New Bathymetry from the 2011 Canada—U.S. Joint Expedition for Continental Shelf Mapping in the Arctic Ocean

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SUMMARY

In August and September of 2011, Canada and the United States combined resources for a fourth season of joint extended continental shelf data acquisition and mapping in the Arctic Ocean. The 2011 cruise was a combined expedition of the icebreakers *CCGS Louis S. St-Laurent* and *USCGC Healy*. As in previous expeditions, *Louis S. St-Laurent* was equipped with a seismic profiling system and *Healy* with a multibeam system. Both ships were fitted with high-resolution subbottom profilers. The 2011 joint expedition began with a long northward seismic line from the Chukchi Plateau, over the Alpha-Mendeleev Ridge, through the Makarov Basin, and onto the Lomonosov Ridge. Although primarily a seismic line, high-quality multibeam and single-beam bathymetric data were obtained. At the northern end of this line, at 88° 28' north latitude, the priority shifted to bathymetry along the flanks of the Lomonosov Ridge and across Marvin Spur. From there, the ships again crossed the Alpha-Mendeleev Ridge, collecting bathymetry and subbottom profiles over highly irregular seafloor characterized by hyperbolic echoes. The ships continued eastward, pushing into areas of the Arctic never before penetrated by icebreakers, and collecting the first lines of multibeam bathymetry in these areas. At Sever Spur an AUV was successfully deployed under the ice from *Louis S. St-Laurent* resulting in the acquisition of high-quality multibeam bathymetry crossing the Spur. During the AUV deployment, *Healy* detached for additional bathymetric mapping. The combined data sets greatly improved the quality of seafloor bathymetry in this area with important extended continental shelf implications.

Key words: Arctic, Extended Continental Shelf, Bathymetry, Icebreaker

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In August and September of 2011, Canada and the United States combined resources for a fourth consecutive season of joint extended continental shelf data acquisition and mapping in the Arctic Ocean. The 2011 cruise was a combined expedition of the icebreakers *CCGS Louis S. St-Laurent* and *USCGC Healy*. As in previous expeditions, *Louis S. St-Laurent's* primary mission was seismic reflection profiling. In addition to its seismic system, Louis S. St-Laurent was equipped with a Knudsen 320 B/R Plus 12 kHz single beam echo sounder and a Knudsen 3260 chirp high resolution (~3.5 kHz) subbottom profiler (Mosher, et al, 2011 and Canadian Hydrographic Service [Biggar], 2011) and a 12 kHz Knudsen 320M helicopter-borne spot sounder. *Healy's* primary mission was multibeam echo sounding. *Healy* was equipped with a Kongsberg EM122 (12 kHz, 288 beam) multibeam echo sounder. *Healy* also operated a Knudsen 320B shallow-penetration chirp subbottom profiling system (~3.5 kHz) (Mayer and Armstrong, 2011).

Healy departed Barrow, Alaska on August 16th; *Louis S. St-Laurent* departed Kugluktuk, Northwest Territories on August 18th. An August 23rd rendezvous of the two ships took place near the northern end of Chukchi Plateau. Before the rendezvous, *Healy* spent five days mapping the continental slope of the Barrow Margin. Seafloor mapping operations began with a Conductivity Temperature Depth (CTD) cast to establish a sound speed profile and a multibeam patch test to calibrate any timing or attitude offsets. On the second day of mapping, an interesting conical-shaped feature measuring 500 meters across and 80 meters high was located in 2000 meters of water. Although similar in size and shape to the ice-cored "pingos" often found on shallower water of the nearby Mackenzie River delta, this feature, shown in Figure 1, is much deeper than we would expect for a pingo. Pingos have not been charted off the Alaska coast; however, the presence of this feature suggests that their existence should not be ruled out.

