Object Detection Using Multibeam Echosounder Temporal Imagery

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Abstract - Previous experiments using an EM3000 shallow water multibeam echosounder have revealed its capabilities and limitations with respect to object detection. Generally, we have seen that small objects such as a 500lb ground mine can be detected in less than 20 meters of water in the nadir and near nadir beams when the object is proud of the sea floor. Our previous experiments were all conducted on flat seafloors, which means that we have not tested the horizontal accuracy or repeatability of the integrated multibeam system, just its vertical resolution. In October 1999 and December 2000, experiments were undertaken in Sidney, BC in order to find mine like objects in an area of dynamic topography. In each experiment we surveyed an area with both slope and bedrock outcrop ranging from 8 to 15 meters depth. We then placed 4 mine like objects in this same area and then ran new survey lines. The before and after surfaces were gridded and then subtracted from each other in order to remove all effects of slope and outcrop in hope of leaving only the mine like object proud of the resultant zero-mean surface. In effect we were testing not only the vertical resolution of the echosounder but also the horizontal repeatability of the positioning system. In the two separate experiments we used a total of three different GPS receivers to measure the survey vessel's horizontal position. This paper discusses the results of the temporal analysis performed with respect to each of the GPS sensors used onboard.

I. Introduction

In previous experiments we have evaluated an EM3000 Multibeam Echosounder (MBES) as an object detector. We discovered that objects approximately the same size and shape as a 500lb mine could be detected as bathymetric anomalies but not as amplitude backscatter anomalies [1]. The mine-like-objects (MLO) that were detected were at a distance generally no greater than 15 metres from the MBES transducer face. In a subsequent experiment [2] we determined that two Digital Terrain Maps (DTM) could be differenced resulting in a zero-mean surface with a bathymetric anomaly showing a MLO that was present in only one of the DTMs. This most recent experiment however, was conducted over a flat sea floor and errors in horizontal positions were nearly irrelevant. The experiments described in this paper went a step further than the one in 1998 by differencing DTMs over a dynamic sea floor.

In the two experiments described here, we placed MLOs on a dynamic seafloor in order to determine if temporal analysis (change detection) could be employed as an object detection tool. Object detection in previous experiments was simple: Since the seafloor was flat and featureless, any robust bathymetric anomaly that appeared *had* to be the object. When the before DTM (no MLO) was subtracted from the after DTM (containing the MLO) a zero mean surface resulted with the bathymetric anomaly standing out. Horizontal positioning errors were irrelevant, as there were no features near the MLOs that had to cancel themselves out in the differencing routine. This paper describes the experiments and the results observed from differencing temporal imagery over a dynamic seafloor as well as the importance of horizontal positioning accuracy.

II. Experiments

In October 1999, an experiment was conducted in Patricia Bay, close to the Institute of Ocean Sciences (IOS), in Sidney British Columbia. An area of approximately 200 metres by 200 metres averaging 15 metres in depth was surveyed using an EM3000 MBES. This area was specifically chosen for the dynamic nature of the bathymetry where there are bedrock outcrops as well as flat featureless areas. The depths in this area range from 7 metres to 17 metres (Fig 1). Once the baseline survey was completed, four large PVC pipes, roughly the size of a 500lb mine (Fig. 2), were laid approximately in the positions labelled in Figure 1. Surface floats marked the PVC pipes and the survey launch's coxswain was instructed to pass within 10 metres of the floats in order to ensonify the PVC pipes in the near-nadir regions of the MBES. Several passes were made over the MLOs and horizontal positions were recorded using a POS/MV 320 as well as a Novatel RT20. Both GPS units received C/A differential corrections from the British Columbia Active Control System via MSAT receiver.

