Monitoring Shoreline And Beach Morphologic Change At Kennedy Space Center, Cape Canaveral, Florida

Final Report, May 2009- Oct. 2013

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Executive Summary

This final report provides a summary of work conducted for the period 1-May-2009 through 30-Sep-2013, as required by contract #98217 between the University of Florida (UF) and InoMedic Health Applications (IHA), the environmental contractor for the National Aeronautics and Space Administration (NASA). In addition, this report provides special attention to the work conducted over the most recent reporting period (1-Oct-2012 through 30-Sep-2013), whose results were not previously reported upon. Findings from work conducted prior to October 2012 can be found in previous annual reports (Jaeger et al., 2010; Jaeger et al., 2011; Adams et al., 2012).

A presidential initiative has been proposed to improve, expand, and modernize the Kennedy Space Center infrastructure. Even with the modernization efforts, launch operational imperatives will keep much of that infrastructure within 800 m of the Atlantic Ocean coastline. Shoreline retreat near existing infrastructure threatens these facilities as well as critical endangered-species habitat along several kilometers of the Cape Canaveral shoreline. The drivers of the spatial patterns of accretion and erosion observed at KSC have not been identified, but are likely due to sea level rise and interaction of the offshore wave energy with the unique shoal bathymetry and the underlying geologic framework.

To better understand the evolving geomorphology and patterns of shoreline accretion and retreat along the Cape Canaveral coast, UF researchers, in collaboration with the United States Geological Survey (USGS), have established a monitoring project at the NASA-KSC site. The project uses real time kinematic (RTK) global positioning system (GPS) field surveys, remote sensing via fixed camera observations, wave monitoring and modeling, and sediment analyses.

UF has been collecting high spatial density RTK-GPS data since May 2009, resulting in 72 RTK-GPS surveys over the study period. Of the 72 individual surveys conducted, 53 represent "regular-monthly" observations and 20 represent "rapid response" observations, which were conducted to better document the retreat and recovery of the beach as a result of a particular high-energy wave event (a distant or nearby storm). Data from all surveys have been quality-controlled, analyzed, and provided to IHA personnel. Herein, we report on the full record of shoreline change monitoring, including the period not addressed in the previous Annual Reports (Phases 1, 2, and 3). The fixed camera observations provided a proxy record of nearshore (subtidal) morphologic change over the northern-most ~3km of the study region – from the Eagle 4 security tower southward, since April 2010. The remote sensing/camera work was presented in Task 2 of the Phase 2 Annual Report for this project (Jaeger et al., 2011). Wave monitoring and wave transformation modeling has revealed a complex refraction pattern, which varies as a function of deep-water wave direction and period, due to the Cape Canaveral shoal complex. This refraction pattern likely explains the presence of erosional hotspots (EHS) that threaten NASA-KSC infrastructure. The wave modeling work was presented in Task 3 of the Phase 2 Annual Report for this project (Jaeger et al., 2011). Beach sediment samples were collected to assess the sedimentary characteristics of the study area for the period May 2009-May

2011. The beach sediment analysis work was presented in Task 4 of the Phase 2 Annual Report for this project (Jaeger et al., 2011).

Over the 53-month study period, the NASA-KSC beach exhibited spatially distinct, seasonal behavior. As a result of our study, we have organized the NASA-KSC coastal reach into 4 (alongshore) regions on the basis of this spatially consistent behavior. Beach width, as measured from the dune crest to the position of the mean high water shoreline position, is the primary metric used in this assessment. Beach width variability is greatest at the north end of 'False Cape', where the historical trend in shoreline position transitions from decadal narrowing (to the north) to decadal widening (to the south). In each of the 4 regions, a seasonal signal in shoreline position (beach width) is evident, characterized by beach widening from late spring to early fall and abrupt retreat during winter nor'easter season.

Introduction

The effects of climate change on sea level and ocean wave conditions will produce changes in spatial and temporal patterns of nearshore water levels and sediment transport, resulting in morphologic adjustment of beach and dune systems. Recent geomorphic changes within the coastal zone at Kennedy Space Center (KSC), Cape Canaveral, Florida, are threatening NASA infrastructure and have altered endangered wildlife habitat. Because of the lack of previous coastal information at this site, there is a critical need to provide a baseline understanding of the coupled beach-dune response to the wave climate.

Since 2008, the USGS has been conducting a dune vulnerability study to provide a decision support system for the environmental management team at NASA-KSC. A major component of this project requires observations of shoreline and beach morphologic variability in order to assess current risk and to help predict and evaluate future risk.

In support of the USGS study, and to better understand the coastal geomorphology and patterns of shoreline accretion and retreat along the Cape Canaveral coast, a project was initiated by the University of Florida (UF), using real time kinematic (RTK) Global Positioning System (GPS) surveys to monitor beach topographic change. We focus in this report on presenting shoreline width results, as this parameter directly influences the potential (along with dune height) for dune inundation and/or erosion during storm events. Initially, UF conducted a 12-month pilot study of topographic monitoring from May 2009 – April 2010. The findings from that work are summarized in the Annual Report for Phase 1 (Jaeger et al., 2010). After the pilot study, UF was contracted for an additional year of observations, which expanded the effort to include remote sensing via fixed camera observations, wave monitoring and modeling, and sediment analyses in addition to the ongoing RTK-GPS topographic monitoring. The findings from that work are summarized in the Annual Report for Phase 2 (Jaeger et al., 2011). Following Phase 2, UF was awarded an additional two-year contract to continue only the RTK-GPS surveys to monitor beach topographic change. This report provides results from the final year of observations (Oct.

1, 2012 – Sept. 30, 2013), the second year of the current contract, in the context of the overall (4.5 year) project.

Herein, we (1) describe the physical setting of the study site, (2) refer to prior published reports that describe the methods used to monitor beach topographic change, (3) present the observations, which include: (a) wave climate analysis for the 53 month study interval; (b) basic information on survey dates and data collection; and (c) shoreline change analyses of mean high water (MHW) and upper beach shorelines. We conclude by drawing some connections between the wave forcing and the observed shoreline change.

Physical Setting

The beach at NASA-KSC is part of Cape Canaveral-Merritt Island sedimentary complex (Fig. 1). The ~10 km coastline of the space center is bordered on the north by the Cape Canaveral National Seashore and on the south by the Cape Canaveral Air Force Station. Within 800 m of the KSC shoreline, substantial critical infrastructure is present, including Launch Complexes 39A, 39B, and 41 (Fig. 2).

The Cape Canaveral coast is within a microtidal setting with a mean tidal range of 1.03 m and an average spring tidal range of 1.19 m (NOAA, 2011). Cape Canaveral is classified as an intermediate beach following the classification scheme by Wright and Short (1984), although in the northern 1 km of the study area the beach tends toward the reflective end member and in the southern 3.5 km it tends toward the dissipative end member. The nearshore zone is characterized by the presence of two sand bars throughout the year that migrate onshore and offshore as forcing conditions change (Kline, 2013). The offshore bathymetry is complex exhibiting a series of transient oblique shoals and large cape associated shoals that trend to the southeast from the tips of both False Cape and Cape Canaveral (Fig. 1).

Long-term shoreline change trends and variability about the trend in shoreline positions were calculated for the study area in three discrete intervals: 1875-2008, 1875-1969 and 1969-2008 by Dean (1998) and Absalonsen and Dean (2010) (Fig. 3). These rates were calculated from surveys conducted by the Florida Bureau of Beaches and Coastal Systems (BBCS) and the Florida Department of Environmental Protection (FDEP) at 1,000-foot intervals along the shore at virtual monuments. The study documented both spatial and temporal variability in long-term shoreline position trends and in deviation about the trend throughout the study area. Examination of both the long-term interval (1875-2008) and the early interval (1875-1969) suggests that the shoreline is experiencing relatively slow retreat (erosion) in the northern portion of the study area (Regions 1 and 2) and relatively rapid advance (accretion) in southern portion of the study area (Regions 3 and 4).

Based on the long-term shoreline change rates and geomorphic characteristics, the study area can be divided into four distinct regions (Fig. 3). From north to south, Region 1 is northernmost ~1.5 km of the study area is characterized by long-term stability with a

single dune ~ 4m in elevation (NAVD 88). This area also has the highest average foreshore slopes in the study area. The next ~5 km, Region 2, is characterized by a single, frequently over washed dune and long term net retreat. Foreshore slopes in this area are highly variable. Region 3 is centered at False Cape and is characterized by an aspect change in the coastline with low dune ridge sets and proto-dunes. This area also has variable foreshore slopes but is on the average more gently-sloped than the area with historic retreat, to the north, and is a region of net advance. Region 4, the southernmost 1 km of the study area is characterized by a series of low dunes, but lacks proto-dunes, and is also characterized by historic long-term accretion, despite severe retreat (~ 5.5 m/yr) recently (1969-2008). Foreshore slopes in this region are gentle, but with less variability than those in Region 3.

The antecedent topography of the Cape Canaveral-Merritt Island (CC-MI) complex plays an important role in the coastal processes of the area. The system has not yet reached geomorphic equilibrium with respect to sediment supply and climate forcing following the sea level rise following the last glacial maximum ~20 k years ago. Prior to the industrial revolution, global sea level reached a stable level, close to its modern elevation, ~6000 years ago (Miller et al., 2005). Given the recent acceleration of sea level rise, it appears that the CC-MI complex is undergoing morphologic adjustment. Merritt Island comprises two cape features formed at two different sea level high stands during Marine Oxygen Isotope Stage (MIS) 5, ~the last 125,000 years (Figs. 4 and 5). Based on optically stimulated luminescence dating, the west side of Merritt Island was formed during the second sea level high stand during MIS 5c (~105ka) (Rink and Forrest, 2005). This side of the island was formed when global sea level was ~ 3-4 m lower than today. The east side of Merritt Island (LC-39A, LC-39B, VAB and Industrial Area) was formed during the third MIS high stand 5a (~85 ka) (Rink and Forrest, 2005; Burdette et al., 2010). The east side of Merritt Island was formed when global sea level was 2-3 m lower than today. As sea level dropped during the Laurentide Glaciation, Banana Creek likely incised through Merritt Island and flowed through the modern shoreline just north of LC-39A. At its maximum extent Merritt Island was probably further seaward than today. As sea level rose in the past 17,000 years following the last glacial maximum (LGM), the island eroded forming Cape Canaveral proper. Cape Canaveral is currently migrating to the south as a large-scale (~60 km^2) landform. Migration proceeds by eroding older ridges in the north (near LC-34, LC-20, LC-19 and LC-16) and depositing to the south of the tip of the cape. False Cape (LC-41, LC-40 and LC-37) was formed after sea level reached its present level and Cape Canaveral formed. False Cape continues to grow eastward and seaward today.

