Observations of Large-Scale Beach Cusps
In the Florida Panhandle and Alabama

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ABSTRACT

The Gulf of Mexico shoreline along the Florida Panhandle and Alabama coasts is frequently affected by the presence of large-scale beach cusps and other rhythmic alongshore variations. These shoreface and submerged features exhibit a broad range of expression, extending in alongshore length from tens of feet to several thousand feet, with cross-shore amplitudes that can exceed one hundred feet. The variations in beach width caused by the larger cuspate features can create hot-spot erosion areas, posing a threat to upland infrastructure. Using an extensive set of beach nourishment project monitoring data, these features are characterized across various beach segments in the study area. The features observed are further described in terms of their planform shape, or beach state, generally following the beach classification scheme of Wright and Short (1984). Different datasets also reveal the changes in beach state, based upon incident wave conditions. Severe storm impacts tend to reset the shoreline to a two-dimensional longshore-uniform state, after which calmer weather introduces three-dimensional features along the beaches.

Within this dynamic environment, annual beach profile monitoring surveys are conducted along fixed survey transects. The geometry of the cuspate features relative to the fixed survey transects each year introduces the potential to calculate changes in shoreline position and beach volume that may not be representative of the overall changes occurring along the shoreline segment they represent. As an example in this setting, comparison of average beach segment shoreline changes described by discrete survey monuments at 1,000-ft spacing versus shoreline changes measured at much denser spacing via digitized aerial photography reveals a potential for error of 15% or more in some cases.

To address these issues and better describe representative shoreline and volume changes occurring between monitoring surveys, analyses have been performed to augment the collected beach profile data. Aerial photography is used to improve representative shoreline change calculations and determine the extent of influence of the cuspate features. Characteristic profiles can be generated to determine average volume changes, and the overall envelope of surveyed beach profiles can be used to determine the extreme conditions. In general, the present system of monitoring, including the collection of digital orthophotography, is opined to be adequate to document overall project performance. The significant increase in survey data needed to completely describe the full range of cusps sizes in each annual survey is deemed unwarranted due to the increased expense. The presence and effect of beach cusps and crescentic bars on the existing datasets, however, should be acknowledged and the potential for error due to these features noted in any analyses.

INTRODUCTION

The collective inspection of an extensive set of beach nourishment project monitoring data along the Gulf of Mexico shoreline in the Florida Panhandle and Alabama reveals a broad range of highly three-dimensional and temporally variable morphological conditions across the study area. These data, collected to monitor littoral performance and document the pre-tropical storm season conditions of the engineered beach projects, include beach profile survey data and digital aerial orthophotography. Aerial photography collected through the seasons reveals the variation of the local morphology (or "beach shape"), including the impacts of storms, the appearance of erosional hot-spots, the development and migration of small- and large-scale beach cusps, the growth and change of rip-current channels, and the formation of other large-scale rhythmic shoreline features. These observations are compared to published data describing and categorizing similar features (van Enckevort et al., 2004). The morphological conditions and changes are found to be consistent with existing literature describing evolving changes in beach state (Wright and Short, 1984, Ranasinghe et al., 2004, etc.).

In this setting, beach nourishment projects are generally surveyed on an annual basis to document littoral performance over time and to establish the pre-storm condition of the engineered beaches prior to each tropical storm season. These surveys typically employ a test plan based upon beach profile surveys collected at fixed cross-shore transects, spaced roughly 1,000 ft apart along the shoreline following the Florida Department of Environmental Protection (FDEP) "R-monument" survey system[1]. Standard monitoring of the projects is supplemented by the collection of controlled digital orthophotography. Inspection of the survey data and the aerial photography reveals the interaction of the fixed survey transects with the dynamic morphology of the beaches. On some occasions, it has been noted that the alignment of the transects creates a potential for bias in the survey results, particularly when comparing the profiles to a previous data set collected during a different beach state.

The study area consists of the Gulf of Mexico shorelines of Escambia County, FL, and Baldwin County, AL, including Pensacola Beach and Perdido Key, FL and Orange Beach and Gulf Shores, AL (Figure 1). In the study area, two large-scale beach nourishment projects are monitored on an annual basis, as described above. In Escambia County, the 8.1-mile Pensacola Beach, FL, Beach Restoration Project was constructed in 2002-2003 and subsequently renourished in 2005 following Hurricane Ivan (OAI, 2007a). In Baldwin County, the 15.3-mile Orange Beach/ Gulf State Park/Gulf Shores Beach Restoration Project was built in 2005-2006 (OAI, 2007b).

