REPORT # 4: THE ARGUS BEACH MONITORING STATION AT THE MOUTH OF THE COLUMBIA RIVER - NORTH HEAD, WA

This report covers the maintenance and data collection from
1 April 2006 – 30 September 2006
and
analysis of data from
February 2004 – September 2006

by

NorthWest Research Associates (NWRA)

Submitted to:

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1. INTRODUCTION

This report was prepared by NorthWest Research Associates for the Portland District of the US Army Corps of Engineers. This is the fourth in a series of reports that describe the Argus monitoring of the 2.5 km long Benson Beach, north of the north jetty of the Columbia River (Figure 1). Included with this report are archival CDs of Argus image data (snapshots, timex, and variance) and pixel time series data for process studies (runup, waves, and currents) acquired from 1 April 2006 through 30 September 2006. These data and the concomitant analysis products can also be acquired via the web site (www.planetargus.com/north_head).

In addition to providing data and analysis products, this report also serves as a reference for new system information (i.e., metadata) and for monitoring and maintenance activities. A detailed description of installation, metadata, and data collection procedures can be found in Report #1.

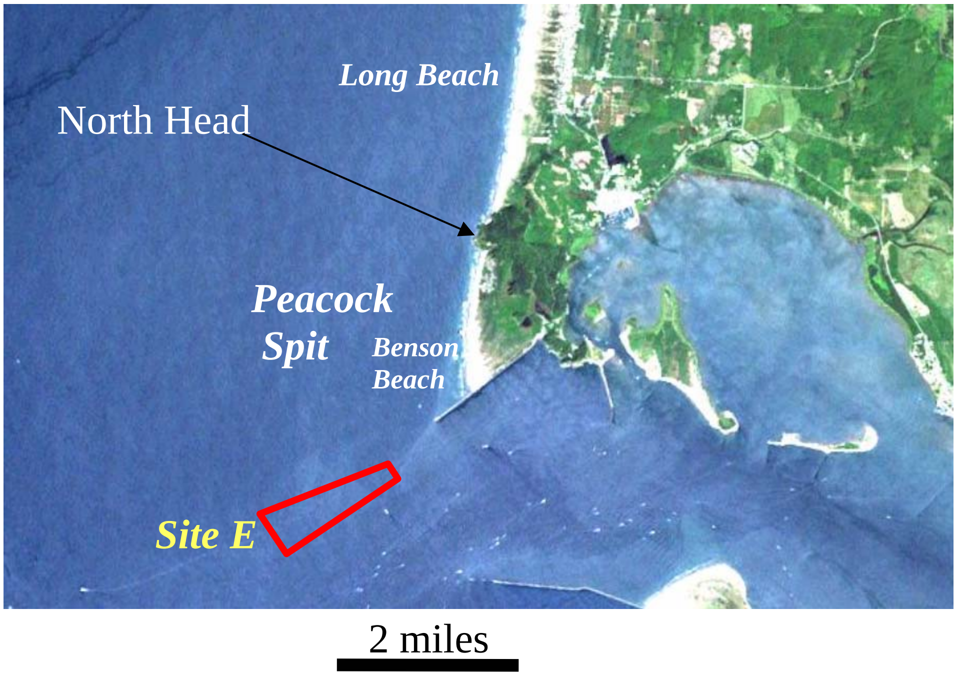


Figure 1. Location map of the areas of interest. (Image provided by H.R. Moritz.)

2. DATA COLLECTION, AVAILABILITY, AND PRESENTATION

2.1 Hour Image and Pixel Time series Collection

During daylight hours, the ABMS collects hourly images of several types: 1) the basic **snapshot image**, 2) the digitally averaged time-exposure image (the **timex image**), and 3) the **variance image** (10 min pixel intensity variance statistics).

These images are collected from all cameras. At the top of the hour, cameras 1 and 2 collect images for 10 minutes, followed by cameras 3 and 4, then by cameras 5 and 6, and the last set of cameras (7 and 8), which collect images from thirty to forty minutes past the hour. Once every hour, these images are sent by phone line and the internet to the NWRA offices for archiving, updating of the web site, and image processing. Unique to the North Head site is the additional transmission of snapshot images (cameras 1-4) every 20 minutes.

Arrays of pixel time series data are collected at the North Head site for the following purposes:

1) peak wave direction and period ("Alpha" arrays),
2) depth profiles ("Bathy" arrays),
3) alongshore current ("V bar" arrays), and
4) wave runup ("Runup" arrays).

The last 10 minutes of an hour are used to collect pixel data. These data are collected in camera pairs. Cameras C1 and C6 acquire pixel data four times per day, as do camera pair C5 and C6. These camera pairs are providing Alpha, Bathy, and Vbar pixel array data at specified locations and times (details are found in **Report #1**). Camera pair C6 and C7 collect Runup data once per day. We stopped the collection of Vbar arrays in Fall 06 after determining that the camera geometry does not provide the pixel resolution required for this technique. In addition, pixel data collection was stopped in mid November 2006 due to phone line communication difficulties prohibiting night-time data dumps of this high-volume data. It is anticipated that pixel collection will resume at a later date. Pixel data are collected for potential future analysis in case these data are deemed important to understanding nearshore processes at this beach.

2.1.1 Data Collection Interruptions

Problems with data collection between April 2006 and October 2006 occurred in June and August. The problems and their solutions are detailed in **Section 3** of this report. Data collection losses occurred as follows:

2-6 June 2006: All camera images were lost because the on site SGI computer malfunctioned and would not respond to a remote reboot. The SGI required two separate attempts at on site rebooting. (In the Fall of 2006, this computer was replaced because of continued malfunctions.)

18-21 August 2006: No images lost! Near real-time image downloads from site to NWRA and the web site were stopped during this time due to a communication glitch in the modem/router.

2.2 Web-Accessible Images and Data Products

In October 2005, a new version of the North Head web site (www.planetargus.com/north_head) was launched to make it easier for people to find the image archives, pans, and plans, as well as to provide an outlet for data reports, presentations, and community news/discussion. Data analysis products beyond the panoramas and plain view images are available from this new web site. On the main page, a couple of example data analysis products are provided to help draw attention to the availability of these products. On the left-hand side-bar, a link, "Data Products, News, And Discussion" leads to a page called the "North Head Journal" that provides an easy format for finding data products (either by searching keywords, choosing categories, or choosing dates). This page also allows for community discussion.

2.3 Archival Storage of Argus Images and Pixel Collection

North Head data is stored in several locations and on several media. Data are stored on the computer hard drive located in the North Head lighthouse (for 30+ days) and on the hard drives on two computers at NWRA. These hard drives are backed up on tape nightly, and full monthly tape backups are stored at on offsite location.

In addition to the above, the complete set of image data is available from the NWRA computers via the Argus web site, and all data (image and pixel) are burned to four sets of CDs monthly. One set is left at NWRA, one set is stored offsite, one set is sent to Kent Hathaway at the USACE FRF in Duck, NC for pixel analysis, and one set is sent to Rod Moritz along with the reports.

2.4 Meetings and Presentations

None

3. SYSTEM MAINTENANCE AND IMPROVEMENTS

The following is extracted from the system maintenance and improvement log for the time period of 1 April 2006 through 30 September 2006.

3.1 System Repair And Maintenance Logs

3.1.1 2-6 June 2006

Problem: Data not transmitting from North Head.

Solution: Ranger Julie provided a hard reboot on Sunday (4 June) that provided more diagnostic information and Pat, our on-site consultant, spent two hours at the lighthouse on Tuesday (6 June) night further diagnosing the problem with NWRA folk via phone. Not an easy feat! He said the sunset was not to be beat, though.

Details: It appears that the SGI computer got hung up and that a remote reboot could not revive it. The SGI responded only to Pat's mechanical shut down via the console power button. The reason for this remains a mystery. .

Images Lost: 2-6 June 2006

3.1.2 18-21 August 2006

Problem: Data not transmitting from North Head

Solution: Remote reboot of the RM 356 modem/router

Images Lost: None

3.2 Maintenance of Video Capture Equipment for PIV Analysis

NWRA is providing Dr. Tom Lippmann with on-site maintenance for his North Head video capture equipment that is used for Particle Imaging Velocimetry (PIV) analysis of surface currents. PIV is a velocity measuring technique where patches of texture are mapped through imaging sequencing. In the case of video imaging of the ocean surface, foam patches are tracked.

Three video capture receivers (VCRs) were integrated into the Argus data capture system on 20 September 2005 to collect video images from Cameras 4, 5 and 6. Video data has been scheduled to be collected at 10am PST for one hour, once per day.

NWRA's on-site consultant visits the site once or twice per month to swap video tapes, to reset the recorder clocks (necessary because of clock drift), and to correct any malfunctions. He posts the tapes to Dr. Lippmann in Ohio and emails Dr. Lippmann with a report on the status of the data collection.

4. SYSTEM METADATA

To be able to analyze Argus image data for quantitative information, metadata is required that further describes image parameters and how the image was obtained. Metadata is stored in the Argus msql database, available for retrieval by Argus data analysis programs. Image metadata includes camera lens focal lengths and distortion parameters, camera focal plane location in local coordinates (e.g. NAD83 and NAVD88), and the location of features in each camera’s field-of-view (known as Ground Control Points, GCPs). This information is also provided in Report #1, along with a description of the coordinate systems used at this site.

4.1 Geometry Solutions

Geometry solutions have been acquired for every camera. Cameras with views over the open ocean have one geometry solution, acquired with the help of jet skis in the summer of 2004 (**Report #1**). Cameras with views of the jetty and beach have geometry solutions that are updated hourly to correct for camera movement due to the heating and cooling of the cast iron dome of the lighthouse lamp room (**Report #1**).

To update the geometry solutions, timex images are compared against image templates. New solutions can be made automatically as long as there are no changes in permanent features in the template. When there are changes, manual intervention is required to “reset the template.” Most North Head geometry templates lie along the top of the north jetty. The features of interest are the notches in the jetty. When USACE repairs these jetty notches, the template must be reset. Template resets have become more common since the north jetty was repaired between May and December 2005. The geometry solution for Camera 4 is no longer corrected automatically because a large portion of the tip of the jetty (the only template reference for this camera) fell into the sea sometime between 28 December 2005 and 7 January 2006. Its final geometry solution was acquired on 28 December 2005.

4.1.1 Data Quality Control using the Geometry Solutions

Computation of the geometry solutions for every image provides the first Quality Control (QC) pass at the data. To obtain geometry solutions, cameras C5, 6, and 7 must have high enough quality images to use the jetty features (for C5, 6) and shore feature (C7) to correlate well (90% confidence) with the geometry templates. If fog or rain obscure the image, then the correlations will be low, there will be no geometry solution, and the set of images for that time will not be made into panoramas, plan views, nor used in subsequent shoreline or bar analysis.

A second level of QC is accomplished by reviewing plan-view and panoramic images that have passed the first level of QC. The misalignment of the jetty, or of the shoreline, is further indication of bad geometry solutions. The cause of this is typically a change in the features in the camera’s template view (i.e., changes in the shape of the top of the jetty). To correct this, a new template is createad and new geometry solutions are made.

The final set of plan-view and panoramic images available on the web site, and described in **Section 5.2**, serve to provide the list of QC’d images.

4.2 Field Data

The capability of the ABMS is enhanced when local tide, atmospheric, and ocean wave data are also available. Traditional bathymetric surveying using RTK GPS on a beach buggy also provides quality control and confidence in the quantitative data products provided by the ABMS (**Section 5.1**). All of these are available for the North Head site.

4.2.1 Tide and Barometric Pressure Data

No tidal station exists near the North Jetty of the MCR or Benson Beach. Therefore, tide predictions for this site are used. Tide predictions for Benson Beach are provided to NWRA by Rod Moritz of the Corps' Portland District. These predictions are derived from code created by NOAA-NOS for use by the Corps in the proximity of the North Jetty. For more information on tide predictions and barometric pressure corrections, please refer to **Report #1** and to Section xx below.

Available from the North Head web site (links described in **Section 5.2**), is the Excel spreadsheet containing the NOAA NOS tidal predictions, with conversion to meters relative to NAVD88, and with the barometric pressure corrections. These data were used, along with predictions of wave setup and swash amplitudes, to determine the shoreline water elevation for the purpose of mapping elevation contours at different tidal stanzas.

4.2.2 Ocean Wave Data

The primary source for offshore wave information comes from NDBC buoy 46029 (Columbia River Bar). This buoy is 37 km southwest of Benson Beach. Therefore, a 10sec wave takes ~80 minutes to propagate from the buoy to the beach (its average group speed is ~ 8 m/s). And, because of shallow water refraction, it is appreciated that wave directions in deep water do not indicate wave angles of incidence to the beach. Available from the North Head web site (links described in **Section 5.2**), is the Excel spreadsheet containing these data.

Occasionally this buoy is lost. A study of two alternative NDBC buoys, 46089 off of Tillamook, and 46041 off of Cape Elizabeth, indicates that both are reasonable replacements. The Columbia River buoy has been used for wave height, and peak period and direction data, with the exception of 01 December 2004 through 1 May 2005 when the Cape Elizabeth buoy (46041) was necessarily substituted.

5. ANALYSIS

5.1 Argus Intertidal Bathymetry: Comparisons with GPS (Buggy) Data

Intertidal bathymetry data, using a RTK GPS on a beach buggy, were collected by the WA Dept of Ecology (WADOE, George Kaminisky and Peter Ruggiero) on nine days during the period of time that Argus data were also collected. These days are: 20 Feb 2004, 30 July 2004, 20 Sept 2004, 20 Feb 2005, 23 Aug 2005, 19 Sept 2005, 15 Oct 2005, 15 Nov 2005, and 27 Feb 2006. On all days but 19 September 2005, 15 October 2005, and 27 Feb 2006, there is good quality Argus data available for comparison between these two methods of collecting intertidal bathymetry.

5.1.1 Argus shoreline contour elevation mapping

Good quality Argus data for bathymetric mapping requires good camera-visibility, low amplitude (Hrms < 2m), and a large range of tidal stanzas (waterline elevations) during daylight hours available over a one- to three-day period of time. An additional constraint, that will be discussed in more detail in the following sections, is that Argus shoreline contours be acquired only during flood tides; contours collected during ebb tides will be shown to be of lower quality.

It was determined that for Benson Beach, shoreline contour elevations between 0.69 and 2.26m NAVD88 can be typically obtained in one- to three-day blocks of time, a couple of times per month if both ebb and flood tides are used. In the near future, we will investigate whether this range of elevations is obtainable when restricted further to using data acquired during only flood tide.

The upper 2.26m limit of the shoreline elevation range is MHHW and, as such, is a reasonable reference for the upper bound in sand volume analysis. The 0.69 to 2.26m range also includes the MHW (2.0m NAVD88) datum used by WADOE for shoreline-change monitoring.

