Storm-Induced Beach Change (SBEACH)
High-Frequency Storm Erosion
Model Study for Broward County

Office of Resilience and Coastal Protection

Florida Department of Environmental Protection

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1. Background and Objective

The SBEACH (Storm-Induced BEAch CHange) model is used by the Florida Department of Environmental Protection to evaluate coastal erosion from the impact of high-frequency storm events in support of regulatory and beach management programs. The SBEACH model, developed by the U.S. Army Corps of Engineers, is an empirically-based numerical model for predicting short-term profile response to storms. The SBEACH model calculates beach profile changes, with emphasis on beach and dune erosion, bar formation, and movement. It is a cross-shore sediment transport model such that the longshore processes are considered uniform and neglected in the calculation of profile changes. The model was initially formulated using data from prototype-scale laboratory experiments, and further developed and verified based on field measurements and sensitivity testing (Larson and Kraus, 1989).

The present study provides a model calibration of SBEACH for high-frequency erosion analysis of Broward County. To accurately apply the SBEACH model for a high-frequency storm event, it is essential to have the model calibrated in the project area under similar storm conditions. This calibration requires detailed pre- and post-storm beach profile surveys that represent a storm's effects on cross-shore beach change, and coincident information regarding the wave and water level conditions. This study presents eroded dune and beach profiles due a high-frequency storm event, with a return interval of 15–25 years, in Broward County using the latest version (4.03) of the SBEACH model. All data resources for analysis and input files required to run the SBEACH model are documented.

2. Model Calibration

Searches for available surveyed beach profiles associated with a tropical storm or hurricane for Broward County resulted in a limited set of data with enough completeness and quality for model calibration. A set of beach profiles in part of Broward County were surveyed before and after Hurricane Irma (2017).

2.1. Storm Data

Hurricane Irma made landfall on Cudjoe Key on September 10 as a Category 4 hurricane (Figure 1). Irma then weakened to Category 3 status, prior to another landfall on Marco Island later that day with maximum winds of 115 mph and minimum central pressure of 936 mb (Cangialosi et al., 2018). The system then degraded into a remnant low on September 12 over Alabama, ultimately dissipating on September 13 over Missouri. Data products available for Hurricane Irma involve the archived storm data from the National Hurricane Center (2019), including storm track and six-hourly measures of barometric pressure, sector-based winds (wind speed-based radii) and forward speed. Published reporting available for Hurricane Irma include the tropical cyclone report developed by Cangialosi et al. (2018), which documents a full meteorological narrative of the storm.

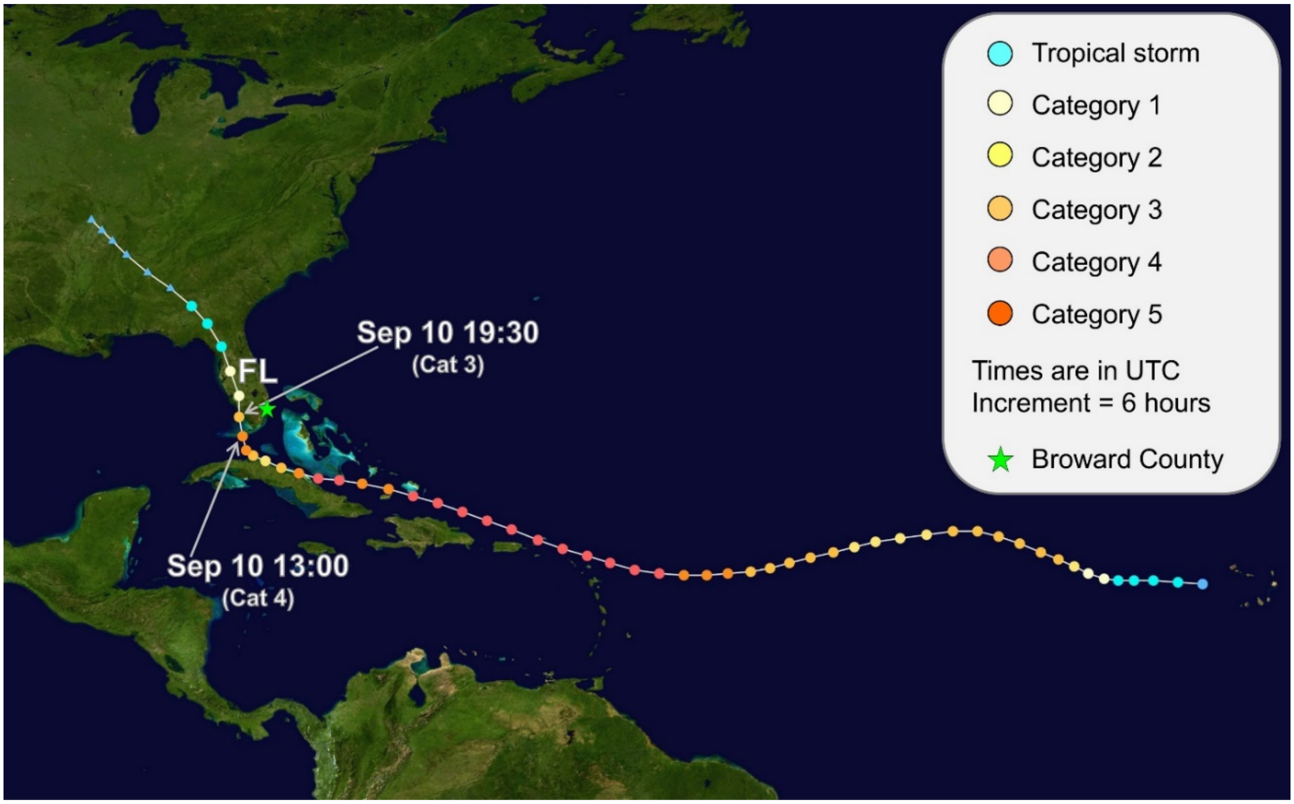

Figure 1. Storm track of Hurricane Irma 2017 (National Hurricane Center, 2018).

