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Assessing the Influence of Acoustic Variation on the Acquisition of Bathymetric Surveying Data

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SUMMARY

The field of hydrographic surveying is inherently important to achieving a true understanding of the world that underlies the vast bodies of water that cover the earth. Gaining a visual perspective of the seafloor topography provides understanding to the evolvement of the earth, the formation of ecosystems, and awareness to where maritime transit is safest. Obtaining insight into these areas of interest is dependent on the appropriate application of acoustic hydrographic survey methods to achieve the most accurate estimates of the seafloor. Multibeam sonars provide a more efficient means to collect data; however, there are numerous variables must be accounted and considered when evaluating the data collected. Factors such as, errors contributed from equipment or human error and in general the physical characteristic that are part of the ocean itself, must all be considered in the evaluation process, prior to coming to any conclusion regarding hydrographic data.

In this study I will determine the uncertainties of depth estimates of the seafloor that relate to the survey design and sound velocity. The survey design and collection of sound velocity were all conducted of the coast of Vancouver Island, B.C. near the entrance of the Strait of Juan de Fuca. The data collected processed through the CARIS-HIP/SIPS 7.1 and ArcGIS 10.1 software programs. The assessment will show how the change in sound velocity over time will influence the bathymetric reading, if not corrected for. The differences in bathymetric depth readings will show a correlation to the changes in sound velocity.

ABSTRACT

Bathymetric measurements for seafloor estimates are influenced by a number of factors, one being the change in of sound velocity in the water column. Consideration of and correction for changes in sound velocity through the water column is necessary when in pursuit of achieving accurate depth estimates of the seafloor. I will show that through comparison of sound velocity profile data collected during the Depending on the degree of precision required for a specified seafloor requirement is dependent on the number of sound velocities applied.

INTRODUCTION

The methods and techniques used in hydrographic surveying have come a long way since the first surveys conducted under the authorization of Congress and direction of President Thomas Jefferson in 1807. The United States, among other nations, have deemed a level of importance into the study of hydrography, specifically with regard to our oceans. This shared interest led to the formalized establishment of the International Hydrographic Bureau in 1921, followed by the intergovernmental Convention in

1970, when the name was changed to International Hydrographic Organization (IHO) (International Hydrographic Organization, 2011).

The objectives of the IHO are to 1.) Coordinate the activities of national hydrographic offices, 2.) Maintain uniformity in the generation of nautical charts and documents, 3.) Adopt reliable and efficient methods of carrying out and exploiting hydrographic surveys, and 4.) Continue to contribute to the development of the science in the field of hydrography and the techniques used in oceanography (IHO, 2011).

The objective of this research paper is to determine the uncertainties of depth estimates of the seafloor relate to the survey design and sound velocity (SV). Taking the basic understanding that sound velocity is influence by temperature, density and depth; the assessment will determine whether there is a correlation to variations in depth estimates regarding 1.)time, 2.) area, and 3.) time and area; with regard to sound velocity for the selected region. Use of both a Conductivity, Temperature, and Depth (CTD) system and Expendable Bathythermographs (XBT) sensors were used obtain sound velocity profiles (SVP) during the survey, to confirm water column variations.

The design of the survey allows for one area to be evaluated five times over a 7.5 hour time segment, with four sound velocity data collections. This allows for the hypothesis that characteristics of the water column will change over the 7.5 hour survey enough that the bathymetric readings will be varied. The importance of this variance in this survey is not necessarily important. However, in other surveys that require the greatest degree of precision, accounting for changes in sound velocity over a course of time, may prove to be of great importance. I speculate that to improve the degree of precision in the depth reading, only considering sound velocity that more frequent sound velocity data collections would lead to more precise bathymetric estimates.

METHODS

Survey course plan and design–

The objective of this survey course plan is to gain optimal coverage over the 'target' region; the design of the survey will do just that. However, the survey site location and the survey design require mindful maneuvering, because of the deploy and recovery of two CDTs and deployment of two XBT sensors, to collect sound velocity data, while operating in the major sea lane entering and exiting the Strait of Juan de Fuca.

