics again but the streamer failed after the first few shots (Line 1402).

Lines 1403 and 1404 form a strike line paralleling Gakkel Ridge in an attempt to cross features that meet the 1% criteria. To accomplish this, the LSSL broke ice ahead, then returned and deployed gear and surveyed back up its own track with the Fox in the lead. Heavy ice eventually forced a shut down as the streamer had failed. On recovery the streamer was tangled around the sled with about three wraps. About 88 km had been made with the two lines.

Line	Start time	End time	Start Shot	End Shot	Start Lat	Start Long	End Lat	End Long	length (km)
LSL1401	143243	220318	1	2153	87.404561	19.275866	87.599520	16.593313	30.76
LSL1402	024558	025203	2154	2180	88.127131	-7.627556	88.126646	-7.582199	0.19
LSL1403	172223	191328	2181	2648	88.115430	5.210505	88.092613	7.939776	10.92
LSL1404	225013	164008	2649	6259	88.110076	7.905569	88.459588	22.677701	77.47
LSL1405	050148	091158	6260	7096	88.080144	44.214480	88.184512	43.725131	17.84
LSL1406	192303	232358	7097	7729	88.742758	43.890006	88.835548	45.047683	14.75
LSL1407	032338	113558	7730	9337	88.821348	45.268332	88.974631	44.177907	23.93
LSL1408	221308	013933	9338	9930	89.109734	44.864162	89.262917	45.075989	18.87
LSL1409	104008	174818	9931	10782	89.430978	46.791013	89.688868	50.439650	32.74
LSL1410	141018	214308	10783	12213	89.476182	-40.693493	89.288581	-74.019415	47.67
LSL1411	040823	130758	12214	23427	77.526054	-153.90709	77.391272	-137.133589	420.78
LSL1412	013723	094208	23428	24991	75.551332	-131.98183	75.348936	-133.534035	49.94

Table 1.1 Line start and end

Lines 1405 to 1409 form a discontinuous line heading north toward LR. In each deployment, the LSSL had run ahead to break a track first. In each case, the streamer eventually failed at the forward connector. Heavy ice breaking requiring undo revs on the propellers and too much stress on the seismic system is the ultimate cause of the streamer failures. An attempt to run a seismic line from the North Pole to the Lomonosov Ridge failed as we were unable to break through ice floes.

Line 1410 is a 47 km-long seismic line at the base of LR. It was acquired from Amundsen Basin toward the ridge where tracks were opened while surveying for a foot of slope point. We had excellent results on this line with no streamer failures. On recovery of the sled, however, the crimping on the lift wire failed. No further seismic lines were acquired in Amundsen Basin as we were forced to leave the survey area due to heavy ice and low fuel conditions.

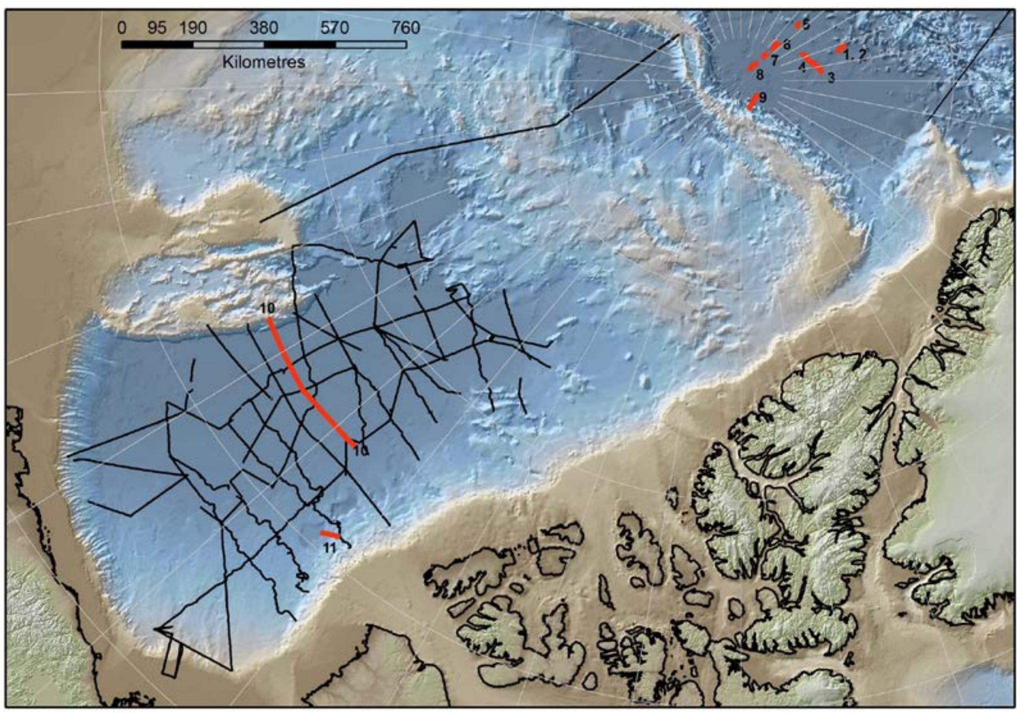


Figure 1.5. Map showing seismic track (red lines) and line numbers. Black lines represent seismic data acquired during the 2007 and 2011 LSSL programs.

Line 1411 forms a 421 km-long seismic profile across Canada Basin, from Northwind Ridge toward the Canadian Archipelago margin. The intent was to pick up a sediment thickness point close to Northwind Ridge that was unobtainable in the original submission due to a data gap, and proceed across the basin to get a good section over the extinct spreading ridge, then cross a FOS point on the Canadian margin and tie into the 2500 m contour off the archipelago. We acquired high quality data across the basin and tied into an existing survey line on the Canadian margin, but ice continued to thicken as we proceeded east. We had to pull the gear on the morning of September 11 as ice was too heavy to make progress with the seismic gear. In heavy ice, the Fox is too narrow for the Louis to follow. We continued multibeam and chirp to cross the existing FOS 3 and then tied into the 2500 m contour.

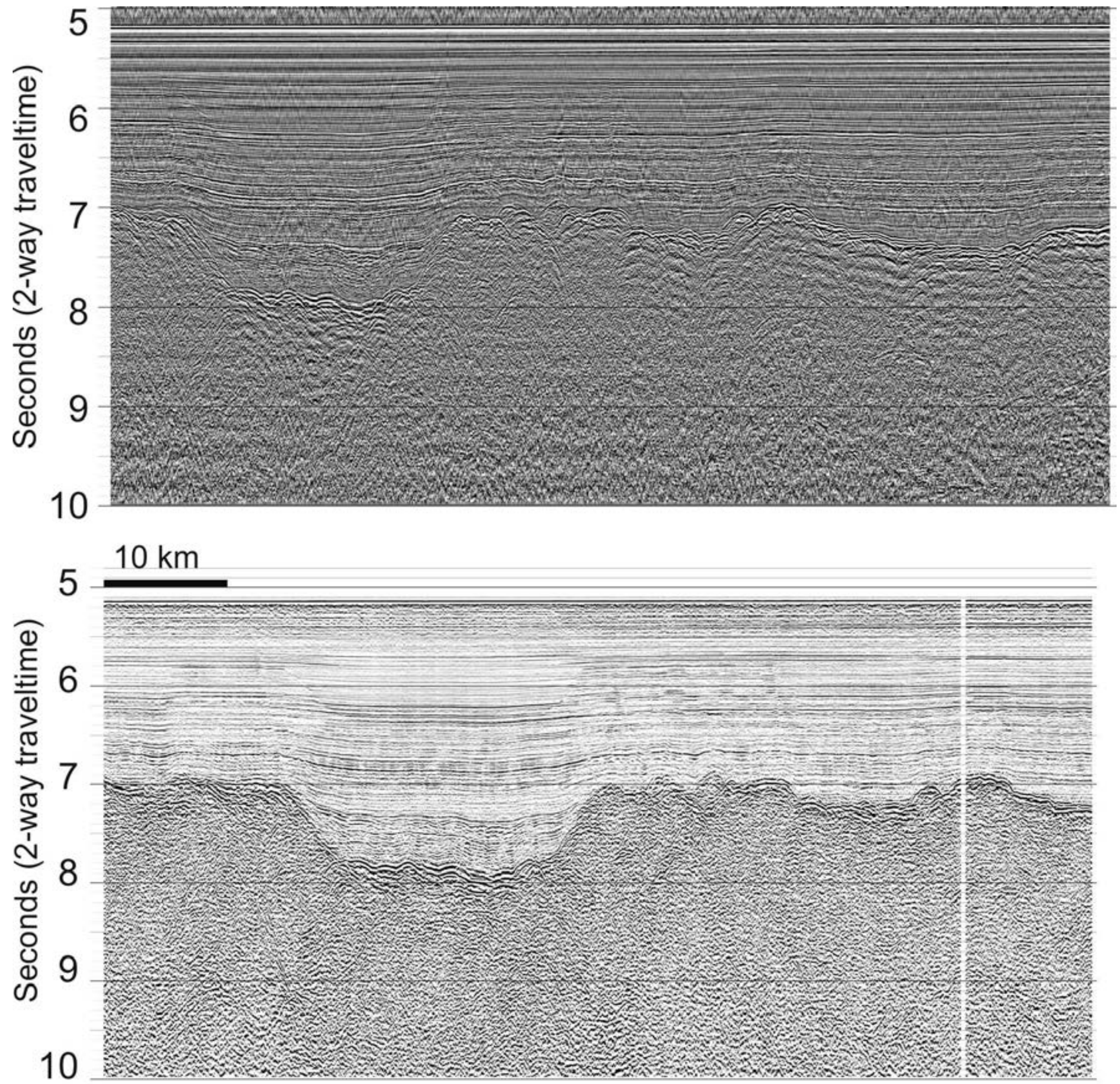


Figure 1.6. An example of seismic data acquired during this mission. Top is the brute stack and bottom is the final processed version.

On September 12, we deployed the seismic gear again to attempt a line downslope from the 2500 m contour across the Canadian Arctic Archipelago slope (Line 1412). After about 50 km, however, we got stuck several times in a heavy floe. The hydrophone streamer failed and we pulled the gear. Every float had been ripped off the streamer and the acoustic release had snapped off (i.e. PVC snapped in two) and was lost. The streamer must have been caught between ice blocks and was pulled through at a sharp angle, shearing everything. The streamer was heavily damaged.

Refraction Results

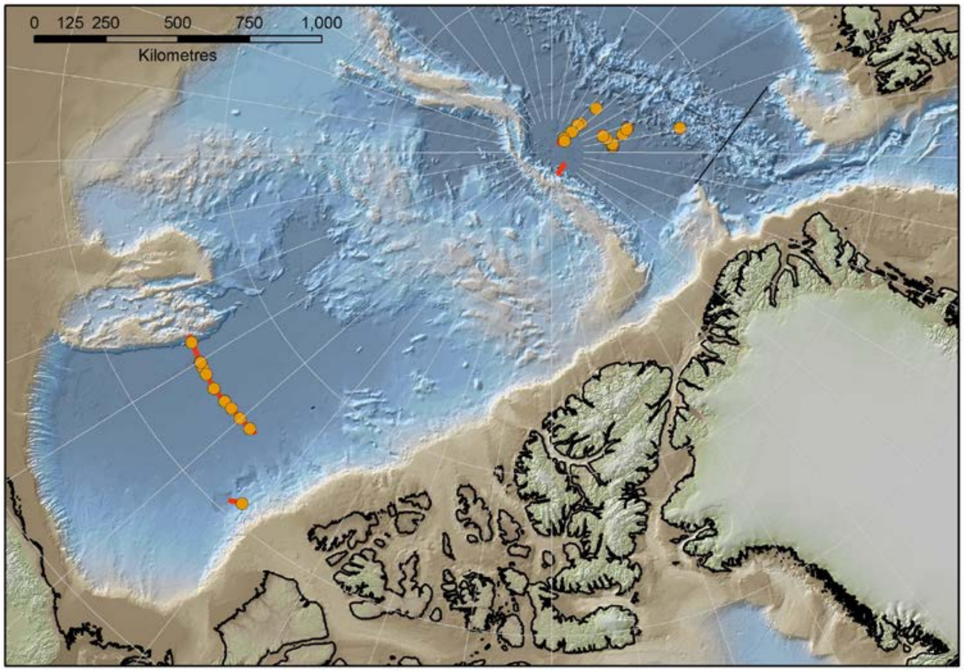


Figure 1.7. Sonobuoy drop locations (orange dots) along seismic lines.

<u>Methodology</u>

Ultra-Electronics marine expendable sonobuoys (Model 53C) were used to acquire wide angle reflection and refraction data for measuring seismic velocities, required to convert seismic reflection travel-time to depth. Sonobuoys were deployed at irregular but frequent periods, particularly over line segments meant to be greater than 35 km in length (see Fig. 1.7, Table 1.2). In previous years, the sonobuoy hydrophone was generally activated at 60 m water depth; however, signal failed to be transmitted at this depth for several sonobuoys and it was changed to 300 m. This likely is not the reason for the failures, however it was left at 300 m for the sake of consistency.

Sonobuoy-received seismic signals were radio-telemetered to two Winradio Model WR-G39WSBe VHF sonobuoy receivers. A stacked Yaggi array of two Andrews DB292-C VHF antennas, cut to respond to frequencies between 150 and 160 MHz were fitted to the aft railing, port side of the "crow's nest". This array has a 15° beam width pattern focused astern of the vessel. A high pass RF filter prevented damage to the sonobuoy receivers from the strong signal of the Helicopter DF beacon. Signal reception was excellent, often received between 30 and 35 km. A second set of Andrew's Yaggi antennas were mounted to the forward facing side of the crow's nest railing, providing an identical forward looking antenna array to the aft array. An RF antenna selector relay was installed between the two arrays, the output of the relay fed to the WinRadio receiver. Control of this relay was via a switch in the seismic lab where the operator could select the forward or aft looking array via the switch. This forward array permitted receiving signals from sonobuoys deployed in front of the ship. Due to problems with transmission, however, no sonobuoy record was successfully acquired by forward deployment.

Sonobuoy	Latitude	Longitude	Comments
Test	85.99495	10.917377	Test Sonobuoy
1A	87.756194	14.01875	SonoBuoy deployed but never surfaced. Helicopter deployed.
1B	87.756194	14.01875	SonoBuoy deployed but never surfaced. Helicopter deployed.
1C	87.562678	17.663865	Collected data for a minute and then it stopped transmitting.
1D	87.586677	16.993446	No Data. Ice closed in over it immediately.
3A	88.114965	5.236471	Did not open.
3B	88.114601	5.317256	60m? Did not open.
3C	88.111796	5.548857	Surfaced and Transmitting. Buoy was 'deaf', transmitting RF but no data.
3D	88.095606	6.981143	Surfaced and Transmitting. Buoy was 'deaf', transmitting RF but no data.
4A	88.113214	7.955754	Surfaced and Transmitting.
4B	88.267643	14.196503	Stopped Working After 15 Minutes.
4C	88.347237	17.36016	Surfaced and Transmitting.
4D	88.088821	44.131964	Surfaced and Transmitting. Logging not turned on until 06:35:00.
6A	88.746266	43.87106	Surfaced and Transmitting.
7B	88.84024	45.76525	Surfaced and Transmitting.
8A	89.110333	44.856237	Surfaced and Transmitting.
9A	89.429707	46.703296	Surfaced and Transmitting.
10A	89.475247	40.522956	Surfaced and Transmitting.
11A	77.501458	-152.847469	Surfaced and Transmitting.
11B	77.401933	-149.0625	SB11B was apparently never functional. Surfaced but no signal.

11C	77.427373	-149.836098	Appears to be mute. Transmitting fine, but no hydrophone signal.
11D	77.426062	-149.768222	Surfaced and Transmitting.
11E	77.381414	-147.954708	Surfaced and Transmitting.
11F	77.325059	-145.687394	Surfaced and Transmitting.
11G	77.356817	-143.376267	Signal looks odd. No data.
11H	77.357503	-143.319092	Surfaced and Transmitting.
11I	77.374642	-141.976176	Surfaced and Transmitting.
11J	77.38781	-140.114839	Surfaced and Transmitting. Not much signal. Ship off course to south.
11K	77.389725	-138.086179	Surfaced and Transmitting. Time posted altered.
12A	75.551339	-131.983141	Surfaced and Transmitting.

Table 1.2. Summary of sonobuoy deployment

Sonobuoys were deployed in Amundsen and Canada basins where the seafloor was usually flat. Sonobuoy radio signals were recorded in the seismic Lab on GSCA Portable DIG Unit 4, software version 1.4.2, as standard SEG-Y files. The record window length was generally 20 seconds. Thirty sonobuoys were deployed with thirteen failures (Table 1.2). High quality records were obtained for the majority of successful deployments (Fig. 1.7), although ship to sonobuoy offsets will be irregular due to erratic forward progress during ice breaking. The cause of failures was inconsistent (Table 1.2).

Helicopter and ship-to-ship communications resulted in high frequency interference and blanking on digitized records (Figs. 1.8 to 1.10). Scanning of the frequency channels on the WinRadio also interfered with the sonobuoy records creating a noise train with a length of 8 s and a period of 10–14 s (Fig. 1.10). FM bursts of noise of unknown source with a length of 2–4 s and frequencies in the range of interest continue to plague the sonobuoy recordings (Fig. 1.10)

<u>Processing</u>

Preliminary processing of the sonobuoy data was undertaken during the cruise using a C-based program called *SeisWide* developed by Deping Chian. Processing of the data consisted of:

- SEG-Y files converted to small-endian format
- Traces converted to offset using navigation data from SEG-Y headers
- Time delay of 47 ms introduced to data
- First-breaks picked
- Offsets converted to true ship–receiver distance using the travel-times of the first-breaks and the velocity model of Arctic waters developed by Lebedeva-Ivanova (2011).

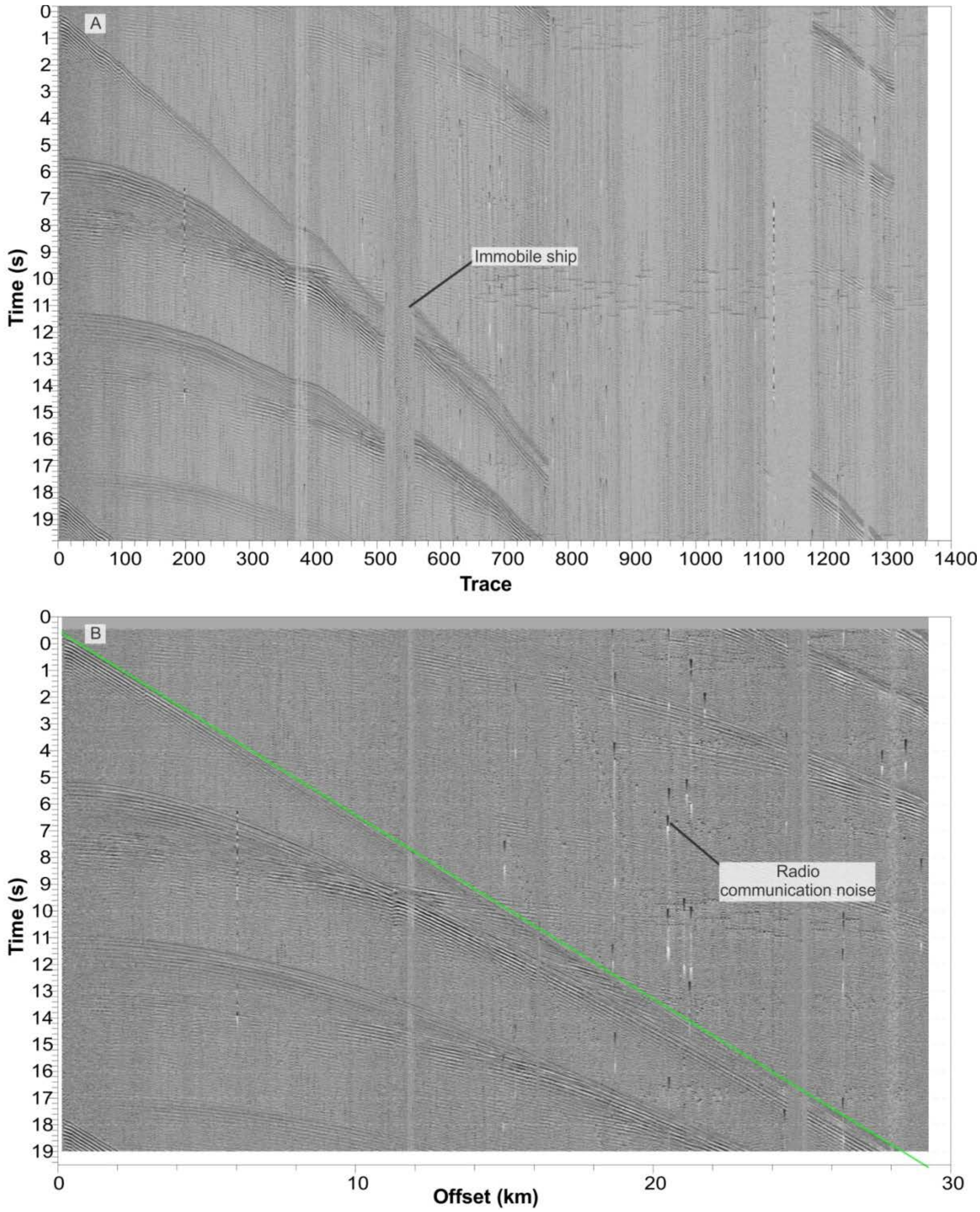


Figure 1.8. A) Raw and B) processed versions for record SB9A. Note times when the ship was immobile in panel A and the communication bursts in panel B. The green line represents the direct wave.

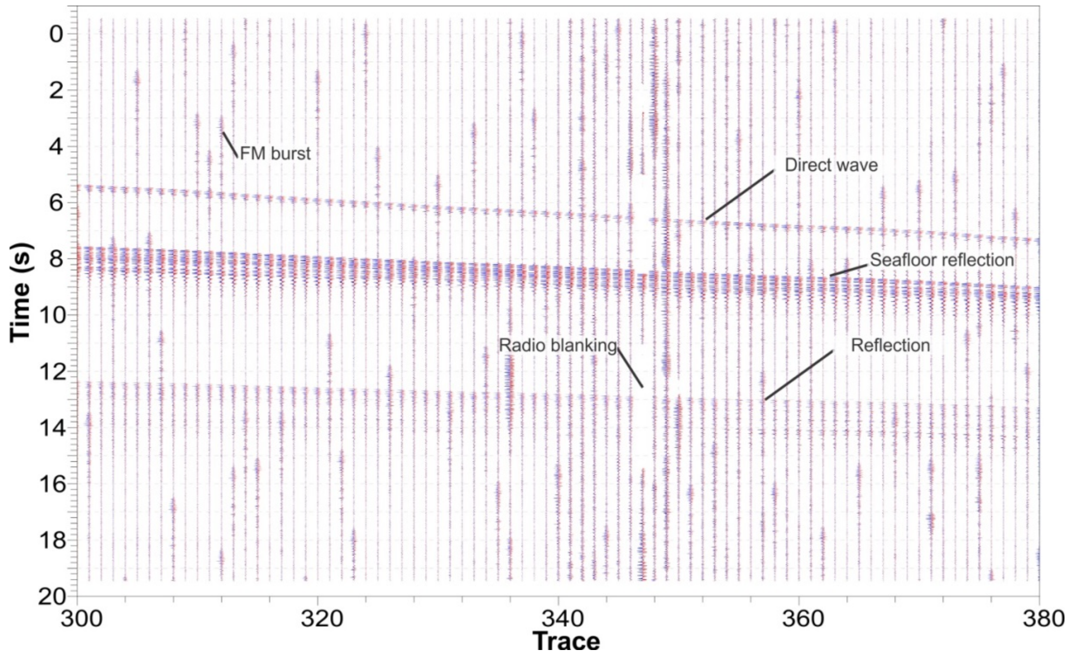


Figure 1.9. A part of seismic record SB8A. Note the quasi-periodic nature of the FM bursts.

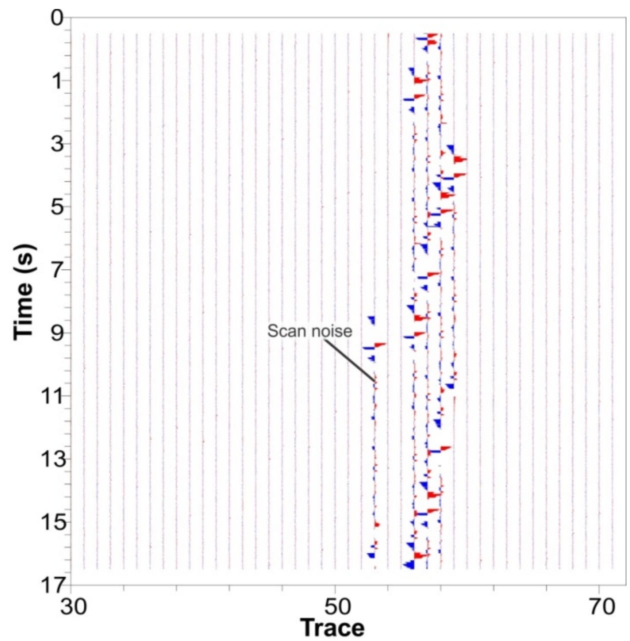


Figure 1.10. An example of 8 s noise from frequency scan from a blank record (no sonobuoy deployment).

Bathymetry

8355 line-km of multibeam bathymetric data were acquired during the Canadian Polar Expedition 2014, extending from St. John’s, NL to Kugluktuk, Nunavut. The hydrographic survey was carried out following the guidelines as stated in the ISO 9001:2008 Standard, Quality Manual for the Canadian Hydrographic Service as well as CHS Standards for Hydrographic Surveys and the Hydrographic Survey Management Guidelines. The survey is estimated to have achieved IHO S44 and CHS Order 1a accuracies for both (THU) Horizontal Accuracy and (TVU) Vertical Accuracy for Reduced Depths.

The field program took place from August 8th to September 18th, 2014 and encompassed 42 days.

The 2014 entire track is shown in Figure 1.11 and a zoom of the track within the Arctic Ocean is shown in Figure 1.12. The primary survey platform was the CCGS *Louis S. St-Laurent* (LSSL) which was accompanied to the survey area by the icebreaker CCGS *Terry Fox* (TFOX). The survey region was located north of Ellesmere Island extending to the North Pole. A series of parallel survey lines were run extending from Amundsen Basin to the crest of Lomonosov Ridge. The primary objective of the survey was acquisition of multibeam bathymetric and sub bottom profiler data.

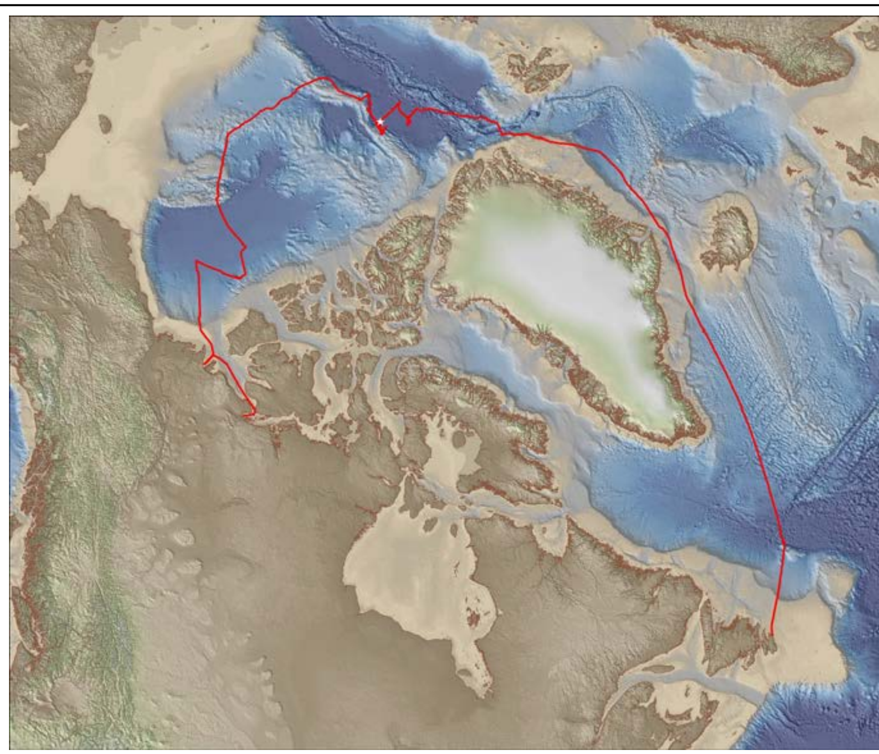


Figure 1.11. Total track with multibeam data acquisition

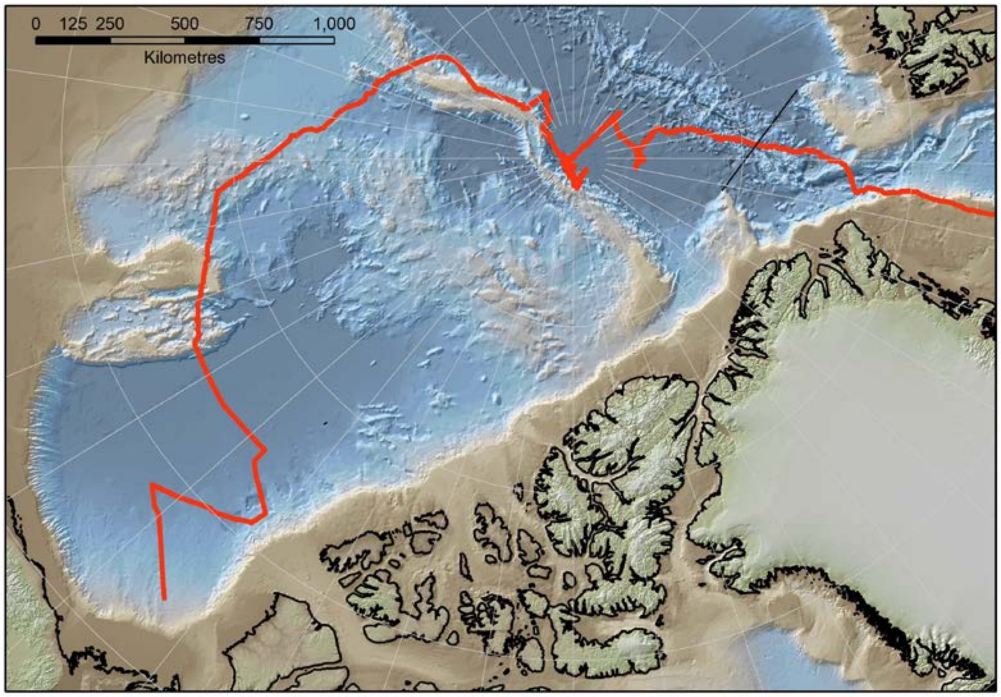


Figure 1.12. Ship's track during which multibeam bathymetry and Chirp subbottom profile data were collected.

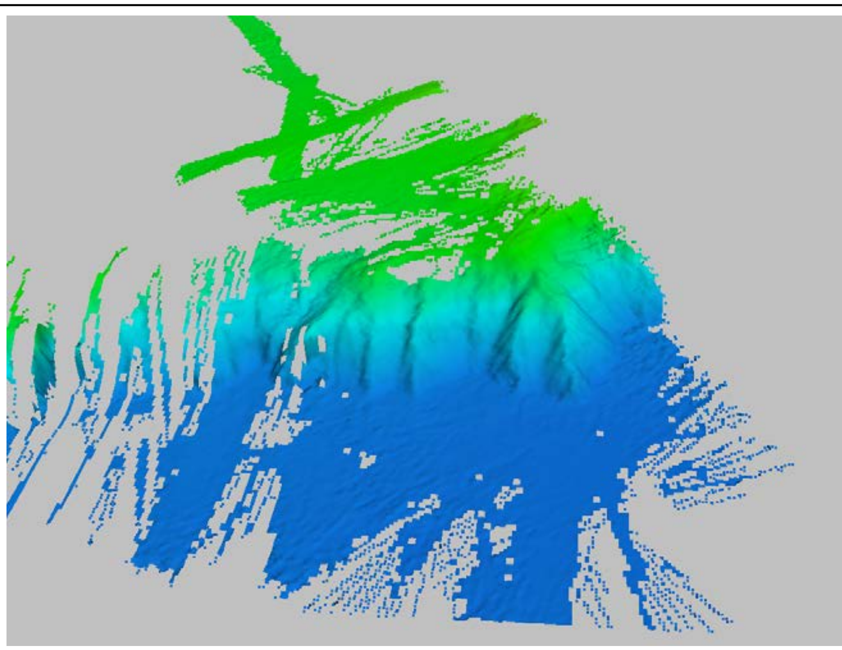


Figure 1.13. Example of multibeam data acquired at the base of Lomonsov Ridge

Hydrographic Equipment

Kongsberg EM122 Multibeam Echosounder – 12-kHz full ocean depth
Seafloor Information System (SIS) 4.1.5
Applanix POSMV V5 – Position and Orientation SystemPOSVIEW 8.15
AML Micro X SV and Minos X Sound Velocity Sensors
AML Seacast 3.2.1
Lockheed Martin MK21 – Expendable Sound Velocity System

The *LSSL* was fitted with a Kongsberg EM122 12kHz (1x2 Degree) Multibeam Echosounder (hull mounted behind ice protected acoustic windows) and an Applanix Position and Orientation System (POSMV) a mere few months prior to the 2014 survey season. See Chapter 2 for full details. Figure 1.13 shows an example of a multibeam data mosaic compilation from this expedition and Figure 1.14 shows results of collecting data in heavy ice.

Sound velocity profiles collected by both expendable conductivity/temperature/depth sensors (XCTD) and time of flight sound velocity profilers (SVP) are introduced to the multibeam acquisition system Seafloor Information System (SIS) immediately as they become available during multibeam acquisition. However, when surveying primarily single line tracks, the profile introduced is essentially a model of the water column in the area that the vessel has already departed. With some analysis it was concluded that the resulting potential depth disparity was insignificant and would have fallen within the survey specification error budget (Order 1a), across the depth ranges.

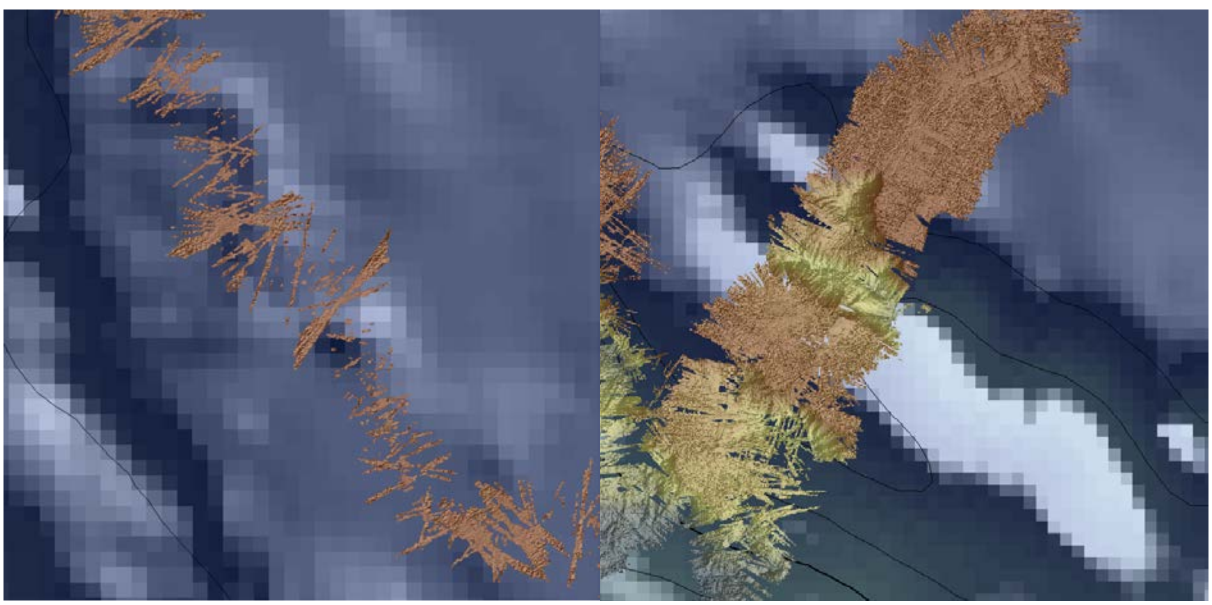


Figure 1.14. To the left shows the sounding pattern while breaking heavy ice. To the right is sounding coverage using the survey pattern termed "the Macarena".

