UNCLOS Under Ice Survey – An Historic AUV Deployment in the Canadian High Arctic

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***Abstract* - In March and April 2010, an ISE Explorer Autonomous Underwater Vehicle (AUV), built for Natural Resources Canada (NRCan), was deployed to Canada's high Arctic. Its mission was to undertake under-ice bathymetric surveys in support of Canada's submission to establish the outer limits of its continental shelf under the United Nations Convention on the Law of the Sea (UNCLOS). During this deployment several under-ice records were broken and several new technologies were demonstrated.**

NRCan's AUV is an ISE Explorer class vehicle, with several innovative additions to make it suitable for arctic survey work. Most notable are a 4000 m depth rated variable ballast system, a 1500 Hz long-range homing system, and under-ice charging and data transfer capabilities. A Short-Range Localization (SRL) system was also developed for close range positioning. The homing and SRL systems were developed by Canadian defense scientists and engineers at DRDC (Defence Research and Development Canada).

The Explorer's range was extended to approximately 450 km by adding a hull section to accommodate extra batteries. The scientific payload onboard included a Seabird SBE49 Conductivity-Temperature-Depth (CTD) sensor, Knudsen singlebeam echosounder, and a Kongsberg Simrad EM2000 multibeam echosounder. In order to optimize battery endurance, the plan was to only turn on the EM2000 at strategic locations (i.e. potential sea mounts) along the mission path.

The Main Camp near Borden Island (78°14'N, 112°39'W) was the launch site for the AUV. It was launched from an 8 m by 3 m ice hole, cut through 2 – 3 m thick ice. After several test dives, the first mission was a transit to a Remote Camp, 320 km to the northwest. The AUV autonomously homed into the Remote Camp and was secured with the help of a small remotely operated vehicle (ROV). Without being removed from the water, it was charged and survey data was downloaded, all through a 1.3 m by 2 m ice hole. Subsequently, a second survey mission was undertaken in a region known as the Sever Spur (~79°N, 115°W), which returned back to the Remote Camp. Finally, it embarked on a return transit mission to the Main Camp for recovery. The AUV spent 10 days under ice before being successfully recovered. In total, close to 1000 km of under-ice survey was accomplished between the 3 missions. The AUV reached depths of 3160 m and transited at an average speed of 1.5 m/s at an altitude of 130 m above the seabed. From operating entirely under ice, to surveying in such a challenging environment, to the distances and objectives, this is an historic milestone in AUV and polar science. ISE, DRDC and NRCan are now preparing for a 2011 deployment to collect additional arctic survey data.

I. INTRODUCTION

AUVs have shown repeated success for under-ice operations in the past two decades with notable examples including Theseus operations in 1995-1996 [1][2][3][4], Autosub [5] in 2005, and others over the years [6][7][8][9][10]. This recent deployment of an Explorer AUV under ice surpasses all previous known records for continuous operation, distance travelled and operational risk. The keys to the team's success were:

1. A robust and reliable vehicle based on decades worth of AUV evolution and proven performance.
2. A state-of-the-art homing system.
3. Sound risk evaluation and mitigation practices, including endurance testing.
4. Structured and detailed mission planning using a rich and adaptable task language.
5. Experienced operators and appropriate resources available.

The current generation Explorer is designed and built by International Submarine Engineering Research Ltd. and has evolved from AUV designs dating back to the 1980's. The Explorer is considered a commercial-off-the-shelf (COTS) vehicle [11] and has been used by various agencies worldwide, including Ifremer in France [12], University of Bremen

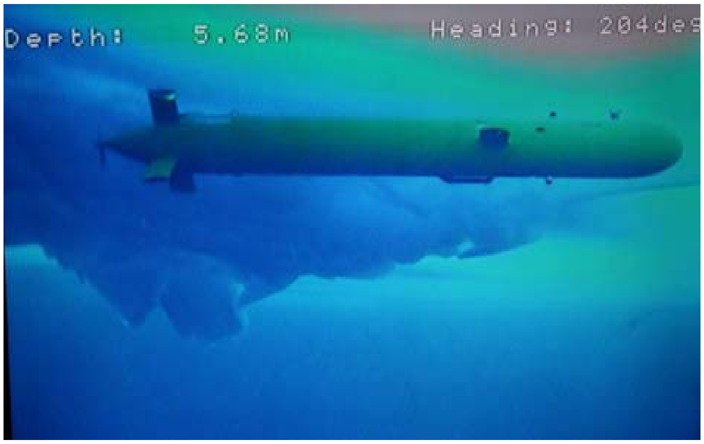

Figure 1. ROV display of the AUV parked next to an ice keel at 79° N.

