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Sediment Transport Study: Phase Two

Baseline Observations and Characterization of Sediment Transport Processes for the Reedsport Wave Energy Site

Prepared by
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On behalf of Oregon Wave Energy Trust

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This project was carried out collaboratively by Oregon State University (OSU) and the Oregon Department of Geology and Mineral Industries (DOGAMI) and involved continuation of the beach monitoring program begun in summer 2009 to determine baseline conditions and beach variability at the site of the planned Reedsport wave energy conversion array. In effect this project was phase two of the work documented in the December 2009 OWET report 'Baseline Observations and Modeling for the Reedsport Wave Energy Site' by Ozkan-Haller et al. Core elements of the monitoring program include:

- ARGUS video monitoring of nearshore bar morphodynamics;
- In-situ nearshore bathymetric measurements using a Personal Water Craft (PWC)-based surveying system; and
- Topographic beach and shoreline observations to document the natural variability over seasonal to interannual time scales.

This approach serves two key objectives:

1. Extends the field-based beach monitoring program established in Spring 2009 to document changes to the beach and nearshore bars, and enables comparisons of the measured changes with the natural envelope of variability determined for the Reedsport site and elsewhere. The Argus observing work will yield a series of rectified maps of the seasonal variability of the local shore and sand bar morphology. This should allow characterization of the system for this baseline year.
2. Provide an updated bathymetric survey of the nearshore and offshore zones (to depths of ~25 m MLLW) enabling an improved understanding of the spatial (and vertical) variability of sand movement in those areas.

Motivation and Goals:

Wave energy conversion devices are expected to reduce wave energy in their lee. Multiple devices can create rhythmic wave height variations shoreward of the array of devices that could significantly alter the natural range of beach morphodynamics. The over-arching objective of this study is to understand if these variations cause changes in the surf zone circulation patterns and alter the shoreline configuration. This project aims to extend the field-based beach monitoring program begun in spring 2009 to document changes to the beach and nearshore bars, and enables comparisons of the measured changes with the natural envelope of variability determined for the Reedsport site and elsewhere.

Project Status:

During winter 2010 we continued the beach monitoring program initiated in spring 2009. A second underwater bathymetry survey undertaken in July 2010 resolved significant offshore migration of the outer sandbar. Shoreline and video monitoring have been continued on a bi-weekly (ARGUS) to bi-monthly (GPS beach surveys) basis through the end of August 2010, resolving the seasonal variability of the Reedsport site for the 2009-2010 period.

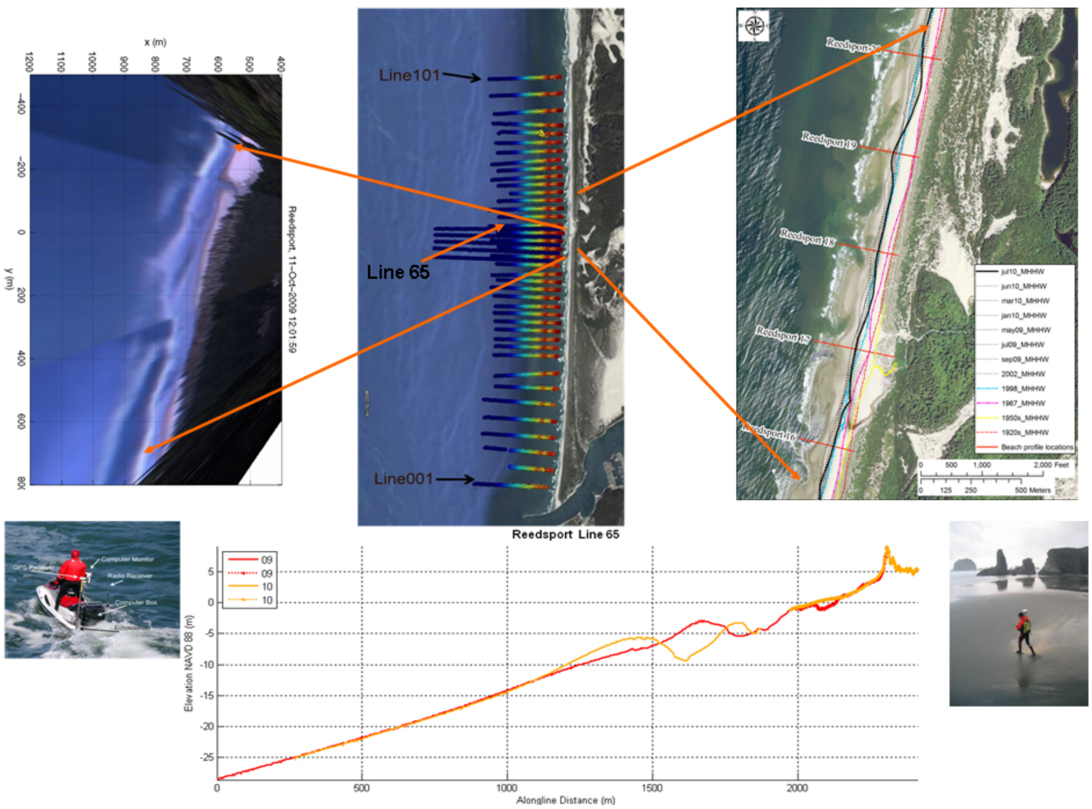

Figure 1. The project involves ARGUS video monitoring of underwater features (upper left), nearshore bathymetric measurements (lower left, upper middle, lower middle, and topographic beach measurements (upper right, lower middle, and lower right).

Overall Findings: Morphology of the Beach

- A multiple submerged bar system exists in the surf zone in this area. The nearshore bathymetry survey in July 2009 indicates a very straight and parallel sub-tidal outer bar approximately 500 m from the shoreline.
- Our second nearshore bathymetric survey revealed significant offshore sandbar migration in the study area, consistent with similar observations elsewhere in the Pacific Northwest.
- The bathymetry survey in summer 2009 indicated the presence of well-resolved mega-ripple features with 20m-length scales and 20cm height and located in 8m water depth. This feature may be indicative of biological activity and was interestingly absent during the 2010 survey.
- The bars observed with the video system through August 2010 appear highly variable with variability out to 1km from the shoreline. The sand bars also display alongshore variability that is more pronounced during mild wave conditions.

- On the dry beach, sand accumulates in the form of a berm at 2-4m elevation sometime after winter conditions have subsided. The berm is then eroded during the subsequent winter.
- Changes in the sand beach envelope of variability (range of vertical and cross-shore profile changes) appear to be generally consistent with observations of beach changes taking place elsewhere on the Oregon coast. Vertical changes identified on the north Umpqua Spit is on the order of 1-1.5 m, which is slightly lower than observations of vertical beach changes on the northern Oregon coast and is probably due to the short period of observations undertaken near Reedsport.
- Shoreline position over the 6 months of data collection changed by as much as 70m. Alongshore variability of the shoreline is also on the order ~100m, with some of the largest changes occurring due to the initial development and eventual expansion of rip embayments along the shore.

Next Steps

This report summarizes the results of 12 months of beach, nearshore, and bathymetric changes at the Reedsport site, providing coastal managers with initial baseline information concerning the morphodynamics of beaches on the north Umpqua Spit. However, to facilitate an improved understanding of the spatial and temporal range of beach and nearshore variability, we recommend continued monitoring of the beaches and bars in order to better refine the normal range of changes taking place on the north Umpqua Spit. This is because:

- The regular observations of shoreline and beach variability have so far only covered approximately a 12-month period. Hence, in its current form the data set is of limited value, in part because it only spans a single winter season.
- Avoiding gaps in the observation record (i.e. as will occur over the next 12 months until OPT installs its single buoy now scheduled for 2011) will ensure a more complete understanding of the background variability at the site. The continuation of these observations is crucial for resolving our understanding of the degree of beach and nearshore variability at multiple time scales, important for differentiating between effects from OPT's WEC array versus the 'normal' range of variability typical of beach morphodynamics on the north Umpqua Spit.
- Once OPT's WEC array is installed, the bathymetry and shoreline observations should still continue so that the effects of the buoy field can be distinguished from background variability at the site.

In the following we report on each component of the study. In particular, Appendices A-C contain reports on the beach and shoreline morphodynamics, bathymetric survey, as well as video observations of the submerged bathymetry and nearshore bar dynamics.

Appendix A

Monitoring Beach and Shoreline Morphodynamics

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Introduction

The wave climate offshore the Pacific Northwest (PNW) coasts of Oregon and Washington have been identified as an ideal environment for the establishment of wave energy devices that can be used to harness the energy potential provided by ocean waves. Since wave energy arrays by definition will remove a portion of the energy of the waves and will create a shadow region of lower wave energy landward of the devices, there remain concerns about the potential effects such devices may have on the morphodynamics of beaches adjacent to wave energy farms.

To understand the potential effects of wave energy arrays on sediment transport processes, a collaborative team of investigators from Oregon State University (OSU) and the Oregon Department of Geology & Mineral Industries (DOGAMI) initiated a field-based monitoring program in May 2009 in order to begin documenting the natural variability of the beach, nearshore and wave climate adjacent to the proposed Ocean Power Technology (OPT) Reedsport wave energy site, located offshore from the north Umpqua Spit. Core elements of the monitoring program included measurements of the waves and currents in the vicinity of the planned wave energy array, numerical modeling of the background wave climate, and nearshore bathymetry and shoreline observations to document the baseline conditions at the project site [*Ozkan-Haller et al.*, 2009]. Phase 1 of the project (funded by the Oregon Wave Energy Trust (OWET)) focused on documenting baseline conditions at the Reedsport OPT site, commenced in May 2009 and concluded on December 31st, 2009. Early in 2010, additional funding was provided by OWET that enabled the period of baseline data collection to be extended over the latter half of the 2009/10 winter and throughout spring and early summer, capturing one full year of beach and nearshore observations.

This report describes and summarizes baseline observations from one component of the observation program focused on monitoring the response of the beach and shorelines along approximately 16 km of the North Umpqua Spit shoreline.

Methodology

Approaches for Monitoring Beaches

Beach profiles that are orientated perpendicular to the shoreline can be surveyed using a variety of approaches, including a simple graduated rod and chain, surveying level and staff, Total Station theodolite and reflective prism, Light Detection and Ranging (LIDAR) airborne altimetry, and Real-Time Kinematic Differential Global Positioning System (RTK-DGPS) technology. Traditional techniques such as leveling instruments and Total Stations are capable of providing accurate representations of the morphology of a beach, but are demanding in terms of time and effort. At the other end of the spectrum, high-resolution topographic surveys of the beach derived from LIDAR are ideal for capturing the 3-dimensional state of the beach, over an extended length of coast within a matter of hours; other forms of LIDAR technology are now being used to measure nearshore bathymetry out to moderate depths, but are dependent on water clarity. However, the LIDAR technology remains expensive and is impractical along small segments of shore, and more importantly, the high costs effectively limits the temporal resolution of the surveys and hence the ability of the end-user to understand short-term changes in the beach morphology [*Bernstein et al.*, 2003].

Within the range of surveying technologies, the application of RTK-DGPS for surveying the morphology of both the sub-aerial and sub-aqueous portions of the beach has effectively become the accepted standard [*Bernstein et al.*, 2003; *Ruggiero et al.*, 2005; *Allan and Hart*, 2007], and has been the surveying technique used in this study. The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 30 satellites and their ground stations, originally developed by the Department of Defense. In its simplest form, GPS can be thought of as triangulation with the GPS satellites acting as reference points, enabling users to calculate their position to within several meters (e.g. off the shelf hand-held units), while survey grade GPS units are capable of providing positional and elevation measurements that are accurate to a centimeter. At least four satellites are needed mathematically to determine an exact position, although more satellites are generally available. The process is complicated since all GPS receivers are subject to error, which can significantly degrade the accuracy of the derived position. These errors include the GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere and multipath effects (where the signals bounce off features and create a poor signal). For example, hand-held autonomous receivers have positional accuracies that are typically less than about 10 m (<~30 ft), but can be improved to less than 5 m (<~15 ft) using the Wide Area Augmentation System (WAAS). This latter system is essentially a form of differential correction that accounts for the above errors, which is then broadcast through one of two geostationary satellites to WAAS enabled GPS receivers.

Greater survey accuracies are achieved with differential GPS (DGPS) using two or more GPS receivers to simultaneously track the same satellites enabling comparisons to be made between two sets of observations. One receiver is typically located over a known reference point and the position of an unknown point is determined relative to that reference point. With the more sophisticated 24-channel dual-frequency RTK-DGPS receivers, positional accuracies can be improved to the sub-centimeter level when operating in static mode and to within a few centimeters when in RTK mode (i.e. as the rover GPS is moved about). In this study we used a Trimble© 24-channel dual-frequency 5700/5800 GPS, which consists of a GPS base station (5700 unit), Zephyr Geodetic antenna, HPB450 radio modem, and 5800 "rover" GPS (*Figure 1*). Trimble reports that the 5700/5800 GPS system have horizontal errors of approximately ±1-cm + 1ppm (parts per million * the baseline length) and ±2-cm in the vertical [*Trimble*, 2005].

To convert a space-based positioning system to a ground-based local grid coordinate system, a precise mathematical transformation is necessary. While some of these adjustments are accomplished by specifying the map projection, datum and geoid model prior to commencing a field survey, an additional transformation is necessary whereby the GPS measurements are tied to known ground control points. This latter step is called a *GPS site calibration*, such that the GPS measurements are calibrated to ground control points with known vertical and horizontal coordinates using a rigorous least-squares adjustments procedure. Performing the calibration is initially undertaken in the field using the Trimble

TSC2 GPS controller and then re-evaluated in the office using Trimble's Geomatics Office software. However, in order to undertake such a transformation, it is necessary to either locate pre-existing monuments used by surveyors or establish new monuments in the project area that can be tied to an existing survey network.

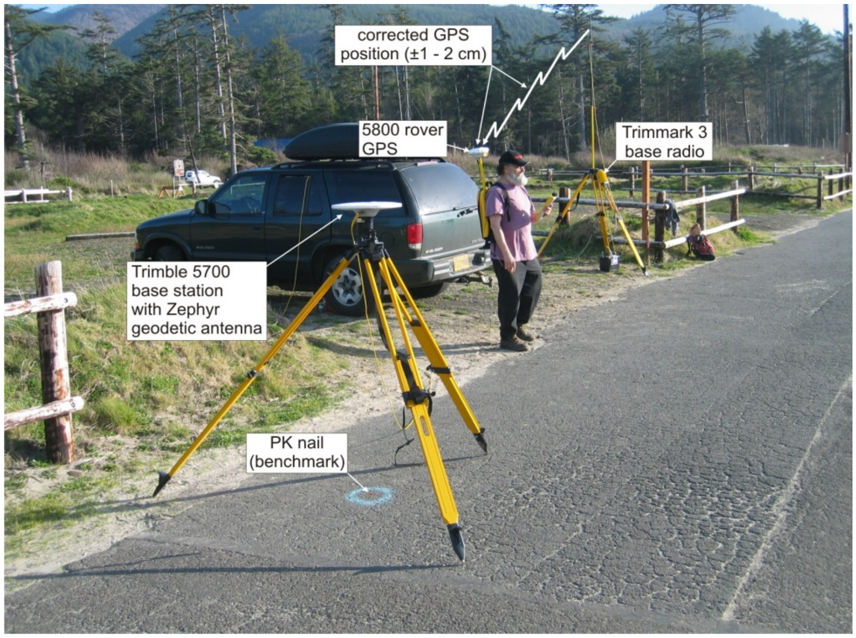

Figure A1. The Trimble 5700 base station antenna located over a known reference point at Cape Lookout State Park. Corrected GPS position and elevation information is then transmitted by a radio modem to the 5800 GPS rover unit.

