Shoalwater Bay Berm Monitoring

2014-2016 Assessment of Coastal Morphology Change

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2014-2016 Assessment of Coastal Morphology Change

by

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Executive Summary

This report has been prepared for the U.S. Army Corps of Engineers (USACE) by the Washington State Department of Ecology Coastal Monitoring & Analysis Program (CMAP) to summarize the acquisition and processing of bathymetric and topographic data of the nearshore, beach, and dune along Graveyard and Empire Spits on the north shore of Willapa Bay, Washington, as well as provide an analysis of morphological change over the two-year survey period. Data were collected semiannually in late summer and early spring beginning in September 2014 and ending in September 2016. Repeat monitoring provides critical data for determining potential risks to the USACE coastal storm damage reduction project as well as to State infrastructure.

Five surveys were performed using a combination of data collection techniques, including multibeam bathymetry, boat-based lidar, and ground-based GPS topography, to obtain full coverage of the approximately 9 km-long survey area from the west side of the WA State Route (SR) 105 groin to Toke Point. In the cross-shore, surveys extended approximately from -25 ft mean lower low water (MLLW; -8 m NAVD88) to mean high water (MHW; 2.2 m NAVD88) on the landward side of the berm. Each survey took 8-12 days to complete with a crew of 5-6 people.

All data were referenced to the same GPS base station monument installed prior to the first survey in 2014, and are relative to NAD83(2011) Washington State Plane South in horizontal and NAVD88 in vertical, using GEOID12B, in meters. The high-resolution multibeam and lidar point cloud data were combined with the ground-based GPS points using linear interpolation and gridded at 1-m to generate a continuous topobathymetric digital elevation model (DEM) of the survey area. The DEMs were analyzed to assess morphology change over time.

Change analyses over this two year period show that the west end of the berm experienced significant erosion, retreating by 340 m (1,115 ft) along its center axis. The upper beach and lower beach face adjacent to and offshore of this section also eroded, with net sediment transport toward the southeast, resulting in the accumulation of nearly an equal volume of sediment across the beach face and nearshore region seaward of the central section of the berm. The crest elevation of the berm to the southeast of the eroded section lowered by an average of 0.7 m while also widening and aggrading on the landward side.

To the northwest of the project site, Graveyard Spit experienced significant shoreline retreat and overwash, especially during the winter 2015-16 El Niño, exposing SR 105 along the backside of the barrier to wave action for the first time. Graveyard Spit is sediment starved and will likely continue to erode without external sediment input.

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Introduction

Over a period of two years, from September 2014 to September 2016, the Washington State Department of Ecology Coastal Monitoring & Analysis Program (CMAP) performed a series of five surveys to collect continuous, high-resolution nearshore bathymetry and beach topography data of the Shoalwater Bay/North Cove area located along the north shore of Willapa Bay in Pacific County, Washington (Figure 1). The purpose of these surveys was to monitor a 2.5 km-long berm constructed in 2012 by the U.S. Army Corps of Engineers (USACE) along Empire Spit and quantify morphological changes along the shoreline extending from the SR 105 groin to Toke Point as part of the Shoalwater Bay Shoreline Erosion Project.

As outlined by the USACE in the Cooperative Agreement, this monitoring program is needed to:

1. Provide the data necessary to quantify the level of protection provided by the Shoalwater dune restoration project. The restored dune provides coastal storm damage reduction for the Shoalwater Indian Reservation and requires periodic renourishment to maintain the designed level of protection. These monitoring data will be critical in determining the rate of erosion and quantities required for the next planned nourishment.
2. Monitor the morphology of Graveyard Spit over time to comply with prior agreements with U.S. Fish and Wildlife Service regarding habitat provided to listed Endangered Species Act species Western Snowy Plover.
3. Provide data necessary to refine the sediment budget for the Willapa Bay inlet which includes the rapidly eroding shoreline adjacent to SR 105.

Monitoring took place twice annually, in late summer and early spring. Late summer surveys were collected between August and September to avoid impacts to snowy plovers. Early spring surveys were conducted between March and April. The monitoring survey methods included a combination of multibeam bathymetry, boat-based topographic lidar, and ground-based GPS topography at a sufficient resolution to capture geomorphologic features.

Cross-shore survey transects were spaced 100 m apart, with 95 transects over 8 km of shoreline. Bathymetric survey lines extended to a minimum of -20 ft mean lower low (MLLW) offshore to overlap with annual USACE condition surveys of Willapa Bay and as close to mean high water (MHW) as possible onshore in order to provide sufficient overlap with the topographic surveys. Topographic surveying extended landward of the dune crest to sufficient distance as to capture the backshore elevation landward of the restored dune (approximately to mean high water). Survey density was increased near important morphologic features such as inlet migration events, dune scarping/notching, and overwash fans to provide sufficient resolution to develop a surface map. These and other morphological features were resolved with a combination of boat-based lidar and ground-based GPS contour mapping by backpack and an all-terrain vehicle (ATV).

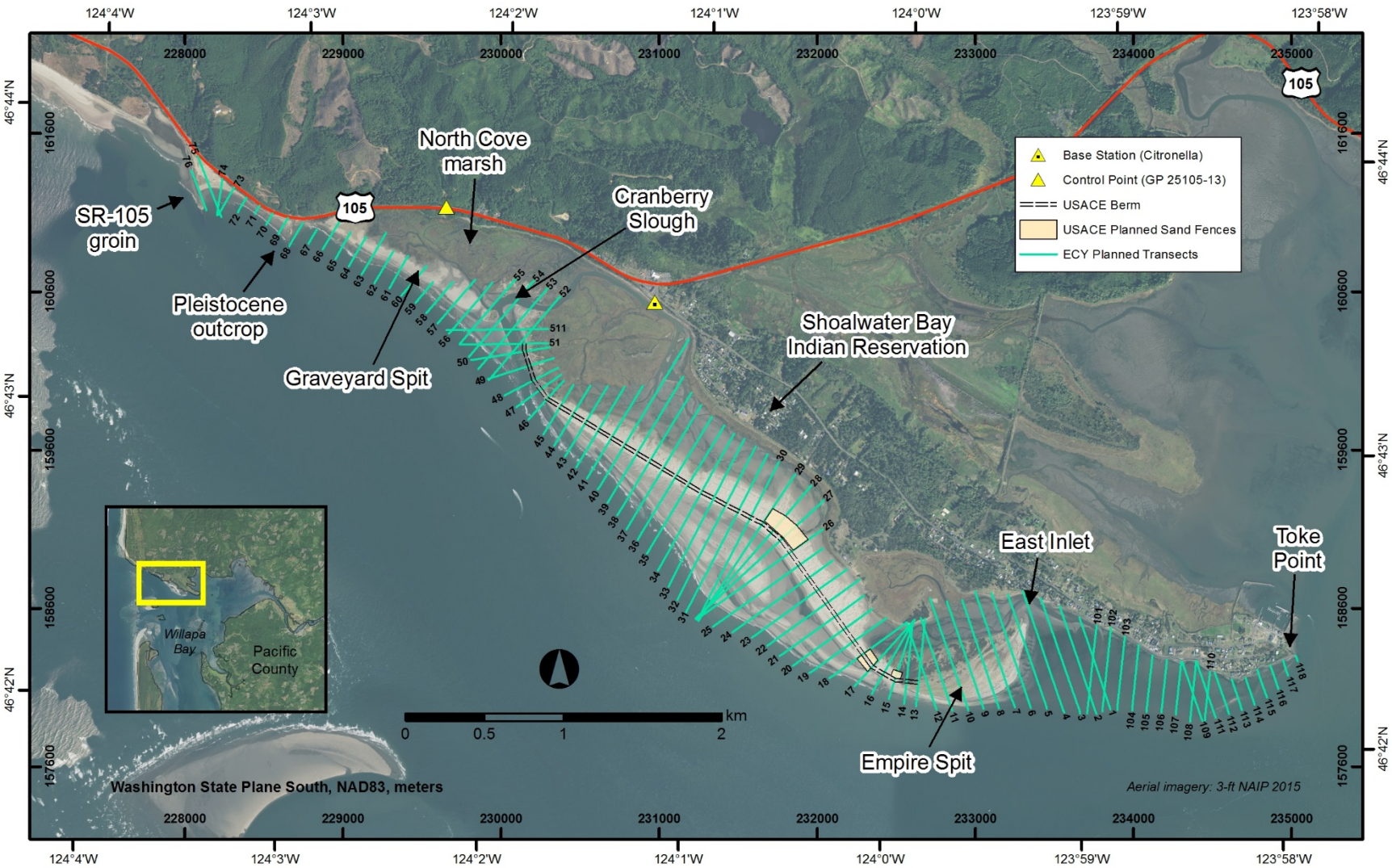

Figure 1. Survey area map, showing location of base station, control points, and planned 100 m-spaced transects.

Methodology

Mobilization

In order to produce a continuous digital elevation model (DEM) across the land-water interface, complementary survey methods were employed. Nearshore bathymetry data were collected using multibeam sonar deployed from CMAP's research vessel, the R/V *George Davidson*. Topographic data were collected remotely from a mobile laser scanner mounted to the cabin top of the R/V *George Davidson*. Additional ground-based topographic data were collected on foot with GNSS rovers mounted on backpacks and an ATV.

The R/V *George Davidson* is a 28 x 10-ft aluminum, twin-hull landing craft specifically designed for shallow water surveying, with an 18-inch draft and a drop-down bow door to facilitate beach landings for loading and offloading personnel and cargo at remote beaches for ground-based topographic surveying (Figure 2). The twin-hull design provides exceptional straight line tracking capability as well as side-to-side stability while surveying in most sea conditions.

Figure 2. Photo of the research vessel used for the boat-based lidar survey, the R/V *George Davidson*

For the first two surveys (September 2014 and April 2015), a single multibeam echosounder (MBES) was used for the bathymetric mapping, deployed from a moon pool along the centerline of the vessel. In spring 2015, CMAP acquired a second MBES and installed a dual-head, dual-

mount MBES system in which two sonars were deployed simultaneously, each from a side mount near the vessel's stern (Figure 3). The dual-head system greatly improved data collection speed and enabled increased coverage for the subsequent three surveys, increasing the swath width from about 4 to 6.5-8 times the water depth.

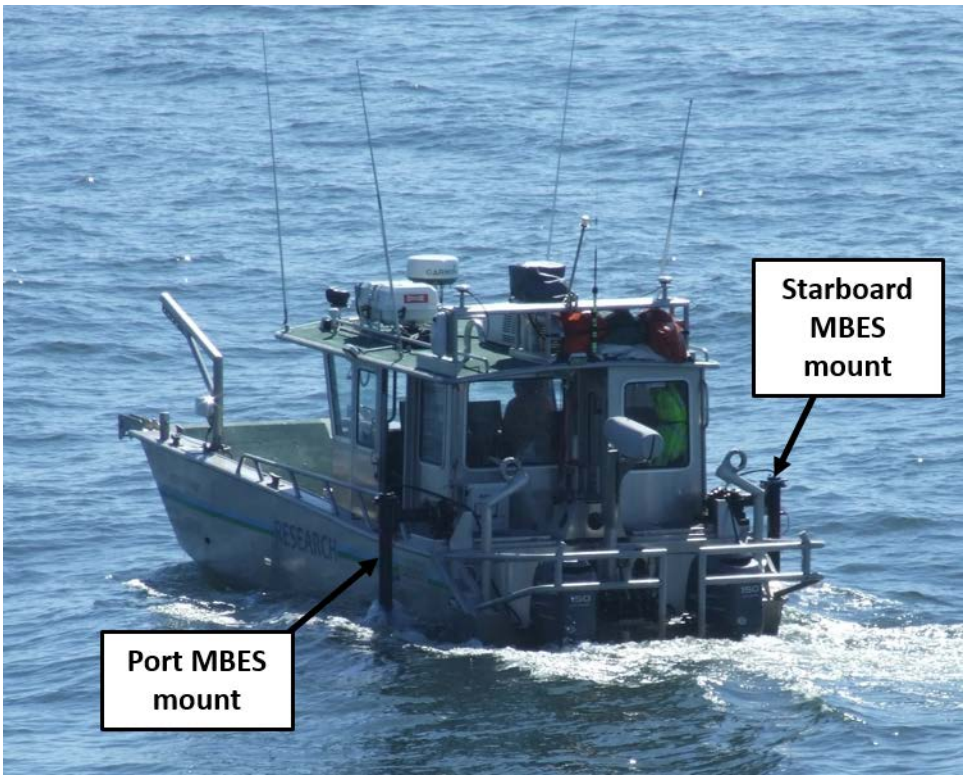

Figure 3. Photo of R/V George Davidson dual-head, dual-mount multibeam echosounder (MBES) system with both sonar heads deployed over the side of the vessel

On the cabin top of the R/V *George Davidson* is a dedicated mount designed to securely and repeatably hold the laser scanner, inertial measurement unit (IMU), and two Global Navigation Satellite System (GNSS) antennas (Figure 4). The IMU is mounted immediately adjacent to the laser scanner in order to most accurately account for the motion experienced by the scanner while surveying. The GNSS antennas are mounted with a separation distance of 6 ft to best resolve the vessel heading.

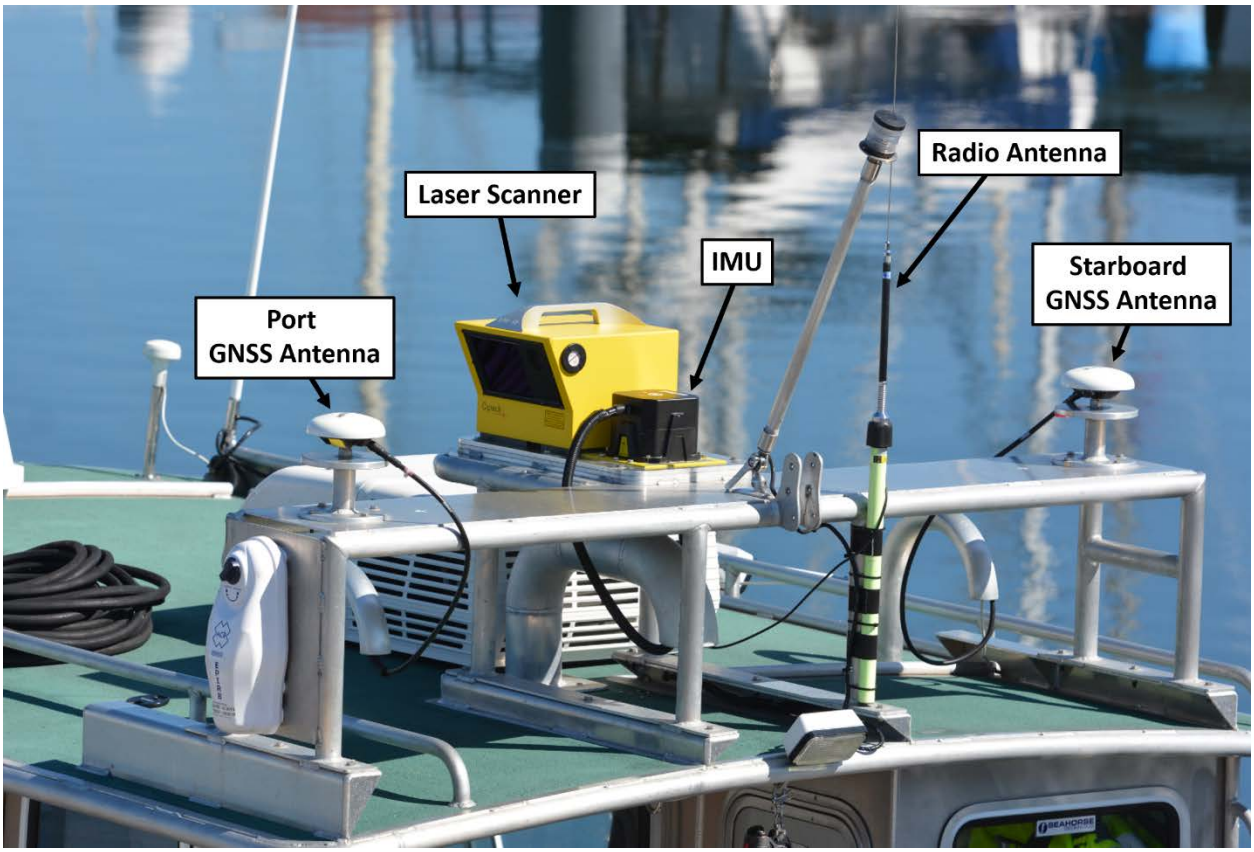

Figure 4. Photo of R/V *George Davidson* cabin top mount with survey equipment

The location of all onboard sensors are referenced to a single point on the deck in the cabin, near the vessel's center of rotation. A standard patch test was conducted during each survey in order to update the pitch, roll, and heading offsets between the MBES system and the IMU reference frame. Laser boresight angle measurements were established independently with an Optech consultant and were held constant from survey to survey.

Equipment

High-resolution bathymetry data were collected using an R2Sonic 2022 wideband shallow water multibeam echosounder (MBES; Figure 5). The 2022 can operate at a range of frequencies between 170 to 450 kHz, with an additional frequency for ultra-high resolution at 700 kHz. A swath of data consists of 256 soundings and can be up to 160 degrees wide. The 2022 has a ping rate up to 60 Hz and a 1 x 1 degree beam width at nadir when operating at 400 kHz, the frequency used for this project.

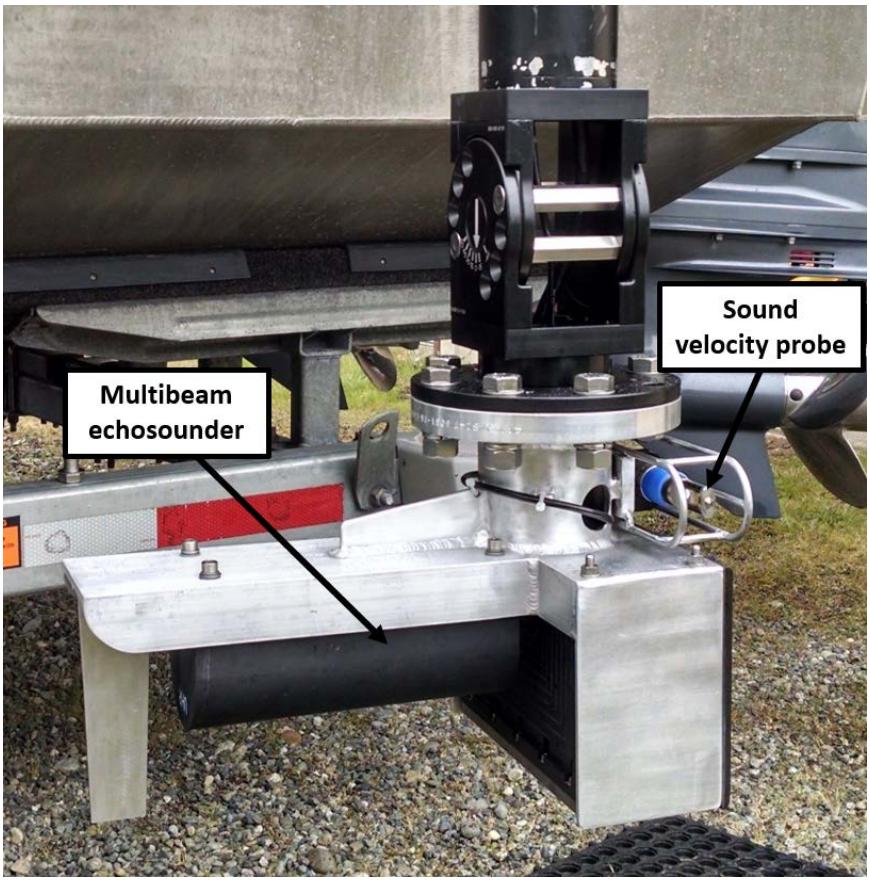

Figure 5. Multibeam echosounder and sound velocity probe used for bathymetric surveying

Sound velocity measurements are taken throughout the survey. An AML Oceanographic Micro-X sound velocity probe is mounted to the port MBES bracket that continuously measures the speed of sound at the sonar head and uses the data for beam steering in real-time (Figure 5). In addition, sound velocity casts are collected by hand-deploying an AML Oceanographic Minos-X profiler over the side of the vessel to measure the speed of sound throughout the water column (Figure 6).

Figure 6. Photo of surveyor collecting a sound velocity cast over the side of the vessel during a bathymetric survey

An Optech ILRIS HD-ER laser scanner with motion compensation was used for lidar data collection. The laser scanner has a maximum range of up to 1,800 m (1.1 mi) and a repetition rate of 10,000 Hz. The raw positional accuracy of the scanner is specified to be 0.7 cm (0.02 ft) at a distance of 100 m (328 ft), where it has a beam diameter of 1.9 cm (0.06 ft). The laser has a narrow beam divergence of 0.15 mrad, which corresponds to an increase of only 1.5 cm (0.05 ft) in diameter per 100 m distance. This Class 1M infrared laser has a wavelength of 1,535 nm and is eye-safe throughout all operating ranges except when passing through optical aids, such as magnifiers, binoculars, and telescopes. The wavelength of the laser is absorbed by water, which allows for a distinct waterline where wave swash is not present; however, returns on wet beaches are sparse.

The laser scanner and multibeam echosounders are coupled with a GNSS-aided inertial navigation system, the Applanix Position and Orientation System for Marine Vessels (POS MV 320 V5 RTK), used for georeferencing and motion compensation to obtain accurate positioning of the lidar and multibeam data. The POS MV consists of an IMU with three gyroscopes and three accelerometers, two GNSS antennas, and a computer system. The vessel's motion (roll, pitch, and heading) can be resolved to an accuracy of < 0.02°. Real-time heave measurements are

accurate to approximately 5 cm (0.16 ft), which can be improved to 2 cm (0.07 ft) after post-processing.

A Trimble R7 GNSS base station provides real-time kinematic (RTK) corrections to the vessel via radio transmission, allowing for positional accuracies on the order of ± 8 mm + 1 ppm x baseline length in horizontal and ± 15 mm + 1 ppm x baseline length in vertical. Based on the location of the base station, this equates to accuracies of ± 1.2 cm (0.04 ft) in horizontal and ± 1.9 cm (0.06 ft) in vertical during the survey. Additional Trimble GNSS rovers are mounted to backpacks worn by land-based surveyors and an ATV, which collect data points every 0.75 m.

Data collection

Five surveys were conducted between September 2014 and September 2016 in the late summer and early spring with a combination of multibeam bathymetry, boat-based lidar, and ground-based GPS methods (Table 1). Boat-based lidar data were typically collected 1-2 hours before and after the lowest tide within the survey window, as were the lowest portions of the cross-shore beach transects. Multibeam bathymetry data were collected during the remainder of the survey window with the shallowest areas collected at the highest tides each day.

Table 1. List of survey dates and activities performed on each day, including boat-based lidar, multibeam bathymetry (MBES), ground-based GPS topography (Topo), and other activities such as Structure from Motion (SfM)

Date	Field Session	Field Activities			
		Lidar	MBES	Topo	Other
9/9/2014	Summer 2014	X	X	X	Monument install & lidar target setup
9/10/2014	Summer 2014	X	X	X	Lidar target setup
9/11/2014	Summer 2014	X	X	X	
9/12/2014	Summer 2014		X	X	
9/13/2014	Summer 2014		X	X	
9/14/2014	Summer 2014	X	X		Lidar target test
9/15/2014	Summer 2014	X	X		MBES patch test & lidar target test
9/16/2014	Summer 2014	X	X		
4/13/2015	Spring 2015			X	
4/14/2015	Spring 2015	X		X	
4/15/2015	Spring 2015	X		X	MBES patch test
4/16/2015	Spring 2015		X	X	
4/17/2015	Spring 2015		X	X	
4/18/2015	Spring 2015		X	X	Lidar target setup
4/19/2015	Spring 2015	X	X	X	Lidar target setup
4/20/2015	Spring 2015	X	X	X	
4/21/2015	Spring 2015	X	X	X	
4/22/2015	Spring 2015	X	X	X	

4/23/2015	Spring 2015		X	X	
4/24/2015	Spring 2015		X	X	
8/25/2015	Summer 2015			X	
8/26/2015	Summer 2015		X	X	
8/27/2015	Summer 2015		X	X	Lidar target setup
8/28/2015	Summer 2015	X	X	X	
8/30/2015	Summer 2015	X	X	X	
8/31/2015	Summer 2015		X	X	MBES patch test
9/1/2015	Summer 2015		X	X	MBES patch test
9/2/2015	Summer 2015		X	X	
4/3/2016	Spring 2016		X	X	SfM target setup
4/4/2016	Spring 2016		X	X	
4/5/2016	Spring 2016		X	X	SfM target setup
4/6/2016	Spring 2016		X	X	SfM target setup
4/7/2016	Spring 2016		X	X	SfM & lidar target setup
4/8/2016	Spring 2016		X	X	SfM target setup & SfM flight
4/9/2016	Spring 2016	X	X	X	Lidar target setup & MBES patch test
4/10/2016	Spring 2016			X	
4/11/2016	Spring 2016			X	
4/12/2016	Spring 2016			X	
4/15/2016	Spring 2016				SfM target setup & SfM flight
4/18/2016	Spring 2016			X	
9/14/2016	Summer 2016		X	X	
9/15/2016	Summer 2016		X	X	Lidar target setup
9/16/2016	Summer 2016	X	X	X	Lidar target setup
9/17/2016	Summer 2016		X	X	
9/18/2016	Summer 2016	X	X	X	
9/19/2016	Summer 2016		X	X	
9/20/2016	Summer 2016		X	X	
9/21/2016	Summer 2016		X	X	MBES patch test
9/22/2016	Summer 2016			X	

Each day, a local GNSS base station was set up on an epoxy survey monument, Citronella, installed prior to the first survey in September 2014 (Figure 7). The base station was set to transmit real-time kinematic (RTK) corrections to the POS MV on the vessel and all GNSS rovers used on land as well as log raw GNSS data at 1 Hz for post-processing. The coordinates of the monument are provided in Table 2.

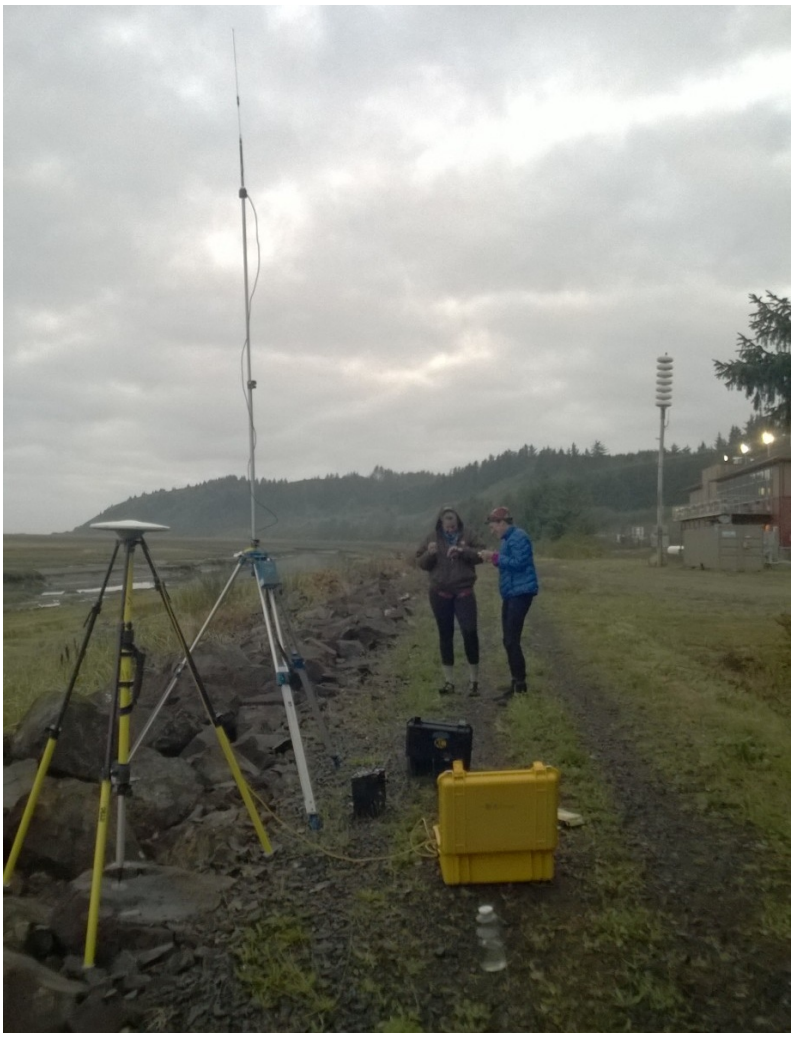

Figure 7. Trimble R7 GNSS base station set up on Citronella

Table 2. Coordinates established for monument Citronella; values relative to NAD83(2011) Washington State Plane South, with elevation relative to NAVD88 (GEOID12B), meters

Easting	Northing	Elevation	Latitude	Longitude	Height
230974.708	160533.458	4.845	46 43 24.96493	124 1 13.9894	-19.240

The multibeam sonars was operated at 400 kHz with a maximum swath of 120°; a narrower swath was used for deeper water (> 10 m) to maintain adequate point density. With the dual-head system, data was collected using alternating pings of the same frequency to minimize differences in backscatter intensity between the two heads. Data were collected with 100% overlap to eliminate gaps and more accurately discern features. The vessel speed was kept at 3.5 kt or slower to maintain coverage of a 0.5-m grid in the field. Sound velocity casts were collected at the beginning and end of each day, at hourly intervals during the day, and whenever the discrepancy between the active profile and the real-time sound speed at the sonar head is greater than 1-2 m/s. During high tide, bathymetry data were collected as close to shore as possible,

navigating in water as shallow as 1-m below the sonar head (~1.7 m water depth) in order to maximize the potential for overlap with topographic data collected at low tide.

During lidar acquisition, the vessel slowly moves alongshore at a speed of ~1 kt while the laser continuously scans in a vertical line pattern to the port side of the vessel. The angular interval between laser pulses is set at 0.09°, which equates to a vertical point spacing of 1.6 cm (0.05 ft) at distance of 100 m (328 ft). An object's range is determined by measuring the last returned laser pulse. The distance of the scanner to the shoreline typically varied between 20-100 m (~65-330 ft), depending on water depth and breaking waves. Ground control targets (1 m^2 sheet metal, spray-painted flat white or covered with a checkerboard pattern of alternating engineer-grade reflective material and either black vinyl or flat black paint) were set up on the beach for checking positional alignment of the laser point cloud with independently surveyed GPS points (Figure 8). High-resolution digital photographs of the shoreline are taken from the vessel simultaneously to document the landscape.

Figure 8. Photo of ground control targets used during the lidar survey

Data from the POS MV were integrated with the MBES and lidar data in Quality Positioning Services (QPS) QINSy hydrographic survey software (v8.10 or earlier), which was also used for navigation. In real-time, the incoming lidar and MBES data were set to populate a 0.5-m grid viewed by "hit count" (the number of data points within one grid cell), standard deviation, and elevation to assist the boat and survey equipment operators in acquiring sufficient coverage and perform an initial quality check of the data. Position and orientation data from the IMU are logged at 10 Hz for post-processing.

While the boat-based lidar provides high density data, it performs best at ranges < 450 m (~1,500 ft) and on high relief topography. Because most of the survey area was wide and flat, it was necessary to map a large part of the beach using traditional ground-based GPS methods. Beach

topography data were collected on foot with Trimble GNSS receivers mounted to a backpack and on an ATV. Surveyors collected data by walking along the 100 m-spaced cross-shore transects and alongshore features or contours, especially in areas inaccessible by the ATV, such as troughs, submerged tidal channels, mud flats, and sand fences (Figure 9). The ATV was used to map large-scale coastal morphologic features and to densify the topographic data on the sandy beach and berm (Figure 10).

Figure 9. Photo of surveyors collecting ground-based RTK-GPS beach topography data

Figure 10. Photo of surveyor collecting ground-based RTK-GPS beach topography data on an ATV

Data processing and analysis

Data logged by the base station were used to post-process the vessel's position in Applanix POSPac MMS v7.2 (or earlier) to correct any RTK dropouts experienced in the field[1]. The resultant Smoothed Best Estimate of Trajectory (SBET) file was applied to the MBES and lidar data in QINSy v8.1 Processing Manager to adjust the point cloud position. Updated roll, pitch, and heading offsets were applied to the MBES data after processing the patch test in QINSy Validator. SVPs were checked for errors and re-applied to the MBES data where needed as indicated by the survey notes.

The post-processed MBES and lidar data were gridded at 1 m (except for the Sep-2014 data, which were gridded at 0.5 m) using the Combined Uncertainty Bathymetric Estimator (CUBE) algorithm and cleaned in Fledermaus v7.5.2 (or earlier). Vegetation was removed from the lidar point cloud as best as possible to represent only the beach surface. Photomosaics were generated by stitching overlapping photographs together using Autopano Giga Pro v3.0.3 and used to help interpret the point cloud.

