Establishing a multibeam sonar evaluation test bed near Sidney, British Columbia

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ABSTRACT

The Canadian Hydrographic Service (CHS), Naval Oceanographic Office (NAVOCEANO) and the Ocean Mapping Group of the University of New Brunswick (OMG) collaborated on establishing a multibeam sonar test bed in the vicinity of the Institute of Ocean Sciences in Sidney, British Columbia Canada.

This paper describes the purpose of the sonar evaluation test bed, the trials and tribulations of two foreign governments collaborating on projects of mutual interest, the evaluation areas and their characteristics for sonar testing, and sample results of sonar evaluations using this test bed. Some target detection comparisons of several systems over a range of artificial sonar targets will also be given.

1. BACKGROUND

The Naval Oceanographic Office (NAVOCEANO) is tasked to meet the U.S. Navy's worldwide hydrographic, oceanographic, and environmental survey requirements, which are allocated on a priority basis by the Unified Commands. NAVOCEANO's parent command, Commander, Naval Meteorology and Oceanography Command oversees administration and funding for operation of six T-AGS 60 class oceanographic ships. NAVOCEANO plans and coordinates surveys in accordance with Navy requirements and provides the survey and support personnel to accomplish the missions. Hydrographic and oceanographic bathymetric surveys are a fundamental mission performed on these platforms. For hydrographic surveys, hydrographic survey launches (HSLs – see Figure 1) are utilized as "force multipliers" for the ships, facilitating bathymetry missions in depths otherwise inaccessible to the ship for reasons of water depth or manoeuvrability. While the mission focus for NAVOCEANO assets is to support the U.S. Navy Fleet, secondary data uses also benefit commercial maritime safety and academic/scientific purposes.

NAVOCEANO plans for life-cycle replacement of existing survey systems as the employed technology ages and its logistic support becomes limited or unavailable. A 10- to 12-year equipment lifespan is typically anticipated and programmed for budgeting purposes. The T-AGS 60 ships have just completed their life-cycle replacement of the hull-mounted bathymetric sonars, and the HSL systems are now the focus for life-cycle replacement by the NAVOCEANO Engineering Department. Equipment upgrades are periodically implemented over the life of NAVOCEANO systems providing stepped increases in functional capability. With a life-cycle replacement, however, significant new capabilities and features become available as a result of technological advancements. The planned HSL overhaul includes implementing the very latest in multibeam sonar technology. Desired major improvements are greater working depth range and swath width, increased bathymetric accuracy with finer spatial resolution, and increased along-track sounding density facilitating gap-free coverage and improved feature detection capability at faster vessel speeds than previously possible.

Figure 1 - NAVOCEANO HSL

As Canada's hydrographic authority, The Canadian Hydrographic Service (CHS), a part of the Department of Fisheries and Oceans (DFO), surveys the country's navigable inland and marine waters – to the edge of the continental shelf and beyond. CHS charts are the "road maps" that guide mariners safely from port to port. They provide an incredible wealth of detail: depths, buoys, lighthouses, hazards, and more. CHS continues to use the latest technologies such as multibeam sounders and the satellite-based Global Positioning Systems (GPS) to make the work done today more comprehensive and accurate than ever before. CHS is committed to continuous innovation as it provides its clients with high-quality charts and publications to help them navigate safely. Its role is ever more vital in light of increasing commercial shipping, fishing activity, recreational boating, and the development of ocean resources.

Like NAVOCEANO, CHS' once state of the art multibeam sonars are getting "long in the tooth" (the first EM3000s were purchased in 1996, including Serial No. 1). A life-cycle replacement strategy is being developed. Needless to say, CHS was very interested in gaining early first-hand experience with the EM2040 multibeam sonar as a potential upgrade path and in witnessing world-class testing and acceptance methodology as conducted by NAVOCEANO and John Hughes Clarke of University of New Brunswick.

The Ocean Mapping Group (OMG) is a research unit within the department of Geodesy and Geomatics Engineering at the University of New Brunswick. The Group specializes in researching the capability of integrated swath sonar systems. A major part of that research is testing and analysing the resolution and accuracy capability of the latest swath sonar systems. The collaborative EM2040 trials are the most recent example of this program and follow on from two decades of operational trials for national hydrographic agencies from Canada, New

Zealand, Australia, the United Kingdom, the Netherlands and the United States. All the research results of these trials are used in internal undergraduate and graduate teaching. The results are also rapidly communicated to the global offshore survey community through the Multibeam Sonar Training Course, offered three times annually worldwide.

The Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) was founded in 1999 with two main objectives: to develop tools to advance ocean mapping and hydrography and to train the next generation of hydrographers and ocean mappers.

The JHC is a formal cooperative partnership between the University of New Hampshire and the National Oceanic and Atmospheric Administration (NOAA) whose aim is to create a national center for expertise in ocean mapping and hydrographic sciences. CCOM, a complementary university center, expands the scope of ocean mapping interaction and collaboration with the private sector, other government agencies, and other universities.

CCOM/JHC benefits from the testing procedures as they expose the Center to the latest technological advances in seafloor mapping systems and allow better understanding of new features and functionality of mapping systems in a controlled environment. Working in close cooperation with other research groups, manufacturers, and mapping agencies fosters further cooperation and promotes an environment where the exchange of ideas, best practices, institutional knowledge, and know-how can benefit all parties involved.

2. INTRODUCTION

A competitive procurement process was conducted in 2011 for the next-generation life-cycle replacement and support for NAVOCEANO's existing hull-mounted HSL multibeam sonar systems. The Hydrographic Multibeam Replacement (HMR) system deliverables from this best-value contract would also include pole-mount and autonomous underwater vehicle (AUV) versions.

A demonstration approach was incorporated into this procurement process. Rather than award a contract based solely on evaluating paper proposals, it included a demonstration test for validating that the system could meet the specified requirements. The demonstration would thereby avoid costly HSL implementation delays from deficiencies detected only after contract award and subsequent acceptance testing. Following a successful demonstration, a final award could then be made to the winning vendor, and HMR implementation within the NAVOCEANO HSL fleet could begin.

Nearly 200 individual test items were detailed in the demonstration test. These items fell into five testing categories that evaluated system performance and survey efficiency, user interfacing, system interfacing, construction and design, and data products and tools.

Validating the system sonar performance and survey efficiency requirements was considered the most critical aspect of the demonstration and largely dictated the location providing the best environment necessary for evaluating the system in accordance with requirements. This category tested essential performance characteristics including electronic stabilization from motion effects, sounding density, sounding distribution modes, ping rates, bathymetric uncertainty, swath coverage versus depth, feature detection capability, and automated bottom tracking over a variety of terrain and bottom types.

Concurrent testing with other established sonar systems provides a control reference to compare and contrast the system under test. These established systems help assess performance capabilities and unique features of the tested system. The proposed Kongsberg EM2040 sonar made it to the demonstration phase for the HMR contract. The EM2040 is Kongsberg's next generation hydrographic multibeam sonar intended to replace the EM3002. The primary contractor was Kongsberg Underwater Technology Inc. (KUTI). Systems available for comparison testing included the Kongsberg EM3002 and Reson 7125 multibeam sonars.

2.1. Establishing a Test Location

A successful HMR contract demonstration is critically dependent on the test locale. Numerous factors were considered in selecting an area, and risk assessments were made considering how well each factor could be contained or controlled during the test period. Ultimately, having the time and funding to test were key drivers in the risk assessment. A test period allocating each suitable vendor up to two weeks of installation and demonstration time with a week’s allowance for down days by weather, boat problems, etc. was formulated. The factors gauged critical to a successful demonstration were the following:

- Suitable water depth and its proximity to port operations;
- Existing baseline data (available ground truth);
- Water space availability;
- Environmental considerations;
- Suitable platform availability; and
- Logistical support.