Survey Benchmarks and GPS Control

In order to establish a dense GPS beach monitoring network, we initially identified the approximate locations of the profile sites used in this study in a Geographical Information System (GIS). A reconnaissance trip was undertaken in late April 2009 with the objectives being:

1. To locate existing survey benchmarks in the vicinity of the field site,
2. Field check potential new survey benchmark locations and install these in the vicinity of the beach and
3. Layout and initiate the first survey of the beach monitoring network.

Figure 2 shows the general layout of the final survey network, which consists of 26 profiles sites spaced approximately 500 m apart and extending from the north Umpqua jetty in the south to Tahkenitch Creek in the north. As can be seen in the figure, three permanently monument survey benchmarks were established by DOGAMI that would serve as GPS control for the beach profile surveys, bathymetry survey[1], and rectification of the ARGUS[2] video imagery. The benchmarks (OWET 1-3) were installed on April 26th, 2009 and were constructed by first digging 1 m deep (10" diameter) holes, into which aluminum sectional

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[1] *Surveys of the bathymetry were undertaken on two separate occasions (6-9 July 2009 and 13-17 July 2010) by Dr. Peter Ruggiero, Department of Geosciences, Oregon State University.*
[2] *ARGUS video images were collected by Dr. Rob Holman, College of Oceanic and Atmospheric Sciences, Oregon State University.*

rods were inserted and hammered to additional depths of approximately 4 – 8 m (12 - 24 ft, *Figure 3A and 3B*). The rods were then capped with a 2½" aluminum cap (Oregon Department of Geology and Mineral Industries stamping on top), and concreted in place (*Figure 3C*).

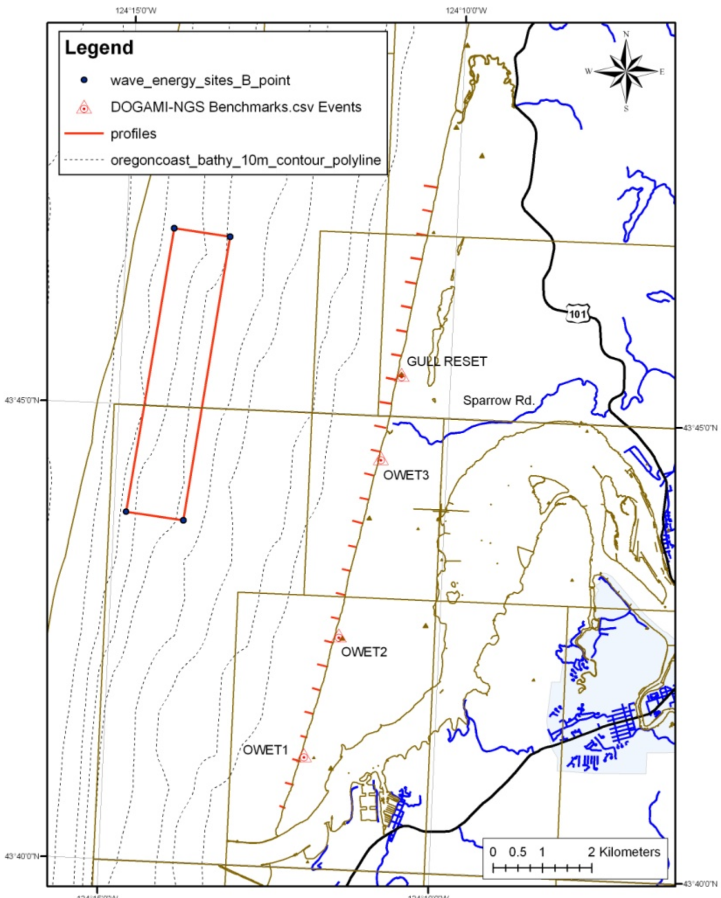

Figure A2. Map shows the location of the study site, beach monitoring network and DOGAMI survey monuments.

Survey control along the North Umpqua Spit shore was initially established by occupying two Watershed Sciences benchmarks[3] and one National Geodetic Survey monument. Additional survey control and field checking was provided using the Online Positioning User Service (OPUS) maintained by the NGS (http://www.ngs.noaa.gov/OPUS/). OPUS provides a simplified way to access high-accuracy National Spatial Reference System (NSRS) coordinates using a network of continuously operating GPS reference stations (CORS, http://www.ngs.noaa.gov/CORS/). In order to use OPUS, static GPS measurements

[3] As part of calibrating the collection of Light Detection and Ranging (Lidar) data on the southern Oregon coast in 2008, Watershed Sciences established numerous survey monuments on the south coast. Coordinates assigned to these monuments were derived from multi-hour occupations of the monuments and were processed using the Online Positioning User Service (OPUS) maintained by the NGS. (http://www.ngs.noaa.gov/OPUS/). In many cases, the same benchmarks were observed multiple times and the horizontal and vertical coordinates were continually updated.

are typically made using a fixed height tripod for periods of 2 hours or greater (*Figure 3D*). OPUS returns a solution report with positional accuracy confidence intervals for adjusted coordinates and elevations for the observed point. In all cases we used the Oregon State Plane coordinate system, southern zone (meters), while the vertical datum is relative to the North American Vertical Datum of 1988 (NAVD88).

Figure A3. A) Installation of the survey benchmarks involved first digging a 1 m (3 ft) deep (10” diameter) hole, and B) hammering sectional aluminum rods to depths of 4 – 8 m (12-24 ft), C) capping the rods and concreting in place. D) GPS observation of the OWET 1 survey monument. E) A site calibration is performed on the OWET 2 benchmark using the TSC2 controller.

For the initial Reedsport survey, the 5700 GPS base station was located on the OWET1 monument (*Figure 2*) using a 2.0 m fixed height tripod. Survey control was provided by undertaking 180 GPS epoch measurements (~ 3 minutes of measurement per calibration site) using the three control sites identified in *Table 1*, enabling us to perform a GPS site calibration which brought the survey into a local coordinate system (*Figure 3E*). This step is critical in order to eliminate various survey errors that may be compounded by factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. In addition, because the 5700 GPS base station was located on each of the OWET (1-3) benchmarks for several hours (typically 2- 6 hours, over multiple days), the measured GPS data from the base station and rover GPS were able to be submitted to OPUS for online processing. *Table 2* shows the final derived coordinates assigned to the three benchmarks and their relative uncertainty based on multiple occupations. It is these final coordinates that are used to perform a GPS site calibration each time a field survey of the beach and shoreline is performed.

Table A1 **Survey benchmarks used to initially calibrate GPS surveys of the beach near Reedsport. Asterisk signifies the location of the GPS base station during each respective survey. NGS denotes National Geodetic survey monument, WS denotes Watershed Sciences monument.**

Name	Northing (m)	Easting (m)	Elevation (m)
6NCM2 - WS	232574.125	1209536.395	5.498
6NCM1 - WS	257724.630	1215506.527	66.410
SOOS - NGS	252644.942	1209669.065	5.500

Table A2 **Final coordinates and elevations derived for the three DOGAMI OWET benchmarks established on the north Umpqua Spit. The variance reflects the standard deviation derived from multiple occupations.**

	OWET 1 (m)	variance (± m)	OWET 2	variance (± m)	OWET 3	variance (± m)
Northing	231039.181	*0.004*	233473.260	*0.003*	1203406.530	*0.003*
Easting	1201842.604	*0.014*	1202548.920	*0.004*	237078.110	*0.004*
Elevation	8.416	*0.011*	11.629	*0.005*	9.184	*0.039*

Beach Monitoring

Having performed a GPS site calibration, cross-shore beach profiles are surveyed with the 5800 GPS rover unit mounted on a backpack, worn by a surveyor (*Figure 4*). This was undertaken during periods of low tide, enabling more of the beach to be surveyed. The approach was to generally walk from the landward edge of the primary dune or bluff edge, down the beach face and out into the ocean to approximately wading depth. A straight line, perpendicular to the shore was achieved by navigating along a pre-determined line displayed on a hand-held Trimble TSC2 computer controller, connected to the 5800 rover. The computer shows the position of the operator relative to the survey line and indicates the deviation of the GPS operator from the line. The horizontal variability during the survey is generally minor, being typically less than about ±0.25 m either side of the line, which results in negligible vertical uncertainties due to the relatively uniform nature of beaches characteristic of much of the Oregon coast [*Ruggiero et al.*, 2005]. Based on our previous research at numerous sites along the Oregon coast , this method of surveying can reliably detect elevation changes on the order of 4-5 cm, that is well below normal seasonal changes in beach elevation, which typically varies by 1 - 2 m (3 - 6ft) [*Allan and Hart*, 2007; 2008].

Table 3 indicates the dates when field surveys were performed. To supplement the GPS beach survey data and to extend the time series, Light Detection and Ranging (Lidar) data measured by the USGS/NASA/NOAA in April 1998 (post 1997-98 El Niño) and in 2002 (post extreme 1998-99 winter season) have been also analyzed, along with more recent Lidar data collected by Watershed Sciences in summer 2008 for DOGAMI. Each of these was separately processed, gridded and analyzed, in a Geographical Information System (GIS) (e.g. ArcGIS and MapInfo) enabling their integration into the beach profile dataset.

Figure A4. A) Laura Stimely from DOGAMI surveys the top of a dune erosion scarp on the north Umpqua Spit. B) Beach surveys are extended out across the surf zone to wading depth.

Table A3 **Dates when field surveys were undertaken on the north Umpqua Spit.**

Survey #	Beach Profile Survey Date
1	27 - 28 April 2009
2	6 - 9 July 2009
3	17 - 19 September 2009
4	17 - 18 November 2009
5	25-26 January 2010
6	4-5 March 2010
7	10-11 June 2010

Analysis of the beach survey data involved a number of stages. The data was first imported into MATLAB[4] using a customized script. A least-square linear regression was then fit to the profile data. The purpose of this script is to examine the reduced data and eliminate those data point residuals that exceed a ±0.5 m threshold (i.e. the outliers) either side of the predetermined profile line. The data is then exported into an EXCEL database for archiving purposes. A second MATLAB script takes the EXCEL profile database and plots the survey data (relative to the earlier surveys) and outputs the generated figure as a Portable Network Graphics file (*Figures 5 and 6*).

Figures 5 and 6 provide two representative examples of the range of beach profile changes measured at the Reedsport 15 and 8 profile sites. Both figures incorporate results from the Lidar analyses flown in 1998 and 2002 by the USGS/NASA/NOAA and in 2008 by DOGAMI. In both cases, the *light grey* shading highlights the maximum and minimum beach changes (excluding the Lidar data, which exhibits a lot of noise at lower beach elevations, which probably reflect wave swash on the lower beachface), while the *dark grey* shading indicates the typical range of variability determined as ± 1 standard deviation about the mean profile. As more beach change information is collected, the dark grey shading will be constrained further and will provide an indication of the normal expected ranges of response. As can be seen in *Figure 5*, the seasonal variability of the beach is on the order of 1 – 2 m, depending on where you are on the beach. Higher on the beach face between the 2-4 m elevation contours, a berm can be observed in *Figure 5* that developed in late summer 2009 and reflects the normal post winter aggradation of the beach. Of interest, our most recent survey in July 2010 indicated that many of the beach profile sites had beach elevations that were typically at the lower end of the normal range (e.g. *Figure 5*), and may be a function of the unusually higher wave heights observed in the 2010 spring and early summer.

[4] Computer programming languages.

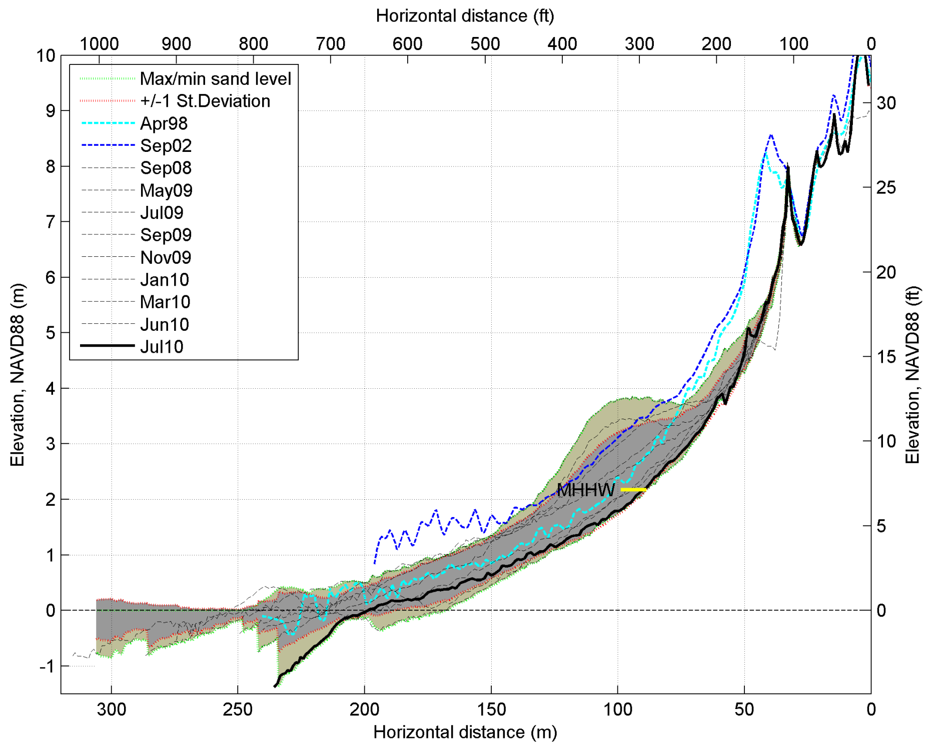

Figure A5. Example of beach profile changes measured at the Reedsport 15 beach profile site.

The Reedsport 8 profile site indicates a similar seasonal range of beach elevations, which varies from 1 – 2 m (*Figure 6*). However, it can be seen that our most recent survey undertaken in July 2010 was well below the normal range, which can be attributed to the development of a large rip embayment that formed in spring 2010 that produced localized scouring of the beach face causing the beach foreshore elevation to be significantly lowered (*Figure 6*). Furthermore, over a period of a few months the rip embayment began to migrate northward, widening slightly adjacent to the Reedsport 8 profile site. This is shown in *Figure 7*, which highlights the change in the mean shoreline position between the two surveys. Based on this last figure, the alongshore extent of the embayment was on the order of 720 m in length.