Data Quality

During heavy ice breaking, data quality suffered immensely, providing little information of value (Figure 1.14). For critical areas, it was necessary to implement a survey pattern we called the Macarena (to accompany the hokey-pokey by the Healy and the pirouette by the Oden). The LSSL would turn 90º to the track line and, remaining stationary, acquire multibeam the full swath width (4-7 times water depth) and sweep the beams fore and aft to obtain lateral coverage. The LSSL would then steam along the proposed track for about 10 km and repeat the procedure.

Figure 1.15 shows an example of data acquired in open water conditions (but at 16 knots speed) in comparison with data acquired earlier by the USCGC *Healy*. This example shows the strong agreement between the two data sets.

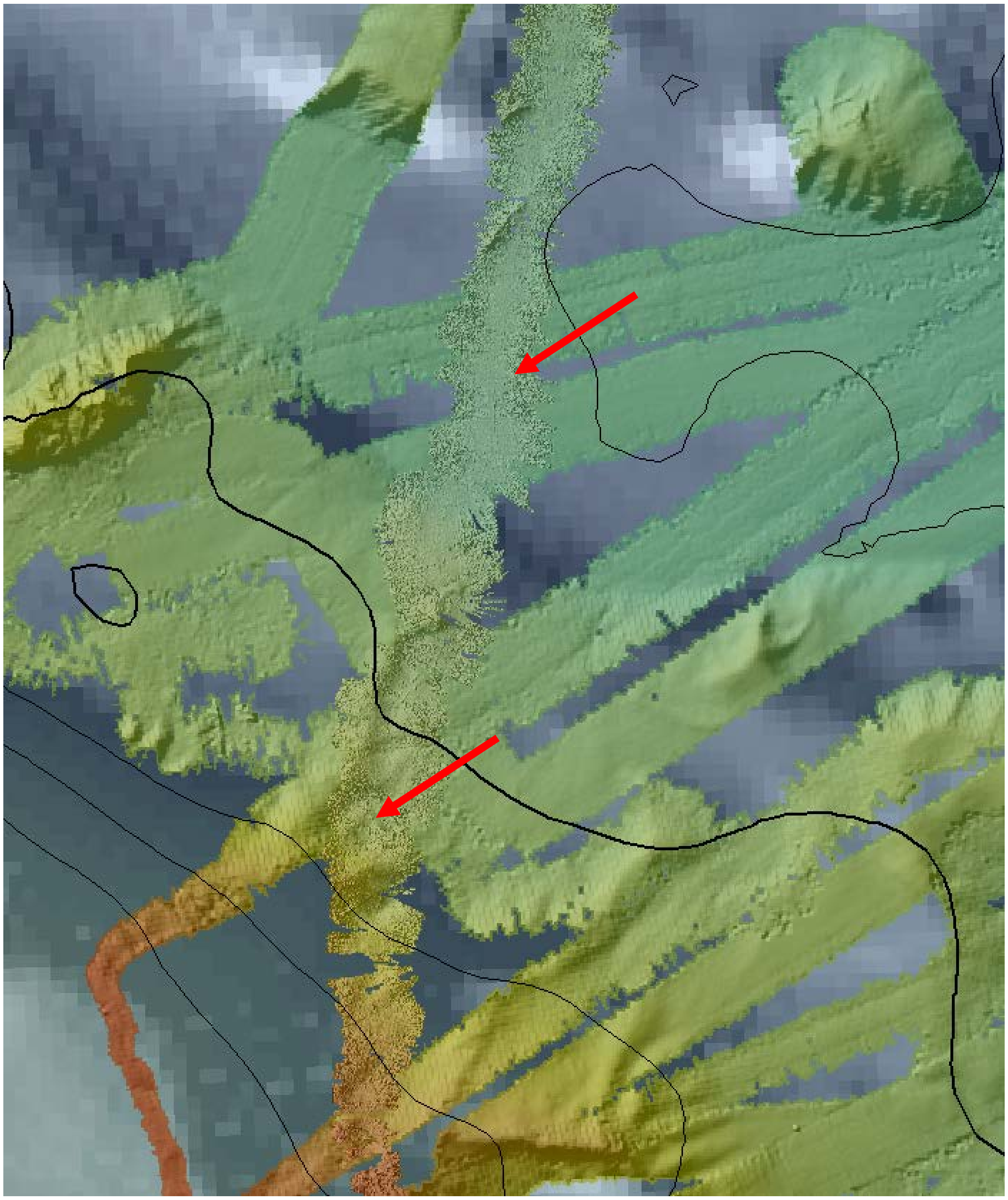


Figure 1.15. Comparison of LSSL 2014 data with multibeam data acquired by the USCGC Healy. Red arrows indicate the LSSL2014 data.

Knudsen 3.5 kHz Swept Frequency Hull Mounted SubBottom Profiler

In 2011, the Knudsen 3.5 kHz hull mounted subbottom profiler was used without success. Prior to the 2014 survey, the system was specially modified by Knudsen Engineering Ltd. to have a reduced power output of 8KW at 3.5 kHz. This modification was made in order to boost the output power of the 12 kHz channel within the same system to 4KW.

In 2014, the Louis S. St-Laurent had a Kongsberg EM122 deep water multibeam echosounder installed. The EM122 operates at 12 kHz, thus eliminating the need for a 12 kHz single beam. As a result, it was decided to return the Knudsen 3260 Chirp system to Knudsen to reverse the modifications. These modifications resulted in a Knudsen system with 3.5 kHz output power of 10KW and an output impedance of 50 ohms. Figures 1.11 and 1.12 show the track locations for subbottom profiler acquisition.

The sea-chest installed in the vessel consists of 12 transducers (4x4 pattern with corners removed). Prior to the 2014, the wiring configuration of the transducers resulted in a 33 ohm impedance. This was deemed a suitable match to the transceiver which had a 40 ohm output impedance (when configured as an 8KW output). In order to impedance match the 10KW transceiver, it was necessary to re-wire the junction box for the transducers.

The transducer junction box is located in a crawl space in the lower part of the forward engine room. Each of the Massa transducers has a typical impedance of 100ohms at 3.5kHz. Prior to the 2014 survey, the junction box was wired as 2 parallel banks of 6 transducers in series, producing 33 ohms impedance. The junction box was replaced for 2014 with a new junction box wired with 4 parallel banks of 3 transducers in series. This resulted in a combined impedance of 75 ohms at 3.5 kHz. It should be noted that although it appears to be slightly mismatched with the transceiver (50 ohms), this was the recommendation from Knudsen Engineering and also reflects the fact that the impedance curves for the individual Massa transducers is lower below 3.5 kHz and that the Knudsen 3260 is chirped from 2.3-5.3 kHz.

Performance Comments

The hull mounted Knudsen system showed major improvement over its previous configuration. It still lacked penetration and detail in deeper water. This is likely due to the 2.5" of hull that the sound must penetrate on transmission and reception. When breaking ice, the hull reverberation, bubbles from the bubbler system and large bits of ice adversely affect the record. Figure 1.16 shows examples of data acquired in 2014.

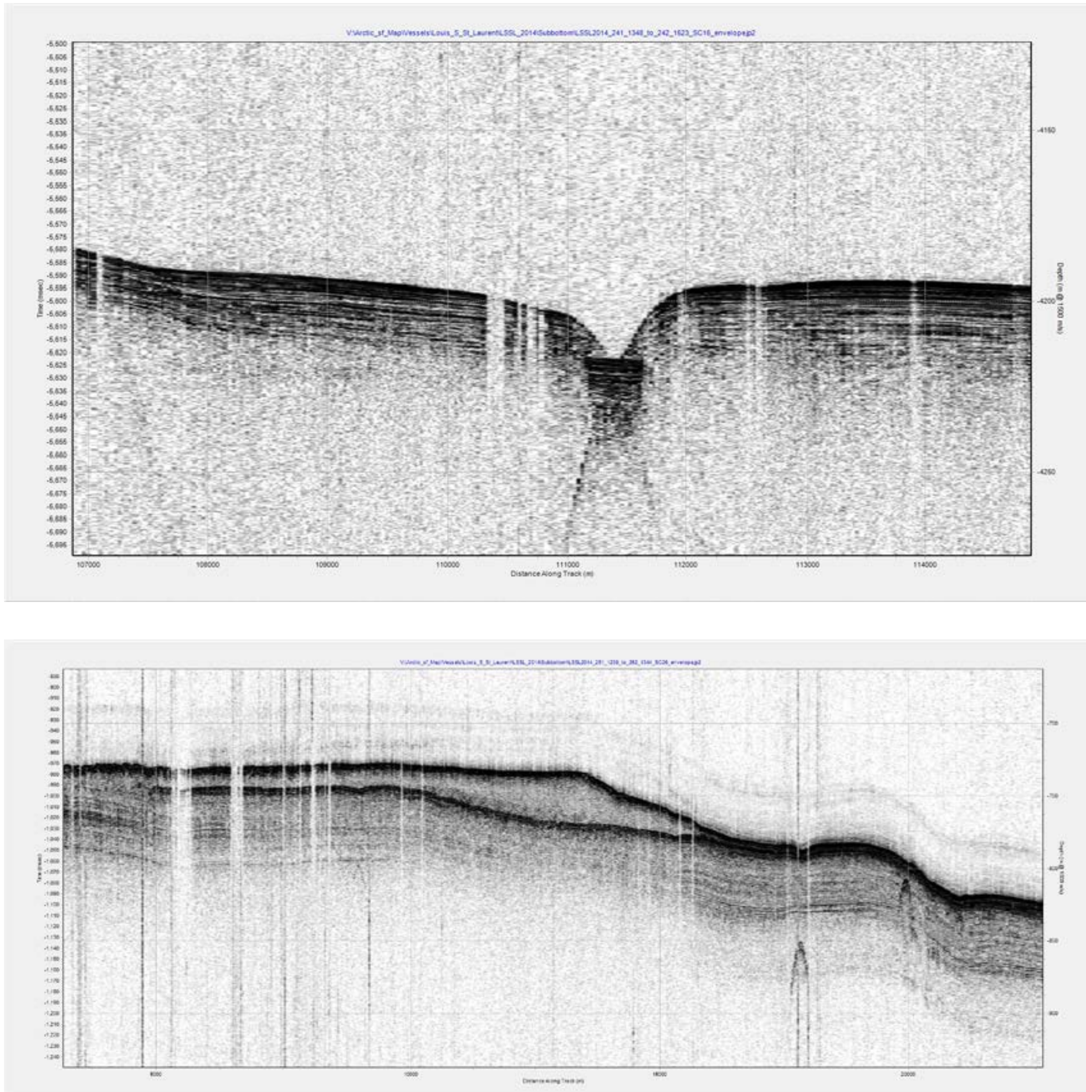


Figure 1.16. Examples of Knudsen Chirp subbottom profiler data from the Canadian Polar Expedition, 2014. Top is an example from the Amundsen Basin, crossing the NP28 Channel, in 4200 m water depth. Lower image is the top of the Chukchi Plateau in 700 to 800 m water depth.

Sea Ice and Weather

Ice

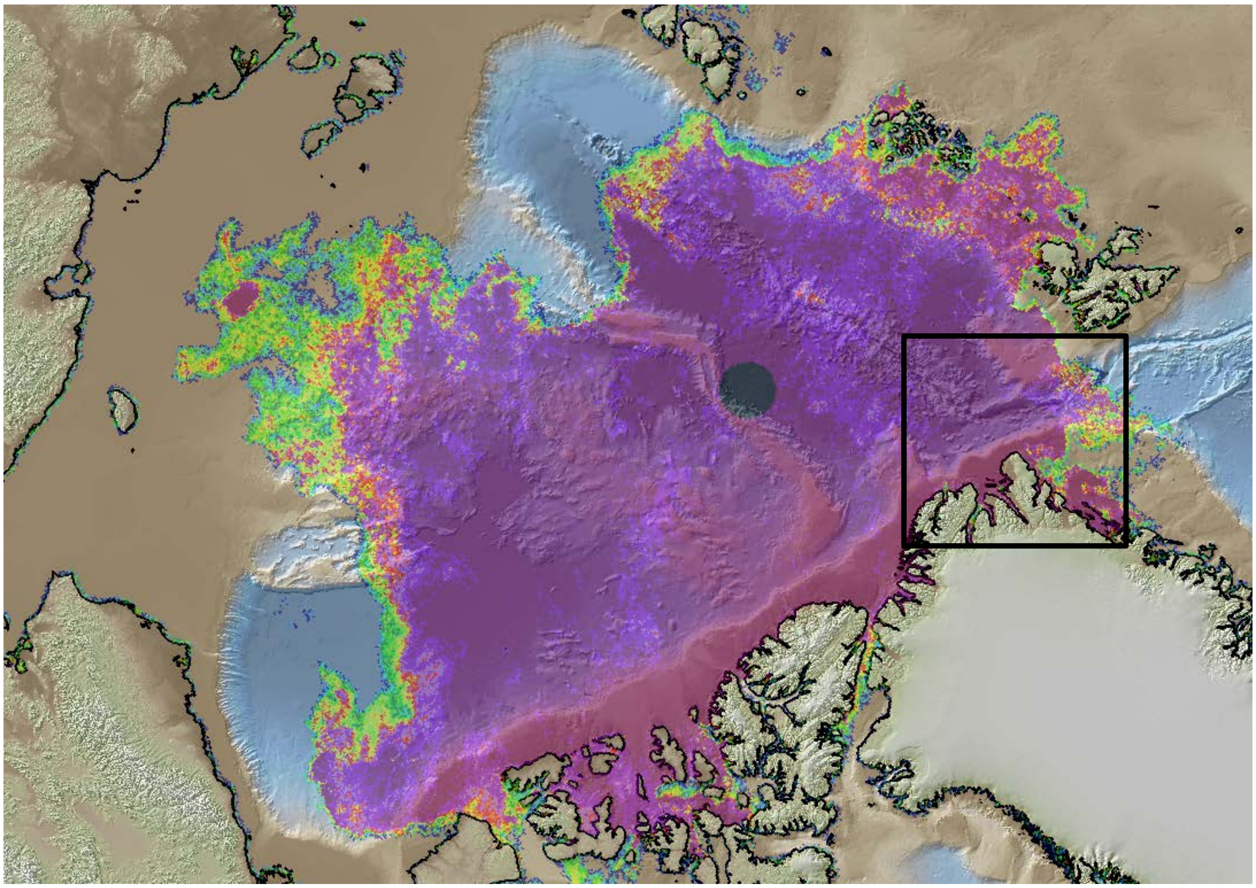


*Figure 1.17. Advanced Microwave Scanning Radiometer - Earth Observing System II(*AMSR-EII*) image of September 16, 2014; the ice minimum for this season Purple is 100% ice cover. The black box encompasses the broad region of the survey area, showing that the complete survey was within 100% ice cover.*

Ice conditions were not favourable for surveying in 2014, at least not in the survey region (Figures 1.17, 1.18). Ice was mixed multi-year and single year but the most complicating factor was that there was no melt season in the summer of 2014. Snow remained on the surface and masked the underlying ice. It was not possible, therefore, to recognize multi-year from first or second year ice based on its tell-tale turquoise colour. Collision of pans of multiyear ice generated <12 m high ridges, which were impossible to break through (e.g. Figure 1.18). As a result of these conditions and the nature of the two ice breakers, it was generally necessary for the *Louis S. St-Laurent* to break ice ahead of the *Terry Fox*. When acquiring seismic reflection data, therefore, the *LSSL* had

Figure 1.18. CCGS Terry Fox hung up on a pressure ridge.

to break ice ahead for ~10 km, then return along its path, deploy seismic gear, get the *Terry Fox* in the broken lead and then follow the *Fox* for the 10 km of the lead, recover the seismic gear and repeat the procedure again. For acquisition of multibeam data, the procedure outlined above (the Macareno) was followed. To further complicate matters, the radarsat ice imagery was typically of poor quality (Figure 1.19) at reasonable scales of operation.

Ice was too heavy to conduct operations in Makarov Basin, thus on September 4th, the Captain elected to head back to Kugluktuk via the Siberian margin where ice conditions were lighter. Because of light ice conditions on the transit, time was saved and permitted surveying in Canada Basin. A west to east transect seismic line was run. As we approached the Canadian margin, ice again became exceptionally heavy with mixed multi-year. The hydrophone streamer was damaged in heavy ice on September 13th and seismic operations were terminated. We broke out of the ice on September 16th, within the Amundsen Gulf.

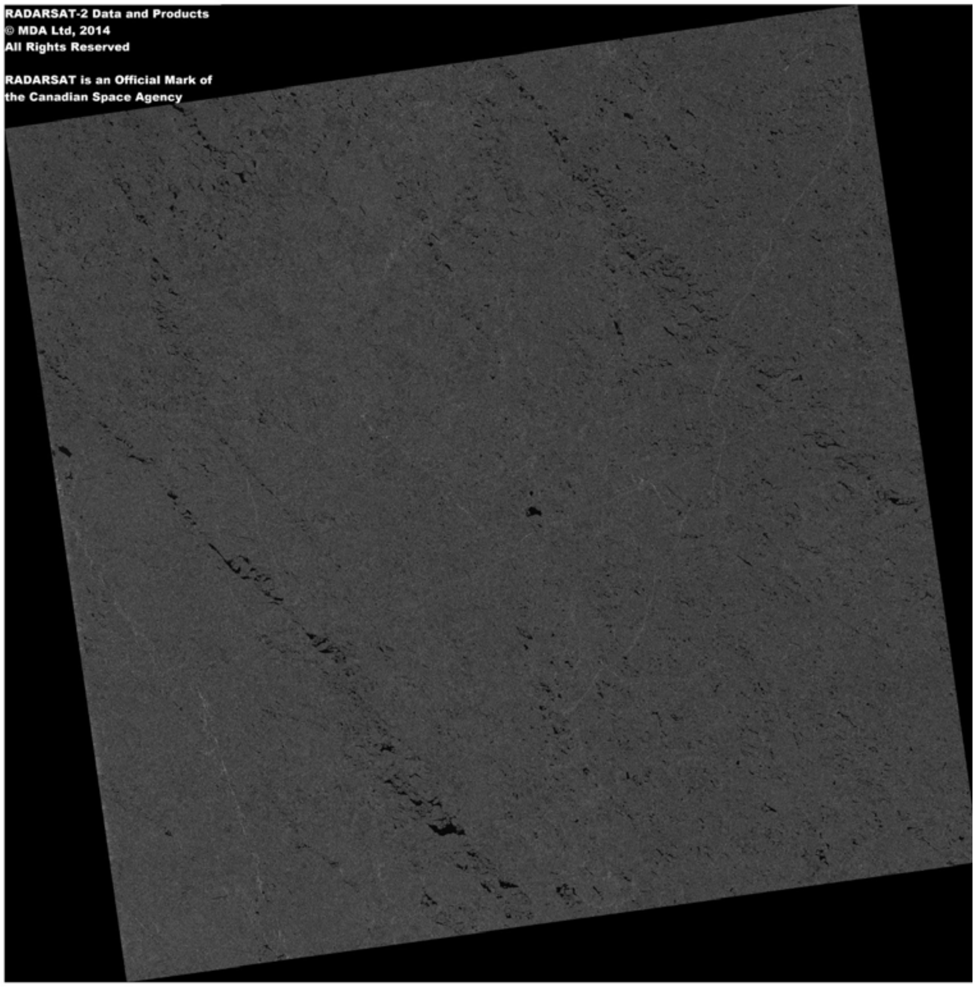


Figure 1.19. Example of Radasat ice imagery from August 21, 2014. The image is about 90 x 90 km in dimension. Blackest colours represent possible open water conditions (leads and polynyas). One can see little open water in this image, typical of conditions in 2014.

Weather

In general, weather varied little over the course of the expedition. Winds tended to be light and variable, skies overcast and with frequent fog and fog patches. The fog made it difficult for reading ice conditions, and prevented helicopter operations for ice reconnaissance. The helicopters were used only for 15 hours during the entire mission, and that included mobilization and demobilization. Temperatures hovered between +2 and -6ºC and there was an occasional day of snow. Light winds generally meant that our track stayed open for a second pass during seismic operations, but significant drift was noted from one pass to the next.

Operational Constraints

Mammal Interactions and Mitigation

Although it is extremely unlikely that the mission would encounter any marine mammals in the survey region, appropriate mitigative measures were adopted to address the potential of any marine mammal interaction. These measures included "**ramping-up**" the pneumatic energy source array and 24 hour **observation for marine mammals** by 2 Inuit observers to ensure no marine mammals were within **1000 m radius** of the array. If spotted within this 1000 m radius, the source array would be shut down until the ship or animal exceeded the 1000 m radius. It should be noted that during this and the previous five years of seismic exploration in this same region, no cetaceans were seen by native observers. During seismic operations, no animals were observed. Two polar bear sightings were made during transits (Table 1.3).

All standard mitigative measures pertaining to the use of seismic pneumatic energy source arrays for exploration were adopted and followed by the mission. For marine mammals, especially whales, it has generally been accepted that a safety zone with a radius of 500 m from the sound generating source is sufficient to eliminate potential for impact (LGL 2005, DFO 2007). In the case of this expedition, a 1000 m shutdown radius was implemented, thus is particularly conservative. Note that sound level of about 176rms dB re 1 µPa at 500 m is about the same sound production level that is produced by cracking and breaking pack ice that is prevalent in this high Arctic environment (Greening and Zakarauskas 1984), and represents a background noise level. Further mitigative measures with respect to potential marine mammal interaction with the project were adopted:

- Alteration of vessel speed/course providing it did not compromise operational safety requirements
- Pneumatic energy sources shut down if any marine mammal entered or was anticipated to enter the 1000 m safety zone through observations by a trained marine mammal observer on the research vessel
- Pneumatic energy source start-up procedures did not commence unless a full 1000 m safety zone was clear of any marine mammal by visual inspection by a trained marine mammal observer for a continuous period of at least 30 minutes.
- The pneumatic energy source array was "powered down" during transit from one seismic line to another.
- Total shut down of all pneumatic energy source activity occurred and did not resume until all marine mammals cleared the 1000 m safety zone.
- Pneumatic energy source start-up procedures included a "ramping up" period where individual guns were brought online one at a time.

- The location of the LSSL2014 mission did not take place in the vicinity of any beluga harvest area or during the period of beluga harvest.
- There were 2 marine mammal observers on board the seismic research vessel. Note that there was 24 hours of light in this region during most of the survey that aided the observers in spotting marine mammals.

With respect to polar bears, it is highly unlikely that the sub-sea sound produced will impact bears if they are encountered. When spotted by a trained marine mammal observer within the 1000 m safety zone, all of the above mitigative measures were applied to ensure that no project interaction occurred.

With respect to marine fish and invertebrates, there are no commercial or traditional native fisheries in the area surveyed. In addition, scientific studies have indicated that no fish kills have taken place and attributed to seismic exploration activity and no measurable impact on phytoplankton, zooplankton as well as fish eggs, larvae or juveniles have been reported at distances of 8 metres from the seismic sound source.

Overall, by adopting all industrial mitigative standards as well as more stringent measures discussed above, no measurable environmental impacts were predicted nor observed.

Date	Time	Julien Day	Latitude	Longitude	Visibility (nmi)	Species	Nu.	Comments
8-16-14	1709	228	78.466667	6.583333	15	Seal	1	Ring seal in the water
8-20-14	1805	232	86.150000	11.850000	15	Bear tracks	1	Bear tracks port side
9-02-14	0725	245	88.716667	-128.816667	15	Ring seal	1	In front of ship
9-05-14	2230	248	84.080000	-154.520000	2	Polar Bear	2	Off the port side
9-09-14	0108	252	77.500000	-154.520000	3	Ring seal	1	On ice port side
9-10-14	1950	253	77.383333	-139.900000	10	Polar Bear	1	Bear tracks

Table 1.3: Mammal sightings

Acknowledgements:

The scientific party wishes to thank Captains Potts and Barron and the Officers and Crew of the Canadian Coast Guard Ships *Louis S. St-Laurent* and *Terry Fox*. Without their enthusiastic and always cheerful efforts, the 2014 program would not have been at all possible. There are many, many people on the ship and ashore who worked tirelessly to make this expedition happen in a short time frame. It is a credit to their dedication that this mission was able to happen at all and we'd like to thank each and every person. The authors would like to express our highest appreciation, respect and admiration for the technical crew of the scientific party. The program would definitely have not achieved success without the long hours of commitment and their innovative solutions to unique problems that arise from working in the harsh environment of the Arctic.

Chapter 2

Hydrographic Field Report

Introduction

Article 76 specifies a mechanism for defining the continental margins beyond the 200 nautical mile (M) limit. In order to extend boundaries beyond the 200 M limit, Canada must acquire hydrographic, geophysical and geological data to define the limit of Canada's continental shelf as stipulated under Article 76 for making such claims. To this end, Canada has undertaken a program of data acquisition along a number of its frontier regions. Specific to this expedition, Fisheries & Oceans Canada in concert with Natural Resources Canada, acting on behalf of the Government of Canada, are operating a project in the high Arctic Ocean to acquire necessary hydrographic and marine geophysical and geological data. Field activities planned for 2014 represent the sixth year of such activities in the high Arctic region. The project bounds and ship's track are shown in Figure 2.1.

2014 operational plans are for seismic reflection data, 12 kHz multibeam sounder data (EM-122),, and 3.5 kHz sub-bottom profiler data to be acquired continuously, as ice conditions permit behind the Canadian ice-breaker *CCGS Louis St. Laurent*.. The *CCGS Louis S. St-Laurent* will be accompanied by the icebreaker *CCGS Terry Fox*.

The Department of Fisheries and Oceans – Canadian Hydrographic Service (DFO-CHS) is responsible for a number of conditions under Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS) to delineate/survey/establish the continental shelf for Canada's territorial submission:

- mapping baselines from which the extent of the territorial sea is measured;
- mapping the 2500 metre isobath and the Foot of the Slope;
- Optimising the location of boundary lines at calculated distances. (60, 100, 200 and 350 nautical miles);
- Populating data bases with the above data and outputting in the form of charts, maps and diagrams

The region of the survey is from Amundsen Basin to Lomonosov Ridge, north of Ellesmere Island and Greenland, extending to beyond the North Pole. A series of parallel lines are planned to extend from Amundsen Basin to the crest of Lomonosov Ridge. The intent of these survey lines is to 1) measure sediment thickness, to establish the 1% thickness formula as prescribed in Article 76; 2) to detect the base of the continental slope along Lomonosov Ridge where it abuts Amundsen Basin; and 3) to measure the 2500 m contour

Survey Overview

The hydrographic survey was carried out following the guidelines as stated in the ISO 9001:2008 Standard, Quality Manual for the Canadian Hydrographic Service as well as *CHS Standards for Hydrographic Surveys* and the *Hydrographic Survey Management Guidelines*.

The survey is estimated to have achieved IHO S44 and CHS Order 1a accuracies for both (THU) Horizontal Accuracy and (TVU) Vertical Accuracy for Reduced Depths.

The field program took place from August 8th to September 18th, 2014 and encompassed 42 days. The expedition commenced from St. John's, NL and terminated at Kugluktuk, Nunavut.

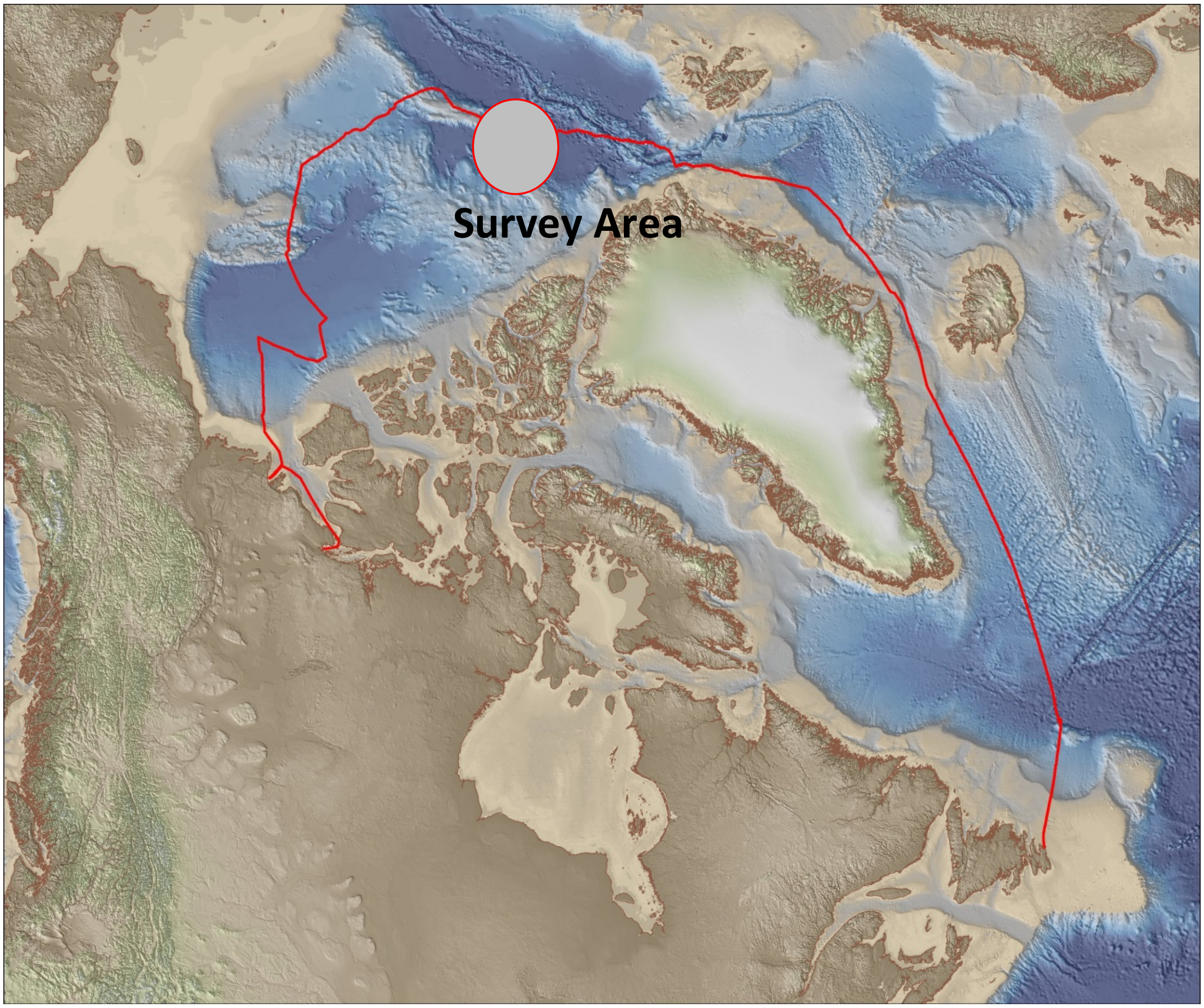


Figure 2.1 Track and project bounds.

Personnel

Most of the CHS staff were on board the Canadian Coast Guard Ice Breaker *Louis S. St-Laurent* (*LSSL*) because Sea Trials were wrapping up as we made our way to St. John's Newfoundland. One hydrographer arrived with the changing Canada Coast Guard crew and joined (*LSSL*) on

August 6th, 2014 in St. John's NL. LSSL departed on August 9th and the *CCGS Terry Fox* (*TFOX*) on August 8th with a staff of four hydrographers (Table 2.1).

Name	**Position**	**Dates**
Paola Travaglini	Hydrographer-in-Charge	August 08 – September 18
Chris LeBlanc	Hydrographer	August 08 – September 18
Jim Weedon	Hydrographer	August 08 – September 18
David Levy	Electronics Technologist	August 08 – September 18

Table 2.1. List of Canadian Hydrographic Service Staff.

Hydrographic Equipment

CCGS Louis S. St-Laurent
Kongsberg EM122 Multibeam Echosounder – 12-kHz full ocean depth

- Seafloor Information System (SIS) 4.1.5

Applanix POSMV V5 – Position and Orientation System

- POSVIEW 8.15

AML Micro X SV and Minos X Sound Velocity Sensors

- AML Seacast 3.2.1

Lockheed Martin MK21 – Expendable Sound Velocity System

Multibeam Echosounder

The *LSSL* was fitted with a Kongsberg EM122 12kHz (1x2 Degree) Multibeam Echosounder (hull mounted behind ice protected acoustic windows) and an Applanix Position and Orientation System (POSMV) a mere few months prior to the 2014 survey season.

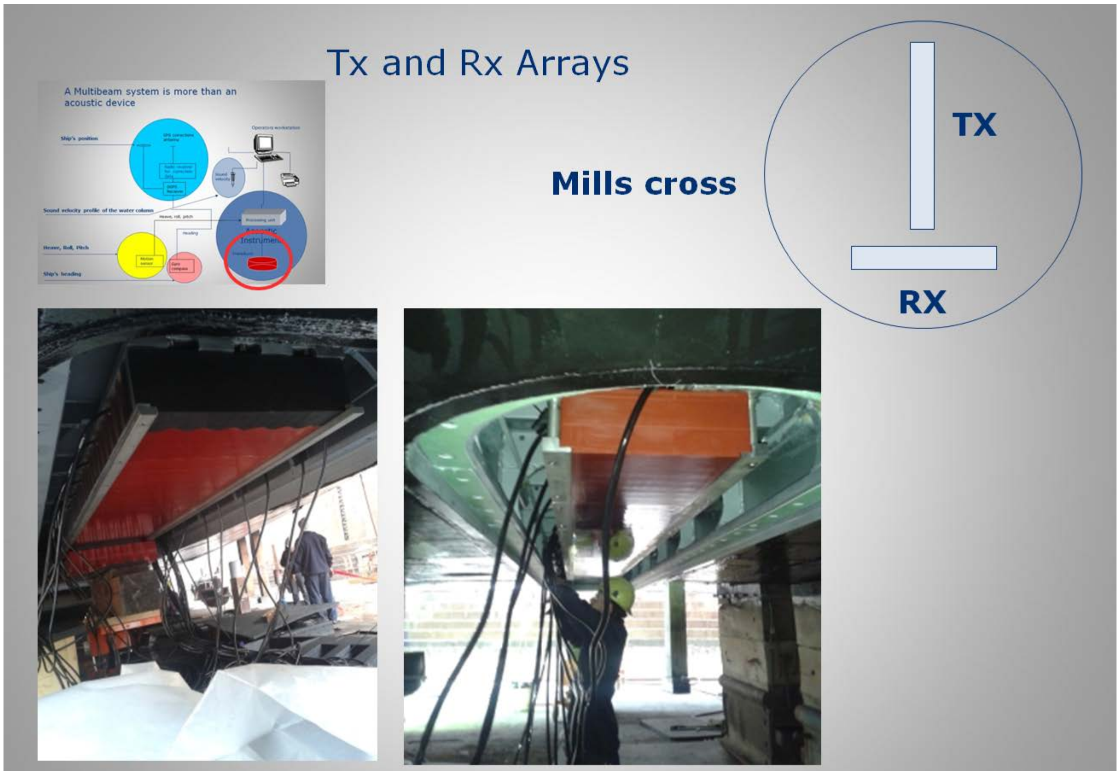


Figure 2.2. Design and installation of the EM122 multibeam system on the hull of the CCGS Louis S. St-Laurent. The transmit element install is shown on the left and the receive element is shown on the right.

In the 1°x2° configuration installed on *CCGS Louis S. St-Laurent* the transmit (Tx) transducer dimension is about 8m x 1m and the receive (Rx) is 4m x 1m. See Figure 2.2 for photos of these elements as installed on the hull of the vessel.

Figure 2.3. Installation of the EM122 multibeam system on the hull of the CCGS Louis S. St-Laurent.

A 12 cm thick polyurethane elements (ice windows) reinforced with titanium rods are mounted flush to the hull, leaving a few centimetres (water filled) space between their inside and the transducer elements. The Rx transducer (with ice protection) is further covered with an additional titanium plate (Fig. 2.3).

The major components of the multibeam system are shown in Figures 2.4 to 2.6 below including photos of these elements are shown in Figure 2.5. The Plan of Survey from the vessel sensor alignment survey is shown in Figure 2.7. The operator's work station was located in the wet lab on the third deck (Fig. 2.8).

