Side Scan Versus Multibeam Echosounder Object Detection: A Comparative Analysis

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Abstract – The undisputed remote sensing tool for detailed sea floor object detection is the side scan sonar. From pipelines, to downed aircraft, to mines, a side scan sonar's unique characteristics effectively ensonify and subsequently display these objects. For bathymetry, the Multibeam Echosounder (MBES) has quickly proven its superior capabilities. An MBES's unique characteristics allow it to provide 100 per cent ensonification of the sea floor while meeting or even exceeding IHO specifications. During the 1997 Coastal Multibeam Sonar Training Course in Victoria, BC, inert mines were laid at different depths and then ensonified by a side scan sonar and an MBES. The aim of this exercise was to compare the detection characteristics of the two sonars using one of the inert mines. This paper is a discussion of that comparison and the lessons learned. Comparative imagery is used to illustrate the success of each sonar in illuminating the mines to the operator. Unaided visual detection is not always the most efficient method for finding objects in large quantities of MBES data; therefore, subtractive temporal analysis was implemented in order to enhance the MBES object detection process. As well, a simple automated detection algorithm was used successfully on the temporally differenced images. The background, implementation and results of the MBES subtractive analysis performed in the area of the inert mine will be compared to the detection achieved using the side scan sonar. Finally, conclusions will be drawn as to the efficacy of the MBES as an object detection sonar.

I. Introduction

The geometry of a side scan sonar's transducer in relation to a target is the key factor which makes the side scan such a successful tool for object detection. The shadows cast behind an object, proud of the sea floor, are the telltale sign that an object has just been ensonified. The geometry of a Multibeam Echosounder's (MBES) transducer in relation to sea floor targets results in the loss of almost all shadow-casting capability. An operator wishing to use an MBES for object detection must then rely on the MBES's other characteristics in order to look for any objects. These characteristics are of course: high-resolution bathymetry and amplitude backscatter coupled with a positioning capability allowing for very accurate repeatability.

During the 1997 Coastal Multibeam Sonar Training Course in Victoria, BC, inert mines were placed at various depths in Patricia Bay. The focus of this paper is on one particular mine and the side scan and multibeam imagery gathered on and around that mine. Several passes were made by each sonar over and beside the 2000lb mine in order to compare their respective abilities in displaying the mine to the operator.

The side scan sonar's real time capability to detect the 2000lb mine was excellent. Images and a discussion of the results are discussed in this paper, however since the efficacy of side scan sonar for object-detection is already well documented, it is not our intent to delve into too much detail with respect to this particular capability. Instead, we focus on the MBES' capabilities and the post-processing techniques used to detect the mine. Unlike the side scan sonar, the MBES required post processing in order to allow any results to be seen. Specifically, we compared the digital terrain models (DTM) of the same area before and after the mine was present. The results of using an MBES as an object detection sonar are discussed in detail. Finally, conclusions are drawn as to how an MBES could be used with respect to object detection.

II. Area and Object

The practical portion of the Multibeam Course was held at the Institute of Ocean Sciences on the shore of Patricia Bay, north of Victoria. It was in this bay that the Divers of the Canadian Navy's Fleet Diving Unit (Pacific)

Figure 1 – MK 25 2000lb Mine

placed three inert mines on its relatively featureless sandy-clay sea floor near the Institute. A 2000lb inert mine (Mk 25) was placed at 30 meters depth and it was ensonified by a 100 kHz side scan sonar and a 300 kHz (1.5 degree beam width) MBES. The mine itself (Figure 1) was cylindrical in shape with a length of 2.13m and diameter of 0.58m. The side scan sonar ensonified the mine six times at various ranges all within 100 meters. The MBES passed over or beside the mine a total of nine times allowing for ensonification in both the amplitude-detect nadir and near nadir beams as well as the phase-detect off nadir beams. Although two other smaller mines were placed at shoaller depths, not enough data was collected by either sonar to present any significant results.

III. Side Scan Sonar Results

The side scan sonar used was the Simrad Mesotech 972. The 972 was operated in the 100 meter range mode and was connected to a Triton-Elics ISIS collection system. The side scan sonar allowed the operator to consistently detect the mine in real time on both the 972 and ISIS displays. Furthermore, the ISIS display allowed the operator to measure the target in order to confirm the object dimensions as those of the Mk 25 mine. During post-processing, the operator detected position was compared with the known position of the mine to ensure that that the detection was successful. Figures 2a and 2b are screen captures from the ISIS Target Utility. The images show the Mk 25 as seen on the 972 port and starboard channels whereas Figure 3 shows more information on the contact. At the time of the survey, the 972 had a degraded port channel, which is apparent in the imagery. The result of the contact measurement performed by the operator (magenta and blue lines around the mine) as well as other relevant information is displayed in the *Contact Measure* section. Other information in Figure 3 includes the position of the mine calculated by ISIS, which was reasonably close (~20 meters) to the actual position of the mine. The tow fish had no transponder system, which accounts for the positional discrepancy.