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[1] In coastal Alabama, the Alabama Department of Environmental Management's "B-monuments" were supplemented by virtual monuments to reduce the monument spacing to roughly 1,000 ft.
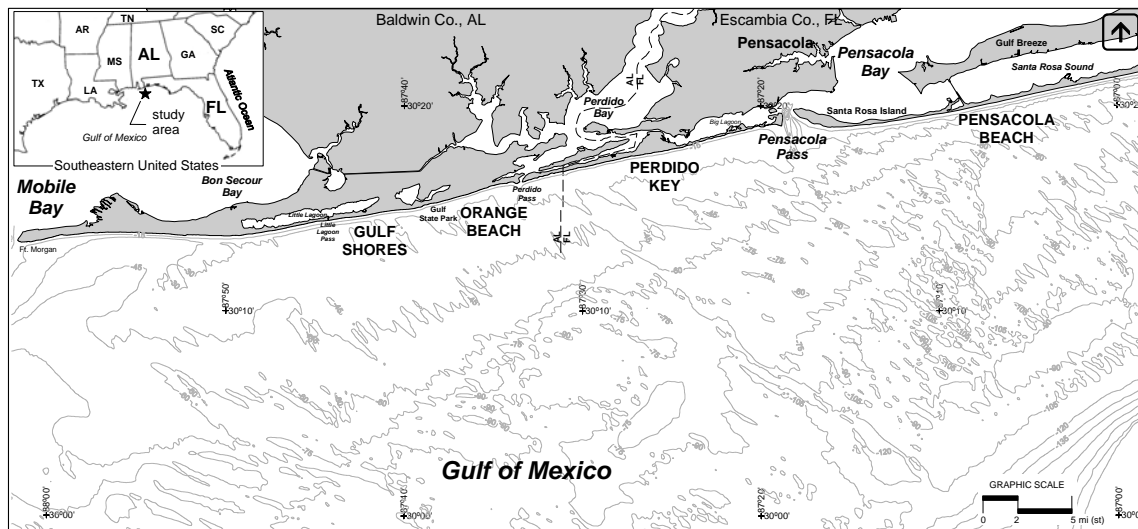
Figure 1   Location map of coastal Escambia County, FL, and Baldwin County, AL.

CLASSIFICATION OF BEACH MORPHOLOGY

In one of the most widely-referenced discussions regarding beach morphology, Wright and Short (1984) introduced a classification scheme of six beach states to describe the range of beach and nearshore bathymetric conditions they observed along 26 different beaches in Australia. These beach states are briefly summarized as follows (adapted from Wright and Short, 1984):

- **Dissipative**
  - Flat, shallow beaches with significant subaqueous sand storage, no significant bar formation (two-dimensional bathymetry – uniform in the alongshore)
- **Intermediate: Longshore Bar-Trough**
  - Steeper, reflective beach face with deep trough and distinct offshore bar (mildly three-dimensional)
- **Intermediate: Rhythmic Bar and Beach**
  - Moderate to steep beachface, shoreline marked by mega cusps, variable alongshore depths of crescentic bar and trough features (moderately three-dimensional)
- **Intermediate: Transverse Bar and Rip**
  - Variable beachface slope along distinct mega-cusps, crescentic bar features welded ashore at horns, (highly three-dimensional)
- **Intermediate: Ridge-Runnel or Low-Tide Terrace**
  - Moderate beachface slope with low-tide step fronting low-tide terrace crossed by mini-rip channels (skewed or shore normal), no distinct offshore bar features (mildly to moderately three-dimensional)
- **Reflective**
  - Steep, deeper beaches with minimal subaqueous sand storage, no significant bar formation (two-dimensional bathymetry)

Ranasinghe et al. (2004) discuss the changes in beach state that occur as wave conditions change. In general, as wave heights increase -- or sediment size decreases -- the beach shifts toward the dissipative state. Through the use of hourly video images

collected over several years at Palm Beach, Sydney, Australia, the somewhat systematic change in intermediate beach states from the more uniform Longshore Bar-Trough state to the more irregular Transverse Bar and Low-Tide Terrace states was documented. The cycle was found to be initiated by the occurrence of a strong storm event, which "resets" the beach system toward the more dissipative and two-dimensional Longshore Bar-Trough state. The subsequent period of calmer weather produces the transition to the higher three-dimensional states, persisting until another storm event resets the system.

Van Enckevort et al. (2004) present a summary of published observations of crescentic sand bars world-wide and discuss the two most common hypotheses regarding the formation of these large features. The first theory is based only upon the hydrodynamic forcing caused by the local wave climate, with no feedback from the local morphology included. Many investigators following this hypothesis describe the cusp formation as a result of standing edge (shore parallel) wave effects (Komar, 1998, among others). The near-bed velocities caused by the nodes and crests of the standing edge waves create sediment transport patterns that lead to the formation of the cusp features. The second theory, called self-organization, requires some level of perturbation in the seabed, which then alters the hydrodynamic forcing in the nearshore. The feedback of the change in the seabed to the hydrodynamics allows for the growth of various cuspate features.

OBSERVATIONS OF BEACH MORPHOLOGY IN THE STUDY AREA

With the available digital orthophotography and various sets of airborne LIDAR survey data in the present study area, the various beach states typically occurring within the project area can be classified according to the Wright and Short scheme. In nearly all cases available to the authors, extending back to the early 1970's or before, the beach states in the project area fall within the intermediate range. Along the Gulf of Mexico shorelines of Escambia and Baldwin Counties, the typical beach profile is characterized by a small inner bar or terrace feature lying above -5 ft MSL within 300 to 400 ft of shore, and a larger longshore bar located roughly 500 to 900 ft from the shoreline and above -20 to -25 ft MSL (approx.). Sub-tidal beach slopes range from 1:40 to 1:50, typically, and beachface slopes typically range from 1:8 to 1:12. The tide range in the area averages 1.1 feet, and reaches a spring range of over 1.8 ft.

The inner bar demonstrates a higher degree of variability, exhibiting the entire range of intermediate beach states described above, and frequently containing rip channels of various orientations. The outer longshore bar frequently exhibits some level of alongshore rhythmic variability, occasionally transitioning to a pronounced crescentic condition in which the inshore portions of the bar weld ashore at the horns of mega-cusps along the shoreline.

Figure 2 depicts an example of shoreline conditions along Pensacola Beach, FL, photographed in October 2000. In the photo, the nearshore zone exhibits a highly three-dimensional transverse bar and rip beach state, while the offshore bar appears generally inactive and relatively uniform in the alongshore. The cusps typically extend several hundred feet alongshore, with amplitudes (horn-to-embayment distance) of 50 ft or more.