Ideally, we would have chosen MLW (0.31m NAVD88) or MLLW (-0.05m NAVD88) as the lower bound. However, it is difficult to obtain these low shoreline elevations, particularly in the winter months when wave heights are higher and the concomitant shoreline elevation expressions of wave setup and swash are greater. In moderate winter wave-height-conditions (Hrms ~ 2m), wave setup and swash can increase shoreline elevation over tidal elevation by order 1m on this beach. Thus, the elevation contribution of wave setup and swash has made it difficult to frequently (i.e., 2x/month) map shoreline elevations below 0.6m NAVD88. The 0.69m NAVD88 bound was the lowest elevation determined to be obtainable at a frequency of 2x per month, again when contours were collected during both ebb and flood tides.

5.1.1.1 Calculating Argus contour elevations

Argus timex images are used to map the x,y position of the 10-minute average shoreline location. Using a 10-minute average provides a clean visual demarcation of the shoreline that averages out both the nominally 10sec wave swash and the longer period, 30-100sec shoreline expression of the infragravity waves.

The shoreline elevation is not measured directly by Argus images. Argus images are two-dimensional images that therefore only map directly onto two-dimensions of space. The interface of the water with the dry-beach identifies the x,y location of a constant elevation. The elevation value is determined by six contributing terms and factors: 1) tides, 2) barometric pressure, 3) wave setup, 4) wind setup, 5) swash amplitude, and 6) the bias of the image in defining the average swash location. Of these, only wind setup is not measured or modeled on this beach; we therefore necessarily limit ourselves to calm wind conditions. Described below are methods for estimating each of the remaining terms and factors.

5.1.1.1.1 Barometrically-corrected tidal elevation

At Benson Beach, we calculate barometric-corrected tides from the modeled tidal elevations and offshore measured barometric pressure (**Section 4.2.1**). Change in sea level due to barometric pressure change is approximated with the simple relationship - 1-mbar decrease in barometric pressure provides a 1cm increase in sea level. Therefore, assuming that 1014-mbar as the standard atmospheric pressure for the tidal predictions,

Corrected tide prediction (cm) = Tide prediction (cm) + (1014 - barometric pressure).

5.1.1.1.2 Wave setup and swash

Wave setup is modeled using the method of Aarninkhof et al (2003) that incorporates the standard wave decay model (Battjes and Janssen, 1978) with the roller model of Svendsen (1984) and Stive and De Vriend (1994) and the inner surf zone bore model (to carry the computations to zero depth) of Aarninkhof and Roelvink (1999).

The swash is also estimated using the method of Aarninkhof et al (2003) of an empirical formulation for sea, swell, and infragravity swash heights as a function of Iribarren number (and therefore of wave height, period, and foreshore beach slope; Holman and Sallenger, 1985; Ruessink et al., 1998).

Both the wave setup and swash amplitude models require input conditions of offshore wave height and period, and the foreshore beach slope. The Hrms wave height and peak period are provided by the offshore NDBC buoy 46029 (Columbia River Bar). Foreshore beach slope is estimated from “uncalibrated” Argus bathymetry. The method of estimating beach slope is explained below in **Sections 5.1.1.1.4 and 5.1.1.2**.

Wave setup and swash elevations both increase with increased wave height, period, and foreshore beach slope. Given that the greatest uncertainty in the shoreline elevation estimate is associated with the modeling of wave setup and swash, as opposed to tides, we minimize potential model error by constraining the Argus shoreline mapping to low wave heights (Hrms < 2m). Argus installations around the world typically constrain shoreline mapping for conditions of Hrms < 1m. However, because offshore rms wave heights rarely fall below 2m during the winter months in the Northwest, we necessarily must tolerate greater wave height conditions.

5.1.1.1.3 Image bias of the average swash location

Extensive studies have been made of the Argus identification of the interface of the water and shoreface (Plant and Holman, 1997; Aarninkhof et al., 1997; Davidson et al., 1997; Aarninkhof and Roelvink, 1999). We employ the "edge detection" method developed at Delft Hydraulics (Aarninkhof and Roelvink, 1999). Comparison of this method with traditional survey techniques has shown that the Argus-detected shoreline location is always shoreward of the actual average swash location. This shoreward bias of the edge detector is ~30% of the swash amplitude (Aarninkhof, pers. comm.). To correct for the bias, a Kosc factor is multiplied on the swash amplitude. Of the five beaches analyzed to date, Kosc varies between 1.22 and 1.56 (Aarninkhof, pers. comm.). The Kosc factor for Benson Beach was determined to be 1.3 by comparing Argus-derived bathymetry with WADOE's GPS-Buggy-derived bathymetry.

5.1.1.1.4 Equation for the Waterline Elevation

The equation used to estimate the elevation of a time-averaged shoreline contour (Zwl) detected using the Argus image and edge detection software is comprised of three elevation terms: 1) barometrically-corrected tide (Ztide, **Section 5.1.1.1.1**), 2) modeled wave setup (Zwave, **Section 5.1.1.1.2**), and 3) modeled swash (Zswash, **Section 5.1.1.1.2**) modified by the factor, Kosc (**Section 5.1.1.1.3**) -

$$Zwl = Ztide + Zwave + (Kosc)(Zswash).$$

5.1.1.2 Argus waterline contour data preparation – estimating foreshore beach slope

To prepare the Argus shoreline waterline data for comparison with GPS-buggy bathymetry data, the foreshore beach slope must first be estimated. To do this, we employ an iterative scheme. In the first pass of this two-step iteration, the initial elevations of the x,y contours are modeled for their Zwave and Zswash contributions assuming a beach slope of 0.025 (**Section 5.1.1.1.2**). From these contours the alongshore-average beach slope of the lowest elevation range of contours available is calibrated (between 0.5 and 1.5m NAVD88 in the analysis presented in this report). In the second, and final pass of this iterative process, the estimated beach slope is used to calculate the final Zwave and Zswash terms and therefore the final total (Zwl) elevation of each of the x,y contours.

It is assumed that any changes in contour elevation between the first pass and second (and final) pass will not materially affect the beach slope calculation because the elevation of all contours will be subject to approximately the same elevation correction. And, it is assumed that this offset will not significantly alter the range of elevation (i.e., 0.5-1.5m) used in the definition of foreshore beach slope.

Table 1 provides the alongshore average (over the 2km of beach) interidal (0.5-1.5m NAVD88) beach slopes used for the final wave setup (Zwave) and swash models (Zswash) contributions to the Argus contour elevation estimations on the six dates compared with GPS Buggy data.

Date	Intertidal Beach Slope	Comments
20 February 2004	0.044	0.053 slope for 1.5-2.5m elev
30 July 2004	0.016	0.042 slope for 1.5-2.5m elev
20 September 2004	0.026	0.028 slope for 1.5-2.5m elev
20 February 2005	0.022	0.026 slope for 1.5-2.5m elev
23 August 2005	0.01	0.015 slope for 1.5-2.5m elev
15 November 2005	0.042	0.042 slope for 1.5-2.5m elev

Table 1. The alongshore average (2km) intertidal (0.5-1.5m NAVD88) beach slope determined from an initial Argus intertidal bathymetry (**Sections 5.1.1.1.2 and 5.1.1.1.4**). Note the large range in intertidal beach slope.

5.1.2 WA DOE intertidal bathymetry maps

The Washington State Dept of Ecology surveys Benson Beach several times a year using an all terrain vehicle (buggy) equipped with RTK GPS. The procedure is to drive the buggy up and down (parallel to) the shoreline covering elevations from nominally +4m to 0m NAVD88 as the buggy follows the tide in and out. These buggy data are provided to NWRA as x,y,z text files after going through quality checks.

It is estimated that the vertical rms error of this buggy data is ~10cm (Ruggiero, pers. comm.). For comparison with Argus bathymetry data, NWRA grids these buggy-track data using a ”loess” interpolation (cross-shore steps = 5m; alongshore steps = 10m). These interpolated data are then ready for comparison with the Argus shoreline contour elevation data.

5.1.3 Comparison of Argus shoreline contours with GPS buggy bathymetry

A comparison of Argus shoreline contour elevations with the GPS-buggy bathymetry provides: 1) confidence in the Argus methods and models, and 2) calibration of the Kosc factor used on the swash term (**Section 5.1.1.1.2**). The Kosc is a term known to vary between 1.22 and 1.56 on the five beaches studied to date. As discussed in **Section 5.1.1.1.3**, this term accounts for the shoreward bias of the identification of the average swash location. On Benson Beach, a Kosc factor of 1.3 was found to be, on the average, the optimal value for maximizing the regression skill between the Argus and Buggy contour elevations over an intertidal range of nominally 0.5 to 3.0m NAVD88. A Kosc of 1.3 is applied in all comparisons provided below.

5.1.3.1 Comparisons: Argus Data Acquired for Flood versus Flood and Ebb Tides

Through the exercise of comparing the Argus and GPS Buggy bathymetries, a pattern was observed that suggested that the best comparisons (lowest offset and rms error) were for Argus contours collected during flood tide. Further investigation confirmed this.

An example of the improvement in Argus contour elevation comparison with WADOE GPS-buggy bathymetry when contours collected only during flood tide are used is shown in

Figure 2. This improvement was found on all six days analyzed (**Table 2**). There was no improvement in the linear regression statistics when the data contained only contours acquired during ebb tide.

In hindsight, we hypothesize that this is a result of the visual clues used by Argus to identify the water edge on this highly dissipative beach. Because it is common for this beach to have a swash that is fully dissipated before reaching the maximum excursion of the swash, there is minimal (white) bore line. Therefore, the shoreline edge detector for this beach may be using the difference between dry and wet sand as a dominant visual clue; other less dissipative beaches have stronger white bores at the water's edge that can provide strong visual demarcations. As such, the detector would expectedly perform better during flood when the tide in encroaching onto a dry beach.

DATE	FLOOD TIDE ONLY		FLOOD & EBB TIDE	
	Mean Error (cm)	RMS Error (cm)	Mean Error (cm)	RMS Error (cm)
20 Feb 2004	-1.4	10.6	11.7	30.6
30 July 2004	-3.4	8.9	-10	18.8
20 Sept 2004	-5.2	9.3	-21.2	26.7
20 Feb 2005	8.9	11.5	10.1	14
23 Aug 2005	0.2	9.3	-11.3	20
15 Nov 2005	-7.3	10.9	-10.2	30.6

Table 2. The mean (offset) and rms error of the linear regression of Argus contour elevations with the average elevation of the interpolated GPS-Buggy data along each of the Argus x,y contours. There are typically 15 contours to compare with elevations spanning 1 to 3m NAVD88. Shown are the statistics for contours mapped during both flood and ebb tides and for contours mapped during only flood tides. The mean and rms error statistics improve significantly when only contours mapped during flood tide are used. No improvement was found with contours mapped during only ebb tides. A Kosc = 1.3 was used in the Argus elevation equation (**Section 5.1.1.1.3**).

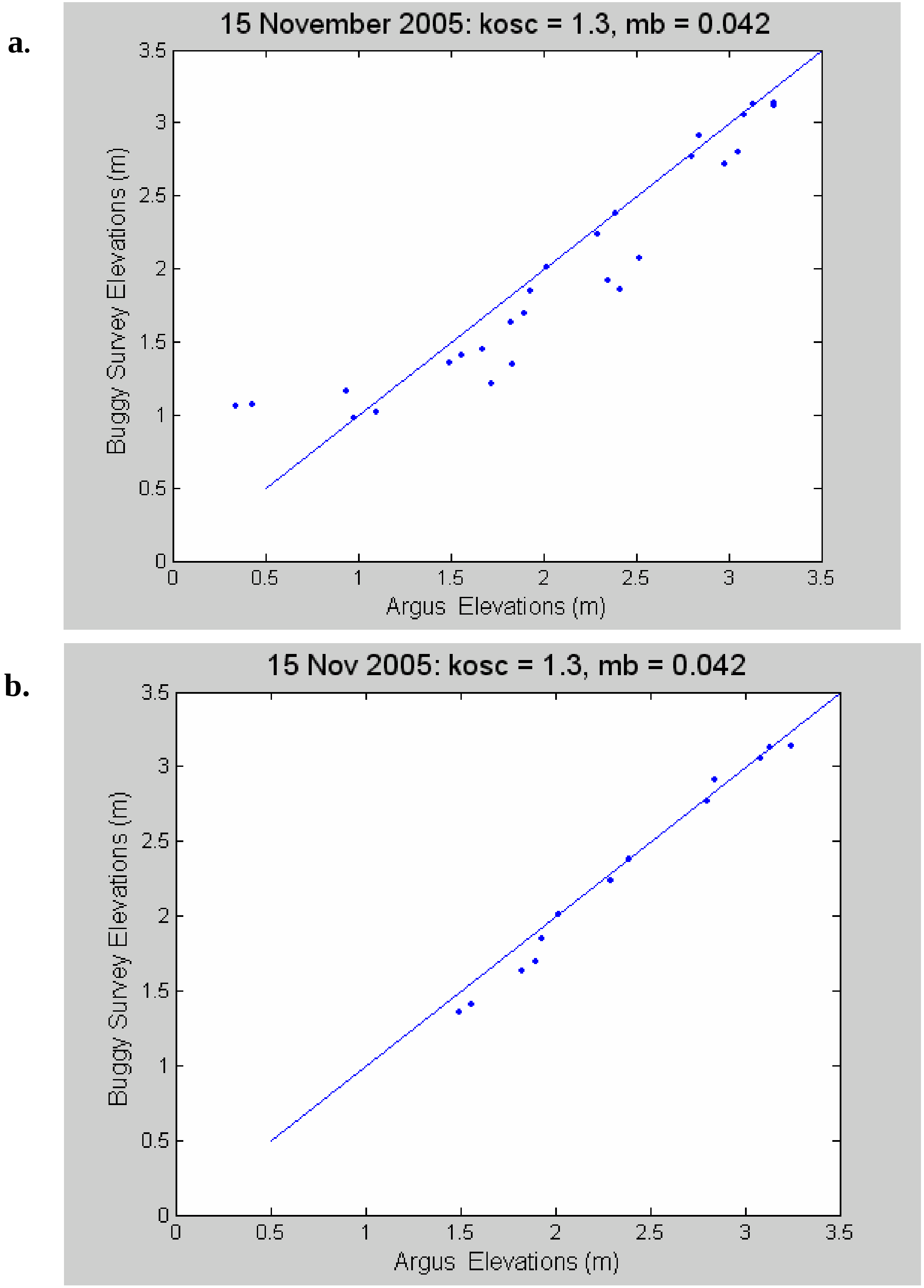


Figure 2. Argus contour elevations compared with the average elevation of the interpolated GPS-Buggy data along each of the Argus x,y contours. Contours acquired during a) both ebb and flood tides, b) only flood tides. The mean (offset) and rms errors are listed in **Table 2**.

