CCGS Amundsen: A New Mapping Platform for Canada's North.

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Introduction

In 2003, through a joint CFI, NSERC funded program, the decommissioned 1200 class icebreaker Sir John Franklin (now CCGS Amundsen) was brought back into service as a multidisciplinary science platform for research in the Canadian Arctic. As part of this, the ship was equipped with a variety of acoustic and supporting survey instruments to make her capable of state-of-the art seabed mapping.

She went into service in August and is currently frozen in for the 2003-2004 winter in Franklin Bay, NWT as part of a year-long observation program. Her current work is as part of the CASES program which finishes in 2004, but she is the mainstay for ArcticNet that will be running for up to the next 14 years.

CASES or the Canadian Arctic Shelf Exchange Study is a multi-disciplinary project, which encompasses a large variety of scientific research in order to better understand the Mackenzie Shelf, and more generally the Western Arctic, ecosystem. This research focuses on the effects of global warming on the biological and physical processes that make up this ecosystem. ArcticNet is a newly funded National Centre of Excellence that will continue Science in the Arctic, focusing on in this case of pan-Arctic issues associated with the predicted retreat of the polar ice cap as part of modeled greenhouse gas response.

A sub purpose of both these studies is to examine the geology of the polar shelves and then relate it to the overall purpose of the project. Along with physical sampling of sediment, acoustic imagery was collected to support this effort. This imagery was used to determine optimal sampling locations, create a detail picture of the seabed morphology and seafloor reflectivity characteristics, and provide general safety of operations information. The different types of acoustic data/imagery collected were the bathymetry and backscatter from the Simrad EM300, and sub-bottom profiles from the Knudsen 320R. Discussing the sonar systems and their data will be the main focus of this paper.

The paper describes in detail the different instruments and platform used in the collection of this data. There will be discussions on the efficiency and quality of this system as a surveying tool, operational and processing hurdles that had to be overcome, and the future use of this platform.

CCGS Amundsen

The primary collection platform for the sonar equipment is the newly outfitted CCGS Amundsen (formerly Sir John Franklin). The ship is 98 metre 1200 class ice-breaker completely rigged for various scientific activities and capable of extended stay in the Arctic. The vessel is equipped with two different sonar's for both geological and bathymetric mapping, the Kongsberg-Simrad EM300 multibeam and a Knudsen 320R sub-bottom profiler.

Knudsen 320R

A prime requirement of the CASES and ArcticNet programs was to be able to delineate the thickness and acoustic character of surficial sediments to depths of at least 50m where possible. Although towed, high bandwidth boomers and chirp systems were initially considered, the reality of Arctic operations meant that there would be limited opportunity to safely deploy such a towbody. Thus a hull-mounted system was chosen to ensure data collection, even if at slightly lower resolution at full ship speed (up to 16 knots) during routine transit operations even whilst breaking ice.

Subbottom profilers in the 3.5 kHz range have been used routinely by research vessels for the past 40 years. Such systems rely on either a continuous wave or correlated pulse (chirp) and traditionally the topside electronics has been all analog. Excellent quality records have been derived by using large format electrostatic plotters. The trends in the last 10 years however, have been towards increasing use of digitization and digital signal processing. As part of this the majority of the US research fleet have upgraded their topside electronics for 3.5 kHz to use the Knudsen 320R chirp electronics. This was chosen for the Amundsen and the system in entirely digital without any real time hard copy paper records.

The K320R sub-bottom profiler is a chirp sonar system that sweeps through a band of frequencies between 2-7 kHz with a nominal frequency of 3.5 kHz. This particular system employs a total of 16 transducers (Massa TR-1072’s) to make a single 10 kW source with a beam width of 30deg. This system is capable of full ocean depths and can obtain sediment penetration up to 70m in soft sediments.

