



Identifying a historic shoreline using fine-scale slope variation

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NONTECHNICAL SUMMARY

Much of the popular news is focused on our changing climate and the future of sea level rise. As sea levels continue to rise, the shoreline continues to retreat upland and replaces the previous lowstand. A rise of just one meter could displace millions of people and cause billions of dollars of damage. This research identifies a historic submerged shoreline along the continental shelf of Vancouver Island, Canada. This historic shoreline was established during a glacial maximum period and subsequent shorelines were formed due to the change in sea level throughout the period of glacial melt beginning ~14,300 years ago. As the glaciers retreated and sea level rose, historic shorelines were established episodically on the seafloor, until our present shoreline corresponds to current sea level. To identify the historic shoreline, data was collected using a Kongsberg EM302 multibeam echosounder on 27 January 2013 aboard the *R/V Thomas G Thompson*. The EM302 system uses an acoustic signal at a known frequency and records the reflections, or echo to measure the depth of the seafloor and create a bathymetric image of the ocean floor. Evidence of a historic shoreline at a depth of 93 meters was observed on the seafloor, which corresponds to previous research delineating the low-stand of sea level at the time of the glacial period ~14,300 years ago. Using slope variation along the area examined as a historic shoreline and bathymetric images of depth, we are now able to investigate the rate of sea level change through direct observations of historical shorelines.

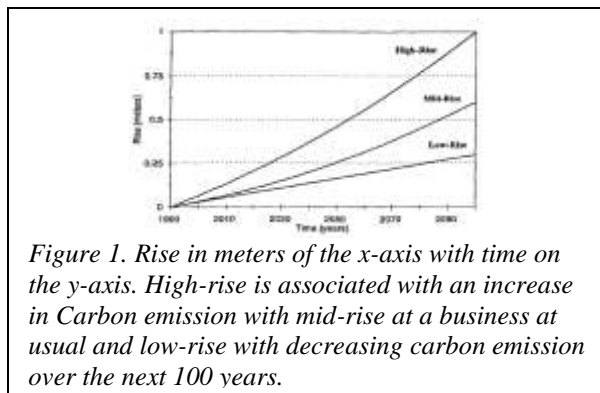
ABSTRACT

With sea-level projected to rise up to one meter in the next century, understanding the history of sea level rise is of great interest. This project identified a low-stand occurring during a glacial period ~14,300 years ago. A historic shoreline was observed at 93 meters in depth offshore of Vancouver Island using a Kongsberg EM302 multibeam echosounder onboard the *R/V Thomas G Thompson* on 27 January 2013. The multibeam soundings along the transect line from the current shoreline to this historic low-stand were post-processed in CARIS HIPS 7.1 to produce a bathymetric base surfaces at a spatial resolution of 10 meters. Slope variation along the transect line was derived using ArcGis 10.1 and changes in slope of greater than 5° were highlighted as potential regions of subsequent historic shorelines. The variation in slope along a survey transect from a depth of 147 meters to 83 meters shows evidence of changes in the processes related to shoreline development. This method of identifying historical shorelines using slope variation confirms previous work identifying low-stands during past glaciation periods and offers insight into measures of historic sea level rise. Identifying historic shorelines and using them to observe sea level rise can aid in the understanding of future sea level rise.

