

Multibeam Echosounder and Mobile Laser Scanning Data Report for Coastal and Marine Spatial Planning Olympic Coast, Wahkiakum County, and Mouth of the Columbia River

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Summary

The Washington State Department of Ecology Coastal Monitoring & Analysis Program (CMAP), performed multibeam and boat-based LiDAR surveys to collect high-resolution nearshore bathymetry and coastal topographic data along the Olympic Coast, in Wahkiakum County, and around the mouth of the Columbia River (MCR) in support of Coastal and Marine Spatial Planning. During September 14-16, 2012, MBES and MLS surveys were performed around the MBES surveys were performed in September 2012 around La Push around the Quillayute River mouth including James Island. During the same time MLS surveys were also performed extending from northern Rialto Beach to the southern end of First Beach. During May 7-10, MBES and MLS surveys were performed in Wahkiakum County at Elochman Marina and Cathlamet Channel. During May 21-24, MBES and MLS surveys were performed at the MCR at the Ilwaco Marina and Baker Bay. During June 24 and 28, 2012, MLS surveys were performed along the coast of the Quinault Indian Nation.

All surveys were performed using CMAP's new research vessel, the R/V *George Davidson*, a 28-ft Aluminum-hulled Munson Packcat beach-landing craft designed specifically for shallow water surveys (Figure 1). For the mobile LiDAR survey, the R/V *George Davidson* was equipped with an Optech ILRIS-ER laser scanner with motion compensation and an Applanix Position and Orientation System for Marine Vessels (POS MV 320 V5 RTK), consisting of an inertial measurement unit (IMU), two GNSS antennas, and a computer system (Figure 2), which supplies the acquisition computer with accurate timing for synchronization of LiDAR data along with the real-time position and orientation of the vessel. For the MBES surveys, the R/V *George Davidson* was equipped with an R2Sonic 2022 multibeam system also integrated with the POS MV 320 V5 RTK.

Survey Preparation & Test Scan

An assessment of existing geodetic control was performed in preparation for our surveys. National Geodetic Survey (NGS) monuments were found to be located in areas relevant to our fieldwork, but most lacked accurate vertical positions. In contrast, Washington State Department of Transportation (WSDOT) monuments were found to be located mostly along roads, and not sufficiently close to the coast. Geodetic control monuments were installed as needed particularly along the Olympic Coast as described in our companion report.

A significant amount of work went into equipment setup and systems integration on the R/V *George Davidson* in preparation for the surveys. Vessel setup, with both hardware and software, is arguably one of the most important steps in ensuring quality data is collected. First we determined accurate lever arms and sensor mounting angles. Initially, in lieu of a more exact method which was not available at the time, we used a tape measure to roughly determine the offsets between the IMU, GNSS antennas,

laser scanner, and vessel's reference point¹. Next, a GAMS calibration was performed in order for the POS MV to determine the offset between the two GNSS antennas. This was done by trailing the boat around a circular track until the error in the positional accuracy was at a minimum and the antenna offset was resolved.

Once the lever arms are entered into the POSView software, the laser's boresight angle measurements need to be calculated to describe the rotational misalignments between the IMU and laser scanner. To perform this calibration, a series of targets were placed within the scanner's field of view at varying heights and distances (Figure 3). Before scanning, the targets were surveyed using a Trimble R8-3 GNSS receiver. The positions for the center of the targets were converted to Earth-Centered Earth-Fixed (ECEF) coordinates. Next, a detailed scan of the targets was performed. Using Optech MatchView 1.0 Beta 5 software, the target coordinates are matched to the data points collected with the scanner so that roll, pitch, and heading angles can be calculated. However, due to complications with the MatchView software and, potentially, not having accurate enough coordinates from the survey methods with the R8 (e.g., holding the antenna level over the survey target, using a tape measure to determine the target's center), the boresight angles could not be calculated. Roll, pitch, and heading angles can be entered into the software post-survey, until more accurate boresighting took place². Plots of the installation parameters and performance metrics (e.g., RMS values for position, PDOP, GAMS solution) exhibited acceptable levels of error in our initial setup. The real-time performance metrics showed ~0.5 m error in our overall positional accuracy, while the smoothed performance metrics were on the order of 10-11 cm error.

Since last June, CMAP has made significant improvements toward building confidence in our system setup through assistance from additional survey professionals as well as refining our data collection methods by experience. In October 2012, a professional laser scan of our boat was performed by David Evans and Associates (Tacoma, WA) with all of our survey equipment mounted (Figure 4). Having accurate locations for the sensors and, therefore, the associated lever arms between sensors is vital for being able to produce highly accurate data. Until that point, we had been using sensor locations that were derived using a tape measure, which may only have been accurate to ~5-10 cm. By the end of April 2013, reference points for all of the onboard sensors (e.g., laser scanner, IMU), as well as a number of additional reference points etched into the aluminum of the vessel, were established with millimeter accuracy from the laser scan. Thence forward, we have been surveying with these offsets entered into QINSy in real-time. For all data collected before April, the datasets can be replayed in QINSy with the correct inputs and the point cloud can be regenerated.

In addition, though we were never able to sort out the boresight misalignments from the calibration scan we performed last June, with the help of one of our hired survey specialists, Azing Vondeling from iLinks, the offsets between the laser and IMU have now been accurately identified. At the end of April, Azing assisted with optimizing our survey capacity, helping us to set up our system so that we could collect multibeam sonar and laser data simultaneously. Furthermore, we performed a proper laser patch

¹ On October 8, 2012, David Evans and Associates performed a complete laser scan of the R/V *George Davidson*, providing us with accurate coordinates for all survey equipment. These coordinates can be used to replay any previously collected data, with the assumption that data quality will improve.

² On July 2, 2012 we redid the boresight scan with David Keck, a representative from GeoLine, using a Trimble total station so the targets could be surveyed more accurately for comparison with the laser scanner data. This will improve our measurement of the boresight angles and further improve data quality.

test by driving around a light pole in a vacant parking lot from many different directions at various distances away from the pole. The idea is that if the laser is properly aligned with the IMU, then no matter which direction or at what distance the laser hits an object, the object should be located in the same place. Azing determined that in order to align the laser point cloud precisely, an additional Y-offset of 5 cm needed to be applied to the coordinates derived from the boat scan.

With confidence in the angular alignment and sensor reference points, we can now move forward with replaying the data in QINSy, and applying the post-processed vessel track generated in POSpac MMS (Applanix; Ontario, Canada), which uses the updated ephemeris data from the satellites to more precisely define the vessel's position during the survey. After the final data is produced, the point cloud will be edited, both manually and through the use of automatic filters in Qloud (Quality Positioning Services; The Netherlands), to remove any outlying data points, reflections of the water, and returns off vegetation to the extent possible. In some places, there were either birds or people walking along the beach, which may also complicate processing. The digital photos taken will help discern questionable data or anomalous features. Panoramas are generated by stitching overlapping photos together using Autopano Giga Pro v. 3.0.3 (Kolor; France) which accounts for a moving reference point, since photos are being taken from the vessel as we navigate along the shoreline (Figure X). Once the point cloud is cleaned, cross-shore profiles can be extracted and statistics about beach and bluff slope can be generated using newly acquired software, VG4D-SmartLiDAR (Virtual Geomatics; Houston, Texas). Data from multiple surveys will be compared to conduct change analysis and 3-D visualizations can be generated using Fledermaus (Quality Positioning Services; The Netherlands).

Data Collection

Surveys were planned around the tide, aiming to scan the most important areas between 2-3 hours before and after the lowest daytime tide. Likewise, MBES surveys were performed between 2-3 hours before and after the highest daytime tide. Priority areas were identified before the survey began in order to coordinate placement of targets with the ground crew.

During data collection, the laser continuously scans in a vertical line, bounded by the scanner's field of view ($40^\circ \times 40^\circ$). The laser scanner looks off the port-side of the vessel; therefore, surveying can only take place in a westward direction along the shoreline. While the vertical spacing is fixed during the survey, data density alongshore is controlled by the speed of the boat. For this reason, it is the job of the computer operator to monitor the data streaming in real-time to ensure adequate data density is obtained. Heading and attitude (pitch, roll, yaw, and heave) data were generated by the POS MV at 100 Hz to account for the motion of the vessel. In real-time, position and orientation data is fed to the acquisition computer along with the 3-D laser point cloud. The data from these two systems was integrated via QINSy 8.1 software and was continuously monitored throughout the duration of the survey to check for data coverage and any gross errors (Figure X). As the boat moved alongshore, George Kaminsky took digital photos to simultaneously document the landscape. The photos will aid in data processing, facilitating the ability to discern anomalous features in the laser point cloud.

The boat operator used a built-in Garmin GPS to navigate a certain distance offshore, as best as possible, by following contour lines on a chart (Figure 5B). From an earlier evaluation of the Optech ILRIS-ER scanner, it was determined that the maximum distance an adequate density of data points can be achieved on flat, wet surfaces is ~ 450 m. For this survey, we aimed to stay within 200-250 m of shore as was possible based on the safety of navigation. Throughout the survey, the boat operator and data

collector worked closely together, communicating about optimal operating distance from shore, navigational safety, and data gaps. There were a few instances where kelp, erratic rocks, or extremely shallow waters challenged safe boat operations and the survey distance from the shoreline had to be adjusted. Distance from shore was also increased at times to ensure the entirety of the bluff was within the laser's field of view. It was often necessary for the boat operator to rotate the vessel to port or starboard in order to rescan an area such as along a shoreline bend, acutely-angled irregular topography, or low-sloping areas. By rotating the boat multiple times forward and back, the laser can sweep across the landscape, increasing the data density each time an area is rescanned. As this was our first survey and the boat was not completely outfitted, the data acquisition computer operator and the boat operator were located on opposite sides of the cabin, facing different directions. For future surveys, it is preferable for the boat operator and data collector to be stationed next to one another so that data acquisition needs can more easily be communicated.

Survey Control

Along the Olympic coast, targets were randomly placed along the coast to serve as ground control points for the boat-based LiDAR survey (Figure X). The targets were 60 cm square, constructed out of plywood, and painted with a white circle centered on black background, outlined with a white border (Figure 8C). These targets were installed with wooden stakes pounded into the ground on top and at the base of bluffs, as access allowed (Figure 8A and 8B). During installation, a 2-ft level was used to ensure the target was set up level and plumb. The targets were then surveyed using a Trimble R8-3 GNSS receiver connected to the internet via a Wifi hotspot device to gain access to the Washington State Virtual Reference Network (WSRN) and obtain real-time corrections. The GPS antenna was placed at a fixed distance above the target's center for a 30-second occupation; a final target position is then obtained by averaging these observations, and adjusting for the vertical offset. The target positions will be used to check the accuracy of the georeferenced point cloud.

In addition to the plywood targets, the on-ground survey crew also took GPS positions for several easily distinguishable topographic features along the shoreline (e.g., the corners of a revetment at the base of the landfill).

Data Processing and Analysis

All data is being "replayed" using the correct inputs so that a new georeferenced point cloud is generated. Additional filters are being applied at this time to clean up the data in ways that were unknown during the actual survey (e.g., range filter, quality filter, etc.). In addition, the position data from the survey can be post-processed in POSpac using a network of CORS stations, in conjunction with our local base station, now that precise ephemeris data is available. The resulting SBET is applied to the point cloud during replay to update the vessel's position.

After the final data is produced, the point cloud is manually edited to remove any outlying data points. Additional filters can be applied, for example, in an attempt to remove vegetation based on intensity of returns. In some places, there were either birds or people walking along the beach, which may also complicate processing. The digital photos taken will help discern questionable data or anomalous features. Once the point cloud is clean, cross-shore profiles can be extracted and statistics about beach

and bluff slope can be generated. After multiple surveys are conducted, we will be able to conduct change analysis to quantify sediment eroded from the bluffs.



Figure 1. Ecology's new shallow water survey vessel, the R/V *George Davidson*.