The original plan presumed testing aboard a NAVOCEANO 46’ *Bertram* boat using a pole-mount apparatus for the transducer rigging in the summertime out of Key West, FL.

2.1.1. Suitable Water Depth and its Proximity to a Base of Operations

The water depth requirements ran from 2 meters to 400 meters over variable terrains and bottom types. The desired seafloor includes bottom types from hard rock to sand and soft mud. Areas of relatively smooth and flat bottoms at 25 m, 50 m, and 100 m were needed to accommodate sonar calibration and generate statistical results for assessing the bathymetric uncertainties and determining the systematic and random errors present. A stable bottom was needed to support long-term deployment of artificial targets in 20- to 40-m water depths. A key element was to have these suitable bottom types all within relatively close proximity to a base of operations.

2.1.2. Existing Baseline Data (Ground Truth)

The presence of existing ground truth data was highly desired as a basic assessment means to validate the performance of the system under test. This data could be used both for selecting specific areas of interest and for comparison against the test data.

2.1.3. Water-space Availability

Assured test area accessibility was needed well in advance of the test period. This factor considers whether special permits are required to work in or transit through areas that are under jurisdiction by Federal, state, or local authorities. Specific areas may be restricted as marine sanctuaries or test ranges. Safety of marine mammals in the areas was a consideration. Finally, test areas could not be in zones that were so heavily trafficked by recreational or commercial watercraft such that it would be difficult to run repetitive survey lines.

2.1.4. Environmental Considerations

The testing locale needed to be conducive to performing the demonstration. Small boat operations exposed to open ocean conditions are readily impacted by even minor sea states. An area prone to major seasonal storms (i.e., tropical storms and hurricanes) adds significant risk to test completion; even the threat of a serious storm can so disrupt the testing that it effectively cancels it.

Although weather is considered the predominant environmental factor affecting testing, the water mass characteristics must also be considered and capturing its variability. These characteristics include volume sound speed variability, both spatially and temporally. The tidal range and cycle may also impact accessibility and sound speed variability.

2.1.5. Suitable Platform Availability

The platform used to conduct the contractual testing needed enough space to comfortably accommodate six passengers for an entire work day. The demonstration needed allowance for two vendor personnel, a minimum of three NAVOCEANO personnel (for survey navigation, data logging, and test monitoring), and an independent multibeam sonar expert.

2.1.6. Logistical Support

The shore-based needs for conducting the demonstration test included:

- Shipping and receiving facilities;
- Easy air and ground transportation for personnel;
- Storage facilities for equipment stowage and staging;
- Hotel or portable office space for data post-processing;
- Port services with a boat lift; and
- Industrial support capable of designing and fabricating specialized mounting apparatuses and providing fork lift and crane services.

These above requirements were needed in close proximity to the boat marina used.

Evaluation of these key factors revealed that the intended Key West site had significant risks that could jeopardize completing the demonstration test. An alternative location was sought by NAVOCEANO, and conversations between the authors explored the viability for conducting the demonstration testing from the Institute of Ocean Sciences (IOS) in Sidney, BC on Vancouver Island.

After much corresponding between parties and analyzing risk factors, it was readily apparent that the Canadian site greatly mitigated every high risk factor in the Key West plan. It also provided the means for expanding the testing goals to include the dual-headed multibeam sonar testing and AUV testing. Table 1 compares the risks between the Key West and Sidney sites.

The demonstration planning progressed, and it became clear that the Sidney area and environs contained a plethora of specific areas that together constituted a unique sonar test bed for comprehensively testing shallow water multibeam sonar systems, perhaps unparalleled elsewhere in the world (Figure 2). The test bed incorporated:

- Wreck sites for imagery testing and mast-tracking;
- Various flat areas of different depths for accuracy testing;
- Areas of different bottom types (e.g. eel grass, sand, mud, gravel) and topographies (e.g. flat, sloping, sand wave fields and fjords) for bottom tracking tests; and
- Targets (e.g. artificial 1-m and ½-m concrete cubes, and natural boulder field targets) for feature detection testing.

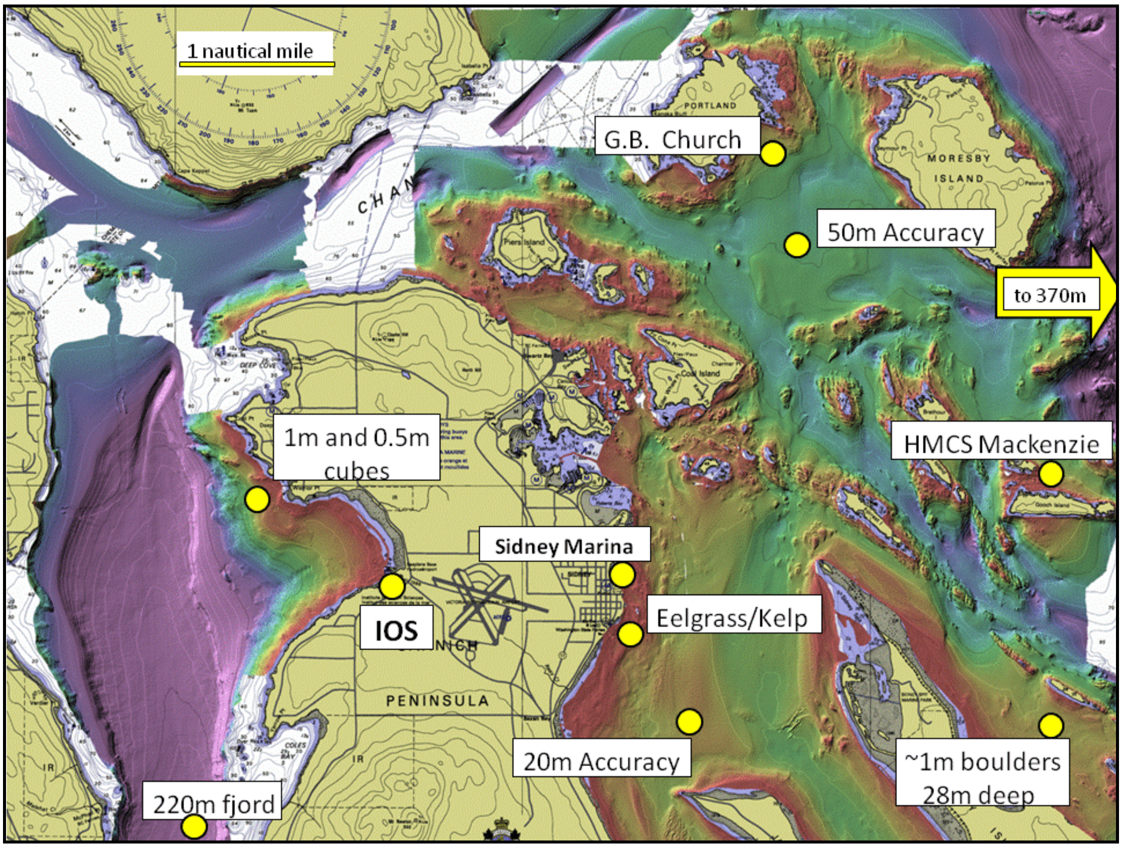

Figure 2 – Sonar test bed areas near IOS used for EM2040, REMUS/EM3002 and Reson 7125 testing

Once the testing location settled on the Vancouver Island location, a NAVOCEANO Remote Environmental Measuring Unit (REMUS) model 600 autonomous underwater vehicle (AUV) equipped with an EM3002 multibeam and Edgetech sidescan sonar (Figure 3, right) was included in the test scope. The REMUS AUV testing also included evaluating a newly integrated navigation capability – the Kongsberg High Position Acoustic Positioning (HiPAP) system and Hugin AUV Navigation Processing Suite (NavP). This extended testing was conducted using an additional NAVOCEANO platform, a SWATH (Small Water-plane Area Twin Hull) boat (Figure 3, left).