The back-beach setting is characterized by ridge and swale topography. In the area of Eagle 4 and southward 2.5 km, the beach is backed by tightly spaced ridges (strand plain), higher than those found landward and to the south. It is possible that these closely spaced ridges provide a sediment source to the beach, given the pattern of truncation of the ridges by the modern coastline. From 2.5 - 6.5 km south of Eagle 4, an area of frequent dune overwash, the sand ridges backing the shoreline are spaced further apart and are lower in elevation than those near Eagle 4. The inter-swale lowlands behind the shoreline are filled with fine-grained, organic material that is easily erodible. This material is exposed regularly on the shoreface (Fig. 6), during seasonal retreat events. The combination of the increased spacing between sand ridges, fine-grained material in the ridge swales, and the lower elevation of

the dune field may contribute to a sand deficit as retreat has proceeded over historic times. This area has been susceptible to overwash since at least the 1940's as seen in historical air photographs, and there is evidence of a breach and formation of an inlet some time before 1943 in the area between LC-39A and LC-39B (Fig. 7). Additionally, as Banana Creek incised through the area between LC-39A and LC-39B during the Last Glacial Maximum low stand, additional sand may have been removed, contributing to the paucity of sediment and observed long-term retreat.

The origin of the bathymetry offshore of the Merritt Island-Cape Canaveral complex is not fully understood, but may be a product of the history of transgression and regression associated with sea level oscillation.

Methods

Detailed descriptions of field survey methods, image processing, and GPS accuracy and precision testing can be found in the body and Appendices of Phase 1 Annual Report of the project (Jaeger et al., 2010).

Detailed descriptions of GPS analysis methods, fixed camera data collection techniques, wave instrument deployment, numerical modeling of wave transformation and sediment analysis can be found the Phase 2 Annual Report of the project (Jaeger et al., 2011).

The content of the Phase 3 Annual Report (Adams et al., 2012) was generated using the methods provided in the Phase 1 and Phase 2 Annual Reports. Likewise, the observations collected during the most recent study period (Oct. 2012 – Sept. 2013) utilized the methods described in the previous annual reports. For detailed descriptions of these techniques, we refer the reader to the references above.

Observations

Wave Climate Analysis-Results and Interpretation

For the five calendar years during which our study was conducted (2009-2013), we compiled wave climate observations, including significant wave height (H_S), dominant wave period (T_D), and peak wave direction, from two National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center instruments: 1) Buoy 41009, located 20 nautical miles east of Cape Canaveral (H_S and T_D only until late 2012), and 2) Buoy 41012, located 40 nautical miles east-northeast of St. Augustine, which serves as a directional wave proxy during the period for which no directional data were collected by Buoy 41009. Figure 8 shows the wave climate throughout the study period.

The typical seasonality in wave climate along the central Florida Atlantic coast consists of a relatively quiescent summer wave field (H_s ~0.5-1.5m) with easterly directions, followed by the onset of northward-moving tropical cyclones (H_s up to 5m), which arrive episodically until the mid-fall, after which Nor'Easter storms bring energetic wave

conditions. Tropical storms and especially long-duration (>3 day) Nor'Easter storms are considered to be the strongest geomorphic influence along this shoreline, driving dune overwash and shoreline retreat. During Nor'Easters, wave directions migrate from north-northeasterly to easterly orientations over 3-7 day intervals.

RTK-GPS Survey Data Collection Statistics

Dates and logistical data of the RTK-GPS data collected over the course of the study period have been compiled in Table 1, which includes the number of data points collected and the percentage of data filtered out in the quality control process for 5-cm and 10-cm precision, respectively. Notably, the quality control procedure that filters for data points with better than 10-cm vertical precision typically retains >99% of the data collected.

Table 1. Table of survey dates and logistical statistics of each survey

Survey No.	Survey Date	Points Collected	Points Used (5 cm)	% Lost at QA/QC (5 cm)	Points Used (10 cm)	% Lost at QA/QC (10 cm)	Filename in Master_Survey_QC_Files
1	6-May-09	28,346	28,265	0.3%	28,344	0.0%	CpCnv_090506_QC_Bch
2*	24-May-09	16,927	16,653	1.6%	16,922	0.0%	CpCnv_090524_QC_Bch
3*	28-May-09	18,954	18,327	3.3%	18,952	0.0%	CpCnv_090528_QC_Bch
4	6-Jun-09	28,394	24,572	13.5%	28,390	0.0%	CpCnv_090606_QC_Bch
5	6-Jul-09	38,925	32,349	16.9%	37,370	4.0%	CpCnv_090706_QC_Bch
6	1-Aug-09	50,694	48,617	4.1%	50,568	0.2%	CpCnv_090801_QC_Bch
7	5-Sep-09	38,980	36,978	5.1%	37,866	2.9%	CpCnv_090905_QC_Bch
8	5-Oct-09	36,853	29,362	20.3%	33,987	7.8%	CpCnv_091005_QC_Bch
9	6-Nov-09	35,897	31,577	12.0%	35,147	2.1%	CpCnv_091106_QC_Bch
10	1-Dec-09	34,854	33,869	2.8%	34,600	0.7%	CpCnv_091201_QC_Bch
11	3-Jan-10	36,933	35,248	4.6%	36,932	0.0%	CpCnv_100103_QC_Bch
12	31-Jan-10	37,472	36,624	2.3%	37,126	0.9%	CpCnv_100131_QC_Bch
13	28-Feb-10	29,734	28,660	3.6%	29,001	2.5%	CpCnv_100228_QC_Bch
14	27-Mar-10	35,697	35,246	1.3%	35,526	0.5%	CpCnv_100327_QC_Bch
15	2-May-10	40,374	37,659	6.7%	38,643	4.3%	CpCnv_100502_QC_Bch
16	27-May-10	26,639	26,594	0.2%	26,626	0.0%	CpCnv_100527_QC_Bch
17	2-Jul-10	13,475	12,547	6.9%	12,820	4.9%	CpCnv_100702_QC_Bch
18	25-Jul-10	17,692	15,781	10.8%	16,590	6.2%	CpCnv_100725_QC_Bch
19**	28-Jul-10	25,821	23,476	9.1%	24,193	6.3%	CpCnv_100728_QC_Bch
20**	31-Jul-10	16,647	14,891	10.5%	15,682	5.8%	CpCnv_100731_QC_Bch
21	28-Aug-10	28,310	26,922	4.9%	27,850	1.6%	CpCnv_100828_QC_Bch
22	2-Oct-10	18,569	17,479	5.9%	18,439	0.7%	CpCnv_101002_QC_Bch
23#	3-Oct-10	18,847	18,188	3.5%	18,773	0.4%	CpCnv_101003_QC_Bch
24&	9-Oct-10	24,692	24,160	2.2%	24,621	0.3%	CpCnv_101009_QC_Bch
25	24-Oct-10	34,338	31,605	8.0%	33,423	2.7%	CpCnv_101024_QC_Bch
26	20-Nov-10	27,675	26,785	3.2%	27,374	1.1%	CpCnv_101120_QC_Bch
27	21-Dec-10	102,419	101,636	0.8%	102,044	0.4%	CpCnv_101221_QC_Bch
28	24-Jan-11	88,429	87,004	1.6%	88,409	0.0%	CpCnv_110124_QC_Bch
29	18-Feb-11	41,209	38,999	5.4%	41,154	0.1%	CpCnv_110218_QC_Bch