In the months following the condition shown in Figure 2, several structures along the Pensacola Beach shoreline were undermined and damaged by the encroachment of the erosional hot-spots created at the embayments of the cusps (Figure 3). In the example shown in Figure 3, the cusps were observed by the authors to have migrated slowly to the west, consistent with the observations of Dean and Miselis (1993) for the same study area. One of the cusp features migrated across the property shown, leading to foundation damage during typical winter storm conditions.
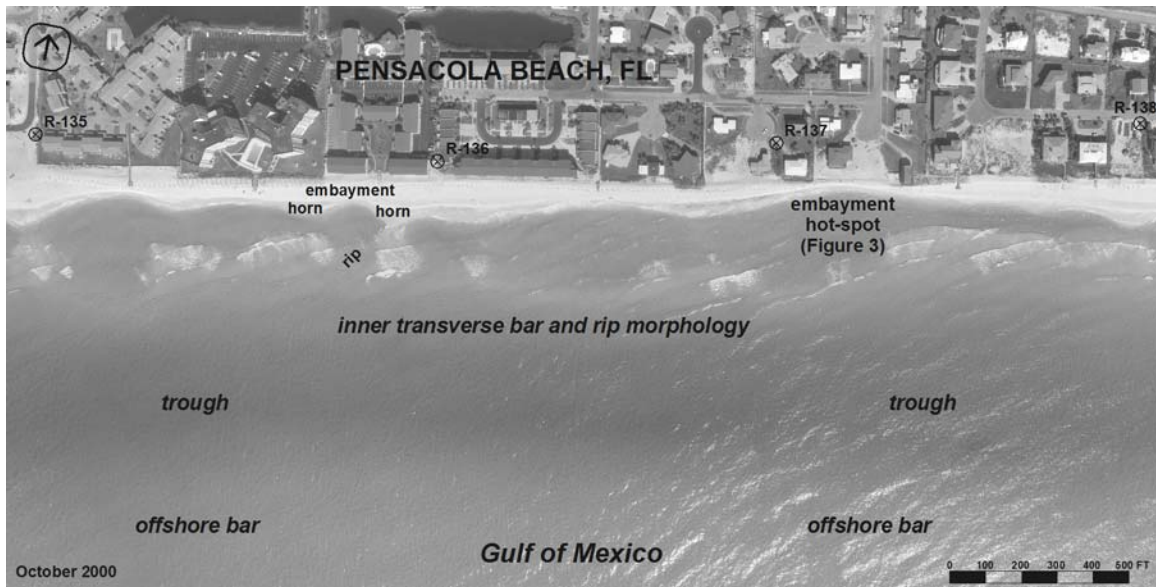

Figure 2   Shoreline conditions along the Gulf of Mexico shoreline of Pensacola Beach, FL, in October 2000, demonstrating the highly irregular nearshore bathymetry marked by beach cusps, transverse bars, and rip channels (Wright and Short, 1984). Accompanying that condition is a relatively uniform offshore bar.

Figure 3   Structural damage along the embayment of a beach cusp at Pensacola Beach, FL (Dec. 2000).

The patterns of beach cusp horns and embayments shown in Figure 2, along with the visible areas of wave breaking and the intervening rip channels, provides a demonstration of the mechanisms responsible for the formation and maintenance of the mega cusps. As described by van Enckevort et al. (2004), wave breaking across the shallow bar areas at the horns occurs before wave breaking along the deeper embayments. The difference in breaker locations sets up a circulation pattern in which flows are directed onshore by wave breaking at the horns and then diverted toward the adjacent embayments. Near the center of the embayments, the excess flows are directed offshore through the rip channels.

Table 1 lists the characteristics of beach cusps compiled from digital orthophotography and other data sources along the study area. The data in Table 1 are intended to generally represent "commonly occurring" conditions along each shoreline segment, although a wide range of beach states and cusp sizes can and do occur at each segment. In fact, along each beach segment, several scales of beach cusps frequently occur simultaneously, indicating the recent changes in wave climate along that particular beach segment (Figures 4 and 5). In many instances, small-scale swash-zone cusps, on the order of 10-50 ft in alongshore length, occur in tandem with the larger cusps described in the table.

Table 1   Observations of Beach Cusp Characteristics:
Gulf Shores, AL, to Pensacola Beach, FL

Location	Observation Date	Typical Length, L (range, ft)	Typical Amplitude, A (ft)	Sub-tidal Beach slope
Gulf Shores, AL (West Beach)	May 2004[1]	3,200 (2,200 – 4,000)	100 - 140	1:50
Gulf Shores, AL (West Beach)	May 2007	3,000 (2,300 – 3,500)	60 - 90	1:50
Gulf Shores, AL (East Beach)	May 2004[1]	2,900 (2,000 – 3,900)	50 -150	1:45
Orange Beach, AL	May 2004[1]	1,800 (1,100 – 3,000)	20 - 100	1:40
Orange Beach, AL	May 2007	1,500 (1,000 to 2,900)	40 - 100	1:40
Perdido Key, FL	March 2004	900 (400 - 1,500)	15 - 90	1:40
Perdido Key, FL	April 2006	950 (400 – 2,000)	20 - 120	1:40
Perdido Key, FL	December 2006	500 (300 – 2,000)	15 - 80	1:40
Pensacola Beach, FL[2]	1973 - 1992	380 (250-400)	25 - 50	--
Pensacola Beach, FL	October 2000	420 ft (150 – 1,900)	10 - 90	1:50
Pensacola Beach, FL	May 2007	330 (100 – 700)	10 - 50	1:50

Note: Mean tidal range: 1.1 ft, spring tidal range: >1.8 ft   Sediment: quartz sand, D_{50} ~ 300 microns
[1]Matching crescentic bars visible
[2]Miselis and Dean (1993)

While the table suggests a distinct east-to-west increase in the scale of beach cusps, there are significant localized exceptions to that trend within the 35-mile study area. For example, the western end of Pensacola Beach and the shoreline west thereof (toward Pensacola Pass, Figure 1) frequently exhibit mega-cusp features exceeding over 3,000 ft in length (see Figure 4). As suggested by Table 1, typical cusp features in the area extend for a few hundred feet, and along the central and eastern portions of Pensacola Beach, this is indeed the case.