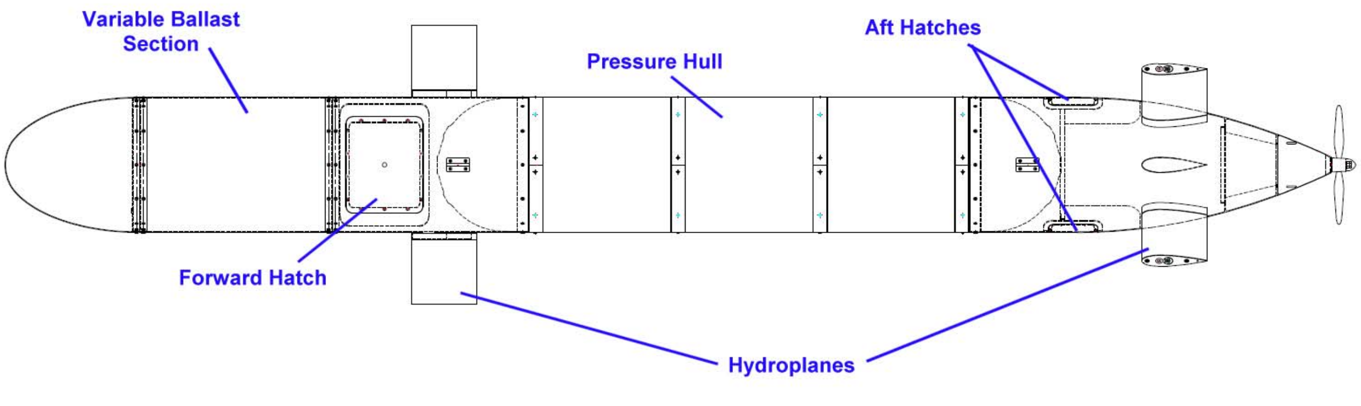

Figure 2. Outline view of the Explorer AUV in the under ice configuration

(Germany), University of Southern Mississippi (USA) and Memorial University of Newfoundland (Canada).

In the sections below, we describe how the AUV was adapted for under-ice deployments, including: the vehicle characteristics; homing system; risk evaluation; mission planning, and operations. Lastly, we present some results and look ahead to future deployments.

II. VEHICLE DESCRIPTION

The AUV is similar to previous Explorer vehicles, the major changes being the depth rating, the battery capacity, the variable ballast system and the underwater mateable connector. Key characteristics are listed in Table I.

III. HOMING SYSTEM

The homing system consists of:

1. A custom 7-element hydrophone array designed by DRDC and manufactured under contract by Omnitech (Dartmouth, Nova Scotia). The array is installed in the nose on vibration isolating rubber mounts (see Fig. 3).
2. Software algorithms run on the Ancillary Homing & Localisation System (AHLS), mounted on the forward payload tray inside the pressure hull. These algorithms take the raw hydrophone data and generate vertical and horizontal angles from the hydrophone array to the detected sound source. This data is passed via an Ethernet link to the Vehicle Control Computer (VCC) which can act on the data to steer the vehicle towards the sound source. Custom vehicle task verbs were developed during the course of the project to enable the homing function to be included in the mission programming.
3. A broadband acoustic projector (sound source) [13] lowered through an ice hole from the surface. The projector emits a continuous tone at 1367 Hz.
4. Surface equipment to generate the tone, including signal generator, power supply etc.

