This paper is contained in the proceedings of the ASCE Coastal Sediments 99 conference held in Hauppauge, Long Island, NY on June 21-23, 1999; pgs. 2534-2549.

BEACH, DUNE AND OFFSHORE PROFILE RESPONSE TO A SEVERE STORM EVENT

Mark E. Leadon, M.ASCE [1]

Abstract: Extensive field survey data collected prior to and following the impact of Hurricane Opal in 1995 on the Panhandle Coast of Florida provides a very comprehensive database, possibly the most comprehensive ever collected, by which to document and analyze sand transport response to a severe storm event. Profile surveys obtained prior to the hurricane were compared with post-storm surveys to document beach and dune erosion and related offshore sand transport along the Florida Panhandle Coast. The most severe dune erosion occurred near and to the right-hand side of the location of the hurricane landfall. High erosion was documented across the entire Panhandle Coast for a distance of over 150 miles (241 km.). Erosion trends across an analyzed portion of the Panhandle Coast show clear correlation to beach slope and to the scale parameter, A, which corresponds to profile shape. Upland lake outlet features appear to increase storm-induced beach erosion in the vicinity of the outlets. Offshore deposition of eroded sand extended to water depths of 40 feet (12 m.) below 0.0 (NGVD). Periodic follow-up surveys over a 2 to 3 year period after Opal have shown some beach and nearshore bar recovery, but little natural dune recovery or landward redistribution of deeper-water sand accumulations deposited by Hurricane Opal.

INTRODUCTION

Hurricane Opal, which struck the Panhandle Coast of Florida just east of Pensacola Beach on October 4, 1995, was one of the most severe hurricanes to impact Florida in the 20th century. The storm track of Hurricane Opal is depicted in Figure 1. Opal caused more structural damage along the Florida coast than all prior hurricanes and tropical storms combined since 1975, a 20-year period which included Hurricane Andrew and Hurricane Eloise. The vast majority of damage within coastal areas was the result of excessively high storm surge and waves and associated erosion, rather than wind damage. Post-storm reports have documented storm damage and various storm characteristics, including wind speed and barometric pressure, as well as, storm hydrograph and high water elevations, and offshore wave conditions (Mayfield1995; Leadon 1996; Leadon, Nguyen, and Clark 1998).

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Opal reached category 4 status (based on the Saffir-Simpson scale) as it approached landfall with maximum sustained surface winds reaching 150 mph, although the winds reduced to about 110 mph just prior to storm landfall at Pensacola Beach near the western end of the Panhandle Coast on October 4, 1995. Storm surge elevations obtained from a National Ocean Survey tide gage located near the end of the Panama City Beach pier in Bay County, approximately 80 miles (129 km.) east of the storm's landfall location, measured +8.3 feet (2.53 m.) above National Geodetic Vertical Datum (NGVD).

High water marks were measured between +12 feet and +16 feet (3.7-4.9 m.) above NGVD

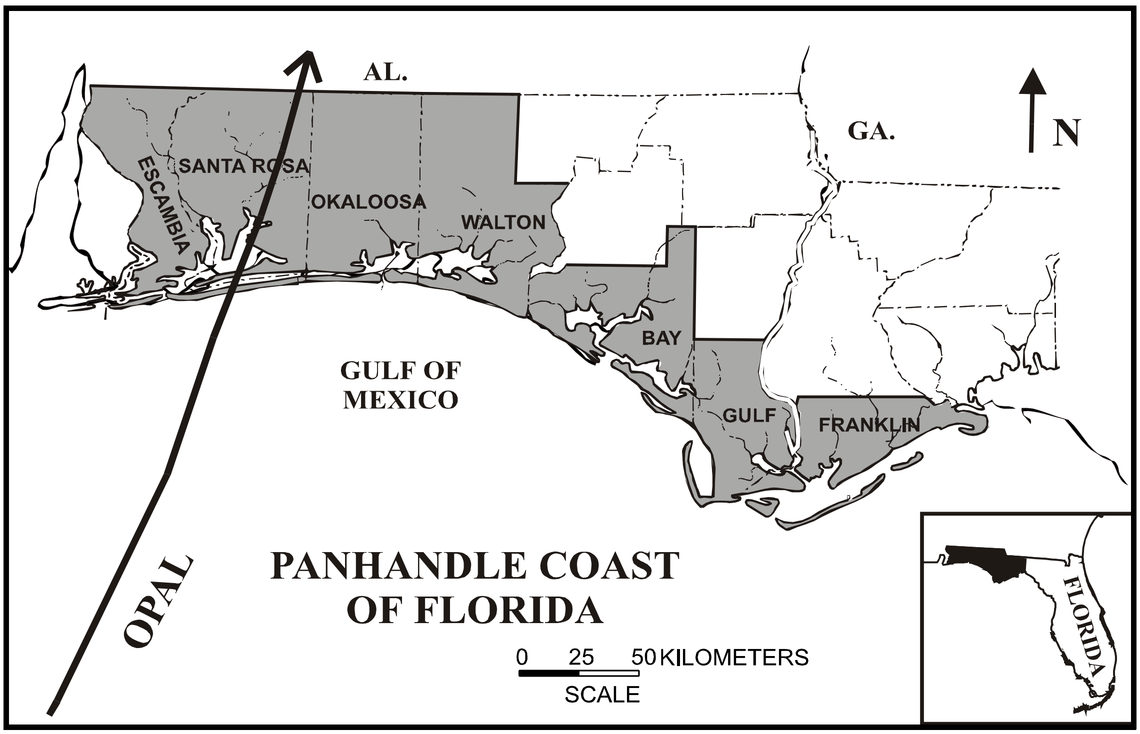

Figure 1. Hurricane Opal storm track across Florida Panhandle and impacted coastal counties.

throughout shorefront buildings from Panama City Beach westward to near the location of storm landfall. Wave setup computations (Dean, unpublished; Chiu and Wang, personal communication) confirmed the validity of the high water elevation measurements. Offshore NOAA wave buoys measured wave heights on the order of 25 feet (8.5 m.) with wave periods reaching 14 seconds during the time of Opal's approach to landfall.

Areas of high continuous dunes experienced substantial recession, while lower dune areas experienced tremendous dune overwash. The Florida Bureau of Beaches and Coastal Systems (BCS) acquired extensive survey data throughout the Florida Panhandle to document the beach and dune erosion caused by Opal, as well as, offshore bathymetric changes which resulted. Post-storm aerial photography was also obtained which documents the extensive overwash across the Panhandle counties. The focus of this paper is analysis and discussion of beach and dune erosion resulting from Hurricane Opal along the Florida Panhandle coast, erosion trends, correlation of erosion trends to profile characteristics, and offshore profile changes and post-storm profile response and recovery over a two to three year period following the hurricane.

