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2008 Joint United States-Canadian Program to Explore the Limits of the Extended Continental Shelf Aboard U.S. Coast Guard Cutter Healy—Cruise HLY0806

September 5–October 1, 2008

Barrow to Barrow, Alaska

Jonathan R. Childs, Peter J. Triezenberg, and William W. Danforth

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Jonathan R. Childs,[1] Peter J. Triezenberg,[2] and William W. Danforth[3]

Abstract

In September 2008, the U.S. Geological Survey (USGS), in cooperation with Natural Resources Canada, Geological Survey of Canada (GSC), conducted bathymetric and geophysical surveys in the Arctic Beaufort Sea aboard the U.S. Coast Guard cutter ***USCGC Healy***. The principal objective of this mission to the high Arctic was to acquire data in support of delineation of the outer limits of the U.S. and Canadian Extended Continental Shelf (ECS) in the Arctic Ocean in accordance with the provisions of Article 76 of the Law of the Sea Convention.

The ***Healy*** was accompanied by the Canadian Coast Guard icebreaker ***Louis S. St- Laurent***. The science parties on the two vessels consisted principally of staff from the USGS (***Healy***), and the GSC and the Canadian Hydrographic Service (***Louis***). The crew included marine mammal and Native-community observers, ice observers, and biologists conducting research of opportunity in the Arctic Ocean.

The joint survey proved an unqualified success. The ***Healy*** collected 5,528 km of swath (multibeam) bathymetry (38,806 km^2) and CHIRP subbottom profile data, with accompanying marine gravity measurements. The ***Louis*** acquired 2,817 km of multichannel seismic (airgun) deep-penetration reflection-profile data along 12 continuous lines, as well as 35 sonobuoy refraction stations and accompanying single-beam bathymetry. The coordinated efforts of the two vessels resulted in seismic-reflection profile data of much higher quality and continuity than if the data had been acquired with a single vessel alone. Equipment failure rate of the seismic equipment gear aboard the ***Louis*** was greatly improved with the advantage of having a leading icebreaker. When ice conditions proved too severe to deploy the seismic system, the ***Louis*** led the ***Healy***, resulting in much improved quality of the swath bathymetry and CHIRP sub-bottom data in comparison with data collected by the ***Healy*** in the lead or working alone.

Ancillary science objectives, including ice observations, deployment of ice-monitoring buoys and water-column sampling for biologic (phytoplankton) studies, were also successfully accomplished.

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Introduction

In September 2008, the U.S. Geological Survey (USGS), in cooperation with Natural Resources Canada, Geological Survey of Canada (GSC), conducted bathymetric and geophysical surveys in the Arctic Beaufort Sea aboard the U.S. Coast Guard cutter ***USCGC Healy***. The principal objective of this mission to the high Arctic was to acquire data in support of delineation of the outer limits of the U.S. and Canadian Extended Continental Shelf (ECS) in the Arctic Ocean in accordance with the provisions of Article 76 of the Law of the Sea Convention.

The ***Healy*** was accompanied by the Canadian Coast Guard icebreaker ***Louis S. St-Laurent*** ("***Louis***") (fig. 1). The science parties on the two vessels consisted principally of staff from the USGS (***Healy***) and the GSC and the Canadian Hydrographic Service (***Louis***). The crew included marine-mammal and Native-community observers, ice observers, and biologists conducting research of opportunity in the Arctic Ocean.

Louis departed Kugluktuk, Nunavut, Canada on August 22, and collected bathymetric and seismic reflection profiles for 18 days in the central and eastern Beaufort Sea before rendezvousing at lat 82°52' N. and long 141°54' W. on September 9 with the ***Healy***, which had departed Barrow on September 5. The two vessels worked in tandem for 18 days, with the ***Healy*** escorting the ***Louis*** during seismic-reflection profiling, and the ***Louis*** escorting the Healy when heaviest ice conditions precluded deployment of the seismic-reflection system. The ships parted company at about midnight on September 27 the ***Healy*** returning to Barrow on October 1 and the ***Louis*** to Kugluktuk on October 3 (fig. 2). Detailed trackline navigation for the two ships is shown in figure 3. Jackson and DesRoches (2010) compiled a cruise report for the Louis leg.

U.S. participation in the partnership was carried out in accordance with a Project Annex to the Memorandum of Agreement between the USGS and GSC for joint studies. USGS activities in mapping the ECS are coordinated through the ECS Interagency Task Force, comprised of representatives from the USGS, the U.S. Department of State, the National Oceanographic and Atmospheric Administration (NOAA), and several other governmental agencies. Further information on the task force and its activities is posted at *www.continentalshelf.gov* .