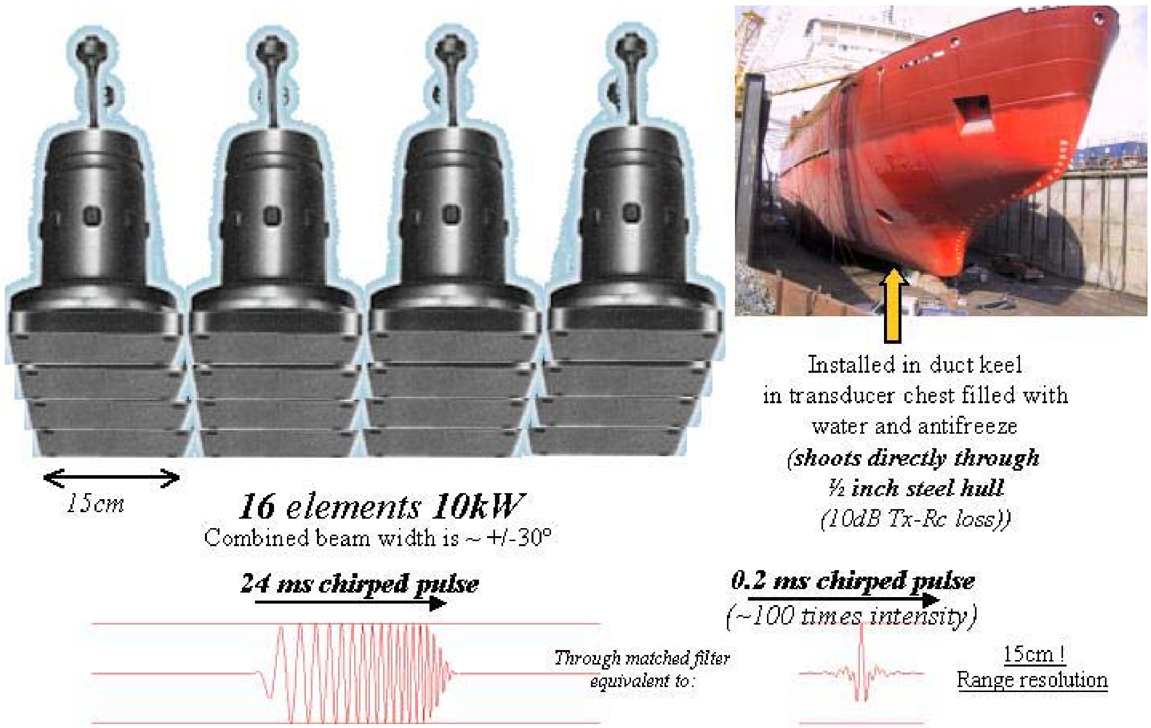

Fig 1: K320R array configuration and location onboard CCGS Amundsen.

Ideally an ice-reinforced acoustic window could have been used. However, to save costs and for simplicity, this sonar actually shoots through ½ inch of steel inside the hull of the vessel, creating a 10dB tx-rc loss. The 16 elements are mounted in a 4x4 configuration immersed in a transducer well filled with glycol and water and with a 10m stand pipe to minimize cavitations.

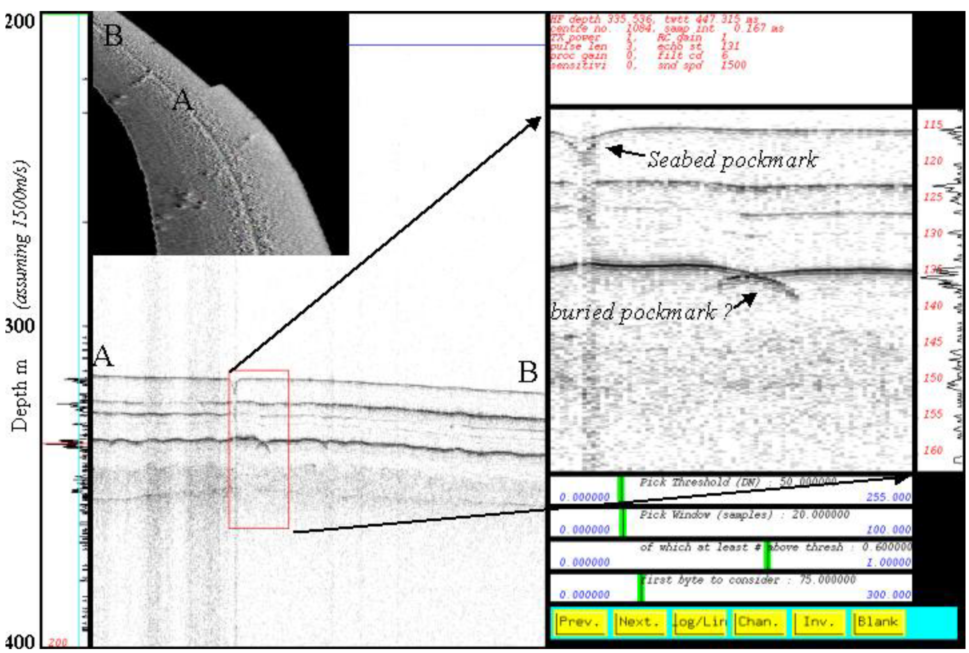

Fig 2: Illustration of data support from the K320R

The example above shows an oblique run of EM300 data extracted from a swath corridor that indicated the presence of surface pockmarks. The 3.5 kHz data support that interpretation, indicating the maximum likely depth of the origin of the gas (to shallowest unperturbed reflector). Since the data is completely digital, the image can be interrogated interactively (UNB in-house tool shown in slide).