The comprehensive goals of the testing effort became:

- Conduct contractual demonstration testing of the single-head EM2040 sonar system;
- Separately test a dual-head EM2040 system to assess its benefits and tradeoffs;
- Conduct comparison sonar testing with other systems;
- Conduct HiPAP and NavP testing to assess REMUS positioning improvements; and
- Collect lessons learned for future HMR operational use.

Figure 3 - SWATH boat (left) and REMUS AUV with EM3002 being deployed (right)

3. COLLABORATION

Enabling NAVOCEANO to conduct sonar trials in Canada required significantly more effort than first realized. A never-ending stream of bureaucratic roadblocks, both in Canada and the United States, was encountered and needed resolution. Fortunately, a few key people went above and beyond to help leap these hurdles. From the initial project discussions at CHC in June 2010 to within just a few weeks of deploying targets and operating AUVs in August 2011, the battle was still being waged against the forces of "you can't do that and this is why not."

The risk analysis assessment (Table 1) provided strong impetus and support from NAVOCEANO management to pursue the Canadian testing route. As the project unfolded, the next steps involved:

- Creating a data sharing agreement between all the collaborating parties;
- Securing the use of a Canadian Coast Guard (CCG) vessel to carry out the tests;
- Obtaining clearance for a NAVOCEANO SWATH boat to work in Canadian waters;
- Finding a funding mechanism by which monies could be legally transferred from the U.S. Government to the Canadian Government for testing support expenses;

- Conducting an environmental assessment for permanently deploying concrete blocks on the seafloor;
- Transporting the 12 concrete blocks to the test area and deploying them (about 3 tonnes apiece for the 1-m cubes);
- Obtaining security permissions for U.S. Government personnel and contractors to utilize IOS workspaces;
- Investigating possible ways for non-DFO personnel to use Canadian government IT networks; and
- Obtaining IOS available office space for testing personnel.

Table 1 - Comparison of potential location areas/risk factors associated with tests

Location Risk Analysis		
Risk Factor	**Key West, FL**	**Sidney, BC**
Suitable water depth / Proximity to base of operations	Hours for test area transits **(High risk)**	Minutes for test area transits **(Low risk)**
Existing baseline data	Dated, questionable availability **(High risk)**	Recent, with high confidence **(Low risk)**
Water-space availability	Dolphins, rec. boats **(Medium risk)**	Rec. boats, orcas **(Medium risk)**
Environmental	Significant potential for tropical systems interrupting test **(High risk)**	Calm; requires tight water mass monitoring **(Low risk)**
Suitable platform availability	HSL - too small; *Bertram* - questionable availability **(High risk)**	*Otter Bay* - available; SWATH boat – in Keyport, WA **(Low risk)**
Logistical support	Limited resources, potential delays **(High risk)**	Full industrial support available **(Low risk)**
Overall Risk	**High**	**Low**

The baseline ground truth data was needed to organize a test schedule and determine testing logistics. NAVOCEANO and OMG were granted access to the existing CHS multibeam data in the potential test areas via user licence agreements with CHS.

The Canadian Coast Guard Launch (CCGL) *Otter Bay* is periodically funded for West Coast CHS hydrographic work from a Canadian government vessel fund. The *Otter Bay* is equipped with an EM3002 multibeam sonar and ancillary equipment for hydrographic surveying, configured very similarly to that of the HSLs. Using the vessel for the HMR demonstration test was an ideal choice as only minor vessel modifications were needed, thus minimizing cost. The scope of the NAVOCEANO testing work was outside the CHS funding envelope and the vessel had to be independently scheduled and funded outside the planned surveying season (i.e., from mid-August to mid-September). An arrangement was made allowing CHS to buy additional time aboard the vessel for this purpose.

While it was initially thought that an existing U.S. Navy to Canadian Navy arrangement would suffice for transferring funds for *Otter Bay* usage, the legal counsels decided the arrangement did not permit such exchanges. After multiple iterations over many months of effort on the part of NAVOCEANO, CHS, OMG and KUTI staff, a collaborative arrangement between CHS and KUTI was developed that provided a funding conduit.

Internet connectivity for NAVOCEANO personnel via DFONET at IOS was pursued, but IT security policies precluded accessibility. A workaround provided Internet access using cellular phone service.

The NAVOCEANO SWATH boat in Keyport, WA required clearances to operate in Canadian waters. These clearances were granted through the Canadian Foreign Affairs department.

Permission was given by CCG at IOS to station three 20-foot shipping containers on site (with gear to support the REMUS AUV trials) and tie-up the SWATH boat in the small-boat basin. An arrangement was made for off-hours access of non-IOS personnel, and for building passes and visitor IDs. CHS personnel were on-site during the off-hours as part of DFO security requirements.

Before any of the concrete blocks could be deployed and used as sonar targets, an extensive Environmental Assessment was first required, which was then posted to the Internet for a 15-day public review period. Staff at DFO's Marine Environment and Aquaculture Division, Ecosystems and Fisheries Management and the Canadian Environmental Assessment Agency (CEAA) were very helpful in the environmental assessment process. Navigable Waters Protection Act approvals were also required because of the shallow depths (20 m) of the nearshore blocks.

Attempts to secure CCG buoy tender availability for concrete block deployment in the target range were unsuccessful. CCG then referred us to the DND barge with its 50-tonne crane. Negotiations with the Queen's Harbour Master provided two days barge use for deploying all 12 targets in their desired Patricia Bay and Saanich Inlet locations.

Transport Canada has authority regarding CCG vessel operating restrictions, including occupancy limits and personnel qualifications for various operating conditions. For sheltered waters, eight persons were allowed aboard, which included the captain and a qualified CHS hydrographer. The remaining six spaces could then be occupied by NAVOCEANO, contractor and OMG personnel. Open water crossings limited the non-CHS personnel count to four.

Otter Bay underwent minor under hull modifications (Figure 4) to support the testing effort. Original plans incorporated a side pole-mounted HMR testing configuration, but considerable difficulties were foreseen in this arrangement. CHS and CCG personnel then accommodated a temporary fixed hull mount for the period. Hull mounting would insure the sonar was not subject to structural flexing, bending, or rotating that would degrade the performance measurements and it would also better represent the HSL mounting and thus, performance.

Figure 4 - *Otter Bay* (left); pod modifications/adaptor plate/EM2040 (right)

The local industry and CHS support personnel were also able to design and fabricate the adaptor plate for the *Otter Bay* EM2040 mount (Figure 4, right).

Additional benefits of the IOS location and the CHS collaboration included availability for other platforms (e.g. CCGS *Vector*, with an EM710, Figure 5) to run through the target test areas with their sonars to obtain another comparison dataset.

Figure 5 - CCGS *Vector* (EM710 0.5 x 1.0)

The local Sidney industries had the capability to design and fabricate a number of 1-m and ½-m cube solid concrete targets (Figure 6) for underwater feature detection testing. The 1-m cubes were constructed to test sonars against the standard IHO-S44 (5th edition) Special Order feature detection requirements in 40 m depth. The ½-m cubes were constructed to provide a far more challenging test and would assess the system's scalability, that is, does a 1-m target in 40 m depth appear like a ½-m target in 20-m depth? The seafloor layout of these targets is shown in Figure 7. The target multiplicity provided a better statistical assessment of sonar performance. Solid concrete cube targets were employed for this test, some with pipe protrusions to simulate mast-like structures.