Previous surveys

This Joint United States-Canadian program was designed to build on much-earlier work conducted by the USGS (with Canadian participation) in the Arctic aboard the ***USCGC Polar Star*** in 1988, 1991, and 1992. Those data are reported at: *http://pubs.usgs.gov/of/2004/1243/*

Seismic reflection and refraction data were acquired in the Arctic from the ***Healy*** in 2005 (cruise HLY0503) and 2006 (cruise HLY0602). These surveys were funded by National Science Foundation, and were not associated or funded through the U.S. ECS Interagency Task Force. Further details are posted at:

http://icefloe.net/hly0503/HLY-05-03-MGG_Final_Report.pdf
http://icefloe.net/healy-2005-cruise-reports
http://icefloe.net/healy-2006-cruise-reports

More recently, the program is a continuation of a series of Arctic surveys (2003, 2004, 2007, 2008) conducted with the ***Healy*** in the Arctic by the University of New Hampshire's Center for Coastal

and Ocean Mapping and NOAA Joint Hydrographic Center, including in 2008 the previous survey HLY0805. Reports on these surveys and resulting data are posted at:

http://www.ccom.unh.edu/publications/Mayer_03_cruise_report_HE-0302.pdf
http://www.ccom.unh.edu/publications/Mayer_04_cruise_report_HE-0405.pdf
http://www.ccom.unh.edu/publications/Mayer_07_cruise_report_HE-0703.pdf
http://www.ccom.unh.edu/publications/Mayer_08_HEALY_0805_CRUISERPT.pdf

In 2007, the GSC and the Canadian Hydrographic Serice conducted geophysical and bathymetric surveys aboard the ***Louis*** in the Arctic in single-vessel mode. The data from this survey are currently proprietary.

Scientific party

Table 1: HLY0806 Science Party

Name	Institution	Position
Kevin Berberich	National Ice Center/NOAA	ice analyst
Tom Bolmer	Woods Hole Oceanographic Institution	science technical support
Kelley Brumley	University of Alaska, Fairbanks	graduate student
Dale Chayes	Lamont Doherty Earth Observatory, Columbia University	science technical support
Jonathan Childs	USGS	chief scientist
Pablo Clemente-Colon	National Ice Center/NOAA	scientist
William Danforth	USGS	scientist
Rebecca Gast	Woods Hole Oceanographic Institution	scientist
Don Graham	USCG/Electronic Systems Support Unit	computer technicisn
Michael Merchant	USCG/Electronic Systems Support Unit	network administrator
Ellyn Montgomery	USGS	scientist
George Neakok	Barrrow Arctic Science Center Native	community liaison
Thomas O'Brien	USGS	scientist
Justin Pudenz	NOAA	mammal observer
Steve Roberts	University Corporation for Atmospheric Research	computer engineer
Jessica Robertson	USGS	media relations
Robert Sanders	Temple University	scientist
Capt. John Stewart	CCG	CCG command liaison
Peter Triezenberg	USGS	scientist
Brian Van Pay	U.S. Department of State	geographer

Underway geophysical data acquisition and processing

Complete details of all the geophysical, oceanographic, and meteorological sensors aboard the ***Healy*** are presented in appendix C, the onboard data synopsis by the technical support staff, consisting of Dale Chayes, Steve Roberts, and Tom Bolmer.

During the cruise, data acquisition was synchronized to Greenwich mean time (Universal Time Coordinated [UTC]). During two-ship operations, both vessels synchronized their clocks to UTC minus

6 hours (Mountain daylight time). When the ***Healy*** operated alone, ship clocks were set to UTC minus 8 hours (Alaska daylight time).

The ***Healy*** is equipped with a SeaBeam 2112 swath bathymetric system and a Knudsen 320 B/R bottom sounders, both hull mounted. Two Bell BGM-3 gravimeters were installed for the cruise in the IC Gyro space. The quality of these datasets varied widely, depending on ice conditions and ship operations.

Data acquisition was continuously monitored throughout the cruise by scientific and technical watchstanders. The scientific watchstanders worked 12-hour watches (05:30 - 17:30 and 17:30 - 05:30 local ship time and were responsible for monitoring all of the underway equipment. During each watch, they would adjust acquisition parameters for the SeaBeam and Knudsen systems, ensure that data files were being updated, note anomalies or changes in operations in the e-log, and inform the ship's technical staff when an instrument malfunctioned.

Although minor malfunctions occasionally interrupted data acquisition, these gaps were typically no more than a few minutes. No major instrument failures of the multibeam or subbottom profiles occurred during the cruise.