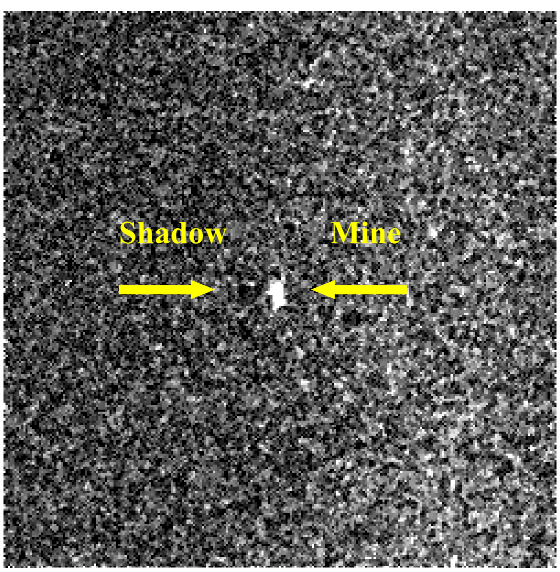


Figure 2a – MK 25: Port Channel

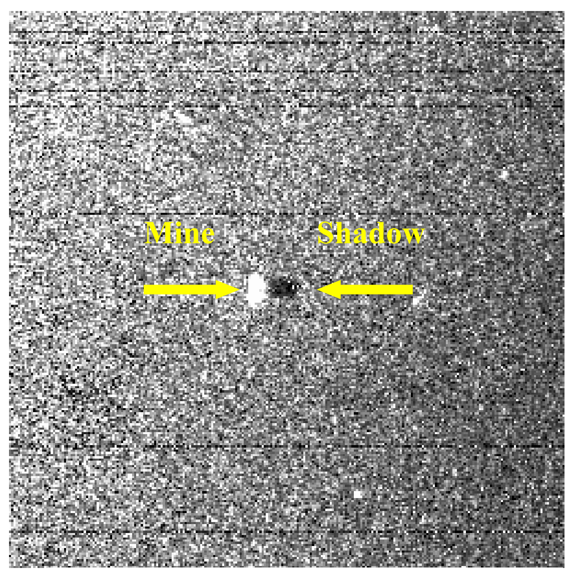


Figure 2b – MK 25: Stbd Channel

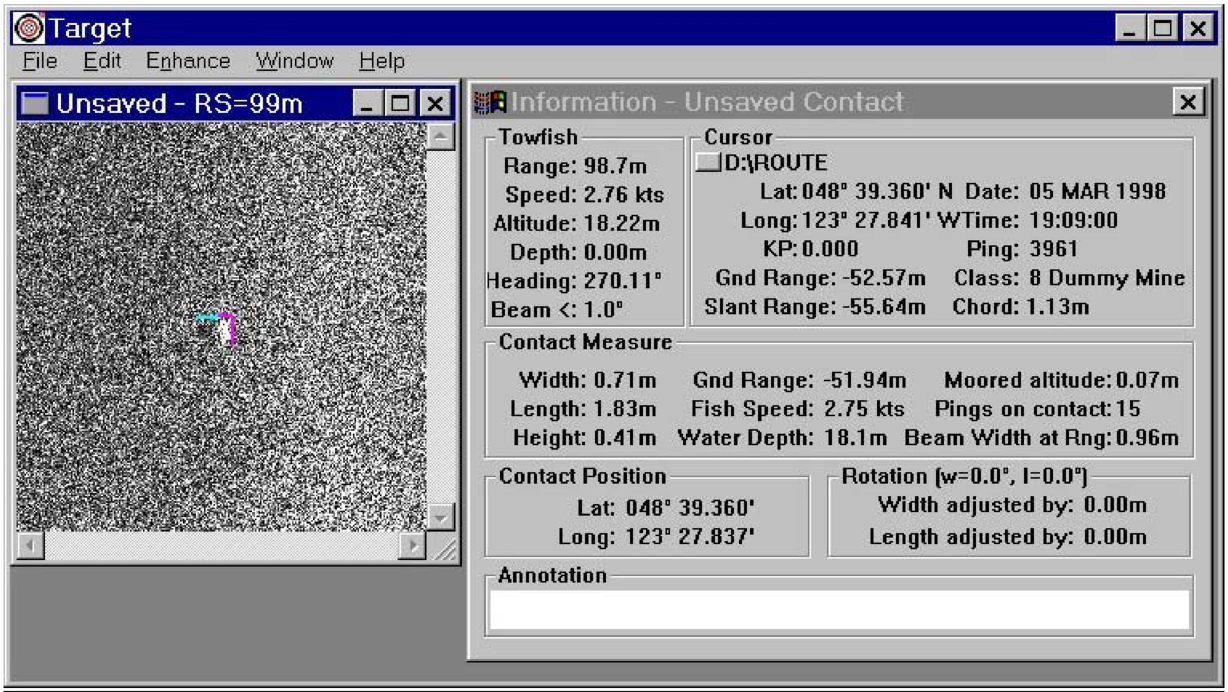


Figure 3 – MK 25 in ISIS Target Utility

Ultimately, the shadows cast behind the MK 25 allowed the operator to readily detect it. The low grazing angle of a side scan sonar beam over the sea floor makes it ideal for object detection. The examples above reinforce the efficacy of this type of sonar as an object detector.

IV. MBES Object Detection – Amplitude Backscatter vs. Bathymetric Anomalies

The fact that an MBES transducer is rigid-mounted to the hull of the survey vessel means that its position may be calculated as accurately as that of the positioning system in use. Coupled with the capability of forming discrete beams, the MBES is the tool of choice for bathymetric surveys. Given an MBES's positional capabilities, subsequent passes over the same stationary object should yield exactly the same georeferenced position. The small difference (if any) in the contact's position is of great advantage when looking for objects which must be revisited for purposes of *in situ* identification either by ROV or diver. Unfortunately however, the fixed transducer results in broad grazing angles that are not conducive to real time object detection using the same shadow-casting principles of the side scan sonar.