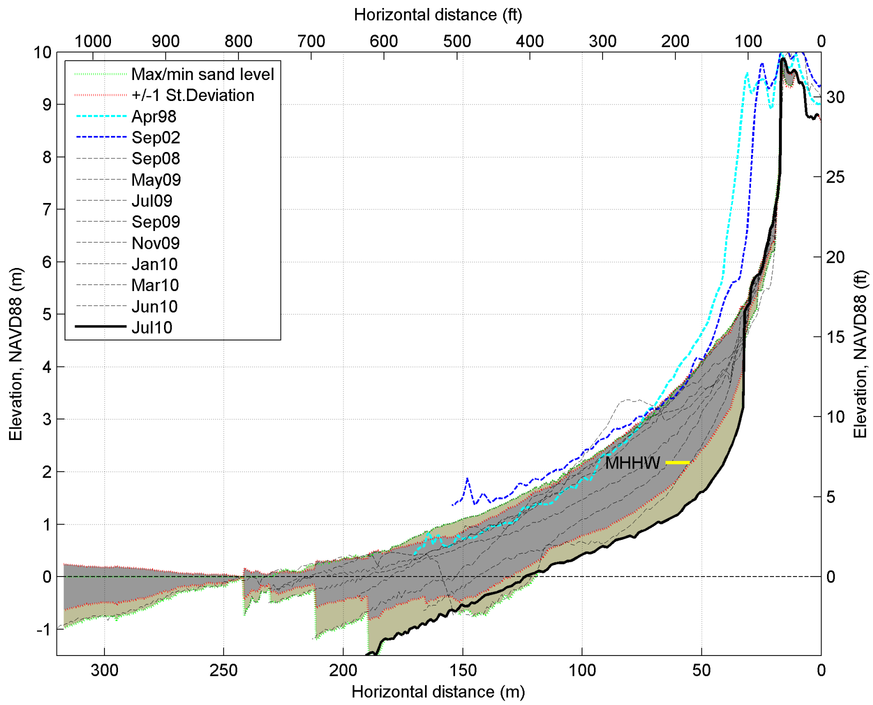

Figure A6. Example of beach profile changes measured at the Reedsport 8 beach profile site.

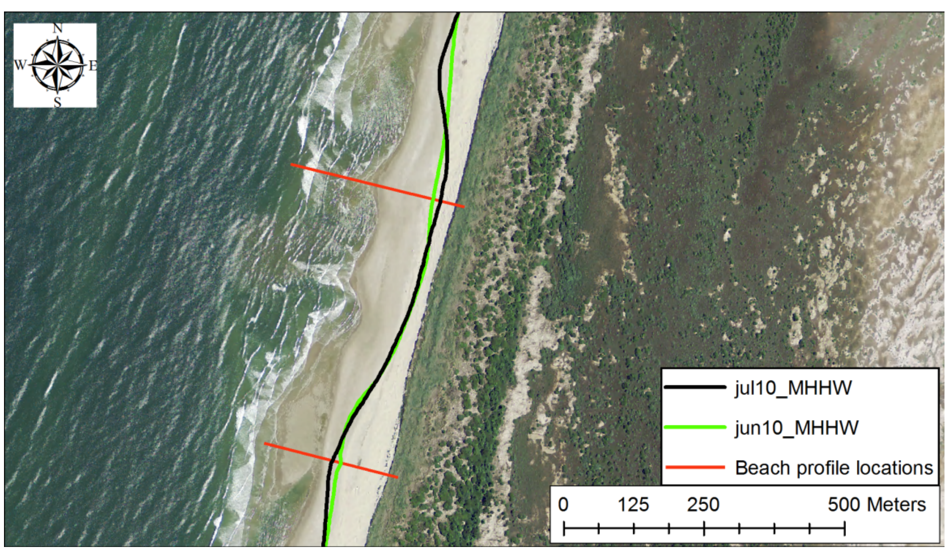

Figure A7. A rip embayment that formed adjacent to the Reedsport 8 profile site.

Finally, the complete suite of beach profile measurements have been uploaded to the Oregon Beach and Shoreline Mapping and Analysis (OBSMAP) website maintained by DOGAMI for easy viewing and can be accessed using the following link: http://www.oregongeology.org/sub/Nanoos1/Beach%20profiles/OWET_Cell.htm.

Shoreline Changes

While beach profiles provide important information about the cross-shore and to some degree the longshore response of the beach as a result of variations in the incident wave energy, nearshore currents, tides, and sediment supply, it is also necessary to understand the alongshore variability in shoreline response that may reflect the development of large morphodynamic features such as rip embayments (e.g. *Figure 6*), beach cusps, and the alongshore transport of sediment. To complement the beach profile surveys initiated along the Umpqua Spit, surveys of a tidal datum-based shoreline were also undertaken. For the purposes of this study we used the Mean Higher High Water tidal datum measured at the Charleston tide gauge as a shoreline proxy and is located at an elevation of 2.17 m NAVD88. Measurement of the shoreline was undertaken by mounting the rover 5800 GPS on to the side of a vehicle and driving two lines above and below the MHHW contour in order to bracket the shoreline. The GPS data were then gridded in GIS in order to extract the 2.17 m shoreline proxy.

Besides the measurement of contemporary datum-based shorelines, historical shoreline positions were also compiled in a GIS. Early National Ocean Service (NOS) surveyors originally mapped these latter datasets for select periods on the Oregon coast including the 1920s, 1950s and 1970s. In addition, Ruggiero et al. (2007) is presently completing a study of long-term trends of coastal change for the Pacific Northwest coasts of Oregon and Washington. In this latter study, Ruggiero and colleagues have digitally orthorectify a suite of aerial photographs flown in 1967 along the Oregon coast, ultimately deriving a 1967 shoreline for the entire coast.

Figure 8 provides an example of the complete suite of shoreline positions determined for the North Umpqua spit and immediately adjacent to the north jetty. The black dashed lines indicate the most recent measurements of the mean shoreline position determined by GPS (multiple measurements undertaken between May 2009 and June 2010) and from Lidar analyses (2002 and 2008). Included in the figures is the position of the shoreline in 1998, immediately following the major 1997-98 El Niño (cyan-colored line), and the position of the shore in 1967 (Magenta), 1970s era (orange) and 1920s era (red). Several important shoreline characteristics can be identified from these data that are worth noting:

1) The contemporary beach (i.e. shoreline changes during the past decade) exhibits considerable cross-shore and alongshore variability in the shoreline positions, which range from horizontal excursions as low as 10 m to as much as 100 m.
2) The large shoreline excursion identified at the Reedsport 2 beach profile site in 1998 (*Figure 8*) can be attributed to the development of a rip embayment that formed in late winter/early spring 1998. This latter feature is analogous to the rip embayment that formed between the Reedsport 7 and 8 profile sites shown in *Figure 7*.
3) The 1920s era shoreline was located some 150 to 300 m further west of its present position. This latter result reflects the effects of jetty construction at the mouth of the Umpqua River.

Shoreline changes due to jetty construction at the mouth of the Umpqua River have clearly had the most significant effect on shoreline variability over the past 100 years. *Figure 9* presents a summary of these changes for selected periods and is based on the analyses of *Lizarraga-Arciniega and Komar* [1975]. The north jetty was the first to be constructed and was built between 1923 and 1930. *Figure 9A* indicates the pre-jetty shorelines in 1903 and 1916. Following jetty construction, the shoreline rapidly advanced in order to produce a straight shoreline essentially parallel to the prevailing wave climate such that the beach would in time begin to again experience a zero net sand drift. To the south, the uncontrolled shoreline fluctuated widely. Construction of the south jetty was initiated in 1933, *Figure 9B*, and immediately resulted in sand building up to its south, while the shoreline within the mouth began to recede landward. To the north, the shoreline continued to prograde seaward, albeit at a slower pace. To counteract the erosion between the jetties, the US Army Corps of Engineers constructed a middle jetty, *Figure 9C*, which immediately resolved the erosion problem. Over time, the shorelines to the north and south of the jetties reached a new equilibrium, *Figure 9D*, such that they now fluctuate in response to the prevailing wave climate, variations in the storm tracks and change in ocean water levels.

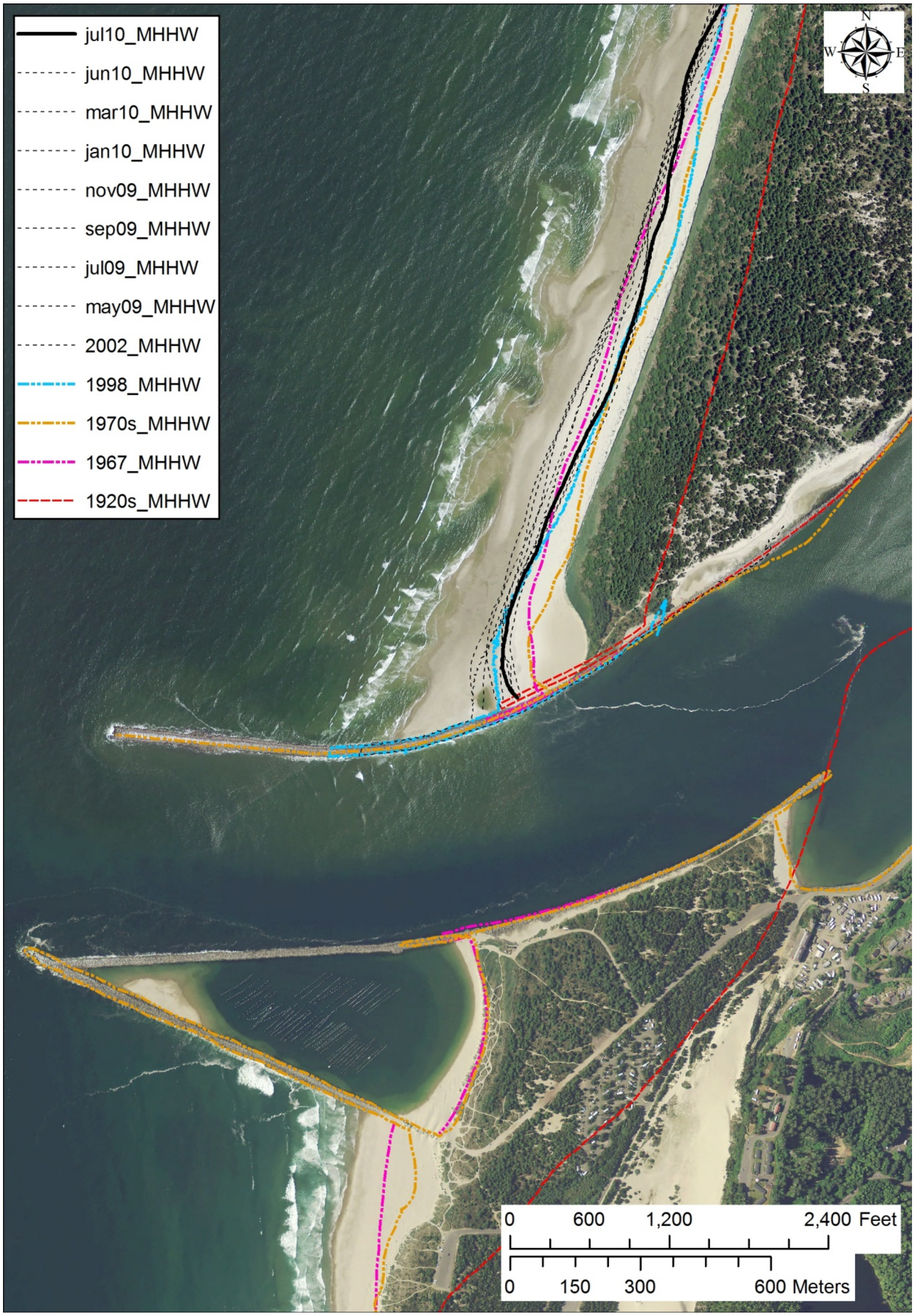

Figure A8. Historical and contemporary shoreline changes derived from multiple data sources including NOS Topographic "T" sheets, Lidar data flown in 1998, 2002 and 2008, and RTK-DGPS surveys of a tidal datum-based shoreline.

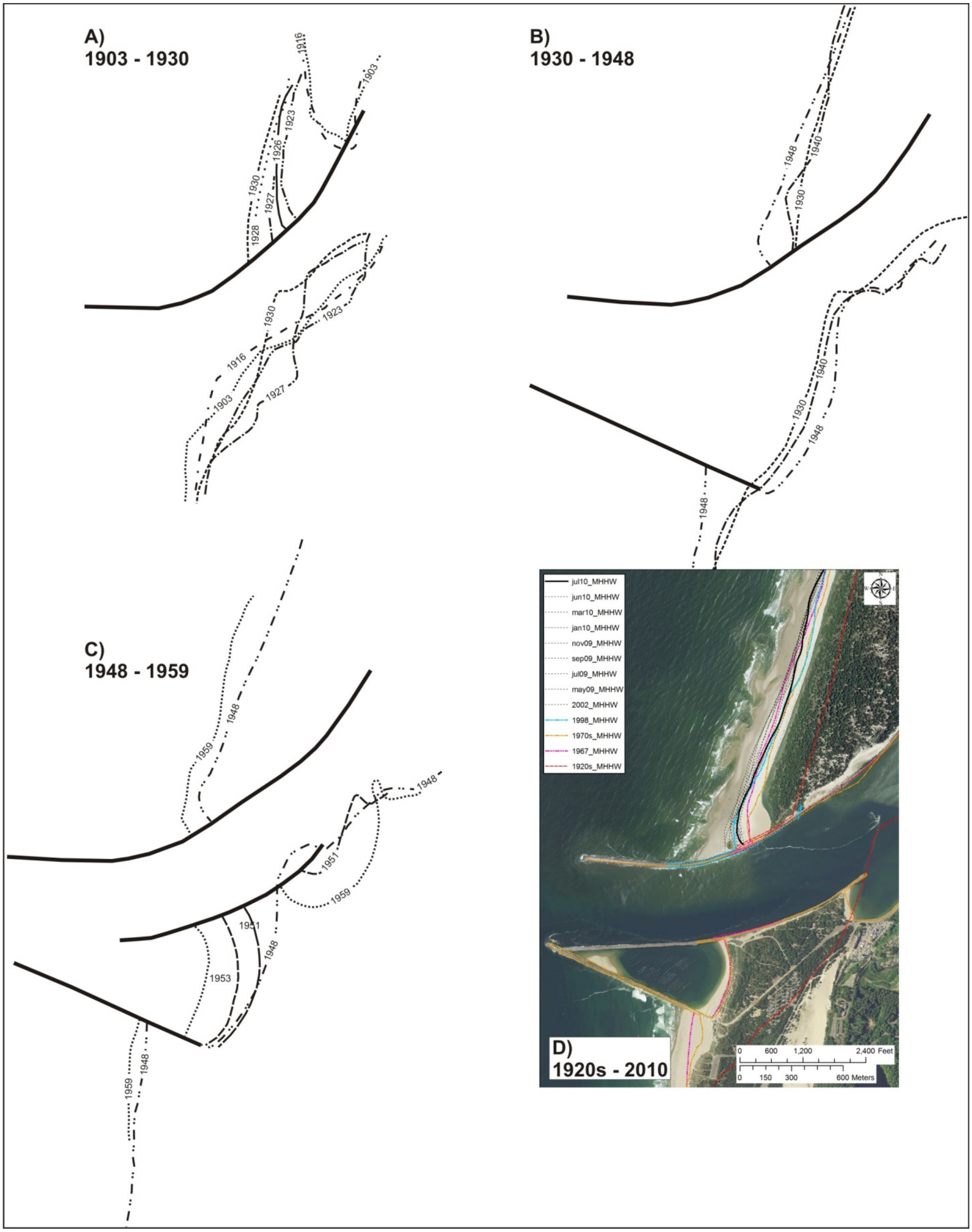

Figure A9. Compilation of shoreline changes due to jetty construction on the Umpqua River (After Lizarraga-Arciniega and Komar (1975).

Finally, *Figure 10* presents a synthesis of recent shoreline changes and has been determined from all the beach profile data. The top plot in *Figure 10* shows the response of the 6 m (18 ft) contour over the past decade and provides a measure of the response of the beach to ocean storms, while the lower plot provides a measure of the normal seasonal range of variability determined lower down the beach face at the 3 m (9 ft) contour elevation. In all cases, we have used the 1998 shoreline as our baseline from which all subsequent changes are compared against. In *Figure 10* top, the green dots denote the position of the dune face as of July 2010, while the blue dots indicate the position of the dune in 2002. As can be seen in the top plot, the southern profile sites (particularly profiles 3-9) have experienced significant erosion over the past decade, with the dune face having eroded landward by some 20-30 m (60 – 100 ft); this response is not surprising and is consistent with observations undertaken elsewhere on the Oregon coast [*Allan and Komar*, 2002; *Allan et al.*, 2003; *Allan et al.*, 2009] . Only three of the profile transects indicate some nominal evidence of accretion (profiles 11, 21, and 22).