Over the duration of the program, the ***Healy*** collected 5,528 km of swath (multibeam) bathymetry (38,806 km^2) and CHIRP subbottom profile data, with accompanying marine gravity measurements. The ***Louis*** acquired 2,817 km of multichannel seismic (airgun) deep-penetration reflection-profile data along 12 continuous lines, as well as 35 sonobuoy refraction stations and accompanying single-beam bathymetry. The coordinated efforts of the two vessels resulted in seismic-reflection profile data of much higher quality and continuity than if the data had been acquired with a single vessel alone. Equipment failure rate of the seismic equipment gear aboard the ***Louis*** was greatly improved with the advantage of having a leading icebreaker. When ice conditions proved too severe to deploy the seismic system, the ***Louis*** led the ***Healy***, resulting in much improved quality of the swath bathymetry and CHIRP sub-bottom data in comparision with data collected by the ***Healy*** in the lead or working alone (fig. 4).

Multibeam swath bathymetry

Acquisition

Multibeam echosounder data were collected onboard the ***Healy*** using an L-3 Communications SeaBeam 2112 instrument that was permanently installed on the hull. Data were recorded on a Silicon Graphics O2 workstation running acquisition software from SeaBeam. Raw data were saved to disk in the MB-System MB10 data format ID 41 (Caress and Chayes, 2011):

http://www.ldeo.columbia.edu/res/pi/MB-System/html/mbsystem_formats.html

Primary navigation and motion data (heave, pitch, roll, heading) were measured with an Applanix POS/MV-320 sensor, and these data were integrated with the multibeam data acquisition, ensuring that the ship's motion was compensated for and applied to the data in real time. Navigational data from the POS/MV-320, which were incorporated into the multibeam data acquisition and stored in the raw datafiles, recorded the position of the center of the SeaBeam transmit array. Sound velocity at the keel (for the beamformer) was calculated from sea water temperature and conductivity that was measured with a SeaBird Thermosalinograph. Sound-velocity profiles were constructeded from underway measurements with eXpendable BathyThermograph (XBT), Conductivity-Temperature-Depth (CTD), and eXpendable CTD (XCTD) instruments, as well as historical data, to ensure proper

ray tracing through the water column. Data were corrected for sound-velocity, refraction, and draft in real time by the sonar data acquisition program, and incorporated into the MB-System datafiles.

Processing

The raw data files were brought into the CARIS HIPS & SIPS 6.1 utilizing the CARIS conversion wizard, which converts all the data packets in the raw multibeam files to the internal CARIS format. Before running the conversion, a vessel file Healy0806.hvf was created with sensor data for roll, pitch, heave, gyro, navigation, and swath 1 activated. The sensor offsets were entered into the data-acquisition system during setup and applied during acquisition. Accordingly, these offsets were all set to zero in the vessel file and not applied during the conversion or processing steps.

The converted data were stored on disk in a project folder that contained a subfolder named after the vessel file. That folder was further subdivided into Julian days, with each Julian-day folder containing all the line files for that day.

The raw data were stored in files named according to a convention: sb2005J_Dhhmm.mb41, where J_D is the Julian day and hhmm are hours and minutes in UTC, and transferred from the data server and converted to CARIS readable format, as described above. Each hour of each Julian day had a unique file, which was saved in the corresponding project and vessel folders.

The Universal North Polar Stereographic Projection system was used for the project map projection, with a central meridian of -160°, latitude of true scale 75° N, and WGS84 the ellipsoid of reference system.

Swath editing was first performed manually to each line, and obviously erroneous soundings were removed from the data files. Auxiliary-sensor-data editing was not performed during processing since those corrections were applied during data acquisition, as mentioned above. Sound-velocity corrections were not applied during processing, having been applied during data acquisition as well. Tide loading is a required process in the CARIS processing workflow. Because no tidal data are available for the Arctic, for this survey a file zerotide.tid was created with a zero tide value for the entire cruise . Navigation and tide corrections were applied to each observed and edited sounding as the final step in the processing workflow.

A CARIS BASE surface (grid) was then generated as an initial view to inspect the data quality and to remove bad soundings if needed. A horizontal resolution of 100 m per grid node was used when creating the grid.

Each grid was examined to detect erroneous soundings that may have been missed on the first editing pass, by using the swath editor if needed. Once these soundings were removed from the datafiles, the grid was recomputed to reflect the editing. The holes in the grid were then filled in by a mean interpolation, using the average of neighboring pixels. A matrix of 5x5 and 6 neighbors was used to fill in the smaller holes.

Processing of the multibeam data corresponding to 24 hours of acquisition was carried out systematically with the CARIS HIPS & SIPS 5.4 software during a watch of 12 hours. The processed lines were added to the field sheets at the end of each Julian day.