PROFILE DATA COLLECTION

The BCS maintains a series of survey monument locations along the Florida coast spaced generally on 1000 foot (305 m.) intervals at which beach and dune profile survey data, as well as, offshore profile data is collected. Survey monuments are numbered sequentially in each Panhandle county beginning with the first range (R1) followed by subsequent ranges in ascending order from west to east.

Pre-storm profile data collected within short time periods prior to Opal's landfall was available for a wide segment of the Panhandle Coast. In particular, extensive coverage of beach, dune, and offshore profile data collected in Walton County in June 1995 and in Bay County in March 1995 (see Figure 1 for county locations), 4 months and 7 months, respectively, before the hurricane provides excellent pre-storm data to compare with post-storm profiles obtained in October 1995. The large number of post-storm profile lines that were obtained in those two counties also contributed to the quality of the data set.

Pre-storm data from other Panhandle counties, although not as extensive as Walton and Bay, also provide data for comparison with post-storm data. Table 1 below outlines the available profile data. Data for Escambia and Santa Rosa counties is combined.

TABLE 1. Summary of Profile Data Analyzed to Assess Hurricane Opal Impact

County	# of Profiles *	Survey Dates (month/year)**
Escambia /Santa Rosa	17 (24%)	(Pr) 3/93,8/95; (Po) 1/96,2/96,12/96, 7/97,7/98
Okaloosa	28 (56%)	(Pr) 1/90; (Po) 11/95,3/96,10/96, 1/98
Walton	116 (91%)	(Pr) 6/95; (Po) 10/95,2/96,10/96,11/97
Bay	101 (70%)	(Pr) 3/95; (Po) 10/95,1/96,9/96, 3/97
Gulf	12 (7%)	(Pr) 7/93,8/94; (Po) 3/97
Franklin	21 (9%)	(Pr) 6/95; (Po) 7/96

* Percentage reflects number of profile lines with usable data out of total survey stations; the values for Escambia County include only those east of the approximate Opal landfall.

** (Pr) indicates Pre-storm, and (Po) indicates Post-storm

No appreciable storm activity occurred in Walton and Bay counties between the pre- and post-Opal surveys. Post-storm surveys were obtained in these two counties within just a few days of Opal's landfall. Although minor storm activity did occur in other Panhandle counties, such as Okaloosa, Gulf and Franklin, between pre- and post-Opal surveys, documented storm erosion other than that attributable to Opal was shown to be negligible.

The situation in Escambia and Santa Rosa counties was somewhat different. No significant erosion occurred after a September 1993 survey until August 1995 when significant beach erosion from Hurricane Erin occurred. Erosion from Erin was documented by survey profiles obtained immediately after the storm in August 1995, 2 months prior to Hurricane Opal. No other survey data was obtained before Opal in October 1995, and thus, there is no documentation of beach recovery following Erin. However, beach recovery was visually observed. The post-Opal surveys in eastern Escambia and Santa Rosa counties were not obtained until 2 to 3 months following the hurricane as a result of destruction of survey control monuments and subsequent necessary monument reestablishment. The delay in post-Opal profiling creates uncertainty with regard to beach recovery prior to the post-Opal surveys; however, again, beach recovery was visually observed. Erosion computations given herein are based on an assumption that beach recovery over the 2 months between Erin and Opal was approximately the same as beach recovery over the 2-3 months between Opal and post-Opal surveys. Based on this assumption, Opal erosion was computed using 1993 pre-storm surveys. Dune recession impacts from Erin were negligible.

The only offshore data collected immediately (3 days) after Opal consisted of a bathymetric survey of the Panama City area in Bay County by the U.S. Army Corps of Engineers using the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system (Lillicrop and Banic 1992). However, profile surveys including substantial offshore data collected periodically from early 1996 through 1998 document post-Opal profile response throughout much of the Panhandle region.

PROFILE RESPONSE

Contour recession and volumetric erosion computations were performed to quantify profile response to Hurricane Opal along the Panhandle coast. Extensive beach and dune erosion was documented, as well as, significant offshore bar migrations through the evaluation of survey data.

Beach and Dune Erosion

The measured erosion from Hurricane Opal exceeded beach and dune erosion documented after some other hurricanes impacting the Gulf of Mexico coastline within the United States, including Hurricane Frederic and Hurricane Eloise. Hurricane Eloise made landfall in 1975 along the Florida Panhandle Coast in Walton County, just east of Hurricane Opal's landfall location, as reported by Chiu (1977). The Hurricane Eloise erosion data was the most complete data prior to Opal and has been a major source of data for calibration of dune erosion predictive numerical models (Hughes and Chiu 1981, Vellinga 1983, Chiu and Dean 1984, Kriebel and Dean 1984, Kriebel 1986). The Hurricane Opal data is more expansive than the Eloise data in the number of survey stations alongshore and in the inclusion of significant offshore data.

Dune contour recession was evaluated using the 10 foot (3 m.) contour elevation, above NGVD, as a reference. Average dune recession of 142 feet (43 m.) was measured near and to the right of the area of storm landfall in Escambia and Santa Rosa counties (combined) with average dune contour recession ranging from 36 to 52 feet (11-16 m.) measured across an area extending up to 100 miles (161 km.) east of the landfall location. Average beach recession, using the 2 foot (0.6 m) NGVD contour as a reference, on the order of 30-40 feet (9-12 m.) was measured across an area extending almost 100 miles east of storm landfall.

Average measured beach and dune volumetric erosion (above 0.0, NGVD) ranged from 38 cu.yds./ft. (95 cu.m./m.) near the storm landfall location to 5 cu.yds./ft. (13 cu.m./m.) in locations over 100 miles (161 km.) east of storm landfall. Contour recession and volumetric erosion values computed for each of the coastal counties along the Panhandle region are compiled in Table 2. It is important to consider the number of profiles available in each county given in Table 1 when reviewing the erosion values in Table 2. The erosion values given in Table 2 demonstrate the widespread extent of Opal's erosional effects. The apparent global erosion trend across the Panhandle is, as expected, for highest erosion near and to the right hand side of the hurricane's landfall and reducing with distance away from landfall. The values for Escambia/Santa Rosa counties include impacts of Hurricane Erin, as discussed earlier. As a worst case scenario, if no beach recovery is assumed following Erin and Opal, then maximum beach recession and volumetric erosion from Erin is 20% of the total given in Table 2. Beach recovery was visually observed following both hurricanes. All values in Table 2 are given in SI units and are rounded to the nearest whole number.

TABLE 2. Summary of Measured Beach and Dune Erosion from Hurricane Opal

County	Recession (m.)				Erosion Volume (cu.m.)	
	Beach (2 ft.(.6m) contour)		Dune (10 ft.(3m) contour)		(Above NGVD)	
	Avg.	Max.	Avg.	Max.	Avg./m.	Total ($x10^6$)
Escambia * /Santa Rosa	-9	-20	-43	-98	-95	- 1.5
Okaloosa	-12	-63	-16	-52	-45	- 1.0
Walton	-11	-22	-14	-47	-68	- 2.8
Bay	-9	-46	-11	-37	-33	- 2.2
Gulf **	+1	-13	-15	-31	-44	-----
Franklin **	+1	-19	0	-19	-13	-----

* Values for Escambia County include only the eastern 30% of that county to the right of Opal landfall and is combined with Santa Rosa County. These two counties reflect some inclusion of Hurricane Erin erosion.