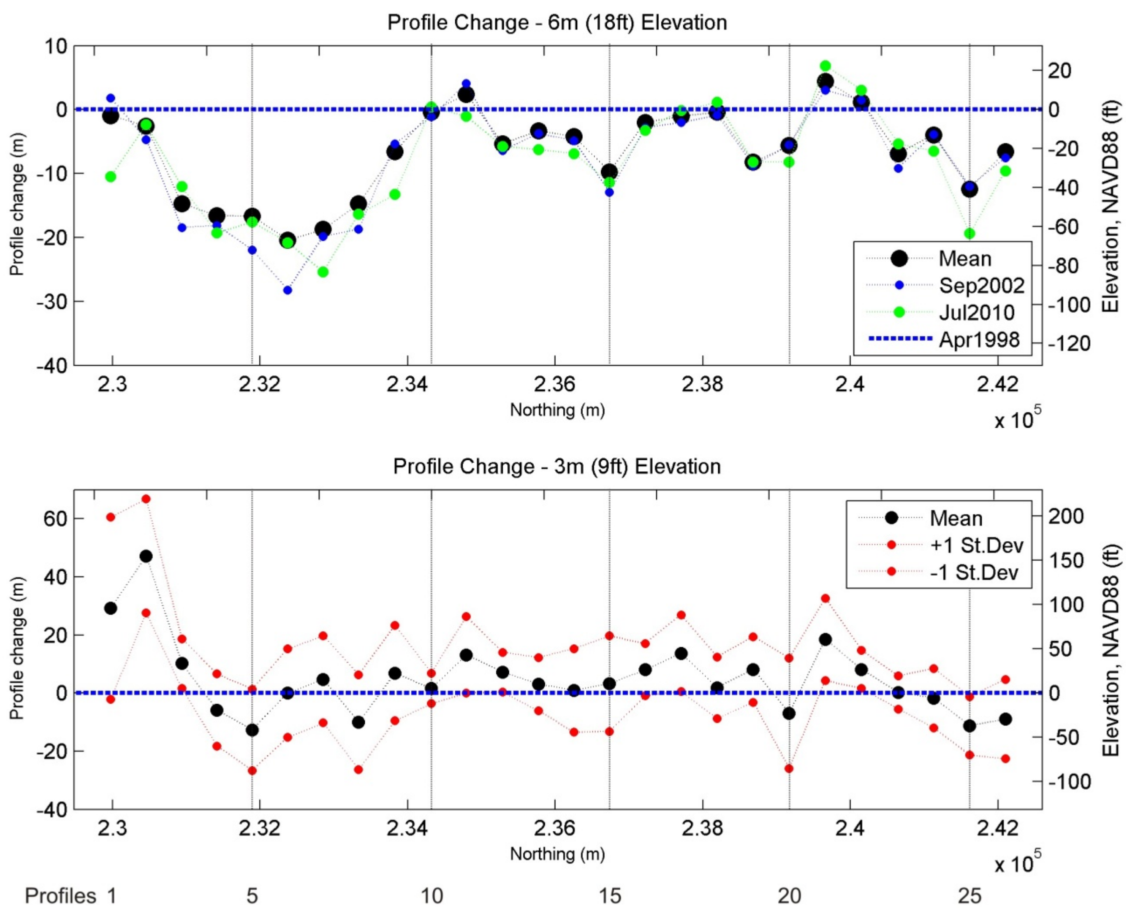

Figure A10. Alongshore response in the 6 m (18 ft) and 3 m (9 ft) contour elevations, highlighting recent storm effects (upper plot) and the typical range in shoreline response (lower plot).

The bottom plot in *Figure 10* highlights the range in shoreline response caused largely by the seasonal shift from summer wave conditions to winter conditions. Based on these data (including the previously flown Lidar data), the mean seasonal shoreline excursion for the North Umpqua Spit is 26 m (85 ft), with a standard deviation of ±10.8 m (35.4 ft). Thus the typical seasonal range of beach response varies from as little 15.2 m (50 ft) to as much as 36.8 m (120.7 ft). These results will be refined further as additional data is collected in subsequent years.

Summary

In April 2009, DOGAMI staff installed a beach monitoring program to assist with characterizing the baseline level of beach variability along the north Umpqua Spit and especially landward of the proposed Reedsport wave energy array. Over the past 12 months, DOGAMI has collected a total of 208 beach profile surveys along the spit and derived multiple GPS shorelines as well as having assimilated historical shorelines from early NOS Topographic “T” sheets. In addition, DOGAMI staff has assisted colleagues at OSU by providing survey control for the collection of nearshore bathymetry and ARGUS video images of the nearshore. Over time as more data is collected and synthesized, an improved understanding of the natural level of beach and shoreline morphodynamics will be gained, proving researchers with the necessary information to better characterize any potential future effects to the beach system in response to the installation of wave energy arrays.

Appendix B

2010 Nearshore Bathymetric Data Collection at Reedsport, OR

Peter Ruggiero and Erica Harris

Oregon State University

Photo by Andrew Stevens

Between the dates of 14-17 July 2010 Oregon State University performed a nearshore bathymetric survey along the beaches immediately north of the Winchester Bay North Jetty using the Coastal Profiling System (high-speed maneuverable personal water-craft (PWC) equipped with an echo-sounder and Global Positioning System, see Figure B1). The primary goals of this work were to assess baseline nearshore morphological conditions along the study site and to assess annual nearshore bathymetric changes. This is the second year of surveys conducted in this area with the first data collected between the dates of 6-10 July 2009.

Our field team consisted of Dr. Peter Ruggiero, Justin Brodersen, Erica Harris, Jeremy Mull, Heather Baron, and Jeff Wood (Table B1). The survey consisted of 45 cross-shore transects extending from between 2 to 4 km offshore to approximately 1-2 m water depth in the surf zone. Topographic data was collected synoptically with the bathymetry data by Jon Allan of DOGAMI to enable a complete mapping of the nearshore planform.

Table B1. Reedsport nearshore bathymetry survey participants and their affiliations. The survey was conducted between 14 and 17 July, 2010.

Participant	Responsibility	Affiliation
Peter Ruggiero	Principal Investigator	Oregon State University
Justin Brodersen	Faculty Research Assistant	Oregon State University
Erica Harris	Graduate Research Assistant	Oregon State University
Jeremy Mull	Graduate Research Assistant	Oregon State University
Heather Baron	Graduate Research Assistant	Oregon State University
Jeff Wood	Undergraduate Research Assistant	Oregon State University

Field Equipment and Data Quality

The Coastal Profiling System (CPS), mounted on a Personal Watercraft (PWC), consists of a single beam echo sounder, GPS receiver and antenna and an onboard computer (Figure 1). This system is capable of measuring water depths from approximately 0.5*m* to well over 50*m*. The survey-grade GPS equipment used in this project have manufacturer-reported RMS accuracies of approximately ±3*cm* + 2ppm of baseline length (typically 10*km* or less) in the horizontal and approximately ±5*cm* + 2ppm in the vertical while operating in Real Time Kinematic surveying mode. These reported accuracies are, however, additionally subject to multi-path, satellite obstructions, poor satellite geometry and atmospheric conditions that can combine to cause a vertical GPS drift that can be as much as 10*cm*.

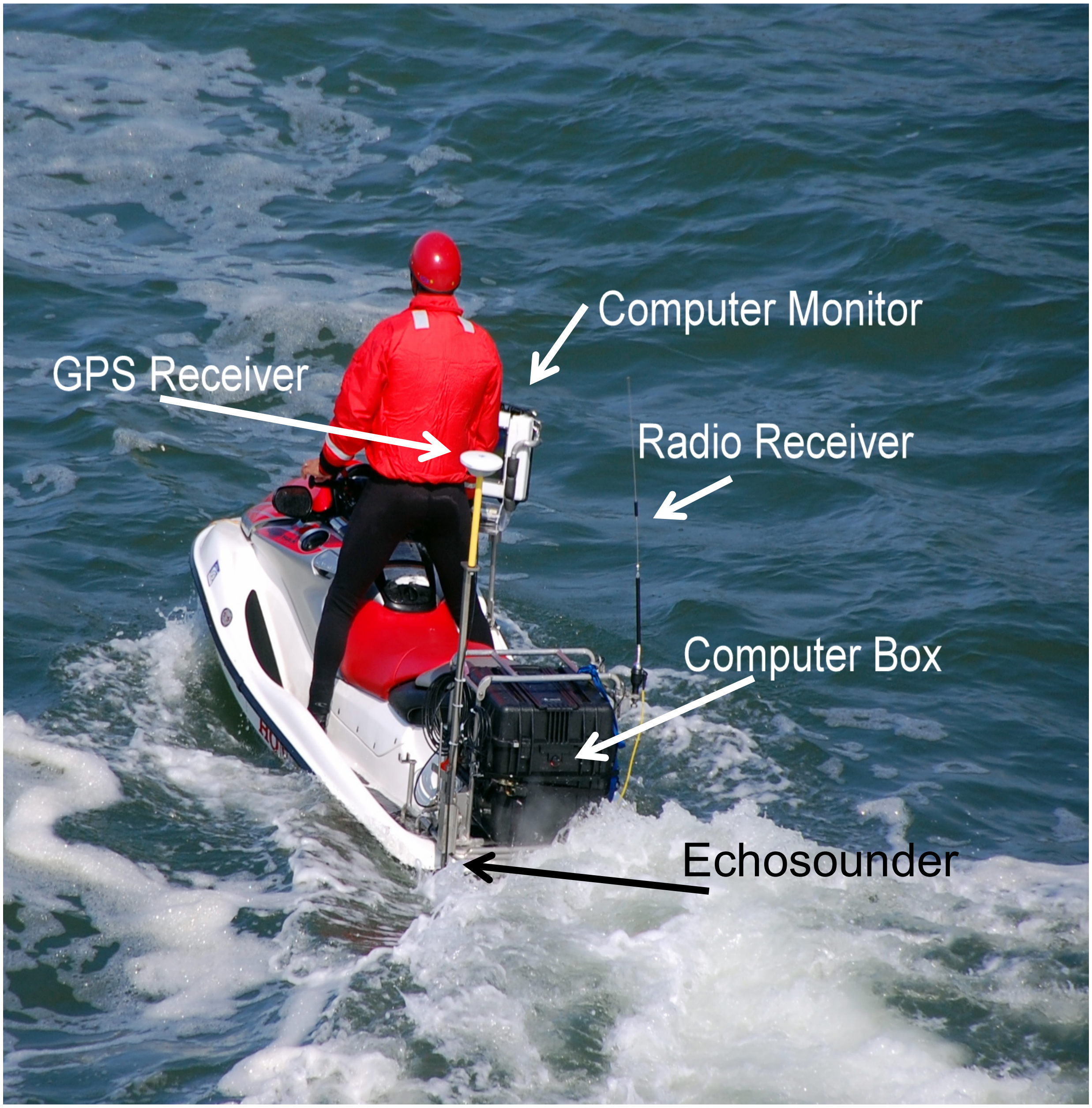

Figure B1. Data acquisition boat and onboard equipment.

While the horizontal uncertainty of individual data points is approximately 0.05*m*, the CPS operators cannot stay "on line," in waves and currents, to this level of accuracy. Typically, mean offsets are less than 2.0*m* from the preprogrammed track lines and maximum offsets along the approximately 2*km* long transects are typically less than 10.0*m*. While repeatability tests and merges with topographic data collected with an all-terrain survey vehicle or a backpack suggest sub-decimeter vertical accuracy, a conservative estimate of the total vertical uncertainty for these nearshore bathymetry measurements is approximately 0.15*m*. For more information regarding equipment, field techniques, and data quality please refer to Ruggiero et al., 2005 and Ruggiero et al., 2007.

Data Processing and Archiving

Our survey data was collected in the horizontal datum Oregon State Plane South, NAD83 (m) and the vertical datum NAVD88 (m) as referenced to a local geodetic control network setup by Jon Allan of DOGAMI. Data processing was carried out using the Matlab script *transectViewer.m* developed by Andrew Stevens from the US Geological Survey in coordination with Peter Ruggiero of OSU. This code loads and displays the raw data files and allows the user to navigate through the data and perform appropriate filtering and smoothing. Obvious bad data due to echosounder dropouts or poor returns are easily eliminated from the data record. Various smoothing operations can be applied to eliminate scales of morphological variability below which the user is not interested. Due to the high quality of the raw data in the Reedsport survey only very moderate smoothing was performed (10 point median average for both 2009 and 2010 datasets, Figure B2).

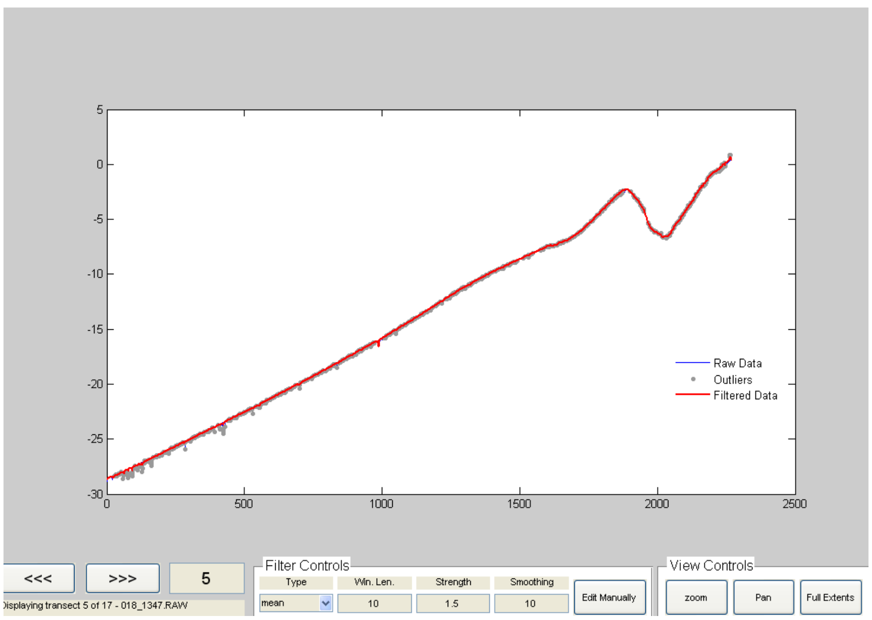

Figure B2. Example profile collected off the coast of Reedsport displayed in transectViewer.

Data Coverage

The surveyed area stretches approximately 13.7*km* alongshore with cross-shore transects extending ~2 *km* offshore (Figure B3). Five lines (# 56, 58, 60, 62, 64) had extended coverage to a distance of 4*km* offshore.