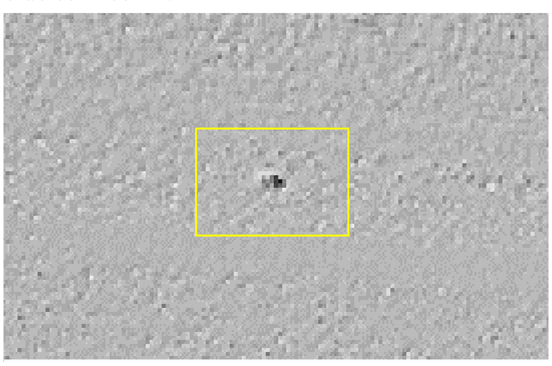


Figure 4a – MK 25 in MBES Sun Illuminated Bathymetry

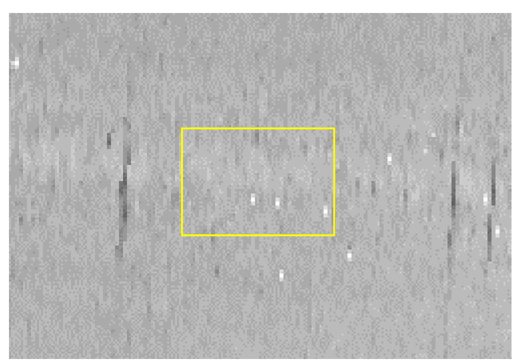


Figure 4b – MK 25 in MBES Amplitude Backscatter

Since we knew that an MBES could detect objects in the same manner as a side scan sonar we concentrated on its high-resolution bathymetry in order to detect the inert mines in Patricia Bay. We did not examine the use of amplitude backscatter from the MBES, as previous attempts in other surveys were unsuccessful [1]. For example, Figure 4a is sun-illuminated bathymetry with a box around the mine itself. Figure 4b is an amplitude backscatter image of the exact same area as in 4a however the reader will not notice any distinguishing features on or around the mine. The amplitude backscatter output from the MBES was of no help in locating the inert mine.

Figure 4a has already illustrated the capability for the MBES to distinguish the bathymetric anomaly associated with the MK 25 mine. The size of the nadir footprint of the 1.5 degree beamwidth MBES at 30 meters is approximately 0.8 meters in diameter and over 3 meters for the extreme outer beams. Given the size of the beams versus the size of the mine it was expected that the bathymetric anomaly created by the mine would be resolved by the MBES. This did in fact occur, which is seen above in Figure 4A in the near nadir region.

V. MBES - Object Detection Potential

Two factors control the potential bathymetric target resolution capability of an MBES:

- the sounding solution spacing and
- the quality of the bottom detection for each solution.

Solution Spacing

The two factors that must be considered with regard to solution spacing are along track and across track spacing. In the along track direction, an EM3000 has an inter-ping rate that can be described as follows [2]:

$$dt = 32 \text{ msec} + 5.5 \text{ msec/m} * Z \text{ m}$$

From the above formula the inter-ping rate at 10m is 87msec, at 20m is 142msec, and at 30m is 197msec. Given the preceding calculations and a vessel speed of 8 knots, the distance between successive pings at 30 meters depth is approximately 0.6 meters. Since the size of the nadir (smallest) beam at 30 meters is 0.8 meters, a target the size of the Mk 25 mine will not “fall between the cracks”; it will be ensonified.

While in restricted waters, short period heading changes are of small amplitude along a survey line. In the open ocean however, wave driven course shift can be up to +/- 10 degrees with periods similar to the ocean wave spectrum (4-12 seconds). This results in both divergent and convergent clustering of the outer swath data. It is possible to either not ensonify a sea floor object at all or ensonify it more than once along the same survey track line. Careful consideration must be given to track spacing when the effects of yaw are pronounced.

Looking now at the across track spacing factor, the EM3000 sonar uses beams spaced in an unusual manner. For computational speed reasons the receive beams’ orientations are fixed with respect to the physical sonar frame. The beam spacing is 0.9 degrees at nadir but the spacing is increased by the secant of the steering angle (thus 1.8 degrees at 60 degrees). The across track EM3000 beam density is as follows:

Incidence Angle (deg)	Depth (m)		
	10	20	30
0	6.4	3.2	2.1
20	6.0	3.0	2.0
40	4.9	2.4	1.6
60	3.2	1.6	1.1

Table 1 – Across Track Beam Density (beams/m)

Bottom Detection Quality

Statistical testing of field data has shown that the sounding solutions have standard deviations at the level of about 10-15 cm for depths less than 30m [2]. These results are only valid for resolving topographic wavelengths that are large with respect to the beam therefore we need to quantify the beam footprints.

The EM3000 uses a horizontally aligned transverse receive array. While beams formed at boresite have a beamwidth of 1.5 degrees, those steered off to the side have beamwidths that grow with the secant of the steering angle (at 60 degrees this would be 3 degrees). If these outer beams hit a flat seafloor, their across track dimension is greater than that at nadir by a factor combining their increased beamwidth and the obliquity (a second secant term). Thus the beam footprints are ~4 times larger in the across track dimension in the outer beams, which results in a loss in target resolution capability. The effect of broader across track dimensions however, can be minimised by the use of phase detection methods [3]. With appropriate phase detection, targets with wavelengths as short as the along track dimension may be resolved. In order to take advantage of this however, the across track beam spacing (as opposed to the width) must be at this level or tighter, which is not the case for the EM3000. In the future, equidistant beam spacing has been proposed for the EM3000 (Hammerstad pers. comm.) but this has not been implemented to date. This would partly offset the loss of target detection capability in the outer beams that is so clearly evident in the results of these trials.