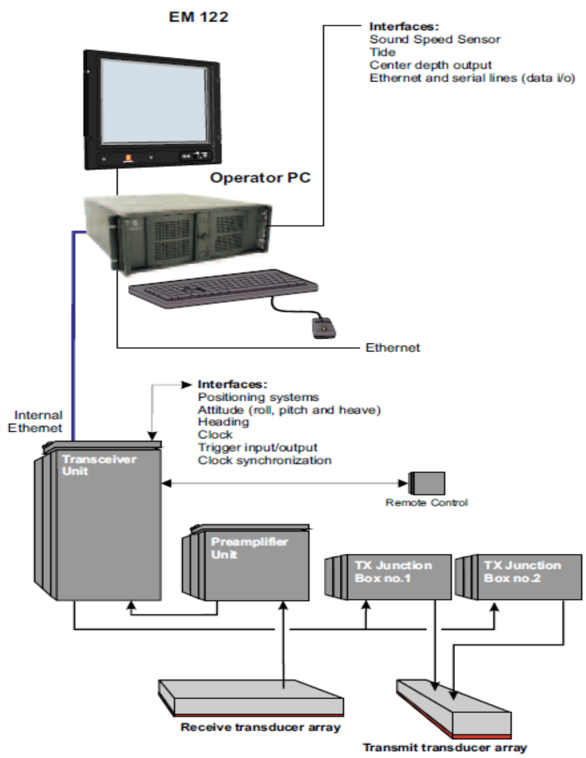
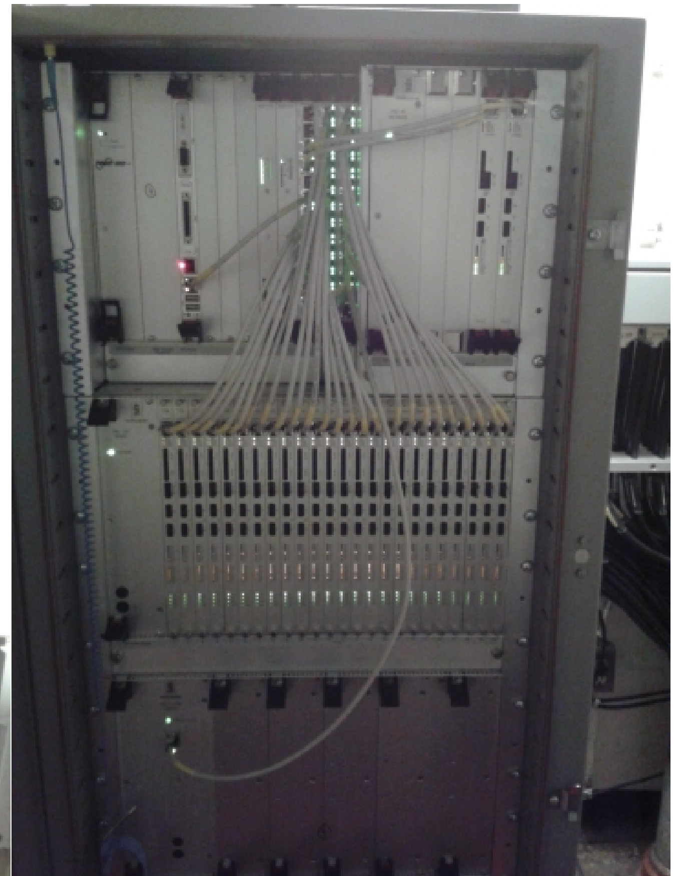


Figure 2.4. Configure of shipboard elements of the Simrad EM120 system

Preamplifier Unit



Transceiver Unit

TX Junction Box no. 1 and no. 2

Figure 2.5. Photos of various components of the EM120 system

Figure 2.6. Locations of various components of the EM system. The two POS MV antennae are located on the ship's mast and the Inertial Motion Unit (IMU) is located in the Emergency Generator Room,

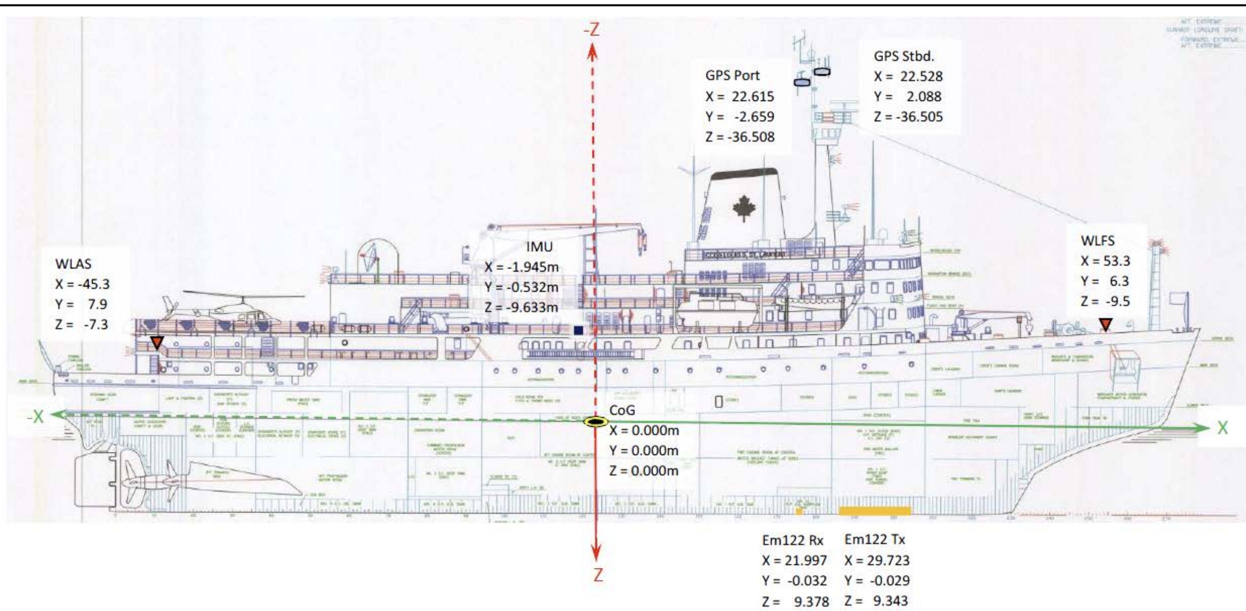


Figure 2.7. The Plan of Survey from the vessel sensor alignment survey.

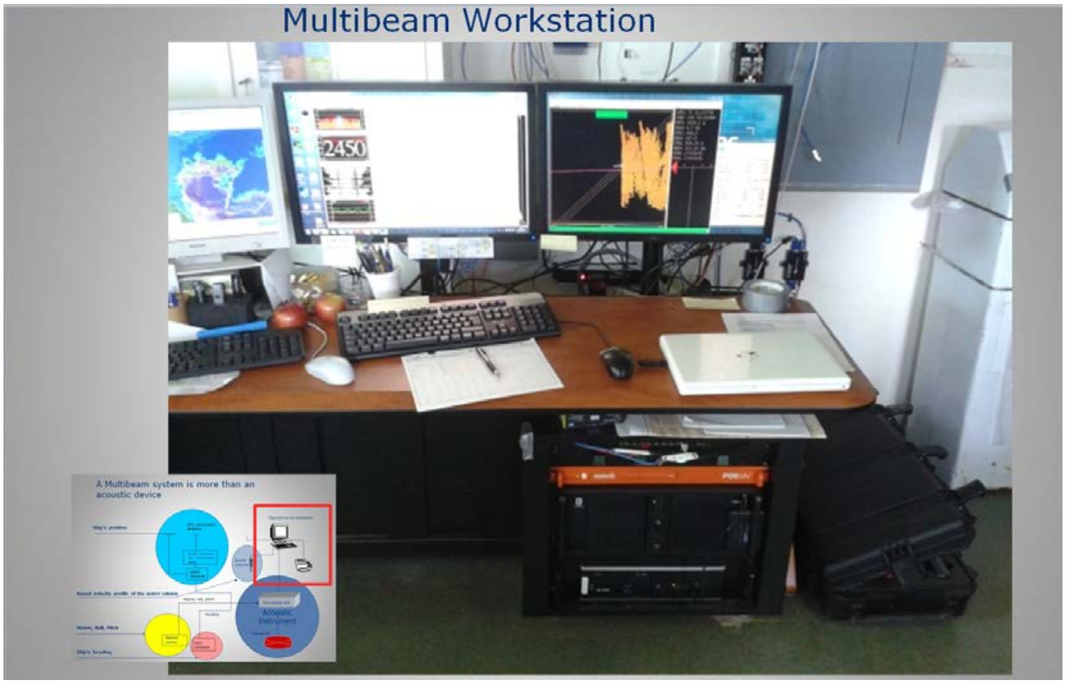


Figure 2.8. The Operator Station is located in the Forward Lab on the 300 deck.

Sound Speed Control

Sound velocity profiles collected by both expendable conductivity/temperature/depth sensors (XCTD) and time of flight sound velocity profilers (SVP) (Fig. 2.9) are introduced to the multibeam acquisition system Seafloor Information System (SIS) immediately as they become available during multibeam acquisition. Locations of deployments are shown in Figure 2.10 and a compilation of results are shown in Figure 2.11. When surveying primarily single line tracks, the profile introduced is essentially a model of the water column in the area that the vessel has already departed. With some analysis it was concluded that the resulting potential depth disparity was insignificant and would have fallen within the survey specification error budget (Order 1a), across the depth ranges.

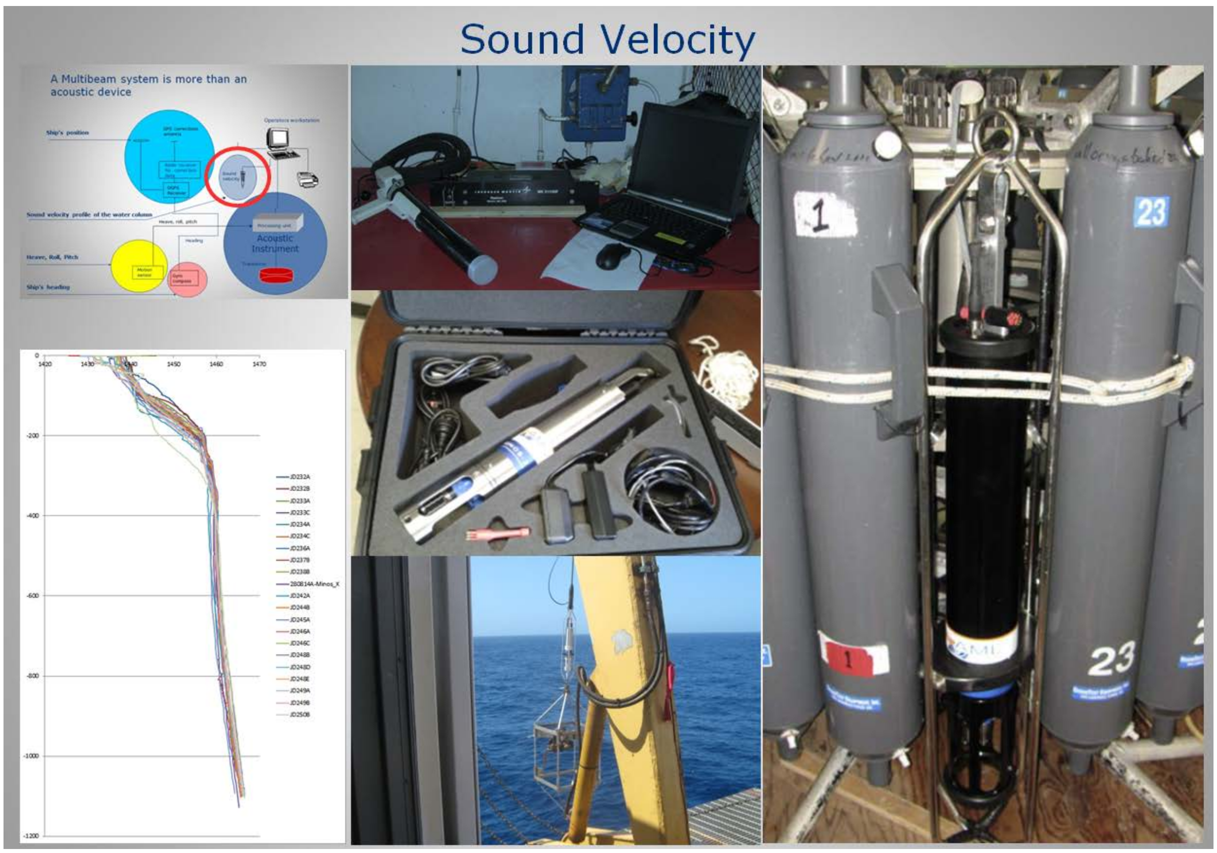


Figure 2.9. Expendable Probe set up with launcher, AML sensor deployed from the oceanographic winch and XCTD rosette with housing for the AML sound velocity probe.

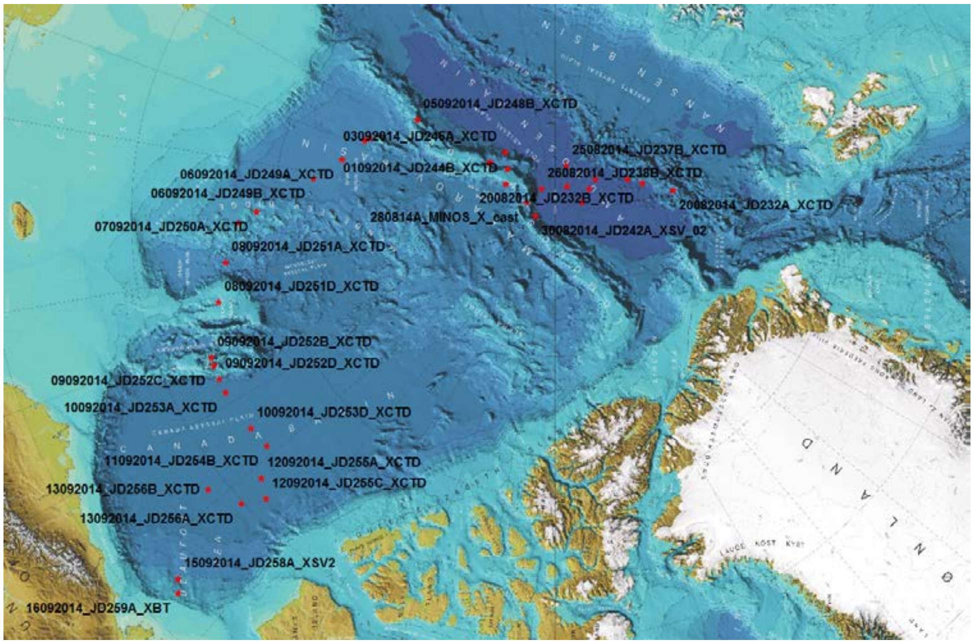


Figure 2.10. Locations of SVP profiles

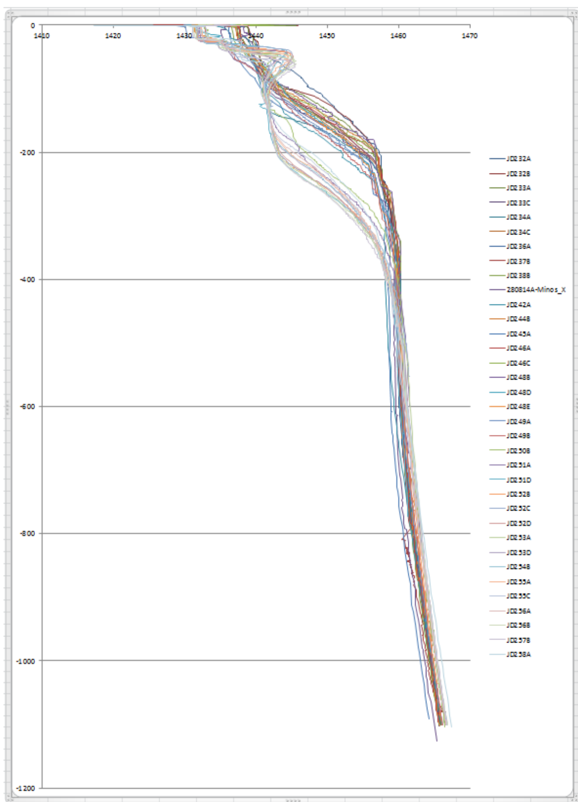


Figure 2.11. Sound velocity profiles from XCTD casts.

Horizontal Datum

Positions within the survey datasets are referenced to World Geodetic System 1984 WGS 84 (G1150). It should be noted that while WGS 84 (G1150) positions are wholly compatible with NAD83 (CSRS) they are not identical – generally speaking the horizontal difference between WGS 84 and NAD83 is approximately 1.5m in the survey area. That said, considering THU expected for this IHO Order 1a Survey is ~105m at average depth of 2000m, the difference between the WGS 84 and NAD 83 is considered insignificant and therefore if NAD83 horizontal positions are required they can be considered equivalent.

Water Level Reductions

Considering the intended output from this survey (IHO Order 1a - Areas shallower than 100 metres where under-keel clearance is less critical but features of concern to surface shipping may exist.) and using an average depth of 2000m as 'd' in the IHO Standard Equation - the allowable TVU must be <26m which indeed the data has achieved (by comparison with overlapping datasets from other surveys/agency data). Tidal characteristics in the survey area are not well understood or modeled – that said the tidal amplitude is expected to be insignificant for this survey application. Therefore taking these factors into account, the survey data was reduced using a 'zero-tide' file so as to not introduce any additional unknowns into the dataset.

Multibeam System Calibration

The EM122 multibeam echo-sounder was installed on the *CCGS Louis S. St-Laurent* (*LSSL*) in 2014. This sounder was trialed and calibrated with the assistance of representatives from Kongsberg Maritime before going into service in the Arctic during the 2014 season. A patch test was conducted the first day of sailing to refine any residual mounting angles.

Data Processing

Bathymetric data were downloaded daily from the multibeam acquisition system aboard *LSSL* and backed for redundancy. Bathymetric data were logged on *LSSL* using Kongsberg Seafloor Information System (SIS). Data were converted to CARIS HIPS format and processed according to CHS ISO9001:2008 process documentation as well as *CHS Standards for Hydrographic Surveys* and the *Hydrographic Survey Management Guidelines*. The data were processed using the CHS processing bathymetric workflow shown below (Fig. 2.12).

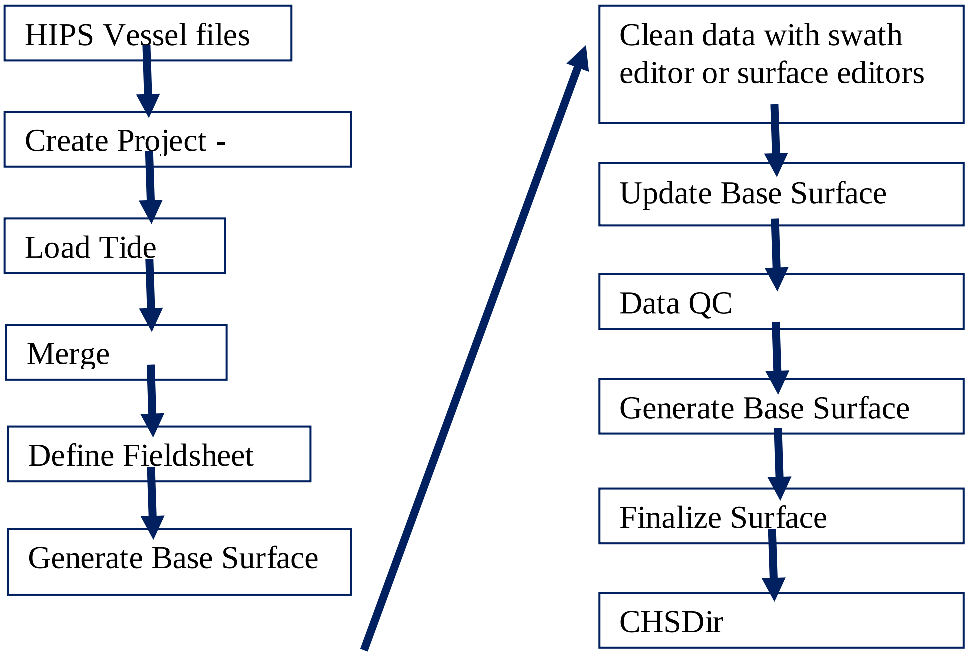


Figure 2.12. Bathymetric data work flow.

Summary of Standards Achieved

As required considering the average depth of the survey area, hydrographic data collected is estimated to have achieved IHO S44 and CHS Order 1a accuracies for both Horizontal Accuracy (THU) and Vertical Accuracy for Reduced Depths (TVU) as outlined in *CHS Standards for Hydrographic Surveys* as well as IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44) 5th Edition February 2008 (Figure 2.13).

Using an average depth of 2000m as 'd' in the following equation – the allowable TVU must be <26m which indeed the data has achieved (by comparison with overlapping datasets from other surveys/agency data) and the THU of the survey exceeded 105 m horizontally (as recorded by Applanix POSMV software). See Figure 2.13 for more detailed breakdown.

$$\pm\sqrt{a^2 + (b \times d)^2}$$

Where:

a represents that portion of the uncertainty that does not vary with depth

b is a coefficient which represents that portion of the uncertainty that varies with depth d is the depth

$b \times d$ represents that portion of the uncertainty that varies with depth

IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44)
5th Edition February 2008

TABLE 1
Minimum Standards for Hydrographic Surveys
(To be read in conjunction with the full text set out in this document.)

Reference	Order	Special	1a	1b	2
Chapter 1	**Description of areas.**	Areas where under-keel clearance is critical	Areas shallower than 100 metres where under-keel clearance is less critical but *features* of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.
Chapter 2	**Maximum allowable THU 95% *Confidence level***	2 metres	5 metres + 5% of depth	5 metres + 5% of depth	20 metres + 10% of depth
Para 3.2 and note 1	**Maximum allowable TVU 95% *Confidence level***	a = 0.25 metre b = 0.0075	a = 0.5 metre b = 0.013	a = 0.5 metre b = 0.013	a = 1.0 metre b = 0.023
Glossary and note 2	***Full Sea floor Search***	Required	Required	Not required	Not required
Para 2.1 Para 3.4 Para 3.5 and note 3	***Feature Detection***	Cubic *features* > 1 metre	Cubic *features* > 2 metres, in depths up to 40 metres; 10% of depth beyond 40 metres	Not Applicable	Not Applicable
Para 3.6 and note 4	**Recommended maximum Line Spacing**	Not defined as *full sea floor search* is required	Not defined as *full sea floor search* is required	3 x average depth or 25 metres, whichever is greater For bathymetric lidar a spot spacing of 5 x 5 metres	4 x average depth
Chapter 2 and note 5	**Positioning of fixed aids to navigation and topography significant to navigation. (95% *Confidence level*)**	2 metres	2 metres	2 metres	5 metres
Chapter 2 and note 5	**Positioning of the Coastline and topography less significant to navigation (95% *Confidence level*)**	10 metres	20 metres	20 metres	20 metres
Chapter 2 and note 5	**Mean position of floating aids to navigation (95% *Confidence level*)**	10 metres	10 metres	10 metres	20 metres

IHO STANDARDS FOR HYDROGRAPHIC SURVEYS (S-44)

IHO S44 ORDER 1a SURVEY TABLE		
	ACCURACY (m)	
DEPTH (m)	DEPTH	POSITION
100	1.39	10.0
200	2.65	15.0
500	6.52	30.0
1000	13.01	55.0
1500	19.51	85.0
2000	26.00	105.0
2500	32.50	130.0
3000	39.00	155.0
5000	65.00	255.0

IHO S44 ORDER 1a SURVEY TABLE
Figure 2.13. IHO Standards for hydrographic surveys

Survey Deliverables

Survey deliverables are as follows:
1. Multibeam bathymetry data sets of Article 76 related targets (See Figure 2.2)
2. GPS Observables
3. Sound velocity profile (SVP) data
4. Final Field Report

Chapter 3

Acquisition and Processing of the Seismic Reflection Data

Introduction

Between August 21st and September 13th, a total of 745.86 line-km of 16-channel seismic reflection data were acquired in three regions: the abyssal plain of the Amundsen Basin; the steep slope along the Eurasian side of the Lomonosov Ridge; and, the northern Canada Basin between the Northwind Ridge and the continental slope offshore of Prince Patrick Island. Survey operations were conducted using the *CCGS Louis S. St-Laurent* as the platform for the seismic operations, and the *CCGS Terry Fox* as the lead icebreaker. In the Amundsen Basin and over the Lomonosov Ridge, the ice concentration was 9 tenths or greater. The second-year floes comprising much of the icepack were frequently under compression, with their thickness generally ranging between 1 and 2 m. Water depths along the seismic profiles in these regions were between 2650 and 4365 m, but they exceeded 4275 m for 75% of the total survey distance. In the northern Canada Basin, the ice conditions were relatively light over the Northwind Ridge and they became increasingly difficult toward the Prince Patrick margin. The water depths during this leg of the survey ranged between 1290 and 3820 m.

The seismic lines were planned along straight tracks that were designed to meet the survey objectives. However, as anticipated, difficult ice conditions caused the ship tracks to deviate significantly from the planned tracks. The bridge crew of both vessels worked together to plot and maintain the straightest possible course through the icepack while avoiding significant ridges and thick floes. To maximize the total distance surveyed in the time that was available, no overlaps between lines were made and data gaps were not re-shot. Lines were terminated whenever malfunctioning equipment or heavy ice conditions made the data acquisition infeasible, and a new line was started at each deployment of the gear. The lines are named LSL1401 through LSL1412. Summary information about the profiles is given in Table 3.1.

Line	First File ID	Last File ID	# Acceptable Shot Records	Start Coord.	End Coord.	Line-km	Average Shotpoint Spacing (m)	Bathymetric Range (m)	Start Date (UTC)	End Date (UTC)
LSL1401	1	2153	2116	87.4046° N 19.2759° E	87.5995° N 16.5933° E	30.76	15	4218 4354	14:32:43 21/08/2014	22:03:18 21/08/2014
LSL1402	2154	2180	26	88.1271 -7.6276	88.1266 -7.5822	0.19	7.3	4346 4347	02:45:58 23/08/2014	02:52:03 23/08/2014
LSL1403	2181	2648	468	88.1154 5.2105	88.0926 7.9398	10.92	23	4337 4345	17:22:23 23/08/2014	19:13:28 23/08/2014
LSL1404	2649	6259	3531	88.1113 7.9158	88.4596 22.6777	77.47	22	4340 4355	22:54:28 23/08/2014	16:40:08 24/08/2014
LSL1405	6260	7096	734	88.0801 44.2145	88.1845 43.7251	17.84	21	4352 4363	05:01:48 25/08/2014	09:11:58 25/08/2014
LSL1406	7097	7729	633	88.7428 43.8900	88.8355 45.0477	14.75	23	4342 4350	19:23:03 25/08/2014	23:23:58 25/08/2014
LSL1407	7730	9337	1076	88.8213 45.2683	88.9746 44.1779	23.93	22	4336 4348	03:23:38 26/08/2014	11:35:58 26/08/2014
LSL1408	9338	9930	593	89.1097 44.8642	89.2629 45.0760	18.87	32	4308 4329	22:13:08 26/08/2014	01:39:33 27/08/2014
LSL1409	9931	10782	850	89.4310 46.7910	89.6889 50.4396	32.74	39	4253 4283	10:40:08 27/08/2014	17:48:18 27/08/2014
LSL1410	10783	12213	1431	89.4762 -40.6935	89.2886 -74.0194	47.67	33	2652 4163	14:10:18 30/08/2014	21:43:08 30/08/2014
LSL1411	12214	23427	10925	77.5261 -153.9071	77.3913 -137.1336	420.78	39	1293 3817	04:08:23 09/09/2014	13:07:58 11/09/2014
LSL1412	23428	24991	1564	75.5513 -131.9829	75.3489 -133.5340	49.94	32	2740 3206	01:37:23 13/09/2014	09:42:08 13/09/2014
Survey (total/avg)		24991	23947			745.86	30			

Table 3.1: Summary of shot records. ***Note:*** *the shot numbers listed on the gun controller were not logged by the data recording software and are not written in trace headers of the shot records. Therefore the file ID numbers were used in place of the shot numbers for the purposes of data processing.*

Acquisition Parameters

Seismic source

The seismic source for this survey was a cluster of three Sercel G-guns having a combined volume of 1150 $in^{3.}$ The airguns were suspended in a triangular configuration beneath the tow sled. The two aft airguns each have a volume of 500 in^3 and were separated from each other by a distance of 1.00 m. The forward 150 in^3 airgun was suspended centrally between, and 1.24 m ahead of the aft airguns. This cluster was towed immediately behind the stern at a depth of 11.2 m below the sea surface.

Shot interval

The three airguns were fired simultaneously at regular time intervals using an air pressure of 1950 psi. There was a 46 ms mechanical delay in firing of the airguns with respect to the electronic trigger pulse. Shooting was based on time rather than distance in order to minimize stress on the equipment while operating under variable ice conditions. This strategy has an additional benefit of increasing the trace density of the sonobuoy records and increasing the effective fold of the processed seismic reflection profiles. Experience gained in previous surveys has demonstrated that the reflection data can be successfully binned and processed despite the irregular trace spacing in the mid-point and common receiver gathers that is produced by shooting on time rather than distance.

In water depths of 4.3 km, the shot interval should normally be greater than about 28 to 30 s in order to avoid overprinting the records with energy from the third primary multiple of previous shots. This energy, which is commonly called the wrap-around multiple, can be a serious form of coherent noise that is difficult or impossible to eliminate during processing. A 30 s shot interval would translate to a shot spacing of about 60 m at a typical survey speed of 4 knots, which would yield a low trace density and likely cause mid-point binning of the data to be ineffective. Fortunately, the multiple energy is attenuated by spherical spreading in the deep water and also by scattering of the reflections from the base of the sea ice (Lykke-Andersen *et al.*, 2010).
An initial shot interval of 12 s was chosen at the start of the survey based on the experience of colleagues at the Geological Survey of Denmark and Greenland who collected the LOMROG seismic surveys over the Amundsen Basin (Lykke-Andersen *et al.*, 2010). Stacking of the shot records during acquisition of line LSL1401 revealed however that the wrap-around multiple energy was significant, probably because the source was larger than that used for the LOMROG surveys. Consequently, the shot interval was increased to between 18 and 20 s depending on a qualitative assessment of the level of multiple contamination. For shallower water depths, over the flank of the Lomonosov Ridge, the following shot intervals were used:

- 12 s for < 3 s of water ;
- 16 s for 3–4 s ;
- 17 s for 4.0–4.8 s ; and,
- 18 s for 4.8–5.0 s .

The distance between shotpoints varied during the survey as a function of these shot intervals and also the vessel speed over the ground, which fluctuated significantly during periods of heavy icebreaking. The average shot spacing along each seismic line is listed in Table 3.1.

Source wavelet

Calibrated far-field recordings were made during the 2010 field program for various combinations of the three airguns (Mosher *et al.*, 2011). These are plotted on Figure 3.1, which illustrates that the source wavelet includes a series of residual bubble pulses for an interval of at least 150 ms after the primary pulse. Thus each primary reflection on the unprocessed seismic record is followed by a complex train of reverberations. Power spectra for the various airgun combinations are plotted on Figure 3.2. The notch centred at about 65 Hz is caused by the source ghost (*i.e.* the reflection of the primary from the sea surface above the source). Relatively little power appears to be generated by the airguns at frequencies higher than this source ghost notch, so the practical seismic bandwidth is 3 to 65 Hz. Additional notches within the practical bandwidth, at about 12 and 19 Hz for example, are caused by destructive interference between the primary and the bubble pulses. These notches have a negative impact on both the depth of penetration and the resolution of the source wavelet.

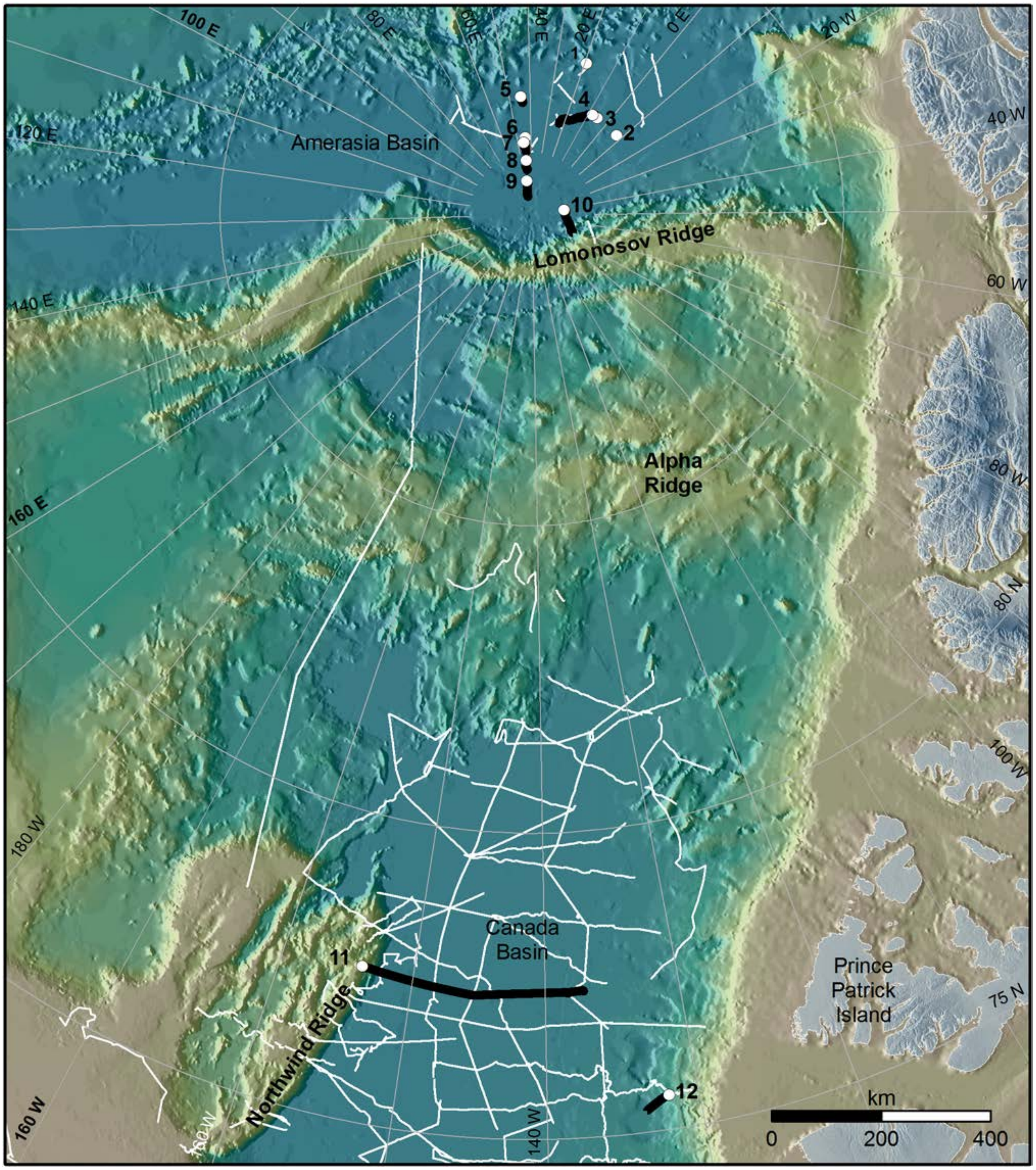
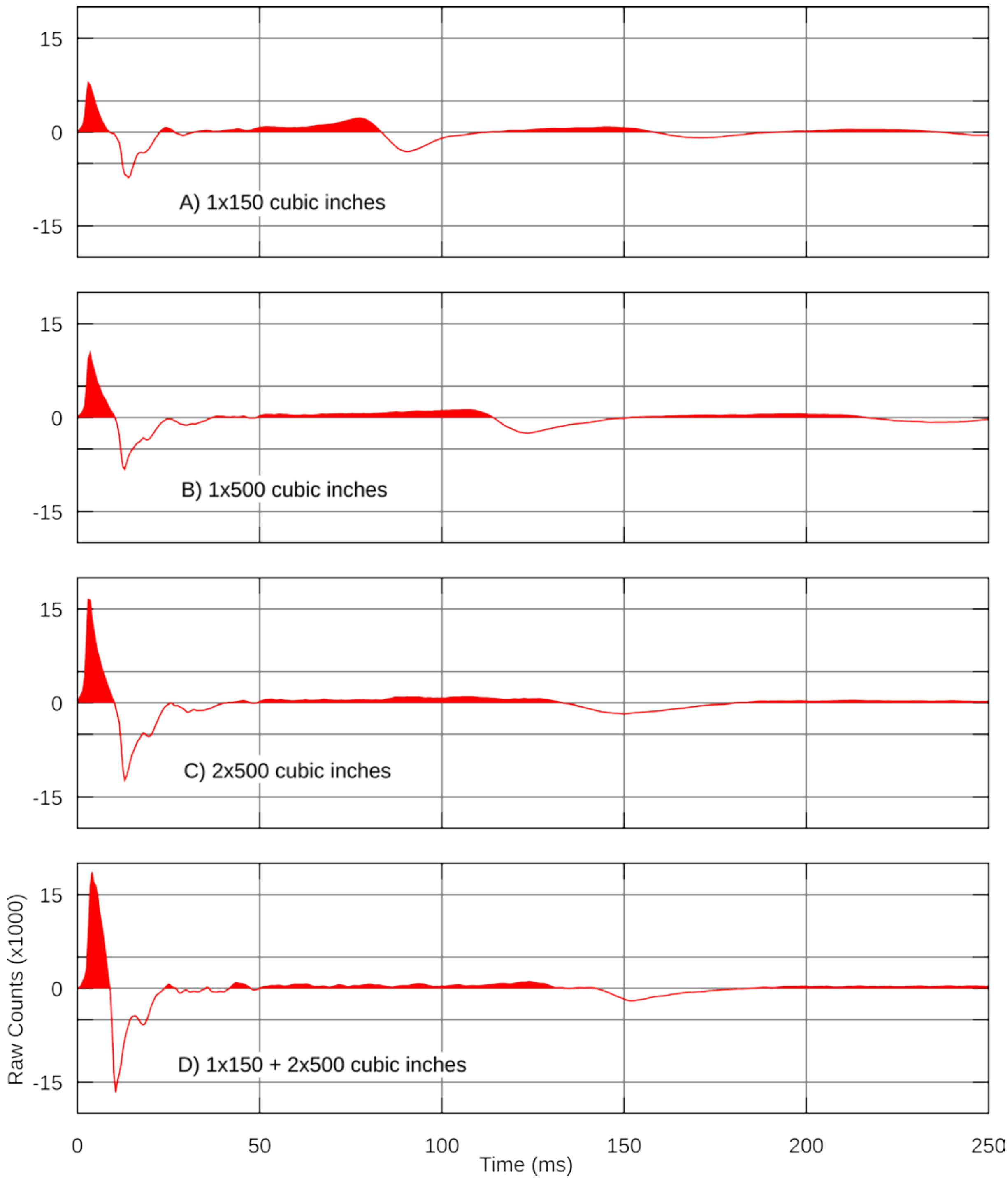


Figure 3.1: Location map of the survey area. The black tracklines indicate the 745.86 line-km of 16-channel, short-offset seismic data that were acquired during the 2014 cruise aboard the CCGS Louis S. St-Laurent. The labelled dots indicate the start of each line. Tracklines from the 2007 through 2011 datasets collected by the Geological Survey of Canada, and also the LOMROG datasets collected by the Geological Survey of Denmark and Greenland, are shown in white.



