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# U.S. Law of the Sea Cruise to Map the Foot of the Slope and 2500-m Isobath of the U.S. Arctic Ocean Margin. Cruise Report for 2004

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# CRUISE REPORT

## USCGC Icebreaker *Healy* (WAGB-2)

### U.S. Law of the Sea cruise to map the foot of the slope and 2500-m isobath of the US Arctic Ocean margin

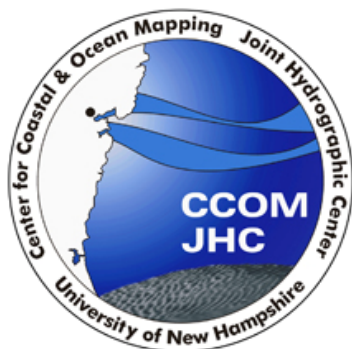
CRUISES HE-0405

October 6 to October 26, 2004

Nome, AK to Barrow, AK

Larry A. Mayer

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



February 15, 2005

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## INTRODUCTION

The objective of this cruise was map the areas in the Arctic Ocean over which the United States might claim under Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS).

Under Article 76 of UNCLOS, coastal states may, under certain circumstances, claim jurisdiction over “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, a recent claim by Russia for extension of their limits in the Arctic and Bering Seas, as well as the recognition that implementation of Article 76 could confer jurisdiction and management authority over large and potentially resource-rich areas of the seabed beyond its current 200 nautical mile (nmi) limit, has renewed interest in the potential for a U.S. claim.

A detailed analysis of the relevance of current U.S. data holdings to a potential claim has recently been completed (Mayer, Jakobsson and Armstrong, 2003). Included in this analysis is the identification of regions where the collection of new, modern multibeam sonar data would substantially improve the quality of a potential claim under Article 76. Among the areas where new multibeam data would improve a claim were identified, the Arctic is outstanding in that the existing database is far too sparse to support a well-defended claim. The data are especially sparse in areas where the perennial ice cover has prevented surface ships from operating. In addition to directly addressing Law of the Sea issues, the new data collected also significantly adds to data needed to support the growing recognition of the critical role that the Arctic Ocean plays in the climatic and tectonic history of the Earth. The new bathymetric data (as well as associated CTD measurements) will help define the nature of deep circulation in the Arctic Basin as well as the history and distribution of ice in the region, a key component of the global climate system.

The United Nations Convention on the Law of the Sea defines the conditions under which a coastal state may claim jurisdiction over regions beyond their current recognized 200 nmi limit (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 being claimed is a “natural prolongation” of the nation’s landmass, known in legal parlance as the “test of appurtenance.” 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 bathymetry and nature of the seafloor in a region. For example, if a coastal state has a narrow physiographic shelf bounded by a seaward subduction zone (that clearly indicates the transition from continental to oceanic crust) there is no natural prolongation of the continental shelf.

Once a natural prolongation is demonstrated, a coastal state may extend their “continental shelf” beyond the existing 200 nmi limit based on either of two formulae. The distance formula allows an extension of the shelf limit 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). The sediment thickness formula allows the extension of the shelf limit to a point where the sediment thickness is 1 percent of the distance back to the foot of the slope. Whichever formula line is most advantageous to the coastal state may be used and they can be combined for the most advantageous claim. There are limits to the extent of a claim (limit lines) – the extended claim 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 a claim for an extension of the juridical 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 10 years to submit all data and evidence supporting its claim to the United Nations Commission on the Limits of the Continental Shelf (CLCS) who evaluate the veracity of the claim

The largest potential for extension of the juridical 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 ridges 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 ridges: the Northwind Ridge, the Chukchi Cap and Rise, and the western (Arlis, Sargo, and T3) plateaus (which are located beyond the agreed 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

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 claim in ice-covered regions of the Arctic. This was in recognition of the fact that a claim under Article 76 must be substantiated by high-quality bathymetric and geophysical data, and that the existing bathymetric database in the Arctic is, in many areas, inadequate. The USCGC *Healy* (WAGB-2), equipped with a SeaBeam 2112 (12 kHz, 120 beam) swath mapping system, was chosen for this task.

A 10 day, 3000 km long exploratory mission (*Healy* Cruise 0304, September 1-11, 2003) from Barrow, Alaska, to the Chukchi Borderland demonstrated the viability of this

approach. 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. The cruise 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 claim),
- 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.

## **CRUISE OVERVIEW** (Figure 1)

Healy Cruise HE-0405 was conducted from October 6 to October 26, 2004, originating in Nome and ending in Barrow, Alaska. The cruise ran 6700 km of tracklines in 20 days and completed most of the mapping of the 2500-m isobath (begun on HEALY 0304) as well as a detailed survey of the “foot of the slope” over a segment of the continental margin east of Barrow, AK. 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. We 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.

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 a claim 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 325 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.

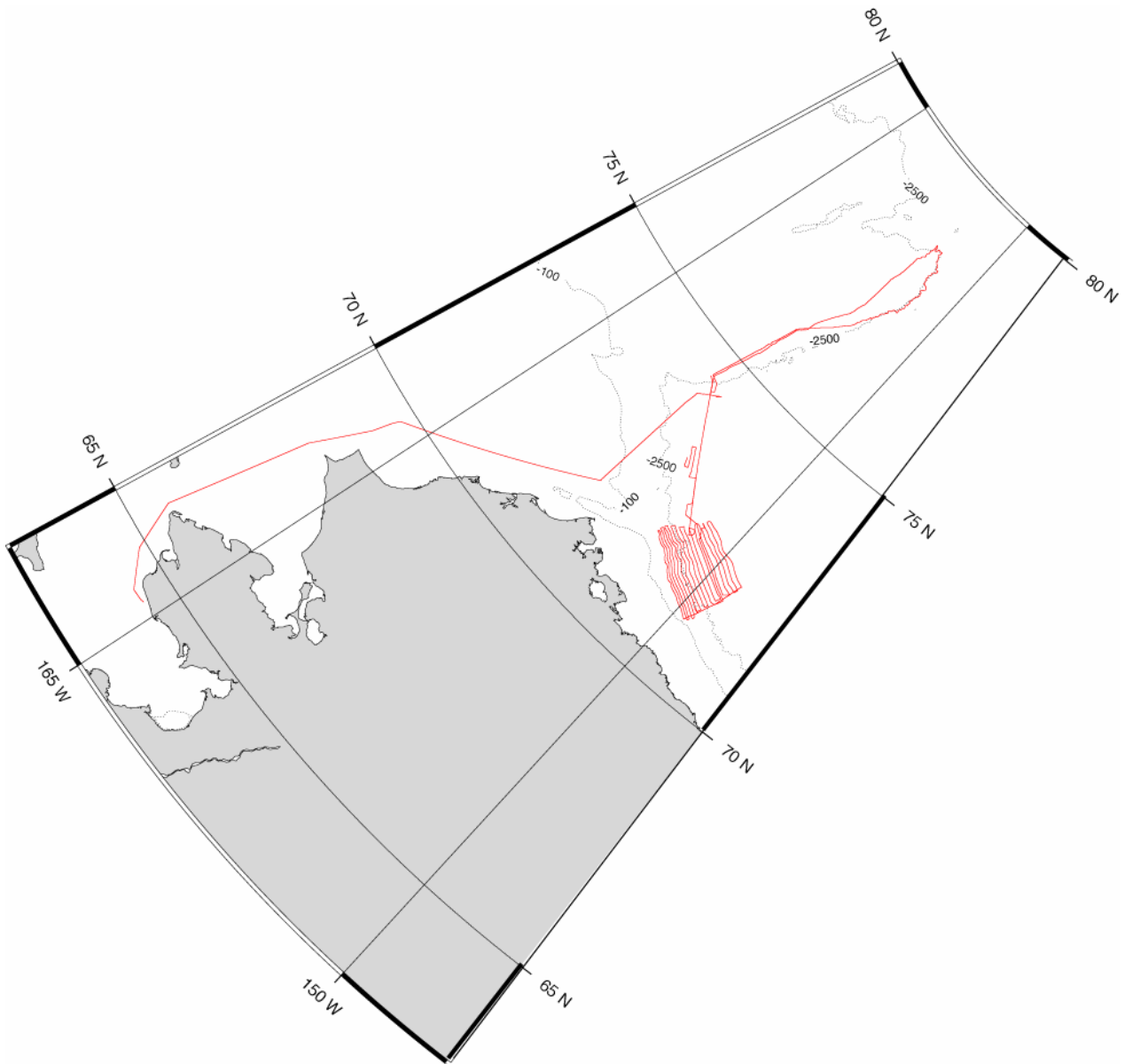


Figure 1. Cruise track for HEALY-0405

## SENSORS AND INSTRUMENTS

The data collected on HEALY-0405 is summarized below. For the most part these data are automatically logged by the ships SCS system. Only the multibeam and 3.5 kHz subbottom data (and appropriate navigation and water property data) were monitored during normal watch operations. Where appropriate – the SCS channel ID is also listed.

### UNDERWAY SENSORS

#### METEOROLOGY

Measurement	channel ID	Collect Status	Interval	Instrument
Air Temperature	079	Continuous	1 sec	R.M. YOUNG/Model 41372LC/LF
Dew Point	080	Continuous	1 sec	R.M. YOUNG/Model 41372LC/LF
Relative Humidity	081	Continuous	1 sec	R.M. YOUNG/Model 41372LC/LF
Barometer	082	Continuous	1 sec	R.M. YOUNG/Model 41372LC/LF
Relative Wind Speed	049	Continuous	1 sec	R.M. YOUNG/Model 09101-SE
Relative Wind Direction	050	Continuous	1 sec	R.M. YOUNG/Model 09101-SE
True Wind Speed	44	Continuous	1 sec	DERIVED
True Wind Direction	45	Continuous	1 sec	DERIVED

#### SONARS

Measurement	channel ID	Collect Status	Interval	Instrument
Bathymetry		continuous	varies	ODEC Bathy2000
Bathymetry		continuous	varies	Knudsen 320B/R
Bathymetry		continuous	varies	SEABEAM 2112

#### OCEANOGRAPHY

Measurement	channel ID	Collect Status	Interval	Instrument
Conductivity	TSG fwd	Continuous	10 sec	Seabird 21
Salinity	TSG fwd	Continuous	10 sec	Calc from Primary Temp
Sea Surface Temp	TSG fwd	Continuous	10 sec	Seabird 21
Conductivity	TSG aft	Continuous	10 sec	Seabird 21
Salinity	TSG aft	Continuous	10 sec	Calc from Primary temp
Sea Surface Temp	TSG aft	Continuous	6 sec	SBE 911
Fluorometry	Fwd	Continuous	5 sec	Turner Designs SCUFA
Fluorometry	Aft	Continuous	6 sec	Turner Designs SCUFA
ADCP 75khz		continuous	varies	RDI Instruments
ADCP 150khz		continuous	Varies	RDI Instruments
TEMP/Sound Velocity	XBT	As needed		Sippican MK21 Deck Unit



## NAVIGATIONAL INSTRUMENTS

Measurement	channel ID	Collect Status	Interval	Instrument
P-Code GPS (Fwd)		continuous	1 sec	Trimble
Attitude GPS		continuous	1 sec	Ashtech
Glonass GPS		continuous	1 sec	Glonass
Gyro		continuous	1 sec	Sperry
P-Code GPS (Aft)		continuous	1 sec	Trimble Centurion

## **SEABEAM OPERATIONS (Dale Chayes)**

### **Watch Standing**

The science party stood regular, three person underway watches in the Computer Lab.

### **System Inputs**

#### **Sound Speed at Keel**

During this leg we experienced very low surface sound speeds, well below 1440m/s. The low sound speeds were found in heavily ice covered areas during most of the northern portion of the leg. Due to problems with the ability of the SB2112 to handle sound speeds at the keel below 1440 m/s the manual sound speed at the keel was set to 1441m/s.

#### **Sound Velocity Profiles**

Sound speed profiles constructed from CTDs taken during the leg and from XBT and XCDT profiles. Updated profiles were entered as the water column changed.

#### **Navigation and Heading**

Navigation and heading information were provided by the ship's Integrated Bridge System (IBS) in real-time. There were no significant interruptions to the data stream from the IBS during the cruise

#### **Time Synchronization**

Time of day synchronization was provided by the IBS during this cruise. 1PPS was provided from the Centurion P-Code GPS Receiver in the Computer Lab.

#### **Attitude**

The MRU provided attitude input to the SB21126 for the most of the cruise. The new Applanix POS/MV was tested for a short period while in deep water off the shelf after installing a different version of the POS/MV interface code in the SB2112 system. An Applanix POS/MV-320 GPS aided inertial measurement system was installed on the Healy in Japan. The system worked well on the transit up from Japan in deep water. Based on our previous experience, the POS/MV was not used to provide attitude data for the SB2112 in shallow water.

The POS/MV was unstable and kept powering down during the early part of HLY-0402. This problem has not been seen since a PAR sensor, which was mounted above the POS GPS Aerial, was lowered. It is believed that this instability was caused by multipath problems due to the position of the PAR sensor.

At the break between HLY0403 and 0404 a loaner POS/MV-320 from Applanix was installed to replace the original unit. Some continued unreliability with the performance of that unit led to us installing updated firmware from the manufacturer.

At the beginning of this leg the IMU cable was swapped with a spare and the system has been very stable since.

There was one unexplained lockup of the POS that was temporally associated with a fault in the SB2112 even though the two systems are not connected and installed in very different locations on the vessel.

## **Performance**

### **System performance in ice**

There were extensive periods of icebreaking during this leg, with prolonged sequences of 'Backing and Ramming'. During these periods the only decent soundings were obtained during the short acceleration periods between backing and ramming. This process came to be known as "ratcheting" and was used when the ice cover was such that we could make continuous way but thick enough to completely prevent any soundings.

### **TSG**

Significant periods of time were spent in heavy ice when the seawater intake has to be shut down and we had to rely on manual input of sound speed at the keel. Due to the inability of the SB2112 to handle low sound speed inputs this was not as serious a problem as it should be.

It is recommended that a SeaBird SBE xx through hull temperature probe be installed for use when heavy ice conditions prevent use of the sea water system.

It is also recommended that further thought be applied to the problem of making sea water available even in heavy ice.

### **Navigation Resolution**

The navigation input format to the system is fixed to accept minutes to 2 decimal places. This results in some visible jitter on the real time display.

The science party merged POS/MV navigation into the multibeam data as part of their post-processing.

### **Shallow Water Performance**

During the transit to and from the survey areas a total of several days was spent in shallow water on the shelf. When the SeaBeam is operated in water depths of less than 250m of water the sonar array is operating in the near field, so the beam forming is poor. This results in data of much lower quality than in deeper water.

During several days of surveying in very calm open water at depths 1,500 to 3,000m of water the SB2112 performed as well or better than it ever has.

### **VRU error messages**

Although bursts of VRU error messages while operating with the MRU6 are commonly observed very few were seen during this leg.

It is expected that when the new POS/MV installation is fully commissioned the MRU6 will be used as a backup.

### **Ping Rate**

The SeaBeam is internally limited to a minimum ping interval of 1.5 seconds. This limit comes into play in water less than about 500m deep. This results in the along track coverage in shallow water to be poor due to the sample rate limitation.

### Apparent attitude errors:

For years there have been suspicions that the “ruffles” observed in SB2112 data might be the result of errors in attitude. This cruise provided an opportunity to test this theory. We extracted the time of ping and the pitch angle at ping from the SeaBeam 2112 raw data file using the MB-Sytem utility *mblist*. The GMT utility *sampl1d* was then used to apply a spline interpolator to the data files from two independent attitude sources: an Applanix POS/MV-320 and a Thales (ex Ashtech) ADU5 to provide pitch angles at the time of transmit for each of these sources. A sample of this data set is shown in Figure 2. SeaBeam has tried several times to address this problem with out success. Since they consider the SB2112 a nearly obsolete system it is unlikely that they will be willing and able to successfully resolve this issue if we were to press the point.