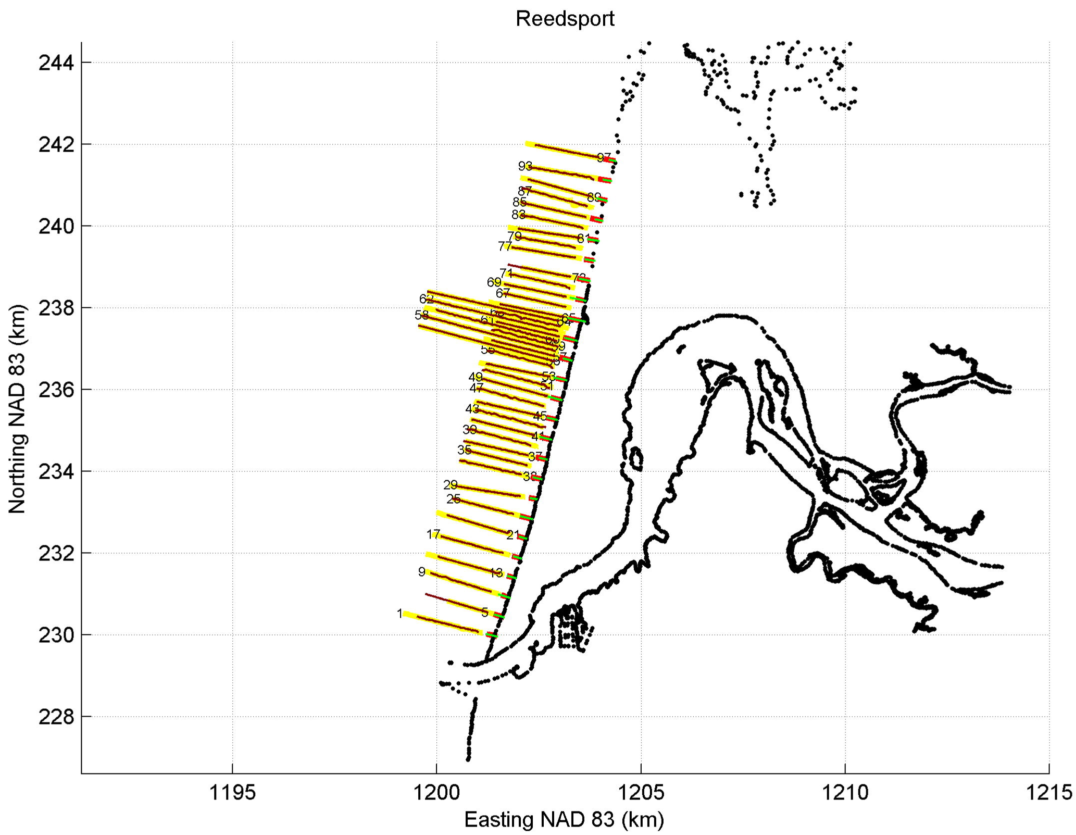

Figure B3. Collected bathymetry transects off the coast of Reedsport, yellow from 2009 and red from 2010.

Reedsport Nearshore Bathymetry
Figure B4 shows a typical cross-shore profile that was collected by both of OSU's survey vessels during the 2010 survey. The agreement between the two lines demonstrates the repeatability of the survey techniques employed in this project.

Figure B5 shows three typical nearshore bathymetric profiles along the study site. The area is characterized by a large subtidal outer sandbar approximately 2 to 3 meters in height and a more subdued subtidal middle sandbar. Profiles that the bathymetry transects overlapped with the topographic transects also reveal low amplitude intertidal inner bars (Figure B5). In 2009 the subtidal outer sandbar crest was typically in approximately 2 to 3 m of water (NAVD88) and about 400 to 500 meters from the shoreline (~3m contour) while the landward trough was in approximately 5 to 6 m of water. Between summers 2009 and 2010 significant offshore sandbar migration occurred and the outer bar in July 2010 was in about 5 to 6 m of water (NAVD88) about 700 to 800 from the shoreline.

Figures B6 and B7 are gridded surfaces of the 2009 and 2010 surveys and the associated difference map. These figures illustrate that primary morphological changes that occurred between 2009 and 2010 was the offshore migration of the linear outer sandbar.

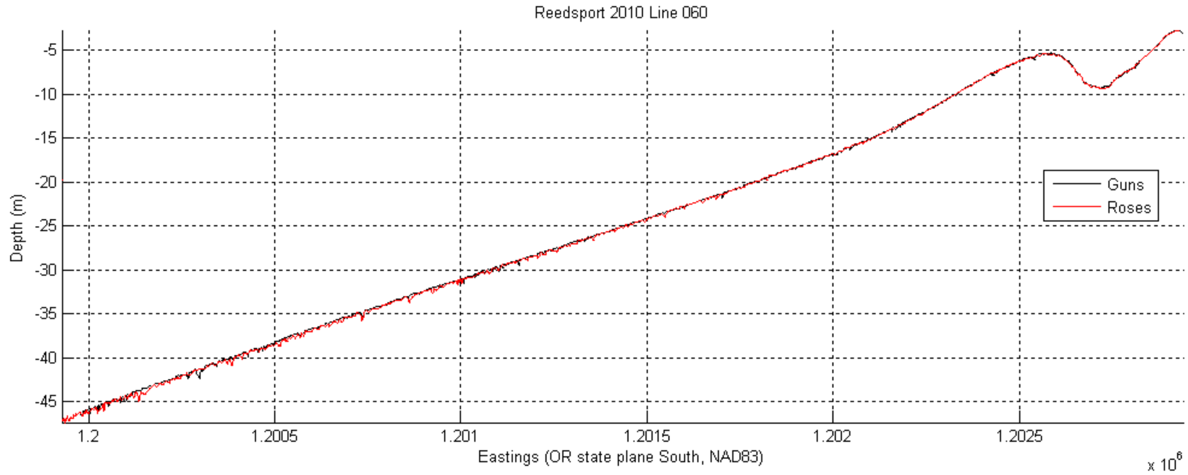

Figure B4. Example cross-shore transects show repeatability between 2 survey vessels, SV/Guns and SV/Roses.

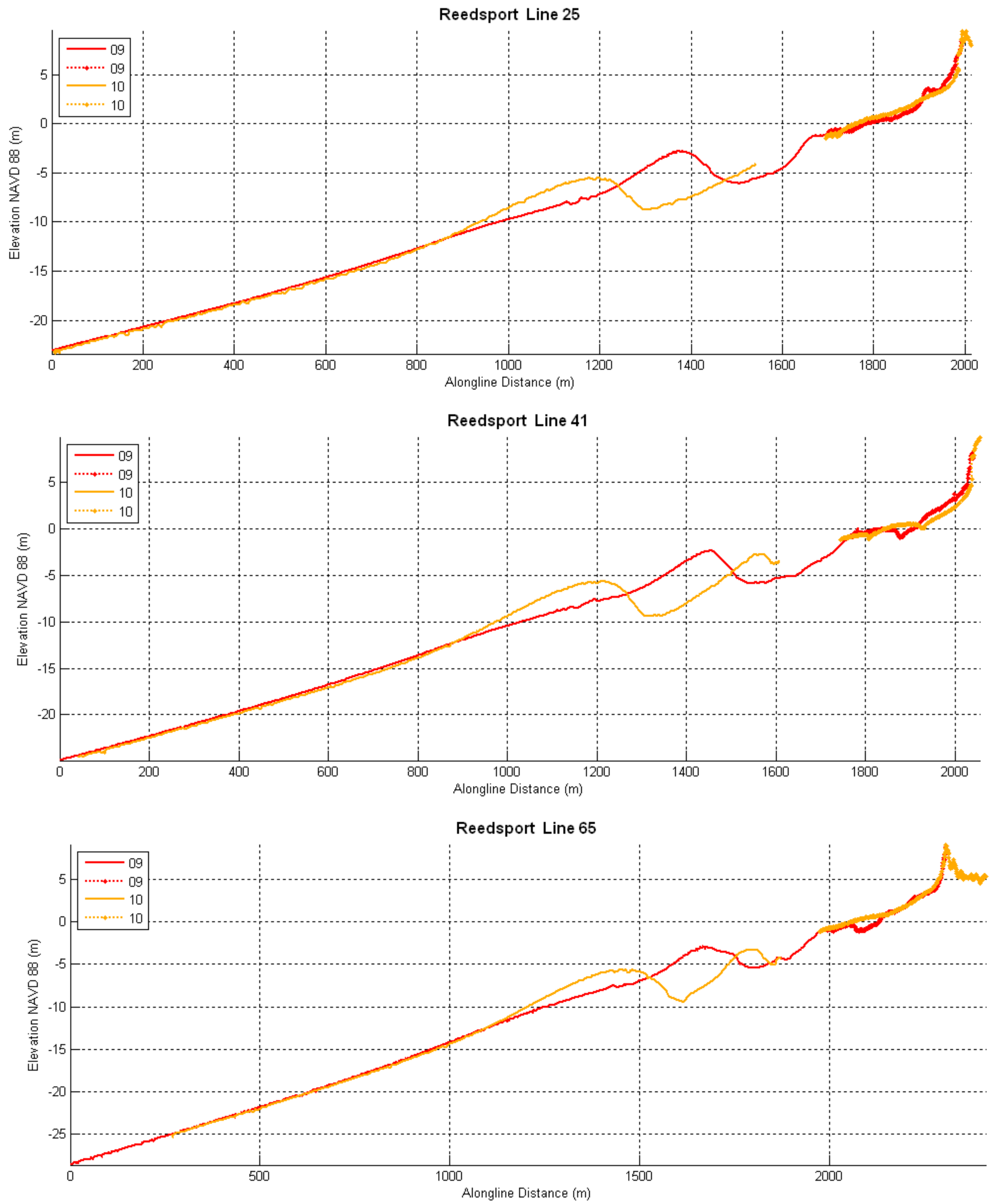

Figure B5. Example cross-shore transects show morphological changes between summer 2009 and 2010.

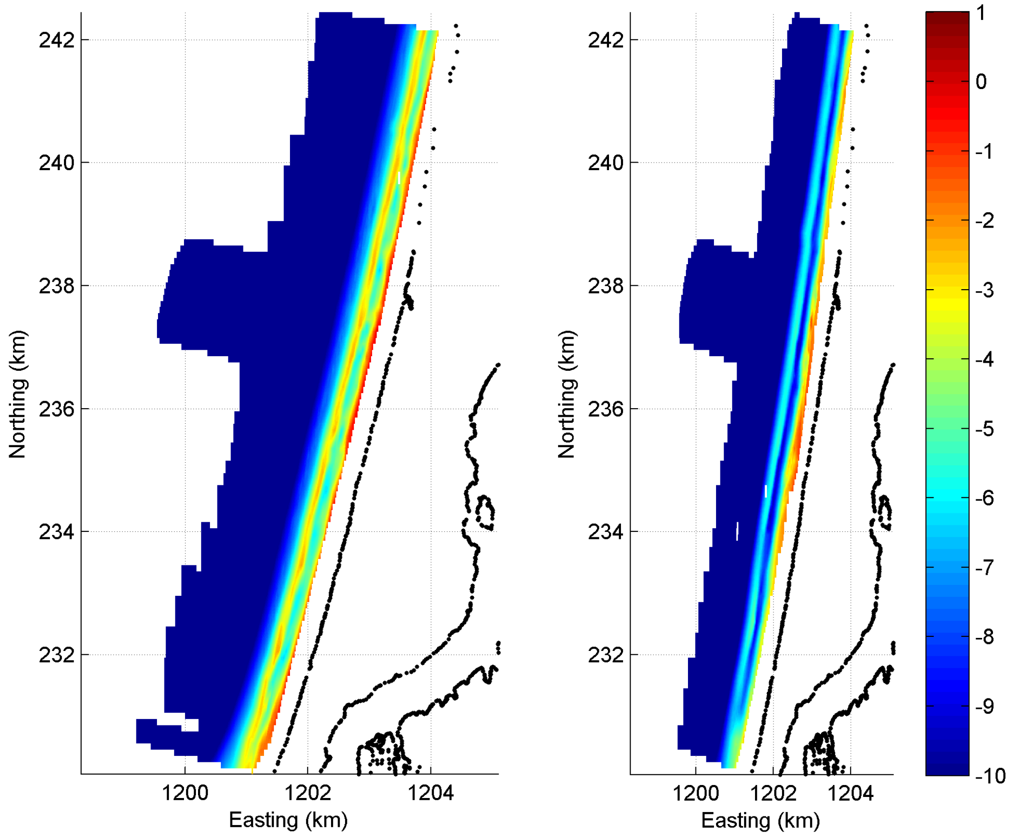

Figure B6. Gridded nearshore bathymetry from left panel) 2009 and right panel) 2010. The color map has been limited to water depths less than 10 m NAVD88 to demonstrate the remarkably linear outer sandbar present during each of the surveys. The difference in the colors of the sandbar features indicates that in 2009 the bar was in 2 to 3 m of water while in 2010 the bar was in approximately 5 to 6 m of water.

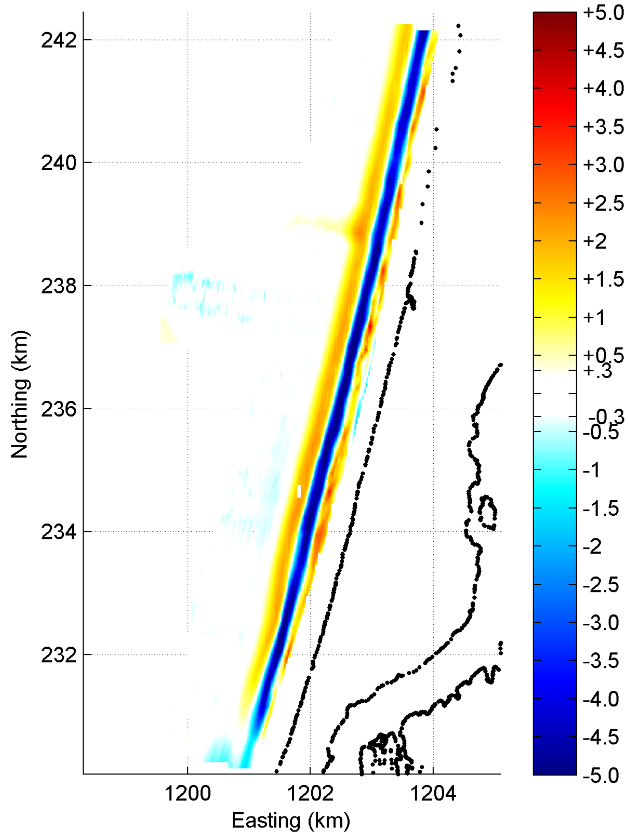

Figure B7. Gridded nearshore bathymetry difference map showing the differences between the 2010 and 2009 nearshore bathymetric surveys. Warm colors represent sediment accumulation while cool colors represent sediment erosion. The linear alternating colors demonstrate that the primary morphological change that occurred between 2009 and 2010 was the offshore migration of the outer sandbar.

Deliverables

Reedsport survey data are provided in 2 folders, one each for the 2009 and 2010 surveys. Inside the bathymetry folders are 44 individual cross-shore profiles collected by the data acquisition boats. The naming format is rp09_linenumber_b.xyz. Each file is composed of 3 columns of data: Eastings, Northings, and elevation (depth in meters) with reference to Oregon State Plane South, NAD 88(m) in the horizontal and NAVD 88(m) in the vertical. The data can be found at: ftp://cil-ftp.oce.orst.edu/pub/outgoing/OWET/.