Combining our knowledge of the beam spacing and bottom detection methods, synthetic modelling [4] has predicted that sonars with characteristics close to an EM3000 will be right at the limit of meeting the new IHO criteria. Unpublished Field observations on 1-2m boulders support this. Mine hunting criteria is more stringent, but allows for the possibility of using the sonar from a tow fish rather than the generally more distant sea surface.

VI. MBES - Object Detection Observations

Several passes (nine) were made over or near the MK 25 mine in order to allow the MBES to ensonify the mine with different beams. We were fortunate in that a mine-like object was already present 20 meters northeast of the MK 25, with approximate dimensions of 1.6m x 1.2m x .5m. We did not identify this object but believed it to be a rock. Table 2 below shows the results of the nine passes in the area and detection results of both the mine and the rock. In the 'Results' column *No Coverage* means the mine was not ensonified, *Strong Detection* and *Detection* imply the object was readily apparent, and *Weak Detection* implies that beforehand knowledge of the object's location was required in order to identify it. The MBES in use had 127 beams with amplitude detection in the near nadir beams and phase detection in the outer beams.

Line Number	MK 25			Rock		
	Result	Beam No.	Amplitude Or Phase	Result	Beam No.	Amplitude Or Phase
21	Lost in turn		A	Detected	13,14	P
22	No coverage	N/A	N/A	No coverage	N/A	N/A
23	Strong Detection	64,65,66, 67,68	A	Detected	22,23	P
24	Strong Detection	41,42,43	A	Weak Detection	12,13	P
25	Not Detected	18	P	No Coverage	N/A	N/A
26	Not Detected	11	P	No Coverage	N/A	N/A
27	Not Detected	115	P	Strong Detection	54,55,56, 57	A
28	Not Detected	118	P	Detected	97,98,99	P
29	Not Detected	123	P	Not Detected	110	P

Table 2 – Detection Results of MK 25 Mine and Nearby Rock

From Table 2 it can be seen that the MBES had little difficulty in detecting the two objects when they were in the near nadir (amplitude detect) regions. The only exception to this is the very first line where the MK 25 was in the nadir beams but was lost while the survey vessel was turning. The results in the outer (phase detect) beams however were not as consistent. The two objects were detected in the outer beams less than half of the time. Figure 5a below is from line no. 23 with the MK 25 in the nadir beams (64,65,66,67,68) and the rock in the outer beams (22,23). Figure 5b shows line number 28 with the rock in the outer beams (97,98,99) with the MK 25 lost in the extreme outer beams (~118).

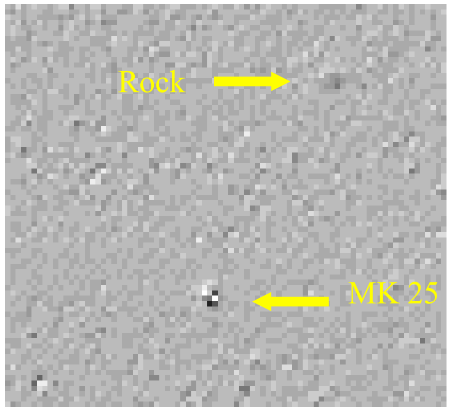


Figure 5a

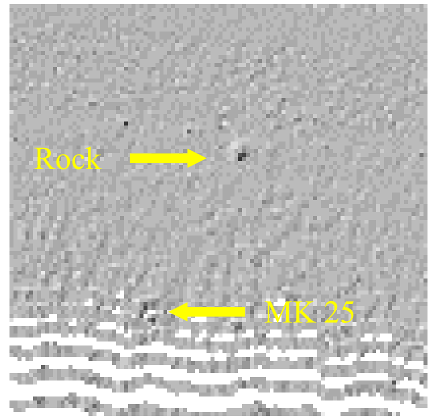


Figure 5b

VII. MBES Object Detection via Temporal Analysis

In section VI above we showed that the MBES used was capable of consistently detecting the MK 25 mine in the near nadir regions and sometimes in the outer regions as well. Figure 4A clearly showed the bathymetric anomaly associated with the mine and one can draw the conclusion that real time mine detection is possible. This may be true, but what about the case where the object is located in a clutter field? It is reasonable to expect that the object in question may have been introduced into an area where tens, hundreds, or even thousands of similar sized objects have been in place before the new object was introduced. Real time detection using the MBES will occur but what exactly will be detected? How will the operator determine which of the mine like objects is *the* mine and which are similar sized objects? The answers to these questions may lie in the Mine Counter Measure technique known as Route Survey.

Route Survey is a side scan sonar technique where an area of interest (such as a critical shipping route) is surveyed before the threat of belligerent mines becomes a reality. Once the area is mapped, and the post processing is performed, all mine like objects are identified and catalogued. Should the shipping route be mined, a subsequent survey is executed and temporal analysis performed. Those objects which appear in the 'after' survey and not the 'before' are then scheduled for identification either via an ROV or other techniques. This is an efficient and popular MCM technique practiced by many countries including Canada.