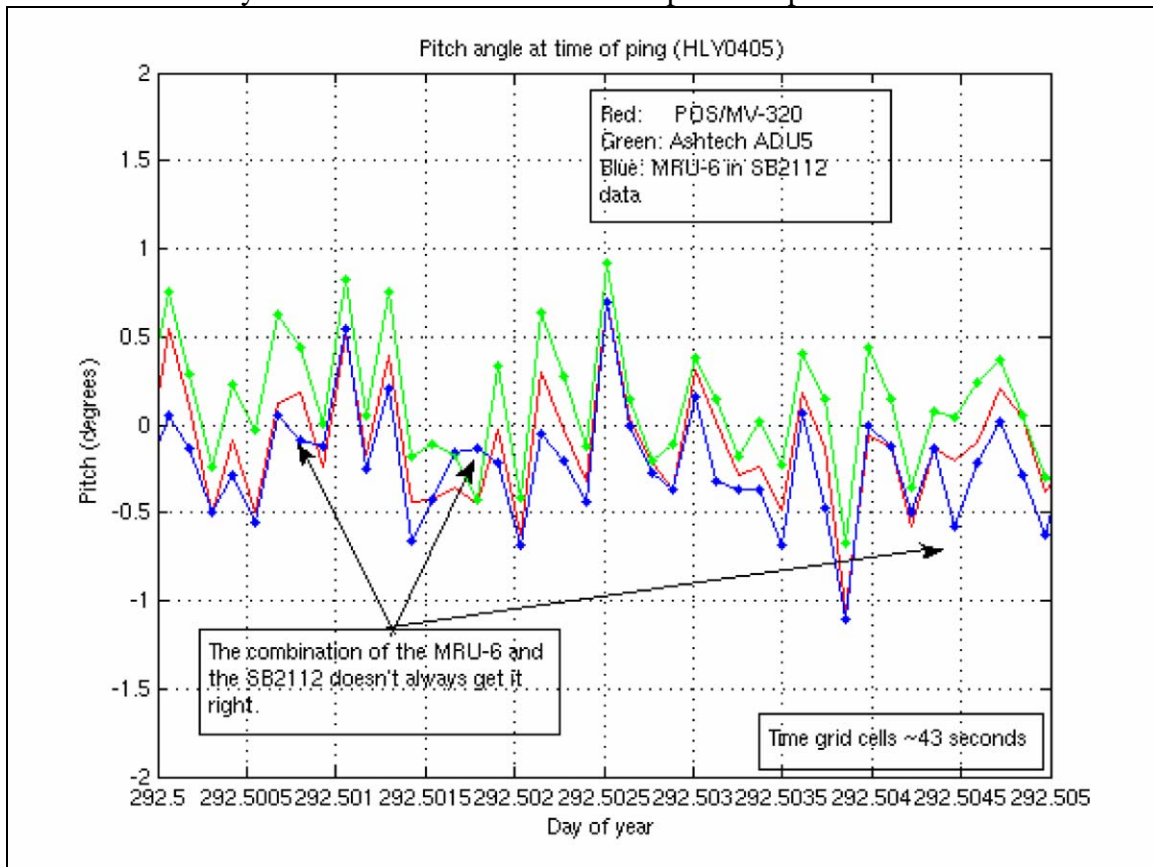


Figure 2: Comparison of pitch angle at the instant of SB2112 transmit ( $T_0$ ) with the pitch measured by the POS/MV-320 and the Thales/Ashtech ADU5. Note the instances where the pitch angle reported by the SB2112 is out of phase with both the POS/MV-320 and the ADU5.

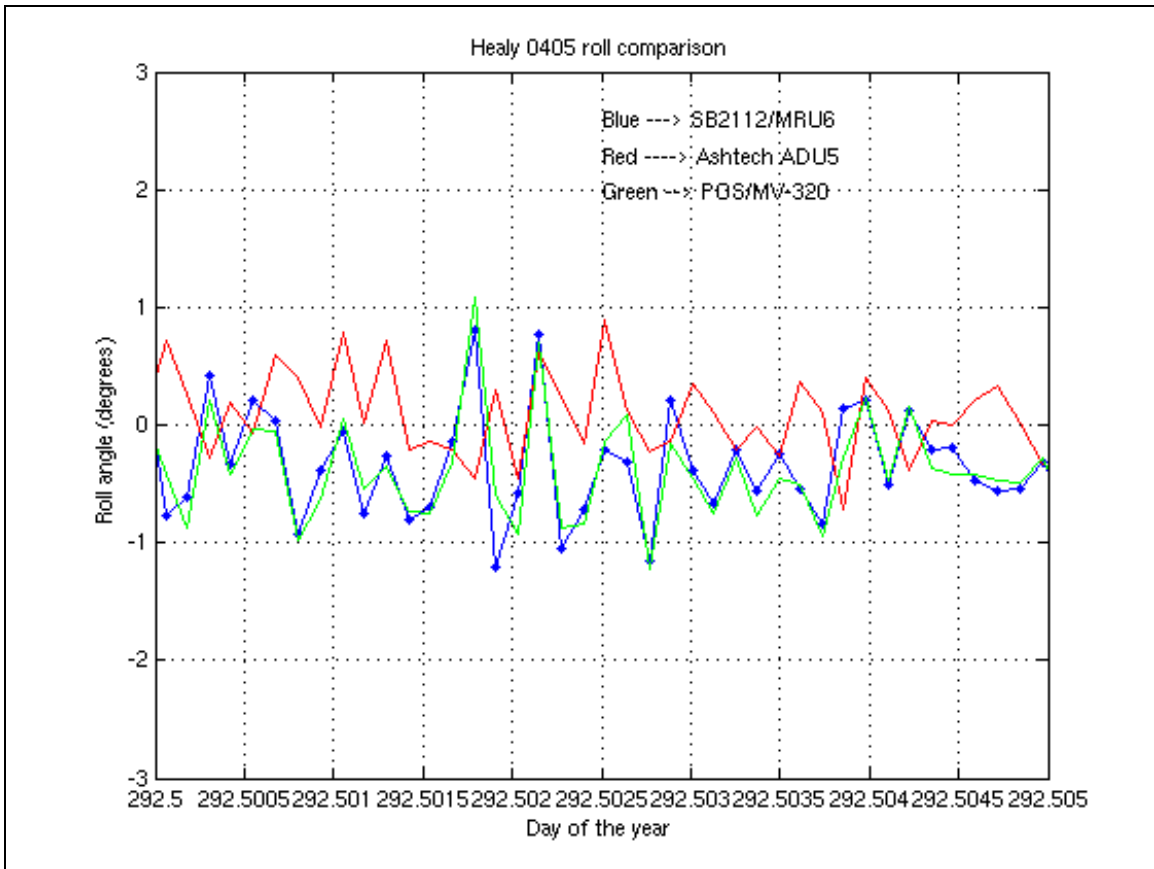


Figure 3: Comparison of roll angle at the ping instant for the same period as shown in Figure . An offset adjustment has been applied by adding the mean of each signal. Note the agreement between the roll from the MRU-6 and the POS/MV and the disagreement with the ADU5 in this example.

## SCIENCE SYSTEMS (Dale Chayes)

The following sections address the state and usage of Healy's science systems during this leg. The order of system names matches the system definitions used in the electronic log (*elog*) used during HLY0405.

### ADCP (150khz)

The ADCP 1050 was run routinely during this leg. On previous legs this system was rebooted every day. The system ran normally without rebooting.

### ADCP (75khz)

The ADCP 750 was run routinely during this leg. It locked up and was rebooted at least eight times.

### Aft P-Code (Trimble Centurion)

Data was collected and logged but not used. There were no known problems.

### Ashtech 3DGPS (ADU5)

The recently installed ADU5 was used during this leg.

The ADU5 stopped sending attitude data NMEA messages on October 19<sup>th</sup>. It was restarted, reconfigured and resumed sending data.

### **CCTV**

Last year a small black and white monitor was installed on the shelf above the multibeam displays so that the science underway watch could see the forward looking camera mounted in Aloft Conn. This monitor was replaced with a larger, color monitor for this leg. The improved definition was a significant assistance to watch standers who were manually changing the multibeam from manual to automatic gating in open water.

### **C-Keel Auxiliary Computer**

*Ckeel* exhibited signs of imminent disk failure late in the previous leg. Val and Ethan moved all most all of the critical services off of this computer onto *posmvnav* at the end of the leg. We did not use *ckeel* on this leg

### **CTD**

The MSTs took two CTD stations during this leg to provide accurate sound speed profiles for use in the multibeam. These stations went well.

### **DI/RO Pure Water Systems**

There was no need for DI water on this leg.

### **Fluorometer**

The Scuba in associated with the forward TSG was run during this leg but the data as not of interest to the science party.

### **Forward P-Code (Rockwell Collins)**

Data was collected and logged but not used. There were no known problems.

### **General Purpose Data Processing Computers**

Coakley used map-2 for processing and analysis of the gravity data.

### **General Purpose Science Workstations**

The science party made casual use of the public workstations in the lab and the conference room.

The CTD data was processed into sound speed profiles on one of the public workstations using SeaBird's software.

The G4 Mac in the Future Lab was used extensively by Dr. Coakely, mostly as an X-terminal.

No known problems

### **Gravity Coring Equipment**

Not used.

### **Gyro Compasses**

Data was collected and logged but not used. There were no known problems.

### **Integrated Bridge System**

IBS provided position, heading and time of day data to the SB2112 in real-time during this leg. No known problems.

### **Map & Map-2 & Pproc Auxiliary Computers**

*Pproc* was not used during this leg

*Map* was used as an X-terminal.

*Map-2* was used for processing and analysis of gravity data and for automatic quality checking, plot generation, etc.

*Map-2* was also the host for a number of server processes described elsewhere.

### **Multibeam Router**

The multibeam router performed normally during this leg.

### **(Science) Navigation System Auxiliary Computer**

*Posmvnav* was used to log data from the POS/MV-320 and to host some of the sound speed at the keel processes that used to run on *ckeel*.

### **Piston Coring Equipment**

Not used.

### **POS/MV**

The POS/MV-320 had only one significant failure on this leg.

It also exhibited not-unexpected behavior of slowly losing its ability to produce very high accuracy heading during very long straight survey lines. This is a known behavior of POS/MVs.

At the beginning of this leg an alternate IMU cable was installed. It is possible that the original cable was the source of at least some of the previous instability.

At the end of the last leg a firmware update was installed that removed the need to restart the POS every seven days. The longest continuous run so far has been 266 hours.

### **Science Data Network (general)**

Compared to earlier legs, there were very few significant perturbations in the science network during this leg.

A spare 1 TB snap server was installed in the racks, brought on line and configured to verify it's condition and because it was felt that it was safer there than on the deck.

### **Science Hoist/A-Frames/Capstans & Cranes**

Limited use on this leg. No problems to report.

### **Science Uncontaminated Seawater System**

The seawater system was used when in open water but only to provide flow to the forward TSG

### **Science Reefer/Freezer/Climate Control Chambers**

Not used.

### **SCS Logging System**

#### **Restarts**

SCS was restarted on October 19<sup>th</sup> because the bridge P-code receiver was restarted and the data was arriving at SCS but not logging the data. After the restart the data was logged.

#### **Missing and/or duplicate data records:**

During this leg we learned that there were problems with data logged by SCS on previous legs. These problems appear to be SCS-related.

During the periods listed below SCS appears to have been having difficulty collecting data from the various sensor devices. The BGM-3 gravimeter data was the first noted by Dr. Bernie Coakley to have missing data. When checking corresponding dates and time it was found that most if not all devices encountered data collection issues. It doesn't appear to be specific to one sensor.

The suspect dates are 05/15/2004 to 06/29/04. After 06/29/04 the occurrence of suspect data is much less frequent if not at all present. See Appendix 4 for detailed listing of missing data and duplicate records.

### **SDN Time Servers**

The starboard timeserver was used during this leg. The port server was not turned on because we do not have an antenna mounted to support it.

### **SeaBeam 2112 Multibeam Sonar**

#### **Sippican Mk21 XBT System**

Several expendable XBT and one XCDT probe were launched to document the sound speed profile. A number of probes failed to reach the expected depth.

There appears to be no spare hand-held launcher or deck cable.

#### **Sperry Speed Log (SRD-5000)**

Data was logged but not used for science. No known problems.

#### **Sub-Bottom Profiler (Bathy 2000)**

The Bathy 2000 was used for the entire leg. It was used in the configuration where the Bathy 2000W (Windows) NFS server segmented the data files into reasonable “chunks”.

The Bathy was restarted about nine times to recover from various failure modes including but not limited to lock-ups.

#### **Sub-Bottom Profiler (Knudsen)**

Not used on this leg.

#### **Terascan**

There were sporadic problems with the automatic update of position. ETMC Perron is still working with the vendor to resolve this issue.

#### **TSG**

For the northern portion of the leg the ice was too thick for the new science seawater system and the TSG was secured. It operated properly when in open water.

One of the valves in the TSG plumbing in the BioChem lab is broken and should be repaired.

#### **Weather Station**

The RM Young weather sensors worked well during this leg.

This may be the first leg in a number of years that worked in air temperatures less than -10°C. We discovered that the RM Young translator that handles the temperature data was configured with a limited width field for air temperature. When the temperature dropped below -10°C it reported only asterisks in all data fields. The translator near the QMs planning station on the starboard side of the bridge was re-programmed to accommodate the full range on October 10<sup>th</sup> at about 0530Z.

#### **Winches/Wires/Displays**

Two CTD stations were taken specifically to get accurate sound speed profiles. No problems were reported with the winches, wires or displays.

#### **Elog**

The electronic log was used extensively by this science party and performed well. We asked them not to use the search capability as this has a known bug that can cause the server to fail.

#### **Gravimeter**

There were no major problems with the temporarily installed Bell BGM-3 gravity meter during this leg.

## **SV2000**

It appears that the logging process for the SV2000 was running during this leg but no data was actually logged. The cause is under investigation.

## **Map-2 Server**

### **DocManager**

An updated version (0.47) of the open source DocMgr document management software was installed on map-2 during this leg. After a couple of configuration updates

### **PostgreSQL**

An updated version of *postgresql* was installed on *map-2* to replace the older version that was on *ckeel*. This server is used to support docmgr and the older electronic notebook that we no longer use.

### **Web services:**

The index page for the *map-2* web server was updated to reflect changes in the locations of the services moved off of *ckeel*

### **Axis WebCam**

This was a small science party with a focused underway mapping objective. They were standing relatively simple underway watches in the forward end of the Computer Lab. There was no science usage in the main lab so the “board of lies” web page was not used during the leg.

Casual monitoring indicates that the page updated regularly during the leg.

### **QC plots**

During this leg we reached temperatures colder than  $-10^{\circ}\text{C}$  and discovered that the formatting of the new style (Lamont Data System) automatic QC plot temperature range stopped at  $-10^{\circ}\text{C}$ . The plotting script was updated to have a new lower bound of  $-30^{\circ}\text{C}$ .

Added an automatically updating navigation plot

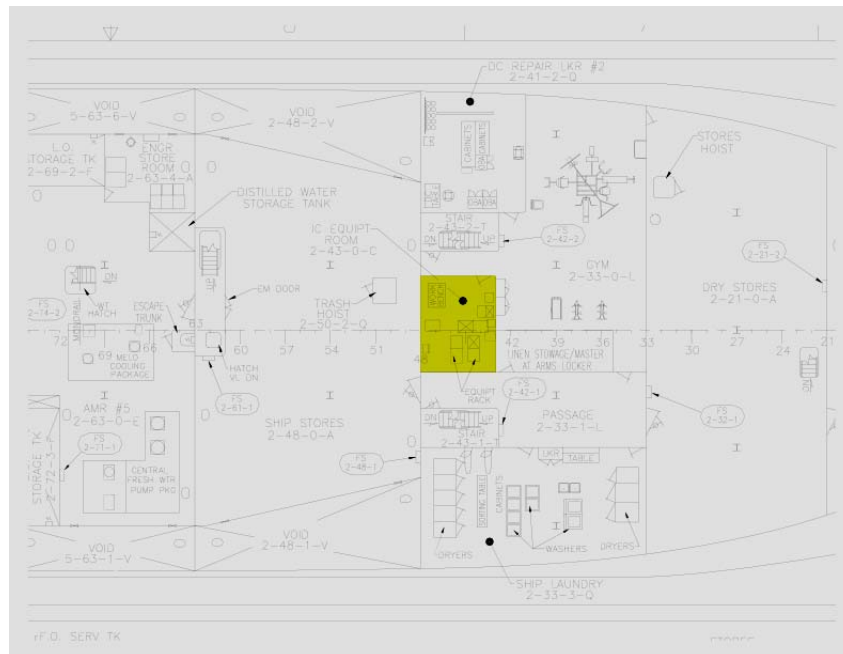


## GRAVIMETER REPORT (Bernie Coakley)

### Gravimeter Installation

The National Geospatial Intelligence Agency agreed to fund gravity data acquisition during the Summer 2004 USCG Healy program to augment their gravity data holdings in the Arctic. With the agreement of the CO (Dan Oliver) and the support of all the Summer program chief scientists (Jackie Grebmeier, Larry Mayer, Lee Cooper, Rob Pickart and Larry Mayer) a Bell BGM-3 underway marine gravimeter [Bell and Watts, 1985] was installed in Seattle on 15 and 16 March 2004. An initial gravity tie was not made, as the Healy was docked within 50 feet of a known NAVOCEANO gravity base station (#0033.25 on Pier 36, Berth-B). The estimated meter bias obtained for this time was 855002.2 mGals.