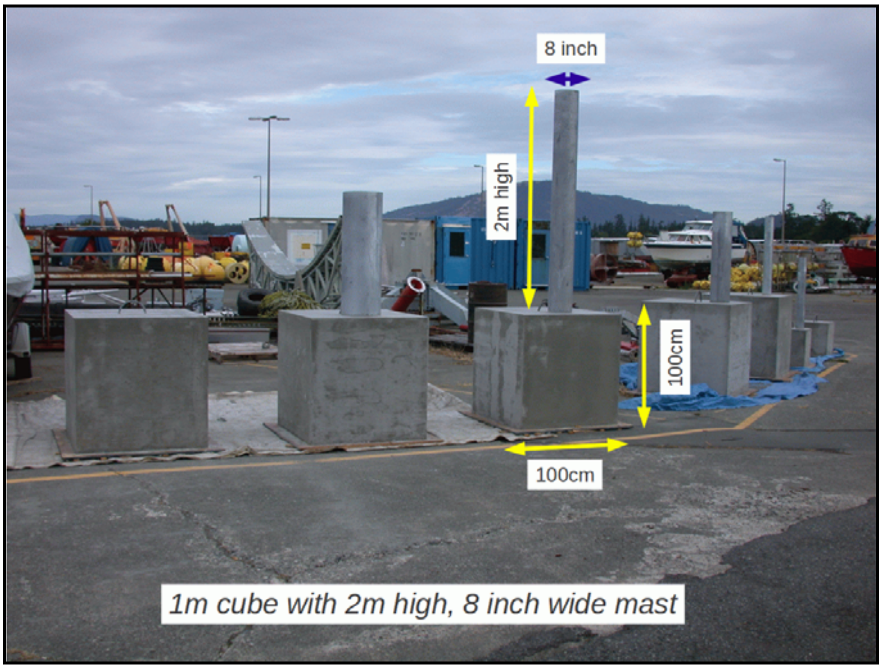

Figure 6 - Some of the 12 concrete and steel targets that were fabricated on-site at IOS

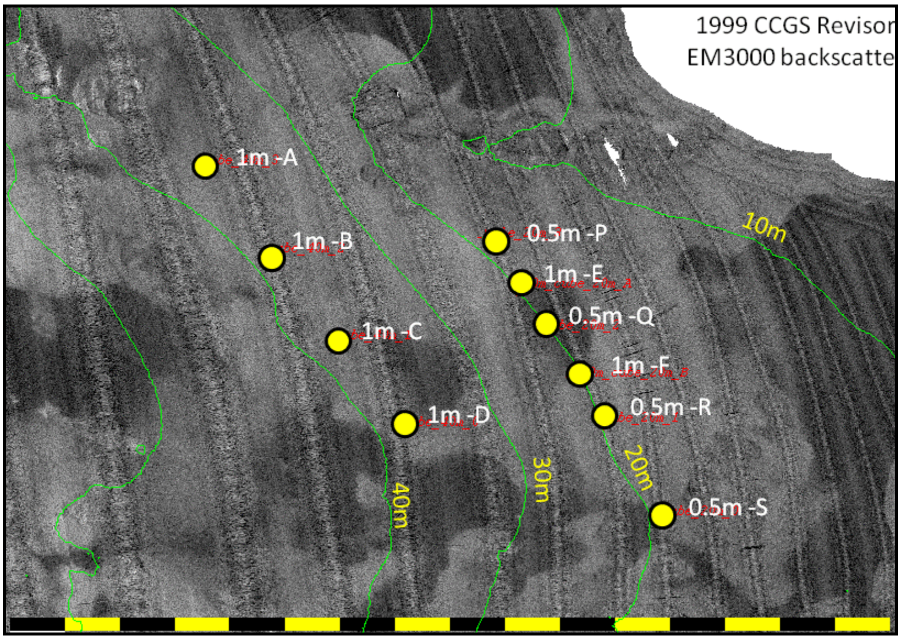

Figure 7 - Proposed 40-m and 20-m depth target locations on hard substrates

4. RESULTS

Once all the targets were deployed and all the logistical details of personnel, vessels, equipment, travel and accommodations were established, the various system evaluations began.

4.1. EM2040

The testing conducted on the *Otter Bay* EM2040 installation included:

- Bathymetric accuracy tests in 20, 50, 80, 170 and 400 metre depths using different frequencies and sonar settings;
- Target detection capabilities at 300 and 400 kHz, for various swath angles and sonar settings;
- Water column capabilities over fish schools, wrecks and artificial dive sites;
- Motion compensation capabilities;
- Extinction depth and maximum coverage widths over different seabed types;
- Boulder detection and sidescan imagery comparison to Remus AUV data

These tests were carried out at the yellow-dotted sites shown in Figure 8.

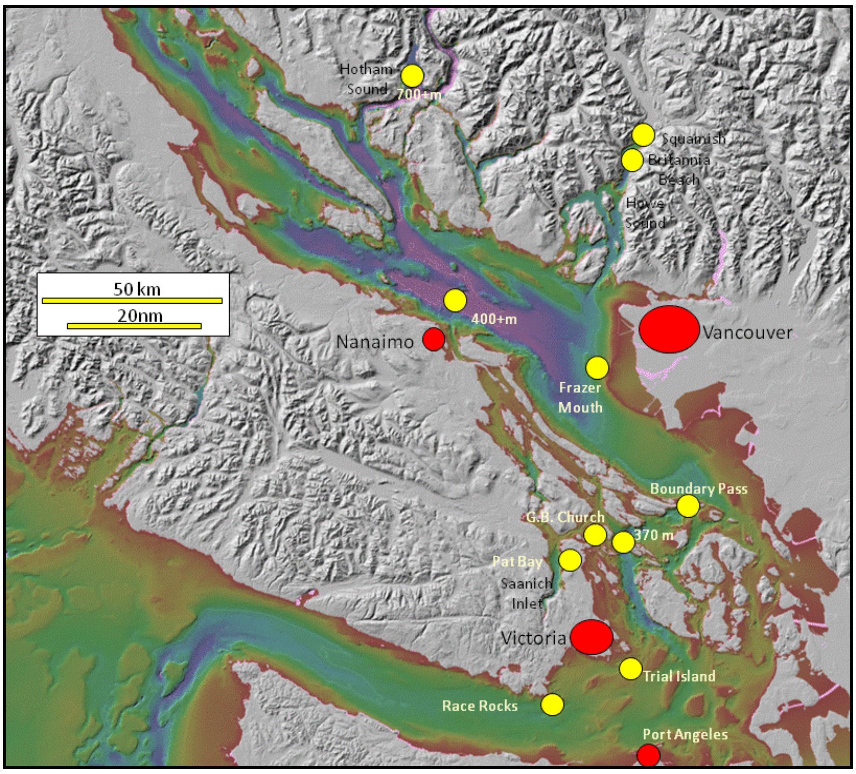

Figure 8 – Overview of EM2040 test areas (yellow dots)

4.1.1 Target Detection.

Tens of passes were made over the test bed's concrete targets in 20 and 40 metres water depth using different frequencies and sonar settings and different swath angles. Sample water column imagery results over a few of the 1-m targets are shown in Figure 9 with a picture of the corresponding target. Each water column imagery graphic depicts the bottom tracking shown as black dots. The dots correctly track the sea floor and even capture tracking along the top of the concrete cube. The mast-like pipe protrusions on some of the targets are not tracked as bottom, but are still visually evident in the imagery and properly dimensioned vertically.

The 1-m targets were generally easy to pick out in the EM2040 real time seabed imagery view in 40-m depth, but the ½-m targets in 20-m were far more difficult to depict in real time and often required post processing investigation to observe with certainty.