Survey Site–

Initial determining factors that lead to the selection of the survey site 1.) It is in route to Vancouver Island, B.C., 2.) the openness of area, allowing maneuvering space for the ship

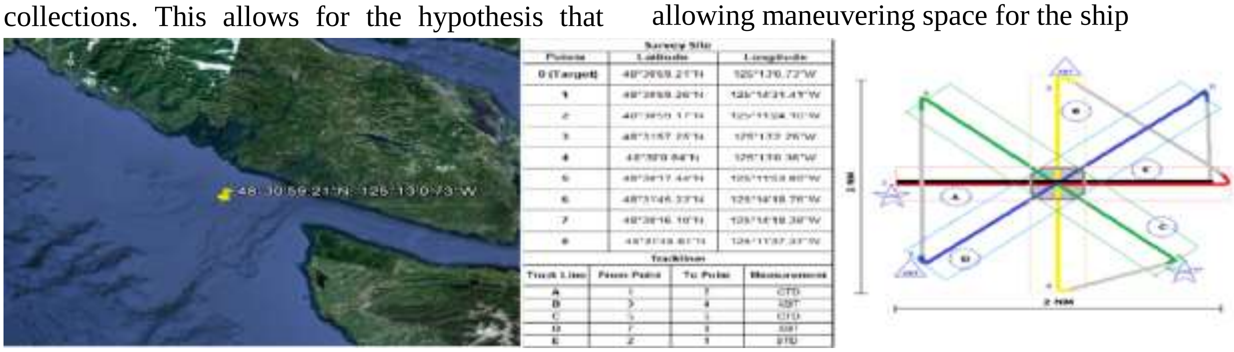


Figure 1. Survey sight off the coast of Vancouver Island, B.C., left. Mark points and transects with latitude and longitude, for the course of the survey course plan design, center. Survey area is approx. 2NMx2NM, consisting of 5 transect lines (A, B, C, D and E), two CTD collection locations (marked by star), and two XBT deployment areas (marked by triangles). Shaded grey area is the "target" area. Design allows for optimum seafloor coverage over target region, right.

to comply with the survey design, and 3.) According to existing charts and ship wreck database resources a shipwreck rest on the seafloor. The location of the survey site is off the coast of Vancouver Island, B.C., at 48°30'59.21"N, 125°13'0.73"W, at the Strait of Juan de Fuca entrance. Initially the determined ship speed was scheduled to be four knots to ensure optimal seafloor coverage; this speed was increased six knots, to reduce the interference of transiting vessels in the sea lane. Each transect of the survey covers a distance of two nautical miles in each direction, for a total of five survey lines passing over the target area, forming an 'octagon' over the seafloor area to be evaluated.

Survey process–

The survey started at point 1, to the west of the target area, where the first CDT cast was conducted. After the CTD was back onboard the temperature and density profiles were recorded prior to making the transit to point 2, creating transect line A (red line). Once at point 2, preparations for the deployment of the first XBT were made and executed as we made the turn at point 3 while in transit. Temperature and density profiles were generated in a SVP file that were recorded, before entering the target region, while transiting to point 4, creating transect line B (yellow line). Transect line B runs perpendicular to transect A; creating a box over the target area. The remaining transects will resurvey over this target region at opposing angles, creating an "X" increasing the data points, of depth estimates for evaluation, in the target region. Once transect B was completed, the ship made its way to point 5