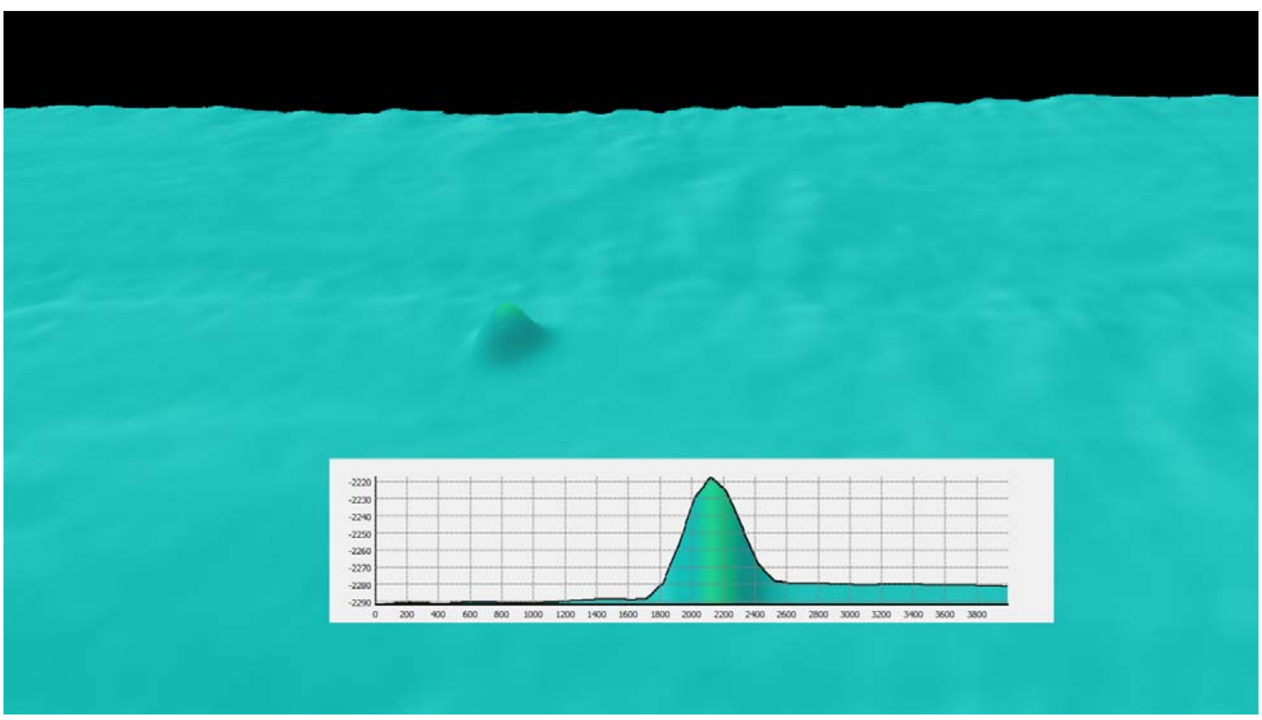

Figure 1—Conical pingo-like feature at 2000-meter depth.

Very calm seas on August 19th contributed to detection of a severe sound-speed problem. Significant refraction errors were creating noticeable "frowns" in the multibeam data (Figure 2). A CTD cast detected the presence of a relatively warm and low-salinity layer at the surface, positioned on top of the colder, saltier water in the main portion of the water column. Without wind and waves to disturb the surface, the two layers were not mixing. When *Healy* was stopped, the sound speed correction using data from the CTD cast corrected the multibeam data. As soon as *Healy* began making way, however, and despite the application of an appropriate sound speed profile, the refraction anomaly returned. We speculate that although the *Healy's* multibeam transducer, at eight meters depth, was deeper than the surface layer, when the ship was moving through the water, the surface layer was drawn under the hull where it anomalously refracted the sound rays at the transducer. Twenty-seven knot winds and two-meter seas the next day eliminated the problem. Efforts to remove the refraction artifact are ongoing at the University of New Hampshire.

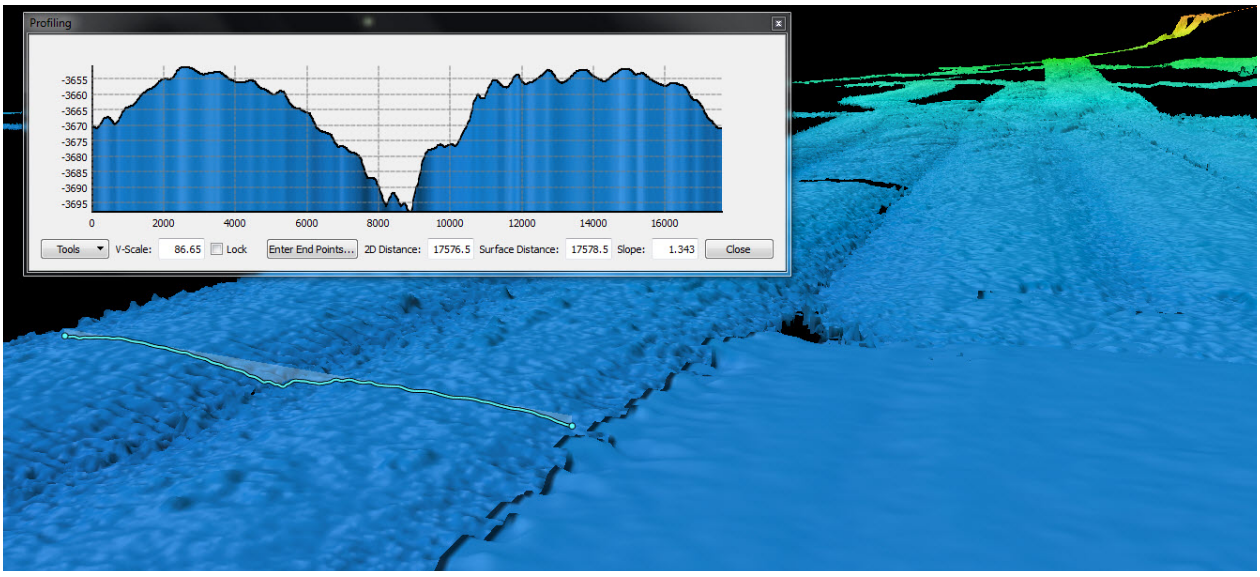

Figure 2—Refraction artifacts in multibeam data off Barrow Margin (12X vertical exaggeration).

After completing 18,070 square kilometers of mapping on the Barrow Margin, *Healy* transited northwest to meet *Louis S. St-Laurent* at the rendezvous position. The ships met on August 23rd. After rafting together for science planning meetings, the two ships separated and began a long northward line of seismic profiling. *Healy* led to break ice, and *Louis S. St-Laurent* followed, towing seismic gear in the open path created by *Healy*. This line extended more than 1300 kilometers, beginning on the Chukchi Plateau, crossing the Mendeleev Plain, the Alpha Mendeleev Ridge complex, and the Makarov Basin, and ending nine days later, on the Lomonosov Ridge only 172 kilometers (93 nautical miles) from the North Pole. We had been concerned that the POS/MV GPS-aided inertial positioning system would fail to operate properly at these high latitudes. One of *Healy's* two POS/MV units did lose track at nearly 88°N, and could not regain track for several days; the second unit maintained track throughout the mission.