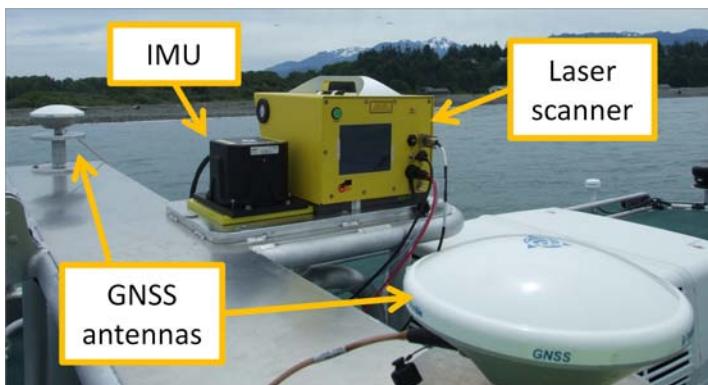


Figure 2. Location of equipment for mobile LiDAR surveys mounted to a platform atop the R/V *George Davidson*.



Figure 3. Placement of 14 targets within the laser scanner's field of view, at varying heights and distances.

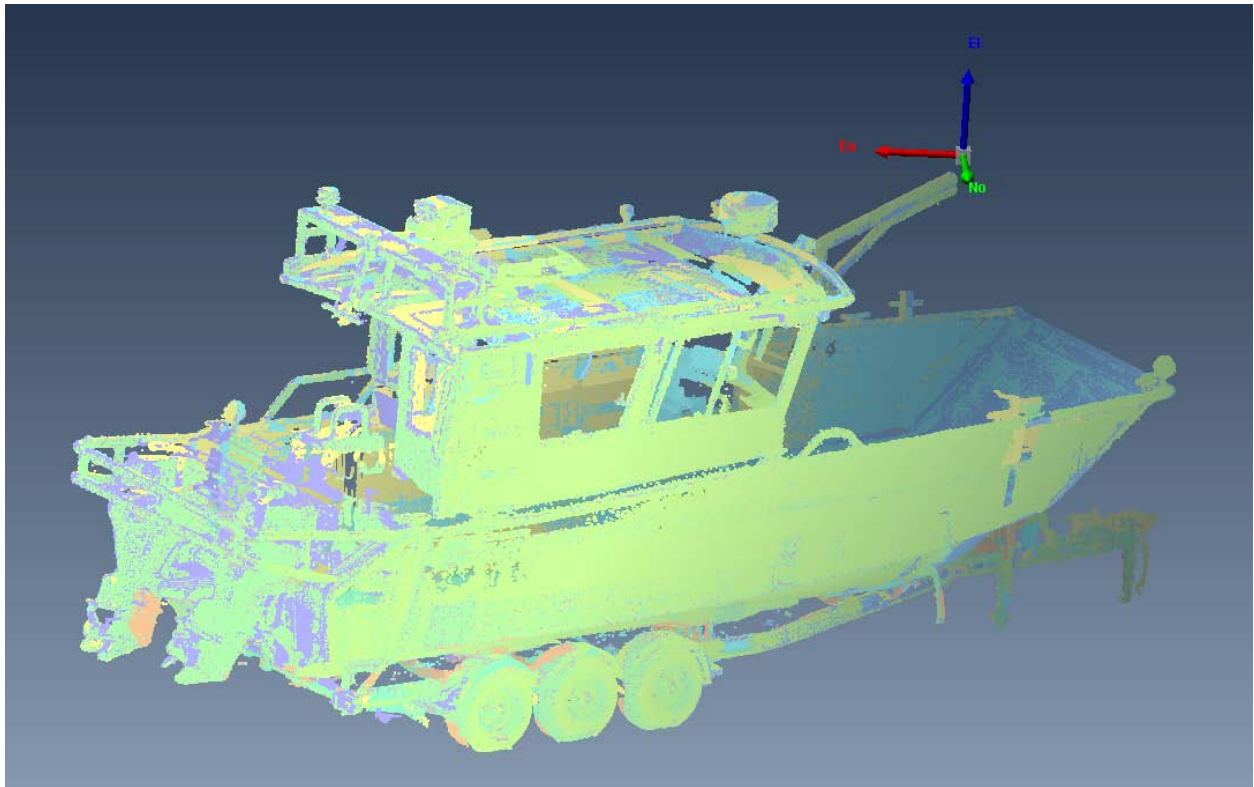


Figure 4. Point cloud from the laser scan performed of the R/V *George Davidson* by David Evans and Associates in order to establish accurate positions for all of the survey equipment on the vessel.

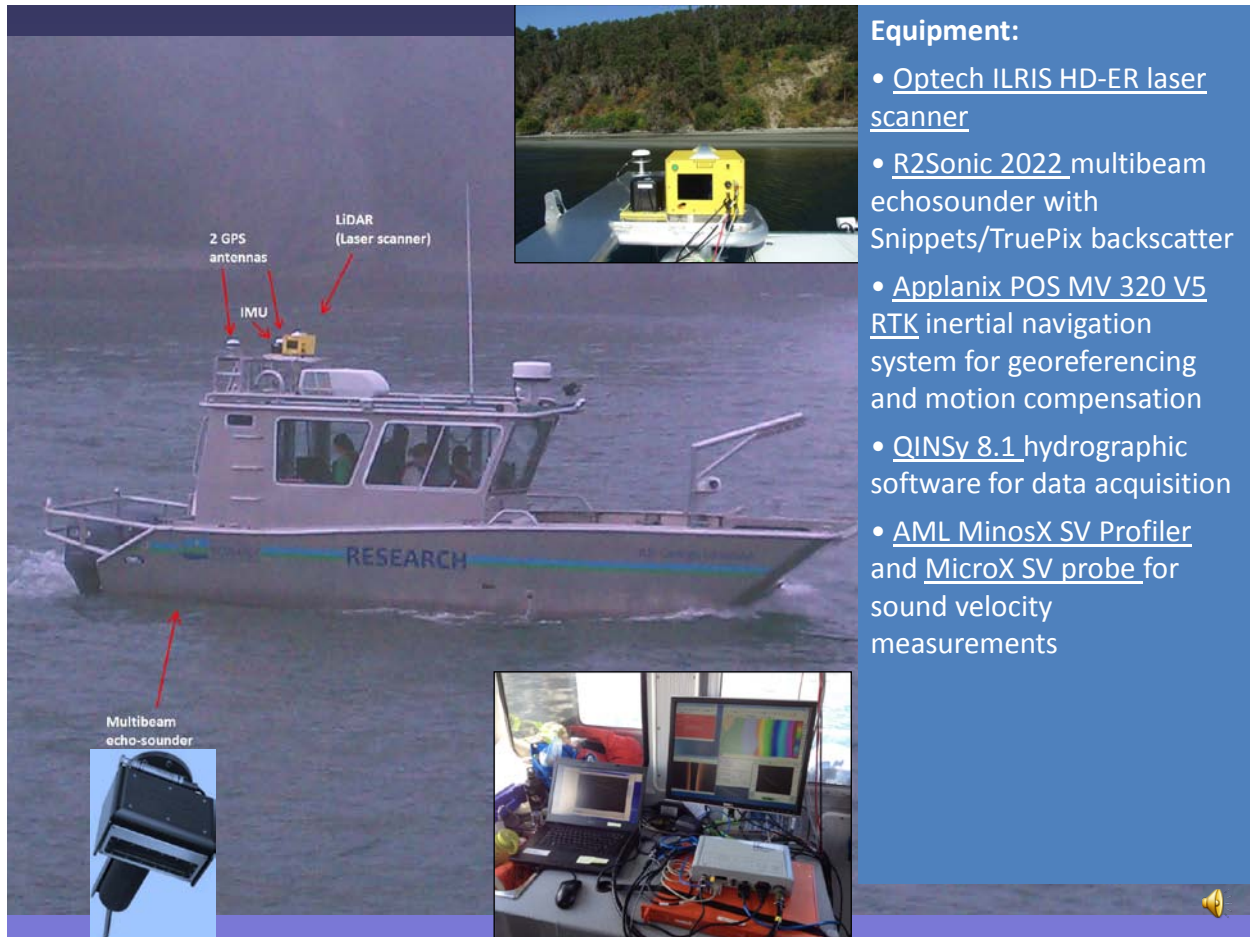


Figure X. Equipment for MBES and MLS surveys on the R/V *George Davidson*.

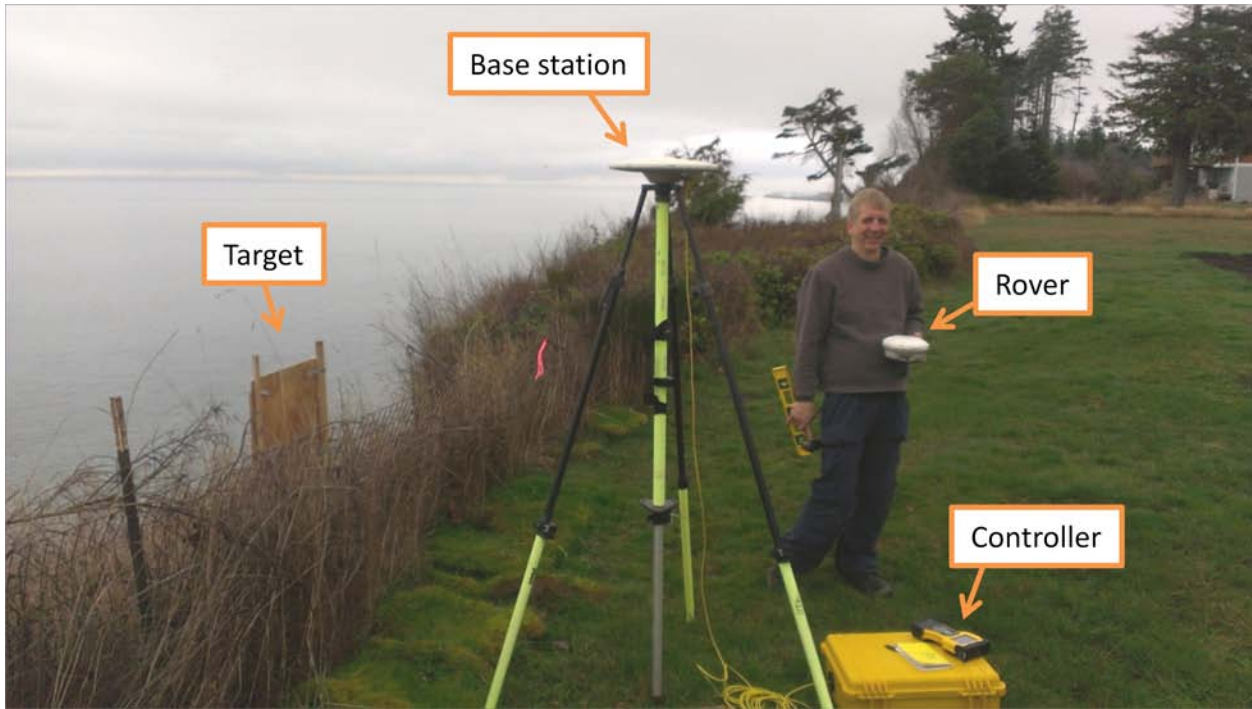


Figure X. Photo showing on-ground survey equipment: the GPS base station setup to log observations during the day; a plywood target setup at the edge of a bluff as a ground control point; and the GPS rover and controller used to survey the position of the target.