The final step in the processing workflow was to convert the BASE surface grids into Fledermaus dtm/geo files for three-dimensional presentation of the processed dataset.

CTD/XBT

XBT casts were conducted at regular intervals to establish sound-velocity profiles to correct the multibeam bathymetry. In addition, CTD casts, during which water samples were also collected, were

done as time and operations schedules permitted. The details of the CTD and XBT data acquisition are found in Tables A-2 and A-3 in Appendix B.

Chirp sub-bottom profiler

Acquisition

The Knudsen BR-320 bottom profiler generally functioned well in the ice, maintaining a lock on the bottom even under heavy ice conditions. The primary effect of heavy ice was to introduce gaps into the data.

During earlier ***Healy*** cruises, the Knudsen's performance in ice was considered far superior to that of the ODEC Bathy-2000, which required extensive intervention to maintain bottom lock while icebreaking. Accordingly, the ODEC system was not used during cruise HLY0806.

The Knudsen system tracks the bottom return and generates a digital single-beam depth record. Unlike the SeaBeam system, which uses a dynamic sound-velocity profile model to transform travel time to true depth, the Knudsen system uses a much simpler constant-velocity factor of 1500 m/s. Thus, digital depths from the Knudsen are different from and less accurate than the SeaBeam centerbeam depths.

Processing

A discussion of CHIRP systems and signal processing implemented onboard the ***Healy*** is presented in appendix E.

Gravity Anomaly Data

Two Bell BGR-3 gravimeters (BGM-221 and BGM-222) were installed on the ***Healy*** for the entire 2008 campaign. Details of the installation and operation of these instruments are presented in appendix D of the report posted at:

http://ccom.unh.edu/publications/Mayer_08_Healy_0805_CRUISERPT.pdf

The two gravimeters operated continuously during the period between the ***Healy***'s departure from Seattle on June 25 and its return on October 15. However, BGM-222 reportedly lost power while in port prior to the mission, and the meter may have sustained a "thermal shock", that could have affected the drift characteristics and meter constant in unpredictable ways. However, the BGM-222 raw data have subsequently been determined to be valid.

A gyroscope within BGM-221 failed during the cruise, resulting in a data gap of approximately 7 days (Julina days 262 thru 268) before the instrument was repaired.

Drift measurements for the two meters were estimated over approxinately 300 days, during which the BGM-221 drifted imperceptibly (0.25 mGal over the entire duration) and the BGM-222 drifted slightly more (14.1 mGal over the 300-day duration).

Crossing differences in comparision with other ***Healy*** cruises in 2008, 2009, 2010, and 2011 for the two gravimeters are listed in Table 2 below.

Table 2. Mis-ties (in mGals) at line crossings for two gravity meters (BGM-221, BGM-222) during four ***Healy*** Arctic cruises, 2008 to 2011.

	HLY-08-221	HLY-09-221	HLY-10-221	HLY-11-221	HLY-08-222	HLY-09-222	HLY-10-222	HLY-11-222
HLY-08-221	0.07	0.07	0.12	0.16	0.19	-0.03	0.34	0.17
HLY-09-221	0.08	0.08	-0.08	-0.04	0.05	-0.17	0.18	0.02
HLY-10-221	-0.12	0.08	0.01	0.01	-0.03	-0.21	0.13	-0.02
HLY-11-221	-0.16	0.04	0.02	0.02	0.12	-0.06	0.28	0.11
HLY-08-222	-0.19	-0.05	0.03	-0.12	0.05	0.05	0.29	0.07
HLY-09-222	0.03	0.17	0.21	0.06	0.03	0.03	0.46	0.25
HLY-10-222	-0.34	-0.18	-0.13	-0.28	-0.29	-0.46	0.11	0.11
HLY-11-222	-0.17	-0.02	0.02	-0.11	-0.07	-0.25	0.04	0.04

Acoustic Doppler current profilers (ADCP)

Both of the hull-mounted Acoustic Doppler Current Profilers (7k and 150 kHz) operated continuously throughout the cruise. No interests in the ADCP data were identified during or after the cruise, and accordingly no further examination, processing, or quality control was done with these data.

Ship operations

A summary chronology of joint mission activities is presented in table 3.