Figure 3—1300-kilometer (700-nautical mile) bathymetric track line from Chukchi Plateau to Lomonosov Ridge; background bathymetry from IBCAO (Jakobsson, et al, 2008).

On the Lomonosov Ridge, the joint mission shifted from seismic profiling to bathymetry, with a goal of obtaining bathymetric swaths from Lomonosov Ridge down to the Makarov Basin, and across the transition zone from the abyssal basin onto Marvin Spur. The plan in this area was for *Louis S. St-Laurent* to deploy an AUV for under-ice bathymetric surveying of part of Marvin Spur, and for *Healy* to operate independently, surveying a different portion of Marvin Spur. Although the under-ice AUV mission was aborted as a result of ballasting issues, during the period September 3rd to September 5th, *Healy* was able to survey most of a known but previously poorly mapped feature (Figure 4.) rising abruptly from Makarov Basin. When surveying features known previously only from isolated soundings, and when time was not available for systematic surveys, the multibeam watch team aboard *Healy* guided the ship from the survey lab, recommending courses to steer or providing screen-display aiming points for the conning officers on the bridge. With this method, the key goals of the extended continental shelf task at hand, such as locating the slope/abyssal plain transition or the 2500-meter isobath, were accomplished most efficiently.

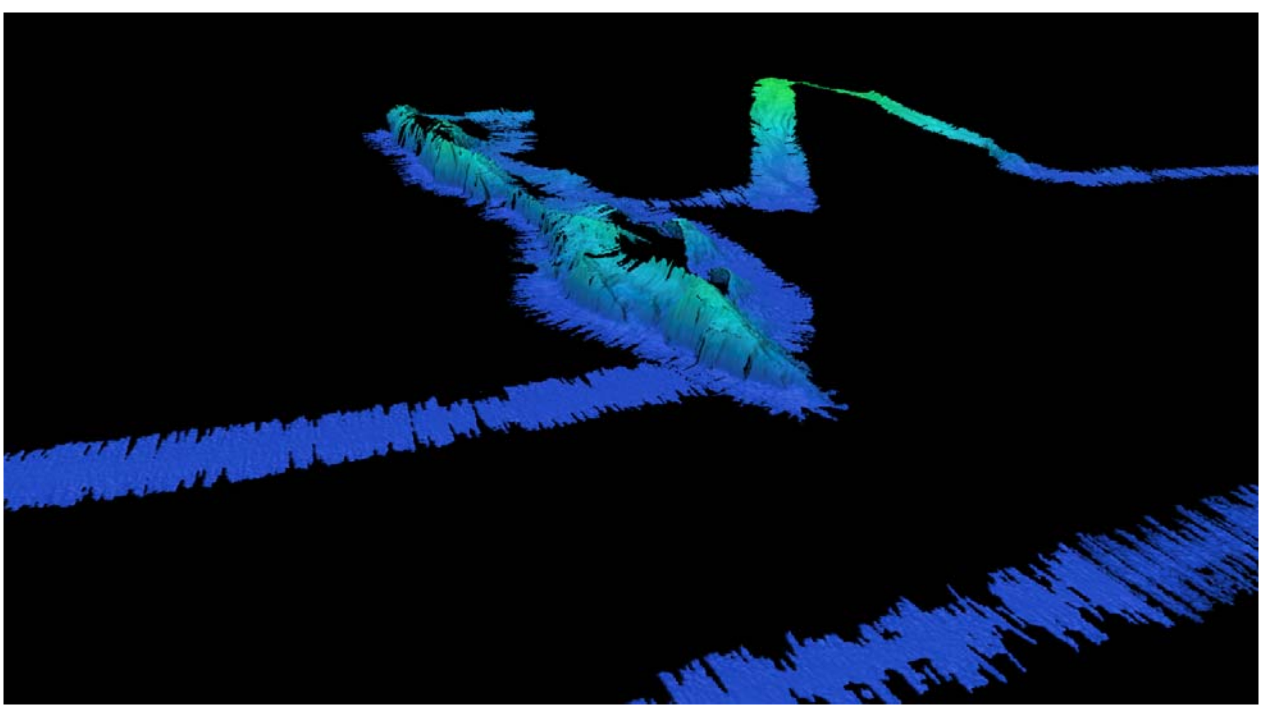

Figure 4—New bathymetric data for Marvin Spur feature in Makarov Basin area.

More so than in previous Arctic bathymetry cruises, this cruise afforded the opportunity to take CTD casts relatively frequently. In addition to the AUV deployment, there were periodic stops to repair the seismic array as well as stops for ship machinery maintenance—most of these also associated with open pools of water in the ice. With the diminishing ice cover in the Aortic, even near the North Pole, more areas of open water for Conductivity-Temperature-Depth (CTD) deployment have become available (Figure 5). In addition to the CTD casts, *Louis S. St-Laurent* took periodic velocimeter (SV) and expendable sound velocimeter (XSV) casts, *Healy* took regular expendable bathythermograph (XBT) casts.

The hydrographers aboard *Louis S. St-Laurent* also took advantage of pools of open water to obtain helicopter spot soundings off the ships' tracks. Seventy five spot soundings were obtained during the cruise (Figure 6).

Figure 5—CTD deployment in a pool of open water in the ice pack.