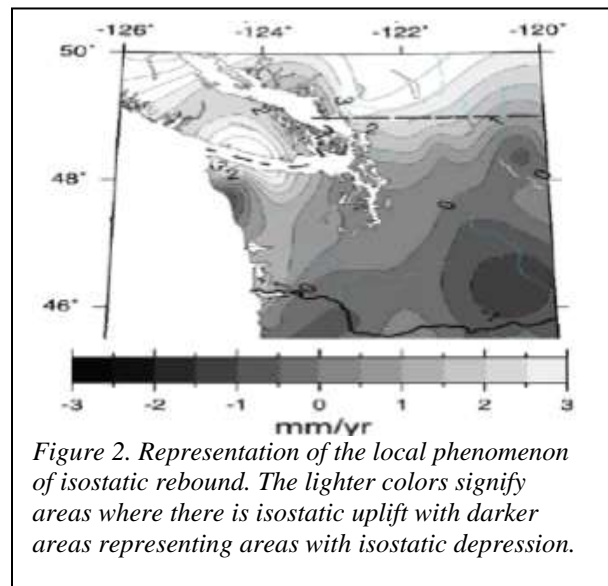
INTRODUCTION

With sea level projected to rise up to one meter in the next 100 years, further knowledge on historic shorelines is necessary (Houston, 2013, Church et al., 2011). Without any precautions, damage to buildings will be severe and repopulation of coastal communities will be imminent (Nicholls and Leatherman, 1996, Small, 2004). To deal with the forthcoming changes, both local and global challenges will need to be addressed as there are many different factors affecting sea level (Cayan et al., 2008). Historical records used to construct the sea-level history over the last 20,000 years include fossil dating on coral terraces as well as calcareous marine organisms collected with marine sediment cores (Hanebuth et al. 2000, Peltier and Fairbanks, 2005, Stanford et al., 2011). However, using high resolution bathymetric surfaces to identify historic shorelines can provide a clearer and more accurate rate of sea level rise since the last glaciation period (Stea et al., 1994).

Globally, sea level rise has the potential to be catastrophic. Around the world, coastal communities are becoming more densely populated which is leaving them at an increased risk (Mitsova et al., 2012). There are different factors including thermal expansion and sea-ice melting that increase global sea-level rise (Bouttes et al, 2013). Different scenarios will need to be addressed with the multiple pathways that society will potentially take in the future to predict future sea level rise (Obeysekera and Park, 2012) (Figure 1). Additionally, land-based ice melt is also extremely hard to predict but has been showing an upward trend over the last 100 years (Hanna et al., 2013).



Local estimations can cause even further complications. The coast of Washington is one of the most physically dynamic regions in the world (Mote et al, 2008). There is local atmospheric circulation and also tectonic movement, which can severely alter the rate of sea level rise (Lambeck and Chappell, 2001). In Neah Bay, Washington, there is isostatic rebound, a local phenomenon, occurring at 3mm/yr (Figure 2) (Mote et al, 2008). However, the waters around Neah Bay are rising at the global average of 1.7mm/yr. Therefore, the rate of sea level rise will be skewed and a false perception will be grasped that sea level is decreasing at a rate of 1.3 mm/yr. These phenomena are highly variable and unique to the geography of the region and therefore local.



Establishing a historic shoreline can help in improving accuracy and determining sea level rise from the last glaciation period to the present (Stea et al., 1994). This study proposed to identify a historic shoreline off the southwestern coast of Vancouver Island, Canada, using a Kongsberg EM302 multibeam echosounder (Figure 3). The methods used to identify historic shorelines are highly affected by the isostatic adjustments and are therefore representative of local sea level rise (Basset et al., 2005). Based on previous research, a historic shoreline should be located at 90 meters which is associated with a meltwater pulse between 14,300 and 12,800 years ago (Stanford et al., 2011). Using a bathymetric image of the

seafloor to help identify a low-stand can help in furthering our knowledge of historic sea level rise.



Figure 3. Map of the study area. The transect line was taken off the coast of Southwestern Vancouver Island from 48° 31.289 N, 125° 22.45 W to 48° 32.278 N, 125° 24.203 W.

METHODS

The bathymetric survey data was collected using a Kongsberg EM302 multibeam echosounder hydrographic acoustic system aboard the *R/V Thomas G Thompson* on 27 January 2013. A single line hydrographic survey was conducted across the continental shelf of Vancouver Island, Canada from 48° 31.289 N, 125° 22.45 W to 48° 32.278 N, 125° 24.203 W covering depths from 83 to 147 meters (Figure 3). An expendable bathy thermograph, XBT, acquired a sound velocity profile for the area of the transect line. The survey was conducted at a speed of 6 knots or slower. The Kongsberg EM302 operating at 30 kHz and a 70° beam angle allowed for a swath to four times the depth (Figure 4). Once the acoustic “pings” were reflected back to the ship from the seafloor, the Kongsberg Seafloor Information System (SIS) acquisition software continually georeferenced the

returns and converted them into depth soundings.