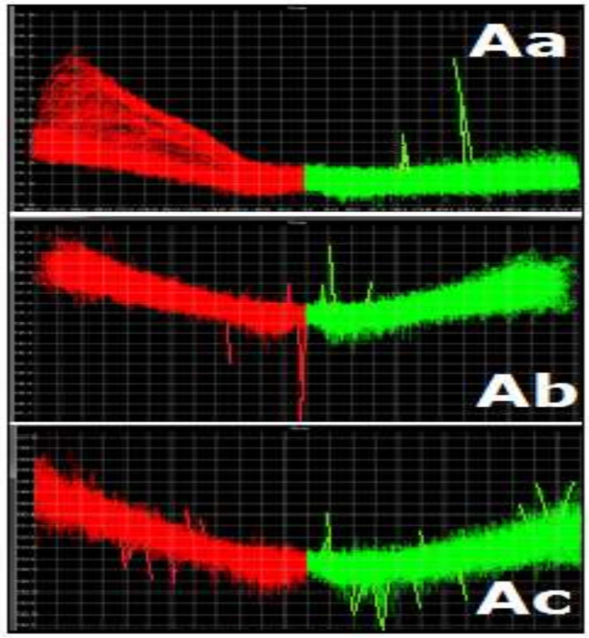


Figure 3. These are some examples of the spikes that the filters and the manual editing process remove. These spikes could be a result of floating detritus or sediment, either way a determination that they do not correlate with the general trend of the seafloor justified their removal.

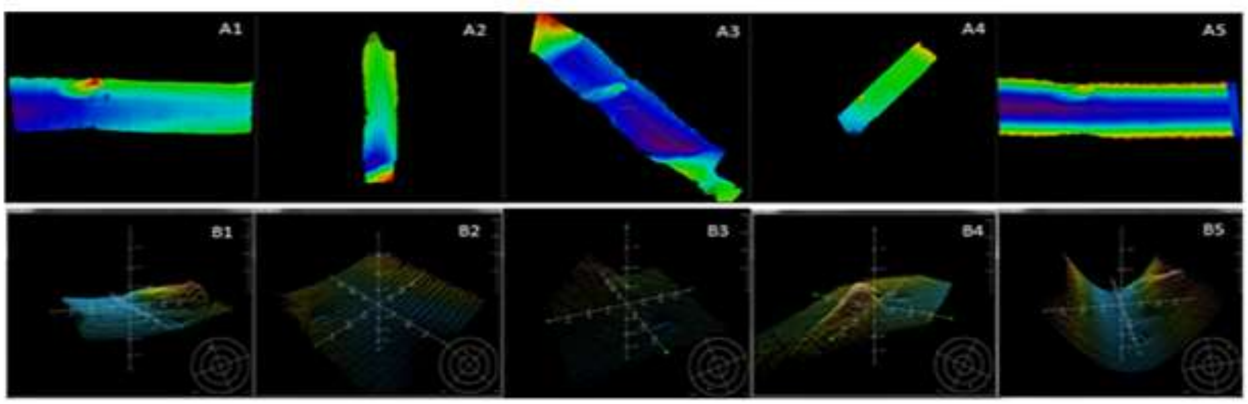


Figure 2. : In CARIS HIPS/SIPS 7.1 raw data images of the five transects from the Jan 27, 2013 survey, at 10m resolution (A1-A5). During the editing process the stray data points, spikes, were removed using filters and manual selection methods (Aa and Ab). Final editing actions were conducted in the 2-D and 3-D subset editor, here 'floating' data points and 'below depth' points were removed (B1-B5).

and preparations for the second CTD cast were made. At point 5, the ship stopped and the CTD was deployed gathering sound velocity data. Once the CTD was back on board, we continued towards point 6, creating transect line C (green line). Upon completing transect C we continued on to point 7, where the last XBT sensor was deployed, as we made the turn in the direction of point 8, without stopping the ship. In route to point 8 transect line trackline D (blue line) was created. During the transit to the last transect line; a baseline standard measurement for sound velocity data, of 1500 m s^{-1} was used (need to get reference). This last transect line was a second pass over transect line A, but will be referred to as transect line E, once back at point 1 survey was completed (Fig. 1).

Data Processing-

To edit the raw sonar data that was collected I utilized the CARIS-HIP/SIPS 7.1 data processing software program (Fig.2, A1-5). This program allows for the manipulation of bathymetric datasets through the use of an extensive suite of hydrographic data processing tools. Each transect line of raw data was uploaded to CARIS-HIP/SIPS 7.1 for the editing, where specific characteristics were removed from the dataset creating a fieldsheets and base surfaces for each transect. Additionally, this is where the resolution for which the data will be evaluated at is determined; I chose a 10 meter resolution.