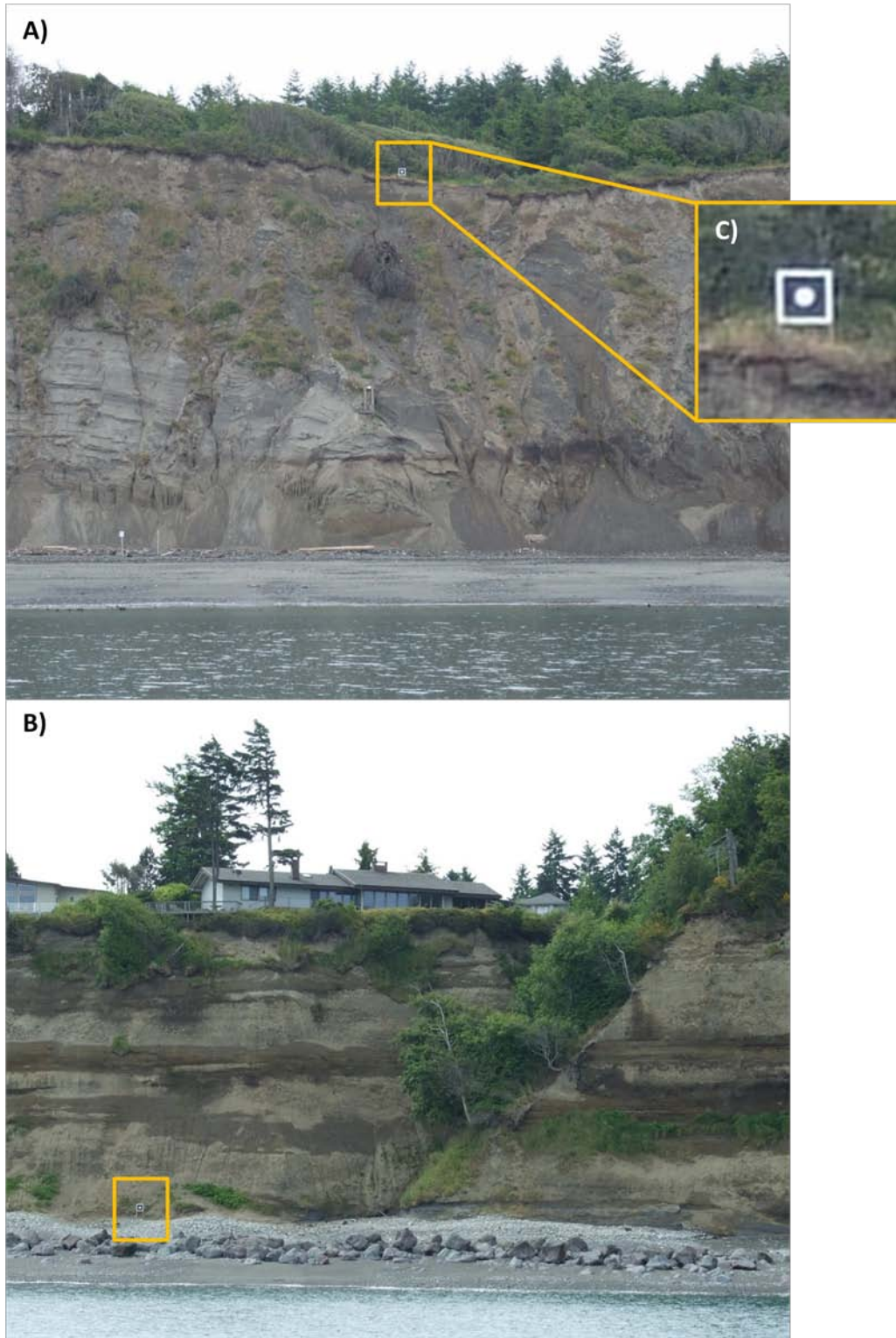


Figure X. Examples of target placement at the top (A) and base (B) of a bluff, along with a blown up view of the target design (C).



Figure X. Photos showing plywood targets installed and surveyed in as a ground control points for the laser point cloud.

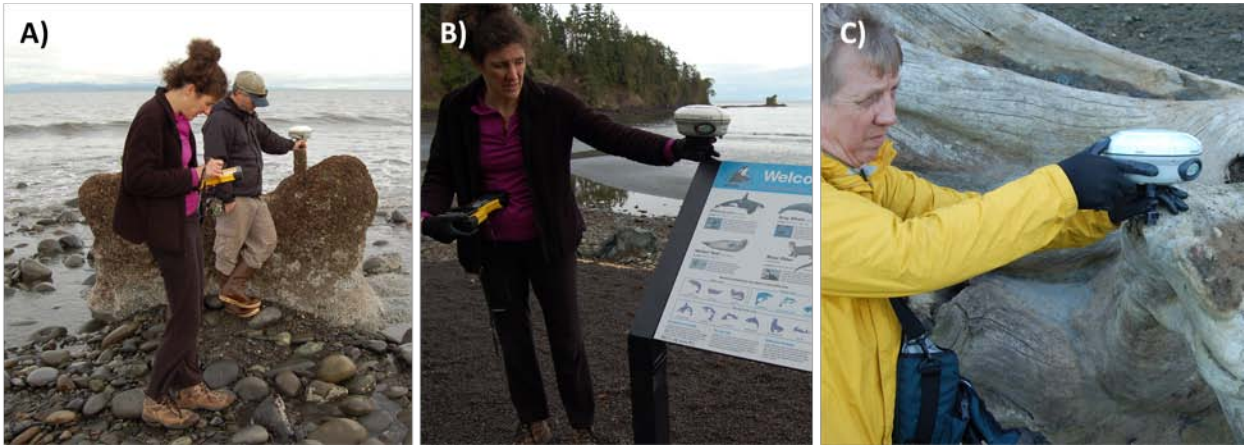


Figure X. Photos showing surveying of various features on the beach to use as additional ground control points.

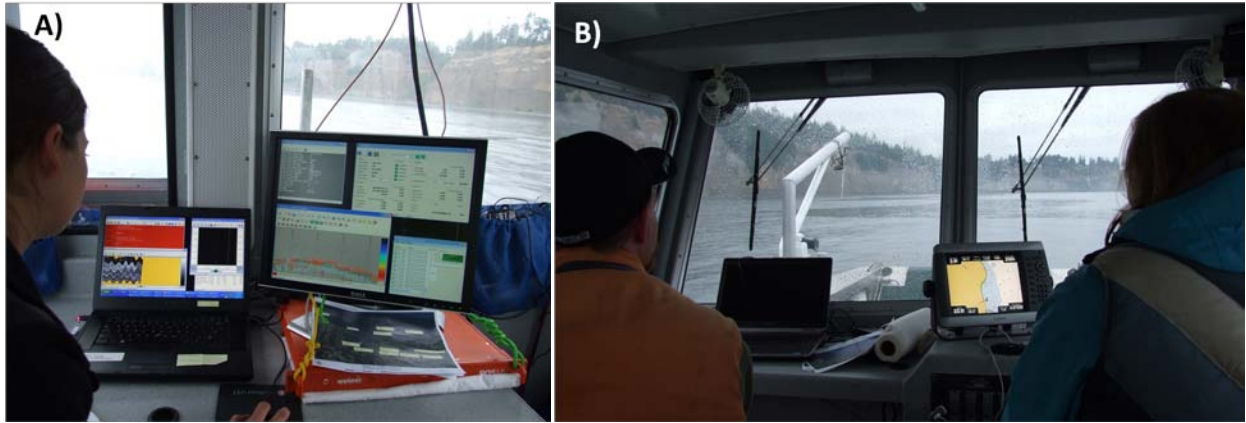
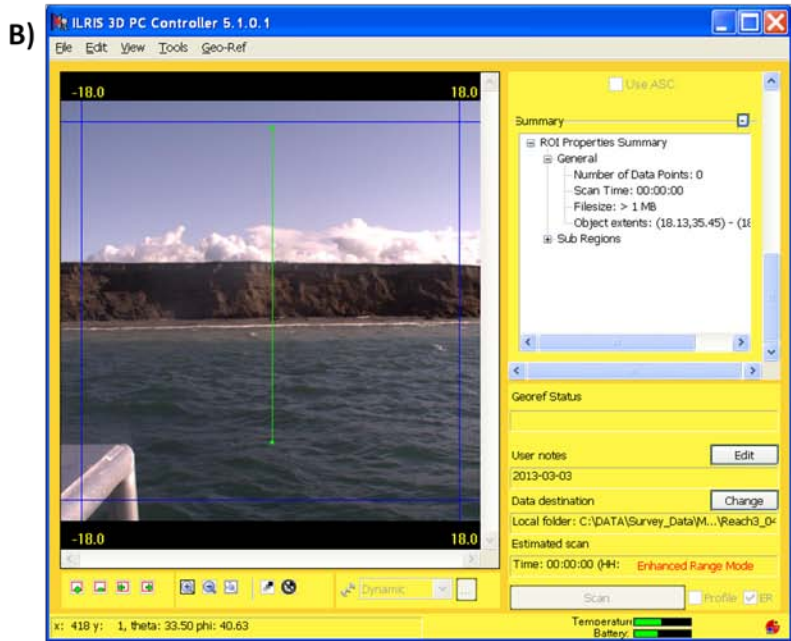
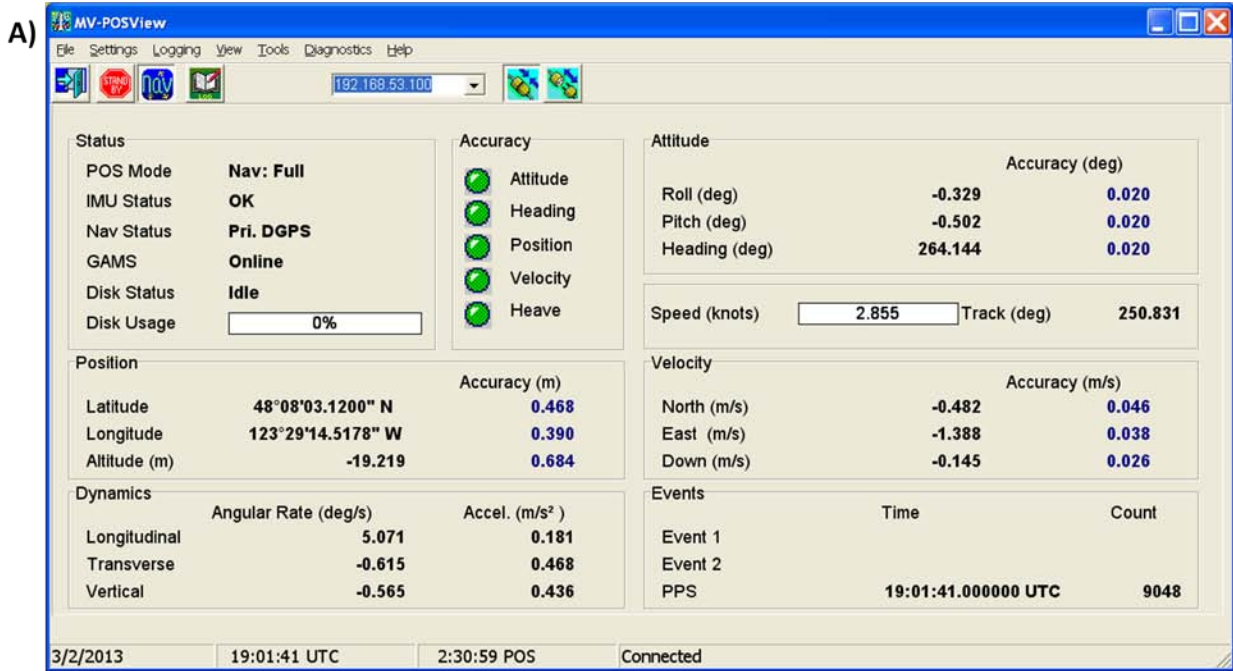


Figure X. A) Computer operator, running QINSy acquisition software to collect and monitor data in real-time. B) Boat operator using built-in Garmin GPS and echosounder to navigate.