2.1a. Storm Tide Data

For the model calibration, measured storm tide generated by Hurricane Irma is essential. Two types of data were collected to represent the storm tide along the open coast (Table 1): (1) water levels measured via temporarily established USGS tide gauges (USGS, 2019); and (2) water levels measured via permanently established NOAA tide gauges (NOAA, 2019). Time-series gauge data were available for seven USGS short-term monitoring stations located along the open coast of Palm Beach, Broward and Dade Counties. Additional data were available for one NOAA gauge located at Virginia Key (Dade County). Figure 2 displays a locator map of the tide gauging stations. Three of the eight stations (PAL03587, PAL17786 and MIA03483) are located inshore, within the intracoastal waterway, where there is a dominant sheltering effect of the storm tide and an almost complete absence of wave setup. Two stations (MIA03476 and 8723214) are located at an inlet, where there is a partial sheltering of the storm tide. All three of the Broward County stations (BRO20853, BRO03527 and BRO03495) are located on the open coast, providing the most representative data of the open-coast storm tide hydrograph. The peak storm tide in Broward County measured 3.72, 4.04 and 4.36 feet (NAVD) at the three gauging stations. By comparing the measured storm tide data (peaks) with the total storm tide values for various return periods listed in Table 2 (Division of Water Resource Management, 2014), it shows that Hurricane Irma generated total storm tides of 10-year return period for Broward County. Therefore, Hurricane Irma was selected as the high-frequency storm to calibrate the SBEACH model for Broward County.

Table 1. Tide gauge data for Hurricane Irma along the Southeast Atlantic Coast Region.

Station	Name	Lat (°N)	Lon (°W)	Agency	Inshore, inlet or open coast	Peak (feet, NAVD)
PAL03587	John D. MacArthur Beach State Park	26.8249	80.0426	USGS	Inshore	2.21
PAL17786	Public dock on IWW	26.6923	80.0494	USGS	Inshore	2.32
BRO20853	Pompano Beach Pier	26.2353	80.0879	USGS	Open coast	3.72
BRO03527	Pier off Commercial Blvd.	26.1894	80.0945	USGS	Open coast	4.04
BRO03495	Dania Beach Pier	26.0583	80.1110	USGS	Open coast	4.36
MIA03483	Golden Beach	25.9600	80.1220	USGS	Inshore	3.33
MIA03476	Sunny Island Ocean Walk Park	25.9008	80.1237	USGS	Inlet	3.32
8723214	Virginia Key	25.7317	80.1617	NOAA	Inlet	3.84

The time-series storm tide data for the seven USGS gauging stations span less than 24 hours (Figure 3). Moreover, measurement of storm tide elevations was only possible when the water level exceeded the height of the device, whereby the rising and falling limbs of the hydrograph were not measured. To that end, the USGS storm tide data are exclusively reliable for assessment of the peak water level. On the other hand, the NOAA data span continuously over the full storm duration. Figure 4 displays a 36-hour record of storm tide data (centered in time about the peak surge) for the NOAA gauging station at Virginia Key, which shows an increase in water level of 1–3 feet above the corresponding astronomical tide. This 36-hour storm tide hydrograph reasonably represents the open-coast storm tide of Hurricane Irma and served as the basis for the input hydrograph of the SBEACH model calibration.

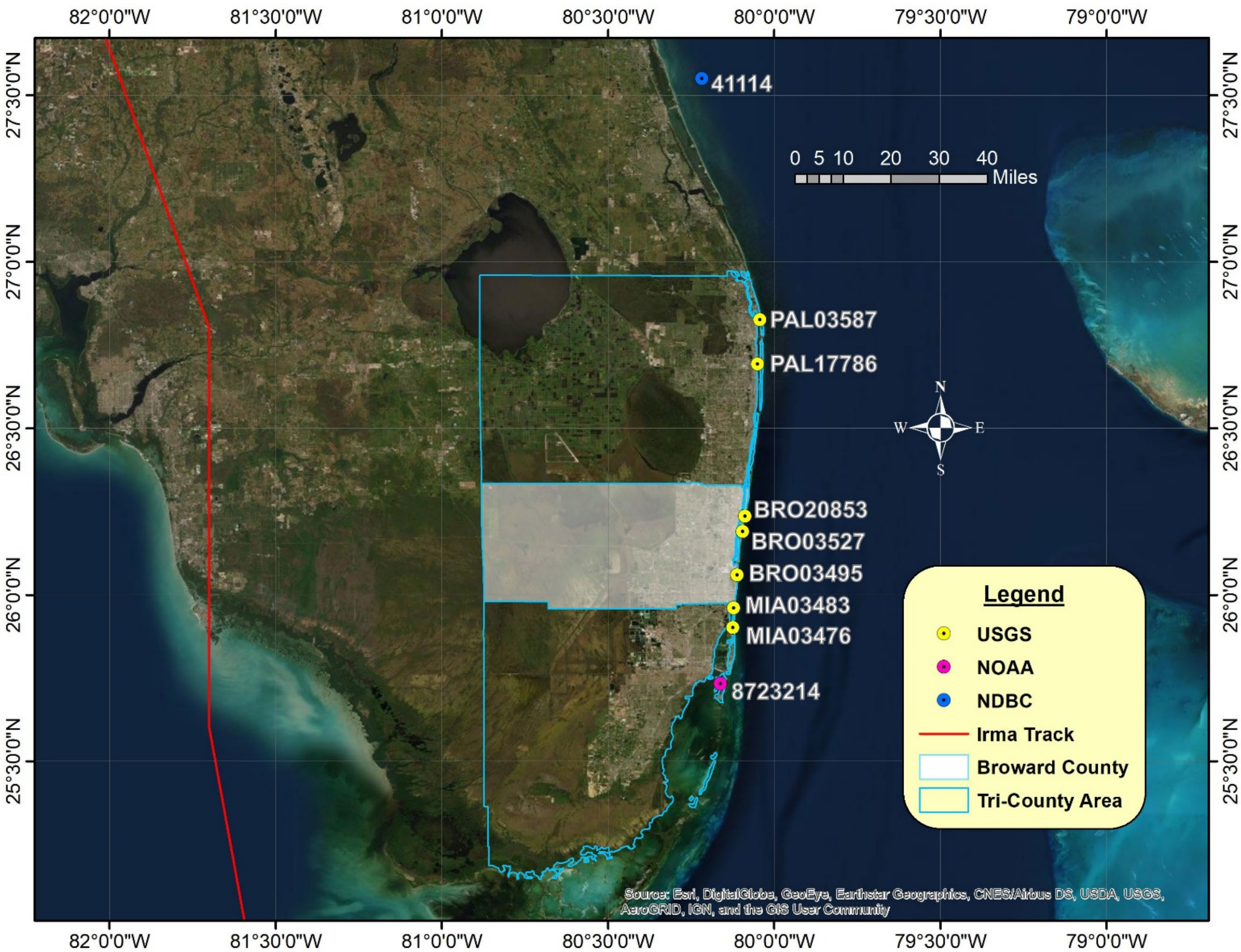

Figure 2. Monitoring stations for Hurricane Irma within Palm Beach, Broward and Dade Counties.