15
0
-15
A) 1x150 cubic inches
B) 1x500 cubic inches
C) 2x500 cubic inches
D) 1x150 + 2x500 cubic inches
Raw Counts (x1000)
0
50
100
150
200
250
Time (ms)

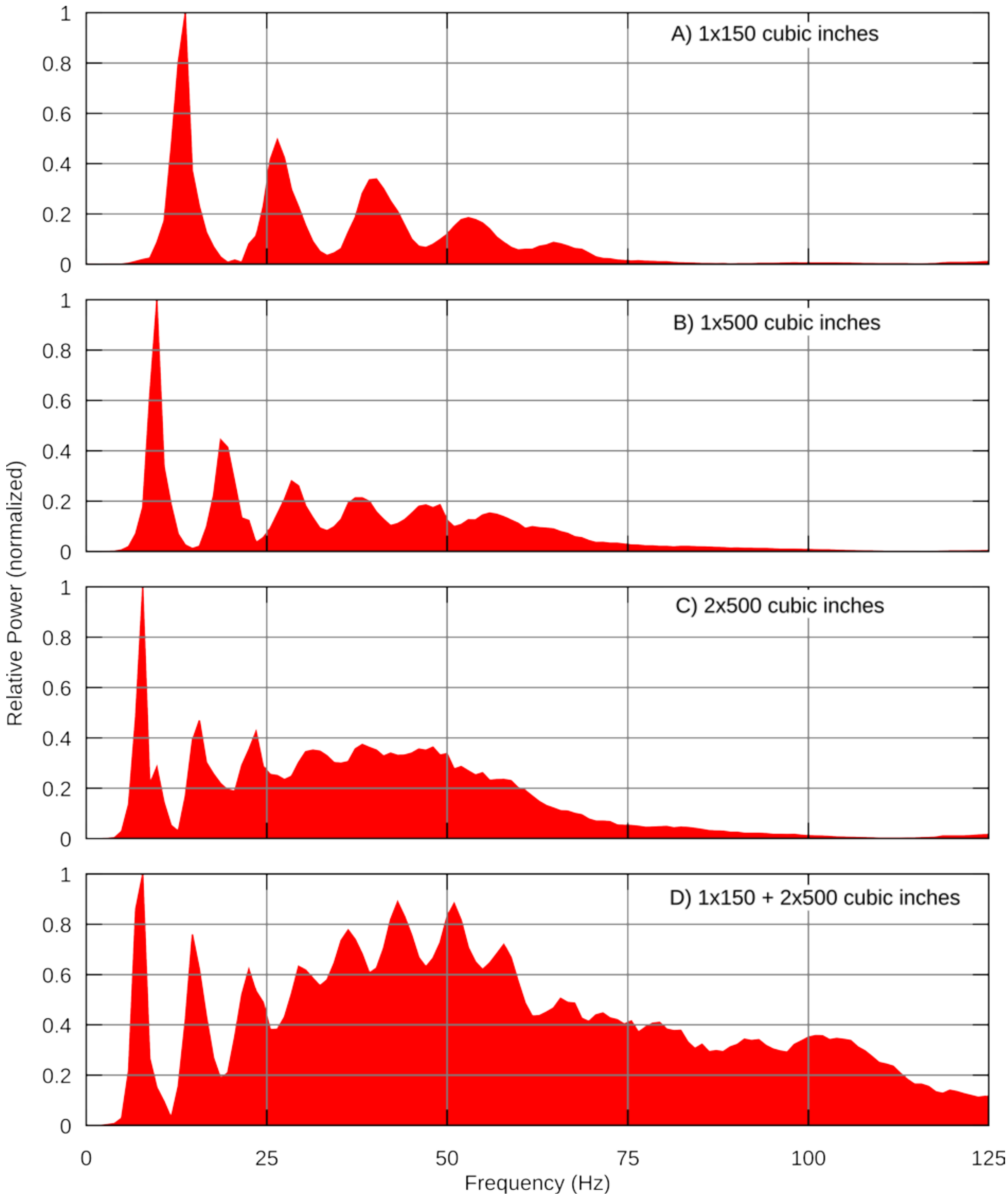


Figure 3.2: Source wavelets (top four panels) and respective power spectra (bottom four panels) recorded by Mosher et al. (2010) for various combinations of airguns in the cluster. The source is towed at a depth of 11.2 m beneath the sea surface. Total source volumes are 150 in^3; 500 in^3; 1000 in^3; and 1150 in^3.

Receiver array

The receiver array consisted of two active GeoEel streamer sections, each 50 m long, with 64 equally spaced hydrophones. These were configured into 8 channels per active section with 8 hydrophones per group. Accordingly, there were a total of 16 active channels with a group interval of 6.25 m.

Icebreaking operations lead to frequent course deviations, changes in speed, and even complete stops. Also there can be significant water temperature and salinity changes around the icepack, meaning that correct balancing of the streamer is difficult to obtain over the duration of a survey. Wooden floats were placed at three positions along the length of the streamer to increase buoyancy, but active control of the streamer was not attempted because of the risk that streamer birds might become caught in the ice. As a result, the receiver depths varied significantly along the length of the streamer and also from one shot to the next. Depth differences of greater than 10 m between the inboard and outboard receiver groups were common, and the streamer sank at rate of 2.5 to 3.0 m per minute during periods when the forward motion of the ship was stopped by heavy ice.

Source-to-receiver offsets

The Novatel Global Positioning Satellite (GPS) antenna located above the wheelhouse top at frame 198 of the ship was used as the fixed navigation point for the survey. The source and receiver offsets relative to the fixed navigation point are shown on Figure 3.3.

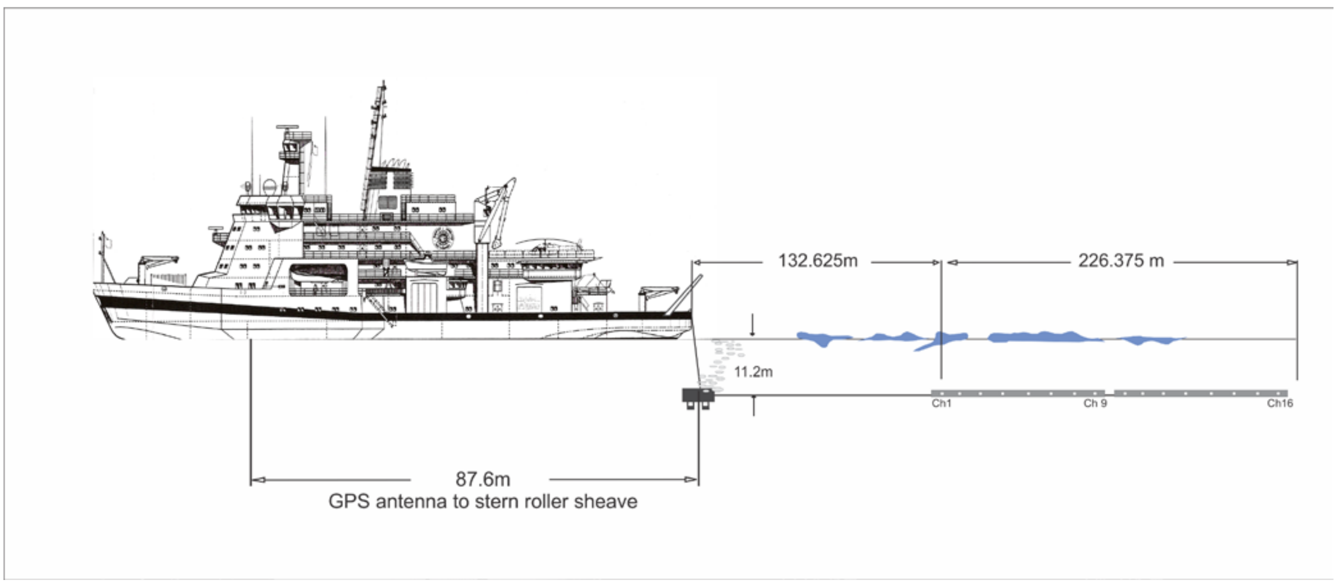


Figure 3.3: Source-to-receiver offsets for the towing configuration that was used in the Arctic icepack.

Data recording

Digitizing Software Parameters

The seismic reflection data were recorded using the Geometrics GeoEel system that is fully described by Mosher *et al.* (2011). With this system, the analog hydrophone signals are converted to

24-bit digital traces by digitizing units in the streamer and are automatically summed for each receiver group. The trace data from each receiver group are broadcast, via ethernet connection in the streamer, to the multithreaded CNT-2 software (version 5.36) running under the Windows XP operating system (service pack 3) on a personal computer in the seismic lab.

The CNT-2 software provides a user interface for configuring the GeoEel system, for monitoring the data quality during acquisition, for testing the receiver array, and for recording the data to magnetic disk drive and/or magnetic tape. Additional data, such as measurements from the streamer depth sensors, can also be logged by the CNT-2 software through a serial communications port. The recording parameters that were used during the survey are listed in Table 3.2.

Parameter	**Value**
Sample interval	2 ms
Recording window	11.5 s
Recording delay	0.05 s
Recording format	SEG-D 8058 revision 1
Active channels	1 through 16 (near trace = 1; far trace = 16)
AC coupling	disabled
Shot/file number comparison	disabled
Preamp gains	+18 dB on all channels
Transconductance	20 Volt/bar

Table 3.2: Recording parameters used with the Geometrics CNT-2 software during the survey.

Data Storage

Digital shot records were stored on magnetic disk drive, one file per shot record, in the Society of Exploration Geophysicists SEG-D 8058 Revision 1 format. Included in each SEG-D file is a variable-sized external header containing the GPS navigation strings including date (UTC), geographic position in degrees and decimal minutes (reference ellipsoid: World Geodetic System, 1984), water depth from the 3.5 kHz sounder, speed through the water, heading, speed over ground, and course over ground.

The SEG-D files were copied every half-hour onto a separate magnetic disk drive installed on the recording computer. Upon completion of each line, all associated shot records and log files were copied onto two additional hard drives.

Data Quality Monitoring and Seismic Watch keeping

During acquisition, the CNT-2 user interface was used to automatically plot each shot record, the amplitude spectra of each trace, a log of diagnostic messages, and a simple brute-stack record section. An example monitor display is shown on Figure 3.4. This provided immediate, shot-by-shot feedback on the GeoEel system performance and confirmation that the data were of acceptable quality. The software is capable of displaying a bar graph of root-mean-squared noise levels within a user-defined window for each shot record, but this function appeared to cause the software to crash and so this function was abandoned.

Watch keepers kept a half-hourly log of the following system parameters: calendar day, UTC time, latitude, longitude, line segment, water depth, course over ground, heading, speed over ground, speed through water, ship's bubbler (on/off), streamer system (port/starboard), streamer leakage, streamer current, streamer voltage, streamer depth (inboard/outboard), seismic source system (port/starboard/tow depth), shot number, total source volume, number of airguns, firing rate, record length and recording delay. An electronic copy of the watch keepers' log is included with the cruise documentation.

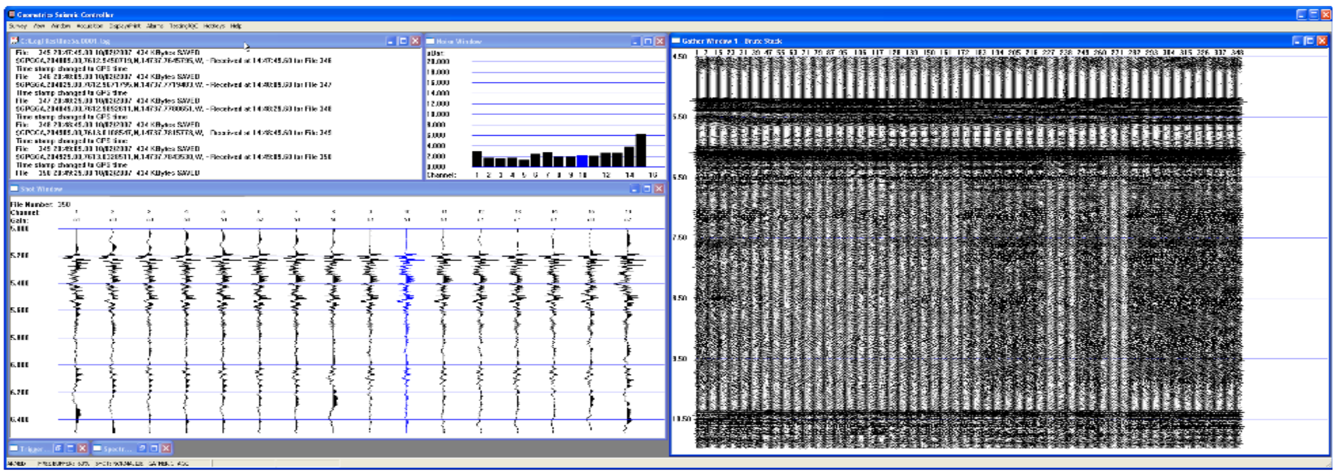


Figure 3.4: Screen capture of the CNT-2 graphical user interface showing a message log (top left), RMS noise chart (top middle), shot record (bottom left), and brute stack (right). The software also allows the frequency spectra of each trace to be monitored (not shown).

Data Processing

The Globe Claritas commercial software package (version 6.1) developed by the New Zealand Institute of Geological and Nuclear Sciences was used to process the seismic data during the cruise. The   software was installed on a Dell Precision M6800 laptop (Intel Core i74800MQ CPU@ 2.70 GHz x 8) running the 64-bit Ubuntu Linux operating system (version 14.04 LTS). An external 500 gigabyte, universal serial bus hard-drive was used to store copies of the raw and processed datasets. The signal processing workflow is described in the following sections, and it is summarized as follows:

1. Read shot records
2. Extract navigation and assign survey geometry
3. Filter high amplitude coherent and random noise on shot gathers
4. Filter high amplitude random noise on common receiver gathers

5. Suppress primary multiples
6. Convert to minimum phase wavelet
7. Compensate for seismic attenuation
8. Deconvolve short-period reverberations before stack
9. Apply normal moveout correction and stack mid-point gathers
10. Deconvolve short-period reverberations after stack
11. Filter noncoherent noise on stacked records
12. Migrate the stacked records
13. Apply time-varying bandpass filter and final trace balance
14. Output processed records

Read shot records

Individual shot records were read using the SEG-D Revision 1.0 standard. Erroneous shot records were removed from the data stream at this stage. Traces on legitimate shot records were de-biased by subtracting the mean amplitude of the trace from each sample, and then the shot gathers were converted and saved to a Claritas extended SEG-Y format. Line LSL1402 was not included in the processing sequence since it comprised only 26 shot records.

Extract navigation and assign survey geometry

The following information was extracted from the SEG-D external trace headers and written to a comma separated value text file: shotpoint, longitude, latitude, water depth from the 3.5 kHz sounder, speed through the water, speed over the ground, UTC time, day, month, year, streamer depth at channel 1, and streamer depth at channel 16. This information was used to design bins spaced at a regular 12.5 m interval along the track of each seismic reflection profile. The in-line halfwidth of each bin was 25 m, and the cross-line halfwidth was 75 m. Traces were assigned to all of the multiple overlapping bins in which they were located. This strategy ensured that each bin was assigned traces from multiple shots, typically yielding an effective fold of between 3 and 6 depending on the spatial density of the shotpoints. An example of the mid-point bins and trace assignments is shown on Figure 3.5.

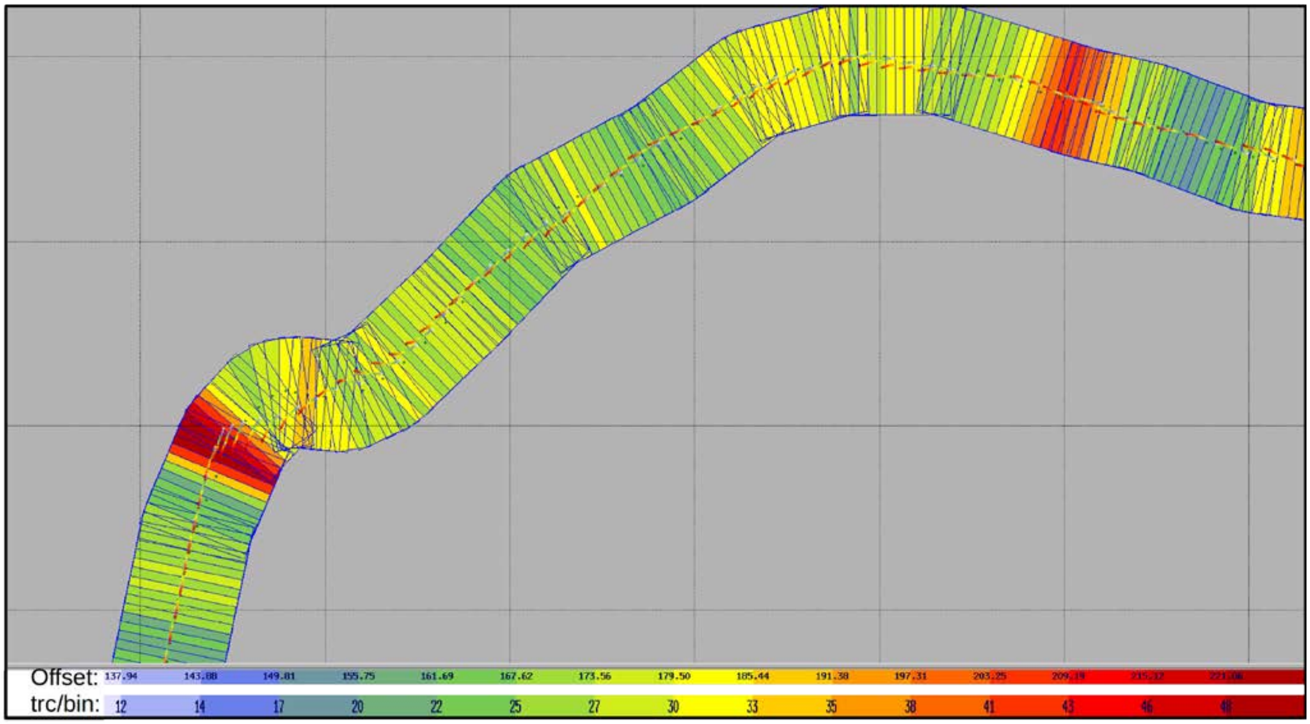


Figure 3.5: Example of mid-point binning along LSL1404. Shotpoints are indicated by the green crosses. Each 25 x 75 m bin is outlined in blue and colour-filled to indicate the number of traces within the bin. The receiver positions are plotted as colour-coded dots according to offset. The along-track bin spacing is 12.5 m so that most bins received traces from 4 different shots. The acquisition direction was from left to right. The horizontal and vertical grid lines are spaced at 250 m.

Fluctuations in the receiver depths change the way in which the receiver ghost interferes with the primary reflections. The depth fluctuations also correspond to significant changes in the two-way travel time with respect to the seismic datum, which causes mis-positioning of the reflection events and loss of resolution due to misalignment of the mid-point trace gathers. These issues can be largely corrected during processing if the receiver depths are known with reasonable accuracy. Depth sensors were installed close to receiver groups 1 and 16 of the GeoEel streamer. However the measurement values reported by the inboard sensor are clearly incorrect. Those reported by the outboard sensor are plausible, but they appear to be incorrectly calibrated. A comparison is shown on Figure 3.6 of the sensor measurements versus the receiver depths that were calculated using the receiver ghost reflection along line LSL1401. This ghost reflection was interpreted from a bandpass filtered autocorrelation of the seismic traces extracted within a 1.0 s window beneath the seafloor. Its two-way travel time was then converted to depth below the sea surface using sound speed profiles that were measured in the water column during the survey. This procedure was used to calculate receiver depths at channels 1, 8, and 16 for all the seismic lines in the survey. The depths at the remaining channels were interpolated.

Time shifts were calculated to correct the total two-way travel time to the seismic reference datum of sea level using the source depth, the receiver depths, the firing delay, the recording delay, and also a delay to compensate for the minimum-phase filtering that is described in the next section. The time shift calculated for each trace was stored in the trace header so that it could be applied a later stage in the processing. A summary of the time shifts applied to each line is given in Table 3.3.

Line	**Recording delay**	**Firing delay**	**Combined source-receiver delay (min : max)**	**Filtering delay**	**Total delay (min : max)**
01	+50	-46	+13 : +53	-10	+7 : +47
03	+50	-46	+15 : +47	-10	+9 : +41
04	+50	-46	+13 : +110	-10	+7 : +104
05	+50	-46	+13 : +50	-10	+7 : +44
06	+50	-46	+13 : +29	-10	+7 : +23
07	+50	-46	+13 : +48	-10	+7 : +42
08	+50	-46	+13 : +54	-10	+7 : +48
09	+50	-46	+14 : +32	-10	+8 : +26
10	+50	-46	+16 : +25	-10	+10 : +19
11	+50	-46	+13 : +47	-10	+7 : +41
12	+50	-46	+15 : +45	-10	+9 : +39

Table 3.3: Time shifts applied to correct the two-way travel times of seismic traces in the survey to sea level. All shifts are in milliseconds.

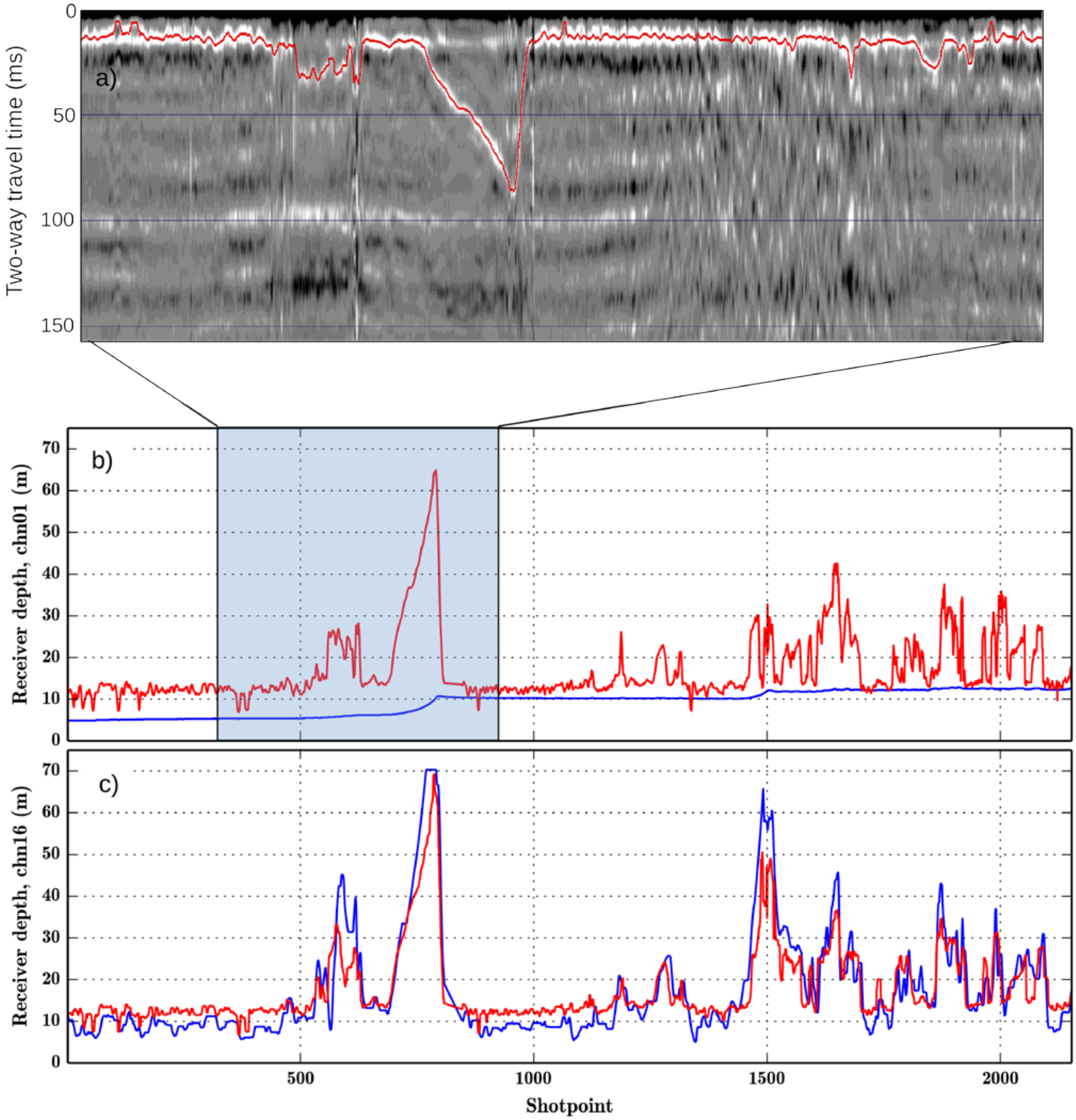


Figure 3.6: Receiver depths along line LSL1401. a) Autocorrelation of seismic traces extracted within a 1.0 s window beneath the seafloor for the shotpoint range that is highlighted. The receiver ghost is the event that is marked by the red horizon. b) Receiver depths at channel 1 as reported by the streamer sensor (blue) and as determined from the ghost horizon (red). c) Receiver depths at channel 16 as reported by the streamer sensor (blue) and as determined from the ghost horizon (red).

Filter high amplitude coherent and random noise on shot gathers

Vibrations travelling along the length of the streamer, which is a phenomenon known as cable strumming, caused high amplitude linear noise on the shot records that frequently contained more power than the signal. This form of noise is potentially a serious problem, but the combination of a relatively short streamer with small offsets and deep water means that primary reflection events exhibit little or no moveout. They are essentially horizontal on the shot gathers, while the linear coherent noise typically has apparent velocities of between 200 and 800 m/s. Thus the high amplitude noise from cable strumming was effectively removed through straightforward application of a smoothed mute in the *F-K* domain.

Since data re-acquisition to replace noisy or erroneous records was infeasible during this survey, traces with high or even extreme noise levels were retained in the processing stream. During icebreaking operations, the noise can vary significantly from shot to shot, and from channel to channel. To characterize the high amplitude noise efficiently, a semi-quantitative index was calculated for each trace of the shot gathers using the following steps, which are derived from a method called water-level deconvolution:

1. apply a minimum phase Butterworth bandpass filter of 2/4/80/240 Hz;
2. extract the seismic amplitude samples within a 600 ms window starting at the seafloor, which is a window in which the signal-to-noise ratio is typically high but which exceeds the interval of most high amplitude random noise bursts;
3. determine the range between the 90^{th} and the 10^{th} percentiles of the extracted amplitudes for use as an arbitrary threshold distinguishing between signal and high amplitude noise;
4. calculate the discrete Fourier transform for each of the windowed traces;
5. set to zero any of the real Fourier coefficients that exceed the signal threshold;
6. derive an estimate of the noise by taking the discrete inverse Fourier transform;
7. assign a noise index to the trace by calculating the root-mean-square amplitude of the noise estimate.

To suppress the high amplitude noise, a series of minimum-phase Butterworth filters were applied to each trace. A relatively mild low-cut was applied to traces with noise indices of less than 1000, comprising 90% of the dataset, while a stronger low-cut was applied to traces with noise indices of 1000 or greater. The threshold value of 1000 was chosen from inspection of the cumulative sample distribution (Figure 3.7) and iterative testing. The Butterworth filters were designed also with a notch-cut corresponding to the lowest frequency bubble pulse of the recorded source wavelet (Figure 3.5). For example, a notch-cut was designed at 11.6 Hz for the 500+150+500 in^3 combination of airguns in the cluster at a tow depth of 11 m. The filters that were applied to the traces in the present survey are illustrated on Figures 3.8 through 3.10, and the passband parameters are listed in Table 3.4.

Trace amplitudes were balanced before application of the *F-K* and Butterworth filters using a constant amplitude scalar calculated within a 6.0 s window starting at the seafloor. The inverse scalar was applied after the filtering to remove the effects of the trace balance. The time shifts that were previously calculated to correct the traces to the seismic reference datum were then applied. An example of the results from this stage of the processing is shown on Figure 3.11.

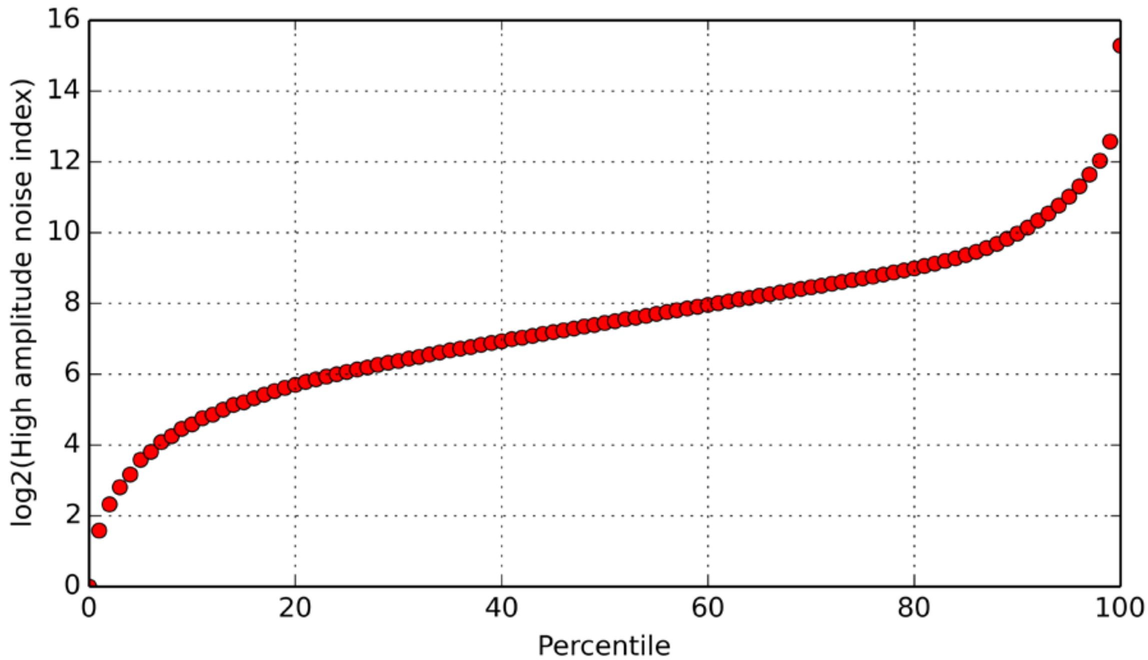


Figure 3.7: Cumulative sample distribution of the high amplitude noise indices for all traces in the survey. The 90th percentile of the sample distribution ($2^{9.976} = 1000$) was chosen as a threshold to identify noisy traces for stronger filtering.

Airgun Combination (in^3)	**Source Depth (m)**	**Noise Index Range**	**Filters (Hz)**
500+150+500	11	< 1000 (low noise)	BP: 4/6/9/12 BP: 11.5/13.8/110/160
500+150+500	11	≥ 1000 (high noise)	HP: 4/13.8 BP: 11.5/13.8/110/160
500+500	11	< 1000 (low noise)	BP: 4/6/9/12 BP: 12.5/15/75/130
500+500	11	≥ 1000 (high noise)	HP: 4/15 BP: 12.5/15/75/130

Table 3.4: Minimum-phase Butterworth filter passbands used for suppression of high amplitude noise on the shot gathers.

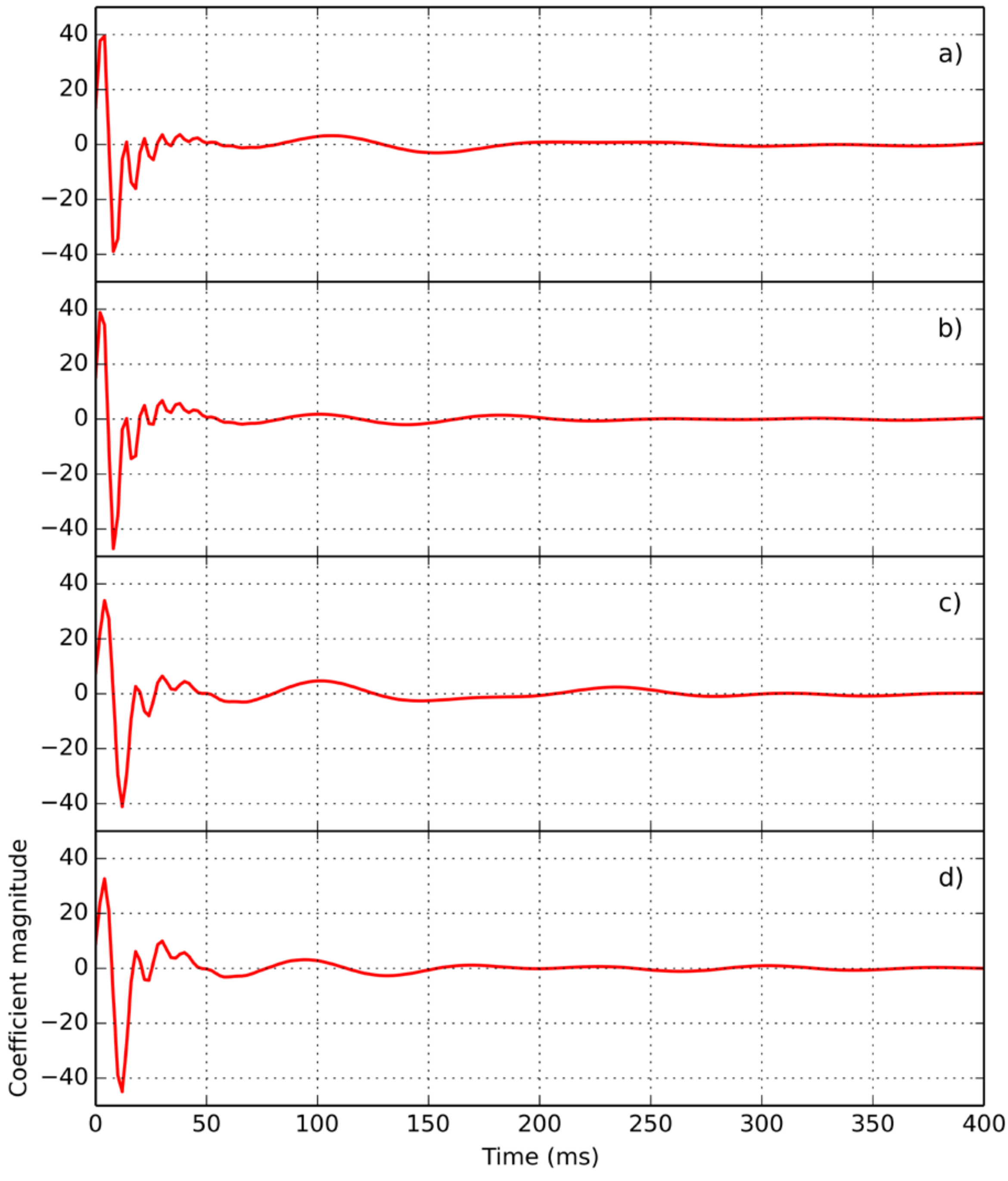


Figure 3.8: minimum-phase Butterworth filters applied to a) traces from the 1150 in^3 source with low noise indices; b) traces from the 1150 in^3 source with high noise indices; c) traces from the 1000 in^3 source with low noise indices; d) traces from the 1000 in^3 source with high noise indices. Note: the actual filter lengths are 10 s.

