CRUISE REPORT

USCGC Icebreaker *Healy* (WAGB-20)

U.S. Law of the Sea cruise to map and sample the U.S. Arctic Ocean margin

CRUISE *Healy* 1603

September 17, 2016 to October 6, 2016

Nome, AK to Dutch Harbor, AK

Larry A. Mayer
Center for Coastal and Ocean Mapping/Joint Hydrographic Center
University of New Hampshire
Durham, NH 03824

Brian Calder
Center for Coastal and Ocean Mapping/Joint Hydrographic Center
University of New Hampshire
Durham, NH 03824

David Moshser
Center for Coastal and Ocean Mapping/Joint Hydrographic Center
University of New Hampshire
Durham, N.H> 03824

October 6, 2016

Table of Contents

INTRODUCTION and BACKGROUND

Healy-1603 (HLY1603) is the tenth in a series of *Healy* cruises dedicated to mapping and sampling regions of the Arctic north of Alaska that may qualify as "extended continental shelf" under Article 76 of the Convention on the Law of the Sea (UNCLOS). Five of these cruises (*Healy*-0302, *Healy* -0405, *Healy*-0703, *Healy*-0805, and *Healy*-1202) were single-ship operations led by scientists from the University of New Hampshire that focused on the collection of multibeam echo-sounder bathymetric, and shallow, high-resolution chirp sub-bottom profiler data (and some sample collection). In 2008 there was a second *Healy* cruise (*Healy*-0806). led by scientists from the U.S. Geological Survey that worked together with the Canadian icebreaker *Louis S. St. Laurent (LSSL)* to collect multi-channel seismic and multibeam echo-sounder data in the ice-covered regions. The success of the 2008 two ship operation led to a second two-ship operation, *Healy*-0905, in 2009, a third in 2010 (*Healy*-1002) and a fourth, *Healy*-1102, in 2011, with scientists from the University of New Hampshire leading operations on the *Healy* during these joint missions. During *Healy*-1603, the *Healy* operated on her own but the mission included collaborative work (dredging) on behalf of Canada. As part of this collaborative effort the *Louis S. St. Laurent (LSSL)* collected seismic data on behalf of the United States, earlier in September.

Under Article 76 of UNCLOS, coastal states may, under certain circumstances gain sovereign rights over the resources of the seafloor and subsurface of “submerged extensions of their continental margin” beyond the recognized 200 nautical mile limit of their Exclusive Economic Zone. The United States has not yet acceded to the UNCLOS. However, increasing recognition that implementation of Article 76 could confer sovereign rights to large and potentially resource-rich areas of the seabed and subsurface beyond its current 200 nautical mile (nm) limit has renewed interest in the potential for accession to the treaty and in the collection of the data necessary to establish sovereign rights to the resources of the seafloor and the subsurface beyond 200 nm (referred to as the 'extended continental shelf' or ECS).

The Convention on the Law of the Sea defines the conditions under which a coastal state may extend its continental shelf over regions beyond the 200 nm EEZ (UN, 1982). These conditions involve the definition of a juridical or legal “continental shelf” that differs significantly from standard morphological descriptions of continental margins. A key element of this definition is the demonstration that the extended area is a “natural prolongation” of the nation’s landmass. There are no explicit guidelines for demonstration of “natural prolongation” of a state’s land territory. The determination must be based on a general knowledge and interpretation of the morphology, geology, and nature of the seafloor in a region.

Once a natural prolongation is demonstrated, a coastal state may extend their “continental shelf” beyond the 200 nmi limit based on either of two formulae. The distance formula allows an extension of the shelf to a line that is 60 nmi beyond the “foot of the continental slope” (defined to be the point of maximum change in gradient at its base). This line is known as the Hedberg Line. The sediment thickness formula allows the extension of the shelf to a point where the sediment thickness is one percent of the distance back to the foot of the slope. This line is known as the Gardiner Line. Whichever formula line is most advantageous to the coastal state may be used and they can be combined for the most advantageous extension. There are limits to the extension (limit lines) – the ECS shall not extend beyond 100 nmi from the 2500 m isobath or not beyond 350 nmi from the territorial baseline (the officially defined shoreline). Again these limit lines can be mixed in whatever way is most advantageous to the coastal state. Thus the definition of the extended continental shelf under UNCLOS Article 76 is based on a combination of bathymetric data (defining the 2500 m contour and the foot of the slope) and geophysical data (defining the thickness of sediment). When a nation accedes to the Law of the Sea Treaty, it has ten years to submit all data and evidence supporting its submission to the Commission on the Limits of the Continental Shelf (CLCS) who evaluate the submission and offer recommendations on it.

The largest potential for an extended continental shelf beyond the current 200 nmi limit of the U.S. EEZ is found in the area of the Chukchi Borderland, a tightly clustered group of generally high-standing, N-S-trending bathymetric elevations that form a natural prolongation from the Chukchi Shelf north of Alaska.

The Chukchi Borderland juts out between eastern Siberia and western Alaska into the deep Amerasia Basin north of the Chukchi Sea. The borderland occupies a rectangular area about 600 by 700 km, or some 4 percent of the Arctic Ocean. This area encompasses three, approximately north-south-trending segmented topographic highs: the Northwind Ridge, the Chukchi Cap and Rise, and the western (Arlis, Sargo, and T3) plateaus (which are located beyond -- westward of -- an agreed maritime boundary line with Russia). The plateau-like crests of the Chukchi Borderland rise, in some cases, as much as 3,400 m above their surroundings and they are relatively shallow (depths between 246 and 1,000 m). The ridges have steep flanks, which in some places exhibit remarkable linearity over hundreds of kilometers, especially along the east side of the Northwind Ridge. Between these ridges lie the Northwind, Chukchi, and Mendeleev "abyssal plains". These lie at depths between 2,100 and 3,850 m

In 2003, Congress (through NOAA) funded the University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) to explore the feasibility of using a multibeam sonar-equipped ice breaker to collect the data needed to make a submission for and extended continental shelf in ice-covered regions of the Arctic. This was in recognition of the fact that a submission for an ECS under Article 76 must be substantiated by high-quality bathymetric and geophysical data, and that the existing bathymetric database in the Arctic was, in many areas, inadequate for these purposes. The test proved successful and since 2003 scientists from the UNH CCOM/JHC) have used the USCGC *Healy* (WAGB-20), originally equipped with a SeaBeam 2112 (12 kHz, 121 beam) swath mapping system and now equipped with a Kongsberg EM122 (12 kHz, 288 beam) multibeam echosounder, to map the bathymetry of the Arctic in support of ECS studies. The *Healy* also operated a Knudsen 320B (now upgraded to a Knudsen 3260) shallow penetration chirp subbottom profiler adding additional pertinent information as well as a BGM-3 gravimeter (on some cruises).

The multibeam echo-sounder and chirp sub-bottom data provided by the *Healy* systems provides the morphological data required to establish the "foot of the slope" (needed for the determination of the Hedberg Line, the Gardiner Line and the 2500 m contour). The seismic system on the *Louis S. St. Laurent* during past cruises have provided sediment thickness information required for establishing the Gardiner Line (once the foot of the slope is determined. The Knudsen system provided additional geological information relevant to the location of the base of the slope and the continuity of sediments in the region.

Previous Cruises: (Detailed cruise reports from each of these cruises can be found at http://www.ccom.unh.edu/theme/law-sea or USGS websites).

***Healy*-0302 Overview:**
A 10 day, 3000 km long exploratory mission (*Healy*-0302, September 1-11, 2003) from Barrow, Alaska, to the Chukchi Borderland demonstrated the viability of using the multibeam echo-sounder in ice-covered waters to follow specific bathymetric targets. The 2003 cruise began at the US-Russian boundary line at 78°-30'N 168°-25'W and followed the 2500 m contour around to 78°-35'N 159°-07'W (Figure 1). The cruise collected ~3000 km of high-resolution multibeam echo-sounder data and made several significant discoveries that include:

- substantially changing the mapped position and complexity of the 2500-m isobath (a critical component of a Law of the Sea submission for an ECS),
- found further evidence for pervasive ice and current erosion in deep water (flutes and scours),
- finding evidence for gas-related features (pock-marks), and
- discovering a previously unmapped seamount that rises more than 3000 m above the surrounding seafloor. This NE-SW trending feature, some 18 km wide and 40 km long with a slightly concave and northward tilted crest, has been officially named *Healy* Seamount.

The full cruise report for *Healy*-0302 can be found at www.ccom.unh.edu/theme/law-sea.

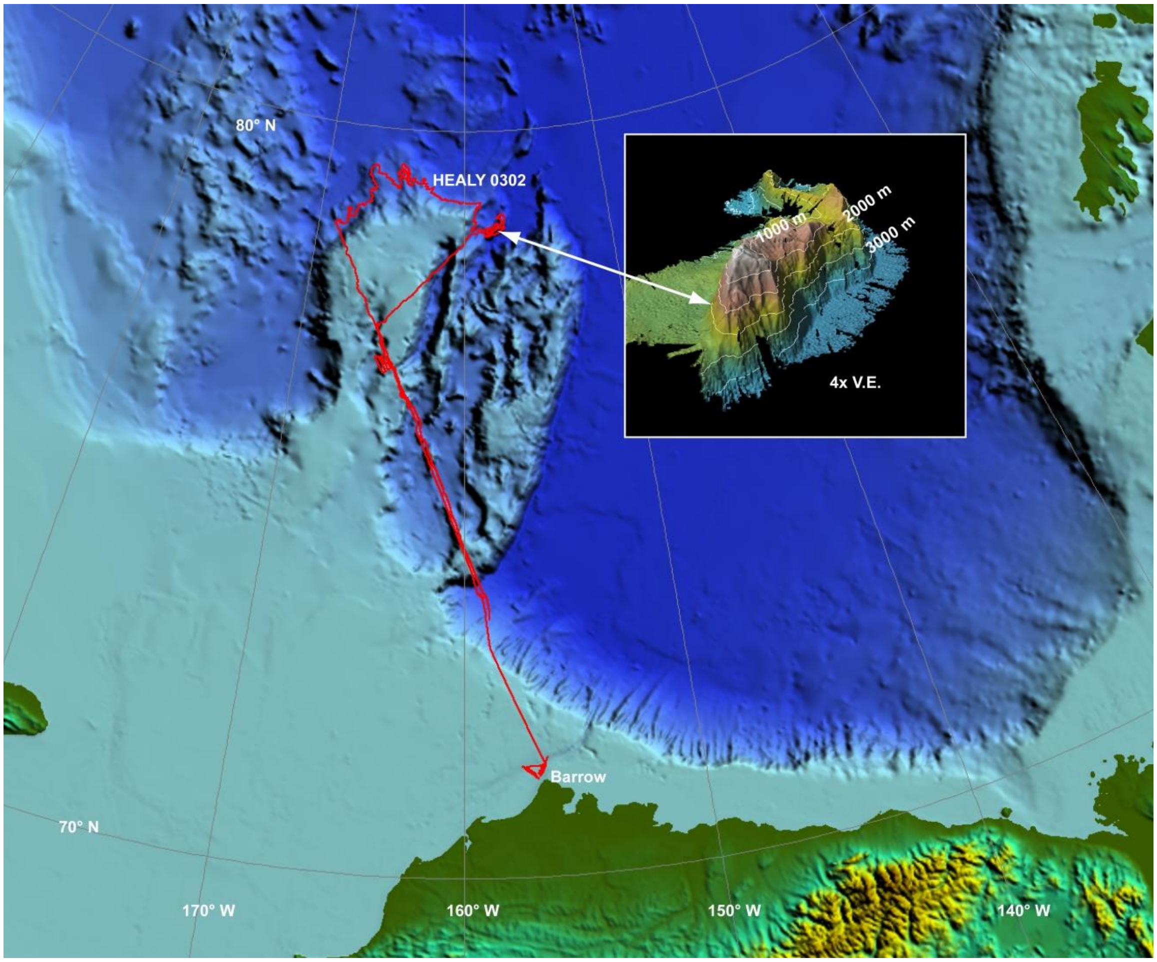


Figure 1. Track of Healy-0302 September 2003.

Healy-0405 Overview:

In 2004 a second, 20-day cruise, *Healy*-0405 was conducted from October 6 to October 26, 2004, originating in Nome and ending in Barrow, Alaska. The cruise covered approximately 6700 km in 20 days and completed most of the mapping of the 2500-m isobath (begun on *Healy*-0302) as well as a detailed survey of the "foot of the slope" over a segment of the continental margin east of Barrow, AK. The total area surveyed during HE-0405 was approximately 20,000 sq. km (5830 sq. nmi). The cruise transited northward from Nome over the Northwind Ridge until it intersected the 2500-m isobath at approximately 77° 10'N, 154° W, the point where the 350 nmi cutoff limit from the coast of northern Alaska intersects the 2500-m isobath on the eastern flank of the Northwind Ridge. Ice was first encountered ice at about 76˚N and by 77˚N the ice was very heavy (9/10 to 10/10) with many ridges and very few leads. Progress was slow and we often had to backup and ram but, nonetheless, we managed to continue mapping the 2500-m isobath up the Northwind Ridge until approximately 78° 45'N. During this time, we covered approximately 100 nmi in 4 days. Data was difficult to collect in these conditions but we were able to continuously map the 2500-m isobath to its furthest north point. About 5000 sq. km (1458 sq. nmi) of seafloor was mapped during the transect to the north and back.

At 78° 45’N, the *Healy* had great difficulty breaking through the ridges (one ridge took more than 8 hours to break through) and the decision was made to move south to the relatively ice-free waters of the continental slope east of Barrow. This area was chosen so that we could define the foot of the slope in the central portion of the northern Alaskan margin. The foot of the slope can be used in this region as a starting point for determination of the “Gardiner Line” – one of the formula lines used for making an ECS submission under UNCLOS Article 76. The survey of the foot of the slope area began on October 18 and continued until October 24. During this time, complete overlapping multibeam-sonar data was collected over a region of approximately 15,435 sq. km (4500 sq. nmi), that ranges in water depth from 800 m to 3800 m. The survey not only delineated the foot of the slope, but it also revealed a complex margin with drift deposits, suggesting contour currents, that are cut by numerous canyons. The full cruise report for *Healy*-0405 can be found at http://www.ccom.unh.edu/theme/law-sea.

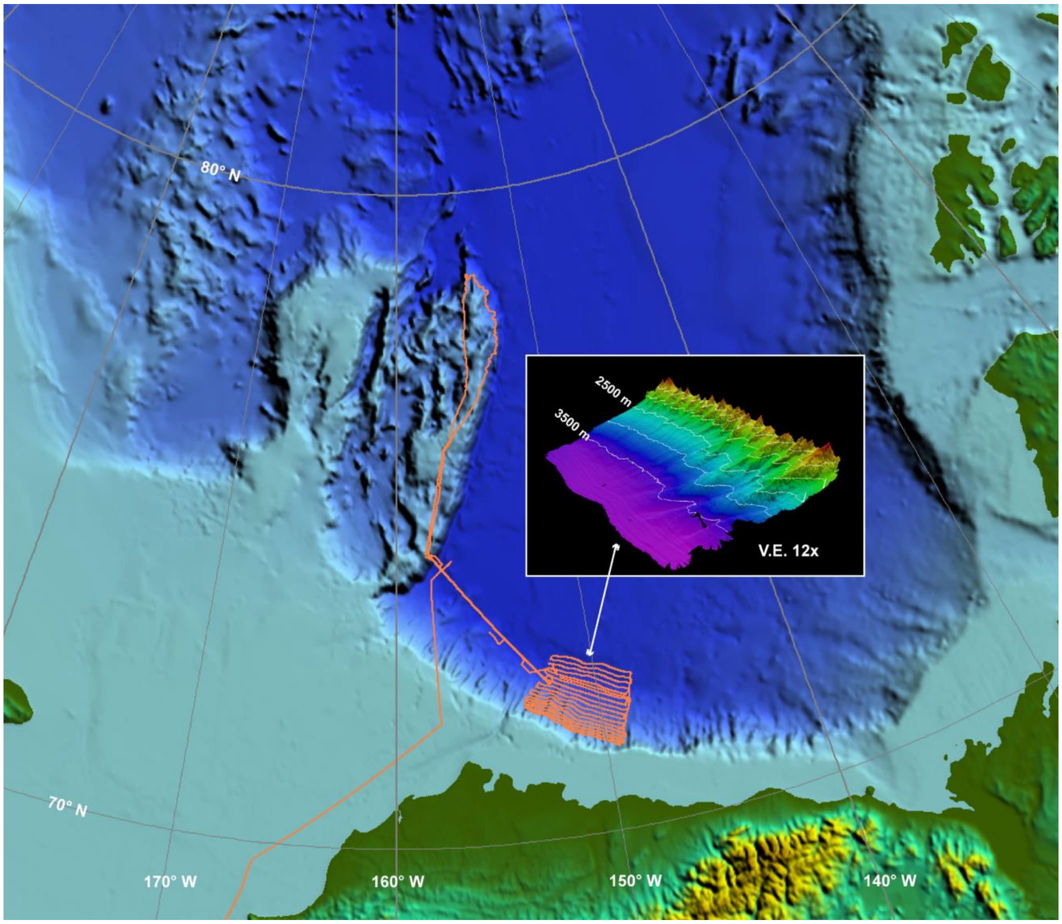


Figure 2. Cruise track for Healy-0405

Healy-**703 Overview:**
Healy-0703 was conducted from August 17 to September 15, 2007, with both embarkation and disembarkation via helicopter transfer from Barrow, Alaska. The cruise track covered approximately 10,000 km (5400 nm) in 30 days (Figure 3). The primary objectives of the cruise were: 1- to complete the mapping of the 2500 m isobath that began on *Healy* 0302 and *Healy* 0405; 2- to begin to define the "Foot of the Slope" around the northern and eastern edges of Chukchi Cap; and; 3- to further map an area of pockmarks originally discovered on *Healy*-0302. Secondary objectives included the recovery and re-deployment of two High-Frequency Acoustic Recording Packages (HARP's), autonomous recording packages designed to record ambient noise levels at the ice margin for periods up to one year, and: the deployment of up to four ice buoys and continuous ice-observation by representatives of the National Ice Center. All objectives were achieved, far beyond expectations.

Using a nominal swath width of approximately 7 km, the total area surveyed during HE-0703 was approximately 70,000 sq. km (20,400 sq nm). The cruise departed Barrow at approximately 1800L on 17 September and steamed northward approximately 50 miles and successfully recovered the first of two HARP buoys. The second was recovered 25 miles further to the northwest. Details of this recovery as well as a description of the purpose and capabilities of the buoys can be found in the HARP Buoy Report later in the cruise report. We next conducted a patch test and a deep CTD cast at the steep southeastern edge of the Chukchi Cap. We first encountered ice at approximately 76N. It was large pieces of thick, multi-year ice but, broken up enough to allow relatively easy passage at 3-6 knots (though we did have to back and ram occasionally). We continued northwest to the intersection of the 2500 m isobath and the U.S./Russian maritime boundary line where we then began an exploratory, zig-zag pattern to better define the foot of the slope. No definitive foot of the slope was apparent until a long excursion to the north revealed a clear transition between the slope and flat-lying abyssal plain sediments at approximately 81 15N. We made several more north – south transits and consistently found this same slope/plain transition occurring on the northern end of the cap above 81N. We continued to run a zig-zag pattern in the north-east quadrant of the cap and also found and developed several prominent topographic highs, one which shoaled above 2500 m and may allow the re-definition of the 2500 m isobath.

A well-developed foot of the slope was traced down and then back up the eastern side of Northwind Ridge, revealing a very sharp and clear slope/abyssal plain transition with the abyssal plain sediments consistently occurring at a depth of approximately 3820 m. Following this transition to the north allowed us to define a continuous foot of the slope around the northern most extreme of Chukchi Cap to the northern most point or our survey (82 17N); at this point, the slope/plain transition appears to continue to the north and east. Returning south, we mapped a seamount that rose from abyssal plain depths (3820m) to less than 2200 m at approximately 80 47N and 171 50W and then proceeded to transit southwest to carry out a detailed survey of a region in which pockmarks were discovered on a previous leg. We left the ice at about 77N but ran into occasional large packs of flows until about 75 N.

Throughout this period (17 Aug to approximately 5 September) ice conditions were variable but for the most part very light considering the latitudes we were at allowing survey speeds to average about 6 knots. Ice flows large enough to support deployment NIC ice buoys were difficult to find but three flows were found and three buoys deployed. A fourth buoy was deployed in open water at the far western extreme of our survey. Details of the ice buoy deployments and ice observations can be found in the NIC trip-report included in this document.

On *Healy*-0302, several large and well-defined pockmarks (probably related to gas extrusion) were discovered in a shallow region of the Chukchi Cap at approximately 76 30N and 163 50W. NOAA's Office of Ocean Exploration asked us to further expand this survey and generate a better map of the distribution of these pockmarks. Our plan called for a survey of two areas, one where the pockmarks were already discovered and one slightly to the north and the east of the pockmark area where there is more of a depth transition and thus we might better understand the relationship of depth to pockmark formation. Our survey of the second (not previously surveyed) region revealed no pockmarks but did show a remarkable series of closely spaced, NW-SE oriented, parallel grooves in depths of approximately 400 to 500 m. Given the remarkably parallel nature of these features, they appear to be related to ice-sheet flow rather than individual icebergs scours. Even more intriguingly, south of these grooves, as the water depths get a bit deeper, there appear to be a series of large, dune-like features that appear erosional in origin in the high-resolution sub-bottom profiles. We speculate that these may be related to flow under an ice-shelf that is not grounded but with near the seafloor.

When we reached the pockmark area, just a few miles south of the scoured region, the winds and seas greatly increased (50 knot winds, 15 foot seas) creating less than optimal mapping conditions but the size and stability of the *Healy* allowed us to continue. An approximately 40 km x 14 km area was mapped revealing numerous pockmarks of various sizes, but typically about 300-400 m in diameter and 30 – 50 m deep. Simultaneous collection of sub-bottom profiles revealed an apparent relationship to subsurface faulting but the nature of this relationship will need further study. Most remarkable was a circle of pockmarks (approximately 20 of them) forming a ring that is approximately 4 km in diameter.

Upon completion of the pockmark survey, the *Healy* transited south to re-deploy the two HARP buoys that were recovered at the beginning of the leg. These buoys were successfully re-deployed approximately 90 and 75 miles off Barrow, to be recovered next year. The *Healy* arrived off Barrow at 0700L on the 15th of Sept with transfer of the science party by helo commencing at approximately 0900L. The full cruise report for *Healy*-0703 can be found at http://www.ccom.unh.edu/theme/law-sea.

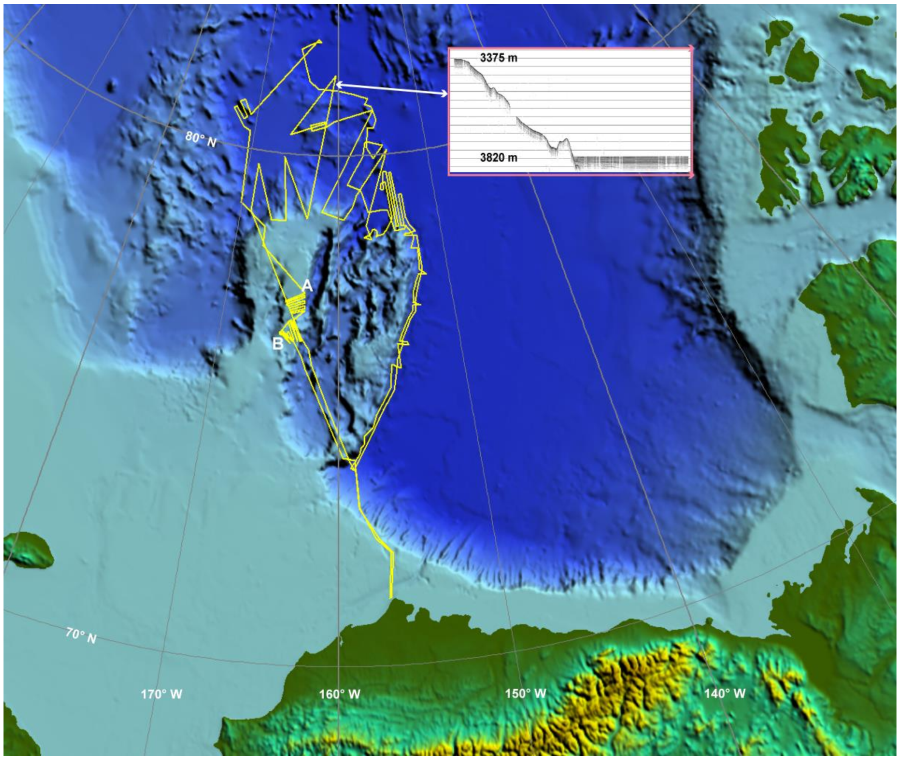


Figure 3. Ship-track for Healy 0703

Healy-0805 Overview:

Healy 08-05 was the fourth in a series of cruises designed to map the seafloor on the northern Chukchi Cap in order to explore this poorly known region and better understand its morphology and its potential for an extended continental shelf under UNCLOS. The mutlibeam echo sounder on board the *Healy* was the primary tool, supplemented by the Knudsen sub-bottom profiler and deep sea dredging operations. The primary targets for the mapping were the delineation of the 2500 m depth contour and the "foot" of the continental slope – the area where the continental margin transitions into the deep sea floor. In addition to its usefulness for Law of the Sea, the seafloor mapping data we collect is also valuable for better understanding seafloor processes, fisheries habitat, and as input into climate and circulation models that will help us predict future conditions in the Arctic. Three ancillary programs also took place during *Healy*-0805: 1- the recovery of High-Frequency Acoustic Recording Packages (HARP's) that are designed to make long-term measurements of ambient noise in the Arctic and that had been deployed on *Healy*-0703; 2- the deployment of several different types of ice-monitoring buoys by personnel from the National Ice Center (NIC), and; 3- the daily observation by a specialist from the Fish and Wildlife Service of both bird and marine mammal sightings. Summary reports of each of these activities are presented at below.

Healy 08-05 departed Barrow on 14 Sept and commenced operations with both mapping and the successful recovery of two HARP hydrophones that had been deployed on *Healy* 07-03. From the HARP sites we steamed north to pick up mapping of the region thought to represent the base of the slope in the vicinity of 82^0 N and 162^0W. Surveying continued east following the morphologic expression of the base of the slope until approximately

150^{0}W where the character of the morphological expression of the base of the slope changed and we switched to a reconnaissance mode of surveying. This mode of survey continued until we reached the easternmost extent of our survey at approximately 139^{0}W. From this point we traveled westward mapping several regions that we suspected shoaled above 2500 m (they did) and then began dredging operations (on 30 August). A total of 3114 linear nautical miles were surveyed (5767 km) on HLY08-05 covering an area of approximately 34,600 sq. km (assuming an average swath width of 6 km).

A total of seven dredges were taken on *Healy*-0805, four on the southern portions of the Alpha/Mendeleev Ridge complex, two on ridges north of the Chukchi Borderland and one in the northwestern Northwind Ridge area. The first dredge site on the southern Alpha/Mendeleev Ridge complex yielded samples from what appeared to be an outcrop of layered sedimentary rock that appeared on shipboard examination to be non-marine in origin. The second dredge from the same vicinity contained over 200 pounds of mud and ice rafted debris. The third dredge, from another feature on the southern Alpha/Mendeleev Ridge Complex, also brought back only mud and IRD. The fourth dredge, from the same general vicinity as the third, was predominantly mud and IRD however there where interesting iron concretions and manganese crusts along with one sample of a possible altered ash deposit. The fifth dredge, from the northern extend of the Chukchi Borderland, recovered over 1000 pounds of mud with about 10 pounds of IRD of various rock types. The sixth dredge from a very steep (about 60 degree) slope on the northern Chukchi Borderland was mud free and contained over 200 pounds of what appear to be basalts. Finally, the seventh dredge from the western wall of Northwind Ridge had very little mud but over 700 pounds of rock that probably represented both outcrop and angular talus from the foot of the steep slope from which it was dredged. Samples from this dredge represented a range of rock types including sedimentary, metamorphic, and possibly basaltic. The full cruise report for *Healy*-0805 can be found at http://www.ccom.unh.edu/theme/law-sea.

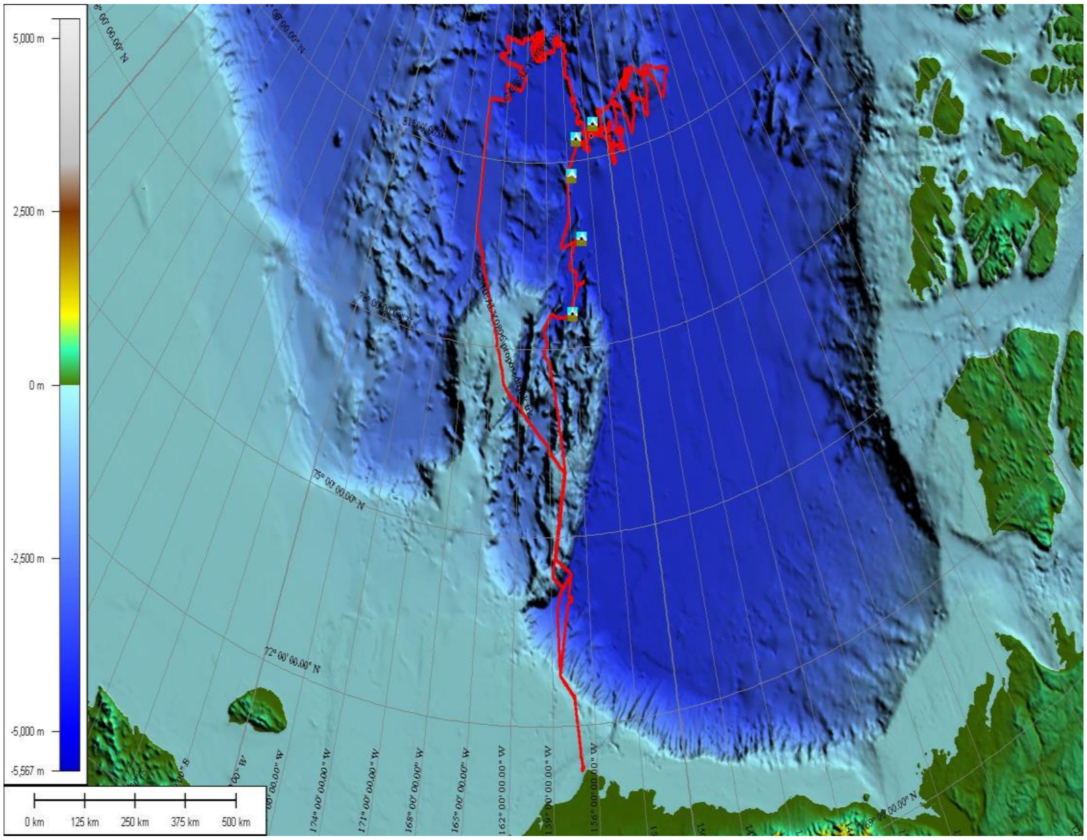


Figure 4. Healy 08-05 – Ship Track 14 Aug –5 Sept. 2008 – Dredge sites indicated by small blue icons. Dredges are numbered sequentially (1—7) from north to south, Dredge Sites 1 and 2 are at the same location and represented by a single icon; dredge sites 3 an

***Healy*-0806:**

Healy-0806 was part of a two-ship operation led by scientists from the U.S. Geological Survey and the Geological Survey of Canada (operating a seismic system on the Canadian icebreaker Louis S. St. Laurent). For details of these operations please see:
Childs et al, 2009.

***Healy*-0905**

With the success of the two-ship operation in 2008, a second joint Canadian/U.S. operation *Healy*-0905 was conducted in 2009. The primary objective was to take advantage of the presence of two very capable icebreakers to collect seismic data in support of delineating the extended continental shelf for both Canada and the United States in regions where a single vessel would have difficulty due to ice-cover. A secondary objective of the joint program was to take advantage of the two vessels to collect high-resolution multibeam echo-sounder data in regions where it would be difficult to collect data with one vessel. In addition to the collection of seismic and bathymetric data, each vessel also carried out ancillary projects including meteorological, oceanographic and ice studies; the *Healy* was also equipped to sample the seafloor with dredges.

The *Louis S. St. Laurent* (*LSSL*) and the *Healy* rendezvoused on 11 August and conducted a seismic source calibration experiment to document the source levels and source signatures of the *LSSL*'s airgun array. After concluding the seismic source calibrations (on 12 August), the *LSSL* deployed its hydrophone streamer, the *Healy* took the lead and the vessels stayed together in the ice until 7 September. By the 7th of September the ice had diminished to the point that the vessels were able to separate, the *LSSL* continuing to collect seismic data and the *Healy* collecting multibeam bathymetry and sampling the seafloor with dredges. Over the course of the expedition, the *LSSL* collected more than 4000 km of high-quality multichannel seismic reflection, refraction and gravity data (Figure 5) and the *Healy* collected 9585 km (5175 nmi) of multibeam bathymetry, sub-bottom profiler and gravity data (Figure 6). Assuming an average swath width of 6.9 km the total area mapped was 66, 135 sq. km (19,280 sq. nmi). The multibeam bathymetry collected during these transects revealed a remarkably flat abyssal plain with an average depth of around 3850m and changes in depth of less than 20 m over hundreds of kms. On several occasions the mapping priorities changed and the bathymetric surveys were conducted over targets of interest. Amongst these targets of interest were the mapping of the foot of the slope in an area on the southern side of the Alpha-Mendeleev ridge complex (at approximately 81 30 N, 143 45W) and the examination of several topographic features that were implied on earlier bathymetric compilations. One such feature which appeared as a single 100 m contour (above the abyssal plain) on a Russian chart, turned out to be an 1100 m high, 26 km long, 7.5 km wide seamount.

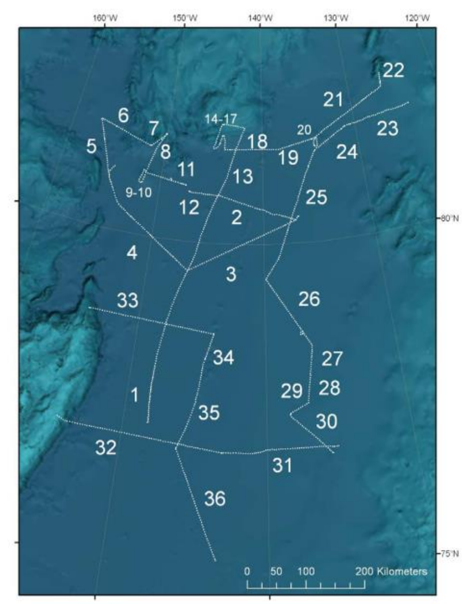


Figure 5. Seismic data collected by LSSL during joint HLY0905.

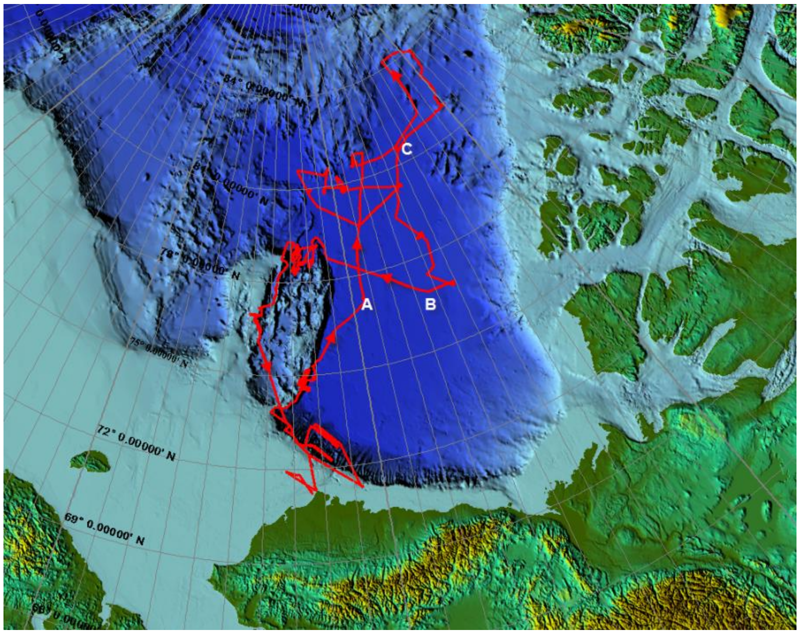


Figure 6. HLY-0905 track line. Point A is rendezvous point for LSSL and Healy on 11 August. Point B is where the two vessels separated on 7 Sept. 2009. Point C is newly mapped seamount.

On 7 September, the ice conditions had evolved to the point where the *LSSL* could continue to collect seismic data without the *Healy* breaking ice in her lead. At this point the *Healy* left the *LSSL* and started to map independently. The *Healy* transited to the northern end of Chukchi Cap and proceeded to survey and occupy 5 dredge stations located on relatively steep slopes amenable to recovery *in situ* material with a dredge. More than 800 kg (1520 lbs) of rock material was recovered from these dredge sites with much ice rafted debris but also many samples that appear to representative of the outcrop. The majority of the material recovered appeared to represent several types of basalts. There was also a large amount of manganese crust, and in the Chukchi region, numerous metamorphic rocks. These samples will be sent to the appropriate labs for full description and analyses.

Four ancillary programs also took place during HLY-0905: 1- the recovery of High-Frequency Acoustic Recording Packages (HARP's) that are designed to make long-term measurements of ambient noise in the Arctic and that had been deployed on HLY-0805; 2- ice observations and the deployment of several different types of ice-monitoring buoys by personnel from the National Ice Center (NIC); 3- the launch and recovery of a SeaEagle glider by representatives of the U.S. Navy supplemented by XBT measurements and meteorological observations, and; 4- the daily observation by a NOAA marine mammal observer of both bird and marine mammal sightings. The full cruise report for *Healy*-0905 can be found at http://www.ccom.unh.edu/theme/law-sea; details of the *LSSL* leg can be found in Mosher et al. 2010.

***Healy*-1002**

Healy-1002 was the third two-ship joint Canadian/U.S. operation, and the second led by scientists from the U.S. Geological Survey and the Geological Survey of Canada (operating a seismic system on the Canadian icebreaker *Louis S. St. Laurent*). For details of these operations please see:
Edwards et al, 2010

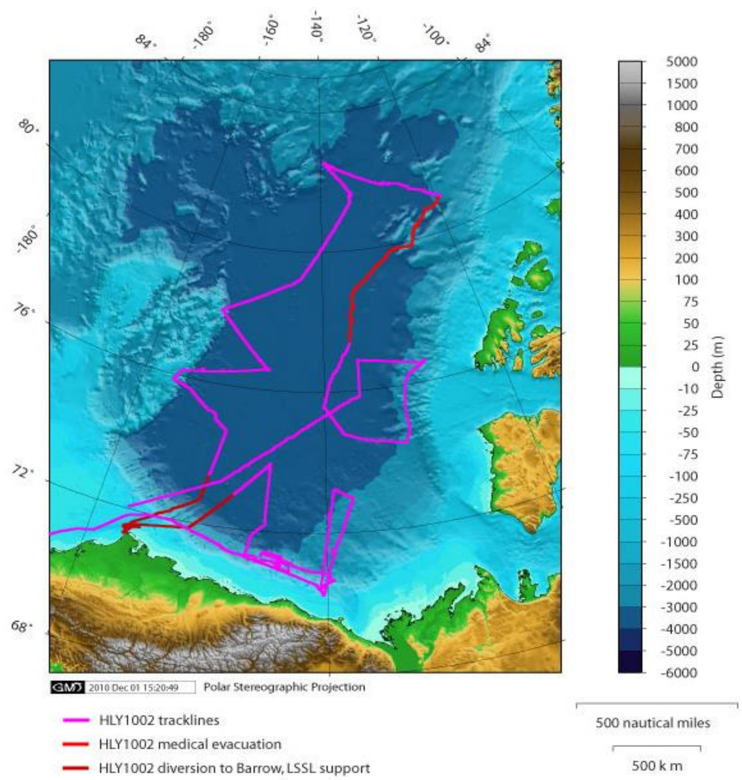


Figure 7. Cruise track for Healy 1002

***Healy*-1102**

Healy-1102 was the fourth in a series of two-ship, joint Canadian/U.S. ECS mapping programs involving the *Healy* and the Canadian icebreaker *Louis S. St. Laurent (LSSL)*. The primary objective was to take advantage of the presence of two very capable icebreakers to collect seismic data (from *LSSL)* in support of delineating the extended continental shelf for both Canada and the United States in regions where a single vessel would have difficulty due to ice. A secondary objective of the joint program was to take advantage of the two vessels to collect high-resolution multibeam echo-sounder data (from *Healy*) in regions where it would be difficult to collect data with one vessel. Each vessel also carried out ancillary projects including meteorological, oceanographic, wildlife and ice studies; the *LSSL* carried a large Autonomous Underwater Vehicle (AUV) to test the feasibility of using AUV's deployed from icebreakers in ice-covered Arctic waters for seafloor mapping, and the *Healy* was equipped to sample the seafloor with dredges should the opportunity arise. Researchers on the *Healy* also hoped to explore the feasibility of using a small autonomous airplane (UAV) to map ice and wildlife around the vessel, but were denied permission by the USCG and thus the program was moved to the *LSSL.*

While waiting to rendezvous with the *LSSL*, the *Healy* proceeded to a region approximately 200 nm WNW of Barrow to continue mapping the margin off the north slope of Alaska in order to delineate the foot of the slope. Survey work in this area was completed on 21 August when it was necessary to depart in order to meet the *LSSL* at the rendezvous point; a total of approximately 25,000 km^2 (7500 nm$^{2)}$ of multibeam sonar data collected in this area

Proceeding from the rendezvous point, the *Healy* took the lead and a remarkable, almost continuous, 750nm seismic line was collected across the top of Chukchi Cap, west of Nautilus Basin, over Alpha-Mendeleev Ridge, across Makarov Basin and partially up the Lomonosov Ridge. Multibeam sonar data was also collected continuously along the 750 nm line (Figure 8). Ice conditions on the Lomonosov Ridge were such that it was impossible to collect seismic data so at this point the *LSSL* and the *Healy* changed positions and the *LSSL* began to lead the *Healy* to optimize multibeam sonar data collection. During collection of multibeam sonar data on the Lomonsov Ridge, the *Healy* reached its furthest north point -- **88º 27.4626' N 159º 22.05' E.**

Moving south from the Lomonosov Ridge multibeam sonar surveying focused on mapping the foot of the slope in the area of Marvin Spur (Figure 8). Heavy multiyear ice made mapping difficult but with *LSSL* in lead, useful data were collected. On 3 September, the *LSSL* separated from the *Healy* to deploy an AUV equipped with multibeam and single beam sonars (see Mosher et al., 2011 for discussion of AUV operations) while the *Healy* continued collecting multibeam sonar data on its own until 6 September.

Upon completion of AUV operations, the vessels joined up together and proceeded with the *LSSL* in the lead, optimizing multibeam sonar data collection while mapping the foot of the slope around the eastern side of the Makarov Basin (Figure 8). Ice conditions were heavy with thick multiyear ice common and much backing and ramming required. Nonetheless the two-vessel combination allowed useable bathymetric and high-resolution sub-bottom data to be acquired. The survey of the foot of the slope around Makarov Basin was followed by a long transit to the southeast across Alpha/Mendeleev Ridge and into Stefansson Basin (Figure 8). The transit continued until the 12th of September when the vessels reached of Sever Spur, a prime target for Canadian ECS mapping. The *LSSL* deployed seismic gear at the approaches to Sever Spur and was able to collect seismic data for 18 hours before ice conditions required recovery of the seismic system. The vessels swapped positions again and proceeded to the east until approximately 80º 9'N, 119º 10'W when ice conditions prevented both vessels from progressing further east. At this point the survey was turned southwest to once again examine the transition from Sever Spur into the Stefansson Basin (Figure 8). At the western edge of this line the seismic gear was deployed again and seismic data collected for another 11 hours. At about 1800Z on the 16th of September the *LSSL* separated from the *Healy* to launch it AUV (see Mosher et al. 2011) while the *Healy* continued to map Sever Spur on its own. The vessels rejoined on 19 September and began a transit into Canada Basin hoping to again collect seismic data. During the deployment of the seismic gear the *LSSL* noted a strange noise coming from one of their shafts. Investigation by small ROV revealed that the main propeller had moved on the shaft and was loose. Operations ceased while the *LSSL* waited for guidance from Canadian Coast Guard Headquarters. The *LSSL* received word to proceed directly to the Northwest Passage and requested that the *Healy* accompany her for some of the way through the ice. This brought to a close the joint science operations of the program. Despite this slightly premature ending to the joint program, all of the objectives originally outlined were more than met.

On 21 September, the two vessels began a transit towards the entrance to the NW Passage, with the *Healy* in the lead to ease passage of the *LSSL* through the ice. The *Healy* continued to collect multibeam sonar data during the transit over the Canada Basin. The vessels stayed together until mid-day on the 22nd when ice conditions lessened to the point that the *LSSL* was comfortable transiting on her own. At this point the *Healy* and *LSSL* exchanged salutes and separated with the *LSSL* heading for the NW Passage and the *Healy* heading towards Dutch Harbor.

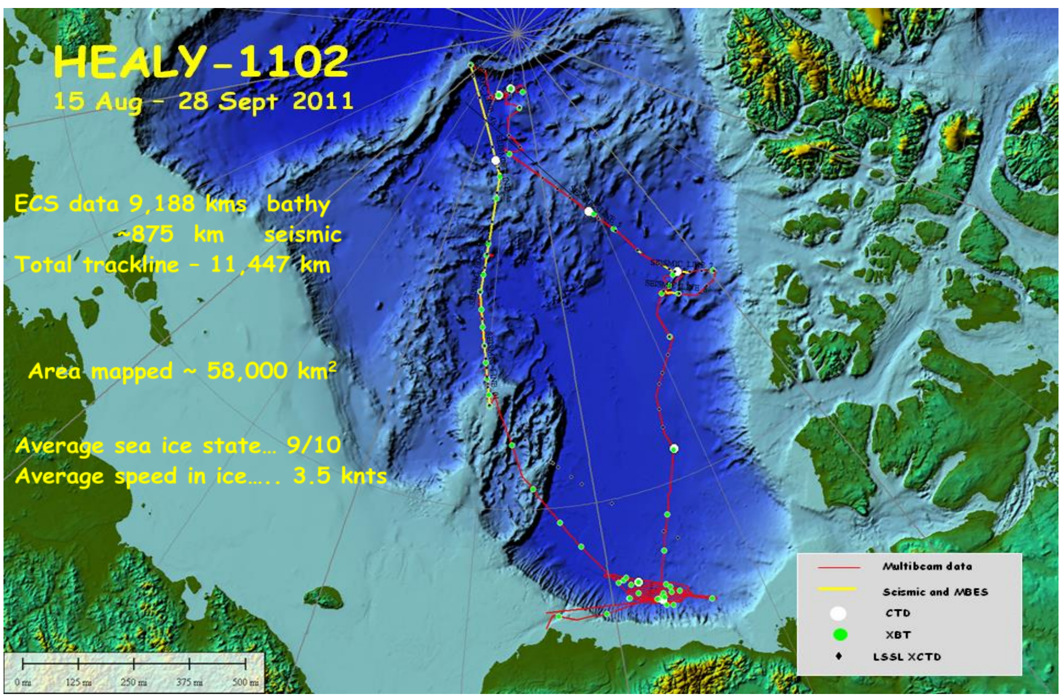


Figure 8. Trackline for Healy-1102. Cross-hatched lines represent seismic data collection lines. Multibeam sonar data collected on all lines.

The *Healy* averaged over 16 knots transiting to Dutch Harbor, arriving at 0900L on 28 Sept. and bringing *Healy*-1102 to an official end. Total track covered on *Healy*-1102 was 11,447 km (6181 nm) with 9188 km (4,961 nm) of multibeam sonar data and 875 km (472 nm) of seismic data collected in support of ECS purposes. These data were collected in average ice conditions of 9/10's ice cover and at an average speed of 3.5 knots in the ice. ECS multibeam data collection covered an area of approximately 58,000 km^2 (16,960 nm^2) adding approximately 20% to the U.S. Arctic multibeam sonar data holdings.

***Healy*-1202**

Healy-1202 was the first single-ship ECS mapping program since 2008. The primary objective of this leg was to collect high-resolution multibeam sonar data in the region north of Chukchi Cap leading into Nautilus Basin in order to unambiguously locate the position of the "foot of the slope" as defined by Article 76 and to better understand the morphology of the northward extension of Chukchi Cap into Nautilus Basin. Secondary objectives included the collection of high-resolution chirp sub-bottom profiles to help in the determination of the location of the foot of the slope, the collection of dredge samples to better understand the geologic nature of Chukchi Cap and its northern extension, and the collection of underway gravity data. Ancillary projects were also carried out including, oceanographic, wildlife and ice studies.

The scientific party of the HLY1202 departed Barrow AK at approximately 1500L on the 26th of August. Enroute to the Chukchi Cap, the *Healy* deployed two "EARS" acoustic buoys on behalf of DARPA/Lockheed Martin at locations approximately 122 and 152 nm north of Barrow in water depths of 3126 and 3751 m respectively. Upon completion of the buoy deployments, the *Healy* continued on into the Canada Basin to the base of the Northwind Ridge for the performance of a patch test and a deep (3850 m) CTD cast was made. The *Healy* then transited over Chukchi Cap to begin a series of surveys designed to ambiguously locate the foot of the slope on the western edge of Nautilus Basin. On 4 Sept 2012, the furthest point north of this expedition was reached at approximately 83d 32'N , 162d 36'W (Figure 9).