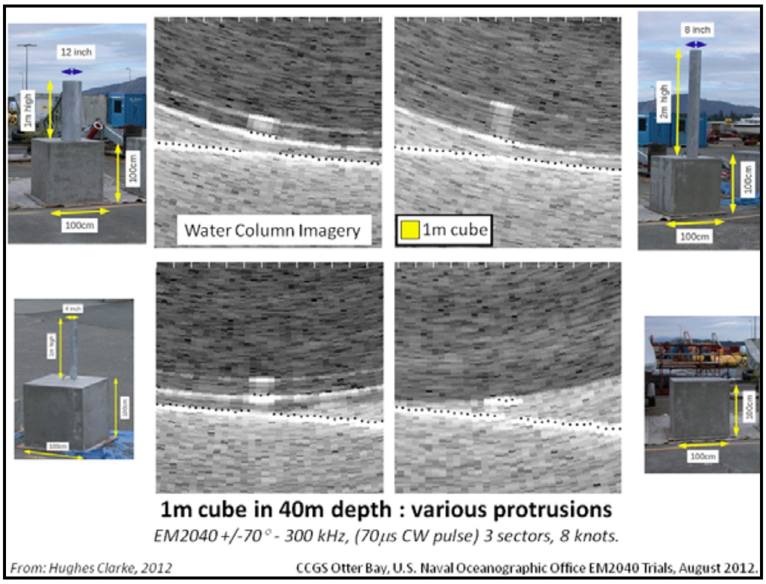

Figure 9 - Water column view of 1-m and 2-m pipe protrusions from 1-m cubes in 40-m

The short pipes of the concrete targets weakly simulate the presence of an actual mast often encountered at wreck sites. The EM2040 surveyed over several artificial dive sites (intentionally-sunken vessels) in the sonar test bed area. Figure 10 shows a water column curtain view of the G.B. Church. The two masts are unmistakably obvious in the image along with significant clouds of fish biologics above the superstructure. A number of stratified acoustic scattering layers are also seen.

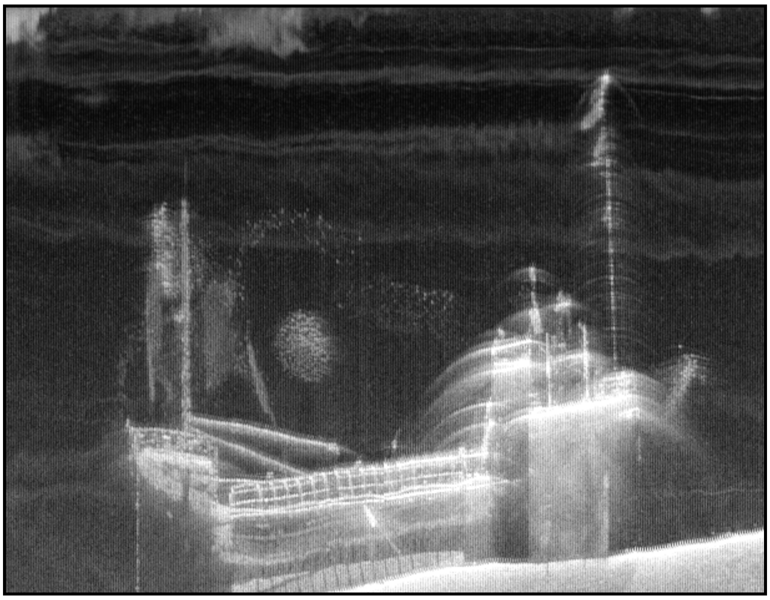

Figure 10 - Water column curtain view of the G.B. Church artificial dive site

4.1.2 Accuracy Tests.

Accuracy tests were conducted in the test bed area using all three operational frequencies and with various pulse settings and opening angles. Basic descriptive statistical analyses providing mean and standard deviation characteristics across the swath were conducted. Sample results of these analyses are shown in Figure 11. Guidance on interpreting multibeam statistical results may be found in Whittaker et al. [2011]. For all tests, sound speed at the transducer face was continuously captured and ingested by a probe located with the transducer while the water column profile sound speed was acquired using calibrated CTD instrumentation and monitored for changes using a moving vessel profiler (MVP).

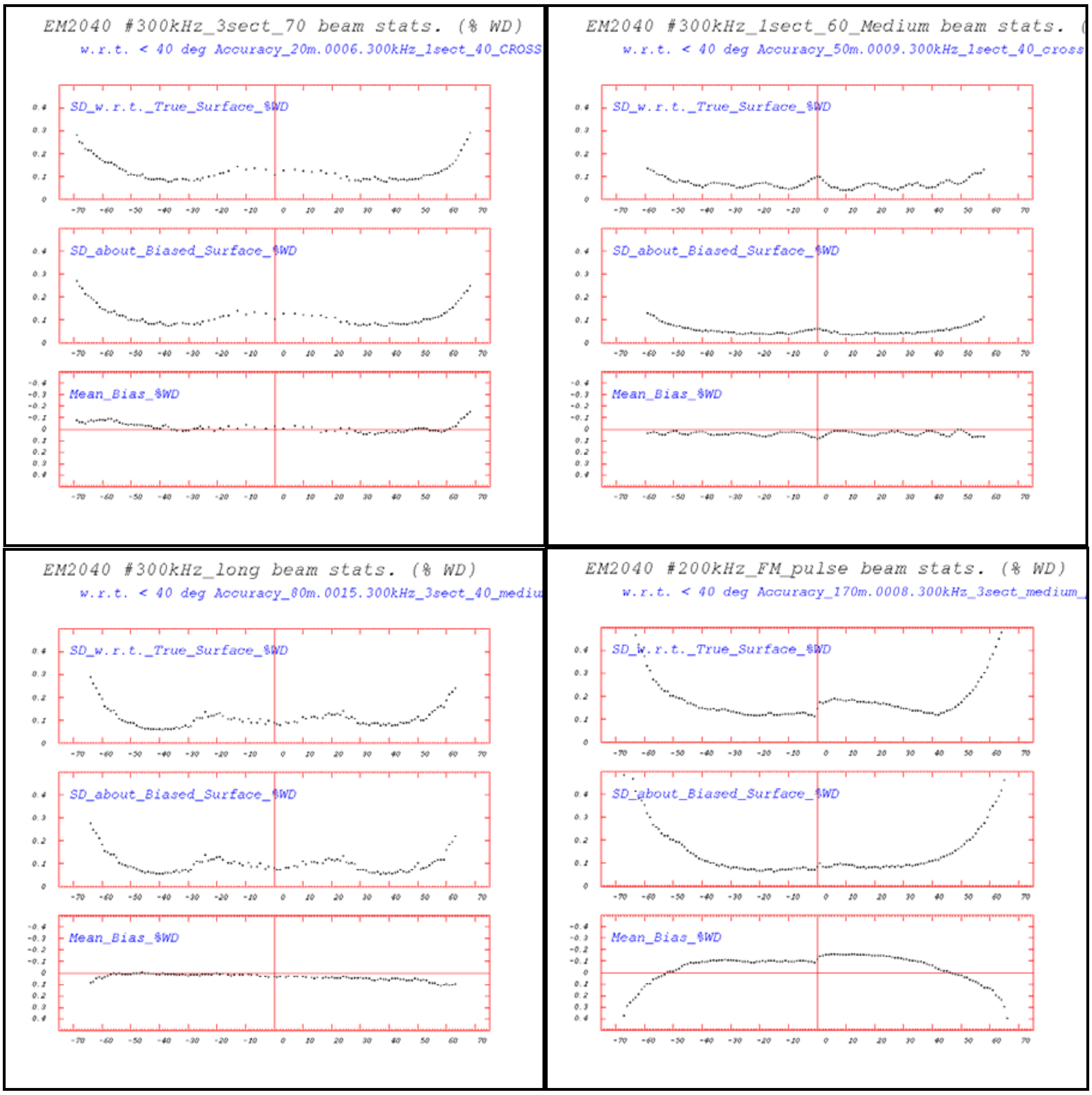

Figure 11 – Sample accuracy statistics (1 sigma) for EM2040. Upper left: 20 metres @ 300 kHz; upper right: 50 metres @ 300 kHz; lower left: 80 metres @ 300 kHz); lower right: 170 m @ 200 kHz with FM chirp pulse.