The causes of these variations in scale are not immediately clear, especially considering the large range of beach cusp scales observed during the same time period (e.g. the May 2004 dataset). As discussed above, various researchers suggest that spatial differences in wave energy and thus hydrodynamic forcing may alter the cusp scales, or that local perturbations, such as shore-face attached shoal features or hard structures (jetties, piers, etc.) may act as triggers or anchor points for cusp development. Along the study area, there are two piers, three tidal inlets ranging in size from very small to very large, and numerous large shoreface-attached sand ridges. All of these perturbations could potentially represent not only sources of wave energy and nearshore current variability, but also anchor points for cusps or rhythmic bars.

Figure 4   Shoreline conditions along the western end of Pensacola Beach, FL in March 2007. Two different scales of beach states are represented. The larger scale, including the offshore bar, exhibits a rhythmic bar and beach configuration with corresponding mega-cusps over 3,000 ft in length, while the inshore profile exhibits a transverse bar and rip state with smaller beach cusps on the order of 200 to 400 ft in length. The smaller inner beach cusps are typically accompanied by a rip channel located at their embayments. East of the pier (background), the rhythmic variations diminish noticeably and only the smaller beach cusp features appear.

Figure 5   Shoreline conditions along the Romar Beach area of Orange Beach, AL, indicating rhythmic bar and beach morphology. Note the small-scale swash-zone cusps occurring along the larger, ~1,000-ft mega-cusp feature and the shallow bar features corresponding to the horns of the mega-cusp (March 2007).

Figure 6 depicts a rather dramatic example of beach mega-cusps and crescentic sandbars along the Gulf Shores, AL, shoreline west of Little Lagoon Pass (West Beach Gulf Shores). These data were captured by airborne laser ranging survey methods in May 2004 (pre-Hurricane Ivan). Along this four-mile segment of beach, large-scale mega-cusps and crescentic sandbars often appear at somewhat regular "wavelengths" of approximately 3,200 ft, in a range of roughly 2,200 to 4,000 ft (Table 1). The features lie along the beach strand at elevations above -20ft MSL (approx.).   The mega-cusps have amplitudes of approximately 125 ft. Referring to Table 1, it is of interest to note that the May 2007 condition along West Beach Gulf Shores was nearly identical to the May 2004 condition depicted in Figure 6, and remains in that general state as of January 2008. In particular, the hot-spot erosion areas created by this configuration still adversely affect this shoreline segment.

Inside each of the large-scale crescentic sandbar/mega-cusp pairs are numerous smaller beach cusps and accompanying embayment rip-channels (Figure 6). Each of the six West Beach mega-cusp pairs captured in the May 2004 dataset contains at least two of these localized channels and as many as six. These features occur on the inner bar, generally above an elevation of -5 ft MSL and spaced several hundred feet apart.   These channels typical exhibit widths of 100 to 200 ft, with relief of two to three feet or more. Such features represent significant hazards to waders and swimmers drifting alongshore, who may unexpectedly find themselves in water depths much deeper than their initial wading depth.