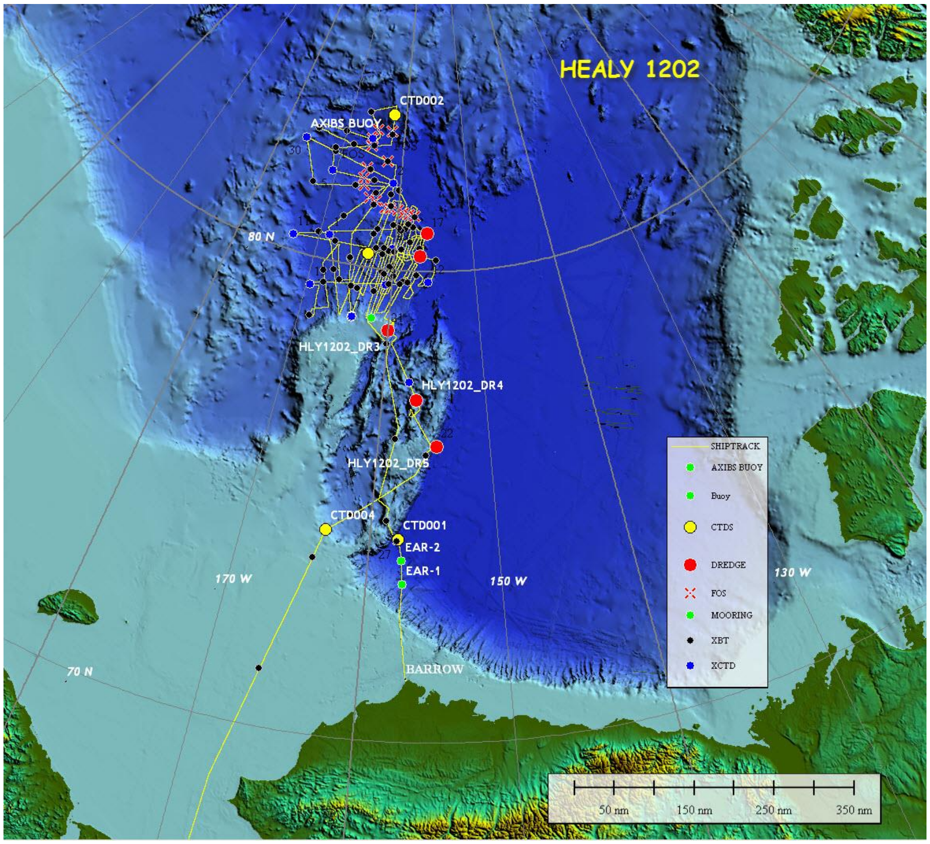


Figure 9 - Healy 1202 ship-track, XBT, XCTD, CTD, buoy, and dredge locations.

In the course this surveying we mapped a spectacular submarine channel that drains from west to east over a distance of at least 160 km with an average gradient of about 0.18 degrees. The channel does not significantly meander but is complex with numerous small tributaries and several bifurcations. The maximum depth of the channel is approximately 80 m. No dredge sites could be identified with slopes greater than 30 degrees in the middle of the northern extension of Chukchi Cap. Instead, two dredge sites (DR-1 and DR-2) were selected on the northeast rim of the northern extension of the Cap. The final three dredge sites (DR-3, DR-4 and DR-5) are located on the northern tip of Chukchi Cap (just west of *Healy* Seamount), in the middle of Northwind Ridge and on the eastern flank of Northwind Ridge respectively (Figure 9).

Upon completing the last dredge site, the "IceGoat Buoy" was deployed for the U.S. Naval Academy and the *Healy* departed for Dutch Harbor (23 Sept), arriving in Dutch Harbor on 27 Sept. Total track covered on *Healy* 1202 was 11,965 km (6461 nm) with 10,030 km (5,416 nm) of multibeam sonar data collected in support of ECS purposes. These data were collected in average ice conditions of 6/10's ice cover and at an average speed of 7 knots in the ice. ECS multibeam data collection covered an area of approximately 68,600 km^2 (20,000 nm^2) adding approximately 25% to the U.S. Arctic multibeam sonar data holdings (Figure 9). In addition to the primary ECS mapping mission of *Healy*-1202, five ancillary programs were accommodated on a non-interference basis. These programs included: 1- Gravity measurements made by Dr. Bernard Coakley Univ of Alaska Fairbanks; 2: ice observations, analyses and reporting along with the deployment of one UpTempO buoy, 1 AXIB seasonal buoys, 1 Argo profiler, 1 USNA "IceGoat" ice buoy and 5 SVP TechOcean and METOCEAN buoys as part of the U.S. International Arctic Ice Buoy Program under the supervision Pablo Clemente-Colon, National Ice Center; 3: a comparative study of historical modern vs historical ice terminology by Matthew Ayre of the University of Sunderland; 4:deployment and development of a geo-referenced ice camera for ice and other studies – Roland Arsenault – Center for Coastal and Ocean Mapping – Univ. of N.H; 5- ocean acidification measurements under the supervision of Lisa Robbins, U.S. Geological Survey, and; 6: marine mammal observations by Mabel Smith, of the Umiaq Inupiat Corporation. The full cruise report for HLY1202 can be found at: http://www.ccom.unh.edu/theme/law-sea.

COMPILATIONS:

As the Center has collected multibeam sonar data in the Arctic we have, after quality assurance, made these data available at our website http://www.ccom.unh.edu/theme/law-sea as well as provided them to a number of national repositories (R2R, NCEI, and NOAA's Ocean Exploration website). We have also contributed these to the IBCAO project and combined them into compilation grids. An example of the latest compilation is presented below (Figure 10). *Healy*-1603 will be added to this compilation and will be available at http://www.ccom.unh.edu/theme/law-sea.

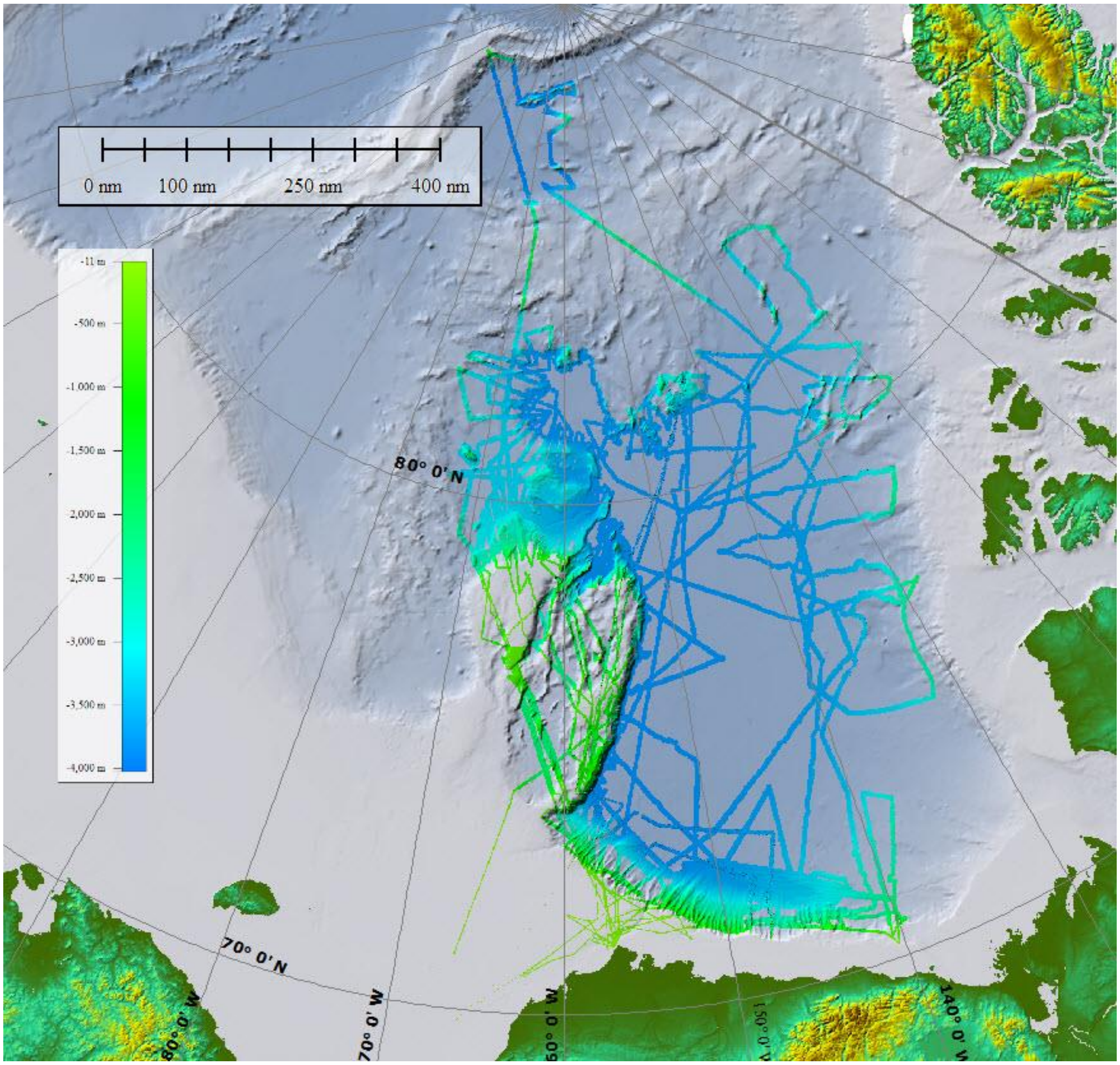


Figure 10. Compilation of all multibeam sonar data collected in support of the ECS project from 2003 to 2016. Data available at http://www.ccom.unh.edu/theme/law-sea.

HEALY 1603 OVERVIEW

Healy-1603 was a relatively short cruise that was scheduled late in the year when *Healy* time became available due to cancellation of a BOEM cruise. Originally scheduled for 11 days, the primary objective of was to collect a few key high-resolution multibeam sonar lines in the region north of the Alaskan north slope margin and on the Beringian margin to verify and further support initial foot of the slope (FoS) picks. With the decision to use *Healy* for ECS operations this season, discussions also began with the Canadians with respect to a possible two-ship operation with the *Louis S. St. Laurent* (*LSL*) which was scheduled for a seismic and mapping mission in the vicinity of the North Pole and the Alpha Ridge during August and September. Logistical constraints prevented the scheduling the ships for joint operations, however, both Canada and the U.S. agreed to extend their respective cruises by five days to accommodate high-priority objectives for each other -- the *LSSL* would attempt to collect a seismic line on the northern extension of Chukchi Cap for the U.S. and the *Healy* would attempt to dredge on the southern Alpha Ridge for Canada. Thus *Healy*-1603 was extended five days with the added objective of dredging on the Alpha Ridge. Ancillary projects on *Healy*-1603 included the deployment of ice buoys under the direction of Ignatius Rigor (University of Washington) and Pablo Clemente-Colón (NIC) (APPENDIX G) and the real-time underway isotopic analyses of seawater samples for ocean acidification studies under the direction of Jonathan Wynn from the University of Southern Florida (APPENDIX H). NIC on board personnel also provided sea ice analysis, tactical navigation support, and daily briefings for the Healy Command and Chief Scientist

Healy-1603 was originally scheduled to depart Nome AK on 18 Sept. 2016 but when the chief scientists arrived in Nome on the 16th of Sept., the *Healy* was already anchored offshore and requested that the small boat transfer to the *Healy* take place on the 17th. With the arrival of the last of the incoming scientific party at 1945L on the 17th the final small boat transfers were made and *Healy* departed Nome at 2130L on the 17th. Given the very tight schedule, long transit distances, and unknown ice and weather conditions, the *Healy* transited at best speed towards Chukchi Plateau, with a line planned enroute to collect a FoS crossing at a location selected by the ECS Planning Office in Boulder. (Figure 11).

Upon arrival on the *Healy*, the incoming science party (see Page 31) and STARC team found a number of problems with the multibeam sonar, the SeaPath IMU and the Knudsen sub-bottom profiling system, the essential systems for this leg. These problems are documented in the Chief Scientists' log (Page 3), the Technical System Report (Page 41) and a separate document specifically dealing with the condition of the multibeam sonar on board. Through diligent work on the part of the STARC Team, Adam Stenseth, Dale Chayes and other members of science party, the multibeam sonar system was made operational, albeit in a state far less than optimal (greatly reduced S/N and swath coverage).

The *Healy* arrived at shelf break north of Barrow at approximately **0240Z 20 Sept. 2016**, commencing the collection of the first FoS crossing line (FoS-1) and finished the line at approximately **00820Z 20 Sept. 2016** (Figure 10). Details of the FoS crossings can be found in Appendix A.

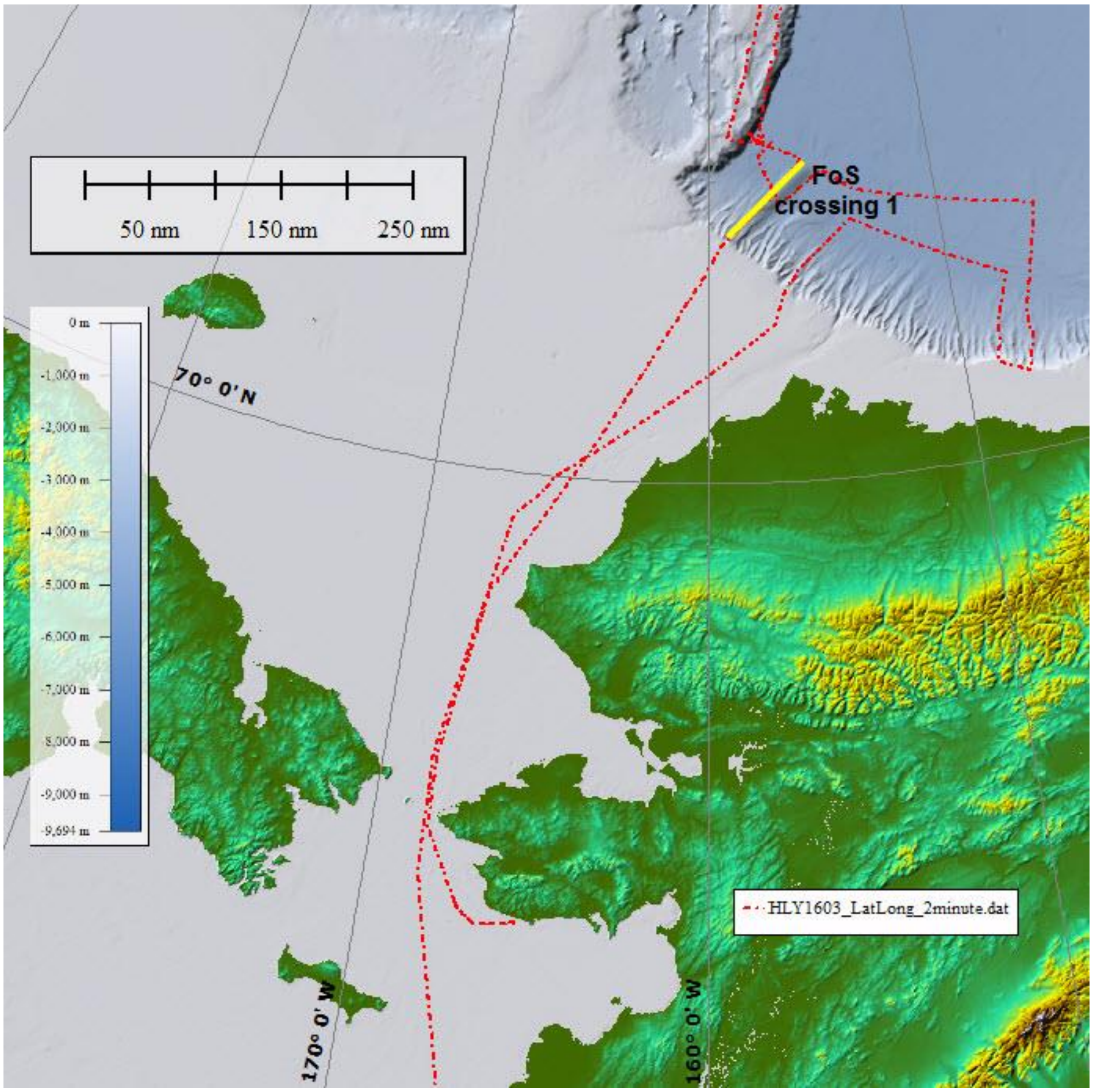


Figure 11. Target FoS line crossing enroute to dredge site

Upon finishing FoS-1 *Healy* turned west to occupy a CTD station in the deep waters of the Canada Basin and then commence a patch test. Weather conditions prevented the launch of the CTD but we were able to launched a Naval Oceanographic Office glider and then proceeded with the patch test after deploying several XBTs. The patch test was completed successfully and indicated that several of the offsets that had been entered into the MB system needed to be updated. A full report on the patch test can be found in Appendix B. The offset updates were entered and we continued at best speed mapping north to the dredge site. A second FoS line (**21 Sept 2300Z - 22 Sept 0145Z)** was collected as we came off the Chukchi into Nautilus Basin (FOS-2- Figure 12). Details of this line can be found in Appendix A.

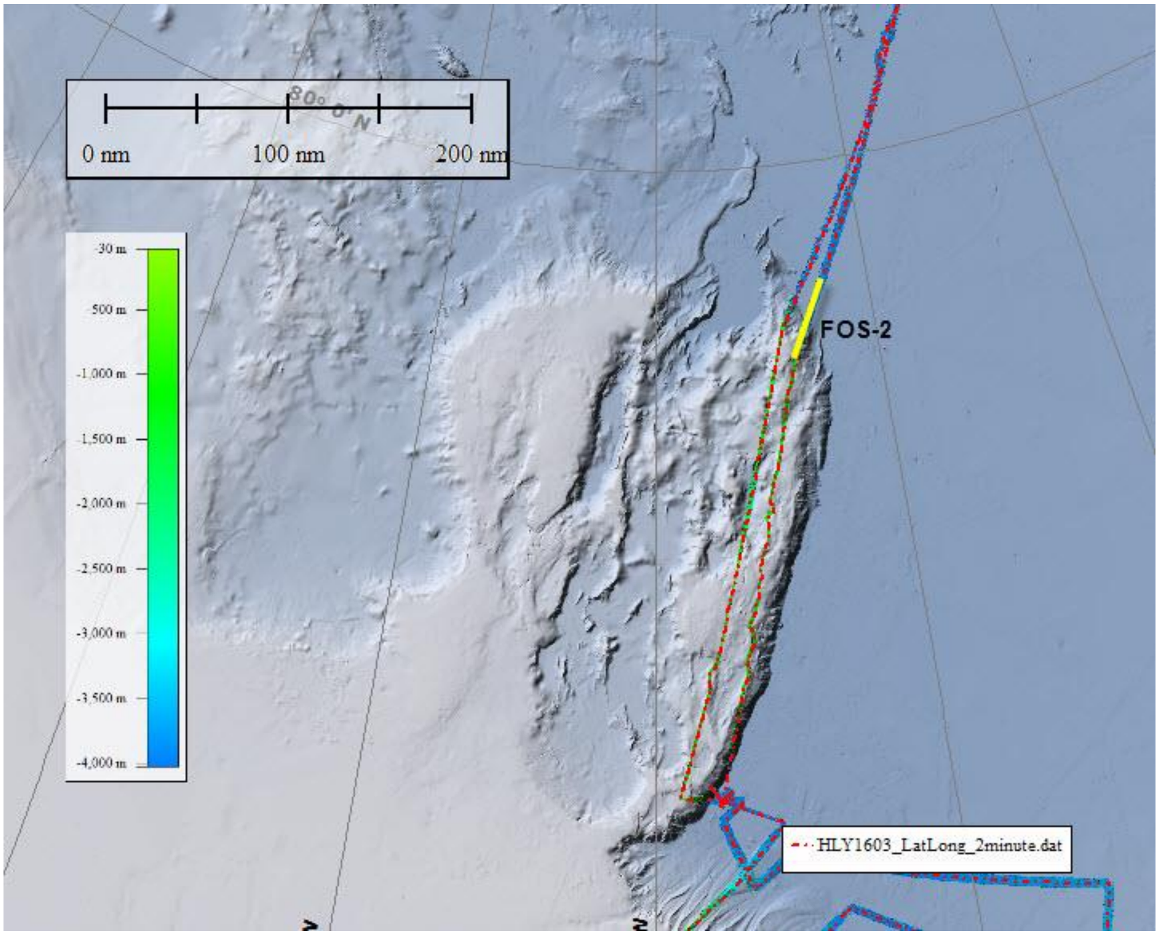


Figure 12. FoS Line 2 coming from Chukchi to Nautilus Basin

Healy arrived in the vicinity of the primary dredge site on the southern Alpha Ridge (Nautilus Spur) at approximately 1200Z on 23 Sept. The site chosen was a small N-S trending extensional basin with 750 m high walls and relatively steep (33-35 degree) slopes on the western wall. Conditions were 10/10 coverage of mostly first-year, but relatively heavy ice. Winds were moderate 15-20 knots. Early morning hours were spent looking at drift which varied from NE to SW -- with dominant vector to SW. A path was broken beyond dredge site and at approximately 1640Z commenced the dredge (Figure 13).

HLY 1603 DR-1
Dredge start position: 82 04.38018 N 142 29.9483 W
Dredge end position: 82.04.06947 N 142 34.4655W
Water Depth: 3285m
Target Depth: 3150-3000m

HLY 1603 DR-2
Dredge start position: 82 04.38018 N 142 29.9483 W
Dredge end position: 82.04.031 N 142 32.999 W
Water Depth: 3285m
Target Depth: 3150-3000m

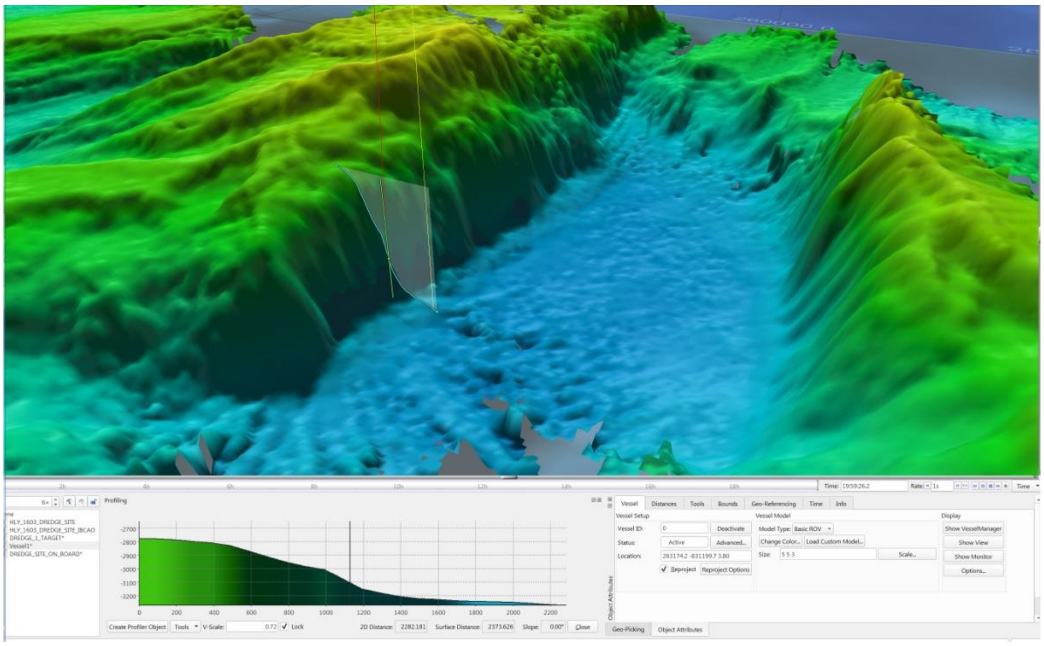


Figure 13. 3-D perspective of dredge site with position of vessel (yellow line and dot) as well as position of dredge target (green line and dot) at beginning of dredge run (6x VE).

Through the course of the five hours on the bottom, there were several bites of 6500lbs of wire tension over the background level of about 5000 lbs. The dredge was recovered at approximately 2200Z with several hundred pounds of mud and 18 lbs of rocks including several large rocks with fresh surfaces. From initial examination these appeared to be volcanic tuffs (Figure 14). A second dredge was attempted at the same site which returned with about 300 lbs of mud and 48 lbs of rocks, some of which were clearly IRD but others which seem to have some fresh surfaces. Details of the dredge operations and descriptions and photos of samples can be found in Appendix C.

Figure 14. Sample returned from DR-1 of what appears to be volcanic tuff.

Upon completion of second dredge we attempted to occupy another dredge site approximately 24 nm to the west of the first site. This site was a constructional high standing approximately 1000m above surrounding seafloor with slopes slightly less steep than the extensional basin. Unfortunately very high winds, low visibility and very difficult ice conditions precluded the attempt. Details of this secondary site can be found in Appendix C. During the transit to and from the dredge sites, two more FoS crossings were made between Alpha Ridge and the Nautilus Basin. Details of these crossings are presented in Appendix A.

With increasingly poor weather and very difficult ice conditions, *Healy* turned south to continue mapping efforts on the Alaskan and Beringian margins. A line was selected south that optimized filling mapping gaps on Chukchi Cap. Another FoS crossing occurred as we came out of Nautilus Basin onto Chukchi Cap (Figure 15). Details of the FoS crossings can be found in Appendix A. We mapped another FoS crossing (6) as we came east off Chukchi Cap. (Figure 16).

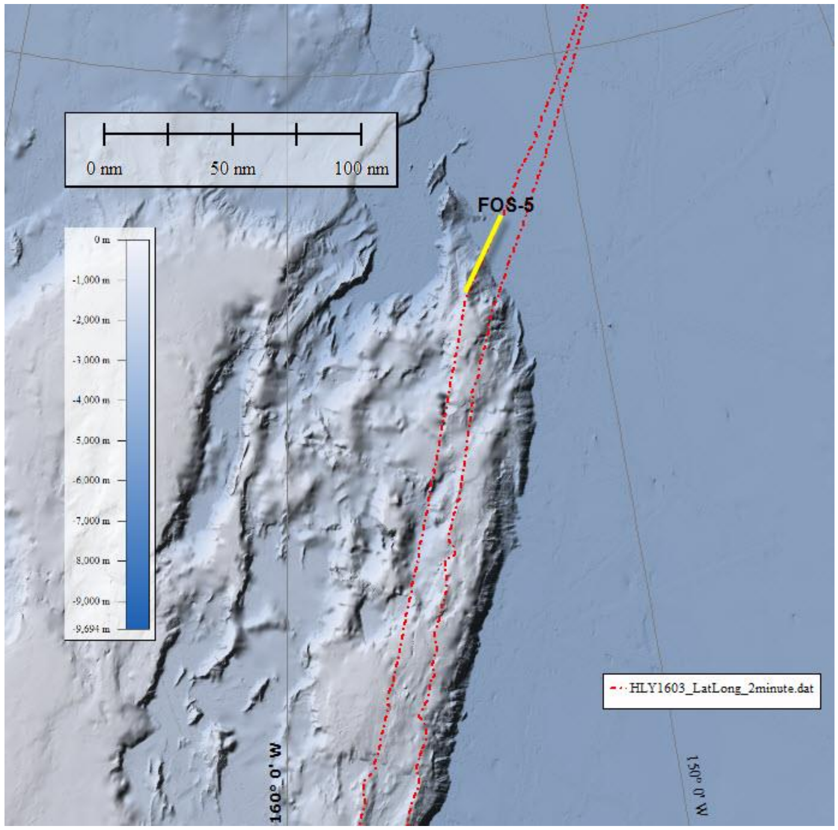


Figure 15. FoS crossing 5 coming onto Chukchi Cap from Nautilus Basin.

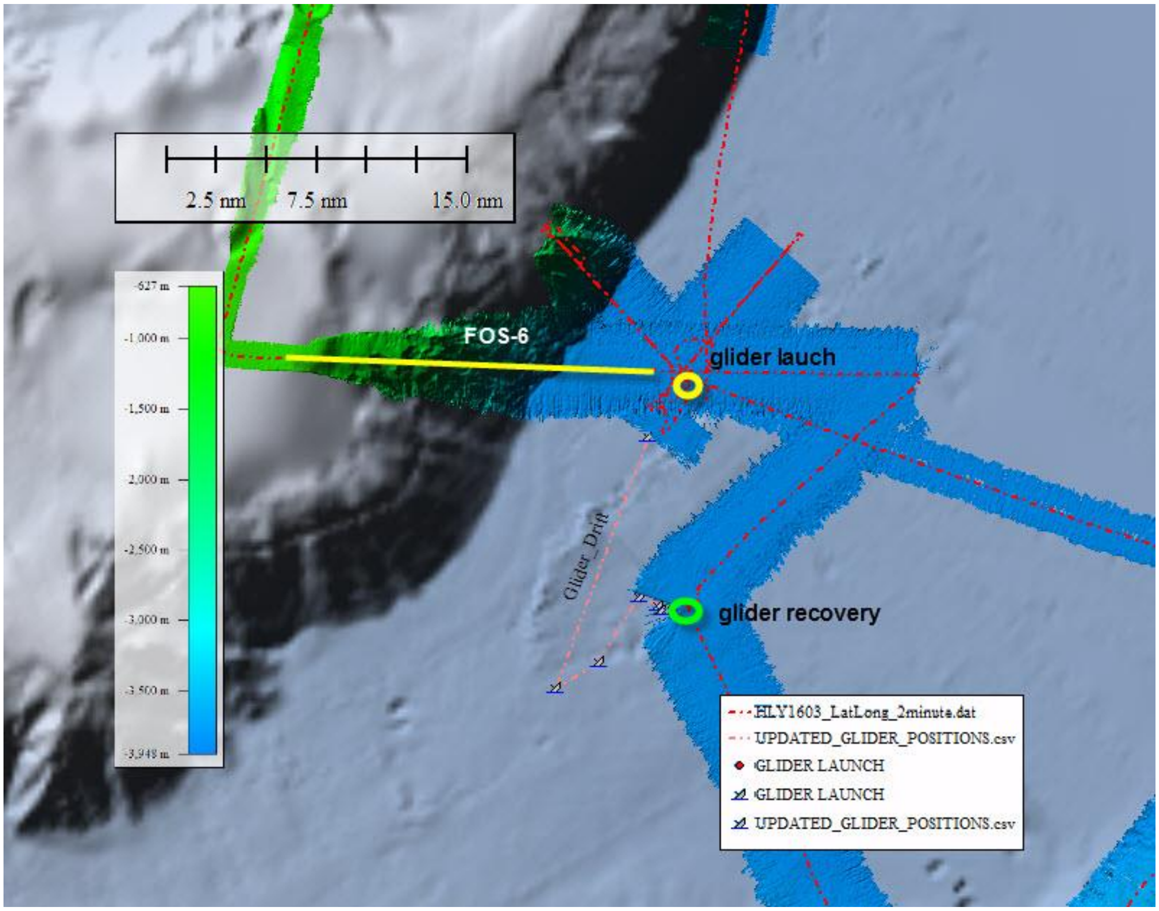


Figure 16. Glider launch point (yellow circle) and recovery point (red circle) and drift path. Yellow line is FoS crossing 6.

The Naval Oceanographic Office reported that their glider had dropped its descent weight during an initial test dive and that it was drifting on the surface. We had tracked the position of the glider and were able to intercept it at approximately 1515Z on 27 Sept. A small boat was deployed and the glider retrieved (Figure 16).

From the glider recovery site we proceeded east to collect several more FoS crossing lines on the Alaskan margin as requested by the ECS Program Office in Boulder (FoS-7, 8 and 9 -- Figure 17).

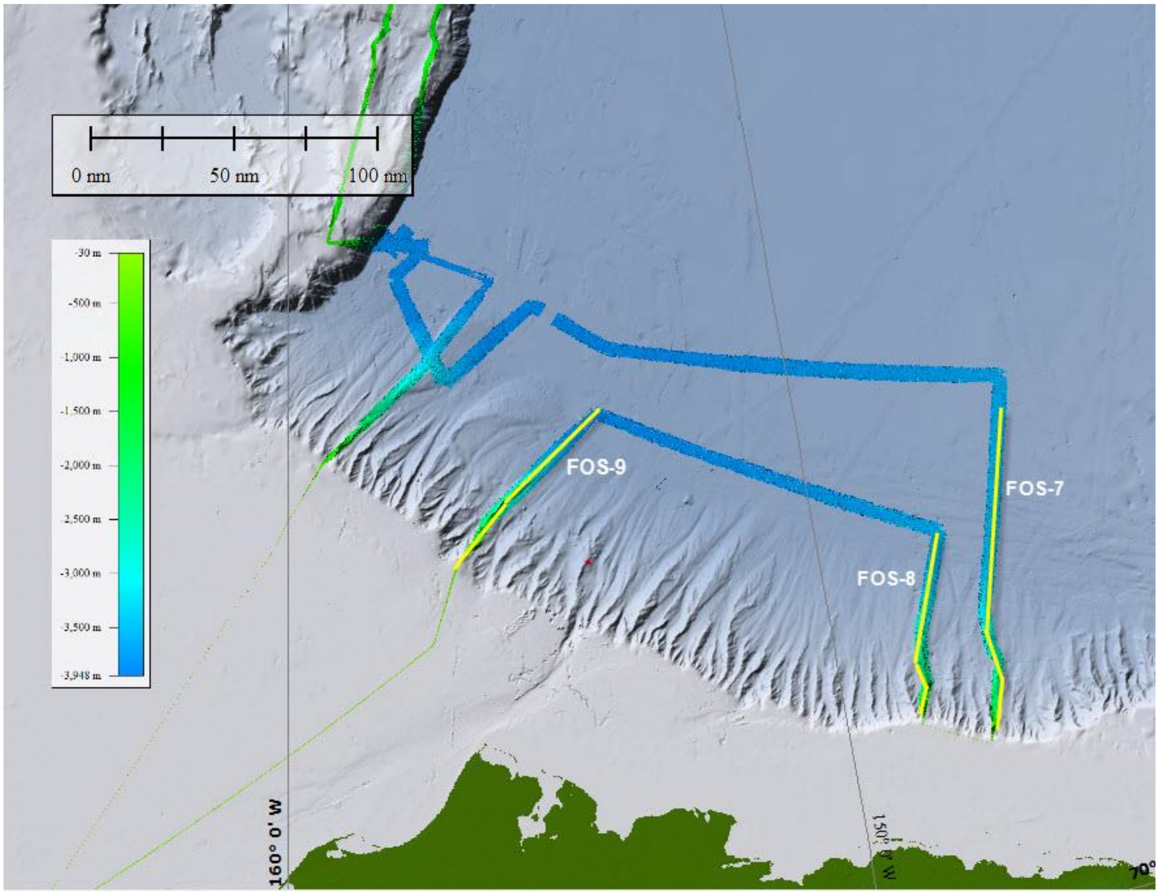


Figure 17. FoS crossing lines 7, 8 and 9 collected on return leg of cruise.

Upon completion of FoS line 9, time constraints deemed departure for the higher priority Beringian margin lines. *Healy* steamed at best speed on the long transit to the Beringian margin arriving on site at approximately 1830Z on 03 October 2016 (Figure 18). We ran the first down-slope line (FoS-10) in relatively benign 9-12 foot seas and 20-30 knot winds, but the sea-state and winds continued to increase as we ran the upslope line (FoS-11). Details of the FoS lines can be found in APPENDIX A. We started a third down-slope line but as weather conditions continued to worsen and with gale warnings forecast, the Captain deemed that it was time to head to Dutch Harbor.

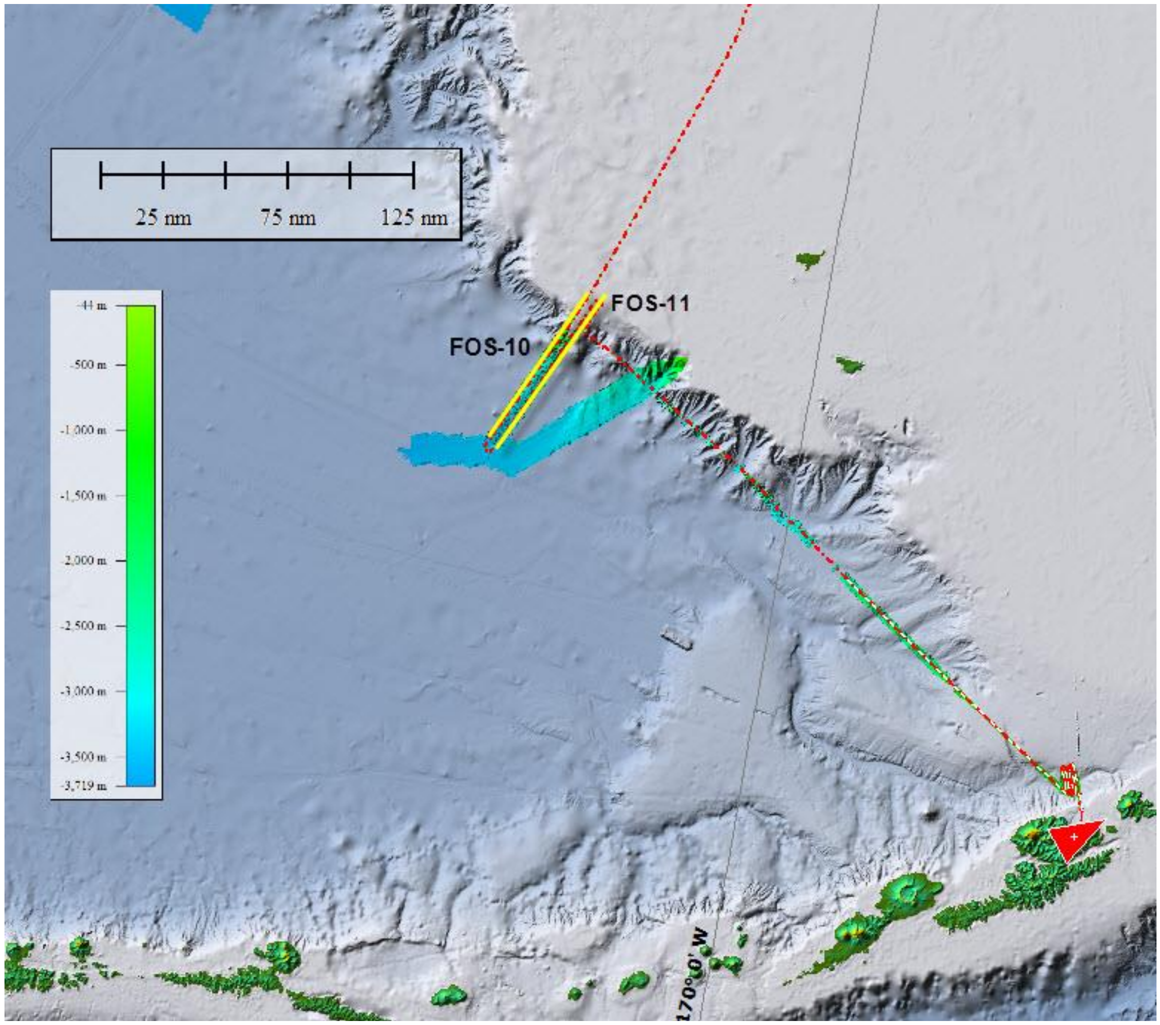


Figure 18. FoS lines 10 and 11 on the Beringian margin.

We arrived in Dutch Harbor at 1800Z on 05 October, having collected a total of 7771 linear km (4196 linear nautical miles) of multibeam sonar and chirp sonar data (representing approximately 14,000 sq. km (5400 sq mi)) of multibeam sonar coverage in support of U.S. ECS activities, including several key foot of slope crossing lines. In the course of this work we collected 65 XBTs, and recovered approximately 60 lbs of dredged rock from the southern Alpha Ridge in support of both U.S. and Canadian ECS efforts. Ancillary projects during the leg included the launch during Healy 1603 of 3 Seasonal Ice Buoys (XIBs) and 4 Surface Velocity Profilers (SVP-Bs) in the Beaufort and Chukchi seas, 3 SVP-Bs in the Bering Sea (APPENDIX G) and a program of real-time underway seawater isotopic analyses to evaluate changes in freshwater sources and surface water carbonate chemistry and the role of changes in the freshwater budget on ocean acidification and the carbon cycle in the western Arctic Ocean (APPENDIX H). An overview of the entire cruise track and closer views of the track in the Chukchi/Canada Basin area and the Beringian Margin area are presented in Figures 19, 20 and 21. A collection of video clips from the cruise can be found at: https://vimeo.com/187496629.

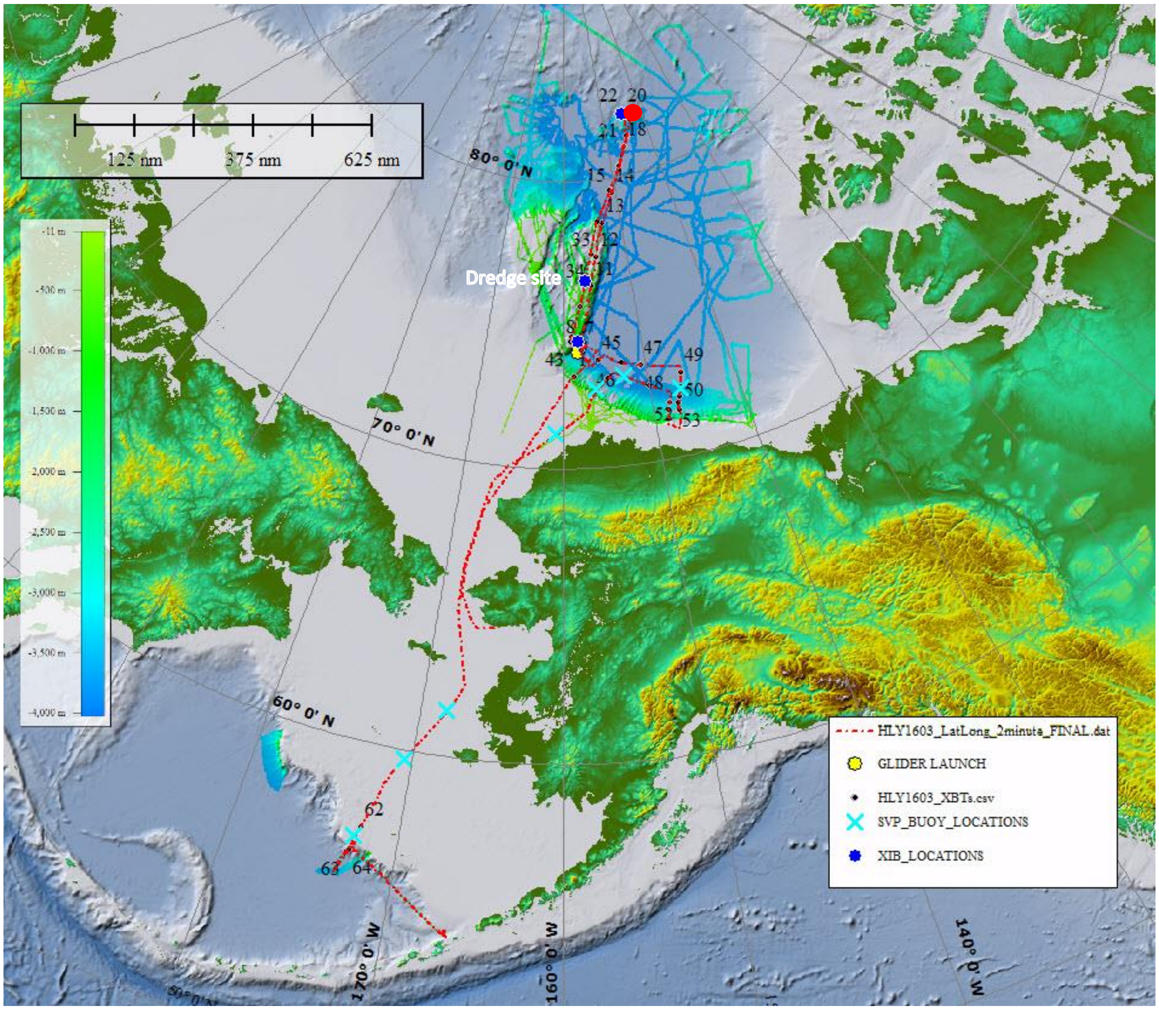


Figure 19. Overview of entire HEALY 1603 cruise

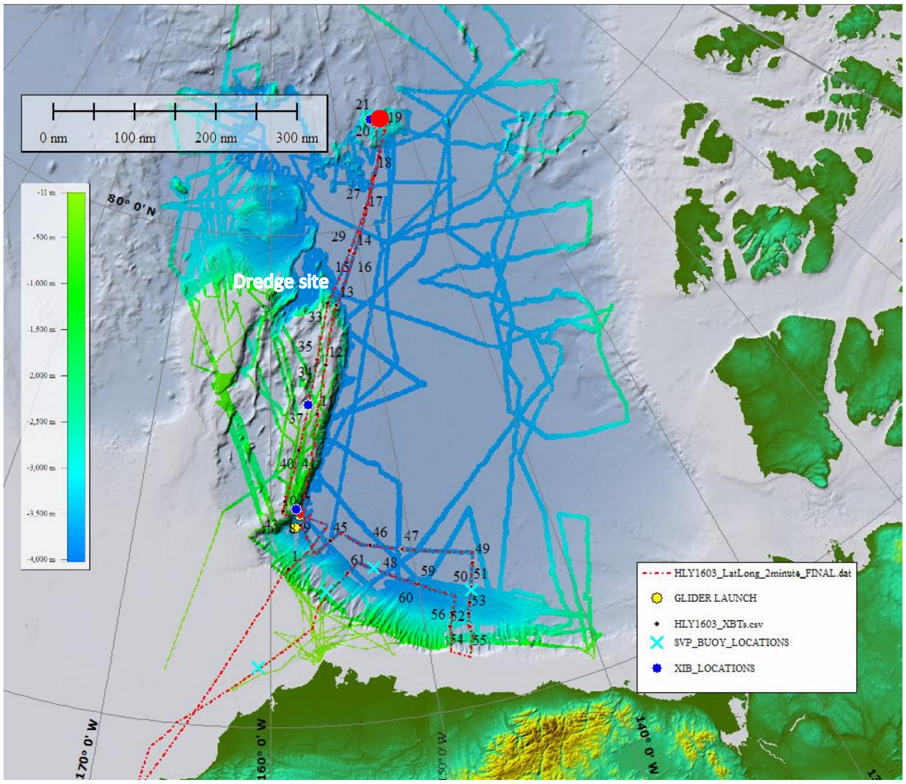


Figure 20. Overview of northern segment of HEALY 1603

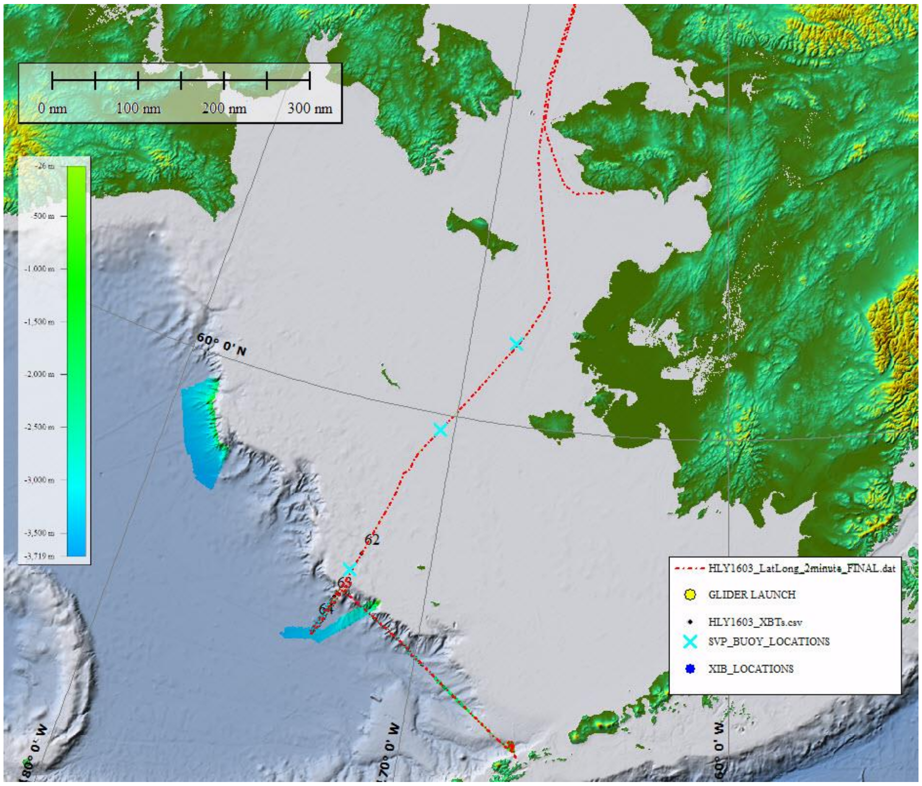


Figure 21. Overview of southern segment of HEALY 1603

Scientific Party

Last Name	First Name	Institution	Position
Mayer	Larry	University of New Hampshire	Chief Scientist
Calder	Brian	University of New Hampshire	Co-Chief Scientist
Baldwin	Kim	University of New Hampshire	Scientist
Bisig	Aaron	National Ice Center	Ice Analyst
Bohan	Margot	NOAA	Scientist
Chayes	Dale	University of New Hampshire	Engineer
Clemente-Colón	Pablo	National Ice Center	Scientist
DiStefano	Masimo	University of New Hampshire	Grad Student
Sanchez	Nilton	University of New Hampshire	Grad Student
Fahy	Jason	USN (LCDR)	Scientist
Hoy	Shannon	University of New Hampshire	Grad Student
Maingot	Brandon	University of New Hampshire	Grad Student
Marcussen	Christian	Geological Survey of Denmark	Scientist
Mosher	David	University of New Hampshire	Scientist
Rigor	Ignatius	University of Washington	Scientist
Szorc	Chris	National Ice Center	Ice Analyst
Vojak	Nick	USN (AG1)	Scientist
Walt	Zach	USN (AG2)	Scientist
Weidner	Elizabeth	University of New Hampshire	Grad Student
Wynn	Jonathan	Univ. of South Florida	Scientist

HEALY 1603
CHIEF SCIENTIST'S LOG
Local Time Zone - UTC -8

17 September 2016 - JD261

Nominal departure time **2000L on 18 Sept**. (0400UTC on 19 Sept) but on arrival in Nome on evening of 16 Sept. HEALY calls and said they would like to do transfer on 17th. Inasmuch as all our folks would be arriving on 17th this was excellent news. STARC group transfers on first boat at 0900L. Group arriving on noon flight transfer immediately after arriving. HEALY calls back and says cannot take last group arriving at 1945L on 17th so will transfer them on 18th. HEALY calls back again and says will transfer group arriving at 1945L so final transfer of personnel is made at about 2000L. During transfer landing craft loses steering and turns broadside to sea making it quite uncomfortable for passengers.