Table 3. Chronology of ship activities during operation of HLY0806 and LSSL2008

Joint US-Canada 2008 Arctic ECS Program Mission Chronology

Healy - single vessel
joint operations - Healy leading
joint operations - Louis leading

	UTC Day-Mo	local DOY	local time	UTC DOY	UTC (z)	UTC delta	vessel		latitude	longitude
F	5-Sep	249	20:00	250	4:00	8:00	Healy	science party aboard Healy		
Sa	6-Sep	250	13:00	250	21:00	8:00	Healy	underway from Barrow		
Su	7-Sep	251	17:00		0:30	8:00	Healy	set science watch		
Su	7-Sep	251	19:00	252	1:00	6:00	Healy	advance clocks +2 hours		
Tu	10-Sep	253	18:00	254	0:00	6:00	both	rendezvous - Louis party arrive healy	81.8659	-141.9398
W	10-Sep	254	0:12	254	6:12	6:00	both	commence joint operations with Louis		
W	10-Sep	254	6:16	254	12:16	6:00	both	SOL seismic		
F	12-Sep	255	22:45	256	4:45	6:00	both	Louis pulled seismic gear; start CTD ops; ship secure for night		
F	12-Sep	256	10:00	256	16:00	6:00	both	Louis in lead for MB		
F	12-Sep	256	10:51	256	16:51	6:00	Healy	Healy enters CA EEZ	80.2666	-128.8300
Sa	13-Sep	257	1:04	257	7:04	6:00	Healy	Healy exits CA EEZ	80.0813	-129.4452
Sa	13-Sep	257	11:30	257	15:30	6:00	both	Resume seismic profiling		
Th	18-Sep	262	0:43	262	6:43	6:00	Healy	Healy enters CA EEZ	79.1831	-132.7897
Th	18-Sep	262	6:30	262	12:30	6:00	both	Louis in lead		
Su	21-Sep	264	19:42	265	1:42	6:00	both	Healy moving back in lead; seismic gear deployed		
Su	22-Sep	265	19:08	266	1:08	6:00	Healy	Healy exits CA EEZ	78.4275	-134.9214

Th	25-Sep	269	8:22	269	14:22	6:00	Healy	Healy enters CA EEZ	77.5747	-136.6713
Th	25-Sep	269	15:30	269	21:30	6:00	both	rafting party - 17 hours		
F	26-Sep	270	9:00	270	15:00	6:00	Louis	conduct airgun signature tests		
F	26-Sep	270	10:30	270	16:30	6:00	both	Louis moves into lead		
Su	28-Sep	271	22:30	272	4:30	6:00	both	vessels separate - joint operations concluded		
Su	28-Sep	272	13:33	272	19:33	6:00	Healy	Healy exits CA EEZ	75.5281	-136.9198
Su	28-Sep	272	17:00	273	1:00	8:00	Healy	retard clocks -2 hours		
W	1-Oct	275	8:00	275	16:00	8:00	Healy	arrive Barrow, science party disembarks		

Data and metadata

Extensive information regarding cruise HLY0806, including links to reports, articles and blogs from the cruise are posted at:

http://walrus.wr.usgs.gov/infobank/h/h208ar/html/h-2-08-ar.meta.html .

All the raw data from the cruise are archived at the National Geophysical Data Center (NGDC) through the Rolling Deck to Repository (R2R) initiative. Complete file manifests and other metadata are posted at:

http://www.rvdata.us/catalog/HLY0806
http://get.rvdata.us/services/cruise/HLY0806.xml

Raw and processed multibeam data and metadata, as well as raw CHIRP subbottom data in SEG-Y format are posted on NGDC's ECS data page:

http://ngdc.noaa.gov/mgg/ecs/cruises.html .

These data are also cross posted on the Web site for the Law of the Sea project at the University of New Hampshire's Center for Coastal and Ocean Mapping (CCOM) data repository at:
http://ccom.unh.edu/theme/law-sea/arctic-ocean

IMPORTANT NOTE: Under the terms of the Memorandum of Understanding between USGS and the GSC, the swath bathymetry and subbottom-profile data acquired during cruise HLY0806 within the Canadian 200-nautical-milewide Exclusive Economic Zone (EEZ) are proprietary, and public release is not authorized at this time. The trackline segments that fall within the Canadian EEZ are listed in table 4.

Table 4 - HLY0806 trackline segments within the Canadian EEZ for which multibeam bathymetry and CHIRP subbottom pdata are on proprietary hold.