[1] An exception is for data collected on September 12, 2014 when the base station fell over and broadcasted incorrect positions during the survey. The POS data were post-processed using Applanix IN-Fusion SmartBase, in which a network of six GNSS reference stations within 85 km of the survey area were used to create the SBET.

Ground-based beach topography data were processed in Trimble Business Center v3.70 to produce final XYZ coordinates. Overlapping data points between surveyors within a 30-cm radius were compared, and data from each surveyor were adjusted for vertical agreement. The GPS data were then compared to both the MBES and lidar datasets to check for discrepancies. The MBES data consistently showed good agreement with ground-based GPS data (< 3 cm, on average), while the lidar data was almost always lower than both the GPS and MBES data by 5-10 cm, on average, though this varied across the survey area.

Where ground-based GPS, lidar, and MBES data were not collected on the same day, actual changes in morphology made comparing data along the shoreline challenging such that an adjustment to the lidar was not always made. More attention was subsequently given to surveying at the same areas on the same days to better ensure comparison and agreement among the three methods.

The cleaned MBES and lidar grids for each survey were combined with the ground-based GPS point data using linear interpolation to produce a continuous topobathymetric digital elevation model (DEM) with a grid-spacing of 1 m. Appendix C shows the final DEMs produced for each survey. Change analyses were performed by differencing the 1-m DEMs to produce surfaces showing spatially varying patterns of erosion and accretion at different time scales (Appendix D).

Results

This section first discusses the quality and extent of the final DEMs produced from the combined data sets for each of the five surveys. Gaps in coverage are identified. The presentation of the DEMs is followed by an overview of morphological changes that occurred between consecutive surveys. Areas with potential artifacts due to insufficient topographic coverage and data density are identified. The signals and patterns of morphologic change exhibited from season to season as well as annual changes between summer to summer for both years are then discussed. Lastly, observations of the total morphological change from September 2014 to September 2016 are documented.

Digital elevation models

September 2014

Figure 11 shows the data collected in September 2014 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data sets as a 1-m, continuous topobathymetric DEM. Multibeam bathymetry data was obtained to depths of more than 7 m NAVD 88 from just west of the SR 105 groin to the southern tip of Empire Spit. Incomplete and shallower data of approximately 5 m or less was obtained along the tidal flats between Empire Spit and Toke Point. Additional multibeam data in this area was not possible to collect due to budget constraints.

Boat-based lidar data was obtained to edge-match or overlap with multibeam bathymetry over nearly the entire area except along the tidal flats between Empire Spit and Toke Point. The tidal flats at the east end of Empire Spit were not conducive to lidar returns due to the wet sediment and low angle of incidence from the boat. Sparse yet contiguous coverage was obtained across the marsh behind Graveyard Spit extending to the tree line along the SR 105 road embankment.

Gaps in the lidar data that were not covered by ground-based GPS topo within 100 m include a persistently wet and mild-sloped intertidal area west of the SR 105 groin where ground-based GPS topo was not prioritized or planned to be collected at cross-shore transects. Similarly, there are some gaps in coverage between lidar and topo across a portion of the wet tidal flats to the west of Toke Point. In this case, cross-shore transects 101-118 were not collected because the soft mud was not walkable. However, because the topography in these two areas was very flat, interpolation over relatively long distances between the data that was collected should be acceptable with little introduced error. Remaining data gaps include the vicinity of East Inlet between the eastern tip of Empire Spit and the Tokeland Peninsula, extending along the back-barrier intertidal bay, and the southern barrier thickly vegetated with scotch broom landward of the dune grass-covered ridges at the distal end of Empire Spit. The MHW shoreline along this back-barrier region was mapped such that any interpolation would inadequately cover the lower-lying complexity of the tidal channels.

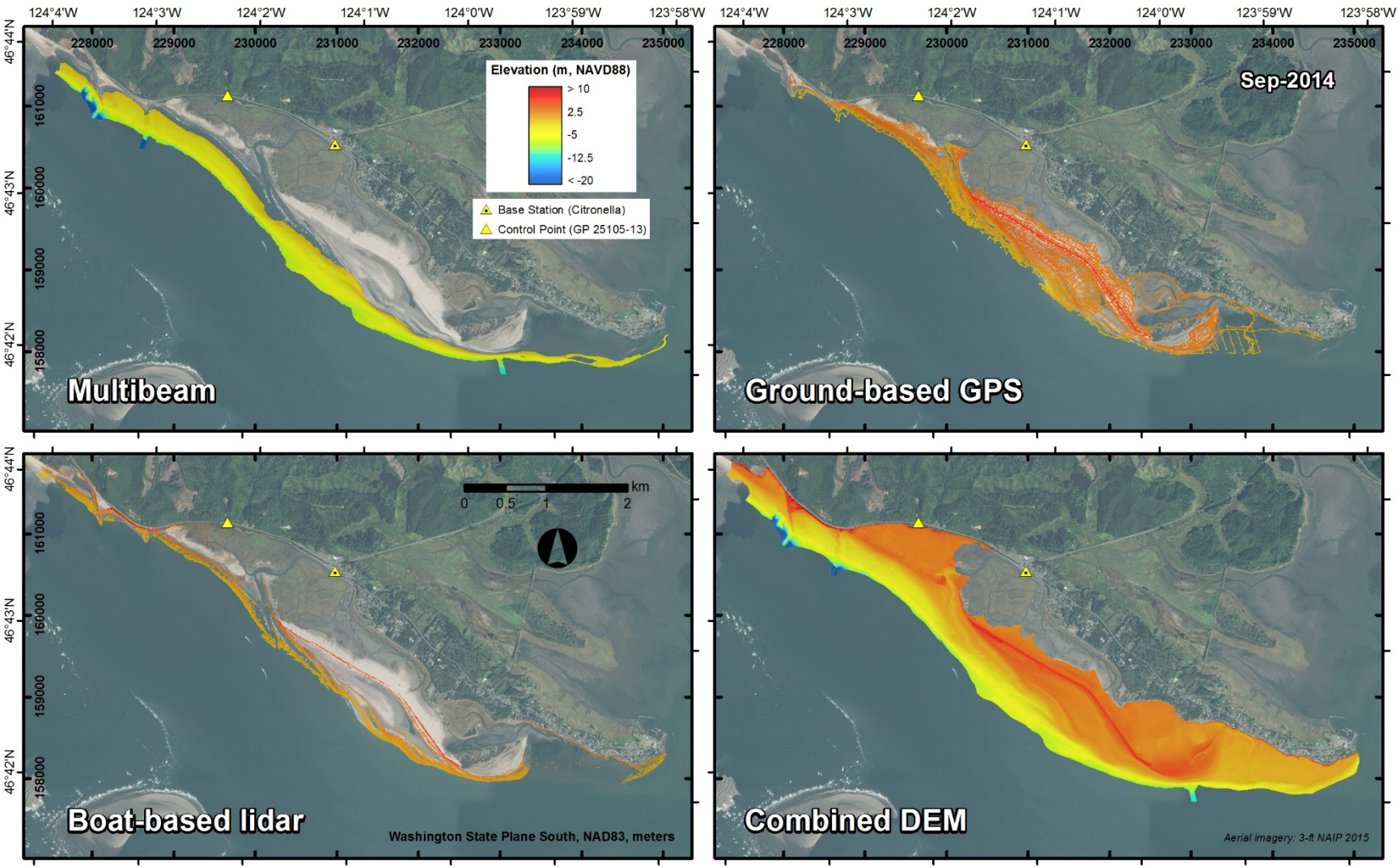

Figure 11. Data collected in September 2014 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data as a continuous topobathymetric DEM with a resolution of 1 m

April 2015

Figure 12 shows the data collected in April 2015 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data sets as a 1-m, continuous topobathymetric DEM. Multibeam bathymetry coverage extended to depths of about 7 m NAVD 88 from the SR 105 groin to Toke Point. Additional multibeam data to the west of the groin was not possible to collect due to budget constraints.

Boat-based lidar data edge-matched or overlapped with multibeam bathymetry including the outer edge of the tidal flats between Empire Spit and Toke Point. The remainder of the tidal flats, East Inlet, and the intertidal back-barrier embayment were surveyed well with GPS topo, which were walkable with the use of Mudders[2].

Due to snowy plover nesting, no GPS topo data were able to be collected between and including transects 29-41 from the landward side of the berm to approximately the MLLW shoreline. This created a large data gap across the broad beach face between approximately MHW and the berm. Boat-based lidar could not fill in this gap due to a large wet trough on the beach at low tide and a shadow zone behind a seaward ridge. As with the previous survey, a gap in the lidar data that was not surveyed with ground-based GPS topo was the persistently wet and mild-sloped intertidal area west of the SR 105 groin. Compared to the previous survey, less lidar coverage was obtained across the marsh behind Graveyard Spit, while there was generally more extensive GPS topo coverage on the landward side of the berm. Transects 5-10 and 23-28 extended landward to the Tokeland Peninsula.

[2] Specialty footwear worn over boots or waders that are designed to prevent sinking into mud and soft sand (see https://www.mudderboots.com/).

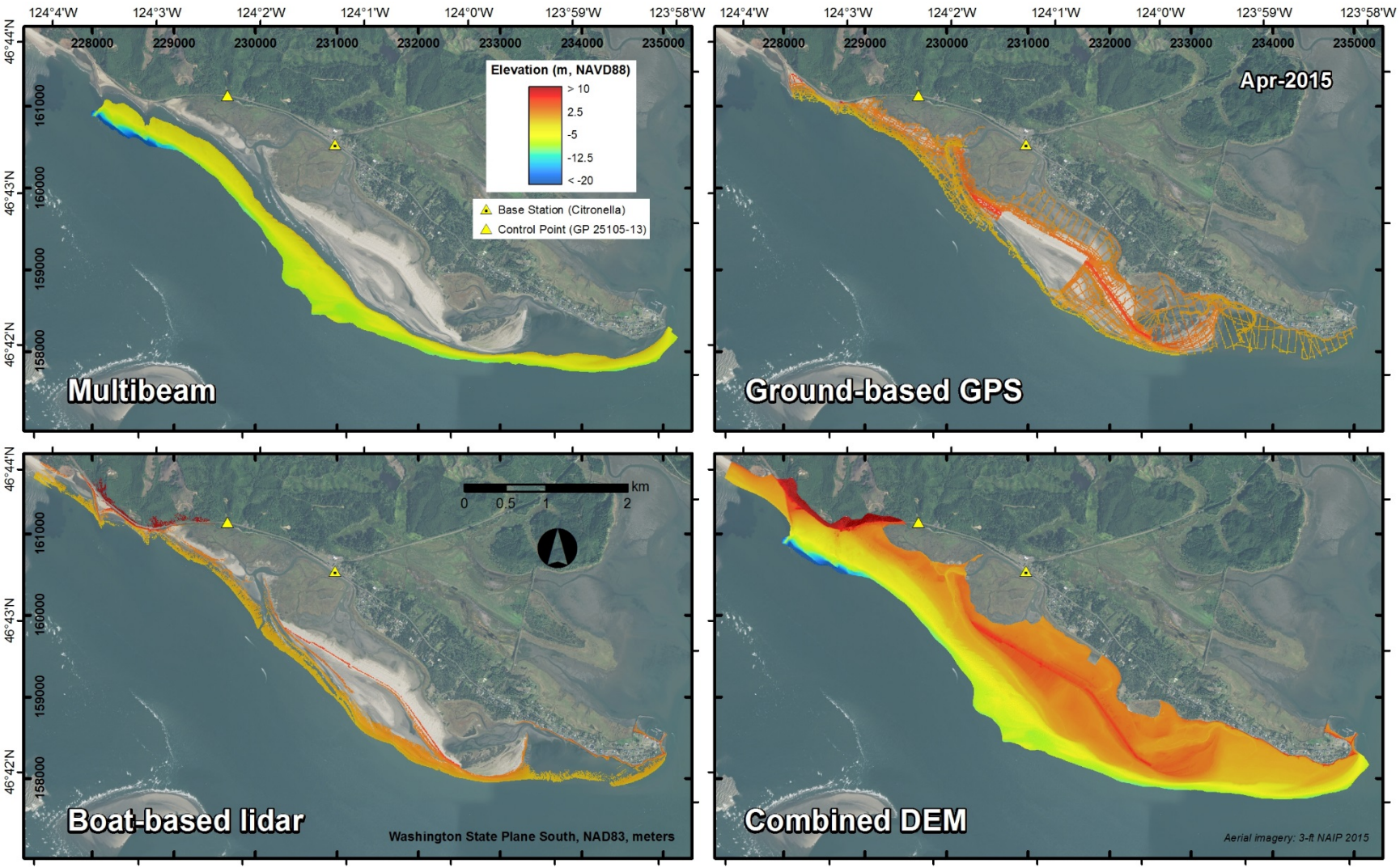

Figure 12. Data collected in April 2015 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data as a continuous topobathymetric DEM with a resolution of 1 m

August 2015

Figure 13 shows the data collected in August 2015 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data sets as a 1-m, continuous topobathymetric DEM. This survey benefited from the installation of a dual-head, dual-mount multibeam sonar system on the R/V *George Davidson*. Multibeam bathymetry coverage extended to approximately 11 m NAVD 88 from just west of the SR 105 groin to the southern tip of Empire Spit, which was greater than previously collected. Additional coverage was obtained around the groin to depths of 30 m or more. Overlap between multibeam and lidar was obtained nearly everywhere except in the vicinity of the marsh outcrops along Graveyard Spit and the groin, which was mostly bridged with GPS topo data.

Due to snowy plover nesting, the use of the ATV was not permitted along the mid-beach between transects 23-38, but GPS backpack data were able to provide good coverage. Gaps in the lidar data larger than 100 m not covered by ground-based GPS topo include the intertidal area west of the SR 105 groin as with previous surveys, and, similar to the September 2014 survey, at the distal end of Empire Spit along the back-barrier intertidal bay and the scotch broom area landward of the dune grass-covered ridges.

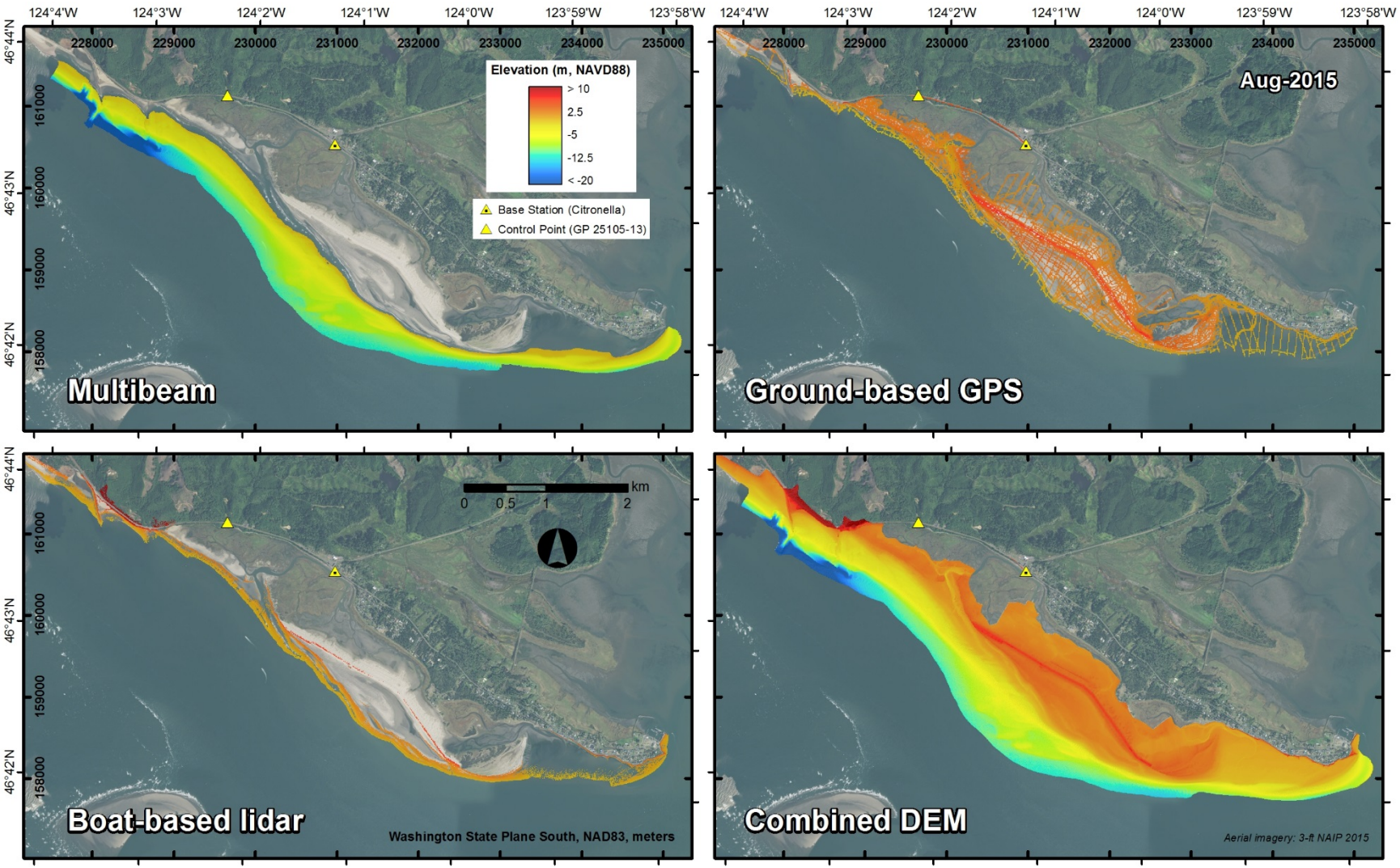

Figure 13. Data collected in August 2015 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data as a continuous topobathymetric DEM with a resolution of 1 m

April 2016

Figure 14 shows the data collected in April 2016 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data sets as a 1-m, continuous topobathymetric DEM. Multibeam bathymetry coverage extended to approximately 11 m or more NAVD 88 from just west of the SR 105 groin to Toke Point. The multibeam coverage mostly overlapped or edge-matched with the lidar coverage and was also bridged with GPS topo data.

Due to substantial snowy plover nesting, only limited escort-based GPS topo surveys were able to be performed from the landward side of the berm to approximately the MHW shoreline between transects 19-42. This created a large data gap across the much of the broad beach face between approximately MHW and the berm. Boat-based lidar could not fill in this gap due to a large wet trough on the beach at low tide and a shadow zone behind a seaward ridge. However, GPS topo data was able to be collected throughout most of the wet trough area at low tide. As with previous surveys, gaps in the lidar data that were not surveyed with ground-based GPS topo data include the wet and mild-sloped intertidal area west of the SR 105 groin and the back-barrier intertidal bay and scotch broom area landward of the dune grass-covered ridges at the distal end of Empire Spit.

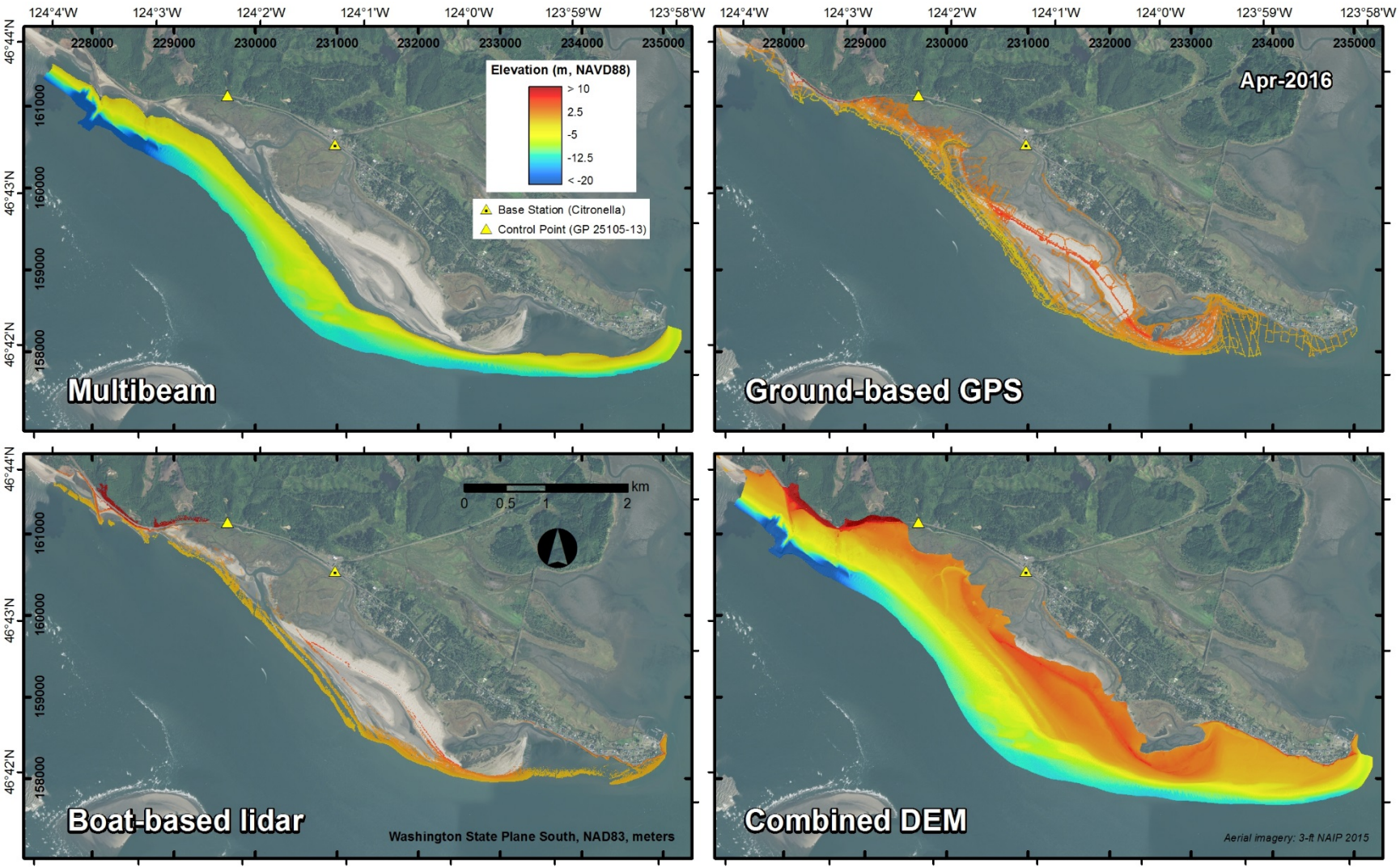

Figure 14. Data collected in April 2016 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data as a continuous topobathymetric DEM with a resolution of 1 m

September 2016

Figure 15 shows the data collected in September 2016 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data sets as a 1-m, continuous topobathymetric DEM. Multibeam bathymetry coverage extended to approximately 12 m or more NAVD 88 over the entire survey area with even more coverage around the groin. The multibeam coverage mostly overlapped or edge-matched with the lidar coverage except across the wet tidal flats to the west of Toke Point. GPS topo data adequately covered all seaward intertidal areas and generally covered all landward areas with higher density than in previous surveys.

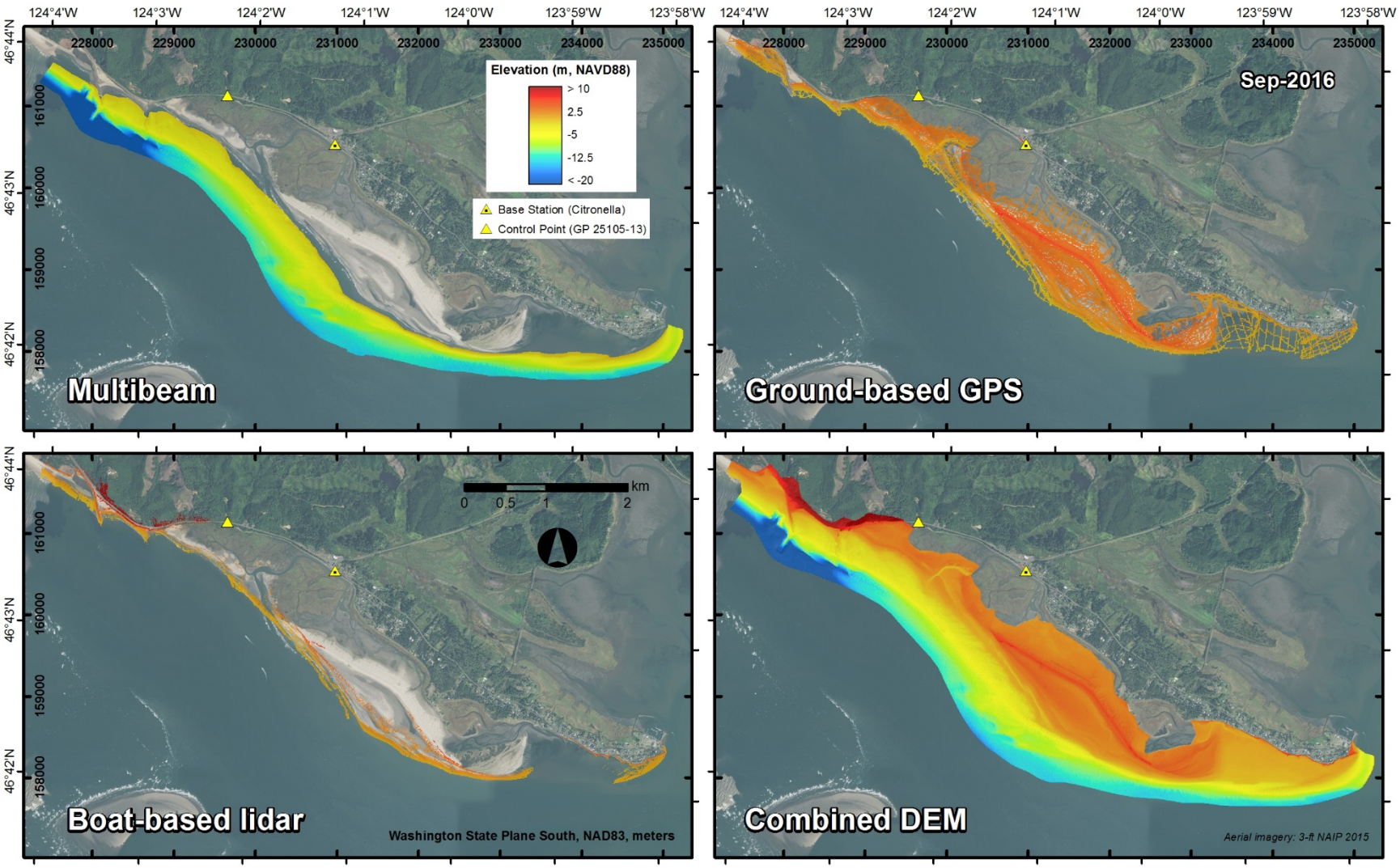

Figure 15. Data collected in September 2016 with multibeam sonar, boat-based lidar, and ground-based GPS methods and the combined product of these data as a continuous topobathymetric DEM with a resolution of 1 m

Morphological change through time

September 2014 to April 2015

Figure 16 shows the topobathymetric DEMs from the September 2014 and April 2015 surveys as well as the change between the two surveys for the entire survey area. The beach face eroded to the west of the SR 105 groin, whereas the beach face accreted to the east of the groin. Two sections of accretion along the SR 105 embankment east of the groin correspond to revetment repairs implemented by Washington State Department of Transportation during the winter of 2014-2015. Modest beach face erosion occurred toward the east, extending to the Pleistocene outcrops (between profiles 68 and 69).

The beach face along the full length of Graveyard Spit eroded, with net deposition along much of the landward side (to the east of profile 64), while the spit was completely lowered and overwashed with no net deposition in the vicinity of profile 65 to the west. The distal end of Graveyard Spit at the juncture with Cranberry Slough (between profiles 54 and 55) also lowered and eroded. The upper beach face eroded along the landward side of Cranberry Slough, extending from Graveyard Spit to profile 35. The shoreface along mid-section of this reach seaward of the Cranberry Slough channel also eroded, while the shoreface and beach face to the southeast accreted, indicating net sediment transport to the southeast along the length of the berm.

The broad beach face landward of the mid-beach ridge showing mostly accretion is likely erroneous due to the inability to collect GPS topo data during the April 2015 survey spanning transects 29-41. Likewise, the band of accretion along the landward side of the berm along this reach with no April 2015 GPS topo data appears to be accentuated, with a lesser amount of accretion occurring on the landward side of the berm toward both the northwest and southeast.

A modest amount of erosion occurred along the upper beach face at the southeast end of Empire Spit (between transects 5 and 15, though the landward edge of the erosion area shown in darker red (between profiles 10 to 14) is an artifact of insufficient GPS topo data in September 2014. A modest area of erosion also appears across the outer tidal flats to the east (between profiles 5 and 109). The changes among the scotch broom and marsh areas on the landward side of the spit to the west of East Inlet are also artifacts of scant GPS topo data in September 2014.

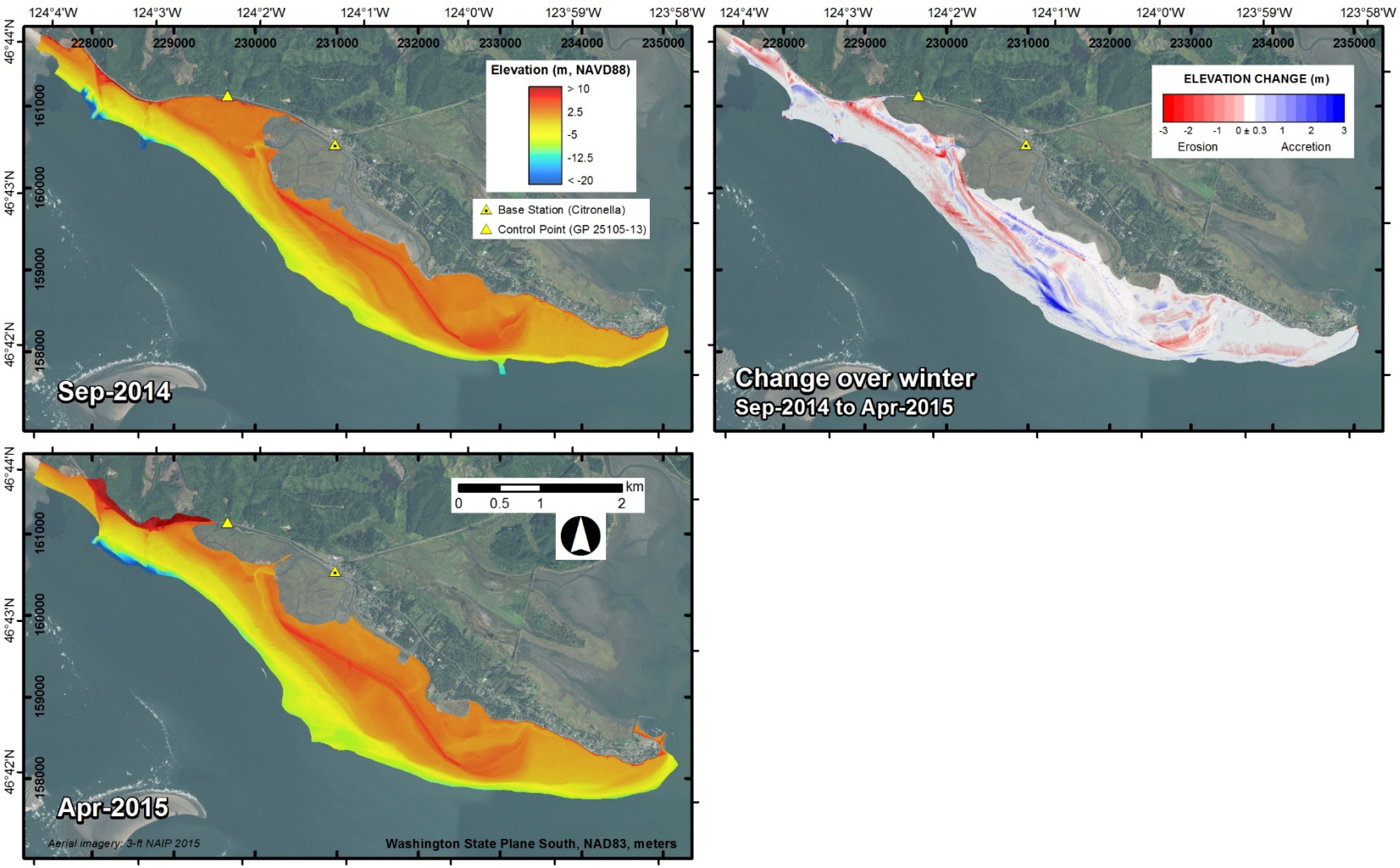

Figure 16. Topobathymetric DEMs from the September 2014 and April 2015 surveys as well as the change between the two surveys for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

April 2015 to September 2015

Figure 17 shows the topobathymetric DEMs from the April 2015 and August 2015 surveys as well as the change between the two surveys for the entire survey area. The upper beach face to the west of the SR 105 accreted while the lower beach face east of the groin eroded and the upper beach face accreted further to the east adjacent to the Pleistocene outcrops, indicating eastward sediment transport.