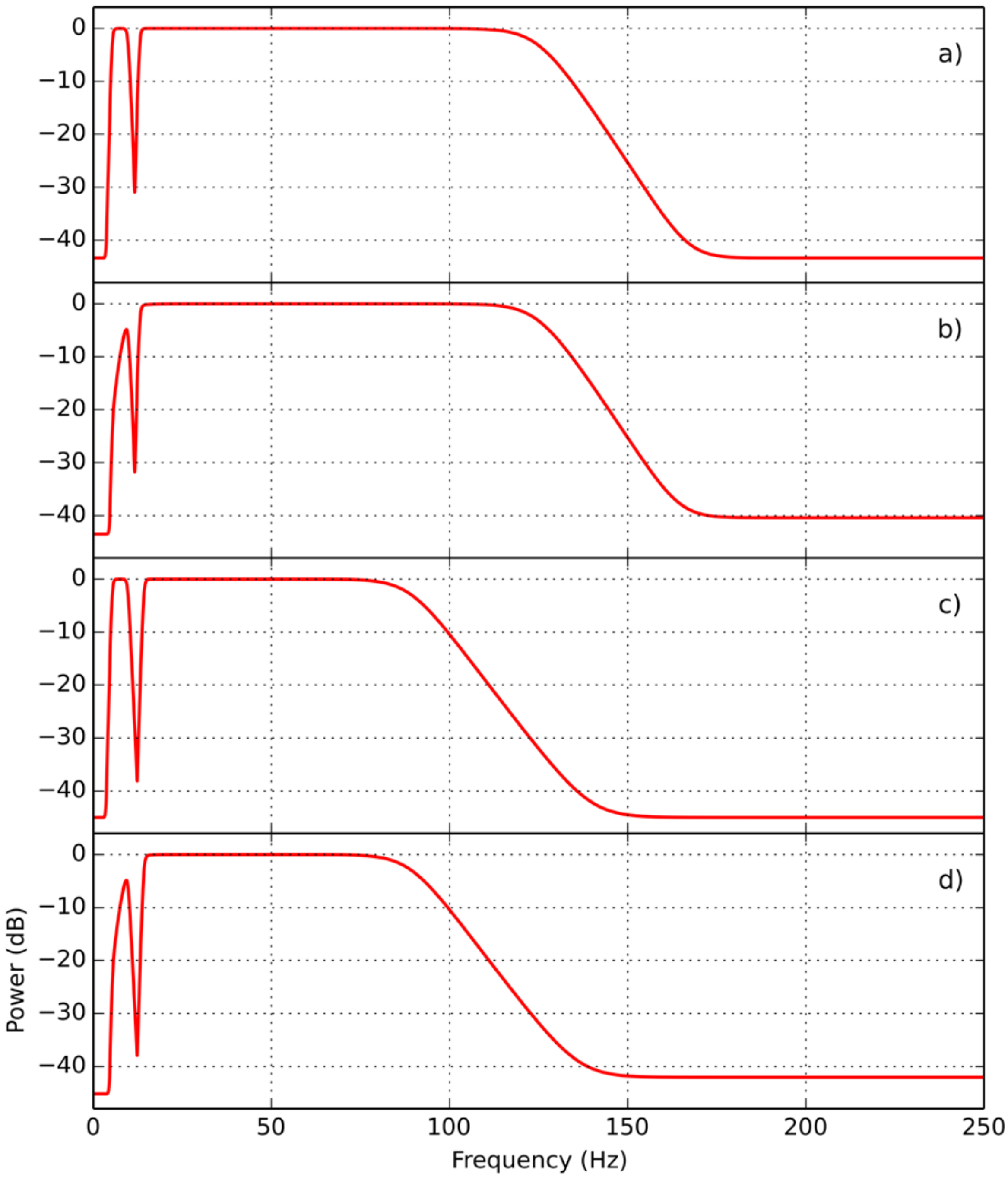


Figure3.9: Relative power spectra for the minimum-phase Butterworth filters shown on Figure 3.8. The filters were designed for a) traces from the 1150 in^3 source with low noise indices; b) traces from the 1150 in^3 source with high noise indices; c) traces from the 1000 in^3 source with low noise indices; d) traces from the 1000 in^3 source with high noise indices.

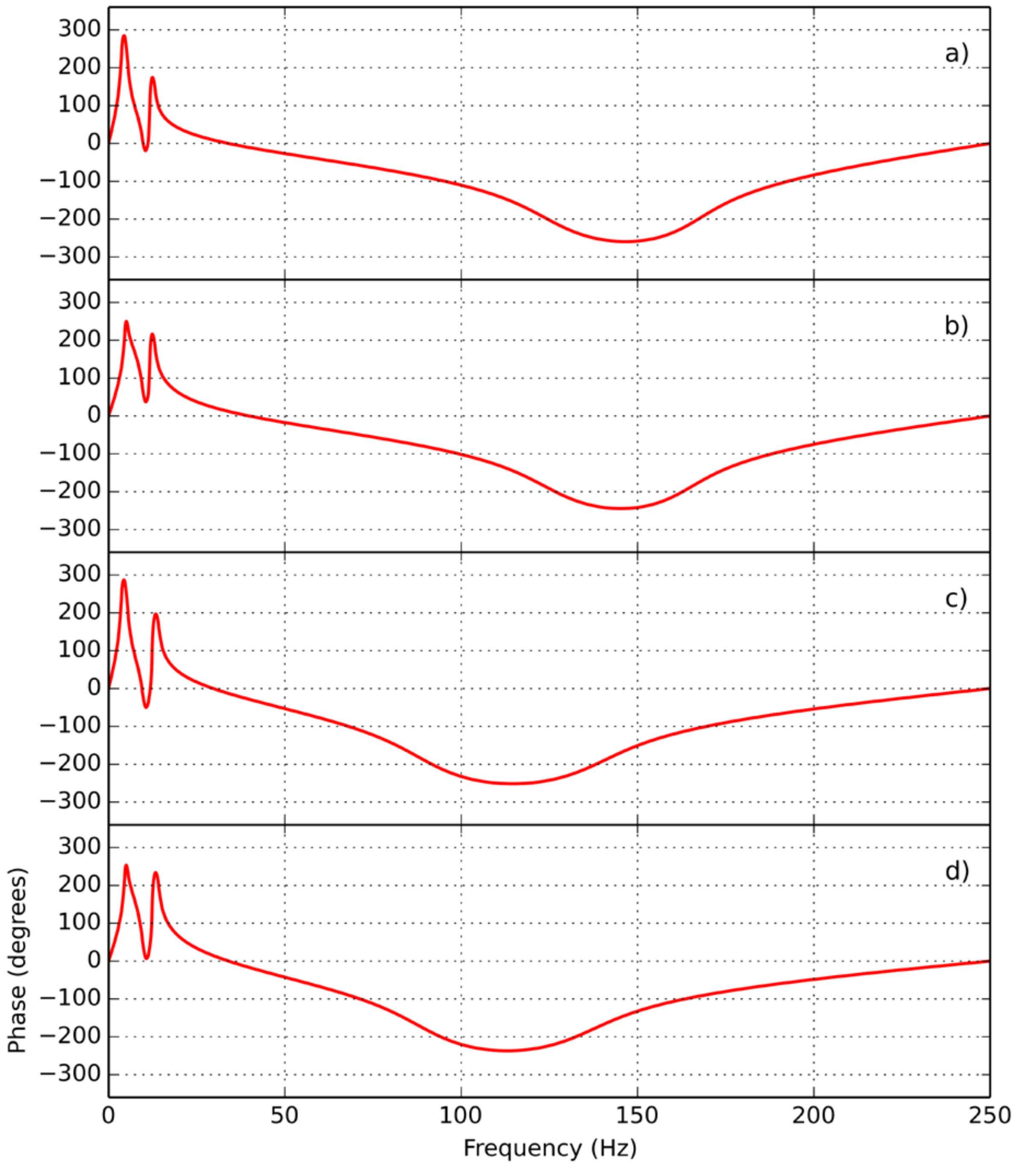


Figure3.10: Phase spectra for the minimum-phase Butterworth filters shown in Figure 3.8. The filters were designed for a) traces from the 1150 in^3 source with low noise indices; b) traces from the 1150 in^3 source with high noise indices; c) traces from the 1000 in^3 source with low noise indices; d) traces from the 1000 in^3 source with high noise indices.

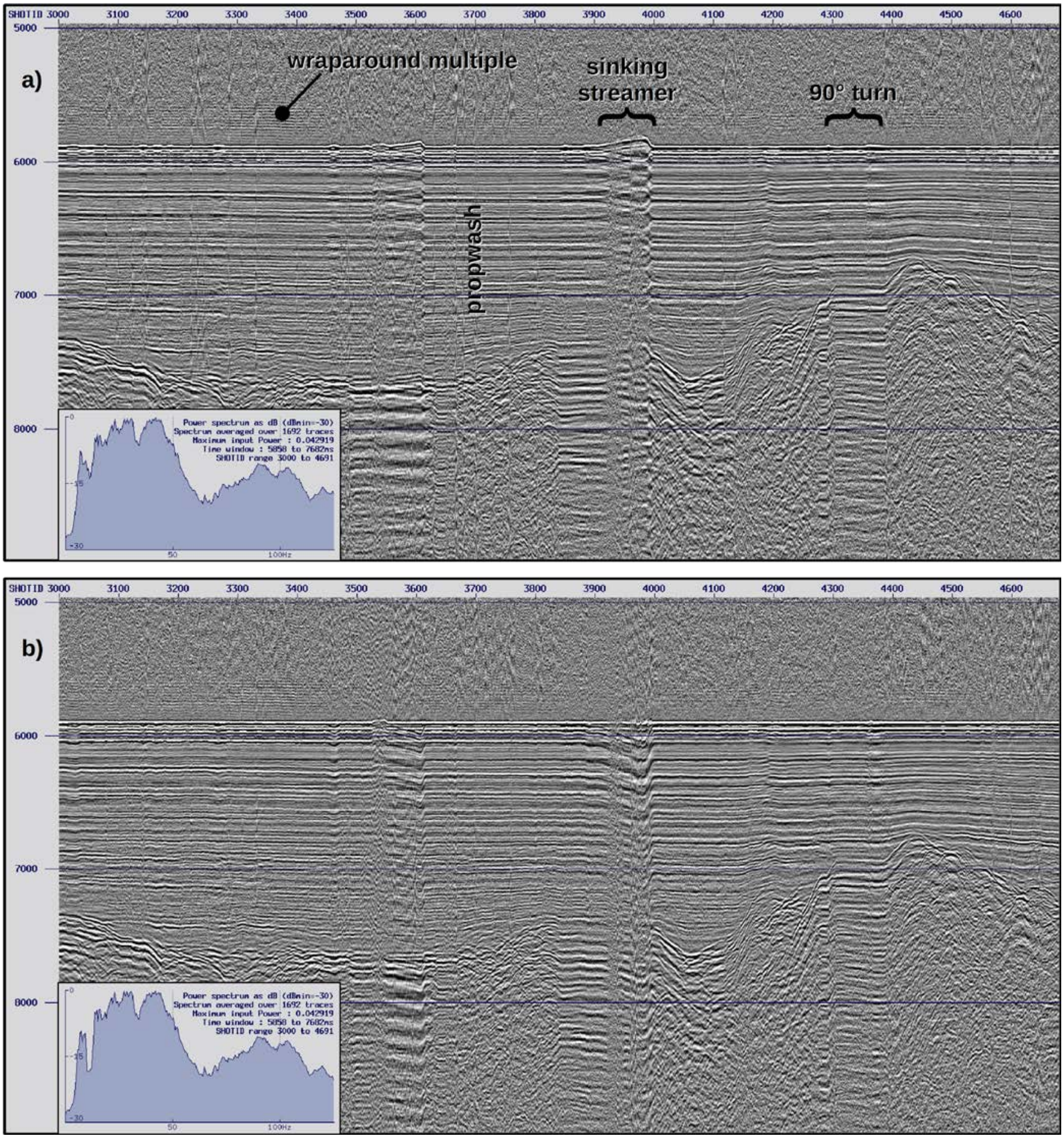


Figure 3.11: Example results along line LSL1404. a) Brute stack of the raw shot records with a broad bandpass filter (4/8/60/80 Hz) and automatic gain control applied. b) Stacked record after application of the Butterworth filters and time shift correction.

Filter high amplitude random noise on common receiver gathers

Prop wash from icebreaking operations creates bursts of high amplitude random noise across the entire seismic bandwidth, but this noise is most problematic below about 28 Hz. An index was developed to characterize the level of high amplitude, low frequency noise on each trace in the following manner:

1. balance the traces using a constant amplitude scalar determined within a 1.0 s window beneath the seafloor;
2. apply a minimum-phase Butterworth filter with a low-pass taper from 7 to 28 Hz;
3. zero all the amplitude samples that occur before the last 2.0 s of each trace;
4. sum the quotient of the instantaneous amplitude and frequency for every sample in the trace;
5. multiply by 10 to create the noise index for each trace.

The cumulative sample distribution of the prop wash indices are plotted on Figure 3.12. A total of 2867 traces for which the index exceeded 1024 were removed from the processing stream at this stage. A threshold of 256, corresponding to the 90^{th} percentile of the noise indices, was used to select 29186 traces that were strongly filtered using a nonlinear technique. For these traces, a model of the noise was constructed by applying total variation de-noising (Rudin *et al.*, 1992) to a 7 to 28 Hz, low-pass filtered version of the trace. The noise model was then subtracted from the original trace to produce an estimate of the signal.

After removing and filtering the noisiest traces in the above steps, the data were sorted to common receiver gathers. A 30 ms horizontal de-spiking filter was used to remove noise bursts that exceeded the average amplitudes of the two adjacent traces by a factor of 4.5. *F-X* deconvolution was then applied to a 19-trace running mix of the common receiver gathers to remove energy having an apparent dip of greater than 120 ms per trace. The traces were sorted back to shot gathers for subsequent processing. Example results from this stage of the processing are shown on Figure 3.13.

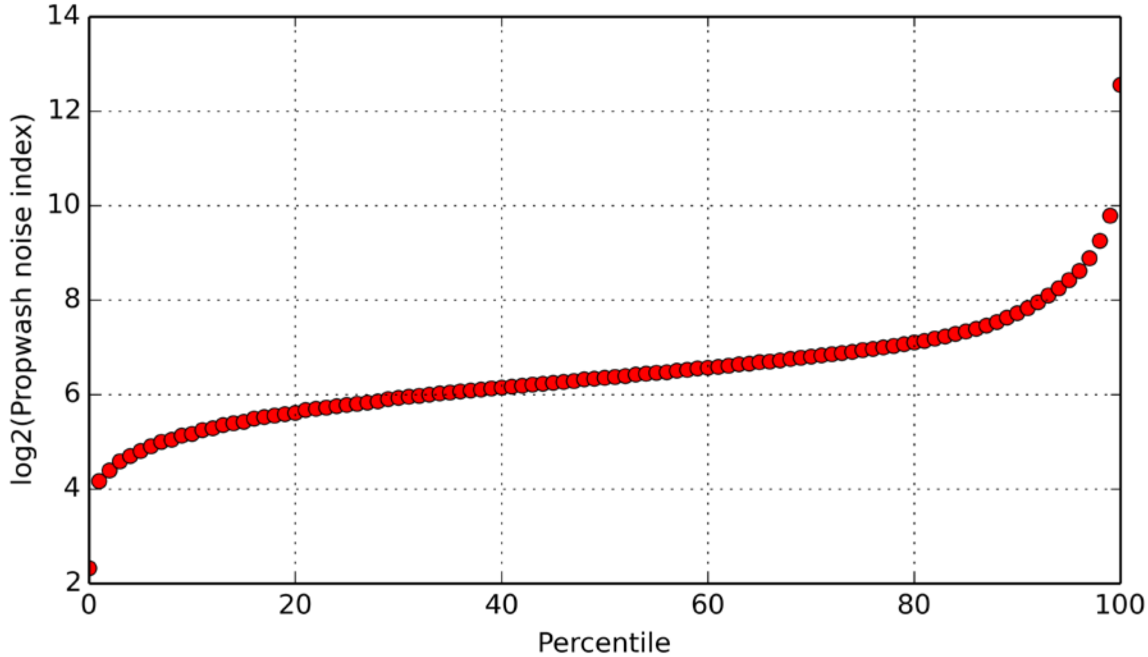


Figure 3.12: Cumulative sample distribution of the prop wash indices.

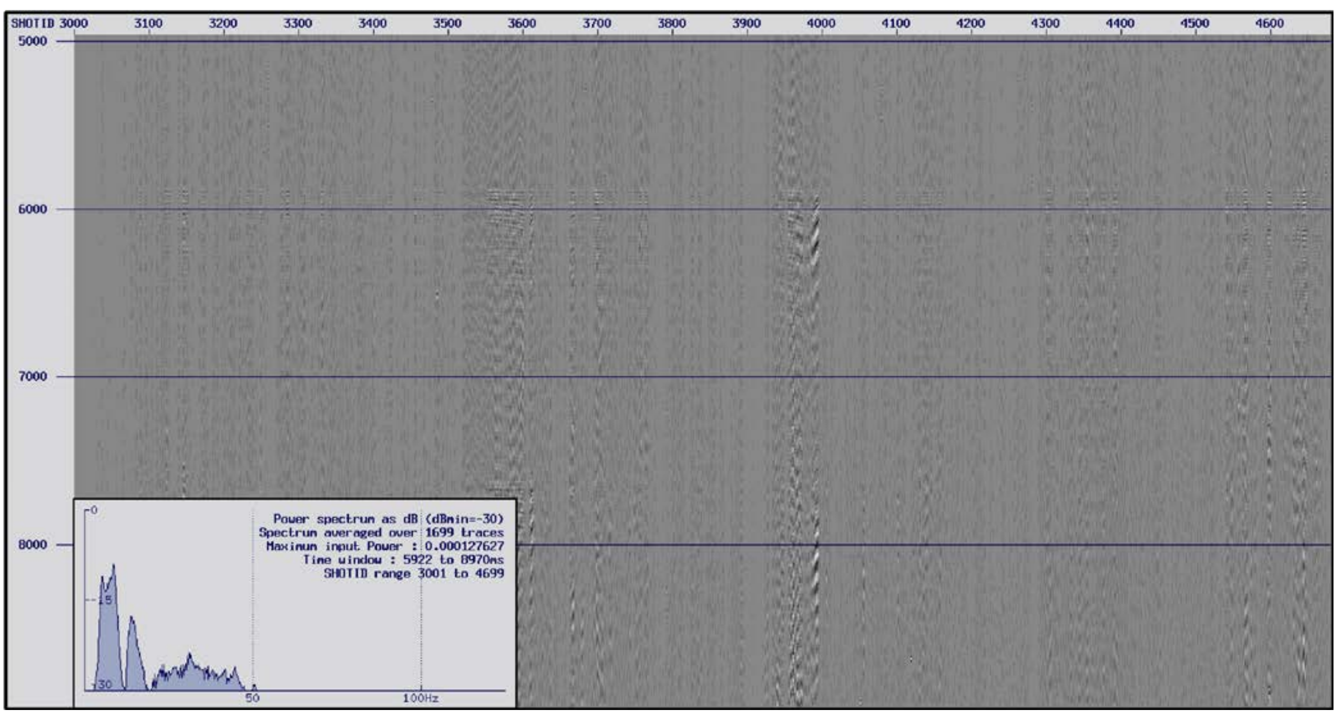


Figure 3.13: Energy removed by the filtering along the same segment of line LSL1404 that is shown in Figure 3.11.

Suppress primary multiples

This step of the processing workflow was applied only to lines LSL1410, 1411, and 1412 since the seafloor was too deep on the remaining lines for the primary multiple to be recorded. A model of the primary multiples was constructed for the shot records using a technique known as surface related multiple elimination (SRME; Vershuur *et al.*, 1992). The results of this technique generally do not match exactly the amplitude and phase of the observations, but they are sufficiently close to be subtracted in an adaptive manner. For the present application, a time-shift of between 0 and 8 ms was applied to each trace of the model in order to maximize the cross-correlation of the model with the data. Adaptive subtraction of the model from the data was then accomplished using an algorithm that is described by Wang (2003).

SRME generally yields poor results for deep-water settings, and in regions with a steeply dipping seafloor. Also the technique assumes a constant shotpoint interval, so it is not well-suited for the present dataset. An alternative approach was tested which involved interpretation of the first primary multiple horizon on poststack records. The stacked record was flattened on this multiple, and then an *F-K* filter was applied to remove essentially horizontal energy within a specified window of the multiple. This alternative approach is effective for abyssal plain settings where the seafloor and underlying layers are highly parallel. However it is not effective for slope settings where there are typically a wide range of dips beneath the seafloor. Also, the *F-K* filtering process has to be repeated for the second, third, and possibly higher primary multiples where they are present in shelf and mid- to upper-slope settings. SRME was chosen for the present study because: a) the objective was to simply reduce the multiple energy in deep-water, and b) a generalized technique was desired that could be applied to line segments from the 2007 through 2011 datasets that are over the shelf and slope.

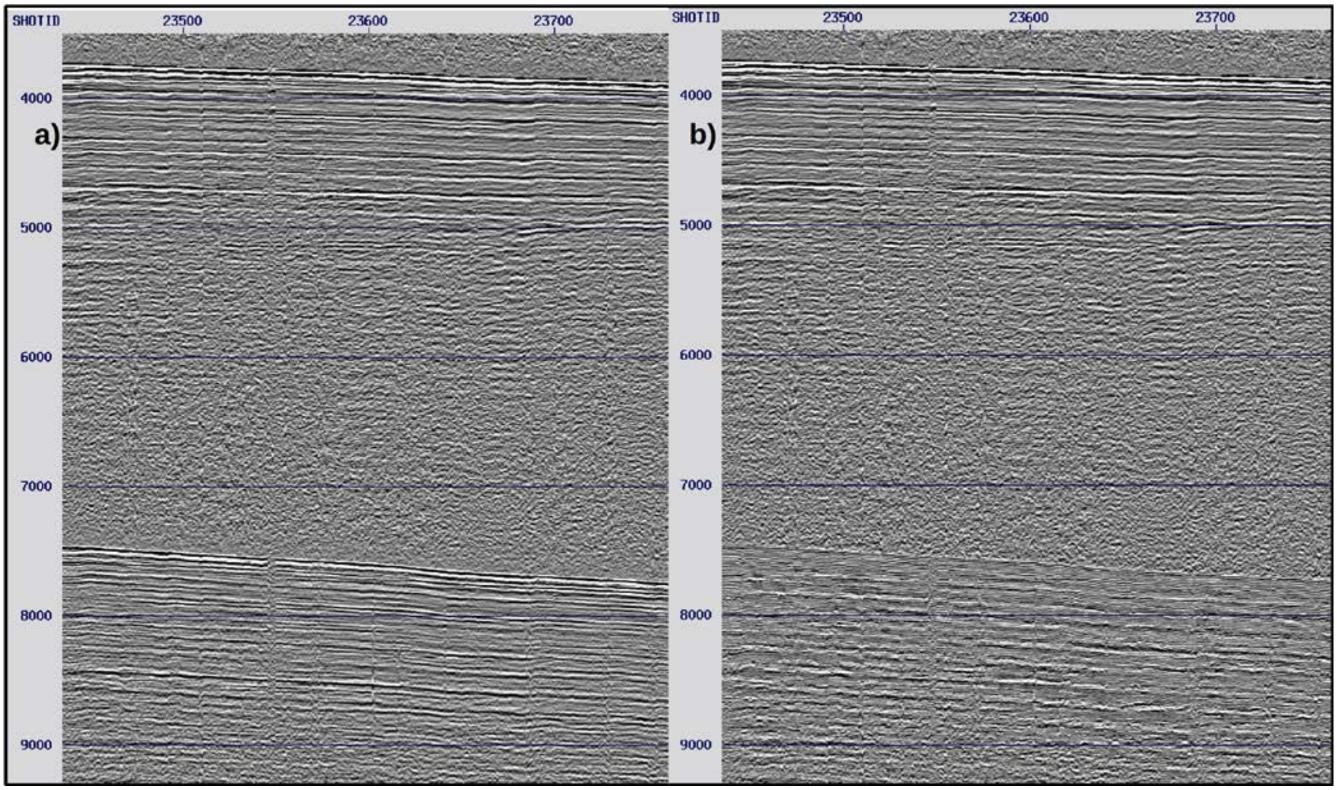


Figure 3.14: Example of results from the multiple suppression technique. a) Near trace plot with t^2 amplitude scaling for a segment of line LSL1412. b) Same segment after surface related multiple elimination.

Convert to a minimum-phase wavelet

A minimum-phase Butterworth filter with a passband of 1/22/65/180 Hz was created for use as a synthetic wavelet. Least-squares matching filters were then designed to convert each of the measured source wavelets to the synthetic wavelet. The matching filter corresponding to the appropriate seismic source was then convolved with each seismic trace in order to obtain the least-squares conversion to the minimum-phase synthetic wavelet.

Compensate for seismic attenuation

The following scalar function was applied to each trace in order to compensate for attenuation of the seismic amplitudes due to geometrical spreading and energy dissipation of the seismic wavefront with increasing distance from the source:

where V(t) is a linearly interpolated discrete function of the root-mean-square velocity with two-way travel time below the seafloor, and α is an empirically determined exponential decay parameter used to characterize the effects of energy dissipation. The velocity profile is listed in Table 3.5. It is based on sedimentary velocity models derived by Shimeld *et al.* (*in prep.*) for the Canada Basin and southern Alpha Ridge. The value of α was chosen to be 0.01 m^{-1} through iterative testing.

t	0	500	1000	1500	2000	2500	3000	3500	4000
V(t)	1477	1510	1579	1677	1796	1926	2061	2200	2340

Table 3.5: The discrete velocity function (m/s) of two-way travel time below the seafloor (ms) that was used to correct for the effects of seismic attenuation.

Deconvolve short-period reverberations before stack

Surface-consistent deconvolution operators were designed on the average auto-correlation functions for each shot and receiver gather. A filter length of 250 ms was selected with a prediction gap of 48 ms. Two overlapping design gates were selected: 1) from 100 to 2400 ms below the seafloor, and 2) from 1100 to 3400 ms below the seafloor. Noisy traces were excluded from the auto-correlation function estimates.

Apply normal moveout correction and stack mid-point gathers

The shot records were sorted to mid-point gathers in order of increasing distance from the bin centres. Normal moveout was generally not measurable because of the relatively short offsets and deep water. It was significant, and corrections were applied, however for water depths of less than about 1500 m. Occasionally there were residual time shifts of generally less than 8 ms between traces in the mid-point gathers. These shifts were likely the result of inaccuracies in the estimated receiver depths, and also the relatively large dimensions of the mid-point bins. The traces were aligned through cross-correlations with an average pilot trace for each ensemble, and then the ensembles were stacked.

Deconvolve short-period reverberations after stack

Residual bubble pulse and peg-leg multiples were further attenuated by applying predictive deconvolution to the stacked records. Deconvolution operators were designed for two overlapping time gates: 1) 50 to 2450 ms below seafloor with a prediction gap of 28 ms, and 2) 1400 to 3800 ms below seafloor with a prediction gap of 34 ms. The filter length was 240 ms.

Filter noncoherent noise on stacked records

A 30 ms horizontal de-spiking filter was used to edit noise bursts that exceeded the average amplitudes of the two adjacent traces by a factor of 4.5. Steeply dipping energy having an apparent dip of greater than 120 ms per trace was removed through *F-X* deconvolution, and a 3-trace running mix was applied using the following weights: 0.2, 0.6, 0.2. The stacked traces were then convolved with a least-squares matching filter that was designed to convert the minimum-phase synthetic wavelet to its zero-phase equivalent.

Migrate the stacked records

Finite difference time migration was applied to the stacked records using a three-layer velocity model. The water layer was assigned a constant average interval velocity based on unpublished oceanographic measurements conducted during the cruise (Figure 3.15; *pers. comm.*, Jane Eert, September 2014). The sedimentary layer was assigned a discrete interval velocity function based on exponential slowness models by Shimeld *et al.* (*in prep*). The crystalline basement beneath the sedimentary layer was assigned a constant velocity of 4500 m/s. Velocity interfaces between the three layers were smoothed using a 500 ms cosine taper to avoid migration artifacts. Initial testing revealed that the record sections were over-migrated. This might be attributed, at least in part, to seismic anisotropy in shales. The velocity model for the sedimentary layer is based on refraction measurements from seismic rays travelling parallel to bedding. In shales, the bedding parallel direction is typically 5 to 20% faster than the bedding perpendicular direction. Furthermore, 2-D migration velocities are not directly equatable to true seismic velocities. In practice, the migration velocities might be varied by as much as ±50% to obtain optimal imaging. Satisfactory migrations in the present study were obtained by reducing the velocities by a factor of between 25 and 35%, which was assessed on a line-by-line basis.

Apply final trace balance and time-varying bandpass filter

The traces of the processed record were balanced using constant amplitude scalars within 1.0 s windows along the length of the trace, with a 50% window overlap. A time-varying zero-phase bandpass filter was applied using the time gates and passbands that are listed in Table 3.6.

Time gate (ms below seafloor)	**Passband (Hz)**
0:1000	2/5/80/120
1500:2500	3/5/45/65
3000:11500	4/6/40/55

Table 3.6: Parameters used for time-varying bandpass filtering of the stacked records.

Output processed records

Final processed line details are given in Table 3.7. The final traces were resampled to a 4 ms time interval and output in digital standard SEG-Y format. Latitude and longitude coordinates are stored, respectively, in byte locations 81 and 85 of the trace headers as arcseconds (x 100). The mid-point bin numbers are in byte location 21, and the shotpoint numbers are in byte location 17. An example of the final processing results is shown on Figure 3.16

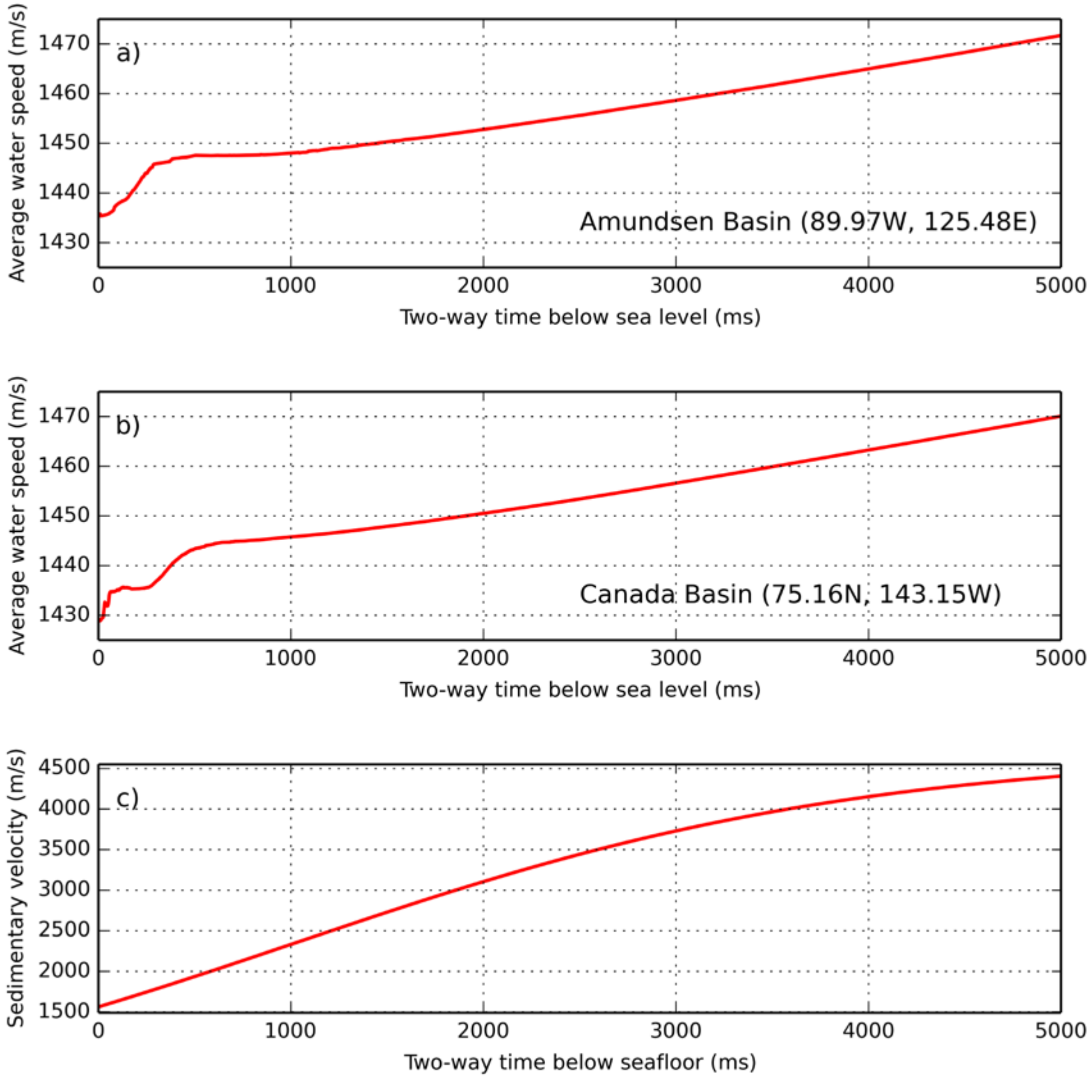


Figure 3.15: Velocity models used for finite difference migration of the stacked records. a) Constant average speed for the water column in the Amundsen Basin (Jane Eert, pers. comm., September 2014). b) Constant average speed for the water column in the Canada Basin (Jane Eert, pers. comm., September 2014). c) Sedimentary velocity profile based on a compilation of seismic refraction measurements in the Canada Basin and southern Alpha Ridge (Shimeld et al., in prep.).

Line t mid-point bin	Last mid-point bin	# traces	First shot	Last shot	Line km
01	2531	2432	1	2122	30.39
03	978	862	2181	2637	10.76
04	6192	6087	2666	6258	76.08
05	1504	1389	6262	7092	17.35
06	1300	1201	7097	7723	15.00
07	1962	1857	7730	9312	23.20
08	1604	1505	9338	9912	18.80
09	2723	2624	9931	10775	32.79
10	3929	3819	12209	10783	47.73
11	33174	33064	12214	23420	413.29
12	4112	4002	24982	23428	50.01

Table 3.7: Summary of final processed record sections from the Louis S. St-Laurent 2014 survey.