(Figure X. Continued on following page)

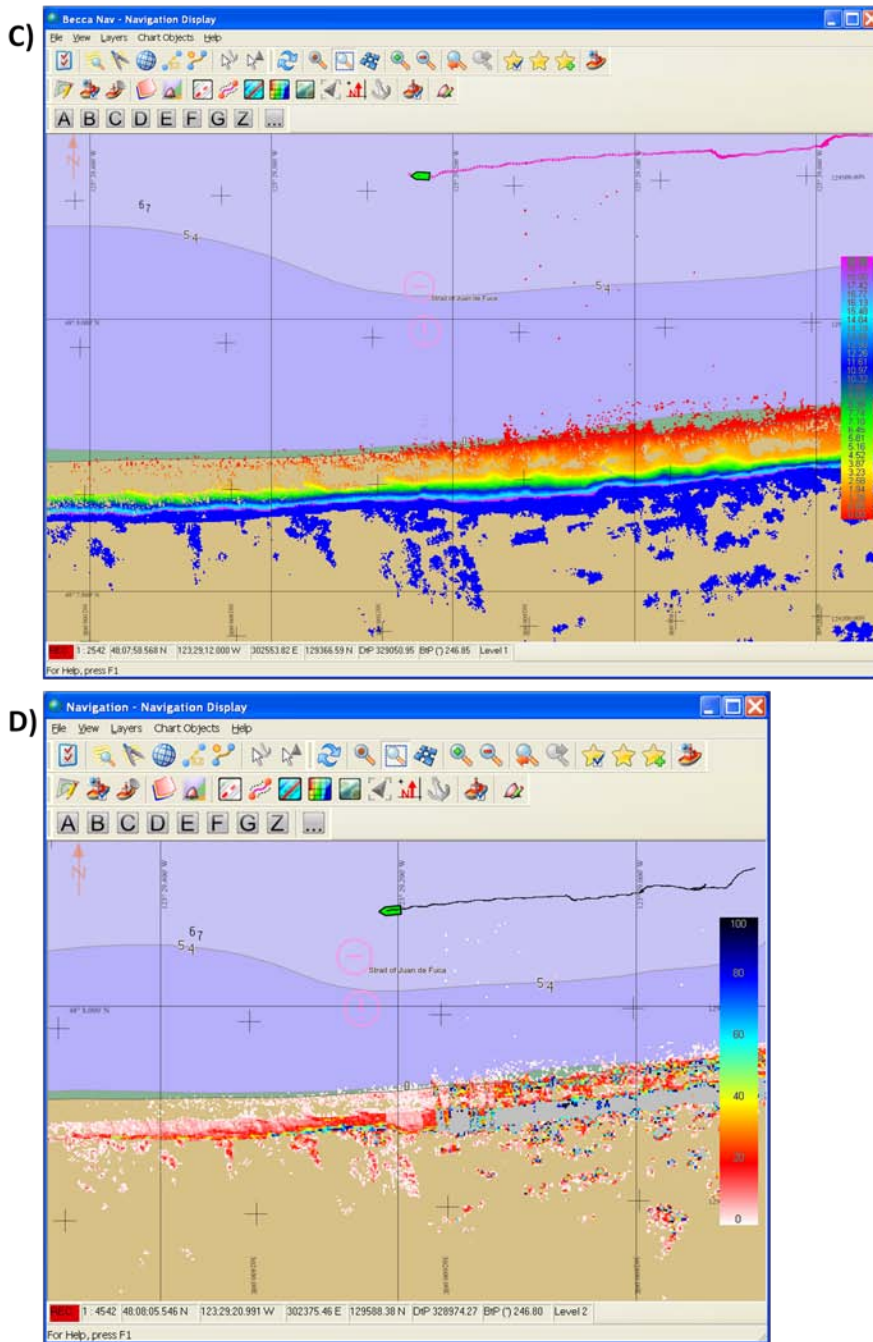


Figure X. Screenshots of real-time data collection control and display windows. A) POSView display window to monitor POS-MV data (e.g., accuracies for the position and attitude of the vessel). B) Optech Controller software to control the laser scanner (e.g., scanning region, point density). C) Navigation display in QINSy Online showing the incoming laser point cloud populating a 0.5-m grid over the background chart, color coded by elevation. D) The same Navigation display window as above, but with the laser point cloud color coded by “hit count,” the number of laser returns within each 0.5 m² grid cell.



Figure X. Adverse weather conditions complicating the survey. A) Foggy conditions obscuring bluff top. B) As a precaution, the laser scanner was partially covered with a garbage bag due to light rain.



Figure X. Example panorama made using Autopano Giga Pro (v. 3.0.3; Kolor, France) from stitching together photos taken during mobile laser scanning.

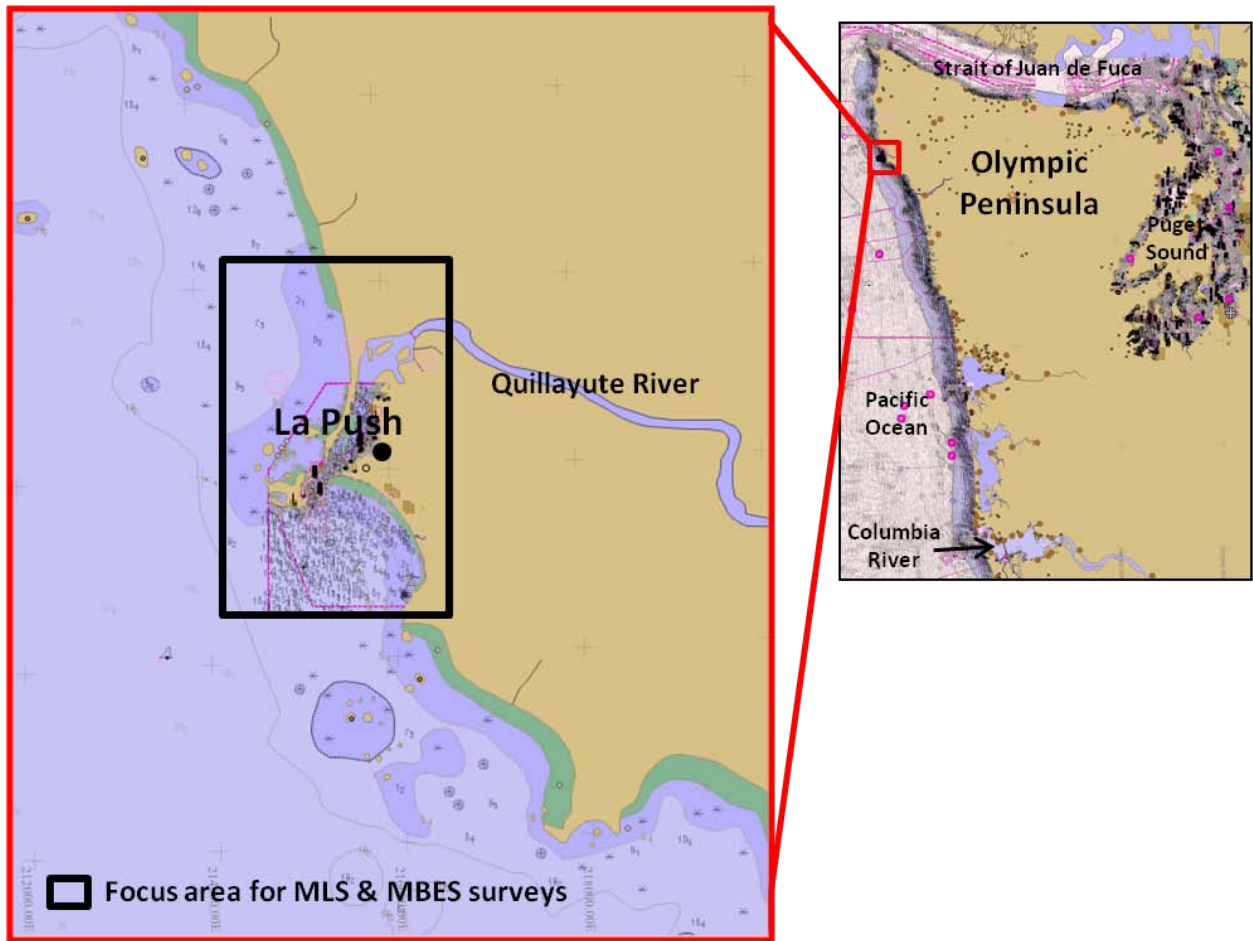


Figure X. Regional and expanded maps showing the Quillayute River mouth at La Push where MLS data was collected in September 2012.

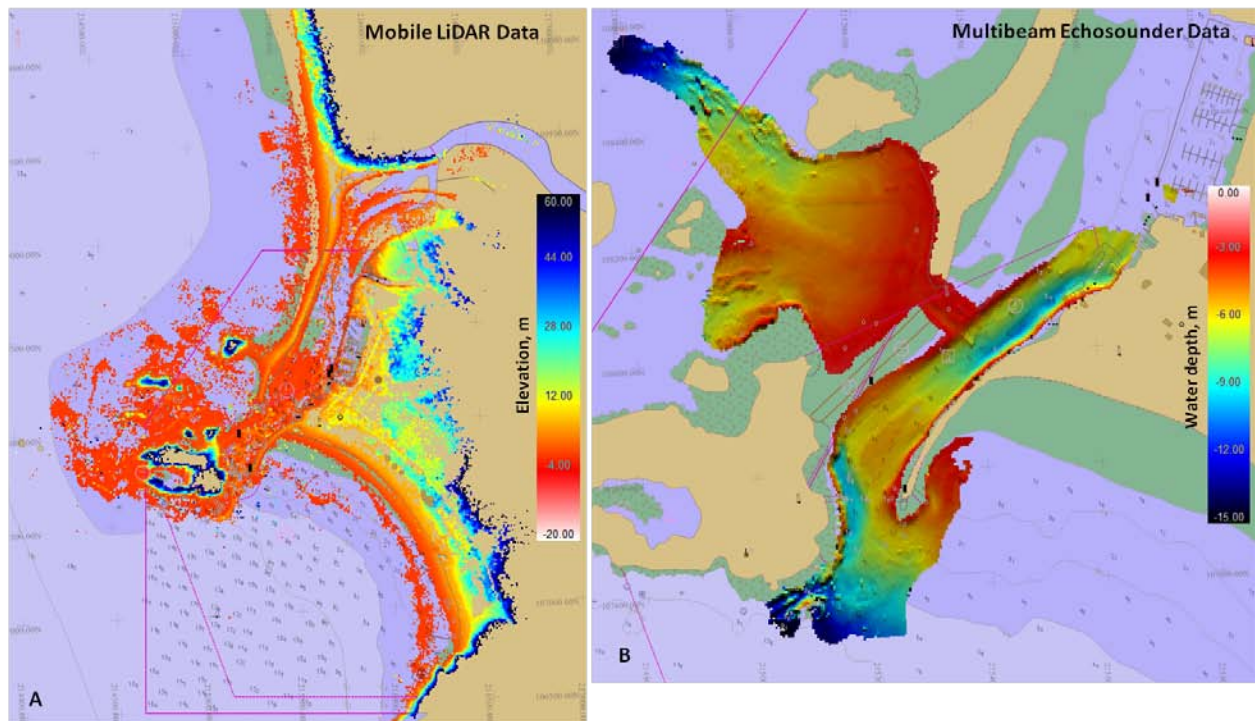


Figure X. Maps showing A) MLS topographic elevation data and B) MBES bathymetry data collected in September 2012 around La Push.