** Minimal data applicable for evaluation.

EROSION RESPONSE EVALUATION

A more in-depth evaluation of erosion response to Hurricane Opal across a portion of the Panhandle counties was performed using the data described above. The area of more in-depth study extended from the location of approximate landfall in eastern Escambia County eastward through most of Bay County to the inlet entrance to St. Andrews Bay just east of Panama City Beach. Patterns of contour recession change and erosion volume change were evaluated. The longshore variation in erosion volume change was compared to other characteristic physical parameters.

Specifically, the pre-storm beach slope and the scaling parameter, A, were evaluated for the Panhandle region in relation to the erosion resulting from Hurricane Opal. The A parameter is contained in the equilibrium beach profile relationship originally derived by Bruun (1954) and further evaluated by and verified by Dean (1977) and given as follows:

$$h(y) = Ay^{2/3} \qquad (1)$$

in which h is the water depth at a seaward distance, y, and A is a scale parameter dependent primarily on sediment characteristics. The A parameter may also be determined by a least-square fit of a measured profile, which is the method used in this study.

This evaluation is similar to the analysis by Chiu (1977) following Hurricane Eloise where extensive pre- and post-Eloise beach profiles were analyzed. Chiu evaluated beach and dune contour recession resulting from Eloise in Walton and Bay counties and compared erosion volume change with changes in pre-storm beach slope. It was shown by Chiu that a correlation existed between erosion and beach slope where higher beach slope corresponded with higher erosion.

Results of the evaluation relative to Hurricane Opal are plotted on the following pages. The depicted contour recession, erosion volume, beach slope, and A value curves are the result of fitting the specific data values to tenth degree polynomials to assist in more clearly observing trends in the data. It is also shown that there are two areas where no data was available. The projected portions of the curves across these two areas are shown in order to assist in observation of trends across the entire study area. The observed trends include both the area-wide, global trend of erosion based on distance from storm landfall and the variation in local erosion which is shown to be correlated to the other described parameters.

Variation in the recession of the 2, 5, 10, and 15 foot (0.6, 1.5, 3.0, and 4.6 m.) contours across this study portion of the Panhandle are shown in Figure 2. As expected, the higher recession occurred closer to the location of storm landfall. The 10 ft. contour recession most clearly depicts that trend. The 15 ft. contour is not seen in Escambia, Santa Rosa, and most of Okaloosa counties because of minimal available data in those locations. Generally, dunes were completely eroded away in those locations as a result of the extensive overwash. Similarities are seen in trends of recession of the 10 and 15 ft. dune contours and of the 2 and 5 ft. beach contours. The 2 ft. and 5 ft. contours appear to reflect effects of beach recovery in the Escambia, Santa Rosa, and western Okaloosa areas probably a result of the data collection occurring over a month following the storm in those areas. A similar expected trend to the dune recession is seen in volumetric erosion across the same study area in Figure 3. The highest volumetric erosion occurred in eastern Escambia and Santa Rosa counties east of the storm landfall location. The trend is similar to the contour recession trend with decreasing volumetric erosion with increased distance from the storm landfall location with the slight exception in eastern Walton County. A plausible explanation of the increased erosion in eastern Walton County will be discussed later in this paper.

The positive correlation between the trend in volumetric erosion and the trend in pre-storm beach slope across the study area, similar to that reported earlier by Chiu (1977), is clearly evident in Figure 3. The subaerial beach slope is considered throughout this paper to be from the 0.0 to 7.0 ft. (0-2.1m) (NGVD) elevation. These trends indicate higher erosion for higher (steeper) pre-storm beach slope and conversely. The apparent exception, again, is eastern Walton County which will be discussed further later. A corresponding negative correlation is evident between the volumetric erosion and the scale parameter, A. The A value is indicative of the general shape of the offshore slope where a higher A value corresponds with a steeper offshore slope and conversely. The trend lines depicted in Figure 3 indicate that lower A values correspond to greater volumetric erosion and conversely.

The correlations discussed above appear to apply primarily to dune areas while a reverse correlation appears to apply to beach areas. Comparison of the beach slope and A value trend lines in Figure 3 with the contour recession trend lines in Figure 2 suggest a positive correlation between beach recession and A value and a negative correlation between beach recession and pre-storm beach slope. Beach recession was higher in areas with lower pre-storm beach slope and higher A value, and lower with the converse. An interesting negative correlation, aside but related to the erosion trends, is between the pre-storm beach slope and the A values. The data depicted in Figure 3 shows a negative correlation between the beach slope and the A values across the defined study area of eastern Escambia County through most of Bay County. This appears to be a basis for storm erosion variation in this area.

The area-wide, global erosion trends depicted in Figures 2 and 3 appear consistent with the global hurricane erosion index, *HEI*, defined by Dean (1999) (equation 2 below) and given as the local hurricane erosion index, *hei(x)*, (equation 3 below) integrated over the shoreline on the right hand side of the hurricane.

$$HEI = \int_0^{10R} hei(x)\,dx \qquad (2)$$

$$hei(x) = \int_0^{10R} W^{5/2}(x,y)\cos\theta\, dy/V_f \qquad (3)$$

where R is the radius to maximum winds, W is the wind speed, the cosine term represents the angle of the wind relative to the shoreline, and V_f is the forward speed of the hurricane.