Jay Turnbull and Tom Bohlmer and Elizabeth Ricci went on first boat to change out POS antenna and cable. When we arrived on board this had been finished but Jay noticed that the Seapath was showing a problem with its 1PPS (dropping out) -- looking at past emails this appeared to have started on 30 August but further analysis implied it may have started on 18 August. We also noticed that time stamp on SIS was showing 2005 dates. A look at 1602 data showed that all data files since 18 August had time stamp of 2005 (Figure 1). It also re-set back to 1 Jan 2005 on at least one occasion.

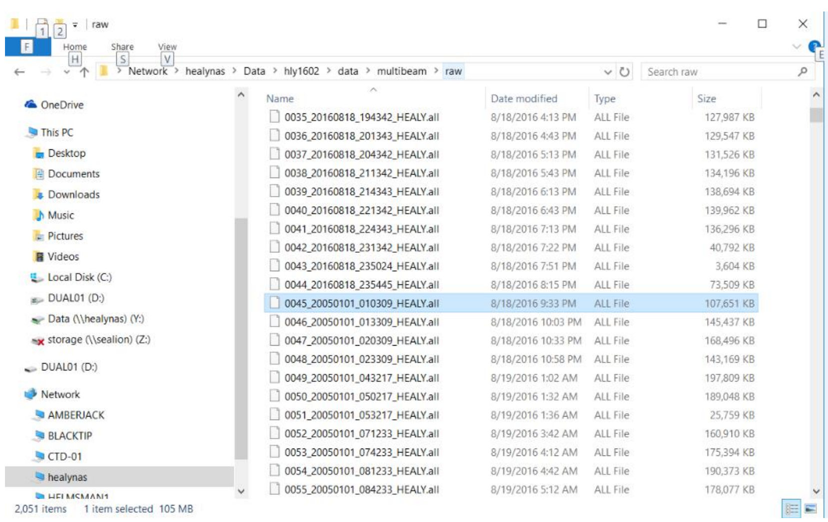


Figure 1. 1602 datafile log showing change in date from 2016 o 2005 on 18 Aug 9:33PM

Looked at POS and it looked better but showed an accelerometer bias error. Decide to swap out POS for primary MRU -- swap fiber cables in TRU - Fiber 15 on lower rack (Seapath) for Fiber 10 on upper rack (POS). POS shows 180 degree error in heading -- Jay working on it and trying to understand.

Underway at 2230L - no contact from Capt or OPS -- quick in-brief and then let people go to bed.

18 September 2016 - JD 262

Jay still working on POS transfer -- underway doing 15 knots.

Dale unpacks gliders and sets up on deck to broadcast -- email to GOC at Stennis.

Meet with OPS and discuss logistics -- still setting up -

1700L - Still no MB.

2100L- Jay swapped the cables to the antennae and this seems to have resolved the 180 degree problem. Brian is looking at pre-1603 data to see if this problem was present in older data or related to the swap of antenna and cable on the 17th of Sept.

2115L - Ran 5 deg rudder circle to calibrate GAMS

2130L - Jay is resetting the TRU and restarting SIS

2339L (0739Z) - BIST attempted with all other sonar systems secured. Test failed for RX noise level and Rx Noise Spectrum, but otherwise passed. Since the ship was in ~30m of water at the time, and doing 15 kt, this is maybe not surprising.

System failed to restart pinging after BIST, however, and the TRU power was cycled in an attempt to clear this condition. It now seems that the problem with the TRU date being in 2005 is due to a failed battery on the TRU's CPU board. The spare TRU CPU board was swapped in, and the battery was confirmed as being good, although the firmware on the new CPU board is not up to date, and causes SIS to complain when the system is started. The system did start pinging, however, and appeared to be collecting data as required.

After approximately 30 min., however, the system reported errors, and then failed completely: the MBES stopped pinging, then lost connection; STARC technicians report that the system TRU was locked up somehow. TRU power was cycled again, but the same situation developed.

The old CPU board (with the bad battery but correct firmware) was re-installed and restarted, and this appeared to have the same problem to start with, but after another power cycle appeared to be working. Since the entire area, currently, looks to be about 40m deep, however, it's hard to tell whether the system is really fixed, or if it's just lurking.

The system is currently generating lines at 30 min. duration, and the ship is proceeding north at approximately 15.5. kts.

19 September 2016 - JD263

0900L (1700UTC) - heading north at 15.5 knots -- MB looking OK - plan on XBT as we cross shelf break.

1200L (2000UTC) - first ice -- small bergy bits and a ridge of ice in the distance to the west.

1400L (2200UTC)- ship lost power

1440L (2240UTC) - underway again

20 September 2016 - JD264

0215L Weather has come up to the extent that it is impossible to safely deploy the CTD sensor, or to use the crane in order to move and deploy the gliders. The ship therefore moved to waypoint 7 to start the patch-test in order to buy a little time in which the weather might improve sufficiently in order to get the CTD over the side.

0240L At start of run-in to waypoint, MBES failed to lock bottom and would not re-start pinging. TRU reset to attempt to recover while XBT/XSV capture is underway.
0300L Dropped two old T-5 probes, but no good profile; tried dropping a newer probe, but wind and cable motion may be the more significant problem. Meanwhile, MBES still failed after TRU reset and SIS reset; running BIST to attempt to identify any particular cause of failure. BIST failed on TX channels with mixture of low impedance and low voltage errors. Second BIST also failed in the same manner.
0430L: Speak to GOC in Stennis to determine how far away from recovery site we can launch. Response is that gliders travel ~10 nm per day - we have approximately 11 days between now and recovery -- therefore suggestion for safety is no more than 90 miles (which is what we are from recovery site now). Can chose another recovery site about 45 miles north of original - but not clear weather will abate in 3 hour steam north. We will see - for now remaining at WP7 running tests on MBES.
0530L: EM122 started up and appeared to be working (though with reduced swath) for approximately 15 minutes then failed again. We secured the MB while steaming to WP7 to begin patch test to see if failure may be related to overheating.
0551L: Approaching WP 5 to begin roll bias test -- turn on MB -- starts up fine -- failed after about 5 minutes. Failure is failure to find or track bottom - -though bottom can be seen on water column display. Bring swath in 15 deg on each side and change to single ping mode. Bottom tracking returned nicely. Brought swath out to +/-60 and switched to very deep mode. Appears to be working. Hmmmm.
0619L-: Start Roll Bias patch lines
0828L - End of Roll Bias patch lines
0925L: Launch NAVO glider
1015L: Start Pitch bias patch test line
1200L: At beginning of second (downslope) pitch bias line, Ignatious and Pablo decided to slow ship and launch ice buoy -- this required us to return to start and redo line at 8 knots
1343L End of pitch bias line
1345L Start steam to dredge site
2200L Started two-hour line changes, synchronizing the MBES and SBP.

21 September 2016 - JD265

0030L Started first regularly scheduled XBT. Running Deep Blue. No MSTs in sight, so STARC and science party conducting the XBT directly.
1600L: Dale did checked on gravimeter (BGM-3) and noticed the Malfunction and DNV lights lit on the BGM-3.
The summary is:
- we replaced the mother board with a spare
- Malfunction and DNV are off, table is erect, we are logging data
- the panel meter is useless
- there is a second spare gyro on board and we put it in w/ the spares in IC/Gyro

We are logging data (I think) and will have a look when we can.

Here is Dale's e-log:

```
Jay, Elisabeth and Dale open inquisition into why the BGM-3 isn't
working.
The DNV and Malfunction lamps are lit on the Control Power Supply.
DNV is lit on the Buffer interface.
A quick, coarse look at the raw data files from HLY1602, it appears
that the problem started between Aug 16 & 18th.
DPM (1) shows voltage cycling up toward 28V where it should be
stable....

Turned CPS power off and back on. The Malfunction light came on, but
not the CPS DNV.

28 volts out of both power supplies when CPS is not connected to the
Sensor electronics.

Followed the troubleshooting chart in the manual (page 5-3), took out
all three boards, put them in one at a time. The Malfunction light is
off without
the Controller card in place. Malfunction light comes on when powered
up w/ Controller card installed. Tried the spare, no difference.
Troubleshooting chart says: replace mother board and check for shorts.
No obvious shorts or damage.
Replaced the mother board (installed S/N 105 , removed S/N 120 )
On power up the DPM is completely useless - display is unstable, values
are wrong, etc.
However, the Malfunction lamp is out.
Removed the table cover and started the table, heard 400Hz come on,
table erected, DNV lamp went out after a while

Will review with shore-side support by email.
-Dale
```

22 September 2016 - JD266

0030L Launched three XBTs, which all failed at the same depth with large positive temperature spikes; converted the first of these (to about 200m) and applied with extended profile. The water appears almost isothermal here.

0100L It appears that we now have data being recorded for the BGM-3, and have recovered the data for the positioning from earlier in the cruise (it was being inadvertently recorded to a hly1602 directory rather than the correct one for HLY16-03, being misconfigured when the cruise swapped over.

0400L Reduced and asymmetric swath observed on MBES. The port side of the swath appears to be affected much more significantly than the starboard side as we start to get more ice. This has reduced the overall swath considerably, and made it asymmetric.

0800L: Jay found where gravimeter data was being sent:

Looks like Jay found where the gravity data was being logged and it now shows up in the "right" place:

/Data/hly1603/data/sensor/serial_logger/bgm-3
bash-3.2$ tail -f bgm-3_20160922060443.raw
1474553702.839 04:025465 00
1474553703.839 04:025467 00
1474553704.839 04:025469 00
1474553705.839 04:025472 00
1474553706.839 04:025469 00
1474553707.839 04:025469 00

1474553708.839 04:025466 00
1474553709.839 04:025467 00
1474553710.839 04:025468 00
1474553711.839 04:025471 00

1400L: Begin to run into heavier ice -- MB not able to track bottom -
1448L: Back and ram for first time!

23 September 2016 - JD267

0145L Ship is making a number of sharp turns in order to line up in an easier pool of thin ice, and thereby make better time towards the dredge site. Still maintaining approximately 6.5 kts towards the dredging area. We have chosen the western wall of an extensional basin with 750 m N-S trending slope of about 30-35 degrees as primary dredging target (Figure 2).

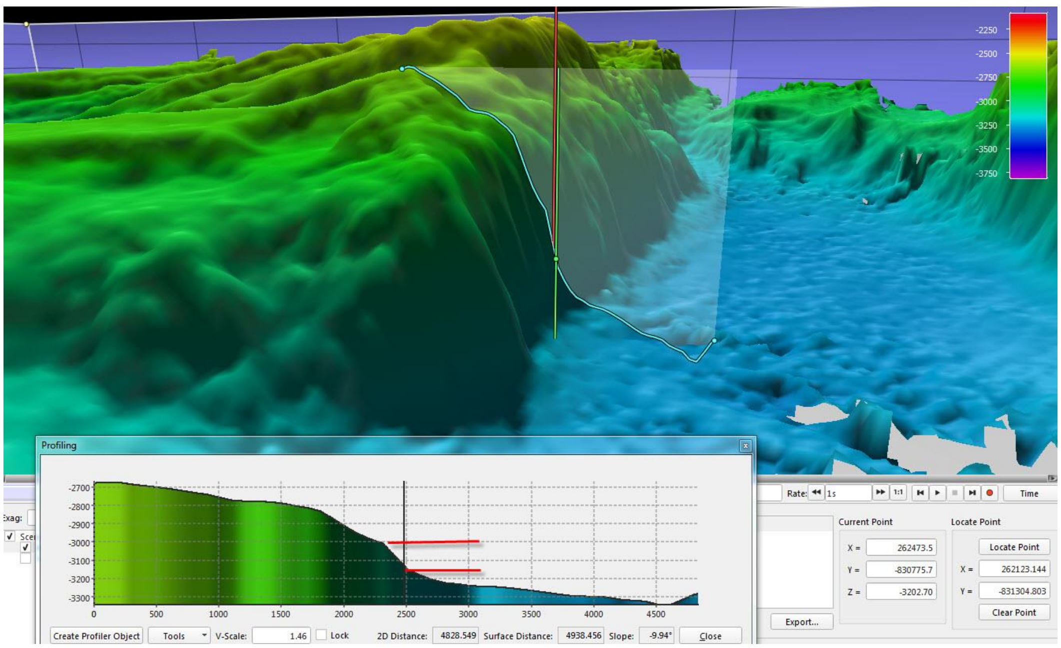


Figure 2. Proposed dredge site -- red lines in inset represent target zone

0400L Approaching dredge site from the northeast. 10/10 ice but mostly first year -- winds 15-20 knots drift test shows net drift to south but variable. Will break track along dredge route (east to west) and the set up for dredge.

0840L - 1400L: Successfully completed first dredge -- had several tension hits of up to 7000 lbs. Dredge returned with mostly mud (about 400 lbs) but several large rocks that looked like they had been broken off outcrop (fresh surfaces) -- rocks appear to be volcanic tuffs.

1530L - 2100L - Successfully completed second dredge on western wall of extensional basin -- about 300 lbs of mud and numerous rocks -- some showing fresh surfaces -- again red, volcanic material.

2120L Secured from two dredges at extensional basin site , and underway towards site 2. First line of data being recorded underway is line 106.

2145L Moving into some thicker ice requiring backing and ramming.

24 September 2016 - JD268

0120L Arrived in the vicinity of the second dredge site, and proceeded to break ice towards the dredge site while waiting for sufficiently rested deck crew to implement the dredge.
0600L Underway again to return to the staging location for the next dredge.
0730L The weather conditions being inclement, the dredge operation was cancelled. Ship turned to depart the area, dropping an ice buoy in the process.
0830L Currently slightly ahead of schedule for Scenario C and given that we will be returning back out of the ice, will likely gain significant time in transits. Have redesigned transit back to return to spot on upper Canadian Basin that showed potential bathymetric target on track up to dredge site and then travel down Chukchi filling mapping gaps. Will the cross Canada Basin to pick up bathy lines across Northern Slope -- most likely be able to complete Scenario D (Figure 3).

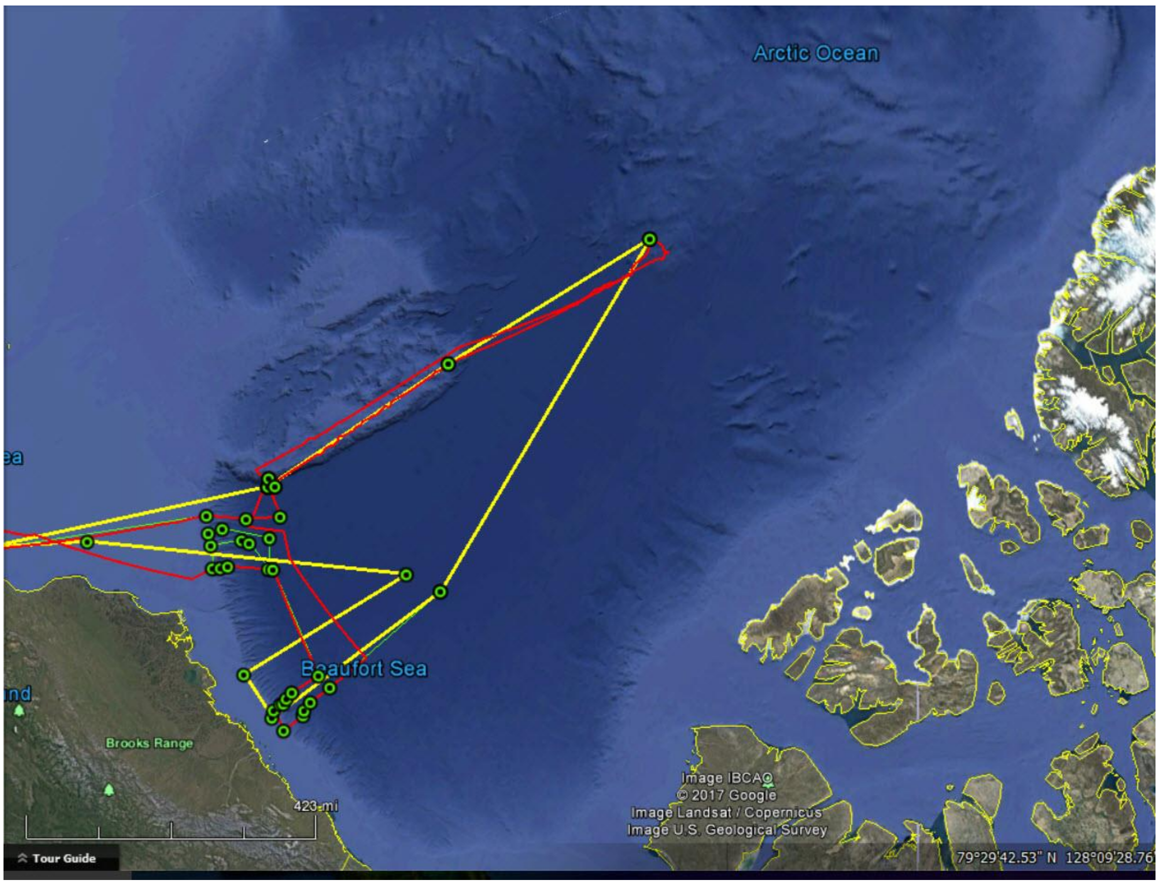


Figure 3. Alternate route back to Dutch (northern-most of red two red-tracks) -- designed to fill mapping gaps on Chukchi and to explore potential bathy target in Canada Basin east of the porch area.

1100L Ice conditions difficult -- will follow best leads out of dredge area rather than optimizing bathy gap filling.

25 September 2016 - JD269

0120L Passed site of potential target in Canada Basin; no evidence on sub-bottom or MBES of the target, even though the track went directly over the highest point in the previous data. Concluded therefore that the previous detections must be been erroneous, possibly related to ice conditions.

0800L - Have just attempted another five XBT launches and had another five failures. Elizabeth is examining the record of launch success and reports:

We have logged 35 XBT launches (have had more attempts when logger does not recognize XBT -- probably another 10 that have not been logged for a total of 45 attempts to date. Of the 35 logged, 11 were useless (no data or less than 100 m). Of the remaining 24, 13 terminate at approximately 300m and 11 appear normal). Turns out these were all T-5s which are rated for only 5 knots and some of these times we were definitely going faster. Also looking at inventory the XBTs used were manufactured in 2010 and there is no XBT box in the reefer with a manufacturing date beyond 2011.

1610L - Next XBT attempt -- this time use T-7 (rated for 15 knots) -- worked much better - but only to 760m -- would rather do that than slow every time - upper water column is key here.

2315L Bridge reporting fog ahead, which requires them to slow to 4-6kts.

26 September 2016 - JD270

0755L Ship slowing to allow deployment of ice buoy.

0805L Ice buoy launched -- will launch XBT next.

1500L As we transit down Chukchi we have crossed a beautiful series of debris flows that look like they may have a glaciated section above them (Figure 4).

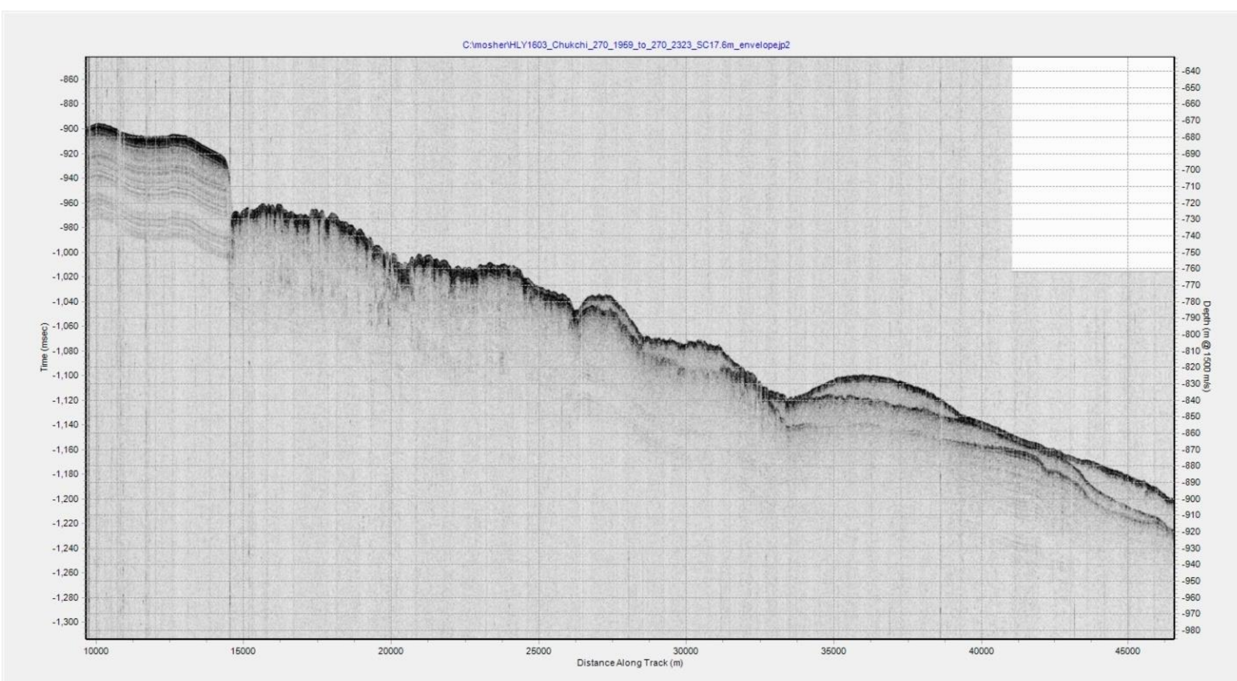


Figure 4. Ice margin? and stacked debris flows on eastern part of Chukchi

27 September 2016 - JD271

0420L Ship turned from waypoint to reposition for glider recovery. Slowing to ~6.5kt in order to arrive at last known glider location at approximately 0630L.

0420L Ship approaching location of glider; lights turned on by GOC; ship searching for visual position.
0715L Glider strobe spotted. Will maneuver slowly to glider until daylight and launch small boat to recover.
1610L- beautiful FoS crossing.

28 September 2016 - JD272

0820L- reached end of eastern line across Canada Basin -- turning south for first FoS line on eastern end -- this is a region that is clearly still influenced by MacKenzie Delta
1030L- sound speed warning on SIS - also small frown as we come up slope -- will slow to 10 knts and deploy SVP ice buoy for Ignatius and take an XBT.
1300L - winds up to 30-40 knts -- have slowed to 10 knots - MB OK but subbottom degrading. Taking another XBT as water masses are changing as we get into shallower water.

29 September 2016 - JD273

0200L Sound speed warning on SIS, immediately prior to expected FoS position; new XBT taken and entered.
0415L Ship reached end of planned downslope line, and turning for transit west across Canada Basin. Speed coming up to 12-13kts for transit.
1245L: All of a sudden the Knudsen started to show high noise levels -- nothing was changed on settings, heading or speed. However we were in middle of fire drill and we confirmed that a fire pump 2 was turned on at AMR-1. When secured, noise went away.
1435L: As we changed course to head up slope data become much noisier -- we are slowing to ten knots - trying that -- also deploying SVP buoy by Ignatius.
1444L: Slowing to 8 knots as we come up across FoS
2009L: Ignatius has deployed another SVP buoy

30 September 2016 - JD274

0200L: Set SVPEditor to Server Mode in order to provide casts through the transit of the Bering Straits. Surface sound speed is divergent (slower) but at 60m it would be hard to get a good cast to compensate.
0809L: Ignatius has deployed another SVP buoy (serial 320260) at 71 09.178 N 160 49.934W.

01 October 2016 - JD275

0500L: Appears that gravimeter has gone down
1300-1400L Jay and Dale replaced control board on gravimeter - fixed problem until 1720L -- failed again
1900L: Continue to transit at about 9-10 knots to Beringian Margin site -- winds 30-40 knts seas 12-18 feet.

02 October 2016 - JD276

2046L: Rigor starting deployment of buoy. Deployed 59d 39.707N, 170d 32.972W 2052L.

03 October 2016 - JD277

0950L: Rigor deploying another SVP buoy. Deployed 56d 51.7187N, 172d 32.796W
1054L: Crossing WP G -- starting first downslope MB line on Beringian Margin -- MB Line number 232
1850L: Crossing WP H
1919: Starting northern line to WP J

04 October 2016 - JD278

0215L: End of line, 5 min. past WP J; turning to parallel line on reciprocal heading at 3 nm off.
0242L: Start of third slope line.
0430L: Captain and Ops come to lab -- weather and forecast getting worse -- call survey to assure that we can get to Dutch.
HEADING TO DUTCH......ETA 10 AM 5 October

05 October 2016 - JD279

0200L: Arrive off Dutch but wont go in till light -- doing small survey as we wait.
1000L: Arrive at buoy -- end of surveying

HLY1603 Technical System Report

Jay Turnbull
Elizabeth Ricci
Tom Buhlmer
Dale Chayes
Adam Stenseth
Larry Mayer

Introduction

This report documents the technical performance and status of science and science related systems during HLY1603 from Nome, AK to Dutch Harbor, AK. HLY1603 was a single ship cruise on the US Coast Guard icebreaker *Healy* in support of the US Extended Continental Shelf mapping program. There were various ancillary programs collecting data about sea ice and ocean chemistry.

Dr. Larry Mayer of the University of New Hampshire Center for Coastal and Ocean Mapping was the chief scientist on the *Healy*. The primary mapping tools for the ECS cruise were the Kongsberg EM122 multibeam mapping sonar, Knudsen 320B/R sub-bottom profiler and dual BGM3 marine gravity meters. Two successful rock dredges were collected.

Table of Major events during HLY1102

Date	Event
2016-09-17	Small Boat Transfer - Nome AK
2016-10-05	Arrive Dutch Harbor

Mapserver

The *Healy*'s real-time Geographic Information System (GIS) saw limited use during *Healy1603* except for general display of ship's position and upcoming waypoints. The current Mapserver has lost many of the essential capabilities of the Mapserver used before 2012, including the ability to show historic multibeam data sets and most importantly, the ability to show multibeam data in real-time. Additionally the ability to display ice buoy movements, AIS traffic and gazetteer information are often-used features not available.

Terascan and DMSP Encryption

We did not use the Terascan system this trip; it's not very good for ice imagery and none of the weather forecast personnel (aboard, USN or USCG) are trained in its use anymore.

Science Internet Connectivity

The VSAT performed well so long as we were in range, and Adam was able to squeeze a few more (geographical) minutes ranging to almost a degree by nudging the system's default behaviors at the extreme edge of rated range (adjusting the sweep-search pattern, changing the signal quality and strength thresholds, etc). By and large the system performed as expected.

The iridium openport was patched into the SDN on the bridge, VLAN'd to a tightly-controlled dual-homed virtual machine in the lab and used explicitly to acquire high-resolution satellite imagery. It was more successful than we expected (performance exceeding that of the Geotraces mission last year, the last time *Healy* spent significant time out of geostationary satellite range), and we were able to get usable satellite imagery throughout the bulk of the far north period.

The iridium reachback system functioned at or above expected parameters. It maintained usable link 95+% of the time, allowing small emails to be transmitted. We started out at a 400k limit for messages, but this was reduced in stages to 150k because the outgoing queue was clogging. This level kept mail flowing quite quickly and only generated a couple of complaints.

EM122:

When the STARC team arrived on board they found several issues with the EM122 including failure of the SeaPath MRU to generate PPS signal, erroneous time-stamping on datagrams, and significant failure of the BIST indicating problems among more than 20% of transmit array. We swapped to POS and eventually got the system running with appropriate time-stamps - though clearly limited transmit power. System would not run in dual pulse mode but was able to collect data in single-pulse mode with limited swath width (2-2.5 times water depth max) throughout the cruise. A detailed report on the EM-122 will be included in a separate document.

SIS Version

SIS Version 4.3.0 was used during this leg. A compound problem presented early in the cruise when, due to a dead battery on the PU card in the EM122 TRU, the initial few days of SIS files were written and logged with incorrect dates (2004-2005 era). The dead battery prevented the system time being maintained in the PU card over TRU shutdown/restart events. This issue, combined with an incorrectly set SIS software parameter (PU-ZDA string not being set to the current time), caused filenames to be written with incorrect dates. The problem was corrected by setting the reference time in SIS to the computer clock, and then setting the reference time back to the PU-ZDA input string.

After the above was resolved, SIS was stable throughout the leg.

Real-time data access

To provide near real-time access to the ***raw.all*** files logged by SIS, we ran an instance of rsync on the SIS computer to copy to *HEALYNAS* from where it is used for processing and archiving. This also allows access to the sound speed profiles (.asvp files) used by SIS from *HEALYNAS,* with data co-located with the multibeam ***.all*** files.

Generating sound speed profiles for SIS

UNH/CCOM SVP Editor Version 1.05 (2012) was used extensively during the leg to edit XBT data and transmit it to SIS. NB - a newer version exists and the shipboard version should be updated

Helm display:

STARC installed a computer with SIS helm display in the meteorological lab, located aft of the chart area on the portside wing of the bridge. The display was and remained operational through the duration of the AWS16 cruising season, albeit inconveniently placed for watch standers.

Ship's ETs installed & configured an overhead display system for the computer, which routed through a switching control system in the nav annex on the starboard wing. Initial installation encountered some problems with power regulation at the point of the switching system, though ultimately this was (temporarliy, as it happened) resolved and the overheads were functional through the duration of at least 1601. At some point subsequent to that, the system stopped working due to power-related failure of electronics in the nav annex area. The exact nature of the failure is still being investigated by the ship ETs and EMs.

Built In Self Tests:

We collected and logged BIST (GUI and TRU) tests extensively at the beginning of the cruise to try to diagnose system problems. The results of these tests are included in a separate document describing EM-122 problems.

Watchstanders:

Watches were stood by three people per 6 hour watch. Each watch had one individual dedicated to processing data and the other two monitoring the EM122 and the Knudsen Subbottom system.

Watch Standers Workstation

During a typical shift a watch stander in the computer lab is required to make operational adjustments of multiple systems such as the MBES, Subbottom profiler, Mapserver, METGps and the ship's camera system. These instruments are presented on 12 LCD displays located along the aft wall of the lab. The way information from these systems is presented onto the displays can be improved. The issue relates to which user interfaces run on which computers and how those computers then display those interfaces across multiple monitors. For example, it was routinely required to obscure the subbottom profiler to view the live METGps feed. The information from both of these systems is was often required simultaneously, thus having to hide a window reduced a watch standers awerness of a critical system. Enough monitors are available to display each critical system. Additionally, the ability to view the ship's navigation system would greatly increase situational awareness. The nav system provides time to target and contact information which if made available could provide insight into the ships navigational decisons. A situation like the ship avoiding another vessel can greatly affect an ongoing survey and could easily be predicted or explained by glancing at the nav screen. Lastly, the watch stander has no tools available to assist in navigational planning of science operations. As things changed during the cruise it was common to require new navigational plans be developed relating specifically to survey planning. For a watch stander to provide a new course of action the ships navigational system and a survey planning tool should be available. The survey tool should also integrated live data from the MBES to ensure full coverage of survey lines.

Knudsen 3260 sub-bottom profiler

When we arrived on board we found that the Knudsen 3260 profiler was not synched with the EM-122 nor was it receiving a heave correction. This situation was eventually remedied (see STARC log) and the system performed well for the duration of the cruise. Watchstanders did not the complexity of needing to make changes on a monitor that was not the prime viewing monitor and not at eye level. . See APPENDIX F for further details on the Knudsen system.

POS/MV-V5:

On the previous Healy cruise leg, the port side POSMV antenna and cable had failed. A spare antenna and cable were brought to Nome for replacement. Installation of the new antenna and cable was performed at anchor and the POSMV heading was observed to be 180° off from the ship's true heading as reported by the ship's gyro compasses. This indicated that the antenna cables were transposed. The antenna cables were connected to the appropriate inputs and this corrected the heading problem. No existing or current documentation of the antenna offsets for the port and starboard POSMV antennae were located.

The POSMV was used as the primary source during this cruise and there were no further or unusual issues.

Seapath 330+:

The Kongsberg Seapath 330+ system was reported to be operational during the previous cruise. STARC technicians on this leg observed the system presenting multiple alarms: Degraded heading and position, degraded heave, pitch and roll, PPS sync lost, and IMU data not valid. Troubleshooting spanned the cruise duration. An investigation of the site installation, in combination with emails to KM Seatex support, determined that the signal carried over the hard-wired signal cable was degraded with high-frequency noise. This cable connects the Seapath PU unit in Rack 4 in the computer lab to the MRU located in IC-Gyro compartment. The cable was disconnected from the Seapath PU and the MRU junction box and taken out of service. A temporary RS422-to-fiber conversion was installed and routed and the Seapath 330+ system cleared the software alarms. The issue will be addressed in port.

CTD System

No CTDs were taken during the leg.

Anemometers

The RM Young ultrasonic anemometer model 85004 mounted on the starboard main mast was observed to report anomalous wind speeds. Visual inspection of the sensor showed ice accumulation on the four ultrasonic horns. The instrument configuration was queried and observed to have its internal 60W heater activated. Testing of the anemometer power supply located in the AloftConn overhead indicated the heater circuit was energized and functional. External environmental conditions prohibited checking the sensor in its installation position on the starboard yard. The issue was not resolved until the ship transited into a warmer environment that melted the ice.

One example of anomalous wind speeds was on September 22 as shown in the figure below.

Port and starboard vane / impeller anemometers were observed to be functional, although data were not being consumed by the MET data acquisition system.

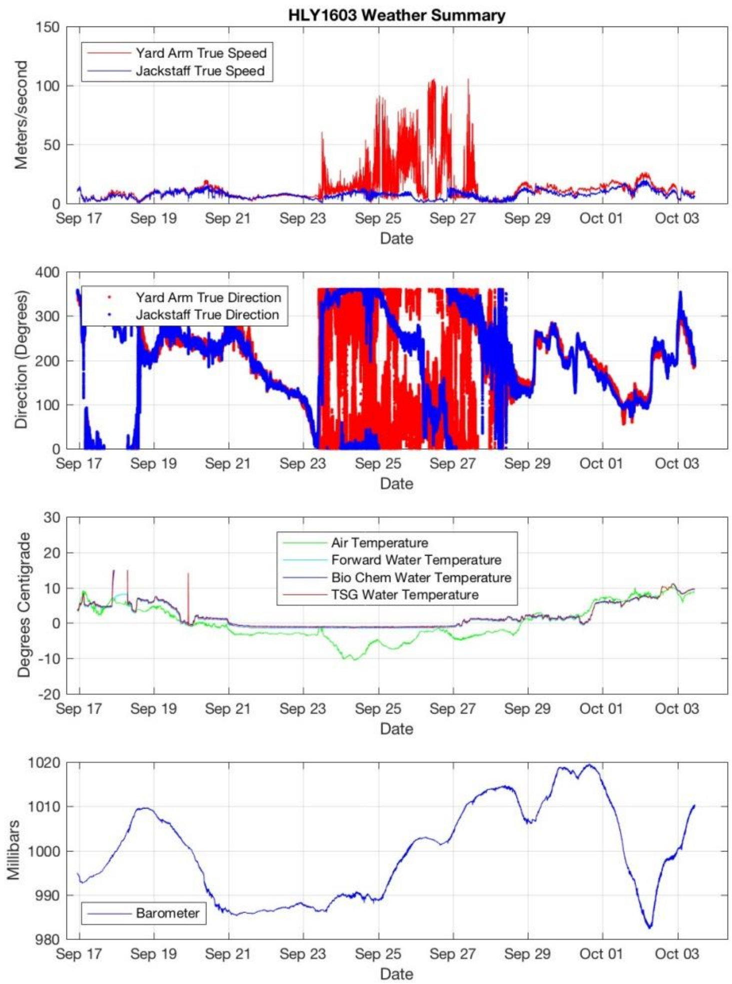
METAQS

The SIO MET System was the primary real-time data logging system for this cruise. All data consumed by the system were logged to *HEALYNAS*. A secondary serial server functioned as the back-up for the real-time system. Time stamp discrepancies in MET generated files were observed for the data files logged on 2016-09-19. Emails to shore determined that the PC clock had drifted and corrected itself against the GPS time.

Data displayed by the MET system were monitored by watchstanders and technicians during the cruise.

Serial01 – This is a secondary backup computer that logs serial data feeds and prepends them with a POSIX time stamp (seconds from the epoch of 0000UTC on 1970/1/1). Data were logged to *HEALYNAS.*

Summary meterogical data are presented below; clearly there was a problem with icing on the yard-arm wind speed sensor between 23 and 27 Sept.

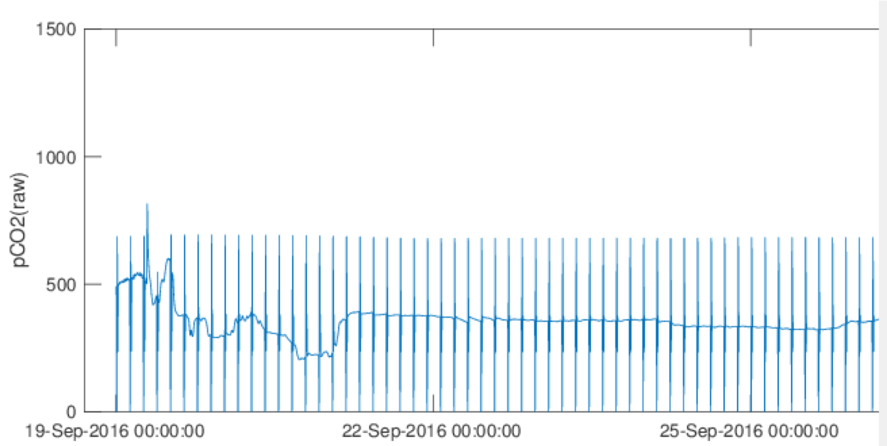


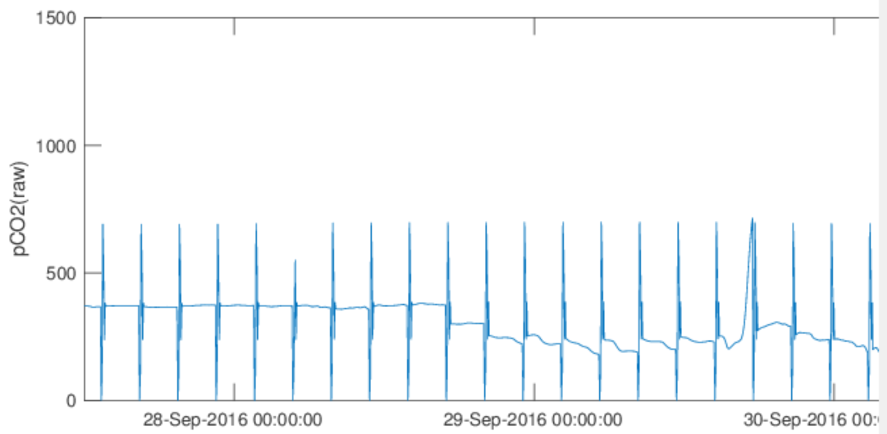
Data Distribution

Tom generated the end of cruise data distribution for the chief scientist and for transfer to R2R.

pCO_2 System

Early cruise through the Bering Sea appears normal. The periodic spikes are when it runs a few standards. In between these the data seems to follow predictable trends. Through the Canada Basin, things seem normal--very steady. But, by the time we leave the Canada Basin, there seems to be a bit of a memory effect that kicks in (following standards), and then some really weird spikes, and long period noise. See examples below:



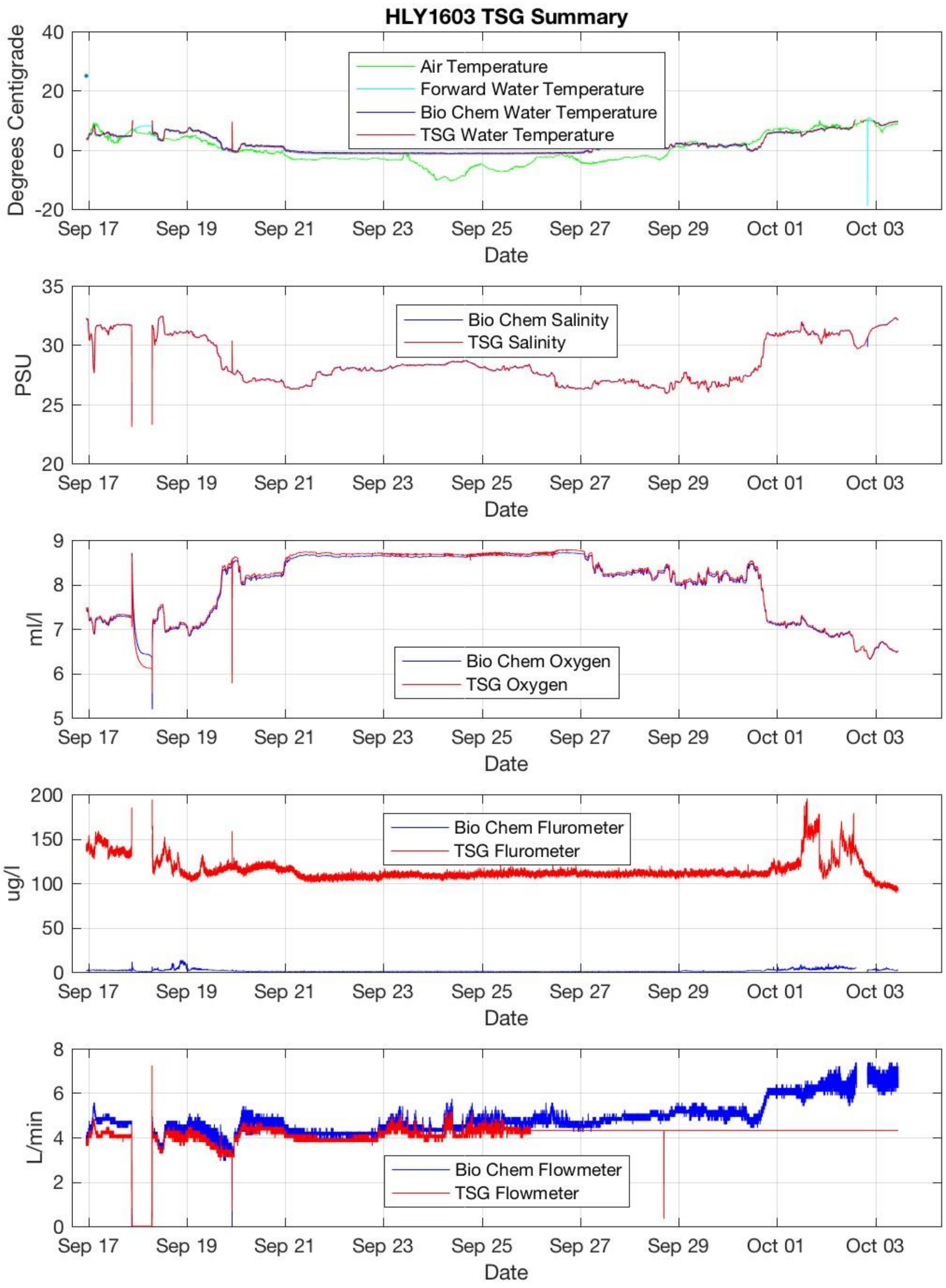


Science Sea Water System (SSW)

On rounds, the port side SSW flow-though system in the wet bio lab compartment was observed to have a leak in the debubbler intake. The intake hose had partially separated from the debbubbler's barbed coupling and water was observed spraying into the overhead. The system supply valve on the starboard bulkhead was secured and the hose reconnected with a hose clamp. The supply valve was opened and controlled flow was reestablished. The main power supply on the starboard bulkhead required a power cycle to return the SSW underway flow through sensors to an operating state.

Flow through sensors

The *Healy*'s flow through sensors for this leg included redundant port and starboard systems of a SeaBird TSG (SBE45), Dissolved Oxygen sensor (SBE43), a remote temperature sensor (SBE3) and a Turner Flurometer, and a flow meter. All data were logged by the MET system.



Flow Meter

The flow meters in the port side and starboard side SSW system functioned normally.

ADCPs

ADCPs were not run during HEALY1603 due to lack of synchonization with EM122.

Expendable Probes (XBTs)

Approximately 65 XBTs probes dropped. At the beginning of the leg there were numerous failures when T-5s were used. Switching to T-7s and Deep Blues which work at higher speed seem to rectify this problem. A detailed log and map of CTD locations can be found in a separate Appendix. The SVP Editor proved extremely reliable and greatly simplified transmission of XBT data to the EM122.

Gravity Meter

BGM-3 Gravimeter:

On initial walk-through of the ship, DNV fault light was found illuminated on the communications module and gyro power supply units. STARC fowarded results from email chain with Potential Fields Group. Essentially, STARC replaced a backplane and the gyros stabilized the platform, and the fault light cleared. The DPM was flaky after this swap, flickering and displaying garbage characters. After about 20 mins the display stabilized and returned to displaying data. Potential Fields Group notified on the fixes. See email sent from Friday 2016-09-23.

Both the IC gyro racks are a cabling mess. There are at least three UPS units unsecured on the floor, and gravimeter spare parts in a plastic tote and plastic pelican case on the floor. Two MRU boxes, one empty, one with an MRU, are on the floor too.

STARC was able to locate gravity data being logged with a time stamp. It is coming in and being logged by serial01 and is being time-stamped as from healynas.healy.polarscience.net - /Data/hly1603/data/sensor/serial_logger/bgm-3/

Of important note, STARC found there are historical gravity data from 2012 seasons onward to the present cruise except for **HLY1301**, for which no serial data for any sensor exist in the data logger folder.

Aloftconn, Aftconn and Main Lab web cameras

The web cameras worked well during this cruise.

Winch wire data monitoring system

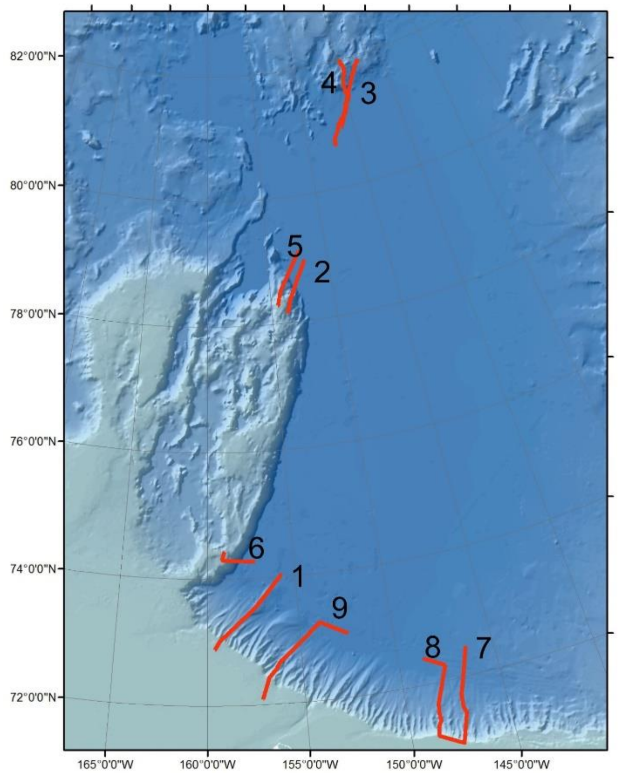
We intended to use the real-time, high precision, scrolling python application that Dale Chayes developed and used during HLY1202 ECS leg to support real-time decision making during dredging operations for this (HLY1603) leg.