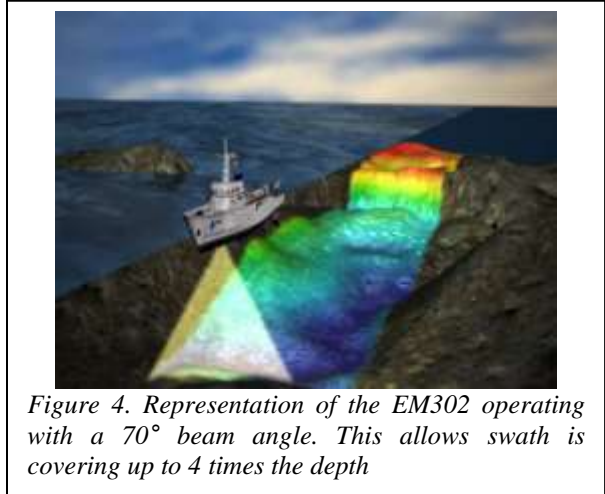


Figure 4. Representation of the EM302 operating with a 70° beam angle. This allows swath is covering up to 4 times the depth

Once the survey was completed, the raw data was transferred into CARIS HIPS 7.1 software for post-processing. First, the vessel configuration file for the *R/V Thomas G Thompson* EM302 system was used to correct for the vessels heave, pitch and roll during the time the survey. Changes in tide height were then corrected for. A sound velocity profile was loaded to correct for variation of the speed of the acoustics throughout the water column during the time of the survey.

Within CARIS HIPS 7.1, swath editing and subset editing were both used to create seafloor base surfaces. Swath editing proved more efficient and was applied first as it allows for sequential analysis along the transect line (Figure 5). After swath editing was completed, it was then edited using subset editor, which enables editing over a predetermined spatial region (Figure 6).

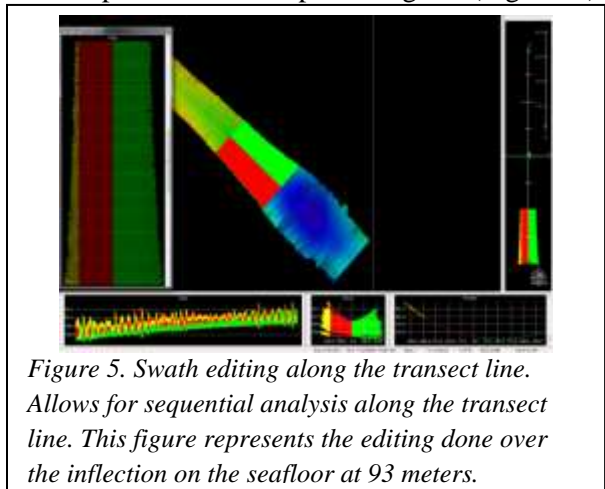
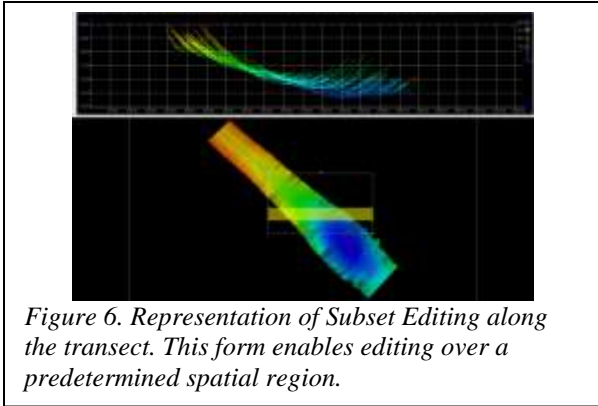
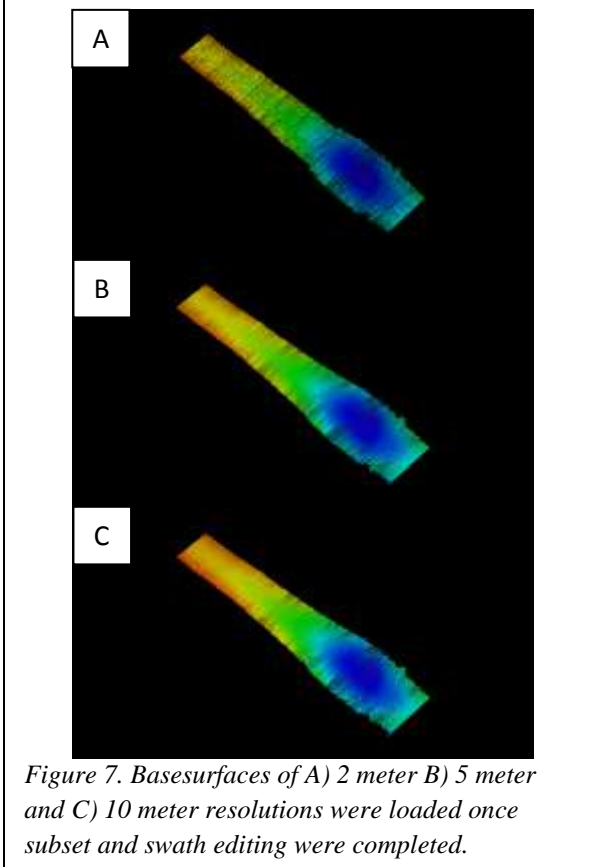