Date time (UTC)	Julian day	Hour	Minute	Latitude N.	Longitude W.	Comment
9/12/2008 16:51	256	16	51	80.26657	-128.83004	Healy enters Canadian EEZ
9/13/2008 7:04	257	7	4	80.08125	-129.44518	Healy exits Canadian EEZ
9/18/2008 6:43	262	6	43	79.18311	-132.78969	Healy enters Canadian EEZ
9/22/2008 1:08	266	1	8	78.42753	-134.9214	Healy exits Canadian EEZ
9/25/2008 14:22	269	14	22	77.57465	-136.67134	Healy enters Canadian EEZ
9/28/2008 19:33	272	19	33	75.52815	-136.91981	Healy exits Canadian EEZ

Acknowledgments

We thank the entire crew of the ***USCGC Healy*** in particular Captain Frederick Sommer, Operations Officer Jeff Stewart and Executive Officer Dale Bateman. We are grateful for the planning and logistical support provided by David Forcucci, USCG liaison in Seattle.

We appreciate the dedication and expertise provided by the ***Healy*** technical support team of Dale Chayes, Steve Roberts, and Tom Bolmer, who compiled the cruise data synopsis in appendix C. Bernie Coakley (University of Alaska, Fairbanks) processed the gravity data and provided the crossover listed in table 2.

We thank Deborah Hutchinson and Ginger Barth of the USGS for their helpful reviews of the manuscript.

This program was conducted under the auspices of the U.S. Interagency ECS Task Force (*http://www.continentalshelf.gov*).

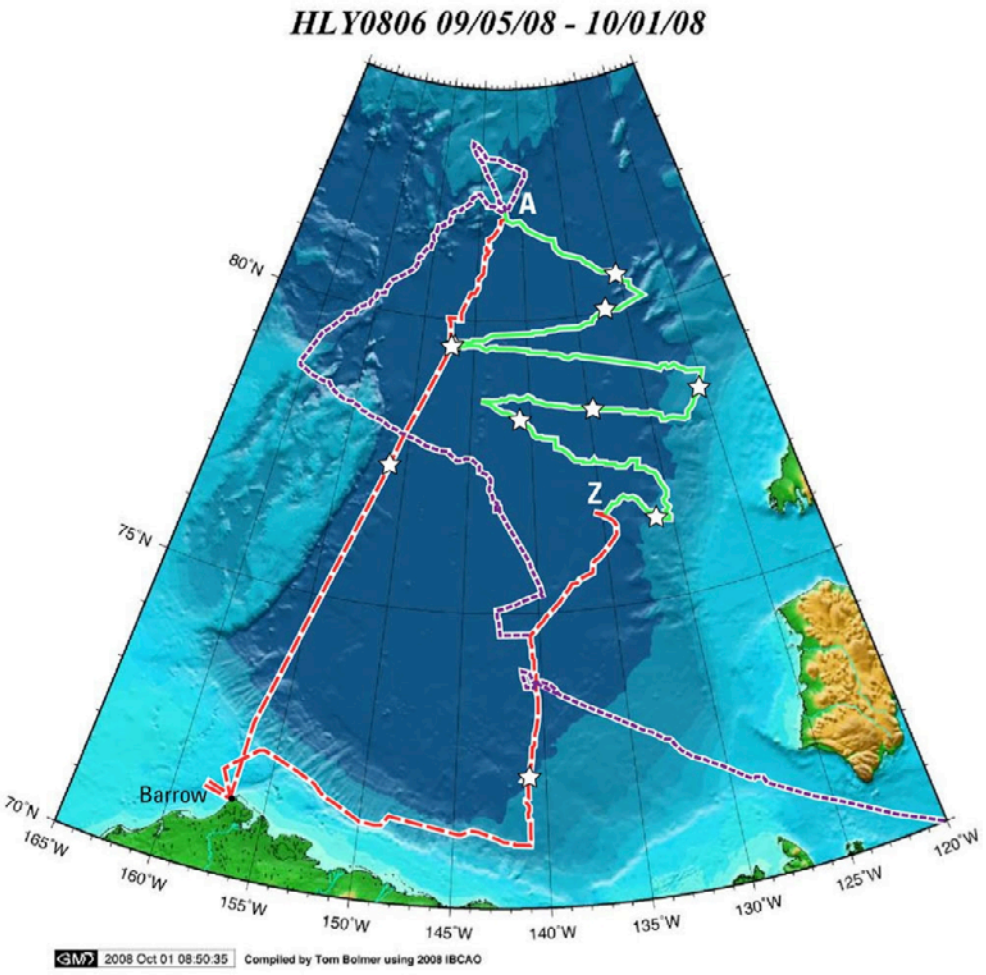
References Cited

Hutchinson, D.R., Jackson, H.R., Shimeld, J.W., Chapman, C.B., Childs, J.R., Funck, T., and Rowland, R.W., 2009, Acquiring marine data in the Canada Basin, Arctic Ocean: Eos (American Geophysical Union Transactions) v. 90, no. 23, p.198

Jackson, H.R. and DesRoches, K.J., 2010, 2008 Louis S. St-Laurent field report, August 22 – October 3, 2008: Geological Survey of Canada Open File 6275, 184 p. [*ftp://ftp2.cits.rncan.gc.ca/pub/geott/ess_pubs/285/285359/of_6275.pdf*].