5.1.3.2 Comparisons: Argus Estimates Using Measured versus Fixed Beach Slope

As discussed in **Section 5.1.1**, the elevation of a waterline measured by Argus is determined from the barometrically-corrected tides and the wave setup and swash models. Both the models require input conditions for offshore wave height and period, and the foreshore beach slope. The Hrms wave height and peak period are provided by the offshore NDBC buoy 46029 (Columbia River Bar). The foreshore beach slope is estimated from “uncalibrated” Argus intertidal bathymetry (**Section 5.1.1.2**).

The foreshore beach slope (measured typically between the 0.5 and 1.5m NAVD88 elevations) varies on this beach from 0.01 to 0.05. An average foreshore beach slope over this 30-month study was found to be ~0.025. **Table 3** demonstrates the magnitude of the mean and rms error that can occur when the beach slope parameter used to estimate the wave setup and swash amplitude contributions to total elevation does not accurately reflect the measured beach slope.

DATE	MEASURED BEACH SLOPE		FIXED 0.025 BEACH SLOPE	
	Mean Error (cm)	RMS Error (cm)	Mean Error (cm)	RMS Error (cm)
20 Feb 2004	-1.4	10.6	25.2	26.5
30 July 2004	-3.4	8.9	-20.6	22
20 Sept 2004	-5.2	9.3	-4.1	8.6
20 Feb 2005	8.9	11.5	5.3	8.9
23 Aug 2005	0.2	9.3	-24.8	26.4
15 Nov 2005	-7.3	10.9	-6.3	10.8

Table 3. The mean and rms error of the linear regression of Argus contour elevations with the average elevation of the interpolated GPS-Buggy data along each of the Argus x,y contours. Shown are statistics for Argus contour elevations estimated with wave setup and swash contribution modeled for a fixed beach slope of 0.025 and a “measured” beach slope (**Section 5.1.1.2**). The improvement in error using measured beach slope is as significant as the improvement using contours mapped only during flood tide (**Table 2**). A Kosc = 1.3 was used in the Argus elevation equation.

5.1.3.3 Comparisons: Argus and GPS-Buggy 2.0m NAVD88 Contours

The 2.0m NAVD88 contour is the nominal MHW shoreline and a proxy for shoreline location. WADOE and NWRA use this contour elevation to monitor changes in shoreline location and shape. The WADOE 2.0m shoreline contours are measured one to two times per year. Argus 2.0m contours are measured bi-monthly and therefore provide increased temporal resolution of shoreline changes. It is therefore critical that the WADOE Buggy 2.0m NAVD88 contours compare well with the NWRA Argus contours.

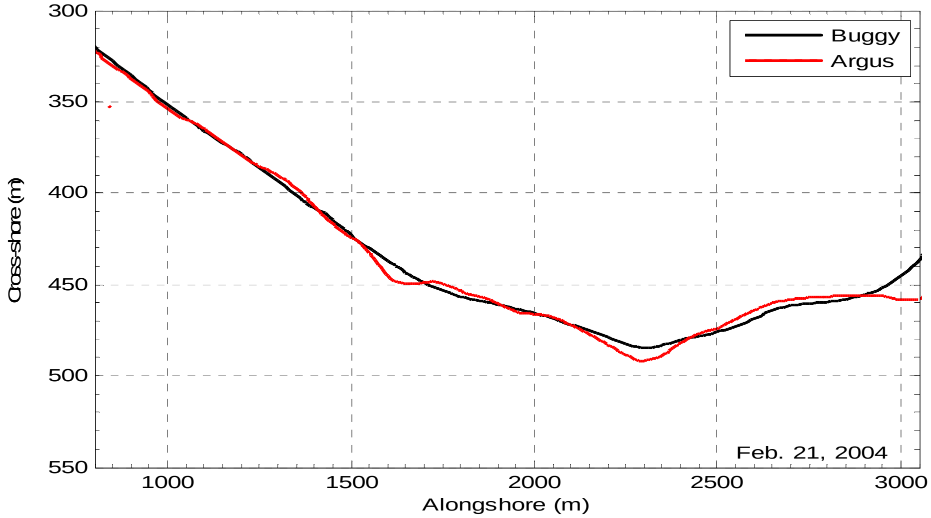
Figure 3 compares the WADOE and Argus 2.0m NAVD88 contour locations. The rms elevation errors between the Argus and GPS Buggy intertidal bathymetries are nominally 10cm (**Table 2**). However, the translation of this error to horizontal error depends on beach slope (**Table 1**).

The comparisons are remarkably good considering the inherent elevation errors of both methods and the interpolation error. The Argus contours are expected to degrade with distance from the camera (increased alongshore position in these figures) because of decreased image resolution. Nonetheless, Argus measurements are in very good agreement out to, and sometimes beyond, 2500m.

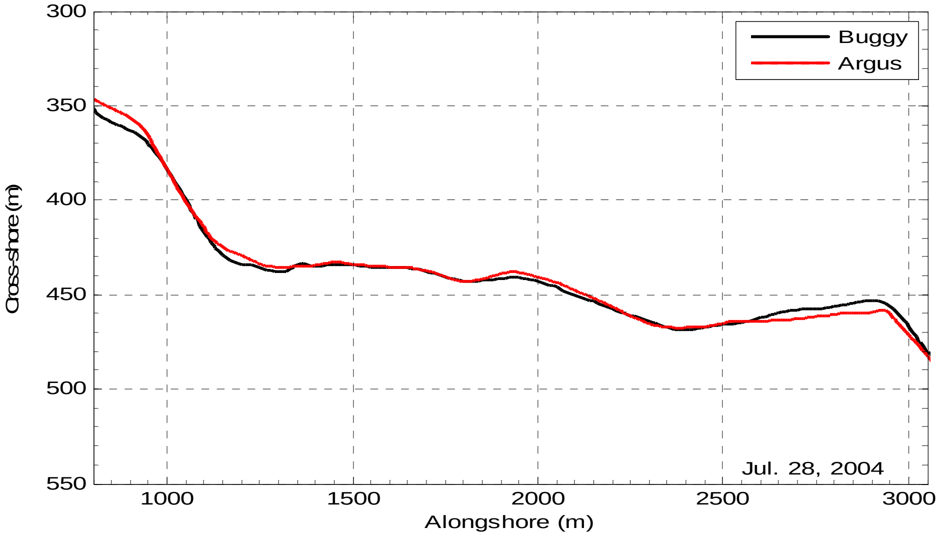
5.1.4 Summary: Argus and GPS-Buggy Bathymetry Comparison

The intertidal bathymetry acquired by NWRA's Argus and WADOE's GPS Buggy have been shown to be in excellent agreement for six bathymetries acquired by both methods between February 2004 and November 2005 (**Tables 2 and 3, Figures 2, and 3**). The alongshore average elevation offset (rms) error between the two methods, for intertidal elevations between 1.0 and 3.0m NAVD88, were found to vary from 0.2 (8.9) to 8.9cm (11.5; **Table 2**). Considering that the expected elevation error for the GPS Buggy system is 10cm (Ruggiero, pers. comm.), the indirect estimation of Argus contour elevations (**Section 5.1.1.1**), and the data interpolation required to compare these two data methods, there is remarkably good agreement; the rms error between the two methods is on par with the expected GPS Buggy system error. **Figure 3** provides the most tangible evidence that both methods are in good agreement.

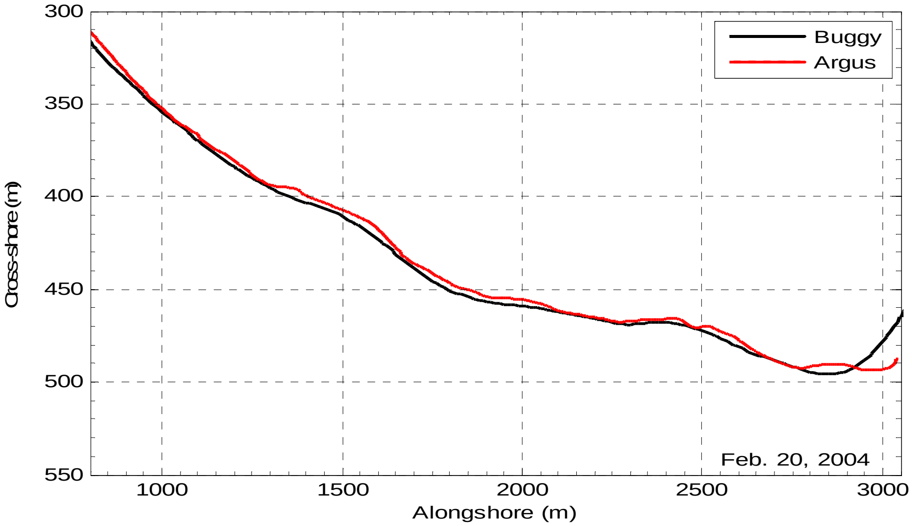
The comparison of these two methods of mapping intertidal bathymetry has resulted in the uncovering of two heretofore previously unknown issues with Argus intertidal mapping on this Northwest beach: 1) the degradation of the quality of the Argus measurement when using contours acquired during ebb tide; 2) the remarkably large changes in foreshore beach slope from storm to storm and concomitant large influence of these slope changes on the Argus contour elevation estimation**.** ***As a result of this exercise, we will be going back through the 30 months of Argus contour data to remove contours acquired during ebb tide, adding new flood tide contours, and reprocessing elevation estimates with "measured" beach slopes using the iterative scheme described.***



Buggy
Argus
Feb. 21, 2004
Cross-shore (m)
Alongshore (m)
300
350
400
450
500
550
1000
1500
2000
2500
3000



Buggy
Argus
Jul. 28, 2004
Cross-shore (m)
Alongshore (m)
300
350
400
450
500
550
1000
1500
2000
2500
3000



Buggy
Argus
Feb. 20, 2004
Cross-shore (m)
Alongshore (m)
300
350
400
450
500
550
1000
1500
2000
2500
3000

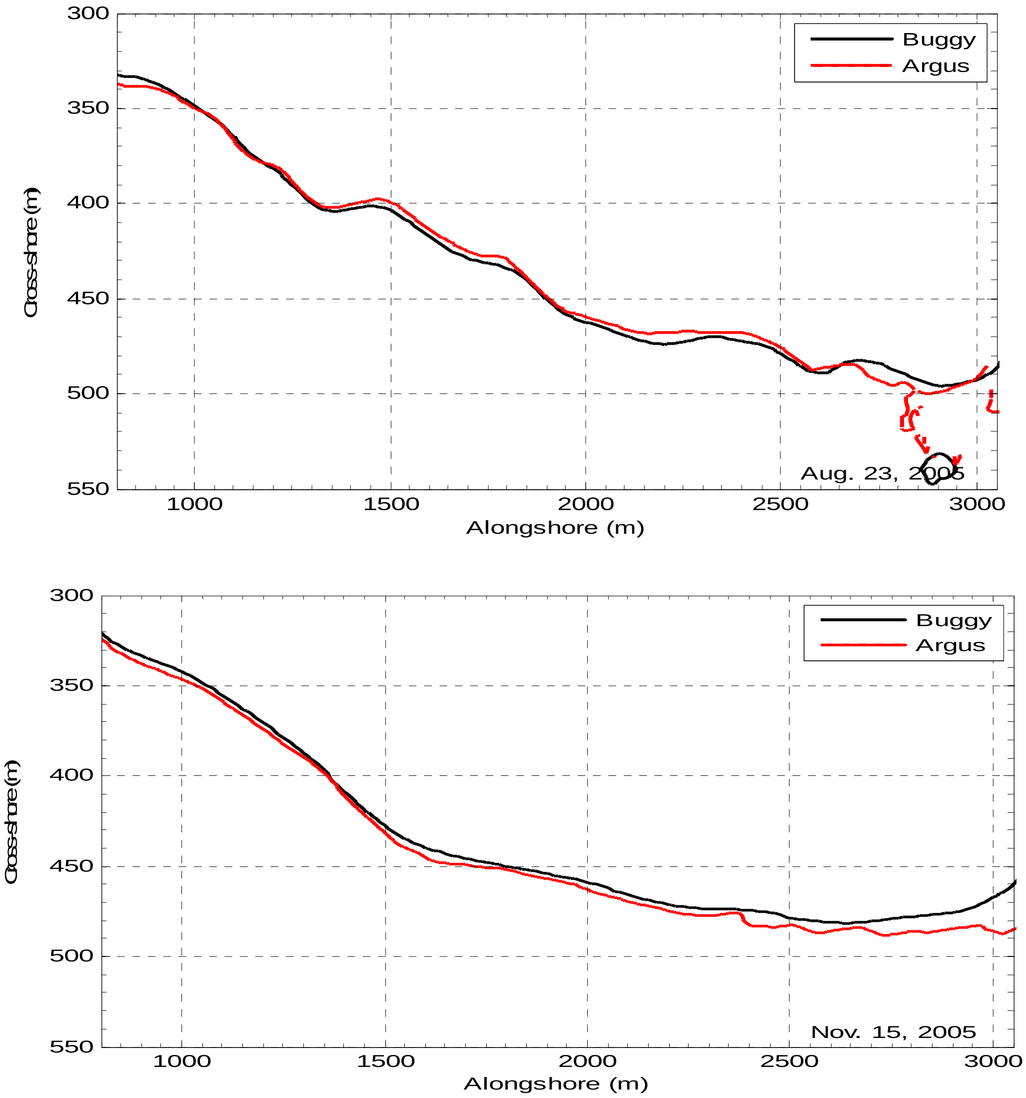


Figure 3. Comparisons of the 2.0m NAVD88 contours as measured by NWRA's Argus and the WADOE's GPS Buggy. The 2.0m elevation contours are from gridded bathymetry with cross-shore steps of 5m and alongshore steps of 5m and 10m for Argus and GPS Buggy, respectively. The comparisons are remarkably good considering the inherent elevation errors of both methods and the interpolation error.

5.2 Basic Data Products

Provided below is a list of data products with descriptions, examples, and product-download availability at NWRA's North Head Argus web site, www.planetargus.com/north_head . Archives of the following basic products can be acquired by clicking on the "Image Archive" links in the left panel:

5.2.1 Hourly images

During daylight, **hourly snapshot, timex, and variance images** (**Section 2.1**) from each of the eight cameras are available from 16 January 2004 forward. These images are updated every hour on the main web page, as well as archived behind the "Image Archive" link. Snapshots from cameras 1 through 4 are additionally available every 20 minutes. These images span the Shallow Water (disposal) Site (SWS) and are used as reference for boaters.

5.2.2 Panoramic and plan-view images

Panoramic and Plan-view images are available from 13 Feb 2004 forward and updated monthly. Only images with acceptable image quality and geometry solutions are used to create these panoramas and plan-views. Therefore this folder can also be used to identify times that met QC requirements. The coordinate system used for the plan-views is the local Argus coordinate for easier reading. However, on request, the NAD83 coordinate system can be applied.

Also available for download on the North Head Argus web site by clicking on the "Results" link in the left panel, and clicking the "Data Briefs" link under "Categories" on the Results web page, are the following products:

5.2.3 Tide and wave field data

Excel spreadsheets that contain **field data (tides and wave statistics)** used in analysis with the Argus images. Field data is provided in calendar years. Filenames are "2004_tides", "2005_tides", 2006_tides, and "NH_waves."