In the Patricia Bay survey, we were able to perform temporal analysis on the area containing the MK 25 mine however we did it in reverse. First the area was surveyed with the mine in place and then resurveyed after the mine was removed. This was done simply due to the availability of the mine and the survey vessel, however the technique itself was not compromised by this reversal of steps. As well, the second survey was performed only with the MBES and not the side scan sonar.

The post processing involved in this temporal analysis was very straightforward. First both surveys were processed independently and 'before' and 'after' DTMs were produced which were binned at 0.5 meters. The DTM without the mine was then subtracted from the DTM with the mine. The resultant surface was then rendered in 3-D using *Fledermaus* from Interactive Visualization Systems. Theoretically one would have expected a near null surface with bathymetric anomalies in the area containing the mine; this was not exactly the case. The bathymetric anomaly created by the mine was observed, but the surrounding surface fluctuated from grid cell to grid cell by as much as 20 centimeters. Regardless, when the mine was in the near nadir beams it was easily visible to the eye in the resultant surface. In the DTMs below, the white vertical line indicates the actual known position of the MK25 mine.

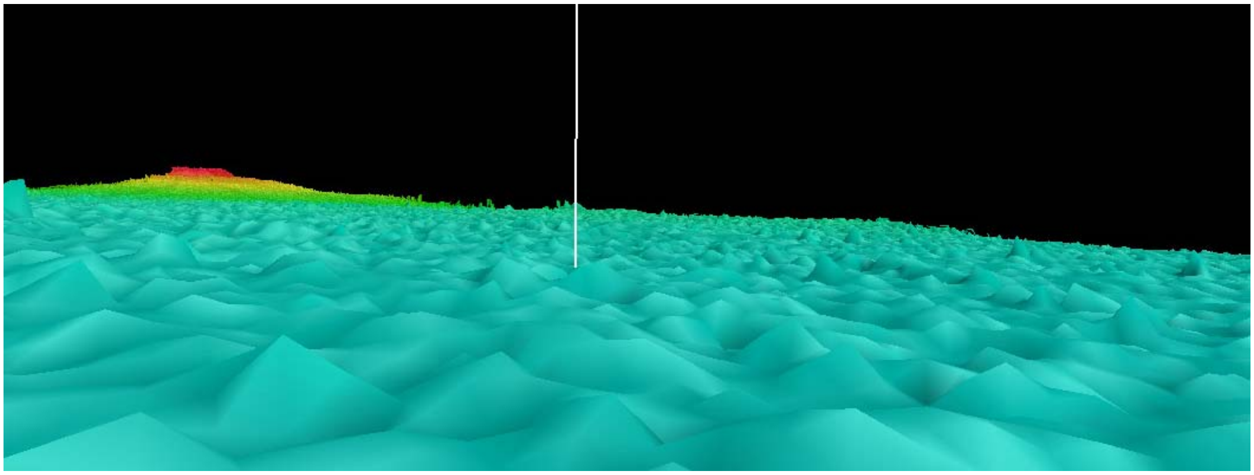


Figure 6a: 3-D DTM of area without the mine

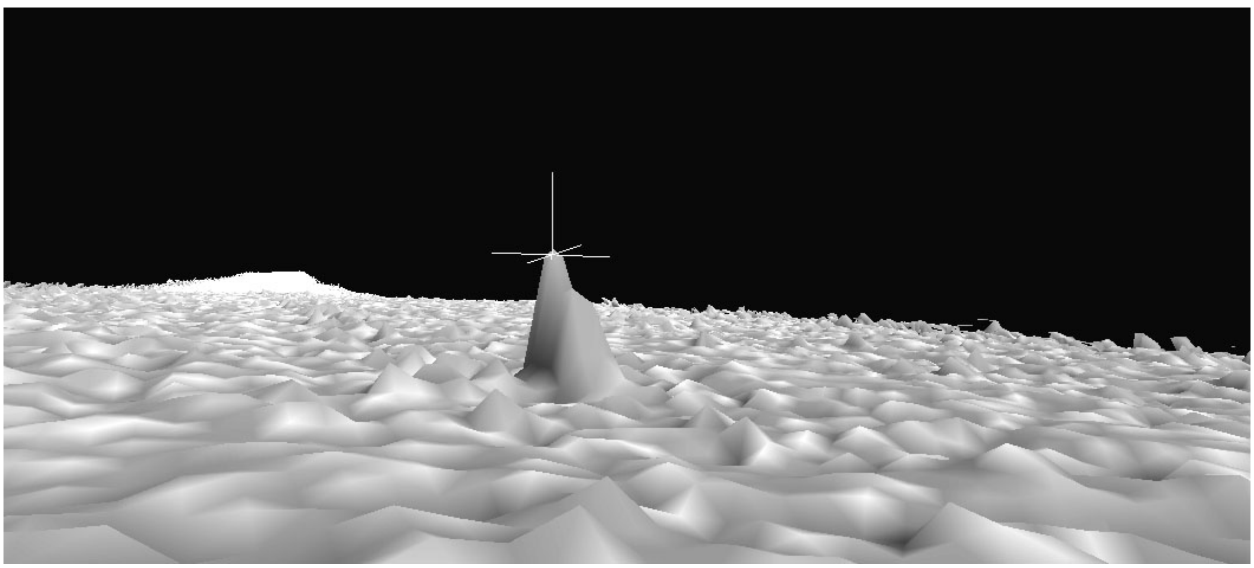


Figure 6b: MK25 Mine on sea floor at 30 meters depth

Table 3 shows the portions of the resultant surfaces where the mine was located. The reader may readily observe whether or not the mine was detected. It can be seen from the images in Table 3 that MBES temporal analysis for the purpose of (new) object detection can be very effective. The detection results previously seen in Table 2 are reinforced by the images in Table 3. Note that the anomalies in Lines 21 and 27 are random in nature and no larger than other surrounding anomalies. Temporal analysis in this experiment proved to be extremely effective. Where the MBES effectively detected the mine, the resultant surfaces highlighted the anomalous soundings that the operator was able to quickly identify. The resolution, and hence detection capability of the MBES in use, was the obvious limitation in this survey. In this particular experiment the MBES had difficulty in consistently detecting the MK 25 mine in the outer beams at the chosen depth of 30 meters.