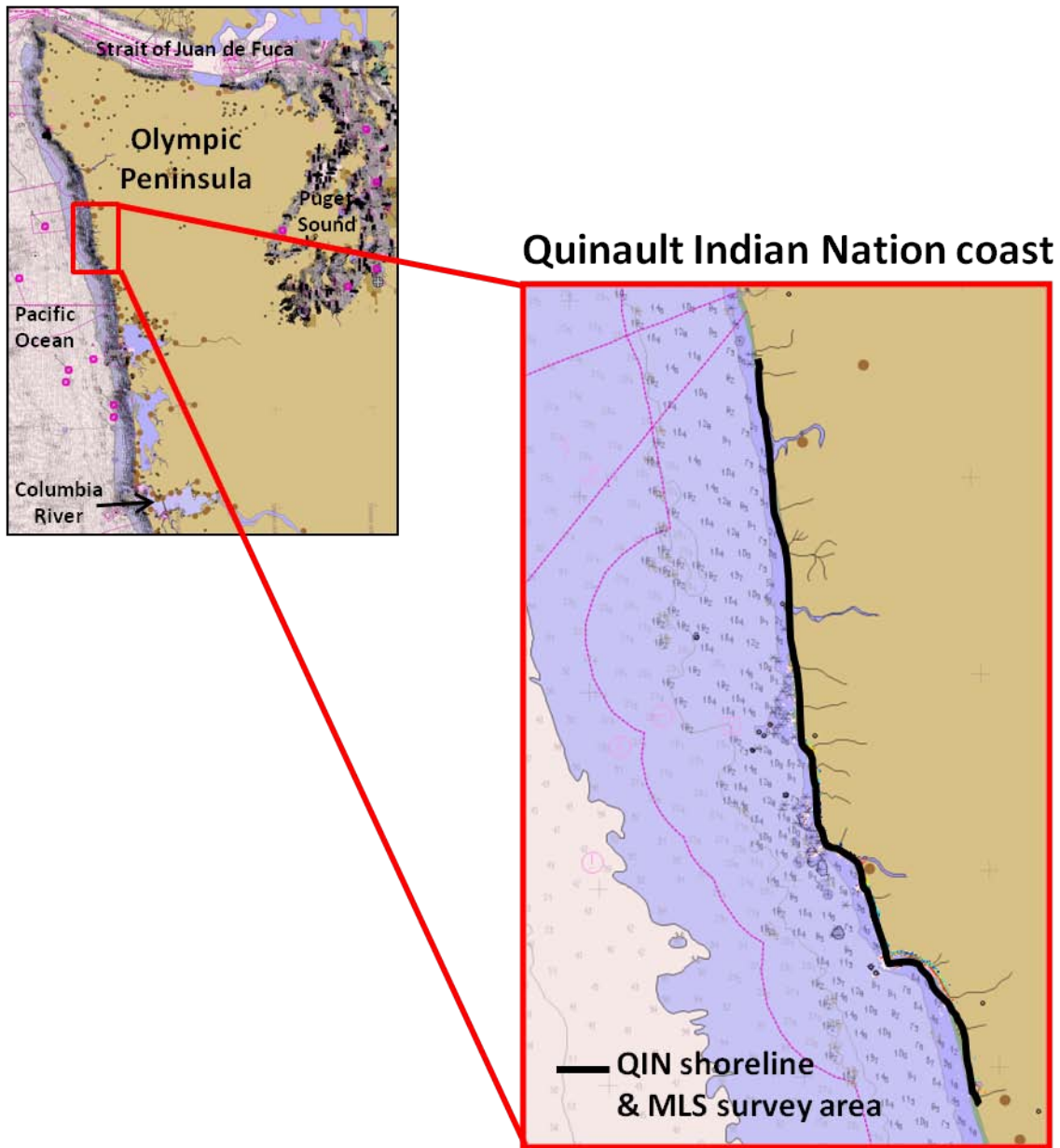


Figure X. Regional and expanded maps showing the coast of the Quinault Indian Nation where MLS data was collected in June 2013.

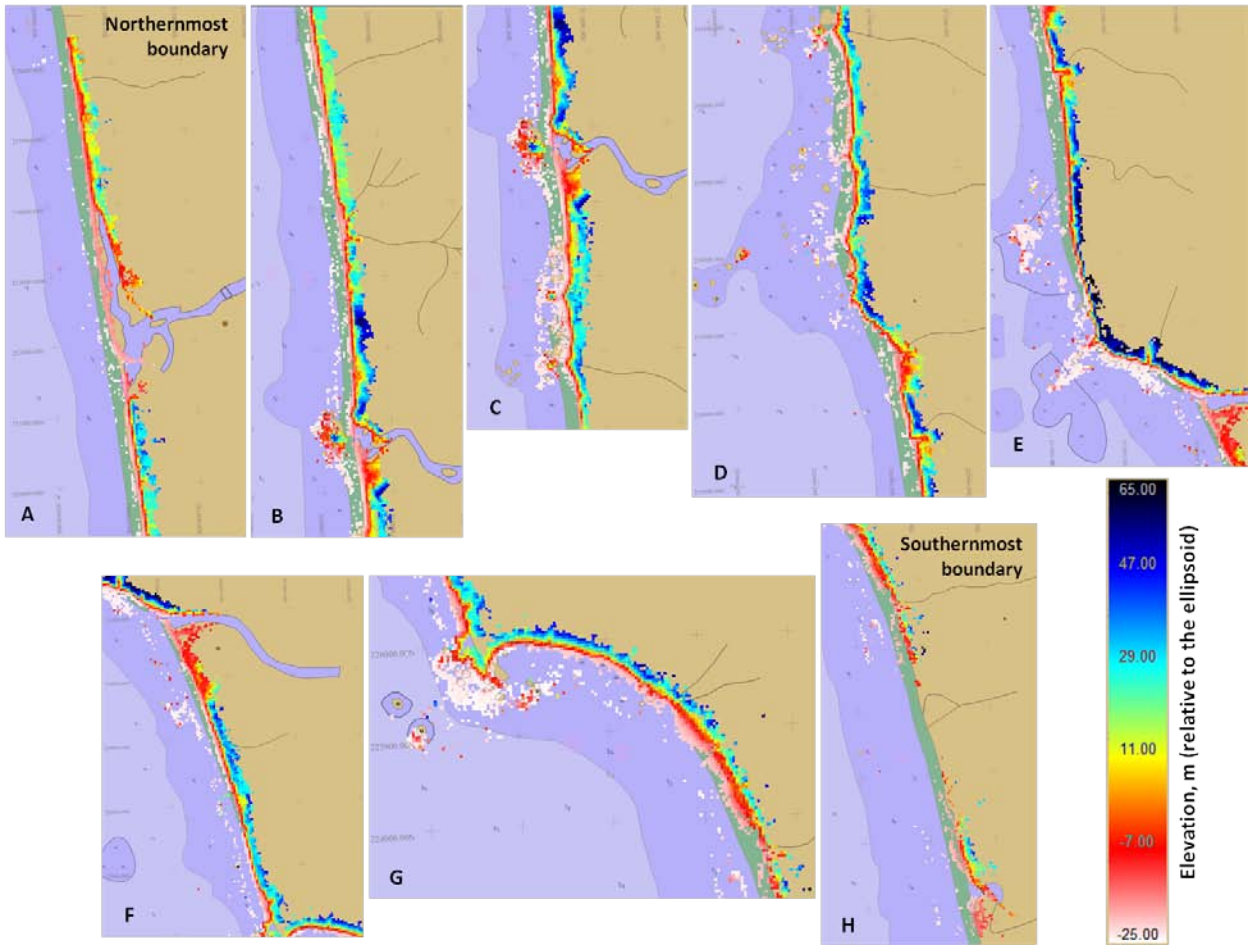
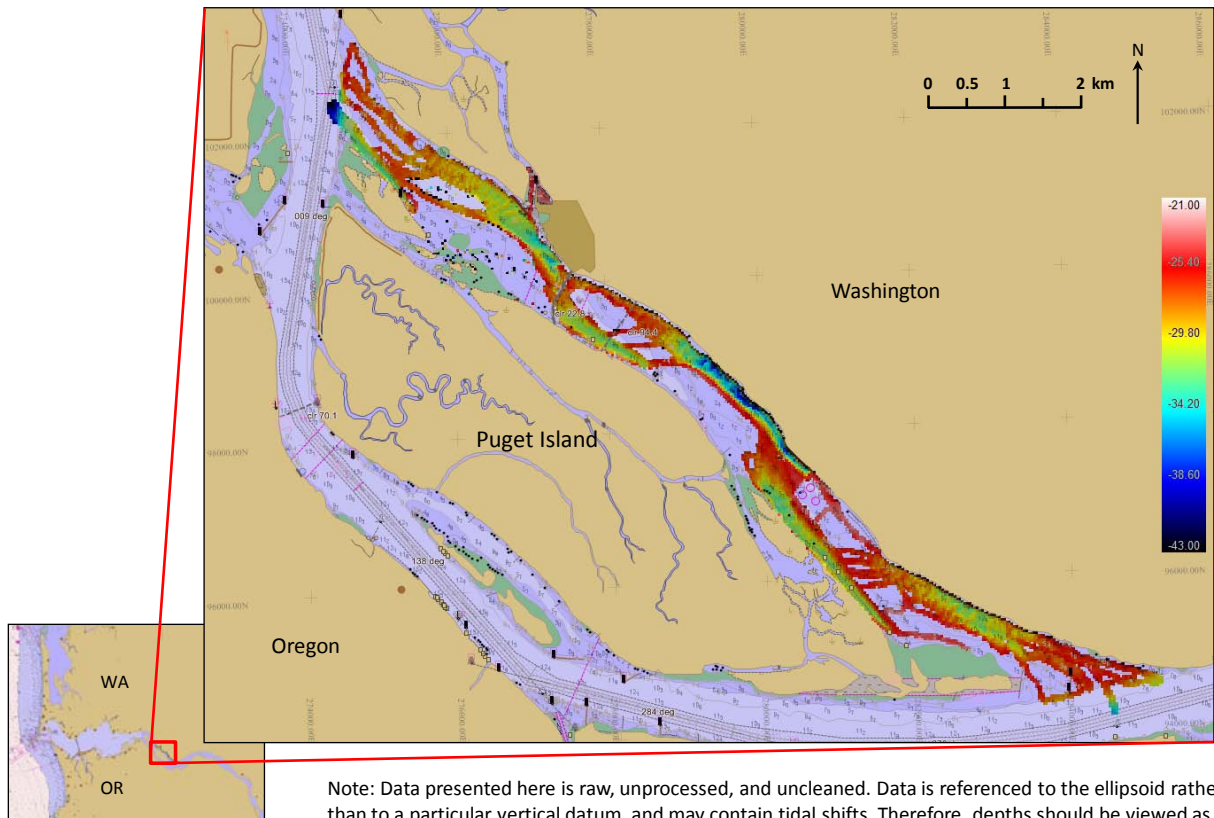


Figure X. Map series (A-H) showing MLS elevation data collected in June 2013 along the coast of the Quinault Indian Nation.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA

Data collected by the Washington Department of Ecology's Coastal Monitoring & Analysis Program on 7-10 May 2013



Note: Data presented here is raw, unprocessed, and uncleaned. Data is referenced to the ellipsoid rather than to a particular vertical datum, and may contain tidal shifts. Therefore, depths should be viewed as relative and not exact. Horizontal positions referenced to NAD 83, WA State Plane South, meters.

Figure X. Overview map of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA

Data collected by the Washington Department of Ecology's Coastal Monitoring & Analysis Program on 7-10 May 2013

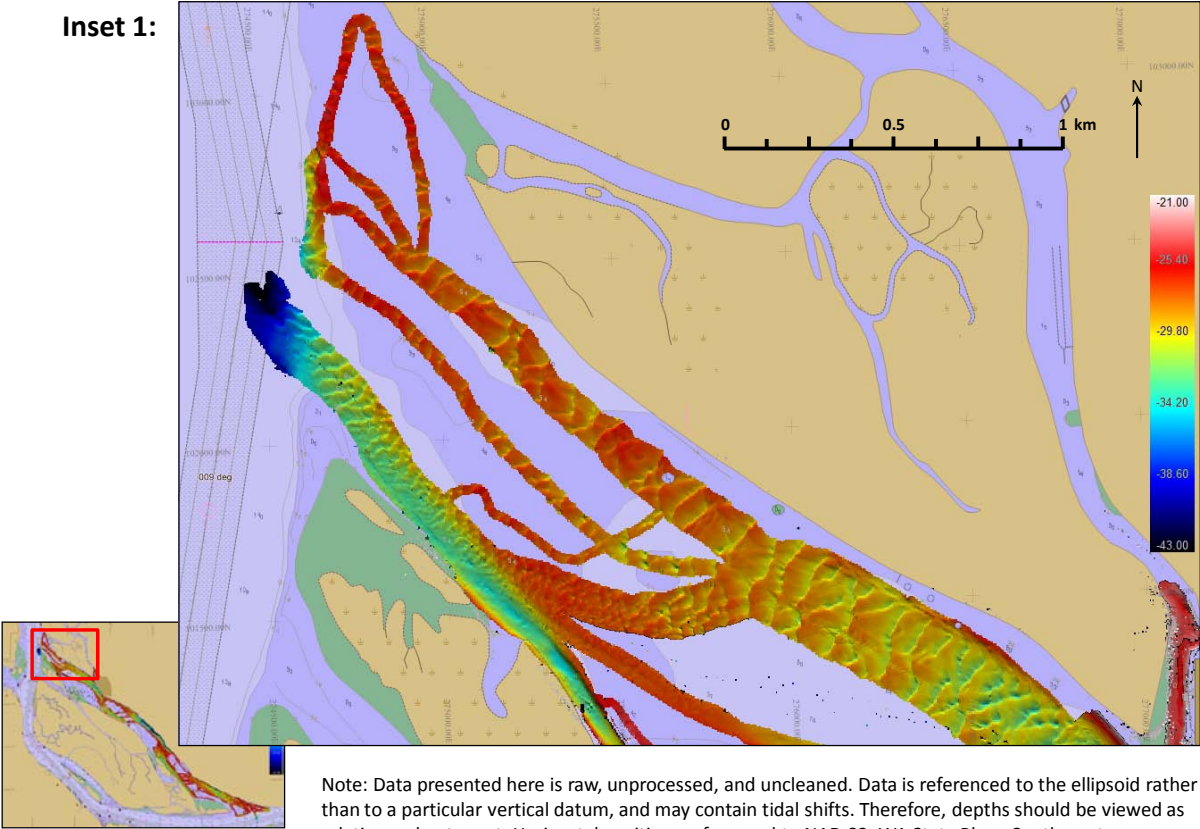


Figure X. Inset map 1 along the westernmost portion of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA