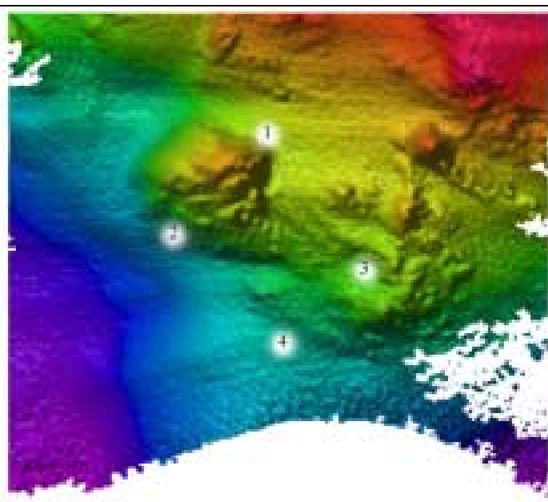


Figure 1 – October 1999 survey area with MLO positions

Figure 2 – PVC Pipe with 500lb Mine

In December 2000, a second experiment was conducted 150m north-west of the October 1999 experiment in order to work in shallower water. A baseline survey was run over an area 80 metres by 30 metres with depths ranging from 3 metres to 11 metres (Fig 3). Four objects were placed along a single line and marked with floats. Two of these objects were the PVC pipes used in the 1999 experiment and two galvanized stovepipes, each seven and eight inches in diameter, were also used (Fig 4). The stovepipes were approximately five feet in length. The survey lines that the launch followed were designed to keep the MLOs within 5 metres (horizontally) of the nadir beams. Horizontal positioning was recorded using the POS/MV 320 as well as a Novatel RT2. The POS/MV 320 received MSAT C/A differential corrections while the RT2 received carrier phase differential corrections from a base station at IOS approximately 2 miles away.

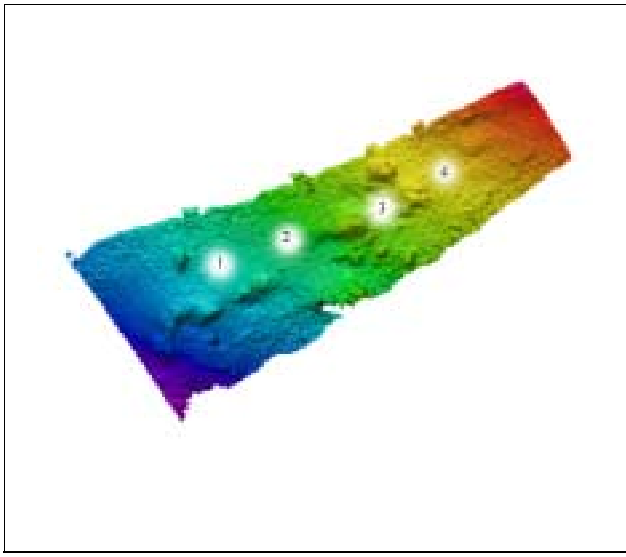


Figure 3 – December 2000 survey area with MLO positions

Figure 4 – December 2000 MLOs

III. Results

October 1999 Experiment

In short, the October 1999 experiment failed to find any of the four MLOs that were laid in the area of interest. In examining the data, two principal reasons for the lack of success were apparent. First, the targets may not have been detected by the MBES. Second, the horizontal positioning accuracy of the GPS units may not have been sufficient to meet the degree of horizontal accuracy required. We were confident that the vertical component of the experiment, namely the height of tide, was not a problem as the tidal reference station was within 1 nautical mile of the survey area, recording heights every minute. In looking at the horizontal accuracy achieved versus what was required it was obvious that the horizontal positioning error needed to be less than the diameter of the MLOs, in this case less than 22cm.