The lower beach face extending along Graveyard Spit and south of Cranberry Slough eroded while the upper beach face accreted, typical of onshore sediment transport during the summer. Further to the southeast, the lower beach face and shoreface showed modest accretion, indicating alongshore transport and net deposition toward the southeast offshore of the north-central portion of the berm. The shoreface offshore of the south-central portion of the berm showed modest erosion, while the upper beach face showed patches of accretion. Onshore intertidal bar migration is shown by the alternating red and blue strips along much of the berm length, though erosion is observed at the northern end of the berm (between profiles 45 and 47).

The changes shown across the broad upper beach face and landward side of the berm along the northern half (between profiles 29 and 41 are erroneous due to the lack of GPS topo data in April 2015. The changes among the scotch broom and marsh areas on the landward side of the spit to the west of East Inlet (and to the west of profile 8) are also erroneous due to insufficient GPS topo data in August 2015. An area of modest erosion is shown south of Toke Point (between profiles 106 and 115), indicating mild northward channel migration.

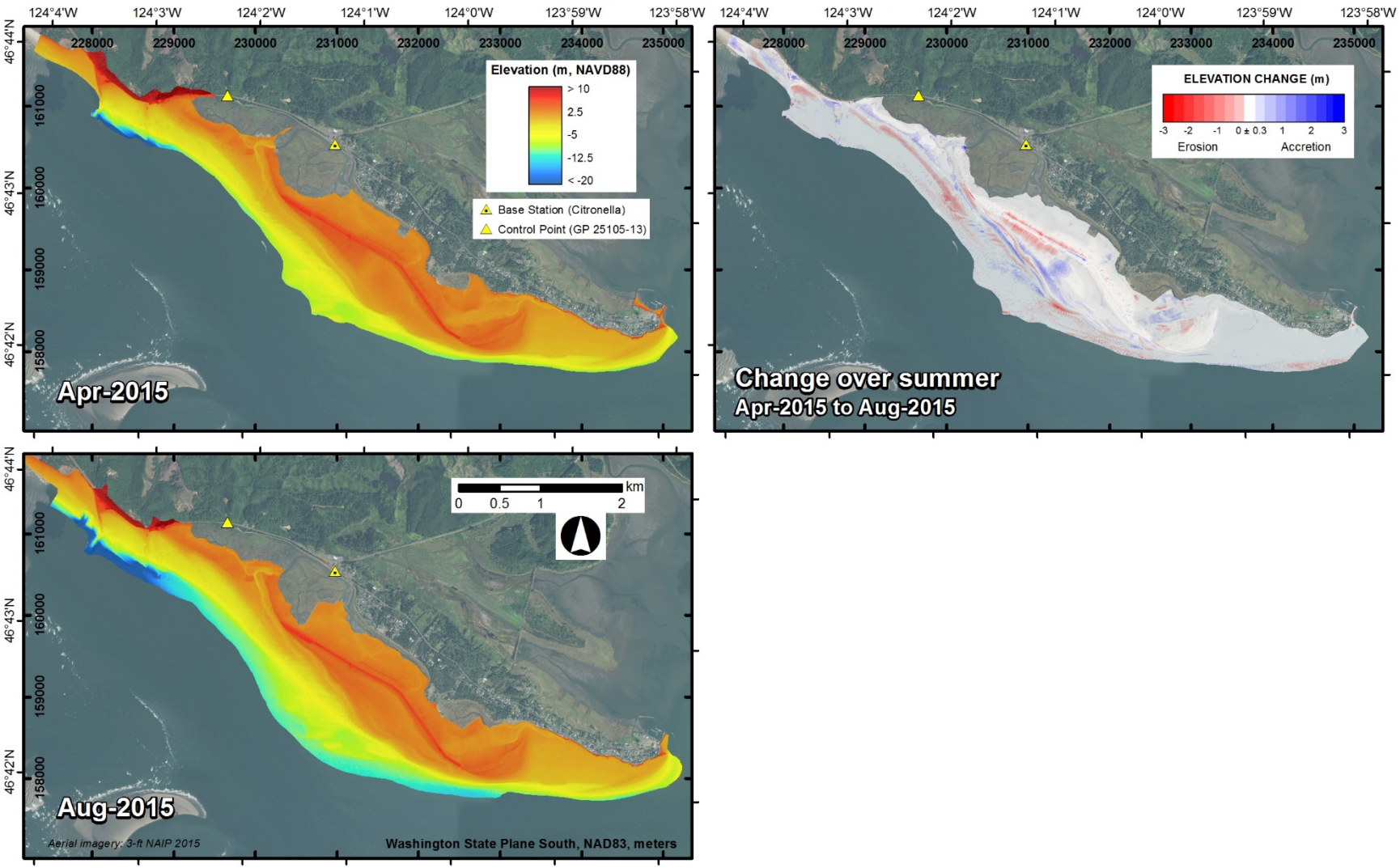

Figure 17. Topobathymetric DEMs from the April 2015 and August 2015 surveys as well as the change between the two surveys for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

August 2015 to April 2016

Figure 18 shows the topobathymetric DEMs from the August 2015 and April 2016 surveys as well as the change between the two surveys for the entire survey area. The upper beach face west of the SR 105 groin eroded while the lower beach face and shoreface show patches of deposition, including a significant accumulation of sediment along the west edge of a deepened ravine cut around erosion-resistant substrate west of the groin. The lower beach face east of the groin accreted while the upper beach face eroded farther east to the Pleistocene outcrops. Sediment deposition occurred offshore of these outcrops and the steep scarp along the ebb channel margin.

The upper beach face eroded along the length of Graveyard Spit with sediment deposition on the landward side across the North Cove marsh, including filling in channels that drained from the north into Cranberry Slough. The Cranberry Slough inlet channel migrated toward the northwest, filling in the old channel and cutting a new one into the distal end of Graveyard Spit. Despite this channel migration, the intertidal width of the slough increased to the southeast, with sediment deposition occurring father landward over the marsh to the south of Cranberry Slough.

The zone of erosion persisted southward (to profile 41), with significant retreat of the berm. The lower beach face offshore of the berm (between profiles 40 and 49) also deepened, with only mild deposition occurring lower on the shoreface in water depths greater than 5 m. This zone of severe beach face erosion along the northern end of the berm was somewhat balanced by a zone of significant lower beach face accretion toward the southwest (between profiles 18 and 39). Accretion is also observed immediately to the southeast of the berm erosion along the upper beach face where it broadens to a wide beach plain seaward of the berm. This accretion zone extends between profiles 34 and 41, although the April 2016 survey lacks GPS topo data southeast of profile 40, so some of the amount of accretion shown is likely to be higher than actual.

Southeast of the berm retreat, the berm became wider and flatter, losing elevation along the crest, while accreting along both the landward and seaward sides, except for the southeast end where a thin strip of beach erosion occurred on the seaward side of the berm. A patch of accretion on the landward side of the berm between profiles 20 and 23 is likely accentuated by a lack of GPS topo data in the April 2016 data.

Modest erosion is observed offshore of the lower beach face accretion zone (between profiles 18 and 39), most significantly along scarps deeper than 5 m water depth. Much of the remainder of the offshore area showed mild net accretion sprinkled with erosion associated with migration of bedforms. The southern edge of the tidal flats extending eastward from Empire Spit prograded slightly southward while the channel edge south of Toke Point migrated slightly northward (between profiles 104 and 114).

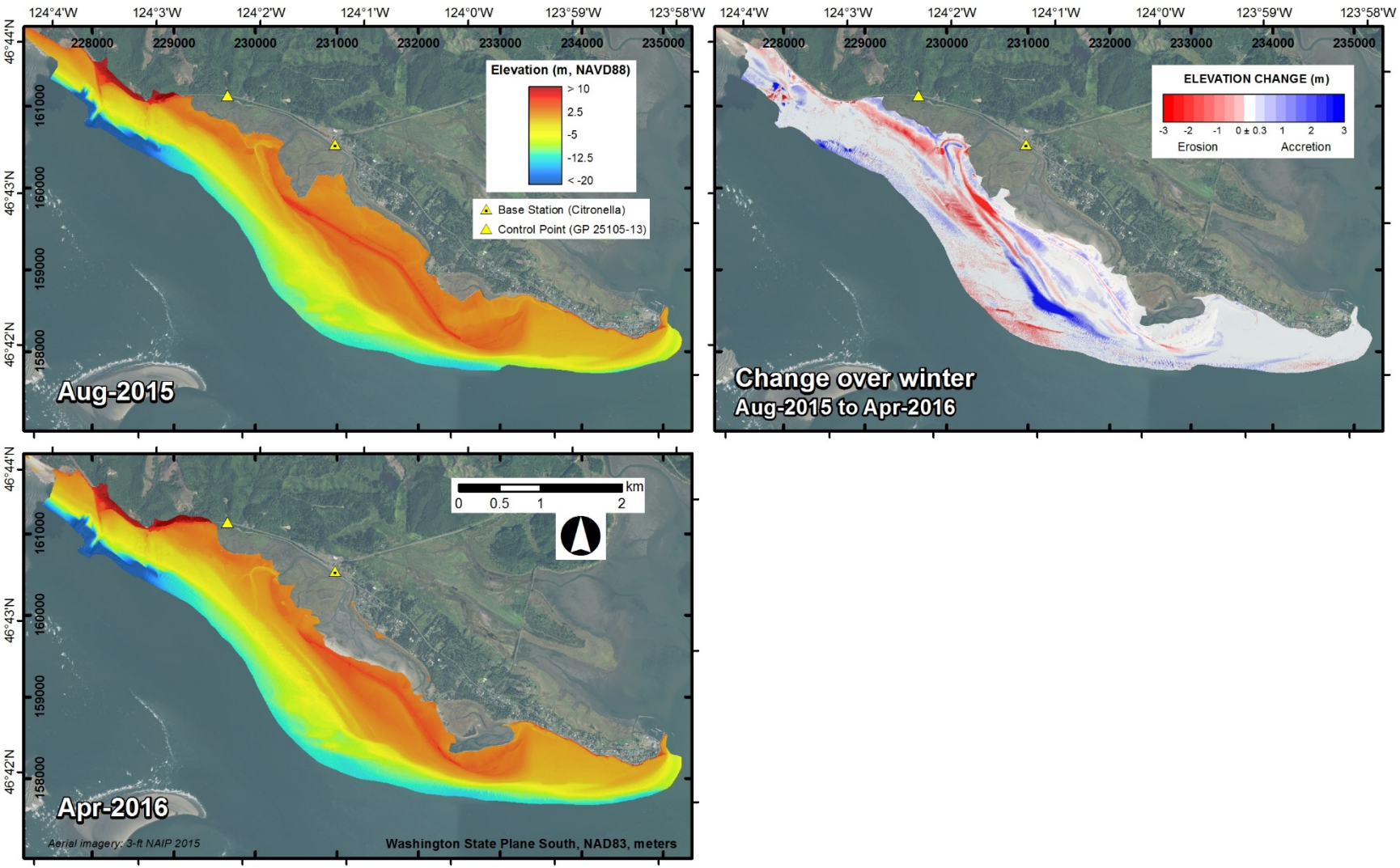

Figure 18. Topobathymetric DEMs from the August 2015 and April 2016 surveys as well as the change between the two surveys for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

April 2016 to September 2016

Figure 19 shows the topobathymetric DEMs from the April 2016 and September 2016 surveys as well as the change between the two surveys for the entire survey area. The upper beach face accreted west of the SR 105 groin while the lower beach face eroded slightly. Sediment eroded around the head of the ravine while more sediment accumulated along the western edge balanced by erosion along the eastern edge, with no apparent change in erosion-resistant substrate. The lower beach face to the east of the groin eroded while the upper beach face accreted, extending to the Pleistocene outcrops.

The lower beach face along Graveyard Spit eroded while the upper beach face accreted, indicating onshore sediment transport. The landward edge of the ebb channel offshore of Graveyard Spit beyond 7-m depth showed modest accretion. The Cranberry Slough inlet migrated to the northwest and developed a primary ebb channel running offshore across the beach face, while filling in the previously dominant channel running southward along the beach.

The lower beach face eroded offshore from the northern end of the berm with onshore accretion of the upper beach occurring farther to the southeast along a narrow strip fronting a narrowed trough that migrated onshore. The upper beach face landward of the lower beach face trough accreted, consistent with net onshore transport. The shoreface accreted offshore of the lower beach face troughs seaward of the mid-section of the berm, while the most offshore portion deeper than 7 m showed modest erosion.

The intertidal beach face accreted along the length of the berm extending to the southern edge of Empire Spit. The northern edge of channel south of the spit and tidal flats showed alternating accretion and erosion consistent with bedform migration, with a mild dominance of erosion toward the eastern end south of Toke Point. Areas of likely erroneous change due to a lack of GPS topo data in the April 2016 survey include the wedge of accretion across the northern portion of the wide upper beach plain, tow patches of mild accretion in the mid-central section of the beach plain, and the patch of accretion in the scotch broom area along the landward portion of the distal end of Graveyard Spit.

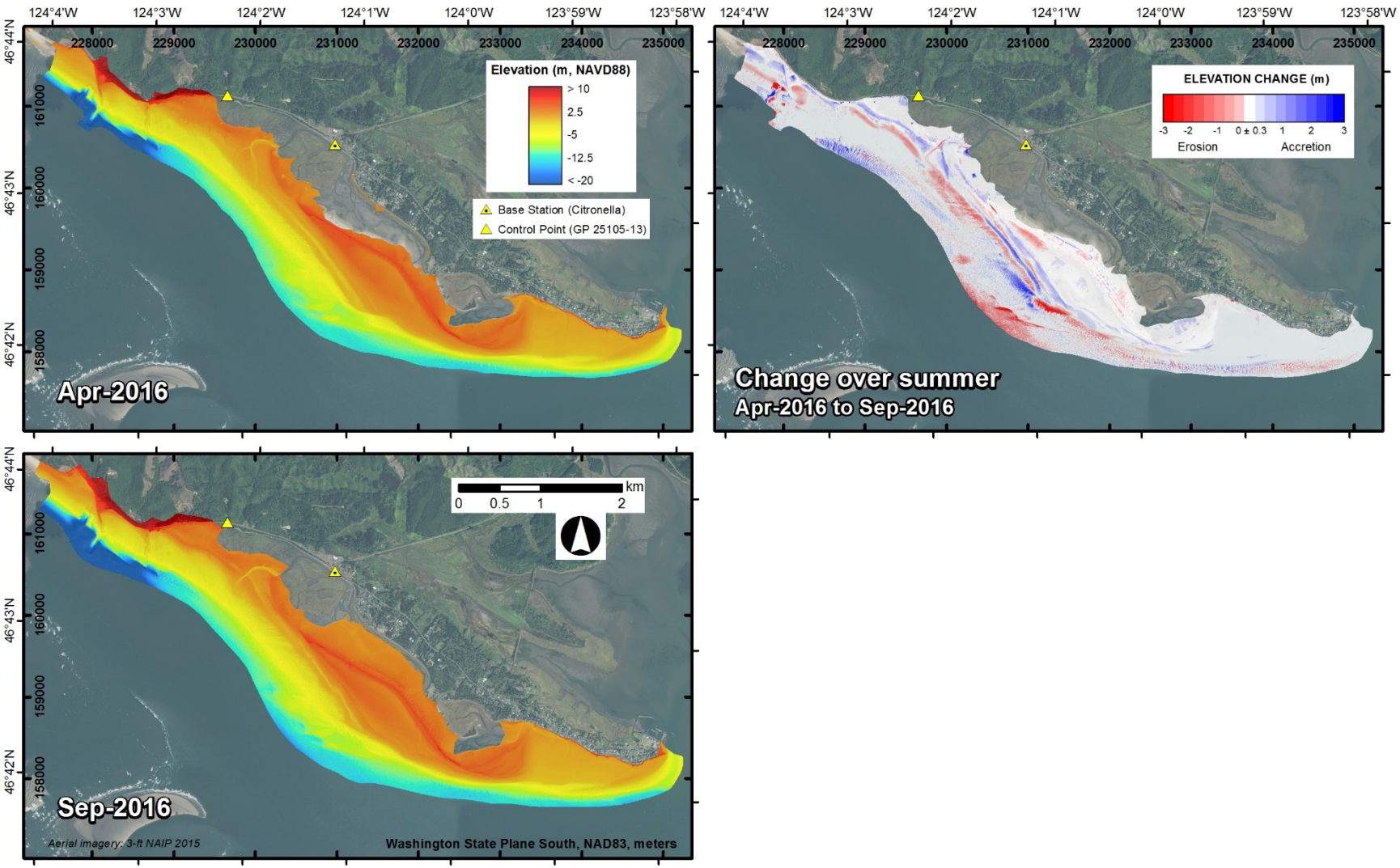

Figure 19. Topobathymetric DEMs from the April 2016 and September 2016 surveys as well as the change between the two surveys for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

Seasonal change

Figure 20 compiles the seasonal changes shown in Figures 9-12 for the entire survey area. It is clear that morphological changes tend to be larger during the winter season, with the most significant change occurring over the 2015-16 El Niño winter (between the August 2015 and April 2016 surveys). Upper beach face erosion is more prevalent during the winter, consistent with higher wave and water levels. Upper beach face erosion west of the SR 105 groin is complemented by lower beach face accretion, indicating offshore sediment transport during the winter, with the opposite change signal and transport direction in the summer.

Alongshore sediment transport patterns between the SR 105 groin and the Pleistocene outcrops alternate seasonally—during winter, sediment deposition occurs across the lower beach face adjacent to the groin while erosion occurs along the upper beach face toward the outcrops; during summer erosion occurs across the lower beach face adjacent to the groin while accretion occurs along the upper beach face toward the outcrops. Along Graveyard Spit, onshore sediment transport occurs during both seasons—during winter upper beach face erosion results in landward overwash deposition; during summer, lower beach face erodes to accrete the upper beach face.

The berm is shown to undergo greater change during the winter than the summer, tending to lower and widen substantially more during the winter season due to higher aeolian transport. Independent of season, there appears to be net accumulation of sediment along the northern ebb channel margin, net erosion along the northern end of the berm, net accretion of the upper shoreface and beach, net erosion of the lower shoreface along the central portion of the berm, and mild net erosion along the northern channel margin south of Toke Point.

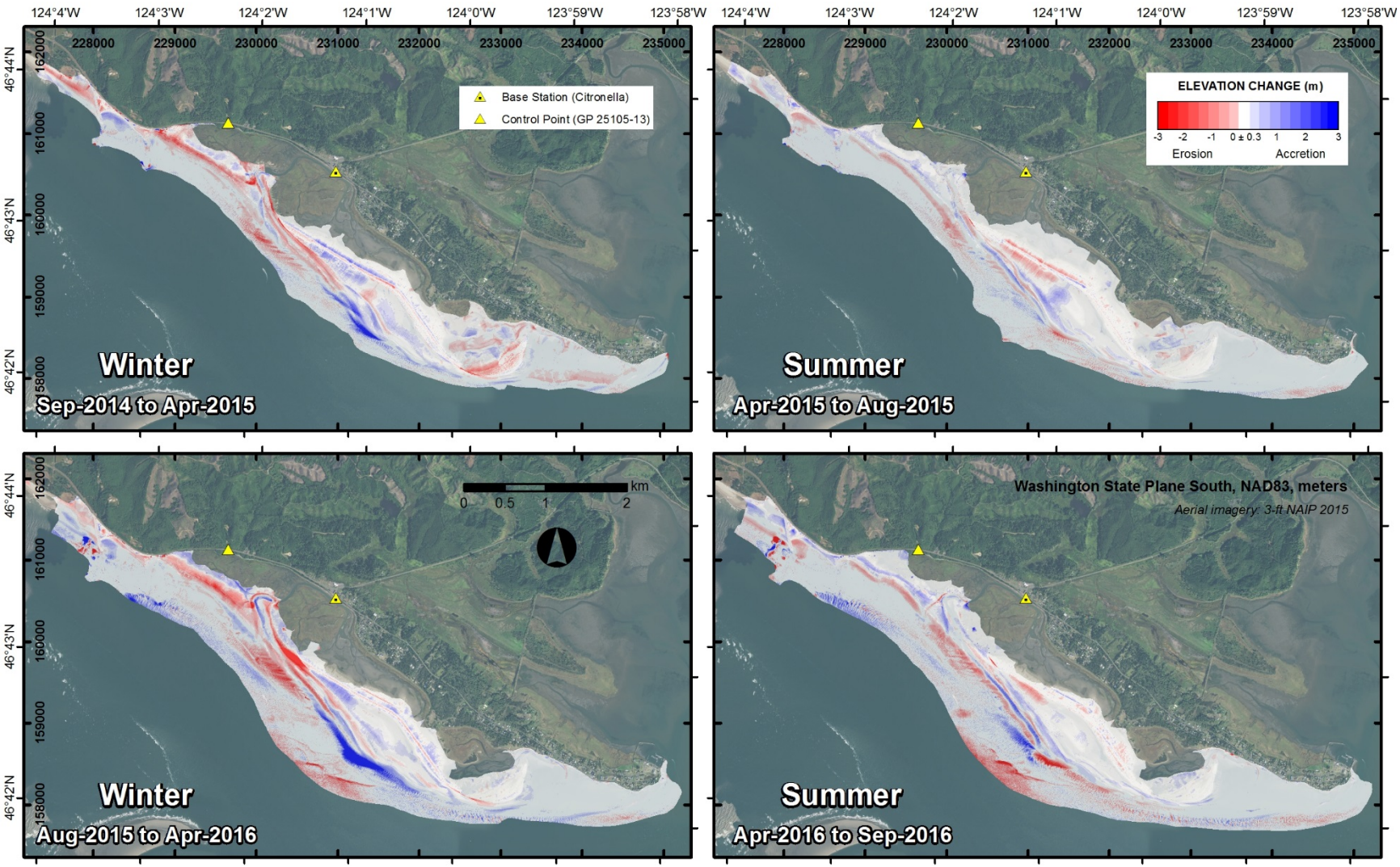

Figure 20. Seasonal beach and nearshore change between September 2014 and September 2016 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

Annual change

Figure 21 shows the annual changes for the entire study area from consecutive summer surveys and the total two-year change between September 2014 and August 2016[3]. Both years have similar patterns of upper beach face erosion west of the SR 105 groin, little net change between the groin and Pleistocene outcrops, accretion offshore of the Pleistocene outcrops, retreat and overwash of Graveyard Spit, net erosion to the south of the Cranberry Slough inlet, accretion and widening of upper beach plain along the mid-section of the berm, modest lower beach face progradation along the distal end of Empire Spit, and mild erosion of the northern channel margin south of Toke Point.

More change occurred during the second year, especially the northward migration of the Cranberry Slough inlet, erosion along the northern end of the berm, and accretion of the lower beach face along the central portion of the berm. The second year had greater offshore coverage to observe the accretion along the ebb channel margin to the south of the Pleistocene outcrops and Graveyard Spit, and erosion of the lower shoreface offshore of the lower beach face accretion zone.

[3] Change plots are shown on one page for comparison with each other. See Appendix D for full-page versions.

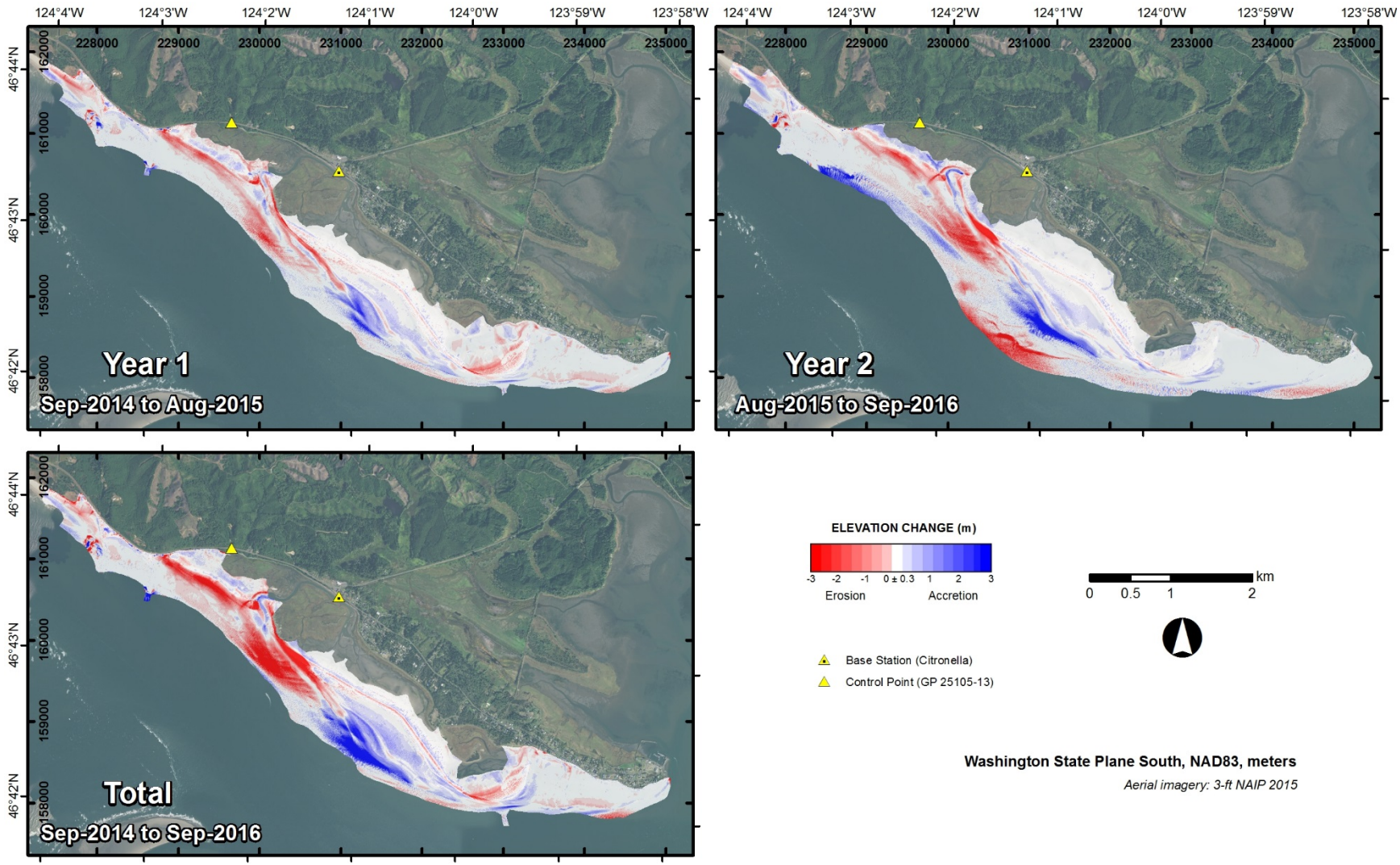

Figure 21. Annual beach and nearshore change for the first and second years as well as the total change from September 2014 to September 2016 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

Total change

Figure 22 shows the total morphological change between September 2014 and September 2016. The cumulative change over the two years shows dominant trends—erosion of the upper beach face west of the SR 105 groin, erosion and landward retreat of Graveyard Spit and truncation of its distal end, erosion of the shoreface, beach, and berm southwest of the Cranberry Slough inlet, accretion of the shoreface and beach along the central portion of the berm, lowering and landward migration of sediment over the length of the berm, and modest berm retreat at the southern end contrasted with modest beach progradation.

Figure 22 includes polygons A-E, where total volume of erosion or accretion has been calculated Polygon A outlines the erosion of Graveyard Spit. Over the two year survey period, Graveyard Spit lost 347,300 m^3 (454,250 yd^3) of sediment over a 193,500 m^2 (2,082,800 yd^2 or 47.8 acre) area.

Polygon B encompasses the erosion of the shoreface, beach, and berm to southwest of the Cranberry Slough inlet. Erosion along the northern end of the berm totals to 1,020,900 m^3 (1,335,300 yd^3) over a 668,200 m^2 (7,192,400 ft^2 or 165 acre) area along a 1.5 km (4,920 ft or 0.9 mi) length of shoreline.

Polygon C delineates the area of accretion along the central portion of the berm. The mid-section seaward of the berm accumulated 965,200 m^3 (1,262,400 yd^3) of sediment, gaining an average of 1.1 m (3.6 ft) of elevation over an 859,200 m^2 (9,248,350 ft^2 or 212 acre) area.

Comparison of the erosion within Polygon B to the accretion within Polygon C indicate the volume of sediment eroded at the west end of the berm roughly equals the volume of sediment accreted on the beach and nearshore at the center of the berm, suggesting net sediment transport to the southeast.

Polygon D outlines the berm that remains landward of the eroded end sections. Within this polygon, the berm crest elevation lowered by an average of 0.7 m (2.3 ft) from 6.2 m (20.3 ft) to 5.5 m (18 ft) NAVD88, while accreting on the landward side. Volume calculations of polygon D suggest a net influx of sediment of approximately 20,000 m^3 (26,000 yd^3) within close proximity of the berm.

Polygon E delineates the area of upper beach face and berm erosion at the southern end. Within this polygon, there was net erosion of the upper beach of 29,200 m^3 (38,190 yd^3) over an area of 24,850 m^2 (267,480 ft^2 or 6 acres).

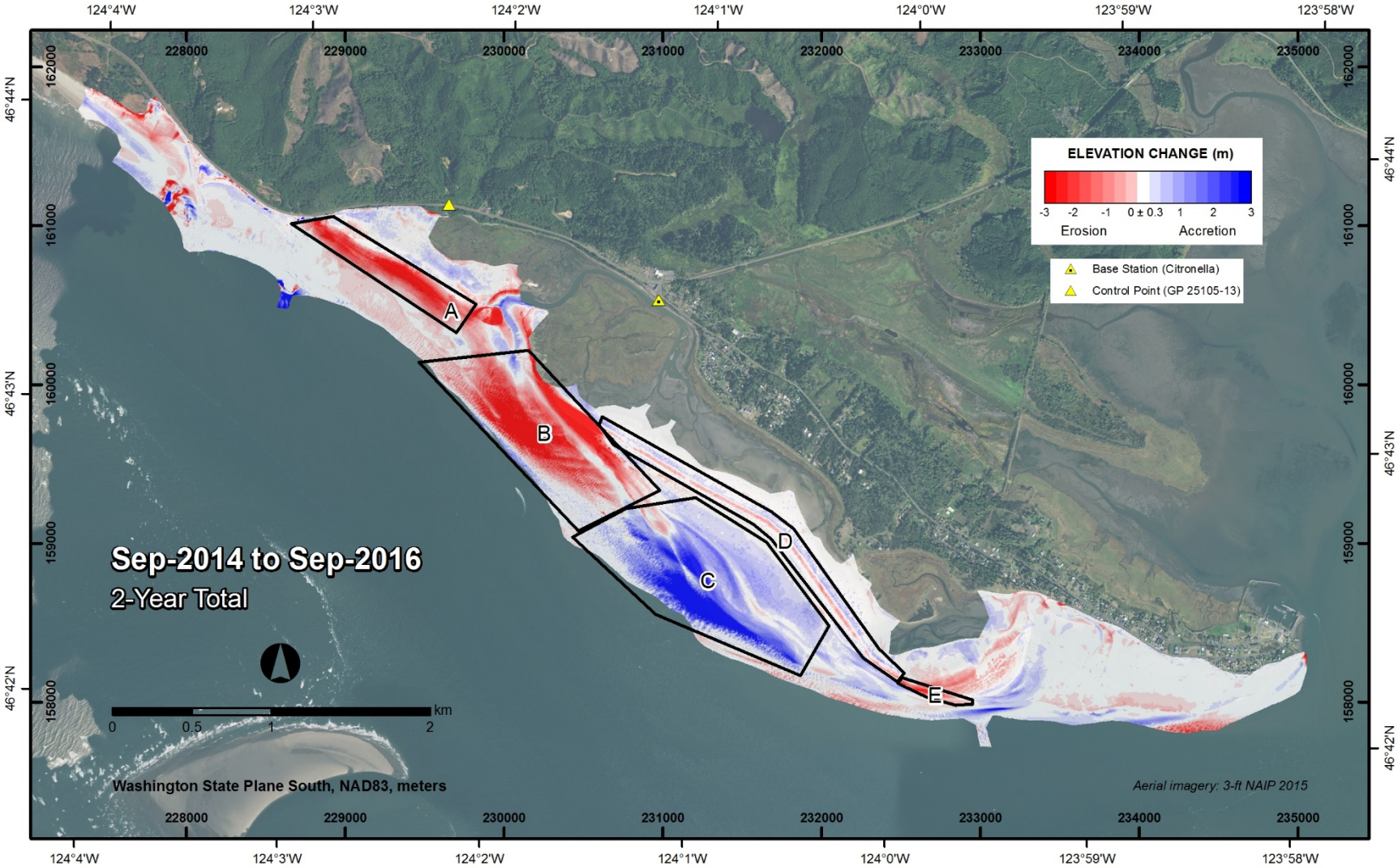

Figure 22. Total beach and nearshore change from September 2014 to September 2016 for the entire survey area with polygons delineating areas where change volumes have been quantified (see text); elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

Figures 23 through 31 provide a more detailed review of changes at sub-areas along the study area. Most of these figures show the time series of surveys with mean high water (MHW) and mean lower low water (MLLW) shorelines and a summary of volume changes over the two-year duration.