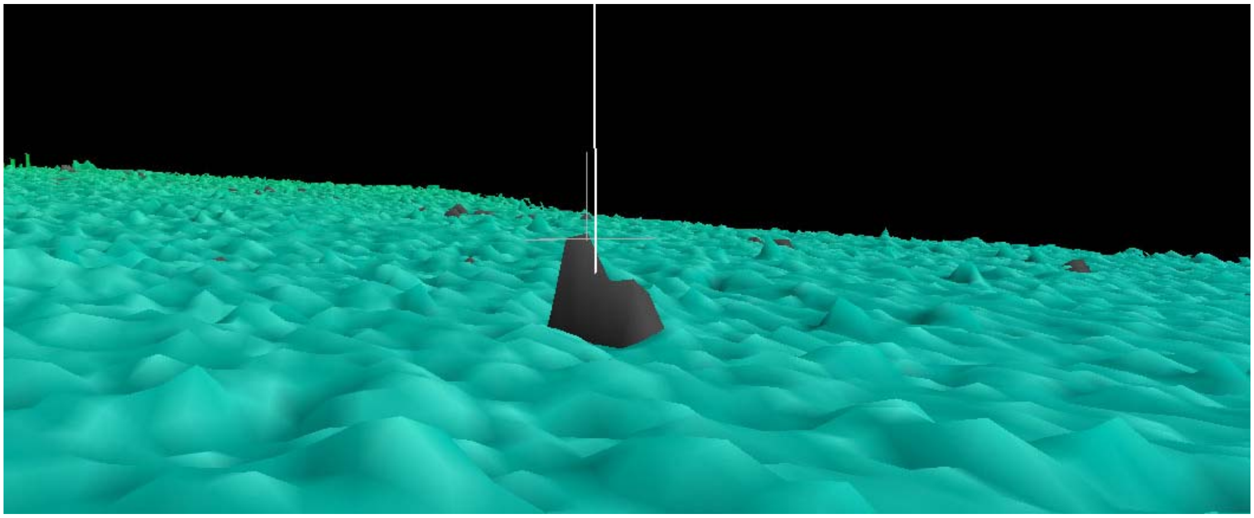


Figure 6c: Mine DTM superimposed over DTM without mine

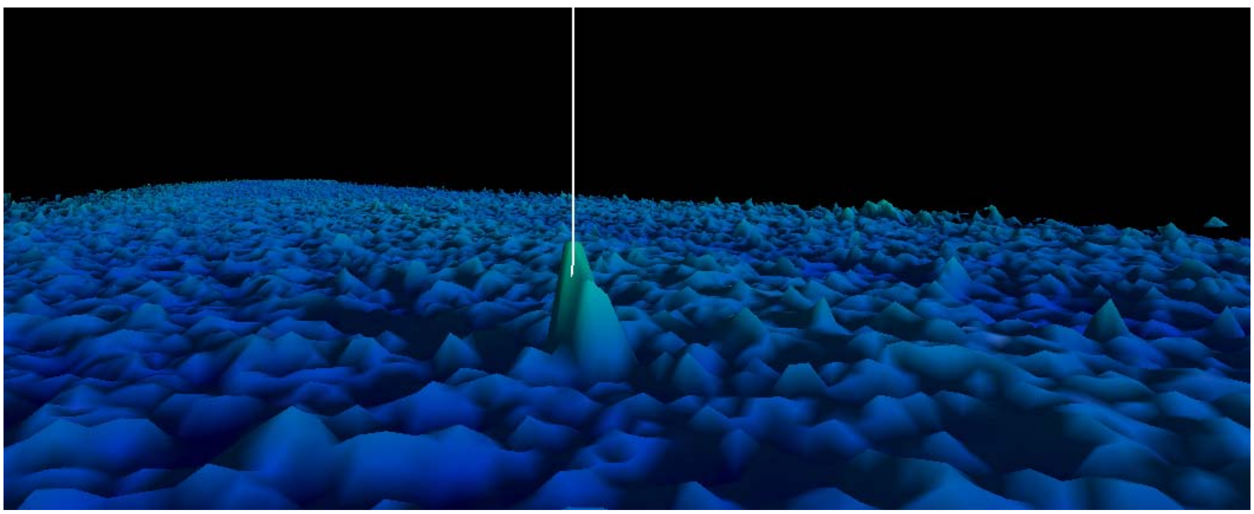


Figure 6d: Resultant surface 6a subtracted from 6b

VIII. Automated Detection Algorithm

In our paper presented at Oceans 97 [1] an automated detection algorithm was discussed. The algorithm was able to extract bathymetric information from the EM3000 raw telegrams and perform object detection. The algorithm looked for bathymetric anomalies the sizes of which were user specified. The algorithm was able to take slope into account but its greatest weakness was that clutter areas containing objects the same size as the object of interest generated multiple possibilities. For this experiment, the algorithm was modified to read in the post-processed DTMs. As in its original version, the algorithm would look for bathymetric anomalies but clutter and slope would be irrelevant, as the differenced images should have removed temporal constants such as these. With regard to slope, it was in fact eliminated in the