In examining the gridded results we saw that that the horizontal accuracy achieved in post processing was 1 to 2 metres. This accuracy was within IHO specifications for special order surveys and “as advertised” for both the POS/MV 320 and the RT20 in Differential C/A mode. Figure 5 below shows the original sun-illuminated

DTM of the sea floor for Line number 11 (before) and the subsequent DTMs created by subtracting Line number 21 using the POS/MV 320 for positioning and the RT20 respectively. Ideally the resultant images show a zero-mean surface with a bathymetric anomaly representing the MLO introduced after the baseline survey. In the POS/MV example, the outline of the bedrock outcrop remains as an anomaly, as well as a small baseline object (at end of arrow), due to a 1.7 metre horizontal misalignment. Positioning using the RT20 yielded better results with less bedrock outcrop remaining in the resultant image however the baseline object is still present.

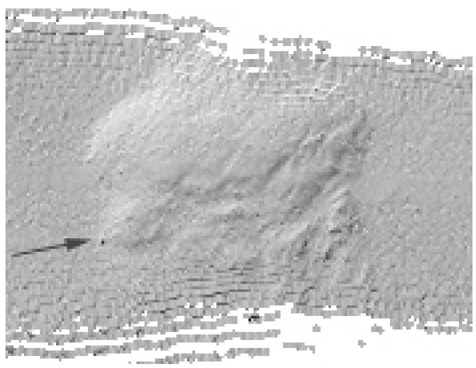
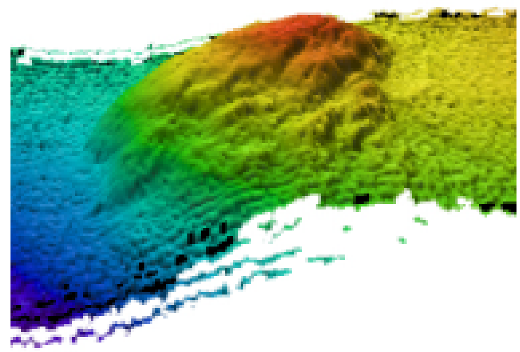
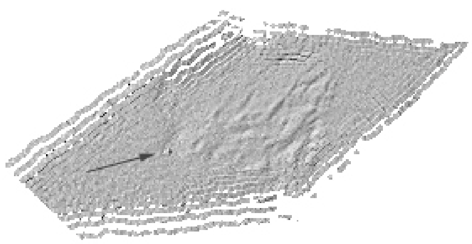
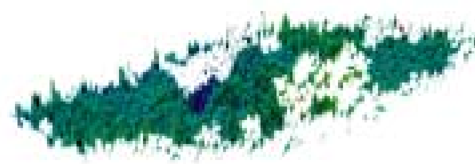
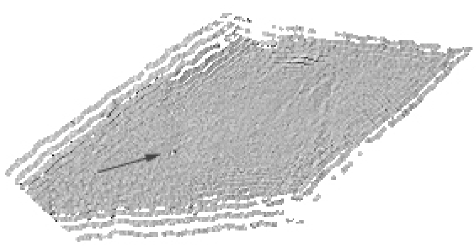
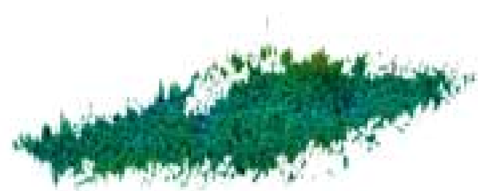
	2D Sun-Illuminated Bathymetry	3-d Colour-Coded Bathymetry
Baseline Swath – Line 11		
POS/MV 320 Line 21 – Line 11 1.7m misalignment		
RT20 Line 21 – Line 11 1.1m misalignment		

Figure 5 – October 99 Baseline and Results from Lines 11 and 21

Examining the resultant DTMs statistically we see that the mean (depth) of the Line 21 result using the POS/MV was -0.007m with a standard deviation 0.116m from over 12 000 samples. The mean of the Line 21 result using the RT20 was 0.06m with a standard deviation of 0.112m from over 65 000 samples. A total of 7 baseline swaths (Lines 8 - 14) and 11 post-MLO swaths (Lines 15 - 26) were collected using the POS/MV 320 and RT20 simultaneously. Table 1 below gives some of the statistics collected.