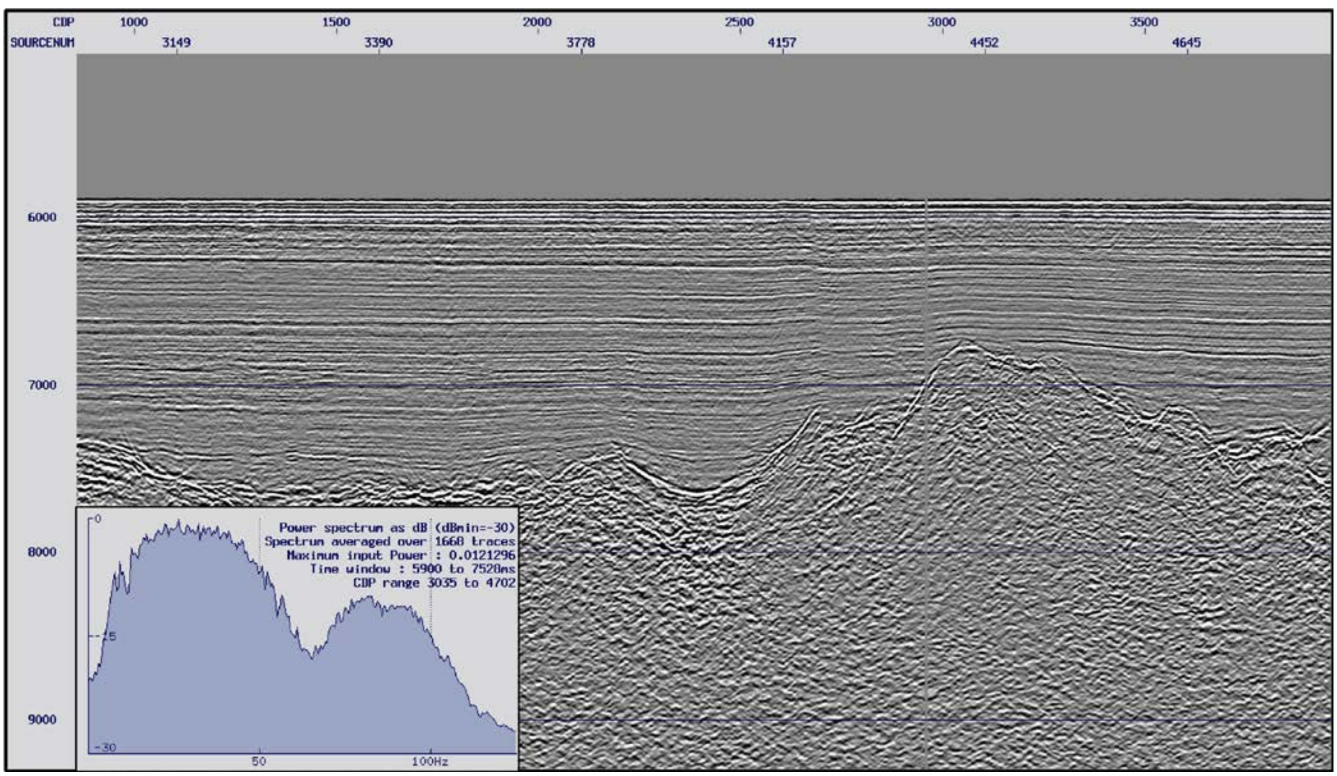


Figure 3.16: Example of the final processing results for the mid-point bin equivalent segment of line LSL1404 that is shown on figures 3.11, 3.13, and 3.14.

Recommendations

1. Accurate measurements of the receiver depths would eliminate static errors, simplify the signal processing workflow, and improve stacking power. The ODDI mini CTD sensors that were used during the *Louis S. St-Laurent* 2009, 2010, and 2011 surveys are ideal for this purpose and should be used in future programs. If not, then depth sensors that are capable of functioning accurately to depths of up to 400 m should be installed in the streamer.

2. Balancing of the streamer is an important consideration for the heavy ice conditions of the polar region in the Amundsen Basin. Data from the present study indicate that the streamer sank at a rate of 2.5 to 3.0 m per minute whenever the forward motion of the ship was stopped, which helped to protect the streamer from the ice. The streamer flew at a reasonably consistent depth of 10 to 25 m at survey speeds of 2.5 to 4.5 knots through the water. This behaviour was ideal, and it was achieved by installing three wooden floats along the length of the active section. However, if the streamer becomes entangled in ice, the floats increase the risk of a snag. If this risk is considered too high for future icebreaker surveys, the streamer should be rebalanced. Otherwise the streamer will fly too deeply and at extreme angles when the average ship speed is less than about 3 knots. This would severely impact the data quality.

3. Before the start of acquisition next season, the depth calibration of each ODDI CTD sensor should be checked by placing the sensors in a permeable container and lowering the package to a known water depth. If depth sensors are installed in the streamer, their calibration should be checked in conditions that are appropriate for the survey.

4. A few months prior to the seismic program, obtain the latest version of the CNT-2 acquisition software and manuals, install two copies of the software on removable hard drives, and create an installation backup. The new software should be tested prior to the start of acquisition. Version 5.36 proved to be reliable and should therefore be kept as a backup in case there are bugs in a later version of the software.

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Chapter 4

Report on the Oceanographic Research

Introduction

Since 2002, IOS has collaborated with international colleagues and institutions in the study of the oceanography of the Beaufort Gyre and Canada Basin. In 2014, following the inclusion of oceanography programs during 2008, 2009 and 2011, Jane Eert and Glenn Cooper of IOS participated in the UNCLOS survey aboard the CCGS Louis S. St-Laurent to conduct physical and chemical oceanographic measurements along the ship's track.

Objectives:

This oceanography program onboard the *CCGS Louis S St-Laurent* took place between August 9th and September 17th on an opportunity basis during seismic and bathymetric surveying for UNCLOS. The purpose was to take measurements of seawater properties in the Arctic Ocean to better understand water mass distributions and the ocean circulation. This is part of the basic knowledge upon which depends sea-ice distribution, heat and freshwater transports, biogeochemical cycles, and their temporal variations in the changing Arctic climate system.

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The shipboard data collection included physical and geochemical sampling:

- Profiles of water temperature and salinity were obtained with the main CTD, and with expendable CTD (XCTD) probes,
- Additional sensors on the CTD profiler collected in situ data on phytoplankton concentrations (fluorometer), optical clarity (transmissometer), dissolved oxygen, and Chromophoric Dissolved Organic Material (CDOM)
- A rosette was used with the CTD to obtain water samples from discrete depths to be analyzed for dissolved oxygen, pCO2, TIC, salinity, nutrients, oxygen isotope ratio, CDOM, radionuclide tracers and barium. Dissolved oxygen and salinity analyses were performed on board.
- continuous underway sampling of near-surface seawater temperature, salinity and phytoplankton (fluorescence), CDOM, and dissolved gases,
- continuous recording of meteorological data (wind speed, air temperature, etc.), navigation data, and soundings.

Figure 4.1 shows the oceanographic sample locations throughout the expedition.

Scientific Personnel:

Jane Eert and Glenn Cooper of DFO's Institute of Ocean Sciences joined the UNCLOS group to do the oceanographic work during this cruise.

Voyage Overview:

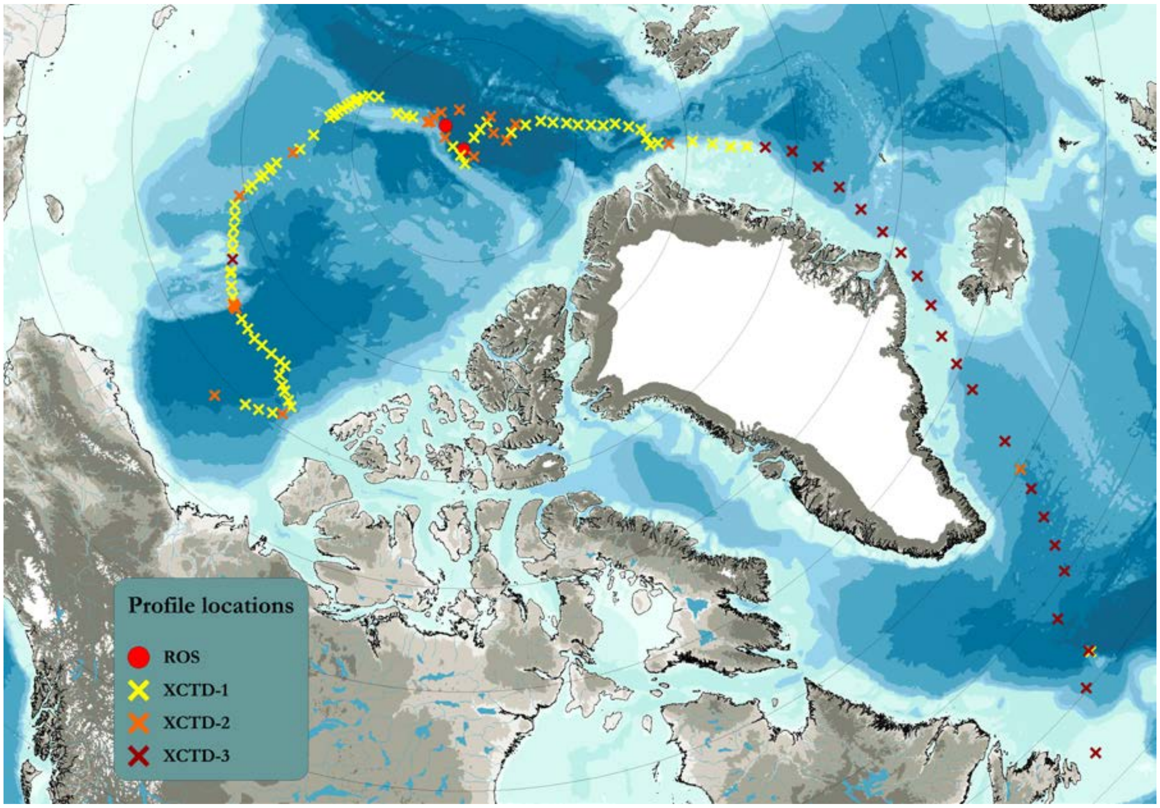

Figure 4.1. The stations where physical and geochemical measurements were taken during 2014-10

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Program Components

Measurements:

- 2 CTD/Rosette Casts at 2 Stations
- 46 Water Samples, to be analyzed for: TIC, pCO2, Salinity, Oxygen, Nutrients, CDOM, Bacteria, Barium, and O-18
- A subset of water samples to be analyzed for radioactive isotopes of iodine
- Underway data collection of ship's meteorological, depth, sea surface, and navigation sensors
- 126 XCTD (expendable temperature, salinity and depth profiler) casts typically to depths determined by probe type, water depth and ice conditions

Program Component Descriptions

Rosette/CTD
XCTD
Underway data collection
Salinity
Dissolved Oxygen

Acknowledgements

Many thanks are due to Dr. David Mosher and his UNCLOS team for generous support during the cruise. Thanks, too, to Paola Travaglini and the hydrographers for combining forces between oceanography and sound speed measurements. I would also like to thank the Coast Guard for their support, particularly Captain Potts and the crew of the *CCGS Louis S. St-Laurent*.

CTD/Rosette

The primary CTD system used on board was a Seabird SBE9+ CTD s/n 0724, configured with a 24-position SBE-32 pylon with 10L Niskin bottles fitted with internal stainless steel springs in an ice-strengthened rosette frame (Fig. 4.2). The data were collected real-time using the SBE 11+ deck unit and computer running Seasave V7 acquisition software. The CTD was set up with two temperature sensors, two conductivity sensors, one oxygen sensor, chlorophyll fluorometer, transmissometer, CDOM fluorometer and altimeter. All these sensors have 0-5v analogue output which is included in the CTD data string. In addition CHS mounted their sound velocimeter in place of Niskin bottle 24, leaving 23 Niskins for water samples.

During a typical deployment:
The transmissometer and CDOM sensor windows were sprayed with deionised water and wiped with a DI water-soaked lens cloth prior to each deployment.
The package was lowered to 10m to cool the system to ambient sea water temperature and remove bubbles from the sensors. The pumps were turned on manually and the system soaked for 2 minutes. The package was then brought up to just below the surface to begin a clean cast, and

lowered to within 8-10m of the bottom at 60m/min. Niskin bottles were closed during the upcast without a stop. The instrumented sheave (Brook Ocean Technology) reads to the winch operator, CTD operator and bridge, allowing all three to monitor cable out, wire angle and CTD depth.

Data/Performance notes:
The SBE9+ CTD overall performance was good. Noise was observed on the oxygen sensor that increased with depth. Editing and calibration have not yet been done, but the core data will likely meet or exceed the SBE9+ performance specifications given by Seabird. Header information of position, station name, and depth has not been quality controlled yet. Salinity and oxygen were sampled from the water and can be used to calibrate the sensors.

Figure 4.2. The 24-bottle rosette with the SBE9+ CTD is deployed from the mid-ships A-frame (photo 2008).

XCTD Report

Overview

Profiles of temperature and salinity were measured on board the *CCGS Louis S. St. Laurent* (LSSL) from August 9 to September 14, 2014 using expendable probes capable of being deployed while the ship was underway. Profiles were collected at 121 stations along the ship's track. Two probes were deployed at 8 of the stations when the first probe did not reach sufficient depth (Fig. 4.1).

Procedure

XCTD (eXpendable Conductivity – Temperature – Depth profiler, Tsurumi-Seiki Co., Ltd.) probes were launched by a hand launcher LM-3A (Lockheed-Martin_Sippican, Inc.) from the stern of the ship into the ocean to measure the vertical profiles of water temperature and salinity. Three types of probes were used, with differing maximum depth and ship speed ratings (see Table 4.1).

Probe Type	Max Depth (m)	Max Ship Speed (Kts)
XCTD-1	1100	12
XCTD-2	1850	3.5
XCTD-3	1000	20

Table 4.1. Types of XCTD probes employed during the survey.

The data were communicated back to a digital data converter MK-21 (Lockheed-Martin-Sippican, Inc) and a computer onboard the ship by a fine wire which breaks when the probe reaches its maximum depth.

According to the manufacturer's nominal specifications, the range and accuracy of parameters measured by the XCTD are as follows;

Parameter	Range	Accuracy
Conductivity	0 ~ 60 [mS/cm]	+/- 0.03 [mS/cm]
Temperature	-2 ~ 35 [deg-C]	+/- 0.02 [deg-C]
Depth	0 ~ 1000 [m]	5 [m] or 2 [%] (whichever is larger)

In this cruise, 128 XCTDs were launched into the Arctic Ocean, at varying intervals depending on the geographic area (Table 4.2). Deployments were close spaced over the Lomonosov Ridge and the east side of the Northwind Ridge in order to capture and shelf-trapped currents. In general, deployments while the ship was stopped were successful, even in very heavy ice, however this was not always possible within the requirement not to interfere with seismic operations. A list of deployments can be found in Table 4.2 and shown in Figure 4.1:

Drop	Date	Time	Lat (N)	Lon (E)	Water depth (m)	Max probe depth (m)
1	Aug 10 2014	03:16	47.1205	-51.1872	270	270
2	Aug 10 2014	09:56	50.1320	-48.3678	2050	100
3	Aug 10 2014	17:34	51.2905	-46.2055	4048	1100

4	Aug 10 2014	22:58	51.4003	-46.2410	4032	1000
5	Aug 11 2014	05:26	52.5175	-45.1190	4039	1000
6	Aug 11 2014	11:40	53.8710	-45.8340	3610	1000
7	Aug 11 2014	17:40	55.1500	-42.5640	3400	1000
8	Aug 11 2014	23:28	56.3597	-41.3078	3199	674
9	Aug 12 2014	05:57	57.6763	-39.8525	3148	1000
10	Aug 12 2014	12:30	59.0238	-38.3462	3119	1000
11	Aug 12 2014	17:57	60.0088	-37.3495	3100	1850
12	Aug 13 2014	00:41	61.4027	-35.8070	2896	1000
13	Aug 13 2014	06:28	62.6937	-34.3447	2840	1000
14	Aug 13 2014	12:32	64.0338	-32.7442	2539	1000
15	Aug 13 2014	18:15	65.2697	-30.9915	1184	1000
16	Aug 14 2014	00:12	66.4585	-28.7918	315	315
17	Aug 14 2014	06:30	67.4618	-25.8890	824	819
18	Aug 14 2014	12:28	68.4975	-23.0303	1503	1000
19	Aug 14 2014	18:28	69.5388	-20.7078	359	356
20	Aug 15 2014	00:30	70.5913	-18.5537	1548	1000
21	Aug 15 2014	06:29	71.7813	-15.9803	1339	1000
22	Aug 15 2014	12:32	72.9177	-13.1000	2660	1000
23	Aug 15 2014	18:25	73.9583	-10.1552	3111	1000
24	Aug 16 2014	00:29	75.1733	-7.6660	3405	24
25	Aug 16 2014	00:35	75.1970	-7.6608	3410	1000
26	Aug 16 2014	06:29	76.4215	-6.9058	1582	1000
27	Aug 16 2014	12:22	77.2718	-6.7518	269	267
28	Aug 16 2014	18:35	78.0000	-6.7333	340	333
29	Aug 17 2014	00:30	78.8363	-5.9613	346	339
30	Aug 17 2014	06:23	79.7387	-5.2443	837	811
31	Aug 17 2014	14:25	80.8100	-5.6428	2568	1850
32	Aug 17 2014	19:31	81.2892	-5.2828	3185	1100
33	Aug 18 2014	00:37	81.6458	-5.8878	3525	1027
34	Aug 18 2014	06:32	81.8080	-3.5602	4100	697
35	Aug 18 2014	13:00	82.0368	-0.8230	3075	1100
36	Aug 18 2014	23:47	82.5478	0.6832	3500	1100
37	Aug 19 2014	08:46	83.1337	2.5173	3914	1100
38	Aug 19 2014	16:48	83.6810	2.5490	4161	607
39	Aug 19 2014	23:14	84.2088	3.7962	4000	1100
40	Aug 20 2014	04:48	84.7787	5.1580	4800	1100
41	Aug 20 2014	09:45	85.2617	7.4233	3241	1100
42	Aug 20 2014	17:00	85.8358	9.9240	4000	1100
43	Aug 21 2014	00:15	86.3310	13.5027	3249	1100
44	Aug 21 2014	07:12	87.0268	14.8852	4362	1100

45	Aug 21 2014	12:13	87.4152	19.4297	4375	1510
46	Aug 22 2014	04:27	87.7508	12.9598	4374	1100
47	Aug 22 2014	11:35	88.0567	5.6865	4365	1847
48	Aug 24 2014	17:22	88.4680	22.7023	4384	100
49	Aug 24 2014	17:42	88.4662	22.7210	4383	1850
50	Aug 24 2014	23:47	88.3648	43.6968	4030	1100
51	Aug 25 2014	04:38	88.0818	44.2508	4395	1850
52	Aug 25 2014	23:14	88.8347	44.9578	4370	797
53	Aug 26 2014	19:17	89.2750	44.2958	4309	1100
54	Aug 28 2014	23:47	89.7298	-130.8840	4220	1100
55	Aug 29 2014	16:53	89.4035	-93.4400	2346	966
56	Aug 29 2014	21:22	89.1850	-88.7162	1501	1456
57	Aug 30 2014	13:30	89.4760	-40.3448	4183	1850
58	Sep 01 2014	00:25	89.4687	152.8237	4259	1100
59	Sep 01 2014	11:30	88.9820	138.2955	3830	1850
60	Sep 03 2014	05:40	88.0193	113.4172	4291	1850
61	Sep 03 2014	19:09	88.0003	124.7978	3164	541
62	Sep 04 2014	01:42	88.0217	132.0288	2466	1850
63	Sep 04 2014	03:34	87.9592	134.9817	1386	1343
64	Sep 04 2014	12:50	87.2753	139.6352	2351	431
65	Sep 04 2014	17:10	86.9953	141.5015	2214	1100
66	Sep 04 2014	22:13	86.5670	143.5823	918	741
67	Sep 05 2014	08:51	85.5118	140.3557	3663	1075
68	Sep 05 2014	11:25	85.0913	142.6747	3335	1100
69	Sep 05 2014	13:04	84.8883	144.7050	3059	1100
70	Sep 05 2014	14:32	84.7423	146.8420	2654	297.5
71	Sep 05 2014	14:36	84.7360	146.9302	2621	1100
72	Sep 05 2014	15:23	84.6553	148.1005	1487	1100
73	Sep 05 2014	16:44	84.5272	150.1915	1591	1035
74	Sep 05 2014	17:49	84.4127	151.7868	2124	1100
75	Sep 05 2014	19:10	84.2497	153.6115	1096	22
76	Sep 05 2014	19:12	84.2468	153.6105	1092	1092
77	Sep 05 2014	20:16	84.1103	155.0670	2808	1100
78	Sep 05 2014	21:23	84.0108	156.7130	1890	1100
79	Sep 05 2014	22:02	83.9392	157.4427	2443	640
80	Sep 05 2014	23:36	83.8270	158.7965	3162	1100
81	Sep 06 2014	08:15	83.2457	166.6753	3062	1100
82	Sep 06 2014	15:25	82.6505	172.1007	2815	524
83	Sep 06 2014	18:01	82.3468	173.3262	2769	1847
84	Sep 07 2014	00:09	81.5815	176.2830	2655	1100
85	Sep 07 2014	02:03	81.3442	177.6625	2652	1100

86	Sep 07 2014	03:07	81.2272	178.3218	2010	1100
87	Sep 07 2014	05:04	80.9693	179.5888	1653	1100
88	Sep 07 2014	06:19	80.7877	-179.8132	1756	1100
89	Sep 07 2014	09:30	80.3750	-178.1743	1654	1100
90	Sep 07 2014	11:22	80.1573	-177.3335	2055	71
91	Sep 07 2014	11:25	80.1572	-177.3330	2055	1100
92	Sep 07 2014	15:18	79.7263	-176.0348	2185	264
93	Sep 07 2014	15:21	79.7263	-176.0347	2185	1850
94	Sep 07 2014	21:15	79.4298	-174.0180	2296	1100
95	Sep 08 2014	00:28	79.2942	-171.3943	2457	1100
96	Sep 08 2014	04:06	79.0950	-168.8457	3069	597
97	Sep 08 2014	07:21	78.8853	-166.5957	2046	1100
98	Sep 08 2014	10:39	78.6953	-164.2842	813	639
99	Sep 08 2014	13:46	78.5037	-162.2573	779	770
100	Sep 08 2014	17:36	78.2038	-159.9982	2127	248
101	Sep 08 2014	18:17	78.1442	-159.7140	2855	1100
102	Sep 08 2014	22:09	77.9000	-157.2272	1626	1100
103	Sep 09 2014	01:34	77.6775	-155.0402	1150	1100
104	Sep 09 2014	03:39	77.5257	-153.9595	1067	1035
105	Sep 09 2014	04:20	77.5252	-153.8480	1536	839
106	Sep 09 2014	06:00	77.5135	-153.3147	2310	1850
107	Sep 09 2014	07:42	77.5013	-152.8455	3060	845
108	Sep 09 2014	08:19	77.4963	-152.6747	3849	190
109	Sep 09 2014	08:23	77.4958	-152.6533	3849	553
110	Sep 09 2014	16:33	77.4382	-150.2560	3844	1100
111	Sep 10 2014	00:03	77.3803	-147.9105	3838	1100
112	Sep 10 2014	06:57	77.3208	-145.5108	3817	1009
113	Sep 10 2014	13:33	77.3557	-143.4375	3807	860
114	Sep 10 2014	22:37	77.3837	-140.8947	3774	1100
115	Sep 11 2014	06:46	77.3895	-138.4927	3725	495
116	Sep 11 2014	13:31	77.3898	-137.1280	3686	1100
117	Sep 11 2014	17:56	76.9017	-136.8450	3679	518
118	Sep 12 2014	00:24	76.6208	-135.1800	3586	1100
119	Sep 12 2014	06:44	76.4747	-134.1512	3453	121
120	Sep 12 2014	07:03	76.4655	-134.1107	3436	989
121	Sep 12 2014	14:12	76.2178	-132.5092	3055	328
122	Sep 12 2014	14:19	76.2145	-132.4912	3048	522
123	Sep 12 2014	19:39	76.0385	-131.4383	2700	1100
124	Sep 13 2014	01:24	75.5538	-131.9765	2769	1530
125	Sep 13 2014	11:15	75.3283	-133.5892	3232	1100
126	Sep 13 2014	18:24	75.0560	-135.8463	3473	1100

127	Sep 13 2014	23:40	74.8510	-138.1345	3532	1100
128	Sep 14 2014	12:26	74.1973	-142.9522	3712	1171

Table 4.2. XCTD Deployment information

XCTD Data Management Policy
The XCTD observations are conducted as part of the PACI (PAN-ARCTIC CLIMATE INVESTIGATION), a collaboration between JAMSTEC and DFO. Data will be shared among the participants of this cruise (2014-10). Sharing the data with third party for the purposes of physical oceanography shall be by mutual consent between JAMSTEC and IOS/DFO.

Science coordinators:
JAMSTEC: Motoyo Itoh (motoyo@jamstec.go.jp)
IOS/DFO: Bill Williams (Bill.Williams@dfo-mpo.gc.ca

Underway Measurements:

This section describes measurements taken at frequent regular intervals throughout the cruise. These measurements include:

- From the seawater loop system: salinity, temperature (inlet and lab), chlorophyll fluorescence and CDOM fluorescence, gas tension, and oxygen saturation.
- Hull temperature
- From the Novatel GPS: all NMEA strings (GPRMC, GPGGA, HEHDT, among others) as well as position, time, speed and total distance
- AVOS weather observations of: air temperature, humidity, wind speed, barometric pressure
- Sounder reported depth
- Ice cameras

Methods

See section below for technical description of monitoring procedures, data flow and network setup.

The Louis uses a 3" Moyno Progressive Cavity pump Model #2L6SSQ3SAA, driven by a geared motor. The pump rated flow rate is 10 GPM. It supplies seawater to the TSG lab, where a manifold distributes the seawater to instruments and sampling locations. On one of the manifold arms, a vortex debubbler is installed inline to remove bubbles in the supply to the SBE-21 thermosalinograph (TSG) and the blue cooler containing the gas tension device and the oxygen sensing optode. Control of the pump from the lab is via a panel with on/off switch and a Honeywell controller. The Honeywell allows setting a target pressure, feedback parameters and limits on pump output.

During 2014-10, the set point pressure was 18.0 PSI. Flow rates to the gas cooler were monitored by an inline flowmeter reporting cumulative counts of propeller turns to logging software. With flow rate measurements, counts per second can be converted to l/min and inferred from this to the TSG and fluorometers (see Fig. 4.3 and 4.4). Water samples were taken at intervals from the loop to calibrate salinity and CDOM. Additional water samples were taken to map surface distributions of TIC (Total Inorganic Carbon), pH and iodine 129.

Two remote temperature sensors are installed in the engine room: an SBE-38 inline thermometer, readings from which are integrated into the SBE-21 data stream, and an SBE-48 hull mounted temperature sensor which is logged separately.
GPS is provided to the SBE-21 data stream using the NMEA from PC option rather than the interface box as in past years.

Weather observations are collected by the AVOS system, provided and maintained by Environment Canada.

Depth is provided by the Knudsen 3.5kHz sounder. Reported values are digitized depth rather than travel time, so it is important to independently log the average sound speed setting on the Knudsen. For the duration of this cruise the sound speed was set to 1490m/s.

Instruments in the TSG were:
Seabird SBE 21 Thermosalinograph s/n 3297
Seabird SBE-38 Thermometer s/n
WET Labs WETStar fluorometer s/n WS3S-367P
WET Labs CDOM s/n WSCD-1281

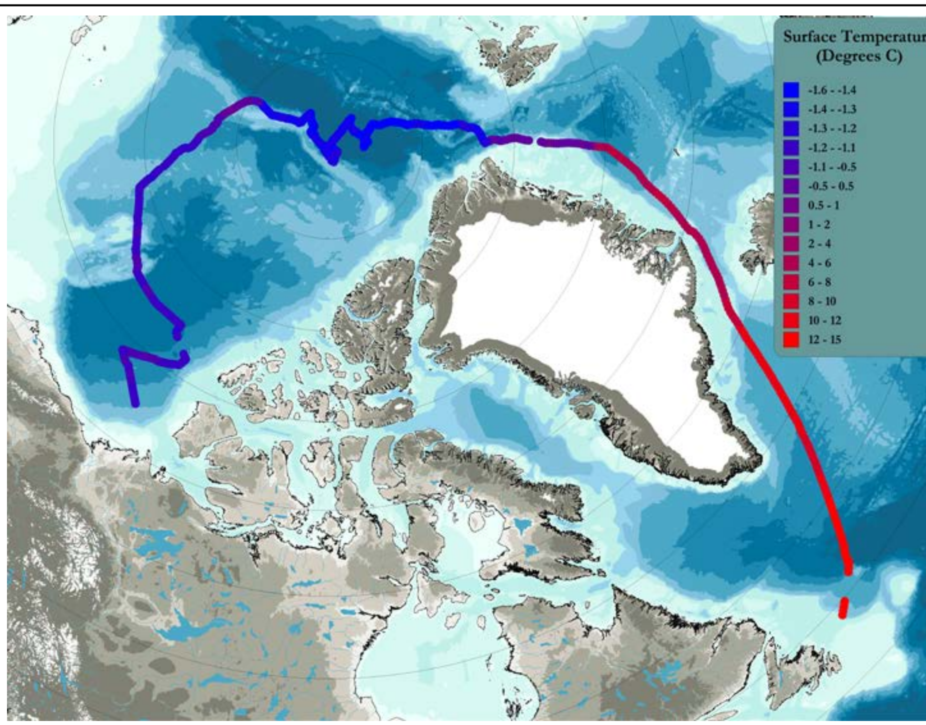


Figure 4.3. TSG inlet temperature for 2014-10

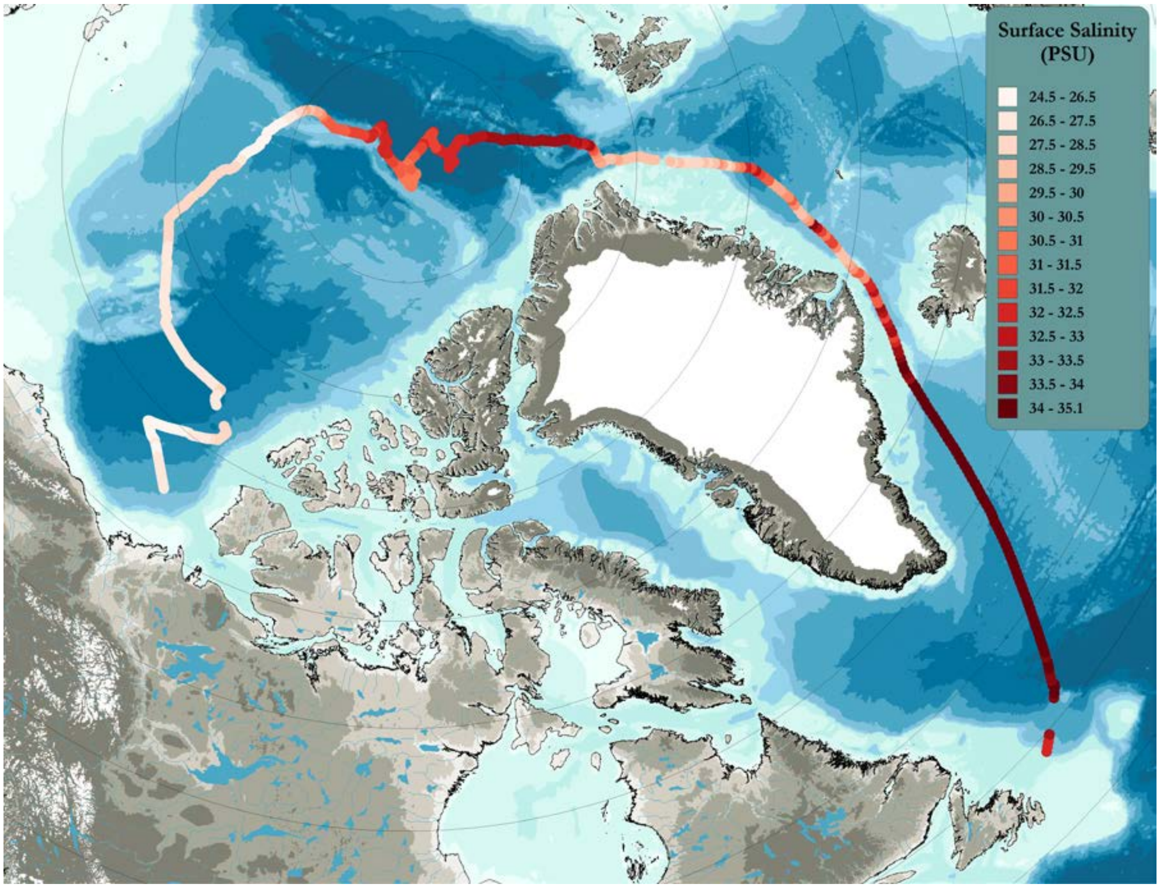


Figure 4.4. TSG salinity for 2014-10

Logging:

1. TSG laptop:
   - Via Seasave: Time, latitude, longitude, lab temperature, SBE-38 inlet temperature, conductivity, fluorescence.
   - Via Hyperterm: SBE-48 temperature at hull
   - Via GTD logging program: Oxygen saturation, gas tension.
   - Via flowmeter logging program: flow rate

Knudsen computer, main lab:

Via Fugawi: Ship's track, including GPS time, latitude, longitude, speed and total distance.

2. SCS Data Collection System:

The ship uses the Shipboard Computer System (SCS) written by the National Oceanographic and Atmospheric Administration (NOAA), to collect and archive underway measurements. This system takes data arriving via the ship's network (LAN) in variable formats and time intervals and stores it in a uniform ASCII format that includes a time stamp. Data saved in this format can be easily accessed by other programs or displayed using the SCS software.

The SCS system on a shipboard computer called the “NOAA server” collects:

- Location from the ship’s GPS (GPGGA and GPRMC sentences)
- Heading from the ship’s gyro (HEHDT sentences)
- Depth sounding from the ship’s Knudsen sounder (SDDBT sentences)
- Air temperature, apparent wind speed, apparent and relative wind direction, barometric pressure, relative humidity, and apparent wind gusts from the ship’s AVOS weather data system (AVRTE sentences). SCS derives true wind speed.
- Sea surface temperature, salinity fluorescence and CDOM from the ship’s SBE 21 and SBE38 thermosalinograph and ancillary instruments
- Sea surface temperature from the SBE48 hull mounted temperature sensor
- SCS derives speed over ground and course over ground

3. Ice Cameras:

Three cameras were installed to record imagery of the ice alongside the ship:

- A StartechXL camera looking over the bow installed on Monkey’s Island. Quality of the images from this camera was so poor as to make them of limited use. Time interval between images was 10 minutes.
- A Startech camera looking down and aft on the port side from Monkey’s Island. This camera had a coloured reference stick in its field of view to estimate thickness of overturned ice. Time interval between images was 10 minutes.
- A GoPro Hero3+ camera installed on the port side of the bridge looking over the bow. Time interval between images varied from 5 seconds to 1 minute depending on conditions. Some long gaps occur when operator error resulted in no images being recorded. Images collected by the GoPro were assembled into 1000 frame animated clips for ease of searching. Some of these clips also capture the difficulties and techniques of icebreaking.

Problems

The Moyno pump and Honeywell controller worked very well again this year. Ice under pressure continues to be a difficult environment for the pump. While it was not turned off down for any extended period, it was unable to keep the 18PSI lab pressure in the heaviest ice areas despite frequent cleaning of the ice strainers by the enginroom crew. As well, the flow to the TSG was often full of bubbles despite the debubbler and careful processing of the time series will be required to remove the affected measurements. The tubing to the gas cooler collects air bubbles that persist – these were flushed out at irregular intervals but reappeared almost immediately afterward when the debubbler was inadequate to the task of removing bubbles from the main flow.

Salinity Sampling and Analysis

Analyst: Glenn Cooper

Overview:

Salinity was analyzed from two rosette casts (UN14-01 and UN14-02) during the 2014-10 mission using a Guildline AutoSal 8400B. Water was obtained from 23 discrete depths for both casts. A total of 5 replicates from different depths were used to estimate precision. Thus a total of 51 samples were analyzed. In addition to rosette samples, sea water loop samples (z ~ 9 m) were taken twice daily. All rosette samples were analyzed on board. Loop samples were stored and will be analyzed later if it is deemed necessary to calibrate of TSG. Loop samples have the potential to bio-foul the salinometer's conductivity cell and electrodes resulting in erratic readings, loss of precision, and accuracy. Thus they are not analyzed unless absolutely necessary or at the end of the mission.