Data collected by the Washington Department of Ecology's Coastal Monitoring & Analysis Program on 7-10 May 2013

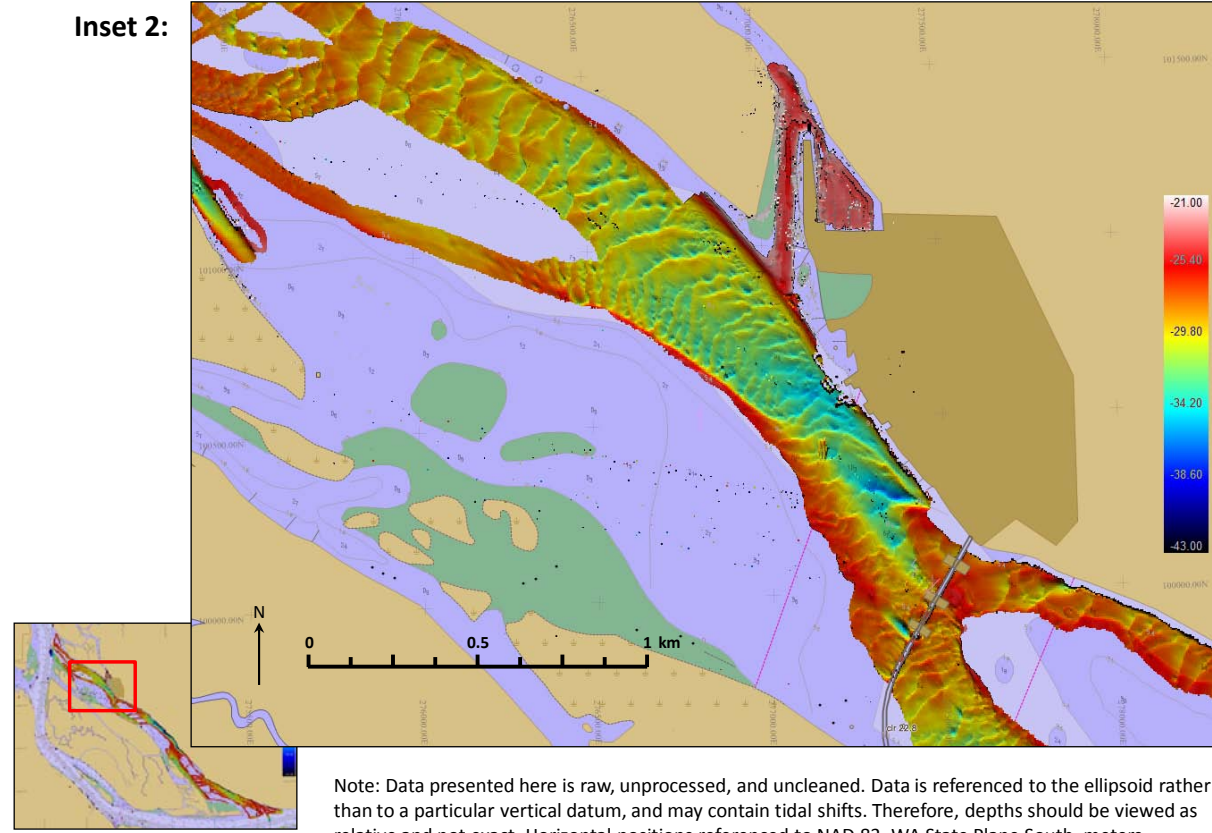


Figure X. Inset map 2 of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA

Data collected by the Washington Department of Ecology's Coastal Monitoring & Analysis Program on 7-10 May 2013

Inset 3:

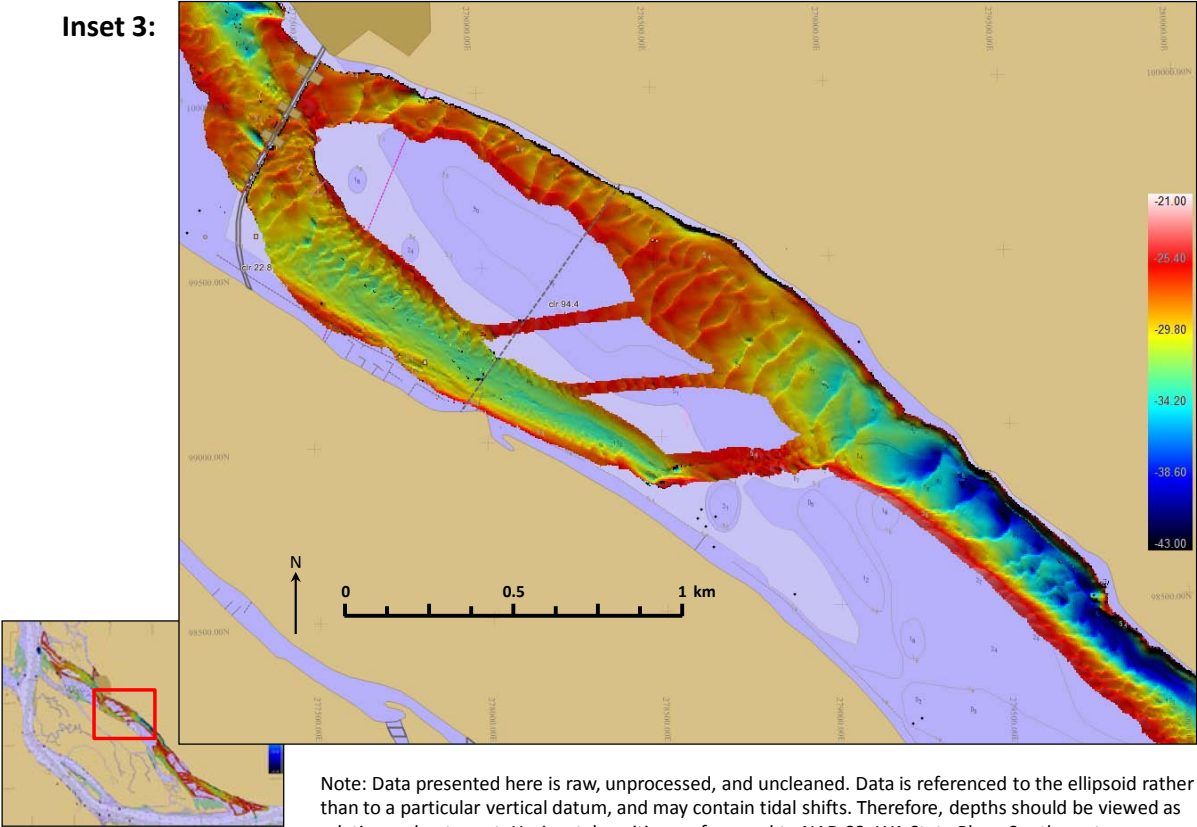


Figure X. Inset map 3 of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA

Data collected by the Washington Department of Ecology's Coastal Monitoring & Analysis Program on 7-10 May 2013

Inset 4:

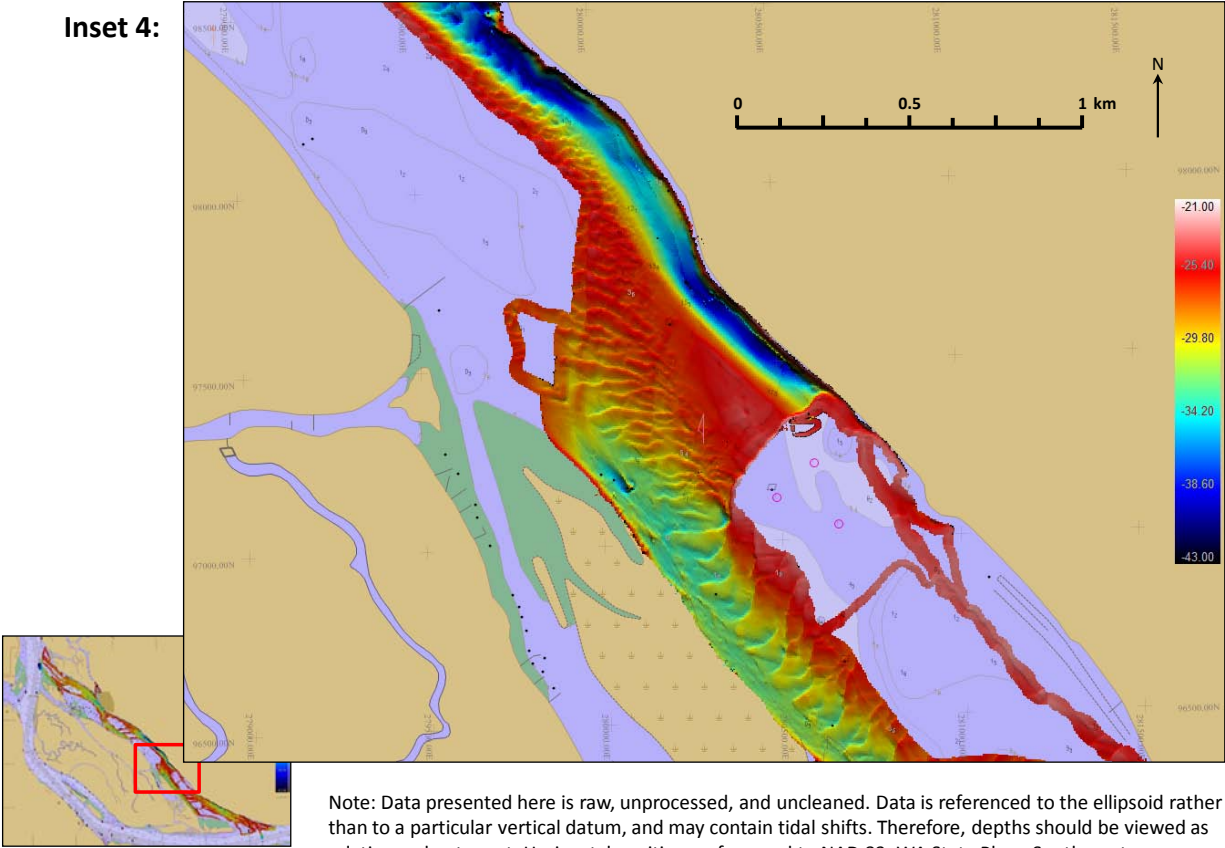


Figure X. Inset map 4 of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA
Data collected by the Washington Department of Ecology's Coastal Monitoring & Analysis Program on 7-10 May 2013