Baseline	Post MLO Line	GPS	Mean	Standard Deviation	Num of Samples
Line 8	Line 23	POS/MV	-0.081	0.066	1498
		RT20	-0.063	0.095	1241
Line 9	Line 15	POS/MV	-0.065	0.083	1655
		RT20	-0.005	0.066	1602
Line 10	Line 20	POS/MV	-0.041	0.098	7353
		RT20	-0.033	0.098	7571
Line 11	Line 16	POS/MV	-0.029	0.097	10081
		RT20	-0.044	0.068	10145
Line 12	Line 18	POS/MV	-0.081	0.129	9664
		RT20	-0.007	0.288	10394
Line 13	Line 17	POS/MV	-0.051	0.230	27531
		RT20	-0.059	0.223	27269
Line 14	Line 19	POS/MV	-0.034	0.160	20981
		RT20	-0.018	0.156	21447

Table 1 – Sample statistics from October 99 Experiment

December 2000 Experiment

The ability of the EM3000 to detect the PVC MLOs regardless of bathymetry in the October 99 experiment was the first question addressed in the December 00 experiment. Two of the original four PVC MLOs, along with an 8-inch and a 7-inch diameter stovepipe (Fig 4) were laid in approximately 6 metres of water on a flat silty sea floor. Several passes were made over the MLOs in order to determine if their physical characteristics were conducive to bathymetric detection by the EM3000. Figures 6a and 6b below show how the three objects looked *when* they were detected.