4.1.3 Extinction Tests

Extinction and coverage tests were conducted in Hotham Sound over both mud and gravel substrates. Hotham Sound is outside the Sidney test bed area, requiring about a day's transit to visit. The Sound has depths of nearly 700 m, allowing a full extinction depth test at shallow water sonar frequencies. The extinction test results are depicted in Figure 12. Muddy bottoms resulted in an extinction depth of about 450 meters while hard gravel bottoms resulted in an extinction depth of about 620 meters. Superimposed in each graphic are five gain/loss contours spaced to represent the theoretical expected coverage results given additional attenuation (or gain) from environmental factors (e.g. warmer water increasing absorption, less bottom reflectivity decreasing the returned signal). The contours are spaced at 10-dB increments.

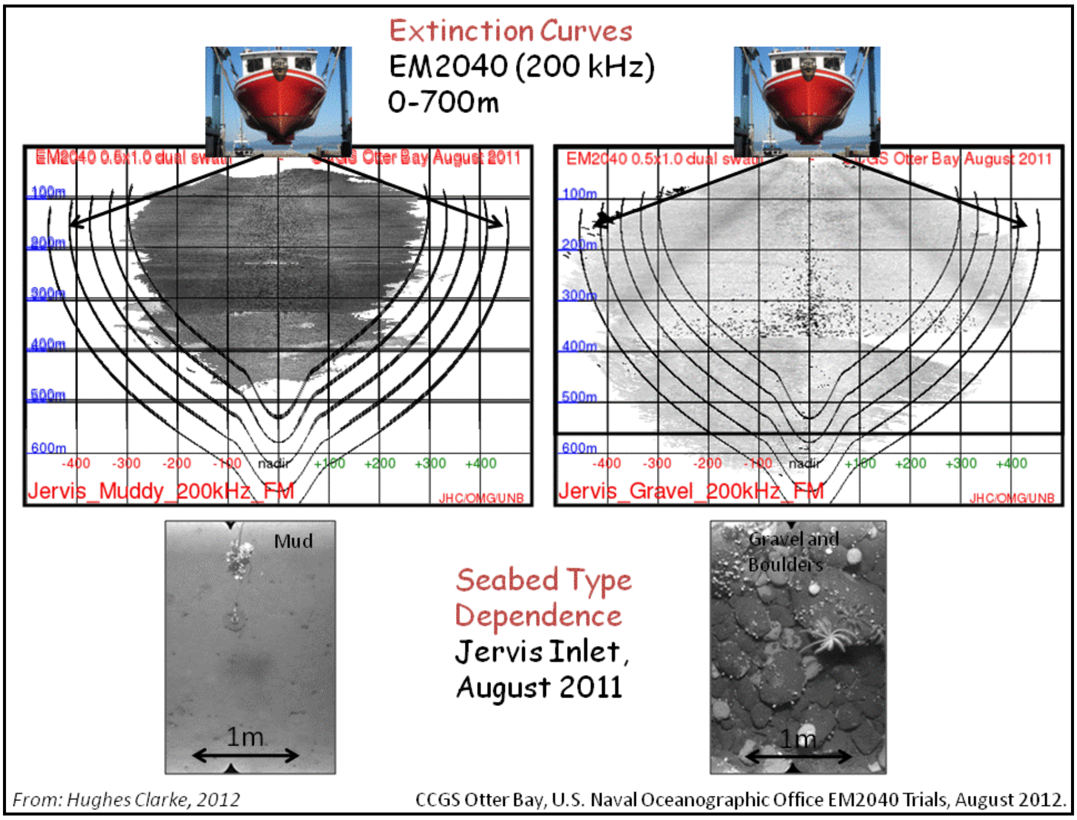

Figure 12 - EM2040 extinction and coverage results in Jervis Inlet - mud (left) versus gravel (right).

4.2. REMUS/EM3002

The primary focus for REMUS AUV testing was evaluating the vehicle's underwater positioning performance using the newly integrated Kongsberg NavP capability and test using the Kongsberg HiPAP acoustic navigation system. The second purpose was to compare the vehicle's EM3002 and sidescan sonar system data against EM2040 data.

The artificial target field in the test bed provided an excellent positioning evaluation source for the REMUS vehicle since the targets were all precisely located from the surface when deployed and from surface vessel confirmation using multibeam sonar. Positioning drift in the different navigation modes was then evaluated. The NavP and HiPAP solutions provided marked positioning improvement.

Figure 13 shows sample results that compare the EM2040 imagery data with the REMUS sidescan data. The EM2040 data over a target is in the top two imagery frames (left and right). The REMUS images are all below the EM2040 image and have the particular sonar geometry drawn above the image graphic. Zoomed images are on the right hand side.

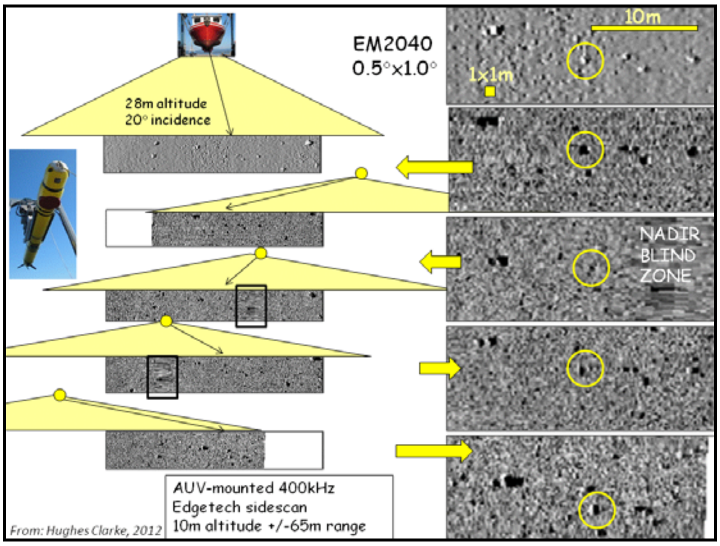

Figure 13 - Comparison of EM2040 sub-metre target detection in 28 m compared to Remus AUV sidescan

4.3. Reson 7125

After EM2040 testing was completed, data was acquired using the Reson 7125 multibeam sonar for evaluation in many of the same EM2040 test-bed locations. An area view of the testing locations and transit lines is shown in Figure 14. Testing included:

- Target detection testing for detecting and tracking of both artificial concrete cube targets and small natural rock targets.
- Coverage extinction testing for determining the achievable swath coverage as a function of depth over differing bottom types.
- Bathymetric accuracy testing using different frequencies in 20, 50, and 80-m water depths.
- Water column wreck tracking and imaging to evaluate system detection of shoalest depths, wreck structure resolution and bottom tracking in complex scattering environments (G.B. Church and HMS Mackenzie wreck sites).
- Spatial resolution testing (fine seabed morphology at Trial Islands).
- Bottom tracking robustness over challenging bottom types (eel grass area in Bazan Bay).