5.2.4 Coordinate reference map

A **Reference map** for converting local Argus coordinates to WA South State Plane coordinates (**Figure 4).** This map is also available as an emf file (for input into MS Word documents) from a link on the "Data Briefs" web page. The filename is, "RefMap." Shown on this map are the North, Middle, and South section reference lines used in the analysis.

5.2.5 Intertidal contour maps

Intertidal contour maps are available from a link on the "Data Briefs" web page in the folder, "IntertidalContourMaps.". The filenames provide information about the files, e.g., “wl_2005.08.21.jpg” denotes this as a jpeg image of intertidal waterlines (wl) acquired on the date, 21 August 2005. **Figure 5** are two examples of intertidal contour maps.

Unlike topo maps, the spacing between contour lines does not provide a visual clue on slope. Instead, the contour lines identify the range and coverage of the Argus survey. Each contour map is a collection of waterline-surveys taken at different tidal stanzas. The maps are generated every two to four weeks; the frequency of map generation is dependent on the range of tides that are available during daylight. For consistency between maps and map analysis products, we choose collection periods that will allow the acquisition of a range of contours from at least 0.69m to 2.26m NAVD88.

5.2.6 Intertidal bathymetry data

For each Argus intertidal bathymetric survey, **Excel files containing intertidal bathymetry data**, in both local Argus coordinates and WA South State Plane coordinates, are provided in the ftp folder, “IntertidalBathymetryData” that is available from a link on the “Data Briefs” web page. The filenames provide information about the files, e.g., “NHIntertidalBathy_2005_03_23.xls” indicates that this bathymetry was acquired on the date, 23 March 2005. Survey data is acquired every two to four weeks; the frequency of intertidal bathymetric data acquisition is dependent on the range of tides that are available during daylight. For consistency, we attempt to collect a range of contours from at least 0.69m to 2.26m NAVD88.

In the next report, these bathymetric data will be reprocessed with Argus waterline contour data restricted to those acquired during flood tides and with the 2-step, iterative beach slope scheme used to more accurately model the wave setup and swash contributions to waterline elevation (Section 5.1).

5.2.7 MHW (2.0m NAVD88) contour locations – a statistical summary

A statistical summary of the Benson Beach **2.0m NAVD88 contour locations** between February 2004 and September 2006 is shown in **Figures 6 and 7**. An emf (for input into MS Word documents) figure and an Excel spreadsheet (“2004_02_2006_09_2.0_shoreline.xl”) of the contour locations can be downloaded from a link on the “Data Briefs” web page.

Also shown in these figures are the contour lines on September 2005, 30 March 2006, and September 2006. These contours are representative of the pre-winter, post-winter, and post-recovery beach conditions, respectively.

In the previous report (Report #3), a study of these and other map statistics indicated that on the south end of the beach, the 2.0m contour has retreated to its 2004 location after having experienced sustained accretion in 2005. And, that the shoreline is at a new minimum (shoreward) location on the north side following the 2005/2006 winter (Figure 7). Figure 6 of this report indicates that the 2006 recovery summer season took the beach to a new maximum (seaward) shoreline location in the middle (2000m) section of this beach but that northern and southern shorelines remain significantly shoreward from the shoreline locations of previous summers.

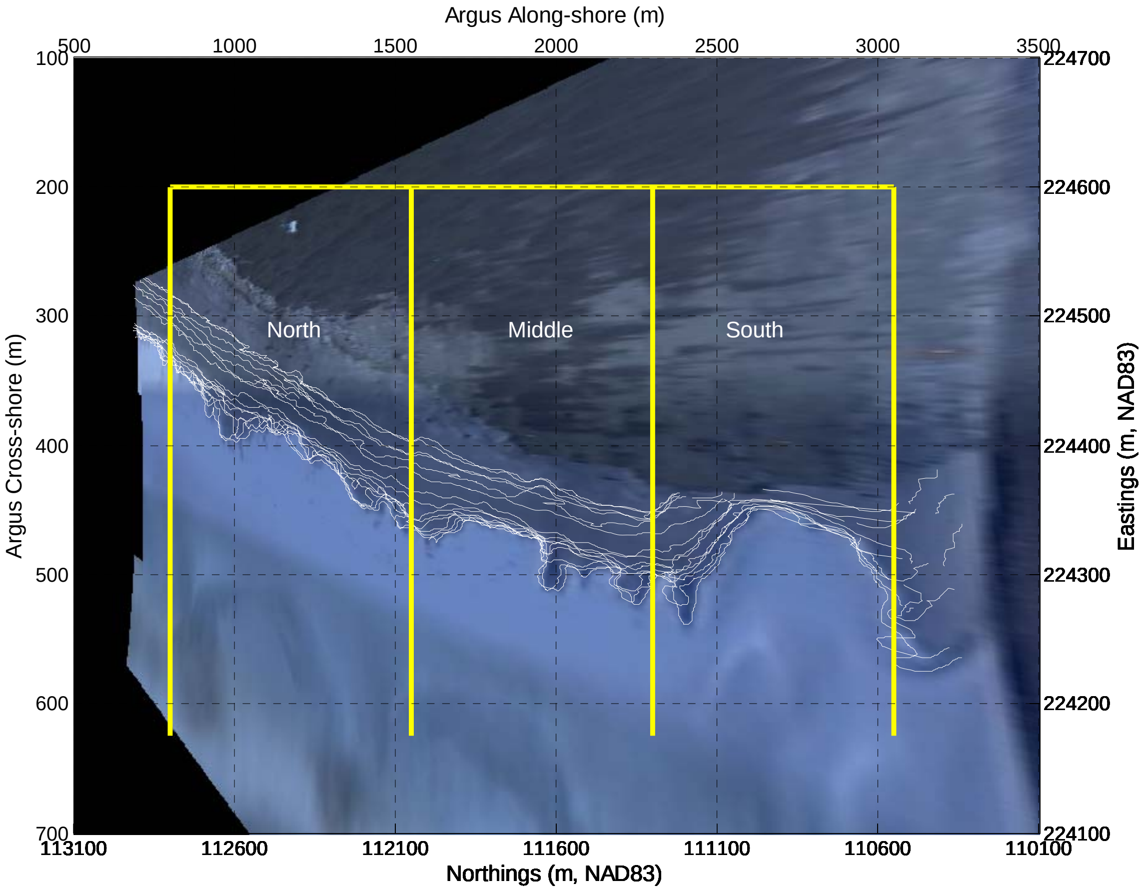


Figure 4. Reference map for converting local Argus coordinates (m) to WA South State Plane coordinates (m, NAD83). Also shown on this map are the North, Middle, and South section partitions used in the analysis of shorelines, dry-beach acreage, and intertidal volumes for this report. (X (local Argus) = - [NAD83 Eastings (meters) – 224800 meters]; Y (local Argus) = - [NAD83 Northings (meters) – 113600 meters]).

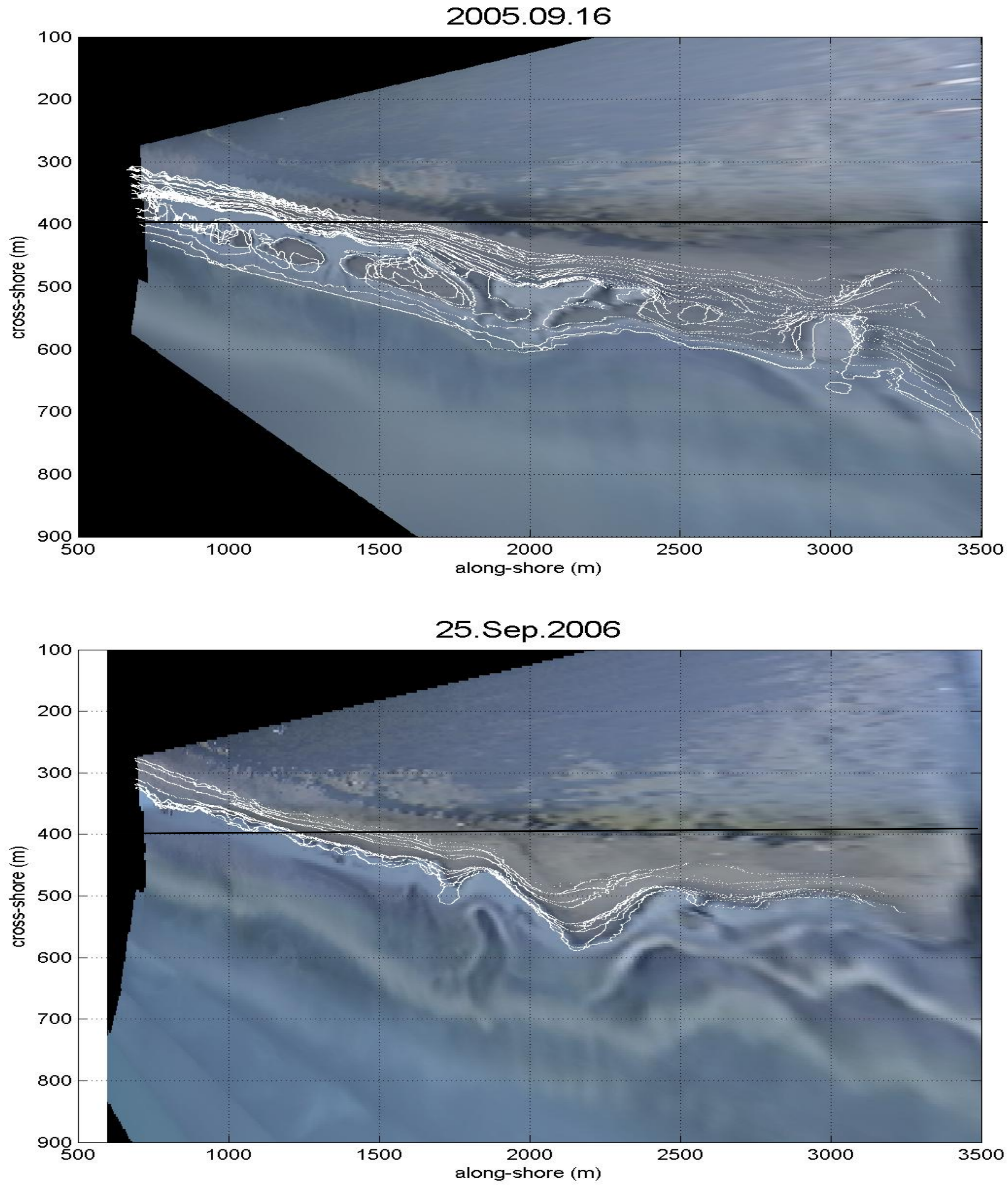


Figure 5. Intertidal bathymetric contours (white lines) overlain on Argus timex plan-views in September of 2005 and 2006. Contour lines are not separated by equal elevation intervals. For reference, the most shoreward (seaward) contours for September 2005 and September 2006 are 3.98 m NAVD88 (0.14m) and 3.73m (-0.4m), respectively. Note the change in location of the vegetation line about 2500m and the retreat on the north side.

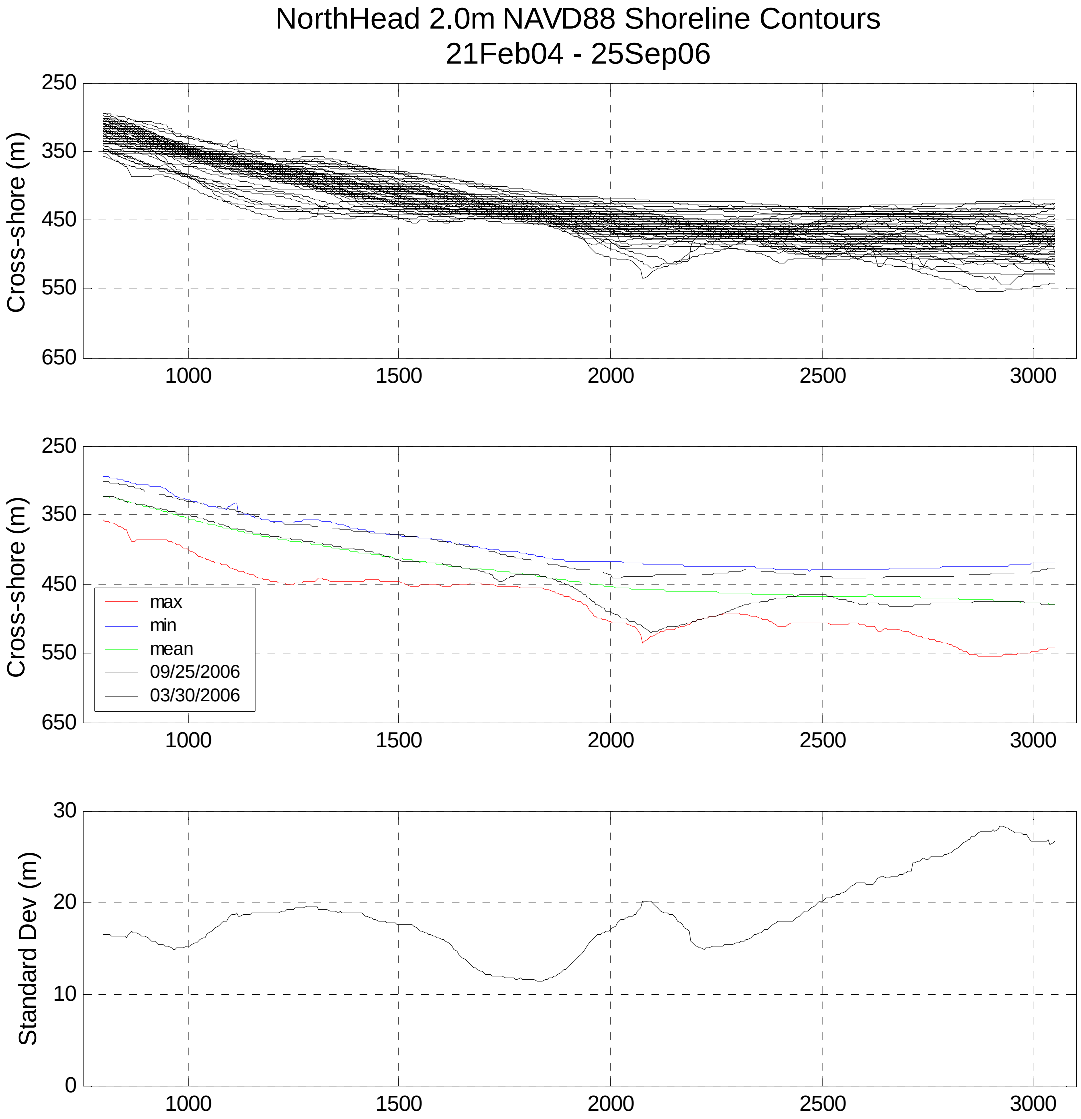


Figure 6. Benson Beach 2.0m NAVD88 shoreline contours and statistics for February 2004 through September 2006: a) contour locations referenced as distance from the arbitrary baseline shown in **Figure 4**; b) the average and extreme (minimum and maximum) shoreline locations; c) the standard deviation of the shoreline location. Also shown are the 30 March (dashed) and 25 Sept (solid) 2006 contours marking the end of the winter 2005/2006 storm season and the summer 2006 recovery season, respectively. Note that the 2005/2006 storm season took the beach to new shoreline minimums (shoreward location) in the north section and the 2006 recovery season took it to new maximum (seaward) shoreline location in the middle (2000m) of this stretch of beach.