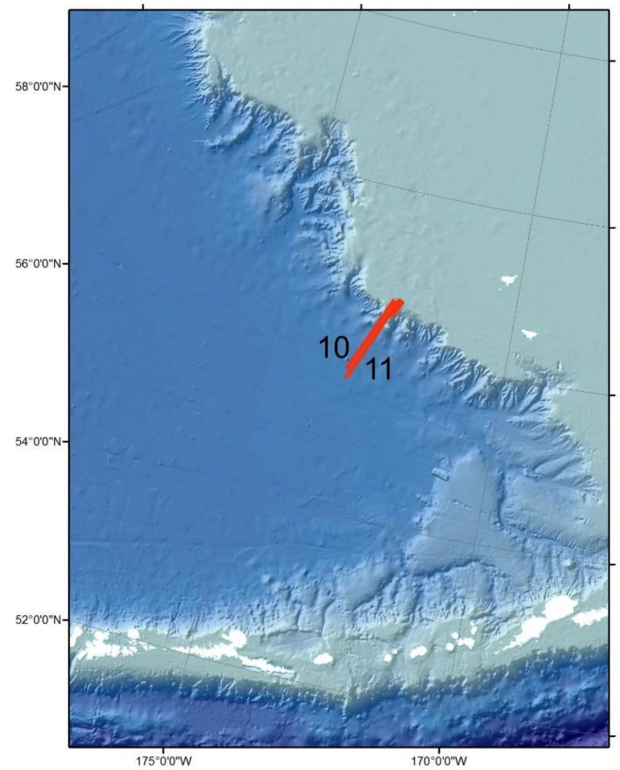
A few days prior to arrival at the dredge site Dale tested the code and found that the real-time UDP datagrams with the winch wire data were not available at the UDP port used in 2012. Exploration of other possible sources and discussion w/ the onboard STARC and C4IT/ESU Polar science technical support did not turn up any answers nor were any forthcoming from shore. Prior to the station Dale was able to verify that the data were being logged by the science data system.

The technical support folks on board were eventually able to provide a source of real-time UDP datagrams in a different format and rate the night before we arrived on station. We were able to modify the code for the real-time high resolution plot running just in time to provide the necessary tension monitoring during the two successful dredge stations.

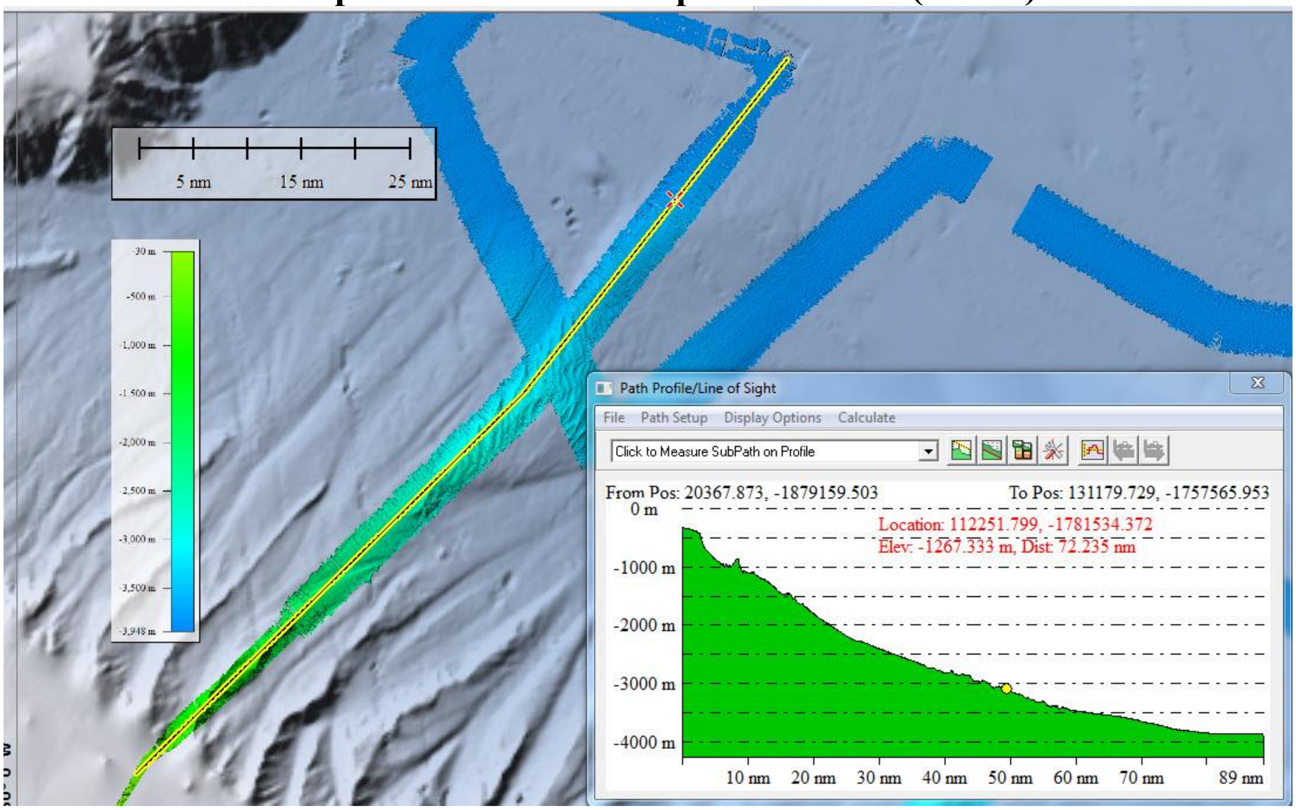
Appendix A: Foot of Slope Crossings

OVERVIEW OF HEALY 1603 FOOT OF SLOPE CROSSINGS

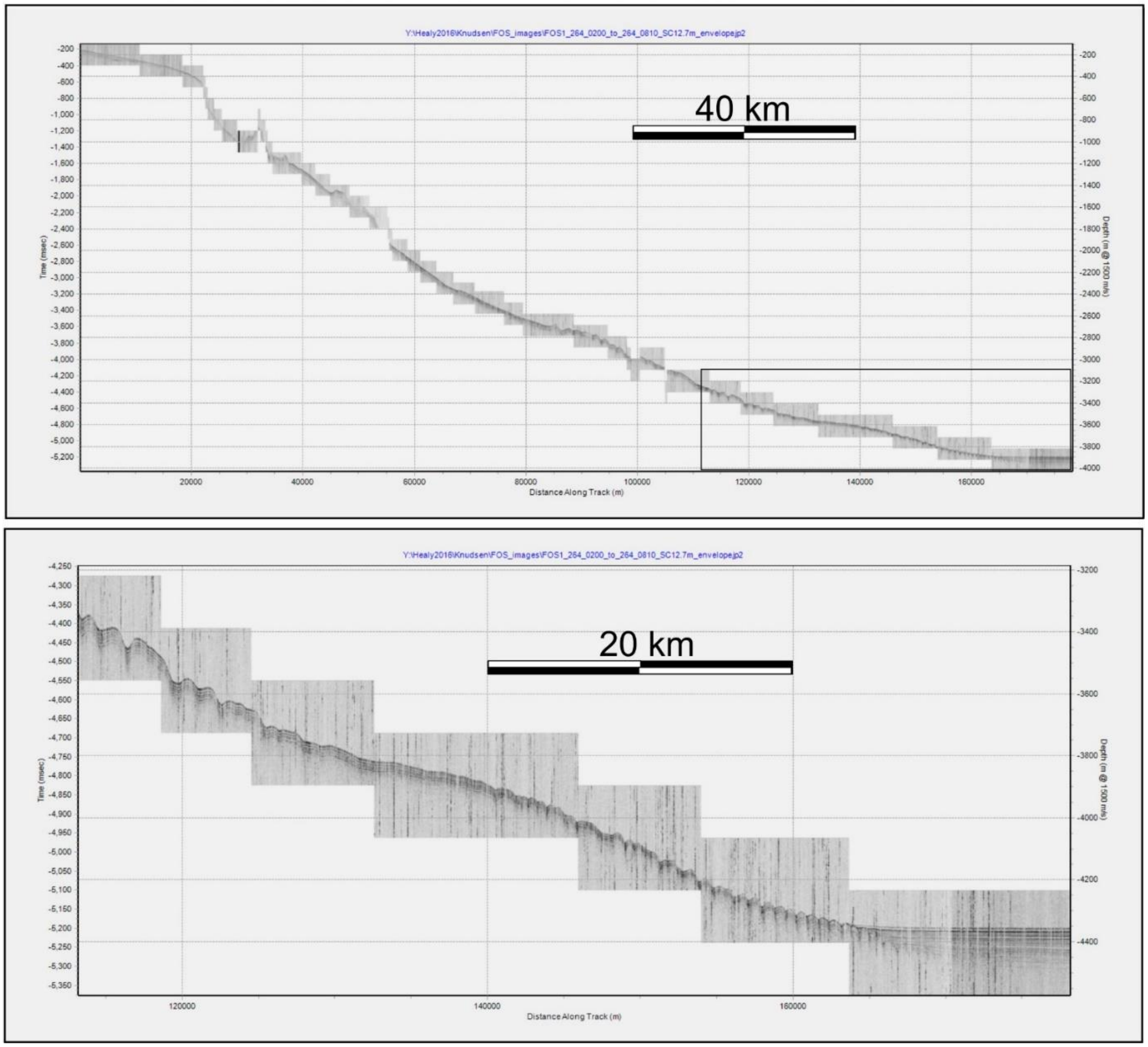




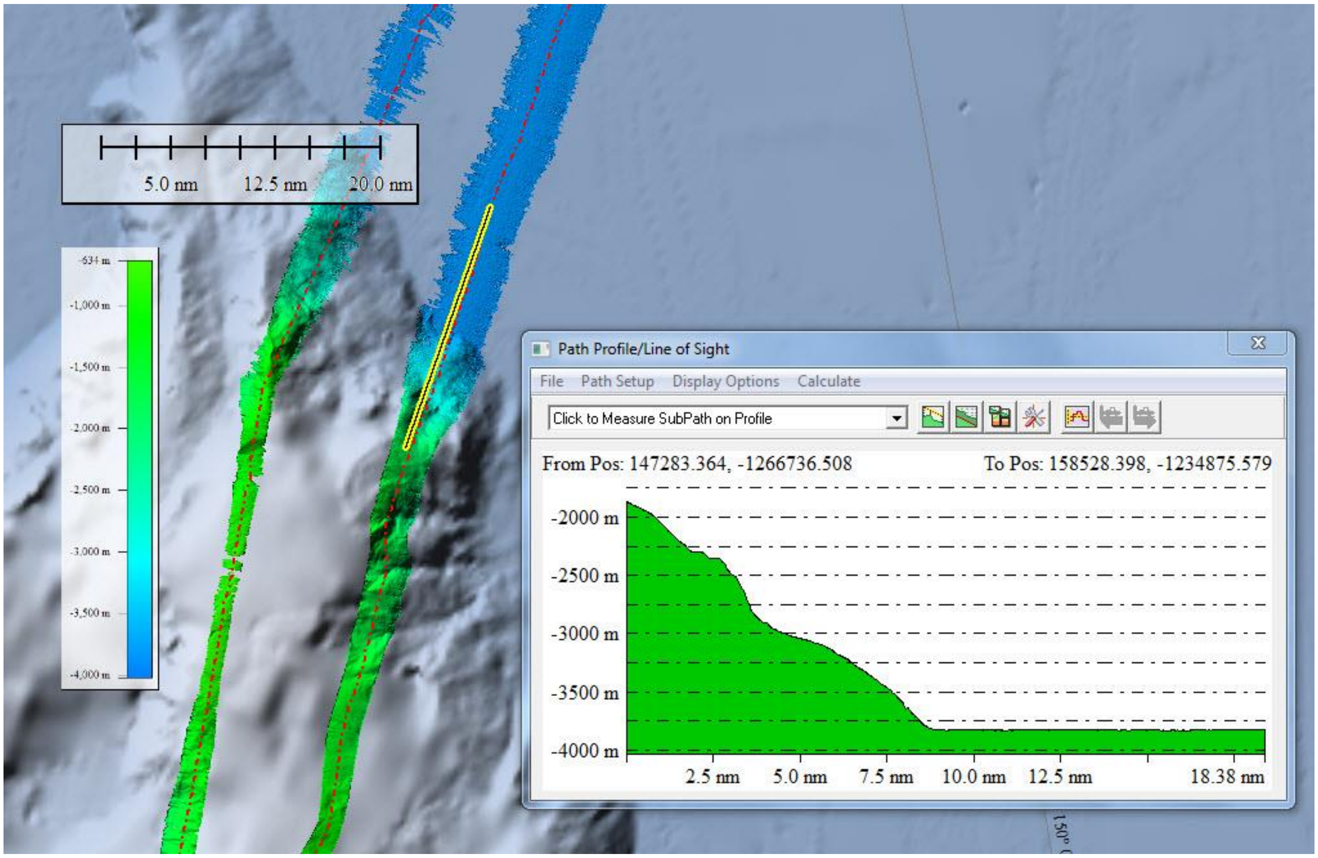
FOS 1 20 Sept 2016 0240Z - 20 Sept 2016 0820Z (JD264)



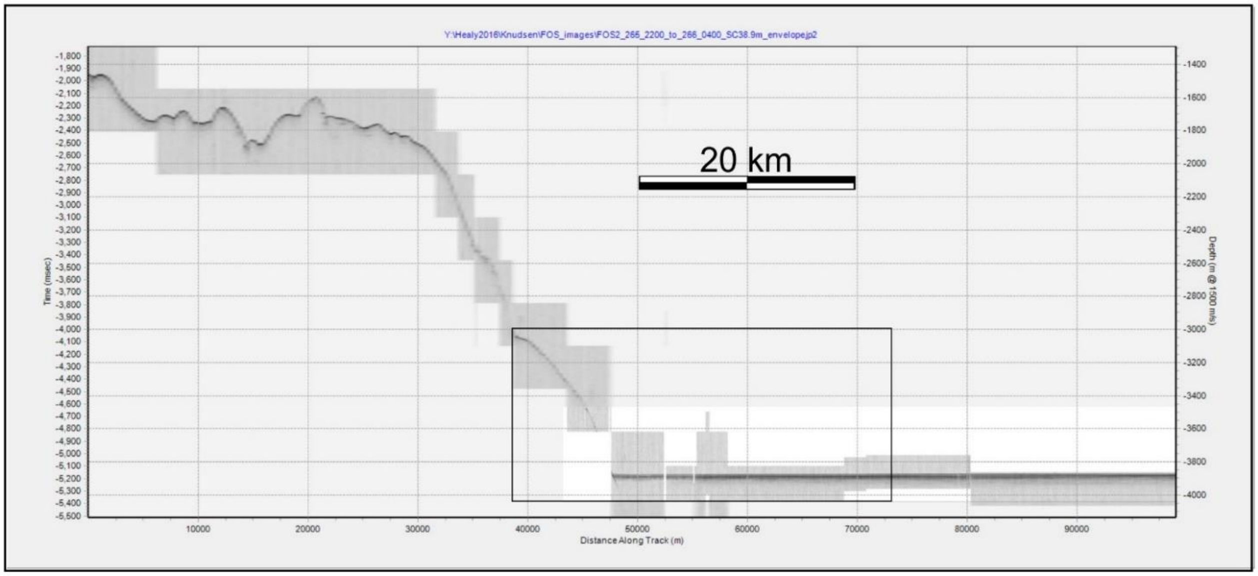
HLY1603 FOS 1 264/0800 - 264/0810

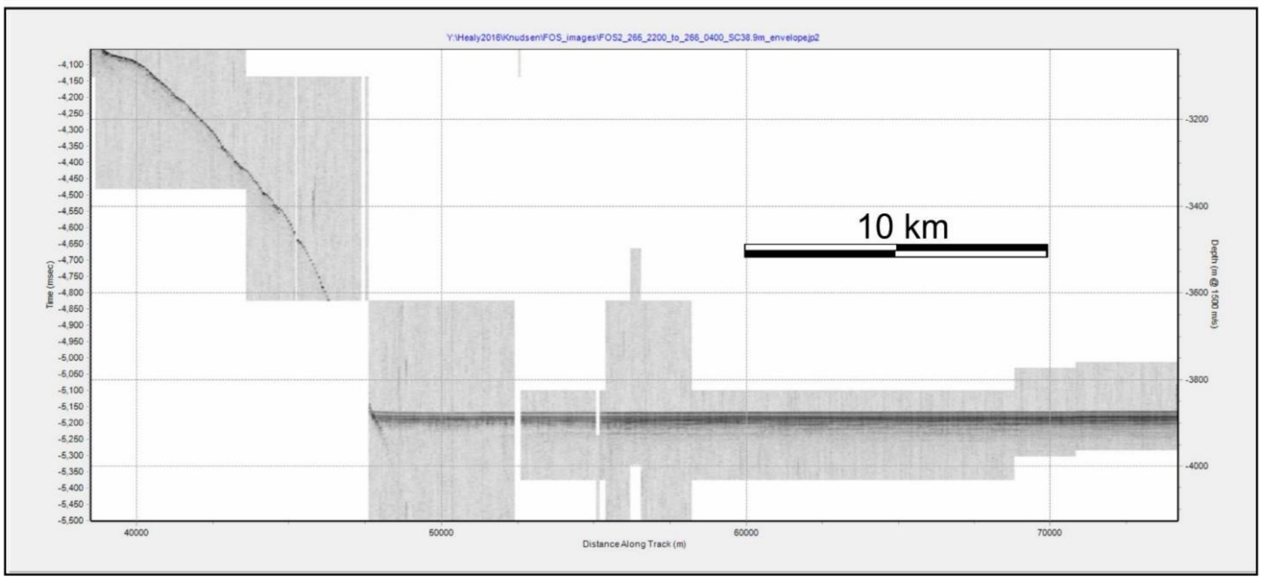


FOS 2 21 Sept 2016 2346Z - 22 Sept 2016 0144Z (JD265 and JD 266)

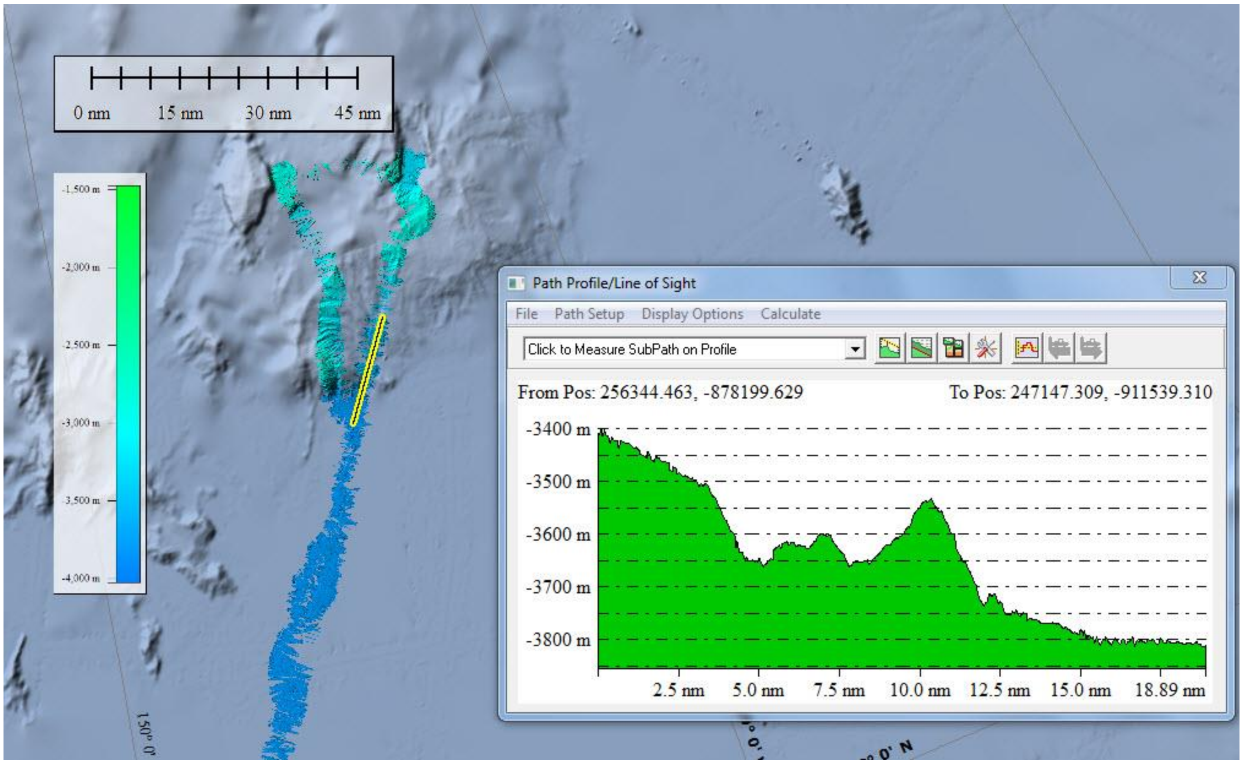


HLY1603 FOS 2 265/2200 - 266/0400

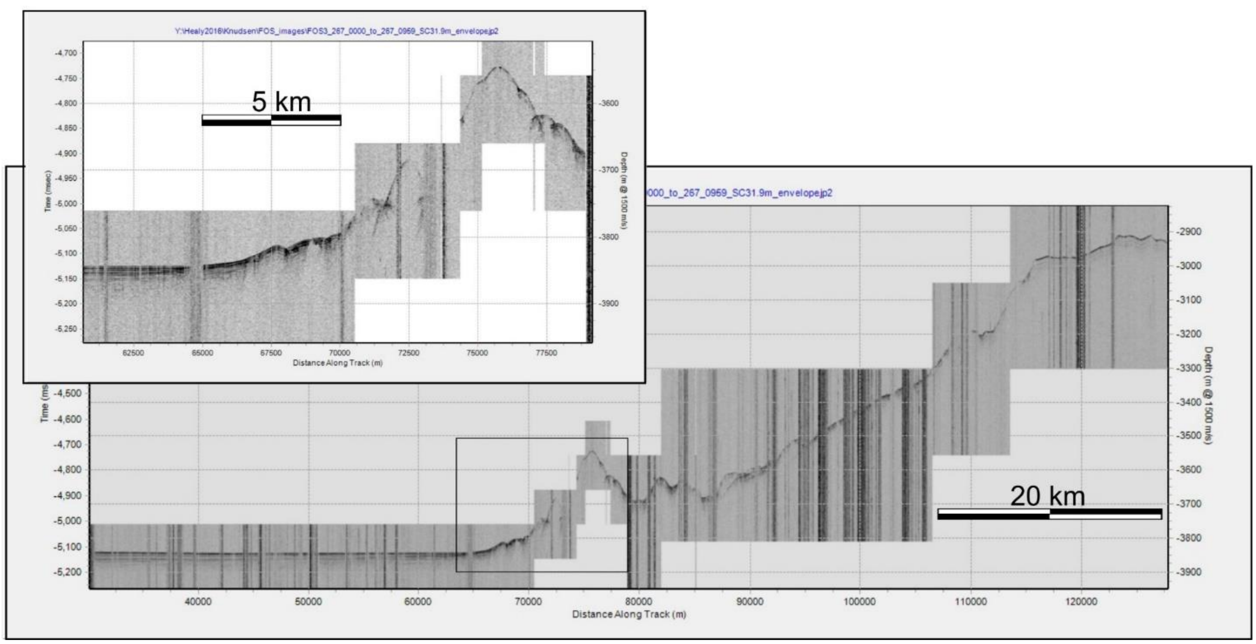




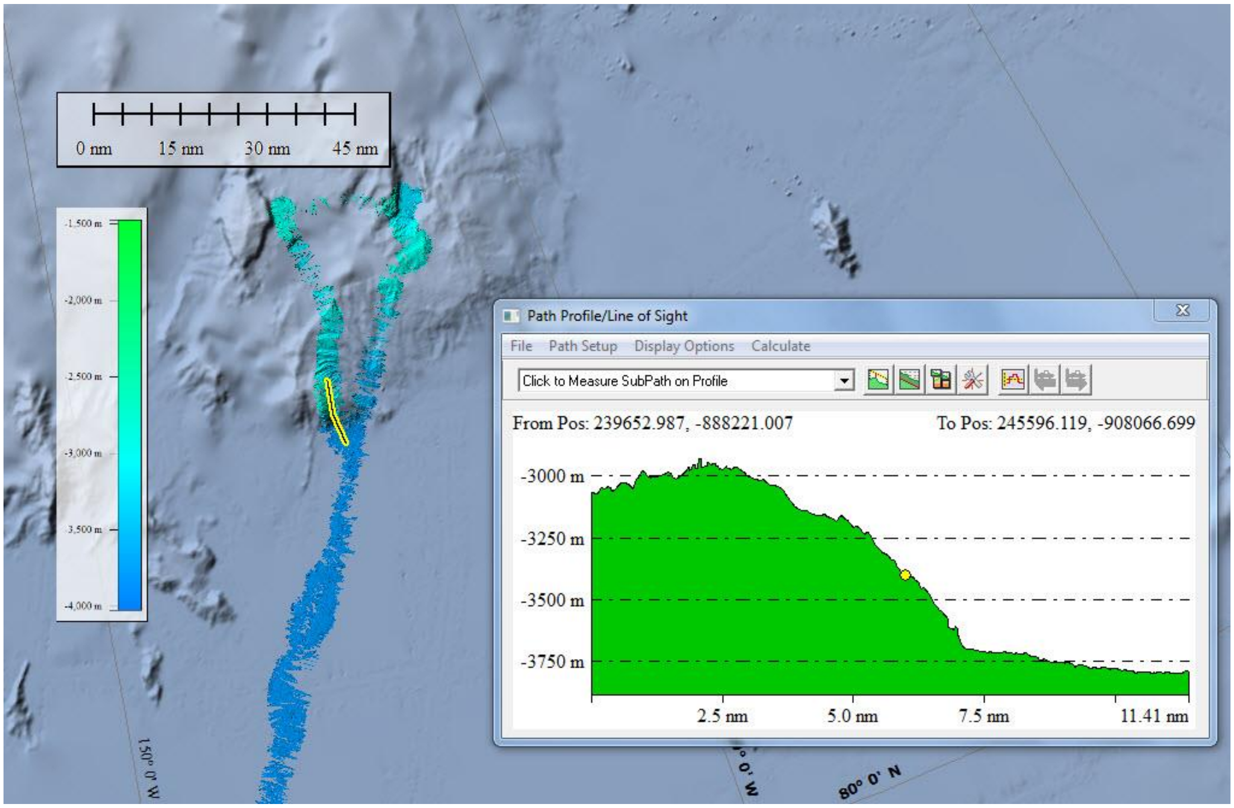
FOS 3 231 Sept 2016 0430Z - 23 Sept 2016 0710Z (JD267)



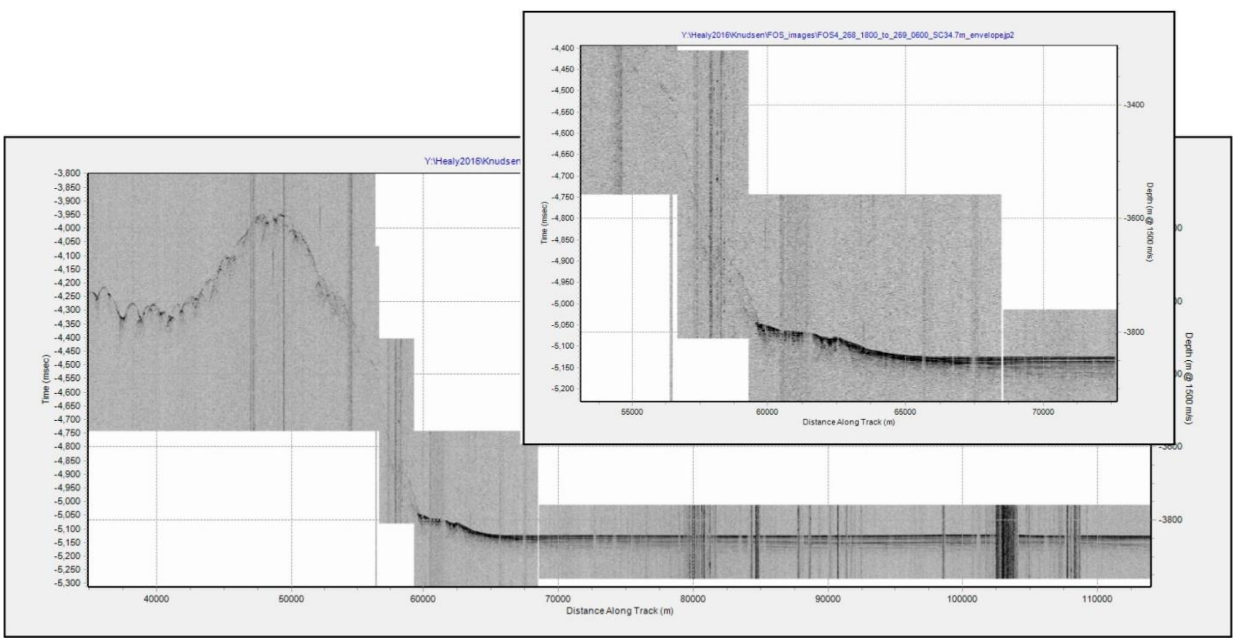
HLY1603 FOS 3 267/0959 - 267/0959



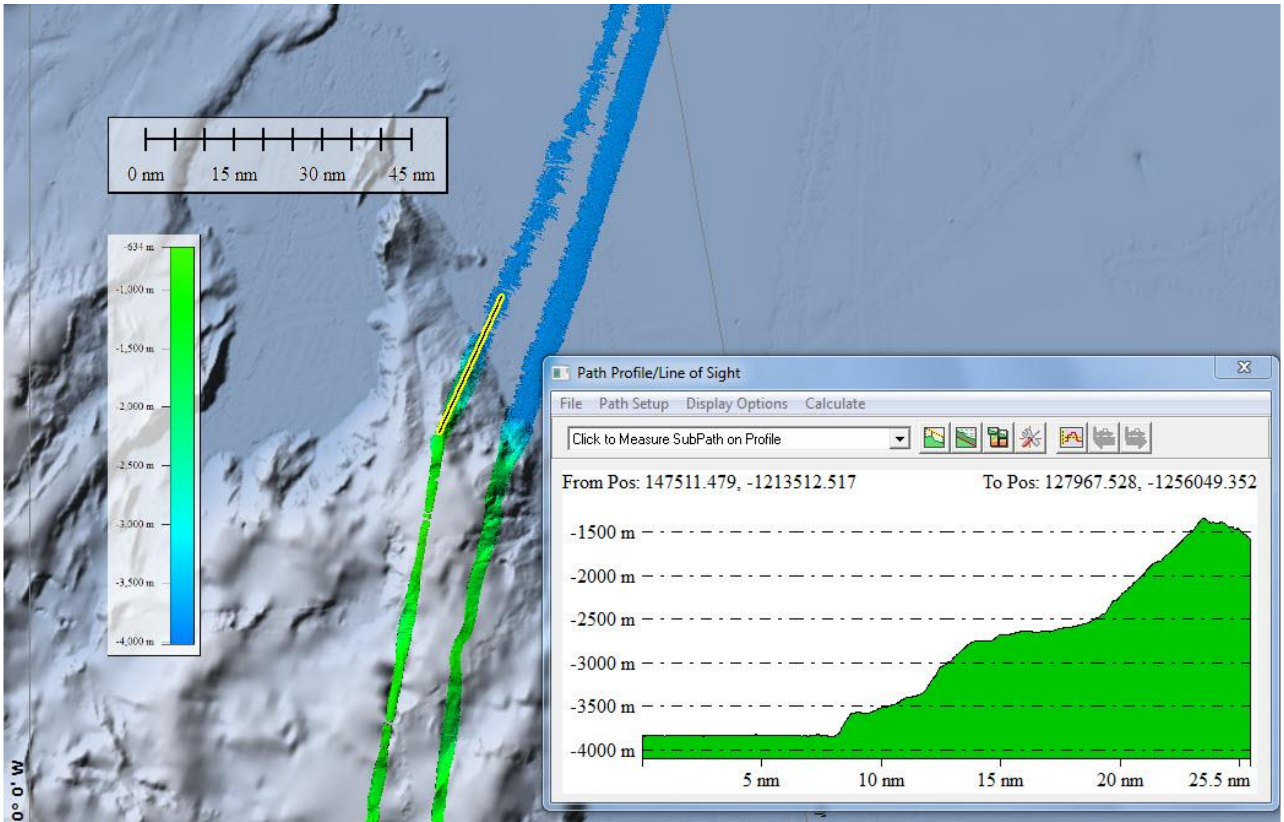
FOS 4 24 Sept 2016 2154Z - 24 Sept 2016 2312Z (JD268)



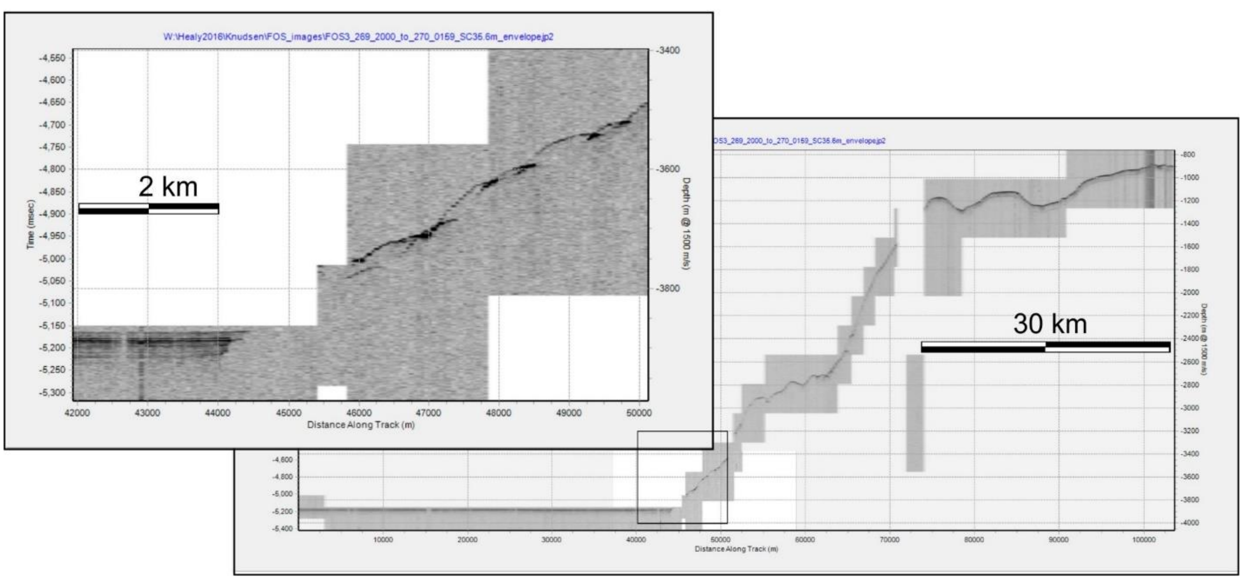
HLY1603 FOS 4 268/1800 - 269/0600



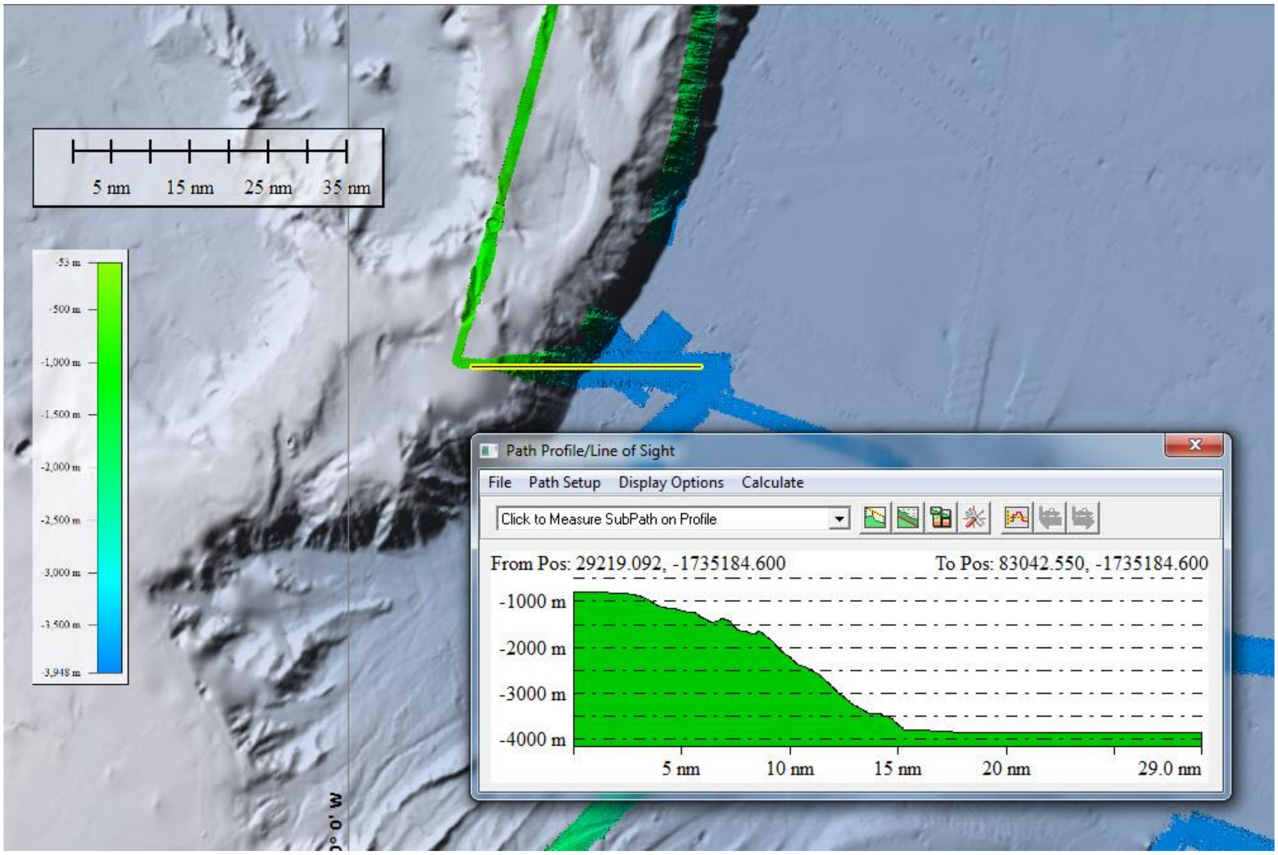
FOS 5 25 Sept 2016 2140Z - 26 Sept 2016 0020Z (JD266 and JD 267)



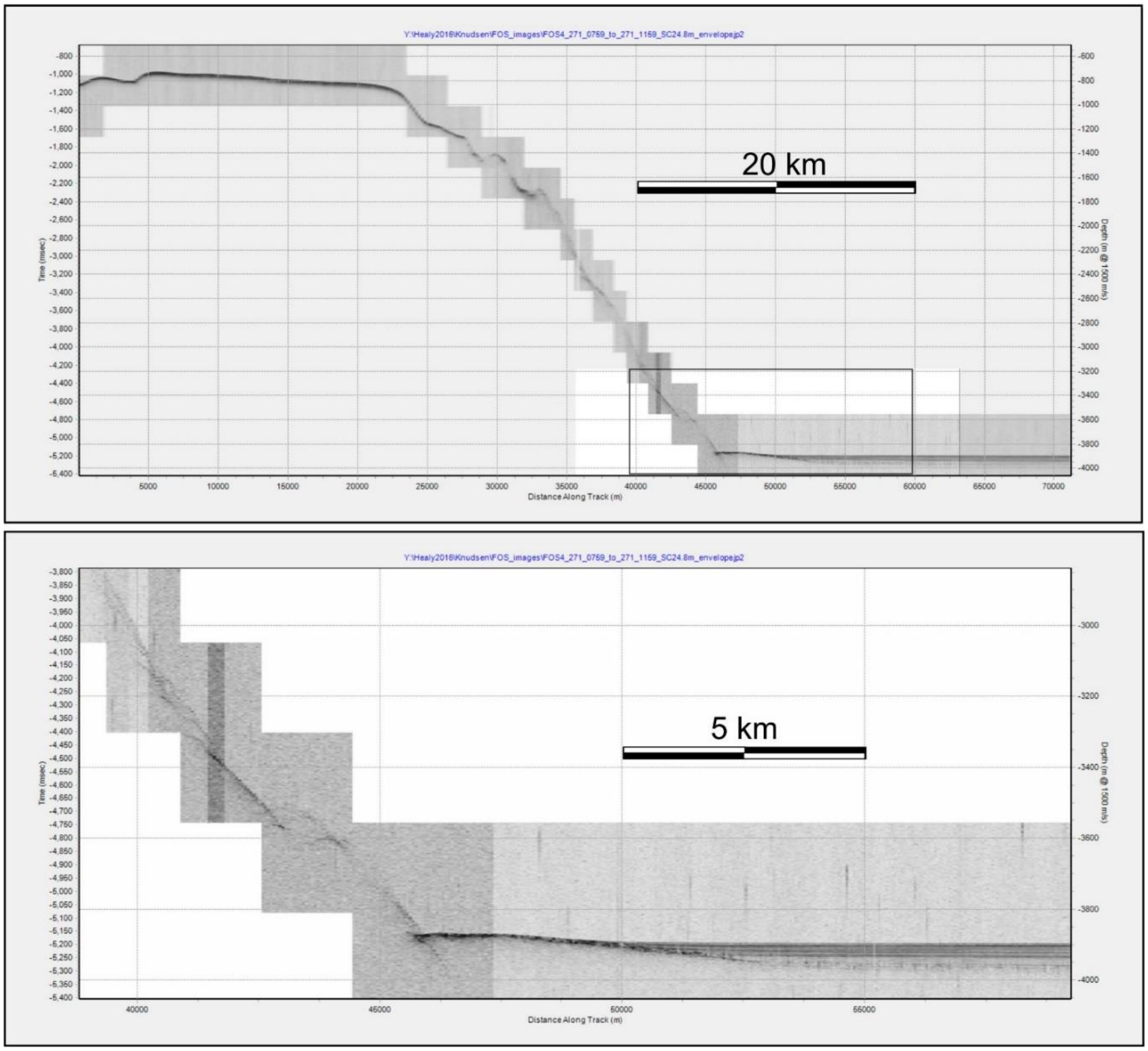
HLY1603 FOS 5 269/2000 - 270/0159



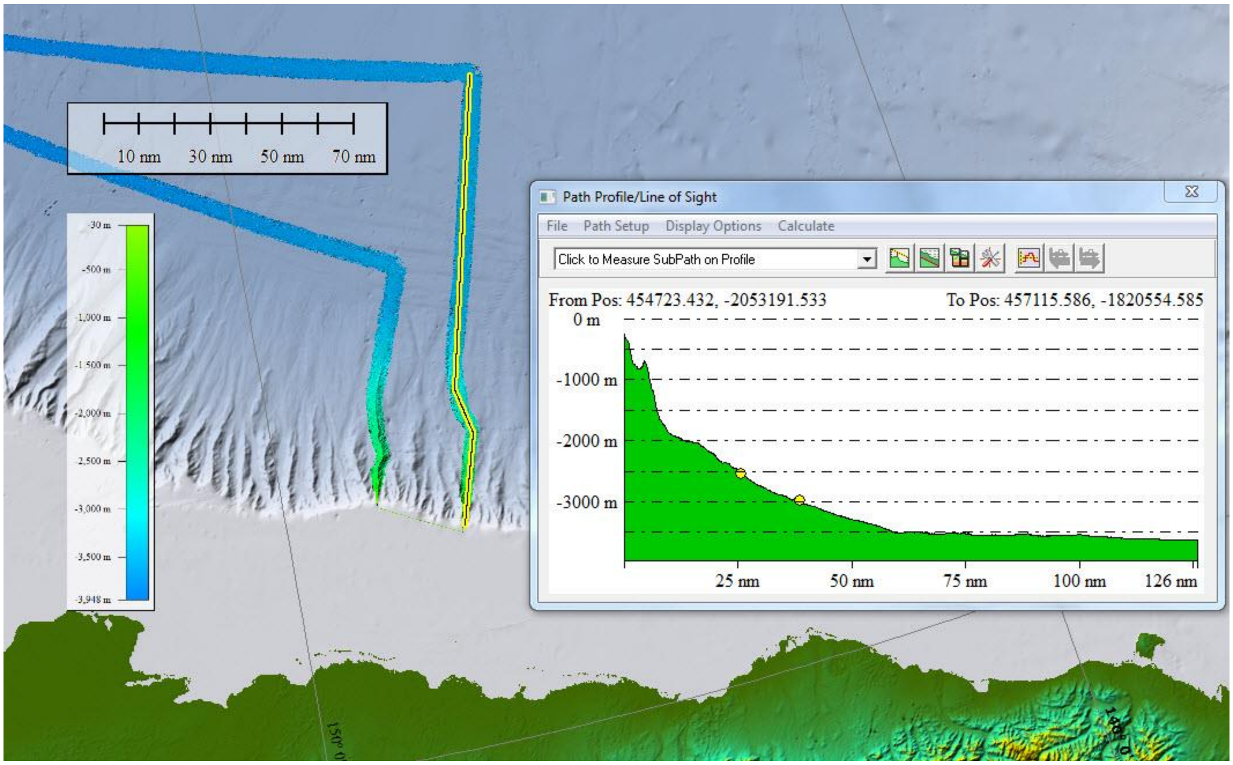
FOS 6 27 Sept 2016 0900Z - 27 Sept 2016 1146Z (JD 271)



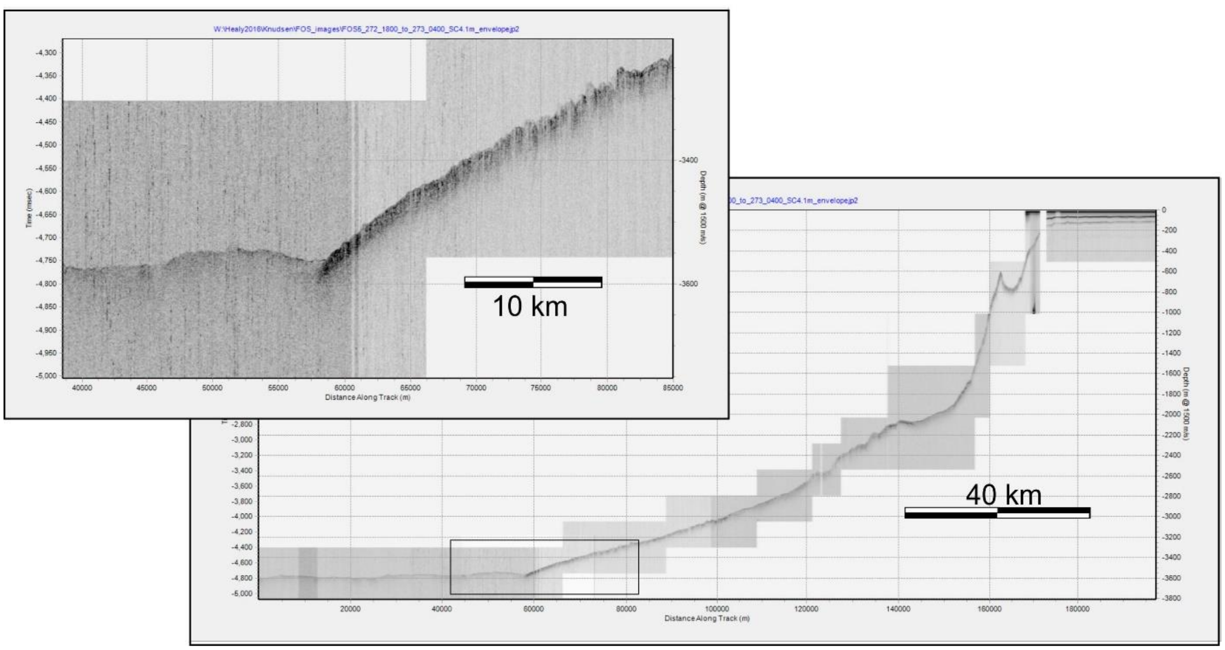
HLY1603 FOS 6 271/0759 - 271/1159



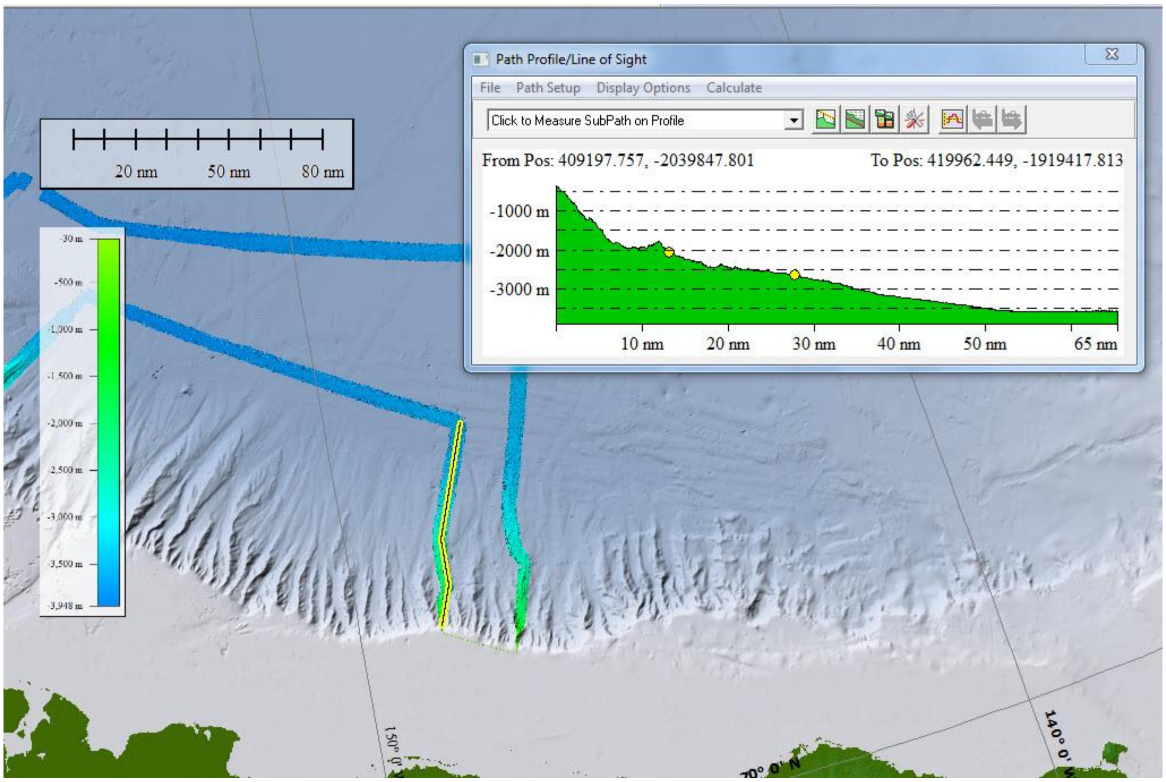
FOS 7 28 Sept 2016 1510Z - 29 Sept 2016 0240Z (JD 272 and JD 273)