EM300

Based on the experience of the Canadian Hydrographic Service and the Geological Survey of Canada, it was considered essential that the ship be equipped with some form of swath sonar system. The choice of system was a compromise. The required range of depth operations to meet the needs of CASES and ArcticNet could have been met with a 100 kHz system. However, such sonar's would have had to be mounted on a retractable ram (all systems on the market today are either curvilinear arrays or tilted pairs). This would have added extra expense and prevented the system being used should ice breaking be likely. Furthermore, all though not an immediate requirement of the polar shelf project, the vessel would be transiting through greater water depths and possibly used in the open Beaufort Sea. Thus a capability that at least allowed some bottom tracking to ~ 2500m was considered an advantage. A flush mounted system was required, that was planar and did not require any protrusions. Systems in the range of 30-50 kHz were considered the optimal compromise and a Simrad EM300 was ultimately chosen.

The EM300 is a shallow to mid ocean depth system (nominally 10m - 5000m), though further into this discussion we will show how this may not be achievable given this type of installation. This system has a nominal frequency of 30 kHz and the transmit fan is split into several frequency coded sectors ranging from 27 -34 kHz. There are 3 or 9 sectors depending on the operating mode, which is depth dependant. These sectors are transmitted sequentially at each ping. The system accuracy is stated to be in the order of 17cm or 0.2% of water depth RMS whichever is greater considering that the system is fully corrected in real-time for sound speed effects and vessel motion. (Konsberg Simrad AS)

The advantage of having a multi-sectored system like this is that allows for active motion compensation on all three axes, i.e. pitch, roll, and yaw. The benefit is that each sector can be independently steered based on vessel motion to maintain uniform sampling perpendicular to the direction of the survey line, or more generally, the traveling direction of the vessel. The Amundsen, being an icebreaker hull is not the most stable open water vessel and this capability provides a significantly improved coverage. The following diagram illustrates the multi-sector/yaw compensation situation.

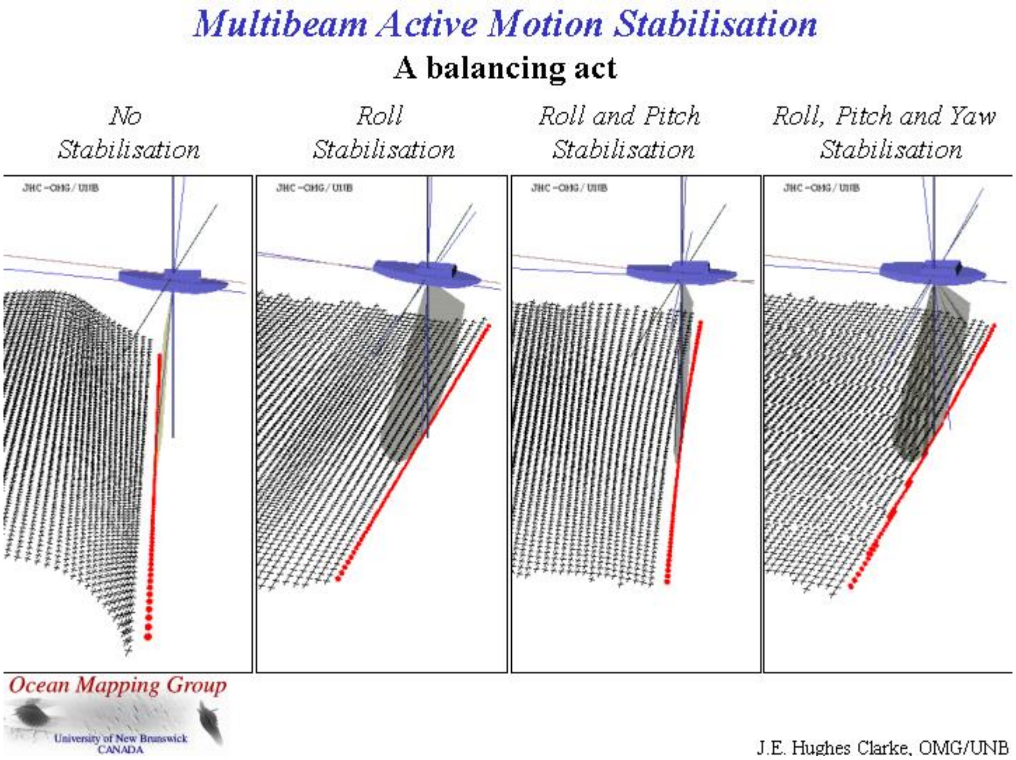

Fig 3: The result of stabilization on all three motion axes.

Installation Complications

One of the major concerns for a swath system on the Amundsen was survivability. Ice reinforced windows would be required and the installation would have to be essentially flush. Traditional all-titanium windows have significant attenuation problems that would drastically reduce the range performance of the 30 kHz system. To get around this, new titanium –polymer windows were acquired which are designed to have only a ~ 10dB net loss over combine Tx. And Rc.

These windows again come as a compromise. Both the Tx. And Rc arrays have to be set back away from the hull surface and thus both are physically masked from achieved the designed angular sectors. That combined with known refractive effects of the windows themselves resulted in an expected loss of achievable angular sector.