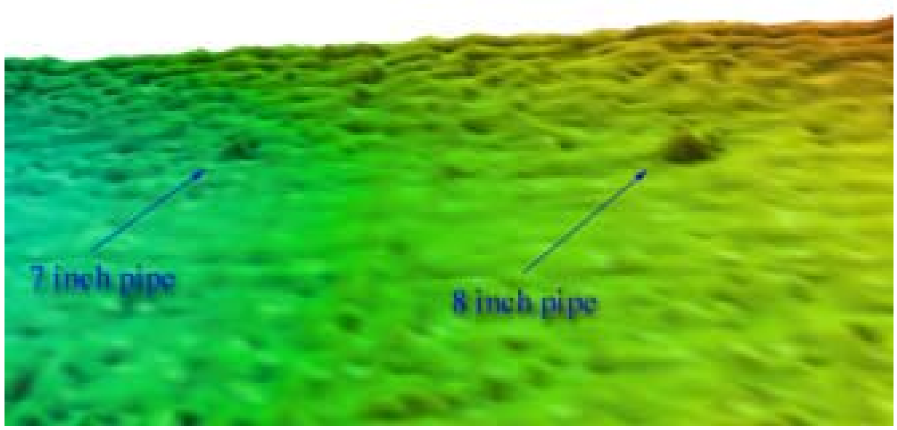


Figure 6a – 7” and 8” stovepipes

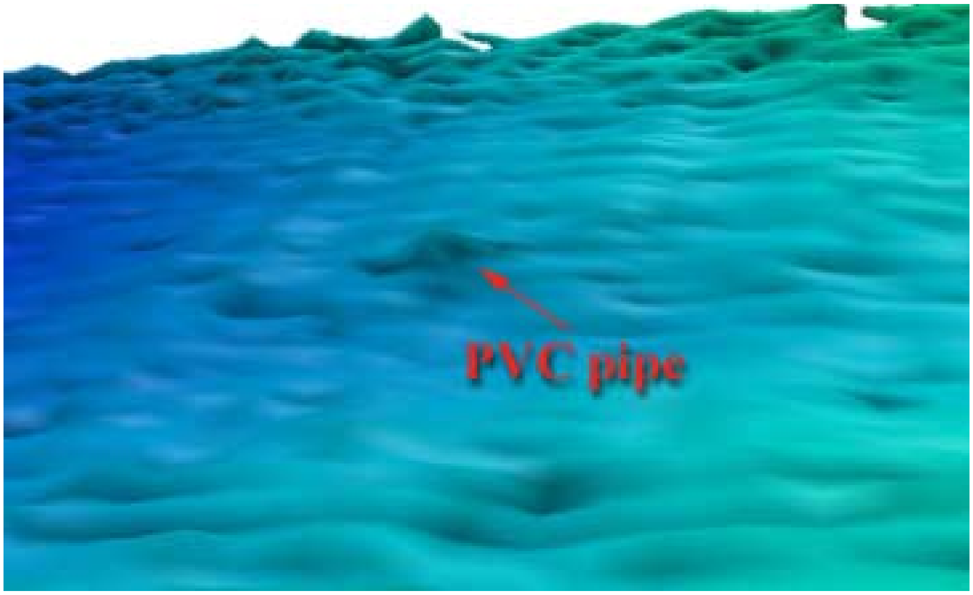


Figure 6b – PVC Pipe

The three objects were ensonified a total of 5 times each. The PVC pipe was detected twice with strong returns, the 8 inch pipe once, and the 7 inch twice. Given the inconsistent results, we realized that even if the horizontal positioning error in the October 99 experiment been smaller than the diameter of the MLOs used, we might not have seen the MLOs regardless. As a result, we did not expect to see the MLOs in all the passes made during the December 2000 experiment.

A total of 12 “before” lines were run over the area of interest for this experiment. Six lines were run directly over the north-east / south-west line on which the MLOs would be laid. Two Lines were run parallel to the north-east / south-west line but offset such that the outer beams would ensonify the points of interest. Finally four north-west / south-east lines were run, one for each point of interest. All lines were run at approximately 5 knots. A total of 13 “after” lines were run over the area where the MLOs were laid. Eight lines were run directly over the north-east / south-west line on which the MLOs were laid. Five north-west / south-east lines were run, one over each MLO with one extra for the most southerly MLO which was a PVC pipe. All the lines were run at approximately 5 knots with the exception of the last, which was run at approximately 13 knots. Note that the line numbers of the two experiments do not match as they were run over different areas.

The positioning in the December 00 experiment consisted of a POS/MV 320 using differential C/A corrections and a Novatel RT2 using real-time carrier phase corrections. Figure 7 below shows a sample of the results achieved. Notice that even though the accuracy of the RT2 for Line 10 was 0.04m some “point source” anomalies resulted. Table 2 shows sample statistics from a subset of all the lines run and Figure 8 graphs those results.

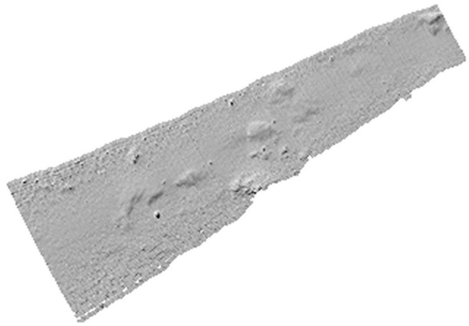
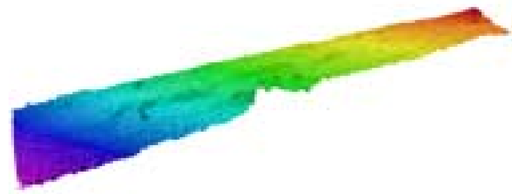
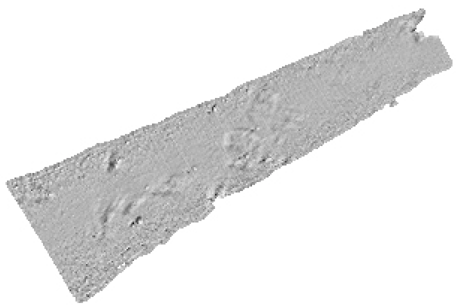
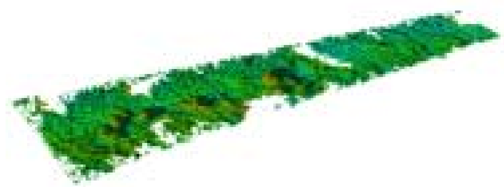
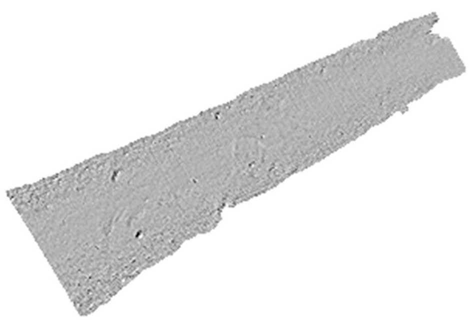
	2D Sun-Illuminated Bathymetry	3-d Colour-Coded Bathymetry
Baseline Swath – Line 22		
POS/MV 320 Line 10 – Line 22 0.4m misalignment		
RT20 Line 10 – Line 22 2.8m misalignment		