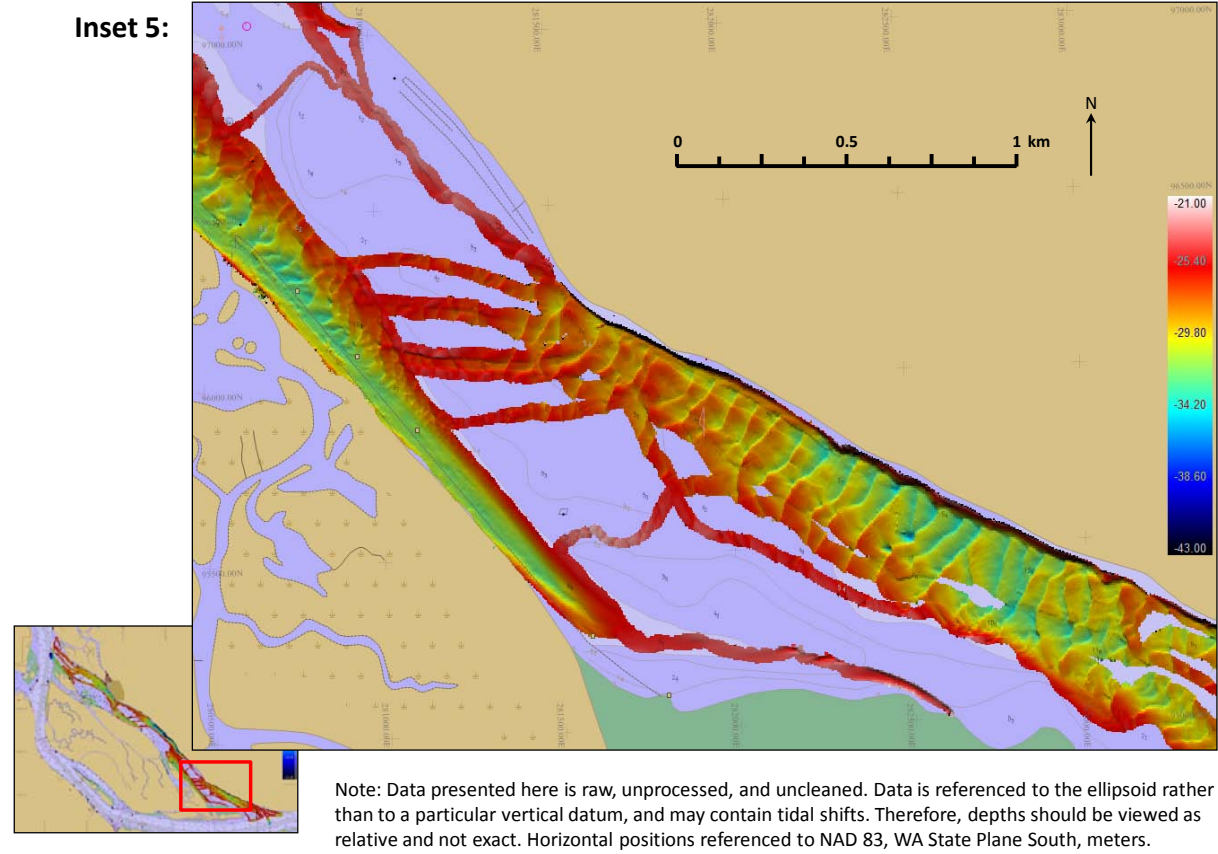
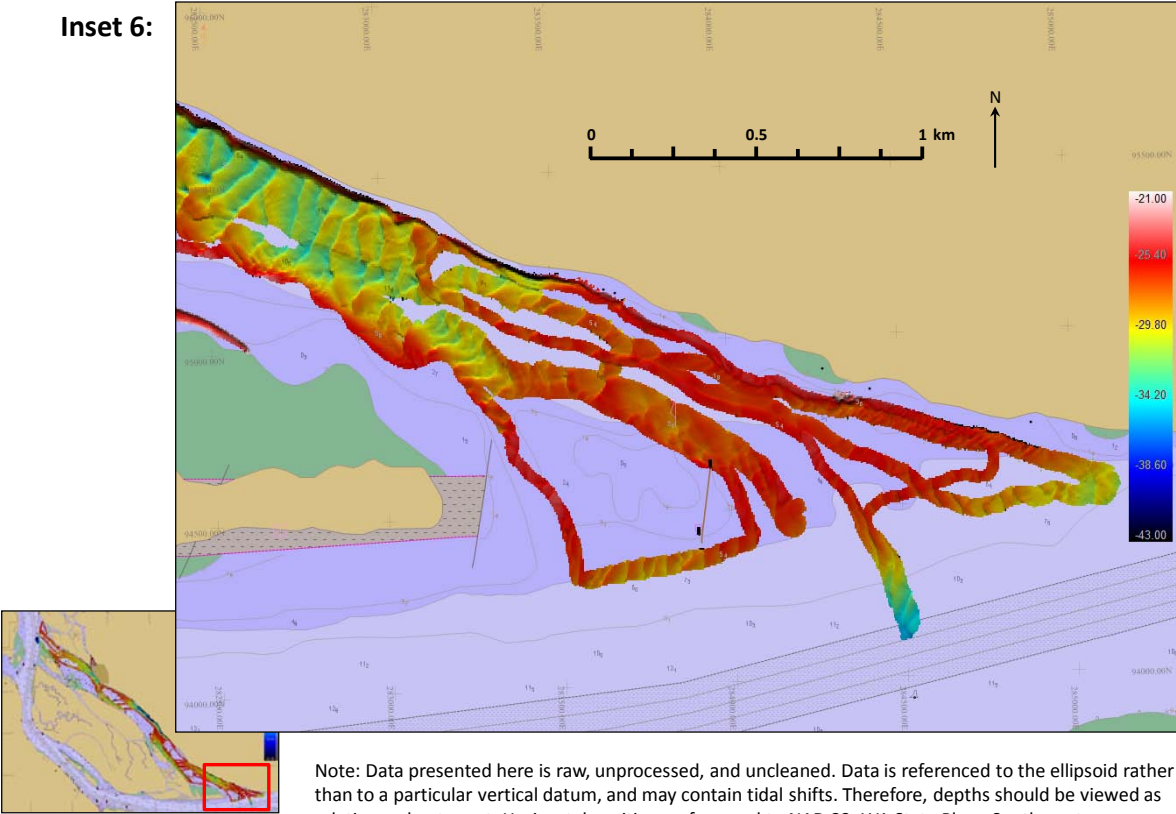


Figure X. Inset map 5 of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

Raw Multibeam Bathymetry Data for Cathlamet Channel, Wahkiakum County, WA

Data collected by the Washington Department of Ecology’s Coastal Monitoring & Analysis Program on 7-10 May 2013

Inset 6:



Note: Data presented here is raw, unprocessed, and uncleaned. Data is referenced to the ellipsoid rather than to a particular vertical datum, and may contain tidal shifts. Therefore, depths should be viewed as relative and not exact. Horizontal positions referenced to NAD 83, WA State Plane South, meters.

Figure X. Inset map 6 of the easternmost portion of the Wahkiakum County survey area showing MBES bathymetry data collected in May 2013.

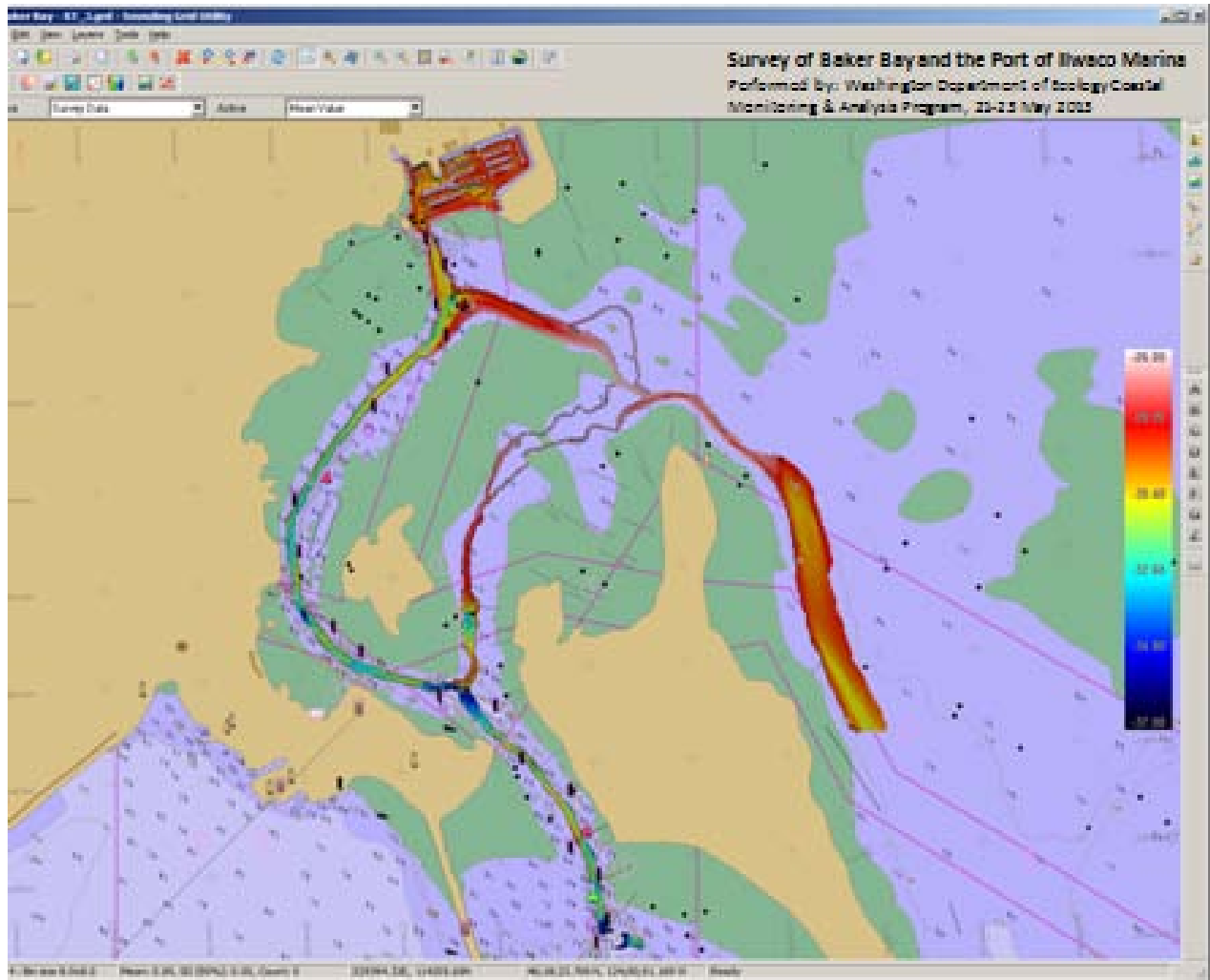


Figure X. Overview of MBES data collected at Ilwaco Marina and Baker Bay during May 2013.

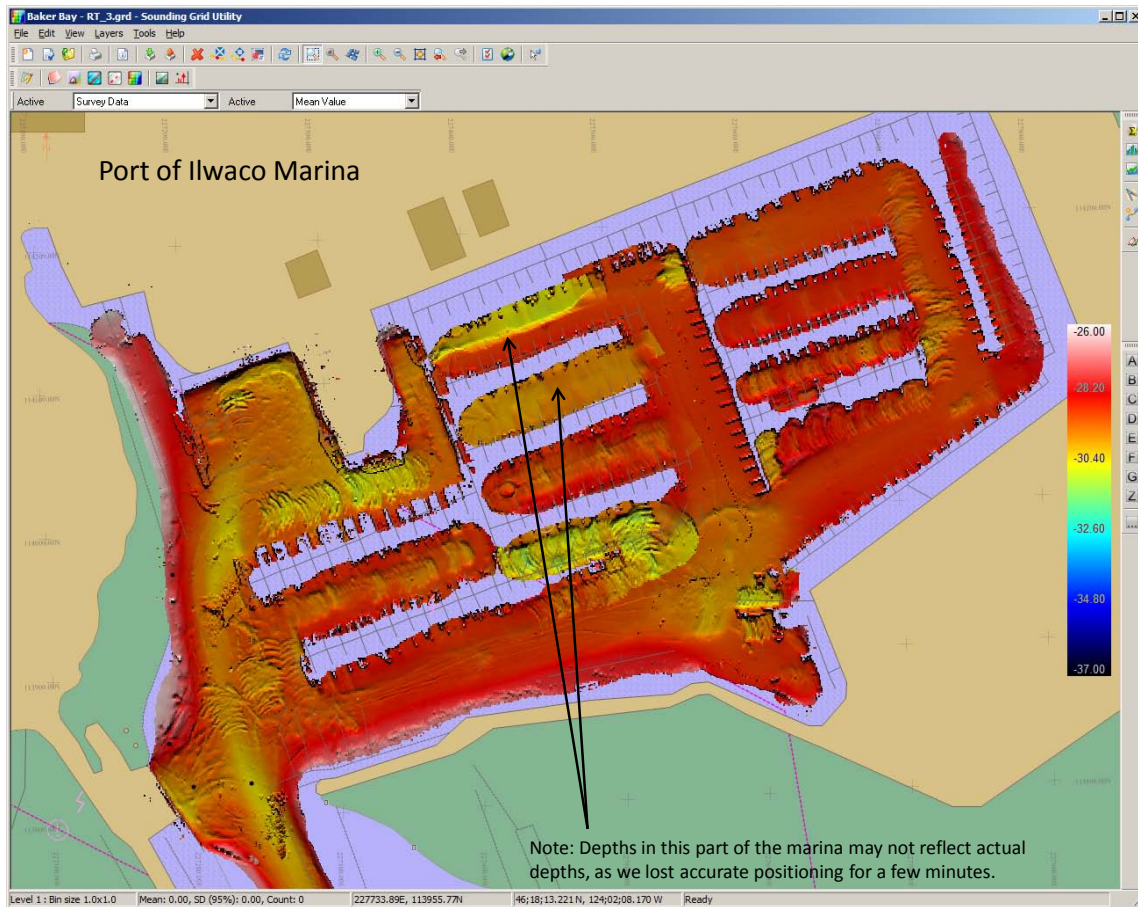


Figure X. Initial MBES data collected at Ilwaco Marina during May 2013.