resultant DTM but some objects were not. Although the MBES was well navigated, objects smaller than the DGPS uncertainty (plus other integration errors) were not exactly in the same position in the before and after DTMs. Despite this problem, the newly modified algorithm still performed well. Figure 7 is the result of the algorithm applied the resultant image from line 23. The algorithm searched for an object 0.5 meters in size with a tolerance of 25 per cent i.e. 0.38m to 0.63m. Note that the rock to the northeast was not removed in the differencing due to its size.

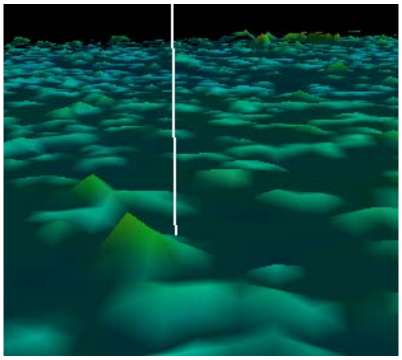
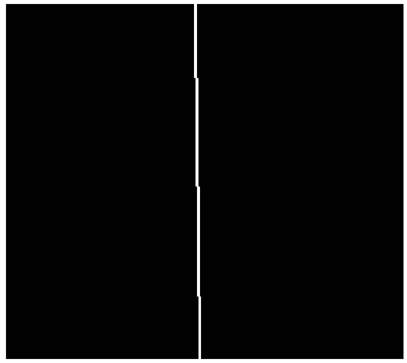
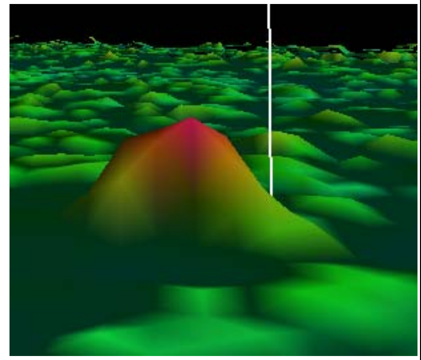
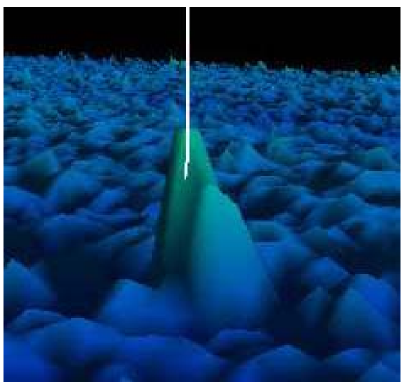
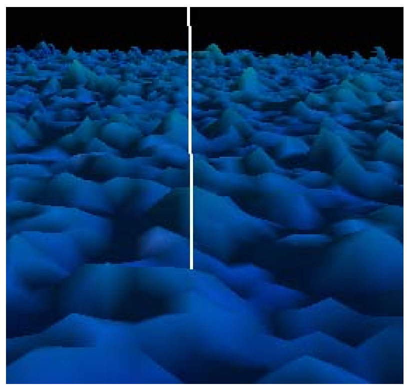
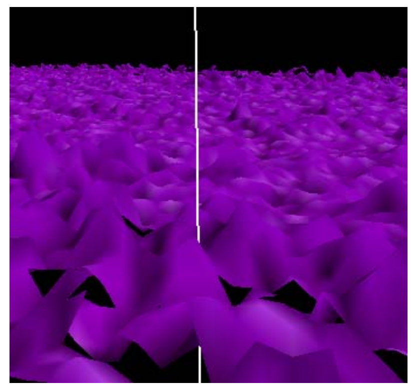
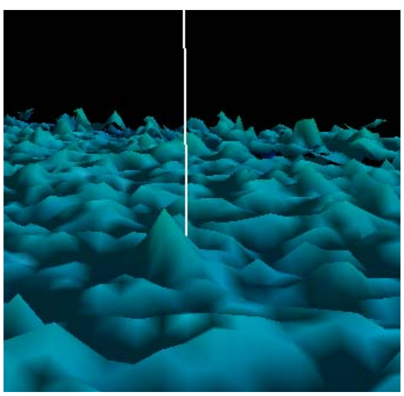
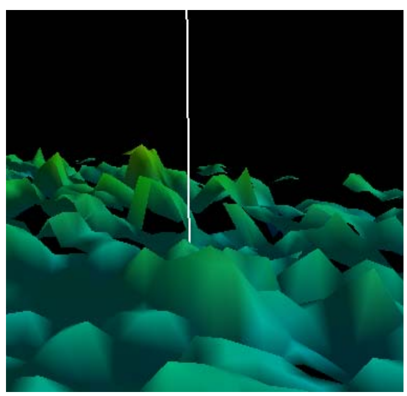
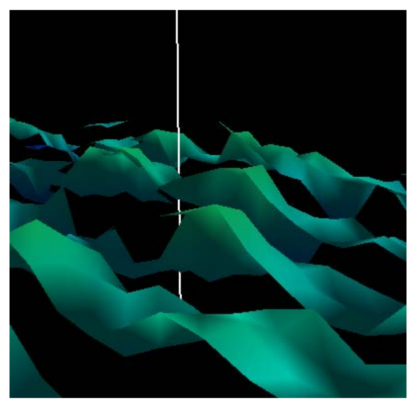
 Line No. 21	 Line No. 22	 Line No. 23
 Line No. 24	 Line No. 25	 Line No. 26
 Line No. 27	 Line No. 28	 Line No. 29