Homing was an essential part of the missions as the remote ice camp was drifting up to 12 km per day. Given the three-day duration of each mission, this meant that the actual

TABLE I
VEHICLE DESCRIPTION

A. ***Key Characteristics***	
Weight	1870 kg
Length	7.4 m
Height	1.4 m (including antennas)
Beam	1.5 m (including fore planes)
Body diameter	0.74 m
Depth rating	5000 m
Energy Capacity	48 kWh (nominal)
Range	450 km @ 1.5 m/s
Pressure Hull	2 hemispherical end domes + 3 cylindrical sections machined from cast aluminum
B. ***Control system***	
Operating System	QNX 4.25
Software	Automatic Control Engine (ACE)
C. ***Communications***	
Acoustic	Teledyne Benthos ATM885 modem
On deck	100 Mbps Ethernet cable
Docked under ice	Ethernet via Underwater Mateable Connector
D. ***Navigation & Positioning***	
INS	IxSea Phins III surface
DVL	Teledyne RDI 300kHz Navigator
GPS	Sound Ocean Systems
Depth sensor	Paroscientific
Bottom avoidance	Kongsberg 675 kHz
Positioning	DRDC Short-Range Localisation (SRL) system Sonardyne USBL system
Homing	DRDC/Omnitech custom design.
E. ***Payload***	
Multibeam Echo Sounder	Kongsberg EM2000 (200kHz)
Single Beam Echo Sounder	Knudsen AASS (118 kHz)
CTD	SeaBird FastCat-49

Figure 3. Homing transducer array mounted in the nose cone. Below it is the 675 kHz bottom avoidance sonar.

recovery location could be more than 30km away from what was originally expected. Adding in potential error from the inertial navigation system meant a homing solution was needed that could function at ranges in excess of 50 km. The end result is a system that worked flawlessly when enabled 50 km away from the sound source, and is thought to have a useful range greater than 100 km in the under-ice Arctic environment. One great advantage of the system is that it generates correct bearing angles even when the sound source is behind the vehicle, which means that if the AUV overshoots the sound source, it is able to turn around and stay in the vicinity. This is exactly what happened during the initial transit to the remote camp, which meant that we had a successful recovery, instead of initiating a “lost vehicle” search process. Indeed, the technique was so successful that it was used as the operating practice for subsequent missions.

IV. RISK EVALUATION & MITIGATION

As with most engineering projects, no risk = no reward. The challenge in this case was to recognize and evaluate the risks, minimize them where practical and maximize the probability of gathering useful data. From a planning perspective, the main risk was loss of the vehicle and therefore any mission data it had gathered up to that point. In open water AUV operations, the Fault Response Table (FRT) is typically set to cause the vehicle to surface in most fault conditions. While this aborts the mission, it usually means a surface asset can locate the vehicle and initiate recovery. Under ice, that philosophy does not apply, so the focus was changed to ways to get the vehicle back to the ice hole, even in the case of unexpected conditions (i.e. faults). If the vehicle were to abort a mission and either park up under the ice, or down on the seafloor, the chances of locating & recovering it were slim. An emergency recovery plan was in place that fortunately never had to be used .

The AUV has a comprehensive FRT which maps the 82 possible detected fault conditions to one of the possible responses based on a combined vehicle mode and mission phase parameter. One of the possible responses is to “jump” to a different section of the mission file, which allows sophisticated contingency missions to be included. For example, in one of our early test missions, a 48V ground fault caused the vehicle to successfully turn around and return to the Main Camp from a distance of nearly 40km. The importance of this type of contingency mission capability cannot be emphasized enough as it can make the difference between a lost vehicle and a recovery. Consider for example, the “dive to depth” emergency maneuver performed by Autosub3 during its mission 341 when it needed to escape from an ice fissure [5].

During preparation for the 2010 deployment, a risk assessment workshop was held to identify likely failure points and develop a model for estimating the probability of success for a given mission. Experts from a variety of agencies including Ifremer (France), the National Oceanography Centre (NOC, UK), University of Southern Mississippi (USM, USA), DRDC (Canada), and ISE (Canada) were involved and collectively this created an invaluable body of experience to draw from. One of the key findings from this workshop, was that a majority of failures occur relatively early in a mission, and thus if the vehicle operates properly for at least 2 hours at depth, it is likely to continue to do so. Another recommendation was to perform endurance testing on the system in the operational configuration.

The majority of our endurance testing was performed in Indian Arm, Vancouver, BC which required the vehicles to be in their open water configuration. Although not exactly the same as the under-ice configuration, it is close enough to evaluate the key subsystems such as propulsion, energy and control. During the endurance missions (60 hrs, 72 hrs and 24 hrs), no significant failures were detected, which provided the confidence to head up to the Arctic and begin testing under-ice. During work up trials in local waters, testing was concentrated on equipment specific to the Arctic operation such as the Variable Ballast System (VBS), the homing system described earlier, and the Short-Range Localisation (SRL) system.