Figure 5. Swath editing along the transect line. Allows for sequential analysis along the transect line. This figure represents the editing done over the inflection on the seafloor at 93 meters.



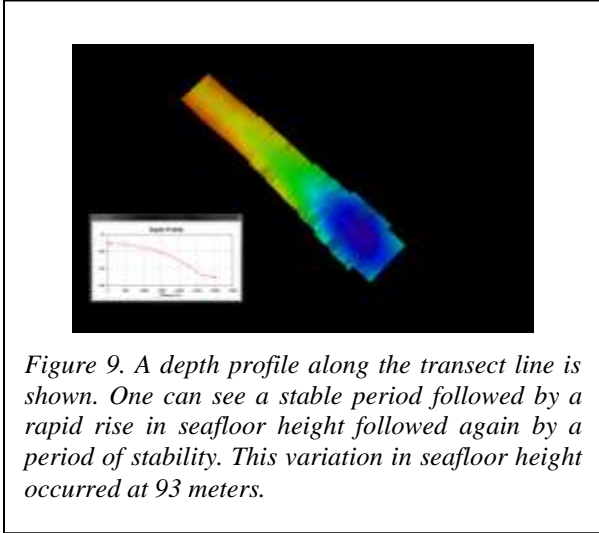
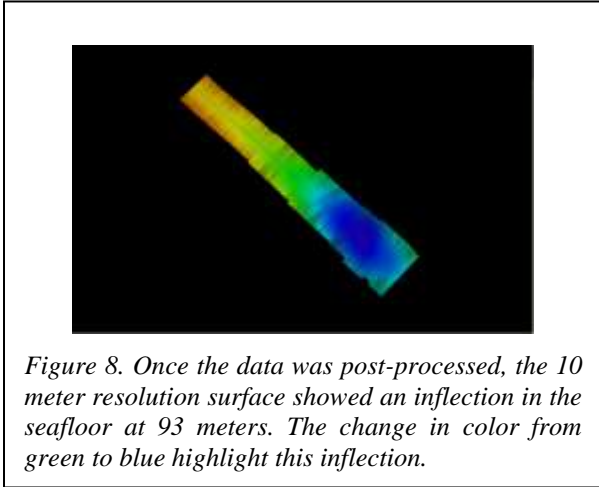
Once the transect line was edited, the combined uncertainty bathymetric estimator algorithm (cube) was used to create basesurfaces of 2, 5 and 10 meter resolutions (Figure 7). The 10-meter resolution was selected as it provided the best representation of the data due to it having fewer data holes than either the 2 or 5-meter resolution surface. This allowed for further analysis to be conducted with the least amount of error associated with the data. This 10 meter cube basesurface was then converted to a BAG file format and imported into ArcGIS 10.1.