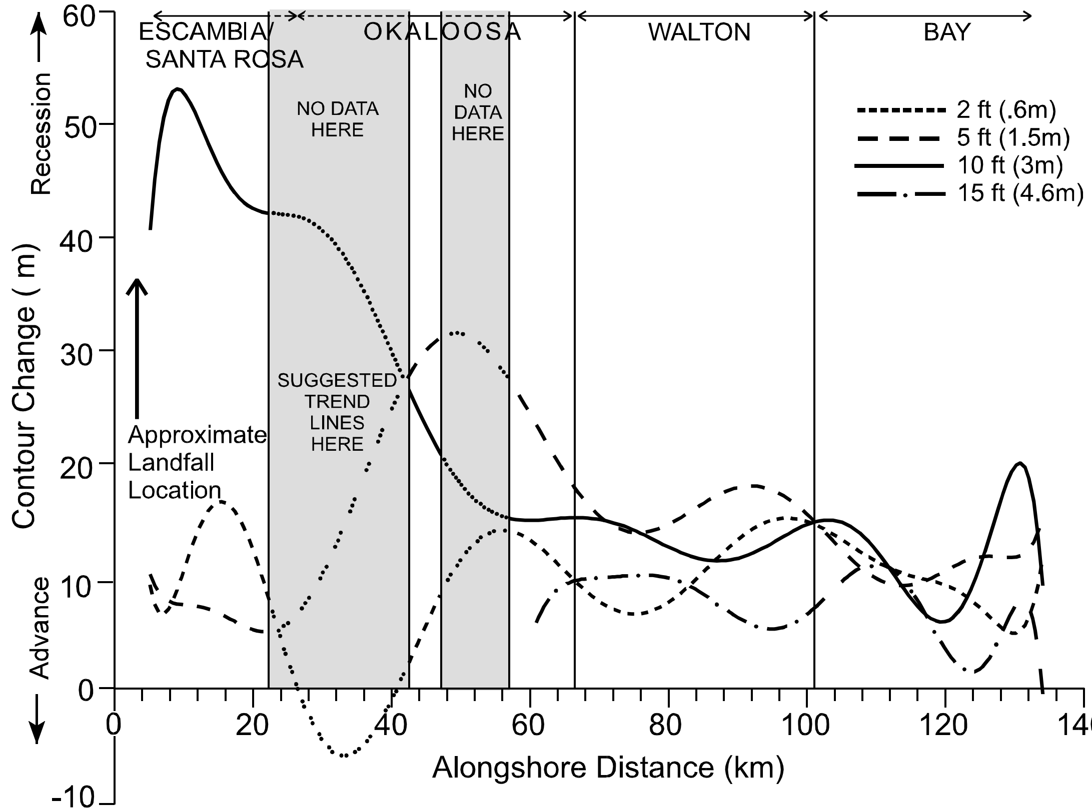

Figure 2. Variation of contour recession along portion of Panhandle Coast.

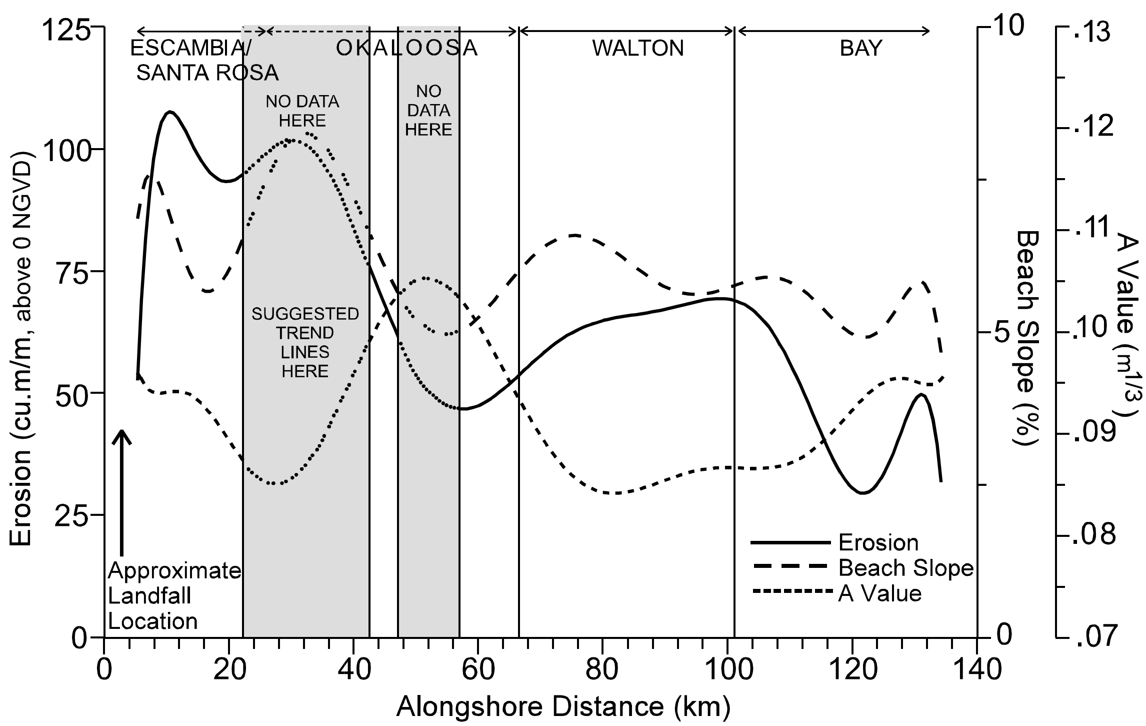

Figure 3. Variation of Opal volumetric erosion, pre-storm beach slope, and scale parameter, A.

The graphic in Figure 4 is reprinted from Dean (1999) and depicts an example of a local hurricane erosion index. The global hurricane erosion index is the integral of the local index over the shoreline on the right hand side of the hurricane. The global erosion trend shown in Figure 3 appears to follow the same general trend as Figure 4 with the exception of local variations as discussed above.

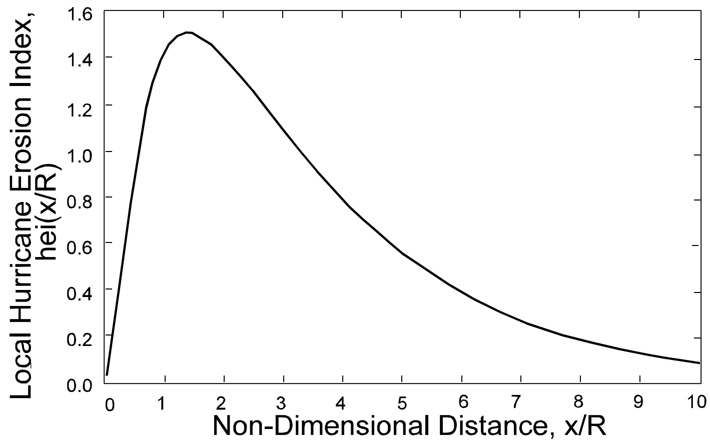

Figure 4. Variation of local hurricane erosion index with non-dimensional longshore distance (from Dean, 1999).

The deviation from the general erosion trend associated with Hurricane Opal in eastern Walton County seen in Figure 3 appears to be the result of the presence of a number of outlets from upland lakes which generally flow from the lakes seaward across the beach/dune profile to the Gulf of Mexico during periods of high rainfall. The outlets form outflow channels which result in breaches through the beaches and dunes in varying degrees. A study by Browder and Dean (1999) has evaluated outlet characteristics in Walton and other Panhandle counties.

The influence of these features on the erosion associated with Opal can be seen in the depiction of outlet locations relative to specific volumetric erosion across Walton County in Figure 5. The outlets located in the eastern portion of Walton County are the largest and the most influential on coastal behavior. Outlets in central and western Walton County are smaller including some apparent remnant outlet areas where small upland lakes are found with no current outlets to the Gulf existing.