The Bell BGM-3 gravimeter was made available to this program under a loan agreement negotiated between NSF and NAVOCEANO. The gravimeter and support electronics were installed by Bernard Coakley (PI; University of Alaska Fairbanks) and Randy Herr (NAVOCEANO) in a portable rack in the IC Gyro room, which straddles the centerline of the ship, on the third level (Figure 4 and 5). The NAVOCEANO data logging computer was provided with NMEA strings from the Centurion P-code GPS receiver (GGA, VTG and ZDA) in the computer laboratory via a serial connection. These data permit the NAVOCEANO data-logging computer to maintain time synchronization to GPS satellites and continuously reduce gravity data while underway. The raw gravity “counts”, which are not logged by the NAVOCEANO computer, were provided via a 2<sup>nd</sup> serial connection to the Healy’s SCS data logger, enabling redundant data logging for the gravimeter output stream for post-cruise data reduction. Integration of the gravimeter with the ship’s information system was achieved with the support of MST1 McFadden.



**Figure 4** – Plan for 3<sup>rd</sup> level deck on Healy. IC Gyro room is indicated by yellow box.

The gravimeter will be removed from Healy in Seattle sometime during the week of November 14<sup>th</sup> through 21<sup>st</sup>. At that time a gravity tie will be made between point

0033.25 and an external, known point at the University of Washington. With this tie, it will be possible to estimate meter drift during the deployment and complete gravity data reduction for the Healy 04 season.



**Figure 5** – Gravimeter as installed for Summer 2004 program on USCG Healy.

### **Gravimeter Operations during Healy 04-05**

Captain Dan Oliver, the CO of the Healy, provided MST support to monitor the meter and ensure rapid identification of meter failure. The gravimeter was run continuously while the Healy was underway. Data logging of the raw Bell BGM-3 counts through SCS began shortly after leaving Nome on 6 October (Julian day 280) at 21:01:21 Z. Data were logged without significant interruption 25 October (Julian day 298) at 00:04:00 Z.

The gravity and navigation data were logged on the NAVOCEANO supplied data logging computer and the Healy data logging system. Gravity data reduction was done using the continuous navigation stream from the POS-MV-320.

### **Data Reduction**

Data reduction begins with the raw one second integer counts generated by the Bell BGM-3 and logged by the Healy's data acquisition system. The POS-MV GPS data stream (position, heading and velocity) was used to calculate the latitudinal correction (for the Earth's shape) and the Eotvos correction (for motion across the rotating Earth).

Meter drift will be estimated post-cruise from the opening and closing gravity ties and used to correct the gravimeter output.

Prior to the deployment of the Bell BGM-3 on USCG Healy it was not clear how the meter and its stabilization electronics would respond to icebreaking operations. Heavy ice was encountered on the northern Chukchi Borderland during this program. Data collected during this segment of the survey (Figure 6) shows that even while backing and ramming, the gravimeter performed well and collected useful data without “dumping” in response to the rapid horizontal transient accelerations. During the remainder of Healy 04-05 program, while making steady way, even while breaking level, continuous ice, excellent gravity anomaly data was acquired.

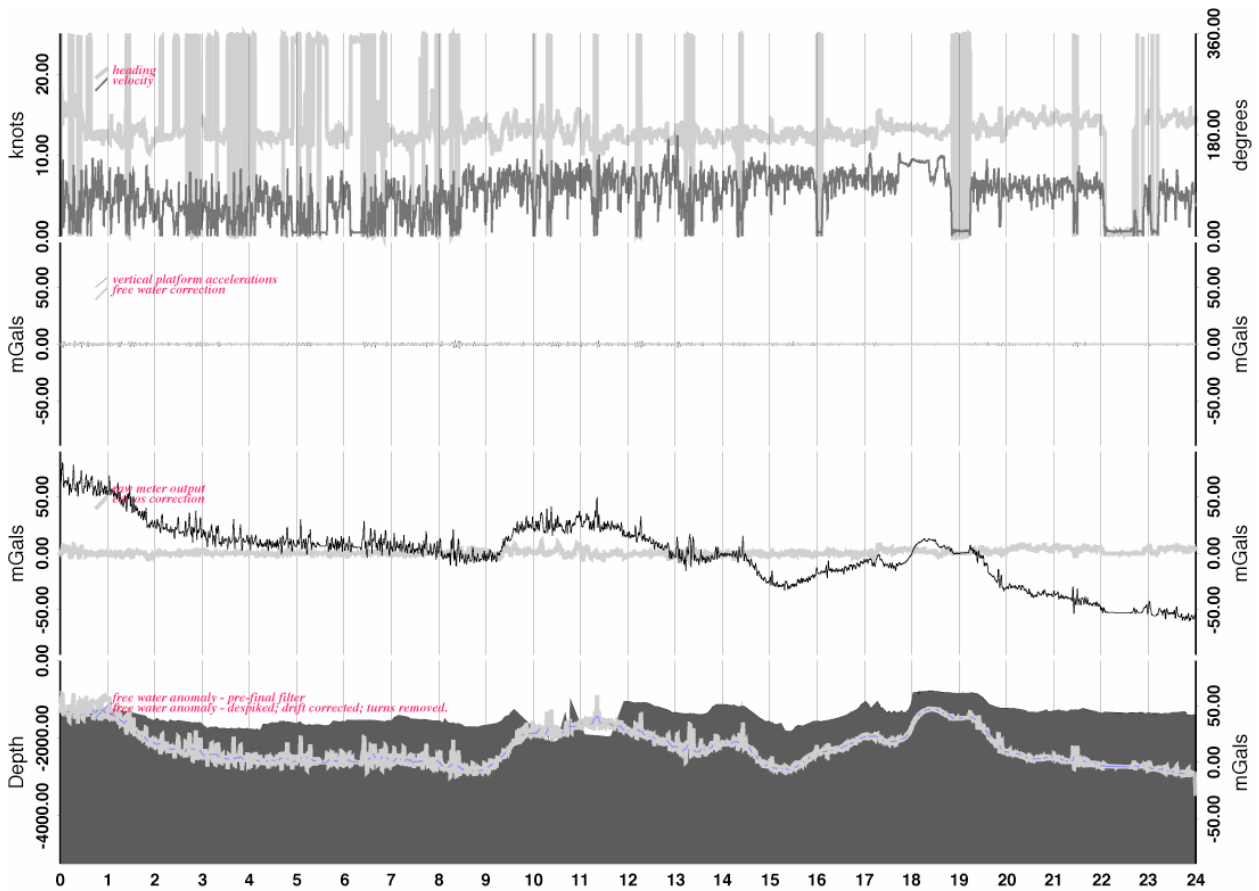


Figure 6 – Gravity anomaly and supporting data collected from USCG Healy Summer 2004. High frequency positive spikes that dominate the raw gravity anomaly data are due to backing and ramming of thick sea ice. These transient are effectively removed by filtering. The gravimeter recovers quickly enough from these rapid horizontal accelerations so that useful data can still be acquired during these operations.

Bell, R.E., and A.B. Watts, 1986, Evaluation of the BGM-3 sea gravity meter system onboard the R/V Conrad, Geophysics 51, 1480-1493.

## **CHIEF SCIENTIST's DAILY LOG:**

**06 October 2004 = JD 280. ALL TIMES LOCAL UTM-8hrs**

Science party gathers at Evergreen Air at Nome Airport at ~0900 awaiting helo transfers. First helo appears at ~0945 – all scientists transferred to HEALY by ~1145L

Transfer to HEALY uneventful and quick. Move aboard and set up during afternoon – 1400 – usual inbrief by HEALY officers and crew:

Underway at ~1300 – steaming towards point “C” – intersection with last year’s track – overall plan is to steam across shallow areas of rise and then pick up the 2500-m isobath near Healy Seamount. Setting things up and turning on sensors.

**7 October 2004 – JD 281**

Steaming at ~16 kts.

Brian – setting up processing protocols and I am trying to set up OziExplorer with real-time nav so that we can follow our progress with respect to the IBCAO bathymetry.

In the course of this we find out that many of the problems identified last year still persist:

- 1- POS-MV is not hooked up to SeaBeam 2112 – there is problem with SeaBeam hanging up in shallow (less than ~250 m) water
- 2- Not set up to use POS for position even when it is connected to SeaBeam
- 3- The integrated Nav still has same instabilities it showed last year – fortunately we still have code to pars nav
- 4- The NMEA drop that we set up last year is gone.

Solutions:

- 1- Brian reactivated last year’s nav parsing code but this year will use the POS GGA and HDT data (there was no POS last year).
- 2- I badgered the ship’s ET’s to build new cable – now have NMEA string coming to laptop

NMEA string to OziExplorer – using NOAA Arctic Chart 16200 (Arctic Coast) – works fine – chart only goes to 74°N though. Also, we want to see bathymetry so trying to use the ALBERS Equal Area version of IBCAO that Luciano created. Goes in to OziExplorer as geotiff fine and it recognizes it as ALBERS equal area – with lat 1 = 90.00°, lat2=90.3° projection meridian = -154° and latitude of origin = 70°g. Problem

arises when bringing in NMEA string – it then seeks image file and thinks it is now Mercator projection.

Resolved but not easy – seems that must first load NOAA chart then import geotiff then turn on nav – but not sure why.

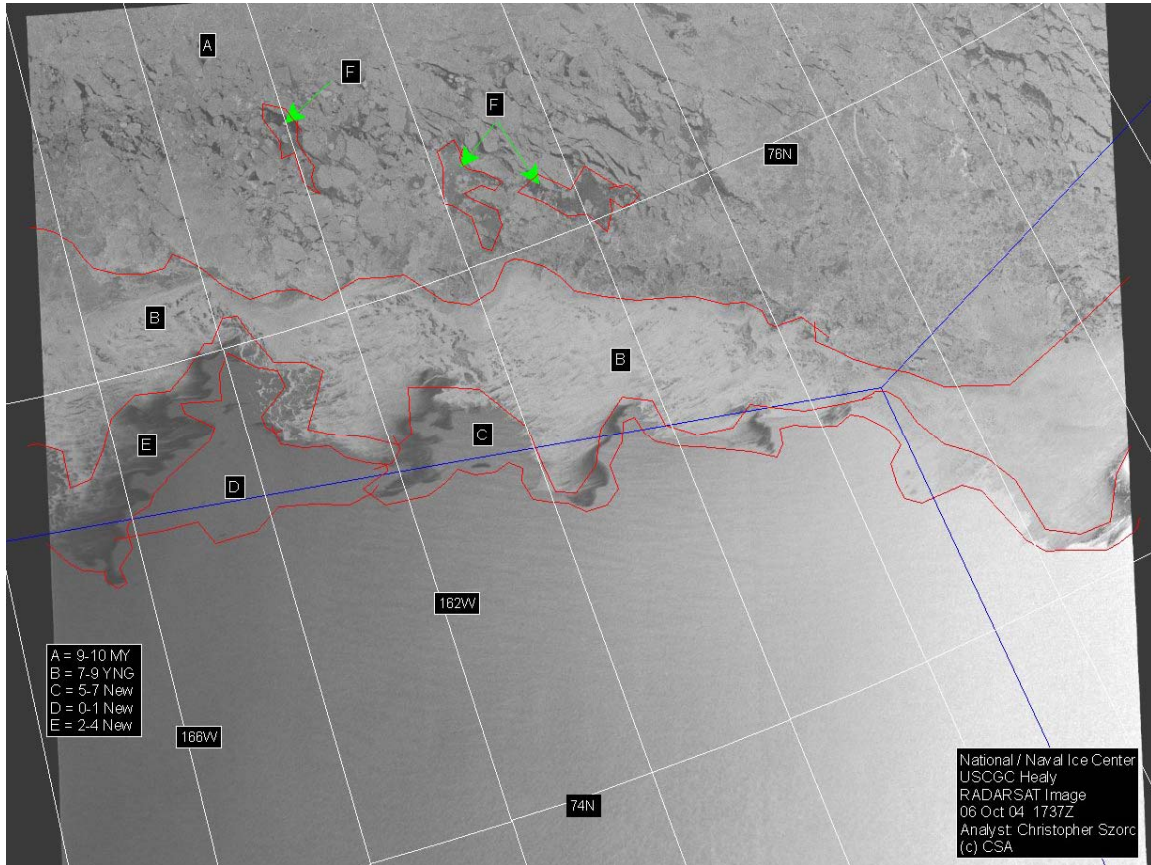


Figure 7. Radarsat ice coverage for 6 October 2004. *Healy* is at 64N at this time (off image) © CSA2004. Image processed at either ASF, Qinetiq or CDPF.

1600L – OPS informs that we must divert to Barrow for offloading a crew member for family emergency.

Continue to work on data flow and data quality as we steam east.

### 8 October 2004 – JD 282

Arrived off Barrow 0830L – winds, wave and snow preclude flying. Wait approx 1 hour to see if there is improvement – none so decision is made to leave. Given transit to Barrow we have decided to run 2500-m line from east to west. This has advantage of bringing us to western end of survey area and beginning the foot of the slope search at this end which involves areas near 80°N – Capt. Oliver advises us that our shiptime next



year (23 June-23 July) is too early in the season and we will probably have heavy ice. This plan allows us to get farthest north sites completed this season.

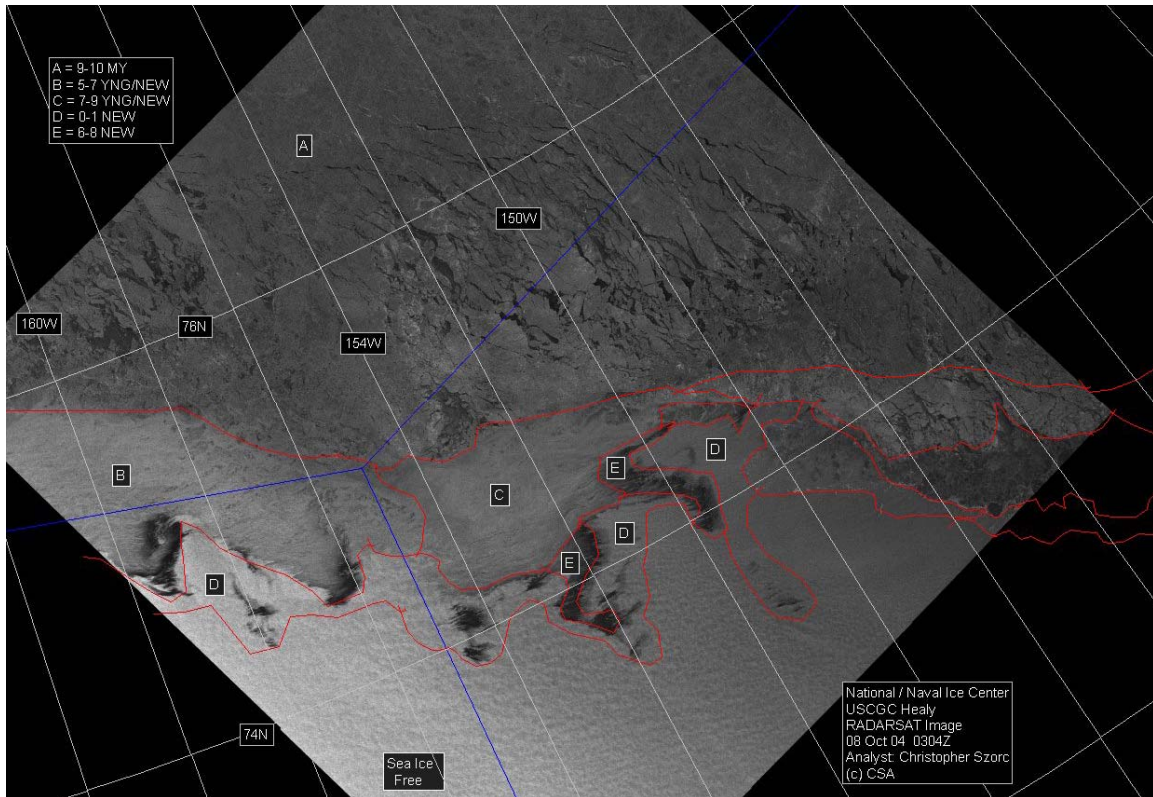


Figure 8. Radarsat ice coverage for 8 October 2004. *Healy* is at 70N at this time – off image. © CSA2004. Image processed at either ASF, Qinetic or CDPF.