As with most underwater systems, some of the most common failure points are underwater connectors and power supplies. To mitigate the effects of failures in these cases, the Explorer is designed with modular sub-systems such that the failure of any one does not necessarily cause the failure of the vehicle as a whole. Furthermore, the control software uses a hybrid hierarchical scheme which allows some behaviors to preempt others. For example, collision avoidance takes priority over altitude keeping.

We have also put a lot of hard work into taking the ideas of modularity and code re-use, and making them a practical reality with the ACE software architecture. The rewards of this are now being seen in terms of reliability. One of the key benefits of ACE is that it consists of software objects named *components* which are individually controlled and tested. The control system behaviour is defined by configuration files specifying the connections between components and can be modified without re-compiling. This leads to a very robust system that can safely be incrementally improved without extensive regression testing.

V. MISSION PLANNING

In general terms the phrase “mission planning” can be taken to mean all the activities which must be planned and taken into account for a successful AUV mission. These range from high level considerations often referred to as “cruise planning” for ship-based operation, as well as the details of each specific dive or mission. Cruise/deployment planning is not discussed further here, but includes:

- Logistics: personnel & equipment
- Spares
- Consumables
- Services (power, water, heat)
- Top side equipment (e.g. GPS, USBL, etc.)
- Emergency procedures
- High level objectives

Dive planning covers the details, including:

- Start & end locations
- Area to survey, or specific track line
- Survey parameters (e.g. depth/altitude, speed)
- Allowable time
- Contingencies
- Fault & operational limits (e.g. max depth)
- Fault responses
- Detailed mission plan file generation
- Mission verification techniques

For a given dive, the tasks the AUV is required to perform are defined by a *Mission Plan* (MP) file. This file is a regular text file with a ‘.mis’ extension and can be created/edited with any standard text editor. MP files contain:

a. Comments
b. Geographic tasks, which inherently involve a position defined by a Latitude & Longitude. e.g. Line Follow.
c. Non-geographic tasks, e.g. Start Timer.

The allowable tasks in an MP file are defined by another text file referred to as the *grammar file* because it describes the “grammar” of the mission programming language. Tasks can be identified with unique numeric *entry labels* so that the mission can include *goto* jumps similar to assembly language programming. This also allows mission files to have several segments, not all of which necessarily get executed (i.e., allowing for contingency plans). For the Arctic mission additional *task verbs* were developed and added to the grammar, increasing the total to 20. For each task, there are several parameters defined in the grammar file, including: depth; speed; waypoint radius etc. A representative list of task verbs is shown in table II.

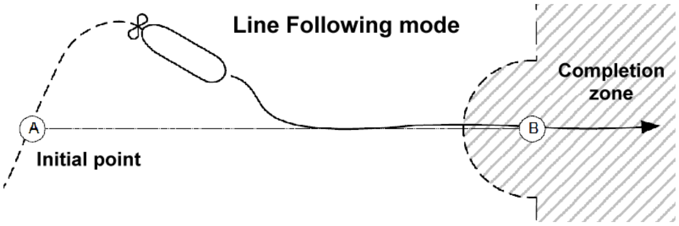

Figure 4. Illustration of a geographic task: Line Follow.

Electronic chart based software is essential to efficient and safe mission planning. The Mimosa package, developed by Ifremer specifically for AUV mission planning, was used. Mimosa allows GIS layers, such as bathymetry and/or satellite photos, to be correlated with chart data and used to graphically draw the desired AUV path, which is then exported as an MP file and downloaded to the vehicle. Another nice feature of Mimosa is that it allows the use of *templates* containing