30	19-Mar-11	72,510	71,394	1.5%	71,812	1.0%	CpCnv_110319_QC_Bch
31	18-Apr-11	72,808	71,527	1.8%	72,801	0.0%	CpCnv_110418_QC_Bch
32	19-May-11	61,345	52,886	13.8%	60,530	1.3%	CpCnv_110519_QC_Bch
33	13-Jun-11	74,034	63,214	14.6%	72,327	2.3%	CpCnv_110613_Bch_(Type)
34	18-Jul-11	65,854	62,189	5.6%	64,761	1.7%	CpCnv_110718_Bch_(Type)
35	15-Aug-11	66,774	51,652	22.6%	63,102	5.5%	CpCnv_110815_Bch_(Type)
36*	26-Aug-11	43,106	40,664	5.7%	43,054	0.1%	CpCnv_110826_Bch_(Type)
37*	27-Aug-11	63,220	60,327	4.6%	62,679	0.9%	CpCnv_110827_Bch_(Type)
38*	28-Aug-11	69,858	63,195	9.5%	67,098	4.0%	CpCnv_110828_Bch_(Type)
39*	30-Aug-11	59,340	46,944	20.9%	53,104	10.5%	CpCnv_110830_Bch_(Type)
40	18-Sep-11	54,422	50,727	6.8%	54,412	0.0%	CpCnv_110918_Bch_(Type)
41	11-Oct-11	59,140	52,158	11.8%	59,089	0.1%	CpCnv_111011_Bch_(Type)
42	15-Oct-11	62,650	60,920	2.8%	61,796	1.4%	CpCnv_111015_Bch_(Type)
43	10-Nov-11	45,314	42,933	5.3%	45,033	0.6%	CpCnv_111110_Bch_(Type)
44	15-Dec-11	60,976	57,286	6.1%	59,974	1.6%	CpCnv_111215_Bch_(Type)
45	7-Jan-12	62,705	58,453	6.8%	61,940	1.2%	CpCnv_120107_Bch_(Type)
46	10-Feb-12	62,013	60,719	2.1%	61,917	0.2%	CpCnv_120210_Bch_(Type)
47	21-Feb-12	43,990	42,849	2.6%	43,510	1.1%	CpCnv_120221_Bch_(Type)
48	8-Mar-12	62,081	57,297	7.7%	61,521	0.9%	CpCnv_120308_Bch_(Type)
49	7-Apr-12	43,321	41,808	3.5%	43,256	0.2%	CpCnv_120308_Bch_(Type)
50	5-May-12	91,830	86,688	5.6%	89,770	2.2%	CpCnv_120505_Bch_(Type)
51	3-Jun-12	67,404	66,321	1.6%	67,237	0.2%	CpCnv_120603_Bch_(Type)
52	3-Jul-12	46,276	46,120	0.3%	46,269	0.0%	CpCnv_120703_Bch_(Type)
53	4-Aug-12	62,145	55,517	10.7%	58,287	6.2%	CpCnv_120804_Bch_(Type)
54	30-Aug-12	67,382	66,291	1.6%	67,137	0.4%	CpCnv_120830_Bch_(Type)
55	27-Sep-12	72,480	71,801	0.9%	72,340	0.2%	CpCnv_120927_Bch_(Type)
56	16-Oct-12	61,989	61,390	1.0%	61,948	0.1%	CpCnv_121016_Bch_(Type)
57	28-Oct-12	50,011	48,810	2.4%	49,564	0.9%	CpCnv_121028_Bch_(Type)
58*	29-Oct-12	40,422	40,056	0.9%	40,390	0.1%	CpCnv_121029_Bch_(Type)
59*	30-Oct-12	43,743	41,134	6.0%	43,384	0.8%	CpCnv_121030_Bch_(Type)
60*	31-Oct-12	58,806	57,428	2.3%	58,798	0.0%	CpCnv_121031_Bch_(Type)
61	15-Nov-12	39,198	38,337	2.2%	38,677	1.3%	CpCnv_121115_Bch_(Type)
62	30-Nov-12	65,910	57,736	12.4%	59,377	9.9%	CpCnv_121130_Bch_(Type)
63	29-Dec-12	57,201	53,627	6.2%	56,654	1.0%	CpCnv_121130_Bch_(Type)
64	30-Jan-13	33,743	32,325	4.2%	33,314	1.3%	CpCnv_130130_Bch_(Type)
65	27-Feb-13	65,016	63,612	2.2%	64,623	0.6%	CpCnv_130227_Bch_(Type)
66	26-Mar-13	64,301	61,309	4.7%	62,038	3.5%	CpCnv_130326_Bch_(Type)
67	24-Apr-13	62,382	60,751	2.6%	61,966	0.7%	CpCnv_130424_Bch_(Type)
68	22-May-13	61,930	53,030	14.4%	59,761	3.5%	CpCnv_130522_Bch_(Type)
69	24-Jun-13	70,258	66,671	5.1%	69,561	1.0%	CpCnv_130624_Bch_(Type)
70	23-Jul-13	44,847	35,777	20.2%	43,363	3.3%	CpCnv_130723_Bch_(Type)
71	20-Aug-13	63,940	59,677	6.7%	62,885	1.6%	CpCnv_130820_Bch_(Type)
72	19-Sep-13	63,488	61,345	3.4%	63,153	0.5%	CpCnv_130919_Bch_(Type)

* Storm Response Survey ** Geoeye Image Capture # Daily Change Test & Weekly Change Test

Shoreline Change -Results and Interpretation

To simplify the analyses of shoreline position change, we focus the presentation of our observations at four specific cross-shore locations (out of 13 total), where we have made detailed sedimentological and topographic studies earlier in the course of our study (Jaeger et al., 2011). Each of these locations is representative of the four behaviorally-distinct portions of the KSC coast, and are identified by a UF Transect ID (used for sedimentological analysis) as well as a DSAS ID (used for topographic analysis):

Region 1. UF T010, DSAS #075
Region 2. UF T035, DSAS #277
Region 3. UF T100, DSAS #682
Region 4. UF T120, DSAS #962

We have also chosen to conduct our shoreline change analyses at two vertical beach levels: (1) the lower beach, at the MHW elevation datum (0.28 m NAVD88), and (2) the upper beach, at the 1.0 m elevation datum. Observations discussed below, as well as the figures, identify which shoreline (MHW or upper beach) is being addressed.

Since Previous Reporting Period (Oct. 2012 – Sept. 2013)

For the most recent reporting period of October 2012 through September 2013, Figures 9a and 9b show the 15 shoreline positions (in map view) of the MHW datum (0.28 m) and upper beach datum (1.0 m), respectively, for the four representative sites (Regions 1-4) within the study area. In Regions 1 -3, seasonal shoreline variability of the lower beach is similar to that of the upper beach (~15 m in Regions 1 &2; ~33 m for Region 3). In contrast, Region 4 exhibits more lower beach shoreline variability than upper beach variability, but has in general has the least variable change throughout the year. The relative magnitude in change between the four regions reflects in some part the general slope of the beach, where the steeper regions 1-2 (more reflective beach profile) have less spatial change than the flatter profiles in Region 3 (more dissipative beach profile).

It is notable that the upper beach shorelines documented in the days immediately following Hurricane Sandy (Oct. 28-31, 2012), shown in red (Fig. 9b), occupy the most landward positions observed throughout the most recent reporting period for all but Region 2, the area witnessing the most frequent dune overwash and chronic retreat.

Over Entire Study Duration (May 2009 – Sept. 2013)

Figure 10 shows time series plots of shoreline position (MHW – upper panel, Upper Beach – lower panel) at the four transects representative of Regions 1-4 over the entire 53-month study duration. Figures 11a and 11b show colormaps of shoreline position (beach width) for the MHW and Upper Beach elevations, respectively.

In all regions, the MHW shoreline appears to exhibit seaward movement during the summer and early fall, followed by retreat that typically occurs in winter, but may come about early (Fall 2011), as a result of tropical cyclone activity. Because the MHW shoreline is within the most dynamic cross-shore region between the berm crest and offshore bars, it

is expected to have greater seasonal variability than the upper beach. The MHW shoreline position in Region 3 (False Cape) is noticeably characterized by significant beach widening over the 2013 calendar year. In contrast, the northern portion of Region 2 (the site of chronic retreat and dune overwash) experiences more pronounced retreat in 2013 than any other period since our observation began in May 2009. In general, the only notable long-term change in shoreline position is an apparent widening in Region 3. However, this is also the region with the greatest magnitude in seasonal change (Fig. 12), so caution should be applied in interpreting the significance of this apparent net change.

The Upper Beach shoreline (1.0 m) also exhibits seasonality in all regions, similar to the MHW shoreline – summer accretion followed by fall/winter retreat. The area of chronic retreat (northern portion of Region 2), however, maintains a relatively narrow beach year-round exhibiting little fluctuation in width. This is likely occurring because the dune has been overwashed along much of this section, so there is little dune sand available to replenish the upper beach during fair weather conditions. Long-term changes of the upper beach width are similar in temporal character to the lower beach, with only Region 3 having an apparent widening in 2013.

Figures 12a and 12b present the alongshore distribution of mean shoreline position (beach width), standard deviation of shoreline position (beach width), and shoreline change envelope (SCE), defined as the difference between the maximum and minimum beach widths over the 53 month study interval, calculated from the 72 RTK-GPS topographic surveys. For both the MHW shoreline and the Upper Beach shoreline, variability in position tends to correlate with beach width, which is likely due to the low sloping character of the wide beaches at the study site.

Discussion

In this report we have focused on the GPS survey data collected during entire project period, which comprises 72 individual surveys consisting of regular monthly campaigns as well as rapid response, storm-related, efforts. We have presented the complete record of shoreline position during the 53-month period from May 2009 through September 2013 and, below, we comment briefly on the observations.

A notable observation made regarding the beach width during the total period of observation is that tropical storms and Nor'Easter storms do lead to landward retreat of both the lower and upper beach (Fig. 9) but that the width tends to return to pre-storm positions within weeks to months following the event. The duration of this restoration period varies in space and time. As noted above, only Region 3 appears to have undergone a net seaward shift following Hurricane Sandy. The causes for this change and the time it takes for different parts of the beach to return to pre-storm width are complex, tied to sediment transport forced by the transformed wave energy in the nearshore region and surfzone (Wright and Short, 1984). However, the offshore data necessary to explain these changes (e.g., surfzone bathymetry, wave energy transformation) were not collected as part of this funded program, so we cannot explicitly identify causative mechanisms at this

time. Interpretation and discussion of shoreline and nearshore changes within Region 1 and the northernmost parts of Region 2 are presented in MacKenzie (2012) and Kline (2013).