Table 2. Total storm tide levels (feet, NAVD) for various return periods and Hurricane Irma.

Return period (years)	North profile	Middle profile	South profile
50	7.7	7.6	7.5
30	6.6	6.6	6.6
25	6.3	6.2	6.2
20	5.9	5.7	5.7
15	5.3	5.2	5.2
10	4.5	4.4	4.5
5	3.0	2.9	3.0
Hurricane Irma (2017)	4.4	4.4	4.4

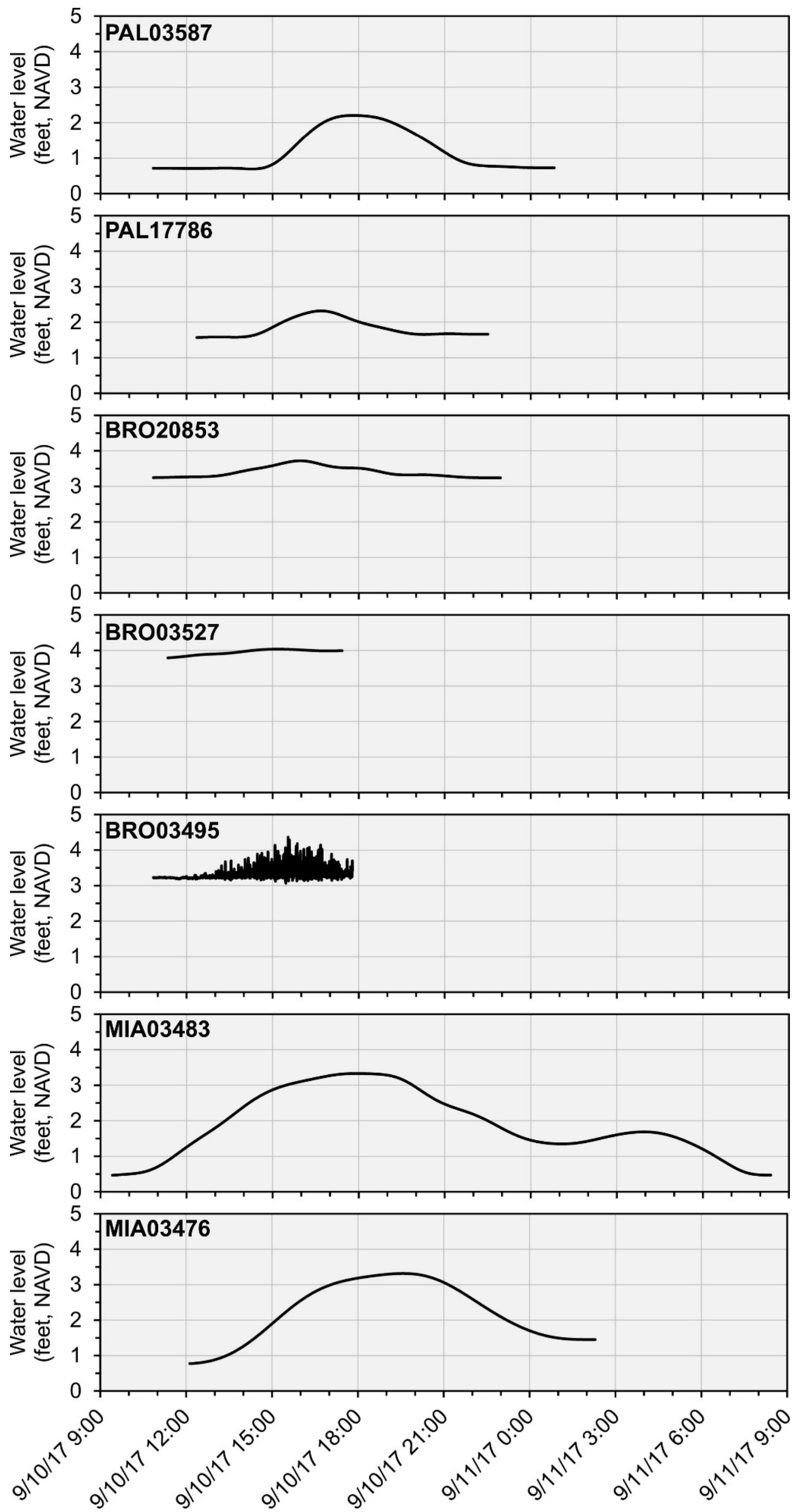

Figure 3. Time-series storm tide (Hurricane Irma) data for seven USGS gauging stations.