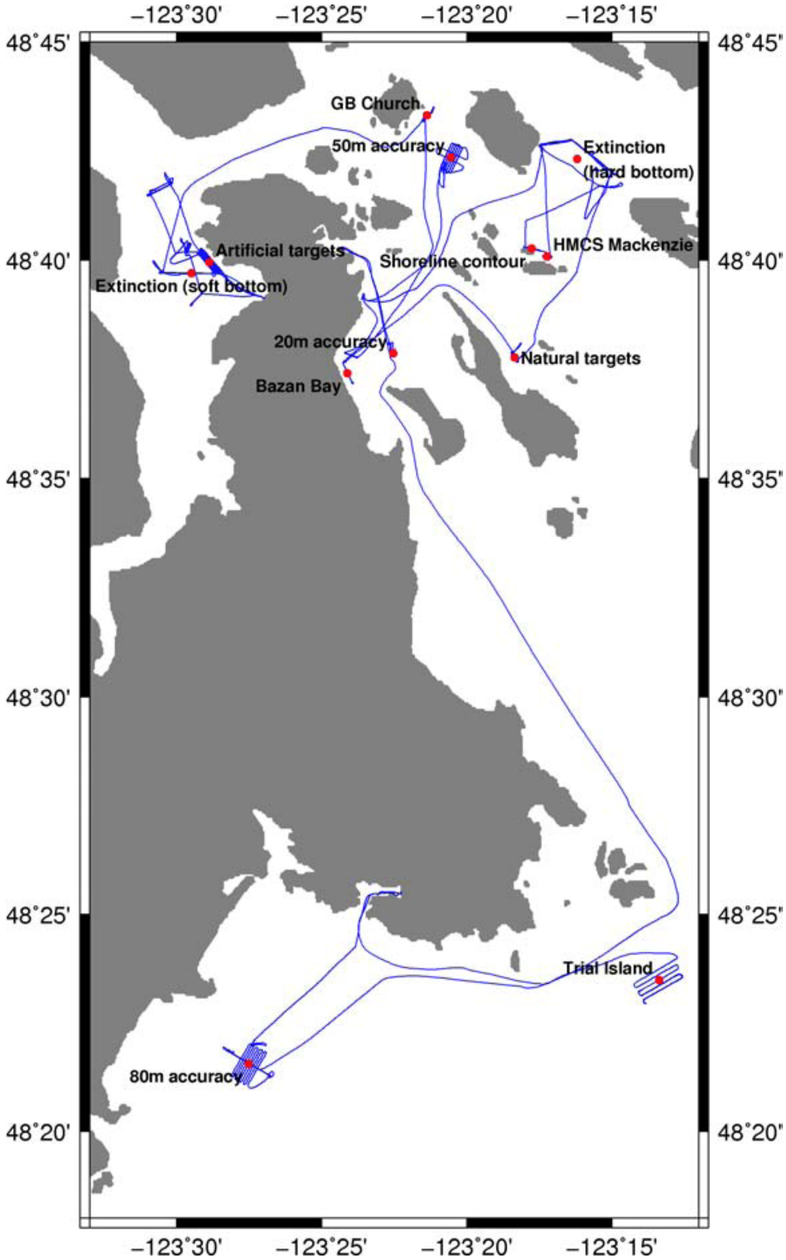

Figure 14 - Map of operational areas within the BC sonar test bed used for Reson 7125 evaluation

4.3.1. Target Detection

The 7125 system detected nearly 100% of the 1-m cubes both at 20-m and 40-m depth and at all angles across the swath and thus meets the IHO Special Order detection requirement. Note that "detected" does not imply "resolved"; rather that a bathymetric shoal was observed over the cubes. The 0.5-m cubes were more problematic and likely exhibit an angular dependence that could be ascertained with further work. See Figure 15 for an example.

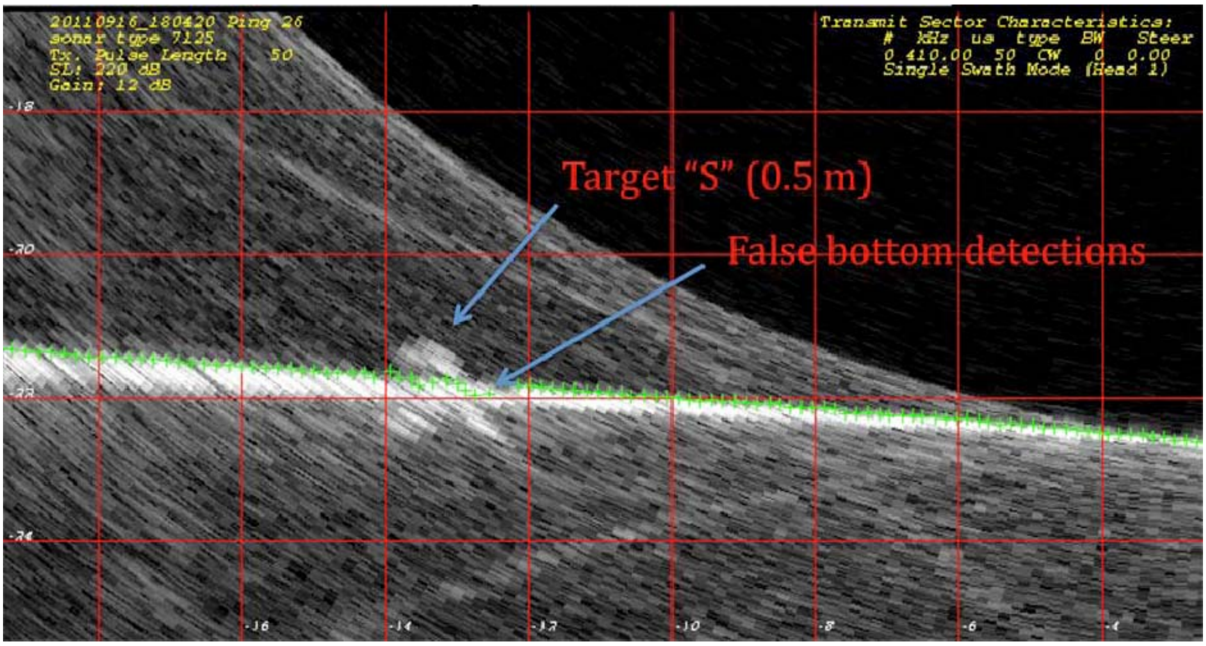

Figure 15 - Bottom tracking solutions (green crosses) plotted over water column imagery

4.3.2. Extinction Tests

The Reson 7125 system maintains full coverage across +/- 70° in 200-kHz mode with FM pulses to a depth of ~200-m over the hard bottom of Haro Strait. The 400-kHz mode became attenuation limited at ~100-m depth and was fully extinct at 300-m depth. Full extinction was not observed in 200-kHz mode due to the limited maximum depth tested. Further field work (or modeling) could be done to estimate the degradation of the 200-kHz swath width beyond the depth where it is attenuation limited. In general, the experimental FM pulse waveforms gave increased coverage over their CW counterparts in both 200- and 400-kHz modes. Some bottom tracking problems were observed in FM mode; however, these were likely due to excessive pulse length selections.

4.3.3. Accuracy Tests

The NAVOCEANO SWATH boat was used for the Reson 7125 evaluations with a dual-headed configuration employing twin bow-mounted poles on a catamaran style hull. The pole installations were suboptimal, resulting in pole-mount wobble, shifting, and deflection occurring throughout the trials. Test data evaluation indicates that the system provides data readily meeting IHO Special Order 1 requirements. Supplemental post processing to this dataset could substantially improve the testing results by mitigating artifacts from the pole-mount arrangement, particularly resolving the intermittent roll artefact and time varying roll misalignment angle (the roll offset changed from day to day). These problems should not be misconstrued as defects of the echo sounder itself, but due to insufficient pole-mount rigidity on this particular installation.