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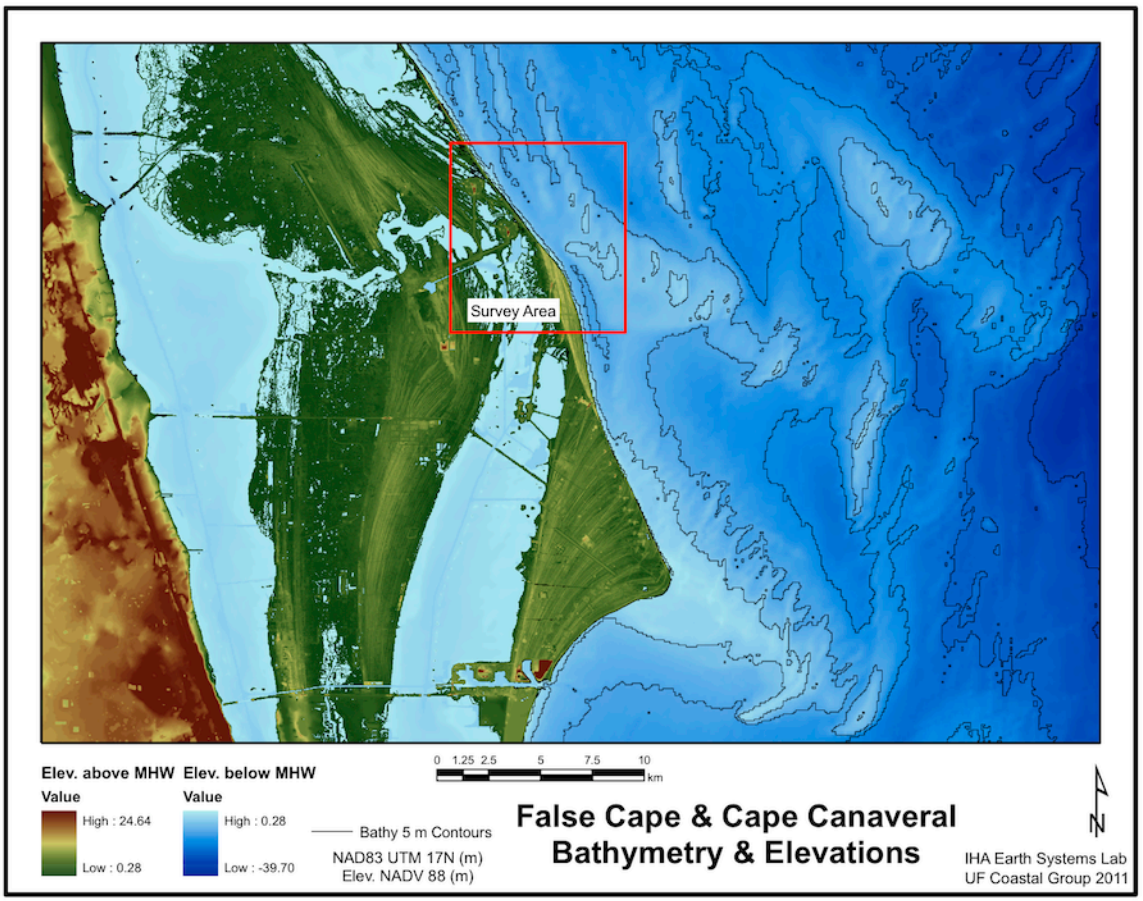

Figure 1. Bathymetry and topography of Cape Canaveral – Merritt Island sedimentary complex. All elevations above mean high water (0.28 m NAVD88) are colored as topography.

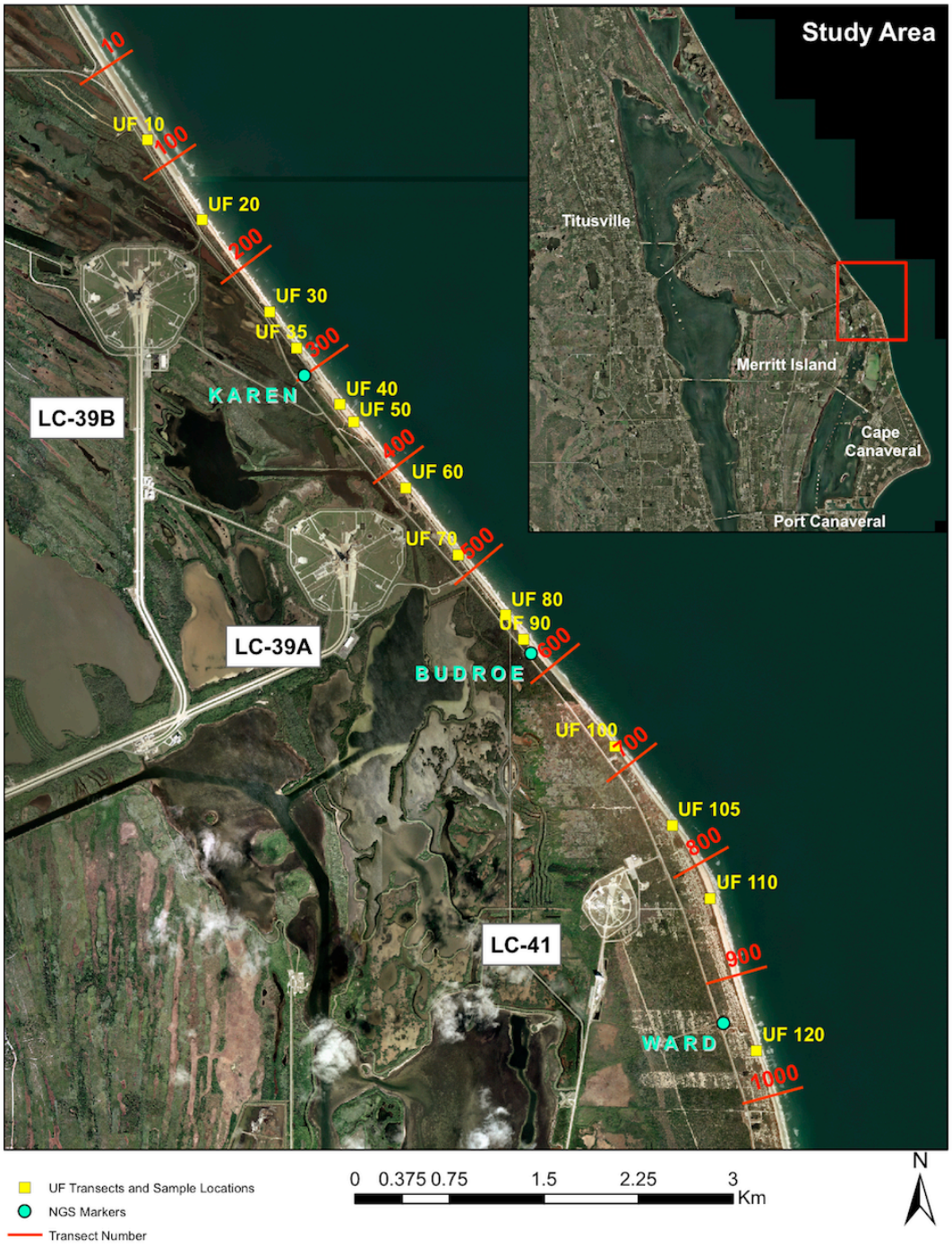

Figure 2. Area of study including NASA critical coastal launch facilities at Launch Complex 39B, retrofit for the heavy lift launch vehicle, Launch Complex 39A, the Space Shuttle Launch platform, and Complex 41 with medium launch capability. DSAS transects (red) are spaced 10 m apart, here referenced at 100 m increments. University of Florida cross-shore and sediment sampling transects are also shown (yellow).

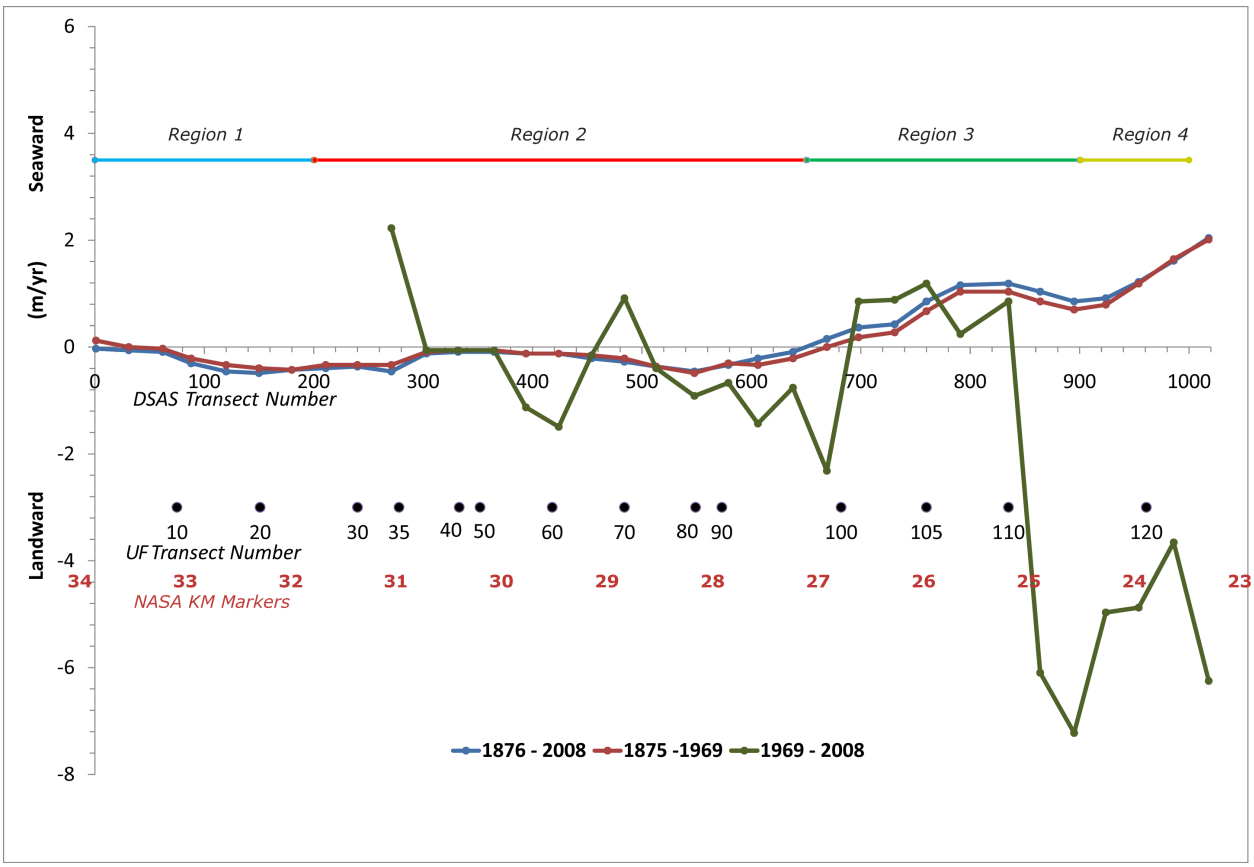

Figure 3. Long-term shoreline change rates for study area after Absalonsen and Dean (2010). The more recent change rates (1969-2008) do not reflect the longer-term rates (1876-2008). Long-term change rate data is sporadic at this site after 1943 due to Kennedy Space Center's designation as a federal facility bordered by a National Seashore and an U.S. Air Base. The KSC shoreline can be divided into four regions with distinctive morphology, grain size, and nearshore wave climate. Alongshore reference systems used in this study are noted.