Figure 23 shows the time series of surveys at the west end of the survey area, immediately west of the SR 105 groin. The surveys show significant local ravines cut into the nearshore shoreface, possibly formed by eddy scour, down-cutting from outflows from along the groin, and/or slumping. The irregular shape of the ravines are maintained over time with fluctuating sand levels across erosion-resistant substrate.

Figure 24 features the area between the SR 105 groin and the Pleistocene outcrops. Over the two-year period from September 2014 to September 2016, there is relatively little net change across the shoreface and beach face. Local changes along the SR 105 embankment revetment are associated with its degradation and repair. Along the lee of the groin is a relatively small area with minor net sediment loss, while the upper beach face shows minor net sediment gain.

No significant change of the exposed Pleistocene outcrops was observed, including during the strong 2015-16 El Niño winter that generally caused greater coastal erosion than the 1997-98 El Niño (Barnard et al., 2017). Change analyses suggest the Pleistocene outcrops serve as a groin that tends to hold sediment in a pocket between the outcrops and the SR 105 groin with seasonal reversals in net sediment transport direction: westward alongshore sand transport over the winter and eastward sand transport over the summer (Figure 25). The surveys reveal sand within deeper channels and pockets of the outcrops with moderate seasonal changes in sand levels but little net change from year to year.

Over the two year survey period, prominent shoreline retreat on the order of 55-110 m (180-360 ft) was observed along the length of Graveyard Spit with an average of 1.8 m (6 ft) elevation loss (Figure 26). Lowering of the spit has led to overwash of the barrier, resulting in flooding of the North Cove marsh and the infilling of tidal channels, as well as endangering a section of SR 105, leaving it vulnerable to flooding by high tides, storm surges, wave run-up, and debris during severe storms.

The time series of surveys at the Cranberry Slough inlet (Figure 27) shows the evolution of the inlet associated with the loss of an erosion-resistant platform along the seaward side of the channel that had originally controlled its position, forcing the channel to bend to the south across the beach face. Following the degradation of the platform during 2015-16 El Niño winter, the bend migrated northward and the NW-SE trending channel remained, but it began to develop a new outflow channel running more directly across the beach face. By September 2016, the channel on the north side became more dominant.

The west end of the berm sustained the most erosion, retreating by 340 m (1,115 ft) from its 2014 position (measured along the berm's center-axis; Figure 28). This erosion occurred primarily during the 2015-16 winter season, likely due to waves, high water levels, and scour from the adjacent drainage channel. The erosion resulted in 25-100 m (~80-330 ft) of shoreline retreat (represented by the mean high water (MHW) contour), with the largest retreat centered on

the berm and less retreat toward the northwest and southeast. The even larger retreat of the MLLW shoreline to the west of the berm and the deepening offshore suggest this area is increasingly vulnerable to erosion. In contrast, farther to the southeast, seaward of the center of the berm, the shoreline prograded by up to 150 m (492 ft) (Figure 29).

The east end of the berm has been stabilized by vegetation and has shown little change between September 2014 and September 2016. The easternmost 215 m (705 ft) of the berm showed a maximum horizontal retreat of 10 m (33 ft) (Figure 30). The adjacent scarp present on the upper beach during the first survey in September 2014 eroded landward 20-30 m (65-100 ft) by September 2016, resulting in die back of the scotch broom by inundation of storm waves. However, in each survey there is negligible change in the position of the MLLW shoreline, and there is modest net seaward progradation of MHW shoreline in front of the berm (Figure 30). Over the two-year period beach accretion is shown seaward of the berm. There is also some evidence of extension of Empire Spit seaward, as indicated by the area of accretion southeast of the scarp as well as a lower elevation band of accretion that was incompletely mapped over the course of the monitoring period.

Figure 31 shows the progradation of the distal end of Empire Spit and the changes at East Inlet, which was insufficiently mapped during the first survey in September 2014, so it was removed from the surface difference plot in Figure 24. The differences appear to be minimal with possible minor infilling of the channel at East Inlet and minor meandering across the upper tidal flats east of the inlet.

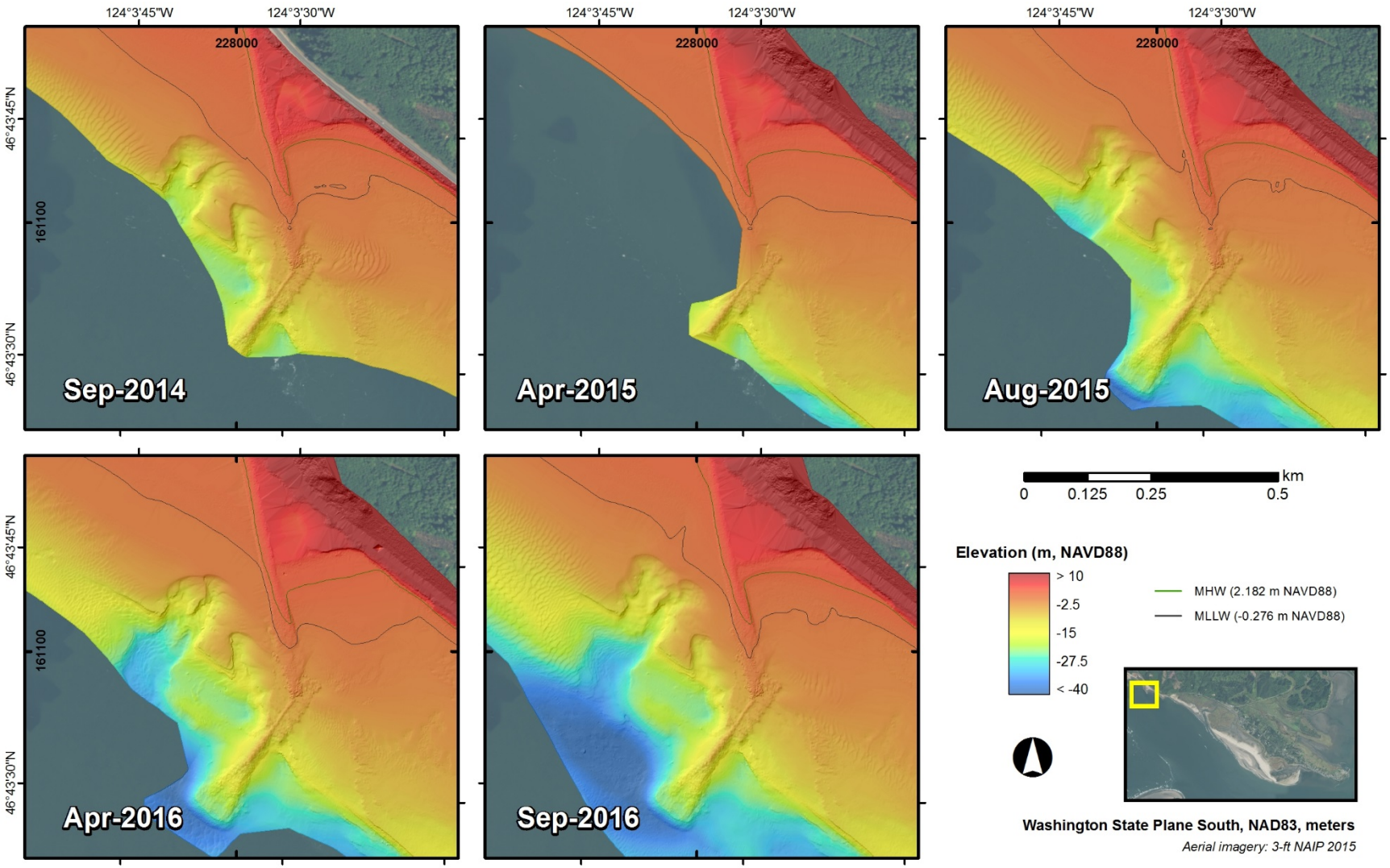

Figure 23. Scour holes northwest of SR 105 groin

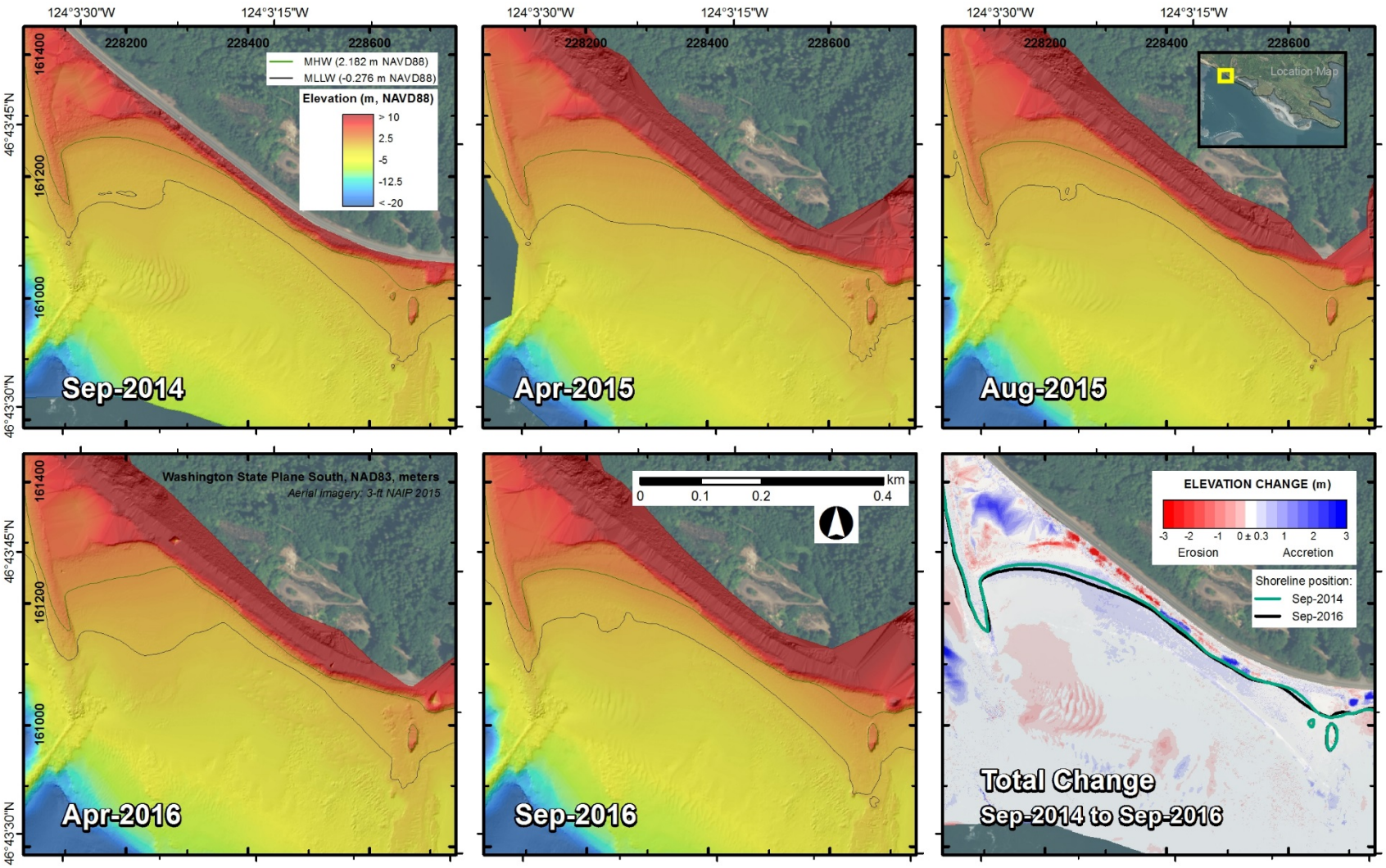

Figure 24. Geomorphic evolution of the shoreline between the SR 105 groin and the exposed Pleistocene outcrops

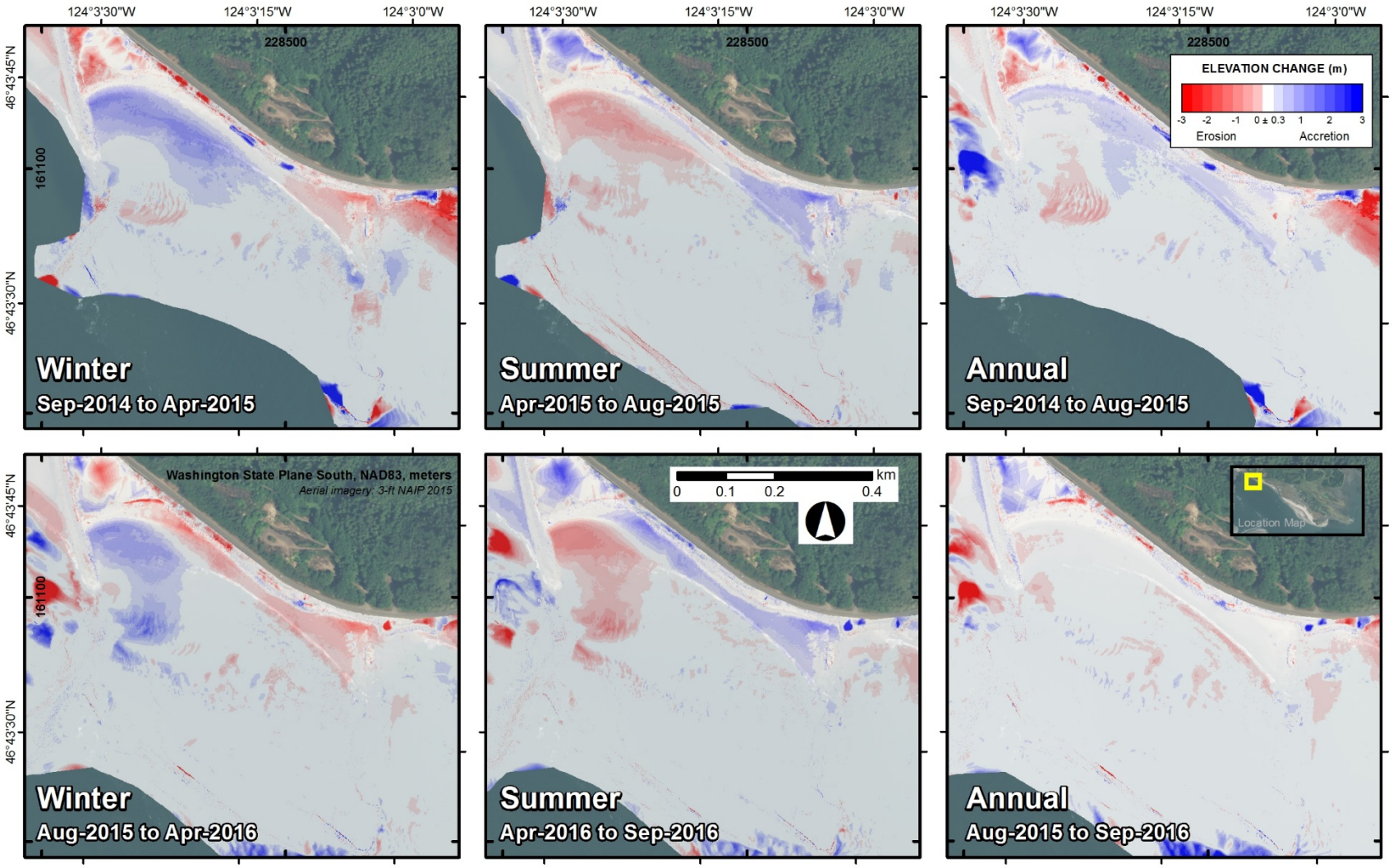

Figure 25. Seasonal and annual change between the SR 105 groin and the Pleistocene outcrops

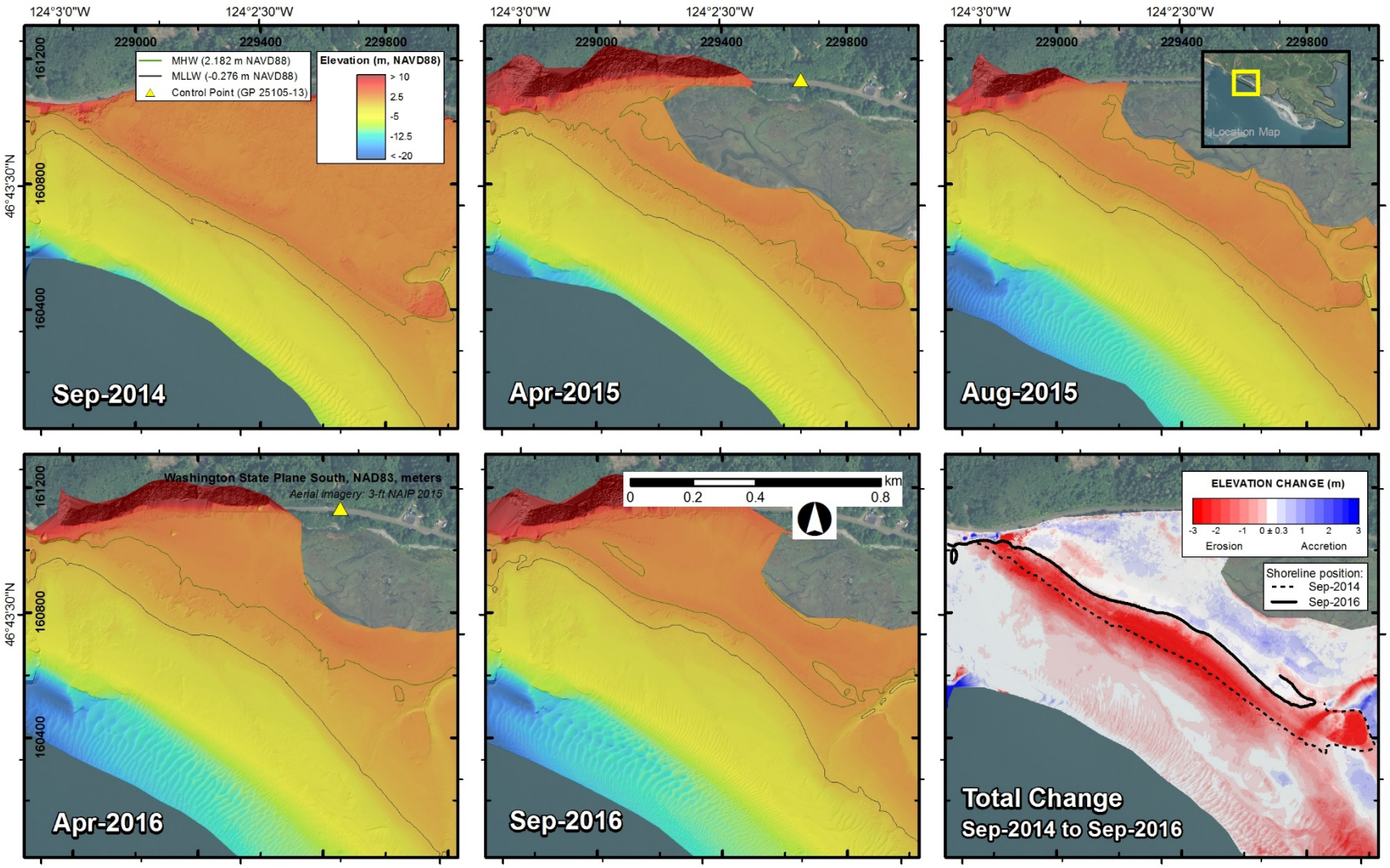

Figure 26. Geomorphic evolution of Graveyard Spit, including change in shoreline position as represented by the mean high water (MHW) contour over the survey period

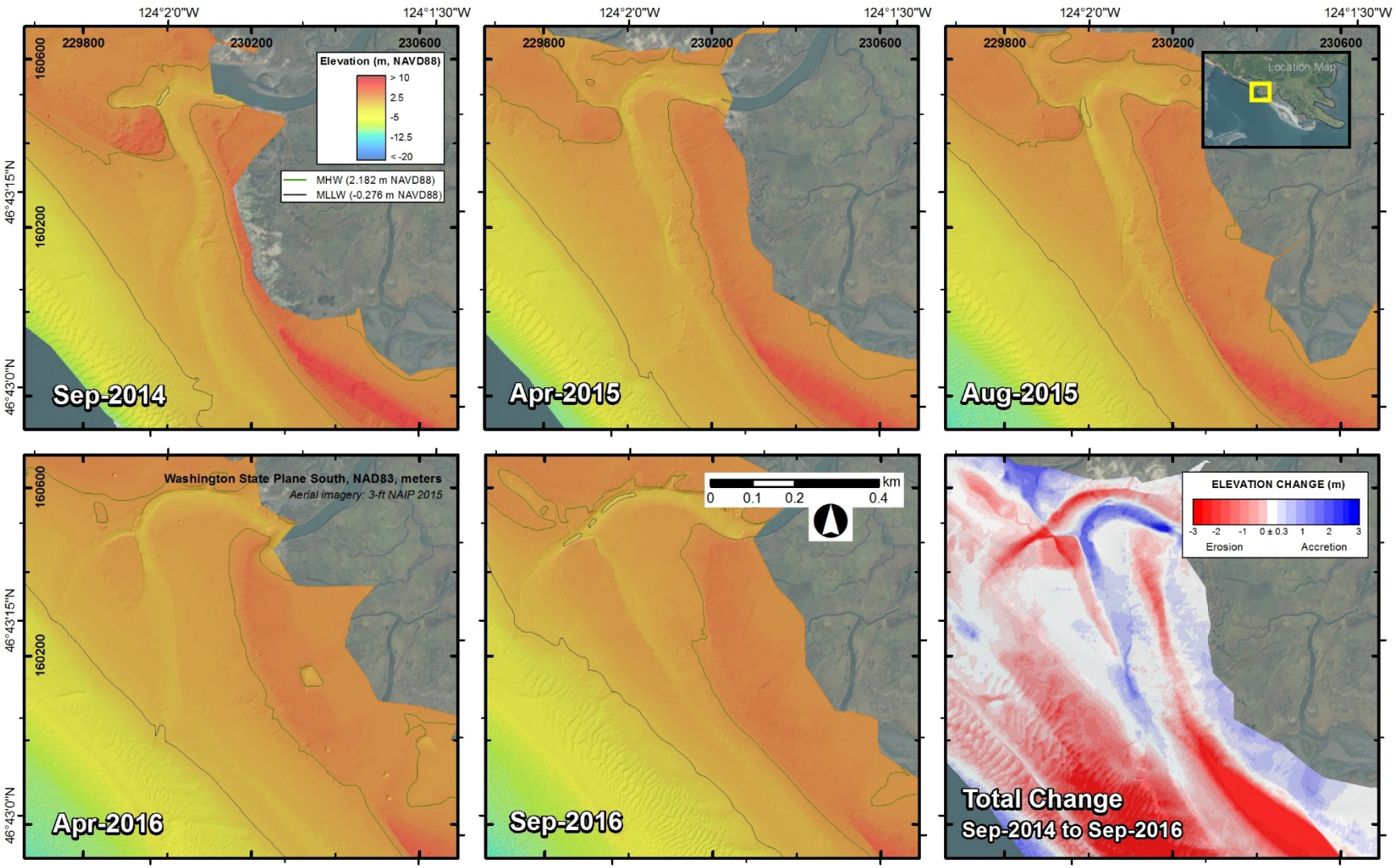

Figure 27. Geomorphic evolution of Cranberry Slough over the survey period

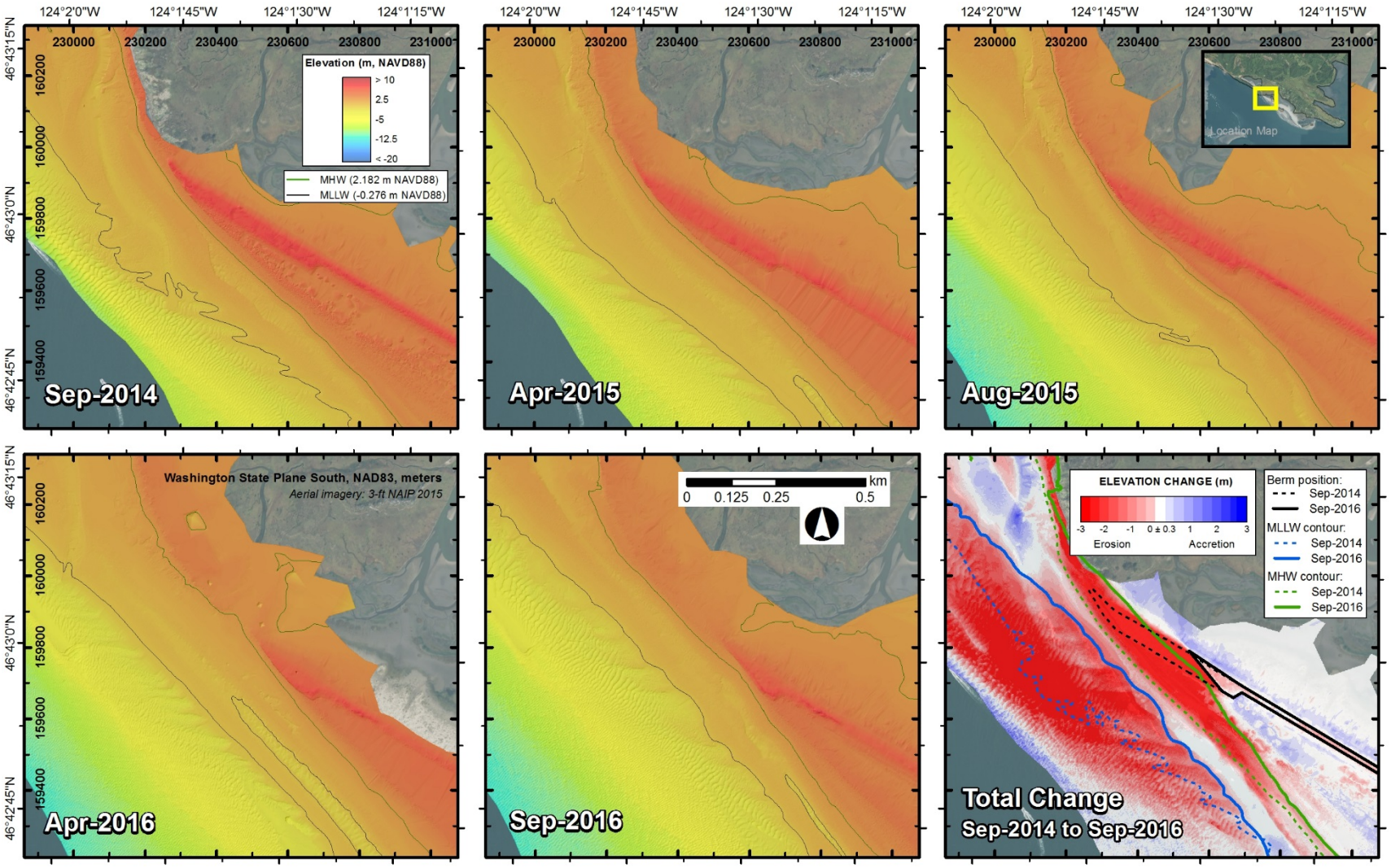

Figure 28. Geomorphic evolution of the west end of the USACE-constructed berm over the survey period, as well as the change in the position of the mean lower low (MLLW) and mean high water (MHW) contours

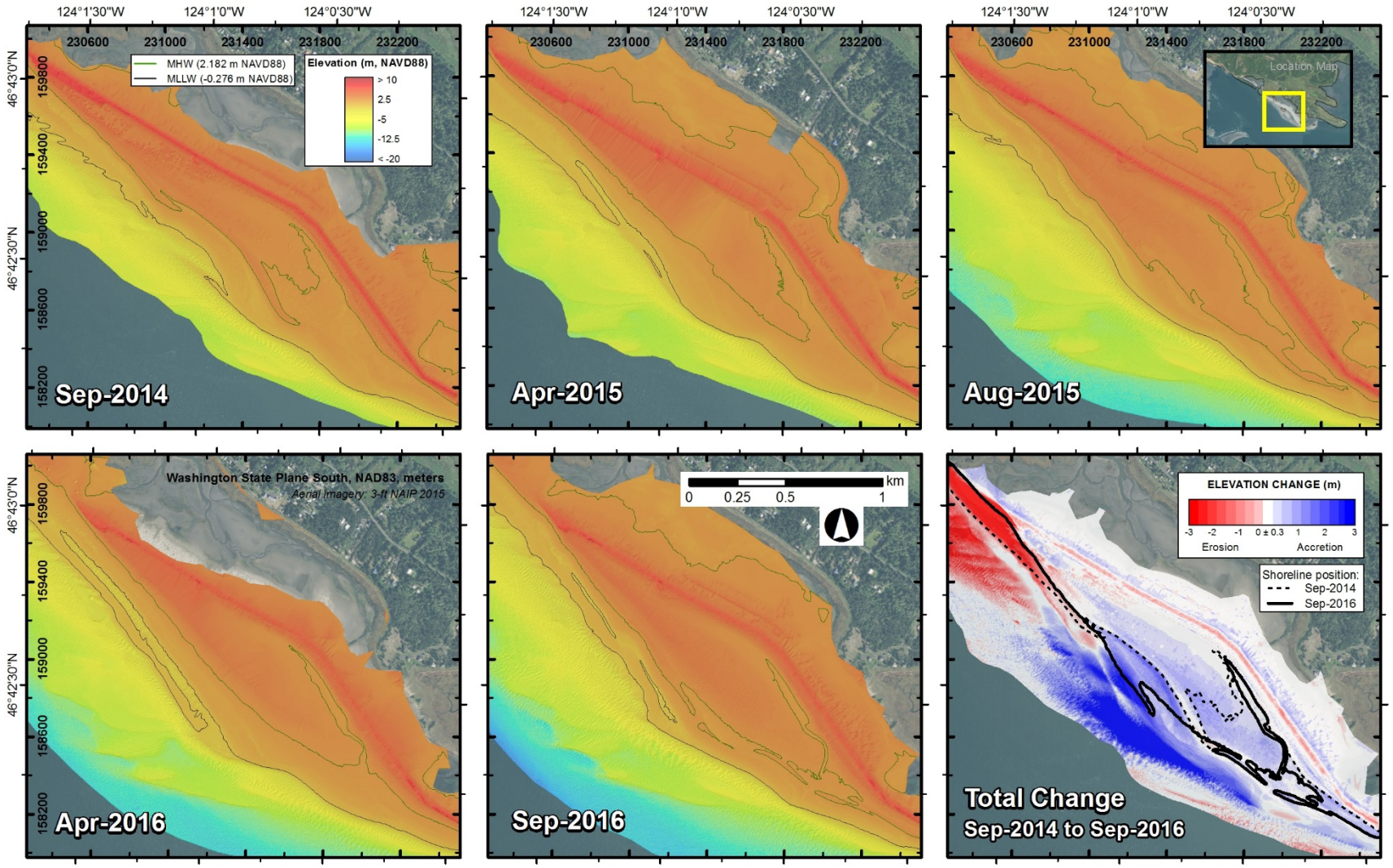

Figure 29. Geomorphic evolution of the USACE-constructed berm over the survey period as well as the change in the shoreline position as represented by the mean high water (MHW) contour