TABLE II
TASK VERBS

Task Verb	**Description**
Box Current	Similar to Circle Current, but uses a figure 8 type box pattern to facilitate INS alignment.
Circle	Circles a supplied position (Latitude, Longitude)
Circle Current	Circles the position the AUV is at when the task is initiated
Final Approach	Combines the Homing mode with a state machine to guide the vehicle towards the recovery point.
Goto	Jumps to the location in the mission file specified by the supplied *entry label* and executes the task at that location.
Homing	Enables the homing mode
Line Follow	Follows a line to the supplied end position; automatically compensating for current etc.
Route	Maintains a supplied heading, depth & speed for a given period of time
Set	Allows a variety of devices and/or modes to be set to a supplied value. e.g. CTD=ON.
Set AHLS	Ancillary Homing and Localisation System specific settings
Set String	Allows sending custom strings to pre-defined devices (e.g. payload equipment)
Set VB	Variable Ballast specific settings
Start Timer	Starts a countdown timer and then proceeds to execute the next task. Used for creating task level timeouts.
Stop Timer	Stops a previously started timer
Target	Aims at a supplied position (Latitude, Longitude)
Target Goal	Aims at a pre-defined position that can be changed via acoustic telemetry.
Wait	Delays execution of the subsequent task by the given number of seconds.
SRL	Aims at a position defined by the Short-Range Localisation system – typically the origin of the SRL co-ordinate frame.

generic mission segments that are position independent and can be use for contingencies. An example snippet from the template used on the return to main camp is shown below:

```
// ----------------------------------------------
// Phase 2 contingency
// LineFollow to Remote Camp at constant altitude
// **** Check hard-coded Lat,Long
entry_label,072
    stop_timer
    set,mission_phase,9
    set,mbes,off
    set,ctd,on
    set_ahls,power,on
    set_ahls,telem,on
    // ****************
    // Linefollow back to remote camp
    // RC @ 01:26Z 79d51.501'N, 119d25.552'W
    // ****************
    line_follow,79.85835,-119.4258667, 15,
      ignore,0,dvl,1.5,altitude,130
    goto,110    // Park up
```

This contingency was only active in the first part of the transit where it made sense to try turning around and heading back to the remote camp. After that the first part of the transit the vehicle was instructed to carry on towards the main camp if at all possible.

More information about Mimosa is available from Ifremer's website at: http://www.ifremer.fr/fleet/systemes_sm/mimosa/index.html.

Before a mission plan was downloaded to the vehicle, it was subject to a formal review process that required at least two qualified people to examine the file in detail. The final approval to commence a mission was always the responsibility of the senior technical authority (DRDC) representative on site. The team developed a mission verification checklist that included verifying each position, all the survey modes and contingencies and the total mission length. Each reviewer signed and dated a copy of the checklist for each new mission. While this process does not guarantee a perfect mission, it does cut down on the number of "operator errors".

VI. INITIAL OPERATIONS

A. Logistics – getting vehicle to Borden.

Two vehicles (numbers B05 and B06), spares & operational equipment were packed into 32 wooden crates and flown to the Polar Continental Shelf Project (PSCP) facilities at Resolute Bay onboard a chartered First Air Hercules aircraft. The B05 AUV sections were unloaded from the large wooden crates and flown to the Borden ice camp onboard a chartered Buffalo aircraft, which had the advantage of a rear loading ramp. The sections were unloaded at Borden using a wheeled Bobcat fitted with forks. Each section was kept on the heated plane until the previous section had been successfully brought into the warm AUV operations tent. Additional equipment was flown up on a variety of DC3 and Twin Otter flights and typically unloaded by hand before being dragged over to the AUV tent by snowmobile. The B06 vehicle was kept in Resolute as a source of "hot spares", with the intention of deploying it if time and conditions allowed.

B. Assembly

The key assembly tasks included: re-running all the cables between the pressure hull sections; re-connecting all the wet cables; re-installing all the battery modules; pressurizing the variable ballast system; closing the pressure hull and finally optimising the static ballast of the system for the local conditions.

C. Launch & Recovery

DRDC personnel were onsite ahead of the AUV arrival and erected the two tents dedicated to its operation. The small tent was used for AUV assembly and also contained the control consoles and the spares. The large tent housed the ROV equipment and had the ice hole cut into the floor. A two-piece gantry system was installed above the ice hole and was used to launch and recover the AUV through the hole at the main camp.