Figures

Figure 1. U.S. Coast Guard cutter ***USCGC Healy*** and Canadian Coast Guard icebreaker ***Louis S. St-Laurent*** breaking through the ice in the Arctic Beaufort Sea.



Above: Tracklines for Louis (short-dashed purple) and Healy (long-dashed red) in the Beaufort Sea. The vessels rendezvoused at A, traveled together along solid green line, and parted ways at Z. Louis' return track (from point Z back to Kugluktuk, Nunavut, Canada) is not shown. Stars, stations where biological samples were collected from Healy.

Figure 2. Tracklines for the ***Louis*** (short-dashed purple) and the ***Healy*** (long-dashed red) in the Beaufort Sea. The two vessels rendezvoused at point A, traveled together along solid green line, and parted ways at point Z. The ***Louis***' return track, (from point Z back to Kuglutuk, Nunavut, Canada) is not shown. Stars indicate stations where biologic samples were collected from the Healy.
[Click on figure for larger version]

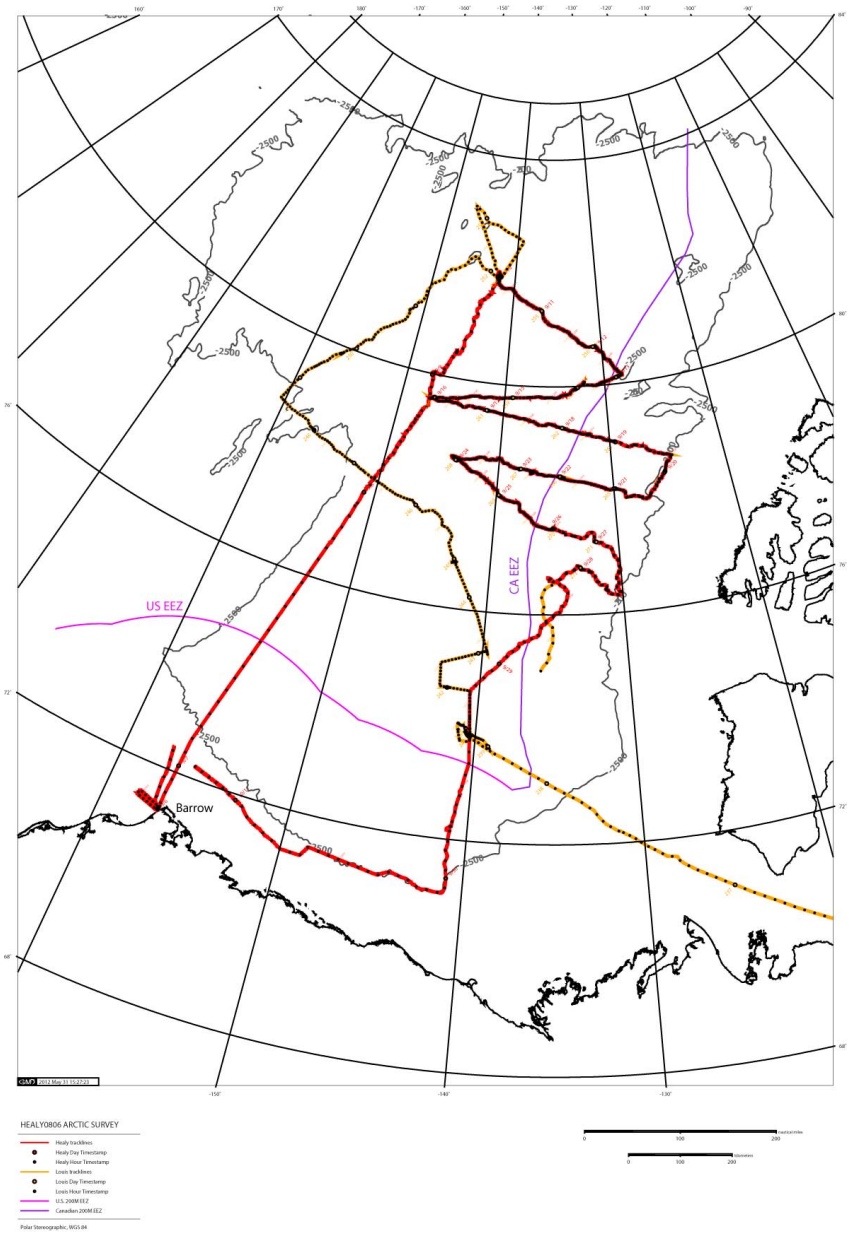