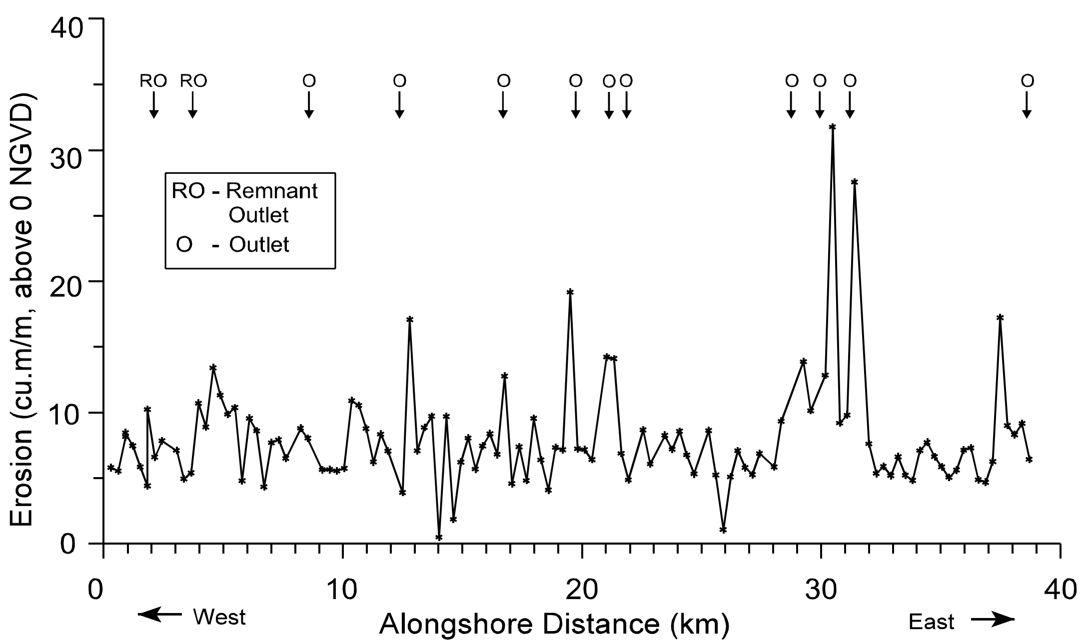

Figure 5. Volumetric erosion relative to lake outlet locations in Walton County.

Post-storm beach slope evaluation was performed in a similar manner to pre-storm slope analysis presented above. A graph showing comparison of pre-Opal with post-Opal beach slope is shown below in Figure 6. In terms of local variations in beach slope across the study area shown, the post-Opal beach slopes follow an interesting negative correlation trend in comparison

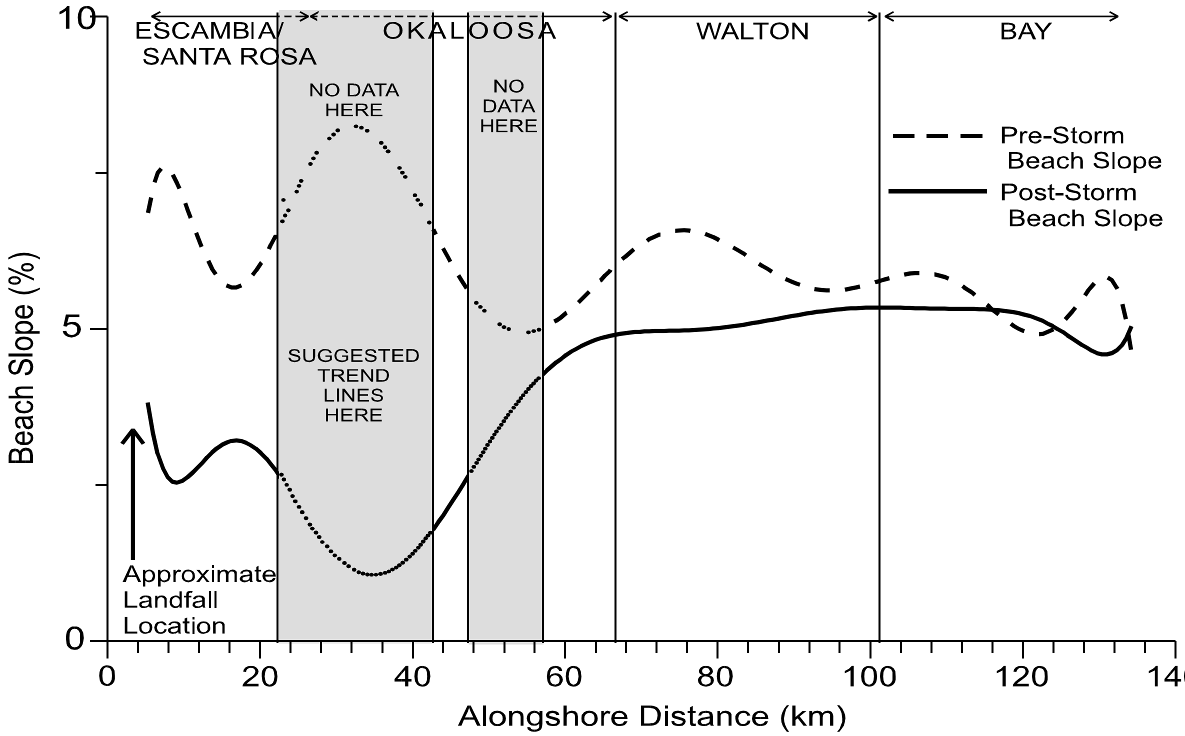

Figure 6. Pre-Opal vs. post-Opal beach slope along portion of Panhandle coast.

with the pre-Opal beach slope trend across the Panhandle. In terms of the general trend, post-Opal beach slopes are seen to be smaller (flatter) in the eastern Escambia, Santa Rosa, and western Okaloosa counties than in the more easterly counties. This corresponds to the locations of more extensive overwash, as well as, locations closer to the position of Opal's landfall. Table 3 lists the average pre-Opal and post-Opal beach slopes for the study area depicted in Figure 6.

TABLE 3. Comparison of Pre-Opal Beach Slope vs. Post-Opal Beach Slope

County	Pre-Opal Slope (Avg., %)	Post-Opal Slope (Avg., %)	Post-Opal Survey Date
Escambia/ Santa Rosa	6.6	2.9	11/95
Okaloosa	5.2	4.1	11/95
Walton	6.1	5.1	10/95
Bay	5.2	5.0	10/95

Some selected examples of typical beach and dune erosion profiles related to Hurricane Opal are shown in Figures 7, 8, and 9 and illustrate profile response at locations in eastern Escambia, western Walton, and western Bay counties, respectively.