At the remote camp, a modified Catchy [14] underwater

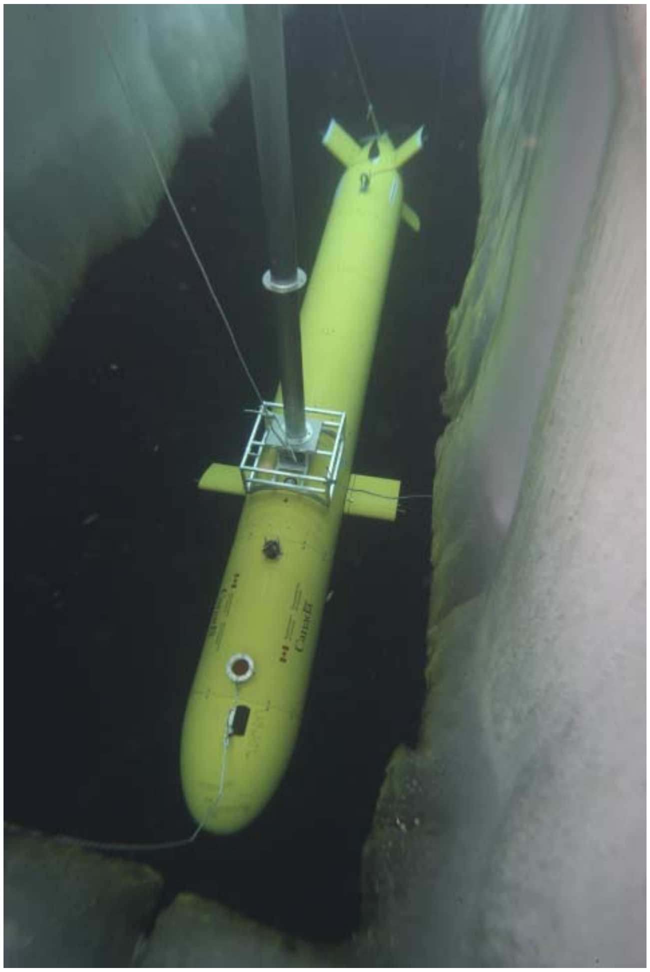

Figure 5. AUV held with Catchy at the main camp.
(Photo courtesy Don Glencross, DRDC Atlantic)

capture system was used to secure the vehicle and allow an underwater connection to be made. Once this connection was mated, payload data and vehicle log files were downloaded at 100Mbs while simultaneously charging the three battery banks at 28 A each. Although other groups have done similar work, we believe this underwater data and charging capability is unique in the field.

VII. SURVEY OPERATIONS

The original intention of the work was to conduct multiple surveys with B05 from the remote camp to collect UNCLOS data. However, as a result of weather delays and the spring ice break-up, operations were curtailed to three full length missions (see Fig. 6); (1) transit from the Borden ice camp to the Remote Ice camp (~ 320 km), (2) a survey of identified features of interest along the continental shelf (~ 280 km), and (3) transit back to the main camp (~ 320 km).

A. Transit to Remote Camp

The transit to the remote camp started in the Wilkin Straight, at the Main Camp, and initially transited to the channel west of Borden Island (~ 50 km and depths exceeding 350 m) before changing heading northwards towards the Remote Camp. Travel over the next 100 km was relatively shallow (less than 500 m) until the shelf break just past the halfway point. From here to the Remote Camp (located at 78º N), depths grew to just over 2100 m. This was the first time that B05 had been operated at these depths.

When acoustic confirmation was first received at the Remote Camp, the vehicle was approximately 4 km out from the ice hole. Our intent was for the vehicle to be homing in at a relatively shallow, 250 m, constant depth mode. Instead, it was discovered that the vehicle had never received a valid acoustic range and was still at a constant altitude of 130 m, an altitude selected for survey purposes, which it kept while continuing to home in on the sound source at the ice camp. This was being observed with the USBL that was passively tracking the system and the vehicle which was reporting its own position, with an offset resulting from INS drift (< 300 m).