Fig 4: Ice-window constraints on the Transmit array.

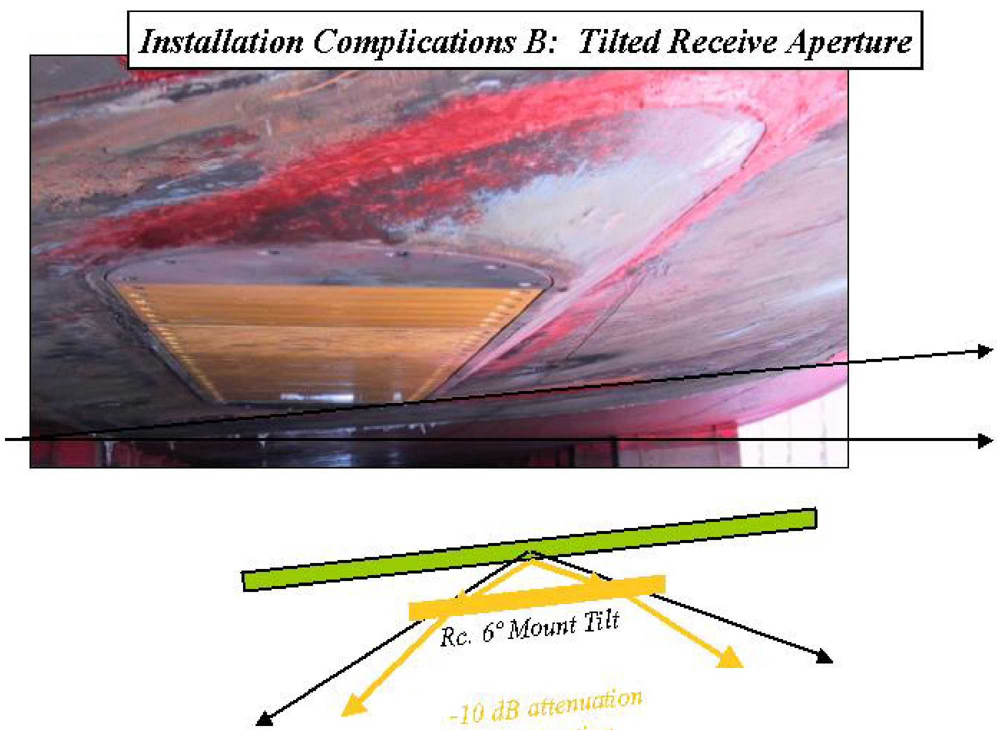

Fig 5: Ice window & Installation constraints on the Receive array

In addition to the limited angular sectors, the available keel space on the Amundsen is not flat and the arrays could not protrude, the receive array is forced to be tilted ~ 6° to port. As a result the achievable sector is actually offset this same amount. It was found that 65° to port and 60° to starboard were the practical operational limits.

Furthermore, increasingly linear T arrays are being mounted on gondolas to place them away from the hull and relatively immune to bubble washdown. As an example the figure below shows the installation of an identical EM300 on the R/V Ocean Alert which proved to provide usable data up to seastate 6. In contrast, the EM300 on the Amundsen must be flush and the low inclination of the icebreaker profile of the hull almost guarantees bubble washdown . Furthermore, the arrays were unavoidably installed to the rear of a large moonpool door that, even when full closed, potentially is a site of turbulence generation.

Fig 6: Comparison of Installation between two different vessels

Nevertheless, in low seastates (less than 2) excellent data was acquired at speeds up to 16 knots indicating that flow and propulsion noise was not a barrier. But, as discussed below, at higher seastates where pitching was pronounced, the mount proved less successful. Fortunately the main area of predicted ship operations is the protected waters of the Canadian Arctic Archipelago.

Horizontal and Vertical Positioning

The vessel is also equipped with all the peripheral devices to make the entire system fully compliant with ocean mapping standards. The positioning is a globally differentially corrected position C-Nav (C&C Technologies) in which we were able to obtain stable corrections at all times including up to 74° north (Resolute). The C-Nav system also performed well inside a Fjord on Baffin Island despite 1000m+ near vertical rock faces that demonstrates the capability of the vessel exploring these features that are common on the Arctic East coast, and still maintaining an accurate position. We intend to also test out the Can-DGPS service, but it was not available in real time at the time of the first vessel transit.

The C-Nav system provides additional promise as a source of vertical control. With the lack of available tidal information in the archipelago and the imperfect modeling of the tidal phase and amplitude variability, a means of tidal constraint is sorely lacking, especially for a vessel that is usually transiting that would not have the time or equipment to set up multiple tide stations. C-Nav is one competing product that is currently claiming decimetre level ellipsoid height accuracies on a global basis. To assess the feasibility of C-Nav as a source of tidal control, an experiment is currently underway (16th Feb-28th March) whilst the Amundsen in frozen into landfast ice. For this 40-day period the elevation of the vessel is being precisely monitored using echo sounding whilst simultaneously running the C-Nav. The tidal ranges in the area are remarkably small (< 50cm) yet, with filtering, convincing M2 and K1 signatures are already being recognized (Wert et al., 2004).