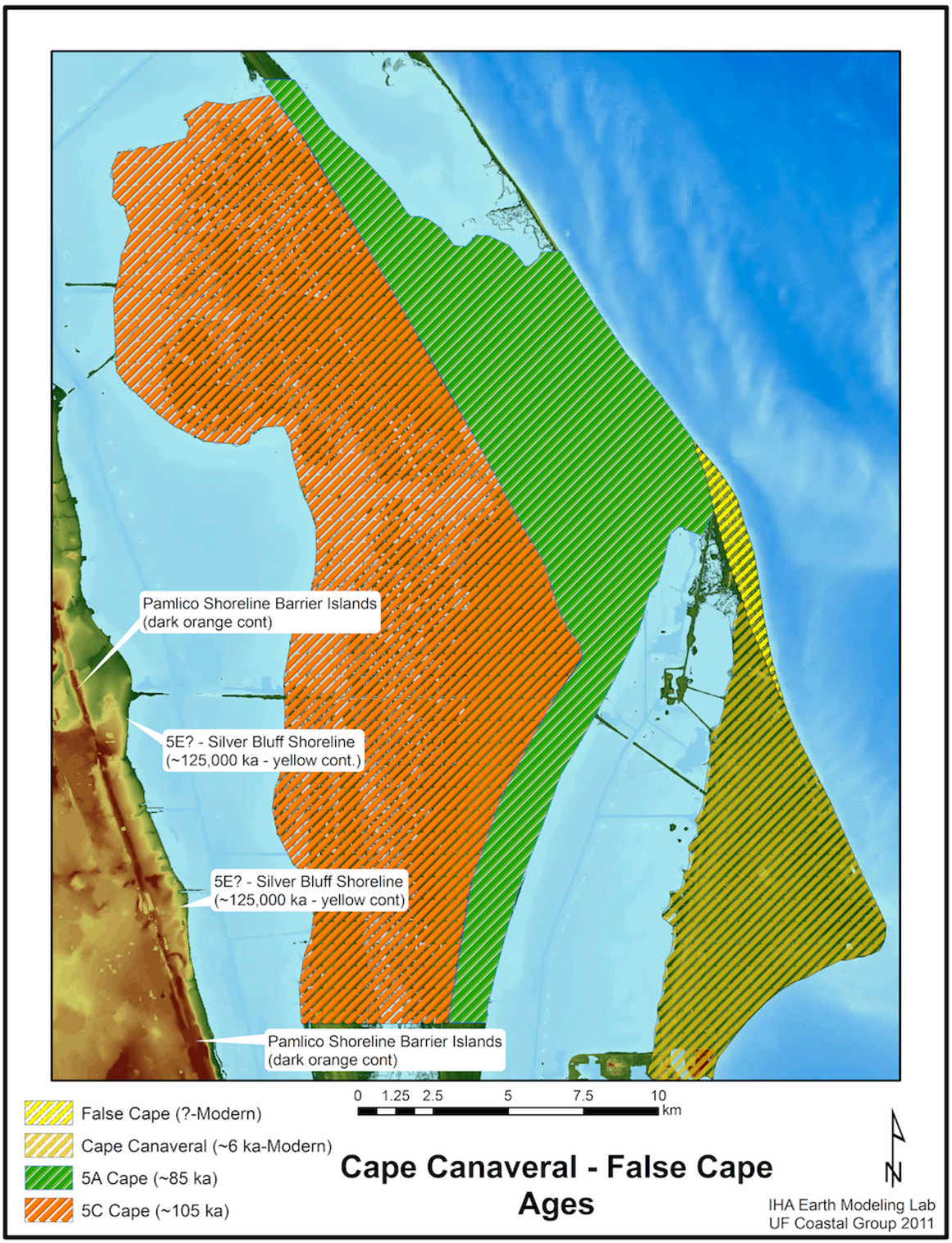

Figure 4. Late Pleistocene shoreline features at Cape Canaveral-Merritt Island sedimentary complex, based on the findings of Rink and Forrest (2005).

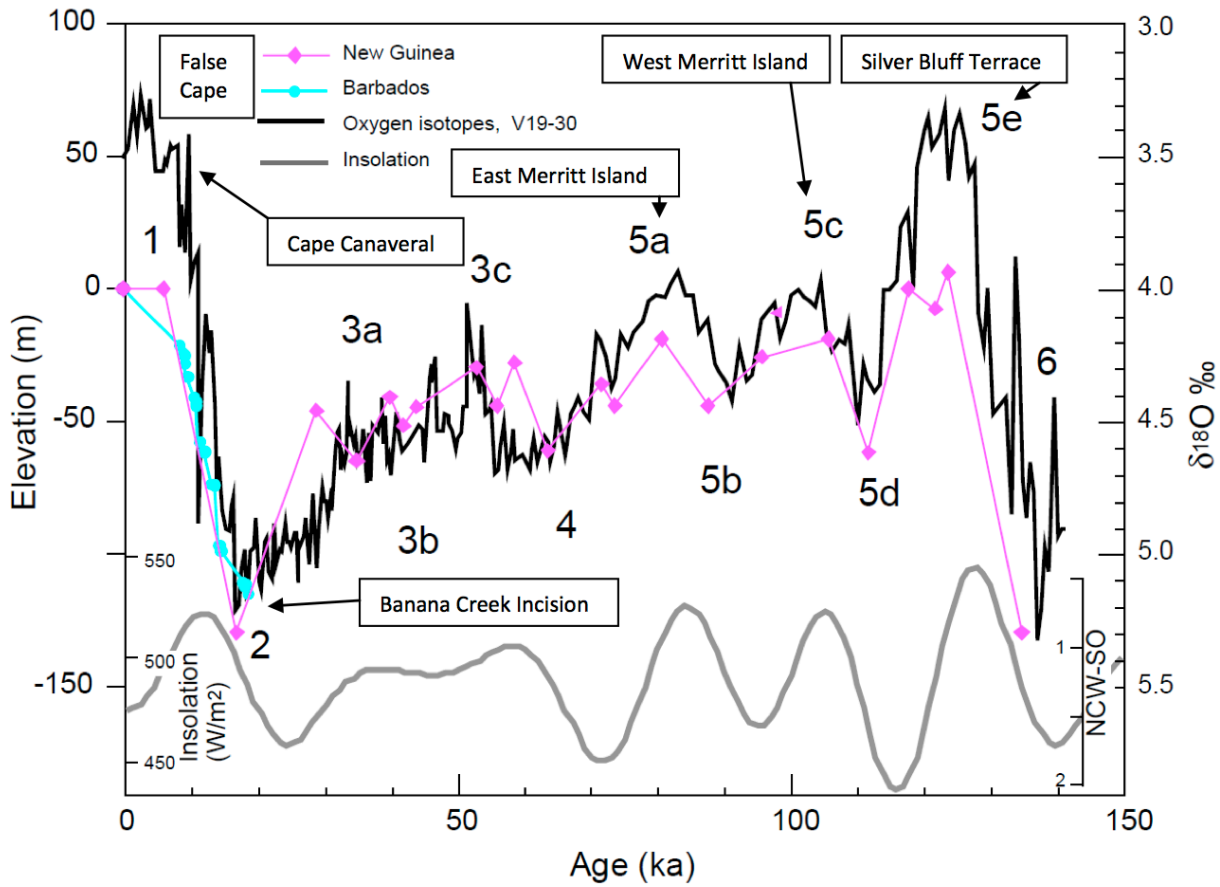

Figure 5. Eustatic sea level trends for the last ~125 ka from Miller et al. (2005). Also shown are hypothesized periods of development/accretion of Cape Canaveral sedimentary features. Marine Isotope Stages (MIS) 1-6 are noted.

Figure 6. Fine-grained, organic-rich sediments and humate sands visible as outcrop on beach face during the winter of 2009-2010 near UF Transect 35 within the area of chronic overwash.

Figure 7. Arial imagery from 1943 showing overwash and possible inlet delta that formed near UF Transects 50 and 60. Current Location of LC-39A is shown as a semi transparent feature for reference.