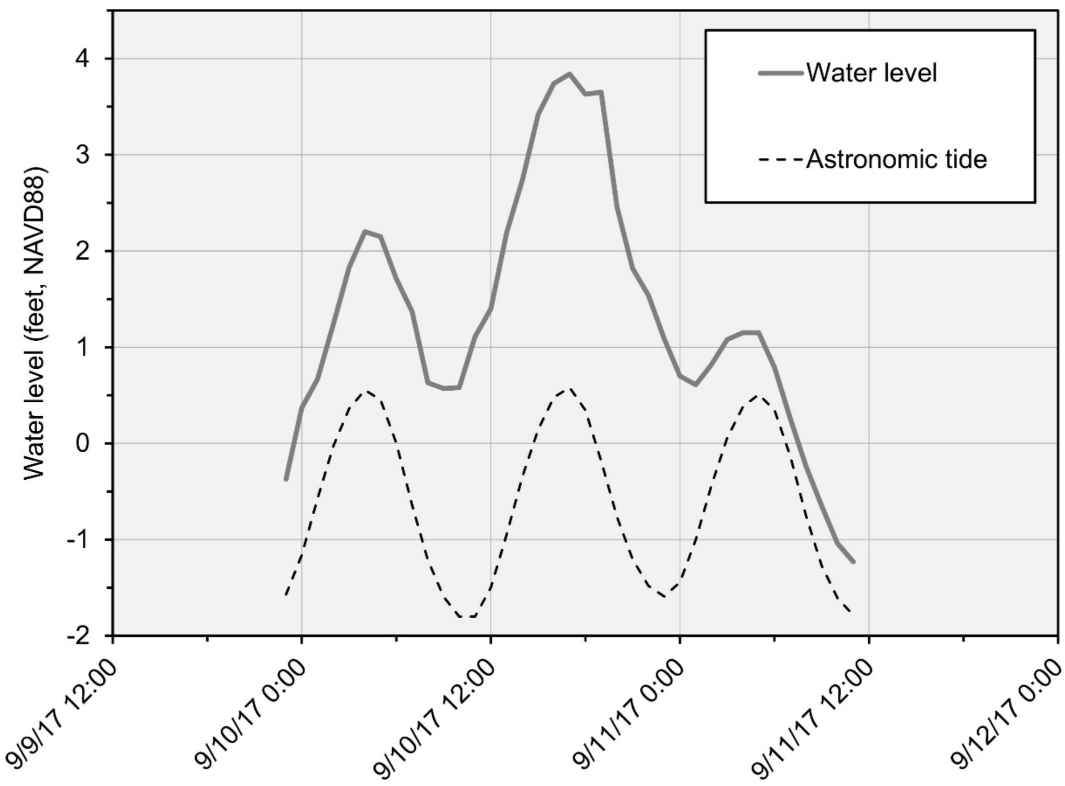

Figure 4. Time-series storm tide (Hurricane Irma) data for NOAA gauging station 8723214.

2.1b. Wave Data

Measured wave data for Hurricane Irma were available from the nearest offshore NDBC station (see Figure 3 for respective location). NDBC station 41114 is located approximately 10 miles east of Fort Pierce (27.550°N 80.217°W) at a nominal water depth of 53 feet. Time-series values of significant wave height and dominant wave period values from the buoy data (NDBC, 2019) are displayed in Figure 5. The data are incremented at a 30-minute interval; however, the data are too noisy to be applied directly as input to the SBEACH modeling. To that end, a six-hour moving average was applied to the raw time-series data. The averaging technique provided a smooth signal of wave heights and wave periods at six-hour intervals over a 36-hour duration for Hurricane Irma (2017): September 9 23:00 UTC – September 11 11:00 UTC (Table 3). Wave direction of 0° (shore-normal) was applied as a constant value for input to the SBEACH modeling.

2.1c. Hydrographic Survey Data

The hydrographic survey data utilized in this study were sourced from Florida Department of Environmental Protection (2019). The first set of profile data, collected in January 2017 (file name BO1701_CPE_1.PRF), captured the dune and berm features of the beach, as well as the nearshore profile out to approximately 3000 feet offshore at nominal depths of 35–40 feet. The BO1701_CPE_1 dataset provided the profile representation of the pre-Irma beach conditions for the SBEACH modeling input data. The second set of profile data, collected in October 2017 (file name BO1710_COE_1.LID), captured the dune, beach and nearshore condition after the impact of Hurricane Irma. The CO1710_COE_1 dataset provided the profile representation of the post-Irma beach conditions for the SBEACH modeling calibration. The profile datasets (pre- and post-Irma) encompassed the full R-monumentation of Broward County (Figure 6). Of the complete set of profiles, consistent profile shapes were discerned among a subset of the overall data. This discernment of the data identified R-monuments 48–53, 55–57 and 59–66 as demonstrating a consistent cross-shore dynamic response with coherent erosional signature at contour elevations of 2–8 feet (MHW) and observable compensatory accretion of sloughed sand at contour elevations of 0–2 feet (MHW). Appendix A displays profile plots of the pre- and post-Irma hydrographic survey data for the 17 R-monuments of Broward County selected for use in the SBEACH model calibration.

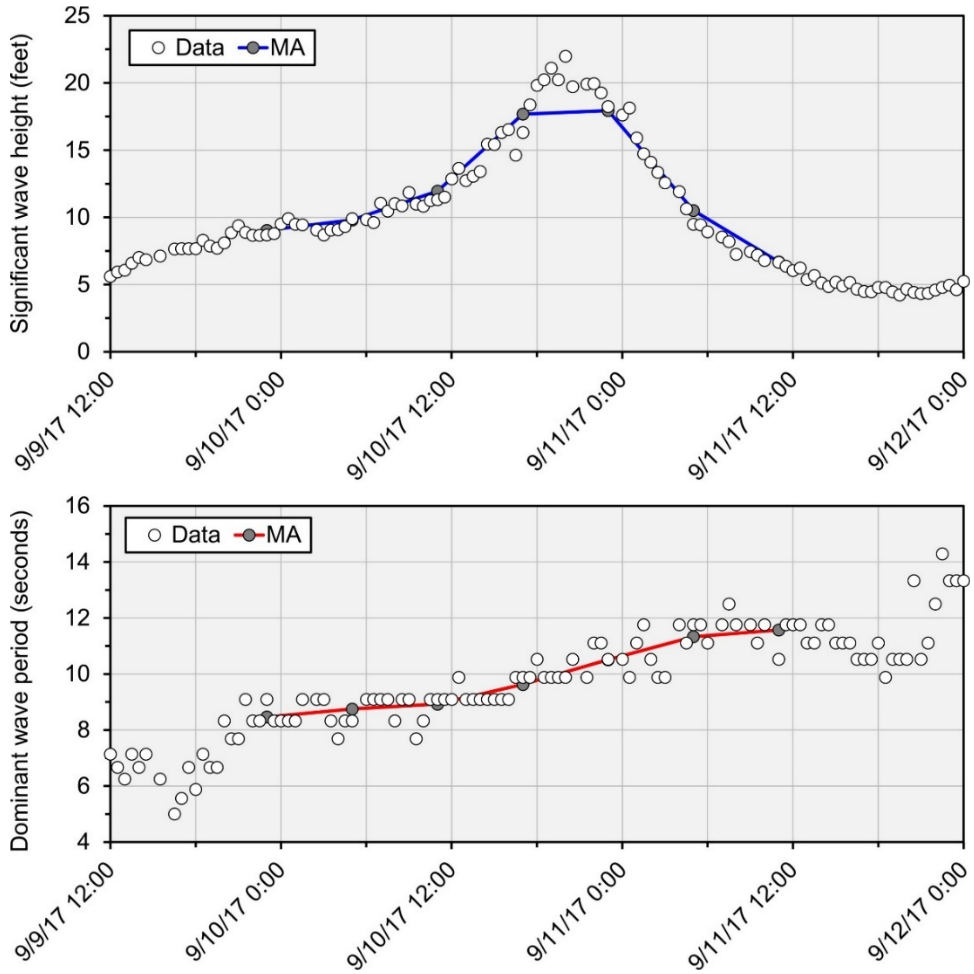

Figure 5. Time-series wave data (Hurricane Irma) for NDBC gauging station 41114.