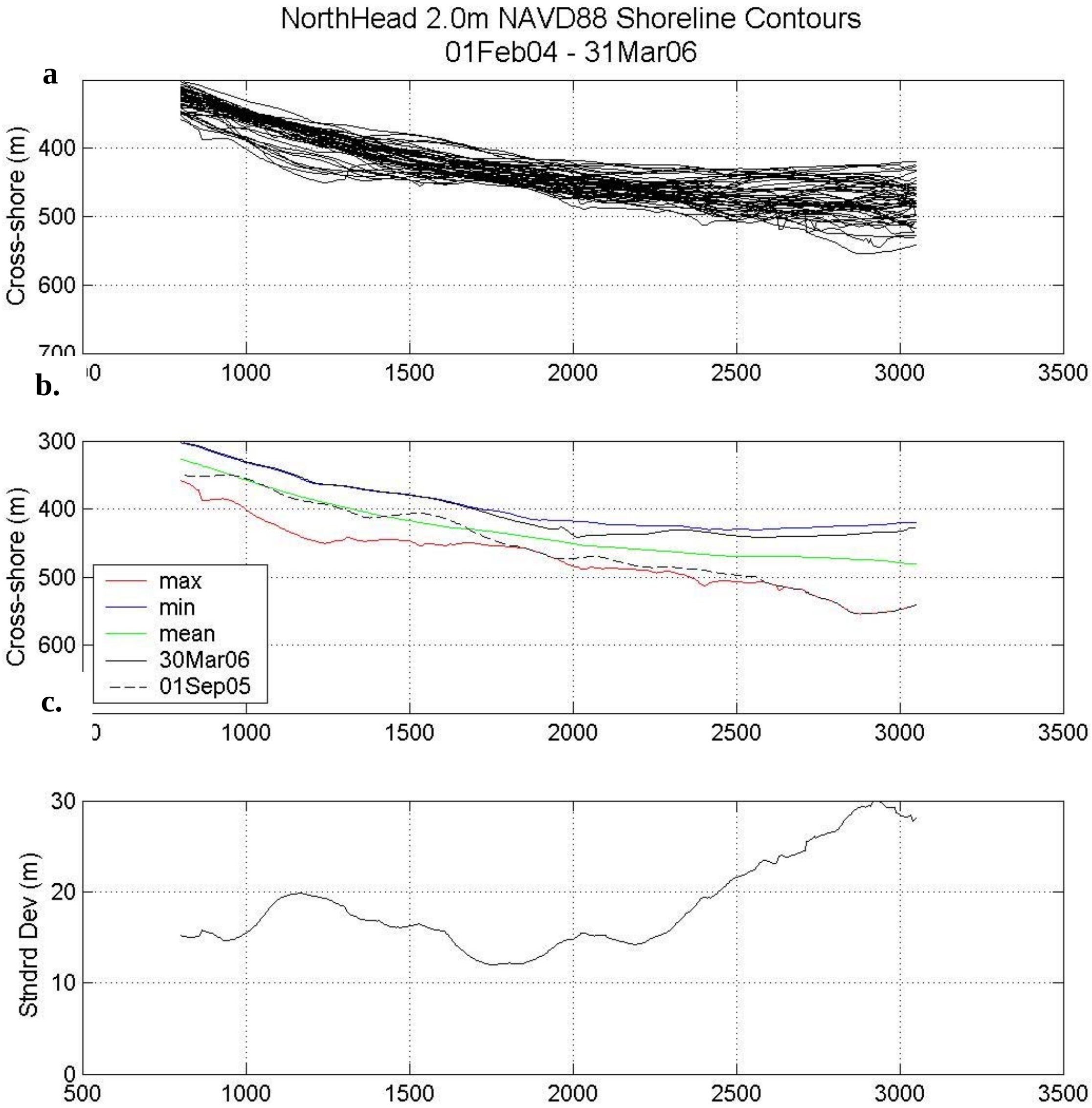


Figure 7. Benson Beach 2.0m NAVD88 shoreline contours and statistics for February 2004 through March 2006: a) contour locations referenced as distance from the arbitrary baseline shown in **Figure 4**; b) the average and extreme (minimum and maximum) shoreline locations; c) the standard deviation of the shoreline location. Note the higher variability of the shoreline at the south end. Also shown are the 1 Sept 2005 and 30 March 2006 contours marking the beginning and end of the 2005/2006 storm season. Comparing this with **Figure 6** shows the new shoreward migration in the middle section (2000m) of the beach during the summer 2006 recovery period. (Taken from Report #3)

5.2.8 MHW shoreline shape changes

1) Another way to look at 2.0m NAVD88 **shoreline shape changes** is provided in **Figures 8 and 9**. Individual shape maps are available from a link on the “Data Briefs” web page in the ftp directory, “AcreageShapeMaps.” The filenames denote the date of the map. Dry-beach area is also calculated, noted in each shape image, and provided as an Excel spreadsheet on the web site with filename “2004_02_2006_09_acreage.xls.”
2) **Intertidal sand volume and dry-beach acreage change** between February 2004 and September 2006 is shown in **Figure 10**. An emf figure is available from a link on the “Data Briefs” web page. The filename is “Volume_T_2004_02_2006_09.emf.” Volume data are also provided in Excel files “2004_09_2006_09_data_T_3050_2.26Z_loess.xls.” Also shown for reference are the periods of time when the north jetty was undergoing repair and dredge material (3, 2.6 and 1.8 MCY in 2004, 2005, and 2006, respectively) was placed in the SWS.
3) The spatial and temporal variability of sand bar locations between February 2004 and September 2006 are mapped using image processing techniques developed, tested, and verified over the past twenty years. Most of the early work occurred at the USACE Field Research Facility in Duck, NC (e.g. Lippmann and Holman, 1989, 1990). More recently, engineers at WL| Delft Hydraulics have applied this remote sensing method to various beaches in Europe, Asia, and Australia (e.g. Wijnberg and Terwindt, 1995; Ruessink et al, 2003).

   The sand bar morphology variability can be succinctly summarized in a slide show. A folder of jpeg files is provided on the web site in the ftp folder, “SandBarMaps” from a link on the “Data Briefs” web page, for this purpose. **Figure 11** is an example of sand bar mapping.

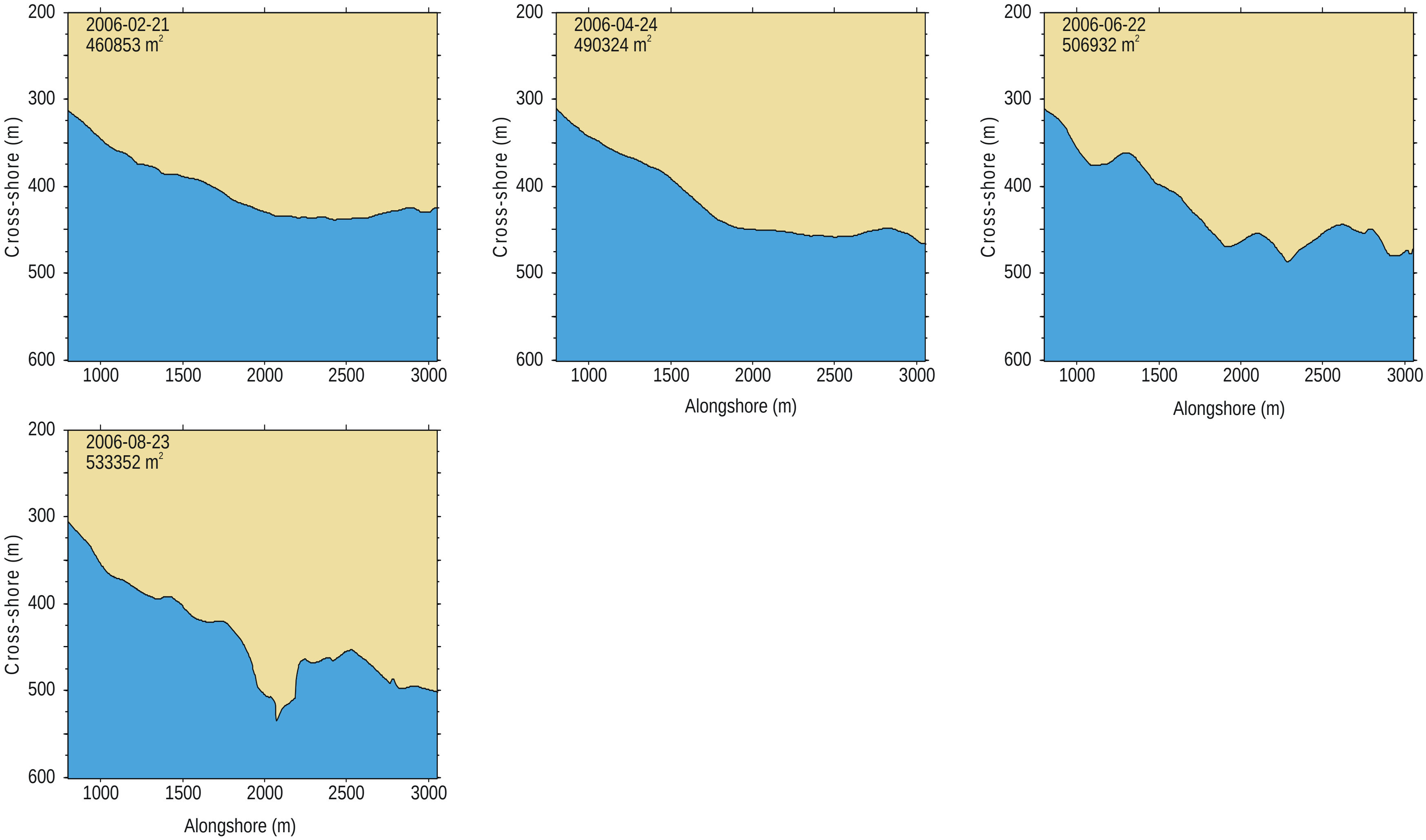


Figure 8. Shape maps of the 2.0m NAVD88 contour from the end of the 2005/2006 storm season to the end of the 2006 summer recovery season. Dry-beach area, between the arbitrary bench mark (x = 200) and the 2.0m NAVD88 contour is calculated and noted in each shape image. Note the absence of any significant recovery in the northern section of the beach.

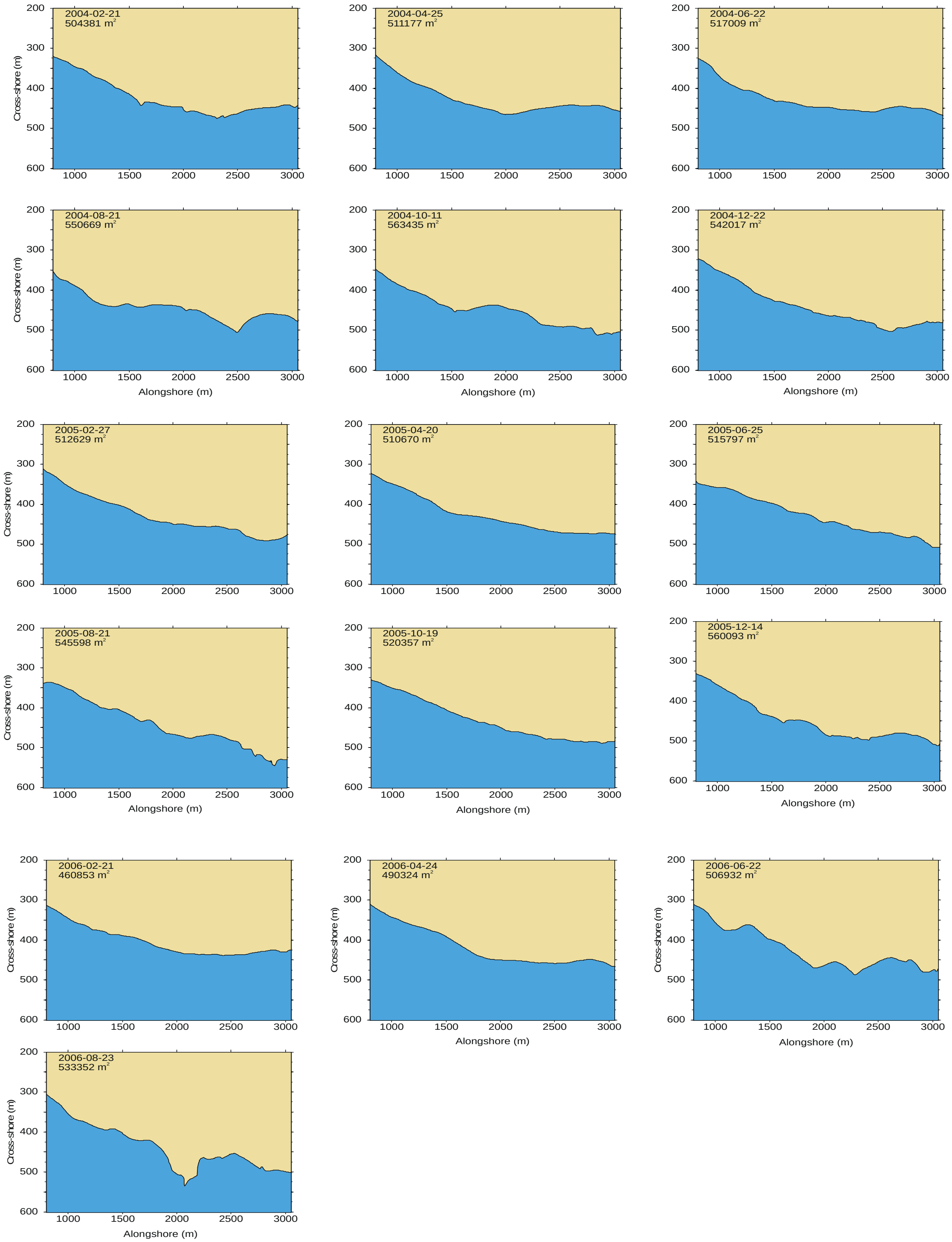


Figure 9. Shape maps of the 2.0m NAVD88 contour in two-month intervals between February 2004 and August 2006.

a.