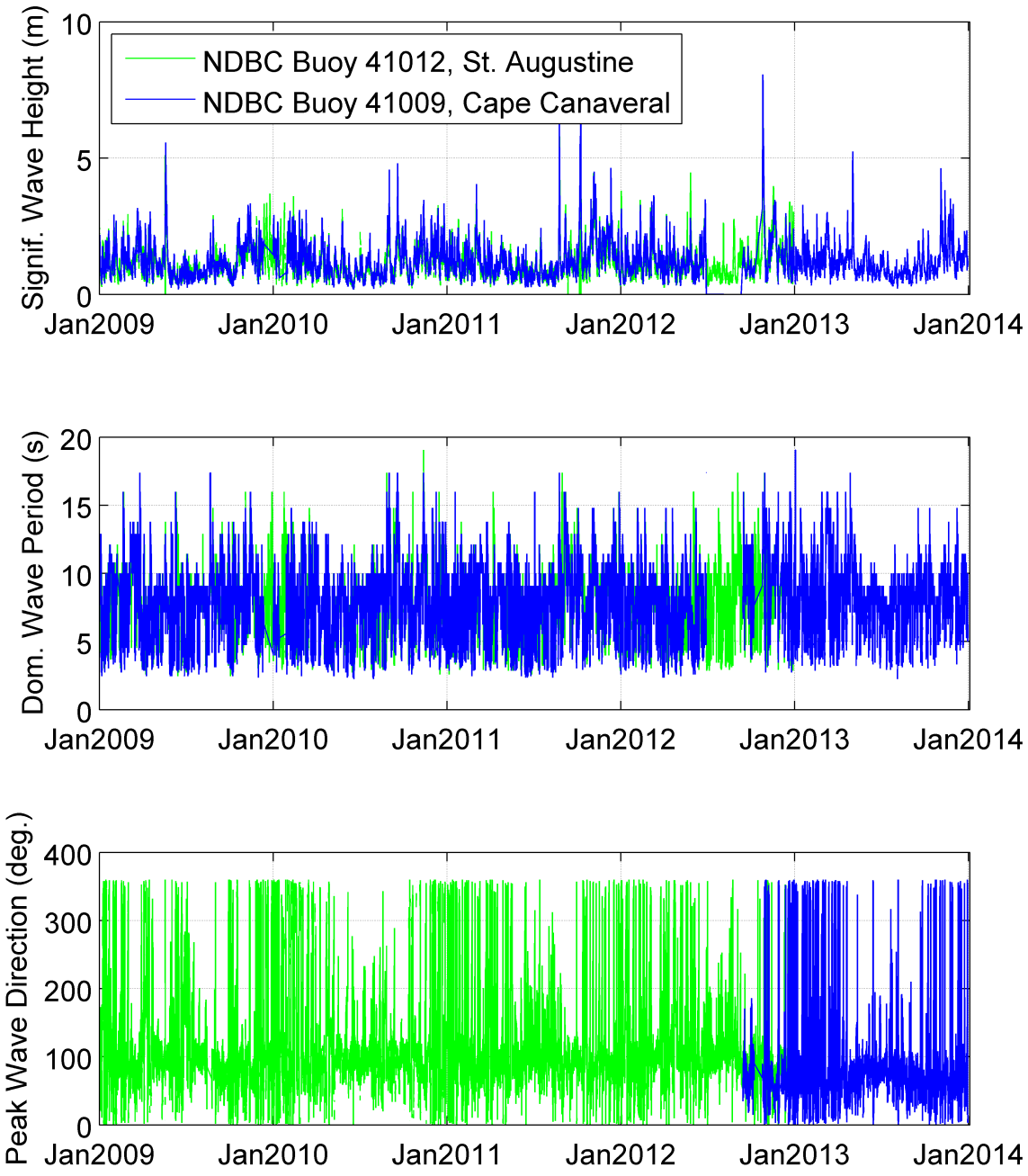

Figure 8. Wave record from NDCB Buoys 41009 and 41012 over the years 2009-2013, covering the entire project study interval.

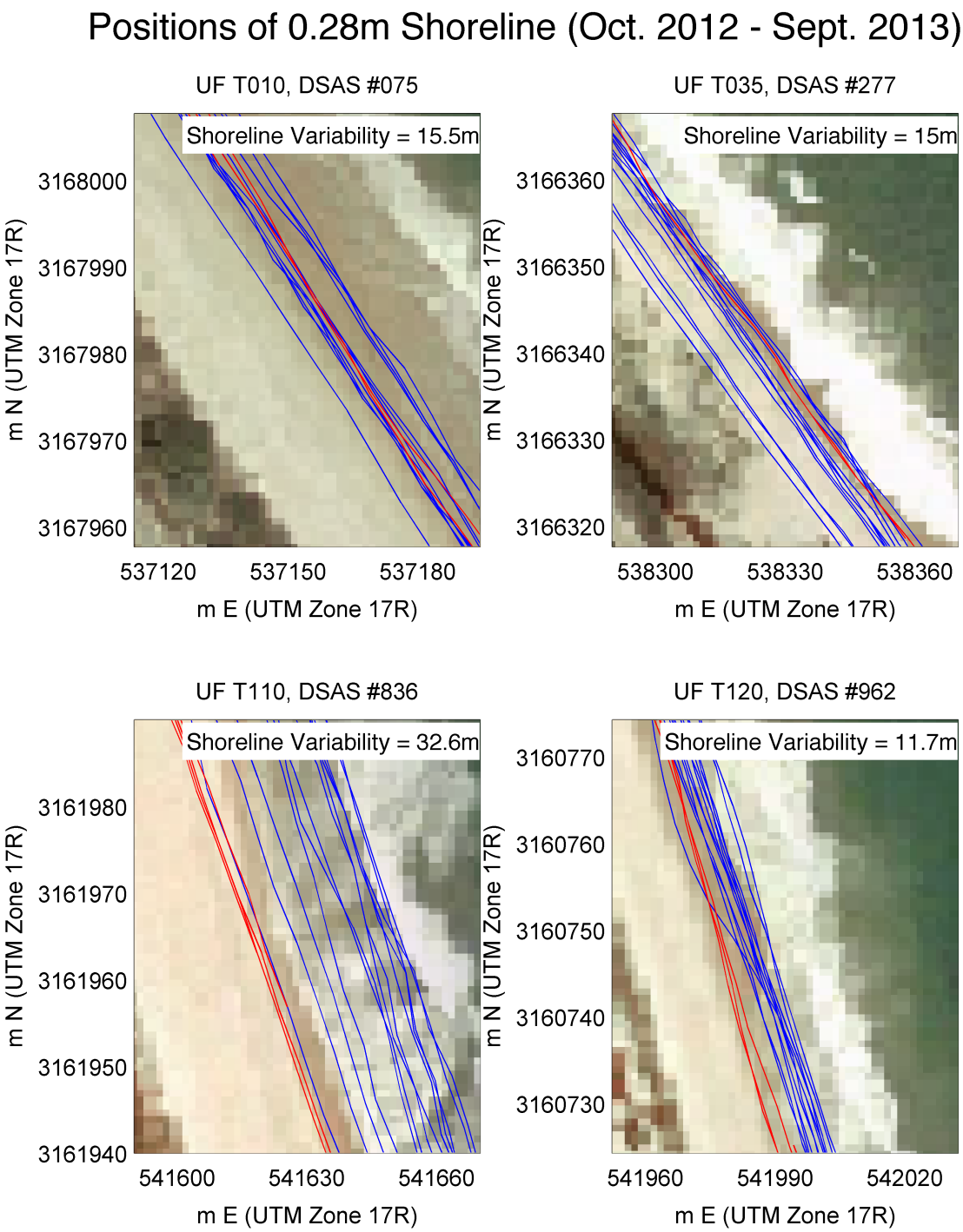

Figure 9a. Positions of the MWH (0.28m) shoreline within 4 regions of the study area for survey dates during the interval (Oct. 2012-Sept. 2013).The red lines represent surveys conducted immediately following Hurricane Sandy (Oct. 28-31, 2012). Spatial units for figures is meters (Universal Transverse Mercator projection, WGS84 datum, Zone 17 North).

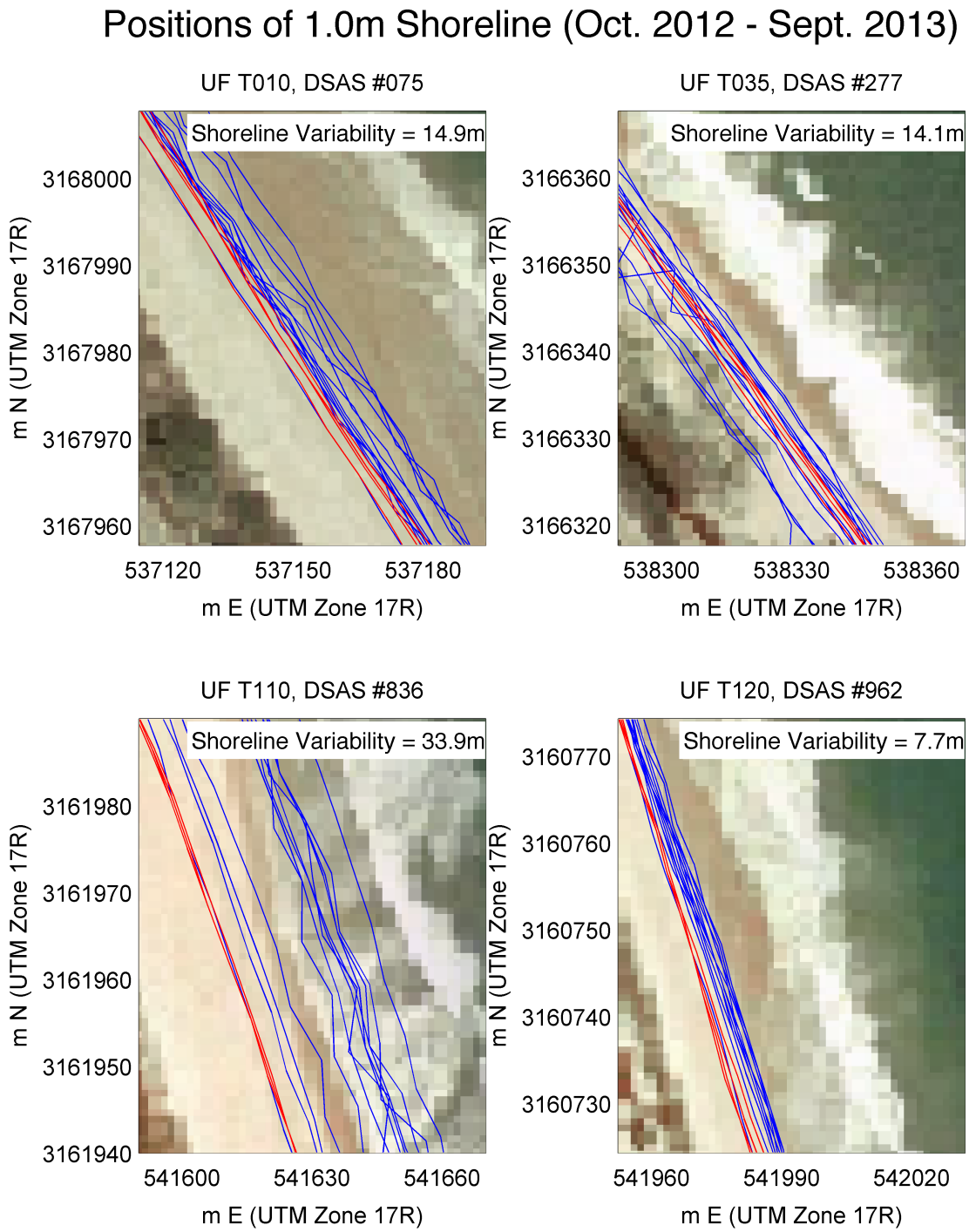

Figure 9b. Positions of the Upper Beach (1.0m) shoreline within 4 regions of the study area for survey dates during the interval (Oct. 2012-Sept. 2013). See Fig. 9a caption for additional details.