If this proves feasible, together with an ellipsoid-geoid separation model for the archipelago, a stable vertical reference might be usable for all Amundsen operations.

Orientation

Based on the successful experience of the CHS, the ship has an Applanix POS/MV 320 system onboard to fully capture the vessel motion history and have that properly applied to the sounding data from the EM300.
For the initial transit, a Seatex MRU-6 was provided by UNB as a backup should there be initialization problems, but fortunately this was not necessary. The vessel also has twin gyrocompasses for heading and these are interfaced to the Simrad as a backup.

Processing Software

The multibeam and sub-bottom data was processed to completion onboard utilizing OMG's SwathEd software, which includes a full suit of data cleaning and visualization tools.

Water Column Control

The vessel is equipped with a BOT (Brooke Ocean Technology) MVP-300 (Moving Vessel Profiler) that is capable of being towed behind the vessel and with a dipping motion constantly collects water column information along the travel path of the vessel. The original idea was that this instrument was to be used ubiquitously and we would import new profiles constantly into the system as they were collected or at least at some pre-defined time period. This would eliminate in real-time or in post-processing the effects of refraction and to a smaller degree, scaling problems.

The reality of the first transit operations was that the crew was concerned for the safety of the system (despite several deployments). A secondary issue became a critical factor however. As the system is fitted with a glass conductivity cell (part of a Seabird 911 CTD) for precise oceanographic observations, it cannot be allowed to fill with fresh water (common at the sea surface on recovery) else it will freeze and destroy the sensor. This problem is handled with the static winch CTD's by immediately bringing the rosette into a heated garage on recovery. As a result until a thermal storage mount is obtained, this will limit the use of the underway CTD operations. Another approach would be to use a sound speed and temperature probe (ideal for hydrographic but less than optimal for oceanographic work).

Operational Survey Procedures

The EM300 equipped Amundsen has the capability of being Canada's premier ocean mapping platform up to its capable operating depth. The full capability of the system has not yet been investigated due to logistical constraints such as time, sea state, and speed. However, small surveys and tracklines were conducted in the Beaufort Sea and Amundsen Gulf, which gave a preliminary look at its capabilities and effectiveness.

At this time, no leg is dedicated to seafloor mapping. Because of the wide range of scientific programs ongoing, every leg is over staffed and multi-mission. As there is such poor knowledge of seafloor morphology in the archipelago, at this time, almost anywhere the vessel steams, it provides insight into hitherto unknown seabed character. Because of the limitations of berthing, one key personnel run the EM300, the K320R and all peripheral systems 24 hours a day. For the first operational leg in 2004, this model proved feasible with all systems (except the MVP for reasons stated above) operating in automatic mode (bottom tracking, depth gating, source level and pulse length selections). For the first 20 days, experiments were conducted with 3 staff on board, but for the last 20 days a sole operator was responsible. With fore-planning the operator could arrange to be awake when station keeping was conducted to start and stop the system. Windows of opportunity prior to station experiments were used to conduct local multiple pass surveys over the area to optimize the location of the experiments. During transit, the instruments were usually unattended. With the exception of significant ice-breaking, data was acquired in this manner very efficiently. A single operator processed the data successfully in the field. Because of the likelihood of accessing watercolumn data after several hours after completion of oceanographic stations, non-standard processing procedures were implemented to allow for full reprocessing of the data after the fact (see below).

Should the vessel be used for sustained systematic survey, however, rather than transit operations, at least 2 and preferably three people would be required.

Archipelago Operations

To examine its capabilities and efficiency, we are going to look at two areas that show its potential for effective ocean mapping. The two areas are the Mackenzie Trough (~70.5 N, 138.8 W, 500-1300m), and the Amundsen Gulf (~70.6 N, 123.0 W, 400-700m). Using these two areas we will examine in general, the efficiency and quality of the data in terms of data resolution, swath width, and survey speeds.

Looking first at the Mackenzie Trough area, the data was collected while steaming off and around the shelf break from ~500 m to ~1300m. In 1300 hundred metres of water we were achieving a swath width of 3.5 to 4.0 km at a speed of approximately 10 knots. The quality of the data was exceptional as we found what appears to be an underwater landslide at approximately 1100 m water depth. Looking at the image below one can notice that the resolution is high enough to show the debris flow from the slide. The image was gridded at 25m that also show that even at these depths, the data density is sufficient enough to provide an accurate depiction of the sea floor.