Steaming for Waypoint 1 – a point chosen in deep basin (>3500 m) that looks relatively flat on IBCAO – plan is to do roll bias test on flat area and then turn NW up slope to NW Ridge to do pitch test.

1200L – start watches

first data sets reasonable for shallow water – processing protocol working fine – generating both projected and unprojected sd files at end of line –

1800 Dale switches out MRU-6 (which was being used for attitude information in shallow water) with POS-MV – need to reboot SeaBeam – crashes on reboot -

1930L – SeaBeam back up – approaching site for XBT and start of region for patch test.

2000L – XBT – shows funny surface structure – surface sound speed does not match keel sensor – off by 6 m/sec – this is too much of a difference – decide to take CTD –

2200L CTD complete – processing data –

CTD entered and looks good –

Begin NE-SW line for Roll bias test  
Data looking good –

SeaBeam crash – (see elog)

### **9 October 2004 L JD-283**

Lost Nav (see elog)

Finish up roll bias line –

0400L course change (c/c) to 320 – for pitch bias test

0420L c/c to 300 to get orthogonal line up slope

running up slope – looking good

0434L – SEABEAM crash – call Dale

reboot –

0515L – back on line now near top of slope – will return on reciprocal course to map downwards and then back up again for pitch bias test

data looking good – as we go down slope – beautiful scalloped edge of Northwind Ridge  
–

0653L – SeaBeam hangs again – call Dale

at bottom of slope – turning back up to do pitch test again – SEABEAM up again @  
0726L

0754L – SEABEAM hangs again after 41 pings – call Dale again –

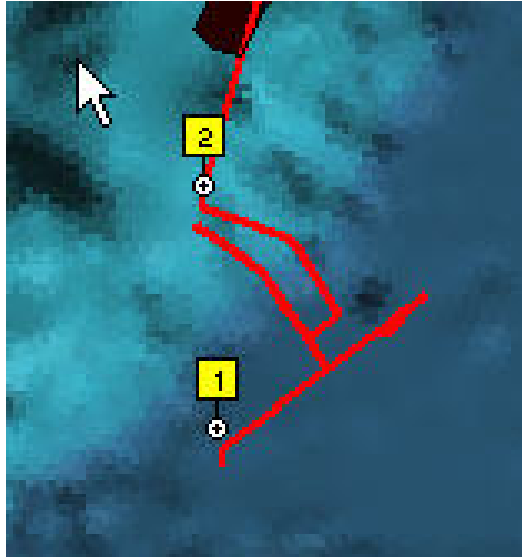


Figure 9. – geometry of attempted patch test

We suspect the SeaBeam hang is the result of the switch to POS MV and will go to MRU-6 with this boot – abort patch test and steam up NW Ridge to get on track for WP3

0857L – on track steaming up NW

0900L Beautiful small pancake ice beginning

1200 – Pancakes becoming much larger

1307L Bathy2000 shows interesting targets – file 1009-02.dat

1430L – hit solid (new) ice cover – slow to 6-7 kts – *THE SUN HAS COME OUT* -- ice line at about 75° 15'N and 157° 43'W

1500L – crash stop test for engineers – SeaBeam continued to function through.

1600L – continues to get colder and heavier ice – SeaBeam is acting in its normal manner – intermittent returns as a function of ice cover

### **10 October 2004 JD 284**

0200L – first back and ram necessary – not a good sign

0400L – Continue to steam north –

0800L – XBT – needed 2 tries – first broke – 2<sup>nd</sup> good to 900 m

0900L – confirmed with Jim – wrong coordinates sent to bridge – have fixed and will give new coordinates.



1000L – second back and ram

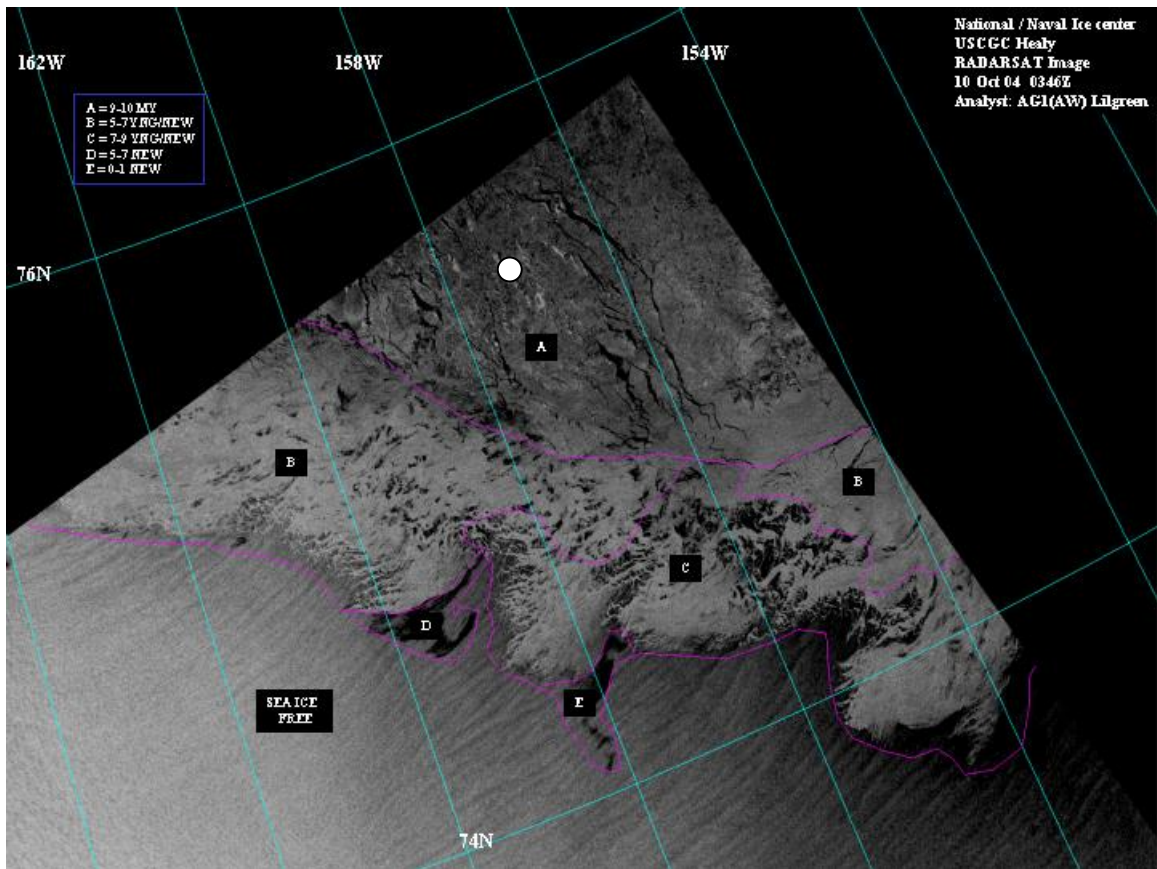


Figure 10. Radarsat ice coverage for 10 October 2004. White circle is approx position of *Healy*. © CSA2004. Image processed at either ASF, Qinetiq or CDPF. (157.33W, 75.71N)

1220L – Polar bear sighted – stopped briefly for a look

1330L – stuck again – several back and rams –and finally free -  
Continue to steam with some difficulty –

1500L – arrive in region of Site M for CTD – no open water – *HEALY* maneuvering trying to open up spot for CTD Water depth about 2200 m.

1600L stopped for CTD station – 2300m on eastern edge of Northwind Ridge – we are on slope – outer beam (west) = 2000 m, outer beam (east) = 2800m – center beam = 2309 m. This will be a deep cast to give us picture of total water column on NWR –

1900L – begin survey of 2500-m isobath – using procedure of directing ship from SeaBeam display – placing cursor where we want them to drive –

1922L – stuck – B&R -- basically there is no open water at all – ice is 10/10 and hard – ice often 6 ft or more thick – new ice with lots of multiyear ice mixed in.

2000L – continue to survey along 2500-m isobath – SeaBeam intermittent but able to follow contour – ice is clearly more difficult than last year and progress slower – sometimes we can make 5 kts but often slowed to less than 3

### 11 October 2004 JD 285

Twilight is at about 0800 but sun doesn't really rise till about 1000 AM – today is relatively clear and cold (-18°C) – continuing to map 2500 m contour – between points M and L – crossed point L at ~0442L –

1000L – stuck on ice ridge – B&R about 10 x – finally getting through

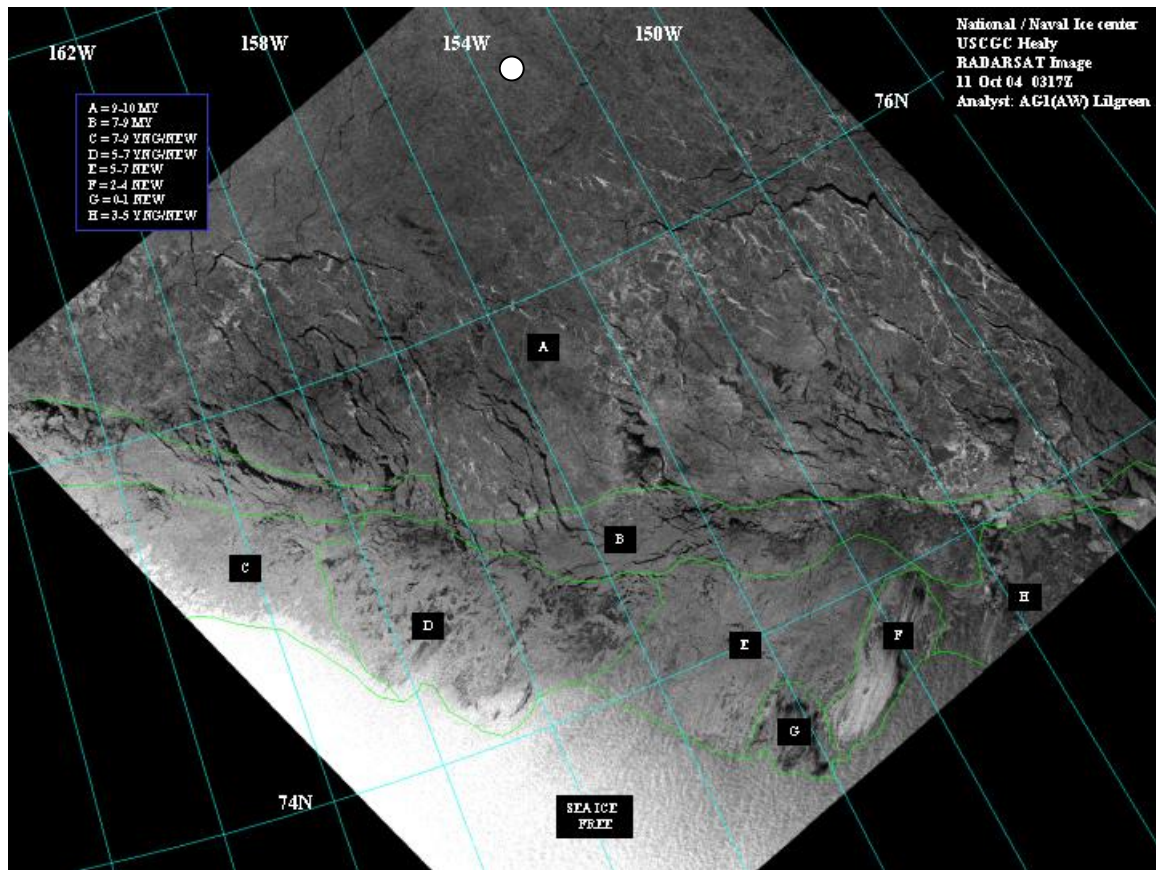


Figure 11. Radarsat ice coverage for 11 October 2004. White circle is position of *Healy*. © CSA2004. Image processed at either ASF, Qinetiq or CDPF.

1500L – data is very intermittent – bottom line is that the only data we are only collecting data WHEN we back and ram – no data as we are breaking ice until we get stuck – no data when stuck – no data when backing down – BUT ... we get quite good data when we move ahead to ram. So....a new strategy.... The RATCHET SURVEY –

we will ask them to move ahead several ship lengths and then back down – even when they are not stuck.

1700L – beginning the ratchet survey approach – seems to be working well – we will have to remember to contact bridge when they don't need to back down.. This approach is slow but at least we are collecting usable data.

### **12 October 2004 JD 286**

~0100L – The 2500-m isobath has turned NE and then turned back indicating a large promontory not on the IBCAO chart – we are now in deeper water and will be heading west to pick up the 2500-m isobath again.

0400L – picked up the 2500-m isobath and are continuing north – the ratchet survey approach is working though we don't cover all that much territory – but it certainly better than collecting no data at all.

0800L – progress at about 2 to 4 km per hour. Every once in a while we get into an area of relatively thin ice with some cracks that allows us to go back to straight survey mode. We inform bridge if we are getting coverage as they break ahead and tell them that there is no need to back down and ratchet.

Several stops of vessel for either generator switchover or loss of shaft –

Making slow but steady progress with useable data – will certainly need to rethink how much we can accomplish – odds of getting higher north for the foot of the slope survey seem quite small and trying to map the foot of the slope in this mode would be foolish – propose that we try to finish the 2500 m contour survey and then go to the southern area off Barrow for the foot of the slope study there. The Captain says this area would be absolutely unworkable next year when we have been scheduled for late June and July.

### **13 October 2004 JD 287**

0400L Ice continues to thicken and temperatures low (-23°C) – as we start this AM we are making very slow progress – took 13 B&R's to get through one ridge – at this rate making about 1 km per hour but still collecting good data. Once through ridge we are making a little better progress – about 2 km per hour.

Overall in the course of the day we have probably made about 1 nm/hr – the ice island at its peak made about 22 km in one day – so at least we are doing better than the ice island.

### **14 October 2004 JD 288**

Surveying continues as before – we are still making about 1 nm per hour – most of the time the B&R is for them (to move ahead) rather than for us (just to obtain data) but on occasion we find thinner ice and fall back to planned ratchet surveying. Have talked with

Captain and conclude that we should keep on going like this till about Saturday (16 October) and then head to survey area off Barrow for foot of the slope survey

Wogs called to mess deck at about 0900L for auction – our wogs are Mashkoor, Monica, John T, Jim Case, Caleb. No-talent show at 1900L – Caleb enthralled crowd with Coast Guardized version of “Anchors Away” – he then proceeds to buy pie at wog-pie auction to throw at Dennis Noble – who takes pie in face with grace.