Initial editing started by selecting a filter range, a trend high and trend low point, to remove random depth readings or spikes that were beyond selected range. Any points that feel outside the range and were determine to be erroneous (Fig. 3, Aa, Ab and Ac). After the filters were applied to each line a manual edit was conducted over the ‘target’ region where all five transects overlapped. When selecting points to be removed manually the points were selected based on whether they were greater than 0.75 m (greater than two grid boxes) deeper or shallower than adjacent readings, unless

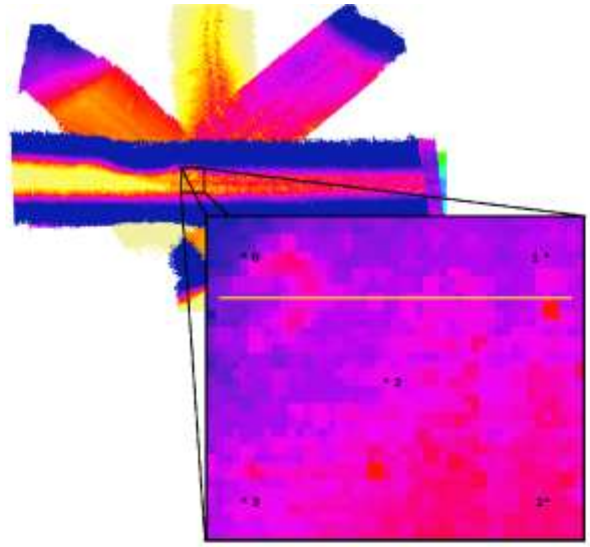


Figure 4. ArcGIS 10.1, image of the transect compilation, with a magnified projection of the Analysis Region (AR). In the AR five points have been selected to for evaluation of depth estimates variance over time, as well as a pixel segment that has been selected for evaluation of depth estimate variance over a distance at various time intervals (yellow line).

a trend appeared in the region. Lastly, using subset editor, for a visual perspective, points that continued to appear inconsistant with the general trend of the seafloor were removed, which only included 17 points (Fig. 2, B1-5).

Once all editing in CARIS-HIP/SIPS 7.1 was completed the fieldsheets were transferred to ArcGIS 10.1, a software program where maps, geo-databases, geospatial data and imagery can be generated for data for analysis. This program also has an array of tools to generate a multitude of data sets, in a multitude of formats.

Unlike in CARIS where the transect lines were processed separately, I laid one on top of the next, from transect 1 to transect 5 (Fig.4) in the ArcGIS program. Once in ArcGIS, features and a precise determination of one feature was identified to be present in all five transects of the ‘target’ area. A dip was identified and determined to have a great enough depth change to qualify its use as a point of reference for evaluation in bathymetric variance. This dip and the area around it, that will be used in the evaluation is a region 490m x 380m, will be referred to as the Analysis Region (AR).