Figure 7 – December 00 Baseline and Results from Lines 10 and 22

The statistics and graph in Figure 8 and Table 2 clearly show that the RT2 resultant DTMs were significantly closer to a zero mean surface that the POS/MV 320 resultant DTMs. As well, the standard deviations seen in each RT2 resultant DTM were smaller than the POS/MV320 resultant DTMs. Although the results obtained were not a surprise, it was interesting to see the results calculated and plotted.

Knowing that the horizontal accuracy of the EM3000 soundings using the RT2 GPS unit, with real time differential carrier phase corrections, was much less than the diameter of the MLOs that had been laid, we expected to find an MLO in at least one of the resultant DTMs. This was, of course, contingent on the MBES having detected one of the MLOs. From the first part of the December 00 experiment, however; we knew that this was not guaranteed. Examining the resultant DTMs, we were not able to detect any bathymetric anomalies representing any of the four targets laid. Using *apriori* knowledge of the position of the targets in each of the after images we were still not able to find bathymetric anomalies representing the targets. Figure 9 below shows some of the results using sun-illuminated bathymetry. Several bathymetric anomalies are present in the resultant imagery below, however, close inspection reveals that these objects were present in the baseline survey.

Baseline	Post MLO Line	GPS	Mean	Standard Deviation	Num of Samples
Line 22	Line 10	POS/MV	0.102634	0.098022	19524
		RT2	0.012583	0.06421	19396
Line 23	Line 11	POS/MV	0.127064	0.118727	15034
		RT2	-0.03003	0.067832	15328
Line 24	Line 12	POS/MV	0.22023	0.135471	11855
		RT2	0.032274	0.051415	11329
Line 25	Line 13	POS/MV	0.168803	0.119337	15542
		RT2	-0.00227	0.061423	15784
Line 26	Line 14	POS/MV	0.419997	0.197116	11951
		RT2	0.025886	0.057559	11864
Line 30	Line 11	POS/MV	0.123682	0.130378	6389
		RT2	-0.03624	0.059356	6435