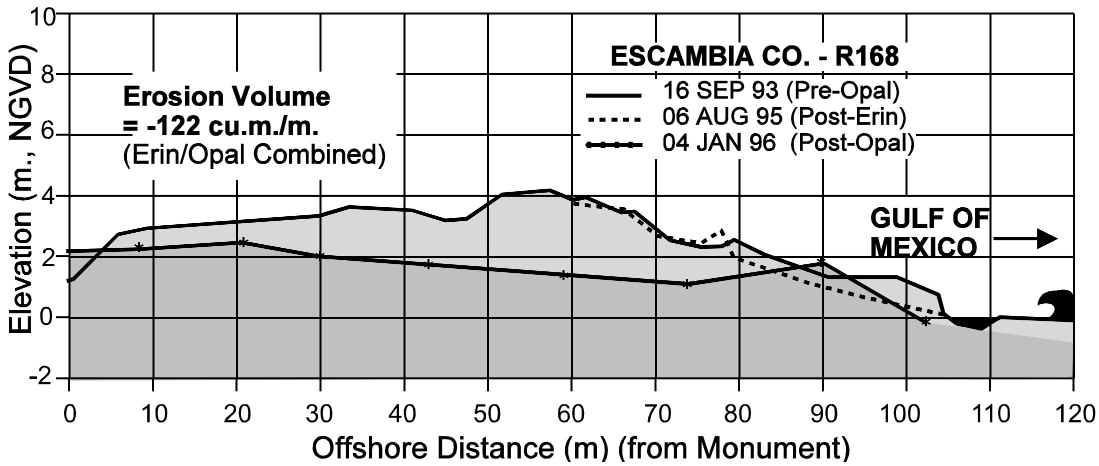

Figure 7. Pre-Opal vs. post-Erin and post-Opal beach and dune profiles.

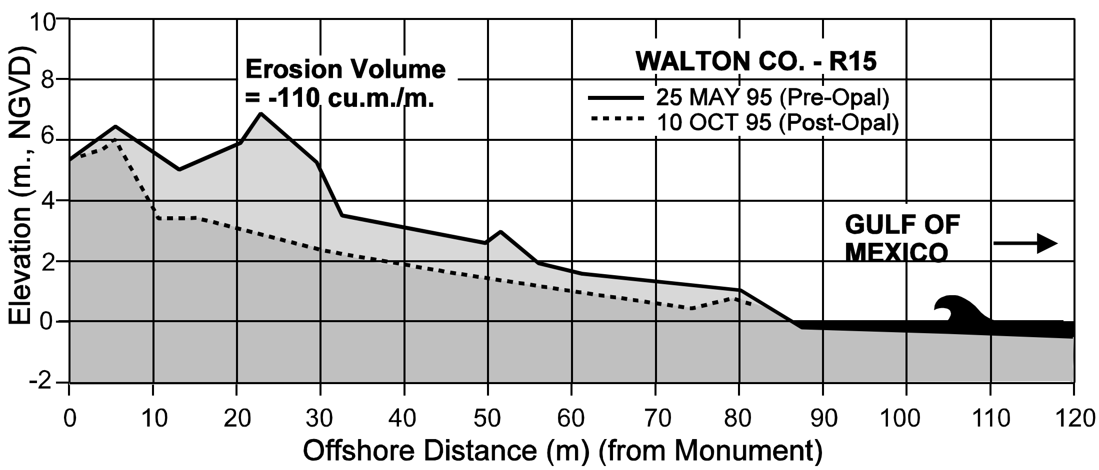

Figure 8. Pre-Opal vs. post-Opal beach and dune profiles.

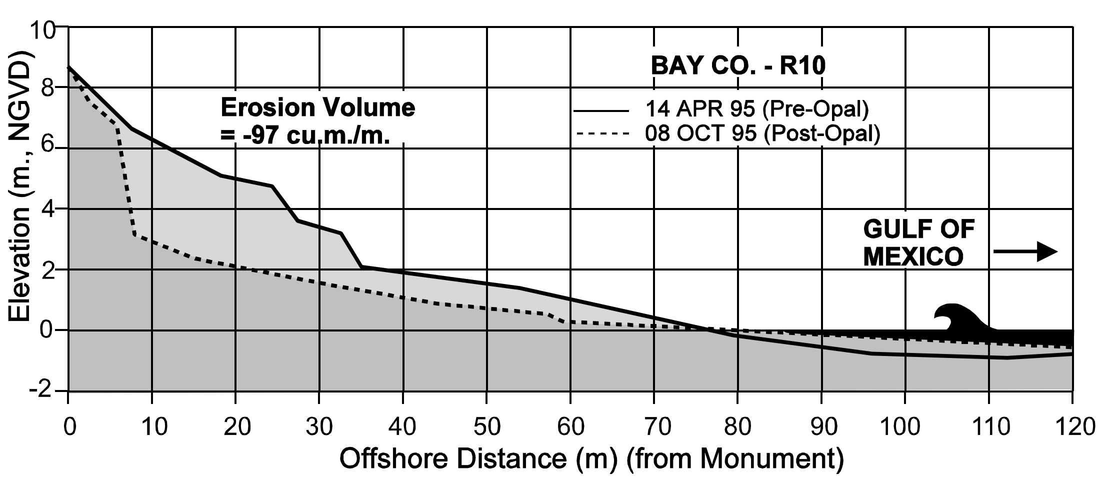

Figure 9. Pre-Opal vs. post-Opal beach and dune profiles.

POST-STORM RECOVERY

A series of post-Opal profile surveys were obtained which document beach, dune, and offshore profile response over a period of 2-3 years following the hurricane. Post-storm recovery activities, such as beach scraping, sand fill placement, and dune restoration, were performed extensively across most of the developed portions of the Panhandle soon after the hurricane's impact. Generally, beach recovery occurred rapidly (within months) throughout the Panhandle region, while dune recovery has been very slow in areas unaffected by assisted dune restoration activities. These observations are consistent with findings by Dean and Suter (1998) who conducted intensive monitoring of post-Opal recovery at selected sites over a two year period.

A depiction of mean high water shoreline changes following Hurricane Opal in the eastern Escambia County and Santa Rosa County area is shown in a planform view in Figure 10. This is the area of highest erosion from Opal. The mean high water elevation is +1.1 feet (.3 m.) NGVD in this area. These shorelines show erosion from Opal, although recovery had already occurred in this area prior to the collection of the data in March 1996, as discussed earlier. The July 1998 shoreline, over two and a half years after Opal's impact and prior to Hurricane Georges' impact (Leadon et al, 1999), shows substantial recovery in the eastern and western portions of this area, but slow recovery in the central portion of this area which is surprising since it is undeveloped and has been stable historically. More study of recovery in this area, as well as, the Panhandle region as a whole is needed.