Table 3 – Visual Summary of MK 25 MBES Ensonification

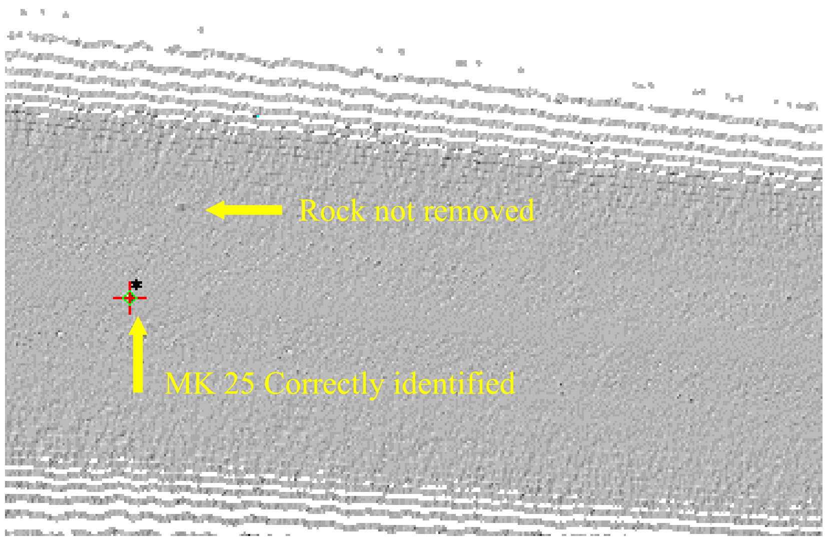


Figure 7 – Results of Detection Algorithm

IX. MBES Object Detection – Discussion

The positional accuracy of an MBES DTM over a side scan sonar image is much greater due to the fixed position of the transducer with respect to the positioning antenna. An MBES' high positional accuracy together with its higher survey speed (versus a traditional single beam side scan) and its reduced draft makes it a desirable tool for object detection. For those wishing to use the MBES for mine like object detection, the limitations imposed by the resolution as well as the detection ability in the phase detect regions lead to the following observations:

a. The size of the footprint versus the size and depth of the object being sought must be calculated and verified by experiment.
b. The line spacing in the survey may have to be limited to the width of the amplitude detect swath if the phase detection characteristics are inconsistent.
c. Decreased beamwidths will allow for either deeper detection of the same object or detection of smaller objects at the same depth.
d. Temporal analysis is an excellent tool for new object detection such as Route Survey.
e. The use of side scan sonar to complement the MBES for object detection, Special Order, and Order 1 surveys is necessary until the object detection characteristics of the MBES are improved.

X. Conclusion

Side scan sonar, when used for object detection, is a proven and capable remote sensing tool. The low grazing angle of the side scan sonar beam over the target and sea floor results in distinctive shadows being cast behinds objects proud of the sea floor. Object detection is greatly enabled by this unique characteristic. Mutlibeam Echosounders, unlike side scan sonars, have their transducers rigidly mounted to the hull of the survey vessel eliminating almost all chances of casting shadows. Using an MBES for object detection requires a focus on the resultant bathymetry rather than (non-existent) shadows. The 2000lb MK 25 mine that was ensonified during Multibeam Course was detected by the MBES but consistent results were only seen in the near-nadir (amplitude detect) beams. Where the MBES was able to detect the mine, temporal analysis performed in the area highlighted the bathymetric anomaly eliminating objects of a more permanent nature. Ultimately temporal analysis is an extremely effectively tool if you fully understand the capabilities and limitations of your MBES. The requirement for a complementary side scan sonar survey to a multibeam survey however cannot yet be eliminated.

XI. Acknowledgements

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XII. References

[1] Brissette, M.B., J.E. Hughes Clarke, J.R. Bradford, and B. MacGowan, 1997, Detecting Small Seabed Targets Using A High Frequency Multibeam Sonar: Geometric Models and Test Results. *Proceedings of the MTS IEEE Oceans 97 Conference*, 6-9 October, Halifax, Nova Scotia, Canada, 8pp.

[2] Hughes Clarke, J.E., 1997, A Comparison Of Swath Sonar Systems Demonstrated At The *1997* US/Canada Hydrographic Commission Coastal Multibeam Surveying Course, http://www.omg.unb.ca/~jhc/uschc97/

[3] Hughes Clarke, J.E., J.V Gardner, M. Torresan, and L. Mayer, 1998, The Limits Of Spatial Resolution Achievable Using A 30 Khz Multibeam Sonar: Model Predictions And Field Results, *Proceedings of the MTS IEEE Oceans 98 Conference*, 28 September – 1 October 1998, Nice, France, 5pp.

[4] Hughes Clarke, J.E., 1998, The Effect Of The Fine Scale Seabed Morphology And Texture On The Fidelity Of Swath Bathymetric Sounding Data*, Proceedings of the Canadian Hydrographic Conference* 98, 10-12 March 1998, Victoria, British Columbia, Canada, 14pp.