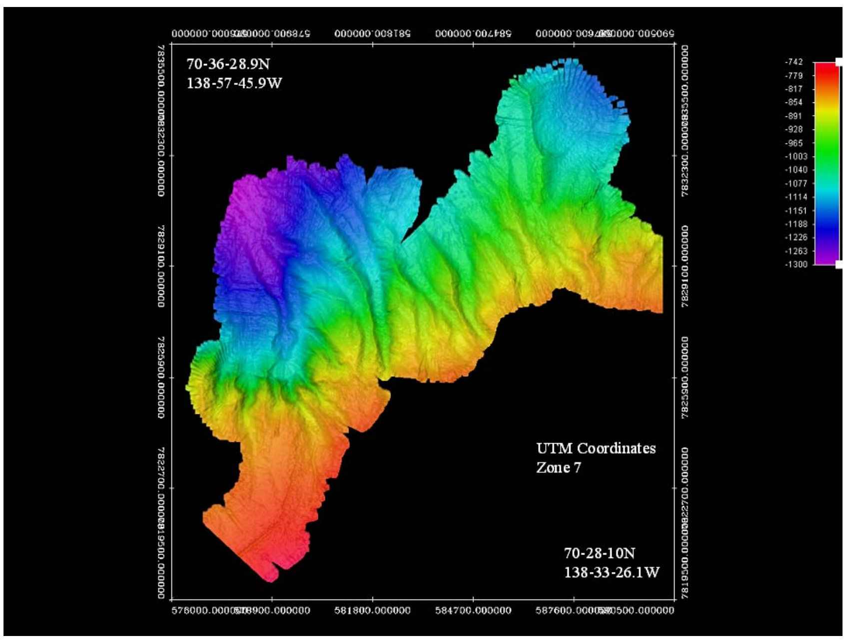

Fig 7: Shelf break in Mackenzie Trough. Notice what appears to be an underwater landslide in the upper right corner.

The survey conducted in Amundsen Gulf is a very good example of the efficiency and quality of this system from a practical standpoint. The survey consisted of 8 lines approximately 10km long and was conducted at a speed of 10 knots. The survey was conducted to achieve 200% bottom coverage to acquire the appropriate redundancy for certain processing requirements. The total area surveyed was ~90 sq km's and total survey time was ~ 6hrs. The ~line spacing was 900m to achieve the 200% coverage, so one could see if the coverage was reduced, a greater area could be examined in the same amount of time. The system can also provide adequate backscatter measurements to aid in the determination of some the characteristics of the seafloor sediment. The following diagram shows the bathymetry of CA-18

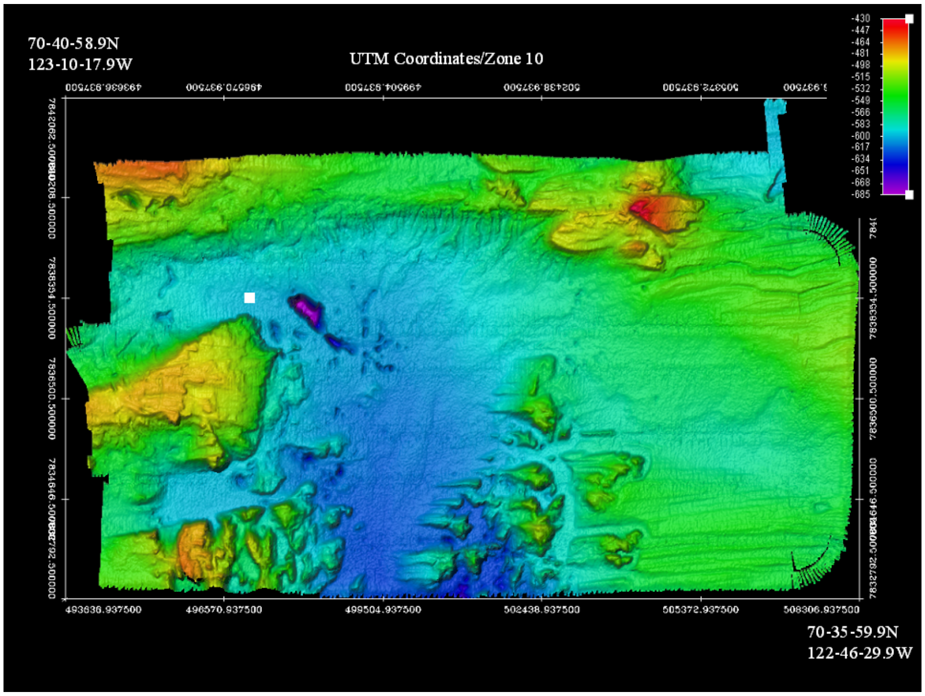

Fig 8: The survey at CA-18 (Amundsen Gulf). The white dot represents the location of a sediment sample.

Specific to the Amundsen, we also incorporate the Knudsen 320R in the data product. The sub-bottom information collected can give somewhat of a 3D cube perspective of all areas surveyed. In conjunction with the backscatter from the EM300, it provides further information into the seafloor type and aid in sediment classification. The following diagram illustrates how we have incorporated all data into one product.