2200L – hit heavy ridge at 78°42.42’N, 154°27.87’W – start B&R –

### **15 October 2004 JD 289**

Continuing to work on same ridge – ice drift setting us NW –  
0247L – after almost 5 hours of B&R Captain calls to say that’s it – he wants to begin to head south – plan is to make way (as best we can) to WAYPOINT 3 on track coming up Northwind Ridge and then try to double up track heading south until we make ice-free waters – then turn east to head for Barrow Shelf foot of the slope survey. – break off point is 78°44’ 48.2æ, 154° 36’ 15.1æ

Continued to have great difficulty breaking through – in about 8 hours of B&R trying to move south we drifted about 6 nm to the north – finally broke through at about 0500L – the rest of the morning was spent alternating between short periods of advance and long periods of B&R.

Continuing to B&R our way south – making slow progress – averaging about 2-3 kts as we gain momentum through the night very intermittent SeaBeam data.

### **16 October 2004 JD 290**

Weather changing – strong winds (30-40 kts) coming from the south – temperatures increasing dramatically – temps approaching -5°C.

~0400L – noticeable change in ice conditions – starting to see many open leads and even large areas of open water – as conditions change we are starting to really make headway (9 kts some times) and also get data on top and western side of Northwind Ridge.

1000L As we head south and find leads and lots of open water – track is taking us east on top of Northwind Ridge – depths as little as 800 m. ETA to Waypoint 3 - now about 7 hours (if we can maintain 9 kts).

1100L – after long period through relatively open water, we are back in the ice – albeit thin and easy to move through – data continues to come in but more intermittently.

1600L - Temperatures continue to increase – seagulls are following vessel. Some snow but relatively warm (-5°C) – still strong winds from south



2200L – for reasons unknown to all – bridge turned south and intersected northward track many miles north of waypoint 3 – no big deal but not sure why this happened – we will start doubling line from this point.

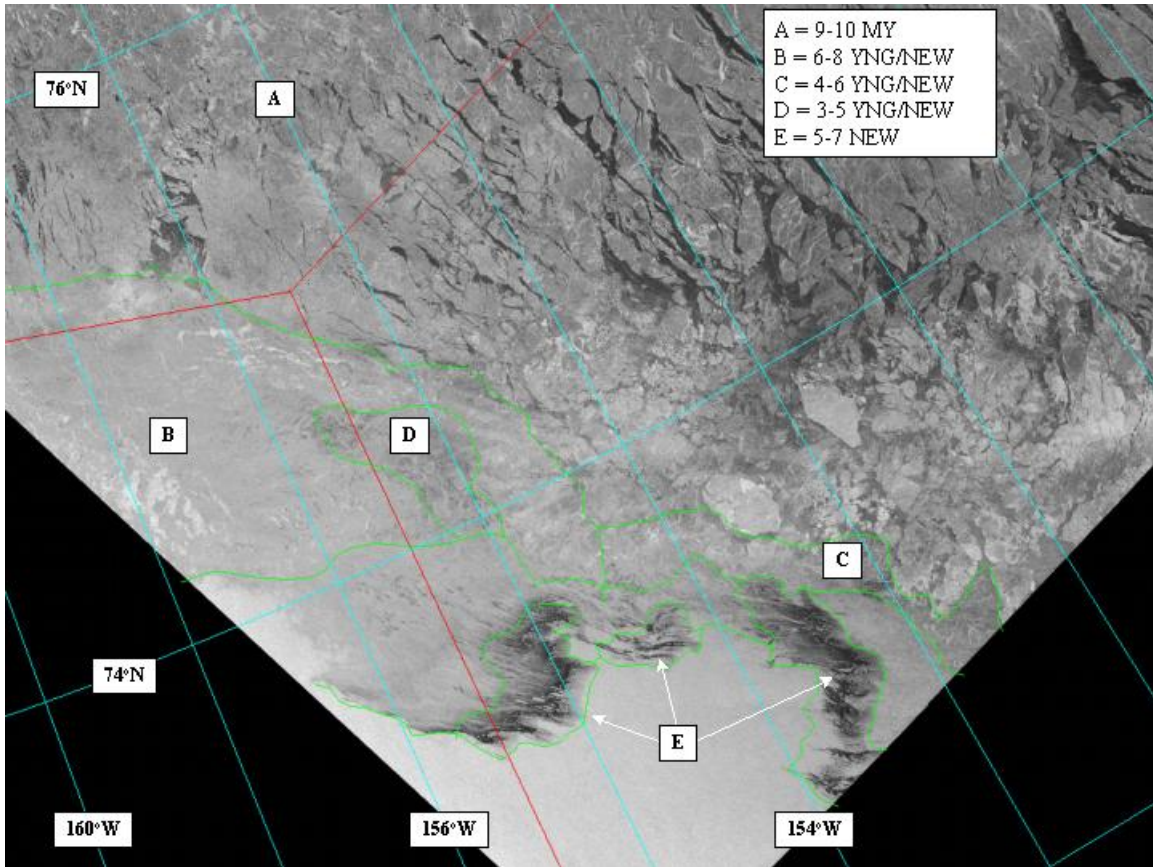


Figure 12. Radarsat ice coverage for 16 October 2004. *Healy* is at 78.2 N, 155W at this point, well north of extent of image, in 10/10 MY ice. © CSA2004. Image processed at either ASF, QinetiQ or CDPF.

### 17 October 2004 JD 291 –

0300L – called to lab as OziExplorer crashed – seemed to be tied to crash of shared (Z) drive that OziExplorer is writing track to. Reboot – ice thin – have been doubling line south but note that we are only making 4 knots – ask bridge to kick it up a knot and ask watch to keep an eye on it – this is just transit and we need to get to the survey area.

0400L – temperatures still very moderate (-2.5°C) and wind is now down (6 kts from south) – collecting relatively good data during transit – occasional ridges but mostly thin ice and some leads. Pancake ice on occasion.

0800L – continuing to waypoint 2 at 5 kts – data looking real good both bathy and SeaBeam – SeaBeam showing about 5 km swath in 1300 m of water – will try 6 kts and see what happens

1200L – ending ice zone at about 75°N – quite sad – no more ice – beginning to feel motion in ship. SeaBeam data continues to be excellent – thought we saw slight refraction and have shifted to deep CTD (CTD1) as it was in area of patch text near where we are (though we are still on the crest of the NW Ridge).

TSG – seawater flow-thru system beginning to work again – tried switching to automatic surface sound speed but it turns out the values must be above 1441 m/s or SeaBeam crashes. Values are now 1432 m/s so we need to wait awhile (may need more flushing of system or maybe it just is this fresh).

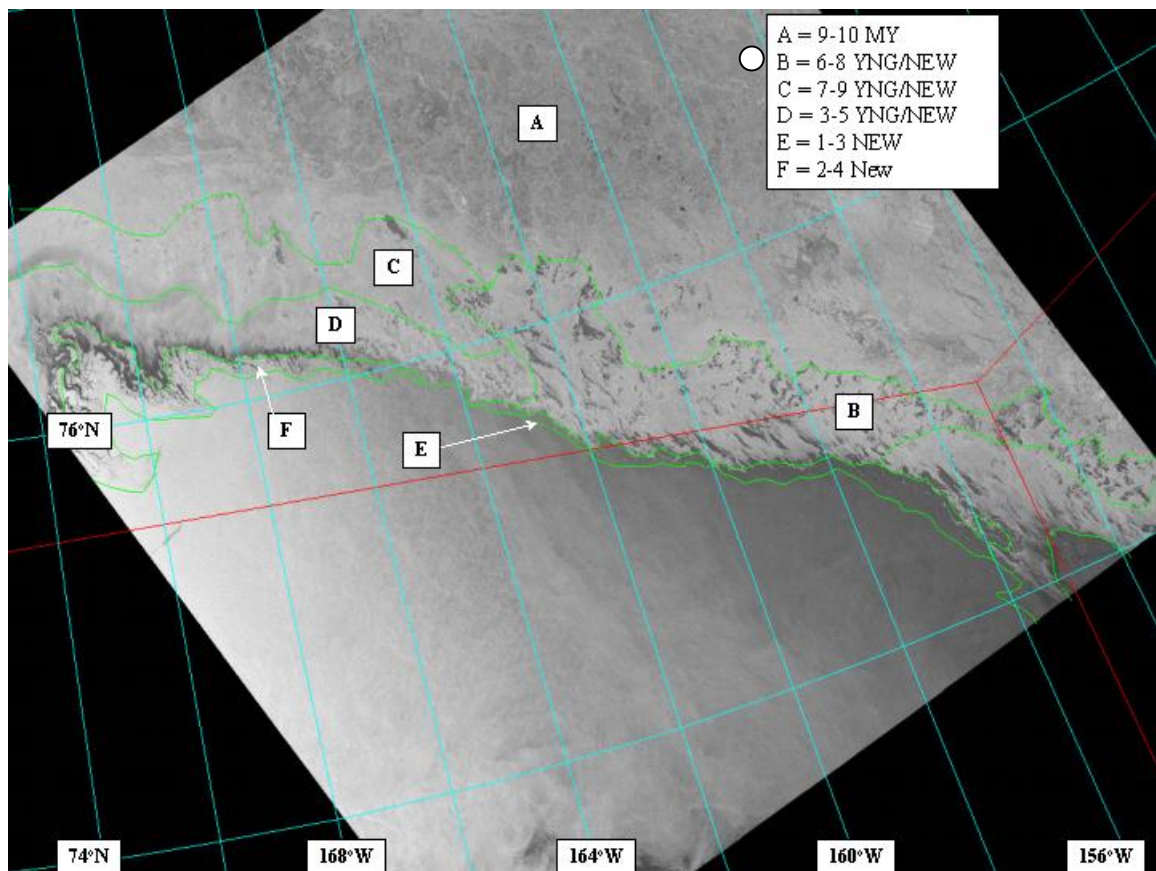


Figure 13. Radarsat ice coverage for 17 October 2004. White circle is position of *Healy*. © CSA2004. Image processed at either ASF, Qinetic or CDPF.

1530L – reached waypoint 2 – end of doubled line – we will now spin around a few times to try to get the POS heading error and attitude error down a bit. Attitude down after first turn – heading still up (0.9 deg) – trying another circle.

1940-2039L – topographic high along track that shows large bedform-like features – features curve around topographic high – intriguingly the swath widens as we cross the high (higher backscatter?). Crash test takes place in middle of this.

2200L – 2330L – another even more pronounced feature – topographic high with steered “bedforms” around it – broader swath despite shoaling – can be bedding planes outcropping but looks more sedimentary – slumps at end of canyon??

### **18 October 2004 JD 292**

0330L – approaching edge of the foot of the slope survey box. There have been series of these interesting features and if we have time we should survey them more completely. Plan is to do an XCTD at the start of the survey. As we approach the survey box we are crossing a promontory that comes up 1000 m to about 2500 m – would rather not take CTD on top of this but rather have deeper water structure (even though we only measure to 1500m with XCTD – also if we have to take CTD would rather be in deeper basin. Nominative start point for the foot of the slope survey is on top of this feature --- will move point further NW so that both sides of feature are included in survey.

0530L – approaching XCTD launch site – first launch failed. Second XCTD does not pass initialization test. Switch to XBT to see if system will clear up and then will try XCTD again. XBT – worked and 2nd CTD worked – will now proceed to starting point for the foot of the slope survey

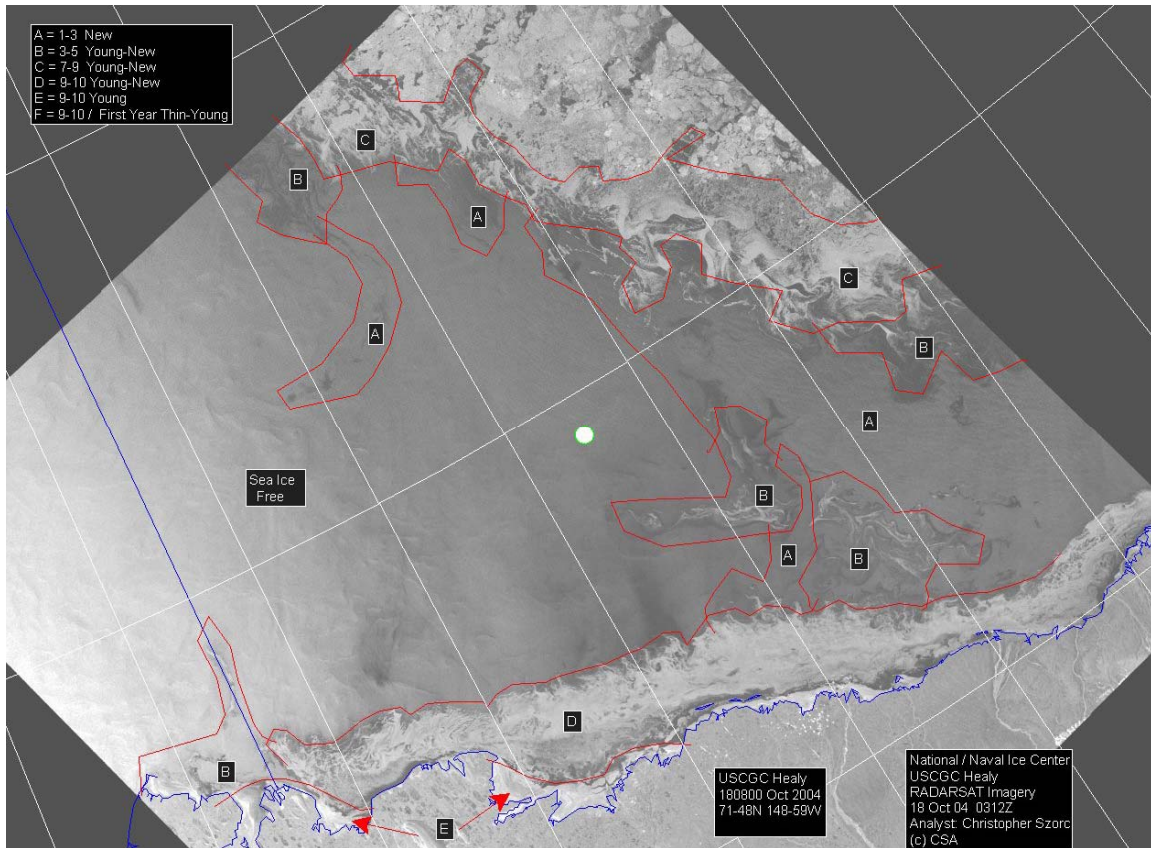


Figure 14. Radarsat ice coverage for 18 October 2004. White circle is position of *Healy*. © CSA2004. Image processed at either ASF, Qinetiq or CDPF.

0700L – starting foot of the slope survey – line 1 – SE-NW (course 123°) – 12 kts – going over a series of promontories – tops of which appear to be about 3000 m – backscatter shows scouring on tops –

1030L – slow to 3 kts for helo ops

NEW WORD!! BOUSTROPHEDONIC – turning like an oxen in plowing –

1438L – end of line 1 – starting a slow turn to port while doing some engine tests -

1600L – end of turn and tests – start of line 2 –

Line 2 progressing apace – crossing a series of promontories thinning seaward.

1030L – called by lab asking what was happening at end of line – Mashkoor noticed that there was a waypoint beyond (west) of the end of the box. Explained that we had modified the western edge of the box so that we covered both sides of 1000 m high that we found. This puts the starting point of each line about 7 nm further west – the surveys stay the same just run a little further west each time. This has been discussed with the



Master Chief on the 0400-0800 watch but seems not to have been transmitted to next watches.

Crash tests cause data dropouts.

### **19 October 2004 – JD293**

0530L – come to lab to find that Caleb and John had made an adjustment to increase swath overlap. Processed data shows that previous 6-7 hours did not have enough overlap leaving big gap between swaths. Must emphasize to our watch that the SeaBeam display is very deceiving – we must process data quickly and determine if we have enough overlap – err on the side of caution.

0700L – winds picked up to 40 knots from SE – vessel has slowed to 4-6 knots – bridge says this is for safety – will take this up with Captain.

0800L – OD says speed is being kept down because of seastate – will kick it up a knot or two and see what happens

0830L – doing 7-8 knots now – no degradation of data.

0900L – end of line 3 – starting turn

1000L - processing of lines has shown a lateral offset of on the order of 100m between lines – e.g. time delay or unaccounted offset – probably due to fact that POS positions have not been compensated for offset between POS and bridges nav system – will check with Dale – can also be Pitch offset or time delay.