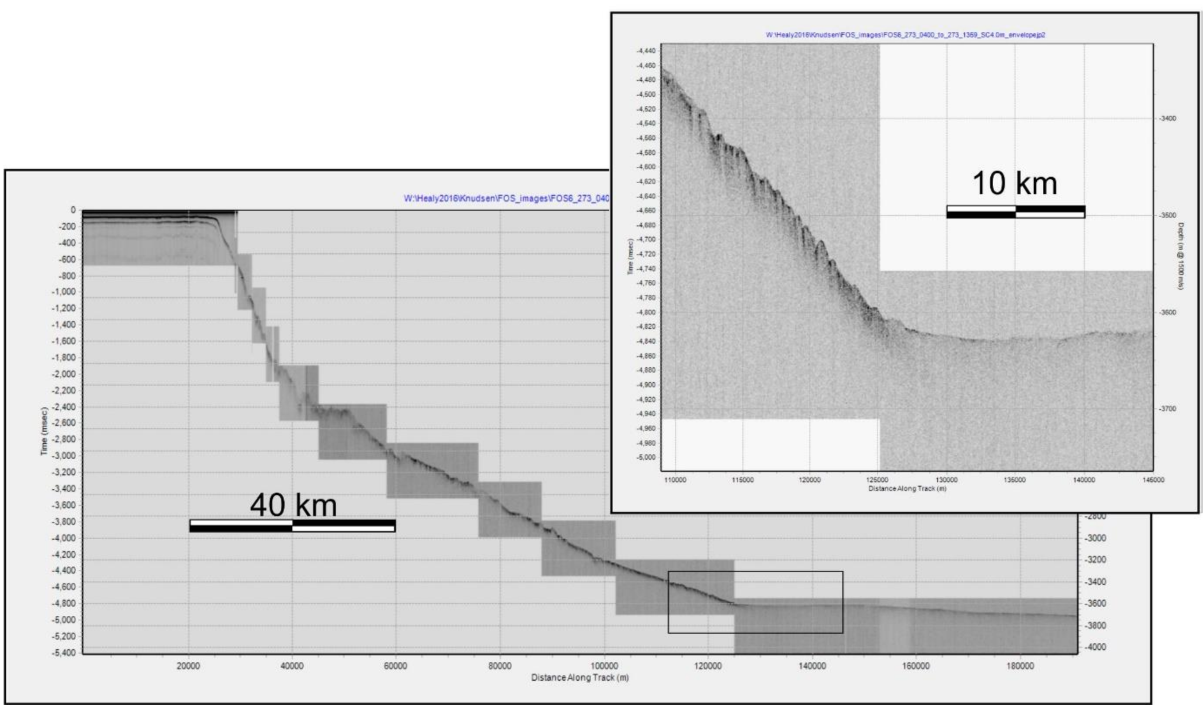
HLY1603 FOS 7 272/1800 - 273/0400



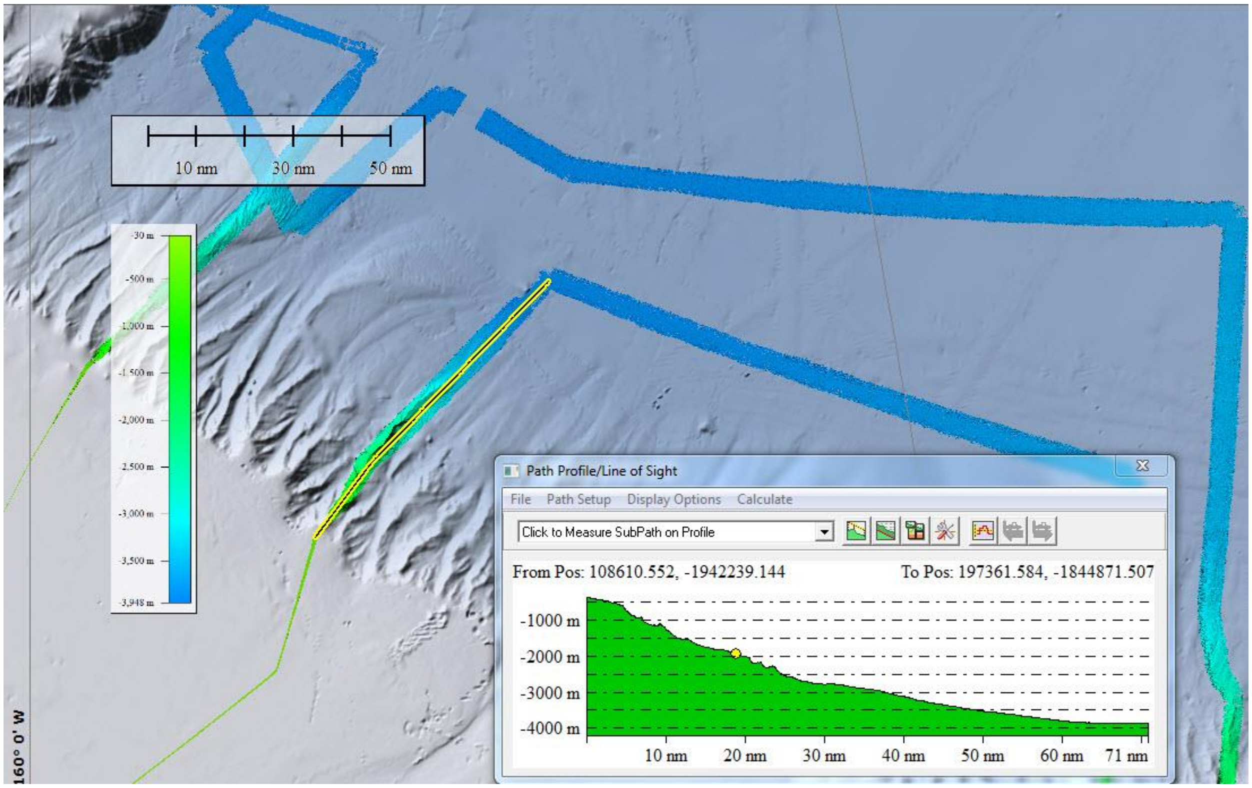
FOS 8 29 Sept 2016 0532Z - 29 Sept 2016 1217Z (JD 273)



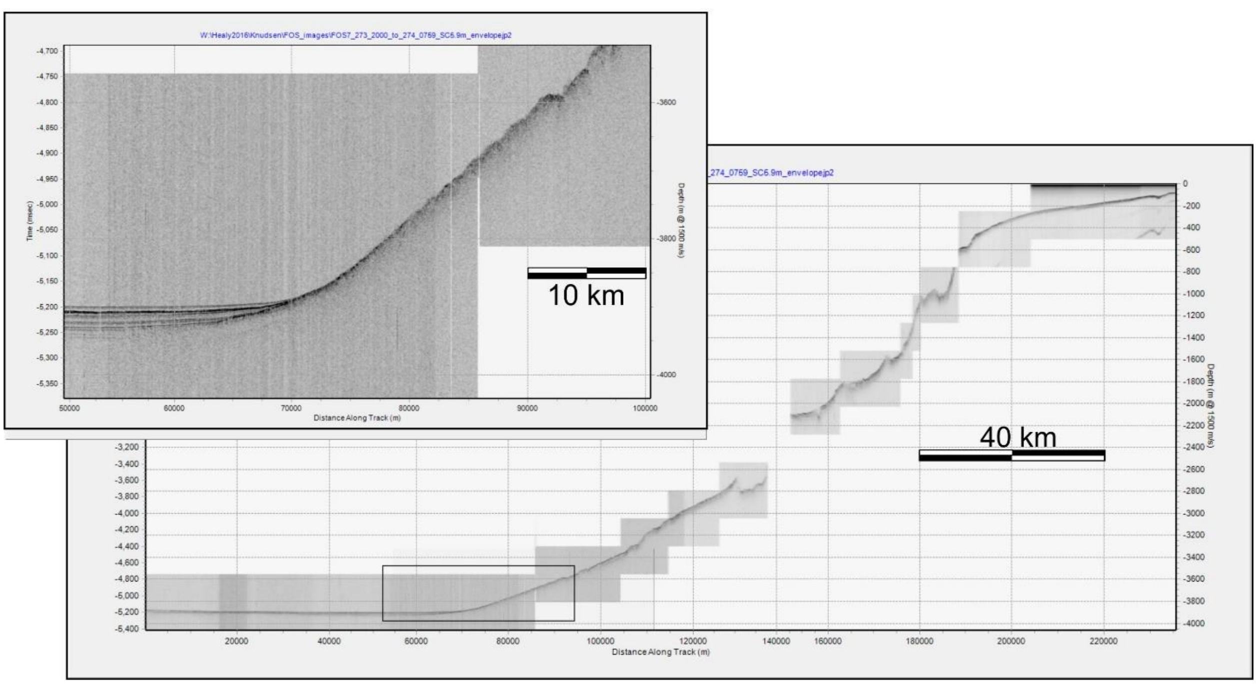
HLY1603 FOS 8 273/0400 - 273/1359



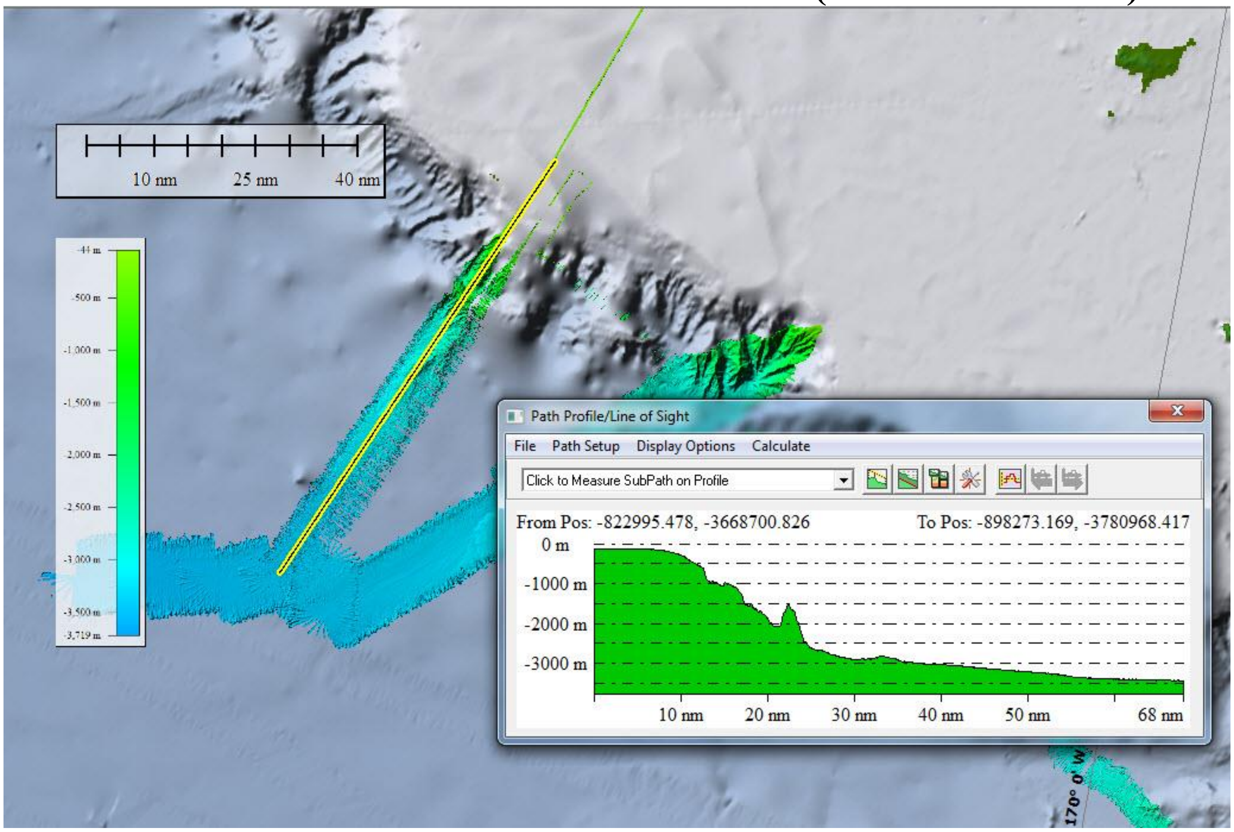
FOS 9 29 Sept 2016 2212Z - 30 Sept 2016 0600Z (JD 273 and JD 274)



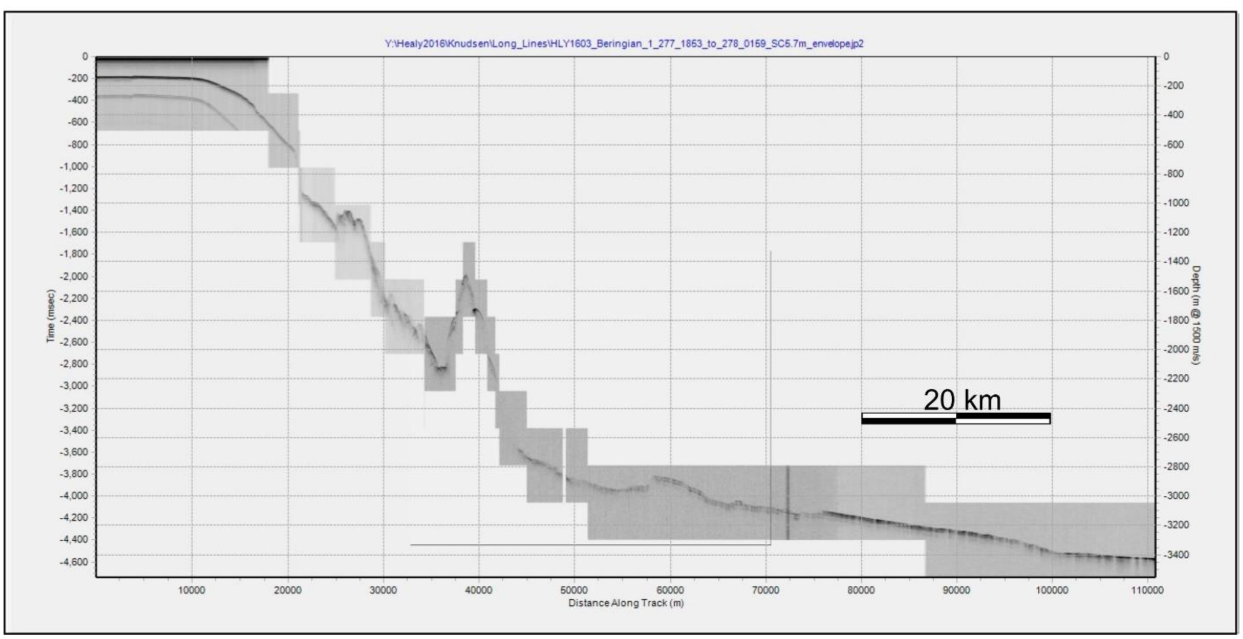
HLY1603 FOS 9 273/0200 - 274/0759



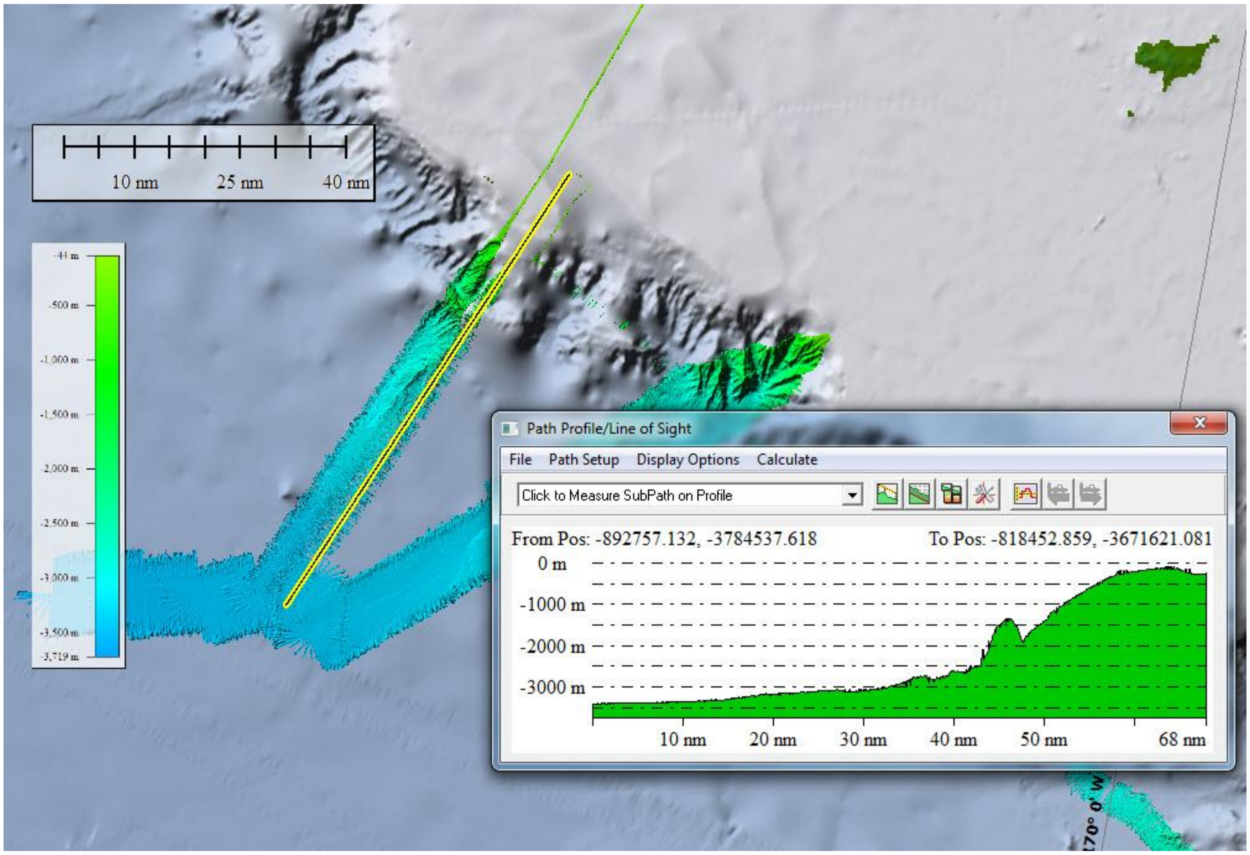
FOS 10 03 Oct 2016 1843Z - 04 Octt 2016 0247Z (JD 277 and JD 278)



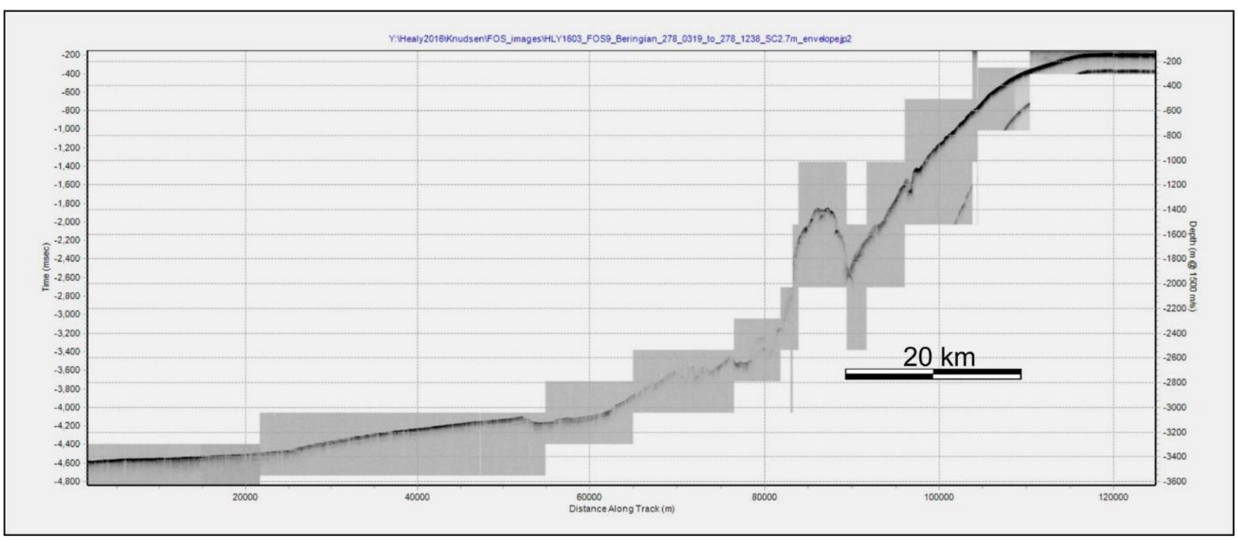
HLY1603 FOS 10 277/1853 - 278/0159



FOS 11 04 Oct. 2016 0523Z - 04 Oct. 2016 1015Z (JD 278)

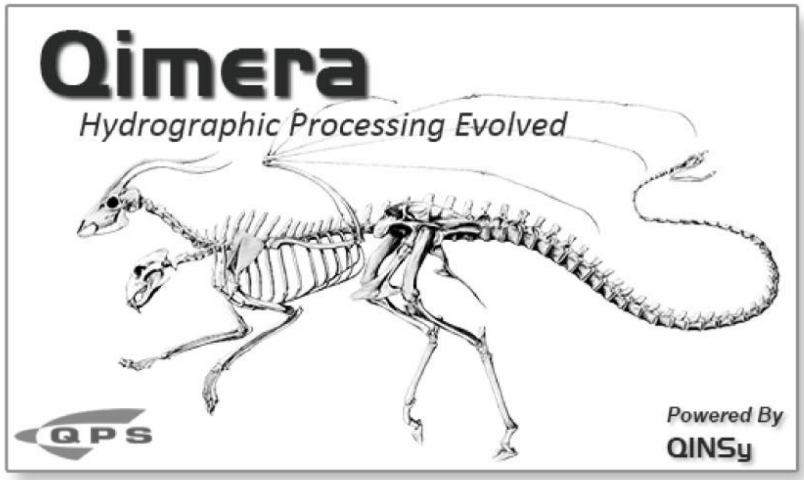


HLY1603 FOS 11 278/0319 - 278/1238



Appendix B: Patch Test Results

This appendix was automatically generated by the Qimera patch-test tool as a result of the analysis of the roll and pitch lines conducted during HLY16-03.



Patch Test

Project: /Users/brc/QPS-Data/Projects/HLY1603_PatchMotionSensor

Time of Report: 2016-09-22 12:59:49

Username: brc

Vessel Name: HEALY_SN106

Lines In Patch Test:

01: 0055_20160920_141937_HEALY (041°, 7.4 kts)

02: 0057_20160920_152119_HEALY (220°, 7.0 kts)

03: 0060_20160920_181543_HEALY (318°, 7.8 kts)

04: 0062_20160920_202614_HEALY (138°, 8.2 kts)

Calibration Step 1

Lines Used:

01: 0055_20160920_141937_HEALY (041°, 7.4 kts)

02: 0057_20160920_152119_HEALY (220°, 7.0 kts)

Calibration Type: MRU Roll

Patch Location: 74° 20'35.45"N, 157° 29'21.27"W

Patch Heading: 41.0°

Patch Width: 13379.69 meters

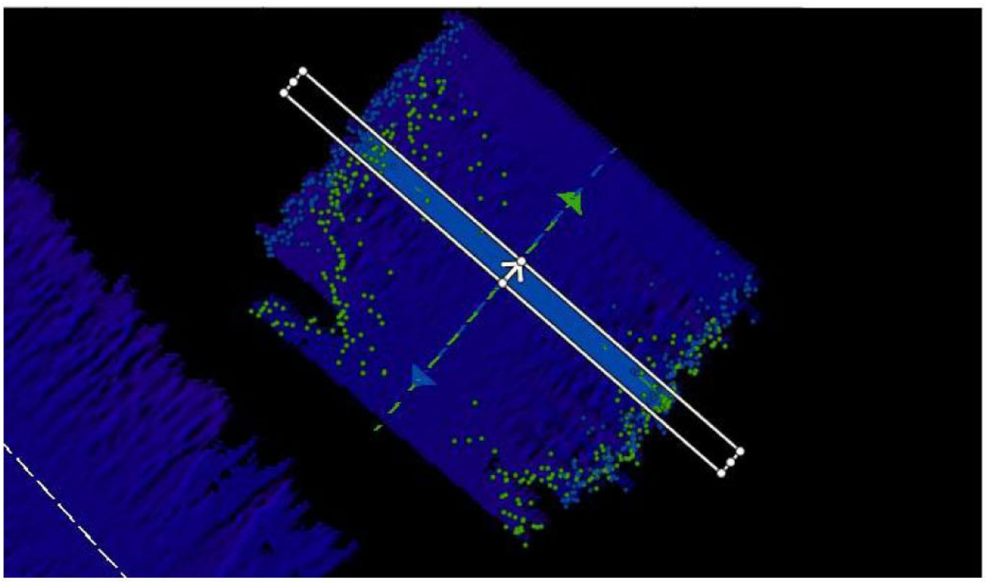
Patch Height: 668.98 meters

Active Motion System: Motion 1

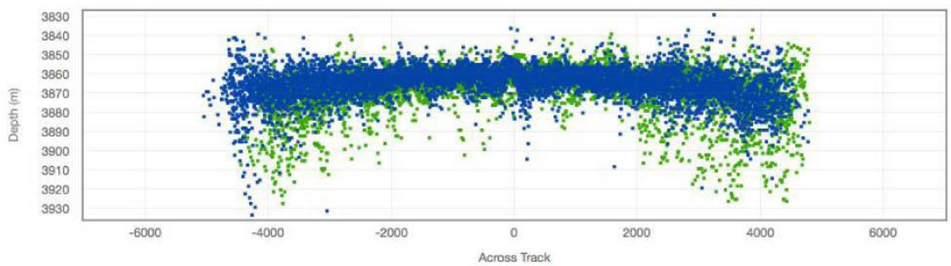
Active Position System: Position 1

Calibration Target: Motion 1

Offset Value: -0.44°



Calibration Area



Calibration Plot

Calibration Step 2

Lines Used:

03: 0060_20160920_181543_HEALY (318°, 7.8 kts)

04: 0062_20160920_202614_HEALY (138°, 8.2 kts)

Calibration Type: MRU Pitch

Patch Location: 74°19'49.40"N, 157°56'25.99"W

Patch Heading: 318.0°

Patch Width: 560.20 meters

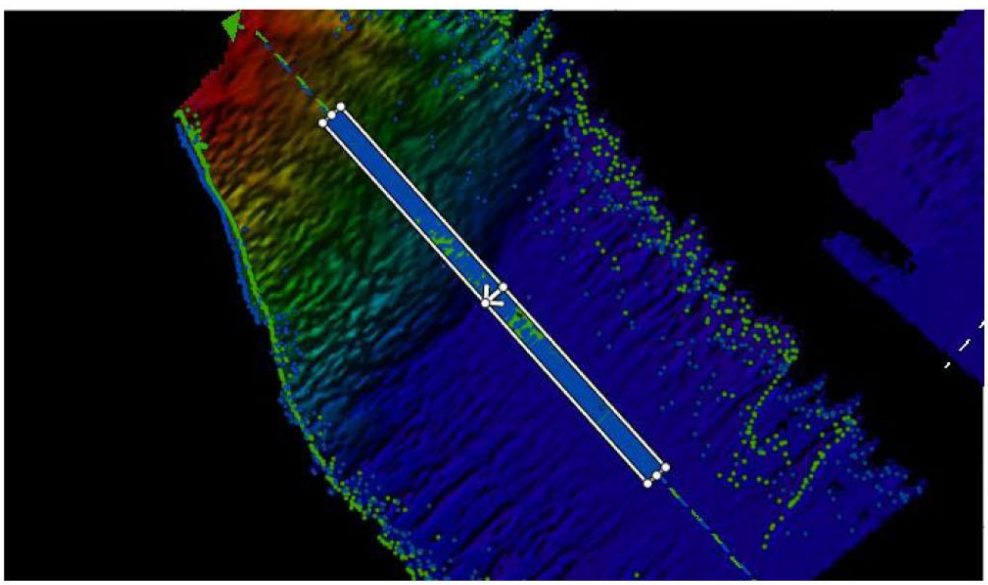
Patch Height: 11204.09 meters

Active Motion System: Motion 1

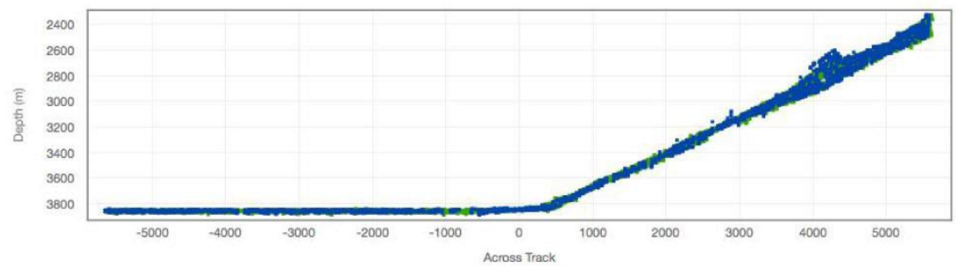
Active Position System: Position 1

Calibration Target: Motion 1

Offset Value: 0.50°



Calibration Area



Calibration Plot

Calibration Step 3

Lines Used:

03: 0060_20160920_181543_HEALY (318°, 7.8 kts)

04: 0062_20160920_202614_HEALY (138°, 8.2 kts)

Calibration Type: MRU Pitch

Patch Location: 74°19'49.40"N, 157°56'25.99"W

Patch Heading: 318.0°

Patch Width: 560.20 meters

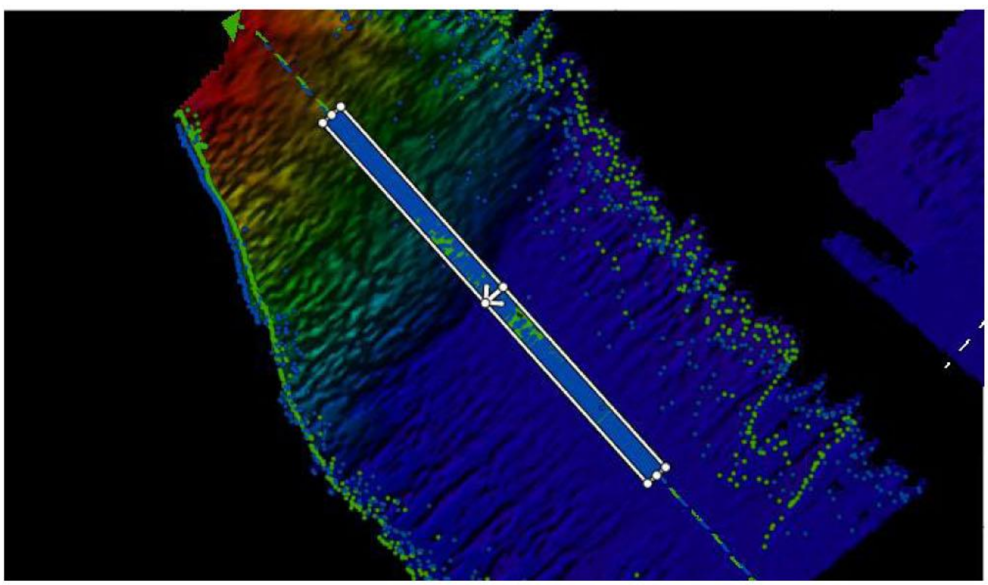
Patch Height: 11204.09 meters

Active Motion System: Motion 1

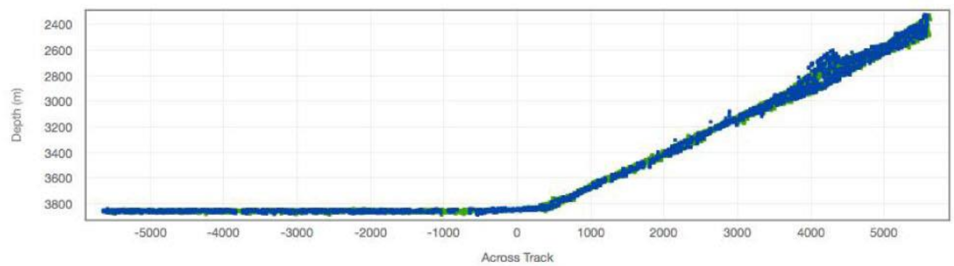
Active Position System: Position 1

Calibration Target: Motion 1

Offset Value: -0.05°



Calibration Area



Calibration Plot

Summary

System	Parameter	Original Value	New Value	Delta
Motion 1	Pitch	-0.96	-0.51	0.45
Motion 1	Roll	0.41	-0.03	-0.44

Appendix C: HEALY1603 DREDGING

As part of our ongoing collaboration with the Canadian government with respect to ECS efforts in the Arctic, it was agreed that the during the 2016 field season, the *Louis S. St. Laurent* would attempt to collect seismic data for the U.S. on the northern extension of Chukchi Cap and the *Healy* would attempt to dredge at a site of interest to the Canadians on the southern Alpha Ridge. Dredge sites were selected based on previously collected *Healy* multibeam sonar data (*Healy 0805 and 1105)* and recently collected (2016) *Oden* multibeam sonar data as well as the time constraints of the *Healy*. Two locations were finally selected though the initial schedule of the HEALY allowed only enough time to occupy a single dredge site.

The two sites selected are both on the southern flank of the Alpha Ridge where it protrudes into the Canada Basin east of Nautilus Basin at about 82 degrees North between about 142 and 146 degrees West (Figure 1).

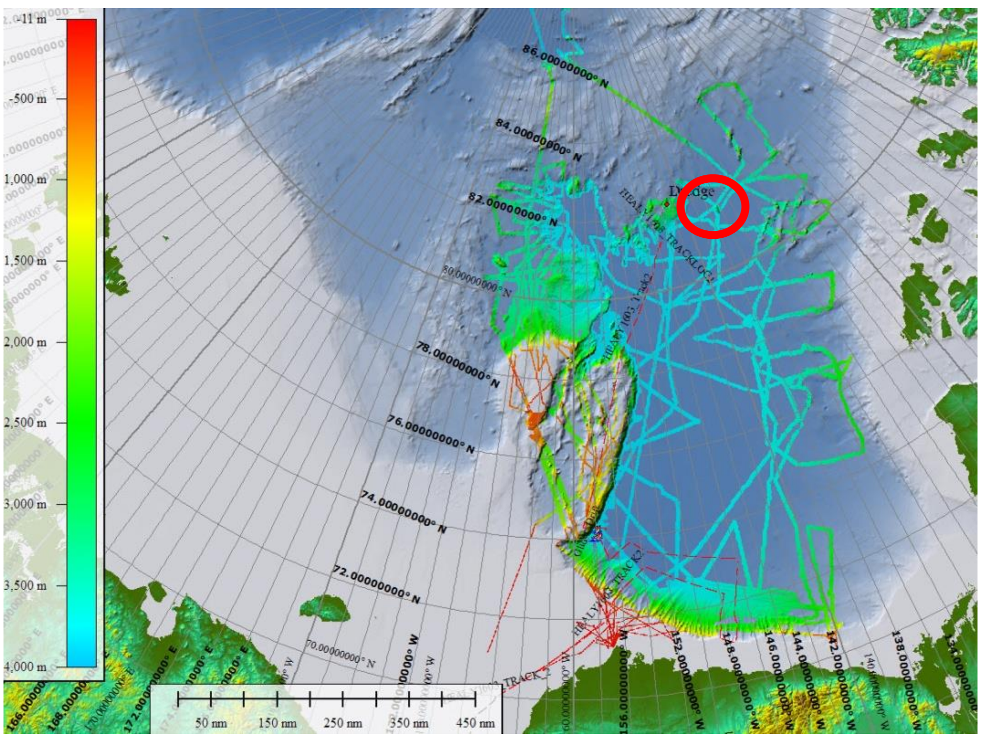


Figure 1. Overview figure showing general location of dredging targets on southern Alpha Ridge (within red circle).

Within this zone were two potential targets that came close to meeting our criteria of slope steepness. Previous experience dredging in this region has shown us that the change for success when dredging is greatly increased if the slopes dredges exceed 35 degrees. The first target to the east appears to be an extensional basin trending N-S that is approximately 8 km wide and 25 km long and the second feature, an apparently constructional feature that also trends N-S and is approximately 13 km wide and 40 long

(Figure 2).

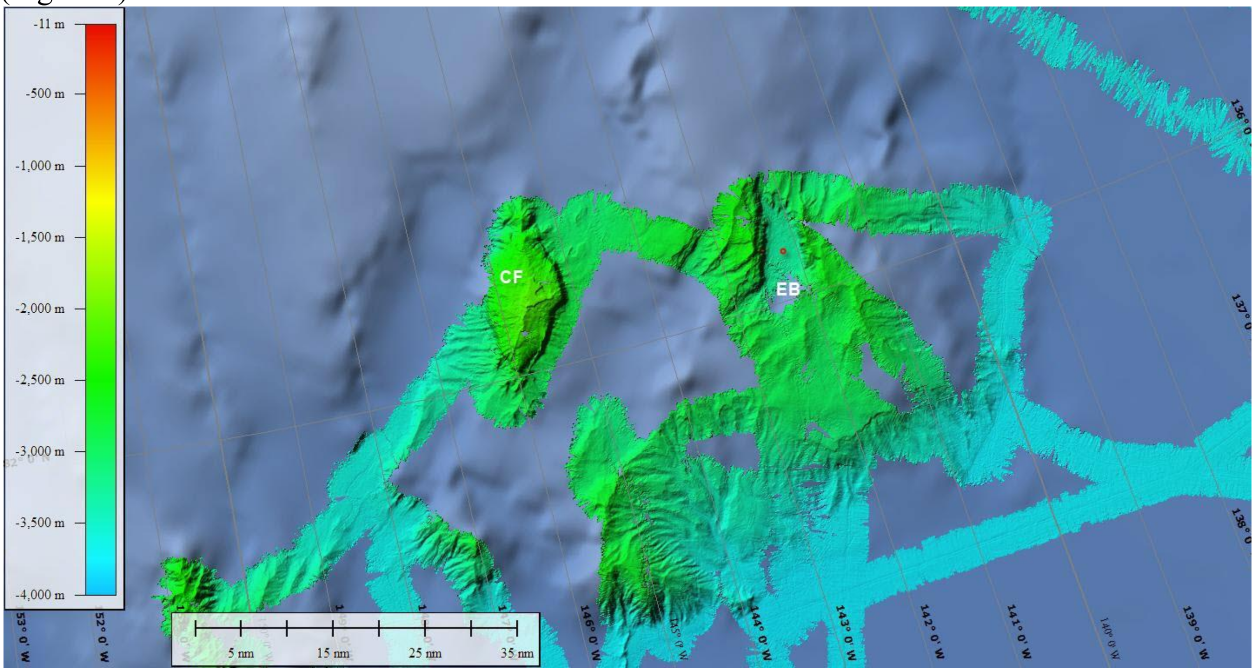


Figure 2. Two potential dredge targets -- EB *- an extensional basin to the east and* CF *a constructional feature to the west.*

The extensional basin is approximately 770m deep with the steepest slopes (approx 34 - 35 degrees occurring on the western wall in a 150 m zone between 3000 and 3150 meters (Figures 3,4 and 5).

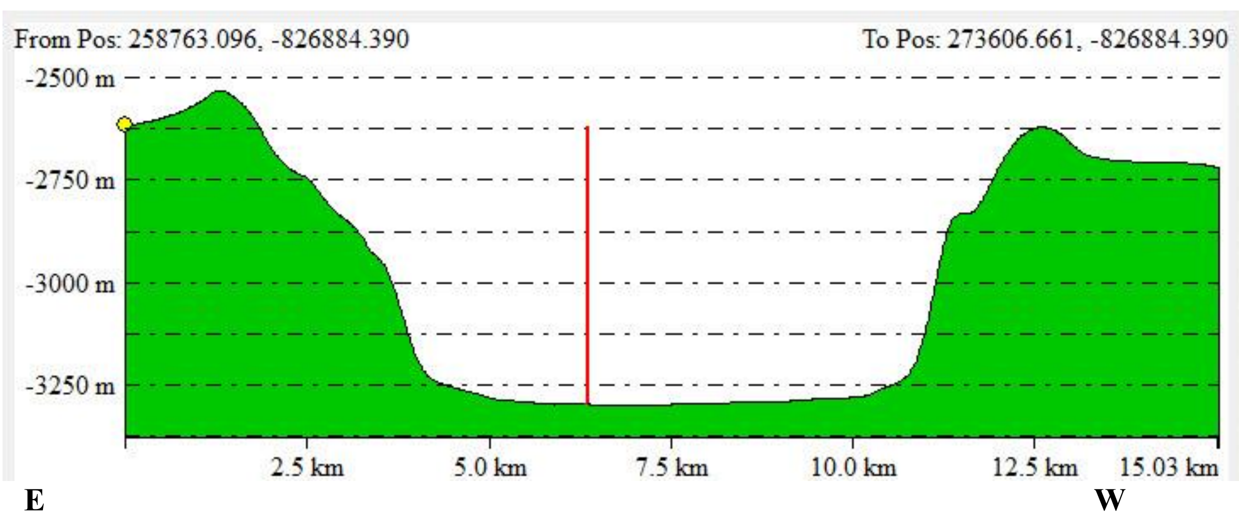


Figure 3. Cross-section of extensional basin

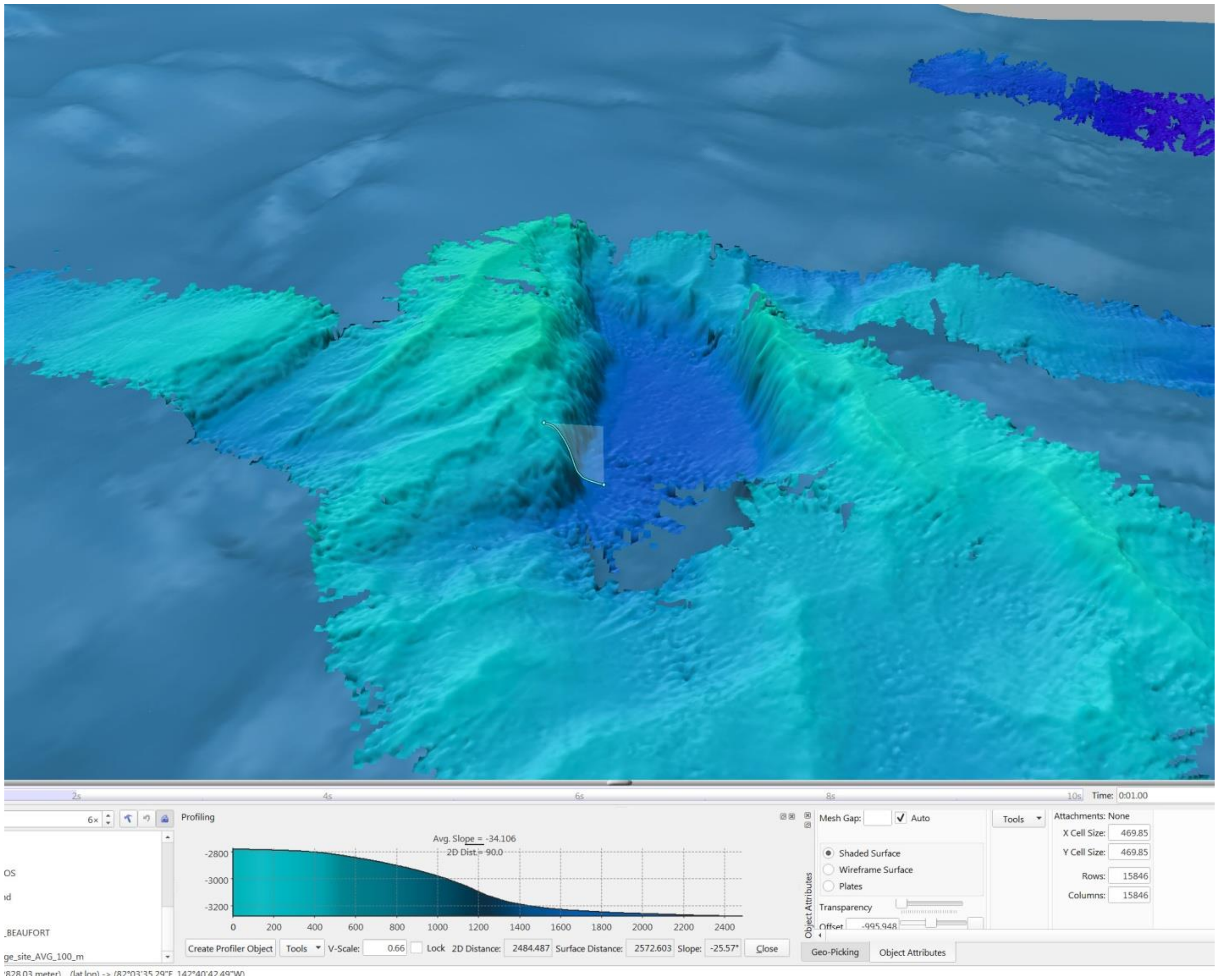


Figure 4. Perspective view of dredging target EB -- steepest slope is found along section of western wall between 3000 and 3150 m - slope here is 34 degrees.

i

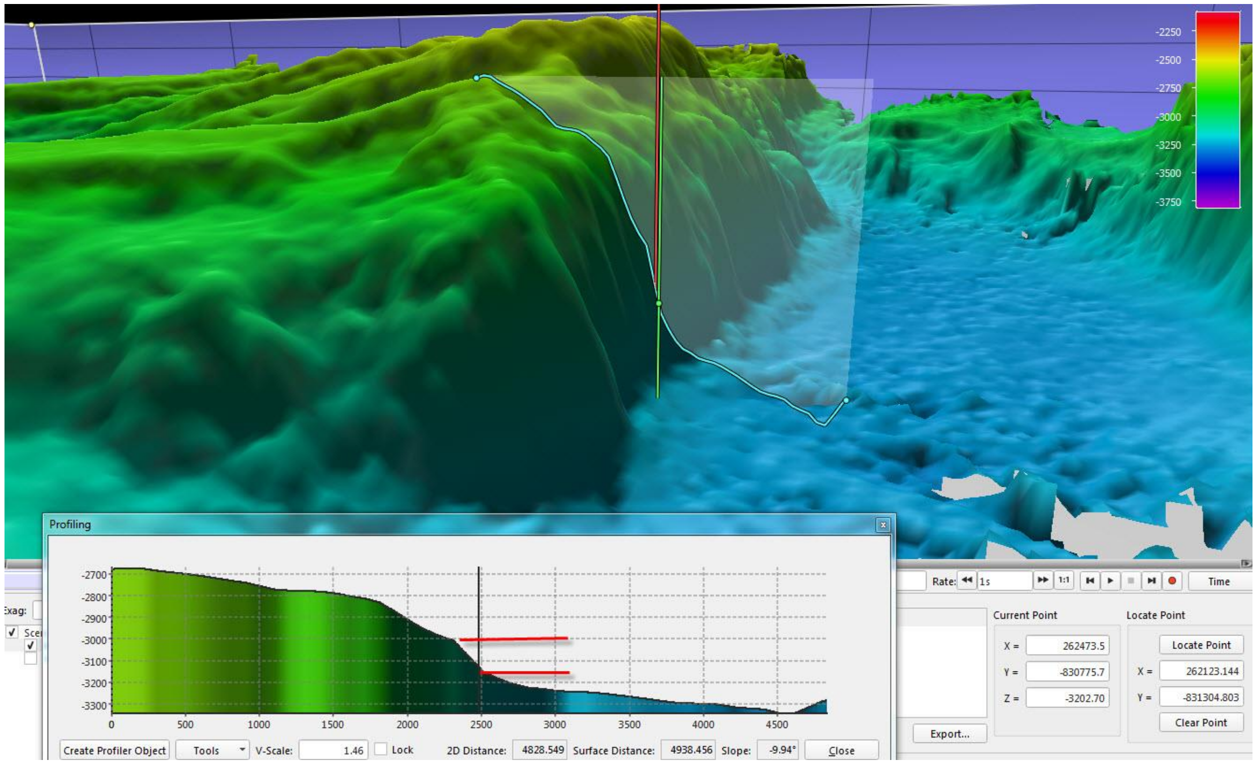


Figure 5. Zoomed perspective view of dredging target EB -- and steep zone found along section of western wall between 3000 and 3150 m - slope here is 34 degrees.