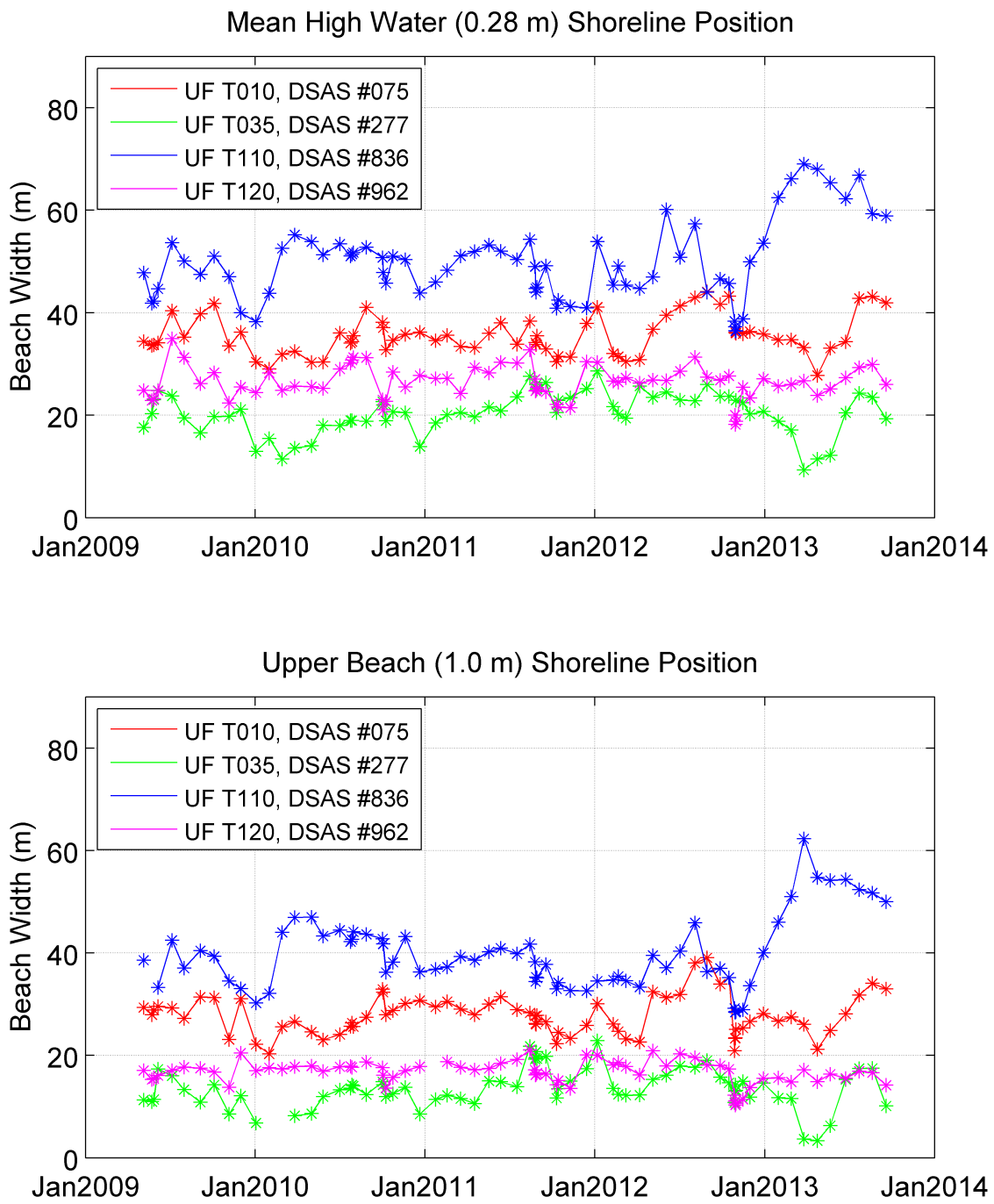

Figure 10. Time series plots of the MHW shoreline positions within 4 regions of the study area for all survey dates during the observation interval.

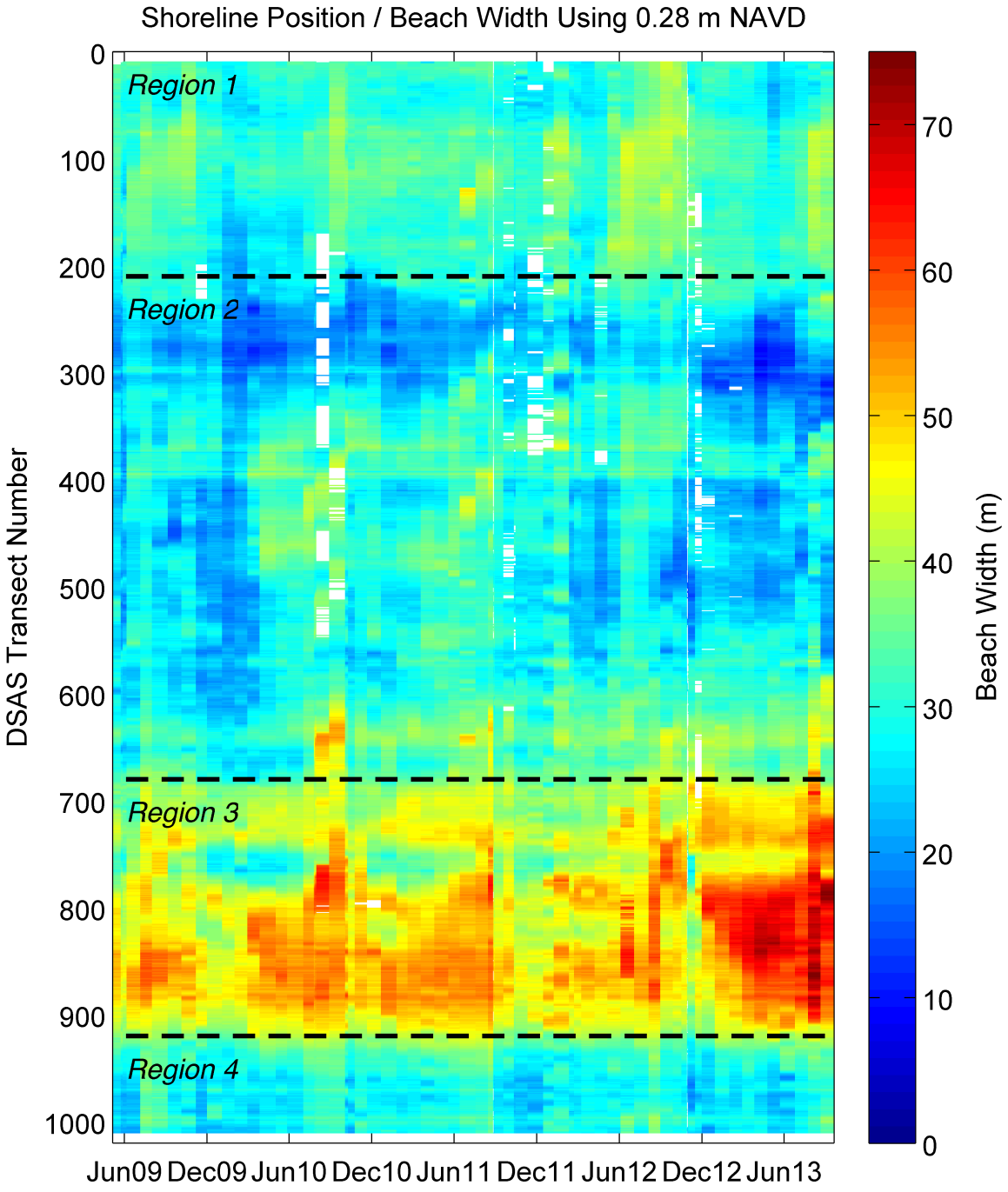

Figure 11a. Psuedocolor time series plot showing alongshore distribution MHW shoreline position (with respect to surveyed dune crest) history during 53-month observation period from May 2009-Sept. 2013. Colorbar values are in units of meters.