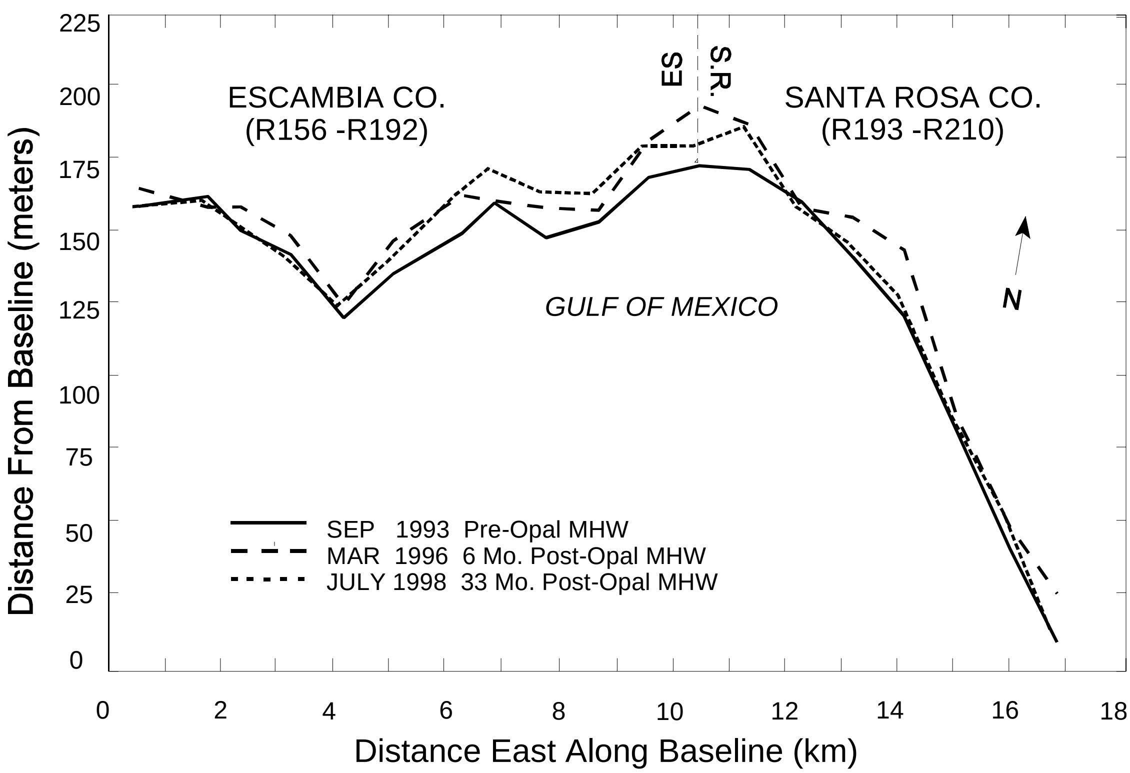

Figure 10. Planform view of pre-Opal shoreline vs. two post-Opal shorelines.

Offshore profile response to Hurricane Opal is documented by a series of post-storm surveys. Representative plots of selected offshore profile surveys are shown in Figures 11 through 13. Offshore response in western Bay County (at the same station, R10, as upland erosion depicted in Figure 9) in Figure 11, which include the immediate post-Opal SHOALS survey, shows extensive offshore deposition from Opal out to depths of nearly 12 meters (NGVD). Very little recovery of that deposited sand is seen through nearly a one and a half year post-storm period, although a trend toward nearshore bar reformation is

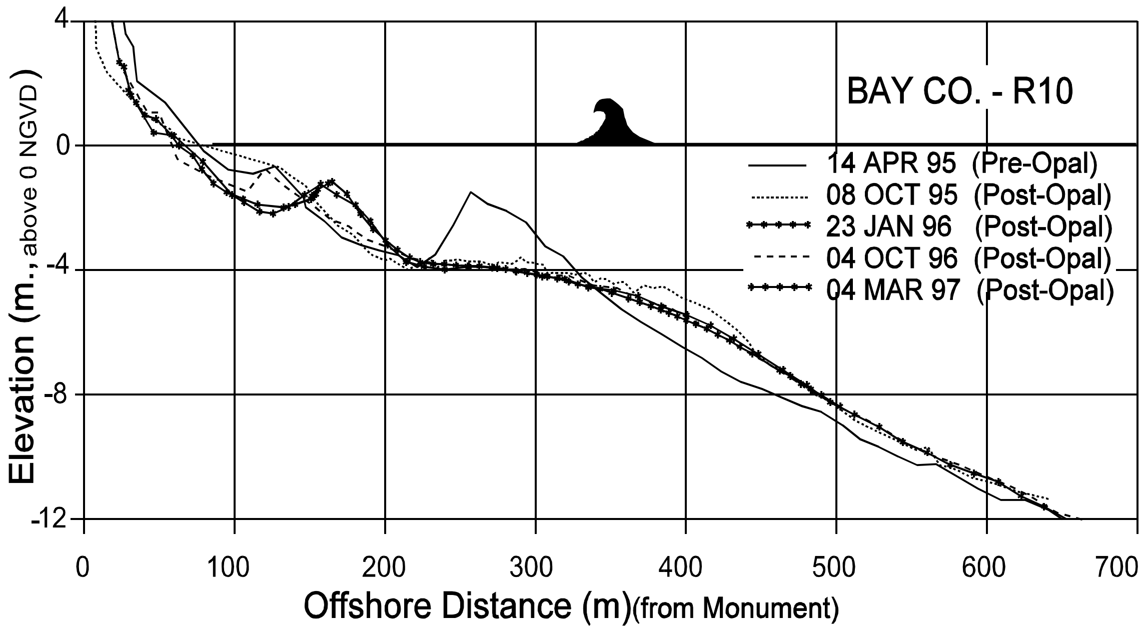

Figure 11. Offshore profile response to Opal in western Bay County.

observed.

An extensive 16 mile beach restoration project in Panama City Beach in Bay County commenced in the fall of 1998. Continued surveying of this area and the beach restoration project will monitor the continued response of the offshore sand deposition from Opal.

Offshore response in an area of Walton County is seen in Figure 12. Average profiles within a 6 kilometer coastal segment (R30-R50) show loss of the nearshore bar with extensive offshore deposition to 12 meter depths (NGVD). Similar to Bay County, partial recovery of the nearshore bar is seen two years after Opal, while recovery of the deep-water deposition feature is not seen. Profile response in Figure 12 shows the additional effects of Hurricane Georges, which made landfall along the Gulf of Mexico coast of Mississippi in September 1998. The November 1998 post-Georges profile shows deeper redistribution of the nearshore bar.

Offshore profile analysis in the Escambia County and Santa Rosa County area was complicated by lack of sufficient data, specifically pre-Opal offshore data, to closely track offshore response. However, average profiles shown in Figure 13, for the same 18 kilometer coastal segment shown in Figure 10, depict a lack of a nearshore bar 5 months after Opal's landfall. Offshore deposition, such as seen in Bay and Walton counties, is presumed, although much of the eroded beach and dune in this area was deposited in a landward direction as overwash. The July 1998 profile, over two and a half years after Opal's landfall, shows reformation of a nearshore bar and apparent recovery of sand lost from Opal to deeper waters. Further monitoring of recovery of the deeper-water deposition by Opal is forestalled by redistribution of the recovering nearshore bar to deeper waters by Hurricane Georges as depicted by the post-Georges profile of October 1998 in Figure 13.