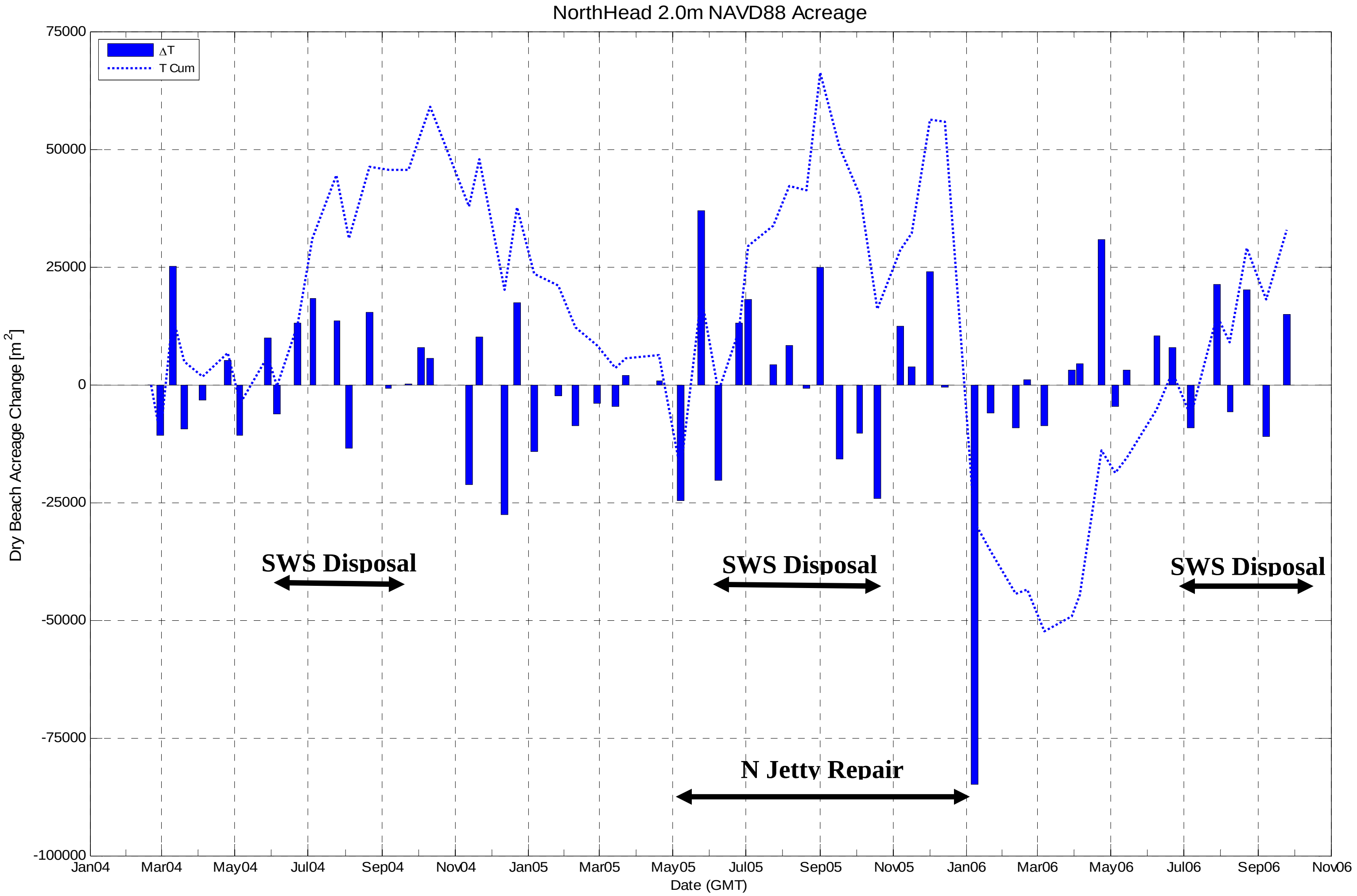
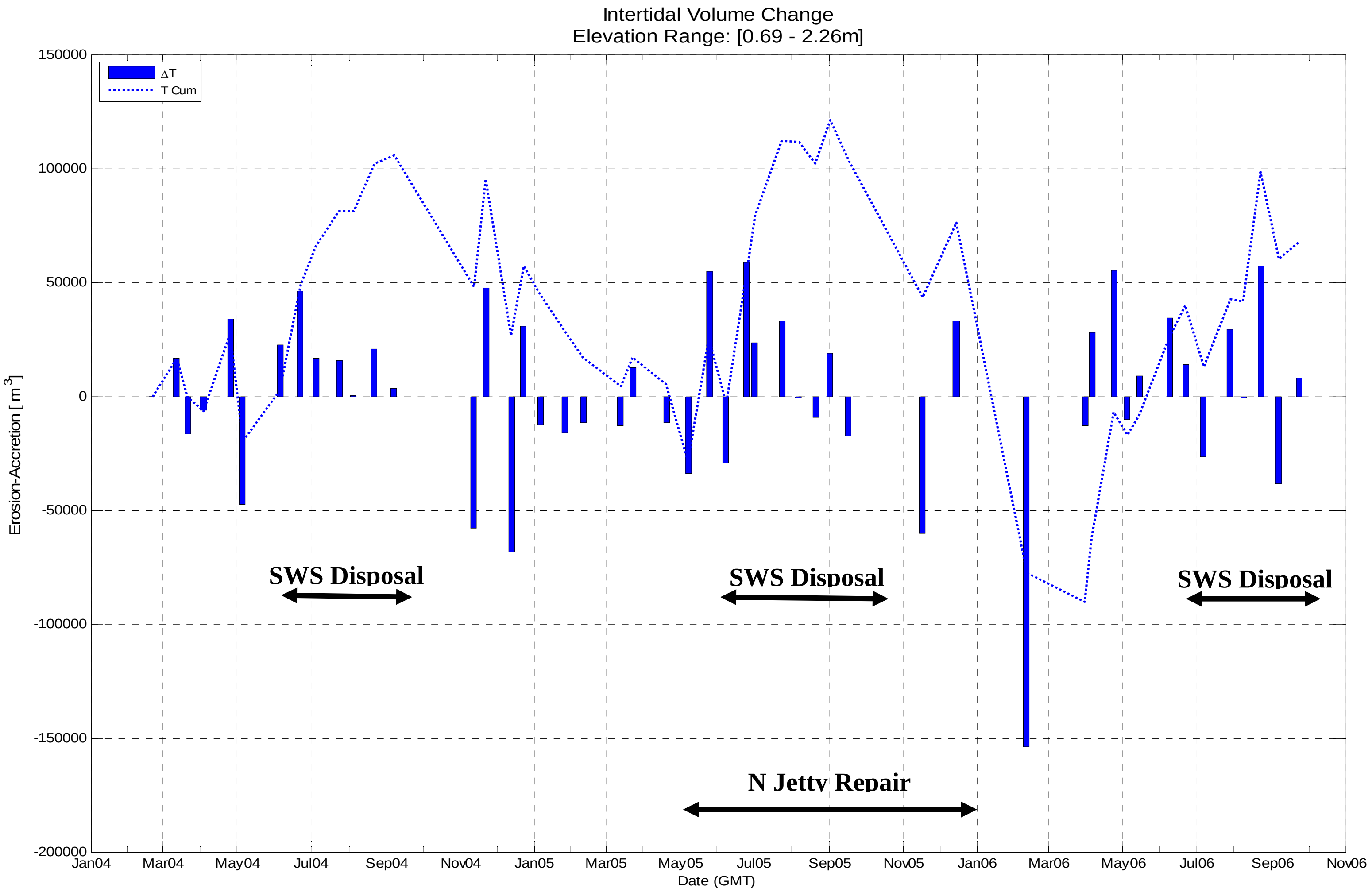


Figure 10. a) Total (T) intertidal san`d volume and b) dry-beach changes from February 2004 through September 2006. Sand volumes are between 0.69 and 2.26m NAVD88 and y = 800 and 3050m; acreage is described in Figure 8. Shown are the change (   ) and cumulative change (TCum). Provided for reference are the periods of time when the north jetty was undergoing repair and dredge material (3, 2.6 and 1.8 MCY in 2004, 2005, and 2006, respectively) was placed in the SWS.

b.


Intertidal Volume Change
Elevation Range: [0.69 - 2.26m]
ΔT
T Cum
Erosion-Accretion [m^3]
150000
100000
50000
0
-50000
-100000
-150000
-200000
Jan04
Mar04
May04
Jul04
Sep04
Nov04
Jan05
Mar05
May05
Jul05
Sep05
Nov05
Jan06
Mar06
May06
Jul06
Sep06
Nov06
Date (GMT)
SWS Disposal
SWS Disposal
SWS Disposal
N Jetty Repair

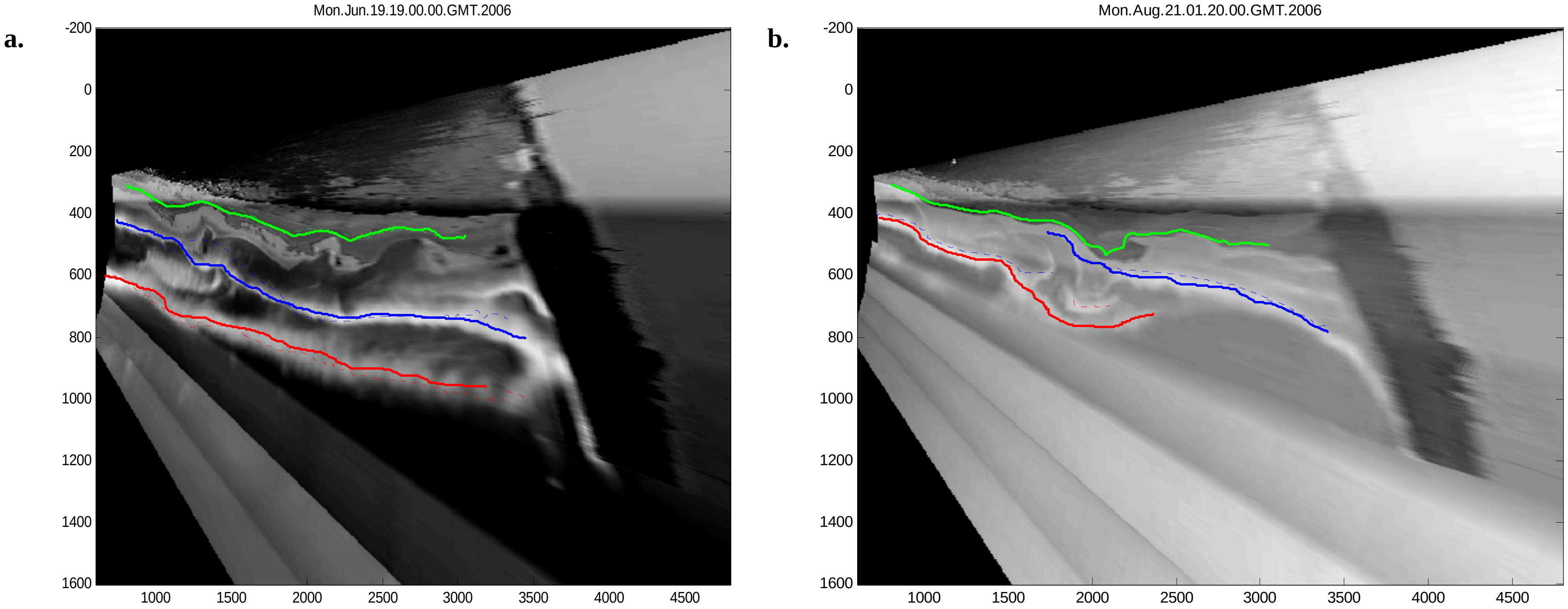


Figure 11. Maps of sub-aqueous sand bars. Solid red and blue lines mark the location of the outer and middle submerged sand bar crest, respectively; the dashed lines are the last measured location of the crest (typically measured 2 weeks earlier). Also shown in green is the 2.0m NAVD88 elevation contour. The seaward protrusion of the 2.0m contour indicates that sand has accreted in the intertidal region about the 2000 location between June and August during which time the northern section of the outer sand bar migrated inshore. The middle bar appears to have attached to the shoreline north of the 2.0m shoreline protrusion and may provide low wave energy conditions for further build up of sand between it and the 2.0m contour to the south of the protrusion.

6. DATA ANALYSIS TOWARD A CONCEPTUAL SEDIMENT PROCESS MODEL

In the previous section, data products were presented with a modicum of description or interpretation. In this section, these products are discussed and derivative products are presented as an aid in developing a conceptual understanding of the Benson Beach sediment system.

6.1 Summary of Findings to Date

Our understanding of the process dynamics of Benson Beach and the implications of these processes for both beach recovery and dredge material placement are summarized to date in three findings below and presented in more detail in the following sections.

- **Finding #1**: The dominant seasonal signal of loss and recovery of dry-beach acreage and intertidal sediment volumes on Benson Beach is associated with the summer onshore migration and attachment of sand bars onto the shoreface and the winter detachment of the sand bars and migration offshore.
    - In addition, there is alongshore variation of the sand bar movement resulting in shoreline contour shape changes.
- **Finding #2**: The summer time disposal of dredge material on the SWS is not only optimal for safety but may also be optimal for sediment transport away from the MCR and onto Benson Beach. SWS sediment may feed the offshore sand bars that then in turn migrate shoreward during the summer months, feeding the inner bars that attach to the shoreface as swash bars. Further study is required to substantiate this.
    - Consideration: Observations on beaches in the Netherlands have shown that the placement of sand on the outside flank of an outer sand bar is optimal for maintaining shorelines at their 1990 locations (a national policy). Thus, the placement of dredge material on the outside flank of the outer bar at Benson Beach in the summer may help to make Benson Beach a repository for the sediment, available for both the protection of Ft Canby Camp Grounds and for net northward transport. ***Feed the sand bars, feed the beach***?
- **Finding #3**: Potential long-term loss (35,000 sq meters) of dry beach acreage (i.e., net shoreward movement of the 2.0m NAVD88, MHW position) is evident at Benson Beach in the Argus surveys following the harsh 2005/2006 winter. The previous 2003/2004 and 2004/2005 winter losses of dry-beach acreage along the full stretch of Benson Beach fully recovered the following summer.
    - Possibility: After extreme episodic events, such as Winter 2005/2006, a new baseline for sediment change may be established about which the seasonal sand bar movement once again changes the beach.

6.2 Finding #1: The dominant seasonal signal of dry-beach acreage and intertidal volume changes on Benson Beach is associated with sand bar movement

The dominant seasonal signal of loss and recovery of dry-beach acreage and intertidal sediment volumes on Benson Beach (**Figure 10**) is associated with the summer onshore migration and attachment of sand bars onto the shoreface and the winter detachment of the sand bars and migration offshore.

In addition, there is alongshore variation of the sand bar movement resulting in shoreline contour shape changes (**Figures 8 and 9**).

6.2.1 On the importance of sand bars in sediment transport

The most significant finding of the previous report (**Report #3**) is the importance of sand bars as a mechanism for sediment transport in the intertidal zone of Benson Beach. Evidence provided showed both a 500m on/offshore range of sand bar movement and bar attachment to the shoreface (**Report #3: Section 5.3.2 and Figures 19-21**).