Sample Collection:

Water samples were collected directly from Niskin bottles following a rosette cast. Glass salinity bottles were used with a two cap system, a nylon insert plug followed by a screw on cap. Bottles and insert caps were rinsed 3 times before filling. Two replicate samples were taken at station UN14-01 and 3 replicate samples were taken at UN14-02.
Samples were transferred to the temperature controlled lab which was consistently maintained between 21and 23°C . Samples were left for several days before being analyzed to ensure the that their temperature had equilibrate close to the analysis temperature of 24^{o}C.

AutoSal Calibration:

The AutoSal Model 8400B (S/N: 69086) was calibrated to an IAPSO Standard Seawater (OSIL, Batch#: P156, K_{15}=0.99984). The conductivity cell was initially conditioned by flushing 10 times with deep seawater. Analysis of the seawater standard obtained a K_{15}=0.999835 which was well within accepted error of ±0.0001. Thus the instrument did not require a standardized adjustment allowing sample analysis to proceeded.

Deep Water Reference:

Deep water remaining in niskin bottle number 2 through 6 from the UN14-01 rosette cast were pooled into a cube container and mixed vigorously to ensure completely uniformity. The water was then dispensed into 26 salinity bottles, becoming the deep water reference (Fig. 4.5). Before and after analysis of each rosette cast samples, a deep water reference was analyzed to monitor the Autosal's drift and precision. The reference was found to have a Practical Salinity of 34.9142 ±0.0008 (n=4). All samples were found to fall within 2 standard deviations of the mean (Fig. 4.5).

Sample Analysis:

Samples were analyzed once they had equilibrated with the lab and were close to the instrument's analysis temperature of 24^{o}C. Before placing a sample on the Autosal it was mixed several times by inversion and the cap and neck of bottle wiped with a damp kimwipe to remove any dried on salt particles. Sample conductivity was measured as outlined in the Institute of Ocean Sciences (IOS) standard operating protocol. As mentioned above, a deep water reference sample was analyzed to check the instruments drift. If the obtained practical salinity for the deep water reference was within ±2 standard deviations of its mean the salinometer did not require recalibration with the IAPSO standard seawater (Figure 4.1). Replicate analysis determined the instrument sample pooled precision for the two casts to be ± 0.0012PSU. This compares favourably to the manufactures stated accuracy of ± 0.002PSU.

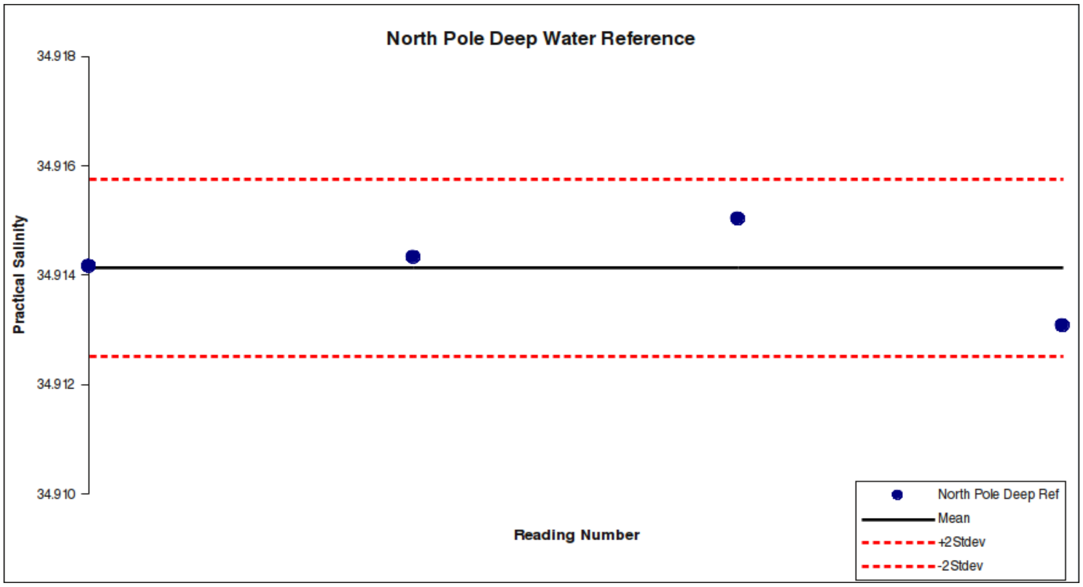


Figure 4.5. Deep Water Reference Analysis Graph

Issues with Salinometer:

1. Initially the AutoSal standby number did not stabilize, and monitoring it overtime showed it slowly creep downwards. Temperature measurement of the water bath found it to be at 15°C rather than the set analysis temperature of 24°C. Further investigation found that the quick electrical disconnects to the both heater lamp sockets were not connect. These were plugged in and the unit turned back on but there was no indication that the heater lamps were turning on. The electrical wires and the heater lamp sockets were removed revealing that ***no*** bulbs were installed in either socket. New bulbs were installed, the unit reassemble, and the power turned on. The unit was left for several days to come up to operating temperature and stabilize whereby the standby number began to stabilize. In future it would be wise to place a note on the front of the unit indicating that the heater bulb have not been installed. This would reduce frustration and loss of needless time trying to troubleshoot the units instability.

2. Turning on salinometer data logger computer resulted in very long load time of the operating system and occasional complete failure of the computer. With time the computer became increasingly more unstable. I noticed that the battery light would flash red briefly then go out. I check the power supply output with a volt meter and found it to be outputting the correct voltage. I plugged in a different power supply which had the same output specifications but still the computer would crash to a black screen. Next the battery removed which fixed the issue. The computer still boots up slowly but seems stable. It has not crashed or blacked out since the battery has been removed. Most likely the battery had expired. A replacement battery is coming with the JOIS group.

3. When running “junk” seawater to condition the conductivity cell I noticed that the readings were very unstable. Initial thought was that the units water bath again was not at the correct temperature or possibly fluctuating. Opening up the unit to insert a thermometer into the water bath I noticed that the impeller pulley was not turning. I gave the impeller drive belt a small wiggle and it immediately started spinning. Looking through the cell viewing tunnel it was clearly evident that water in the bath was being well mixed. The unit was left for several days to stabilize to operating temperature. Again “junk” seawater was run and the conductivity values were found to be stable. No other issues have occurred since.

Dissolved Oxygen Sampling and Analysis

Overview

Dissolved oxygen concentrations were measured on board the *CCGS Louis S. St. Laurent* (LSSL) on August 28 and September 2 at 2 stations. The number of samples analyzed including replicates was 53. Dissolved oxygen concentrations during the surveys ranged from 7.4 to 8.9 ml/l. Greater than 10% of samples were collected in duplicate with a pooled standard deviation of 0.007 (n = 6).

Sampling Procedure

Once the rosette was recovered and wheeled into the sampling shack, the bottle integrity was checked, and then the samples for oxygen were taken first. The DO samples were drawn with a silicone y-tube in which one of the y-arms had a temperature sensor siliconed into the flow of sample being taken. The samples were drawn into a calibrated glass flask with attached stopper and immediately pickled with 1ml of manganous chloride followed by 1ml of alkaline iodine. The stopper was inserted so that no air was present in the sample and the sample was shaken to mix the contents. After about 20 minutes after all the samples were pickled, they were re-shaken and a squirt of D.I water was placed on top of the stoppers to prevent any sample/air interface and the samples were stored at room temperature or refrigerated until analyzed.

Analysis

Dissolved oxygen samples for 2014-10 were analyzed onboard 14-24 hours after collection using an automated version of the micro Winkler technique as modified by Carpenter (1965). The instrumentation and methodology is from Scripps Institute of Oceanography (SIO). Rather than using visible colour as an indicator of the endpoint, it uses the very strong absorption of ultra- violet light by tri-iodide ion at 350nm wavelength. Because this absorption band is quite wide, and 365nm UV sources and filters are readily available, it is the 365nm wavelength that is actually used in the system. In this system, the process of thiosulfate addition to determine the endpoint is carried out just as an analyst manages this function for a visual endpoint titration. The reagent is added rapidly at first and then as changes in UV absorption are noted the rate of reagent addition changes gears and is slowed in increments and finally stopped. The endpoint is approached by adding ever smaller increments until no further change in absorption indicates the endpoint has been passed. For the analyst, the change in colour of the sample has been replaced with the change of voltage from the photodiode detector circuit.

Instrumentation

-system controller-either a P.C. or laptop with USB to RS232 cable (Keyspan)

-2 Brinkmann 665 dosimats, 1 with a handheld keyboard and a 10ml calibrated burette for KIO_3 standard and 1 with a 1ml calibrated burette for Thiosulfate.
-VWR mini stirrer
-Spectronics pencil lamp UV source and mount
-UV detector with a 365 nm filter mounted (lamp and detector are mounted either side of a water bath that sample is placed in)
- a power supply for UV pencil lamp.
-AtoD device (external digitizer made by B&B #232sda12)
-2 platinum surface temperature sensors (1 each for Thiosulfate bottle dispenser and KIO_3 bottle dispenser).

Standards and Blanks

Standards and blanks were run immediately before analyzing. Standards and blanks were also measured whenever any reagents and/or sodium thiosulfate or potassium iodate were changed and before they were used to run any samples. A dedicated Dosimat was used to accurately dispense either 1 ml (blanks) or 10 ml (standards) of KIO_3. Blanks and standards were run in sets of 4 with the criteria that 3 out of 4 had to agree to within 0.0003 (blank value or THIO titer in ml).

A single bottle of Thiosulfate batch #1303A was used for the entirety of the cruise. The observed normality range was 0.00024 N. A single standard, batch 1404A was used. Normally more than one standard should be used in the course of a cruise, but since UNCLOS will be followed so closely by JOIS and there were only 2 casts to analyze, no second bottle was opened.

Precision

For cruise 2014-10, 5 pairs of replicates and 1 set of triplicates were run. The pooled standard deviation was 0.007 based on 13 samples.

Problems Encountered by the Analyst

1) 1 sample was over-titrated twice, with an unusable titration curves for both titrations for unknown reasons.
2.) One sample was lost when two stir bars were added to the flask – they could not be retrieved without affecting the measurement.

Conclusions

Dissolved oxygen sampling and analysis on this cruise was about as trouble free as one could hope for; the results from the duplicates and triplicates well within expected values.

Appendix A

Daily and Weekly Logs

Chief Scientist Daily Log

August 9, 2014, Departed St. John's at 08:30 and left harbour for testing of steering – returned to St. John's to drop off technician. Finally departed St. John's at 13:30 local time. After a few hours out of the harbour, we stopped for packer adjustments on the centre shaft – this took about 2 hours. Our track will take us south of, then east of Greenland , through the Denmark Strait and up through Fram Strait to the pack ice. Our goal then is to work our way over to Amundsen Basin. Multibeam system will be operated the entire time and an MSR (marine scientific research) agreement with Denmark is in place for this operation.

August 10, 13:00 NDT held a science meeting with all scientific staff and Ship's department heads. Reviewed objectives, roles and responsibilities and safety issues as well as ship's rules. Arrived Orphan Knoll about 14:30 NDT and commenced a multibeam patch test which was completed successfully by 21:00 NDT. No sign of earlier issues with the MB near Nadir soundings. Good crossing of Charlie Gibbs Fracture zone and NAMOC is obvious…a good tie point for our Labrador and Newfoundland maps.

August 11, transit continues – seismics being prepared. Passed south of Cape Farrel, where seas were choppy – as per usual as the Greenland Current strikes the Gulf Stream.

August 12 – hove-to for about an hour for the centre shaft again.

August 13 passed the Arctic Circle about 20:30 EST (clocks switched to EST).

August 15, encountered first ice during the night (sooner than expected) and by the 16th, our progress has slowed substantially due to breaking through pan ice – mostly multi-year. Lots of fog in these conditions of open water and ice mixture.

August 17th, Passed 80N. Terry Fox has caught up. We're trying to head NW to pick off sites provided by Denmark and to survey an FoS on the Morris Jessup Rise. Progress is slow – we're in about 9/10ths second year ice with some pressure ridging. LSSL breaking ahead of the Fox so she can save on fuel – she'll do her share of breaking soon. Hove-to again for 2 hours due to centre shaft packing. Through the night, Captain abandoned plans to survey these points and headed East to try and find lighter ice conditions.

August 18. Easterly has not been any better track – mostly second year ice, but puddles and leads. Ice worsens as we progress north and east…fewer puddles and most are frozen over…pressure ridges everywhere. Very slow headway. This is probably as ice jams up as it is pushed into Fram Stait.

August 19. Ice conditions improve through the day and progress is a little better. CIS fly-over today mapped a narrow band around us – mostly 9/10th. Low ceiling all day but freezing temperatures and wind about 10 knots.

August 20. Great conditions – lots of progress overnight but little during the day. Still puddle jumping. Trailed the Terry Fox to see how that was going to work and we deployed the 3.5 kHz sled and a sonobuoy to ensure everything was working. Held first science meeting at 18:30.

Should arrive at first waypoint tomorrow and start shooting seismics. Hull mounted 3.5 kHz system not working all that well…every bang on the hull echoes into the transducers.

August 21 – started shooting in the am…by 9:30 all was in the water and working. Went on helicopter to deploy sonobuoys but both turned out to be duds! Pressure on the ice built up through the day. Deployment of sonobuoys from the stern failed – crushed by the ice. Streamer finally failed after supper – brought it on board and it was wrapped around the sled several times…turns out the repeater sections failed. Resuming to WP 2 with only multibeam and subbottom. Following behind TF, but still getting stuck. Ice under severe pressure

August 22. Beat our way westwards towards LR to get FoS points. Very difficult going. By late afternoon, Captain says we can go no further west. Pressure ridge after pressure ridge. Turned back to head east and shoot seismics on original plan. I noticed our old track had stayed open, so in the evening ~21:00, we deployed seismics…streamer failed with high leakage after first few shots. Brought in the gear by midnight. Pete Vass worked through the night to repair connector and try to rig something to stabilize the connector at the sled. Heading back to WP2.

August 23. Wanted to deploy the gear but when the TF got in the lead it was clear that we weren't going to get a good straight track. Decided that we'd break a track for ourselves, then return and put gear out and then shoot back along the track – the Danish approach. At 15:15, the streamer flooded on a sharp turn – pulling the gear. 19:00, gear back in the water and shooting – continued along the line.

August 24. The Gear worked through the night, surprisingly. Small gun went down but continued and Borden was able to re-sync it in the morning. 13:00h, the streamer failed – water in the connector on the sled. Umbilical was twisted around the sled 3 times. Steaming to WP 8 to run a line from Gakkel Ridge across Amundsen Basin. 2 sonobuous and 61 km of seismics accomplished.

August 25. Deployed gear at 00:00 and in water and shooting by 01:00. Not at WP, but in a good pond for deployment. Gear failed at 05:45. Brought gear on board and early indications suggest not enough sediment to meet the 1% criteria…steaming up the line to redeploy further toward LR. Deployed gear and ran for a few hours before leakage was up…but no failure so continued to shoot. Fox Called and needed to repair a leak in the bearing cooling system…about 2 hours repair. Pulled gear and changed second streamer sections and first connector….cleaned and dried. Gear back in the water by 23:15…no depth reading in second section of streamer now.

August 26. Gear ran overnight although with some leakage. Pulled gear in the morning and made repairs while we steamed ahead for 20 miles, then back 10 miles to redeploy gear. Gear in water about 18:30 and heading up track… winds are light and track stayed open. Good seismics… heading north towards pole.

August 27. Ready to deploy in the morning (ahead 20 back 10 during the night)… we acquired excellent seismics for these 10 miles, then tried to follow the Fox for a few miles extra. By 14:00 we were getting stuck frequently so pulled gear. Steamed towards North Pole and made it there about 19:00 – officially at 19:26 EDT. I advised the Captain that we'd spend no more than 8 hours .

August 28. Left the pole at 0600…Later than expected due to engine room work. Found an open pool for a Rosette sample and sound velocity profile, near the pole in 4200 m water depth. 11:00 started breaking ice toward LR in order to shoot seismics. Complete bust – spent entire day going around a single ice floe. Decided to scrap the seismic line and head east to pick up a FoS on LR.

August 29. Spent the night and morning surveying a potential FoS point that turned out to be an isolated mound. Headed further east along the 2500 m contour, then down slope toward BoS.

August 30. Ran multibeam/chirp through the night and produced a nice bathymetric profile over the night with a distinct FoS. Crossed a linear seafloor depression which we thought must be a fault trace daylighting. We extended the line seaward and then ran a fantastic seismic line from Amundson Basin up on to LR. Perfect conditions – no gear problems at all. Pulled gear in at 18:00. Just putting stress on the lift cable of the tow sled and the crimps sheared….luckily no weight was yet on the sled and it was still in the water – not overhead!!. But it did represent a challenge on how to recover. First, the 3.5 sled was moved to the port cradle and the lift line was taken from it to attach to the air gun sled. The 1" tow cable was used with the tugger winch to pull the sled to surface…then the FRC was put in the water to hook the second lift line to the sled. The sled was brought aboard and put in the stbd cradle. Gear on board by 20:00
Now trying to transit west to other side of date line to work on Siberian side of LR…to get a FoS…lots of trouble with ice.

August 31. Into some tough ice during transit.

September 1. 0530 stopped to refuel the TF. Made only 96 miles during transit (29 hours). 10 hours to refuel TF. Stopped until 21:45 due to repairs to the fox and leaky ballast tank on the Louis…underway at 22:15

September 2. Slow progress through the night but got through the lines to survey in the second FoS point. 13:00, stopped again to do welding repairs in ballast tank of Louis. Stopped for 4 hours. Running rosette sample while stopped. 18:00 commenced transiting to next FoS.

Sept. 3 Entire day surveying the third FoS and running bathymetry line upslope to the 2500 m contour. Ice too thick to use the Fox so LSSL broke ahead 9 km, then turned 90° to the track and swathed along track using the hokey pokey.

Sept. 4 Transiting to the waypoint for a seismic profile from LR into Makarov Basin. Made only 30 miles overnight…ice is too heavy. The Fox is leading but the ice is not under heavy pressure – some closure of the track. Discussed with the Captain about the seismic line…he feels it is not possible with our low fuel and ice conditions. The decision was made before lunch to head out of the ice and back to Canada Basin where we can hopefully collect some useful data. Very disappointed that we could not collect that seismic line!

Sept. 5 Made open water during the night (about 4:30 am) on the Siberian side of LR. Relatively heavy seas greeted us…ugh! We were back into ice by about supper time and began transiting across the ridge towards Podvodnikov Basin. Following the Fox and the multibeam and chirp are looking pretty good. The near-NADIR artefact has returned on the multibeam data, however. It seems to manifest itself most prominently on flat bottoms so must be some sort of beam interference tracking error.

Sept. 6 Crossing Podvodnikov Basin and onto Mendeleev Ridge. Ice mostly first year and easily broken. Making good time and should reach Canada Basin by Monday night at this rate.

September 7. Moved to Central time last night. Still in transit over Mendeleev Rise and heading towards Chukchi Plateau. Ship shut down at 10:30-12:30 to replace bearing oil, then the Fox was shut down for maintenance. Underway again at 12:40. Heading across Chukchi Plateau. Ice is light and still following Fox with terrific data quality on MB and Chirp.

September 8. Moved to Mountain time last night. Continuing transit across Chukchi Plateau - getting some great imagery on the Chirp system. Arrived at the designated waypoint on Northwind Ridge 21:30 and deployed seismics, to shoot a seismic line across Canada Basin – to pick up a sediment thickness point near Chukchi and to get a good crossing of the buried spreading ridge…then to get a profile up the Canadian Arctic Archipelago margin. Took some time to get compressor #1 fired up due to a loose wire, then the Fox had a steering issue, so took an hour or so to make repairs. We started proceeding without an escort as the ice is fairly light. Got underway by 22:15. By 23:15, Fox caught up and took the lead.

September 9. Surveying continues uninterrupted…lots of open water and data quality appears excellent. Still having problems with the sonobuoys. We deployed one by helicopter – Kai and Patrick flew. But never got a response from it?? Maybe no hydrophone? Deployed one from the ship – there was a carrier signal but again, no hydrophone response.

September 10. Seismic throughout the night and day….ice is getting heavier. We went through a large floe late in the morning and got stuck several times. We crossed the spreading centre and now coming to the third waypoint for the approach to the Canadian margin. Ice very heavy so I plotted up an alternate plan for multibeam and chirp acquisition up the margin. Kai plotted up the chirp profile on this transect – very cool…when vertically exaggerated it brings out details that you wouldn't otherwise notice – seems like there are currents down there after all, with drifts and bedforms apparent.

September 11. Pulled seismics at 06:30 … we made a tieline in the basin but did not get into the margin at all…ice just too heavy and getting stuck frequently. Terry Fox just doesn't break a wide enough track. Transited down to 20 mi seaward of FoS3 and then ran a multibeam and Chirp profile up the margin, crossing FoS 3 to get it surveyed…then beyond to tie into the 2500 m line.

September 12. Completed the line to the 2500 m – the slump scar apparent on the IBCAO chart does not exist! We then transited south to run a line across the next slump scar. Decided to run seismics as well – diagonal pattern between two 2007 lines. Ice is heavy. During transit to find a pool to deploy seismics, we encountered a ridge system that took Louis and Fox several hours to break through. 20:00 pm all gear in the water.

September 13. 04:00 called to the seismic lab as the streamer had failed. We were stuck in a heavy floe. Made our way to a pool to recover. Now in full darkness. Gear on board by 05:30 and every float had been ripped off the streamer and the acoustic release had snapped off and was gone. Streamer must have been caught between ice and pulled through at a sharp angle, shearing everything! Streamer is heavily damaged. Continuing down the line with multibeam and chirp. There is not enough time to get the other streamer rigged and I don't want to risk losing it too. Ice continues to lighten up as we head west. Sent the helicopter up for a photo op… Louis broke line (without consultation) and did a circle to break ice on her own – just for the photo op….did not ask or inform the science party. In the afternoon, I discovered that AGAIN we were running a Rhumb line, not great circle. This caused us to miss the crossing of the Polarstern data where the large glacigenic debris flows are. We observed the flows on the Chirp but not where the Polarstern crossed them. Orders were to proceed at 6 knots, then slow to 4 knots to arrive at turnaround point at 0600 (base of Mackenzie fan for FoS 1 survey). Instead, we were doing 8 knots most of the afternoon and evening.

September 14. Finished slope line and deployed the external chirp sled for a line over FoS 1 and up the Mackenzie fan. Data were not as good as the hull-mounted chirp, so we brought it in and topped up the fluid levels and tried again – still not as good. Brought it in and are running with the multibeam and the hull mounted chirp up slope of Mackenzie fan – over FoS 1 and on top of the 2010 seismic line. Lots of >9/10 ice cover.

Sept. 15 . Continued chirp/multibeam line up Mackenzie Fan. Kai discovered chirp was not logging for about 3 hours from 13:30. Encountered heavy multiyear floes by late evening and had to divert from line to get around them.

Sept. 16 Broke out of the ice about 04:00 and finished the line in the morning at about 06:30. Sea states are heavy with strong winds. Continuing to log multibeam and chirp as we transit toward Kugluktuk. Diverted into Franklin Bay late afternoon and sent two helicopters with mammal observers Nelson Ruben and Dale Ruben to Paulatuk. David Levy, Jacques (engineer) and myself flew with them to Paulatuk. Back by 20:00 and continued transit to Kug.

Sept. 17 Transit continued to Kug. Day of packing and stripping apart and stowing gear. Arrived and at anchor by 20:00.

NRCan Weekly Reports

Weekly Report August 9 –August 17

Prior to departure, we lost one of our mammal observers. John Ruben's medical exam indicated a severe lung infection and he was taken to the hospital. He was required to spend a number of days there and arrangements were made to get him back to Paulatuk (August 15). August 9, 2014, Departed three times from St. John's – third time lucky!! First time, dropped off a steering technician, second time a med-evac (Fourth Officer had chest pains). Finally departed St. John's at 13:30 local time. Our transit track will take us south of, then east of Greenland , through the Denmark Strait and up through Fram Strait to the pack ice. Our goal then is to work our way over to Amundsen Basin. Multibeam system will be operated the entire time and an MSR (marine scientific research) agreement with Denmark is in place for this operation. A patch test of the multibeam system was conducted on the flank of Orphan Knoll. All systems checked out well and with no sign of earlier issues with the MB near Nadir soundings. Good crossing of Charlie Gibbs Fracture zone and NAMOC; a good tie point for our Labrador and Newfoundland maps.
We passed south of Cape Farrell on August 11, where seas were choppy – as per usual as the Greenland Current strikes the Gulf Stream. Along the transit we crossed the Arctic Circle on August 14 and 29 crew and science staff were inducted into this famous club. By August 15, we encountered first ice during the night (sooner than expected) and by the 16th, our progress had slowed substantially due to breaking through pan ice – mostly multi-year. Lots of fog in these conditions of open water and ice mixture, which also hinders progress. By August 17th, we passed 80N. Terry Fox caught up and we're travelling in tandem with the LSSL breaking ice. We attempted to head NW to survey an FoS on the Morris Jessup Rise and head into Amundsen Basin. Progress was slow – in about 9/10ths to 10/10ths second year ice with some pressure ridging. Through the night, these plans were abandoned and we headed further east to try to find better ice conditions. The pack ice is further south than typical and will slow progress to the survey area. The Multibeam system is behaving as expected in these ice conditions. As we break ice ahead of the Fox, conditions are rough and data are noisy.

You may have noticed that regular Blogs and Tweets are posted.

Weekly Report August 18 –August 25

Our easterly transit was difficult…pressure ridges made slow headway. The ice is under pressure here as it is pushed through Fram Strait. As we got further east, the pressure eased and we were able to make some headway. We puddle-jumped to avoid pan ice… We trialed a period with the Terry Fox in the lead and deployed the external 3.5 kHz sled and a sonobuoy to ensure everything was working. The hull mounted system is not working all that well in ice – every bang on the hull echos into the transducers. It needs to be isolated from the hull by having a separate acoustic window.
We started shooting seismics on August 21 and the system operated as it should, but by the afternoon the ice came under pressure and we weren't able to continue. The hydrophone streamer

cannot withstand the thrusts of the propellers. When it was brought on board, it was wrapped around the sled several times, indicating the sled was spinning. Five sonobuoy deployments, including two by helicopter, failed. The two by helicopter and one off the stern were duds – i.e. they never surfaced. Two others off the stern of the ship were crushed by ice, we presume, since they worked for only a few minutes. We tried to continue westwards to get FoS points on Lomonosov Ridge but we were unable to get within 120 km of the ridge due to ice conditions. We had to turn back and head east to north east on our original seismic plan (i.e. to collect a strike line at approximately what we believed to be the 1% thickness line). Problems with the streamer continued, so seismics is limited and patchy. The ships cannot keep a straight track and, with the need to apply thrust to the propellers to make turns, that causes strain on the streamer and causes leakage. We tried the "Danish" approach, of running both ships up the proposed track and back again, then deploy the seismics and return along the same track. That is effective as long as the ice is not under pressure, but still we cannot keep straight tracks and still the streamer leakage remains a problem as a result.
On August 25th, we made a point close to Gakkel Ridge in an attempt to shoot a seismic line across Amundsen Basin towards LR. We ran both ships up the proposed route to create a track for ourselves and then tried to run back along the track with seismics – the winds came up to 30 knots and the track was lost, soon after the seismics failed. We continue along this tact in the hope of identifying at least one sediment thickness point and then will continue to try to reach LR again to get FOS points near the pole.

Totals
5821 km total distance covered (multibeam on all the time)
137 line-km seismic
57 xctd (expendable conductivity temperature depth) profiles
4 semi-successful sonobuoys (we have not yet achieved sufficient offset for refraction analysis)

Weekly Report August 26 –September 1
Continued collected seismic data in short segments – using the Louis to break ice ahead and then return and deploy….slow process but the only solution since the Fox cannot break ice or cannot break in a straight line. We were able to watch in one section where the Fox actually rode up a ridge and did not break it. We've managed to collect some descent seismic data with this approach – but only in short segments. We managed to acquire 3 x 10 mile segments on our transit north towards the pole. We made the pole officially at 19:26 EDT on August 27th. We planned to spend a maximum of 8 hours here. We deployed the gangway and people were able to get on the ice and enjoy one of the rare instances where we've had sun. We left the pole at 0600 on August 28, after delays due to engine room repairs. We collected a deep Rosette water sample station and deep sound velocity profile in a nearby polynya. Heavy ice prevent further seismic operations towards the Lomonosov Ridge.
August 29 to 30th, we surveyed parts of Lomonosov Ridge to establish the 2500 m contour and a Foot of Slope position. On the slope transect, we acquired excellent quality multibeam and chirp data; the ice was thin enough that we collected a seismic line from Amundsen Basin up onto the Ridge on the return …turned out to be a fantastic section. We had a "near miss" on recovery of the

airgun sled – the wire crimping let go (a certified crimp). Fortunately, the sled was still in the water and little load had yet been put on the wire, so there was no risk to persons or gear. If that let go when the sled was out of water or overhead, it would have been a different story. After some re-rigging, we were able to recover the sled. We are now trying to transit west to other side of date line to establish the 2500 m contour and an FoS on Siberian side of LR…to get a FoS, but ice has been difficult and the transit has been slow. We are presently refueling the TF, which is a 10 hour operation. The Captain is concerned about low fuel reserves which may require departure from survey area earlier than planned.

Totals

Seismics

LSL1401 30.76 km
LSL1402 0.19 km
LSL1403 10.92 km
LSL1404 77.47 km
LSL1405 17.84 km
LSL1406 14.75 km
LSL1407 23.93 km
LSL1408 18.87 km
LSL1409 32.74 km
LSL1410 47.67 km

total: 275.14 km

10 successful sonobuoys deployments
Total track length (km) during which multibeam and chirp systems were operational. **6927 km**
1 Rosette
66 XCTD casts

Weekly Report September 1 –7

Lost the entire day of Sept 1 to refueling the Terry Fox and waiting for the Fox to implement repairs. Under way at 22:15 that evening. We transited to the west to pick up our second Foot of Slope point nearest the North Pole – just on the Siberian side. Acquired quality multibeam data in the area. We stopped for further repairs – this time to the Louis (leaky ballast tank), for 5 hours, then transited further west for our westernmost foot of slope point. We surveyed the point and then ran a multibeam line upslope to tie into the 2500 m contour. As the ice was too heavy for the Fox to break for us, we had to steam ahead by 9 km (the swath width) and then stop, turn the ship 90 degrees and run the multibeam so the swath aligned along track, then swept the beams back and forth to cover some ground (the hokey pokey manoeuver), then repeated all the way up slope. By Sept 4 we were steaming to run a seismic line but we made only 30 miles over night and the Captain determined that we were too low on fuel to attempt the seismic line….it would require us to break ice, return and shoot the profile.

By noon on Sept. 4, because of the state of low fuel and the heavy ice, we elected to head out of the survey area and transit toward Canada Basin. This is very disappointing as there is much work yet to accomplish for the submission. I would estimate that we accomplished about 1/5 of what needs to be done. The transit will take us toward the Siberian margin to get out of the heavy ice as soon as possible, then skirt the heavy ice margin by transiting across LR, Podvodnikov Basin, Mendeleev Rise and the Chukchi Plateau. We calculated that this transit would take us 6 or 7 days. Ice conditions, however were relatively light (first year with open leads) for most of the transit and it is apparent that we will make Canada Basin by Sept. 8th. We've been following the Terry Fox since the transit commenced, thus the multibeam and chirp data are of excellent quality….not of particularly use for our LoS program, but good for the IBCAO chart and for our seafloor geologic mapping. The multibeam near-NADIR artefact seems to manifest itself most prominently on flat seafloor, so must be some sort of beam interference tracking error. On September 7, we find ourselves transiting across Mendeleev Rise and onto the Chukchi Plateau. Ice is light and still following Fox with terrific data quality on MB and Chirp. As we have time in Canada Basin, seismic and multibeam lines have been planned which will augment our western Arctic submission…some GAR and FOS points are in dire need of supporting evidence , so this represents a good opportunity.

We haven't seen the sun since August 27th and it has mostly been foggy with limited visibility and frequent snow-squalls. A bear with a three year old cub was spotted on September 4 at 83 deg north and an Arctic Fox was spotted before that at about 86 deg north. I think people would rather see the sun at this point in time.

Survey Totals

Total line km (with MB and Chirp data)	8799
Seismic data collection km - 10 lines to date	275
Successful sonobuoys	10
XCTD	97

David Mosher
Chief Scientist

Weekly Report September 7 –14

We finished our transit to Northwind Ridge on September 8. Some terrific looking multibeam and Chirp were acquired during the transit and particularly across Chukchi Plateau. On NW Ridge, we deployed the seismic gear to transect Canada Basin. The intent is to pick up a sediment thickness point close to Northwind Ridge that was unobtainable in the original submission due to this data gap, and proceed across the basin to get a good section over the extinct spreading ridge, then cross a foot of slope point on the Canadian margin and tie into the 2500 m contour off the archipelago. We acquired high quality data across the basin and tied into an existing survey line on the Canadian margin, but ice continued to thicken as we proceeded east. We had to pull the gear in on the morning of September 11 as ice was too heavy to make progress with the seismic gear in the water. The Terry Fox is just too narrow for the Louis to follow, in heavy ice. It is unfortunate to not get a seismic profile across the Canadian margin, but seismic, chirp and multibeam are all of excellent quality for this basin transect. We continued multibeam and chirp to cross the existing FoS 3 and then tied into the 2500 m contour.

On September 12, we deployed the seismics again to attempt a line downslope from the 2500 m contour across the Canadian Arctic Archipelago slop. After about 40 km, however, we got stuck several times in a heavy floe. The hydrophone streamer failed and we pulled the gear. Every float had been ripped off the streamer and the acoustic release had snapped off (i.e. PVC snapped in two) and was lost. The streamer must have been caught between ice blocks and was pulled through at a sharp angle, shearing everything! The streamer is heavily damaged and maybe not serviceable. We continued the line with multibeam and chirp. Unfortunately, ice continued to lighten up as we headed west, and we could have acquired seismic if we hadn't lost the system.

On September 14, we finished this slope line, cross FoS 2 and we tried deploying the external chirp sled for a line over FoS 1 and up the Mackenzie fan. Data were not as good as the hull-mounted chirp, so we switched back to the hull mounted chirp and running the line with it and multibeam over the entire slope of the Mackenzie fan – over FoS 1 and on top of a 2010 seismic line. Surprising, there is lots of >9/10 ice cover in this area, whereas in 2011 it was ice free. We will end the line on the morning of the 16th at the shelf break and then proceed to Kugluktuk for the termination of the expedition on September 18.

Seismic Data

LSL1401 30.76 km
LSL1402 0.19
LSL1403 10.92
LSL1404 77.47
LSL1405 17.84
LSL1406 14.75
LSL1407 23.93
LSL1408 18.87
LSL1409 32.74
LSL1410 47.67
LSL1411 420.78
LSL1412 49.94

total: 745.86 km

Total Line Km with Multibeam and Chirp: 10464

Seismic data total: 745.86 km

Successful sonobuoys : 17

XCTD: 125

Rosette water samples: 2

David Mosher
Chief Scientist.

Canadian Hydrographic Services Weekly Report

Paola Travaglini

Weekly report
Week Aug 09-16
Departed St. John's at 8:30 August 09. The ship conducted steering manoeuvers for 2 hrs just outside the harbour and then returned to St. John's to drop off the testing engineer. We then proceeded with the trip north, however, shortly after departure we needed to return to release one of the crew members due to a medical issue. At 13:00 Aug 09 we departed for survey. In transit we selected a site for calibrating the MB system. We selected some lines off Orphan Knoll to run for the MB Patch test. We conducted the Patch Test, calibrated the system and proceeded to collect data. The 24 hr sounding operations began immediately afterwards and we have been collecting multibeam data and sub-bottom data through-out the transit. For the most part, during the transit, the data has been quite clean (little noise) and the noise detected during the Sea Trials has surfaced in two small areas.

Along the transit we crossed the Arctic Circle and a total of 29 individuals on August 14, comprised of crew, hydrographic staff (Paola Travaglini, David Levy, Chris LeBlanc and Jim Weedon) and NRCan scientific staff, were inducted into this famous club.

On Aug 15 we encountered our first patches of ice and as we move further north the ice is getting progressively heavier. CCGS Louis S. St. Laurent is leading the way, with the CCGS Terry Fox behind, saving fuel for when ice breaking is required.