Table 3. Wave input data for SBEACH modeling.

Model simulation time (hour)	Date and time (UTC)	Wave height (feet)	Wave period (seconds)	Wave direction (°)
0	9/9/2017 23:00	9.04	8.47	0 (shore-normal)
6	9/10/2017 05:00	9.80	8.75	0
12	9/10/2017 11:00	11.95	8.93	0
18	9/10/2017 17:00	17.68	9.63	0
24	9/10/2017 23:00	17.94	10.51	0
30	9/11/2017 05:00	10.51	11.33	0
36	9/11/2017 11:00	6.68	11.57	0

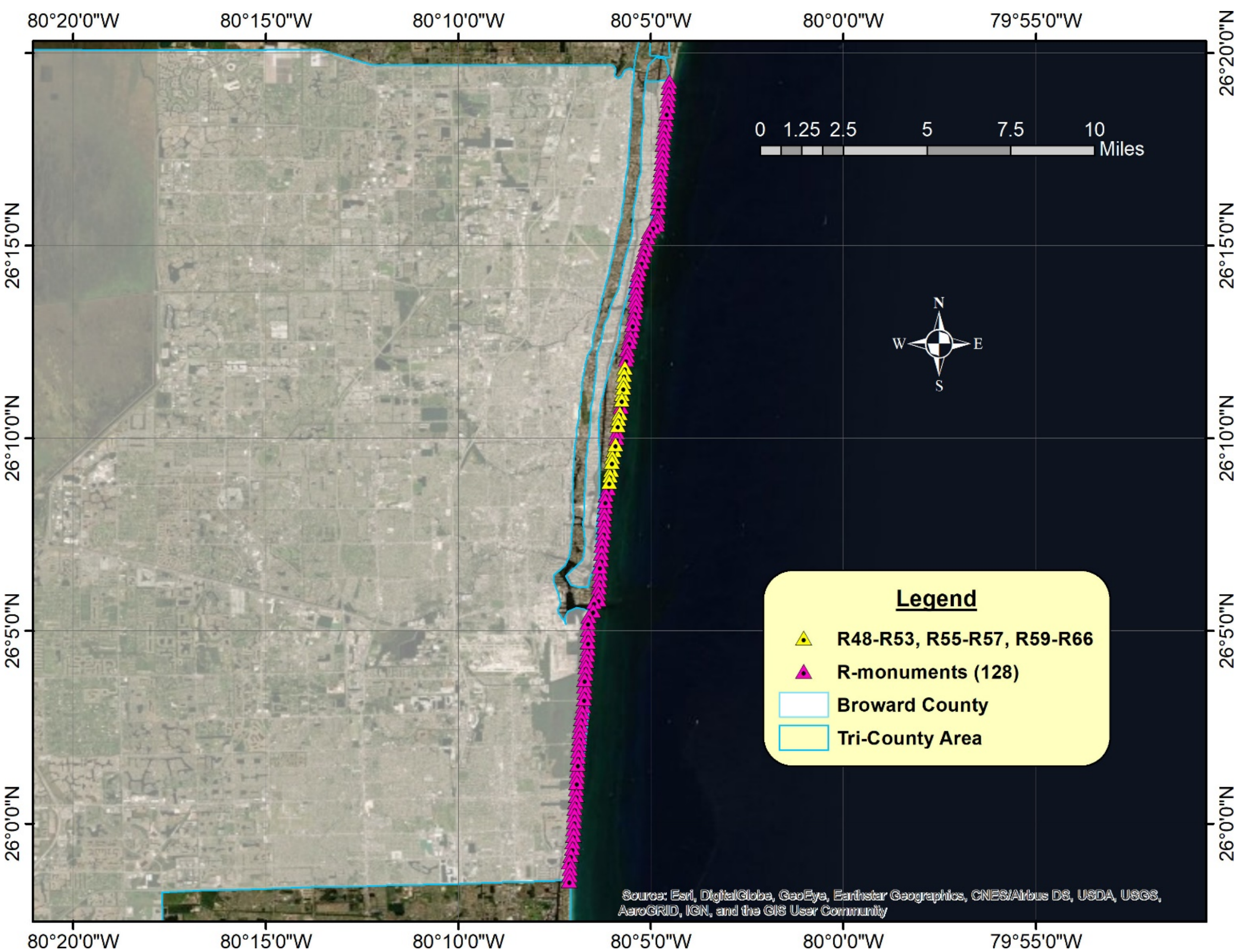

Figure 6. Map of R-monuments, including model-calibration profiles, for Broward County.

2.2. Model Input Parameters

The primary input information for the SBEACH model includes profile, storm and sediment data. Profile data are selected based on the segment of shoreline being modeled. Mean grain size of the beach material is one of the primary sediment data required. Other inputs include model parameters such as grid size, time step and the transport rate coefficient.

The beach profiles were represented in the model using a constant grid scheme with grid cell spacing of 5 feet to generate a detailed result. Each reach was approximately 3000 feet long described by about 600 cells. Sediment data were obtained from beach sediment surveys of Florida's southeastern coast (Charles et al., 1994; Benedet et al., 2004). For the model calibration area, the average mean grain size was 0.375 mm.

The default values for SBEACH are listed in Table 4. A series of model runs was conducted within the range of recommended values to achieve the best fit between measured and calculated erosion profiles.

Table 4. Default values and range of values for SBEACH model input parameters.