Bathymetry Survey 2009 Environmental Conditions											
			Preset Sound	**Waves**				**Wind**		**Temp**	
Site / Date	**Time (PST)**	**Profiles Collected**	**Vel (m/s)**	**Hs**	**Tp**	**Dir**	**Ta**	**Speed**	**Dir**	**Air**	**Water**
		OSU Guns		m	sec	deg	sec	m/sec	deg	°C	°C
Reedsport											
7-Jul	1145-1700	1, 5, 9, 13, 17, 21, 25, 29	1500	1.13	15.38	216	7.49	--	--	--	13.9
			1500								
8-Jul	1306-1632	29, 57, 61, 65, 69, 73, 77, 81, 85, 89, 93, 97, 101, 53, 49	1500	1.21	14.29	210	6.24	--	--	--	14.3
			1500								
9-Jul	1126-1608	29, 33, 35, 37, 39, 41, 43, 45, 47, 51, 55, 59, 63, 67, 71, 75, 79, 83, 87	1500	1.3	8.33	304	7.09	--	--	--	14.4
			1500								

Bathymetry Survey 2010 Environmental Conditions											
			Preset Sound	**Waves**				**Wind**		**Temp**	
Site / Date	**Time (PST)**	**Profiles Collected**	**Vel (m/s)**	**Hs**	**Tp**	**Dir**	**Ta**	**Speed**	**Dir**	**Air**	**Water**
		OSU Guns, OSU Roses		m	sec	deg	sec	m/sec	deg	°C	°C
Reedsport											
15-Jul	1712-1716	60	1500	2	8	323	5.9	--	--	--	9.5
		60	1500								
16-Jul	1223-1658	041, 045, 049, 053, 057, 061, 065, 067, 069, 073, 077, 081, 085, 089, 097	1500	2.5	8	328	6.5	--	--	--	9.3
		039, 043, 047, 051, 055, 059, 063, 067, 071, 079, 083, 087, 093, 101	1500								
17-Jul	1149-1418	005, 013, 021, 029, 035, 039, 056, 064	1500	2.2	9	323	6.2	--	--	--	9.5
		001, 009, 017, 025, 033, 037, 058, 062	1500								

Appendix C

Argus Data Collection at Reedsport, OR

Rob Holman

Oregon State University

Background
The installation of wave energy devices offshore in the Reedsport Wave Energy Park will, by definition, remove energy from the incident wave climate. One concern is that this will create a shadow zone that could alter the morphology of the nearshore beaches. To determine the level of this threat, a monitoring program began June 2009 to measure the base state of the local nearshore environment. This program included traditional GPS survey methods that yielded accurate topography and bathymetry at the times of measurement. However, the nearshore environment continually responds to the varying wave energy, so it will vary in response to storms, seasons and potentially interannual events. Thus, there is need for more frequent measurements of system changes between surveys. Optical remote sensing through Argus methods provides a low-cost approach for providing such data.

December 2009, a first report was submitted describing the variability of the Reedsport sand bar system based on Argus data collected from July through November, months that typically feature low wave energy. The data set was subsequently extended to a full year by including the more energetic winter and spring months. This report describes the results of the full year of Argus data collection.

Objective
The goal of this component of the program was to provide frequent measurements of nearshore morphology variations over a sufficient duration to define a base state, prior to energy device installation. Thus, we hope to define the "typical" nearshore morphology for this site.

Methods
Morphology is the shape of dominant features in the nearshore topography, typically taken as the position of the shoreline, of offshore sand bars (shoals) and potentially of rip channels. It has been shown that these locations can easily be found by observing the average location of wave breaking patterns in the surf zone. Since waves break in shallow water, zones of concentrated breaking correspond to shoals (or to the shoreline for the final shore break of the waves). These patterns can be observed easily in 10-minute time-exposure images. The method of time

exposure imagery was introduced by Lippmann and Holman (1989) and became a core capability in a program of automated observing systems called the Argus Program (fully described in Holman and Stanley (2007)).

Oblique images captured by a typical camera system can in turn be rectified into map images using standard photogrammetric methods (Holland, Holman et al. 1997) if the position of a number of recognizable Ground Control Points (GCPs) are known. Typically one camera will not span the desired field of view, so multiple cameras are used, each pointing to a different part of the beach. Individual images are merged using the same photogrammetry principles. Figure C1 shows an example rectified time exposure image from Reedsport that has been merged from three separate images, each with a different aim point.

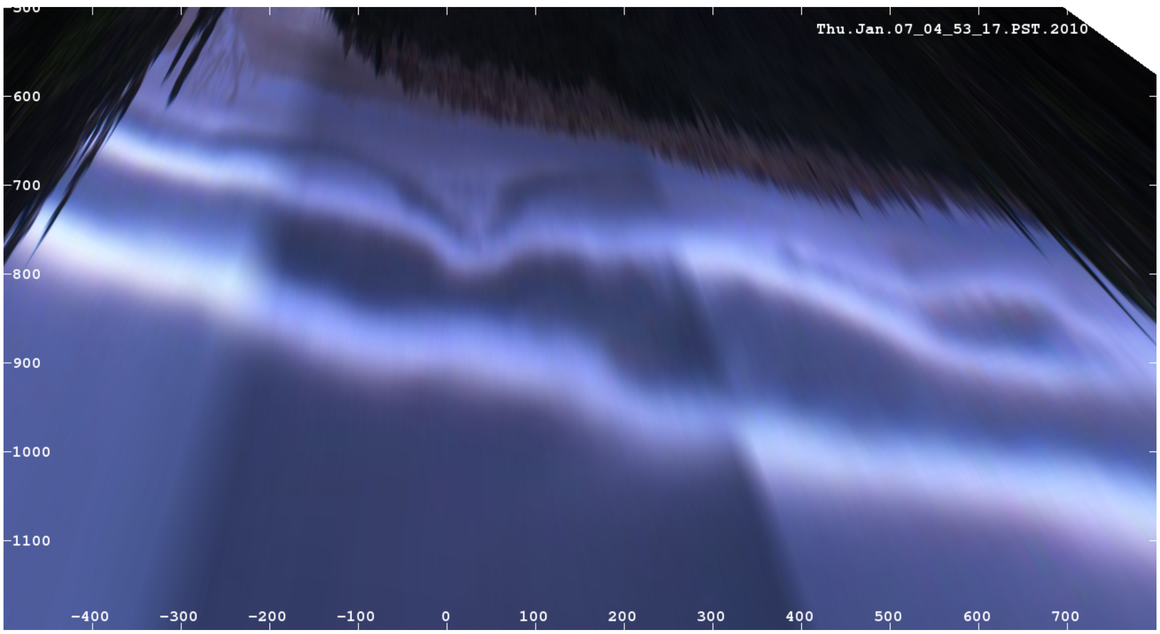

Figure C1. Example merged time exposure image from 7 January 2010. The shore is at the top of the image and seaward is at the bottom. White bands are regions of preferred breaking corresponding to submerged sand bars. Further details are discussed in the main text of the report.

The Argus coordinate system is marked along the borders of Figure C1 and is in units of meters relative to the camera location on the dune. By Argus convention, the cross-shore coordinate (vertical above) is the x-axis and the alongshore coordinate (horizontal above) is the y-axis. A small section of the dry beach is seen for y < -100m at the left top of the figure. However the rest (y > -100) is partially obscured by trees (on the right). The boundaries of the three camera views can be see by the different brightness's of the three different segments of the rectification (due to varying camera gain for each picture).

Sand bars are indicated by white bands, the result of preferred breaking over the shallow regions of the bar. Similarly dark regions (little or no breaking) correspond to relatively deeper water, e.g. the trough separating a bar from shore or from another bar, or the deeper water of a rip channel. Thus a sand bar is clearly seen transecting the figure from x = 750m on the left (north) to 1075 on the right (south). This bar is roughly 200m from the shoreline. Interestingly, a second, smaller and temporary bar-trough feature is seen closer to shore. If you trace a cross-shore transect at y = -200, you will see an offshore sand bar at x = 850m, then a second bar at x = 680, separated from the beach by a narrow (dark) trough at x = 640m. That narrow trough continues alongshore until it turns offshore at y = 30m to form a rip channel (meeting a similar channel from the south from y = 100 to 250m).

Normally, Argus stations are fully automated and return imagery every daylight hour of every day. However, they also require power and Internet access, luxuries that were not available at this site. Thus, for this application, a portable system was designed consisting of a single camera and a special mounting bracket that forced camera alignment to the three required aim directions. During an initial site visit the mounting post and mount plate were installed and survey locations found of the camera and a number of identifiable objects in each view (GCPs).

Data collection was performed by DOGAMI scientists and involved hiking out to the site, mounting the camera in the first aim position, then running a laptop program that acquired the first time exposure image (plus snapshot plus an alternate image type). This was repeated for camera positions 2 and 3. Upon returning to the lab, the geometry of each image was determined using a special software tool, and then merged rectifications such as Figure 1 were found using in-house software.

Collections
At the completion of initial phase of sampling, data had been successfully collected on five separate days but under a somewhat limited range of wave heights. These have been supplemented by nine additional images in the subsequent 7 months that capture the more energetic storm conditions of winter including wave height up to 6.4m. Image dates and wave heights for the full data set are shown in Table C1.

The individual merged rectifications are shown in Figures C2 – C15. Images differ from each other for three reasons. First, the sand bar location and morphological form changes in response to changing wave energy (this is the natural seasonal and storm signals that we wish to measure). For instance, the winter storm bar of January 7, 2010 looks very different from the complex recovering bar system of April 23, 2010. Similarly, the offshore positions of the storm bars from September 17 and January 25 are quite different.

Second, since bar position is revealed by breaking wave patterns, small waves will reveal only a smaller section of the nearshore morphology (e.g 4 November, when the only breaking patterns are close to the shore and obscured by the trees). Similarly, high waves on September 17, November 17 and January 25 reveal breaking over a deeper sand bar, almost 1km from the shoreline. A lack of breaking over this feature in calmer conditions does not imply that the bar is gone, simply that the wave height is too low to reveal it.

Date	Hs (m)
07/08/09	1.2
09/17/09	2.0
10/11/09	0.9
11/04/09	0.9
11/17/09	5.9
01/07/10	1.9
01/25/10	6.4
02/08/10	2.4
03/04/10	2.9
04/01/10	3.7
04/23/10	2.1
06/03/10	2.1
06/11/10	2.2
07/16/10	2.0

Table C1. Dates of image collection (left column) and corresponding significant wave heights (right column). Wave measurements were from CDIP buoy 139 (Umqua) in 186m water depth.

Third, tide level variations also influence the locations of breaking. So, despite a similar wave height, the October 11 image show much more structure than the November 4 image due to the lower tide.

Description of the Reedsport Sand Bar System

The nearshore sand bar system at Reedsport appears to be a primarily a double bar system with a nearshore bar typically 100-200m from shore and an offshore bar up to 1000m offshore (pushing the limits of our shore-based data collection system). The bar is typically more linear during the high wave conditions of fall and winter (November through February) then becomes surprisingly complex in the spring (April through June) as it readjusts to weaker wave forcing. It appears that the system simplifies and straightens during the summer months, leaving a simpler bar system with short scale bars and troughs close to the beach.

The complexity of the spring and early summer bars is somewhat of a surprise. For example, the bar morphology on April 23 is among the more complex that we have seen. The rip channels (dark bands that transect the white sand bars in the cross-shore direction) have a very large cross-shore scale (200m) compared to previous experience. Similarly, the fact that the July, 2010 morphology appears rather different from that of the previous year, July 2009, implies significant interannual behavior that will complicate the definition of a natural base state, prior to installation of offshore wave energy devices.

Summary
Time exposure images show the presence and time-varying morphology of the nearshore sand bar system landward of the Reedsport Wave Energy Park. The system typically has two major bars with outer sand bar changes seen out to at least 1km from shore. The inner bar tends to be linear during sustained winter storm conditions but becomes surprisingly complex under the reduced wave conditions of spring. Differences between summer morphologies in 2009 and 2010 point out the difficultly of identifying a simple baseline beach state which can be compared against morphologies observed after installation of offshore wave energy devices.

The methods used represent a simple and way to collect baseline data on the nearshore morphology at Reedsport.

The time exposure images collected as part of this project are available on line using ftp access. The ftp site is cil-ftp.coas.oregonstate.edu. Files are stored using standard CIL conventions under /ftp/pub/reedy/yyyy/cx/dddddddddd where yyyy is the year (either 2009 or 2010) and dddddddddd is the datestring, for example 026_jan.26.

Timex Images:

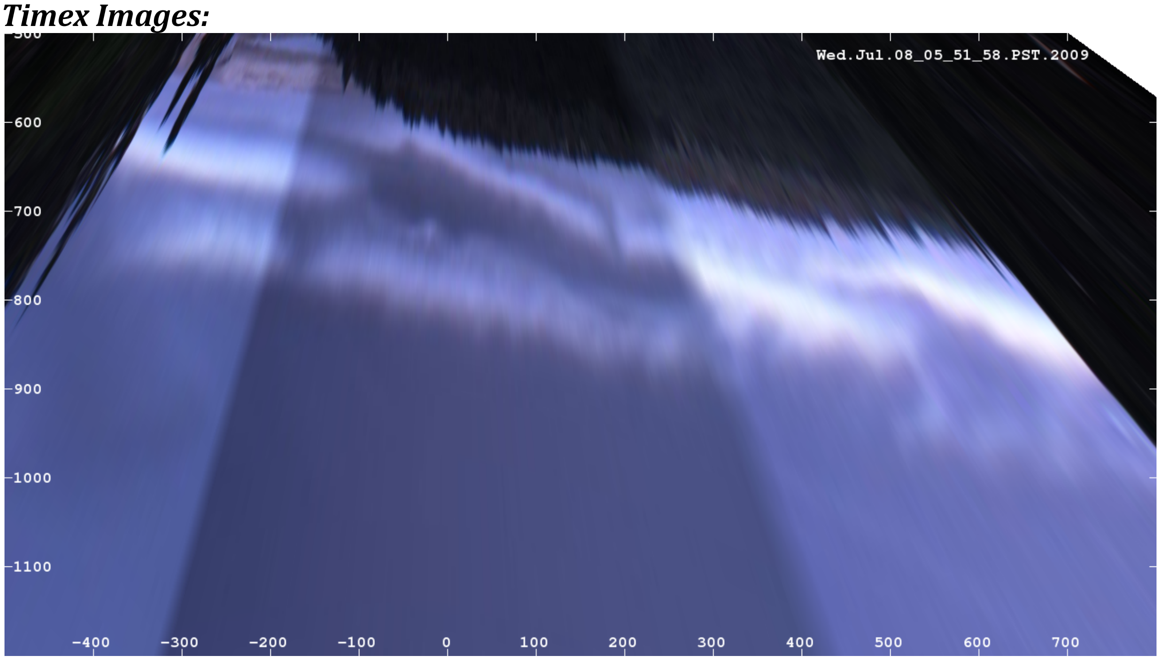

Figure C2. July 8, 2009 merged rectification.