The Multibeam system is behaving as expected in these ice conditions. When the ship encounters larger patches of ice and is required to break through, the system loses bottom for a few seconds. On two occasions we have shut down the acquisition software, reset the Tx and then restarted sounding.
We conduct Sound Velocity casts as required and have used a combination of the expendable probes deployed by DFO Oceanographic staff from IOC as well as our own velocity casts and expendables.

The Novatel system for collecting high latitude, high precision positioning has been set-up. A total of two hours at a lower latitude has been collected. The current plan is to collect a total of 8 days of data, periodically while we work north of 78 degrees.

As always the Captain and crew have been gracious hosts. Many thanks are extended to them.

Weekly report
Week Aug 17-24

Multibeam data collection and processing continues as we transit to our work site. As we enter Amundsen Basin NRCan deploys the seismic gear as a test and all goes smoothly. This is a good opportunity for Science and ship's crew to co-ordinate the procedure. Ice coverage has steadily increased and weather hovers at below zero temperatures. Fog has restricted helicopter flying and ice observing on a few days this week.

After crossing the Gakkle Ridge, a line approximately parallel to Gakkle Ridge is planned for seismic collection. Line information is transferred to the CCGS Terry Fox and after the gear is deployed we begin collecting data with the Terry Fox breaking ice. As we proceed along the route skillful manoeuvering is required by both the CCGS Louis and Terry Fox. After approximately 10 hours of collection and with ever increasing ice pack thickness the gear is retracted and we move to collecting multibeam and consider an alternate plan. When breaking through the ice packs, the surrounding ice pack pressure and winds push back onto the once opened route by Terry Fox and because we are running at a controlled speed while collecting seismic data (3 kn) it is difficult manoeuver through the closing path.

A new route is planned and we head for Lomonosov Ridge to collect data across the ridge for resolving foot of slopes points. As we continue to collect MB data, the Ice Observer flies ahead to spot possible leads for us and monitor ice conditions. We are facing ever increasing ice coverage and thickness as the day progresses and the Ice Observer reports that the route ahead is not presenting any viable leads. After 30 nm of collection and stopping too frequently to break through while facing denser and denser pack ice and ridges at approximately 15 feet high it is decided it is not safe to continue along this route. It would be best to approach the Ridge once we are further north.

As we continue back and now north and wind has shifted the ice pack to the south we are finding the ice thickness has degreased and have successfully collected continuous seismic and MB data.

The marine mammal observers are continuously on watch and it is helped by the perpetual daylight in these northern latitudes.

Science meetings are planned each evening for a weather and ice report followed by quick briefings from each discipline. This provides a good opportunity to discuss the day's events and plans for the next day.

Weekly report
Week Aug 25-Aug 31, 2014

Multibeam data collection and processing continues. Ice coverage and negotiating a route through the ice packs has us collecting meandering paths at times. At the times when we were stopped for some repairs to ship or gear we took the opportunity to test out a sounding technique. The EM122 has the ability to steer/project beams forward and aft by 10 degrees (+10° and -10°). We tested this practice by steering the beams, first forward by 10 degrees, with 1 degree increments after every 4-5 pings, and then repeating this procedure by steering the beams 10 degrees aft at 1 degree increments. The whole procedure takes approximately one hour to complete. We collected a footprint that was 1500m fore and aft. This could be useful if we come up to an area impenetrably by ice – we can scan 10° fore and aft while stationary.

Our transit and seismic route in Amundsen Basin then takes us turning towards Lomonosov Ridge and **at 19:26, on August 27, 2014 we arrive at the North Pole!** This marks the 20th anniversary, almost to the day, of the CCGS Louis S. St. Laurent's first visit to the pole. We had the opportunity to walk off the ship and enjoy this historic day. Many photos were taken and we could not resist a favourite Canadian pass-time as hockey sticks were on hand. Who could have predicted that for the many of us growing up playing street hockey, we would one day be playing at the North Pole! Some crew and staff participated in the "Ice Bucket Challenge" - a fundraiser for ALS research. A bucket of water was topped up with snow and then participants would dump the bucket of icy water over their heads –brrrrrrr. We had brought the CHS flag with us, so the CHS staff took a few photos with our crest. North Pole certificates and expedition badges, designed by David Mosher (Chief Scientist, NRCan), were presented the next evening at an evening social.

At the end of our stop-over, we conducted a deep CTD rosette cast (4260m). Our SVP probe was deployed in one of the rosette housing slots. This deep cast would help us bench mark subsequent sound velocity casts as we neared the survey sites for collecting bathymetry for the ever crucial foot of slope (FOS) and 2500m contour. Oceanographer Jane Eert had sent down stainless steel mugs with this cast and during the North Pole certificate ceremony she graciously presented everyone with their own mug and samples of water collected at a depth of 4212m.

From the Pole we made our way to our first foot of slope area, collecting seismics where we could. The ice has really limited collection this field season. As we neared the first FOS area at the eastern/northern flank of the Lomonosov Ridge, we slowed down to ensure best coverage. We had identified a feature on the IBCAO data set as a potential FOS and set out to run a line across it. After the first pass it was evident that the feature was either offset on the IBCAO data set or perhaps did not exist. We conducted a search by running one short line on either side of the original line. Feature was indeed there, however when we ran the line back in the direction of the ridge it was closer to Lomonosov Ridge than originally mapped. We did identify the 2500m depths with this pass and so continued to our next FOS area by tracking and collecting the 2500m contour.

We reached our next FOS area and then collected a line down slope, ending at the FOS. Once at the FOS area we took the opportunity to conduct a sounding manoeuver coined the "pirouette" by the Danes. While on point/position, the ship would rotate on-the-spot, as slow as possible. This technique collects data in a circular pattern, the diameter of which is the full beam width at depth. At 4000m depth and with settings at full swath with (70° per side), we could collect a 16km circular foot print. This proved quite effective. NRCan ran a seismic line over the FOS area and beyond as the multibeam and sub-bottom profiler had picked up a trench like feature.

We are now making our way to the next FOS area and will also be transferring fuel to the CCGS Terry Fox upon arrival.

Science meetings continue most evenings for a weather and ice report followed by quick briefings from each discipline. This provides a good opportunity to discuss the day’s events and plans for the next day.

Appendix B: Bridge Instructions

Bridge Instructions, August 12, 2014

FID_	LatDM	LongDM	Type
WP1	86° 45.04'	-12° 00.18'	Waypoint 1 SOL1
WP2	88° 03.92'	6° 15.44'	Waypoint 2
WP3	88° 50.90'	42° 06.85'	Waypoint 3
WP4	88° 31.20'	67° 08.94'	Waypoint 4 EOL1/SOL2
WP5	88° 30.92'	-177° 34.26'	Waypoint 5 EOL2

Bridge Instructions, August 20, 2014

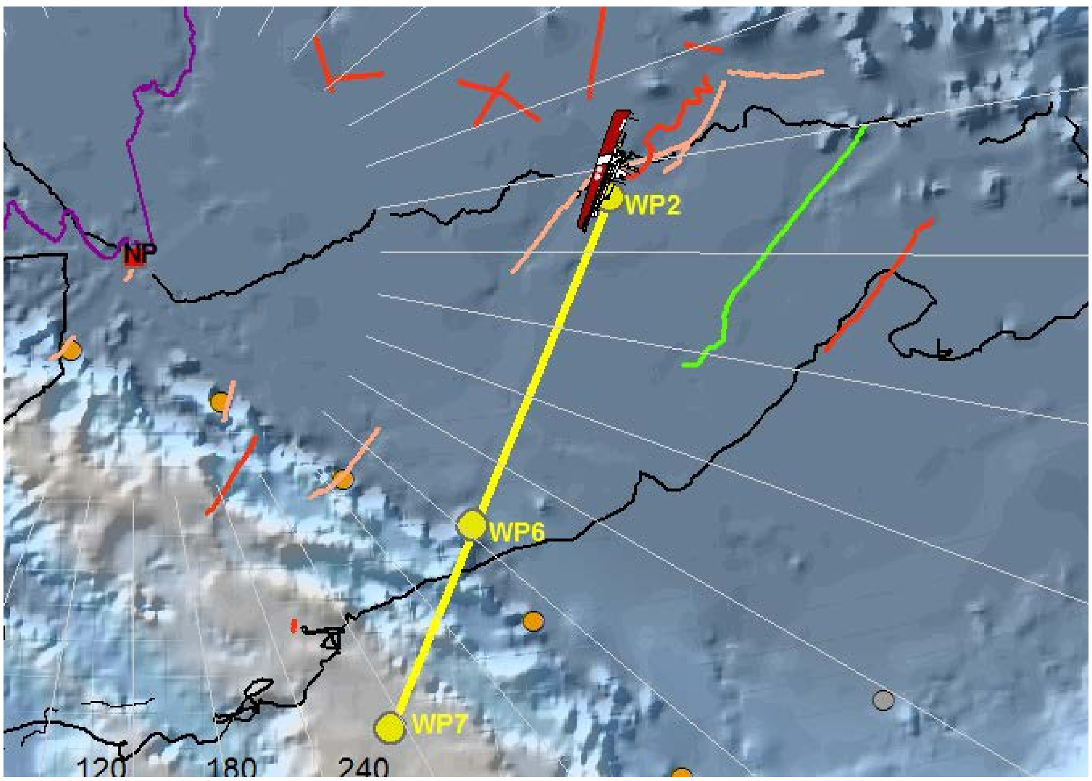
FID_	LatDM	LongDM	Type
WP1	87° 25.6'	19° 31.00'	Waypoint 1 SOL1
WP2	88° 03.92'	6° 15.44'	Waypoint 2 EOL2
WP3	88° 50.90'	42° 06.85'	Waypoint 3
WP4	88° 31.20'	67° 08.94'	Waypoint 4 EOL2/SOL3
WP5	88° 30.92'	-177° 34.26'	Waypoint 5 EOL3

Bridge Instructions, August 22, 2014

FID_	LatDM	LongDM	Type
WP2	88° 03.92'	6° 15.44'	Waypoint 2 SOL2
WP6	88° 12.87'	-38° 54.04'	Waypoint 6
WP7	87° 47.865'	-61° 33.26′	Waypoint 7 EOL2/SOL3

Drop WP 3, 4, and 5.

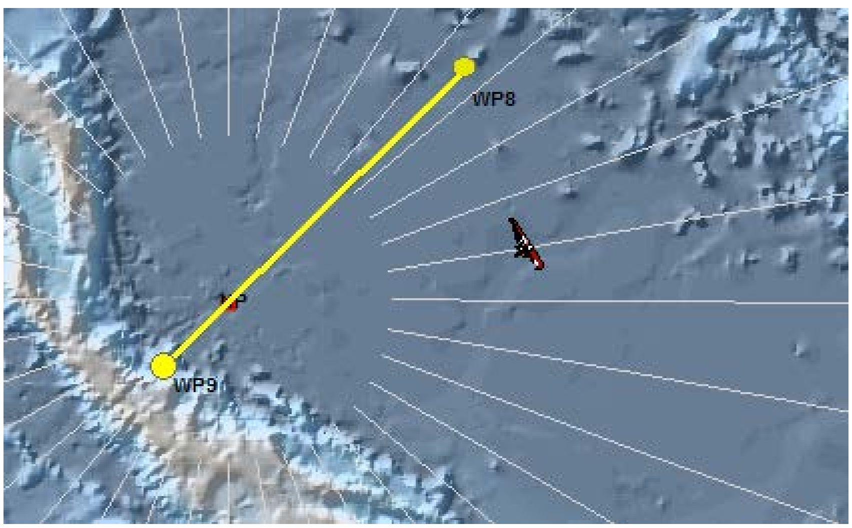
Transit to WP6 towards Lomonosov Ridge. WP6 is a critical point. We will spend some time surveying around WP6, including deploying the external 3.5 kHz subbottom profiler. We will then continue up to WP7 to ensure we capture the 2800 m contour.



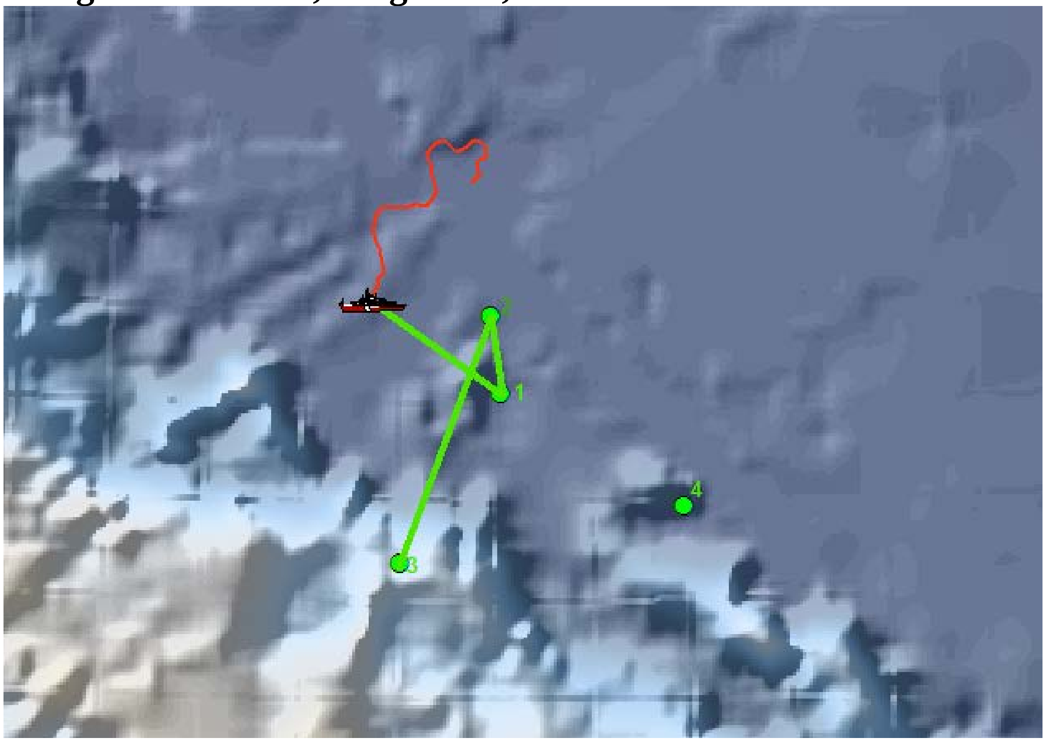
Bridge Instructions, August 23, 2014

FID_	LatDM	LongDM	Type
WP8	87° 57.42'	44° 30.00'	Waypoint 8 SOL
WP9	89° 22.82'	-135° 35.32'	Waypoint 9 EOL

If the hydrophone streamer fails but we are getting good signal on the sonobuoy, then continue along line. If the sonobuoy expires and ice conditions are good and guns are still operating, then deploy another sonobuoy. In the morning, we will bring in the seismic gear. When the seismic gear comes onboard (potentially in the morning)…transit to WP8. When seismic gear is fully repaired, begin seismic line to WP9. It is anticipated that ice conditions will start out good, if no pressure and become increasing difficult along the line.

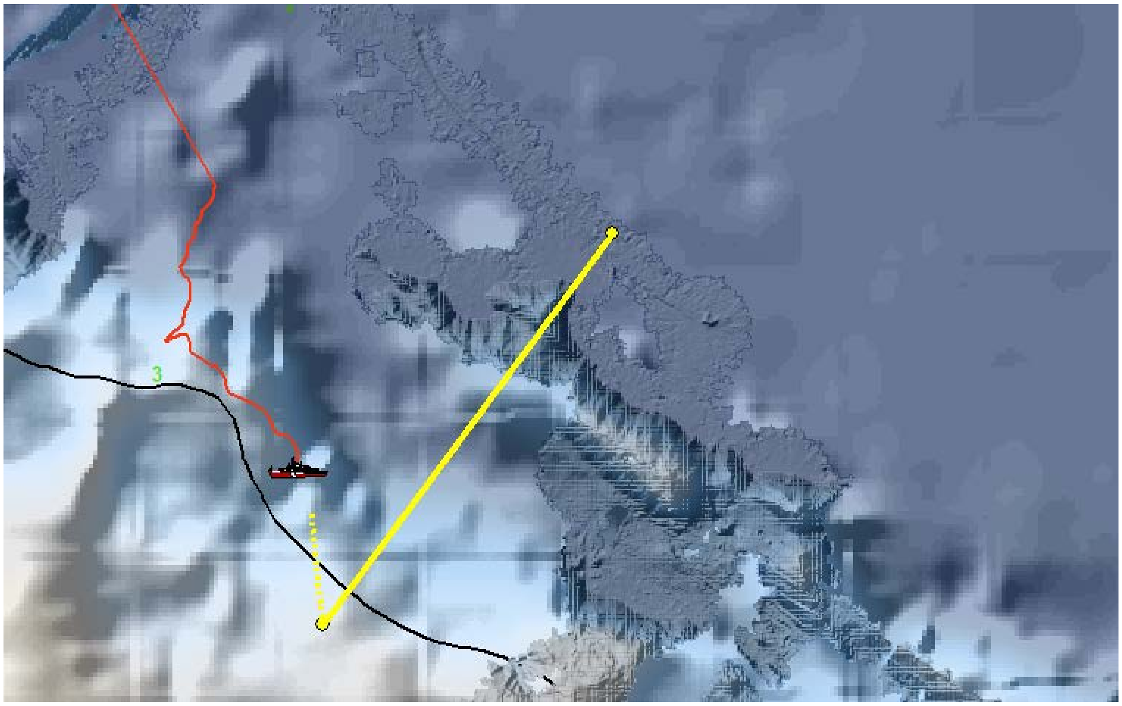


Bridge Instructions, August 28, 2014



Proceed to
(1) 89° 40.9'N 90° 34.4'W

If structure (mound) exists, we will survey it for a foot of slope by running the following line with Terry Fox in the lead.
(2) 89°46.5N 94°00.4'W to (3) 89°25.4N 103°44.8'W
Multibeam watch keeper will call it if this structure exists.
If structure does not exist, we will continue east to
(4) 89°27.61'N 62°50.36' W

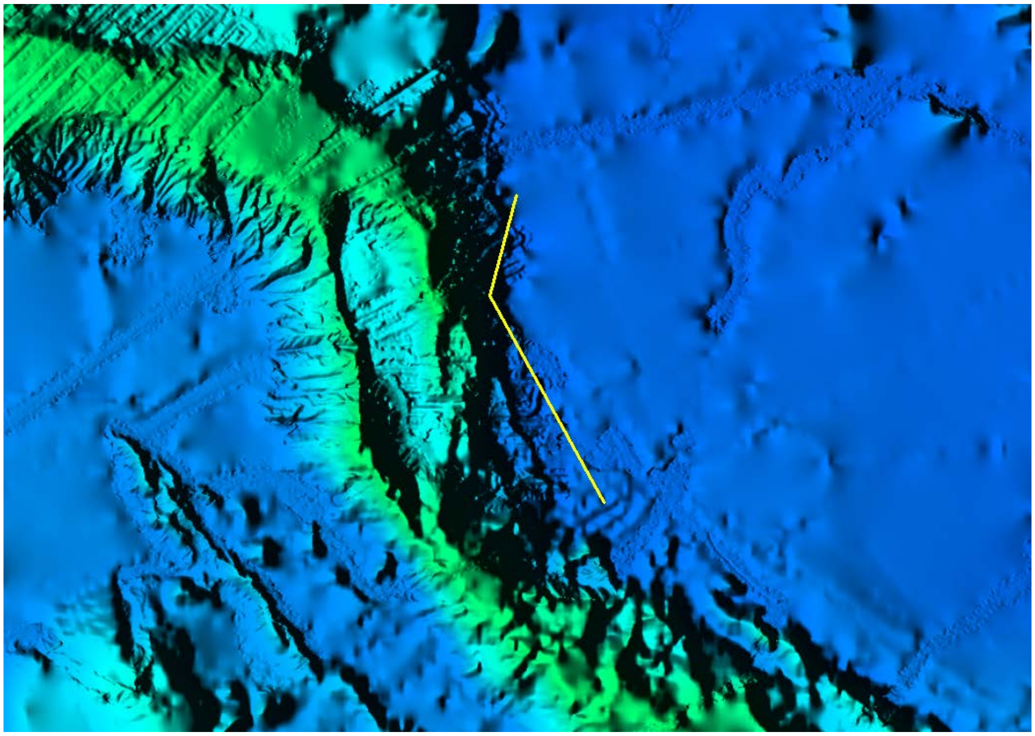


August 29, 2014

Hydrography lab will call up when to break current line and steer to WP(1) to run a multibeam profile across the ridge to intersect the base of slope zone at WP(2). Speed of 3 to 4 knots seems to optimize data quality. Fox to remain in the lead.

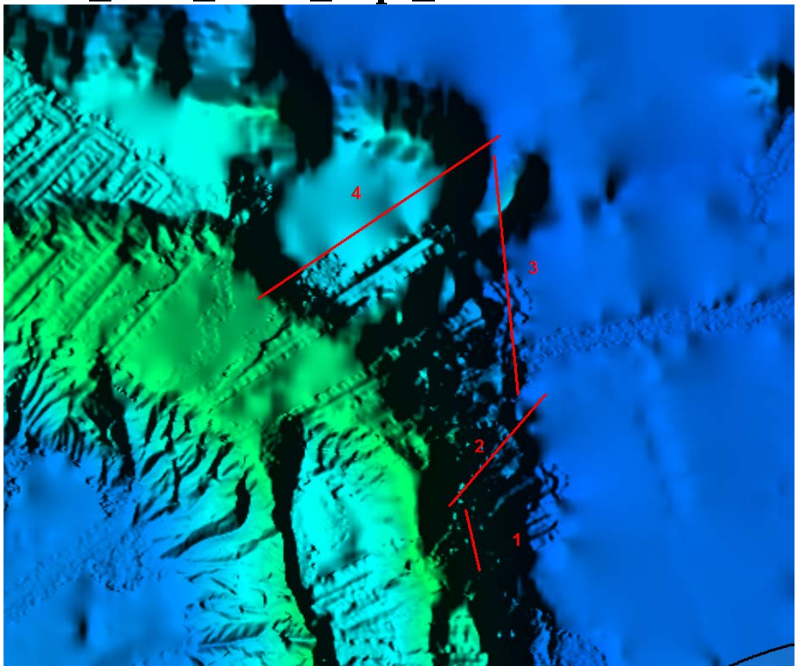
(1) 89° 11.60’N 87° 38.76’W

(2) 89° 28.05’N 54° 36.81’W



2014_AUG31_route
1, 89.6815756156 ,-157.5520326180
2, 88.9700105670 ,136.8837571492
3, 88.7184072814 ,120.3594849536

2014_FOS_track_Sept_01



Multibeam and Chirp lines – LSSL to follow FOX

Line 1

1	88° 44.51' N	136° 18.32' E
2	88° 39.51' N	118° 43.86' E

Line2

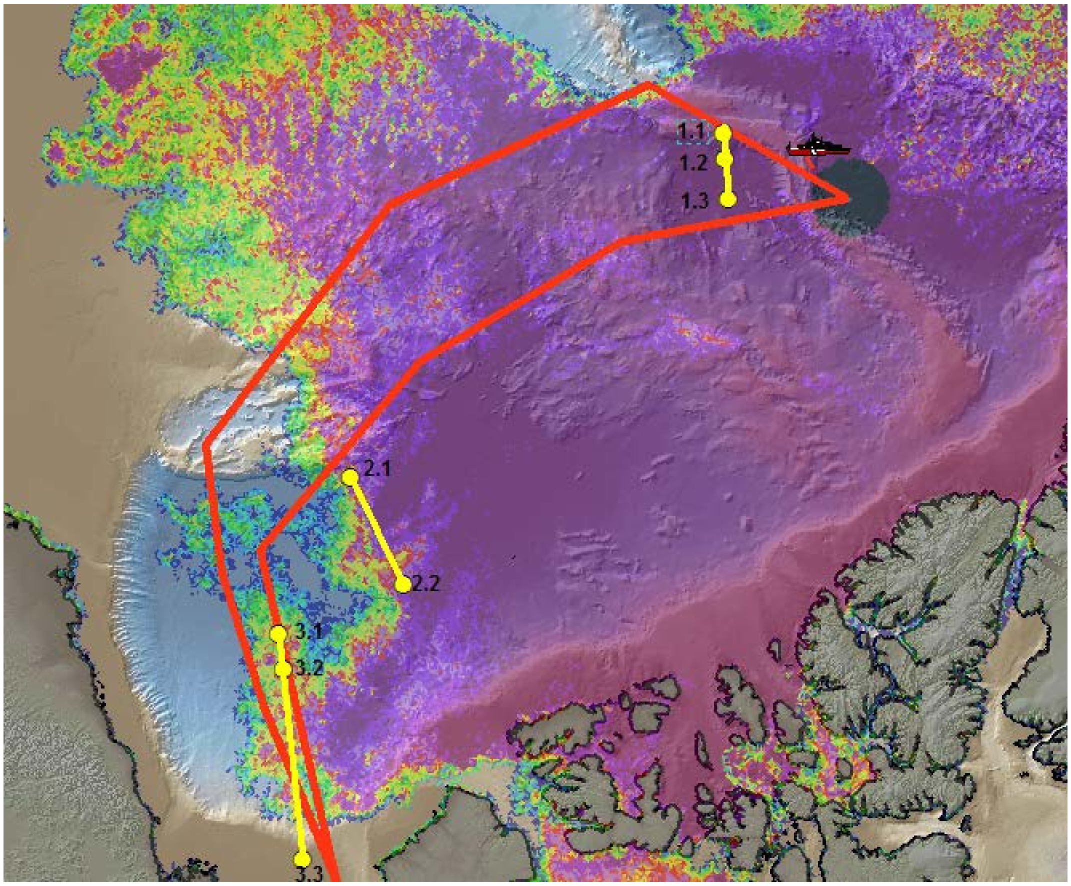
3	88° 37.18' N	121° 32.78' E
4	88° 00.19' N	113° 11.72' E

Line 3

5	87° 57.51' N	112° 16.16' E
6	87° 57.77' N	134° 55.90' E

Line 4

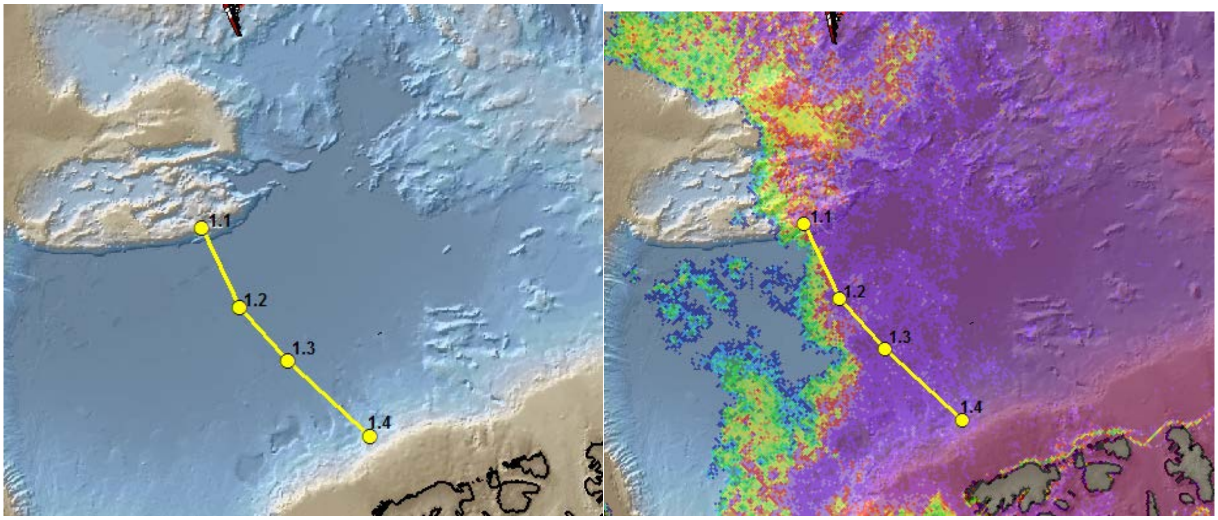
7	88° 55.33' N	140° 07.23' E
8	88° 46.925' N	135° 13.21' E



September 3, 2014 Bridge instructions.

WP	Ops	Latitude	Longitude	Lat_Deg	Lat_min	Long_deg	Long_min
1.1	seismic	152.4413455	86.94443956	152	26.48	86	56.67
1.2	seismic	162.4063194	87.19724531	162	24.38	87	11.83
1.3	seismic	-179.9766003	87.37568314	-179	58.60	87	22.54
2.1	seismic	-151.4103693	77.49484688	-151	24.62	77	29.69
2.2	seismic	-139.6342431	77.05790728	-139	38.05	77	3.47
3.1	MB & Chirp	-143.4581445	74.27706195	-143	27.49	74	16.62
3.2	MB & Chirp	-140.9732361	73.8447113	-140	58.39	73	50.68
3.3	MB & Chirp	-130.3331989	71.13112089	-130	19.99	71	7.87

Bridge Instructions September 07. 2014

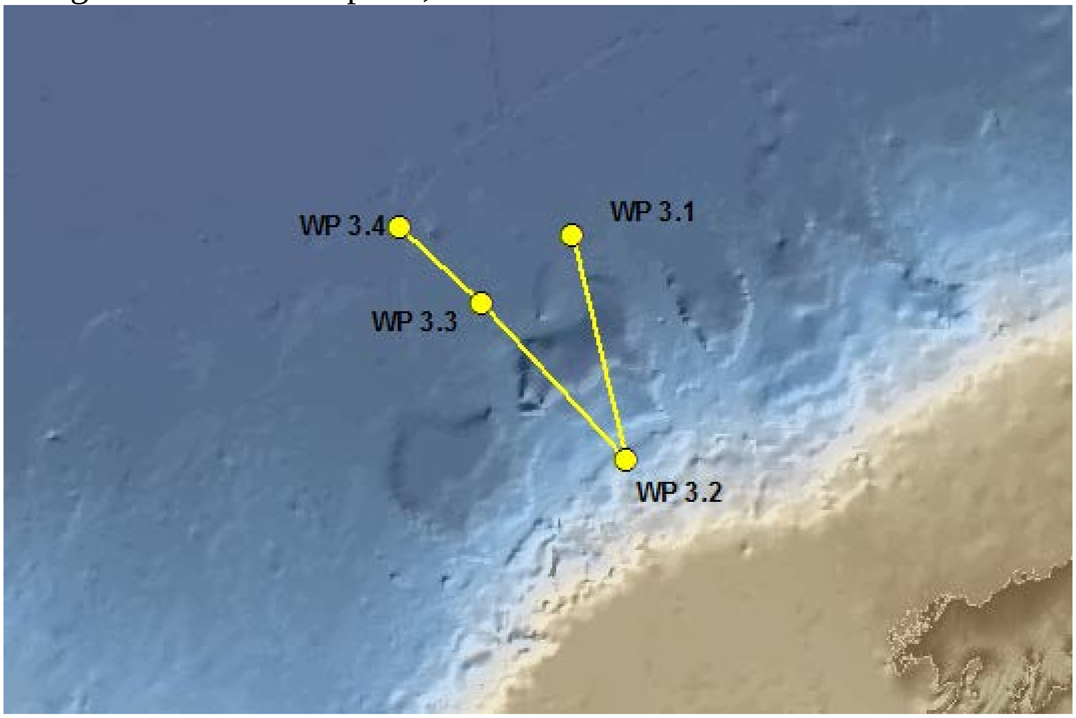


Deploy seismic gear at WP1.1 and proceed easterly through subsequent waypoints at 4 to 4.5 knots with the Fox leading the Louis. Straight lines are critical for refraction experiment. After WP1.3 we will proceed as far as possible depending upon ice conditions.

WP1.1	77°31.70’	-153°57.84’
WP1.2	77°19.04’	-145°22.59’
WP1.3	77°23.34’	-138°18.61’
WP1.4	77°21.23’	-127°11.70’

David

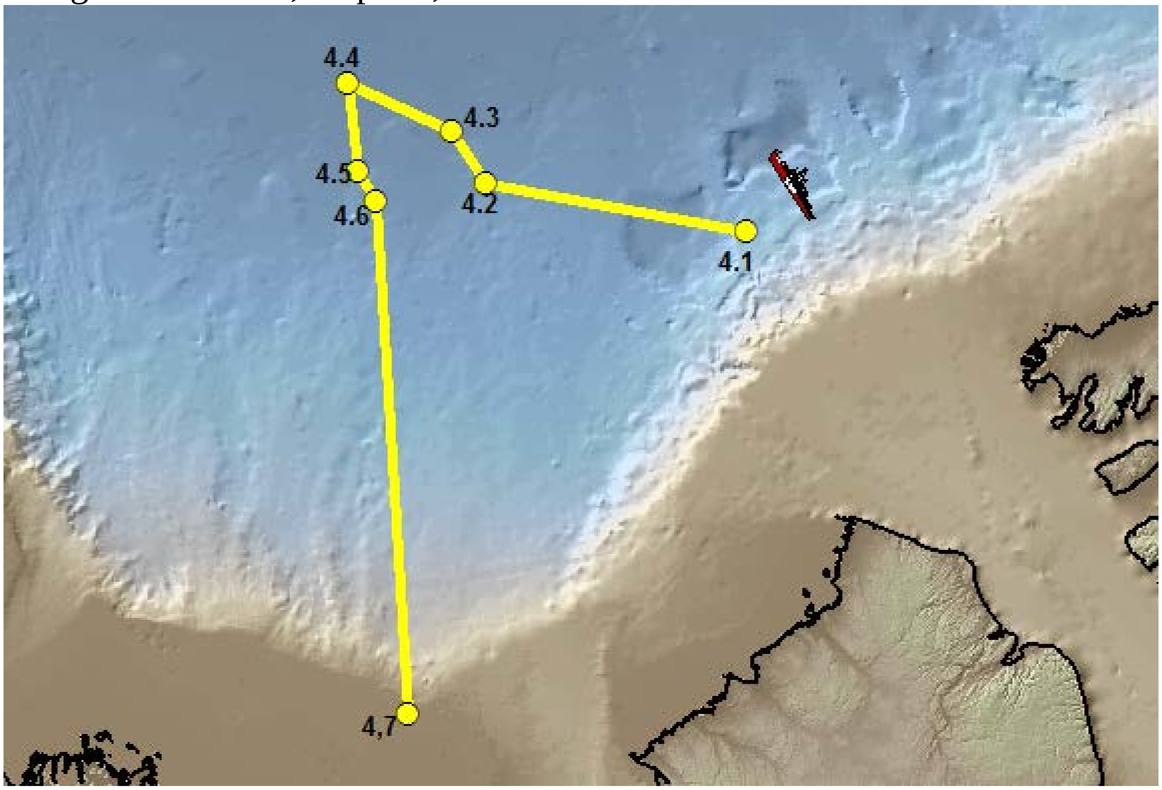
Bridge Instructions Sept 10, 2014



WP	Latitude	Longitude
WP3.1	76° 40.30	-135° 30.82
WP3.2	75° 55.00’	-130° 42.77’
WP3.3	76° 00.20’	-135° 52.40’
WP3.4	75° 57.50’	-138° 36.85’

If and when it is determined that seismic operations cannot proceed along the current track, we will recover the seismic gear and proceed toward WP 3.1 for multibeam and chirp profiler operations. We would like to survey up to WP3.1, so depending where seismic operations are stopped, it would be best to approach WP 3.1 from the west (i.e. from the basin toward the margin) by approximately 25 Miles. We will survey the proposed pattern with multibeam and chirp, attempting to make the 2500 m contour line at the apex of the turn. The preference is to have the Fox lead and we can survey at speeds up to 10 knots where ice conditions allow.

Bridge Instructions, Sept 12, 2014.



WP	Latitude	Longitude	Lat_Deg	Lat_min	Long_deg	Long_min
4.1	75.5756	-132.0578	75°	34.54’	-132°	03.47’
4.2	74.4933	-138.4082	74°	29.60’	-138°	24.50’
4.3	74.5622	-140.1126	74°	33.73’	-140°	06.76’
4.4	74.2052	-143.0072	74°	12.31’	-143°	00.43’
4.5	73.8447	-140.9732	73°	50.68’	-140°	58.39’
4.6	73.8005	-140.0996	73°	48.03’	-140°	05.97’
4.7	71.2163	-130.7579	71°	12.98’	-130°	45.47’

- Between WP 4.1 and 4.2, collect seismic, Multibeam and Subbottom data at 4 to 4.5 knots with Fox in the lead.

- Between WP 4.2 and 4.4 acquire Multibeam and subbottom data.

- Between WP 4.4. and 4.7, deploy external Chirp subbottom profiler and acquire multibeam and subbottom data at 4 to 6 knots with Fox in the lead.