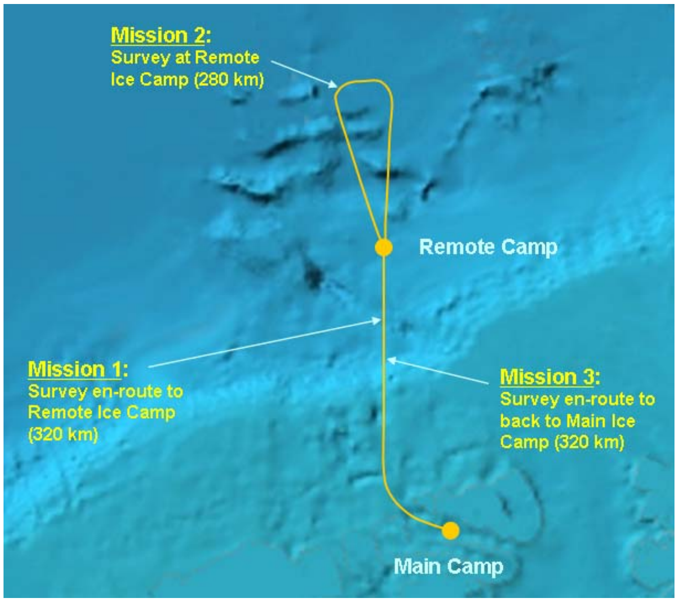

Figure 7. 2010 Arctic Explorer AUV Missions

Figure 6. Remote camp during initial set-up.
(Photo courtesy Dan Graham, DRDC Atlantic)

The recovery strategy that was initiated was for the operators to send an acoustic surface command and to track the vehicle as it started the relatively slow (10º climb angle) ascent spiral to the surface. As the vehicle was no longer within DVL range of the bottom, position offsets were periodically introduced as it came to the surface to correct for currents and drift of the ice camp. The greatest position drifts were observed between 600 – 1600 m depths, which were hypothesized to result from increased currents at those depths. Once in the shallower waters (between 50 – 100 m), the vehicle was kept close to the ice-hole while buoyancy corrections were made for mission completion. The final location of the vehicle (see Fig. 1), was an estimated 30 m from the ice-hole. The total time taken from when the surface command was sent, to when we were able to send the ROV out and attach a line, was 3.5 hours.

B. UNCLOS Survey

Following the transit to the remote camp, the vehicle was held in the Catchy system, data were downloaded and the batteries were re-charged. Then we waited for two days while adjustments to the survey mission plan were being discussed and approved. The changes were mainly as a result of the lessons learned after the transit mission. The final mission plan was for the vehicle to dive to depth, where it would station keep for two hours, before initiating the survey. This period was selected as part of the risk assessment as it was thought likely that any errors might present themselves early on in the mission. The mission plan was to then go beyond the 2500 m contour, to a region where bathymetric charts were indicating a possible sea-mount.

The only other complication that was experienced by the operators was that, during the launch and recovery, communications with the vehicle below ~ 1900 m depth was almost non-existent using the acoustic modems. Still under investigation, it is unclear what caused these problems as several surface modem depths (from 50 – 500 m) were tested as well various relative positions. This complicated matters as the mission plan required an acoustic command to initiate the survey from the holding pattern and then again to initiate the surface procedure in the homing mode at the end of the mission.

The survey was an unmitigated success. The vehicle completed nearly 300 km of survey line for the UNCLOS submission, along which it collected single beam data at a sample rate of 10 Hz (at the 1.5 m/s travel speed this works out to 1 data point every 15 cm). The vehicle also reached a maximum depth of 3160 m past 81º N after passing over the region known as the Sever Spur; a region that has previously seen little to no exploration.

C. *Transit to Main Camp*

After this series of historic firsts, the transit back to the Main Camp was somehwat anti-climatic even though it was still a 300 km mission under-ice and large (> 70 km wide) open leads. It was immediately noticed after release from the tag lines, as the vehicle was diving to depth, that the USBL positioning had stopped working. This was a result of the batteries in the USBL transponder no longer functioning. The issue with this was that we were unable to directly measure the position offset associated with the vehicle once it reached the bottom as we had done in the survey mission. Instead, we ranged from an acoustic modem field that we had surrounding the Remote Camp. Multiple ranges were then used to manually triangulate the position of the vehicle. As this method was not as accurate as the USBL, it was decided to not introduce any position offsets before initiating the transit back to the Main Camp.

Approximately 52 hours later, we started hearing acoustic telemetry packets at the Main Camp and knew the AUV had successfully transited the difficult narrow section and was on the home stretch. A few hours after that, we got confirmation that the vehicle was in homing mode and had made a deviation to port required because of the inertial position drift. We sent an updated *Target Goal* position that brought the vehicle to within 50m of the ice hole and then commanded it to park up under the ice. Apart from no USBL tracking (presumably from dead transponder batteries), everything had been going perfectly up to this point – "high fives" all around.