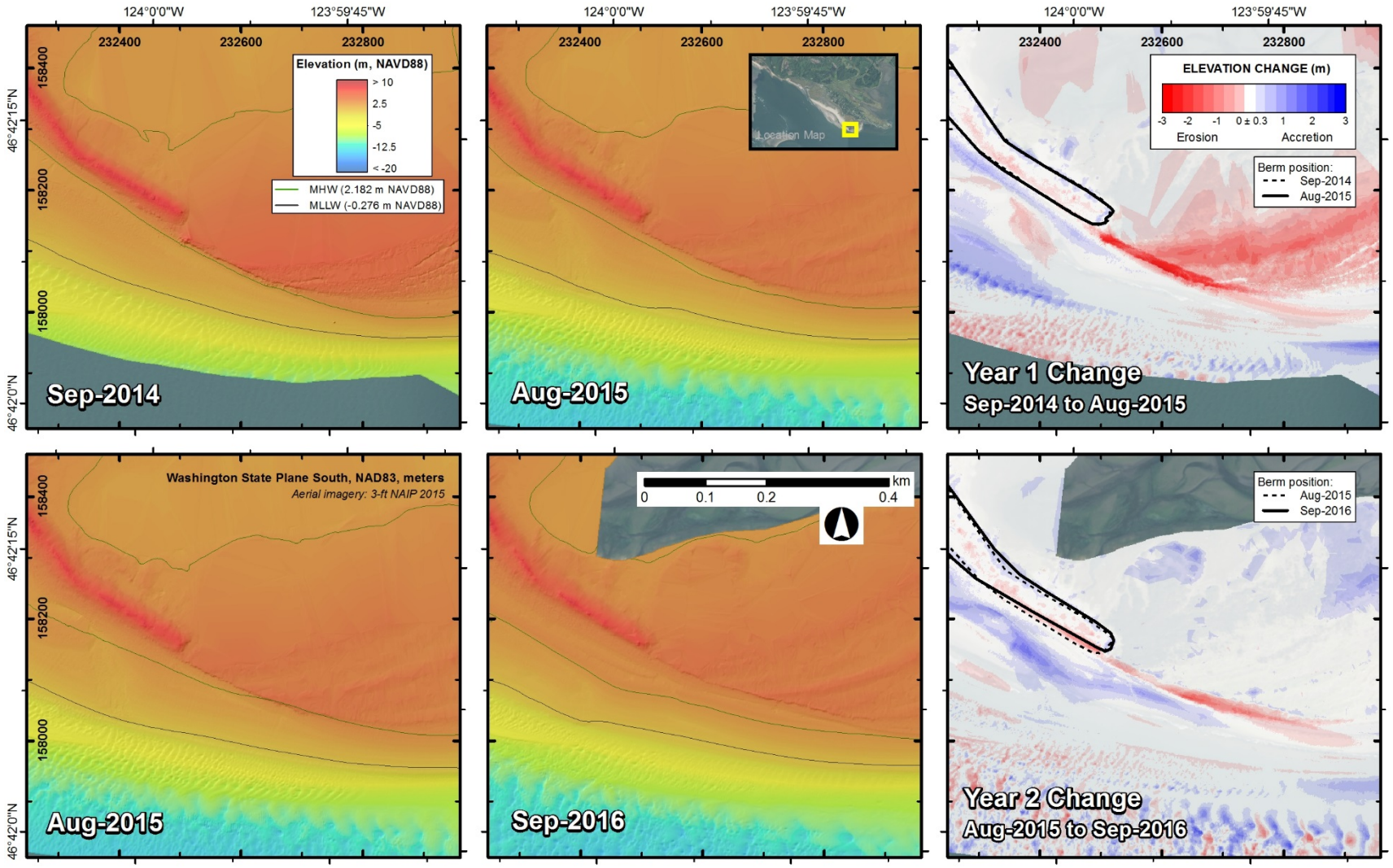

Figure 30. Geomorphic evolution of the east end of the USACE-constructed berm over the survey period

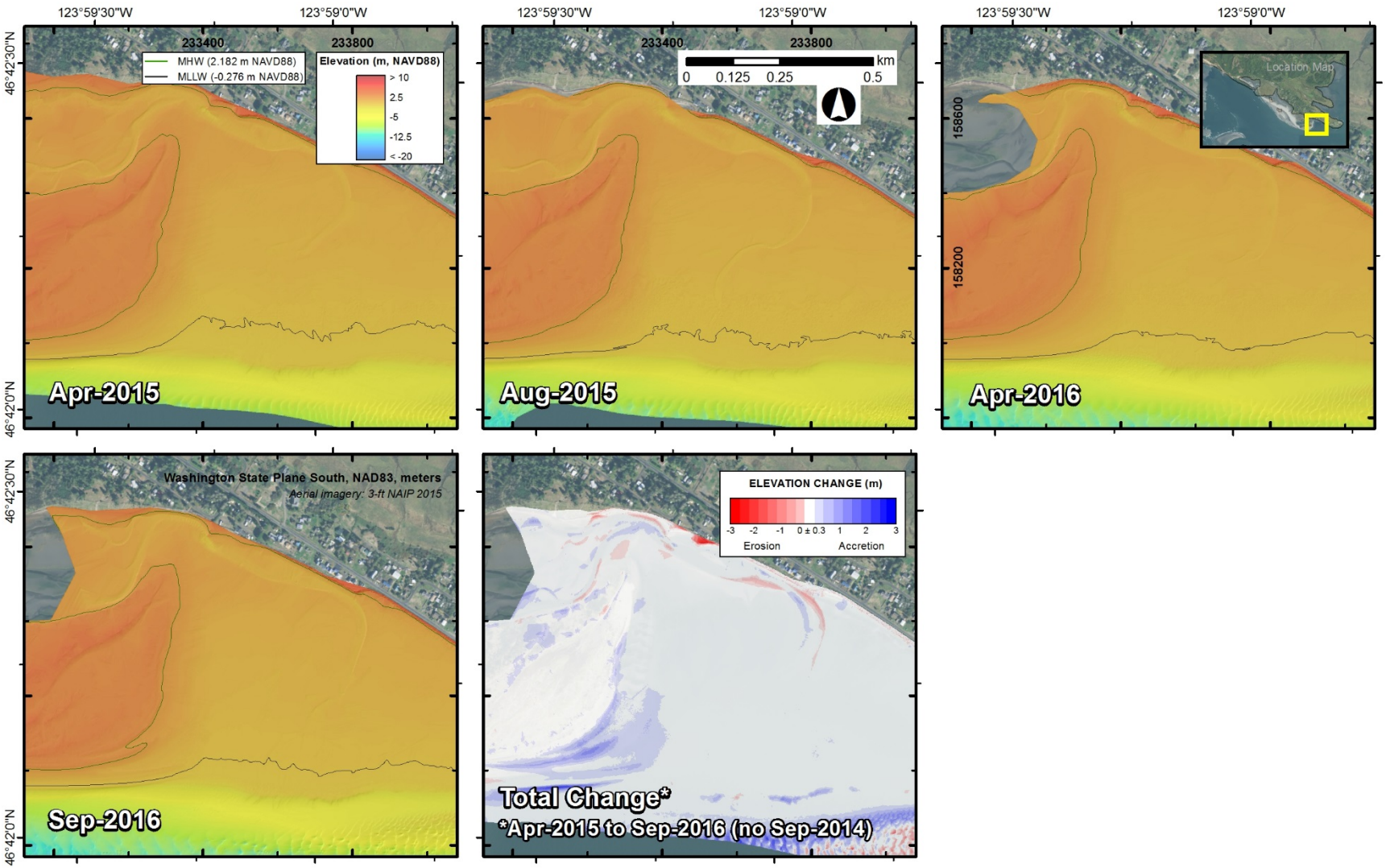

Figure 31. Geomorphic evolution of East Inlet over the survey period, excluding the September 2014 survey

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Conclusions

The monitoring program successfully collected bathymetric and topographic data extending alongshore from the SR 105 groin to Toke Point and across-shore from the lower shoreface across the nearshore, beach, and dune to the back-barrier marsh behind Graveyard and Empire Spits during each of five seasonal surveys from September 2014 to September 2016. Complementary data sets using multibeam bathymetry, boat-based lidar, and ground-based GPS topography were processed and integrated to generate continuous topobathymetric DEMs at 1-m grid resolution. These DEMs were analyzed to assess seasonal, annual, and net two-year morphology changes.

Change analyses revealed that the beach and nearshore along west end of the study area between the SR 105 groin and the Pleistocene outcrops is relatively stable and appears to function as a pocket beach with modest seasonal reversals in sediment transport direction as inferred from erosion and deposition patterns along the shoreline.

Graveyard Spit experienced significant shoreline retreat and overwash, especially during the 2015-16 El Niño winter, exposing SR 105 along the backside of the barrier to wave action for the first time. Graveyard Spit is sediment starved and will likely continue to erode without external sediment input.

The north end of the berm experienced significant erosion, retreating by 340 m (1,115 ft) along its center axis. The upper beach and lower beach face adjacent to and offshore of this section also substantially eroded. Without intervention, the west end of the berm is at high risk of continual losses.

The losses along the north end of the berm were largely balanced by accumulation of sediment across the beach face and nearshore region seaward of the central section of the berm, indicating net sediment transport toward the southeast. The crest elevation of the berm landward of this area lowered by an average of 0.7 m but the berm also widened and accumulated more sediment on landward side. Similarly, the south end of the berm experienced minor retreat, but the fronting beach experienced net accretion.

These monitoring results suggest that time is of the essence to restore Graveyard Spit and prevent rapid shoreline intrusion into North Cove, further exposing SR 105 to erosion, flooding, and overwash of debris. The lowering and overwash of Graveyard Spit also threatens the northwest end of the berm.

A dynamic revetment and dune restoration along the length of Graveyard Spit and along the northwest end of the berm should be evaluated to reduce the retreat of the barriers essential to maintaining the integrity of the back barrier marsh and ultimately flood protection to the Shoalwater Bay Tribe and Tokeland community. The long-term viability of Graveyard Spit may be dependent on restoration of sediment supply that has been diminished by the construction of the SR 105 groin.

The beach and berm condition should be expected to continually evolve. Routine monitoring should be continued to determine berm maintenance requirements and to continue to evaluate its performance. Monitoring is also important for evaluating and designing remedial actions and developing complementary solutions such as a dynamic revetment, dune reconstruction, and sediment nourishment.

References

Barnard, P. L., Hoover, D., Hubbard, D. M., Snyder, A., Ludka, B. C., Allan, J., Kaminsky, G. M., Ruggiero, P., Gallien, T. W., Gabel, L., McCandless, D., Weiner, H. M., Cohn, N., Anderson, D. L., and Serafin, K. A., 2017. Extreme oceanographic forcing and coastal response due to the 2015-2016 El Niño. *Nature Communications*, 8.

Deliverables

In addition to this report, the processed data has been delivered to the USACE in the following files:

1. Multibeam data: 1-m gridded data as ASCII XYZ points (Northing, Easting, Elevation)
2. Laser data: 1-m gridded data as ASCII XYZ points (Northing, Easting, Elevation)
3. GPS beach topography data: ASCII XYZ points (Northing, Easting, Elevation)
4. Combined digital elevation models (DEMs)

All data are referenced to NAD83(2011), Washington State Plane South, with elevations relative to NAVD88 using GEOID12B, in meters.

Appendix A
Environmental Conditions

This appendix provides the wind and wave conditions that occurred during each vessel-based survey. Meteorological data, including wind direction, speed, peak gust, sea level pressure, and air temperature obtained from NOAA National Data Buoy Center (NDBC) Grays Harbor buoy (Station 46211). Wave data, including significant wave height, dominant wave period, and mean wave direction obtained from NOAA National Ocean Service (NOS) Toke Point tide gauge (Station TOKW1 – 9440910). Sea surface temperature taken from the Toke Point tide gauge unless data was unavailable, as was the case for the September 2014 and April 2015 surveys where data from the Grays Harbor buoy was used instead. The local time is shown in Pacific Daylight Time (PDT). Wind and wave direction are given in degrees clockwise from true north (°T).

Table A-1. Wind and wave conditions during the September 2014 survey

Date & Time (PDT)	Wind Dir (^{0}T)	Wind Speed (m/s)	Wind Gust (m/s)	Waves Ht (m)	Waves Period (s)	Waves Dir (^{0}T)	Sea Level Pressure (hPa)	Air Temp (^{0}C)	Water Temp (^{0}C)	Survey Period (PDT)
9/9/2014 8:12	68	2.4	2.9	1.6	8	313	1018.9	13.6	13.2	Start 8:08
9/9/2014 9:12	64	2.6	3.3	1.5	8	311	1019.3	14.6	15.0	
9/9/2014 10:12	77	1.5	1.7	1.5	8	314	1019.8	15.6	14.7	
9/9/2014 11:12	238	0.6	1.9	1.6	8	314	1020.3	16.7	15.2	
9/9/2014 12:12	250	2.0	3.0	1.6	8	313	1020.8	16.8	14.9	
9/9/2014 13:12	244	1.8	4.3	1.6	8	307	1021.0	16.9	14.6	
9/9/2014 14:12	258	5.1	6.1	1.6	8	300	1021.4	16.1	14.8	
9/9/2014 15:12	251	2.3	5.8	1.6	8	299	1021.2	16.8	14.7	
9/9/2014 16:12	233	3.2	6.3	1.5	8	299	1021.3	16.5	14.4	
9/9/2014 17:12	243	3.5	5.3	1.6	8	296	1021.1	15.5	14.5	
9/9/2014 18:12	-	-	-	1.5	8	294	-	-	14.5	End 18:35
Daily Average:	**193**	**2.5**	**4.1**	**1.6**	**8**	**305**	**1020.5**	**15.9**	**14.6**	
9/10/2014 6:12	71	0.8	1.8	1.3	14	272	1022.0	14.1	14.5	Start 6:52
9/10/2014 7:12	132	1.3	1.9	1.3	14	266	1022.2	13.9	14.1	
9/10/2014 8:12	107	1.7	2.0	1.2	15	275	1022.2	14.1	14.2	
9/10/2014 9:12	87	2.9	3.8	1.2	14	275	1022.3	14.3	14.2	
9/10/2014 10:12	99	3.8	4.7	1.2	14	264	1022.6	14.4	14.3	
9/10/2014 11:12	96	2.6	4.4	1.2	14	279	1022.8	14.4	14.0	
9/10/2014 12:12	87	3.2	4.2	1.1	13	279	1022.9	15.1	14.0	
9/10/2014 13:12	135	1.3	1.6	1.2	14	269	1022.5	16.0	14.2	
9/10/2014 14:12	251	2.6	3.9	1.4	13	269	1022.1	17.9	14.5	
9/10/2014 15:12	277	2.6	3.3	1.4	13	273	1021.4	18.7	14.7	
9/10/2014 16:12	300	0.4	2.1	1.4	13	271	1020.8	20.8	14.3	
9/10/2014 17:12	169	0.0	0.5	1.3	14	264	1020.5	22.1	13.9	
9/10/2014 18:12	32	5.0	5.9	1.3	13	259	1020.4	21.8	13.7	
9/10/2014 19:12	336	5.2	6.2	1.3	13	272	1020.5	19.4	14.2	End 19:02
Daily Average:	**156**	**2.4**	**3.3**	**1.3**	**14**	**271**	**1021.8**	**16.9**	**14.2**	

9/11/2014	8:12	53	6.5	8.1	1.1	12	283	1023.2	15.1	13.8	Start 8:08
9/11/2014	9:12	50	9.0	10.6	1.1	12	272	1023.3	15.9	13.7	
9/11/2014	10:12	59	9.1	10.5	1.0	12	283	1023.5	16.8	13.8	
9/11/2014	11:12	63	7.5	9.1	0.9	13	278	1023.5	18.1	13.7	
9/11/2014	12:12	44	7.6	8.8	1.1	11	286	1023.1	19.3	13.8	
9/11/2014	13:12	65	7.4	9.4	1.0	13	275	1022.5	19.8	13.9	
9/11/2014	14:12	52	7.4	9.1	1.1	11	278	1021.8	20.5	14.0	
9/11/2014	15:12	19	8.1	10.5	1.0	11	286	1021.0	21.3	13.8	
9/11/2014	16:12	47	5.3	9.3	0.9	13	269	1020.5	21.2	13.9	
9/11/2014	17:12	33	7.7	9.0	1.0	13	271	1020.0	21.9	13.9	
9/11/2014	18:12	31	6.7	8.8	0.9	12	273	1019.5	22.1	14.0	
9/11/2014	19:12	23	7.5	9.0	0.9	12	276	1019.0	21.9	14.1	End 19:06
Daily Average:		**45**	**7.5**	**9.4**	**1.0**	**12**	**278**	**1021.7**	**19.5**	**13.9**	
9/12/2014	7:12	70	7.0	7.5	0.9	11	282	1016.4	14.0	13.4	Start 7:08
9/12/2014	8:12	72	6.8	7.6	0.9	11	282	1016.1	14.3	13.2	
9/12/2014	9:12	71	5.5	6.7	0.8	11	285	1016.2	15.5	13.0	
9/12/2014	10:12	73	6.5	7.4	0.9	10	283	1016.0	16.6	12.9	
9/12/2014	11:12	67	6.0	7.2	0.8	11	285	1015.7	18.6	13.2	
9/12/2014	12:12	51	6.8	7.8	0.8	12	287	1015.2	20.3	13.5	
9/12/2014	13:12	50	7.0	7.8	0.8	12	287	1014.7	21.5	13.7	
9/12/2014	14:12	48	6.0	7.2	0.8	12	287	1014.3	22.5	13.9	
9/12/2014	15:12	51	5.9	6.5	0.8	11	286	1013.9	23.1	13.8	
9/12/2014	16:12	338	3.7	7.4	0.9	11	286	1013.4	21.5	13.0	
9/12/2014	17:12	326	5.7	6.9	0.9	11	293	1013.2	21.0	13.1	
9/12/2014	18:12	330	7.3	7.9	0.9	11	286	1013.1	21.0	14.0	
9/12/2014	19:12	330	5.6	6.6	1.1	11	279	1013.0	19.9	13.5	End 19:23
Daily Average:		**144**	**6.1**	**7.3**	**0.9**	**11**	**285**	**1014.7**	**19.2**	**13.4**	
9/13/2014	7:12	57	5.3	6.2	1.1	10	286	1013.1	14.5	12.9	Start 7:32
9/13/2014	8:12	53	5.4	5.8	1.0	11	285	1013.3	15.3	13.4	
9/13/2014	9:12	57	4.6	5.3	1.0	11	283	1013.2	15.7	13.4	
9/13/2014	10:12	74	4.5	5.0	1.0	10	292	1013.1	17.5	13.3	
9/13/2014	11:12	64	4.1	4.5	0.9	10	289	1012.9	20.6	13.2	
9/13/2014	12:12	64	4.0	4.4	1.0	10	292	1012.3	23.2	13.2	
9/13/2014	13:12	59	4.4	4.8	1.0	7	313	1011.7	23.0	13.6	
9/13/2014	14:12	70	4.4	4.7	1.0	7	310	1011.3	24.6	14.1	
9/13/2014	15:12	63	2.9	4.2	1.0	7	303	1010.8	26.9	14.2	
9/13/2014	16:12	118	0.5	1.2	1.1	7	306	1010.4	27.7	14.2	
9/13/2014	17:12	325	6.4	7.9	1.1	8	300	1010.3	24.7	13.8	
9/13/2014	18:12	323	8.2	9.1	1.1	7	307	1010.2	23.1	13.7	
9/13/2014	19:12	327	7.0	8.0	1.1	7	307	1010.0	20.9	13.6	
9/13/2014	20:12	332	6.2	7.6	1.2	7	306	1009.8	19.5	13.4	End 19:38
Daily Average:		**142**	**4.9**	**5.6**	**1.0**	**8**	**299**	**1011.6**	**21.2**	**13.6**	
9/14/2014	7:12	54	5.5	6.2	0.9	6	304	1011.1	14.3	13.1	Start 7:14
9/14/2014	8:12	58	6.0	6.8	0.8	6	306	1011.3	14.9	13.1	
9/14/2014	9:12	58	5.4	6.2	0.8	6	306	1011.4	16.7	13.1	
9/14/2014	10:12	63	5.3	5.5	0.8	7	316	1011.5	18.1	13.1	
9/14/2014	11:12	76	3.9	4.5	0.8	7	306	1011.5	20.6	13.2	
9/14/2014	12:12	74	3.4	3.5	0.7	7	313	1011.2	23.0	13.4	
9/14/2014	13:12	54	1.1	1.4	0.7	6	320	1010.9	23.8	13.8	
9/14/2014	14:12	39	1.9	2.1	0.8	6	303	1010.6	26.8	13.9	
9/14/2014	15:12	280	2.7	3.4	0.8	6	299	1010.3	27.1	14.2	

9/14/2014	16:12	264	3.0	4.1	0.7	7	294	1009.8	28.5	14.1	
9/14/2014	17:12	-	-	-	0.7	13	213	-	-	14.3	
9/14/2014	18:12	320	5.4	6.1	0.7	14	221	1009.5	24.9	14.2	
9/14/2014	19:12	330	6.0	6.3	0.7	7	309	1009.4	22.7	14.1	
9/14/2014	20:12	332	6.0	6.3	0.7	7	296	1009.5	21.9	13.9	End 20:04
Daily Average:		**154**	**4.3**	**4.8**	**0.8**	**8**	**293**	**1010.6**	**21.8**	**13.7**	
9/15/2014	7:12	59	4.0	5.0	0.7	18	276	1010.4	15.4	13.4	Start 7:25
9/15/2014	8:12	59	3.5	4.0	0.7	25	237	1010.4	15.4	13.5	
9/15/2014	9:12	61	3.3	3.7	0.6	25	230	1010.2	17.1	13.7	
9/15/2014	10:12	48	2.8	3.1	0.7	18	269	1010.2	17.8	14.1	
9/15/2014	11:12	40	0.9	1.5	0.6	18	269	1010.0	20.6	14.6	
9/15/2014	12:12	243	3.5	5.7	0.6	18	275	1010.1	18.6	14.6	
9/15/2014	13:12	236	3.3	5.1	0.7	22	228	1009.9	18.8	15.4	
9/15/2014	14:12	228	1.9	4.4	0.7	17	282	1009.6	19.0	15.3	
9/15/2014	15:12	237	1.9	3.7	0.7	17	280	1009.3	18.4	15.1	
9/15/2014	16:12	222	0.9	2.9	0.7	17	278	1010.0	17.9	15.1	
9/15/2014	17:12	193	0.5	2.0	0.7	22	226	1010.7	15.6	15.1	
9/15/2014	18:12	194	2.4	4.1	0.9	17	287	1011.0	15.2	14.0	
9/15/2014	19:12	196	2.4	4.4	1.0	22	234	-	14.7	12.9	
9/15/2014	20:12	-	-	-	1.0	17	282	1011.1	15.2	13.1	End 19:46
Daily Average:		**155**	**2.4**	**3.8**	**0.7**	**19**	**261**	**1010.2**	**17.1**	**14.3**	
9/16/2014	6:12	-	-	-	1.1	15	292	-	15.4	13.5	Start 6:48
9/16/2014	7:12	-	-	-	1.1	22	245	1012.4	-	13.5	
9/16/2014	8:12	154	4.4	5.2	1.0	15	289	1012.9	15.8	14.1	
9/16/2014	9:12	143	3.1	3.4	1.0	14	278	1013.1	15.8	14.5	End 9:08
Daily Average:		**149**	**3.8**	**4.3**	**1.0**	**17**	**276**	**1012.8**	**15.7**	**13.9**	

Table A-2. Wind and wave conditions during the April 2015 survey

Date & Time		Wind			Waves			Sea Level	Air	Water	Survey
		Dir	Speed	Gust	Ht	Period	Dir	Pressure	Temp	Temp	Period
(PDT)		(^{0}T)	(m/s)	(m/s)	(m)	(s)	(^{0}T)	(hPa)	(^{0}C)	(^{0}C)	(PDT)
4/14/2015	13:12	258	6.7	8.4	3.5	13	285	1028.7	9.6	11.8	Start 13:13
4/14/2015	14:12	254	8.2	10.8	3.4	13	297	1028.9	9.1	11.9	
4/14/2015	15:12	270	7.4	10.1	3.1	13	296	1029.3	10.0	12.0	
4/14/2015	16:12	260	6.0	8.4	2.7	12	299	1029.7	10.3	12.0	
4/14/2015	17:12	267	7.1	8.5	3.1	13	294	1030.0	9.8	11.9	End 16:52
Daily Average:		**262**	**7.1**	**9.2**	**3.2**	**12**	**294**	**1029.3**	**9.8**	**11.9**	
4/15/2015	8:12	62	3.4	3.8	2.5	11	285	1034.9	4.4	11.4	Start 8:24
4/15/2015	9:12	-	-	-	2.4	11	280	-	-	11.6	
4/15/2015	10:12	-	-	-	2.5	11	285	-	-	11.8	
4/15/2015	11:12	169	2.1	2.6	2.2	11	282	1035.2	9.6	11.9	
4/15/2015	12:12	212	1.3	3.5	2.1	12	273	1035.0	10.9	12.2	
4/15/2015	13:12	238	2.6	5.4	2.1	13	278	1034.7	10.9	12.1	
4/15/2015	14:12	261	4.2	6.7	2.2	11	283	1034.6	11.0	12.3	
4/15/2015	15:12	254	5.0	7.1	2.1	12	276	1034.2	11.1	12.1	
4/15/2015	16:12	257	5.8	7.7	1.8	10	278	1033.6	11.3	12.4	
4/15/2015	17:12	292	6.1	8.1	1.9	11	282	1033.4	11.1	12.3	
4/15/2015	18:12	291	5.6	7.6	1.8	11	279	1032.9	10.9	12.1	

4/15/2015 19:12	-	-	-	1.8	11	286	-	-	12.1	
4/15/2015 20:12	308	4.2	5.3	1.9	11	285	1032.3	9.9	12.0	End 20:03
Daily Average:	**234**	**4.0**	**5.8**	**2.1**	**11**	**281**	**1034.1**	**10.1**	**12.0**	
4/16/2015 8:12	30	1.6	2.4	2.8	20	268	1029.5	7.8	11.9	Start 8:46
4/16/2015 9:12	63	2.2	2.8	-	-	-	1029.1	8.9	-	
4/16/2015 10:12	65	3.9	4.4	-	-	-	1028.7	10.6	-	
4/16/2015 11:12	26	4.8	5.5	-	-	-	1028.4	12.8	-	
4/16/2015 12:12	87	2.0	2.7	3.7	20	271	1027.7	13.5	12.2	
4/16/2015 13:12	153	1.2	1.5	3.9	20	269	1027.0	14.8	12.3	
4/16/2015 14:12	263	2.0	5.0	4.0	18	264	1026.1	16.0	12.2	
4/16/2015 15:12	321	5.6	7.6	-	-	-	1025.4	15.5	-	
4/16/2015 16:12	317	7.4	9.1	-	-	-	1024.7	15.3	-	
4/16/2015 17:12	322	9.3	10.8	-	-	-	1023.9	14.6	-	
4/16/2015 18:12	327	8.9	11.9	-	-	-	1023.3	14.0	-	
4/16/2015 19:12	327	10.5	12.2	-	-	-	1023.0	13.0	-	
4/16/2015 20:12	331	8.7	10.0	4.0	18	264	1022.8	12.0	12.1	End 20:01
Daily Average:	**202**	**5.2**	**6.6**	**3.7**	**19**	**267**	**1026.1**	**13.0**	**12.1**	
4/17/2015 8:12	66	3.1	3.4	3.3	15	272	1024.5	10.0	11.6	Start 8:42
4/17/2015 9:12	48	1.4	1.9	3.0	14	276	1025.0	10.5	11.9	
4/17/2015 10:12	121	1.6	1.9	2.9	15	269	1025.2	11.5	12.0	
4/17/2015 11:12	337	5.2	7.1	2.9	14	265	1025.5	13.3	12.1	
4/17/2015 12:12	324	5.6	7.5	2.8	15	265	1025.8	14.0	12.1	
4/17/2015 13:12	318	6.3	7.5	2.4	13	269	1025.7	14.6	12.2	
4/17/2015 14:12	299	7.3	10.3	2.7	15	269	1025.9	14.1	12.3	
4/17/2015 15:12	303	10.2	12.9	2.5	15	269	1025.7	13.5	12.3	
4/17/2015 16:12	318	9.9	12.2	2.5	15	265	1025.8	13.0	12.3	
4/17/2015 17:12	303	5.6	6.7	2.9	15	272	1025.9	12.8	12.2	
4/17/2015 18:12	301	4.3	7.6	2.7	14	273	1025.7	12.5	11.8	
4/17/2015 19:12	329	4.1	6.3	2.7	14	276	1025.8	11.4	11.9	
4/17/2015 20:12	316	1.8	3.8	2.8	14	272	1026.0	10.8	11.9	End 19:55
Daily Average:	**260**	**5.1**	**6.9**	**2.8**	**15**	**270**	**1025.6**	**12.5**	**12.0**	
4/18/2015 8:12	47	1.9	2.2	2.5	11	279	1028.2	6.9	11.3	Start 8:41
4/18/2015 9:12	65	1.6	2.0	2.3	13	280	1028.2	8.9	11.7	
4/18/2015 10:12	40	0.3	1.0	2.3	11	283	1028.3	11.8	11.8	
4/18/2015 11:12	191	1.3	2.5	-	-	-	1028.2	13.7	-	
4/18/2015 12:12	245	2.6	4.3	-	-	-	1027.9	14.2	-	
4/18/2015 13:12	311	0.3	2.5	2.3	11	282	1027.2	17.0	12.2	
4/18/2015 14:12	331	7.1	8.3	2.0	12	276	1026.7	16.5	13.0	
4/18/2015 15:12	318	6.3	7.7	2.0	13	273	1026.4	16.5	12.2	
4/18/2015 16:12	304	6.1	8.7	2.0	13	278	1025.8	15.6	12.2	
4/18/2015 17:12	320	6.9	8.5	1.9	13	275	1025.2	15.8	11.9	
4/18/2015 18:12	328	9.3	10.5	-	-	-	1024.6	15.1	-	
4/18/2015 19:12	327	8.2	9.8	-	-	-	1024.0	14.0	-	End 18:58
Daily Average:	**236**	**4.3**	**5.7**	**2.2**	**12**	**278**	**1026.7**	**13.8**	**12.0**	
4/19/2015 8:12	339	3.5	4.7	1.6	11	282	1022.7	9.2	11.3	Start 8:02
4/19/2015 9:12	343	3.0	3.8	1.7	11	285	1022.5	11.0	11.2	
4/19/2015 10:12	15	0.5	1.7	1.6	7	300	1022.0	14.1	11.5	
4/19/2015 11:12	48	3.4	4.1	1.5	11	279	1021.7	15.6	11.6	
4/19/2015 12:12	62	0.3	1.2	1.5	8	296	1021.1	17.7	11.8	
4/19/2015 13:12	254	3.6	5.1	1.5	11	282	1020.3	17.9	12.2	
4/19/2015 14:12	275	6.7	7.5	1.5	11	279	1019.6	16.3	12.5	