4.3.4. Wreck Tracking and Imaging

The 7125 proved adept at tracking wreck superstructure for the two wrecks investigated in the test bed. The system was able to track all wreck superstructure and features for the G.B. Church (Figure 16). For the HMCS Mackenzie, the system did not track on a small number of features, but these features were always resolved on other passes. In the case of the G.B. Church, the bathymetric detections alone would have provided the least depths. This is nearly the case with the HMCS Mackenzie, but the fact that a few notable exceptions occurred suggests that wreck mapping should be done with several passes with varying imaging geometries.

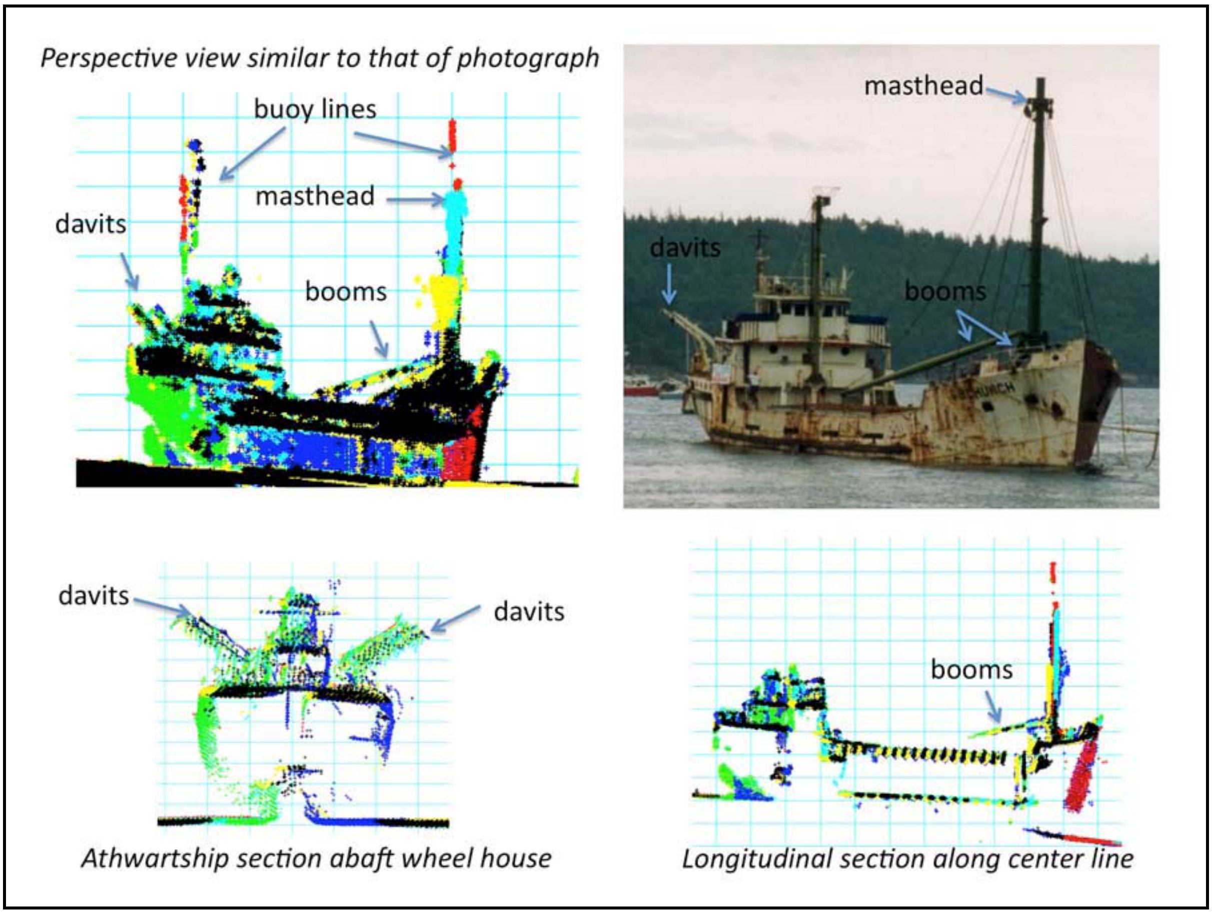

Figure 16 - Detected soundings over G.B. Church, 13 passes, colour-coded by pass

4.4. Testing Location Selection

The NAVOCEANO decision to change the location from Key West, FL to Sidney, BC and collaborate with CHS and OMG and establish this test bed for sonar system evaluation was unquestionably the right decision. The risk assessment was evaluated correctly, particularly considering that tropical weather systems were active over the Key West area during the BC testing period and they most certainly would have shut down or severely curtailed the planned testing. Beyond weather, once the operation began in BC, the real value of this location was realized.

The logistics support provided by DFO, CHS and CCG went far beyond what was even considered as originally needed for the operation and without which would have been extremely difficult and expensive to obtain. The shore based services at IOS were comprehensive and included vessel docking, dry docking, crane services for heavy equipment lifts, fork lifts, etc. Special work areas for conferencing, data post processing, and equipment storage and staging were all made available. Personnel commuter runs between IOS and the work boats to facilitate troubleshooting and other services made for very efficient use of time. Resources of the shipping and receiving department made easy access to shipping services. All of these services were in one location. Moreover, the extensive logistics capability of the IOS location made possible the utilization of the NAVOCEANO SWATH boat that facilitated other testing possibilities (AUVs, sidescans, etc.).

In considering all aspects of location and support with this Canadian venture, it would be difficult to put a price on the benefits NAVOCEANO received that would have been very difficult or costly to otherwise obtain elsewhere.

5. FUTURE WORK

5.1. Status of data

More than two (2) Terabytes of sonar data were collected during the six weeks of summer 2011 testing with the three platforms (*Otter Bay*, REMUS AUV and SWATH boat). The bathymetry data from the EM2040 have been checked by CHS for any needed updates for Notices to Mariners. No updates were found needed, but the minimum charted depth over one artificial dive site does appear to be too shallow. All the EM2040 data are considered superior to CHS existing multibeam data, and are being loaded into our CARIS Bathy DataBASE to supersede the coincident portions of the older data sets. The data will ultimately be used for chart updating.

The data is owned by CHS, under the terms of the collaborative agreement; CHS is responsible for its administration and distribution. The project partners can get access to the data for their own uses through a letter of permission. Interested researchers can get (free) access to the data through a licence agreement with CHS.

5.2. Further analysis

Opportunities will abound for further sonar evaluation and additional research using the vast amounts of sonar data already collected. It’s suggested the data be utilized for graduate level thesis analysis. Imagery analysis of backscatter data was only minimally conducted and further investigation is encouraged to push the technological state-of-the-art in sonar signal processing.

5.3. Future trials planned

NAVOCEANO has tentatively planned to return to the BC test bed area for subsequent testing of EM2040-equipped HSLs, probably in summer 2013. The testing would utilize the 2011 dataset for comparative purposes. Successful testing results will validate the HSLs as ready for operational deployment. Since HSL pairs are assigned to the T-AGS 60 class vessels, HSL pairs will be rotated through the life-cycle upgrade process for operational and support considerations.

6. SUMMARY

The NAVOCEANO / CHS collaborative effort that was implemented for conducting sonar demonstration testing was a far more complicated and logistically challenging endeavour than first realized. It took over a year from first conception to hurdle all the bureaucratic roadblocks and set the pieces in order and get boats on the water. But it was completed, and the results are certainly spectacular. And we can say that the establishment of this test bed will leave a valuable legacy for future evaluations and sonar research. Finally, the effort will facilitate implementing the lifecycle replacement program for NAVOCEANO HSLs.

7. REFERENCES

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For a project of this size, there were many others, of course.

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