RESULTS

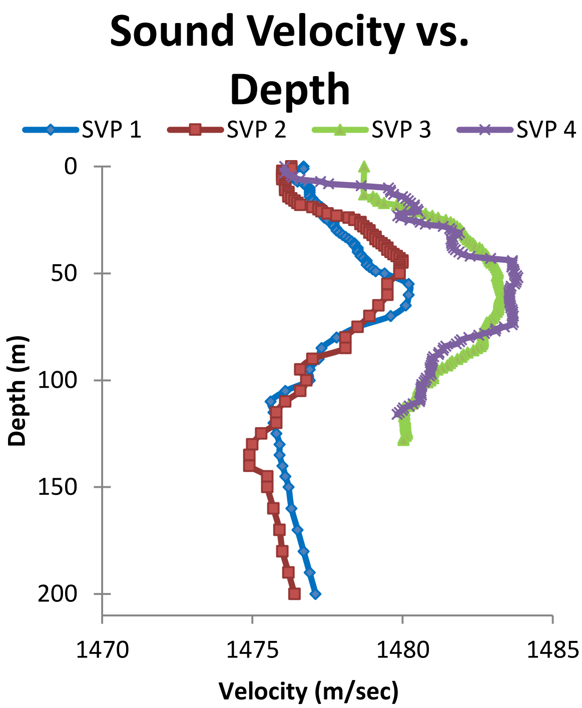
From the beginning of the CARIS editing process through to the end, when selecting the AR, by mere visual observation, it was clear that the bathymetric reading of some transects varied in relation to the others in the survey. The source of the varying depth estimates was speculated to be cause by changes in the water column that altered the speed at which sound was able to move through it, in relations to the time that transpired between passes over the AR. The focus of the research is restricted to observing the changes in sound velocity and the changes in depth estimates. Therefore, unlike a typical survey, we will not be correcting for SV, tide, pitch, heave, or any other influencing factors of bathymetric depth estimates.

In the AR, Figure 4, three datasets for evaluation were compiled for evaluation. The first was a collection of depth estimates for a line segment of pixels that crossed the AR. The second, as the collection of depth estimates at 5 points with in the AR. The third dataset is a collection of depth estimates for the entire AR.

Before evaluating the dataset information, a look at the sound velocity profiles confirmed that, in the short 7.5 hr. survey timeframe there were in fact variances in the water column between each successive pass, (Fig. 5).

The first dataset is a collection of depth estimates for specific points, or locations in the AR, as indicated with numbered (1-5) asterisks in figure 4. At each location, 4 depth estimates without SVP and one with the baseline standard 1500 m s^{-1} have been recorded. With exception to the second location the general trend of the depth estimate is a variation range of 2.5m - 3.25m for a given location. Looking at the means for each location and comparing the means across the 5 locations, there is variation of 1.25m (Fig. 6).

The data from the second dataset collected in the AR came from a line segment of pixels extending across the region, (yellow line in Fig. 4). The line segment extends from west to east 470 m. The depth estimate profiles for each transect illustrate small variations in depth of the seafloor surface, with the greatest difference in the baseline standard transect data, falling well below the first four surfaces. One observation from the



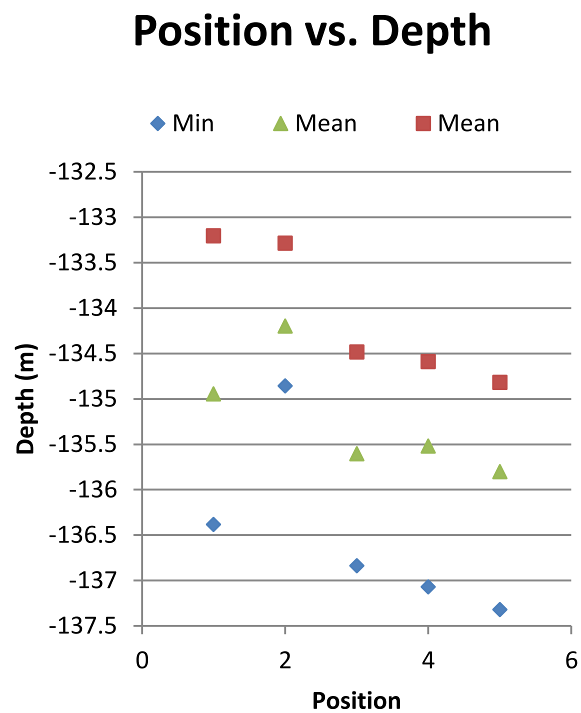


Figure 5. Sound velocity profiles of the first four transects, illustrating changes in sound velocity during the 7.5 hour survey. Not shown is the baseline standard of 1500 m s^{-1}, which is a straight line down ward from 1500 m.