Along the embayments, the narrowed shoreline conditions create localized hot-spot erosion conditions, where dune features and upland infrastructure can be threatened by elevated water levels and storm wave activity. In this particular area, the embayment hot-spots in Figure 6 are exacerbated by local tidal-inlet effects, such that chronic hot-spot areas appear in the same general locations west of the inlet.
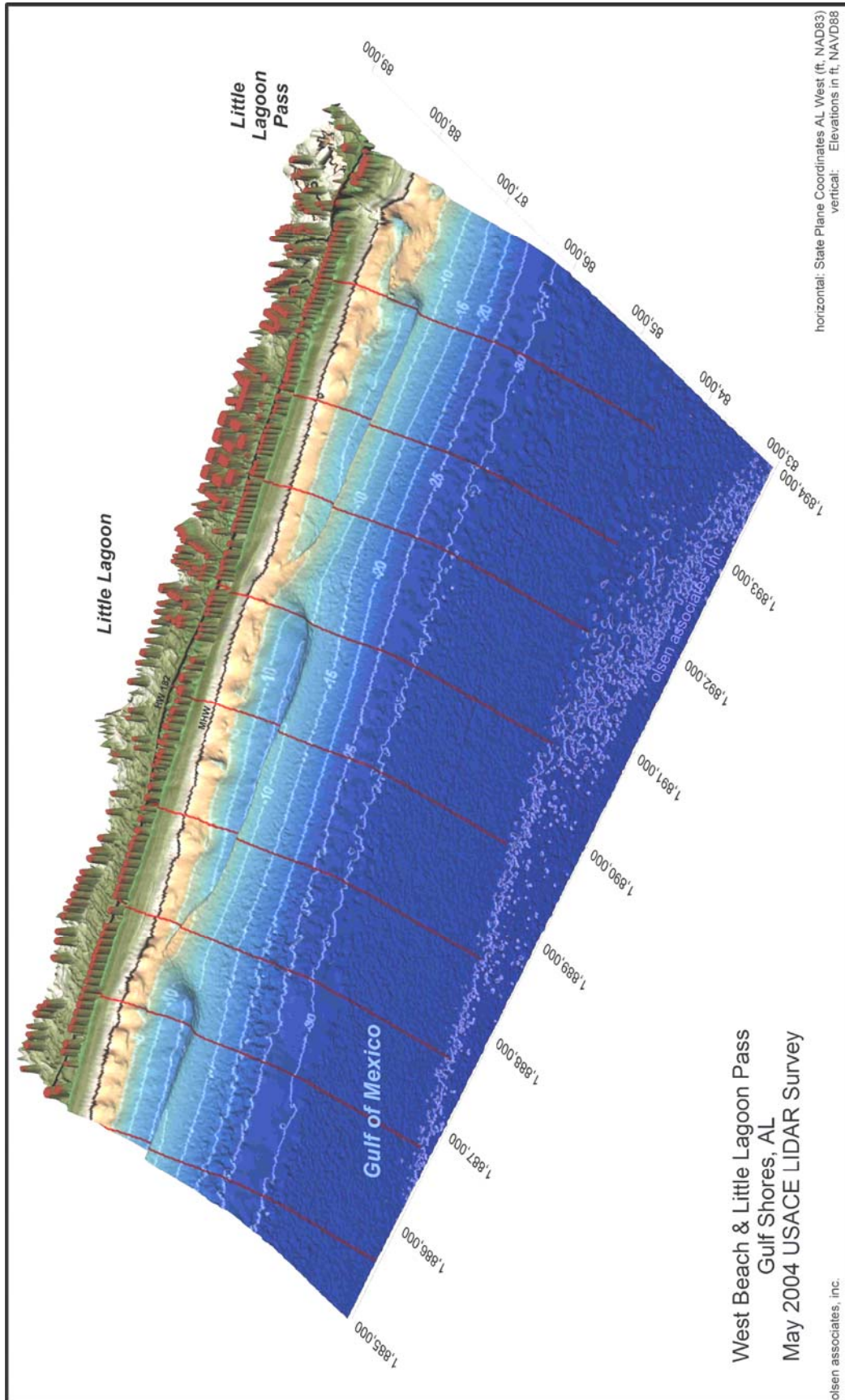
Figure 6   Shaded relief map of the nearshore area west of Little Lagoon Pass, Gulf Shores, AL (May 2004).   Note the locations of the fixed beach profile transects used in annual monitoring.   Elevations in ft, NAVD88.   Data source: USACE SHAOLS database.

Inspection of other aerials and survey data reveal the effects of beach nourishment and storm impacts. Both events tend to reset the local morphology to more two-dimensional longshore-uniform beach states. Beach profile surveys collected following each of the major 2004 and 2005 hurricanes (Ivan, Dennis, and Katrina), all reveal much more uniform profiles with nearly planar upper beach slopes and fewer observed nearshore rip channels. Referring to the Wright and Short (1984) classification, the post-storm morphology approaches a purely dissipative state, but along most segments retains the larger offshore bar (see discussion below). Beach nourishment projects, by design, also tend to erase the nearshore morphology, as the large volumes of added sand are placed in a prescribed, longshore-uniform template that fills in most irregularities. Following both types of events, the nearshore zone begins to transform to more three-dimensional configurations.

INTERACTION OF MORPHOLOGICAL FEATURES AND SURVEY TRANSECTS

As plotted in Figure 6, annual beach profile surveys are conducted throughout the study area along fixed survey transects. These surveys allow for the monitoring of the littoral performance of the beach fill projects and documenting of the conditions of the engineered beaches prior to each tropical storm season. The alongshore variability caused by the cusps and other features obviously presents the potential to affect shoreline position and beach volume change calculations.

Dean (1999) identified the potential for these large-scale cuspate features to threaten coastal construction and influence shoreline change predictions. Dean developed a method of quantifying the variability in the predictions using the FDEP long term database of shoreline data. For example, that research indicated that shoreline change predictions over a 5-yr period can carry as much as 30 to 35 ft of variability (i.e. potential error), due in part to large beach cusps. For this area, such a range is quite significant, given that the long-term erosion rate is relative low, on the order of one to two ft/yr. This variability is in part demonstrated in Figure 6 via comparison of the different survey transects, some of which run across the horns of the mega cusps, while others cross through rip channels in the nearshore, followed by the deep trough and pronounced crescentic bar.

Following Komar (1998), Figure 7 compares cross-sections collected at the ¼-points along one of the crescentic bar/mega-cusp pairs shown in Figure 6 (roughly 800-ft spacing). Each profile is plotted relative to a local baseline drawn parallel to the horns of the mega-cusp. For comparison, Figure 6 plots the location of the pre-established 1,000-ftsurvey transects relative to the ¼-points of each mega-cusp. In this fashion, profiles C and D along the embayment indicate the more than 100-ft amplitude of the mega cusp. Along the horns of the cusp, the profile is nearly planar, exhibiting no significant bar features, while the embayment profiles indicate both a nearshore terrace or transverse bar and rip morphology and the high relief of the offshore trough and bar feature.