The constructional feature stands about 1080 m above the seafloor to the west and about 115 m above the seafloor to the east (Figures 6 and 7). Its walls were slightly less steep than the extensional basin, with the steepest section being found on the eastern flank of the feature between about 2550 and 2670 meters. The slope in this zone was approximately 30 - 33 degrees (Figures 8).

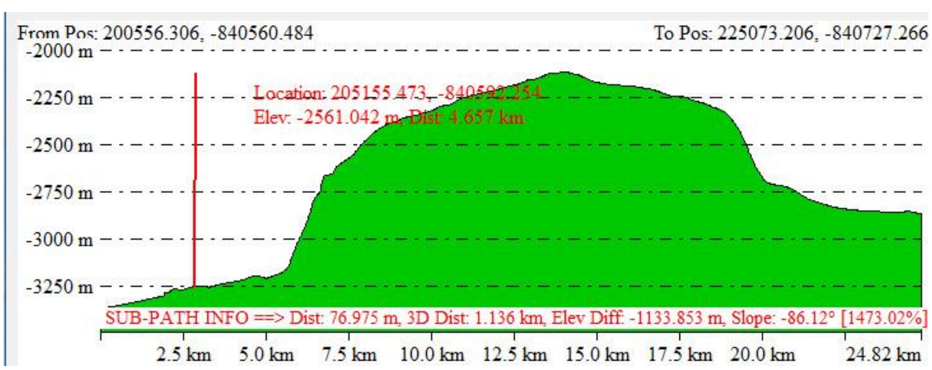


Figure 6. Cross section of dredge target CF.

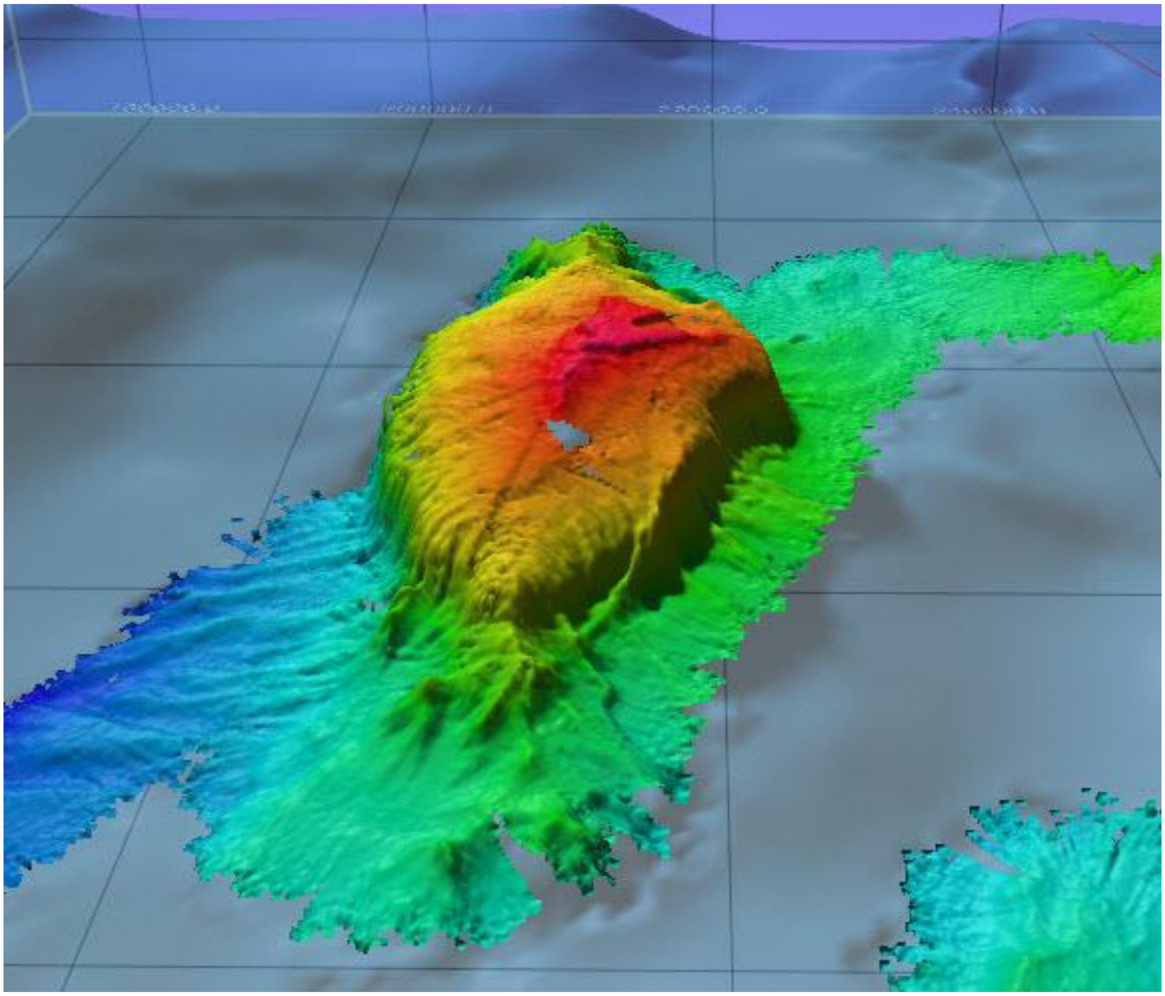


Figure 7. 3-D perspective of constructional feature on Alpha Ridge

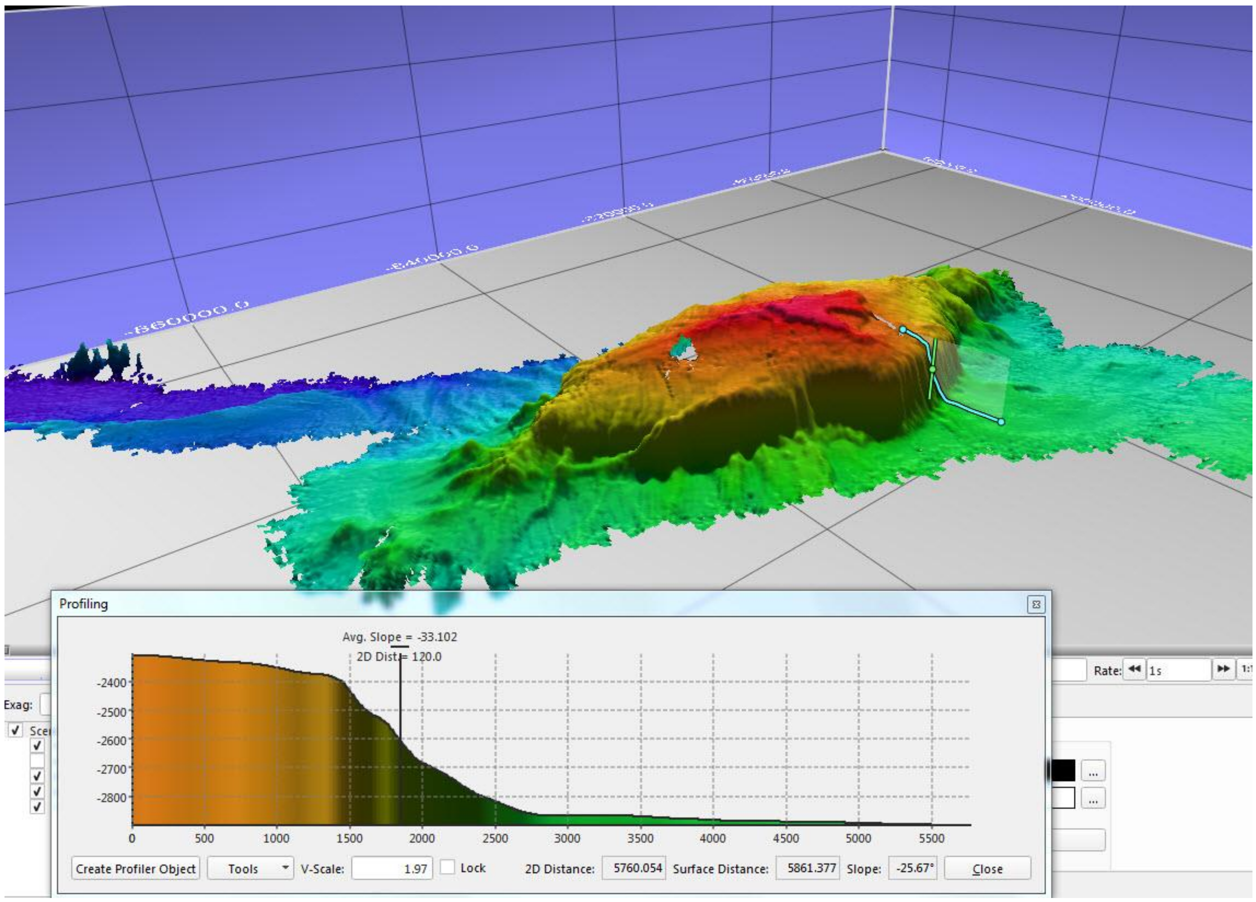


Figure 8. Proposed dredge site on constructional feature. This is the only zone with slopes above 33 degrees.

The extensional basin was chosen as the primary dredge site because its 750 m walls were more likely representative of the nature of Alpha Ridge and the larger target of steeper slope. We arrived at the dredge site at 0400L on 23 Sept. (JD 267) after many hours in heavy ice. Conditions were 10/10 coverage of mostly first-year ice. Winds were moderate 15-20 knots. Spent early morning hours looking at drift which varied from NE to SW -- with dominant vector to SW. Broke path beyond dredge site and at approximately 0840L commenced the dredge.

HLY 1603 DR-1
Dredge start position: 82 04.38018 N 142 29.9483 W
Dredge end position: 82.04.06947 N 142 34.4655W
Water Depth: 3285m
Target Depth: 3150-3000m
Details in Dredge Log (Fig 9).

Ship/leg HLY 1603
Date 23 SEPT 2016/JD 267
Station DREDGE
Time DOY m/d/y
Dredge # HLY1603-DR1
Latitude 82° 04.38018 To
Depth Interval 3150—3000M
Longitude 142°29.9483 To

Site Description & Target: WESTERN WALL OF SMALL EXTENSIONAL BASIN ON SOUTHERN ALPHA RIDGE

Total Weight

% Rock Outcrop % IRD % Mn

Operation	GMT	Depth (m)	Wire Out(m)	Tension	Comment
1634	1634	Permission to deploy			3285 M
OFF DECK ZERO	1642				450 AIR WEIGHT ZERO AT WATER'S EDGE
SPEED->60	1647				INCREASE SPEED AT 1960 LBS
WEIGHT	1704		1,000		
WEIGHT	1722		2,000		3420 LBS
WEIGHT	1742				4860 #
	1754				3257M HT — 3285 KNUDSEN 3274 EM122
OFF BOT	1756		3217.		UP TO 3155
UP AGAIN	1814				UP 50 AT 1 m HT
STOP	1836		3183 m		
STOP			3082 m		
STILL STOPP.	1920	3154 m BY CHART	3082	4910 lbs	NEARING SCARP

p1 of 3

Ship/leg HLY 1603

Date 23 SEPT 2016 / JD 267

Station DREDGE

Time DOY m/d/y

Dredge # 1

Latitude 82° 04.38018 To

Depth Interval 3150 – 3000 m

Longitude 142° 29.9483 To

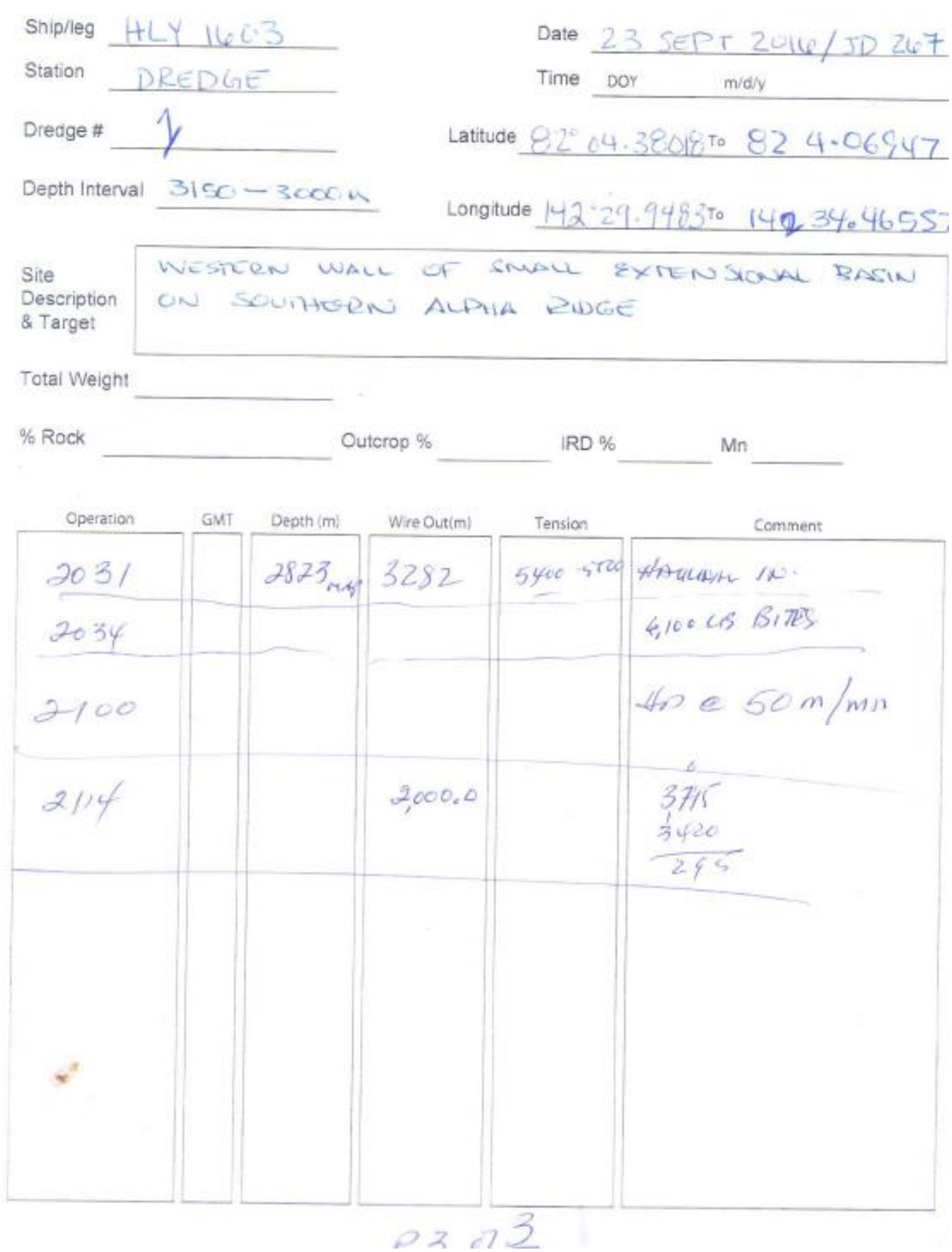
Site Description & Target: WESTERN WALL OF SMALL EXTENSIONAL BASIN ON SOUTHERN ALPHA RIDGE

Total Weight

% Rock Outcrop % IRD % Mn

Operation	GMT	Depth (m)	Wire Out (m)	Tension	Comment
1923			3082.9		SMALL TENSION
1927					PAY OUT TO FIND BOTTOM
1932					INC TO 20 m/M
			3288.9 + 20 to 3309.9		ON BOTTOM
1941					STOP
1942					AHEAD TO COUNTER STERN WAY
1952					WORKING AT LIGHT TENSION
2001					PAY OUT ... @ 20 m/min
STOP 2105			3362		S
2027			3362		HAUL IN AT 20 m/MIN

pz ?. 2


Ship/leg HLY 1603
Station DREDGE
Dredge # 1
Depth Interval 3150 – 3000m
Date 23 SEPT 2016/JD 267
Time DOY m/d/y
Latitude 82° 04.38018 To 82 4.06947
Longitude 142°29.9483 To 142 34.4655

Site Description & Target: WESTERN WALL OF SMALL EXTENSIONAL BASIN ON SOUTHERN ALPHA RIDGE

Total Weight

% Rock Outcrop % IRD % Mn

Operation	GMT	Depth (m)	Wire Out(m)	Tension	Comment
2031		2823	3282	5400 5700	HAULING IN.
2034					6,100 LB BITES
2100					40 @ 50 m/min
2114			2,000.0		3715 − 3420 = 295

p3 of 3

Figure 9. Dredge log of HLY1603 - DR1

Through the course of the 5 hours on the bottom (Figures 10 and 11), there were several bites of 6500lbs over the background level of about 5000 lbs or so (see Tension Log). The dredge was recovered at approximately 1400L with several hundred pounds of mud and 18 lbs of rocks including several large rocks with fresh surfaces. From initial examination these appeared to be volcanic tuffs. A sample index is found in Table 1.

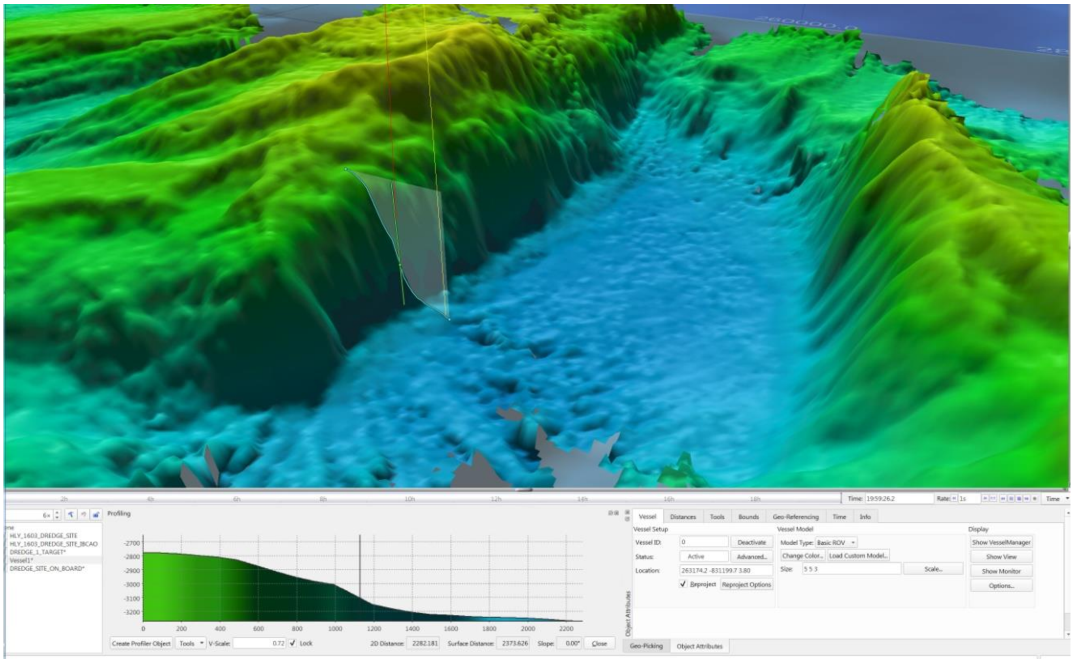


Figure 10. 3-D perspective of dredge site with position of vessel (yellow line and dot) as well as position of dredge target (green line and dot) at beginning of dredge run (6x VE)

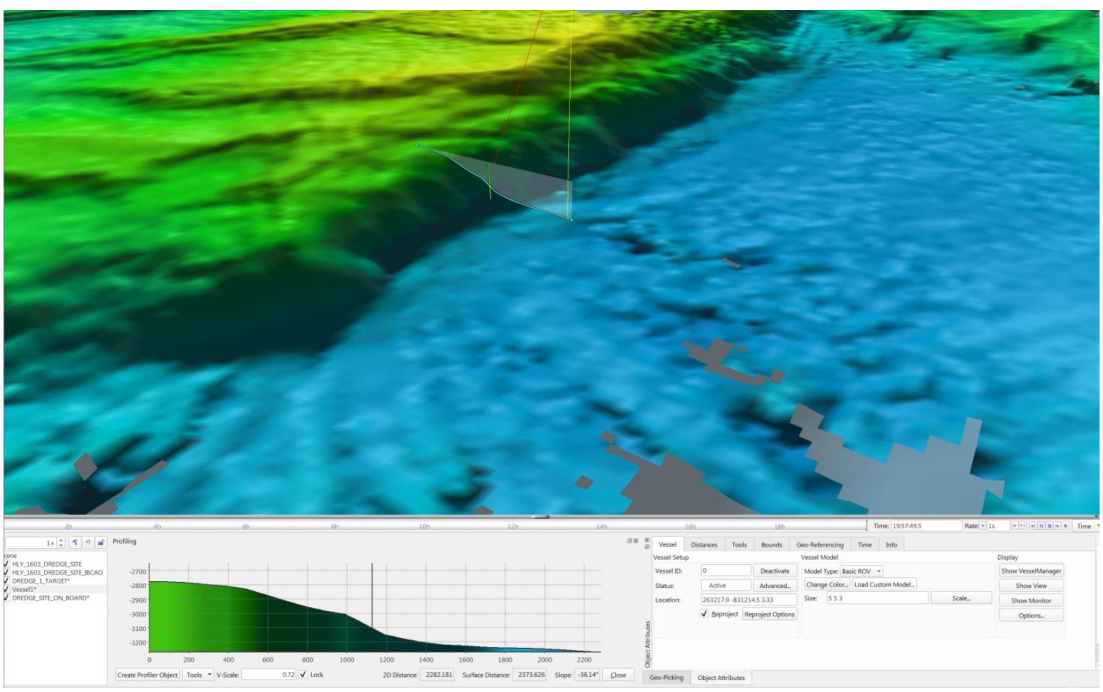


Figure 11. Same view as above with no vertical exaggeration

We decided to attempt another dredge at the same location -- we repositioned the vessel and commenced dredging at 1600L.

HLY 1603 DR-2
Dredge start position: 82 04.38018 N 142 29.9483 W
Dredge end position: 82.04.031 N 142 32.999 W
Water Depth: 3285m
Target Depth: 3150-3000m
Details in Dredge Log (Fig 12).

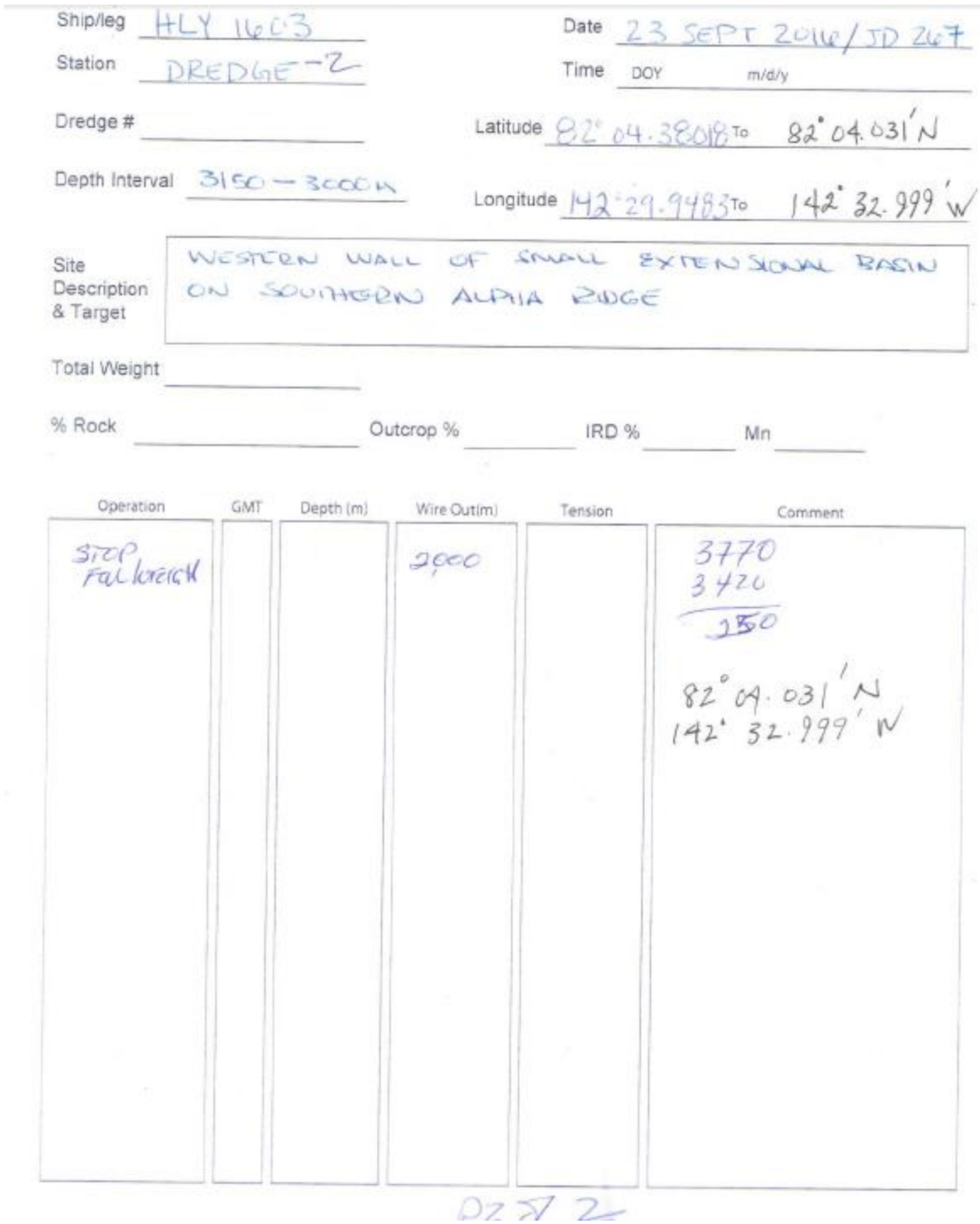
Ship/leg: HLY 1603
Date: 23 SEPT 2016 / JD 267
Station: DREDGE
Time: DOY m/d/y
Dredge #: DREDGE-2
Latitude: 82° 04.38018 To
Depth Interval: 3150 – 3000 m
Longitude: 142° 29.9483 To

Site Description & Target: WESTERN WALL OF SMALL EXTENSIONAL BASIN ON SOUTHERN ALPHA RIDGE

Total Weight

% Rock Outcrop % IRD % Mn

Operation	GMT	Depth (m)	Wire Out(m)	Tension LBS	Comment
START	2319				ZERO IN KNAEL
STOP	0011		3,100 M	4878	STOPPED
COMMENT	0101	~~3384~~ 3200 MAP	3,100	4800	STILL DRIVING TOWARD TARGET
GO FOR BOTTOM	0137	3146	3,100		OUT AT 20 m/min
SPEED UP	0145		3226		TO 30 m/min
	144			4700 ~	ON BOTTOM
BITE	0204		3410	~6,000	
PULL UP 0232	0226	2820	3155	~6000	TO GET OFF BOTT BITES.
~~0312~~ UP @ 25 MIN	0312				



Ship/leg HLY 1603

Station DREDGE-2

Date 23 SEPT 2016/JD 267

Time DOY m/d/y

Dredge #

Latitude 82° 04.38018 To 82° 04.031' N

Depth Interval 3150 – 3000 m

Longitude 142° 29.9483 To 142° 32.999' W

Site Description & Target: WESTERN WALL OF SMALL EXTENSIONAL BASIN ON SOUTHERN ALPHA RIDGE

Total Weight

% Rock Outcrop % IRD % Mn

Operation	GMT	Depth (m)	Wire Out(m)	Tension	Comment
STOP Fall break			2000		3770 3420 350 82° 04.031' N 142° 32.999' W

DZ ∇ 2

Figure 12. Dredge log for HEALY1603 DR2

Dredge 2 came back with about 300 lbs of mud and 48 lbs of rocks, some of which were clearly IRD but others which seem to have some fresh surfaces. A sample index is found in Table 1.

Sub-Subsample Information													
Sample	IGSN	Subsample Name	Sample Type	Parent Name	Parent IGSN	Size	Size Unit	Weight	Weight Unit	Description	Photograph	Notes	Comment
example	ECSXXXYYY	HLY16?? DR1-001	Individual Sample	HLY16?? DR1	ECSXXXXXX	12x6x8	inches	13.7	lbs.	fine grained green schist, blocky fracture, Mn crust ~ .38 cm thick	✓	*whether group thinks of it as archive/working and*	2 pieces
1	ECS005015	HLY1603 DR1-001	Individual Sample	HLY1603 DR1	ECS005000	20x10x10	cm	3.5	lbs.	tuff, blocky, sharp edges, friable. Black Mn crust, thin	✓	Fresh surfaces assume it is is situ as a result.	1 piece
2	ECS005016	HLY1603 DR1-002	Individual Sample	HLY1603 DR1	ECS005000	11x5x5	cm	1	lbs.	tuff, blocky, sharp edges, friable. Black Mn crust, thin	✓	As above but mostly covered with black mn	1 piece
3	ECS005017	HLY1603 DR1-003	Individual Sample	HLY1603 DR1	ECS005000	10x3x3	cm	0.5	lbs.	tuff, blocky, sharp edges, friable. Black Mn crust, thin	✓	Fresh surfaces assume it is is situ as a result.	1 piece
4	ECS005018	HLY1603 DR1-004	Individual Sample	HLY1603 DR1	ECS005000	6x6x2	cm	0.2	lbs.	tuff, blocky, sharp edges, friable. Black Mn crust, thin	✓	Fresh surfaces assume it is is situ as a result.	1 piece
5	ECS005019	HLY1603 DR1-005	Individual Sample	HLY1603 DR1	ECS005000	7x4x2	cm	0.1	lbs.	tuff, fine grained, very friable, Black Mn crust on one surface	✓	Corners are rounded - potentially due to washing	1 piece
6	ECS005020	HLY1603 DR1-006	Fragments	HLY1603 DR1	ECS005000	fragments		0.1	lbs.	tuff, friable, Black Mn crust	✓	Seemingly fragments of previous samples 1-5	15 fragments + several smaller pieces
7	ECS005021	HLY1603 DR1-007	Individual Sample	HLY1603 DR1	ECS005000	12x10x6	cm	4	lbs.	Fine grained chert/dolostone, buff color, blocky but smooth corners	✓	Angular facets but smoothed off - ice rafted	1 piece
8	ECS005022	HLY1603 DR1-008	Individual Sample	HLY1603 DR1	ECS005000	13x7x3	cm	2	lbs.	Grey limestone/dolostone, fine grained	✓	Angular facets but smoothed off - ice rafted	1 piece
9	ECS005023	HLY1603 DR1-009	Fragments	HLY1603 DR1	ECS005000	fragments		0.1	lbs.	Black shale	✓	Smooth - ice rafted	10 pieces
10	ECS005024	HLY1603 DR1-010	Fragments	HLY1603 DR1	ECS005000	fragments		< 0.1	lbs.	Olive colored fine-grained sandstone	✓	Fresh face with smooth corners- ice rafted	6 pieces
11	ECS005025	HLY1603 DR1-011	Fragments	HLY1603 DR1	ECS005000	fragments		1	lbs.	Assortment of ice-rafted pebbles and cobbles	✓		50 pieces
12													
13	ECS005026	HLY1603 DR2-01	Individual Sample	HLY1603 DR2	ECS005001	17x5x4	cm	2.5	lbs.	tuff, semi-angular edges, coarse grained, buff.	✓		
14	ECS005027	HLY1603 DR2-02	Individual Sample	HLY1603 DR2	ECS005001	10x6x3	cm	0.8	lbs.	tuff, coarse grained, buff, sharp edges, colored with Mn crust	✓		
15	ECS005028	HLY1603 DR2-03	Individual Sample	HLY1603 DR2	ECS005001	10x3x4	cm	0.5	lbs.	tuff, coarse grained, buff, sharp edsges, Mn crust	✓		
16	ECS005029	HLY1603 DR2-04	4 Samples	HLY1603 DR2	ECS005001	3 to 7	cm	0.5	lbs.	tuff, friable, coarse grained, buff, sharp edsges, Mn crust	✓		
17	ECS005030	HLY1603 DR2-05	12 fragments	HLY1603 DR2	ECS005001	fragments	cm	0.1	lbs.	black magnese crust	✓		
18	ECS005031	HLY1603 DR2-06	7 fragments	HLY1603 DR2	ECS005001	fragments	cm	1.5	lbs.	bright orange, rhyolitic clay, Mn crust	✓		
19	ECS005032	HLY1603 DR2-07	5 fragments	HLY1603 DR2	ECS005001	fragments	cm	0.5	lbs.	red, claystone (rhyolite?), Mn crust	✓		
20	ECS005033	HLY1603 DR2-08	4 fragments	HLY1603 DR2	ECS005001	fragments	cm	0.5	lbs.	tuff, dark buff, soft and friable	✓		
21	ECS005034	HLY1603 DR2-09	9 fragments	HLY1603 DR2	ECS005001	fragments	cm	0.5	lbs.	tuff, reddish friable, coarse grained	✓		
22	ECS005035	HLY1603 DR2-10	2 fragments	HLY1603 DR2	ECS005001	fragments	cm	0.5	lbs.	tuff, buff color, coarse grained, heavy Mn crust	✓		
23	ECS005036	HLY1603 DR2-11	Individual Sample	HLY1603 DR2	ECS005001	17x17x10	cm	5	lbs.	rounded large cobble, Mn stained... unknown lithology	✓	ice rafted	
24	ECS005037	HLY1603 DR2-12	3 samples	HLY1603 DR2	ECS005001	varies	cm	4	lbs.	massive limestone/dolostone with Mn staining	✓		
25	ECS005038	HLY1603 DR2-13	3 samples	HLY1603 DR2	ECS005001	varies	cm	5	lbs.	massive limestone/dolostone, rounded	✓	ice rafted	
26	ECS005039	HLY1603 DR2-14	4 samples	HLY1603 DR2	ECS005001	varies	cm	5	lbs.	massive limestone/dolostone, rounded, etched	✓	ice rafted	
27	ECS005040	HLY1603 DR2-15	4 samples	HLY1603 DR2	ECS005001	varies	cm	1	lbs.	shaley siltstone, rounded corners, gray	✓	ice rafted	
28	ECS005041	HLY1603 DR2-16	individual sample	HLY1603 DR2	ECS005001	11x7x4	cm	1	lbs.	micacious basalt, semi-angular	✓	ice rafted??	
29	ECS005042	HLY1603 DR2-17	individual sample	HLY1603 DR2	ECS005001	5x5x4	cm	0.25	lbs.	Granite (pink grains), rounded	✓	ice rafted	
30	ECS005043	HLY1603 DR2-18	8 samples	HLY1603 DR2	ECS005001	varies	cm	1.5	lbs.	Chert, very rounded	✓	ice rafted	
31	ECS005044	HLY1603 DR2-19	14 samples	HLY1603 DR2	ECS005001	varies	cm	3	lbs.	assorted, rounded clasts	✓	ice rafted	
32	ECS005045	HLY1603 DR2-20	bunch	HLY1603 DR2	ECS005001	varies	cm	4	lbs.	assorted, rounded clasts	✓	ice rafted	

Table 1. Sample index for HLY1603 DR1 and DR2

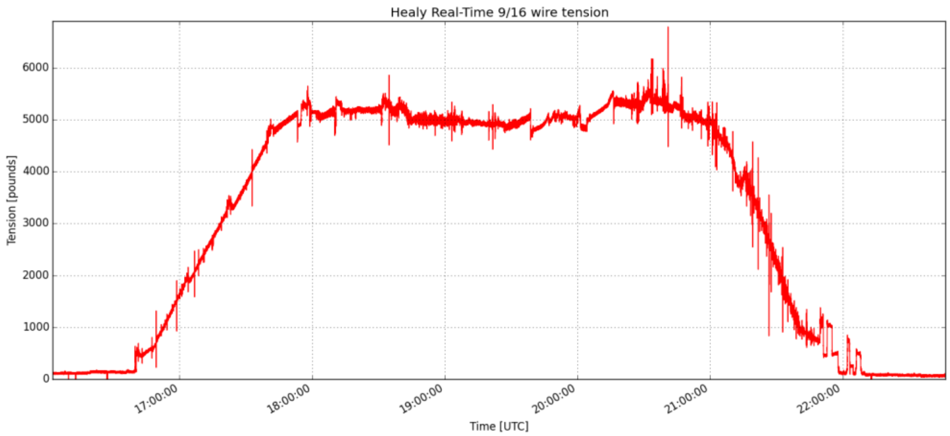


Figure 13. Tension record for DR-1

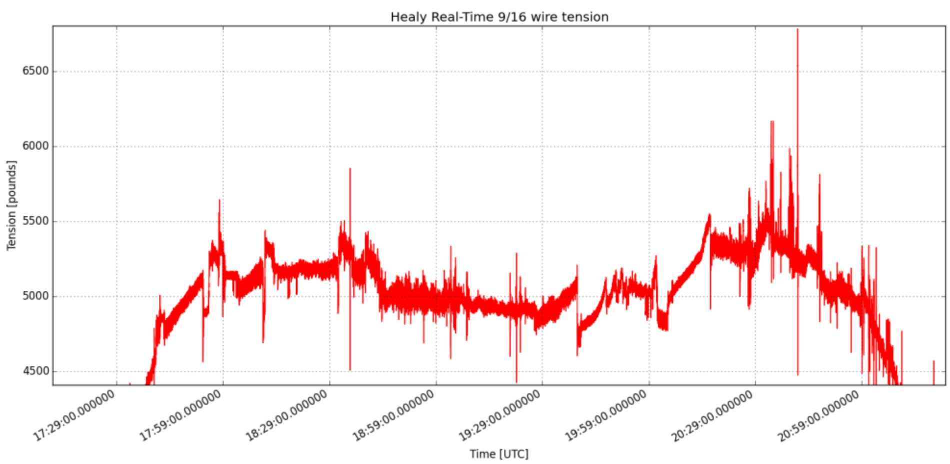


Figure 14. Tension record for DR-1on bottom

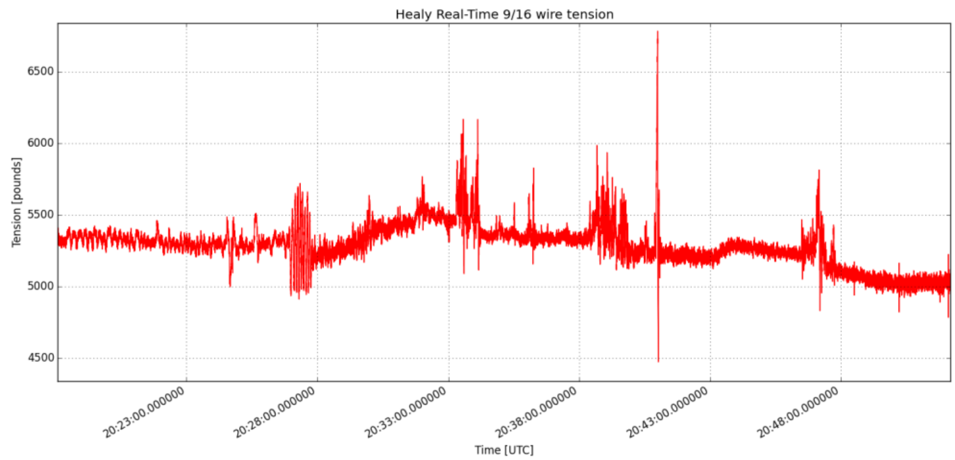


Figure 15. DR-1 Tension record during several large bites

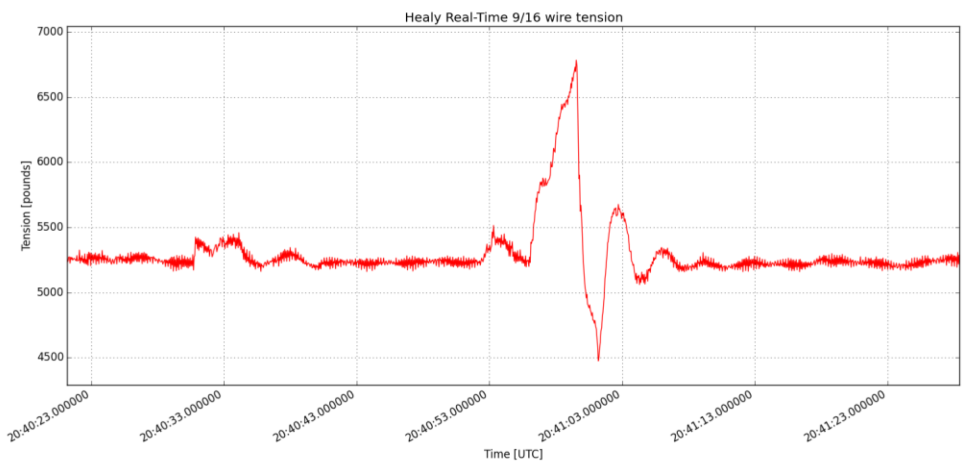


Fig 16. Close up of largest hit in tension on DR-1

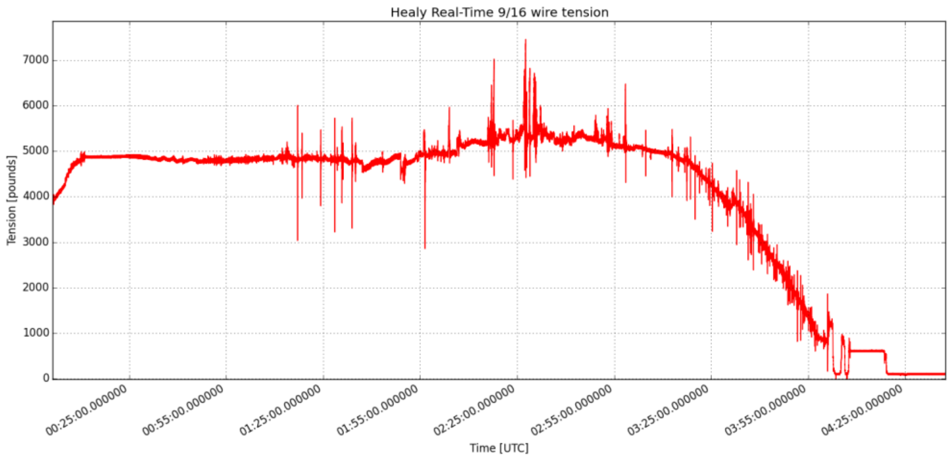


Figure17. Tension record for DR-2

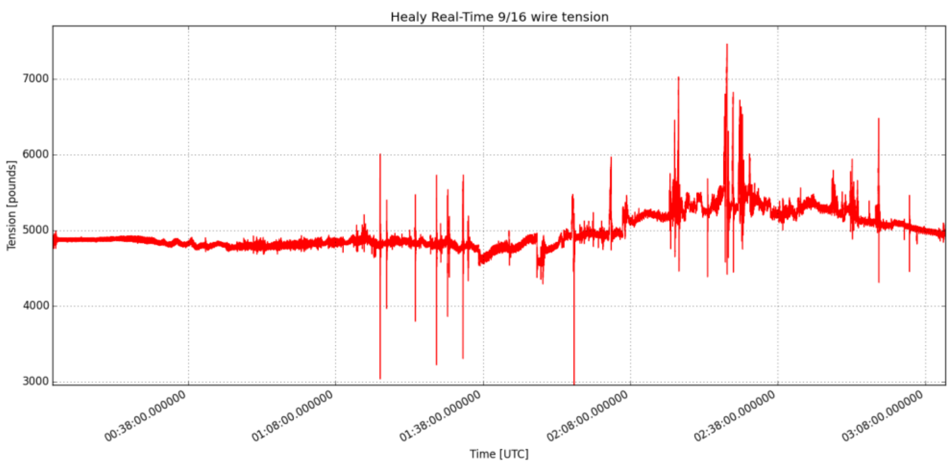


Figure18. Tension record for DR-2 on bottom

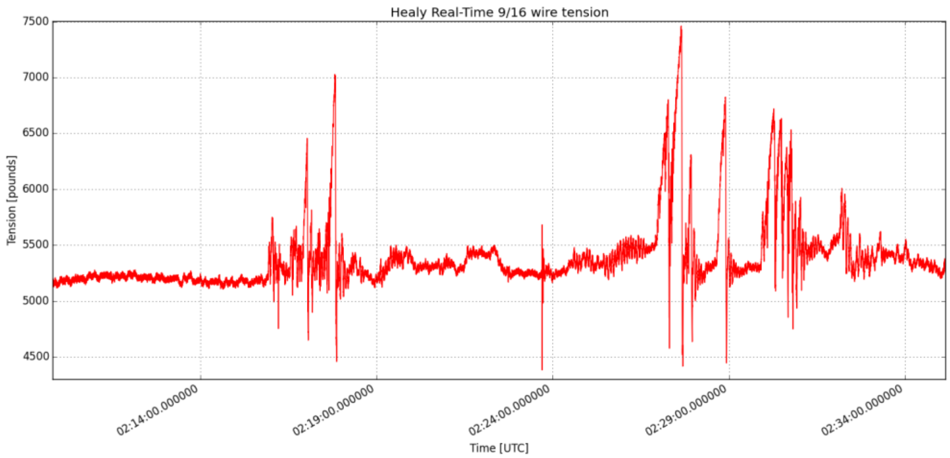


Figure 19. Several large bites in tension on DR-2

Photos of dredge samples. Individual photos available in digital database:

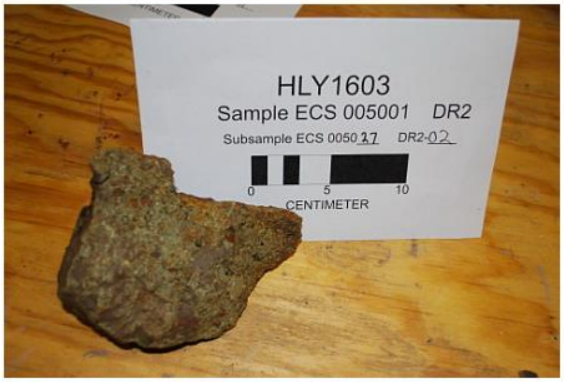

HLY1603
Sample ECS 005000 DR1
Subsample ECS 005021 DR1-7
0 5 10
CENTIMETER


HLY1603
Sample ECS 005000 DR1
Subsample ECS 005022 DR1-8
0 5 10
CENTIMETER


HLY1603
Sample ECS 005000 DR1
Subsample ECS 005023 DR1-9
0 5
CENTIMETER


HLY1603
Sample ECS 005000 DR1
Subsample ECS 005024 DR1-10
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005026 DR2-01
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005027 DR2-02
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005028 DR2-03
0 5 10
CENTIMETER

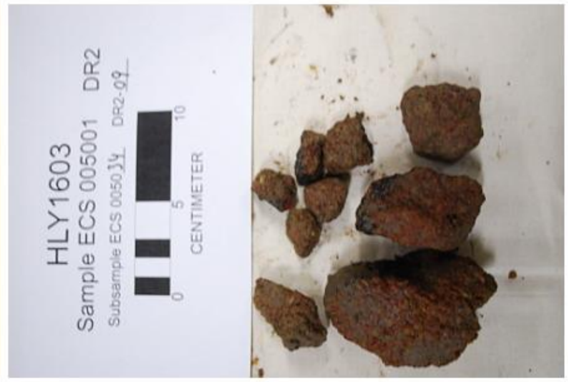

HLY1603
Sample ECS 005001 DR2
Subsample ECS 005029 DR2-04
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005030 DR2-05
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005031 DR2-06
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005032 DR2-07
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005033 DR2-08
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005034 DR2-09
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005035 DR2-10
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005036 DR2-11
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005037 DR2-12
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005038 DR2-13
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005039 DR2-14
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005040 DR2-15
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005041 DR2-16
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR
Subsample ECS 005042 DR2-17
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
Subsample ECS 005043 DR2-18
0 5 10
CENTIMETER