There is also a vertical offset at the western end of line – only on this line and only in this area – this was a time of very high winds (40-50kts) and the ship heading into the sea – perhaps this is due to a shift in trim from wind and wave conditions. The MRU-6 rezeros itself after long-term trim change – we will check ships trim by looking at POS antenna record or the ADU-5 (Ashtec) multi-antenna system

1200L – with turn and heading with the sea the vertical offset seems to have gone away – this probably supports idea of trim change in the way vessel is riding into 40 -50 knt winds. As we progress down line 4 weather improves – also watch is much more cognizant of overlap and overlap issues have been resolved.

1400L – sat down with OPS to go over this issue of overlap – emphasized that the display on bridge is not an indication of coverage and that we must get the bridge watch to follow the cursor.

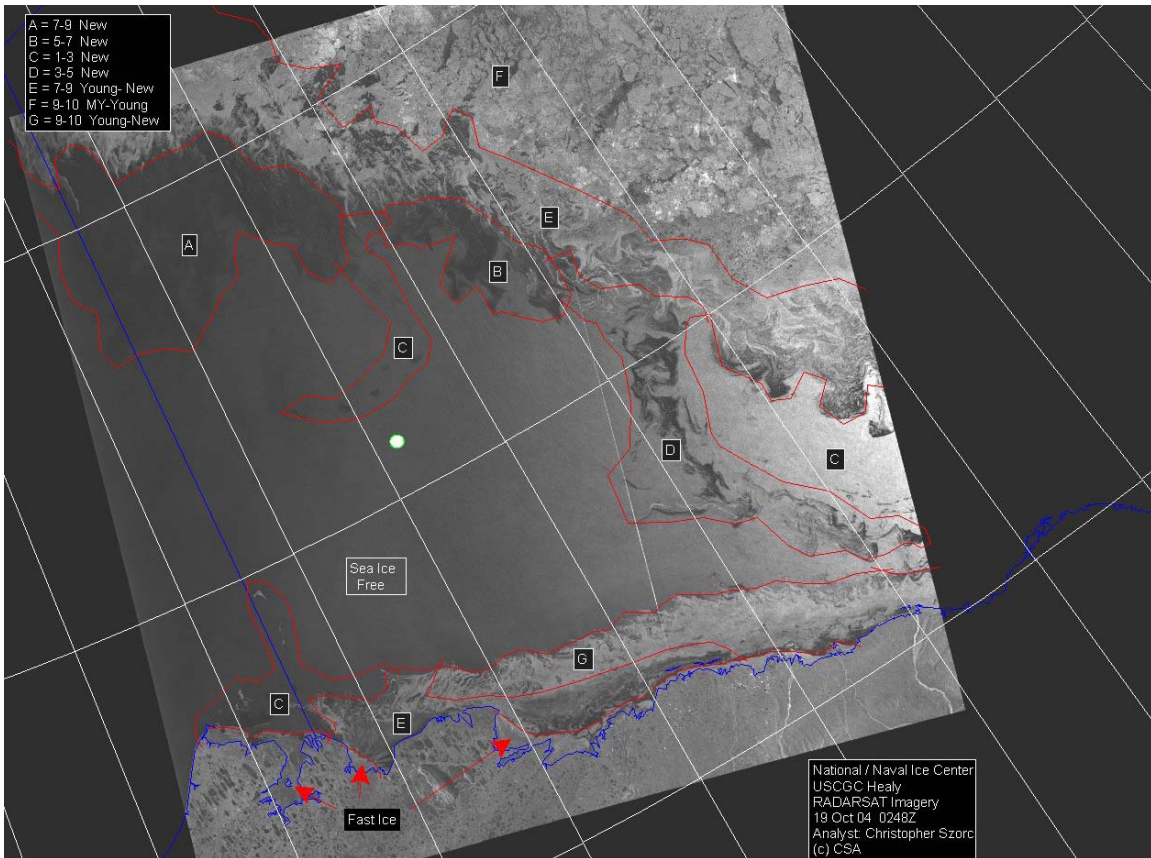


Figure 15. Radarsat ice coverage for 19 October 2004. White circle is position of *Healy*. © CSA2004. Image processed at either ASF, Qinetic or CDPF.

1500L – progressing along line 4 just fine. Dale has been communicating with Peter Lemmond at WHOI – WHOI’s POS interface with the SeaBeam appears to work – despite SeaBeam’s assurance to Dale that he and Peter have the same code, a comparison shows that Dale has ver.6 and Peter ver. 4 and that they are different sizes – Dale would like to try Peter’s version and see what happens.

1700L – at end of Line 4 – Dale switching to POS – engine trials being run – will make slow turn as we do tests. POS seems to work with WHOI code (at least for about 15 minutes) but too many unresolved issues with switch (e.g. no patch test, clear roll bias, etc. that we will return to MRU-6 and play with POS on steam to port).

1800L – begin line 5 – into sea

2000L – Red Sox beat Yankees again – three in a row amazing

## 20 October 2004 – JD 294

0400L to 0600L – track drifting off and losing overlap – John keeps calling the bridge to try to bring them over – finally Master Chief makes 90° turn to south in attempt to show us that he can turn the vessel -- totally destroying data – LM goes to bridge – to explain

that the display that they have is not an indication of the coverage we are getting and that only in the lab can we see the coverage – this seems to be news to them – information is just not getting transmitted from one watch to the next.

0807L to 1607UTC – have crossed beautiful little turbidite channel at base of slope – outflow of canyon - -

0940L – coming to the end of line 6 – bridge informs will do 2 crash stop tests – during turn – will turn back to get a bit deeper on western end of survey where we have promontories.

1020L – begin line 7 – this will be the last of the deep water lines – from here we will pick up the survey at the starting line (1) and work upslope.

1400L - met with Capt, EXO, OPS, Andy and Dale regarding 2006 survey – general consensus is that this is much too early in season to head up beyond 78°N – we asked whether we could work in say the latter half of the time – 15 days in late July and they said it was possible but the odds were not good. Conclusion is that we should seek to swap 2005 time for 2006 time in mid August to September.

1630L – end line 7 – will turn south now and head to line 1 where we will offset and begin the along-slope surveys again.

1950L – start of line 8

## **21 October 2004 – JD 295**

0254L – start of line 9

0800L – had good talk with Captain about using software from the lab that would drive autopilot in areas like this where there is no traffic – this would resolve many of the communications problems we are seeing – Captain is all in favor – like we did on Ewing.

1030L – start of line 10

Brian noticing a small refraction effect – we are consistently taking XBT and the last few have shown a change in the temperature structure but the problem is that the salinity is such here that the XBT may not be a good indicator of the sound speed profile – note for future cruises – stock up on XCTD's or XSVP's it is probably worth the cost.

We'll see how this goes for a while and may need to stop for a CTD.

It may also be a surface effect – TSG is working again and showing salinity of 28 to 29 ppm – temp is -1.2° – this results in a sound speed at the keep of about 1434 m/s – unfortunately the SeaBeam system cannot accept a sound speed less than 1441 m/s or it crashes.

1600L – as we cross the promontories – there is a fairly consistent picture of a good stratified sediment section on their eastern flank and no sediment (or little resolvable sediment) on the western flank. Also the eastern flanks are consistently less steep than the western flanks. Look at 102101.dat – time 0005Z 22 October 04

1815L – start of line 11

depths as shallow as 1880 m on this line – continue to see drift-like sediments on western flanks of promontories.

## **22 October 2004 – JD 296**

0200L – POS having problems – Dale called down to reset – during turns –

0400L – start of line 12

0418L – spin ship twice to reset POS – seems to have worked

0550L – looks like we have a series of tectonically emplaced ridges that are asymmetric (something like hogbacks) – and then a steady east to west flow that has created drift deposits on the eastern slopes and little sedimentation on the steeper western slopes – it is possible that these are symmetric features and the asymmetry is strictly the result of the flow (e.g. giant bedform like features).

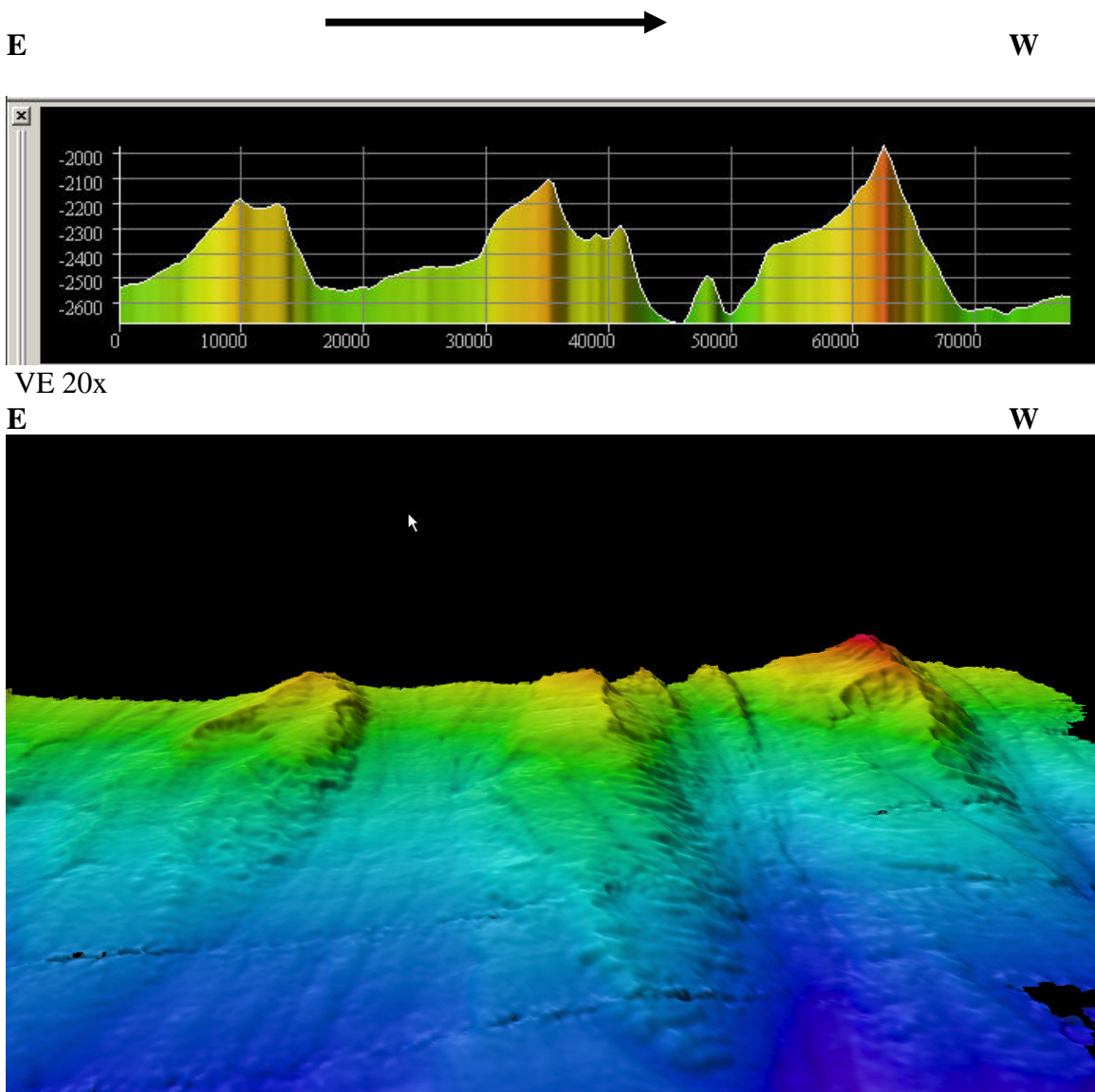


Figure. Top panel: profile across ridges on Barrow margin. Bottom panel: Perspective view of ridges on Barrow margin. Vertical exaggeration 6x, looking south.

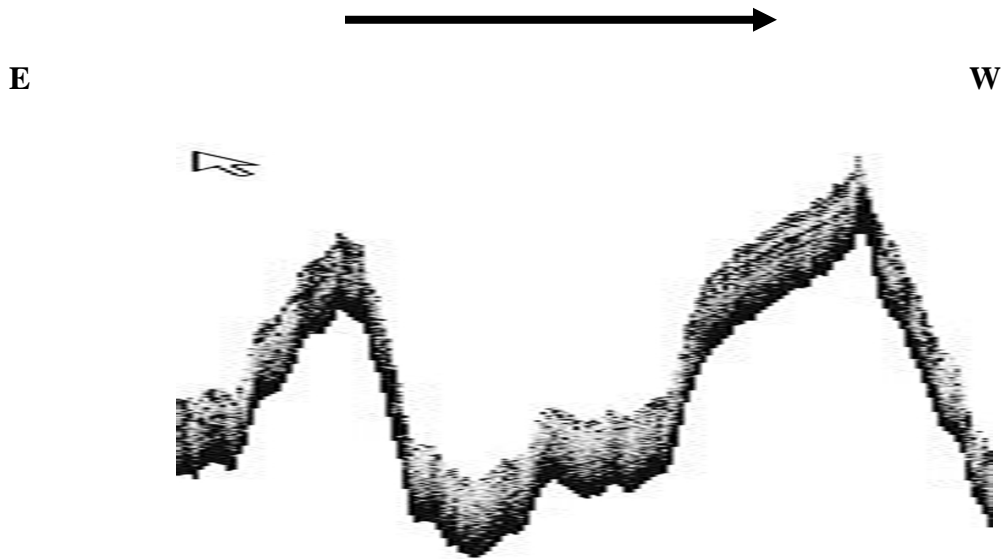


Figure. Bathy2000 3.5-kHz record showing crossing of ridges on Barrow margin.

1102L – end of line 12 --starting turn – informed there will be more “engine tests”

1215L – start of Line 13

2041L – start of Line 14

**23 October 2004 – JD 297**

0400L – Start of Line 15

Have given the Master Chief (Nav Officer) the waypoints for rerunning a line through the middle to pick up gaps and to run back up our line to double up on some of the features we saw – I have calculated we need to finish up this survey at 0400L on Sunday morning to leave about 28 hours of steaming for the extra line.

1200L – Start of Line 16

2000L - Start of Line 17



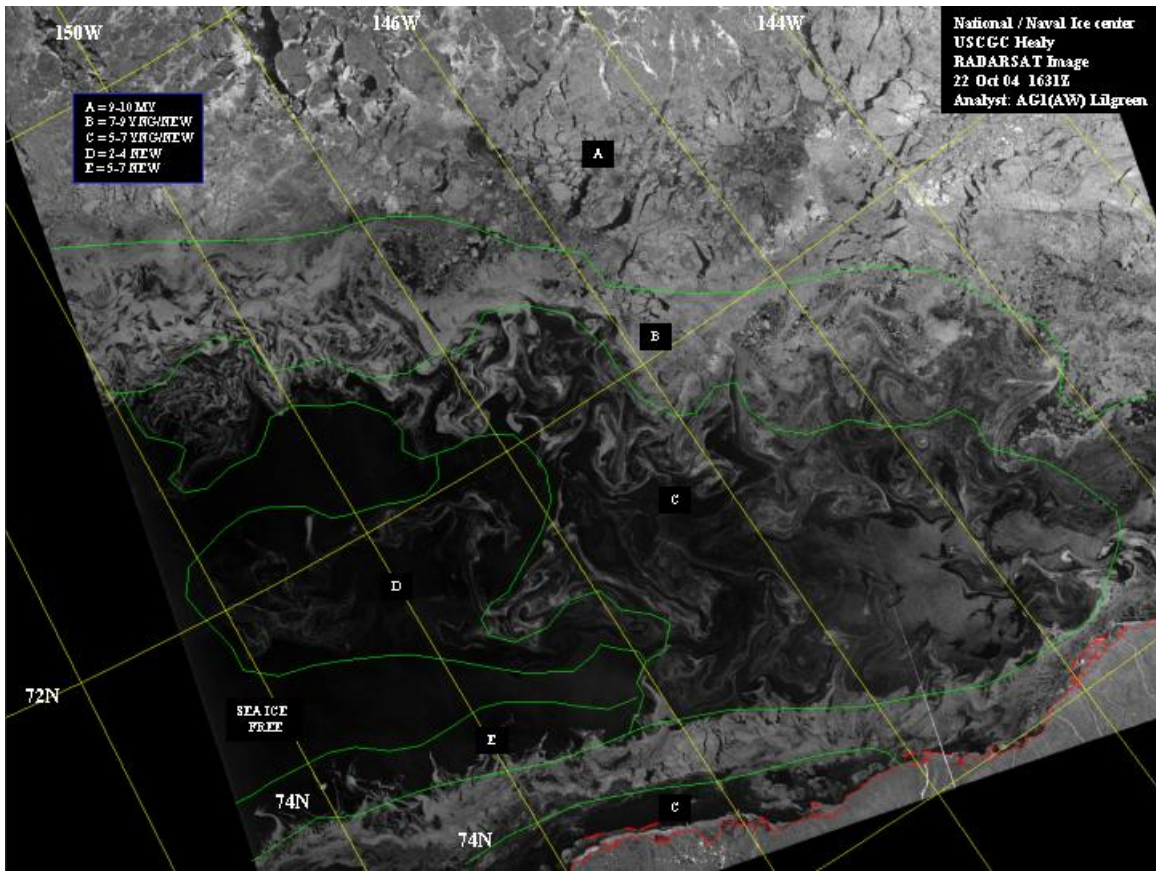


Figure 16. Radarsat ice coverage for 23 October 2004. White circle is position of *Healy*. © CSA2004. Image processed at either ASF, Qinetiq or CDPF.