Comparison of the horn profile (A) to the center embayment profile (C) reveals significant differences in volume across the nearshore and the offshore bar. In the nearshore and trough, a deficit of almost 100 cubic yards per foot of shoreline (cy/ft) was

computed. A portion of that deficit is balanced by gains along the offshore bar, totaling over 60 cy/ft, resulting in a net volume difference of 38 cy/ft. These values are quite significant compared to typical full-scale beach fill placement volumes in the area, which might average 100 cy/ft. Such large changes, however, are generally only found on the largest of mega-cusp features, and for inter-annual survey comparisons would clearly represent the rare worst case scenario, where one transect exactly captures a horn and the next year captures the embayment. In general, the profile coverage along the feature (Figure 6) is typically adequate to capture the overall volume changes using average end-area methods. Attention must be paid, however, to the beach state or condition of each survey set when comparing profiles collected at different dates to determine if the two profiles are representative of the overall shoreline conditions at each date.
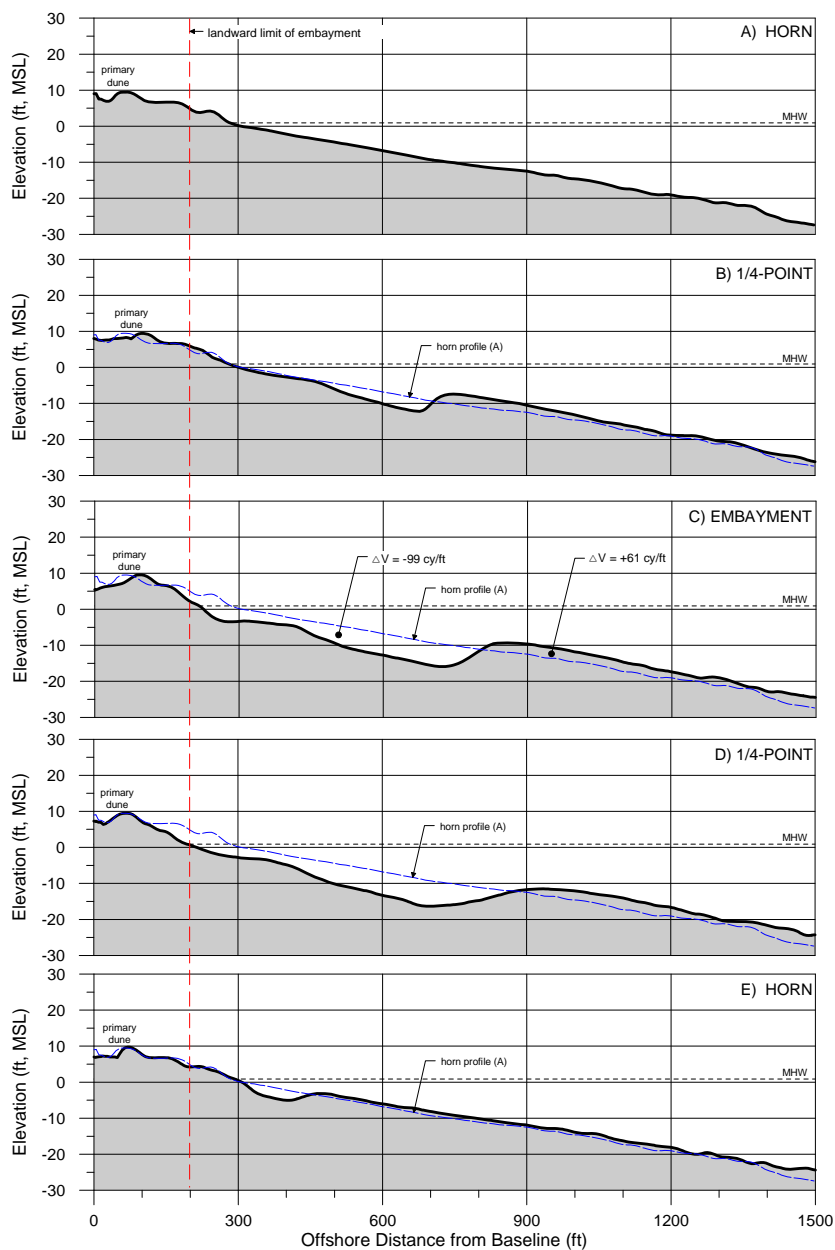

Figure 7 Comparison of beach profile transects across a crescentic bar/mega-cusp pair feature: West Beach Gulf Shores, AL (see Figure 6).

Figure 8 further describes the alongshore variability generated by various cuspate features along the West Beach Gulf Shores segment. Each frame depicts 19 individual survey transects, all shifted to the local Mean High Water Line to demonstrate the range of profile shapes along the beach. The upper and lower frames depict fair weather conditions with highly three-dimensional morphology, while the center frame plots the post-Hurricane Ivan profile set, which demonstrates far more uniform conditions.