HLY1603
Sample ECS 005001 DR2
CENTIMETER

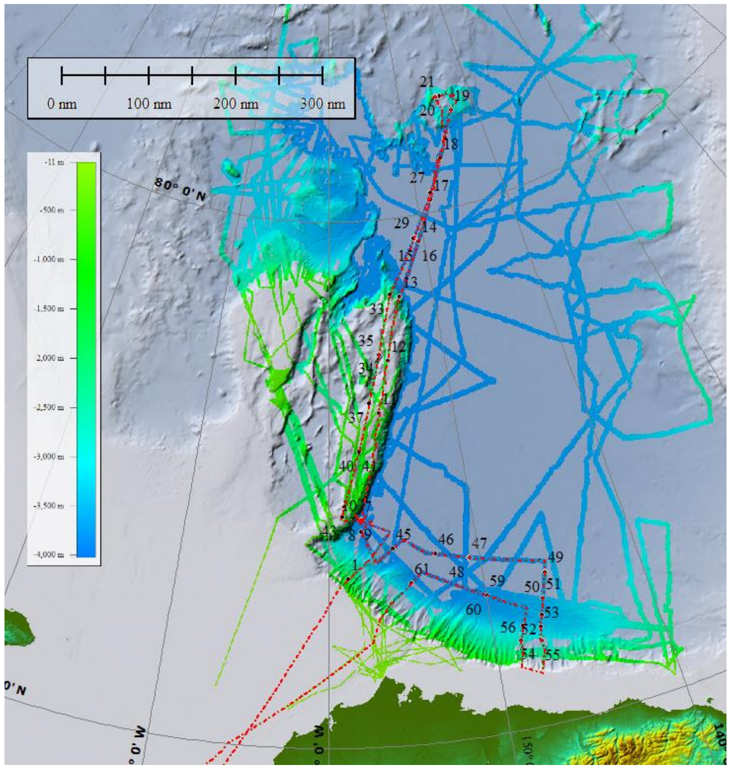

HLY1603
Sample ECS 005001 DR2
CENTIMETER


HLY1603
Sample ECS 005001 DR2

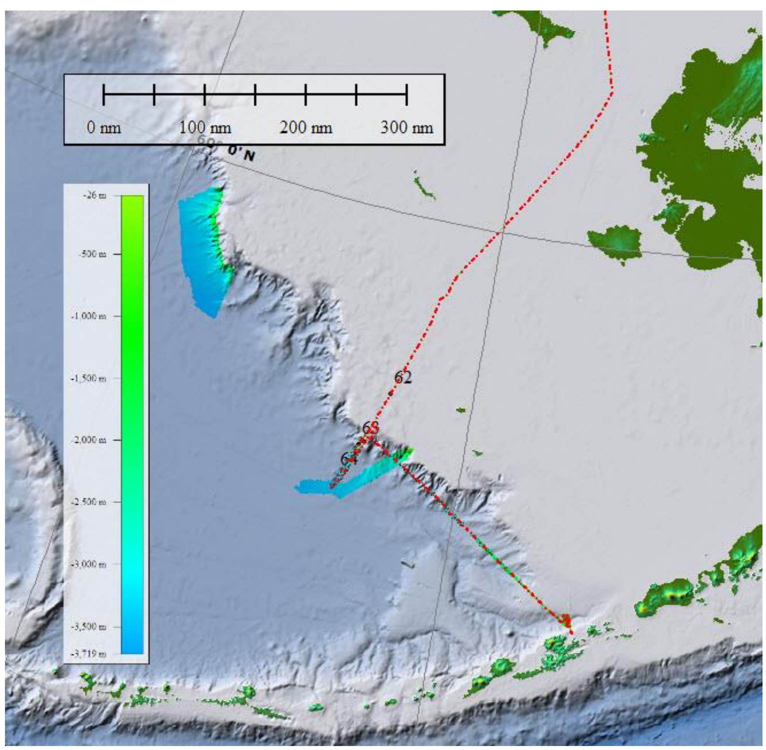
Appendix D: HEALY 1603 XBT LOG

Cast #	Probe type	Date	Time UTC	Serial #	Deepest value in file	Latitude	Longitude	File Name	Speed Knots	Comments	Who
		09/17/16	20:55:41					XBT_T-7_20160917205541.edf	0.0	not work	
		09/20/16	03:25:08					XBT_T-7_20160920032508.edf	15.5	not work	
		09/20/16	03:28:25					XBT_T-5_20160920032825.edf	15.6	not work	
01	T-5	09/20/16	03:29:37	349197	975.0803	73:10.80770N	158:43.34850W	XBT_T-5_20160920032937.edf	15.6		
07	T-5	09/20/16	10:46:51	349195	1661.6539	74:16.22260N	157:43.69140W	XBT_T-5_20160920104651.edf	2.6		Tom
08	T-5	09/20/16	10:55:15	349191	1830.5208	74:16.67050N	157:44.86250W	XBT_T-5_20160920105515.edf	2.6		Tom
09	Fast Deep	09/20/16	11:13:12	15533	871.2688	74:17.78050N	157:43.50250W	XBT_20160920111312.edf	5.3	Renamed original (	Tom
09	Fast Deep	09/20/16	11:13:12	15533	871.2688	74:17.78050N	157:43.50250W	XBT_Fast_Deep_20160920111312-Copy.edf	5.3		Tom
10	XSV-01	09/20/16	11:22:30	32698	571	74:17.77770N	157:40.68880W	XSV-01_20160920112230.edf	5.4	Prelaunch in tube	Tom
11	T-5	09/21/16	08:33:58	349202	518.8932	76:18.56370N	155:55.98180W	XBT_T-5_20160921083358.edf	7.7		Tom
12	T-5	09/21/16	16:07:28	349193	1830.5208	77:17.16360N	154:53.15110W	XBT_T-5_20160921160728.edf	9.6		Tom
13	T-5	09/22/16	00:08:03	349192	1669.8764	78:28.94680N	153:10.42480W	XBT_T-5_20160922000803.edf	10.3		
14	T-5	09/22/16	08:23:42	349194	477.5841	79:28.68930N	150:34.91890W	XBT_T-5_20160922082342.edf	6.6		Tom
15	T-5	09/22/16	08:28:27	349199	581.5626	79:28.98390N	150:34.11890W	XBT_T-5_20160922082827.edf	6.7		Tom
16	T-5	09/22/16	08:31:16	349203	654.2529	79:29.26560N	150:33.35560W	XBT_T-5_20160922083116.edf	6.7		Tom
		09/22/16	15:59:56					XBT_T-5_20160922155956.edf	7.3	not work	Tom
17	T-5	09/22/16	16:05:32	349206	1348.1593	80:13.51620N	148:28.49050W	XBT_T-5_20160922160532.edf	6.0		Tom
18	T-5	09/23/16	00:04:42	349210	1830.5208	80:57.48250N	146:13.59910W	XBT_T-5_20160923000442.edf	5.8		
19	T-5	09/23/16	08:19:18	349211	1464.5721	81:48.72780N	143:16.92180W	XBT_T-5_20160923081918.edf	1.7		Tom
20	T-5	09/24/16	08:19:54	349205	321.5546	82:07.27500N	144:13.21460W	XBT_T-5_20160924081954.edf	1.0		Tom
21	T-5	09/24/16	08:22:24	349204	683.3303	82:07.29760N	144:13.92180W	XBT_T-5_20160924082224.edf	2.7		Tom
22	T-5	09/24/16	08:25:42	349212	526.0911	82:07.38550N	144:16.09350W	XBT_T-5_20160924082542.edf	4.0		Tom
23	T-5	09/24/16	15:50:54	352141	518.2386	82:08.44930N	144:54.82690W	XBT_T-5_20160924155054.edf	0.5		Tom
24	T-5	09/24/16	16:12:27	352142	246.1278	82:08.16040N	144:54.99400W	XBT_T-5_20160924161227.edf	6.0		Tom
		09/25/16	00:01:38					XBT_T-5_20160925000138.edf	7.3	not work	

25	T-5	09/25/16	00:12:59	352150	236.7505	81:18.98540N	145:00.97680W	/XBT_T-5_20160925001259.edf	10.1		
27	T-5	09/25/16	00:15:34	352145	380.6343	81:18.63340N	145:02.43930W	XBT_T-5_20160925001534.edf	10.8		
27	T-5	09/25/16	08:24:59	352146	1205.1978	80:22.33070N	148:14.15610W	XBT_T-5_20160925082459.edf	7.3		Tom
28	T-5	09/25/16	08:35:42	352143	1075.8249	80:21.69550N	148:15.80690W	XBT_T-5_20160925083542.edf	8.6		Tom
29	T-5	09/25/16	16:11:16	352152	114.8734	79:34.77260N	150:51.67990W	XBT_T-5_20160925161116.edf	8.0		Tom
		09/25/16	16:18:19					XBT_T-5_20160925161819.edf	8.0	not work	Tom
		09/25/16	16:19:48					XBT_T-5_20160925161948.edf	7.9	not work	Tom
30	T-5	09/25/16	16:21:09	352147	1278.1495	79:34.01680N	150:54.12570W	XBT_T-5_20160925162109.edf	7.7		Tom
31	T-5	09/25/16	16:27:45	349520	619.9117	79:33.23200N	150:56.76610W	XBT_T-5_20160925162745.edf	7.8		Tom
32	T-5	09/25/16	16:32:11	349516	262.1865	79:32.92130N	150:58.22640W	XBT_T-5_20160925163211.edf	8.1		Tom
		09/26/16	00:01:53					XBT_T-7_20160926000153.edf	10.1	Didn't register Load	
33	T-7	09/26/16	00:06:37	1106694	652.7363	78:32.88180N	154:04.36640W	XBT_T-7_20160926000637.edf	10.1	use	
34	T-7	09/26/16	08:23:25	352148	760.4065	77:25.77100N	155:36.94850W	XBT_T-7_20160926082325.edf	5.7	set up as T-7	Tom
35	T-5	09/26/16	08:31:36	352144	268.2031	77:25.35470N	155:37.78480W	XBT_T-5_20160926083136.edf	5.7	not get very deep	Tom
36	T-7	09/26/16	08:37:27	1106695	760.4065	77:24.91320N	155:38.58170W	XBT_T-7_20160926083727.edf	5.7	use	Tom
37	T-7	09/26/16	16:08:20	1106690	61.9321	76:30.37460N	156:41.46070W	XBT_T-7_20160926160820.edf	1.5	55 and stop	Tom
38	T-7	09/26/16	16:12:55	1106691	111.3191	76:30.31250N	156:41.59880W	XBT_T-7_20160926161255.edf	1.5	Fidled with breach	Tom
39	T-7	09/26/16	16:15:14	1106696	760.4065	76:30.26570N	156:41.72660W	XBT_T-7_20160926161514.edf	1.5	use	Tom
40	T-7	09/26/16	23:59:43	1106701	279.958	75:35.92380N	157:40.18930W	XBT_T-7_20160926235943.edf	9.7		
41	T-7	09/27/16	00:05:51	1106692	658.153	75:35.43370N	157:40.93960W	XBT_T-7_20160927000551.edf	9.7		
42	T-7	09/27/16	07:04:17	1106697	760.4065	74:33.32250N	158:52.57010W	XBT_T-7_20160927070417.edf	9.5	use	
43	T-7	09/27/16	08:08:20	1106693	760.4065	74:22.18600N	159:04.94340W	XBT_T-7_20160927080820.edf	9.9	use	Tom
44	T-5	09/27/16	16:05:56	349521	1581.4067	74:04.61460N	157:44.37440W	XBT_T-5_20160927160556.edf	1.9	use	Liz
45	T-7	09/28/16	00:00:09	1106682	760.4065	73:43.16360N	155:41.75760W	XBT_T-7_20160928000009.edf	10.3	use	
46	T-7	09/28/16	05:07:56	1106678	760.4065	73:32.31250N	152:51.18500W	XBT_T-7_20160928050756.edf	12.3	use	
47	T-7	09/28/16	08:06:39	1106686	445.5403	73:22.91290N	150:40.67600W	XBT_T-7_20160928080639.edf	12.6	Terminate early	Tom
48	T-7	09/28/16	08:14:43	1106679	760.4065	73:22.66280N	150:37.23460W	XBT_T-7_20160928081443.edf	1.6	use	Tom
49	Deep Blue	09/28/16	16:03:17	1179186	316.9487	72:50.35780N	146:02.19780W	XBT_DeepBlue_20160928160317.edf	12.3	terminate early	Tom
50	T-7	09/28/16	16:07:38	1106700	760.4065	72:49.59690N	146:02.97860W	XBT_T-7_20160928160738.edf	12.3	use	Tom
51	T-7	09/28/16	18:30:57	1106683	760.4065	72:21.15550N	146:31.95800W	XBT_T-7_20160928183057.edf	10.0		Liz
52	T-7	09/28/16	20:11:12	1106687	760.4065	72:03.17140N	146:50.54860W	XBT_T-7_20160928201112.edf	12.4		
53	T-7	09/28/16	21:19:36	1106688	760.4065	71:50.13630N	147:04.48410W	XBT_T-7_20160928211936.edf	9.8		
54	T-7	09/28/16	22:46:23	1106684	760.4065	71:36.32170N	147:12.16450W	XBT_T-7_20160928224623.edf	9.9		
55	T-7	09/28/16	22:55:01	1106680	760.4065	71:35.03100N	147:12.40240W	XBT_T-7_20160928225501.edf	10.0		
56	T-7	09/29/16	08:14:17	1106681	405.3606	71:38.94440N	148:24.12260W	XBT_T-7_20160929081417.edf	9.8	terminate early	Tom
57	T-7	09/29/16	08:18:16	1106689	760.4065	71:39.39920N	148:23.96270W	XBT_T-7_20160929081816.edf	9.8		Tom
58	T-7	09/29/16	09:54:05	1106685	760.4065	71:54.92460N	148:04.97690W	XBT_T-7_20160929095405.edf	9.6	use	Tom
59	Deep Blue	09/29/16	16:03:24	1179178	61.9321	72:37.11960N	149:58.68710W	XBT_DeepBlue_20160929160324.edf	12.8	terminate early	Tom
60	Deep Blue	09/29/16	16:05:25	1179182	760.4065	72:37.31750N	149:59.95200W	XBT_DeepBlue_20160929160525.edf	12.8	use	Tom
61	T-7	09/30/16	00:03:11	1106745	760.4065	73:02.39360N	154:37.73640W	XBT_T-7_20160930000311.edf	8.0		
62	Deep Blue	10/03/16	16:06:27	1179183	348.8025	57:13.23970N	172:20.13260W	XBT_DeepBlue_20161003160627.edf	14.0	use To about 120	Tom
63	T-7	10/03/16	21:10:13	1053621	760.4065	56:21.60570N	172:52.96670W	XBT_T-7_20161003211013.edf	8.4	use	Liz
64	T-7	10/04/16	08:23:02	1106738	760.4065	56:24.21740N	172:45.11470W	XBT_T-7_20161004082302.edf	10.7	use	Tom



Location of XBT launches in Chukchi/Canada Basin Area



Location of XBT launches in Beringian Margin Area

Appendix E: HEALY 1603 EM122 Data Processing

Data Flowpath
Data was copied, as soon as it was available, from the Healy data servers onto a hardware RAID1 (dual disc) external disc enclosure hosted on a CCOM/JHC laptop computer. Raw data was preserved, and copies made for processing. Each day, an automatic backup utility was used to mirror the data archive over the network to a second, identical, hardware RAID1 external disc enclosure hosted on a second CCOM/JHC laptop. This ensures that the data was always on at least two separate discs at all times (in addition to the ship's network servers) inside the RAID1 enclosure, and with at most a day's delay, on four independent discs across two RAID1 enclosures on separate machines, any one of which could be used to recover the data in the event of a hard disc failure.

Data processing followed the procedures outlined in the document below:

Data Processing Watchstander Checklist

USCGC Healy (WAGB-20)
US LOTS Mapping Mission (HLY16-03)

Modification Status of this Document

Date/Time	Author	Comment
2007-230/0600	Brian Calder	Initial revision
2007-230/1730	Brian Calder	Modified output products required
2007-231/0230	Brian Calder	Modified required frequency of output products
2007-231/2345	Brian Calder	Small comments on output file name conventions
2007-232/0610	Brian Calder	Added explicit instructions on sub-fieldsheets, and procedure for GIS-index file generation
2007-233/2319	Janice Felzenberg	Modified things to do (copy processed Knudsen images to local hard drive)
2007-234/0420	Brian Calder	Modified location for the ASCII sounding data at end of day to ArchiveData to match original intent
2007-234/0715	Brian Calder	Added instructions for converting the OziExplorer 'as run' route to HyPack/ArcGIS
2007-235/0025	Brian Calder	Reconfigured product creation to reflect making the projected grids in AvgGrid to beat out system noise.
2007-236/0600	Brian Calder	Added smoothing factors for AvgGrid and lower resolution grids, and naming convention for hyper-smoothed grid products.
2008-226/0020	Brian Calder	Updated locations of data from the servers to match the current configuration for HLY0805.
2008-229/1842	Brian Calder	Added instructions on processing Knudsen data from SEG-Y through SonarWeb, and Fledermaus object construct at end of day.
2008-229/1920	Brian Calder	Changed meta-data instructions from manual creation to automatic creation.
2011-227/2250	Brian Calder	First-pass modifications for HLY1102
2011-230/0215	Brian Calder	Modifications for HIPS 7.1 output and Fledermaus 7.3 product generation based on GSF outputs.
2011-231/0830	Brian Calder	Added low-resolution daily product, and updated end of day processing instructions for metadata and GIS products.
2011-240/0640	Brian Calder	Added modified UNCLOS-specific Fledermaus projection information, updated information on colourmap requirements for 4-hr and full-day products. Updated resolutions table in Table 1.
2011-256/0504	Brian Buczkowski	Modifications for processing Knudsen data from SEG-Y through SonarWiz5, and Fledermaus object construct at end of day.
2012-238/0240	Brian Calder	Modifications to adapt to locations for HLY12-02.
2016-262/1850	Brian Calder	Modifications to adapt to locations/methods for HLY 16-03.

Data Locations

Raw data is on Healy's primary data server, copied from a number of different systems; this is the source of all of the data you'll need for the processing. If the data directory isn't already mounted, then mount `\\healynas\data\hly1603` on `Y:` locally (`healynas` is currently 192.168.20.28 and shouldn't move for the duration of this cruise). You should not have to provide login credentials for the system; if it starts asking for a username and password, that's probably a bad sign (and time to call for help).

It is very important that you copy the data from the server in a timely manner (as indicated below). The servers can be a little flakey; you don't want to lose the data because of a system crash. Don't leave it until the end of the watch to copy a chunk of data (no matter how tempting that might be).

All data is to be copied to the local hard drive, mounted as D: The data for the current mission is in `D:\Healy2016`, with appropriate sub-directories for raw data (`RawData`), data being processed (`Processing`), and products being created (`StaticProducts`). Other directories reflect GIS/Mapping products, but don't concern the person working on processing the data at this station.

Time Keeping

All timestamps on the data are referred to UTC (a.k.a. GMT, more or less). If you make a log entry, or comment in this file, please use this timestamp. Local ship's time is Alaskan standard time, which is eight hours behind UTC. That is, 2100 local time is 0500 UTC in the following day (0500+1).

Things You Need To Do

Copy Data to Local Hard Drive

1. At the end of each two hour block, the EM122 system generates a new file. When the next two hour block's file appears in the raw data directory, copy the previous two hour block's file to the local RAID drive raw data directory, `D:\Healy2016\RawData\EM122\2016-DDD` where `DDD` is the Julian[1] day when the data was collected. **Note that there are appropriate desktop shortcuts to the source and destination locations to make finding this easier.** At the end of each UTC day, you should have 12 files in this directory. Due to the way that the Simrad SIS software rolls over files, you can't guarantee that they will always roll over on the hour, so you might have one more or less file each day; this also means that you'll have to keep checking for the new files appearing. Windows 10 (in its infinite wisdom, blessed be the name of Microsoft) will warn you about potentially harmful files on each copy. Ignore it. (That's generally good advice.)
2. At irregular intervals during each day, the Knudsen sub-bottom profiler will generate new files in `Y:\data\singlebeam`. When the next file appears, copy all of the

[1] Pedants will complain that this isn't really a Julian Day, but a "year sequential day", since Julian Days should start at the establishment of the Julian calendar, and increase sequentially since then. Scoff heartily at, and then ignore, such mindless pedantry.

components of the previous file (`.kea`, `.keb`, and several `.sgy`) into `D:\Healy2016\RawData\Knudsen3260`. All files for all days will be kept in the same directory. **It is vital that you do not copy any files until the next one is started** (i.e., until the current file is finalized and closed).
3. When we do a CTD or take an XBT, data files will be generated in `Y:\Raw\ctd` or `Y:\Raw\ctd\xbt`. When the MST tells you that the data is available, copy to `D:\Healy2016\RawData\CTD` or `…\XBT` as appropriate.

Qimera Processing of Data

1. Convert the EM122 data into the Qimera project in `D:\Healy2016\Processing\`.
    a. Choose "Source→Add Raw Sonar Files …" and then select the new line you're adding.
    b. Make sure that the coordinate frame selected says "FG_WGS_84" and nothing else.
    c. Click "OK" to convert all of the files into Qimera.
2. Qimera will prompt you to add to an existing dynamic surface. Select the surface at the resolution appropriate to the depth of the data (see Table I); click OK to add the data.
3. Check the newly added line to consistency with any overlap, and particularly any evidence of refraction (either 'smiles' or 'frowns' across-track). The most efficient remediation mode for the data is typically sub-set mode (i.e., 3D spatial editing), although line-oriented mode can sometimes be more useful for particular problems (for example nadir issues in shallow water). Common sense is the most useful guide, rather than a particular editing dogma: use whatever tool suits the problem.
4. Once all outliers are removed, reprocess any lines that need it.
5. After you're satisfied with the data, add it to the "Overview" dynamic surface by selecting the line, and then clicking "Dynamic Surface→Append Lines …", selecting the "Overview" surface, and clicking "OK".

Product Creation

Product creation doesn't have to happen at the end of every line (although you can do so if you want the practice). You should, however, make a set of products at the end of every watch.

At the end of each watch, follow these steps:

1. Select all of the lines in the sub-product, and export as GSF files:
    a. Select the line or lines being exported.
    b. Right click and select "Export→to GSF" from the context menu.
    c. The files will be exported as GSF in `D:\Healy2016\Processing\Qimera\HLY1603\Export\HEALY_SN106`.
    d. Copy the files to `D:\Healy2016\ArchiveData\2016-DDD` using the default output name given by Qimera.
2. Select all of the lines that have been added in this watch, and generate a new Dynamic Surface for them with "Dynamic Surface→Create Dynamic Surface …"

Make sure to choose the lowest resolution (i.e., that appropriate for the deepest part of the data being processed).

3. Export a static surface from the Qimera dynamic surface by selecting only the dynamic surface being exported, and store in `D:\Healy2016\StaticProducts\2016-DDD` with name `2016_DDD_HHHH_HHHH_RRm.sd` where DDD is the Julian day, the HHHH are the start and end times for the lines, and RR is the resolution chosen from Table I.
4. Export an ArcView grid for the static grid by choosing "Export→Static Surface→to Surface …"
   a. Select 'Export ArcView Grid'; click 'Save'.
   b. Save the file as `2016_DDD_HHHH_HHHH_RRm.asc` in `D:\Healy2016\StaticProducts\2016-DDD`.

At the end of each Julian day (1600 ship's local time), do the following:

1. In Qimera, make 'whole day' projected objects:
   a. Select all of the files for the day, and follow the procedure for #2 in the end-of-watch products to generate a projected grid for the full day; use the "arctic.cmap" colour map (`D:\Healy2016\Processing`). Use the coarsest resolution used to make a product during the day. The file should be named `2016_DDD_ps_RRm.sd`.
   b. If the resolution of 1(a) is finer than 100m, select all of the files for the day, and follow the procedure for #2 in the end-of-watch products to generate a projected grid for the full day at 100m. (This is used to accumulate a working view of the survey at lower resolution.) The file should be named `2016_DDD_ps_100m.sd`.
2. Export the projected grid as a GeoTIFF for the GIS; in Qimera, select "Export→Dynamic Surface→to Image…" and then save as `2016_DDD_ps_RRm.tif` or `2016_DDD_geo_GGs.tif` in `D:\Healy2016\StaticProducts\2016-DDD`.
3. Export the projected grid as an ArcView ASCII grid for the GIS; in Qimera:
   a. Select the appropriate grid, then select "Export→Dynamic Surface→to Surface…"
   b. Select 'Export ArcView Grid'; click 'Save'.fmgt
   c. Save the file as `2016_DDD_ps_RRm.asc` or `2016_DDD_geo_GGs.asc` in `D:\Healy2016\StaticProducts\2016-DDD`.
4. Extract the navigation for the MBES data into the format required for the GIS database. Open a Terminal window, and do:
   a. `cd /Volumes/hly1603/Healy2016/ArchiveData/2016-DDD`
   b. `nav_to_shape.pl 2016-DDD.gen *.gsf`
   c. `posgga_to_shape.pl –a 2016-DDD_posmv_gga_navigation.gen /Volumes/Data/LDS_Data/posnav/HLY1603-posnav.y2016dDDD`
5. Construct the XBT database and plots for any new XBTs:
   a. Run `construct_xbt_database`
   b. Start MATLAB, and ensure that `/Volumes/Healy2016/Processing/bin` is in the path; run the `plot_xbt_ssp.m` script.

c. Navigate to the `/Volumes/Healy2016/Processing/XBT` directory, select all the new XBT SSPs since the last batch (these are made by the `construct_xbt_database` script), and click 'Open'; the code will load all of the SSP files and generate plots as PNGs in the same directory.

d. Move the resulting PNGs into the `/Volumes/Healy2016/GIS/XBT` directory.

6. Tell the person running the GIS workstation that the products are available for ingestion into the GIS.

Recommended Grid Resolutions

The grid resolutions and smoothing factors in Table I are recommendations for product construction at 4hr intervals, and for full-day products when possible. In the case of full-day products where there is a lot of variability in the depth, you may need to make more than one grid to preserve resolution in the shallow areas. Don't make more than 2-3 grids, since it otherwise gets confusing.

The depth ranges in the 'Actual' column here are computed by empirical experimentation, and are approximate. You should endeavor to use the highest possible resolution that results in a grid product without holes; in practice, you should try the next higher resolution as well as the nominal one. So if the maximum depth in your data is 1500m, you would try 30m and 25m (and maybe even 20m) to see if the data will stand up to it, before choosing a final resolution. You can't really tell this from the DTM in DMagic; you need to see the Fledermaus object. If in doubt, you can make a grid at the lowest resolution you think is likely, and then examine it to see where the data starts to fall apart. Make the resolution decision in projected coordinates, and then match in geographic coordinates if possible: you may have to drop the resolution somewhat in geographic coordinates because of the latitude at which we're working.

Grid Resolution		Nominal	Actual	Smoothing	GeoLabel
(m)	(deg)	(m)	(m)	(cells)	
5	4.500E-05	71.59063	<300m	3	0.2s
10	8.999E-05	143.1813	<500m	3	0.3s
15	1.350E-04	214.7719	<1000m	3	0.5s
20	1.800E-04	286.3625	<1250m	3	0.6s
25	2.250E-04	357.9532	<1500m	3	0.8s
30	2.700E-04	429.5438	<1750m	3	1.0s
35	3.150E-04	501.1344	<2000m	3	1.1s
40	3.600E-04	572.7251	<2500m	3	1.3s
45	4.050E-04	644.3157	<3500m	3	1.5s
50	4.500E-04	715.9063	<4000m	3	1.6s
75	6.749E-04	1073.859		3	2.4s
100	8.999E-04	1431.813			3.2s
125	1.125E-03	1789.766			4.0s
150	1.350E-03	2147.719			4.9s
175	1.575E-03	2505.672			5.7s
200	1.800E-03	2863.625			6.5s
225	2.025E-03	3221.578			7.3s
250	2.250E-03	3579.532			8.1s
275	2.475E-03	3937.485			8.9s
300	2.700E-03	4295.438			9.7s
325	2.925E-03	4653.391			10s
350	3.150E-03	5011.344			11s
375	3.375E-03	5369.297			12s
400	3.600E-03	5727.251			13s

Table I: Recommended grid resolutions for the Kongsberg EM122 on USCGC HEALY during HEALY 11-02 (2011).

Overall Data Structure

A standard data structure was established on the RAID1 disc enclosure in order to ensure that data was readily searchable, and to prepare for archival. The overall structure is show in Figure below.

Healy2016					
	Archive Data				
		2016-263			
		…			GSF files exported from Qimera
		206-279			
	Cruise Documents				
		HLY1603_CHI_SCI_LOG.docx			Chief Scientist's Narrative Log
		HLY1603 Technical Report.docx			Cruise Report
		HLY1603 Watchstander Notes.docx			HLY1603 Watchstander Duties
		HLY1603 Watch Schedule.docx			HLY1603 Watchstander Names/Times
		HLY1603 Patchtest Plan.docx			HLY1603 Patchtest Brief for USCGC Healy
		Interesting Features			Images of features in bathy used for cruise report
	Dredge				
		Dredge Site On Board			Planning documents for the dredge sites
		Samples			
			Guidance & Policy		Pre-cruise policy documents from ECS project office
			HLY1603 Samples.xlsx		Spreadsheet of physical sample metadata
			HLY1603 Tow Log Dredge.pdf		Scans of hand-log of dredge metadata
			Photos		
				DR1-*.jpg	Dredge 1 images with sample numbers
				DR2-*.jpg	Dredge 2 images with sample numbers
				Raw_Images	All images of samples (sequential camera IDs only)
	Knudsen				
		Combined_SEGY			SEG-Y data files composited from smaller files
		Examples_JPG			Example imagery from JP2 files in interesting areas
		file_line_comp.xlsx			Processing log for sub-bottom profiler data
		FOS_dox.xslx			Foot of Slope file identification metadata
		FOS_images			Foot of Slope images, SEG-Y snippers and overviews
		GSC_Seismic_Software			Executables for processing software
		JP2_Files			JPEG-2000 files for each composite SEG-Y line
		Knusden_Report			Cruise report component from sub-bottom profiler work
		Long_Lines			Longer composite lines for complete transects
		Raw_SEGY			Source SEG-Y files for compositing
		Shapefiles			ArcGIS shapefiles for each composite SEG-Y file
	Processing				
		arctic.cmap			Standard colormap used for Fledermaus objects
		FMGT			
			Healy1603_UNCLOS.fmproj		Backscatter project for Arctic segment in Polar Sterographic projection
			Healy1603_WGS84.fmproj		Backscatter project for Arctic segment in unprojected coordinates
			Healy1603_BM_margin_ALL.fmproj		Backscatter project for Bering Maring segment
			Healy1603_263.fmproj		
			…		Per-day Backscatter Projects
			Healy1603_279.fmproj		
		Guides			Documents on processing for Qimera and FMGT
		Qimera			
			Healy1603		Processing directory for Arctic segment
				Healy1603_ProcessingLog.xlsx	Processing log for Qimera bathymetric processing
				Healy1603_FMGT_ProcessingLog.xlsx	Processing log for FMGT backscatter processing
			Healy1603_BM_Margin		Processing directory for Bering Margin segment
			Healy1603_Patch		Processing directories for patch test
			Healy1603_Patch2		
			Healy1603_TransitBS		Processing directory for transits between segments
			UNCLOS_PolarStereo_Projection.wkt		Well-known-text projection parameters for Polar Stereographic projection
		Auxiliary Data			Screenshots to support processing
	Raw Data				
		CTD			XBT data used during patch test
		EM122			
			2016-263		
			…		MBES source data from SIS
			2016-279		
			Ancillary Files		Absorption coefficients and ASVP files from SIS
		Knudsen3260			SEG-Y, KEA, and KEB files from sub-bottom profiler
		XBT			EDF files from Sippican XBT launcher software
	Static Products				
		2016-263			Fledermaus SD, GeoTIFF, and ArcGIS grids for each day (Fledermaus SD files with backscatter over bathymetry also provided)
		…			
		2016-279			
			Backscatter		Fledermaus SD, GeoTIFF, and ArcGIS grids of backscatter
		Bmargin			Composite of all lines at Bering Margin segment
		Healy1603_withIBCAO.scene			Fledermaus Scene file of all data, with IBCAO background
		Healy1603.scene			Fledermaus Scene file of all data

Appendix F: HEALY 1603 Knudsen Subbottom Profiler Report

David Mosher and Kimberly Baldwin -- CCOM/UNH

Equipment

USCGC Healy is equipped with a hull mounted Knudsen 3260 Chirp Subbottom Profiler. The transducer bay consists of a 16 element array of TR109 transducers arranged 4x4 in a sea chest in the hull of the ship; the acoustic tile is covered with a titanium plate. The deck unit is in the rack of hardware mid-ships on the 2nd Deck, next to the Gym. The control monitor is at the multibeam workstation where watch keepers could monitor both the multibeam and the subbottom profiler concurrently. Software running the Knudsen is the SounderSuite Echo Control Client Version 4.05.

Acquisition

The Knudsen was activated on departure from Nome, Alaska and left running continuously throughout the expedition, except during the patch test in Canada Basin and Northwind Ridge early in the expedition. It was set at a center frequency of 3.5 kHz with a bandwidth of 3 kHz; thus spans a bandwidth of 2 to 5 kHz. The system was continuously tuned by the watchkeepers to maximize subbottom imaging. For the most part, pulse length varied between 1 and 8 milliseconds, although in very shallow water in the Bering Strait, it was set to 0.0625 ms. Gain levels varied significantly. Gain was entered manually, as bottom referenced TVG did not appear to be operating correctly; gain appeared to be applied from time 0 regardless of the window settings or water depth. Overall power and gain levels varied with bottom imaging and water depth; generally for deep water (>3500 m) a power setting of 3, pulse length of 4 ms and gain of 12-14 was used.

The system was synchronized with the Kongsberg EM122 multibeam system, thus signal initiation was triggered by the EM system to avoid interference with multibeam signals (External Trigger Control, on the Knudsen interface). This synchronization limited trigger frequency to about once every ~15 seconds in deep water (>3000 m), resulting in a sample spacing of one shot every 30 to 60 m, depending on ship speed and water depth, during the majority of this survey. In shallow water, such as in the Bering Strait (40-60 m) shot spacing was on the order of 5 m. Because of the variable trigger rate, trace spacing varies and speed correction was applied post-processing (see below).
Sound speed velocity was set to 1475 m/s. At this velocity, water depths from the multibeam system and from the subbottom profiler generally agreed to within +/-20 m while in the Arctic Ocean. Data display and record window length varied between 200 m and 1000 m. Deep water delays were managed by the operator through phase shifting on the EchoControl interface to track bottom. Metadata, and extracted depth parameters were recorded as flat ASCII in the .KEA files associated with each line. Subbottom profile data were written in Knudsen native binary KEB file format, and to Society of Exploration Geophysics Standard Y (SEGY) format. Segy record parameters were as follows:

Sample Format:	3 (short integer)
Byte Order (Big = true) :	True (Big Endian)
Number of Samples/Trace :	22075 (for 1324.5ms / 1000 m record window)

Sample Interval (usec) :	60
Number of Bytes/Samples :	2
Number of Traces :	299
Deep Water Delay	3311 (operator managed, depending on water depth)
Source X	Position Longitude in radians
Source Y	Position Latitude in radians

Time and navigation data were supplied by the POS-MV system to the Knudsen acquisition unit and are written to the headers of the SEGY files. Heave data were also supplied to the sounder by the POS-MV, so data are heave compensated (but not roll and pitch).

At the beginning of the expedition, on Days 163 and 164 (until 10:10 local time), the SeaPath navigation unit was not functioning; therefore, data from this period have no navigation data, nor heave compensation, and time was taken from the PC clock. Navigation data were merged into the Segy files after the fact. Once the POS-MV was implemented and replaced the SeaPath, then navigation, time and heave data were integrated with the Knudsen 3620 unit.

SEGY, KEB and KEA files were recorded to the local C: drive and automatically copied to the HealyNAS drive under data/HLY1603/data/singlebeam. All files from there were copied to the CCOM Raid AMBERJACK/Heally2016/RawData/Knudsen3260. Segy files were copied from there to AMBERJACK/Healy2016/Knudsen/Raw_Segy.

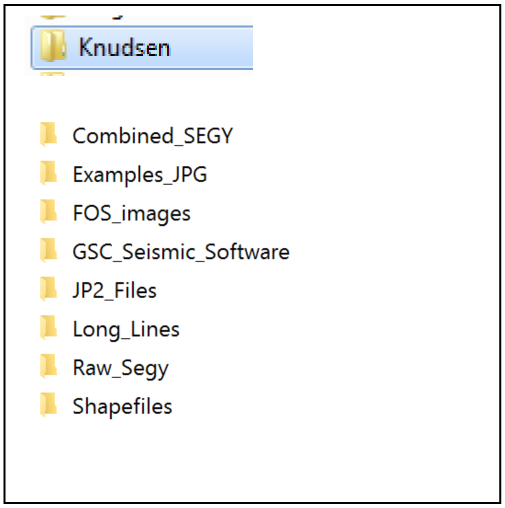
Naming convention on the raw files included line number followed by Day of the Year and Time, as follows:

0064_2016_264_2308_120302_CHP3.5_FLT.sgy

Where 0064 is the line number, 2016 is the year, 264 is the Day of the Year, 2308 is the Time of Day (UTC) in hhmm. 120302_CHP3.5_FLT is added by the software, representing the unit number and the sounder system (3.5 kHz versus 12 kHz).

Line numbers coincide precisely with those of the multibeam data.

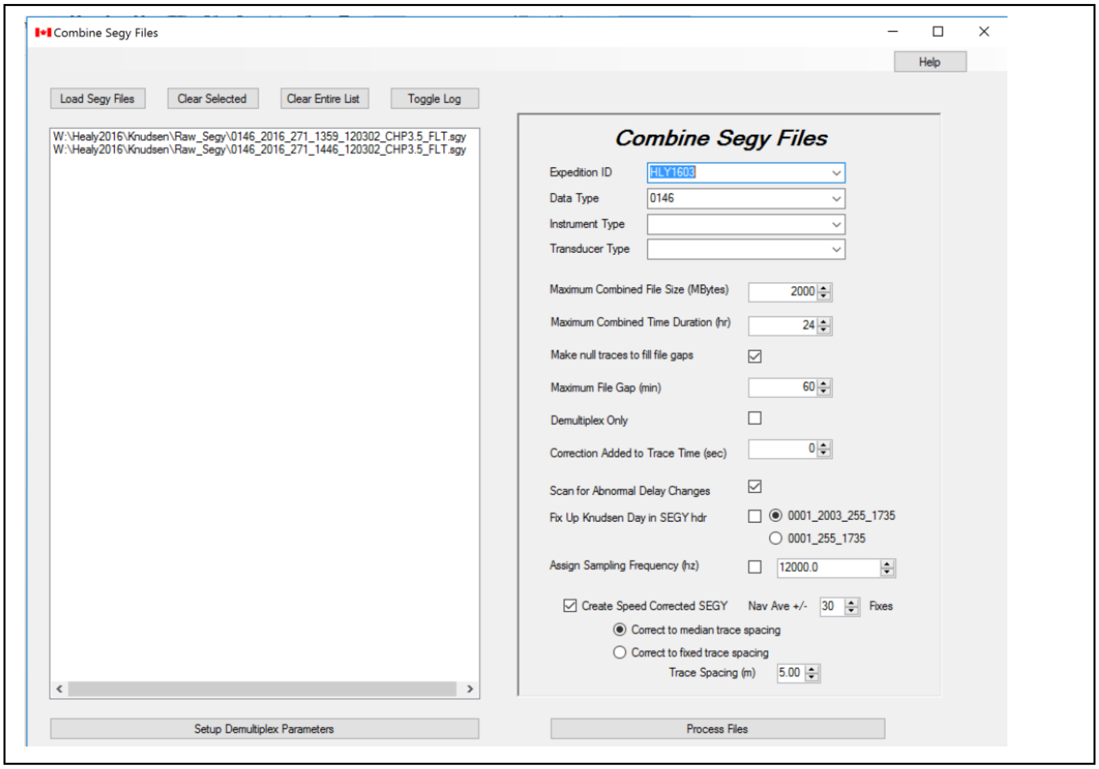
Processing of the Knudsen subbottom data was conducted under the AMBERJACK/Healy2016/Knudsen directory.



Processing

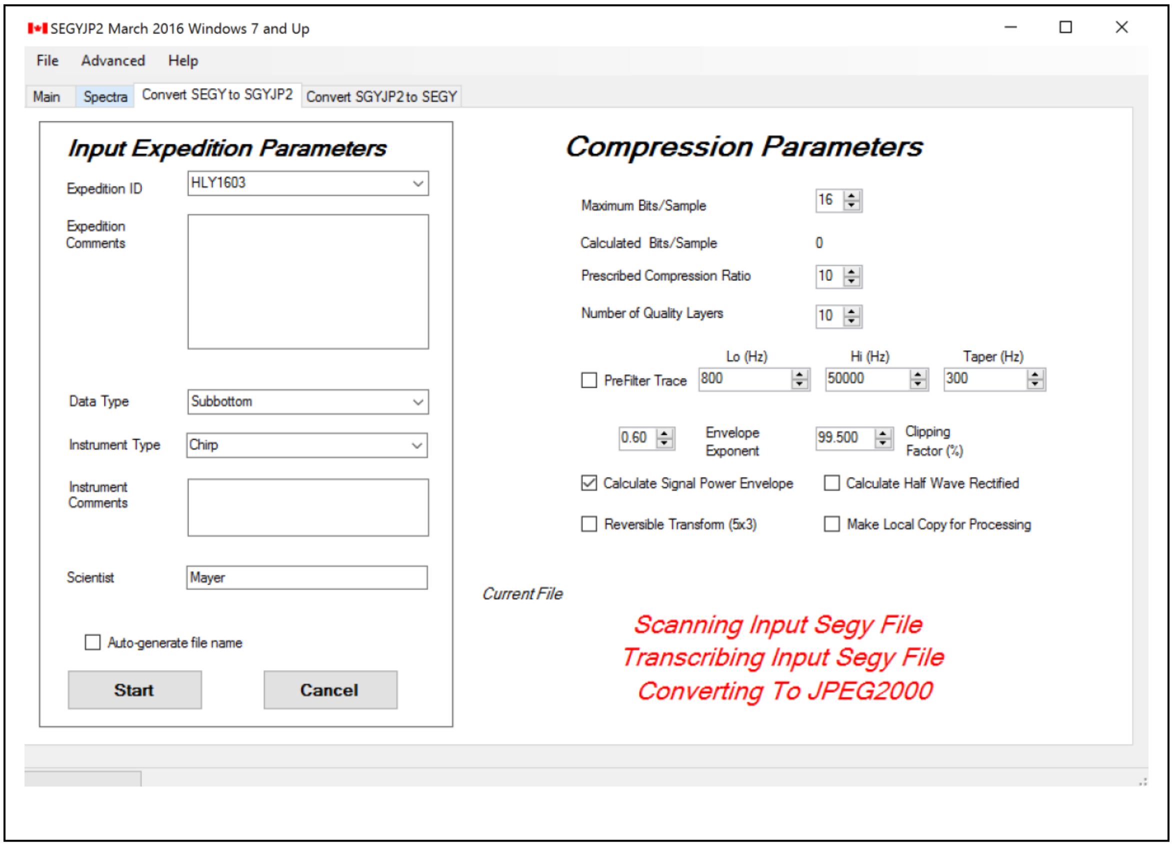
Lines were typically 2 hours in length and for the most part, this interval included just one file. If multiple raw SEGY files occurred per line, then they were combined into a single file, using the NRCan SEGYJP2 suite of software, called Combine_Segy. This software handles multiple files and sorts them according to time in the headers of the SEGY files and outputs them as a single file. It will resample and re-window data if necessary. If a data gap exists, it will not bridge the gap and make separate files, unless over-ridden by the operator (a setting in the GUI of the software). Speed correction was applied at this stage, so within a file, shot spacing is constant, allowing for a constant aspect ratio. Even single line files were run through this speed correction, as trigger rate varied depending on water depth according to the needs of the multibeam system. Segy files were written from the Combine_Segy software to a directory called "Combined_Segy". File naming convention maintains the line number and time information but now includes the cruise identifier and an appended string such as "SC30.1m" indicating a speed correction was applied and the trace spacing is 30.1 m.

HLY1603_0064_264_2309_to_265_0112_SC30.1m.sgy



Files from the Combined_SEGY directory were then converted to a specialized JP2000 format and written to the JP2_Files directory. The NRCan software SegyJp2 does this conversion. It performs a wavelet compression of the SEGY data to produce a compressed image format, but all of the SEGY metadata from the SEGY headers remains in the image headers. Data can be converted back to SEGY format with this same software. For these files the least amount of data compression was utilized (Compression Ratio of 10). Maximum compression (1) would result in much smaller image files, but a little loss of quality is expected.

.

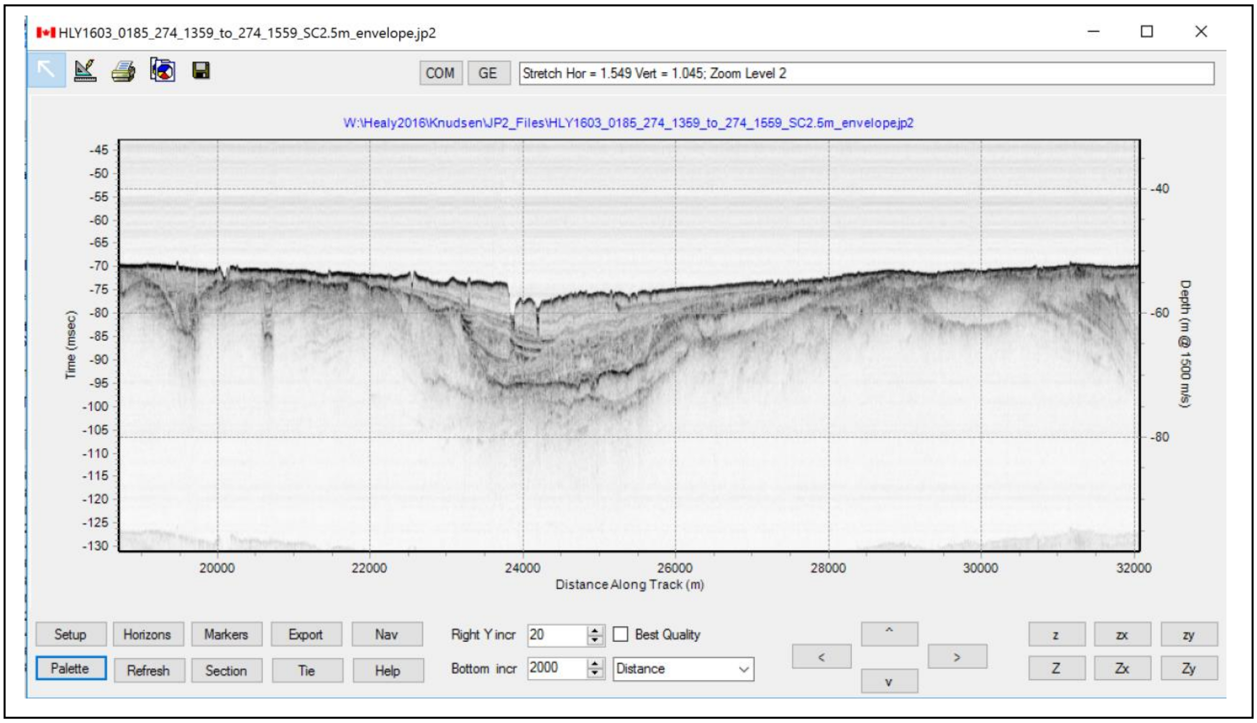


Data were converted with a small clipping factor (99.5%) to eliminate outliers that affect the overall image gain levels, and were converted to display as envelop data (sounder data have little useful phase information and almost always are presented as envelop). Jp2 files maintain the Cruise and line identifiers in the name of the file and are stored in the JP2_files folder.

HLY1603_0064_264_2309_to_265_0112_SC30.1m_envelope.jp2

The addendum of "envelop" to the file name indicates the data are envelope display.

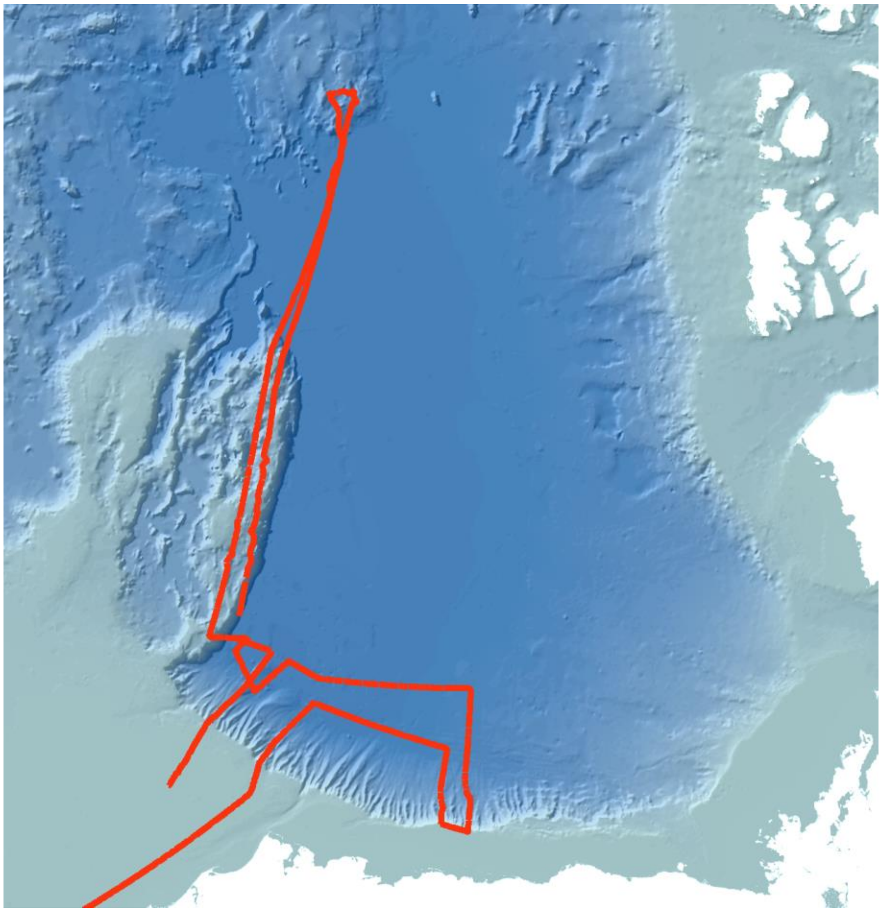
These JP2 files can be displayed in the NRCan SegyJp2Viewer software. This software allows full manipulation of the image for aspect ratio, zoom, display gains etc. It also is able to display trace, time or distance along the X-axis. Distance is only available if navigation is in the headers of the Segy file, which in this case it is integrated. Static images in a variety of formats can be output from this software.