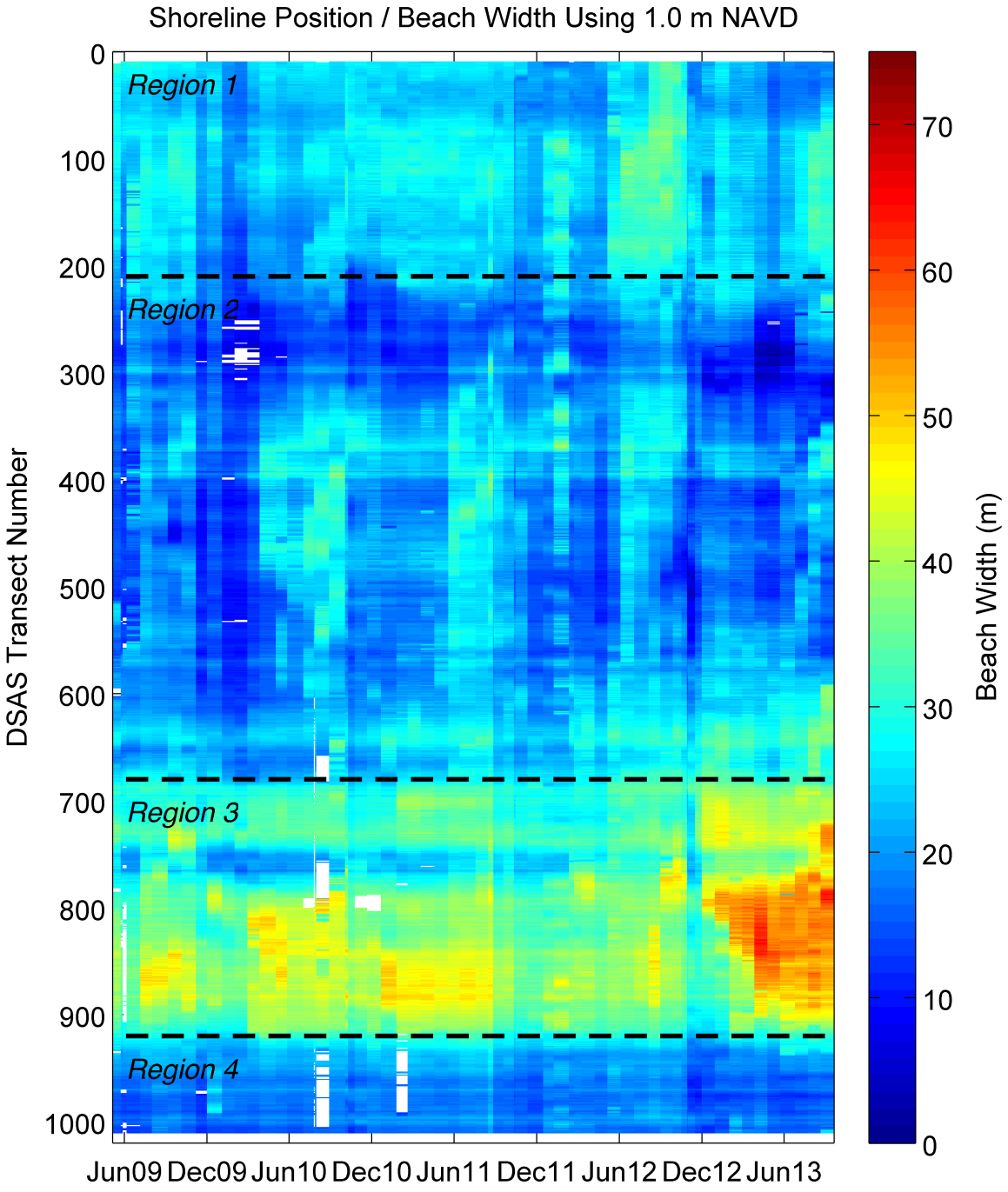

Figure 11b. Psuedocolor time series plot showing alongshore distribution 1-m elevation shoreline position (with respect to surveyed dune crest) history during 53-month observation period from May 2009-Sept. 2013. Colorbar values are in units of meters.

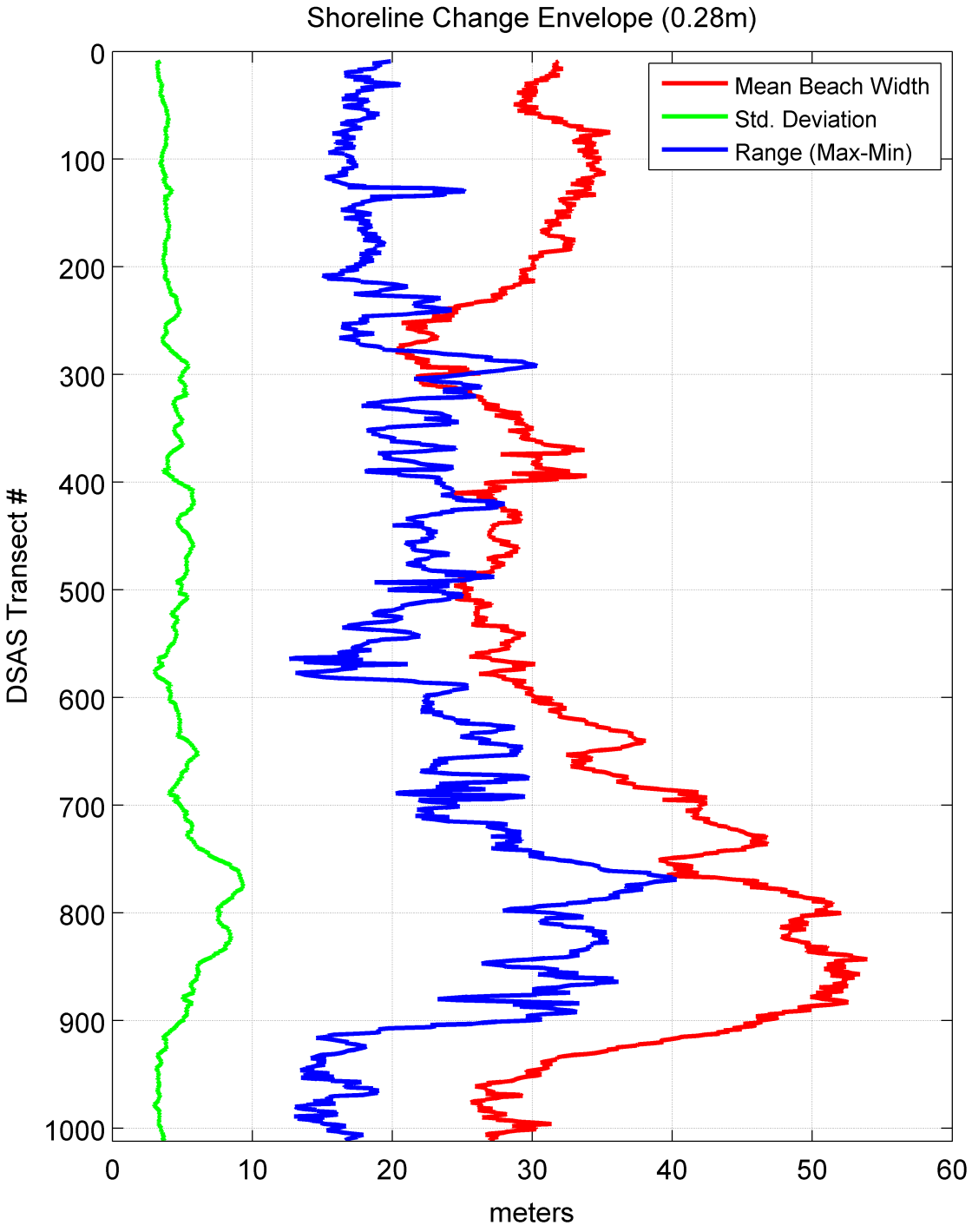

Figure 12a. Alongshore distribution of MHW shoreline change envelope over the 53-month study.

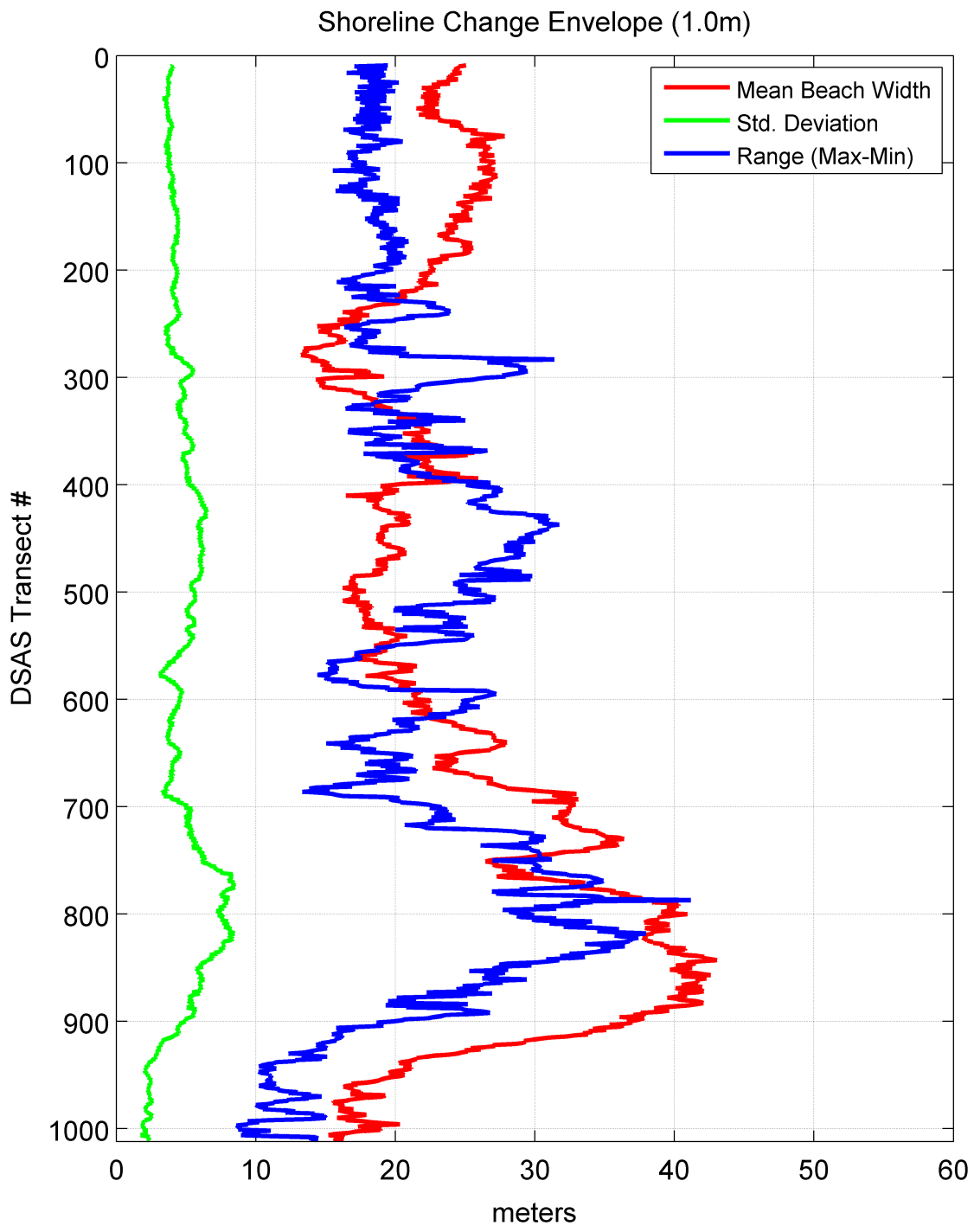

Figure 12b. Alongshore distribution of Upper Beach shoreline change envelope over the 53-month study.