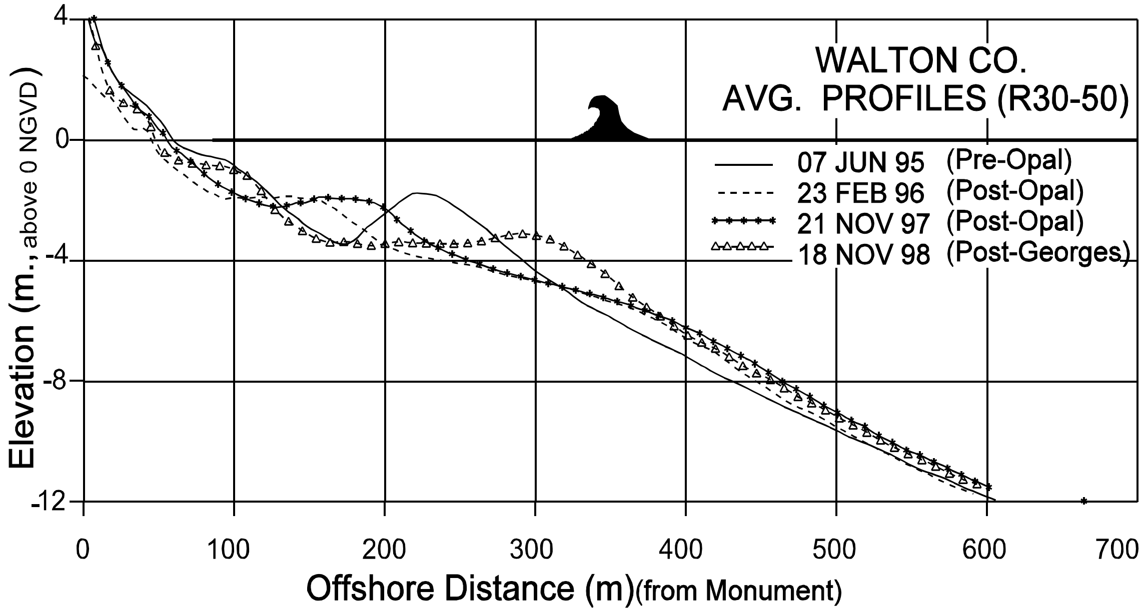

Figure 12. Offshore profile response to Hurricane Opal and Hurricane Georges.

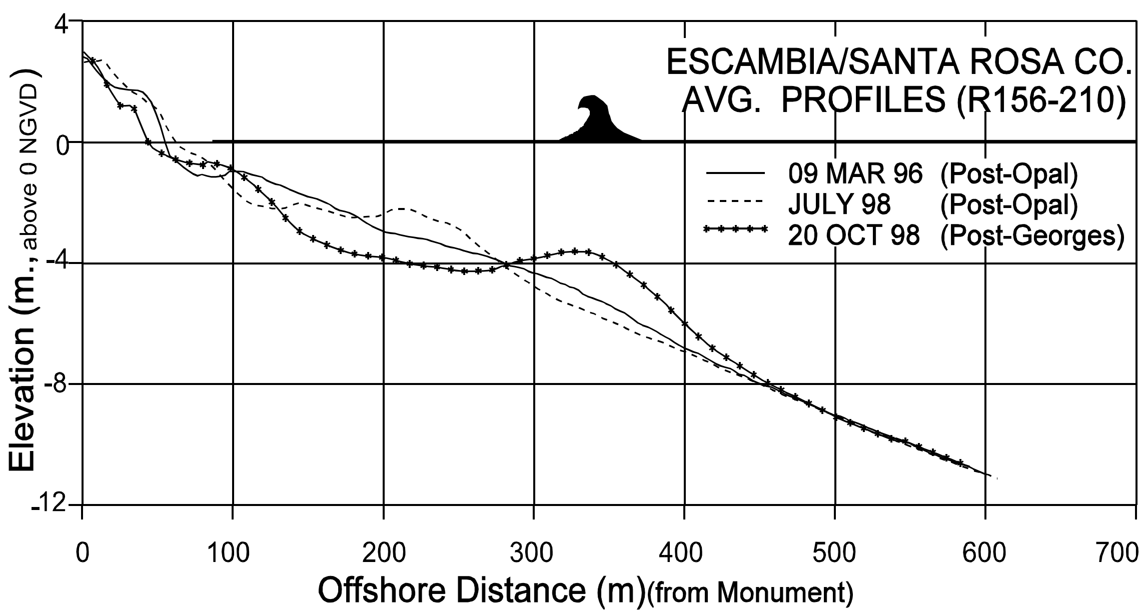

Figure 13. Offshore profile response to Hurricane Opal and Hurricane Georges.

CONCLUSIONS

Extensive beach, dune, and offshore profile surveys collected both before and after Hurricane Opal document beach and dune erosional response and offshore sand deposition to 12 meter water depths in the Gulf of Mexico across the Panhandle Coast of Florida. The alongshore trends in volumetric erosion and dune recession variation follow expected and defined global trends of higher erosion near and to the right of the location of hurricane landfall and decreasing erosion with increasing distance from landfall.

Local dune recession and volumetric erosion variation trends show positive correlation with local pre-storm beach slope variation trends, but negative correlation with local variation trends in the scale parameter, A. Conversely, local beach recession variation trends show negative correlation with pre-storm beach slope variation trends, but positive correlation with the scale parameter variation trends. An interesting negative correlation is seen between pre-storm beach slope variation trends and scale parameter variation trends.

Exception to volumetric erosion variation trend, where increased erosion was computed in eastern Walton County, appears to be related to the presence of upland lake outlets which cut significant breaches through the beaches and dunes. Average post-storm beach slope is shown to be lower (flatter) than pre-storm beach slope, as expected. A global trend of flatter slope near the location of storm landfall and increasing with increasing distance from landfall is shown. An apparent negative correlation between the local pre-storm slope variation trend and the post-storm slope variation trend is also observed from data analysis across the Panhandle study region.

Post-storm beach recovery and a trend toward nearshore bar reformation is observed from profile survey data collected within 2 to 3 years after Opal's landfall. Natural dune recovery has been very slow without the assistance of dune restoration activities. Landward redistribution and recovery of sand deposited by Hurricane Opal into deep water out to 12 meter depths (NGVD) has been very slow. Impact from Hurricane Earl and Georges in 1998 has further slowed post-Opal recovery. Continued monitoring of profile recovery is needed.

ACKNOWLEDGEMENTS

The author would like to to acknowledge and thank Nhan T.Nguyen of the Florida BCS for his diligent assistance in processing and analysis of the data presented in this paper. The author would also like to acknowledge and thank Christine R. Foster for her dedicated assistance in preparing graphic illustrations for this paper. Appreciation is also given to Dr. T.Y. Chiu and Dr. Robert G. Dean for their review of this paper.

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