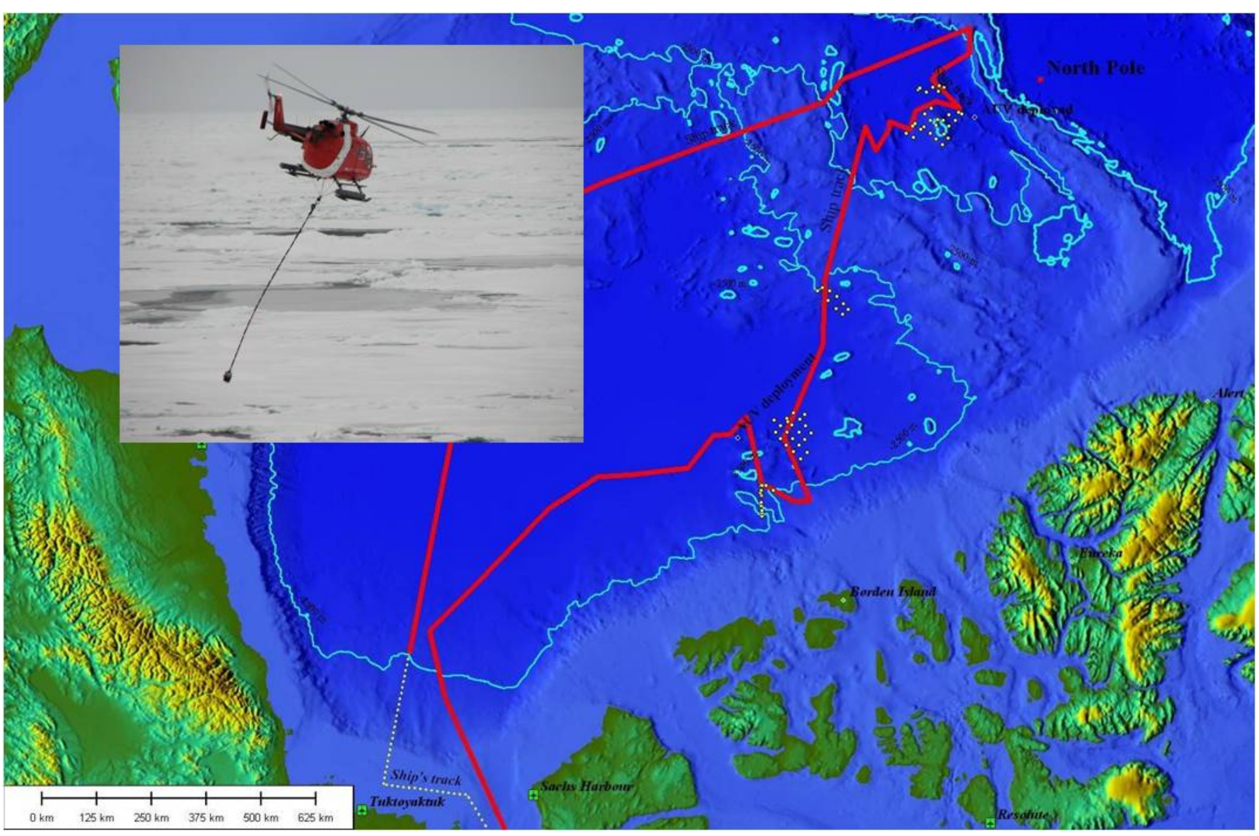

Figure 6—Helicopter spot soundings

After the Marvin Spur survey, the icebreakers traveled to the south, crossing on and off the Alpha-Mendeleev Ridge complex, into and out of the Makarov Basin region. This approach was used in order to locate the zone where the Ridge transitions to the abyssal seafloor of the Basin and to locate points on the 2500-meter isobath. On September 7th the ships crossed over a feature previously only suspected from isolated depth soundings. The multibeam data showed this feature, in the foreground of figure 7, to rise at least 1500 meters very steeply from the flat seafloor of the Makarov Basin. The change in relief meets the criteria for designation as a seamount, but the feature remains to be mapped in detail. Later on that day the multibeam mapping was put on hold for an airdrop of needed repair parts for both ships by a C-130 aircraft from U.S. Coast Guard Air Station Kodiak, Alaska, 3450 kilometers (1860 nautical miles) to the south. In three passes over the ships, the C-130 dropped three separate packages on the ice (Figure 8). All packages were recovered from the ice by a team of *Healy's* Coast Guard crewmembers.