Table 2 – Sample statistics from December 00 Experiment

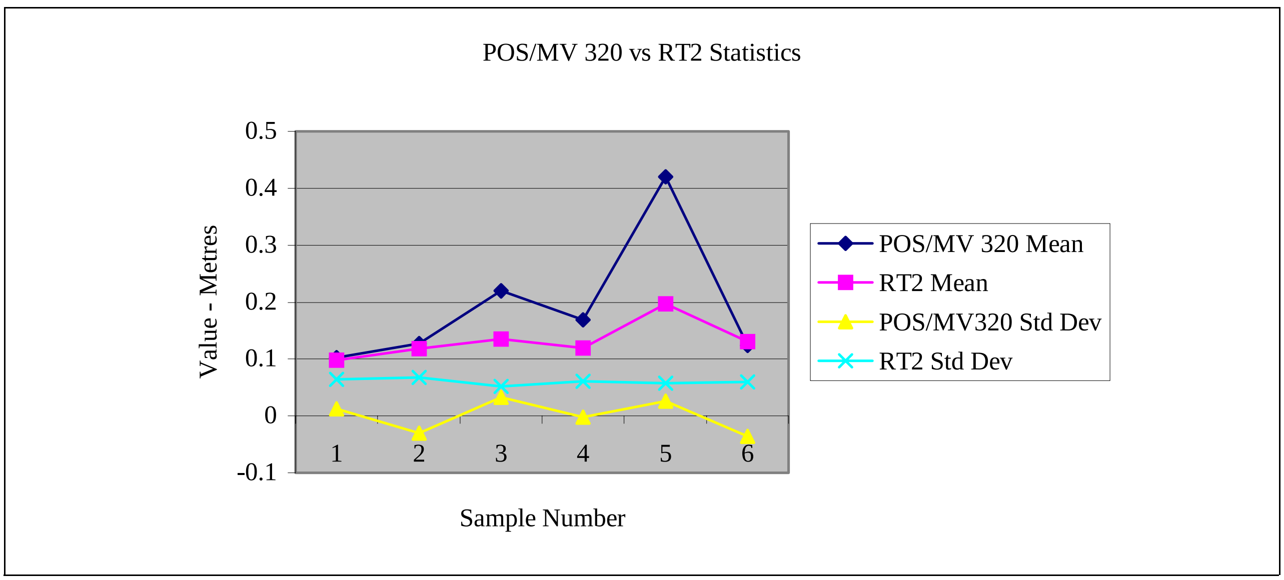


Figure 8 – Graphical analysis of results from Table 2

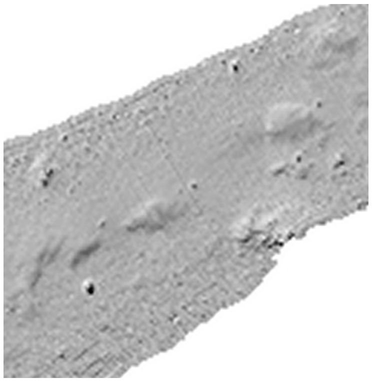
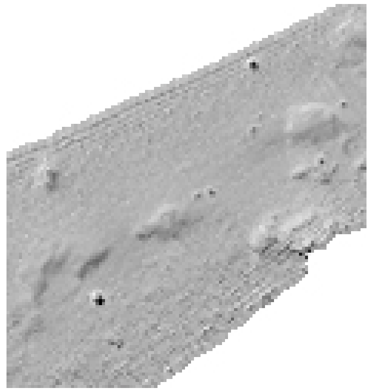
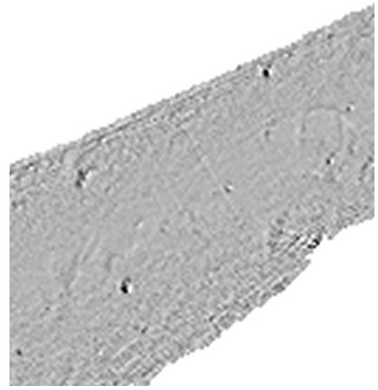
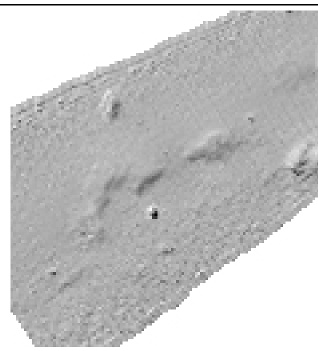
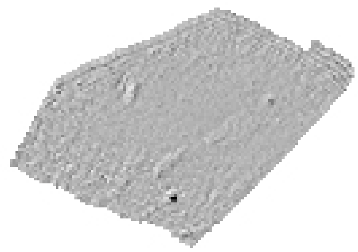
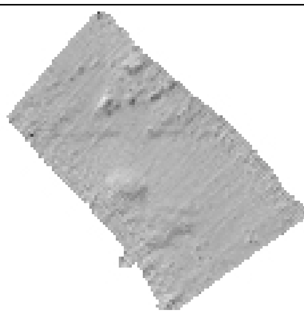
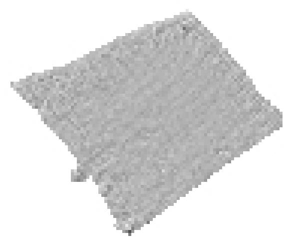
Before	After	Resultant
 Line 22	 Line 16	 Line 16 – Line 22
 Line 29	 Line 15	 Line 15 – Line 29
 Line 32	 Line 17	 Line 17 – Line 32