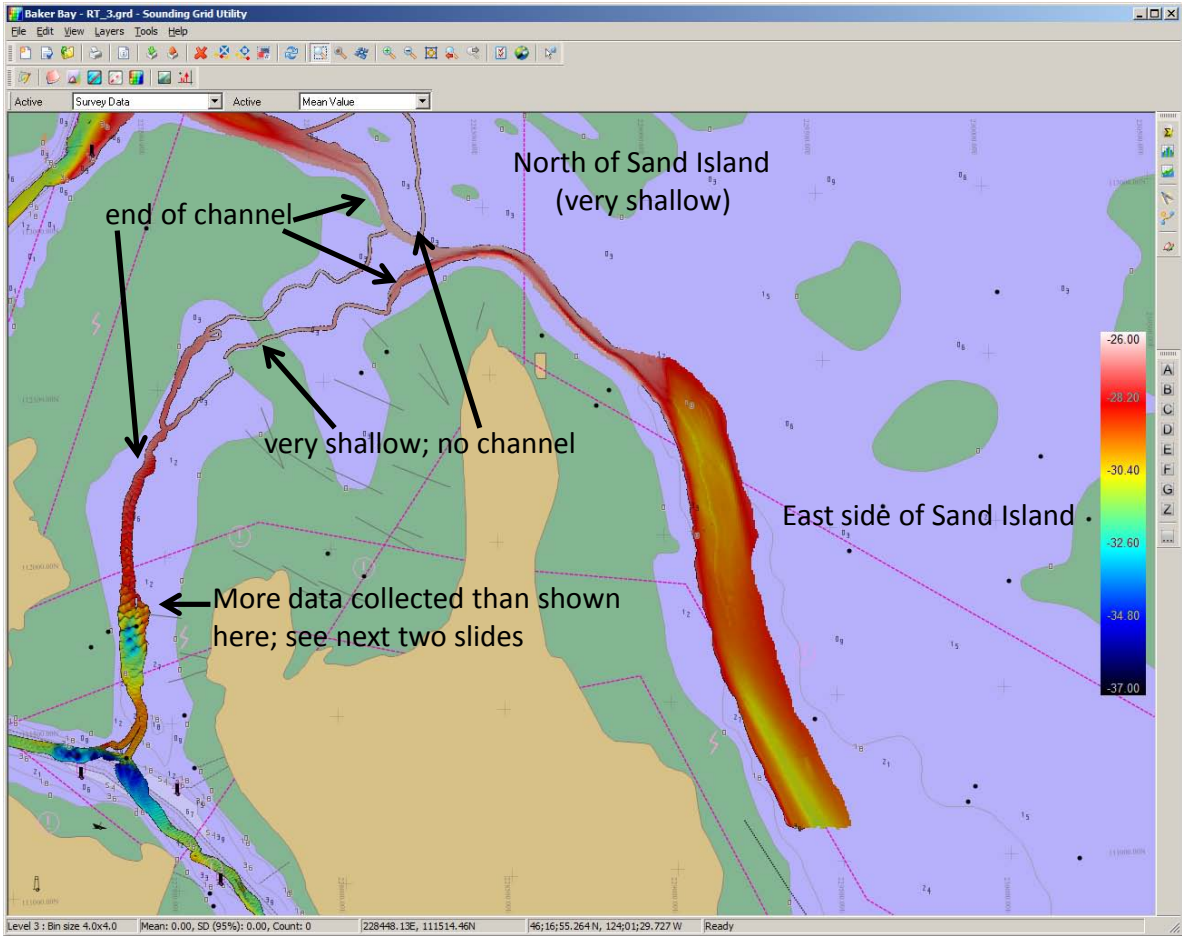


Figure X. Initial MBES data collected in northern Baker Bay during May 2013.

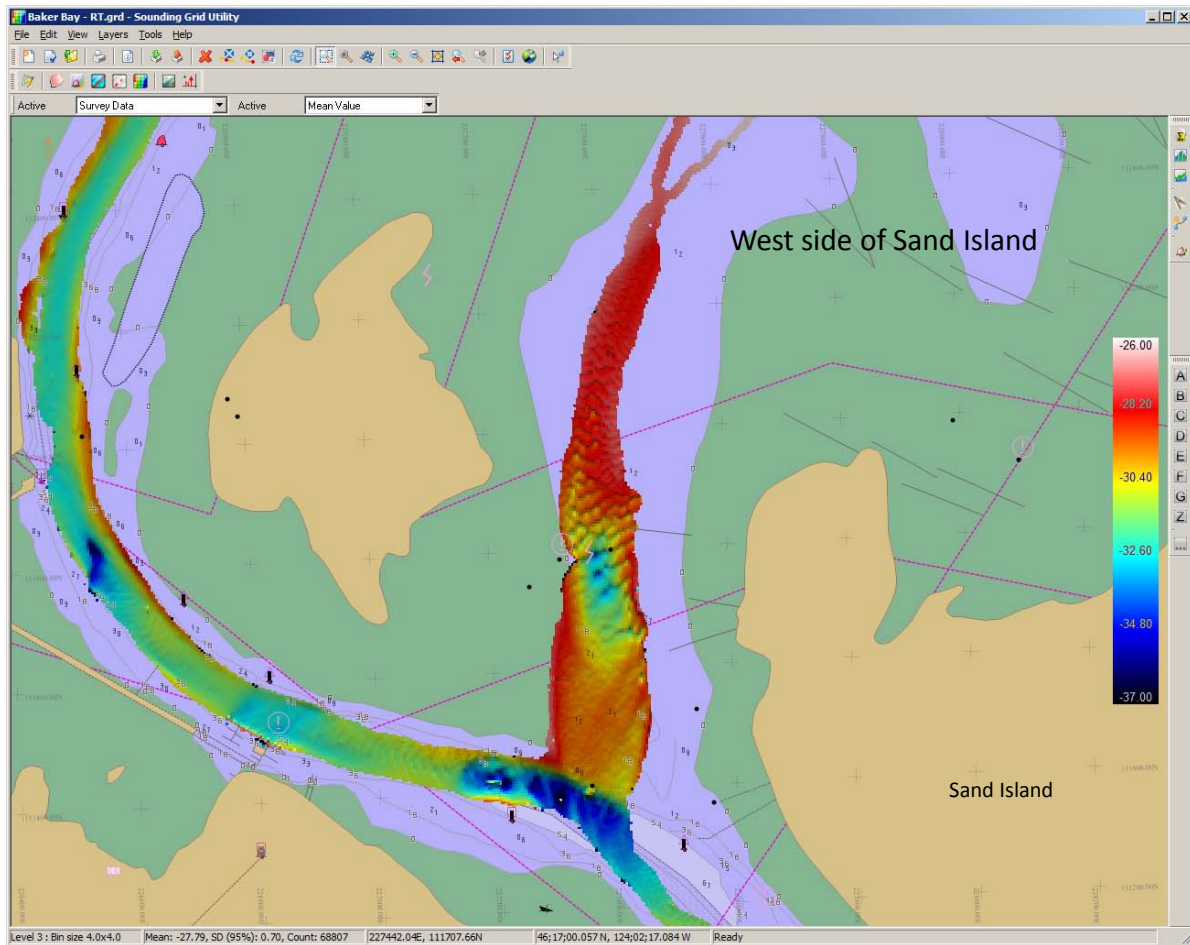


Figure X. Initial MBES data collected in Baker Bay around the navigation channel and west Sand Island during May 2013.

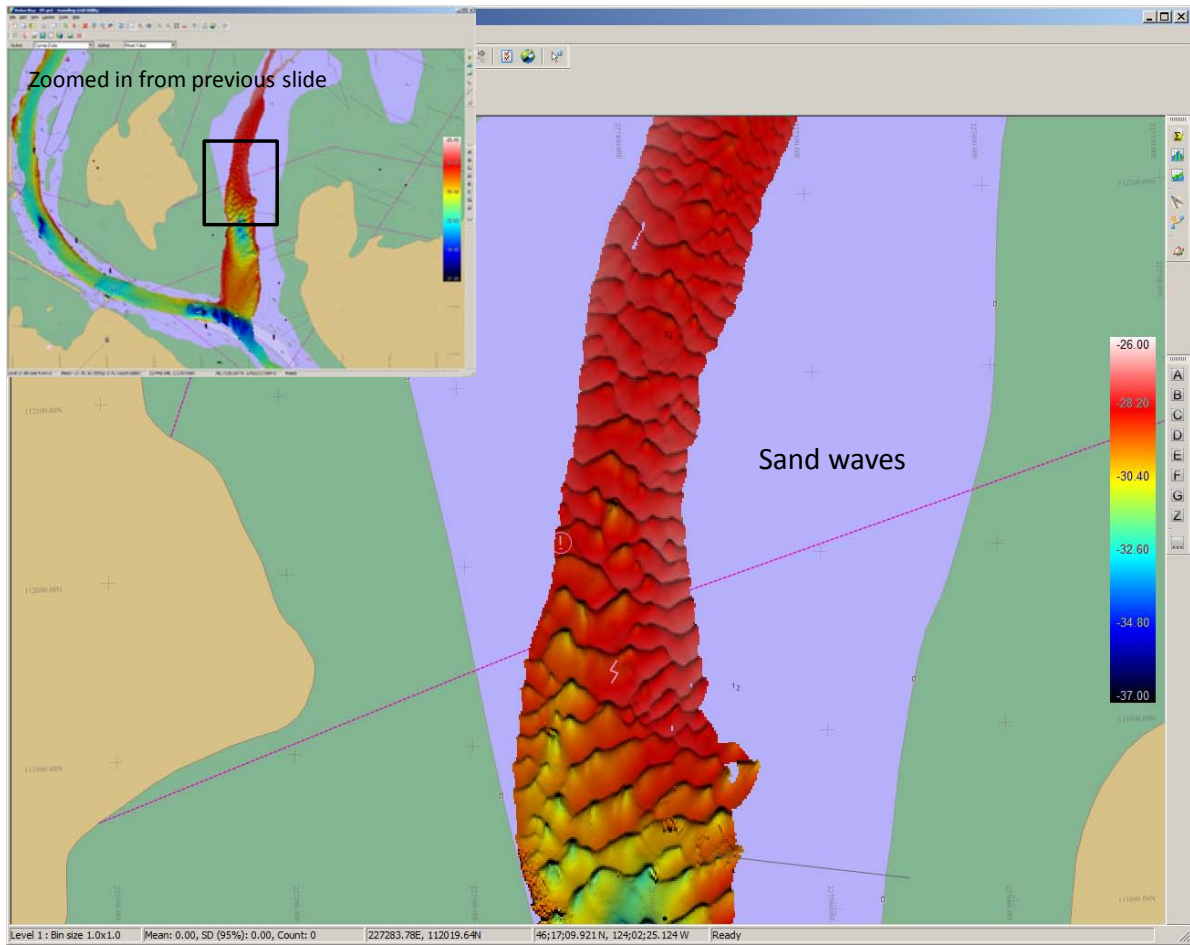


Figure X. Initial MBES data collected in May 2013 around west Sand Island showing details of sand waves.