In Figure 8, both the envelope of profile elevations and the cross-shore range in location of the offshore bar crest vary widely. In the April 2003 and May 2007 datasets, elevations along the submerged portions of the profile lie within a nine- to ten-ft vertical envelope, and the bar crests lie between 350 to 960 ft from the MHWL. The range of bar crest positions follows Figure 6, illustrating the crescentic nature of the offshore bar at that time. Immediately following Hurricane Ivan, profiles along West Beach exhibit much less variability as the beach was transformed to a more consistent longshore bar and trough state (middle frame). Subaqueous elevations lie within a five- to six-ft vertical envelope (or smaller), and the bar crest was found in a much more consistent location between 600 and 880 ft offshore. The post-Ivan profile set likewise illustrates the planar post-storm condition of the upper beach.
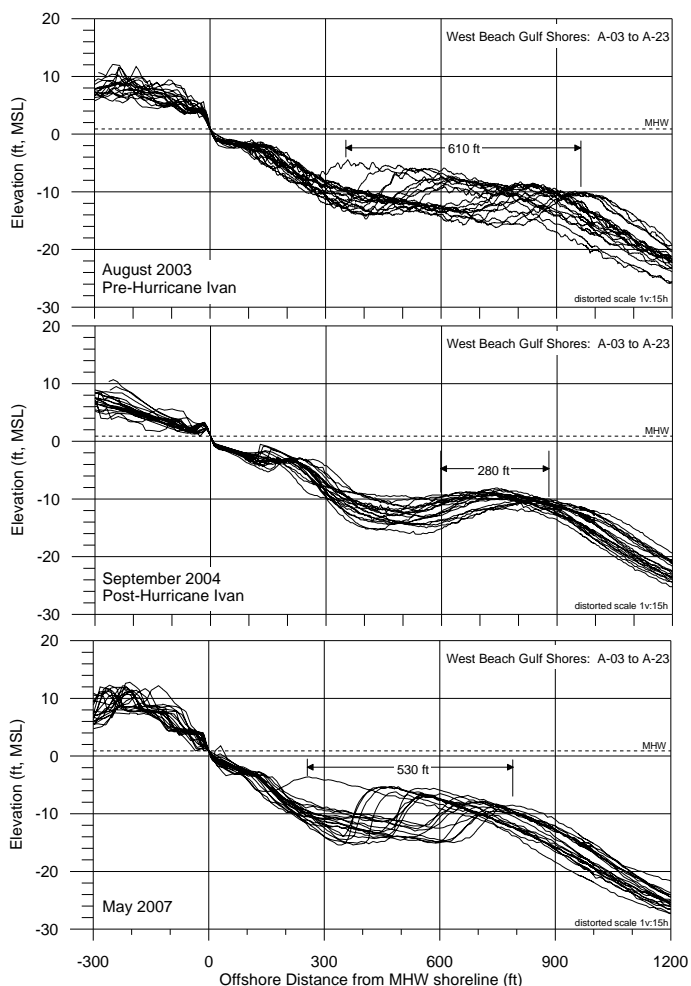

Figure 8   Comparison of the transect-to-transect variation of beach profiles collected during various surveys, West Beach Gulf Shores, AL. Note the range of location of the primary (offshore) bar crest in each survey set.

As suggested in Figures 6 and 7, the alongshore variation in the larger crescentic bars and mega-cusps is generally captured by the beach profile survey spacings. The more localized variations along the shallower inner bar, however, may not be represented by the fixed transect spacing (e.g. Figure 2). With typical alongshore lengths of 200 to 400 ft, the opportunity exists in the worst case for one survey transect to cross a horn feature, while in the following annual survey the same line may cross the deepest part of an embayment feature (or vice-versa). In general, it is observed that the spatial variability in the cusps themselves from one to the next in a single survey is great enough that it is not likely that one survey would capture only embayments, or only horn features. At Pensacola Beach, transect-by-transect comparisons of one-year beach volume changes reveal volume differences of $\pm$ 20 to 30 cy/ft occurring along the beachface and nearshore zone (+5ft to -5ft MSL). In some instances these differences are of opposite sign and occur on immediately adjacent survey transects. These anomalous results can typically be traced to the unfortunate occurrences of lines crossing opposite features of beach cusps in successive years.

Figure 9 depicts a simple illustration, based upon shoreline changes measured at Pensacola Beach between 2006 and 2007. The aerial photo in the figure depicts the more recent shoreline 2007 condition, which exhibits the influence of both a mega-cusp feature and more localized cusps roughly 200 ft in length. The graph plots the MHW shoreline changes measured at each R-monument, simply connected linearly by the solid black line. Inspection of the photograph reveals changes occurring between survey lines that are not represented by the 1,000-ft R-monument data. By digitizing the shorelines in both years' aerial photographs (blue dashed line - guided by the profile data), a more detailed evaluation of overall shoreline changes may be made. In this instance, the R-monument data appear to have been negatively biased by the location of the smaller beach cusps. For the 2006-2007 time period at Pensacola Beach, comparison of the digitized shoreline changes to the measured R-monument changes suggests that the 1,000-ft survey data alone may have overestimated the *average* shoreline recession by just over 15%.