Figure 3. High-resolution tracklines with day/time annotations for the ***Healy*** (red) and the ***Louis*** (yellow). Tracks for both ships are annotated every hour. The ***Healy*** tracks are annotated with month/day, and for the ***Louis*** with day-of-year, which were the conventions used to record dates on the respective vessels. Enlarged view reveals relative positions of the vessels. U.S. and Canadian EEZ are shown for reference. The swath bathymetry and subbottom-profile data acquired during cruise HLY0806 within the Canadian 200-nautical-mile-wide EEZ are proprietary, and public release is not authorized at this time.
[Click on figure for larger version]

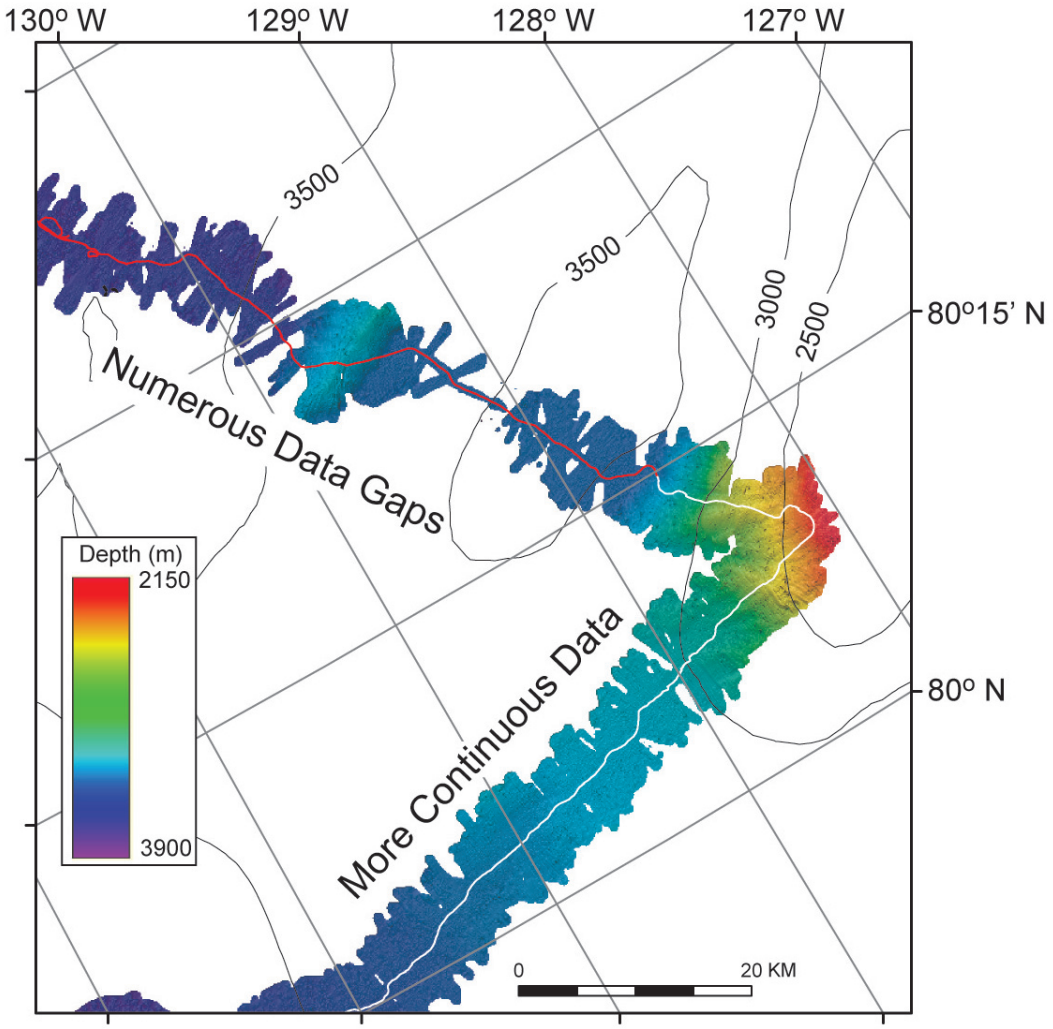


Figure 4. Variations in quality of multibeam swath data coverage with the ***Healy*** breaking ice in front of the ***Louis*** (red trackline along the swath centerbeam) and with the Louis leading the ***Healy*** (white trackline along centerbeam). Note the marked improvement in swath continuity and width when the ***Healy*** is the trailing vessel.