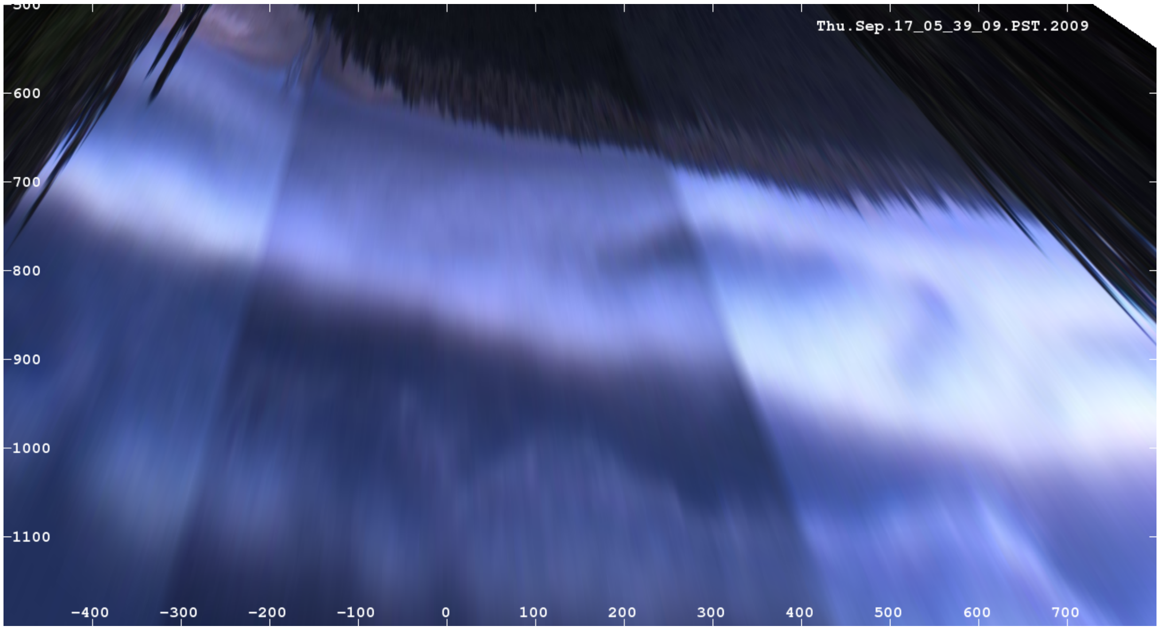

Figure C3. September 17, 2009 merged rectification.

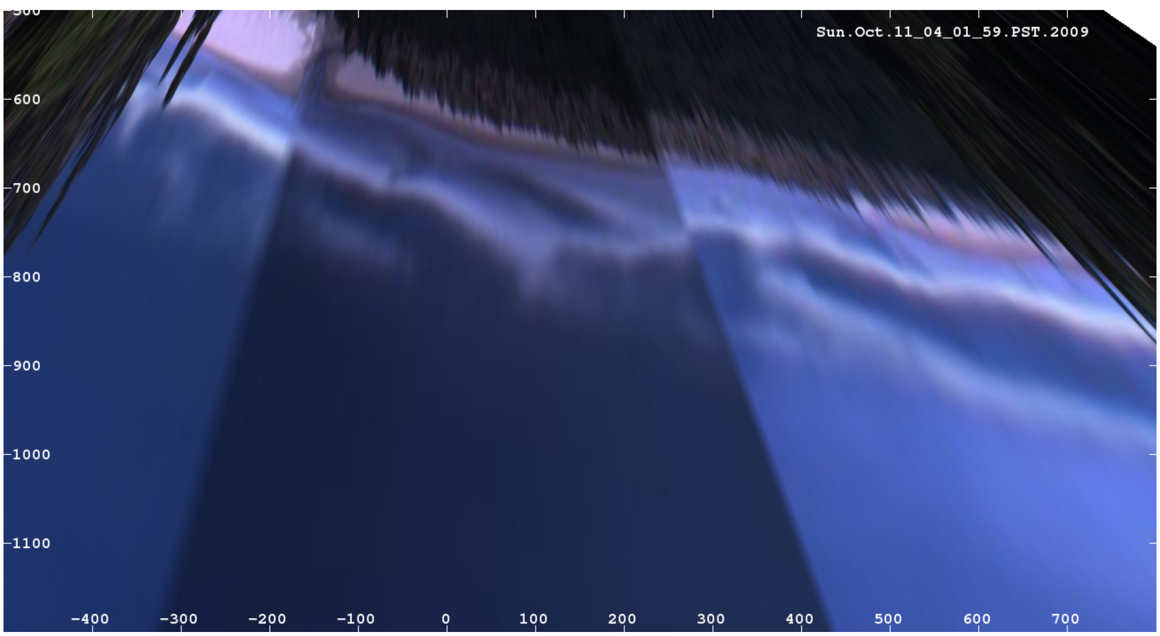

Figure C4. October 11, 2009 merged rectification. While wave heights were low, the tide was also low so that waves still broke over the bar (see Figure 2d).

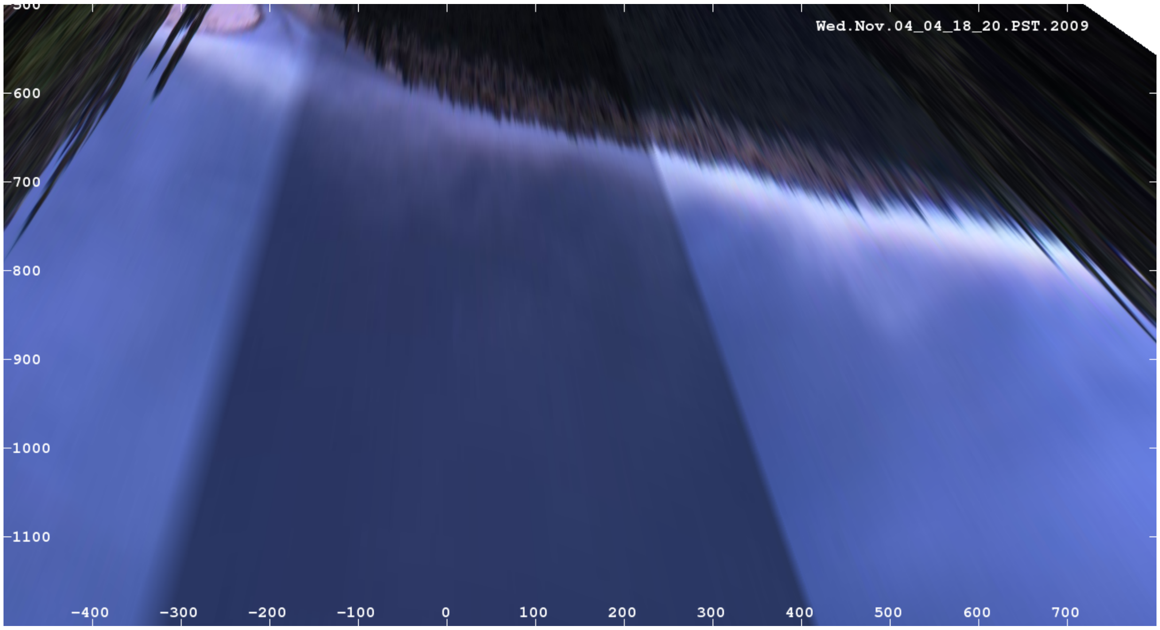

Figure C5. November 4, 2009 merged rectification. The lack of observed bars is only due to the very low wave height and high tide, so that no waves were big enough to break over the bars.

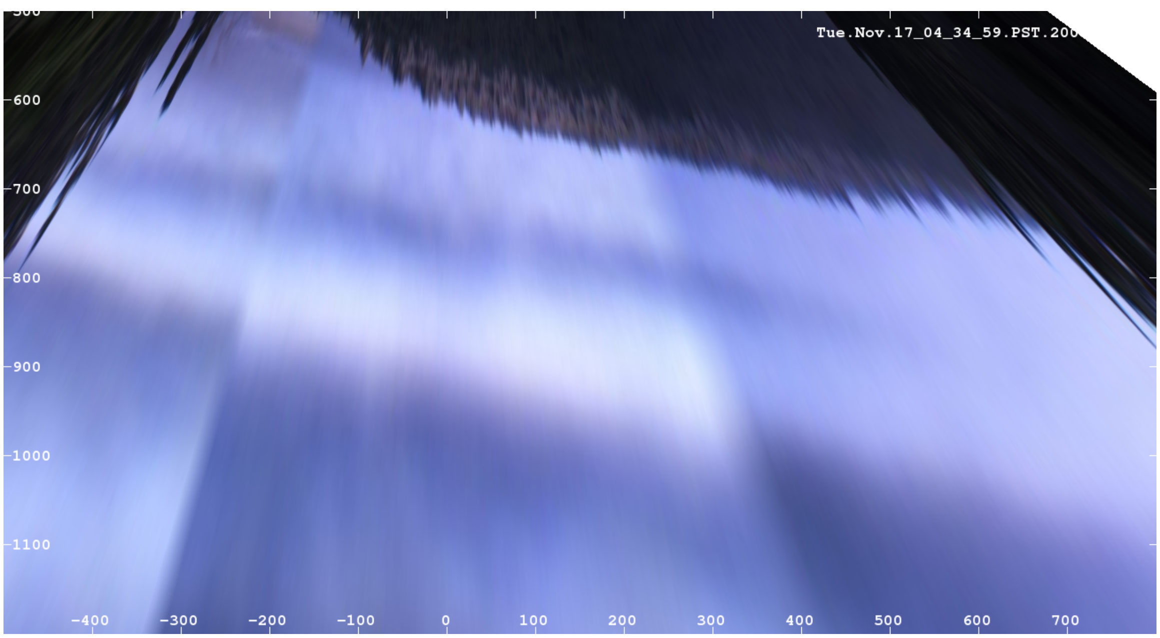

Figure C6. November 17, 2009 merged rectification. Waves were large and broke over a second, offshore bar.

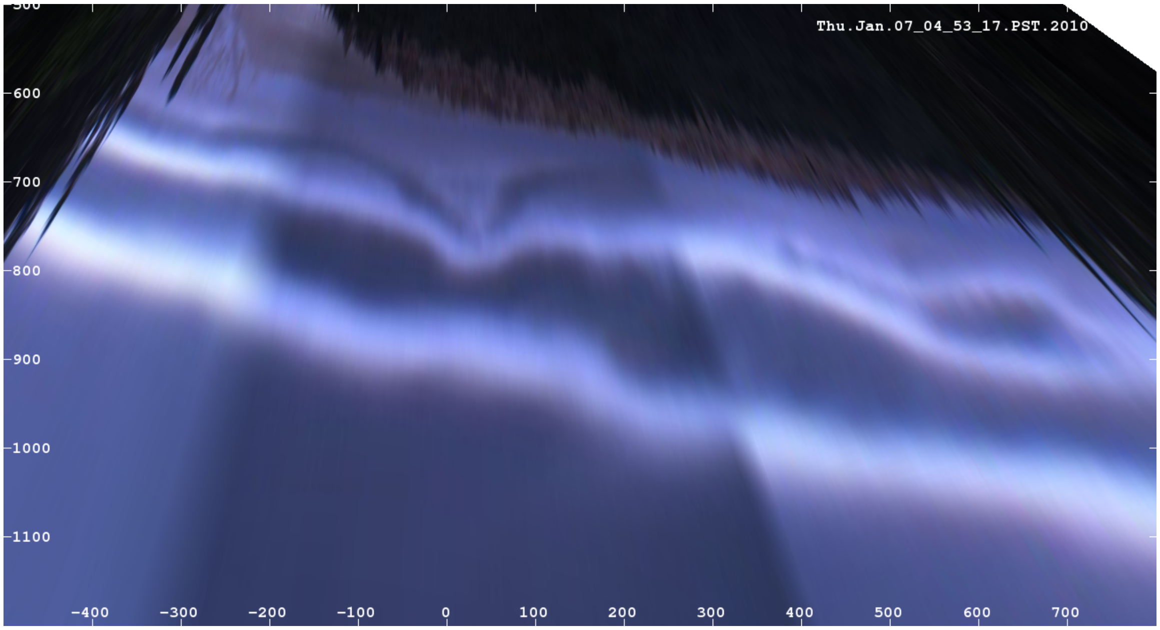

Figure C7. January 7, 2010 merged rectification.

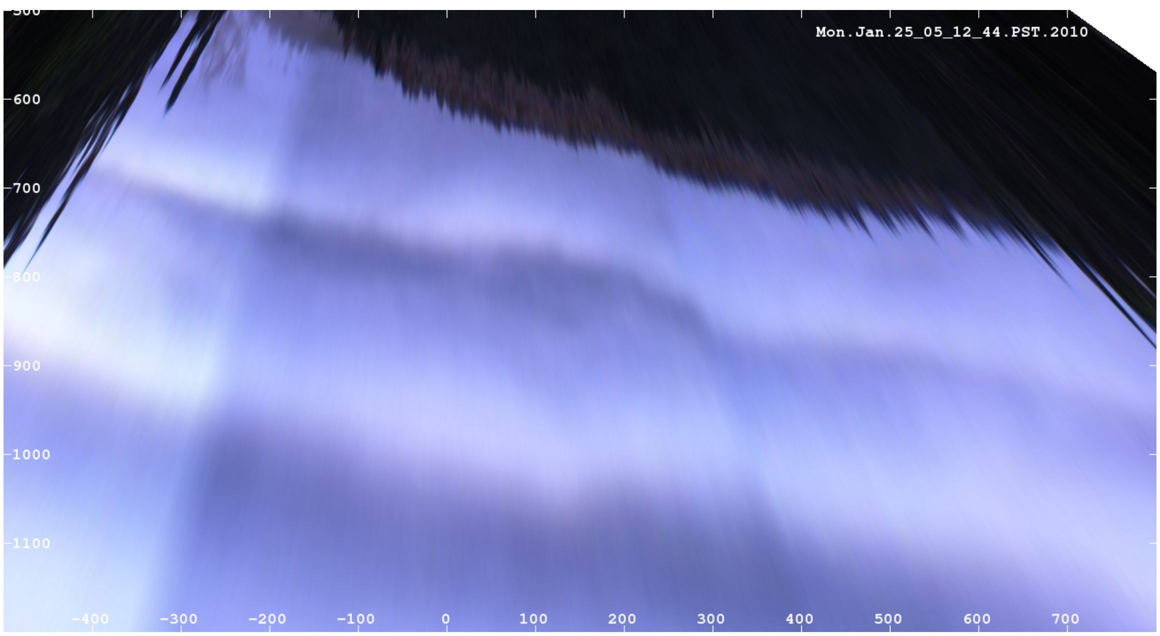

Figure C8. January 25, 2010 merged rectification.

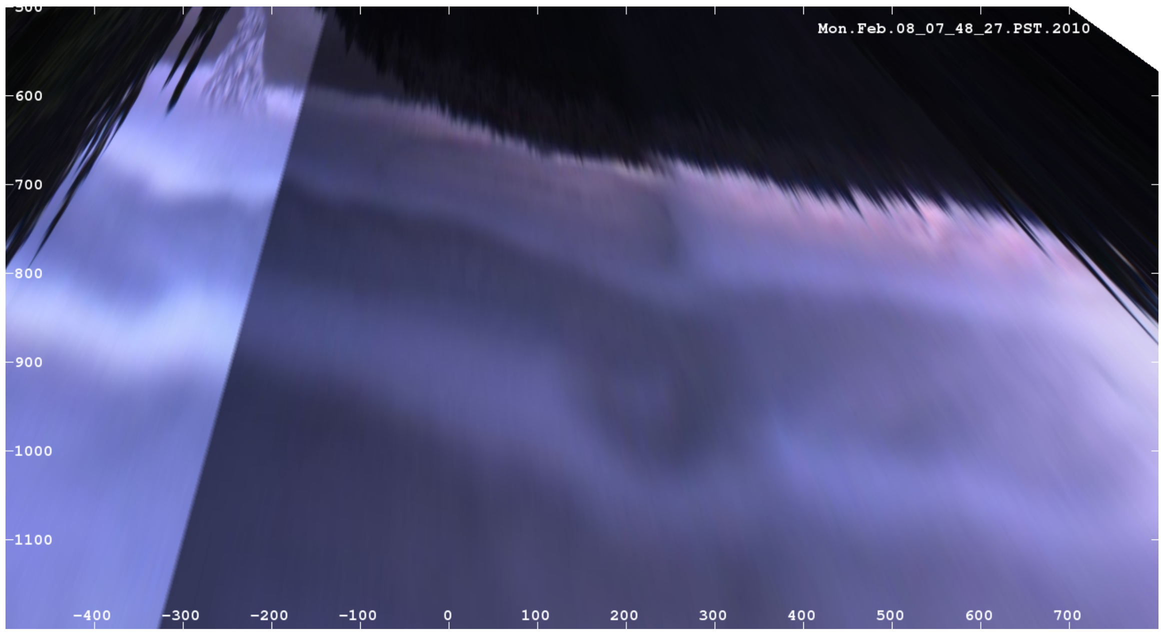

Figure C9. February 8, 2010 merged rectification. Camera gain for the left hand camera (north) was higher so this image is brighter. A small river delta is visible at y = -250 crossing the dry beach.