Figure 9 – Sample Imagery from RT2 postioned Bathymetry

III. Analysis

In the RT2 positioned resultant DTMs the MLOs were not detected. This result was almost certainly due to the size of the MLOs, their acoustic properties, and their distance from the MBES transducer. We believe that if larger objects had been used however they would have most likely have been seen as distinct bathymetric anomalies. Regardless of the detection of the MLOs used however it is more interesting to note the number and magnitude of baseline anomalies present in the resultant imagery. Indeed, from Figure 9 above we can see that in each case the resultant imagery has varying degrees of smoothness. Ultimately we would have expected a perfectly flat surface but this was no the case.

It may be argued that the size of the anomalies and the MLOs used were (too) small to be of any concern. It must be remembered however, that these results would most likely have been identical for objects ten-times the size at ten-times the distance from the MBES transducer face. In order to determine why baseline anomalies appeared inconsistently will require further analysis and experiments. Areas that will require further study will include, but not be limited to, the following:

a. accuracy of local tide versus tide gauge;
b. possible elimination of tide gauge using RTK;
c. any influence of attitude sensor on RT2 positions;
d. analysis of heave, pitch, roll and yaw residuals; and
e. data cleaning and gridding techniques.

IV. Conclusions

The October 99 and December 00 experiments were conducted in order to locate sea floor objects through the use of temporal MBES imagery. In the first experiment it was determined that although the horizontal positioning met IHO standards for a Special Order Survey the accuracy not enough to eliminate baseline objects completely. As well, the first experiment raised questions as to the suitability of the MLOs used with respect to the MBES being able to detect them.

In the second experiment the MLOs were inconsistently detected by the MBES in controlled test runs. Regardless, the experiment used a GPS with real time carrier phase corrections to position the MBES in order to generate before and after DTMs. From this experiment we saw resultant DTMs whose means were closer to zero and whose standard deviations were smaller than the resultant DTMs positioned with C/A DGPS. Despite the increased positional accuracy of the DTMs, baseline anomalies were still present in the resultant DTMs. The presence of these anomalies will have to be investigated further in future experiments.

Despite the inconsistent results and lack of detection of the MLOs used, much was learned in these experiments. First, that bathymetric detection of an object that would most likely generate a shadow zone in side scan imagery is not guaranteed. Object acoustic properties, MBES properties and distance of the object to the MBES must be carefully considered. Second, when looking for objects using temporal imagery the positioning system's horizontal error budget must be smaller than the size of the object being sought. Finally, the size and wavelength of bedforms and discrete objects may influence resultant DTMs if they are within the error budget of the positioning system and the vertical accuracy of the MBES.

V. Acknowledgements

The authors wish to thank George Eaton, Rob Hare, and Kalman Czotter of the Canadian Hydrographic Service (Pacific Branch) for their facilitation of the October 99 and December 00 experiments.

VII. Bibliography

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