While issues of alongshore variations could be resolved by increasing survey density, it is opined that the density would need to be increased by at least a factor of 10 in the longshore (i.e. 100-ft transects) to sufficiently resolve the smaller cusps listed in Table 1. Approaching the limit of survey resolution, LIDAR data could be utilized for monitoring. The significant added cost of LIDAR -- more than an order of magnitude for such a small survey area -- is not practical for annual surveys. At this time, the significant additional survey costs are deemed unwarranted for the purposes of monitoring the beach nourishment projects in the area. Variations induced by beach cusps can be adequately addressed by inspection of the envelope of profiles for the beach segment (or sub-segment) to assess how the individual profiles compare to the overall shoreline conditions for that particular survey date (e.g. Figure 8). This assessment is greatly facilitated by high-resolution digital orthophotography, taken at the time of the surveys and under clear-water conditions.
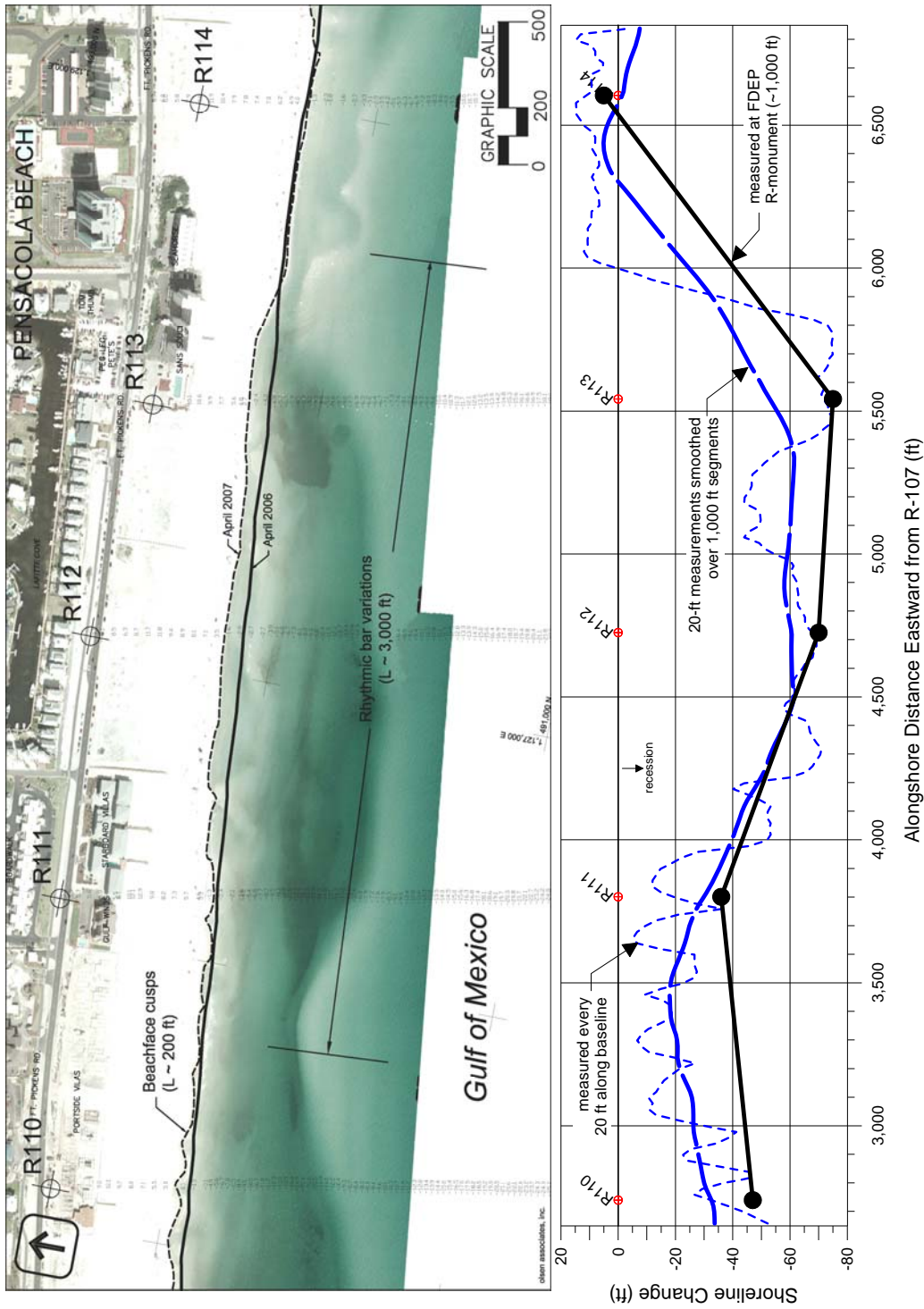
Figure 9 Comparison of shoreline changes computed at 1,000-ft FDEP R-monuments and from digitized aerial photography at 20-ft increments. The digitized data are subsequently smoothed with a 1,000-ft alongshore window. The comparison illustrates the effect of shoreface beach cusps on shoreline change calculations. The aerial photo base likewise depicts the rhythmic variations in the nearshore and along the offshore bar, both of which have significant impacts on volume changes computed from the R-monument surveys (Pensacola Beach, FL, April 2007).

CONCLUSIONS

Using an extensive set of beach nourishment project monitoring data, large scale beach cusps, crescentic longshore bars, and other rhythmic shoreline features are characterized across various beach segments along the Gulf of Mexico shorelines of Escambia County, FL, and Baldwin County, AL. These shoreface and submerged features exhibit a broad range of expression, extending in alongshore length from tens of feet to several thousand feet, with cross-shore amplitudes that can exceed one hundred feet. The variations in beach width caused by the larger cuspate features can create hot-spot erosion areas where upland infrastructure is threatened. The features observed are further described in terms of their shape, or beach state, generally following the beach classification scheme of Wright and Short (1984). Different datasets also reveal the changes in beach state, based upon incident wave conditions. Severe storm impacts tend to reset the shoreline to a two-dimensional longshore-uniform state, after which calmer weather introduces three-dimensional features along the beaches.

Within this dynamic environment, annual beach profile monitoring surveys are conducted along fixed survey transects. The geometry of the cuspate features relative to the fixed survey transects each year introduces the potential to calculate changes in shoreline position and beach volume that may not be representative of the overall changes occurring along the shoreline segment they represent. In this setting, comparison of average beach segment shoreline changes described by discrete survey monuments at 1,000-ft spacing versus shoreline changes measured at much denser spacing via digitized aerial photography reveals a potential for error of 15% or more in some cases.

To address these issues and better describe representative shoreline and volume changes occurring between monitoring surveys, analyses have been performed to augment the collected beach profile data. Aerial photography is used to improve representative shoreline change calculations and determine the extent of influence of the cuspate features. Characteristic profiles can be generated to determine average volume changes, and the overall envelope of surveyed beach profiles can be used to determine the extreme conditions. In general, the present system of monitoring, including the collection of digital orthophotography, is opined to be adequate to document project performance. The presence and effect of beach cusps and crescentic bars on the existing datasets, however, should be acknowledged and the potential for error due to these features noted in any analyses.

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