In ArcGIS 10.1, analysis of variation in slope along the entire transect line was performed using spatial analysis tools. Following the calculation of slope, a line profile was extracted for the slope of each individual raster cell along the center line of each base surface. Changes in slope were derived along the profile and locations where 5° or greater change in slope occurred were identified.

RESULTS

The 10-meter resolution surface, resulting from subset and swath editing, showed an inflection at 93 meters (Figure 8). Furthermore, a depth profile along the transect line showed evidence for geomorphological processes similar to those of shoreline building with the low stand occurring at 93 meters (Figure 9).



Changes in slope along the transect line illustrates an overall decrease in slope (Figure 10). However, there were several sections where the change in slope varied greatly. The frequency of

slope ranging from 0 to 5° along the transect indicates the occurrence of slopes 5° or greater and the most frequent slope occurred between 1 to 3° (Figure 11)

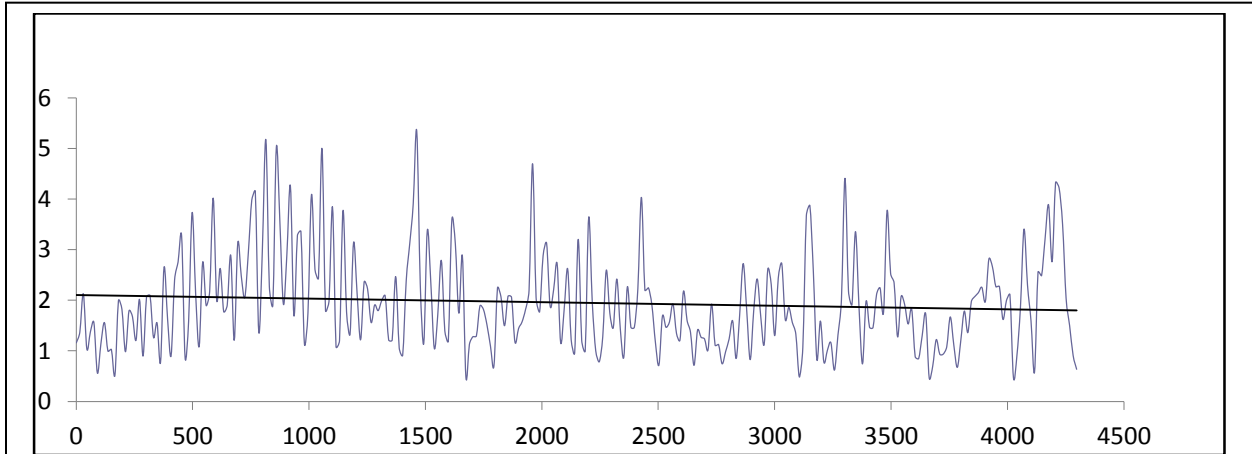


Figure 10. Changes in slope along the transect line. Distance in meters along the transect line is on the x-axis while the change in the degree of slope is represented on the y-axis.