But the fun wasn't over yet! We still had to get the AUV back on deck and unfortunately, when it rose and crossed the 5m depth threshold, acoustic telemetry automatically switched to the lower transducer from the upper, and suddenly we had no acoustic telemetry. This meant we were unable to stop the VB system from pumping to 90 lbs positive buoyancy, so the vehicle was stuck up hard under the ice. After attaching a line with the ROV, we were supposed to make the vehicle heavy and let it hang on the line, while we hauled it into the ice hole. Instead, we had to drag the vehicle along the underside of the ice, which was tedious, laborious and potentially damaging to the vehicle. Fortunately, we got the vehicle onto the gantry system without further incident and were able to finally go to sleep exhausted but happy.

VIII. RESULTS & CONCLUSIONS

A. *Vehicle Performance*

The bottom line is that the vehicle came back after a very ambitious deployment. i.e. "We did it!". Vehicle control & stability were excellent. The homing system worked extremely well. There were a few minor hiccups, but the exhaustive (and exhausting) planning and testing paid off. At the end of the day, there was a weary but happy team.

B. *Multibeam Data*

Fig. 8 shows a sample of the multibeam data collected with an approximate swath width of 100 m at a constant altitude of 50 m, as a result of the shallower depths. This sample was taken from the second mission that was programmed to do a 6 km loop away from the launch site. The area where it is initially loitering is visible at the shallower depths of 115 m.

One of the problems specific to Arctic deployments, is that the sound speed is fed directly from the SBE49 Fastcat CTD to the EM2000 Processing Unit (PU) where it is stored in the datagram. Normal operating protocol is to rinse the CTD after each deployment with freshwater. As we were in a heated tent, no changes were made to protocol and so the conductivity cell cracked as a result of ice expansion from the thermal mass of the instrument itself. Although, a replacement from B06 was on hand, changes in protocol were a necessity for the rest of this deployment and are a necessity for next year. Otherwise, this could jeopardize the quality of the data being generated by the EM2000.

C. *Singlebeam Data*

The Knudsen AASS single beam gathered data for the entire 10 day deployment from the main camp out beyond the remote camp and back. The data from this deployment is currently being analysed by the Canadian Hydrographic

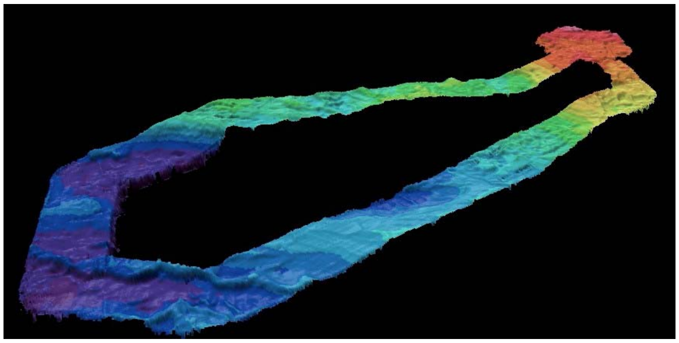

Figure 8. Multibeam bathymetry of the seafloor collected around the Main Camp. Red values represent depths of about 115 m dropping down to ~ 165 m at the dark blue areas. (Image created in Fledermaus^{TM})

Service (CHS), but informally was deemed to be “very good”. For most of the time, the AUV was in altitude keeping mode, so the bulk of the single beam data looks like a line at 130m and is not very meaningful on its own, but needs to be combined with AUV depth and position data and turned into a nautical chart.

D. What Next?

The success of this deployment demonstrates that AUVs are ready for long-range, unsupervised or unescorted missions in harsh environments. This opens up a realm of potential applications, including oil flow mapping as mentioned in [15]. With regard to recent events in the Gulf of Mexico, this may be of particular interest in the near future. However, the next deployment for the two AUVs, named *Qaujisati* (“One who searches”) and *Yamoria* (“One who travels”), so named from the Inuktitut language, is to return to the Arctic in 2011 for further under-ice UNCLOS missions.

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