4/19/2015	15:12	288	7.9	8.9	1.5	7	299	1019.0	15.1	12.1	
4/19/2015	16:12	299	5.8	7.3	1.5	14	278	1018.2	15.8	12.1	
4/19/2015	17:12	330	6.5	9.2	1.6	13	276	1017.7	15.7	12.0	
4/19/2015	18:12	336	5.5	6.2	1.8	13	268	1017.2	15.0	11.5	
4/19/2015	19:12	331	4.7	6.6	1.7	14	271	1016.8	14.1	11.5	
4/19/2015	20:12	327	4.7	5.5	1.8	14	268	1016.5	12.5	11.4	End 20:01
Daily Average:		**250**	**4.3**	**5.5**	**1.6**	**11**	**282**	**1019.6**	**14.6**	**11.7**	
4/20/2015	7:12	329	0.5	0.9	2.2	13	272	1014.7	8.5	11.4	Start 7:15
4/20/2015	8:12	52	1.0	1.4	1.8	13	276	1014.7	8.9	11.3	
4/20/2015	9:12	79	0.6	0.7	2.1	13	271	1014.6	11.0	11.2	
4/20/2015	10:12	130	1.8	2.0	2.0	13	278	1014.4	11.8	11.4	
4/20/2015	11:12	201	0.9	2.4	2.2	13	273	1014.2	16.6	11.5	
4/20/2015	12:12	235	1.3	4.4	2.1	12	272	1013.7	18.2	11.8	
4/20/2015	13:12	252	4.4	6.7	2.1	13	271	1013.3	18.5	12.1	
4/20/2015	14:12	281	6.7	7.3	2.1	14	266	1013.1	16.8	12.2	
4/20/2015	15:12	291	6.0	7.0	2.1	13	271	1012.9	16.1	12.2	
4/20/2015	16:12	295	7.5	9.2	2.1	13	266	1012.7	15.1	12.2	
4/20/2015	17:12	298	6.0	7.1	1.9	13	268	1012.5	14.7	12.3	
4/20/2015	18:12	303	4.5	6.6	2.0	13	272	1012.6	13.5	12.2	
4/20/2015	19:12	301	4.1	5.6	1.8	13	272	1012.5	12.8	12.0	End 19:43
Daily Average:		**234**		**4.7**	**2.0**	**13**	**271**	**1013.5**	**14.0**	**11.8**	
4/21/2015	7:12	289	5.8	6.8	2.1	13	269	1014.6	10.9	11.2	Start 7:52
4/21/2015	8:12	295	6.2	9.5	2.1	13	280	1015.2	11.3	11.0	
4/21/2015	9:12	294	8.1	10.7	2.2	13	272	1015.5	11.2	11.0	
4/21/2015	10:12	303	8.3	10.4	-	-	-	1016.2	11.2	-	
4/21/2015	11:12	303	10.6	14.1	-	-	-	1016.9	11.2	-	
4/21/2015	12:12	304	11.5	16.2	-	-	-	1017.4	11.4	-	
4/21/2015	13:12	306	7.7	12.4	-	-	-	1017.9	11.5	-	
4/21/2015	14:12	315	8.9	11.7	2.7	13	271	1018.6	10.9	11.4	
4/21/2015	15:12	304	11.0	14.7	3.0	13	273	1019.1	10.7	11.5	
4/21/2015	16:12	304	9.3	15.0	2.9	13	272	1019.5	10.6	11.3	
4/21/2015	17:12	293	9.5	13.4	3.0	13	282	1019.7	10.6	11.3	
4/21/2015	18:12	298	11.1	14.1	3.0	13	271	1020.1	10.5	11.2	
4/21/2015	19:12	303	6.9	10.4	2.9	13	275	1020.4	10.2	11.0	End 19:25
Daily Average:		**301**	**8.8**	**12.3**	**2.7**	**13**	**274**	**1017.8**	**10.9**	**11.2**	
4/22/2015	8:12	293	3.5	4.6	2.9	12	275	1023.8	9.4	10.4	Start 7:50
4/22/2015	9:12	303	4.0	5.5	2.9	9	287	1023.9	9.7	10.4	
4/22/2015	10:12	290	6.5	7.5	2.8	12	279	1023.9	9.5	10.5	
4/22/2015	11:12	316	6.4	7.9	2.7	10	283	1024.0	10.1	10.5	
4/22/2015	12:12	297	8.2	9.9	2.7	10	289	1024.0	10.5	10.6	
4/22/2015	13:12	315	4.5	7.6	2.4	11	280	1023.8	10.5	10.8	
4/22/2015	14:12	271	6.3	9.2	2.3	10	278	1023.6	10.5	11.5	
4/22/2015	15:12	283	5.2	8.6	2.6	10	286	1023.6	10.4	11.4	
4/22/2015	16:12	289	6.9	9.3	2.1	8	289	1023.2	10.3	11.9	
4/22/2015	17:12	283	4.5	7.6	2.2	9	285	1022.4	10.3	11.0	
4/22/2015	18:12	296	6.3	7.7	2.3	9	287	1021.6	10.0	11.0	
4/22/2015	19:12	293	4.8	6.6	2.1	13	272	1020.9	9.8	10.8	End 19:25
Daily Average:		**294**	**5.6**	**7.7**	**2.5**	**10**	**283**	**1023.2**	**10.1**	**10.9**	
4/23/2015	6:12	148	6.9	7.5	1.7	10	286	1014.9	8.5	10.6	Start 6:22
4/23/2015	7:12	144	7.4	8.4	1.8	11	286	1014.2	8.5	10.6	
4/23/2015	8:12	148	6.7	8.9	1.7	11	283	1013.6	8.9	10.7	

4/23/2015	9:12	149	8.2	10.9	1.9	11	279	1012.5	9.3	10.7	
4/23/2015	10:12	163	10.0	12.1	2.0	5	199	1012.1	8.5	10.7	
4/23/2015	11:12	161	11.8	14.8	2.4	6	196	1011.2	8.7	10.6	
4/23/2015	12:12	161	12.3	14.3	2.8	7	200	1010.7	8.6	10.5	
4/23/2015	13:12	188	7.6	13.1	2.9	7	197	1011.3	8.6	10.5	
4/23/2015	14:12	193	2.1	5.2	2.5	7	219	1010.9	9.0	10.4	
4/23/2015	15:12	179	3.0	3.9	2.2	7	223	1010.4	9.6	10.6	
4/23/2015	16:12	274	8.4	10.3	-	-	-	1010.4	10.4	-	
4/23/2015	17:12	256	5.3	7.6	2.1	11	275	1010.4	10.7	10.6	
4/23/2015	18:12	250	5.5	7.1	2.0	11	272	1010.3	10.6	10.6	
4/23/2015	19:12	-	-	-	2.2	11	276	-	-	10.5	
4/23/2015	20:12	259	3.5	8.0	2.4	11	272	1009.9	8.7	10.5	End 20:07
Daily Average:		**191**	**7.1**	**9.4**	**2.2**	**9**	**247**	**1011.6**	**9.2**	**10.6**	
4/24/2015	6:12	269	0.7	2.8	3.3	17	271	1008.8	9.5	10.3	Start 6:39
4/24/2015	7:12	338	0.7	2.0	3.6	13	276	1009.1	9.1	10.3	
4/24/2015	8:12	191	4.3	6.1	3.5	14	273	1009.4	10.0	10.3	
4/24/2015	9:12	235	4.1	10.2	3.3	12	276	1009.9	8.9	10.4	
4/24/2015	10:12	283	0.5	3.2	3.4	17	272	1010.4	10.3	10.4	
4/24/2015	11:12	248	1.1	4.2	3.3	13	278	1010.6	11.6	10.5	
4/24/2015	12:12	230	2.2	8.5	3.2	14	285	1010.9	11.2	10.5	
4/24/2015	13:12	284	0.9	2.8	3.3	15	285	1010.6	11.8	10.6	
4/24/2015	14:12	192	2.4	4.8	3.2	13	278	1011.2	10.7	10.8	
4/24/2015	15:12	263	1.0	5.1	2.9	14	283	1011.4	11.3	10.8	
4/24/2015	16:12	196	1.6	5.3	2.9	14	282	1011.5	11.3	10.9	
4/24/2015	17:12	246	4.7	6.3	3.0	13	280	1011.8	10.2	10.9	
4/24/2015	18:12	261	2.3	3.3	2.9	13	275	1011.7	10.2	10.7	
4/24/2015	19:12	289	4.8	6.4	2.7	13	282	1011.9	9.4	10.7	
4/24/2015	20:12	264	1.2	1.3	2.8	13	279	1012.0	8.9	10.7	End 19:50
Daily Average:		**253**	**2.2**	**4.8**	**3.1**	**14**	**278**	**1010.7**	**10.3**	**10.6**	

Table A-3. Wind and wave conditions during the August 2015 survey

Date & Time		Wind			Waves			Sea Level	Air	Water	Survey
		Dir	Speed	Gust	Ht	Period	Dir	Pressure	Temp	Temp	Period
(PDT)		(^{0}T)	(m/s)	(m/s)	(m)	(s)	(^{0}T)	(hPa)	(^{0}C)	(^{0}C)	(PDT)
8/26/2015	8:12	28	1.4	1.7	1.2	10	283	1016.5	13.0	16.9	Start 8:07
8/26/2015	9:12	65	3.5	4.1	1.1	15	265	1016.3	13.6	16.4	
8/26/2015	10:12	73	1.5	2.0	1.2	10	296	1016.2	15.4	15.4	
8/26/2015	11:12	290	0.9	1.1	1.2	10	294	1016.2	18.4	13.9	
8/26/2015	12:12	218	2.2	3.2	1.1	9	297	1015.9	20.5	14.1	
8/26/2015	13:12	248	5.1	5.5	1.0	9	290	1015.7	20.9	15.3	
8/26/2015	14:12	246	3.7	5.2	1.2	10	293	1015.2	23.3	16.5	
8/26/2015	15:12	249	3.4	5.6	1.1	10	290	1015.0	23.6	16.9	
8/26/2015	16:12	279	5.5	6.2	1.1	9	289	1015.2	22.9	18.5	
8/26/2015	17:12	282	4.9	5.4	1.1	9	285	1015.2	22.6	18.6	
8/26/2015	18:12	274	4.0	4.5	1.1	8	289	1015.5	22.5	17.0	
8/26/2015	19:12	225	4.1	6.3	1.1	14	262	1015.9	15.6	16.4	
8/26/2015	20:12	229	3.2	5.0	1.1	15	271	1016.9	15.0	15.5	
8/26/2015	21:12	257	2.5	3.7	1.2	14	265	1017.5	14.7	14.9	End 21:24

Daily Average:	**212**	**3.3**	**4.3**	**1.1**	**11**	**283.5**	**1015.9**	**18.7**	**16.2**	
8/27/2015 8:12	-	-	-	1.0	15	272	-	14.7	-	Start 8:38
8/27/2015 9:12	152	1.3	1.7	1.0	13	258	1019.1	15.0	17.2	
8/27/2015 10:12	216	2.3	3.1	1.1	15	269	1019.0	15.1	16.2	
8/27/2015 11:12	217	1.7	2.4	1.1	15	269	1018.8	16.9	15.0	
8/27/2015 12:12	-	-	-	1.0	15	269	1018.4	17.6	-	
8/27/2015 13:12	-	-	-	1.0	15	261	1018.3	16.9	14.7	
8/27/2015 14:12	234	4.2	7.0	1.1	15	268	1017.8	17.6	15.0	
8/27/2015 15:12	250	6.0	8.1	1.1	15	265	1017.4	17.6	16.9	
8/27/2015 16:12	242	4.3	5.0	1.0	15	264	1016.9	17.8	17.8	
8/27/2015 17:12	207	0.5	1.6	1.0	15	272	1016.0	21.2	18.8	
8/27/2015 18:12	225	2.7	3.3	1.0	15	266	1015.9	17.1	18.8	
8/27/2015 19:12	260	2.2	2.9	1.0	15	271	1015.6	16.3	17.7	End 19:23
Daily Average:	**223**	**2.8**	**3.9**	**1.0**	**15**	**267**	**1017.6**	**17.0**	**16.8**	
8/28/2015 5:12	119	2.7	3.4	1.3	15	272	1015.5	16.1	16.4	Start 5:18
8/28/2015 6:12	144	4.3	5.1	1.4	15	276	1015.4	16.0	16.5	
8/28/2015 7:12	142	4.1	5.0	1.4	14	265	1015.2	15.8	18.3	
8/28/2015 8:12	139	3.5	4.2	1.5	14	269	1015.2	15.8	17.7	
8/28/2015 9:12	148	2.6	3.1	1.4	17	268	1014.9	16.0	17.4	
8/28/2015 10:12	153	2.4	2.9	1.4	15	268	1014.7	16.6	17.0	
8/28/2015 11:12	131	1.1	1.7	1.2	14	271	1014.4	17.2	16.7	
8/28/2015 12:12	250	3.2	3.9	1.0	17	276	1014.5	17.2	17.0	
8/28/2015 13:12	241	3.1	4.0	1.0	13	266	1014.4	16.5	17.0	
8/28/2015 14:12	290	1.3	1.8	1.0	17	271	1013.4	18.3	16.9	
8/28/2015 15:12	217	2.6	2.8	1.0	15	269	1012.6	17.7	17.2	
8/28/2015 16:12	244	1.4	2.3	1.2	15	272	1011.6	18.1	17.8	
8/28/2015 17:12	273	1.4	2.5	1.1	7	200	1010.4	18.0	17.7	
8/28/2015 18:12	217	1.1	1.5	1.2	15	273	1009.7	18.6	18.4	
8/28/2015 19:12	9	2.3	3.3	1.1	15	278	1008.5	19.0	19.0	
8/28/2015 20:12	42	4.2	4.5	1.1	15	275	1007.5	19.2	17.6	End 19:56
Daily Average:	**172**	**2.6**	**3.3**	**1.2**	**15**	**267**	**1013.0**	**17.3**	**17.4**	
8/29/2015 6:12	163	14.8	18.0	1.7	15	278	999.1	17.5	16.7	Start 6:29
8/29/2015 7:12	160	15.7	21.6	2.2	6	186	999.2	17.5	16.7	
8/29/2015 8:12	149	15.2	19.7	3.1	7	185	998.6	18.3	16.8	End 7:43
Daily Average:	**157**	**15.2**	**19.8**	**2.3**	**9**	**216**	**999.0**	**17.8**	**16.7**	
8/30/2014 7:12	180	5.3	7.2	2.4	8	231	1010.3	15.0	15.9	Start 6:56
8/30/2014 8:12	182	7.5	10.3	2.5	8	248	1011.2	14.8	16.0	
8/30/2014 9:12	168	7.9	9.9	2.5	9	230	1012.0	15.3	16.1	
8/30/2014 10:12	185	6.1	9.5	2.6	8	242	1012.8	15.7	16.5	
8/30/2014 11:12	190	6.0	8.3	2.5	13	286	1013.6	16.7	16.5	
8/30/2014 12:12	188	4.9	6.8	2.5	13	289	1014.2	16.8	16.3	
8/30/2014 13:12	191	5.6	8.4	2.4	12	285	1014.7	17.5	16.6	
8/30/2014 14:12	195	5.1	7.6	2.5	13	290	1015.3	17.7	16.7	
8/30/2014 15:12	192	4.8	6.1	2.4	9	251	1015.8	16.9	16.6	
8/30/2014 16:12	192	4.4	6.1	2.5	12	285	1015.9	17.4	17.0	
8/30/2014 17:12	191	5.3	8.8	2.6	12	286	1016.0	17.2	17.2	
8/30/2014 18:12	195	5.4	8.0	2.7	13	286	1016.0	17.2	17.2	
8/30/2014 19:12	182	5.6	7.7	2.5	11	292	1015.8	16.8	17.5	End 19:00
Daily Average:	**187**	**5.7**	**8.1**	**2.5**	**11**	**269**	**1014.1**	**16.5**	**16.6**	
8/31/2015 7:12	171	7.1	9.2	2.3	12	292	1014.9	15.9	16.4	Start 7:27
8/31/2015 8:12	178	8.0	11.0	2.4	8	275	1015.0	15.9	16.5	

8/31/2015	9:12	172	8.0	9.6	2.3	11	282	1015.2	16.2	16.9	
8/31/2015	10:12	176	7.5	10.4	2.4	11	280	1015.5	16.4	16.9	
8/31/2015	11:12	-	-	-	2.4	11	283	-	-	-	
8/31/2015	12:12	185	5.7	8.8	2.4	11	293	1015.7	16.7	16.4	
8/31/2015	13:12	186	5.1	8.5	2.5	11	289	1015.6	16.7	15.9	
8/31/2015	14:12	180	5.2	7.7	2.6	11	285	1015.5	16.2	15.0	
8/31/2015	15:12	177	4.7	6.7	2.5	10	283	1015.1	16.3	14.4	
8/31/2015	16:12	184	6.1	7.9	2.6	10	290	1014.6	16.3	15.3	
8/31/2015	17:12	183	6.3	8.2	2.6	11	287	1014.3	16.6	15.3	
8/31/2015	18:12	181	5.9	7.6	2.4	14	268	1014.0	-	15.7	
8/31/2015	19:12	-	-	-	2.7	11	289	-	-	-	End 18:59
Daily Average:		**179**	**6.3**	**8.7**	**2.5**	**11**	**284**	**1015.0**	**16.3**	**15.9**	
9/1/2015	8:12	184	4.5	6.6	2.5	11	287	1011.8	15.7	15.9	Start 8:38
9/1/2015	9:12	183	6.4	8.5	2.3	12	293	1011.5	-	16.1	
9/1/2015	10:12	192	6.1	8.6	2.4	11	287	1011.3	16.4	16.6	
9/1/2015	11:12	209	4.9	7.2	2.2	12	285	1011.7	15.8	16.4	
9/1/2015	12:12	215	5.8	7.3	2.1	11	282	1011.6	15.2	16.1	
9/1/2015	13:12	168	5.7	7.0	2.3	10	290	1011.3	16.1	16.2	
9/1/2015	14:12	187	4.5	7.1	2.0	11	294	1010.9	16.0	15.9	
9/1/2015	15:12	193	5.5	7.3	2.1	11	299	1010.5	15.7	15.1	
9/1/2015	16:12	237	3.5	5.3	2.1	12	285	1010.5	14.9	15.2	
9/1/2015	17:12	214	3.0	3.7	2.2	12	287	1010.2	14.3	15.6	
9/1/2015	18:12	219	1.9	2.4	2.0	12	286	1010.2	14.5	15.6	
9/1/2015	19:12	191	1.9	3.0	2.0	11	293	1010.2	15.4	16.1	End 18:42
Daily Average:		**199**	**4.5**	**6.2**	**2.2**	**11**	**289**	**1011.0**	**15.5**	**15.9**	
9/2/2015	8:12	213	2.0	2.5	2.5	12	294	1012.3	14.7	15.6	Start 8:44
9/2/2015	9:12	174	2.4	3.5	2.6	12	287	1012.6	15.9	15.6	
9/2/2015	10:12	177	2.4	3.4	2.4	12	293	1013.0	16.8	16.1	
9/2/2015	11:12	200	2.4	4.2	2.6	12	287	1013.4	17.0	16.3	
9/2/2015	12:12	211	3.9	5.8	2.9	10	293	1013.7	17.1	16.2	
9/2/2015	13:12	206	2.8	4.8	2.8	12	293	1013.7	17.4	16.0	
9/2/2015	14:12	-	-	-	2.7	11	294	-	17.3	16.0	
9/2/2015	15:12	219	3.9	5.3	2.7	11	296	1013.9	16.0	15.7	
9/2/2015	16:12	219	4.3	6.1	3.0	11	292	1014.1	16.0	14.9	
9/2/2015	17:12	216	5.2	6.1	2.8	11	290	1014.2	16.0	15.7	
9/2/2015	18:12	209	3.5	4.4	2.5	11	285	1014.4	15.3	16.0	
9/2/2015	19:12	231	2.7	3.6	2.5	12	283	1014.5	15.4	16.3	End 18:46
Daily Average:		**207**	**3.2**	**4.5**	**2.7**	**11**	**291**	**1013.6**	**16.2**	**15.9**	

Table A-4. Wind and wave conditions during the April 2016 survey

Date & Time		Wind			Waves			Sea Level	Air	Water	Survey
		Dir	Speed	Gust	Ht	Period	Dir	Pressure	Temp	Temp	Period
(PDT)		(^{0}T)	(m/s)	(m/s)	(m)	(s)	(^{0}T)	(hPa)	(^{0}C)	(^{0}C)	(PDT)
4/3/2016	11:54	160	1.0	2.1	1.3	12	258	1017.1	12.7	12.8	Start 11:40
4/3/2016	12:54	240	2.1	3.1	1.3	12	261	1016.8	12.7	13.0	
4/3/2016	13:54	240	4.6	5.7	1.4	10	265	1016.3	13.4	13.4	
4/3/2016	14:54	200	2.6	3.6	1.4	11	259	1015.9	14.6	13.9	
4/3/2016	15:54	170	4.1	6.2	1.5	13	249	1015.5	14.5	14.2	

4/3/2016	16:54	180	4.6	6.2	1.3	11	262	1015.1	14.1	14.4	
4/3/2016	17:54	160	7.2	10.3	1.5	12	248	1014.7	11.6	14.3	
4/3/2016	18:54	140	5.7	6.7	1.8	12	244	1014.4	10.0	13.7	
4/3/2016	19:54	150	6.7	7.7	2.0	5	197	1014.0	11.4	13.4	End 19:12
Daily Average:		**182**	**4.3**	**5.7**	**1.5**	**11**	**249**	**1015.5**	**12.8**	**13.7**	
4/4/2016	7:54	260	4.6	7.7	1.3	13	256	1022.4	10.2	12.5	Start 7:39
4/4/2016	8:54	270	6.7	9.3	1.2	13	254	1023.6	9.9	12.3	
4/4/2016	9:54	270	8.2	10.3	1.4	12	258	1024.4	9.6	12.4	
4/4/2016	10:54	240	5.1	6.7	1.2	11	264	1025.4	10.7	12.4	
4/4/2016	11:54	250	6.7	8.8	1.3	12	258	1026.2	11.0	12.5	
4/4/2016	12:54	250	8.2	10.8	1.3	12	261	1027.2	11.3	12.7	
4/4/2016	13:54	250	6.2	9.8	1.4	10	265	1027.3	11.3	12.9	
4/4/2016	14:54	240	5.7	8.2	1.4	11	259	1028.4	10.9	13.3	
4/4/2016	15:54	270	8.2	9.8	1.5	13	249	1028.8	10.7	13.9	
4/4/2016	16:54	240	7.2	10.3	1.3	11	262	1029.3	10.9	13.8	
4/4/2016	17:54	270	6.7	7.7	1.5	12	248	1029.5	10.3	13.9	
4/4/2016	18:54	-	-	-	1.8	12	244	1029.6	10.3	13.5	End 18:46
Daily Average:		**255**	**6.7**	**9.0**	**1.4**	**12**	**257**	**1026.8**	**10.6**	**13.0**	
4/5/2016	6:54	140	4.6	5.1	1.9	7	209	1033.2	9.2	12.5	Start 6:59
4/5/2016	7:54	160	5.1	5.7	1.8	7	217	1033.6	9.4	12.4	
4/5/2016	8:54	160	5.7	6.7	1.8	7	211	1034.5	9.7	12.6	
4/5/2016	9:54	160	5.1	6.7	1.9	7	221	1034.9	9.9	12.4	
4/5/2016	10:54	170	5.1	6.7	1.9	7	210	1035.1	10.7	12.5	
4/5/2016	11:54	170	5.7	6.7	1.9	7	217	1035.8	11.2	12.5	
4/5/2016	12:54	180	5.7	7.2	1.9	7	224	1035.6	11.6	12.6	
4/5/2016	13:54	200	4.6	6.2	1.9	7	230	1035.6	12.3	12.8	
4/5/2016	14:54	190	3.6	5.1	2.0	7	248	1035.2	12.3	12.9	
4/5/2016	15:54	220	2.6	4.1	2.2	7	249	1034.8	12.4	13.3	
4/5/2016	16:54	240	4.1	5.1	2.1	7	254	1034.0	12.0	14.2	
4/5/2016	17:54	270	3.6	4.6	2.2	8	252	1033.2	11.8	13.7	
4/5/2016	18:54	-	-	-	1.9	8	248	1032.8	11.8	13.9	End 19:16
Daily Average:		**188**	**4.6**	**5.8**	**2.0**	**7**	**230**	**1034.5**	**11.1**	**12.9**	
4/6/2016	6:54	50	4.6	5.1	2.3	12	273	1030.4	4.8	12.0	Start 6:50
4/6/2016	7:54	40	3.6	4.6	2.4	12	278	1031.0	5.9	12.1	
4/6/2016	8:54	70	4.6	5.1	2.6	13	273	1030.8	7.0	12.2	
4/6/2016	9:54	70	3.6	4.1	2.4	13	272	1030.7	9.1	12.1	
4/6/2016	10:54	60	2.6	3.1	2.4	12	268	1030.1	11.5	12.3	
4/6/2016	11:54	60	2.6	3.1	2.5	12	271	1029.3	12.9	12.6	
4/6/2016	12:54	40	1.5	2.1	2.1	12	268	1028.4	14.5	12.6	
4/6/2016	13:54	30	5.1	6.2	2.3	11	269	1027.0	16.7	12.8	
4/6/2016	14:54	40	4.6	6.7	2.0	11	275	1025.8	17.4	13.5	
4/6/2016	15:54	40	4.6	5.1	2.2	11	271	1024.6	18.3	13.9	
4/6/2016	16:54	30	4.1	4.6	2.0	10	261	1024.0	18.7	14.3	
4/6/2016	17:54	20	4.1	5.7	2.2	11	272	1023.2	18.7	16.0	
4/6/2016	18:54	20	4.6	5.7	2.0	12	265	1022.5	18.3	15.4	
4/6/2016	19:54	50	5.7	6.2	1.9	13	269	1021.4	16.9	14.6	End 19:40
Daily Average:		**44**	**4.0**	**4.8**	**2.2**	**12**	**270**	**1027.1**	**13.6**	**13.3**	
4/7/2016	6:54	80	9.8	11.3	1.6	11	262	1013.9	12.6	12.6	Start 6:44
4/7/2016	7:54	80	8.8	10.3	-	-	-	1013.9	12.4	12.5	
4/7/2016	8:54	80	7.2	8.2	1.7	11	271	1013.8	13.6	12.8	
4/7/2016	9:54	70	6.2	6.7	1.5	11	265	1013.5	15.6	12.8	

4/7/2016	10:54	70	6.2	6.2	1.7	12	264	1013.4	17.6	12.8	
4/7/2016	11:54	70	3.6	4.1	1.6	11	271	1013.1	17.2	12.7	
4/7/2016	12:54	50	3.1	4.1	1.6	11	265	1012.7	22.3	12.4	
4/7/2016	13:54	-	0.0	0.5	1.5	13	279	1012.5	24.9	11.9	
4/7/2016	14:54	-	-	-	1.5	11	271	1012.5	23.6	12.5	
4/7/2016	15:54	250	5.1	7.7	1.4	12	269	1012.5	21.0	13.8	
4/7/2016	16:54	240	2.6	3.1	1.3	12	266	1012.4	20.5	14.9	
4/7/2016	17:54	100	2.6	2.6	1.3	13	266	1011.8	17.1	14.5	
4/7/2016	18:54	240	2.6	4.6	1.3	12	273	1012.3	17.8	16.6	
4/7/2016	19:54	220	1.5	2.6	1.3	11	265	1012.3	15.7	15.3	End 19:17
Daily Average:		**129**	**4.6**	**5.5**	**1.5**	**12**	**268**	**1012.9**	**18.0**	**13.4**	
4/8/2016	10:54	360	4.6	5.7	1.9	12	268	1014.5	11.6	13.4	Start 11:25
4/8/2016	11:54	340	5.1	6.7	1.9	15	256	1014.4	12.2	13.2	
4/8/2016	12:54	300	7.2	8.8	2.1	15	249	1014.1	13.0	13.2	
4/8/2016	13:54	340	6.2	9.3	2.1	15	245	1013.8	13.0	13.1	
4/8/2016	14:54	320	5.1	6.7	2.4	15	244	1013.4	13.4	12.7	
4/8/2016	15:54	320	5.1	6.7	2.5	11	266	1012.8	14.1	14.3	
4/8/2016	16:54	-	-	-	2.5	14	242	1012.4	13.6	14.5	
4/8/2016	17:54	310	7.7	9.8	2.6	6	310	1012.2	12.4	14.9	
4/8/2016	18:54	320	5.1	9.8	3.0	14	241	-	11.8	15.5	
4/8/2016	19:54	300	5.7	8.8	3.0	7	303	1012.2	10.8	15.5	End 19:26
Daily Average:		**323**	**5.8**	**8.0**	**2.4**	**12**	**262**	**1013.3**	**12.6**	**14.0**	
4/9/2016	6:54	300	2.6	3.1	2.4	13	245	1012.2	9.9	13.1	Start 6:52
4/9/2016	7:54	300	2.1	3.1	2.6	8	300	1012.5	10.2	13.0	
4/9/2016	8:54	350	0.5	1.0	2.9	9	293	1012.7	10.4	13.3	
4/9/2016	9:54	260	2.1	2.6	2.6	12	259	1012.7	10.5	13.4	
4/9/2016	10:54	250	2.6	4.1	2.3	11	268	1013.0	10.7	13.6	
4/9/2016	11:54	230	2.6	3.6	2.3	11	275	1013.2	10.6	13.4	
4/9/2016	12:54	230	2.6	3.6	2.6	9	296	1013.1	10.9	13.1	
4/9/2016	13:54	240	2.6	4.1	2.5	11	278	1013.0	11.1	12.4	
4/9/2016	14:54	-	-	-	2.7	10	282	-	-	-	
4/9/2016	15:54	-	-	-	2.7	11	285	-	-	-	
4/9/2016	16:54	-	-	-	2.5	10	273	-	-	-	
4/9/2016	17:54	-	-	-	2.5	10	280	-	-	-	
4/9/2016	18:54	-	-	-	2.6	11	280	-	-	-	
4/9/2016	19:54	250	3.1	4.1	2.5	10	280	1011.4	10.3	12.9	End 19:09
Daily Average:		**268**	**2.3**	**3.3**	**2.6**	**10**	**278**	**1012.6**	**10.5**	**13.1**	

Table A-5. Wind and wave conditions during the September 2016 survey

Date & Time		Wind			Waves			Sea Level	Air	Water	Survey
		Dir	Speed	Gust	Ht	Period	Dir	Pressure	Temp	Temp	Period
(PDT)		(^{0}T)	(m/s)	(m/s)	(m)	(s)	(^{0}T)	(hPa)	(^{0}C)	(^{0}C)	(PDT)
9/14/2016	8:24	223	4.5	7.0	1.1	13	278	1018.1	11.3	15.4	Start 8:07
9/14/2016	9:24	219	4.3	7.3	-	-	-	1018.7	12.1	15.3	
9/14/2016	10:24	208	5.2	7.9	1.4	12	280	1019.1	13.3	15.2	
9/14/2016	11:24	192	6.0	8.4	1.4	12	280	1019.5	13.5	14.8	
9/14/2016	12:24	212	4.8	6.5	1.6	13	278	1019.6	14.2	13.5	
9/14/2016	13:24	222	2.7	4.1	1.7	12	279	1020.0	14.8	13.2	

9/14/2016	14:24	228	3.8	5.4	1.6	12	286	1020.1	15.1	14.5	
9/14/2016	15:24	242	5.2	6.8	1.5	12	265	-	-	14.9	
9/14/2016	16:24	240	4.6	6.2	1.6	13	268	1020.2	-	15.5	
9/14/2016	17:24	209	4.6	6.4	1.7	12	279	-	-	15.6	
9/14/2016	18:24	219	3.2	5.2	1.6	12	280	1020.5	-	15.9	
9/14/2016	19:24	230	2.6	4.3	-	-	-	1020.4	-	16.4	End 19:15
Daily Average:		**220**	**4.3**	**6.3**	**1.5**	**12**	**277**	**1019.6**	**13.5**	**15.0**	
9/15/2016	7:24	194	0.8	1.9	1.6	11	280	1021.8	14.7	15.4	Start 7:28
9/15/2016	8:24	165	1.7	2.6	1.5	10	290	1021.7	14.6	15.6	
9/15/2016	9:24	169	1.9	2.7	1.6	10	287	1022.0	14.7	15.7	
9/15/2016	10:24	148	0.9	1.8	1.5	11	280	1022.3	14.9	15.2	
9/15/2016	11:24	224	1.7	2.1	1.5	11	280	1022.4	14.8	14.8	
9/15/2016	12:24	152	0.5	1.3	1.5	11	286	1021.9	16.2	14.0	
9/15/2016	13:24	265	2.6	4.5	1.4	12	279	1021.6	16.0	13.8	
9/15/2016	14:24	262	5.4	6.8	1.4	10	285	1021.2	15.5	14.6	
9/15/2016	15:24	264	5.1	6.3	1.3	12	279	1021.1	16.0	15.2	
9/15/2016	16:24	283	4.2	5.5	1.1	11	282	1021.2	16.6	15.7	
9/15/2016	17:24	273	4.8	5.8	1.1	11	276	1020.6	16.4	15.7	
9/15/2016	18:24	297	3.1	3.6	1.0	12	273	1020.3	16.7	15.9	
9/15/2016	19:24	310	3.5	4.3	1.1	11	278	1020.4	14.9	16.5	End 18:48
Daily Average:		**231**	**2.8**	**3.8**	**1.3**	**11**	**281**	**1021.4**	**15.5**	**15.2**	
9/16/2016	7:24	59	0.3	0.6	1.0	10	280	1019.2	13.0	15.4	Start 7:00
9/16/2016	8:24	124	0.0	1.4	0.9	-	282	1019.1	13.3	15.4	
9/16/2016	9:24	148	1.8	2.7	0.9	11	280	1019.1	13.3	15.6	
9/16/2016	10:24	194	1.7	2.3	1.0	11	282	1019.4	13.2	15.6	
9/16/2016	11:24	142	2.1	2.7	1.0	9	285	1018.8	13.4	15.5	
9/16/2016	12:24	211	1.7	2.6	0.9	10	278	1019.0	14.2	15.4	
9/16/2016	13:24	211	2.7	3.4	-	-	-	1018.5	14.6	15.2	
9/16/2016	14:24	214	2.0	2.7	0.8	9	283	1018.5	14.6	15.1	
9/16/2016	15:24	238	2.6	3.1	0.8	10	283	-	14.7	15.3	
9/16/2016	16:24	240	3.0	3.7	0.8	10	283	1017.8	14.6	15.4	
9/16/2016	17:24	247	3.1	3.9	0.8	9	282	1017.7	14.6	15.7	
9/16/2016	18:24	255	2.1	2.8	-	-	-	1017.3	14.5	15.8	End 18:25
Daily Average:		**190**	**1.9**	**2.7**	**0.9**	**10**	**282**	**1018.6**	**14.0**	**15.5**	
9/17/2016	10:24	196	8.3	10.0	2.0	6	196	1013.6	15.4	15.3	Start 10:42
9/17/2016	11:24	201	8.0	10.4	1.9	6	231	1014.5	16.0	15.4	
9/17/2016	12:24	206	7.0	8.3	1.9	17	272	1014.5	16.0	15.4	
9/17/2016	13:24	214	5.7	7.8	1.8	17	269	1015.2	16.1	15.1	
9/17/2016	14:24	217	5.5	8.1	1.8	17	279	1014.8	16.0	14.8	
9/17/2016	15:24	226	5.4	7.0	1.7	17	276	1014.6	16.3	15.1	
9/17/2016	16:24	217	6.3	7.9	-	-	-	-	-	-	
9/17/2016	17:24	188	5.3	6.6	1.7	17	273	-	15.8	15.5	
9/17/2016	18:24	208	6.6	10.1	1.6	15	275	1014.0	16.0	15.7	
9/17/2016	19:24	231	8.1	10.9	1.7	15	276	1013.5	16.2	15.6	End 19:20
Daily Average:		**210**	**6.6**	**8.7**	**1.8**	**14**	**261**	**1014.3**	**16.0**	**15.3**	
9/18/2016	7:24	89	1.4	2.0	-	-	-	1017.9	12.6	15.2	Start 7:49
9/18/2016	8:24	21	1.5	1.8	1.8	13	279	1018.2	12.1	15.2	
9/18/2016	9:24	78	1.1	1.7	1.9	14	276	1018.3	12.3	15.2	
9/18/2016	10:24	95	1.8	2.2	2.0	13	290	1018.5	13.2	15.2	
9/18/2016	11:24	149	2.1	2.4	2.2	14	278	1018.8	14.0	15.3	
9/18/2016	12:24	208	1.5	2.6	2.3	13	289	1018.9	15.6	15.3	