Figure 6. Points 1-5 in the AR selected to represent spatial depth estimates. Minimums and maximums are plotted to illustrate the range in depth estimates, and means are used to illustrate the average of the depth estimates for that specific 10m location.

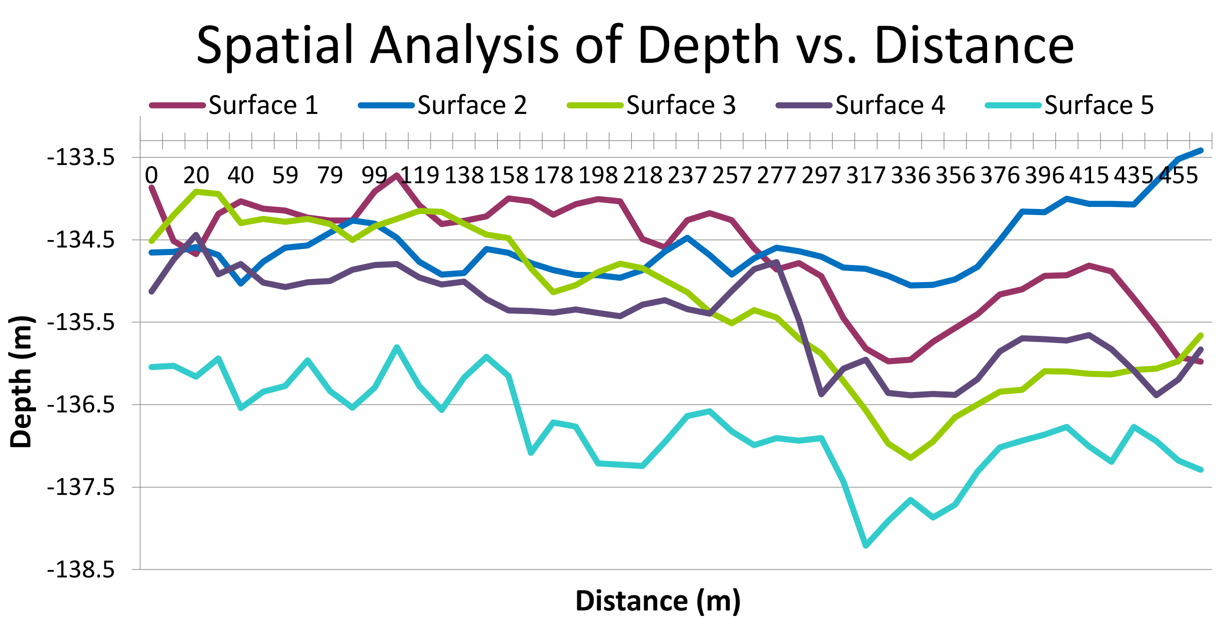
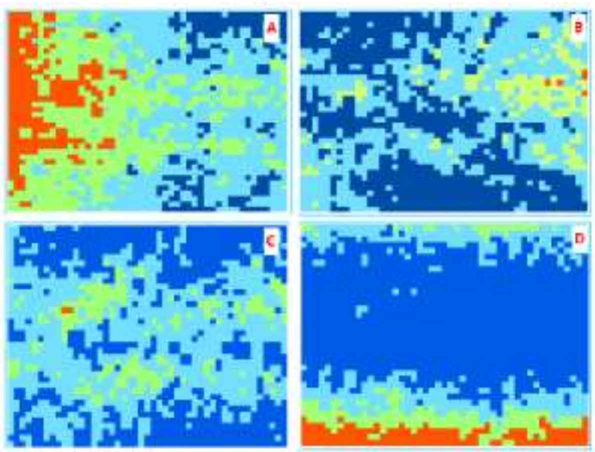


Figure 7. Points 1-5 in the AR selected to represent the spatial depth estimates. Minimums and maximums are plotted to illustrate the range in depth estimates, and means are used to illustrate the average of the depth estimates for that specific 10m location.

data that stands out, in general, is that the depth estimates increase in the downward (negative) direction, for a deeper seafloor estimate. Another interesting observation is that the second and fourth surfaces appear deeper than the first and third surfaces, respectively, on the east end of the line segment (Fig 7). The third dataset is an evaluation of all the depth estimates for each pixel in the AR, covering the entire 470m x 380m area. In figure 8, the orange areas represent the pixels that have the greatest amount of depth variation, while the green are pixels that areas that have the least variation. Surface 1 is being used as the base referance, and is subtracted from each of the following surface.