This SegyJp2Viewer software also allows export of Shape files of the navigation data, suitable for loading into GIS software such as ArcMap. The Shape files provide a ship's track within ArcMap; a click on the track with the Arc identify tool ( ) provides a hyperlink to the Jp2 file, and the subbottom profile data will be displayed. Shape files are kept within the folder AMBERJACK/Knudsen/Shapefiles.

Line files were combined into longer line segments to view data as full transects. These newly combined data were written to a directory called "Long_Lines" and shape files were generated with these longer lines too.

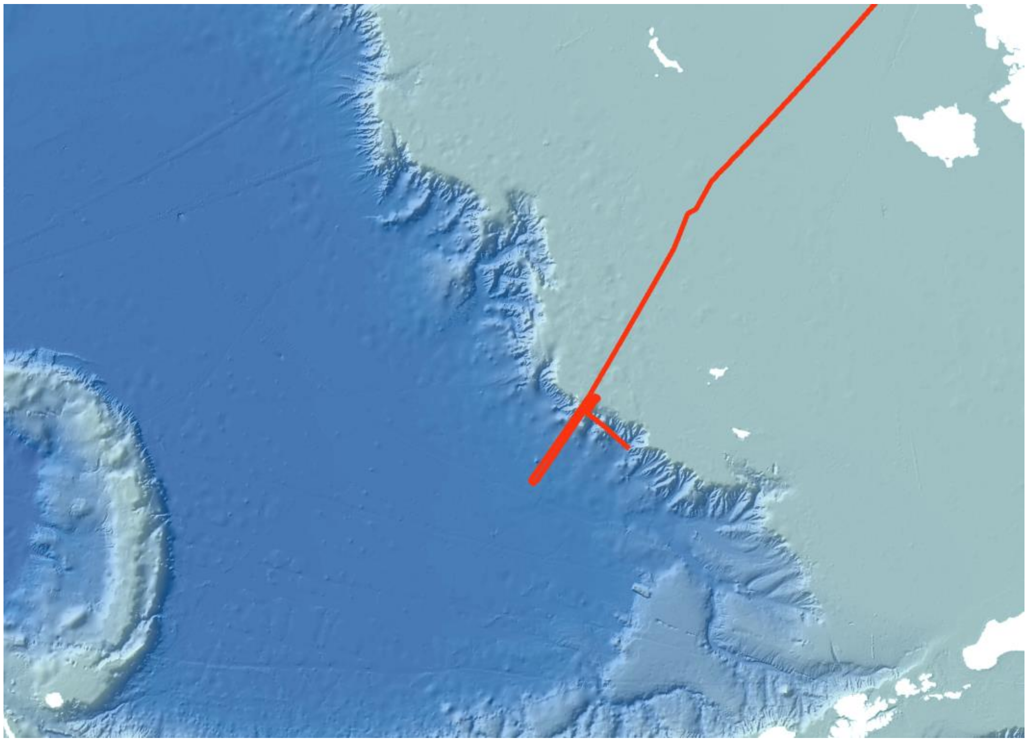
Additional functionality can be achieved with virtual serial port software implemented. A mouse click on the subbottom record will identify that position on the ArcGIS map.



Track map displayed in ArcGIS 10. Background is a render of the IBCAO v.3.1 grid. The red lines represent the ship's track during subbottom profiler data expedition, for the Arctic margin portion of the expedition. Clicking on the track with the "identify" tool in ArcMAP results in a hyperlink that will open the appropriate jp2 file of the subbottom profile.

ArcGIS project

Shape files for the tracks were loaded into an ArcGIS project (Arctic_sf.mxd) that contains a compilation of many subbottom profiles and multibeam grid renders. The project hosts the IBCAO v. 3.1 background grid and the along-track multibeam acquired during this expedition. The Knudsen tracks overlie the multibeam and backscatter to assist in feature identification. All speed-corrected lines were merged into single shape files (**HLY1603_SBP_to_246.shp**). This single shape file can be loaded and contain all of the hyperlinks to the jp2 files. The paths for the hyperlinks are drive specific (absolute paths), so in order to install the entire directory structure on another CPU will require editing the hyperlink paths. This is a simple matter of editing the attribute table of the shape file within Arc and changing the drive letter.



Expedition tracks with subbottom profiler acquisition to Line 246 on the Beringian margin.

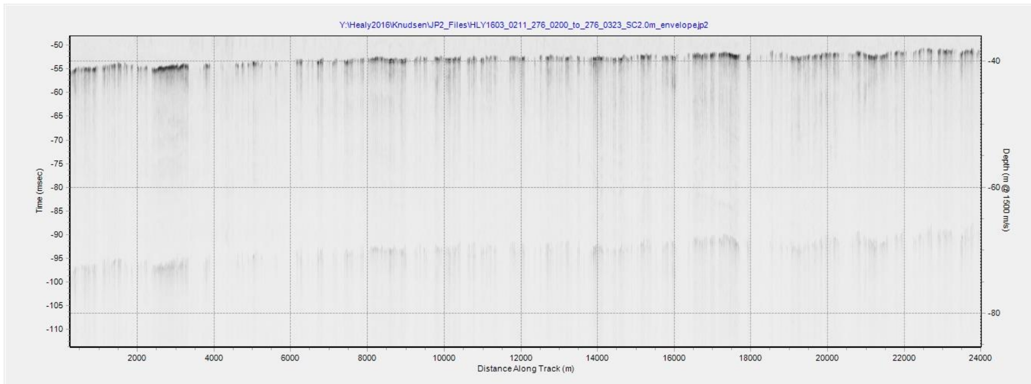
Issues

At the beginning of the expedition, on Days 163 and 164 (until 10:10 local time), the SeaPath navigation unit was not functioning; therefore, raw data from this period have no navigation data, nor heave compensation, and time was taken from the PC clock. Navigation data were merged into the Segy files after the fact. The POS-MV navigation string (NMEA) was used to create a GSC – A file format navigation file (dddhhmmss lat long) and a program was written to write these navigation data into the headers of the segy file in Arcseconds (addnav2sgy.c). The merger is based on day_time, so the segy trace time is read and the navigation file is searched for this time and the associated navigation data is written to the Source_X and Source_Y byte locations in the segy trace header. Linear interpolation is applied if no navigation point falls directly on the time of the trace. Once the POS-MV was implemented and replaced the SeaPath, then navigation, time and heave data were integrated with the Knudsen 3620 unit.

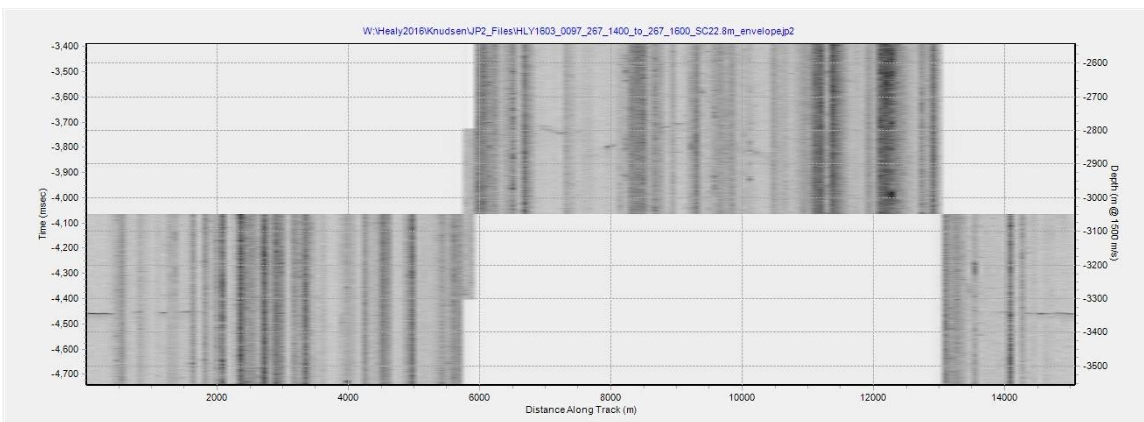
TVG on the unit appeared not to function… gain was applied from time 0, it seemed; even if bottom referenced was chosen.

Auto tracking appeared not to function.

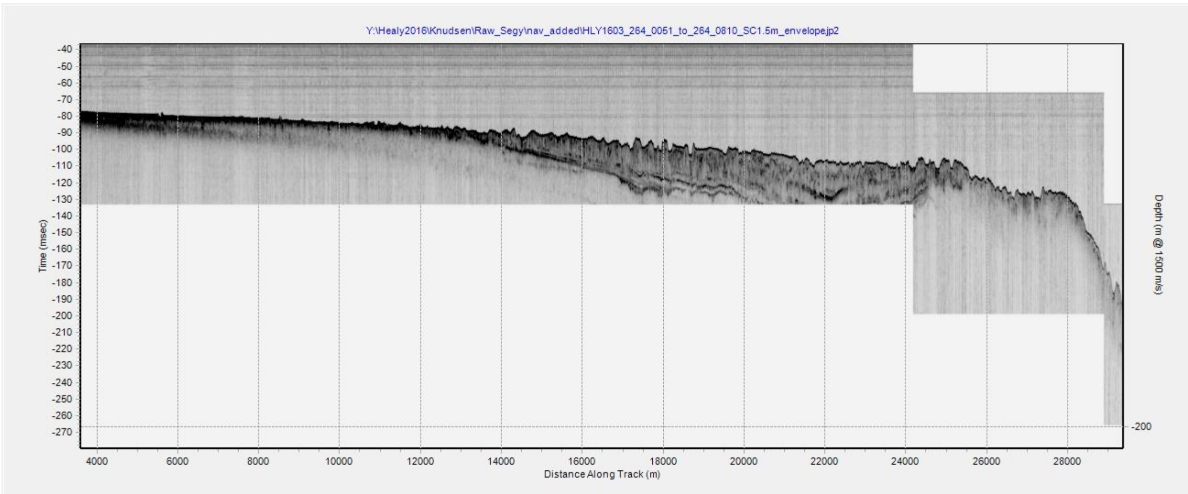
The only other issues were weather related. Data were particularly poor due to weather around Line 211.



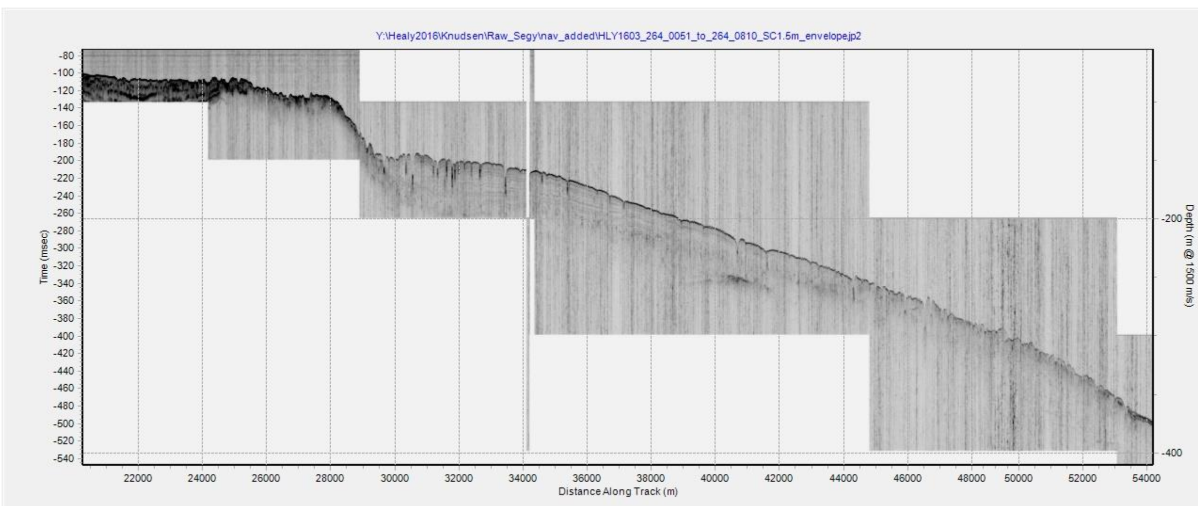
Or due to heavy ice breaking.



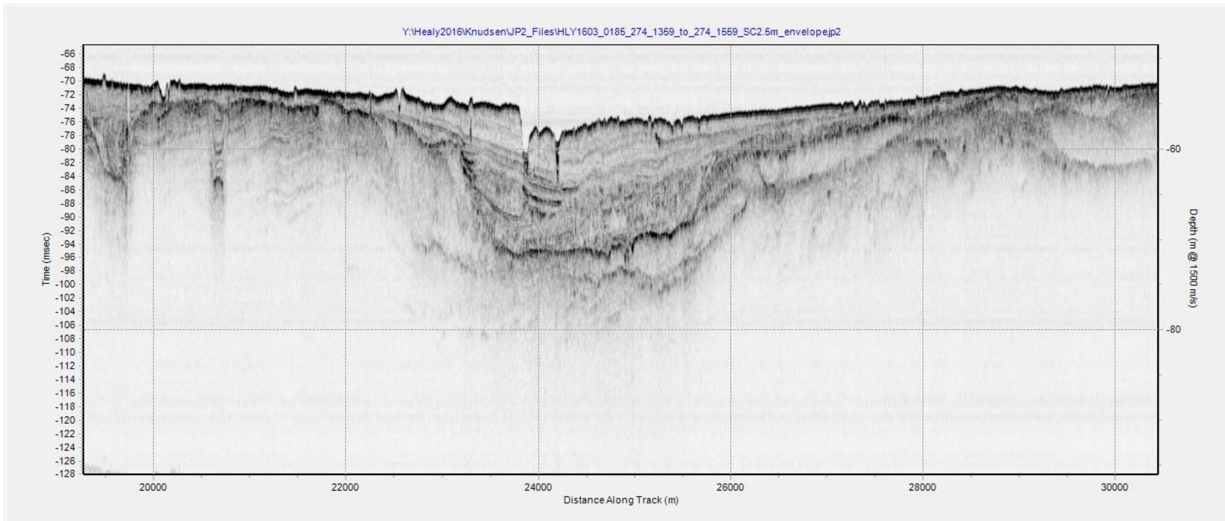
Interesting Tidbits



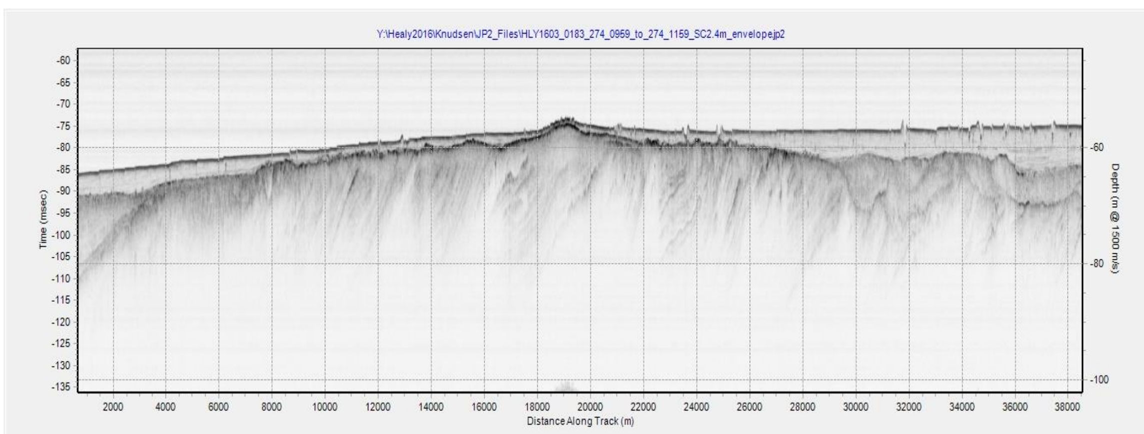
Bering Shelf



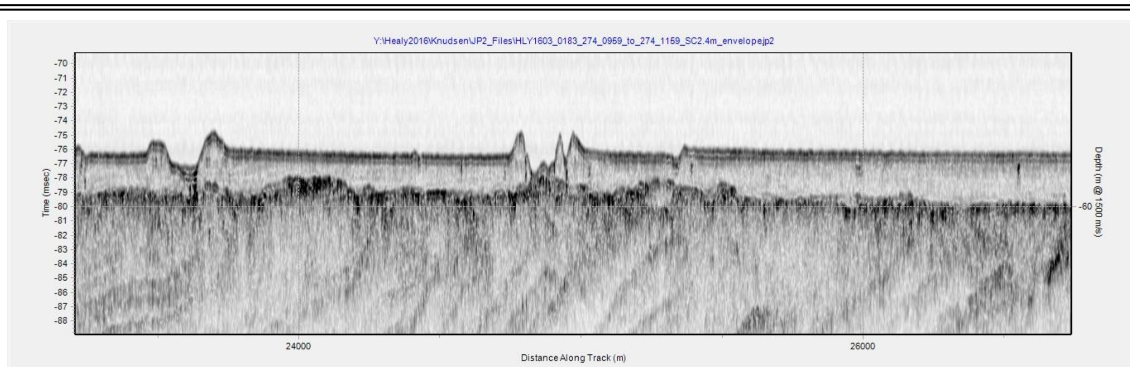
Bering Sea shelf to slope transition in the Arctic.



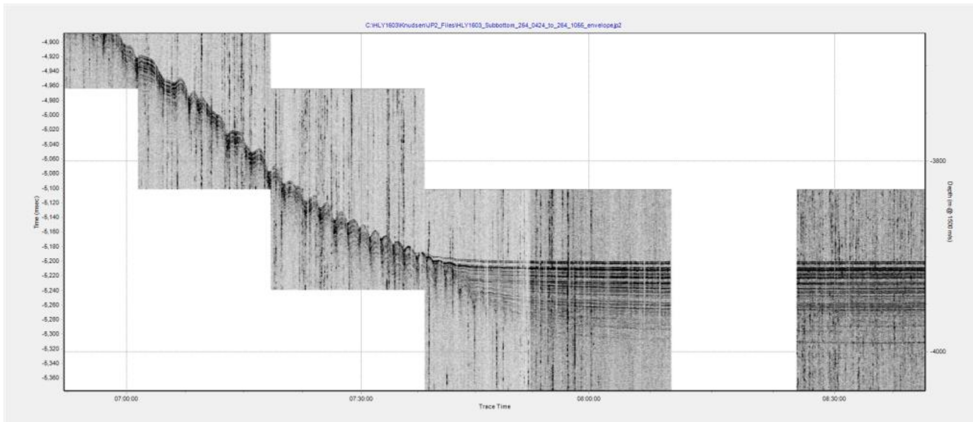
Paleo-channel and ice scour on the Bering Shelf



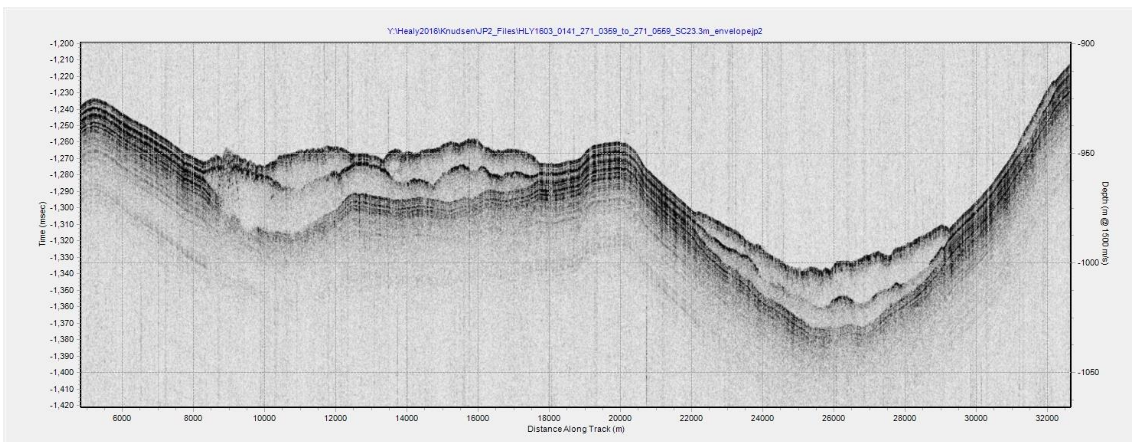
Dipping strata beneath Quaternary ice-scoured cover, Bering Strait



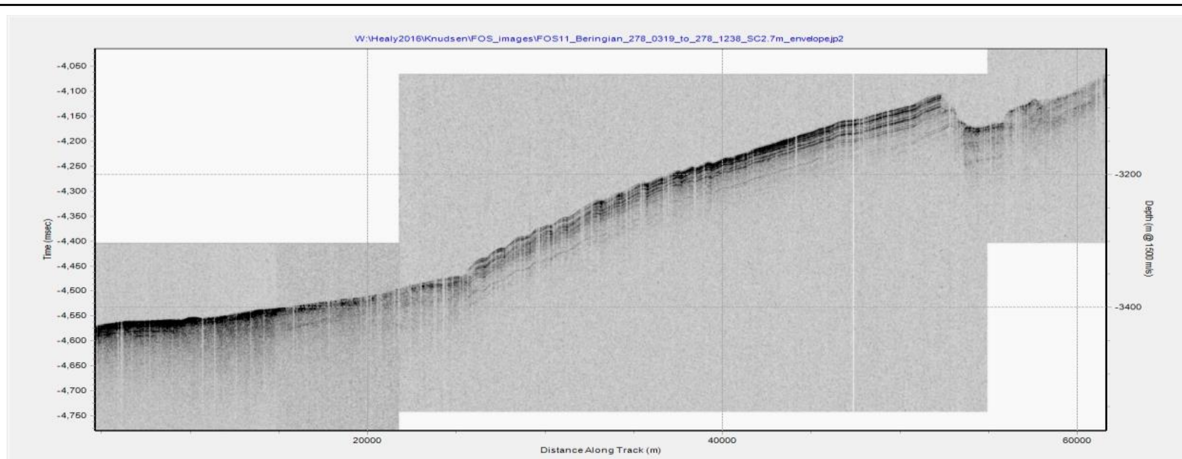
Ice scour on the Bering Shelf



Alaska slope showing sediment waves on a toe of slope fan, onlapped by sediments of Canada Basin



Glacigenic debris flows on the Chukchi Plateau



Slumps and sediment waves at base of Beringian Margin.

Appendix G: HEALY 1603 US INTERAGENCY ARCTIC BUOY PROGRAM REPORT

Ignatius Rigor, Pablo Clemente-Colón, Chris Szorc, and Aaron Sibig

Introduction

Our ability to predict weather and sea ice conditions requires *in situ* observations of surface meteorology, ocean circulation and ice motion. These observations are used in the U.S. National Ice Center (NIC) analyses and are assimilated into National Weather Service (NWS), Navy, and international models used to forecast weather and sea ice on synoptic time scales, and into the many long-term atmospheric reanalyses (e.g., National Centers for Environmental Prediction) that are used for innumerable climate studies. Over the Arctic Ocean, this fundamental observing network is maintained by the US Interagency Arctic Buoy Program (USIABP[2]) and the International Arctic Buoy Programme (IABP), with the invaluable support of logistics-of-opportunity such as provided by the CGC Healy 1603 cruise. In addition to supporting the buoy program deployments, NIC personnel provided on board sea ice analysis, tactical navigation support, and daily briefings for the Healy Command and Chief Scientist.

Deployments

The USIABP loaded 12 Surface Velocity Program (SVP-B) buoys at port in Seattle, Washington, and 4 Seasonal Ice Beacons (XIB) at port in Seward, Alaska. The SVP-Bs measure surface air pressure and surface temperature, and are drogued to follow the 15-m surface ocean currents. The XIBs were developed by the USIABP to survive in the increasing seasonal ice zone of the Arctic. These buoys measure surface air pressure, surface temperature, and air temperature at 2-m height. Both buoy types report their data hourly using the Argos (XIBs), and Iridium (SVP-Bs) satellite systems.

Summary

During Healy 1601 2 SVP-Bs were deployed in the Bering Sea, and during the Healy 1602 cruise 2 SVP-Bs, and 1 XIB were deployed in the Beaufort and Chukchi seas.

During the Healy 1603 cruise 3 XIB and 4 SVP-Bs were deployed in the Beaufort and Chukchi seas, and 3 SVP-Bs were deployed in the Bering Sea (Table 1, and Figures). All observations reported by these buoys are released in near real-time for research by the IABP server http://IABP.apl.uw.edu (e.g., Fig. 5), and posted on the World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) Global Telecommunications System (GTS) for operational weather and sea ice forecasting (e.g. Fig. 6). We also implemented an automatic script to email the observations from all buoys reporting in the Arctic to MSTC Will Wineger and MST1 Sean Carillo to assist with their weather forecasts.

---

[2] The USIABP is managed by the LTJG Micki Ream and Dr. Pablo Clemente-Colón of the National Ice Center, and by Dr. Ignatius Rigor of the Polar Science Center, Applied Physics Lab, University of Washington.

In the long run, we plan to work with STARC to revive the data stream from the USIABP, as well as other data products from the NIC and other satellite sources, to the USCGC Healy so the data may be more easily accessible on the on board map server.

Table 1. Buoy Deployments during Healy 1603					
	Buoy Type	**Serial #**	**WMO #**	**Deployment Date**	**Deployment Position**
1	XIB	145754	4801623	9/20/2016	74.4°N 158.1°W
2	XIB	145898	4801624	9/24/2016	82.1°N 144.9°W
3	XIB	145951	4801625	9/26/2016	76.5°N 156.7°W
4	SVP-B	300234063324170	4801606	9/28/2016	72.3°N 146.5°W
5	SVP-B	300234063323170	4801604	9/29/2016	73.1°N 152.8°W
6	SVP-B	300234063320260	4801607	9/29/2016	72.7°N 156.2°W
7	SVP-B	300234063324140	4801608	9/30/2016	71.2°N 160.8°W
8	SVP-B	300234063225900	4601583	10/2/2016	61.5°N 168.2°W
9	SVP-B	300234063229600	4601584	10/2/2016	59.7°N 170.5°W
10	SVP-B	300234063320140	4601585	10/3/2016	56.9°N 172.6°W
11	SVP-B	300234063320730	Cancelled due to weather and high seas.		

Figures

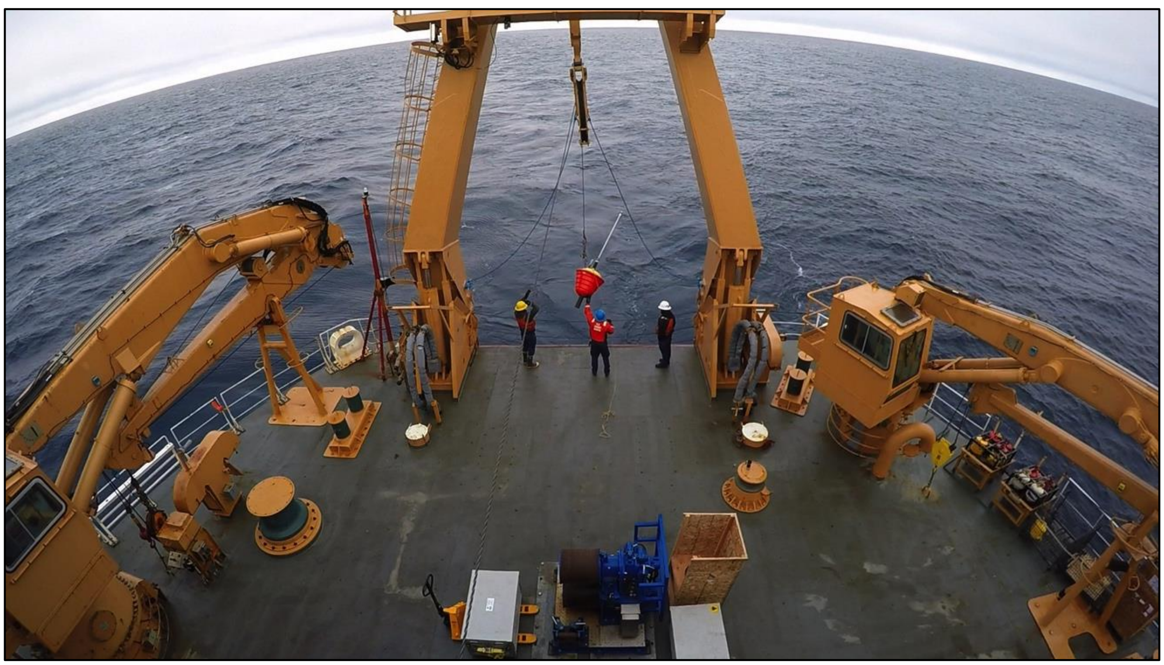


Figure 1. Deployment of AXIB 145754 (WMO # 4801623) in the Chukchi Sea at 74.4°N 158.1°W on Sept. 20, 2016.

Figure 2. Deployment of AXIB 145898(WMO # 4801624) in the high Arctic at 82.1°N 144.9°W on Sept. 26, 2016. As shown in Fig. 7, this deployment fills a critical gap in the Arctic Observing Network.

Figure 3. Deployment of SVP-B 300234063324140 (WMO # 4801608) in the Beaufort Sea at 72.6°N 156.2°W on Sept. 26, 2016 by MSTC William Wineger (facing camera) and MST1 Sean Carillo.

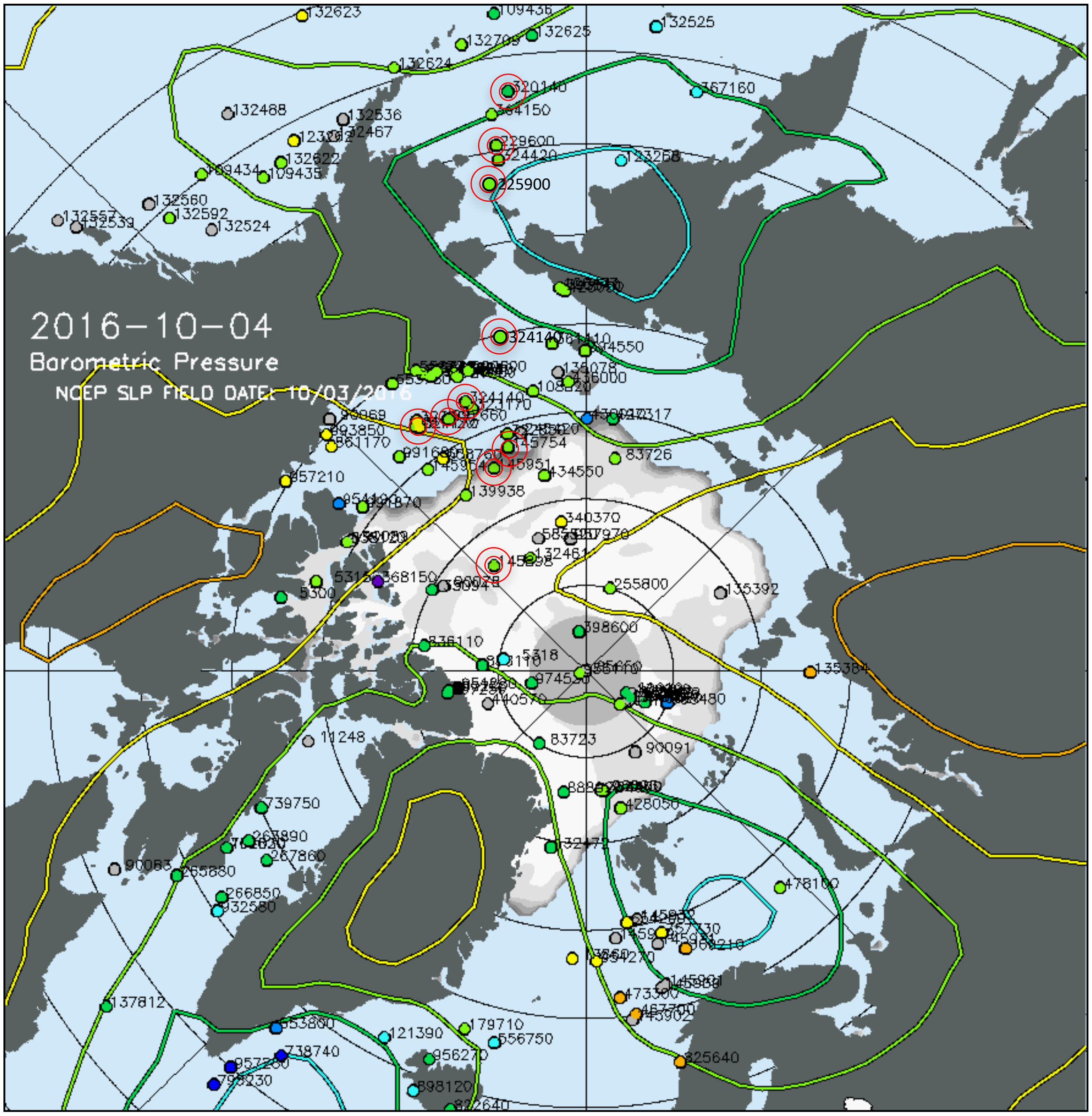


Figure 5. Map of all drifting buoys reporting in the Arctic on Oct. 4, 2016 obtained from the IABP server http://iabp.apl.uw.edu. Buoys deployed by the Healy 1603 cruise are circled circled in red.

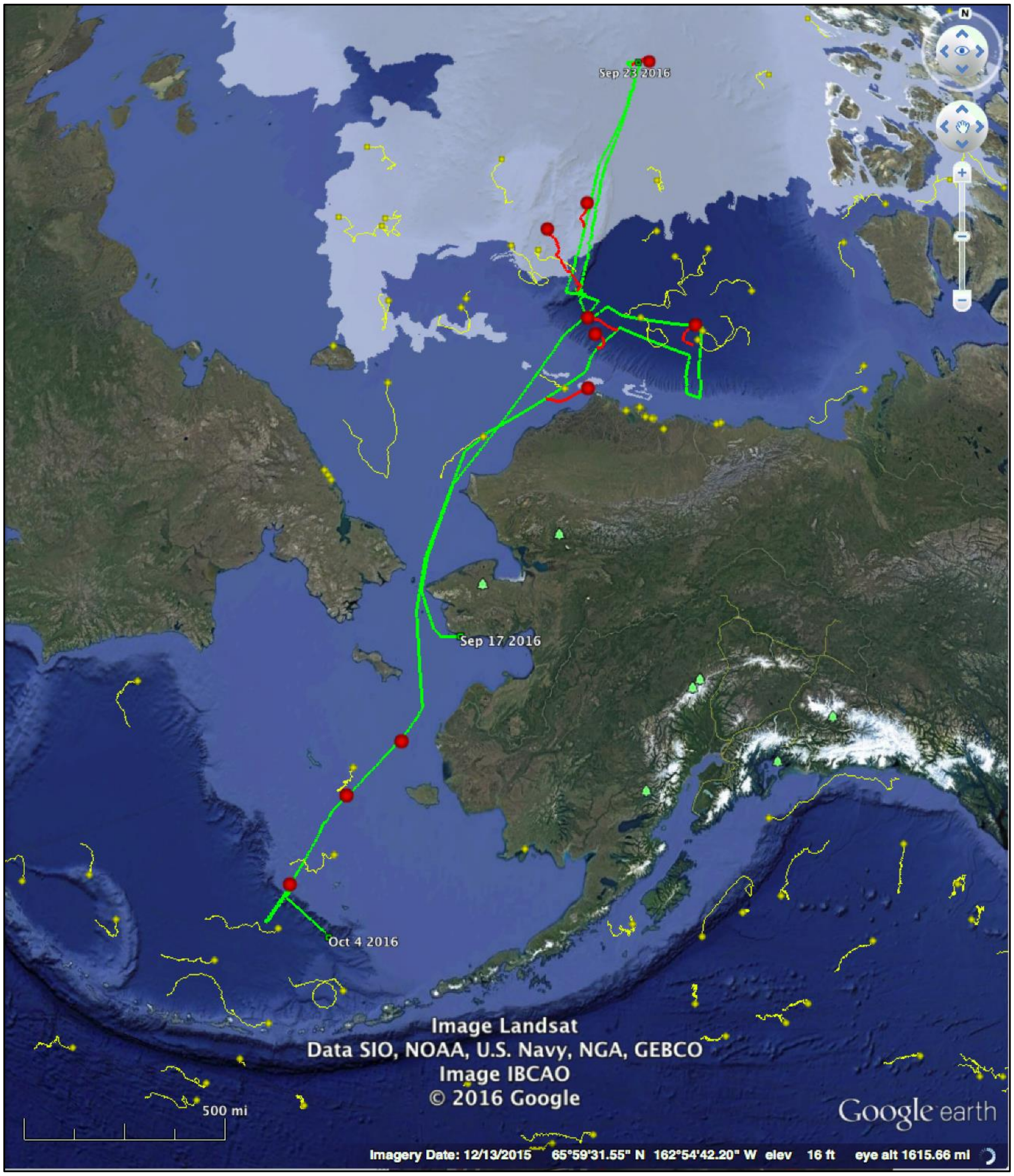


Figure 6. Map of drifting buoy observations available on the WMO/IOC GTS for weather and ice forecasts and analysis by the National Weather Service and the National Ice Center on Oct. 4, 2016. These observations are also assimilated into the National Center for Environmental Prediction climate reanalyses, and by other international forecast and research institutions.

The track of Healy 1603 is shown in green. The NIC Ice Analysis is shown in transparent white. Drifting buoys are shown in yellow, and Drifting buoys deployed during the Healy 1603 cruise are shown in red.

Appendix H: HLY1603 OCEAN CHEMISTRY REPORT

Jonathan Wynn, University of South Florida

Facilities in the main lab and *Healy's* shipboard systems were used to collect data to evaluate changes in freshwater sources and surface water carbonate chemistry (by Jonathan Wynn, University of South Florida). These new data from HLY1603 will be used in conjunction with previous data from HLY1002, 1102 and 1202 to evaluate the role of changes in the freshwater budget on ocean acidification and the carbon cycle in the western Arctic Ocean (Robbins et al., 2013, Wynn et al., in review, Shen et al., 2016).

Water Sample Collection

Discrete water samples were collected at key points along the cruise track, including crossing of previous cruise tracks, major boundaries of sea-ice extent and character, and other hydrographic boundaries. These samples will be analyzed for dissolved inorganic carbon (DIC) concentration, total alkalinity (TA), among other parameters at the US Geological Survey Coastal and Marine Science Center in St. Petersburg, FL. Sample locations are shown in Figure 1.

Underway water isotopic monitoring instrumentation

Jonathan Wynn installed a continuous diffusion-sampling, cavity-ring-down spectroscopy (DS-CRDS) system to the underway flowthrough system of uncontaminated seawater on the *Healy*. The measurements of water isotopic composition will be combined with underway measurements of salinity to quantify the contribution of freshwater sources to surface seawater. The small benchtop installation was operated on a surface area < 1 m^2 in the main lab with a feed from the uncontaminated seawater supply of the *Healy* (Figure 1). At one of the outlets of the seawater supply, a small debubbler was attached from which a flow of 2 mL/min will be drawn from a flow on the order of 1 L/min with excess to *Healy*'s drains. From the debubbler, a peristaltic pump draws seawater into a cooled, insulated box (in Figure 1, the "Esky") equipped with a Peltier heat exchanger (with thermostat at 20°C) to isolate both the water and air intakes from temperature fluctuations in the lab. Air is drawn from the insulated box through Drierite™ tubes and into the DS system. From the "Esky" insulated box, the air and water flow directly into the diffusion sampler contained in a second temperature-controlled box (maintained by electric heat at 27°C) so as to maintain a constant liquid-vapor fractionation factor. Within this box, the diffusion sampler is a small (~10 cm^3), sealed chamber through which a 5 mm dia. Maxiflow™ surgical tubing carries the 2 ml/min flow of seawater. The unsaturated air is pulled from the Esky box by the pumping system of the CRDS system (~ 30 mL/min), through a second length of Tygon™ tubing into the diffusion sampler chamber. The unsaturated air entrains water vapor that passes through the Maxiflow™ vapor-permeable tubing and is then carried, at water vapor saturation, into the inlet system of the CRDS analyzer. A second inlet, controlled by an adjustable needle valve, allows a second flow of unsaturated air, which bypasses the diffusion sampler. This unsaturated air is used to dry the CRDS analyzer (to avoid damage when not in use), and can be adjusted to reduce the vapor pressure, if beyond the ideal range of the CRDS system (~25,000 ppm). Reference waters with known isotopic composition were analyzed from foil-lined bladders (to prevent evaporation), and were introduced at periodic intervals into the DS system via the peristaltic pump, and controlled by a pair of 12V solenoid valves that are switched by the CRDS software. Data were processed shipboard, with isotopic composition referenced to VSMOW scale, and a preliminary results available by the end of cruise (Figure 3).

Combined high-resolution underway freshwater and CO_2 measurements

The underway isotopic data are collected at a frequency of 1Hz, similar to the underway MET system of the *Healy*. After downsampling to ~6 mHz frequency, the isotopic data complement the MET systems underway data collection of salinitity, temperature, and other water chemistry parameters, including the LDEO pCO2 system. These isotopic time series data have been merged with the MET time series, and the combined tracer-pCO2 data will be used to address the role of changes in freshwater cycling on CO2 flux through the western Arctic Ocean.

Robbins, L.L., Wynn, J.G., Lisle, J.T., Yates, K.K., Knorr, P.O., Byrne, R.H., Liu, X., Patsavas, M.C., Azetsu-Scott, K., and Takahashi, T. (2013a). Baseline monitoring of the Western Arctic Ocean estimates 20% of Canadian Basin surface waters are undersaturated with respect to aragonite. *PloS One* 8(9), e73796. Doi: doi:10.1371/journal.pone.0073796

Wynn, J., Robbins, L.L., and Anderson, L.G. (in review). Processes of multibathyal aragonite undersaturation in the Arctic Ocean. *J. Geophys. Res.*, in review, submitted Sept, 2014.

Shen, Y., Benner, R, Robbins, L.L., and Wynn, J.G., Sources, distributions and dynamics of dissolved organic matter in the Canada and Makarov Basins. *Frontiers in Marine Science.* Doi: 10.3389/fmars/2016.00198

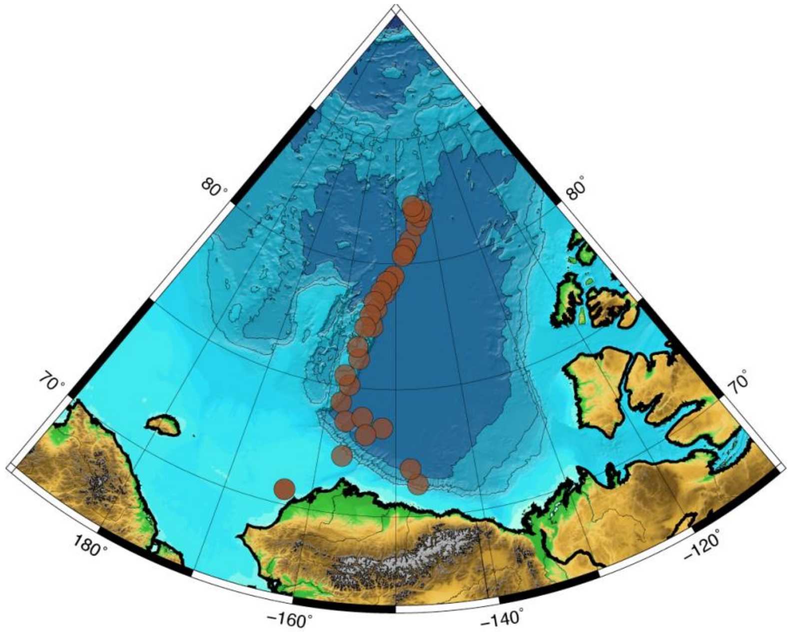


Figure 1. Location of discrete samples collected for offshore analysis from HLY1603.

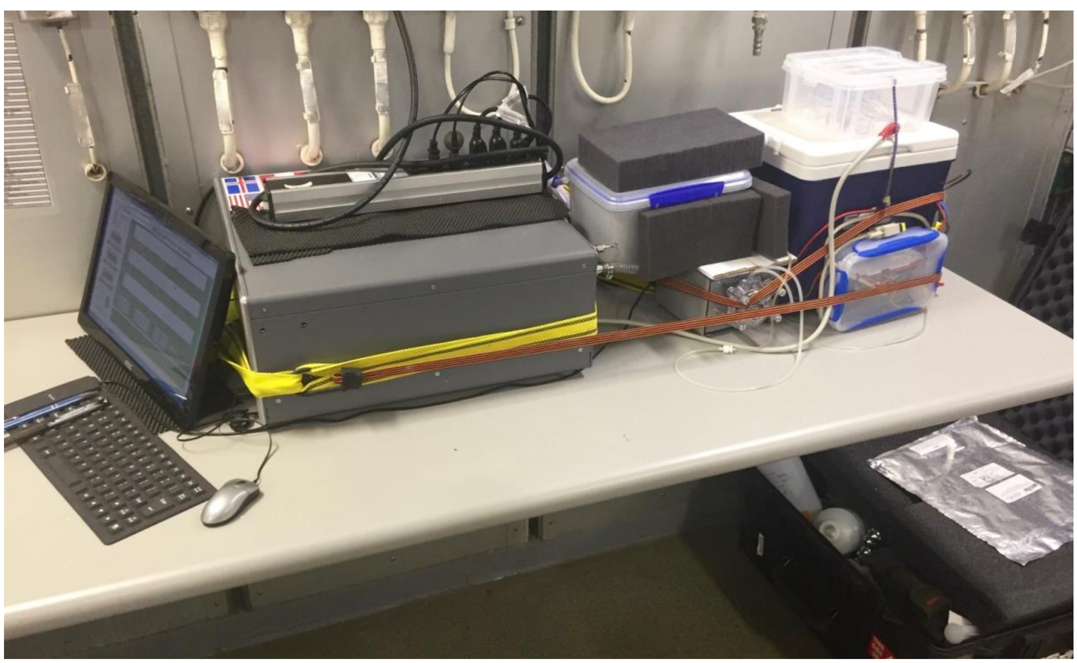


Figure 2. Installation of DS-CRDS system onboard the *Healy* in operation in the Western Arctic Ocean (HLY1603 Mission). Components of the instrument are: (1) flow from seawater supply with debubbler and pressure release, (2) 12V solenoid valves connected to reference waters (kept in 5L supply), (3) peristaltic pump, (4) "Esky" Peltier heat exchanger, (5) diffusion sampler in temperature controlled box, (6) PIcarro CRDS analyzer, (7) Picarro vacuum pump, (8) input/output devices.

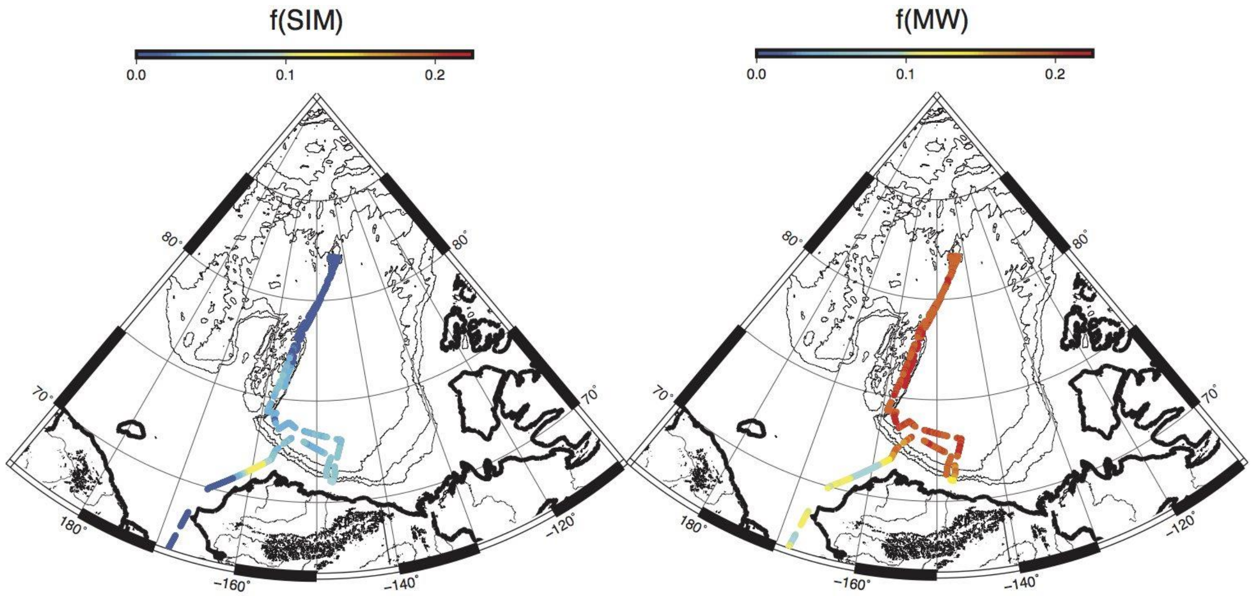


Figure 3. Fractions of sea-ice meltwater (SIM) and meteoric water from HLY1603 (preliminary data, final QA/QC to be continued post-cruise).