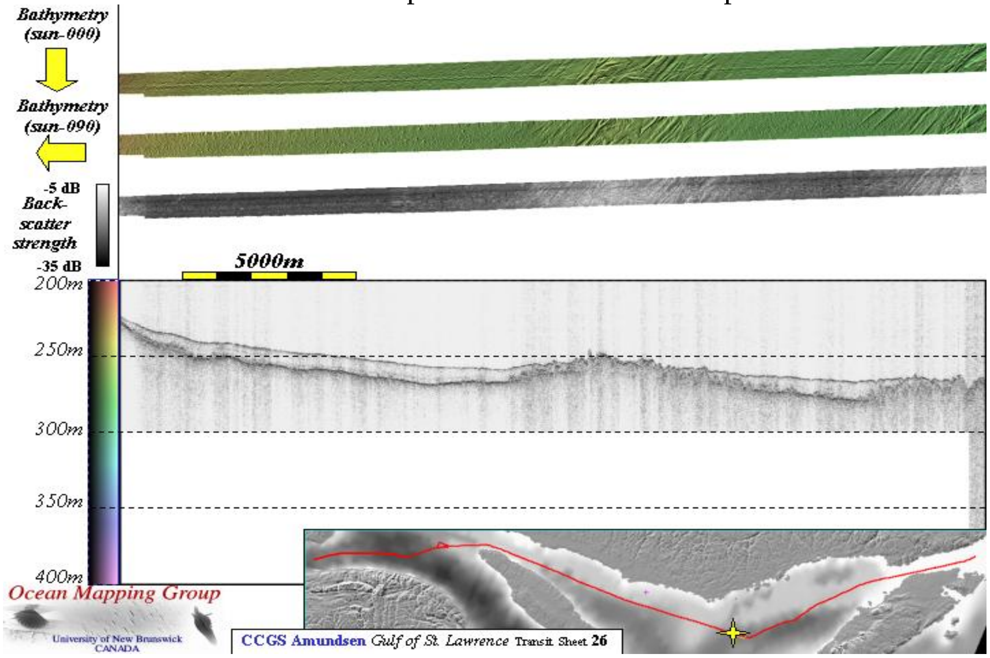

Fig 9: Example of how data from both sonar's are combined to give a 3D perspective. Though this image is from the Gulf of St. Lawrence, all data from the Arctic transit is compiled the same way.

Although the system was operated satisfactorily in depths as shallow as 10m under the keel it is clear that the system is really most efficient in 50m+. In the Archipelago, the usual maximum depths of 500m provided optimum performance of the sonar (within the restricted angular sector imposed by the ice windows).

The complete data set acquired from Pond Inlet to the Mackensie Trough is available online at :

http://chamcook.omg.unb.ca/~local/nwp2003

The data is presented deliberately in a transit model where 25km long sections of data are provided in which two orthogonal sun-illuminations, the multibeam backscatter and the corresponding co-registered subbottom profile are shown superimposed (figure 9). The presentation model differs significantly from that usually used for systematic area-based surveys (for example examine the Shippagan Bay dataset at: http://www.omg.unb.ca/Projects/Shippagan , which contains exactly the same data types but acquired as multiple parallel offset lines). The aim of this transit model is to allow the scientific user the freedom to browse in space or time along the available transects to examine seabed geomorphology and subbottom structure.

As site-specific systematic surveys are collected, they will be presented in the more traditional manner. In addition to the Amundsen data, the multibeam and subbottom data collected in Canadian waters by the USCGS Healy and Japanese RV Marai will be presented in the same manner. It is the intent of the ArcticNet 1.6 project (managed by UNB's Ocean Mapping Group), that all data collected will be made freely available on the web to all interested scientific parties, both nationally and internationally.

Open Water operations.

A brief test of the system was done at transit speed (14 knots) through the Labrador Sea. These proved less successful anytime the vessel would pitch more than ~ 2 degrees. This was the case until vessel speed was brought below 8 knots. It is clear that the compromise implicit in the flush mounting and the icebreaker hull profile provide a high potential for bubble wash down. Further testing of this capability will be performed in Oct-Nov 2004 as she transits home. But at this time, the system should not be committed to open water operations (none are planned for the 2004 field season anyway, and the archipelago is almost always sheltered from fetch).

Processing Considerations

Certain logistical constraints produced collection anomalies that had to be handled in post-processing beside the regular data cleaning and presentation. The biggest one was the inability to collect frequent water column information to derive the sound speed profiles so the system could properly account for acoustic ray-bending effects.

The underlying problem was that due to extensive ice cover this instrument could not be safely deployed and operated. In its absence the only full water column information we were able to obtain was when the vessel stopped at the location of an oceanographic mooring deployment and a CTD rosette was performed. The vessel is also equipped with a sound speed probe that is mounted to the hull to provide real-time transducer surface sound speed to ensure proper beam steering was performed.