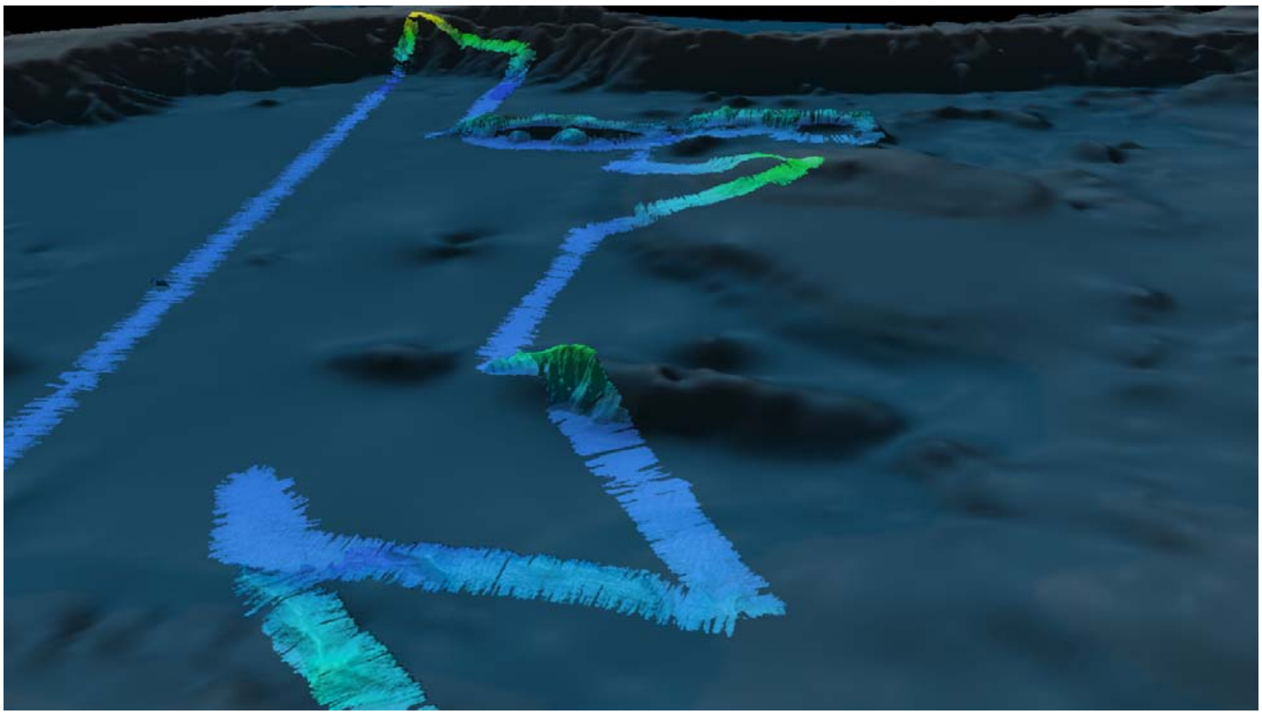

Figure 7—New bathymetry overlaid on IBCAO (Jakobsson, et al, 2008) in Makarov Basin; view looking north, Marvin Spur and Lomonosov Ridge in background.

Figure 8—Air drop of repair parts for *Louis S. St-Laurent* and *Healy* by U.S. Coast Guard C-130 aircraft.

After completing the surveys in the Makarov Basin, *Louis S. St-Laurent* led *Healy* southeast over the Alpha-Mendeleev Ridge complex. For several hundred kilometers along our track, the top of the ridge complex was characterized by very chaotic seafloor. The multibeam echo sounder showed highly irregular 30- to 50-meter-relief features that appeared as a complex set of hyperbolic echoes on the subbottom profiler (Figure 9).

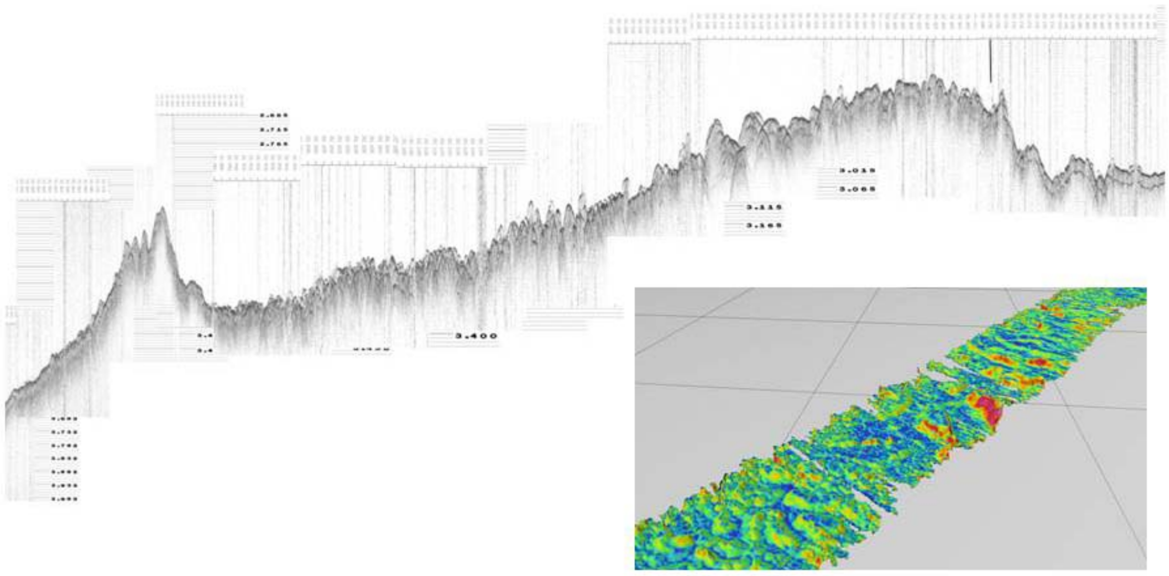

Figure 9—High-resolution subbottom profile (above) and multibeam (inset) images of chaotic seafloor on the Alpha Mendeleev Ridge.

After crossing the Alpha Mendeleev Ridge, and reaching the Stefansson Basin, *Healy* resumed the lead on the south-eastward track in an attempt to begin seismic profiling from *Louis S. St-Lauren.*, However the ice was too heavy and closely packed for *Louis S. St-Laurent* to make progress with the seismic gear in tow and the ships switched the lead again to obtain the best possible bathymetry. The south-eastward and eastward track continued with the ships moving up the continental shelf of the Canadian Archipelago.

Where ice conditions improved, the ships attempted short periods of seismic profiling. Although the ice this year was usually too thick and packed for effective seismic profiling, multibeam bathymetry was possible in areas that were completely impassable just a few years ago. During the periods when *Louis S. St-Laurent* was in the lead, the multibeam data obtained by *Healy* in the broken path was good quality. When *Healy* was in the lead in these heavy ice conditions, the multibeam data were nearly unusable. Figure 10 shows the difference between multibeam data while Healy was in the lead (left) and while following (right).