## 24 October 2004 – JD298

0400L – end of Line 17 – this completes the foot of the slope survey – we will now head north and pick up the line that had all the gaps (between Lines 2 and 3) –

0700L – begin line 18 – splitting difference between Lines 2 and 3

1315L - finish Line 18 – have filled gaps and now heading to original transit line down to foot of the slope survey area – plan is to offset on this line and run up to 2 promontories that we saw coming down that had strange “bedform” looking features. Enroute we will pick about an hours worth to duplicate original line (in opposite direction) to serve as roll bias test.

1430L – getting onto original line

1930L – Approaching first feature – Bathymetry 2000 seismic record shows spectacular features at crest – either bedforms (probably) or slumps or faults – probably bedforms – Multibeam shows real bedform-like features. It is so spectacular that we will stay here

and get a few more lines working shoreward – rather than go on to 2<sup>nd</sup> (less well developed) feature. As we start surveying here – ice suddenly gets thick and swath width is severely reduced – ice comes and goes.

2200L – continue surveying – bedforms appear to get larger up slope and particularly on slopes – also appear cutoff on eastern side –

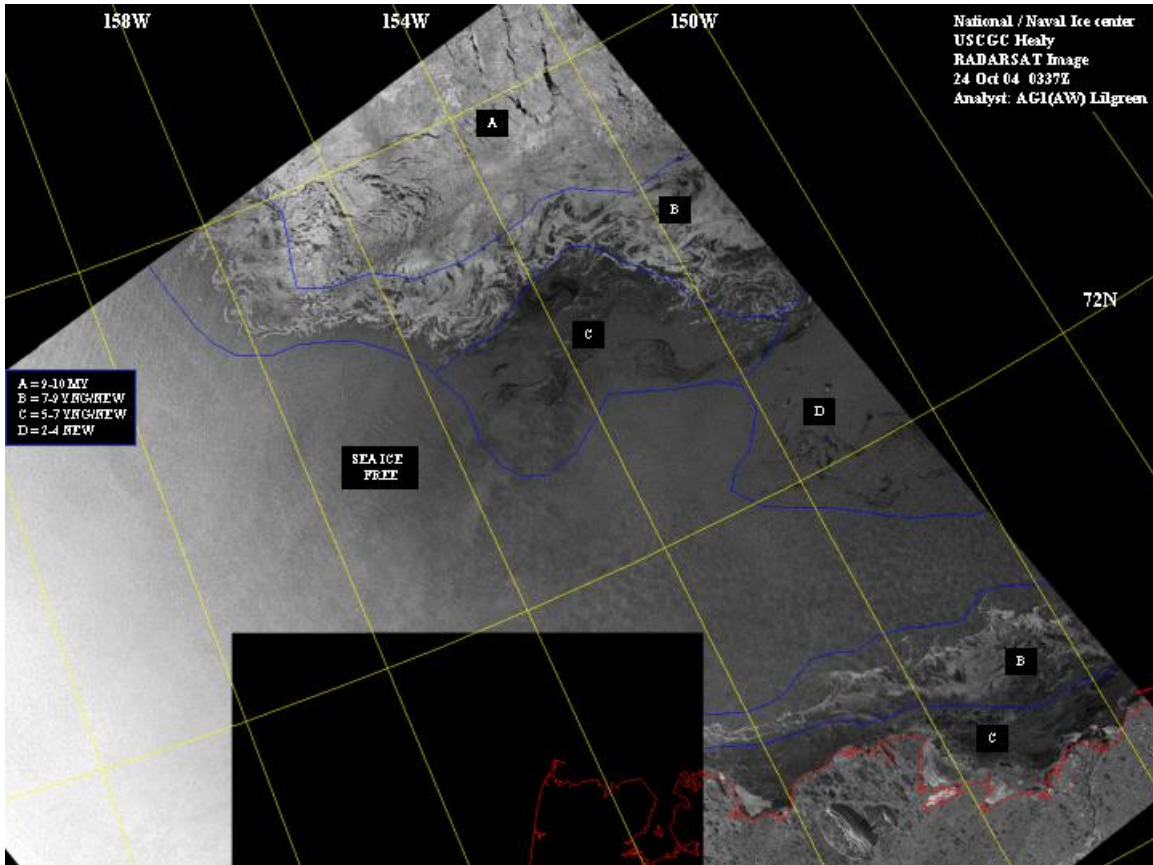


Figure 17. Radarsat ice coverage for 24 October 2004. White circle is position of *Healy*. © CSA2004. Image processed at either ASF, Qinetiq or CDPF.

### 25 October 2004 JD299

0200L – Bridge calls an end to survey – heading to Barrow – will continue to log multibeam for about 15 more minutes over feature and then Dale will switch over to POS for experimentation.



## Appendix I. Cruise Personnel:

### Science Party

Name	Position	Institution	Email
Larry Mayer	Chief Scientist	U of New Hampshire, CCOM/JHC	<a href="mailto:lmayer@unh.edu">lmayer@unh.edu</a>
Andy Armstrong	Co-Director	U of New Hampshire, CCOM/JHC	<a href="mailto:andy.armstrong@unh.edu">andy.armstrong@unh.edu</a>
Brian Calder	Research Professor	U of New Hampshire, CCOM/JHC	<a href="mailto:brc@ccom.unh.edu">brc@ccom.unh.edu</a>
James Case	Database Specialist	U of New Hampshire, CCOM/JHC	<a href="mailto:casej1@cox.net">casej1@cox.net</a>
Monica Cisternelli	Physical Scientist	NOAA	<a href="mailto:monical.cisternelli@noaa.gov">monical.cisternelli@noaa.gov</a>
Bernard Coakley	Senior Scientist	U of Alaska	<a href="mailto:bernard.coakley@gi.alaska.edu">bernard.coakley@gi.alaska.edu</a>
Anders Fertin	Hydrographer	Danish Hydrographic Authority	<a href="mailto:afe@frv.dk">afe@frv.dk</a>
Caleb Gostnell	Grad Student	U of New Hampshire, CCOM/JHC	<a href="mailto:caleb.gostnell@noaa.gov">caleb.gostnell@noaa.gov</a>
Mashkor Malik	Grad Student	U of New Hampshire, CCOM	<a href="mailto:mamalik@cisunix.unh.edu">mamalik@cisunix.unh.edu</a>
John K. Hall	Visiting Professor	UNH, Geological Survey of Isreal	<a href="mailto:john@ccom.unh.edu">john@ccom.unh.edu</a>
Kevin Kelley	Photographer		<a href="mailto:kwkelley02@aol.com">kwkelley02@aol.com</a>
Dennis L. Noble	Author		<a href="mailto:dln@olypen.com">dln@olypen.com</a>
John Taliaferro	Author		<a href="mailto:johntalia@aol.com">johntalia@aol.com</a>

### Ship's Science Technical Support

Name	Position	Institution	Email
Dale Chayes	Senior Engineer	LDEO	<a href="mailto:dale@ldeo.columbia.edu">dale@ldeo.columbia.edu</a>
Robert Arko	Systems Analyst	LDEO	<a href="mailto:racko@ldeo.columbia.edu">racko@ldeo.columbia.edu</a>
Grant Massey	Windows System Administrator	USCG	<a href="mailto:gmassey@pacnorwest.uscg.mil">gmassey@pacnorwest.uscg.mil</a>
Chad Burroughs, IT2	Windows System Administrator	USCG	<a href="mailto:cburroughs@pacnorwest.uscg.mil">cburroughs@pacnorwest.uscg.mil</a>

### Coast Guard Crew (science related)

<b>Name</b>	<b>Position</b>	<b>Institution</b>	<b>Email</b>
Dan Oliver, CAPT	Commanding Officer	USCG	<a href="mailto:doliver@healy.uscg.mil">doliver@healy.uscg.mil</a>
Bill Rall, CDR	Executive Officer	USCG	<a href="mailto:wrall@healy.uscg.mil">wrall@healy.uscg.mil</a>
Daryl Peloquin, LCDR	Operations Officer	USCG	<a href="mailto:dpeloquin@healy.uscg.mil">dpeloquin@healy.uscg.mil</a>
John Reeves, LCDR	Engineering Officer	USCG	<a href="mailto:jreeves@healy.uscg.mil">jreeves@healy.uscg.mil</a>
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Ian Fallon, MST3	Marine Science Tech	USCG	<a href="mailto:ifallon@healy.uscg.mil">ifallon@healy.uscg.mil</a>

## Appendix II – Inventory of Multibeam Sonar Archive Tapes

CGC HEALY LEG HLY-04-05 : MEDIA INVENTORY

8MM(160mXL) ARCHIVE TAPES FROM SB2112:

<u>Tape</u>	<u>Start</u>	<u>Stop</u>
01	2004-10-06 13:30	2004-10-09 01:47
02	2004-10-09 02:00	2004-10-09 03:35
03	2004-10-09 08:40	2004-10-09 12:34
04	2004-10-09 13:15	2004-10-09 14:53
05	2004-10-09 15:20	2004-10-18 23:00
06	2004-10-18 23:12	2004-10-20 00:15
07	2004-10-20 00:35	2004-10-20 01:16
08	2004-10-20 01:20	2004-10-21 02:45 (est.)
09	2004-10-21 02:45	(est.)
10		

## Appendix III: XBT Stations

### CGC HEALY LEG HLY-04-05 : EXPENDABLE PROBE DATA INVENTORY

File Name	File Size	File Format	Date	Time	Longitude	Latitude	Type	Sequence#	Serial#	Depth1	Salinity2	Notes
T7_0045A.EDF	13170	MK21-Export	2004-10-09	03:44:30 158		74						
T7_00045.EDF	27550	MK21-Export	2004-10-09	04:4902W		03.77393N	T-7	45A	50737	400	27.00	bad
			2004-10-09	03:44:30 158		74	T-7	45	50737	850	31.30	
			2004-10-09	04:4902W		03.77393N						
T7_00046.EDF	27578	MK21-Export	2004-10-09	10:56:47 157		74	T-7	46	50739	850	27.00	
			2004-10-09	25.99512W		14.05078N						
T7_00047.EDF	29180	MK21-Export	2004-10-09	21:09:13 157		74	T-7	47	50740	900	35.00	
			2004-10-09	57.35742W		57.67676N						
T7_00048.EDF	29222	MK21-Export	2004-10-10	04:27:37 157		75	T-7	48	50741	900	35.00	
			2004-10-10	16.01953W		47.50391N						
			2004-10-10				T-7	49	50742			bad
T7_00050.EDF	14521	MK21-Export	2004-10-10	10:16:05 156		76	T-7	50	50743	900	27.00	
			2004-10-10	21.47949W		16.12061N						
T7_00051.EDF	8726	MK21-Export	2004-10-10	16:01:38 154		76	T-7	51	50744	900	27.00	
			2004-10-10	57.11621W		41.03857N						
T7_00052.EDF	29182	MK21-Export	2004-10-10	16:10:23 154		76	T-7	52	50745	900	27.00	
			2004-10-10	56.03613W		41.36572N						
T7_00053.EDF	5969	MK21-Export	2004-10-11	04:00:58 153		77	T-7	53	50746	900	27.00	
			2004-10-11	44.67383W		12.60010N						
T7_00054.EDF	30204	MK21-Export	2004-10-11	04:04:34 153		77	T-7	54	1004554	900	27.00	
			2004-10-11	44.70605W		12.86133N						
T7_00055.EDF	29210	MK21-Export	2004-10-11	09:44:48 153		77	T-7	55	1004555	900	27.00	
			2004-10-11	17.71875W		27.06445N						
T5_00056.EDF	2769	MK21-Export	2004-10-11	16:10:35 152		77	T-5	56	286933	2000	27.00	bad
			2004-10-11	50.32227W		40.17773N						
T5_00057.EDF	14920	MK21-Export	2004-10-11	16:15:44 152		77	T-5	57	286934	2000	27.00	bad
			2004-10-11	50.17285W		40.20068N						
T7_00058.EDF	29170	MK21-Export	2004-10-11	16:22:00 152		77	T-7	58	1004556	900	27.00	
			2004-10-11	50.22559W		40.19189N						
T5_00059.EDF	9264	MK21-Export	2004-10-11	22:07:33 152		77	T-5	59	286878	2000	27.00	
			2004-10-11	48.68652W		46.63135N						
T5_00060.EDF	17079	MK21-Export	2004-10-11	22:12:50 152		77	T-5	60	286878	2000	27.00	bad
			2004-10-11	48.73242W		46.61572N						
T5_00061.EDF	68410	MK21-Export	2004-10-12	04:08:51 152		77	T-5	61	286879	2000	27.00	
			2004-10-12	39.41602W		55.96875N						
T5_00062.EDF	68348	MK21-Export	2004-10-12	10:09:08 152		78	T-5	62	286880	2000	27.00	
			2004-10-12	38.68945W		05.22607N						
T5_00063.EDF	47556	MK21-Export	2004-10-12	16:02:49 153		78	T-5	63	286881	2000	27.00	
			2004-10-12	05.26172W		09.27344N						
T5_00064.EDF	48256	MK21-Export	2004-10-12	22:05:50 153		78	T-5	64	286882	2000	27.00	
			2004-10-12	15.39941W		13.29932N						
T5_00065.EDF	26946	MK21-Export	2004-10-13	04:03:03 153		78	T-5	65	286883	2000	27.00	
			2004-10-13	10.66992W		20.29297N						
T5_00066.EDF	68284	MK21-Export	2004-10-13	04:08:35 153		78	T-5	66	286884	2000	27.00	
			2004-10-13	10.66797W		20.29248N						
T5_00067.EDF	8894	MK21-Export	2004-10-13	10:00:30 153		78	T-5	67	286885	2000	27.00	
			2004-10-13	06.52441W		23.31006N						
T5_00068.EDF	24063	MK21-Export	2004-10-13	10:04:01 153		78	T-5	68	286886	2000	27.00	bad
			2004-10-13	06.48926W		23.31543N						
T5_00069.EDF	68400	MK21-Export	2004-10-13	15:58:54 153		78	T-5	69	286995	2000	27.00	
			2004-10-13	07.04688W		26.61572N						
T5_00070.EDF	68327	MK21-Export	2004-10-13	22:05:56 153		78	T-5	70	286996	2000	27.00	
			2004-10-13	20.28223W		30.16895N						
T5_00071.EDF	67298	MK21-Export	2004-10-14	04:04:23 153		78	T-5	71	286997	2000	27.00	
			2004-10-14	39.14746W		32.54199N						
T5_00072.EDF	67540	MK21-Export	2004-10-14	10:01:42 153		78	T-5	72	286998	2000	27.00	
			2004-10-14	48.23633W		37.15430N						
T5_00073.EDF	45156	MK21-Export	2004-10-14	16:06:24 153		78	T-5	73	287001	2000	27.00	
			2004-10-14	58.20898W		42.23486N						
T5_00074.EDF	68312	MK21-Export	2004-10-14	22:33:41 154		78	T-5	74	286999	2000	27.00	
			2004-10-14	13.79492W		41.53271N						
T5_00075.EDF	6032	MK21-Export	2004-10-15	03:26:04 154		78	T-5	75	287000	2000	27.00	
			2004-10-15	26.10938W		39.98438N						
T5_00076.EDF	9937	MK21-Export	2004-10-15	03:30:54 154		78	T-5	76	287002	2000	27.00	
			2004-10-15	26.10840W		40.03809N						
T5_00077.EDF	22045	MK21-Export	2004-10-15	10:04:06 154		78	T-5	77	287003	2000	27.00	
			2004-10-15	34.93945W		44.26172N						
T5_00078.EDF	68338	MK21-Export	2004-10-15	16:13:04 154		78	T-5	78	287004	2000	27.00	
			2004-10-15	32.69629W		39.72998N						
			2004-10-16				T-5	79	287005			bad
T5_00080.EDF	66640	MK21-Export	2004-10-16	06:16:10 154		78	T-5	80	286899	2000	27.00	
			2004-10-16	56.54199W		06.95117N						
			2004-10-16				T-5	81	286899			bad
T5_00082.EDF	68009	MK21-Export	2004-10-16	16:01:26 155		77	T-5	82	286900	2000	27.00	
			2004-10-16	05.37793W		18.42090N						
T5_00083.EDF	13299	MK21-Export	2004-10-16	22:17:52 155		76	T-5	83	286901	2000	27.00	bad
			2004-10-16	44.24512W		43.76904N						