Parameter	Unit	Default value	Range of values
Transport rate coefficient	$m^4\ N^{-1}$	1.75×10^{-6}	$0.25\times10^{-6} – 0.25\times10^{-5}$
Overwash transport parameter	None	0.005	0.002 – 0.008
Coefficient for slope-dependent term	$m^2\ s^{-1}$	0.002	0.001 – 0.005
Transport rate decay coefficient	m^{-1}	0.5	0.1 – 0.5
Landward surf zone depth	feet	1.0	0.5 – 1.6
Effective grain size (D_{50})	mm	0.35	0.15 – 1.0
Maximum slope prior to avalanching	Degree	45	15 – 90
Water temperature	°C	20	0 – 40

2.3. Model Calibration Results

The sensitivity evaluation began with initially setting the model input parameters to the default values (Table 4), except for the effective grain size (D_{50}), which was set to 0.375 mm based on field verification (Charles et al., 1994; Benedet et al., 2004), and water temperature, which was set to 27°C. Wind speed and direction, available as options during the model input, were not included due to the insignificant effect on the model results, whereby those terms were zeroed in the model. The time-series storm tide data for Hurricane Irma measured at the NOAA gauging station (8723214) (Figure 4) served as a basis for the input hydrograph for the SBEACH modeling. Since the SBEACH model calculates and adds the wave setup internally to reach the desired final water level, the input hydrograph was adjusted so that the peak water elevation output from SBEACH agreed with the observed peak storm tides. Table 5 presents the SBEACH input hydrograph in tabular format. The peak water level of the input hydrograph is 0.54 feet. Applying the input hydrograph within SBEACH, the peak water level with wave setup predicted by SBEACH was 4.6 feet, which is representative of the total storm tide level caused by Hurricane Irma along the open coast of Broward County (Table 1).

The average (among the 17 profiles—see Appendix A) erosion distance of the survey measurements versus the SBEACH calculations for contours from 0 to 5 feet above NAVD were used as the principal basis for determining the calibration parameter settings. The lower limit of 0 feet is used because it represents the middle range of the astronomic tide, where most of the beach erosion occurred in the elevation contours above this 0-foot level. The upper limit of 5 feet is used because it represents the higher end of the total storm tide levels experienced along the open coast of Broward County due to Hurricane Irma (Table 1), where most of the beach erosion occurred in the elevation contours below this 5-foot level. Starting with the default values (Table 4), a series of values for each calibration parameter was tested. The transport rate coefficient, the coefficient for the slope-dependent term and the maximum slope prior to avalanching were found to be significant to the calibration results, so they were adjusted individually until reasonable agreement with the measured erosions were achieved.

The final parameter values determined by the calibration procedure are listed in Table 6. These parameter values provided the best replication of the beach erosion observed for Broward County due to Hurricane Irma. Figure 7 shows comparisons of the average contour translation (horizontally) between the measured (survey) and modeled (SBEACH) beach profiles for the 17 R-monuments based on the final model parameter set. The pattern of SBEACH model-predicted erosion contours using the final calibration values are in general agreement with the pattern of measured erosion contours. For the contour levels within 3–7 feet, which were impacted the most by the storm surge and waves, the average (17 profiles) distance of retreat was 21 feet based on the measurements and 17 feet based on the model results, equating to a relative error 19% – an acceptable model approximation of the measured erosion. Plots of measured (pre- and post-Irma) and modeled (SBEACH) beach profiles using the final calibration values for the 17 R-monuments of Broward County are presented in Appendix A.

Table 5. SBEACH input hydrograph values for Hurricane Irma at Broward County.

Time (hour)	Water level (feet, NAVD)
0	-2.10
1	-1.61
2	-1.09
3	-0.53
4	-0.09
5	0.14
6	0.05
7	-0.39
8	-0.97
9	-1.58
10	-1.88
11	-2.03
12	-2.19
13	-1.90
14	-1.11
15	-0.56
16	0.12
17	0.44
18	0.54
19	0.33
20	0.35
21	-0.84
22	-1.48
23	-1.76
24	-2.21
25	-1.73
26	-1.43
27	-0.95
28	-0.51
29	-0.25
30	-0.16
31	-0.37
32	-0.86
33	-1.45
34	-1.94
35	-2.29
36	-2.47

Table 6. Final SBEACH model calibration parameters for Broward County.

Parameter	Unit	Calibration value
Transport rate coefficient	$m^4\ N^{-1}$	1.0×10^{-6}
Overwash transport parameter	None	0.005
Coefficient for slope-dependent term	$m^2\ s^{-1}$	0.002
Transport rate decay coefficient	m^{-1}	0.5
Landward surf zone depth	feet	1.0
Effective grain size (D_{50})	mm	0.375
Maximum slope prior to avalanching	°	30
Water temperature	°C	27