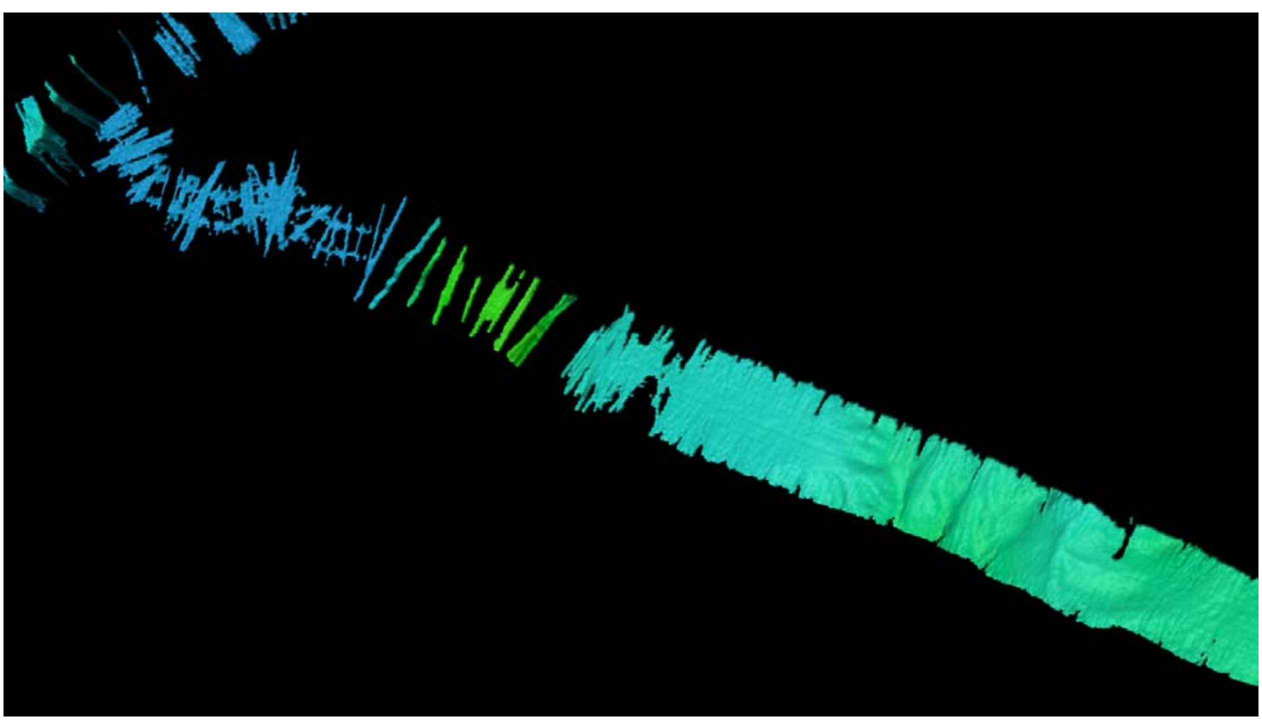

Figure 10—Bathymetric data acquired by *Healy* while leading *Louis S. St-Laurent*, left, and while following, right.

On September 16th, in the area of Sever Spur, the ships terminated their track line and *Louis S. St-Laurent* deployed their AUV for another attempt at under-ice mapping (Figure 11). This deployment was successful, obtaining 110 kilometers of multibeam swaths over Sever Spur (Figure 12). During the two-day AUV mission, *Healy* separated for independent mapping of parts of Sever Spur. Ice in the Sever Spur area was the most difficult of the cruise; multibeam data collection without a lead icebreaker was extremely challenging, with results similar to the results shown in Figure 10. At one particularly dense ice ridge, *Healy* was forced to back and ram the ridge 36 times (Figure 13) over a two-hour period just to move ahead.

Figure 11—*Louis S. St-Laurent* launching AUV (visible alongside) through small opening in the ice pack.

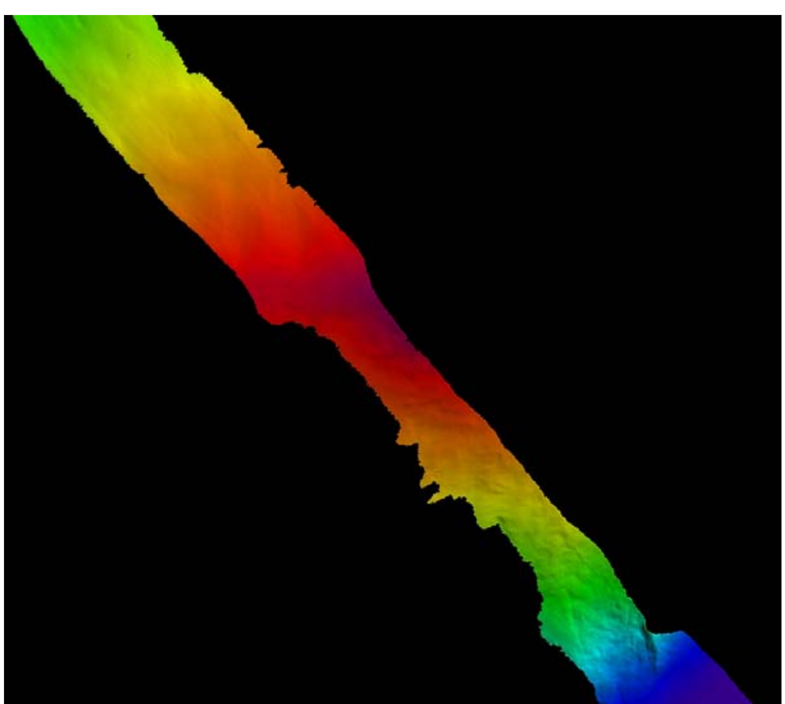

Figure 12—AUV swath over Sever Spur.