6.2.2 Sand bars and the concomitant changes in shoreline contour shape

Observations continues to indicate that changes in the shape of Benson Beach (e.g., the shape of the 2.0m NAVD88 or MHW contour) comes about primarily from alongshore variable sand bar morpho-dynamics (presence, absence, movement, attachment, and detachment). Evidence was provided of the alongshore non-uniformity of bar accretion and detachment (**Report #3: Section 5.3.3 and Figures 21-23**). **Figure 11** of this report provides an additional example of alongshore non-uniform sand bar attachment to the shoreface.

In 2004 the middle and south sections of the beach were aligned approximately north-south (**Figure 9**). In 2005, the beach re-oriented to a NE-SW alignment. In 2006, it appears to have re-adjusted to the 2004 orientation. Beaches are understood to adjust to the dominant direction of storm waves (Donlan et al., 1977; Komar, 1998). Analysis of the local wave direction by way of the deep water directions at the Columbia River buoy and wave refraction over Peakcock Spit will be a good place to start in studying beach orientation as a function of local wave incidence.

Figure 12 details the intertidal sand volume and dry-beach acreage change between February 2004 and September 2006 for the North, Middle, and South sections (**Figure 4**) of the beach. By sectioning the beach into a North, Middle, and South sections, we can examine the changes that result in shoreline contour shape changes**.**

6.2.3 Intertidal sand volume changes as a proxy for intertidal beach profile changes

Sand volume measures are between 0.69m and 2.26m NAVD88. A net change in this volume measurement along the full stretch of Benson Beach denotes an average change in the beach shape between 0.69 and 2.26m NAVD88 (see explanation below). Therefore intertidal sand volume change can be used as a proxy for intertidal beach profile shape changes.

Simple geometry provides that for a fixed elevation range, <u>sand volume decreases</u> will occur when there is:

a. Increase (steepening) in beach slope and therefore decrease in the volume of the prism wedge defining the intertidal volume
    i. this could happen as <u>smaller,</u> <u>summer waves</u> build a steeper, planar equilibrium beach profile (Shepard, 1950; Bascom, 1953; Komar, 1998)
b. detachment of a swash bar or further movement of a sand bar offshore with development of a trough between the foreshore and the sand bar (King and William, 1949; Davis and Fox, 1972; Hayes, 1972, Komar, 1998)

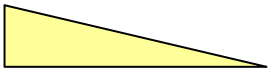
        - i. offshore sand bar movement is expected in <u>high-amplitude, winter-wave</u> conditions (Keulegan, 1948; Komar, 1998; Lippmann and Holman, 1990, 1993; Ruessink et al, 2000)
- c. change in beach profile shape from a planar or concave shape to a convex shape
    - i. however, these shape changes more often translate to smaller volume changes than a) or b)

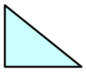
Similarly, for a fixed elevation range, <u>sand volume increase</u> will occur when there is:

- d. decrease in beach slope
    - i. <u>large-amplitude, winter-waves</u> build a lower sloping, planar equilibrium beach profile (Shepard, 1950; Bascom, 1953; Komar, 1998)
- e. attachment of a swash bar with filling in of a sand bar troughs (King and William, 1949; Davis and Fox, 1972; Hayes, 1972, Komar, 1998)
    - i. this onshore sand bar movement is expected in small, <u>summer-wave</u> conditions (Keulegan, 1948; Komar, 1998; Lippmann and Holman, 1990, 1993; Ruessink et al, 2000)
- f. change in beach profile shape from a planar or convex shape to a concave shape

The expected seasonal behavior of planar and sand bar beaches and their concomitant change in intertidal sand volume, as measured between two fixed elevations, is summarized in **Table 4**. On Benson Beach, the summer dry-beach acreage growth (seaward movement of the MHW) coincides with growth of the intertidal sand volume (yellow box under summer season) and the winter acreage decrease coincides with a decrease in intertidal sand volume (blue box under winter season). **Table 4** indicates that Benson Beach intertidal morphodynamic changes are therefore dominated by sand bar movement.

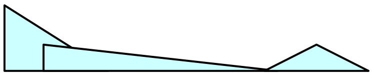
Planar Beaches:





Dominant Morphodynamics	**Winter Season**	**Summer Season**
Planar beaches	Slope decrease	***Slope increase***
Sand bar	***Bar moves offshore***	Bar moves onshore

Sand Bar Beaches:



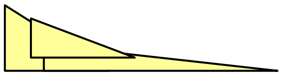


Table 4. Expected changes in intertidal sand volume (***blue = decrease***; yellow = increase) for the seasonal morphodynamic changes associated with planar and sand bar beaches.

a.

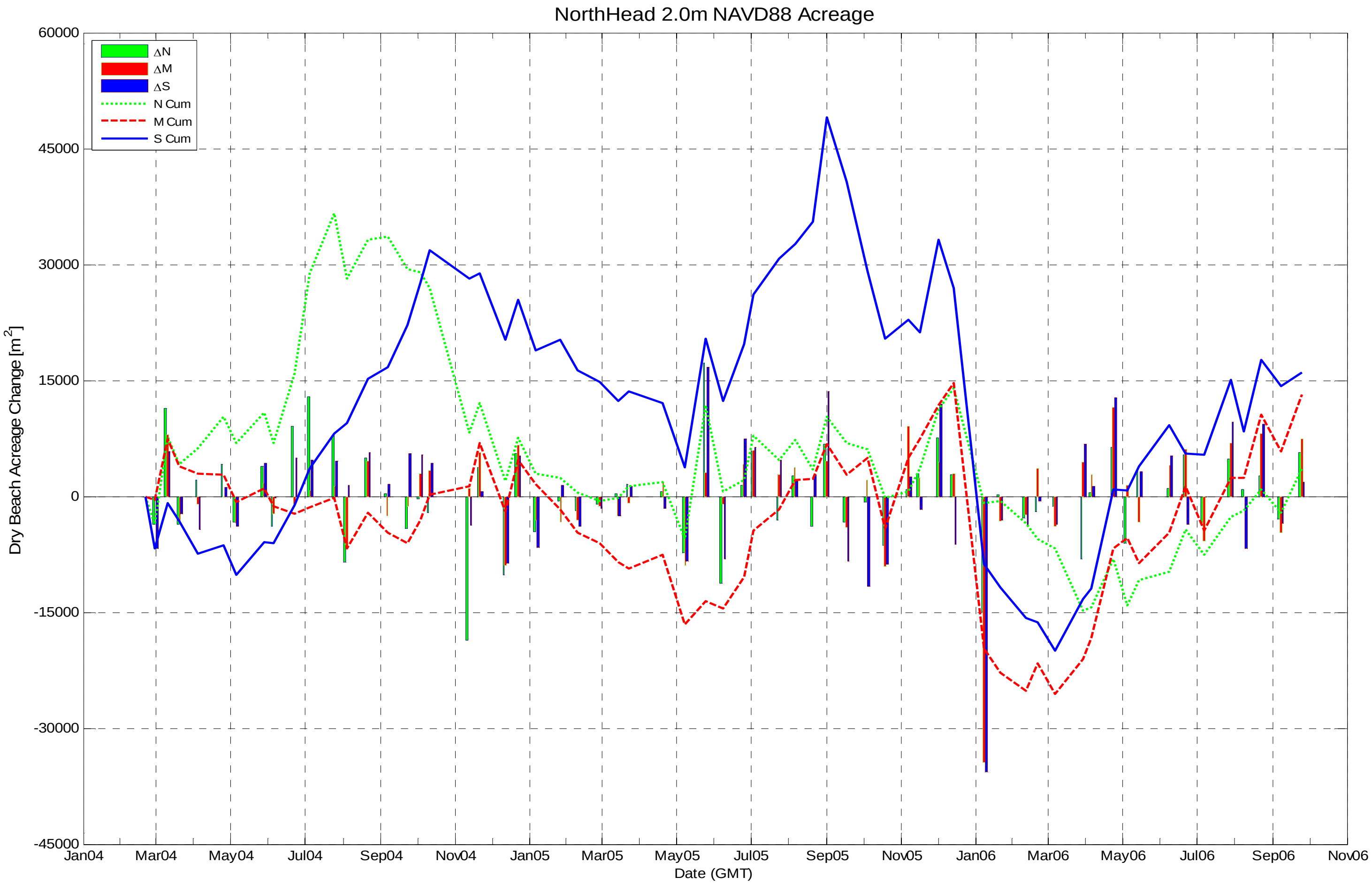
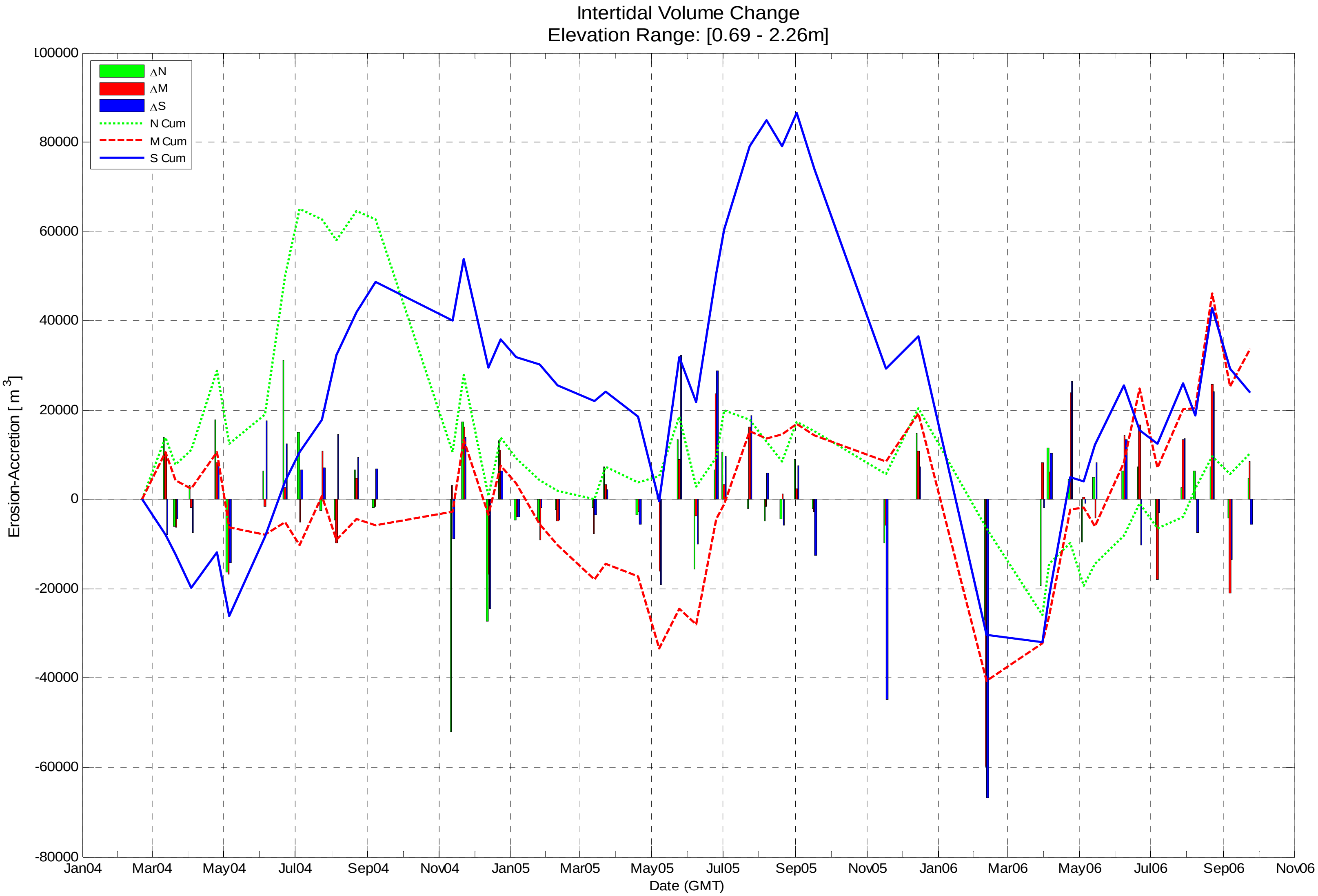


Figure 12. a) Dry-beach acreage and b) intertidal sand volume changes from February 2004 through September 2006 in the North, Middle, and South sections of the beach (**Figure 4**). Sand volumes are between 0.69 and 2.26m NAVD88 and y = 800 and 3050m; acreage is described in **Figure 8**. Shown are the change (ΔT) and cumulative change (TCum). Provided for reference are the periods of time when the north jetty was undergoing repair and dredge material (3, 2.6 and 1.8 MCY in 2004, 2005, and 2006, respectively) was placed in the SWS.

b.



Intertidal Volume Change
Elevation Range: [0.69 - 2.26m]
ΔN
ΔM
ΔS
N Cum
M Cum
S Cum
Erosion-Accretion [m^3]
100000
80000
60000
40000
20000
0
-20000
-40000
-60000
-80000
Jan04
Mar04
May04
Jul04
Sep04
Nov04
Jan05
Mar05
May05
Jul05
Sep05
Nov05
Jan06
Mar06
May06
Jul06
Sep06
Nov06
Date (GMT)

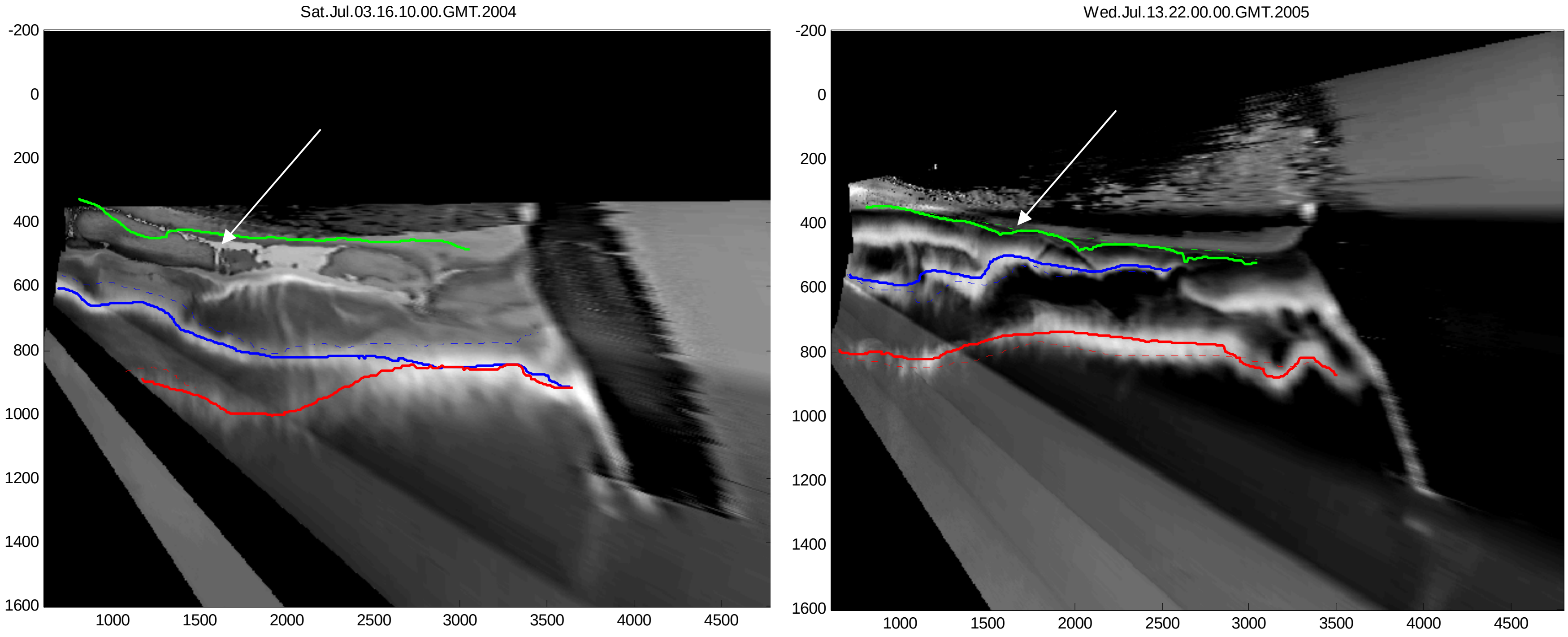


Figure 13. Further evidence of the role of sand bars in intertidal elevation contour and sand volumes changes. Solid red and blue lines mark the location of the outer and middle submerged sand bar crest, respectively; the dashed lines are the last measured location of the crest (typically measured 2 weeks earlier). The green line is the 2.0m NAVD88 elevation contour. Attachment of the inner sand bar (shoreward of the blue, middle bar) to the shoreface and the concomitant movement of the 2.0m contour seaward are observed in the north section in Summer 2004 but not in Summer 2005.