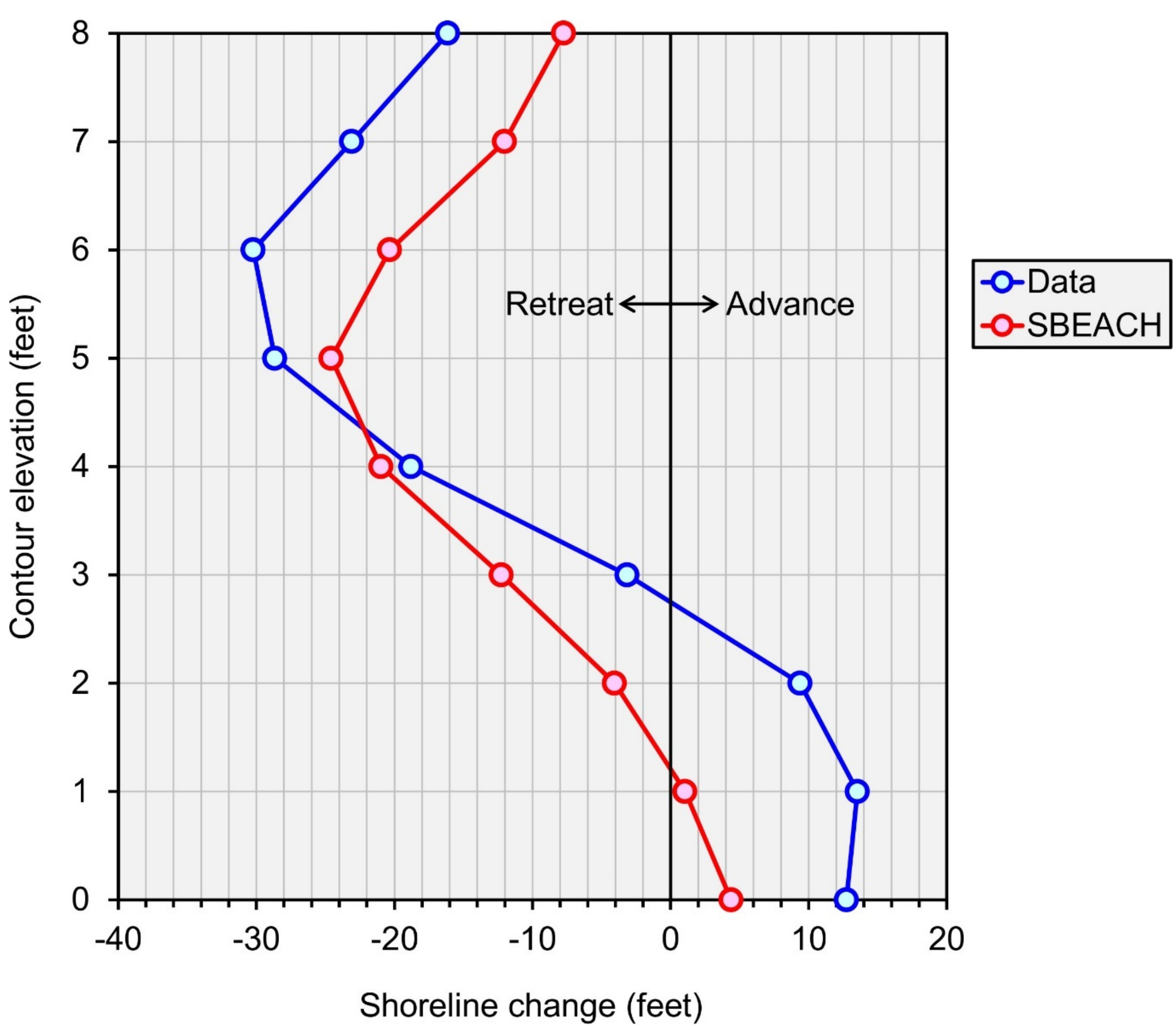

Figure 7. Average contour changes for 17 R-monuments of erosion for Hurricane Irma.

3. Broward County SBEACH Application

3.1. Model Configuration

Configuration of the SBEACH model in Broward County for high-frequency storm erosion will be primarily based on the model calibration results, as shown in Table 6. Countywide sediment data were obtained from the beach sediment surveys for Florida's southeastern coast (Charles et al., 1994; Benedet et al., 2004). A mean grain size of 0.375 mm was assigned to represent Broward County. The wave height was set as 12 feet and the wave period was set to 10 seconds. A 12-foot wave height and a 10-second wave period were chosen as reasonable approximations for a generic high-frequency storm impacting the region. Wave direction, wind speed, and wind direction were applied as a constant zero values for input to the SBEACH model application.

Peak storm tides of 15- and 25-year return periods were developed from 2D storm surge modeling for Broward County (Division of Water Resource Management, 2014) for Broward County. As described for the model calibration, the hydrograph without wave setup was applied since the SBEACH model calculates and adds the wave setup internally to reach the desired final water level. Initially, the SBEACH model output water levels do not agree with the 2D model 15- or 25-year storm because the hydrograph generated by the 2D storm surge model includes wave setup. Basically, the wave setup had been incorporated twice (both the 2D storm surge model and the SBEACH model do not include an option to turn off the wave setup routine). Starting with the 2D model hydrograph, the input hydrograph was adjusted in a series of model runs until the resultant SBEACH model peak water levels were equivalent to the predicted 2D model storm tides. The recommended SBEACH input values to be used in the 15- and 25-year storm erosion calculations are those obtained from the model calibration for Broward County (Appendix B). Time-series values for the adjusted 15- and 25-year hydrographs without wave setup for each reach are shown in Figure 9 and are tabulated in Appendix C.

3.2. Model Application and Results

Representative plots of surveyed profiles and their associated eroded profiles generated from SBEACH for the 15- and 25-year return periods for Broward County are provided in Appendix D. The most updated profiles available for Broward County for SBEACH application included three datasets representative of 2018 conditions: BO1811_CON_1 for Hillsboro Beach – Deerfield Beach (R1–R24); BO1803_AEI_1 for Segment II (R25–R85); and BO1804_ATM_1 for Hollywood Beach – Hallandale Beach (R98–R128). The survey data captured the dune and berm features of the beach and, when necessary, were appended to the post-Irma survey data (BO1710_COE_1) so that the nearshore profile extended out to the depth of closure, at ~3000 feet offshore with nominal depths of 35–40 feet.

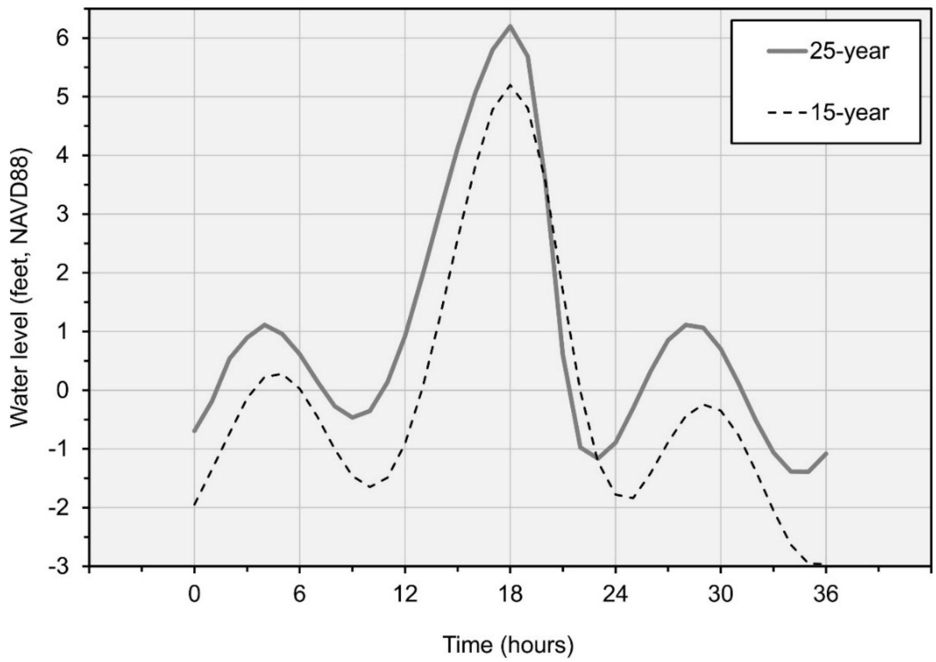

Figure 8. 15- and 25-year hydrographs for Broward County Profiles in SBEACH application.