Surf. 2-1	-2.227 – (-1)	-0.99 - 0	0 - 1	1 - 2.72
Surf. 3-1	-3.319 – (-1)	-0.99 - 0	0 - 1	1 – 1.30
Surf. 4-1	-3.151 – (-1)	-0.99 - 0	0 - 1	1 – 1.27
Surf. 5-1	-4.179 – (-1)	-0.99 - 0	0 - 1	1 – 2.69

Figure 8. Bathymetry depth estimates, a standard deviation representation of variance of the seafloor for the entire AR, 490m x 380m. Panel A is surface 2 subtracting surface 1, Panel B is surface 3 subtracting surface 1, Panel C is surface 4 subtracting surface 1, and Panel D is surface 5 subtracting surface 1.

DISCUSSION

The methods used for editing the transects in CARIS-HIP/SIPS 7.1 was a very conservative editing process, so as to not jeopardized the overall integrity of the data collected for each transect. Removing only data points that are clear erratic and not correlating to the overall seafloor scheme.

Once the editing process was completed in CARIS-HIP/SIPS 7.1 and transferred to ArcGIS 10.1 not further modifications to the data were applied. ArcGIS 10.1 was used as a tool to pull data that could be used to evaluate the changes in bathymetric measurements for each transect, over the course of the survey. The data that was collected in ArcGIS 10.1 a correlation between changes in sound velocity is presented in the changes in the depth estimates.

The strongest variances are evident in the data that was pulled from figure 6 and 8, where the variance values are clearly observable. Thought we cannot assume that the variances are solely attributed to the changes in sound velocity, I believe that it would be safe to assume that the change in sound velocity is the leading contributor to the changes.

Overall, each method used to assess the changes in bathymetric estimates were in agreement that over time as sound velocity changes with time, the bathymetric estimates varied with time as well.

Due to the location of the survey site, open ocean, I am making the assumption that tide is not a major contributing factor. Additionally, given that they sea state at the time of the survey was stable; I am ignoring an influence of pitch, heave, and roll of the ship as a contributor. Since these are the predominate features that could alter bathymetric estimates and I have justify their irrelevance for this survey I believe it is safe to say that the changes in sound velocity was the leading contributing factor.

The IHO stipulates that survey should have a minimum of one sound velocity dataset applied to a survey for every eight hours of surveying (International Hydrographic Organization (IHO), 2011). Taking that data that I collected from a 7.5 hour survey, it is clearly reasonable to see that more frequent applications of sound velocity, will improve the overall bathymetric estimates of a survey.

CONCLUSION

The guidance prescribed by the IHO should be considered just that; guidance. For surveys that require higher levels of precision, more frequent application of sound velocity are justified to improve the overall estimates of the seafloor. However, if the a rough depth estimates will meet the needs of a less stringent final product, then following the IHO eight hour recommendation will suffice. The results provided in this study, clearly indicates that even on small scale and short time frames, sound velocity changes to measureable amounts that influence the final product,

ACKNOWLEDGEMENTS

I want to give a special thank you to Miles Logsdon for his mentorship, guidance and encouragement during the development and execution of this project. As well as a thank you to Clinton Stipek for his help with the CARIS-HIP/SIPS 7.1 software training. Lastly, but by far not the least important, a thank you to all the seniors, professors and graduates student of the Barkley Sound, Vancouver Island, B.C. research cruise team for the great memories that we will share from the experience and the team work and friendships that we will have for the future ahead.

REFERENCE

International Hydrographic Organizaton (IHO), 2011. Special Publication N.44. International Hydrographic Bureau