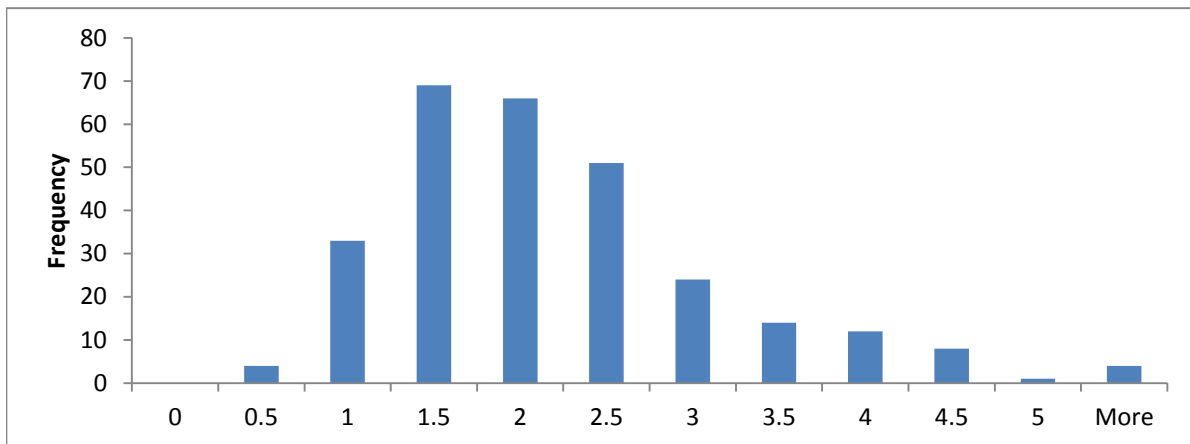


Figure 11. A histogram represents the frequency of slope along the transect ranging from 0 to 5°. There is a much higher frequency of slopes ranging from 1 to 3° with slopes of 5° or greater occurring only five times.

DISCUSSION

The seafloor at 93 meters was examined using the slope profile and over that specific point in depth, the variation in slope was 5°. A predetermined slope of 5° was selected to identify historic shorelines as it represented processes similar to shoreline building. At a depth that is previously identified as a historic shoreline, there was a slope of 5° or greater. This supports that this

location on the seafloor was the historic low stand. Further analysis using a histogram also supported this evidence for a historic shoreline.

A histogram represented the frequency of the change in slope along the transect line. Overall, the majority of the slope angles fell between 1 to 3°. However, there were five data points representing a slope of 5° or greater which agreed with the slope profile. This provided supporting evidence that slopes of 5° or greater were present in the slope profile indicating historic

shorelines during glacial retreat. Further evidence was gained from the depth profile that shows a relatively stable period followed by an inflection in the profile which is then followed by another stable period in slope (Figure 10). This potentially represents a series of shorelines due to glacial retreat 14,300 years ago with a new shoreline formed further up-shore at 12,800 years ago (Stanford 2011). Using these depth and slope profiles, geomorphological features identical to those of shoreline processes are evident.

The four other areas that had a slope of 5° or greater could also potentially be identified as historic shorelines. They occurred at depths that are not identified by any previous research but are areas that could be further examined for potential evidence of low stands. If these other areas of 5° or greater in slope along the transect are identified as historic shorelines, it signifies that sea level rise is not linear but episodic.

The swath and subset editing methods can have a significant effect on the resulting base surfaces. Editing using these methods may be reducing variation by eliminating soundings that would then be used in the base estimator. Also, the use of cube to make basesurfaces can produce different representations of the data. Furthermore, the location of the slope profile line within the base surfaces can also lead to different representations of the data. If it were located five pixels to one side or the other, it could lead to differing results.

CONCLUSIONS

With rising sea levels threatening the livelihood of populations living along coastlines worldwide, understanding the history of sea level rise is imperative. Using quantitative analysis of bathymetric features, a historic shoreline was identified which can then be used to calculate historic sea level rise since the glaciation period from 14,300 to 12,800 years ago. A 5° or greater break in the line profile of slope from a 10 meter resolution base surface of the seafloor above a 100 meter depth represents a shoreline at a glacial maximum and suggest subsequent shorelines during the glacial retreat and associated sea level rise. A historic shoreline at a depth of 93 meters is evident in the seafloor offshore of Vancouver

Island, Canada. This supports previous research identifying a historic low stand at this depth.

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