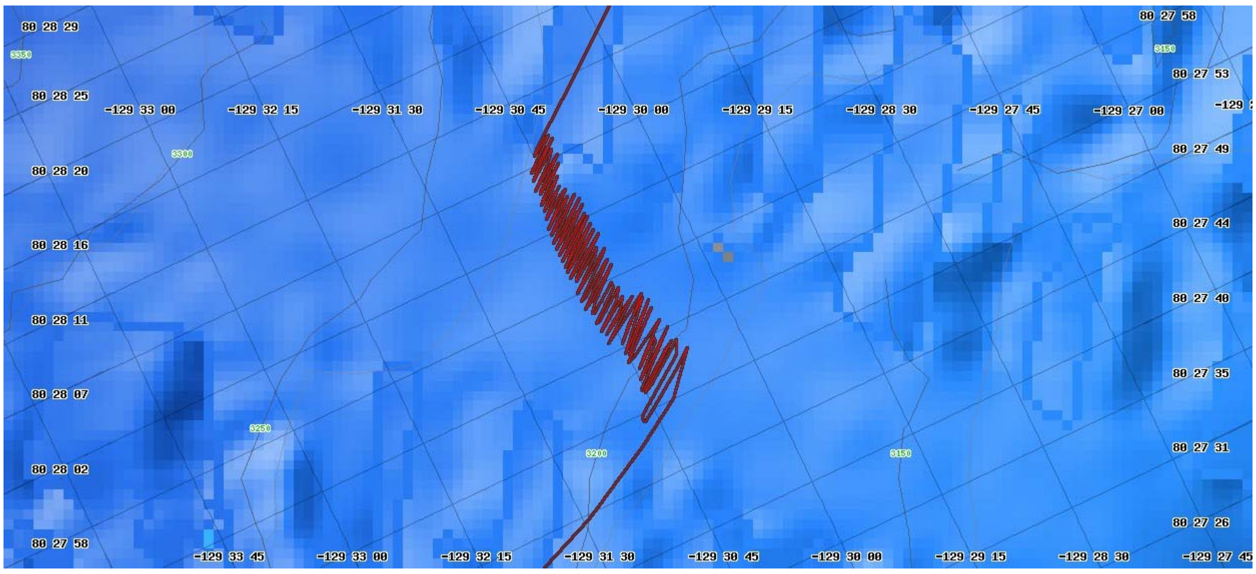

Figure 13—Track plot of *Healy* backing and ramming a particularly heavy ice ridge. The offset to the south is a result of the movement of the ice pack.

During continuous backing and ramming in heavy ice, the turbulence and ice chunks under the transducer never cleared enough for sounding. The *Healy* watch team developed a new approach to multibeam data acquisition in these heavy ice conditions. Using the new approach in these situations, the icebreaker would ram the ice, back up and stop in the water, waiting until the ice cleared from under the transducer. Then the fore and aft beam-steering function of the EM122 would be employed, pinging in steps from 10 degrees forward of vertical to 10 degrees aft of vertical. In this way, a relatively large patch of seafloor was insonified. The ship would then break ice forward for some distance, and once again stop and go through the beam-steering process. The coverage achieved in this way is shown in figure 14.

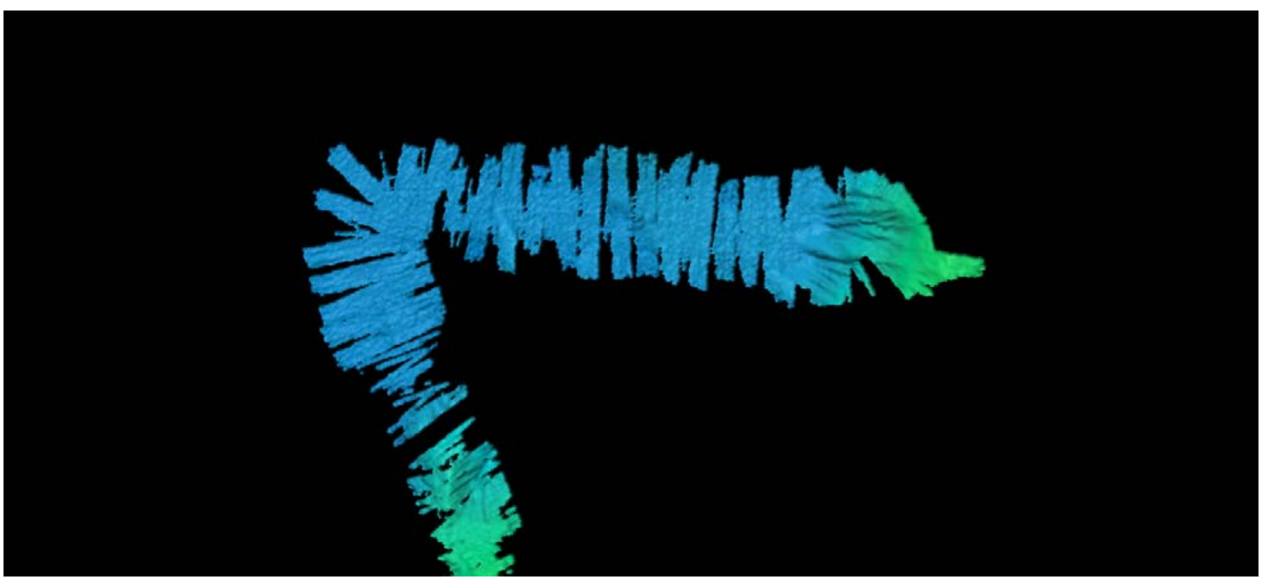
Figure 14—Multibeam echo sounding coverage by beam steering while stopped in heavy ice. Each rectangular patch is a set of steered beams.