9/18/2016	13:24	234	4.3	4.8	2.1	14	282	1019.2	15.3	15.5	
9/18/2016	14:24	246	3.7	5.0	2.0	13	283	1019.3	15.5	15.4	
9/18/2016	15:24	254	3.0	4.1	2.0	11	292	1019.2	16.7	15.3	
9/18/2016	16:24	245	4.0	5.0	2.1	13	280	1019.0	16.3	16.0	
9/18/2016	17:24	228	3.0	4.3	-	-	-	1018.9	16.2	16.0	
9/18/2016	18:24	221	3.5	4.7	2.2	14	278	1018.8	16.2	16.1	
9/18/2016	19:24	210	3.0	4.5	2.2	10	289	1018.8	15.9	16.2	End 19:28
Daily Average:		**175**	**2.6**	**3.5**	**2.1**	**13**	**283**	**1018.8**	**14.8**	**15.5**	
9/19/2016	6:24	224	4.2	5.4	-	-	-	1017.9	15.1	15.9	Start 7:40
9/19/2016	7:24	214	3.6	5.0	2.5	11	287	1018.0	15.1	15.9	
9/19/2016	8:24	230	3.9	6.4	2.5	12	280	1018.4	15.9	15.9	
9/19/2016	9:24	247	3.1	4.3	-	-	-	1018.8	16.4	15.9	
9/19/2016	10:24	258	3.7	5.3	2.6	13	286	1019.4	16.9	16.0	
9/19/2016	11:24	278	4.5	6.9	2.4	12	287	1019.9	16.9	16.0	
9/19/2016	12:24	241	4.0	5.4	2.5	13	283	1020.1	16.7	16.1	
9/19/2016	13:24	250	3.7	5.1	2.4	12	283	1020.4	17.0	16.2	
9/19/2016	14:24	243	3.8	5.0	-	-	-	1020.4	17.0	16.1	
9/19/2016	15:24	249	4.0	5.5	2.3	12	280	1020.6	17.2	16.1	
9/19/2016	16:24	239	3.7	4.6	2.2	10	285	1020.6	16.6	16.2	
9/19/2016	17:24	228	2.5	3.5	2.3	11	282	1020.4	17.1	16.4	
9/19/2016	18:24	228	2.6	4.2	-	-	-	-	16.5	16.1	
9/19/2016	19:24	226	2.6	4.2	-	-	-	1020.4	15.8	16.6	End 19:10
Daily Average:		**240**	**3.6**	**5.1**	**2.4**	**12**	**284**	**1019.6**	**16.4**	**16.1**	
9/20/2016	7:24	83	3.0	3.8	2.3	11	272	1020.2	12.1	16.2	Start 7:21
9/20/2016	8:24	84	3.7	4.3	2.4	11	280	1020.3	12.3	16.1	
9/20/2016	9:24	77	2.2	2.4	-	-	-	1020.3	13.0	15.9	
9/20/2016	10:24	83	0.8	1.2	2.2	11	283	1020.3	14.9	16.1	
9/20/2016	11:24	206	1.4	2.0	2.4	11	289	1020.2	15.7	16.2	
9/20/2016	12:24	325	1.9	2.9	2.3	11	285	1020.0	15.3	16.3	
9/20/2016	13:24	345	1.0	1.9	2.4	11	286	1019.9	16.1	16.2	End 13:41
Daily Average:		**172**	**2.0**	**2.6**	**2.3**	**11**	**283**	**1020.2**	**14.2**	**16.1**	
9/21/2016	7:24	22	0.7	1.6	1.7	12	290	1018.7	10.2	16.0	Start 8:03
9/21/2016	8:24	22	1.7	2.6	1.7	11	292	1018.8	10.6	16.0	
9/21/2016	9:24	73	3.3	4.3	-	-	-	1018.5	12.0	16.0	
9/21/2016	10:24	91	4.8	5.7	1.6	10	290	1018.3	13.9	16.0	
9/21/2016	11:24	89	3.0	3.8	1.5	11	289	1017.9	15.0	16.0	
9/21/2016	12:24	122	1.4	1.8	-	-	-	1017.4	16.4	16.1	
9/21/2016	13:24	267	2.3	4.2	-	-	-	1017.0	17.7	16.4	End 13:16
Daily Average:		**98**	**2.5**	**3.4**	**1.6**	**11**	**290**	**1018.1**	**13.7**	**16.1**	

Appendix B
Tides

Predicted tides and measured water levels for each survey obtained from the NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) for the Toke Point tide gauge (Station TOKW1 – 9440910). Water level values and times of occurrence are listed for the high (H), low (L), higher high (HH), and lower low (LL) tides. The local time is shown in Pacific Daylight Time (PDT). Tide elevations are relative to mean lower low (MLLW) water, in feet.

Table B-1. Predicted and measured tides during the September 2014 survey

Date	Tide Type	Predicted Tide		Measured Tide	
		Time (PDT)	Elevation (ft, MLLW)	Time (PDT)	Elevation (ft, MLLW)
Tuesday 9/9/2014	HH	1:25	9.6	1:18	9.7
	LL	7:48	-1.1	7:42	-1.2
	H	14:00	9.7	14:06	9.4
	L	20:12	-0.4	20:00	-0.3
Wednesday 9/10/2014	H	2:16	9.4	2:18	9.4
	LL	8:31	-0.8	8:24	-0.8
	HH	14:41	9.7	14:42	9.7
	L	21:00	-0.8	20:54	-0.8
Thursday 9/11/2014	H	3:06	9.1	3:06	8.7
	L	9:13	-0.2	9:06	-0.5
	HH	15:22	9.7	15:18	9.4
	LL	21:49	-0.8	21:36	-0.9
Friday 9/12/2014	H	3:57	8.6	4:00	8.3
	L	9:56	0.6	9:36	0.5
	HH	16:03	9.6	16:00	9.6
	LL	22:38	-0.6	22:36	-0.5
Saturday 9/13/2014	H	4:50	7.9	4:48	7.9
	L	10:40	1.4	10:30	1.6
	HH	16:47	9.2	16:42	9.4
	LL	21:30	-0.2	23:18	0.3
Sunday 9/14/2014	H	5:47	7.3	5:48	7.5
	L	11:28	2.2	11:24	2.5
	HH	17:35	8.7	17:30	8.9
Monday 9/15/2014	LL	0:26	0.3	0:24	0.8
	H	6:49	6.8	6:48	7.0
	L	12:22	2.9	12:12	3.3
	HH	18:30	8.1	18:30	8.4
Tuesday 9/15/2014	LL	1:28	0.7	1:30	1.4
	H	7:59	6.5	8:06	6.8

	L	13:26	3.4	13:18	3.9
	HH	19:33	7.7	19:30	8.2

Table B-2. Predicted and measured tides during the April 2015 survey

Date	Tide Type	Predicted Tide		Measured Tide	
		Time (PDT)	Elevation (ft, MLLW)	Time (PDT)	Elevation (ft, MLLW)
Monday 4/13/2015	L	2:35	3.4	2:30	3.6
	H	8:28	7.8	8:24	7.9
	LL	15:21	0.6	15:24	0.9
	HH	21:56	7.6	22:00	7.9
Tuesday 4/14/2015	L	3:52	2.7	3:54	2.9
	HH	9:46	8.0	9:42	7.6
	LL	16:24	0.5	16:18	0.1
	H	22:50	8.2	22:48	7.6
Wednesday 4/15/2015	L	4:58	1.8	4:54	1.2
	H	10:55	8.3	10:48	7.5
	LL	17:20	0.3	17:12	-0.4
	HH	21:39	8.9	23:30	8.1
Thursday 4/16/2015	L	5:55	0.7	5:42	0.2
	H	11:57	8.6	12:00	8.1
	LL	18:11	0.2	18:00	-0.1
Friday 4/17/2015	HH	0:23	9.5	0:18	9.1
	LL	6:47	-0.3	6:30	-0.8
	H	12:53	8.9	12:48	8.1
	L	18:58	0.3	18:42	-0.4
Saturday 4/18/2015	HH	1:05	10.0	1:00	9.1
	LL	7:36	-1.0	7:12	-2.1
	H	13:46	9.0	13:42	8.0
	L	19:43	0.6	19:24	-0.2
Sunday 4/19/2015	HH	1:47	10.3	1:36	9.5
	LL	8:23	-1.5	8:18	-2.5
	H	14:37	9.0	14:30	8.1
	L	20:28	1.0	20:06	0.4
Monday 4/20/2015	HH	2:28	0.4	2:18	9.8
	LL	9:09	-1.6	8:54	-2.2
	H	15:26	8.7	15:24	8.3
	L	21:12	1.5	20:54	1.3
Tuesday 4/21/2015	HH	3:10	10.1	3:00	9.8
	LL	9:55	-1.5	9:48	-1.8
	H	16:16	8.4	16:12	7.8
	L	21:57	2.0	21:48	1.6
Wednesday 4/22/2015	HH	3:53	9.6	3:48	8.9
	LL	10:41	-1.0	10:18	-1.8
	H	17:08	7.9	17:00	7.2

	L	20:44	2.6	22:30	2.0
Thursday 4/23/2015	HH	4:38	9.0	4:36	8.5
	LL	11:30	-0.4	11:00	-0.6
	H	18:02	7.5	18:06	7.5
	L	21:36	3.1	23:12	3.2
Friday 4/24/2015	HH	5:29	8.3	5:12	8.5
	LL	12:22	0.2	12:12	0.5
	H	19:01	7.2	19:00	7.2

Table B-3. Predicted and measured tides for the August 2015 survey

Date	Tide Type	Predicted Tide		Measured Tide	
		Time (PDT)	Elevation (ft, MLLW)	Time (PDT)	Elevation (ft, MLLW)
Tuesday 8/25/2015	LL	4:06	0.5	3:54	0.3
	H	10:36	6.2	10:42	6.2
	L	15:56	3.2	15:54	3.1
	HH	22:01	8.3	21:54	8.2
Wednesday 8/26/2015	LL	5:04	-0.1	5:00	-0.2
	H	11:31	6.7	11:36	6.8
	L	17:01	2.7	16:54	2.8
	HH	23:01	8.7	22:54	8.7
Thursday 8/27/2015	LL	5:55	-0.8	5:48	-0.8
	H	12:19	7.3	12:30	7.5
	L	17:58	2.0	17:48	2.3
	HH	23:56	9.2	0:00	9.3
Friday 8/28/2015	LL	6:42	-1.3	6:36	-1.2
	H	13:02	8.0	13:00	8.2
	L	18:50	1.3	18:48	1.8
Saturday 8/29/2015	H	12:48	9.5	0:42	10.1
	LL	7:26	-1.5	7:30	-0.4
	HH	13:43	8.5	13:36	10.4
	L	19:39	0.6	19:42	2.2
Sunday 8/30/2015	HH	1:38	9.6	1:30	10.7
	LL	8:09	-1.5	8:00	-0.6
	H	14:24	9.0	14:12	9.8
	L	20:28	0.0	20:12	0.9
Monday 8/31/2015	H	2:29	9.5	2:24	10.1
	LL	8:51	-1.2	8:48	-0.4
	HH	15:04	9.4	15:00	10.2
	L	21:17	-0.4	21:06	0.6
Tuesday 9/1/2015	H	3:20	9.2	3:12	9.8
	LL	9:34	-0.7	9:18	0.2
	HH	15:46	9.5	15:36	10.4
	LL	22:08	-0.6	22:06	0.4
	H	4:13	8.6	4:12	9.1

Wednesday 9/2/2015	L	10:19	0.1	10:12	0.8
	HH	16:30	9.5	16:30	10.0
	LL	23:01	-0.5	22:54	0.2

Table B-4. Predicted and measured tides for the April 2016 survey

Date	Tide Type	Predicted Tide		Measured Tide	
		Time (PDT)	Elevation (ft, MLLW)	Time (PDT)	Elevation (ft, MLLW)
Sunday 4/3/2016	L	4:20	3.1	4:12	2.6
	HH	10:14	8.1	10:12	7.6
	LL	16:57	0.5	16:48	0.2
	HH	23:23	8.0	23:30	8.1
Monday 4/4/2016	L	5:20	2.2	5:12	2.3
	H	11:17	8.6	11:12	8.1
	LL	17:48	0.2	17:42	-0.4
Tuesday 4/5/2016	H	0:07	8.6	0:06	7.9
	L	6:14	1.2	6:00	0.6
	HH	12:14	9.0	12:12	8.0
	LL	18:35	-0.1	18:18	-1.0
Wednesday 4/6/2016	HH	0:48	9.3	0:48	8.5
	L	7:03	0.2	6:54	-0.5
	H	13:07	9.3	13:06	8.4
	LL	19:20	-0.1	19:00	-0.7
Thursday 4/7/2016	HH	1:28	9.9	1:24	9.3
	LL	7:51	-0.7	7:36	-1.5
	H	13:59	9.4	14:00	9.1
	L	16:04	0.2	19:42	-0.2
Friday 4/8/2016	HH	2:08	10.3	2:00	10.2
	LL	8:38	-1.2	8:24	-1.8
	H	14:50	9.3	14:42	8.8
	L	20:47	0.6	20:30	0.3
Saturday 4/9/2016	HH	2:50	10.4	2:42	10.1
	LL	9:26	-1.5	9:12	-1.9
	H	15:41	9.0	15:36	8.7
	L	21:32	1.1	21:12	1.0
Sunday 4/10/2016	HH	3:33	10.3	3:24	10.2
	LL	10:16	-1.4	9:54	-1.8
	H	16:35	8.6	16:30	8.2
	L	22:19	1.8	22:00	1.6
Monday 4/11/2016	HH	4:19	10.0	4:12	9.6
	LL	11:07	-1.0	10:48	-1.4
	H	17:32	8.1	17:36	7.6
	L	23:10	2.5	22:54	2.3
Tuesday 4/12/2016	HH	5:09	9.4	5:06	9.2
	LL	12:03	-0.5	11:42	-0.2

	H	18:34	7.6	18:36	7.7
Friday 4/15/2016	L	2:36	3.4	2:48	3.7
	HH	8:29	7.6	8:24	7.5
	LL	15:18	0.9	15:12	0.8
	H	21:58	7.4	22:00	7.2
Monday 4/18/2016	L	5:48	1.8	5:48	1.7
	H	11:44	7.6	11:48	7.5
	LL	17:57	1.2	17:54	1.1

Table B-5. Predicted and measured tides for the September 2016 survey

Date	Tide Type	Predicted Tide		Measured Tide	
		Time (PDT)	Elevation (ft, MLLW)	Time (PDT)	Elevation (ft, MLLW)
Wednesday 9/14/2016	LL	6:00	-0.2	5:54	-0.6
	H	12:22	7.7	12:30	7.5
	L	18:12	1.8	18:06	1.7
Thursday 9/15/2016	HH	0:10	8.8	0:06	8.8
	LL	6:43	-0.6	6:42	-0.7
	H	13:00	8.3	13:06	8.1
	L	18:59	1.0	18:42	1.0
Friday 9/16/2016	HH	0:58	9.1	0:54	9.0
	LL	7:24	-0.7	7:18	-1.0
	H	13:37	8.9	13:42	8.7
	L	19:37	0.3	19:36	0.3
Saturday 9/17/2016	HH	1:46	9.3	1:42	9.2
	LL	8:05	-0.6	7:54	-0.2
	HH	14:14	9.3	14:12	9.6
	L	20:30	-0.3	20:24	0.0
Sunday 9/18/2016	H	2:34	9.2	2:30	9.2
	L	8:46	-0.3	8:30	-0.2
	HH	14:53	9.6	14:54	9.8
	LL	21:17	-0.7	21:12	-0.5
Monday 9/19/2016	H	3:24	8.9	3:24	9.1
	L	9:28	0.3	9:24	0.6
	HH	15:33	9.8	15:24	9.9
	LL	22:06	-0.8	21:54	-0.6
Tuesday 9/20/2016	H	4:16	8.5	4:18	8.4
	L	10:12	1.0	10:00	1.1
	HH	16:17	9.7	16:18	9.6
	LL	22:58	-0.7	22:48	-0.8
Wednesday 9/21/2016	H	5:14	7.9	5:12	7.6
	L	11:00	1.7	10:54	1.6
	HH	17:05	9.4	17:00	9.2
	LL	23:55	-0.4	23:42	-0.4
	H	6:18	7.4	6:18	7.2

Thursday 9/22/2016	L	11:55	2.5	11:48	2.3
	HH	18:01	8.9	18:00	8.6

Appendix C
Digital Elevation Models

Topobathymetric digital elevation models (DEMs) produced for each of the five surveys of the Shoalwater Bay/North Cove shoreline are provided here (Figures C-1 through C-5). DEMs are gridded at 1-m using linear interpolation to create a continuous surface from the multibeam sonar, boat-based lidar, and ground-based RTK-GPS data. All data are referenced to North American Datum 1983, Washington State Plane South, in meters, with elevations relative to NAVD88 (using GEOID12B), also in meters.

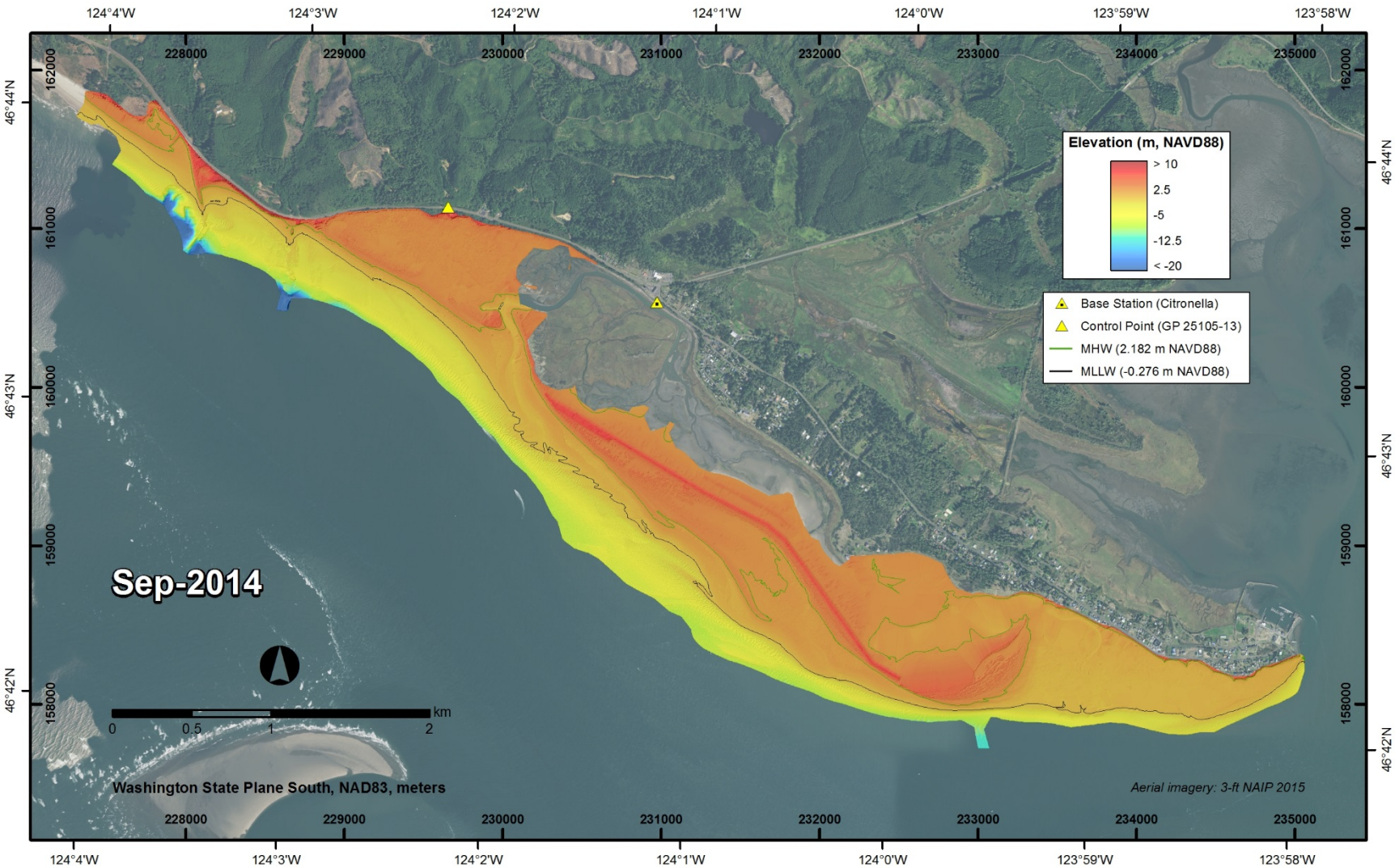

Figure C-1. Topobathymetric digital elevation model (DEM) from boat-based lidar, multibeam sonar, and ground-based GPS data collected in September 2014; DEM resolution is 1 m

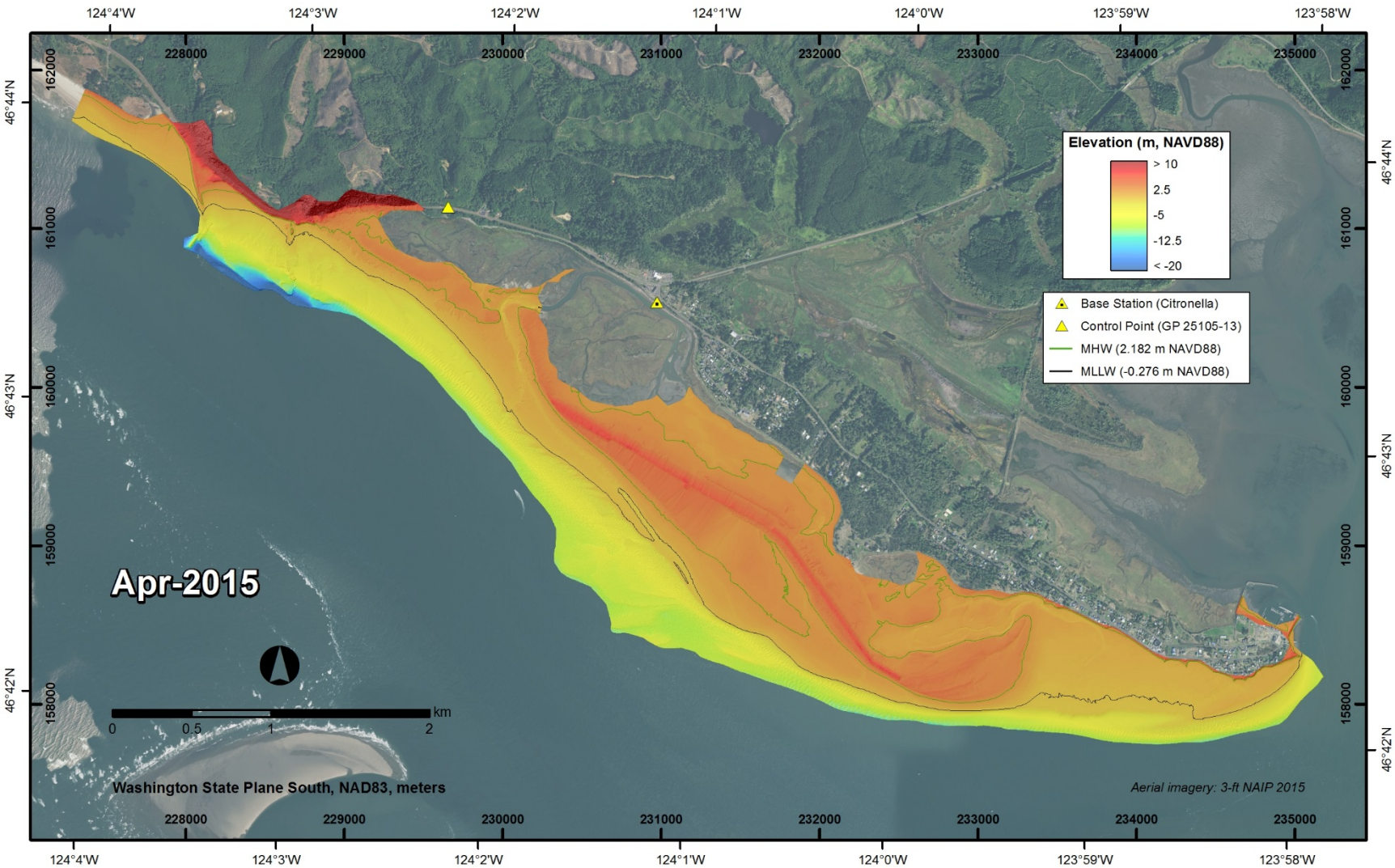

Figure C-2. Topobathymetric digital elevation model (DEM) from boat-based lidar, multibeam sonar, and ground-based GPS data collected in April 2015; DEM resolution is 1 m

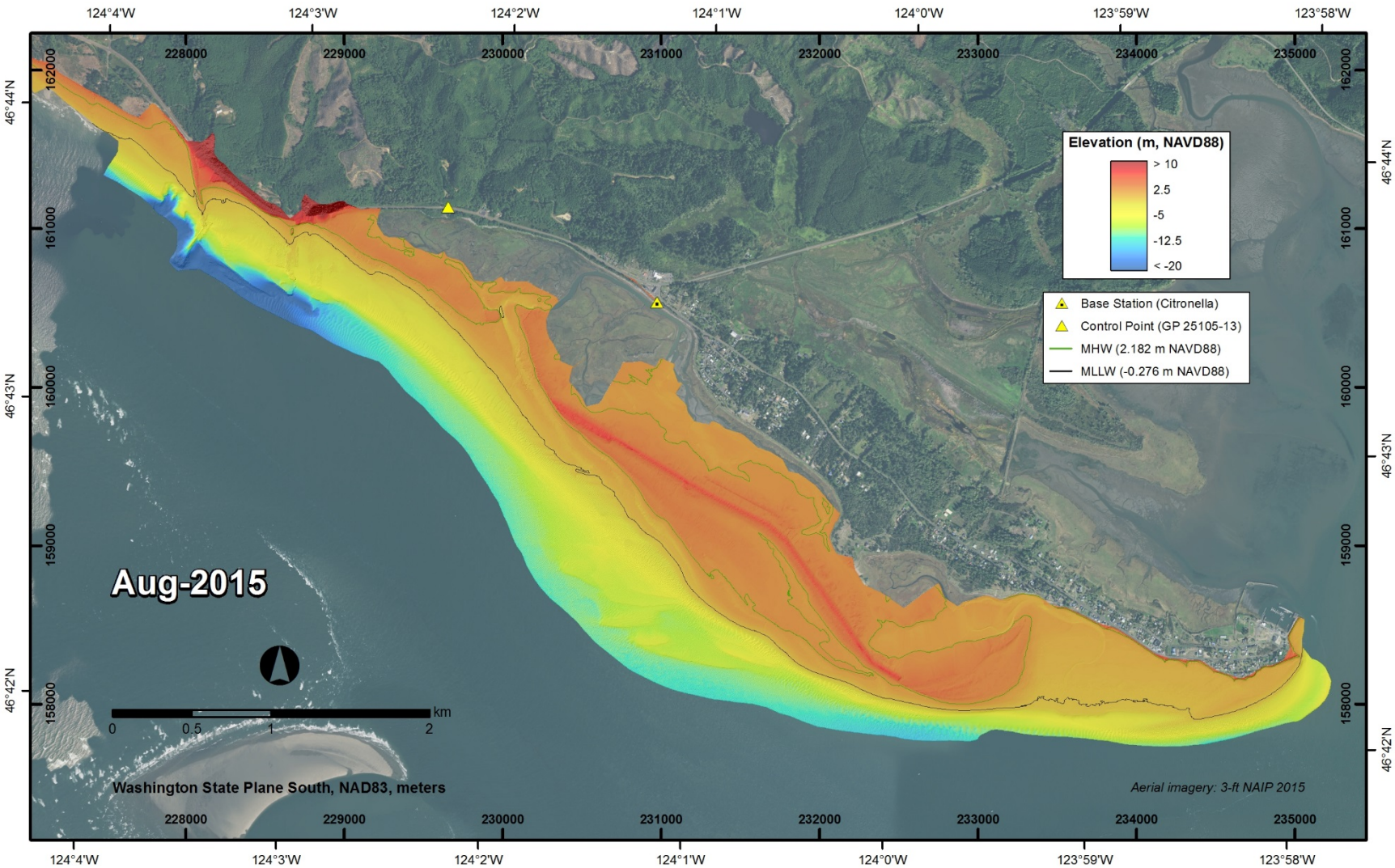

Figure C-3. Topobathymetric digital elevation model (DEM) from boat-based lidar, multibeam sonar, and ground-based GPS data collected in August 2015; DEM resolution is 1 m

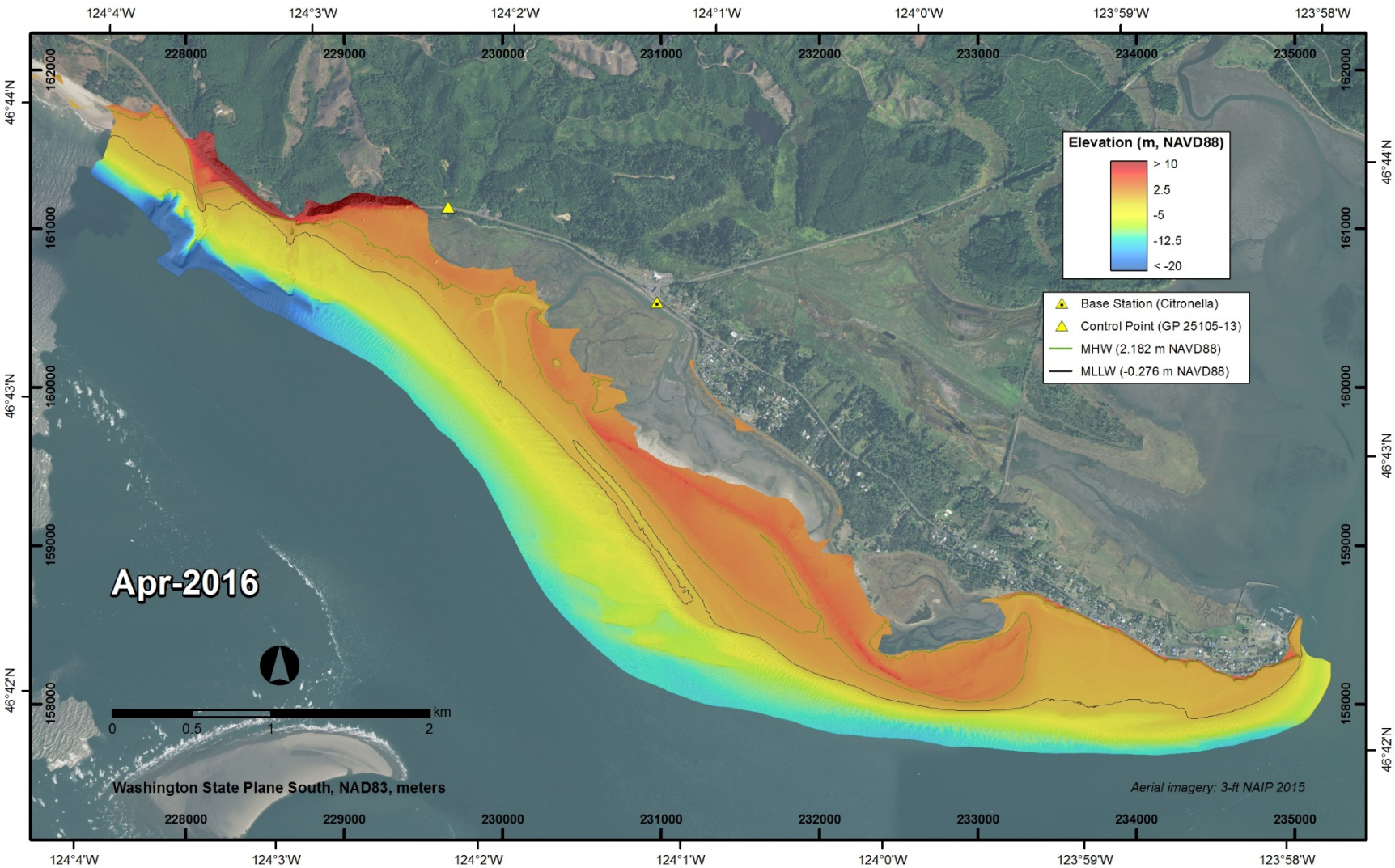

Figure C-4. Topobathymetric digital elevation model (DEM) from boat-based lidar, multibeam sonar, and ground-based GPS data collected in April 2016; DEM resolution is 1 m