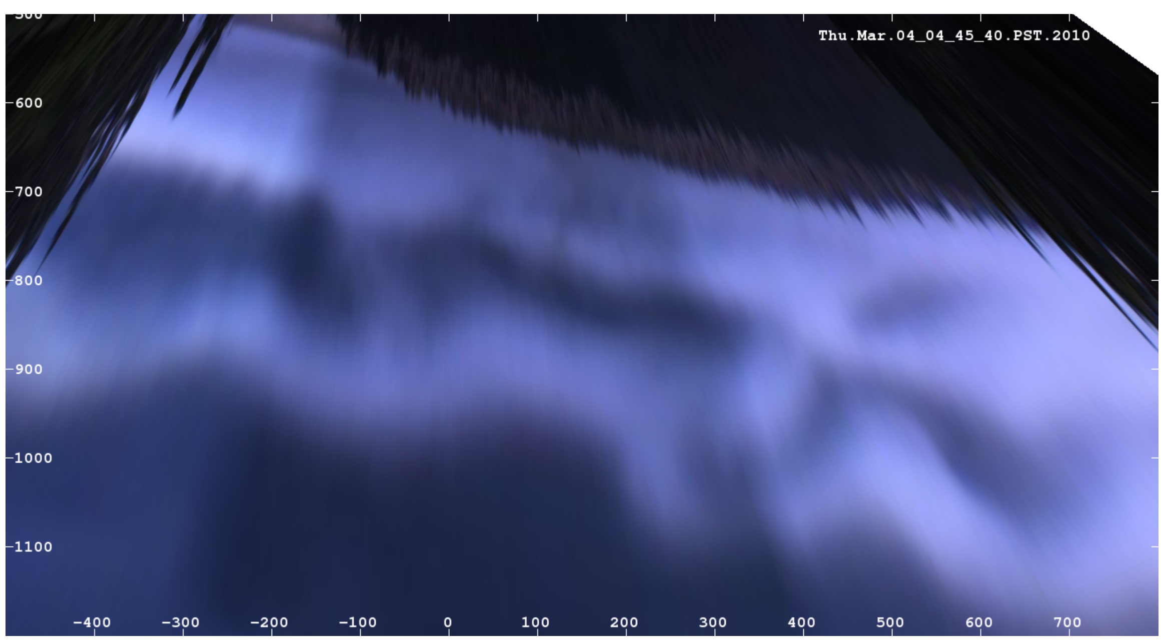

Figure C10. March 4, 2010 merged rectification.

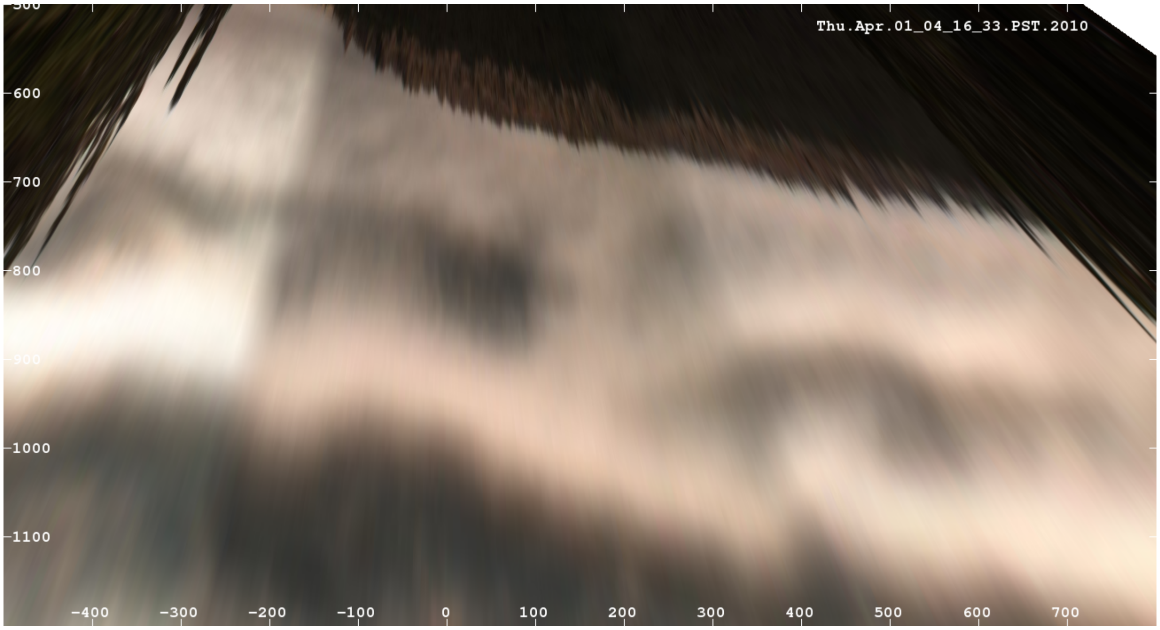

Figure C11. April 1, 2010 merged rectification. The grayer colors of this and the June 3 image are due to differences in camera white balance rather than any natural phenomenon.

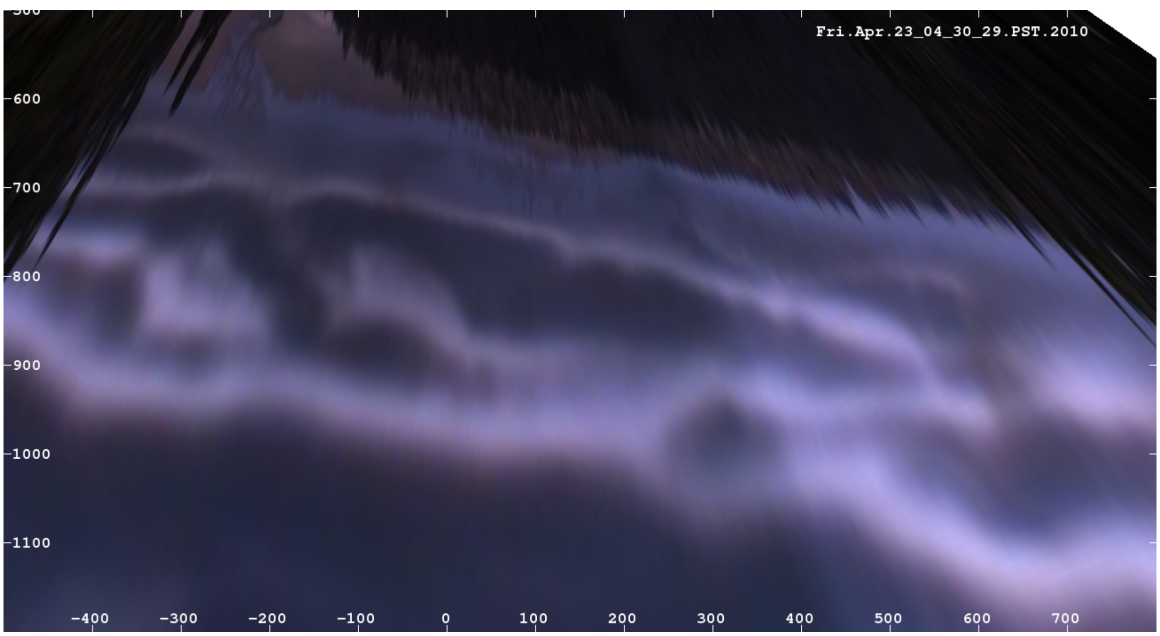

Figure C12. April 23, 2010 merged rectification. This is one of the most complex bar patterns observed.

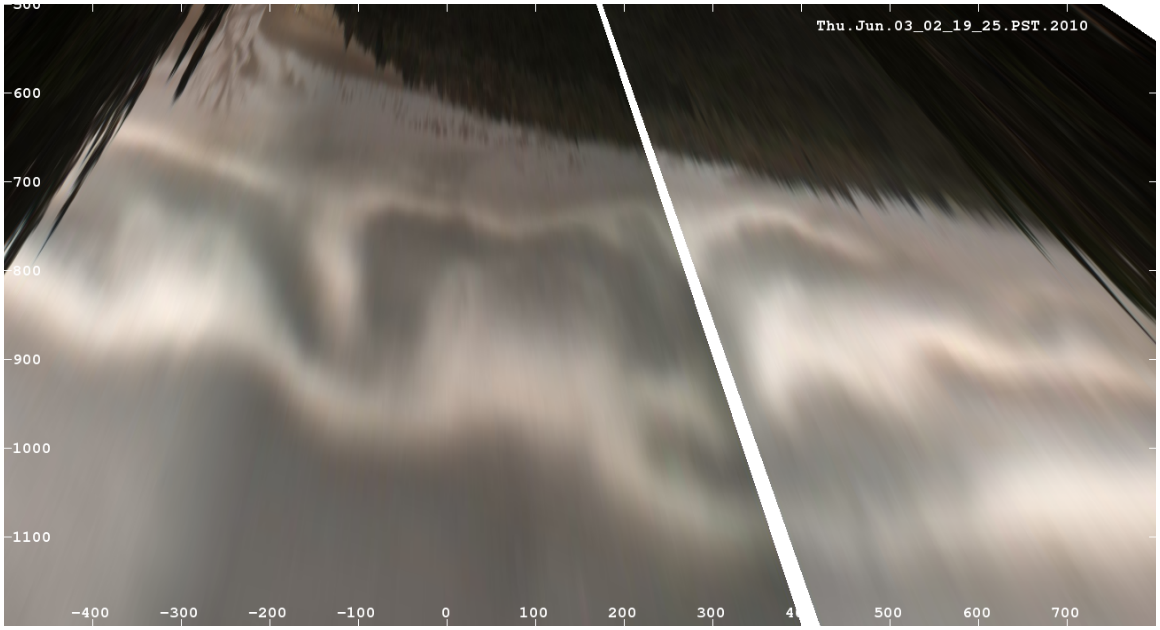

Figure C13. June 3, 2010 merged rectification. The small gap comes from a slight misalignment of cameras when they were set up.

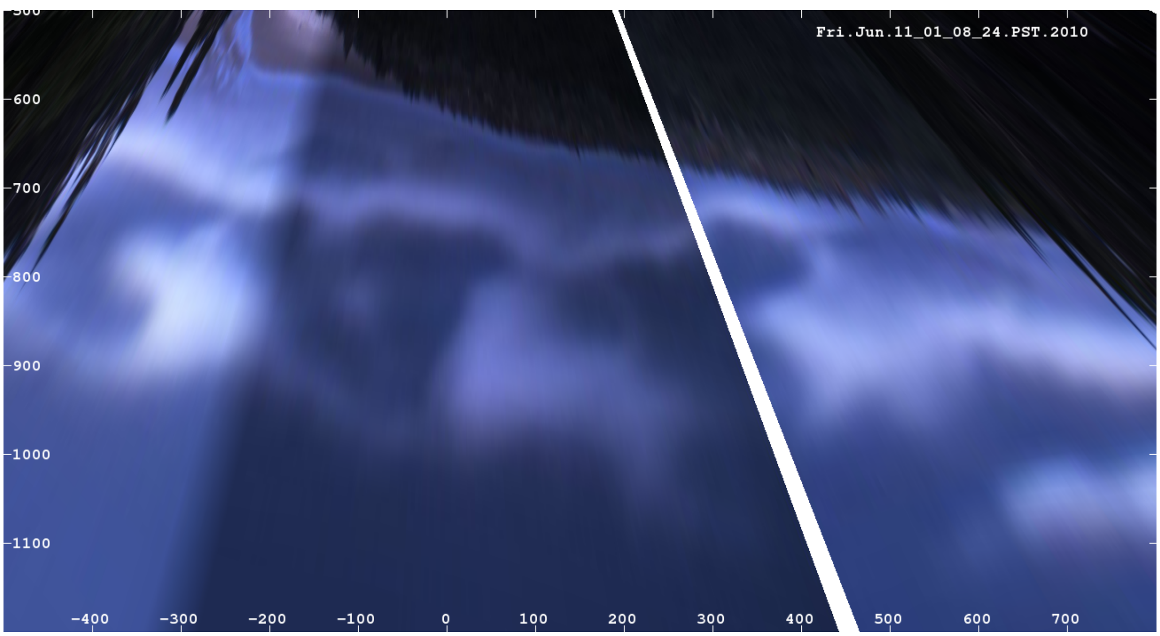

Figure C14. June 11, 2010 merged rectification.

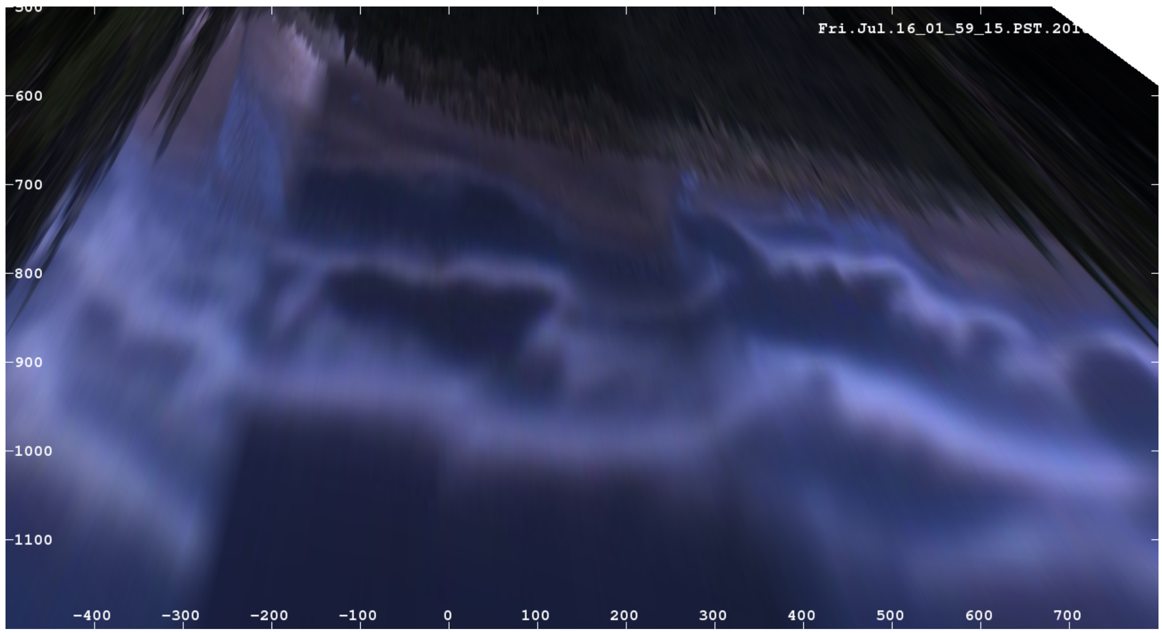

Figure C15. July 16, 2010 merged rectification.

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