6.2.4 The role of sand bars on the <u>north</u> section of Benson Beach

A review of **Figure 12a** reveals that there was net seaward movement of the MHW position (accretion) in Summer 2004 (~30,000 m^2) followed by the expected winter erosion (loss of the ~30,000 m^2). The concomitant increase in sand volume in Summer 2004 (**Figure 12b**) suggests that sand bar attachment to the shoreface is the reason for the seaward movement of the MHW contour. Similarly, the decrease in sand volume in the subsequent winter indicates that the winter movement of the MHW contour shoreward was due to sand bar detachment. And, the absence of subaerial acreage growth in Summer 2005 suggests that the sand bar apparently did not return to the shoreface in Summer 2005.

Further evidence of the role of sand bars in intertidal elevation contour and sand volume changes, is found in the July 2004 and 2005 sand bar maps (**Figure 13)**. Attachment of the inner sand bar (shoreward of the blue, middle bar) to the shoreface is observed in the north section in Summer 2004 but not in Summer 2005. Not shown here, but available on the web site is the sand bar map showing the detachment of the Summer 2004 bar in October 2004.

6.2.5 The role of sand bars on the <u>middle</u> section of Benson Beach

A review of **Figure 12** reveals that in this middle section of Benson Beach, there was little movement of the MHW position or change in the intertidal sand volume in 2004. And, the sand bar maps indicate no significant attachment of the inner bar to the shoreface in this section of beach at this time (i.e., **Figure 13**). In fact, there is a breach in the inner sand bar in this middle section of the beach.

In Winter 2004/2005, **Figure 12** shows winter dry-beach acreage and intertidal sand volume losses followed by recovery in the Summer 2005 indicating new sand bar activity in this section of the beach. (Sand bar activity is also evident in the sand bar maps on the web site.) Summer beach recovery exceeded thresholds of Summer 2004.

6.2.6 The role of sand bars on the <u>south</u> section of Benson Beach

Figure 12 indicates that the south section of the beach experienced net seaward movement of the MHW position and net increase in intertidal sand volume from Winter 2003/2004 until the Winter 2005/2006; the winter and summer changes were superimposed on a 2-year trend in growth. The sand bar maps (available on the web site) suggest that sand bars were feeding this net growth.

6.3 Finding #2: The summer time disposal of dredge material on the SWS is not only optimal for safety but may also be optimal for sediment transport away from the MCR and onto Benson Beach.

Although speculation at this juncture, there is already some basis to consider that SWS sediment may feed the offshore sand bars that then in turn migrate shoreward during the summer months, feeding the inner bars that attach to the shoreface as swash bars. Evidence to suggest this is as follows:

a) Observations in Argus time-averaged images of a wave break pattern sweeping north from the SWS (Oltman-Shay et al, LCRSG meeting, Ilwaco, July 2007).

   i) Wave breaking is an indication of shallow water, and in this case, suggestive of northward movement of the sand from the SWS.

b) Model studies (Gelfenbaum et al., March 2006 presentation at the LCSG meeting in Portland) indicate northward movement of sand from the SWS with a similar dispersal pattern as observed in the Argus images.

c) Surveys of the SWS in November 2005, after dredge disposal from June through October, indicated that ½ of the deposited sediment had moved off the SWS to the north (McKillip, pers. commun.)

d) Argus sand bar images showing a nominally 500m on- and off-shore movement of the outer and middle bars of the three-bar system at Benson Beach and the shoreface attachment of the inner bar in the summer months (**Report #3**)

e) Field studies indicate that the Columbia River littoral cell has net transport northward (Gelfenbaum et al., 2001; Kaminsky et al., 2001, 2003; Ruggiero et al., 2005, 2006)

f) Model, field, and lab studies by the Dutch that demonstrate that a good way to feed the intertidal zone of a beach is to place sediment on the outer flank of the outer sand bar of a beach

   i) This is the present practice of the Dutch whereby 9 million of the 12 million cu-m of sand placed on there beaches annually is now placed on the outer flank of their sand bars (Rijkwaterstadt presentations to the USACE CERB, June 2007)

Consideration: The placement of dredge material on the outside flank of the outer bar of Benson Beach in the summer may help to make Benson Beach a repository for the sediment, available for both the protection of Ft Canby Camp Grounds and for net northward transport during the winter. ***Feed the sand bars, feed the beach***?

6.4 Finding #3: Potential long-term loss (35,000 sq meters) of dry beach acreage (i.e., net shoreward movement of the 2.0m NAVD88, MHW position) is evident following the harsh 2005/2006 winter.

The previous 2003/2004 and 2004/2005 winter losses of dry-beach acreage along the full stretch of Benson Beach fully recovered the following summer. Extreme events like the Winter 2005/2006 storms can set new baselines for seasonal changes in beach contours and sand volumes (**Figure 10**). In the following sections, the affect of this extreme winter is examined for the north, middle, and south sections of the beach.

6.4.1 2005/2006 winter affect on the <u>north</u> section of Benson Beach

This section experienced a new extreme in shoreward movement of the MHW shoreline in the Winter 2005/2006 with ~70% of the loss in subaerial beach recovered in Summer 2006 (**Figure 12**). Intertidal sand volume changes also indicate that the beach did not fully return to its Summer 2005 shape having 10,000 cu meters less intertidal sand volume in Summer 2006. Unlike seasonal changes in MHW location and intertidal sand volume, this loss due may be due to the encroachment of the shoreline onto the steeper back dune (**Figure 5**).

6.4.2 2005/2006 winter affect on the middle section of Benson Beach

The middle section also saw a new extreme in shoreward movement of the MHW shoreline in the Winter 2005/2006 (**Figure 12**). However, unlike the North section, all of the loss in subaerial beach was recovered in Summer 2006.

Recovery of intertidal sand volume in 2006 exceeded volumes in 2005 by 20,000 cu meters. This gain is likely due to a flattening of the intertidal beach as it is building out seaward (**Figure 11**).

6.4.3 2005/2006 winter affect on the south section of Benson Beach

A new extreme in shoreward movement of the MHW shoreline in the Winter 2005/2006 was also observed for the south section (**Figure 12**). And, only 50% of the loss in subaerial beach was recovered in Summer 2006. Intertidal sand volume changes also indicate that the beach did not fully return to its Summer 2005 shape having 40,000 cu meters less intertidal sand volume in Summer 2006. This loss is may be due to a steepening of the previously flat intertidal beach as it is eroding and the MHW shoreline is moving shoreward.

7. REFERENCES

Aarninkhof, S.G.J., P.C. Janssen and N.G. Plant, 1997. Quantitative estimations of bar Dynamics from video images. *Proc. of Coastal Dynamics Conf., Plymouth, UK*, p.p. 365-374.

Aarninkhof, S.G.J. and J.A. Roelvink, 1999. Argus-based monitoring of intertidal beach morphodynamics. *Proc. of Coastal Sediments Conf., Long Island (NY), USA,* p.p. 2429-2444.

Aarninkhof, S.G.J. and J.A. Roelvink, J.A., 1999. Argus-based monitoring of intertidal beach morphodynamics. *Proc. of Coastal Sediments Conf., Long Island (NY), USA,* p.p. 2429-2444.

Aarninkhof, S.G.J., I.L. Turner, T. Donkers, M. Caljouw, and L. Nipius 2003. A video-based technique for mapping intertidal beach bathymetry. *Coastal Engineering 1073.*

Bascom, W. H., 1953. Characteristics of natural beaches. *Proceedings of the 4th Coastal Engineering Conference, Amer. Soc. Civil Engrs*, pp. 163-180.

Battjes, J.A. and J.P.F.M. Janssen, 1978. Energy loss and set-up due to breaking in random waves. *Proc. of 16th Int. Conf. on Coastal Eng. ASCE*, pp. 569-587.

Buijsman, M.C., P. Ruggiero, and G.M. Kaminsky, 2001. Sensitivity of shoreline change predictions to wave climate variability along the southwest Washington coast, USA, *Proceedings of the 4th Conference on Coastal Dynamics, ASCE, Lund, Sweden*, pp. 617-626.

Buijsman, M.C., C.R. Sherwood, A.E. Gibbs, G. Gelfenbaum, G.M. Kaminsky, P. Ruggiero, and J. Franklin, 2003. Regional sediment budget of the Columbia River littoral cell, USA: Analysis of bathymetric- and topographic-volume change, *U.S. Geological Survey Open File Report*, 02-281.

Davidson, M., D. Huntley, R. Holman, and K. George, 1997. The evaluation of large scale (km) intertidal beach morphology on a macrotidal beach using video images. *Proc. Coastal Dynamics Conf., Plymouth, UK*, p.p. 385-394.

Davis, R.A., and W.T. Fox, 1972. Coastal processes and nearshore sand bars. *Journal of Sedimentary Petrology*, 42: 401-412.

Donlan, R., B. Hayden, J. Heywood, and L. Vincent, 1977. Shoreline forms and shoreline dynamics. *Science* 197, 49-51.

Gelfenbaum, G., M.C. Buijsman, C.R. Sherwood, H.R. Moritz, and A.E. Gibbs, 2001. Coastal evolution and sediment budget at the mouth of the Columbia River, USA, *Proceedings of the 4th Conference on Coastal Dynamics, ASCE, Lund, Sweden,* pp. 818-827.

Hayes, M.O., 1972. Forms of sediment accumulation in the beach zone. *In Waves on Beaches, R.E. Meyer (editor), New York: Academic Press*, 297-356.

Holman, R.A. and A.H. Sallenger Jr., 1985. Setup and swash on a natural beach. *Journal of Geophysical Research 90*, 945-953.

Kaminsky, G.M., M.C. Buijsman, D. McCandless, and P. Ruggiero, 2003. Erosion potential analysis of Benson Beach, Report to the Washington State Parks and Recreation Commission, *Washington Department of Ecology publication No. 05-06-101,* 78 p.

Kaminsky, G.M., M.C. Buijsman, and P. Ruggiero, 2001. Predicting shoreline change at decadal scale in the Pacific Northwest, USA, *Proceedings of the 27th International Conference on Coastal Engineering, ASCE, Sydney, Australia*, pp. 2400-2413.

Keulegan, G.H., 1948. An experimental study of submarine sand bars. *U.S. Army Corps of Engineers, Beach Erosion Board, Technical Report No. 5.*

King, C.A.M. and W.W. Williams, 1949. The formation of and movement of sand bars by wave action. *Geographical Journal* 113: 70-85.

Komar, P. D., 1998. Beach processes and sedimentation. *Prentice-Hall, Inc.*

Lippmann, T.C. and R.A. Holman, 1989. Quantification of sand bar morphology: a video technique based on wave dissipation, *J. Geophys. Res.,* 94, p. 995-1011.

Lippmann, T.C. and R.A. Holman, 1990. The spatial and temporal variability of sand bar morphology, *J. Geophys. Res.,* 95(C7) 11575-11590.

Lippmann, T.C. and R.A. Holman, 1993. Episodic, non-stationary behavior of a double bar system at Duck, North Carolina, USA, 1986–1991, *J. Coastal Res., Special Issue No. 15*, 49–75.

Plant, N.G. and R.A. Holman, 1997. Intertidal beach profile estimation using video images. *Marine Geology* 140, 1-24.

Ruessink, B.G., M.G. Kleinbans and P.G.L. Van Beukel, 1998. Observations of swash under highly dissipative conditions. *Journal of Geophysical Research* 103, 3111-3118.

Ruessink, B.G., I.M.J. van Enckevort, K.S. Kingston and M.A. Davidson. 2000. Observations of two- and three-dimensional sandbar behaviour. 169, 161-183.

Ruessink, B.G., K.M. Wijnberg, R.A. Holman, Y. Kuriyama & I.M.J. Van Enckevort, 2003. Intersite comparison of interannual nearshore bar behavior, *J. Geophysical Research* 108(C8).

Ruggiero, P., M.C. Buijsman, G. Kaminsky, and G. Gelfenbaum, submitted. Modelling the effect of wave climate and sediment supply variability on large-scale shoreline change, *Marine Geology*.

Ruggiero, P., G.M. Kaminsky, G. Gelfenbaum, and B. Voigt, 2005. Seasonal to interannual morphodynamic variability along a high-energy dissipative littoral cell, *Journal of Coastal Research,* (21) 3 pp. 553-578.

Shepard, F.P., 1950. Beach cycles in Southern California. *U.S. Army Corps of Engineers, Beach Erosion Board, Technical Memo No 20.*

Stive, M.J.F. and H.J. De Vriend, 1994. Shear stresses and mean flow in shoaling and breaking waves. *Proc. Int. Conf. Coastal Eng. ASCE,* pp.594-608.

Svendsen , I.A., 1984. Wave heights and set-up in a surf zone. *Coastal Engineering* 8, 303-329.

Wijnberg, K.M. & J.H.J. Terwindt, 1995. Quantification of decadel morphological behavior of the central Dutch coast, *Marine Geology*, 126, 301-330.