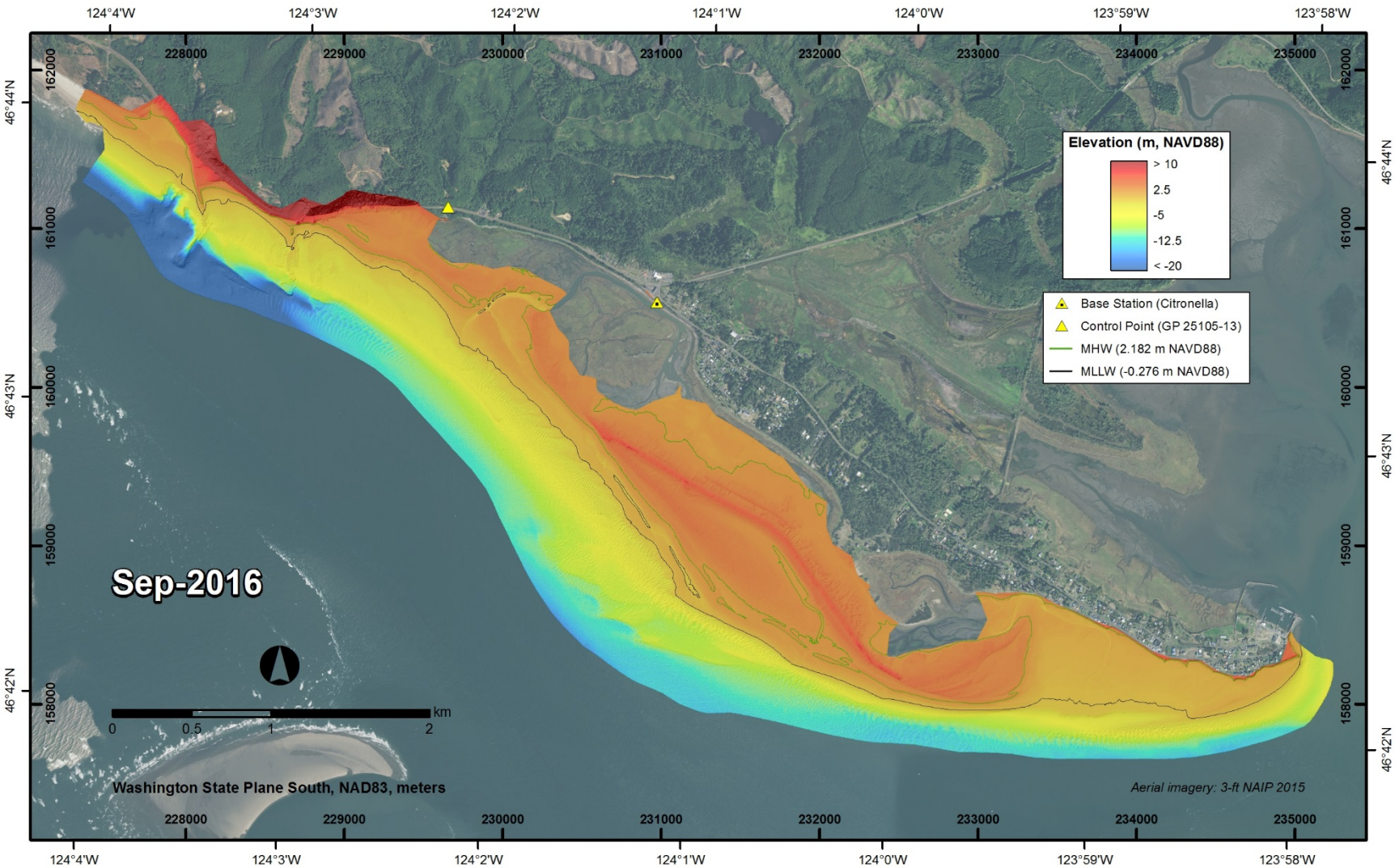

Figure C-5. Topobathymetric digital elevation model (DEM) from boat-based lidar, multibeam sonar, and ground-based GPS data collected in September 2016; DEM resolution is 1 m

Appendix D
Change Analysis Results

The geomorphic evolution of the survey area can be analyzed by calculating the difference in elevation for each 1-m grid cell between two topobathymetric DEMs to assess the change in elevation over different time periods. Winter and summer seasonal changes are shown in Figures D-1 through D-4, while annual changes are shown in Figures D-5 and D-6. Figure D-7 shows the total two-year change that occurred over the survey period from September 2014 to September 2016. Areas of accretion are shown in blue, while areas that have experienced erosion are shown in red. Elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change. All data are referenced to North American Datum 1983, Washington State Plane South, in meters, with elevations relative to NAVD88 (using GEOID12B), also in meters.

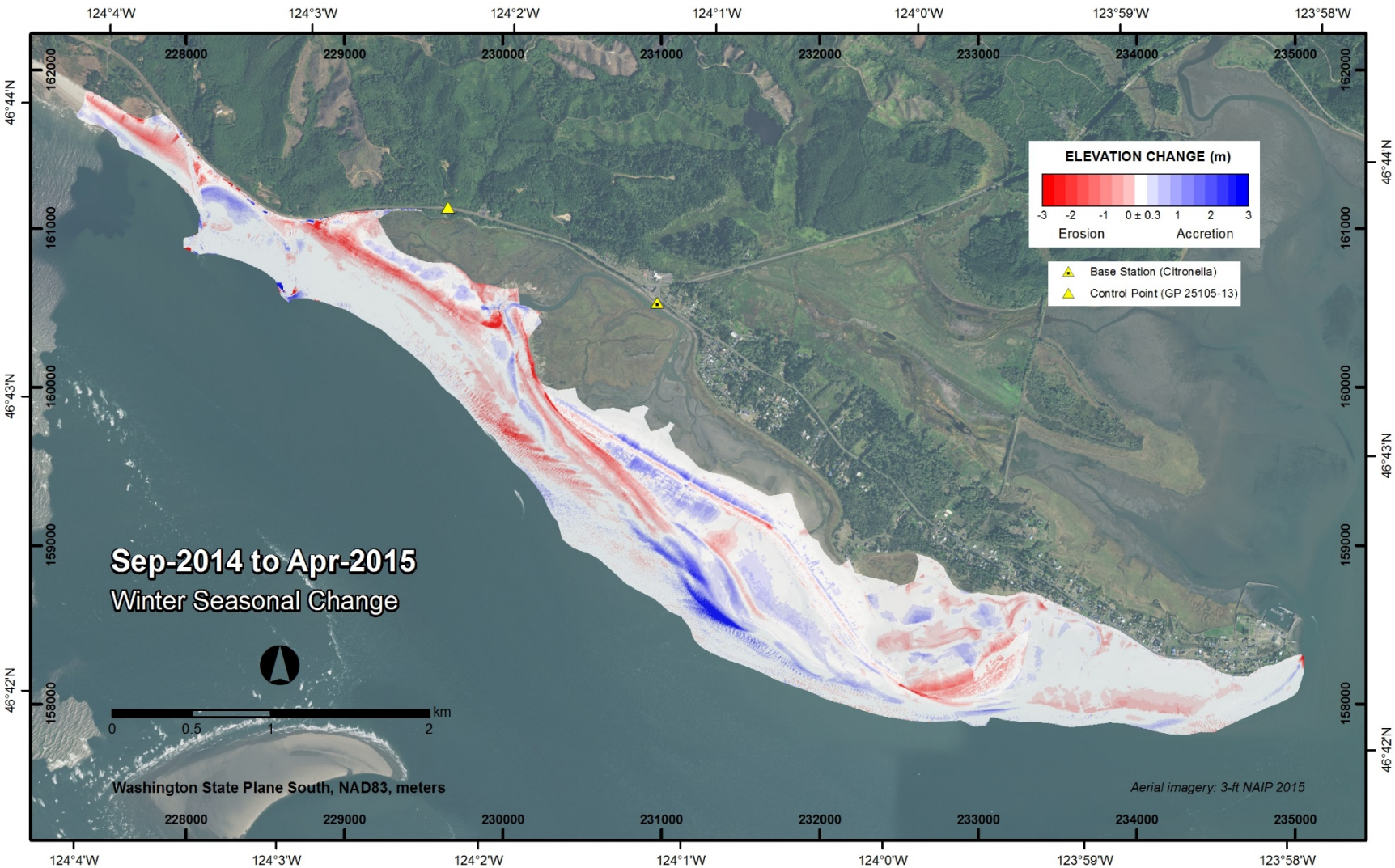

Figure D-1. Winter seasonal beach and nearshore change between September 2014 and April 2015 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

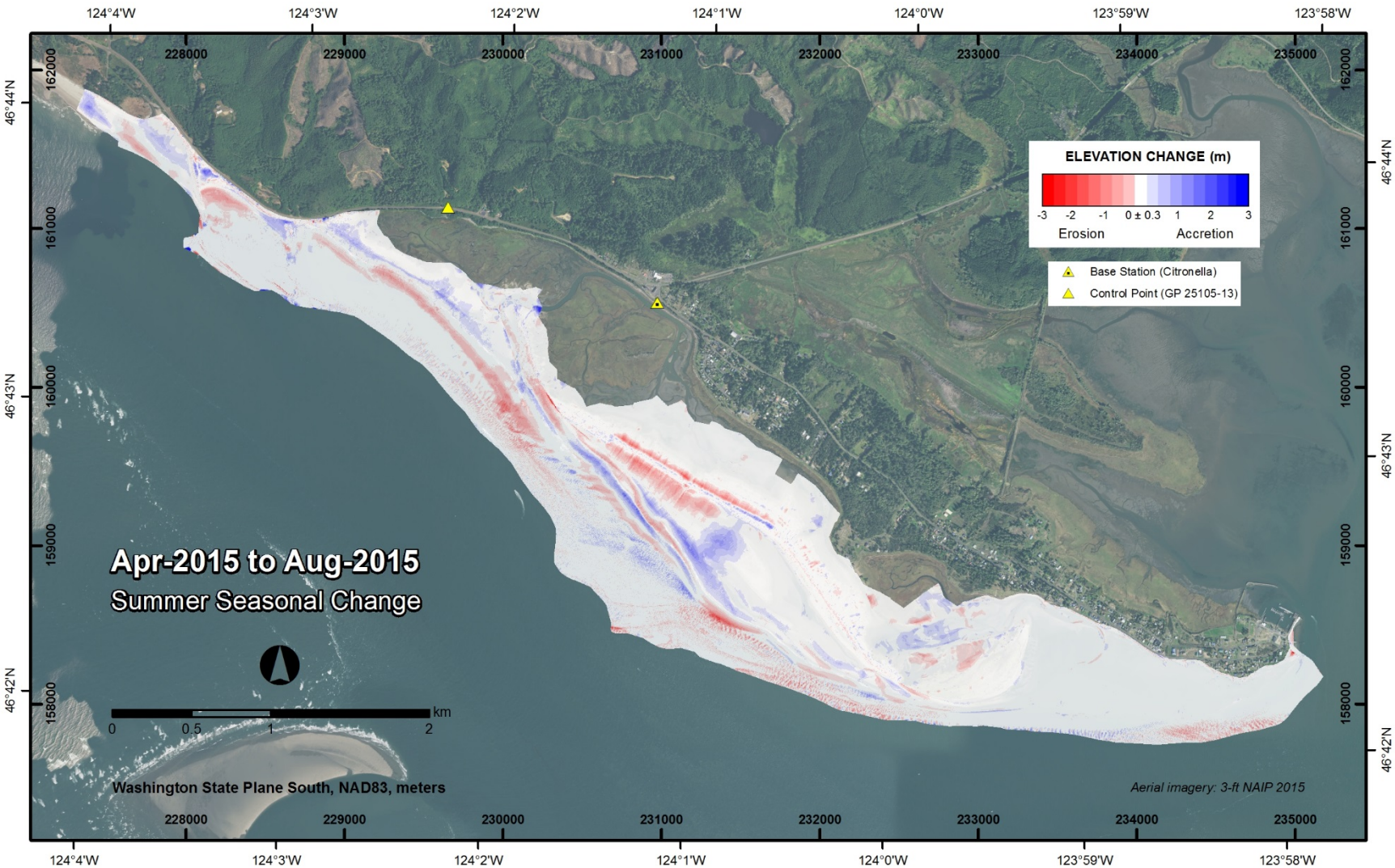

Figure D-2. Summer seasonal beach and nearshore change between April 2015 and August 2015 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

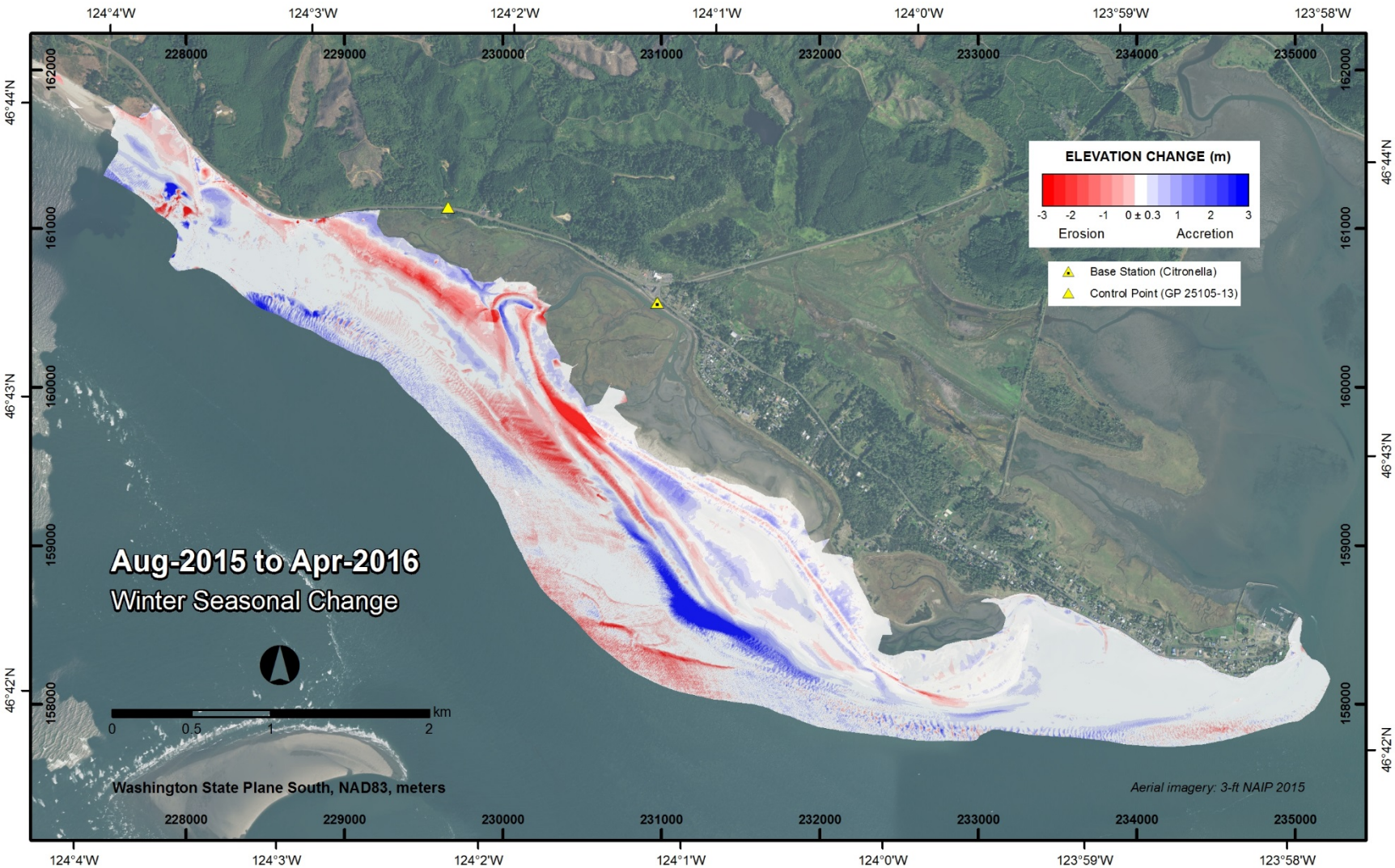

Figure D-3. Winter seasonal beach and nearshore change between August 2015 and April 2016 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

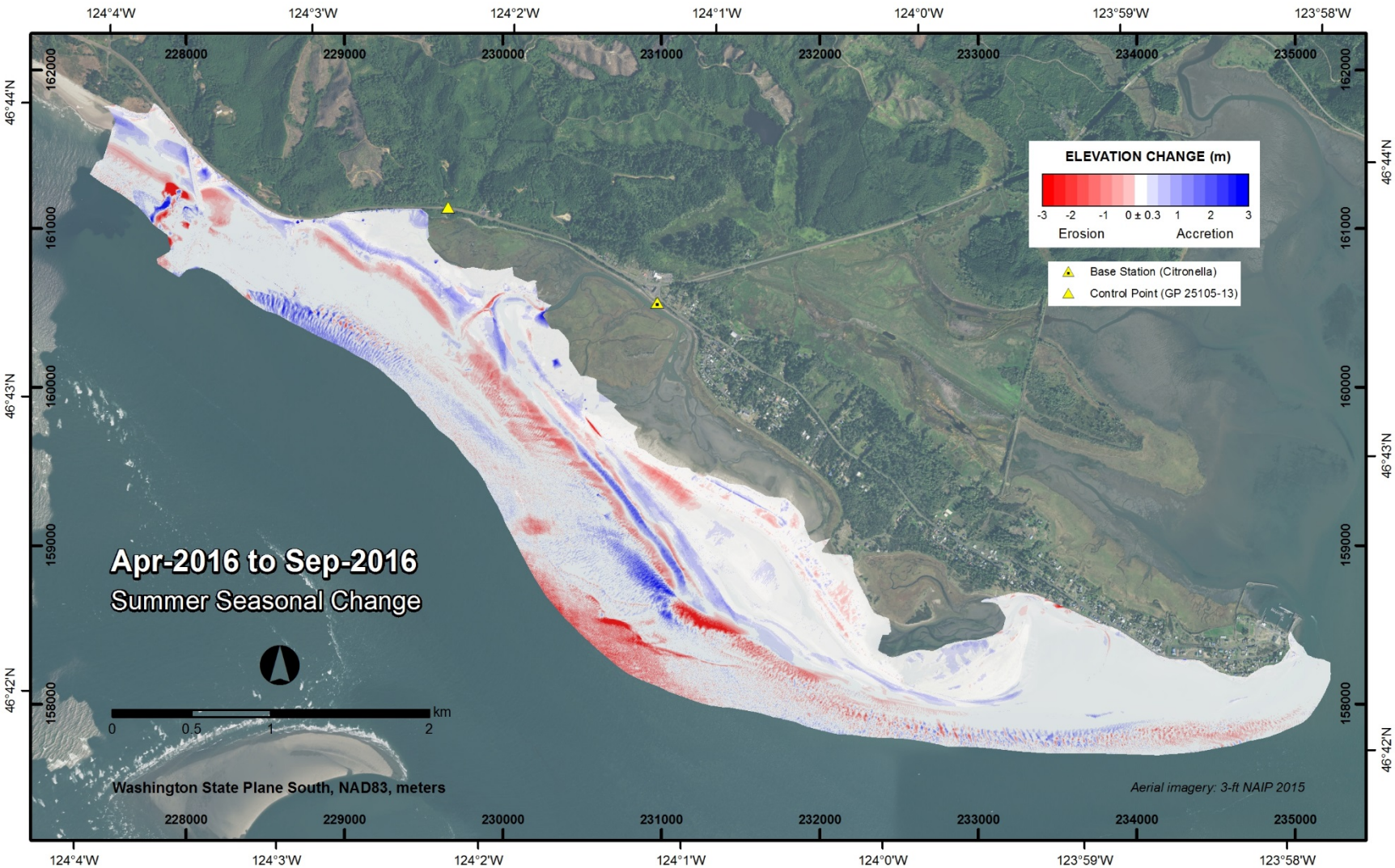

Figure D-4. Summer seasonal beach and nearshore change between April 2016 and September 2016 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

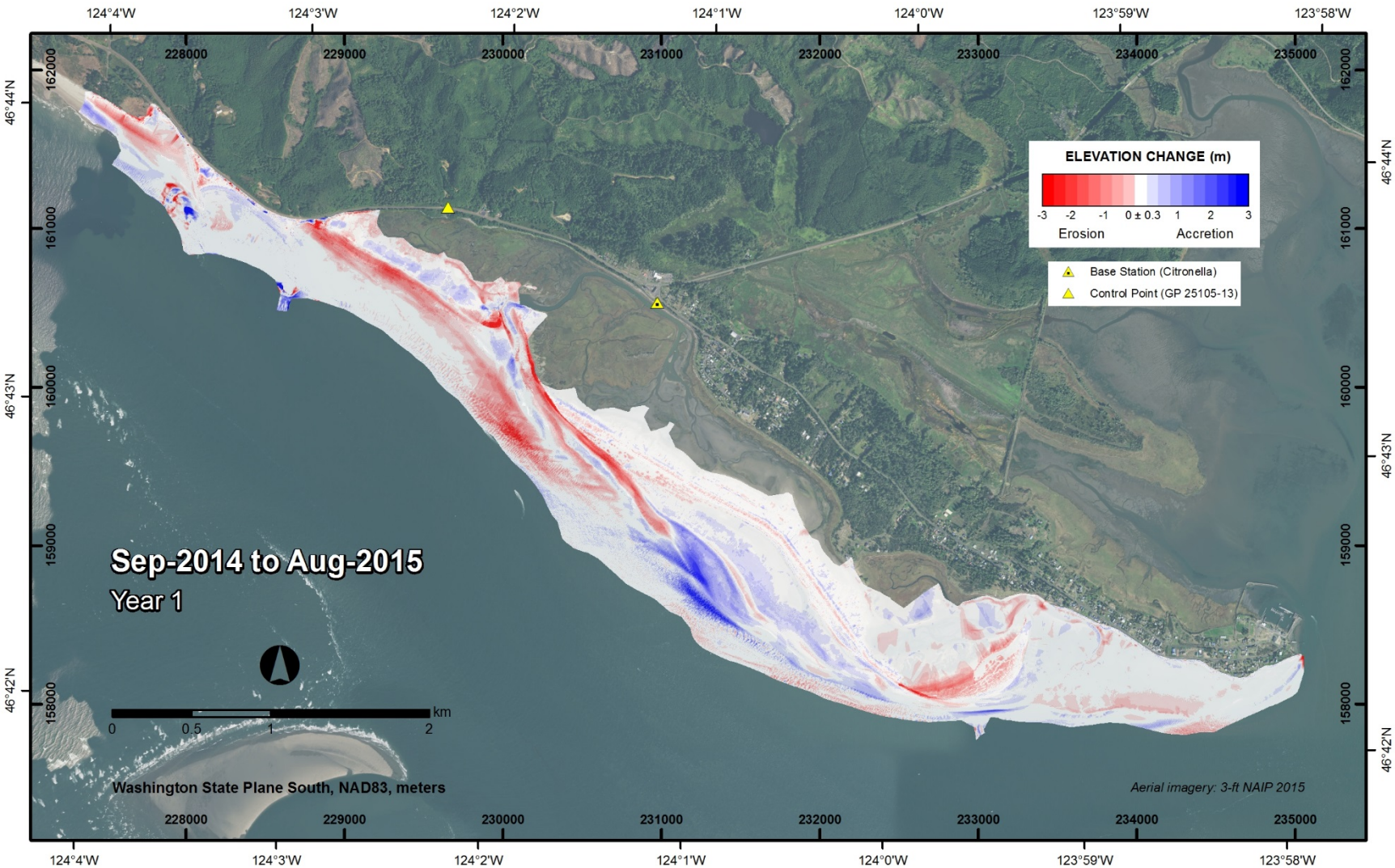

Figure D-5. Annual beach and nearshore change between September 2014 and August 2015 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

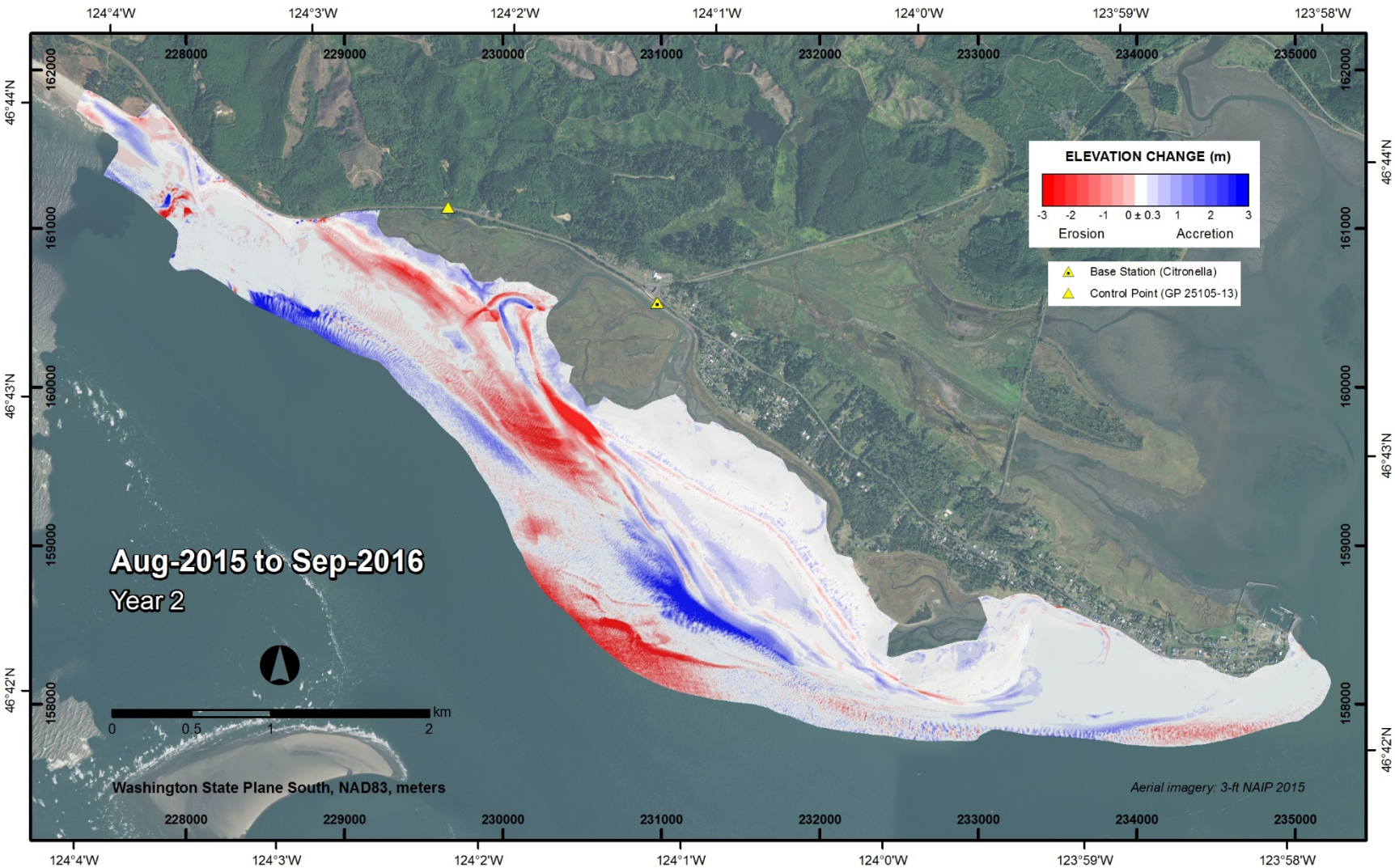

Figure D-6. Annual beach and nearshore change between August 2015 and September 2016 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change

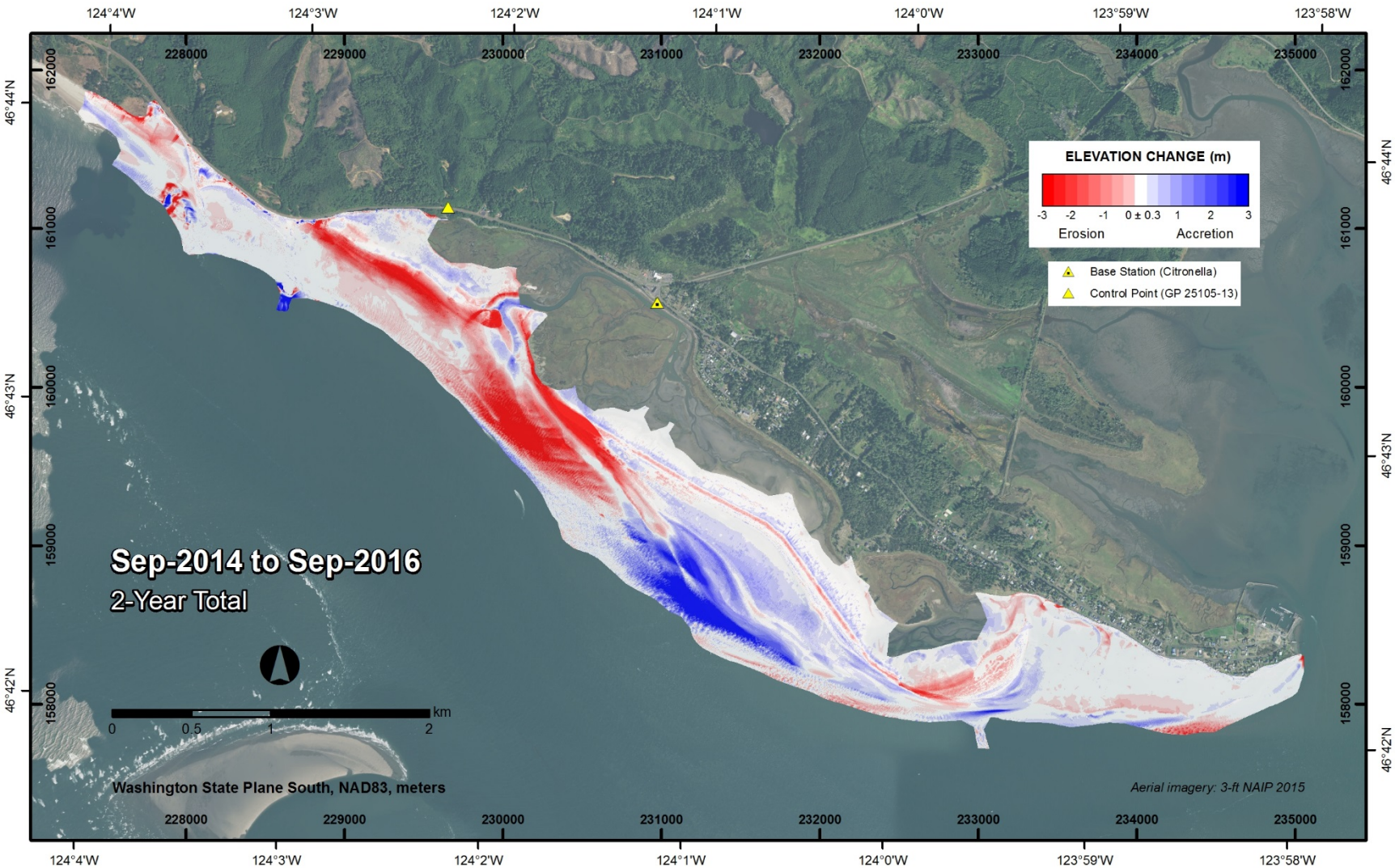

Figure D-7. Total beach and nearshore change between September 2014 and September 2016 for the entire survey area; elevation changes less than ± 30 cm (± 1 ft) are shown in white, indicating no significant change