UNB developed code/procedures for coping with the lack of water column information. The procedure is a multi-step process that starts by ensuring that the surface sound speed is accurate by analyzing the raw data from the probe located on the hull. In areas where the surface sound speed probe supplies grossly erroneous data, the beams have to be re-pointed based on an estimate of the correct surface sound speed. After the re-pointing of the beams, the orientation is re-applied to the transmit and receive beams that finally allows for a re-raytrace of each individual beam through the new water column. The water column is derived through interpolation between each collected profile. Ideally, one would like to have continuous sampling or at least a higher frequency of static samples to compute an accurate solution. These ideas and procedures will be presented as a paper in the upcoming Canadian Hydrographic Conference 2004 in Ottawa.

The sub-bottom processing involved creating usable imagery to be used in conjunction with the EM300 data. In areas with multiple survey lines (systematic survey of parallel lines), this means the creation of stack or fence diagrams of all the profiles existing in the survey. The Knudsen parameters were set to be constant because in real-time we are only interested in looking at the sediment penetration to view sub-bottom stratification or anomalies (buried rock outcrops etc). These parameters now need to be compensated for in order to remove certain problems in the raw data, most noticeably water column noise.

In order to remove the water column, software was developed by the Ocean Mapping Group to merge parameters from the EM300 into the Knudsen. These parameters include the bottom track, difference in sound speed, attitude (mainly heave), draft, and computer time delay. By supplying these parameters to the Knudsen data one can now see the true bottom as determined by the EM300. This was important since due to such a low frequency signal, the digitized bottom track was often a sub-bottom layer, which provided a stronger echo return than the true bottom. With the true seafloor now present, the software now will allow you remove anything above this defined bottom creating a cleaner image for interpretation.

The Future

Starting in the fall of 2004, the vessel will be funded for use in the ArcticNet project, which is the integrated natural/health/social study of the changing coastal Canadian Arctic. Part of the project is studying the natural and physical effects of global warming which in turn is causing a reduction in coastal sea-ice. This sea-ice reduction will cause increase intercontinental shipping by dramatically decreasing the sailing distance between the east and west coast of North America. With this increase in shipping, there will be increase challenges related to Canadian sovereignty and security in the high Arctic. (www.arcticnet.ulaval.ca)

The sonar equipment is going to be used in project 1.6 of theme 1 of ArcticNet. The project is called the Opening of the NW Passage and involves mapping the bottom topography and geological structure of the passage and other Arctic regions as a step toward managing increased ship traffic and resource exploration. The data will also provide information toward assessing the economic/sovereignty, and security implications of an ice free NW Passage. (www.arcticnet.ulaval.ca).

Though ArcticNet is the immediate and most prioritized future, there is time every year to possibly utilize the vessel and its sonar for other applications. Of the ~ 180 day it is available for science, currently only 75-80 days is allocated to ArcticNet. The vessel will be available already deployed in the Arctic for the summer for other operations either nationally or internationally. Possible other uses could include the Canadian Hydrographic Service conducting dedicated hydrography in high priority areas of the Arctic or mainland. Similarly Natural Resource Canada may be interested in its use for resource management, Environment Canada for environmental monitoring, Foreign Affairs for sovereignty and Law of the Sea issue or the Dept of National Defence may have a need for Route Survey or other strategic operations.

One of the major projects under ArcticNet is project 1.2 Coast Vulnerability in a Warming Arctic, which has a requirement for inshore mapping outside the practical range of the Amundsen. For this project it is conceivable that survey launches could be put onboard and in areas of high priority have the launches do the shallow inshore mapping, while at the same time utilize the EM300 to map the deeper offshore areas. This would provide abundance of data relevant to transportation and science in those high priority areas.

CONCLUSION

The CCGS Amundsen is Canada’s newest mapping platform for the country’s Arctic region. It employs two different acoustic surveying systems to fully support bathymetric and geological mapping. These systems come fully equipped with all peripheral devices so that it can fully compensated for vessel motion and position.

Data from both systems did not come without some installation and logistical constraints that had to be recognized and handled in post-processing if applicable. One such problem was lack of water column information. This can be handled with procedures and code developed by the Ocean Mapping Group.

The sonars also proved that it could map the seafloor (<1300 m) efficiently and with high quality in low sea states and ice-free waters. They potentially can be used for mapping in deeper waters, but the open water performance of these systems has not been fully explored and their maximum capabilities are not yet known.

Data products have been created and are available online where scientist and researchers can view the transit and determine where they may want to conduct further studies. This product combines all the acoustic data into one product giving the viewer access to all the data in a single image.

The future of this platform and its acoustic equipment is contained within the ArcticNet project but there is room for other agencies to acquire the vessel for more dedicated mapping projects.

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