T5_00084.EDF	62816 MK21-Export	2004-10-16	22:21:59 155 44.18945W	76 43.81836N	T-5	84	286902	2000	27.00	
T5_00086.EDF	43597 MK21-Export	2004-10-17	08:02:54 156 58.96973W	76 02.73438N	T-5	86	286903	2000	27.00	
T5_00087.EDF	36057 MK21-Export	2004-10-17	13:59:19 157 17.71094W	75 36.06641N	T-5	87	286904	1100	27.00	bad
T5_00089.EDF	34841 MK21-Export	2004-10-17	14:07:15 157 17.73926W	75 35.83447N	T-5	89	286905	1100	27.00	
T5_00090.EDF	35082 MK21-Export	2004-10-17	20:02:38 157 44.73730W	75 01.71826N	T-5	90	286906	1100	27.00	
T5_00091.EDF	34860 MK21-Export	2004-10-18	02:22:17 157 04.68848W	74 05.38477N	T-5	91	286907	1100	27.00	
T5_00092.EDF	35022 MK21-Export	2004-10-18	08:00:44 154 38.65527W	73 13.41943N	T-5	92	286908	1100	27.00	
T5_00093.EDF	68029 MK21-Export	2004-10-18	14:08:21 152 15.50781W	72 28.32178N	T-5	93	286909	2000	27.00	
C3_00094.EDF	339819 MK21-Export	2004-10-18	14:17:17 152 16.36230W	72 28.64893N	XCTD-1	94	4026798	1100	n/a	
T5_00095.EDF	68409 MK21-Export	2004-10-19	02:11:03 150 00.65527W	72 07.23242N	T-5	95	286910	2000	27.00	
T5_00096.EDF	66603 MK21-Export	2004-10-19	08:04:29 151 51.67676W	72 30.27930N	T-5	96	286935	2000	27.00	
T5_00097.EDF	66629 MK21-Export	2004-10-19	08:13:24 151 51.54883W	72 29.62354N	T-5	97	286936	2000	27.00	
T5_00099.EDF	24532 MK21-Export	2004-10-19	14:05:15 149 30.01172W	72 07.91602N	T-5	99	286938	2000	27.00	
T7_00100.EDF	29160 MK21-Export	2004-10-19	20:05:58 149 52.27734W	72 18.41113N	T-7	100	64264	900	27.00	
T7_00101.EDF	29199 MK21-Export	2004-10-20	02:03:00 151 52.25586W	72 37.43652N	T-7	101	64265	900	27.00	
T5_00102.EDF	68409 MK21-Export	2004-10-20	08:04:26 149 07.15820W	72 14.96240N	T-5	102	286939	2000	27.00	
T7_00103.EDF	29159 MK21-Export	2004-10-20	14:03:03 150 03.54688W	72 29.23047N	T-7	103	1004557	900	27.00	
T7_00104.EDF	29187 MK21-Export	2004-10-20	20:03:47 150 51.41602W	72 40.04785N	T-7	104	1004558	900	27.00	
T7_00105.EDF	28851 MK21-Export	2004-10-21	04:20:57 149 01.35840W	71 47.48096N	T-7	105	1004559	900	27.00	
T7_00106.EDF	29137 MK21-Export	2004-10-21	10:38:39 152 39.97852W	72 21.34326N	T-7	106	1004560	900	27.00	
T7_00107.EDF	28966 MK21-Export	2004-10-21	16:05:15 150 18.99023W	71 54.96436N	T-7	107	1004561	900	27.00	
T7_00108.EDF	29095 MK21-Export	2004-10-21	22:01:47 151 00.45508W	71 57.08789N	T-7	108	1004562	900	27.00	
T7_00109.EDF	1319 MK21-Export	2004-10-22	04:04:44 152 21.05664W	72 08.85205N	T-7	109	1004564	900	27.00	bad
T7_00110.EDF	29144 MK21-Export	2004-10-22	04:07:20 152 19.32715W	72 08.83057N	T-7	110	1004565	900	27.00	
T5_00111.EDF	20227 MK21-Export	2004-10-22	10:20:52 149 11.61328W	71 30.60840N	T-5	111	286940	2000	27.00	bad
		2004-10-22			T-5	112	286941			bad
T5_00113.EDF	68152 MK21-Export	2004-10-22	10:39:02 149 15.82520W	71 31.36621N	T-5	113	286941	2000	27.00	
T7_00114.EDF	29094 MK21-Export	2004-10-22	16:07:34 151 38.30957W	71 57.24121N	T-7	114	64170	900	27.00	
		2004-10-22			T-7	115	64171			bad
T7_00116.EDF	29087 MK21-Export	2004-10-22	22:04:05 152 16.07812W	72 01.04199N	T-7	116	64171	900	27.00	
T5_00117.EDF	8094 MK21-Export	2004-10-23	04:10:27 149 02.95605W	71 22.53271N	T-5	117	286942	2000	27.00	bad
T5_00118.EDF	66278 MK21-Export	2004-10-23	04:14:55 149 03.45117W	71 22.19922N	T-5	118	286943	2000	27.00	
T5_00119.EDF	68164 MK21-Export	2004-10-23	10:00:29 152 18.37109W	71 57.15137N	T-5	119	286944	2000	27.00	
T7_00120.EDF	29110 MK21-Export	2004-10-23	15:59:41 151 37.20020W	71 43.44092N	T-7	120	64172	900	27.00	
T7_00121.EDF	29101 MK21-Export	2004-10-23	22:14:56 150 24.38477W	71 29.06250N	T-7	121	64175	900	27.00	
T7_00122.EDF	29068 MK21-Export	2004-10-24	04:02:58 153 36.80859W	72 01.40527N	T-7	122	286945	900	27.00	
T7_00123.EDF	29057 MK21-Export	2004-10-24	04:09:54 153 34.71680W	72 01.30762N	T-7	123	286946	900	27.00	
T7_00124.EDF	29054 MK21-Export	2004-10-24	10:01:05 150 18.56543W	71 25.02295N	T-7	124	64173	900	27.00	
T7_00125.EDF	29139 MK21-Export	2004-10-24	16:00:12 149 07.37891W	72 01.37109N	T-7	125	64174	900	27.00	
T7_00126.EDF	29133 MK21-Export	2004-10-24	22:10:09 152 58.25586W	72 33.70752N	T-7	126	64177	900	27.00	
T7_00127.EDF	29221 MK21-Export	2004-10-25	04:03:01 155 23.10352W	73 21.53809N	T-7	127	64178	900	27.00	

1 Terminal Depth (m) set by operator 2 Assumed Salinity (ppt) set by operator

**Appendix IV. Missing and duplicate gravimeter data records.**

Ashtech\_GGA Hly-04-02 06/14/04 17:22:28 to 17:22:34 Note the missing data and duplicates per second.

06/14/2004,17:22:28.747,\$GPGGA,172227.50,7207.4426,N,15441.0938,W,1,08,01.8,+0  
0019,M,,M,,\*6B  
06/14/2004,17:22:29.278,\$GPGGA,172228.00,7207.4426,N,15441.0939,W,1,08,01.8,+0  
0019,M,,M,,\*60  
06/14/2004,17:22:29.794,\$GPGGA,172228.50,7207.4426,N,15441.0941,W,1,08,01.8,+0  
0019,M,,M,,\*6A  
06/14/2004,17:22:30.341,\$GPGGA,172229.00,7207.4426,N,15441.0942,W,1,08,01.8,+0  
0019,M,,M,,\*6D  
06/14/2004,17:22:32.450,\$GPGGA,172231.00,7207.4426,N,15441.0948,W,1,08,01.8,+0  
0019,M,,M,,\*6E  
06/14/2004,17:22:32.981,\$GPGGA,172231.50,7207.4427,N,15441.0949,W,1,08,01.8,+0  
0019,M,,M,,\*6B  
06/14/2004,17:22:33.497,\$GPGGA,172232.00,7207.4427,N,15441.0950,W,1,08,01.8,+0  
0019,M,,M,,\*65  
06/14/2004,17:22:34.028,\$GPGGA,172232.50,7207.4427,N,15441.0952,W,1,08,01.8,+0  
0019,M,,M,,\*62

Ashtech\_GGA Hly-04-02 06/14/04 18:12:00 to 18:12:14 Note the duplicates per second.

06/14/2004,18:12:00.458,\$GPGGA,181159.00,7207.5064,N,15441.8118,W,1,08,01.7,+0  
0034,M,,M,,\*69  
06/14/2004,18:12:00.943,\$GPGGA,181159.50,7207.5064,N,15441.8119,W,1,08,01.7,+0  
0034,M,,M,,\*6D  
06/14/2004,18:12:01.427,\$GPGGA,181200.00,7207.5064,N,15441.8120,W,1,08,01.7,+0  
0034,M,,M,,\*6D  
06/14/2004,18:12:01.912,\$GPGGA,181200.50,7207.5064,N,15441.8122,W,1,08,01.7,+0  
0034,M,,M,,\*6A  
06/14/2004,18:12:02.396,\$GPGGA,181201.00,7207.5064,N,15441.8123,W,1,08,01.7,+0  
0034,M,,M,,\*6F  
06/14/2004,18:12:02.880,\$GPGGA,181201.50,7207.5064,N,15441.8124,W,1,08,01.7,+0  
0034,M,,M,,\*6D  
06/14/2004,18:12:03.365,\$GPGGA,181202.00,7207.5064,N,15441.8126,W,1,08,01.7,+0  
0034,M,,M,,\*69  
06/14/2004,18:12:03.849,\$GPGGA,181202.50,7207.5064,N,15441.8127,W,1,08,01.7,+0  
0034,M,,M,,\*6D  
06/14/2004,18:12:04.349,\$GPGGA,181203.00,7207.5064,N,15441.8128,W,1,08,01.7,+0  
0034,M,,M,,\*66  
06/14/2004,18:12:04.833,\$GPGGA,181203.50,7207.5064,N,15441.8129,W,1,08,01.7,+0  
0034,M,,M,,\*62  
06/14/2004,18:12:05.349,\$GPGGA,181204.00,7207.5064,N,15441.8131,W,1,08,01.7,+0  
0034,M,,M,,\*69

06/14/2004,18:12:05.865,\$GPGGA,181204.50,7207.5063,N,15441.8132,W,1,08,01.7,+0  
0034,M,,M,,\*68  
06/14/2004,18:12:06.380,\$GPGGA,181205.00,7207.5063,N,15441.8133,W,1,08,01.7,+0  
0034,M,,M,,\*6D  
06/14/2004,18:12:06.880,\$GPGGA,181205.50,7207.5063,N,15441.8134,W,1,08,01.7,+0  
0034,M,,M,,\*6F  
06/14/2004,18:12:07.412,\$GPGGA,181206.00,7207.5063,N,15441.8136,W,1,08,01.7,+0  
0034,M,,M,,\*6B  
06/14/2004,18:12:07.927,\$GPGGA,181206.50,7207.5063,N,15441.8137,W,1,08,01.7,+0  
0034,M,,M,,\*6F  
06/14/2004,18:12:08.443,\$GPGGA,181207.00,7207.5063,N,15441.8139,W,1,08,01.7,+0  
0034,M,,M,,\*65  
06/14/2004,18:12:08.974,\$GPGGA,181207.50,7207.5063,N,15441.8140,W,1,08,01.7,+0  
0034,M,,M,,\*6E  
06/14/2004,18:12:09.521,\$GPGGA,181208.00,7207.5063,N,15441.8141,W,1,08,01.7,+0  
0034,M,,M,,\*65  
06/14/2004,18:12:10.037,\$GPGGA,181208.50,7207.5063,N,15441.8142,W,1,08,01.7,+0  
0034,M,,M,,\*63  
06/14/2004,18:12:10.630,\$GPGGA,181209.00,7207.5063,N,15441.8144,W,1,08,01.7,+0  
0033,M,,M,,\*66  
06/14/2004,18:12:11.146,\$GPGGA,181209.50,7207.5063,N,15441.8145,W,1,08,01.7,+0  
0033,M,,M,,\*62  
06/14/2004,18:12:11.740,\$GPGGA,181210.00,7207.5063,N,15441.8146,W,1,08,01.7,+0  
0033,M,,M,,\*6C  
06/14/2004,18:12:12.271,\$GPGGA,181210.50,7207.5063,N,15441.8148,W,1,08,01.7,+0  
0033,M,,M,,\*67  
06/14/2004,18:12:12.802,\$GPGGA,181211.50,7207.5063,N,15441.8150,W,1,08,01.7,+0  
0033,M,,M,,\*6F  
06/14/2004,18:12:13.318,\$GPGGA,181212.00,7207.5063,N,15441.8151,W,1,08,01.7,+0  
0033,M,,M,,\*68  
06/14/2004,18:12:13.849,\$GPGGA,181212.50,7207.5063,N,15441.8153,W,1,08,01.7,+0  
0033,M,,M,,\*6F  
06/14/2004,18:12:14.349,\$GPGGA,181213.00,7207.5063,N,15441.8154,W,1,08,01.7,+0  
0033,M,,M,,\*6C  
06/14/2004,18:12:14.849,\$GPGGA,181213.50,7207.5063,N,15441.8155,W,1,08,01.7,+0  
0033,M,,M,,\*68

Gravimeter Hly-04-02 06/14/04 17:22:29 to 17:22:34. Note missing data fields

06/14/2004,17:22:29.669,04:025372 00  
06/14/2004,17:22:30.669,04:025372 00  
06/14/2004,17:22:32.669,04:025373 00  
06/14/2004,17:22:33.669,04:025371 00  
06/14/2004,17:22:34.669,04:025372 00

Gravimeter Hly-04-02 06/14/04 18:12:00 to 18:12:14 Note missing data as well as  
duplicates per second.



06/14/2004,18:12:00.693,04:025372 00  
06/14/2004,18:12:01.693,04:025372 00  
06/14/2004,18:12:02.693,04:025372 00  
06/14/2004,18:12:03.693,04:025372 00  
06/14/2004,18:12:04.693,04:025371 00  
06/14/2004,18:12:05.693,04:025372 00  
06/14/2004,18:12:12.677,04:025373 00  
06/14/2004,18:12:12.677,04:025372 00  
06/14/2004,18:12:12.693,04:025373 00  
06/14/2004,18:12:13.693,04:025372 00  
06/14/2004,18:12:14.677,04:025372 00