The two ships rejoined on September 18th after the successful AUV mission, and began a track line to the south. They rafted again on September 20th for closing science meetings, a joint buffet dinner in *Healy's* hangar and some seamanship skill contests in *Louis S. St-Laurent's* hangar. After the rafting, the icebreakers resumed the track south, and parted company on September 22nd. The track south crossed an area of sediment deposition and some striking seafloor features interpreted as debris-flow deposits. Large lenses of acoustically transparent sediment (Figure 15) rest like tongues on the seabed.

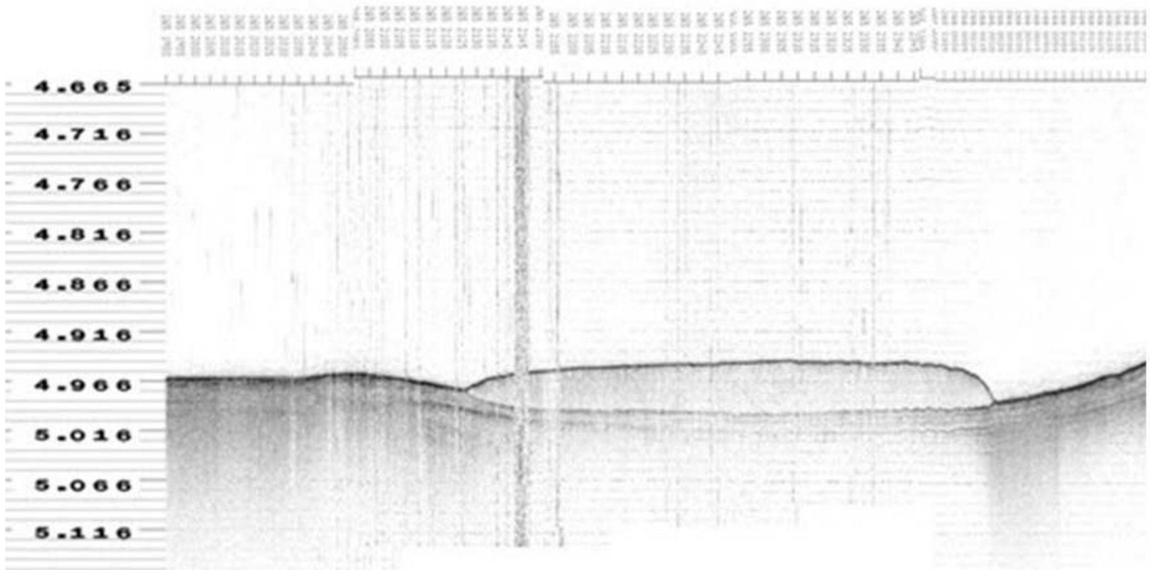

Figure 15—High-resolution CHIRP subbottom profiler image of debris flow deposits.

In addition to the primary seismic and bathymetric missions, several important ancillary science programs were undertaken during part of the cruise. Ice buoys from the U.S. National Ice Center for meteorological and ice pack tracking were deployed from both ships (Figure 16). A U.S. Air Force officer embarked on *Louis S. St-Laurent* to test the practicality of deploying small unmanned aerial vehicles (UAV) from an icebreaker as reconnaissance tools for picking optimum tracks through the ice. Several successful missions were completed using both visible spectrum and infrared video cameras (Figure 17a and 17b). *Healy* carried a team from the U.S. Geological Survey and the University of South Florida who collected air samples, ice samples, continuous and discrete near-surface water samples, and additional water samples at multiple depths during CTD casts. These samples were analyzed for ph, CO_3^{-2}, and other content to document the carbonate chemistry of the Arctic as part of an ocean-acidification study (Figure 18). Also aboard *Healy* were a U.S. Navy meteorological team who launched weather balloons daily (Figure 19), obtaining atmospheric measurements in this region where very few direct measurements of the atmosphere are taken.


Figure 16—Ice buoy deployment by U.S. National Ice Center personnel.

Figure 17a—Color image of *Healy* captured by the U.S. Air Force Raven UAV.

Figure 17b—Infrared Raven UAV image of *Louis S. St-Laurent*, showing ice ridges.

Figure18—U.S. Geological Survey/ University of South Florida ocean acidification measurements aboard *Healy*.

Figure19—Navy and Coast Guard petty officers preparing to launch weather balloon from *Healy*.

The 2011 cruise is likely the last of these joint Canada-U.S. mapping expeditions in the Arctic for the next few years. The U.S. Extended Continental Shelf bathymetric team will return to *Healy* for at least one additional planned cruise in the summer of 2012 to complete additional bathymetry north of Chukchi Plateau. A joint U.S.-Canada single-ship bathymetry project for the Atlantic is being discussed.

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BIOGRAPHICAL NOTES

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