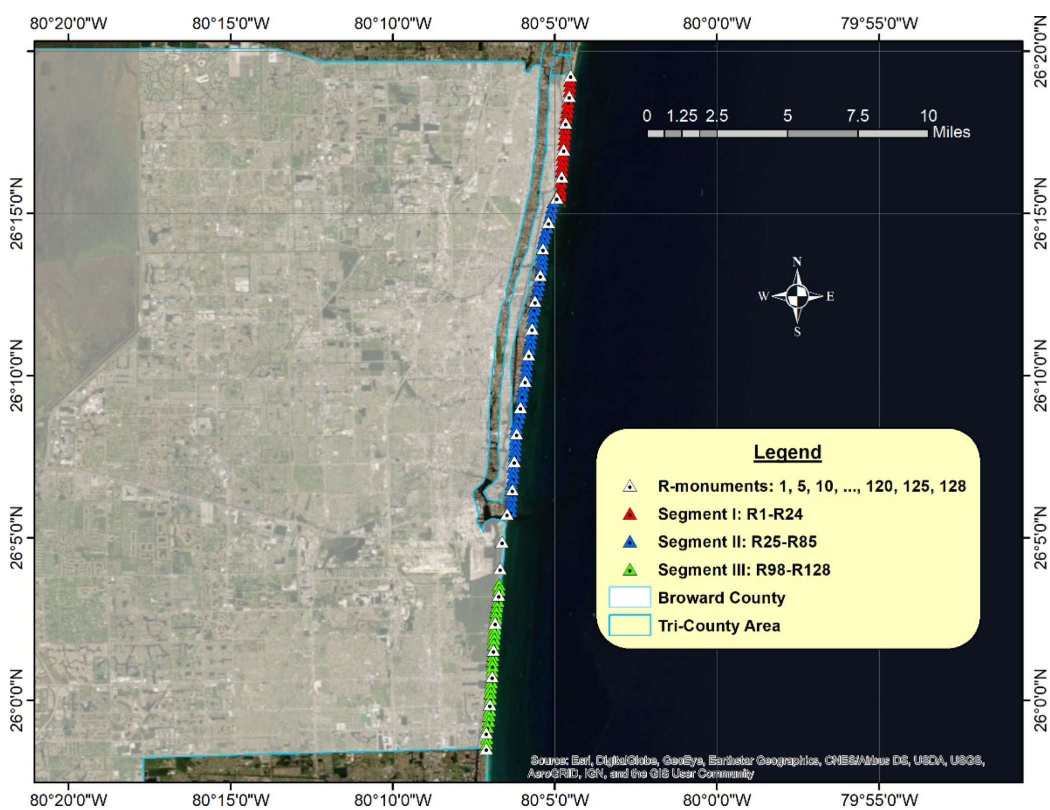

Figure 9. Map of R-monuments, including model-application profiles, for Broward County.

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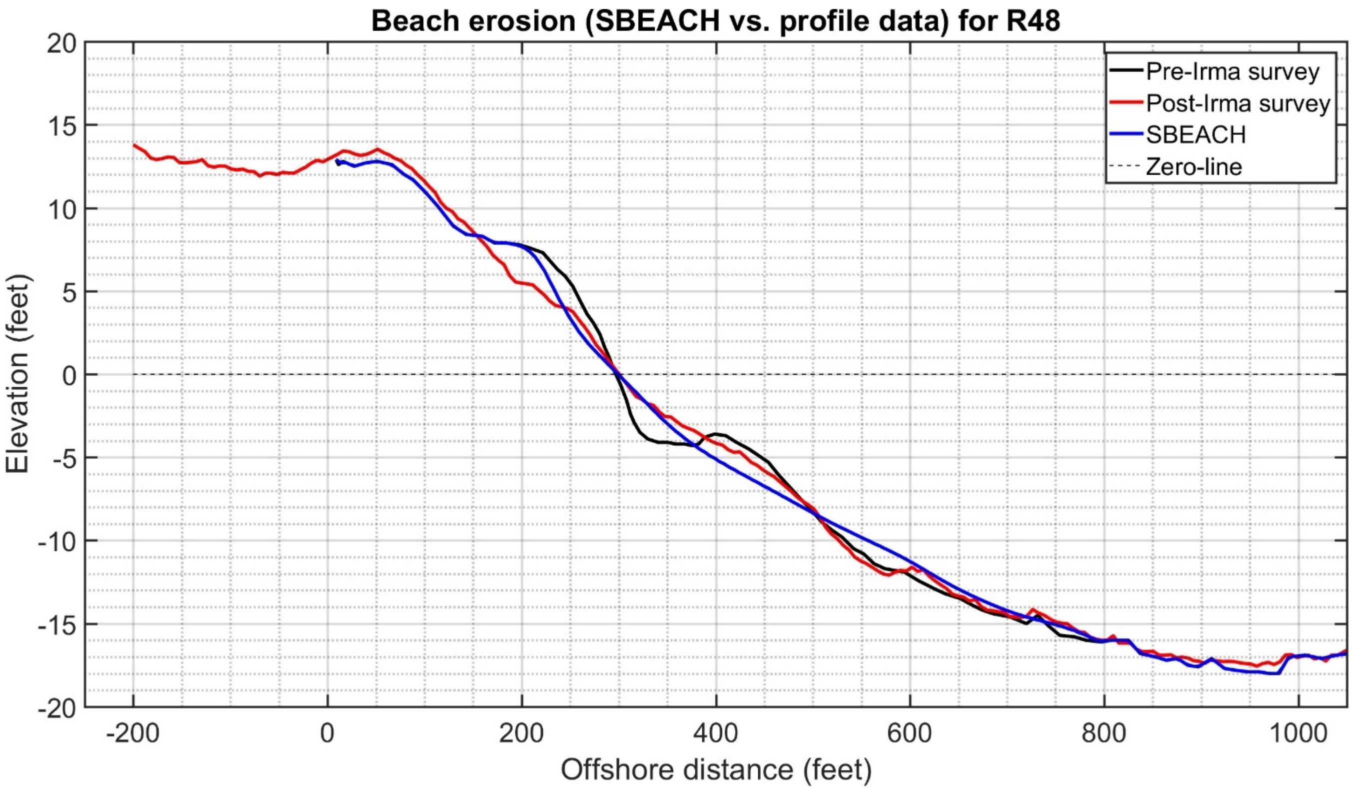
APPENDIX A

SBEACH Calibration Profiles for Broward County


Beach erosion (SBEACH vs. profile data) for R48
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
20
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10
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0
-5
-10
-15
-20
-200
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200
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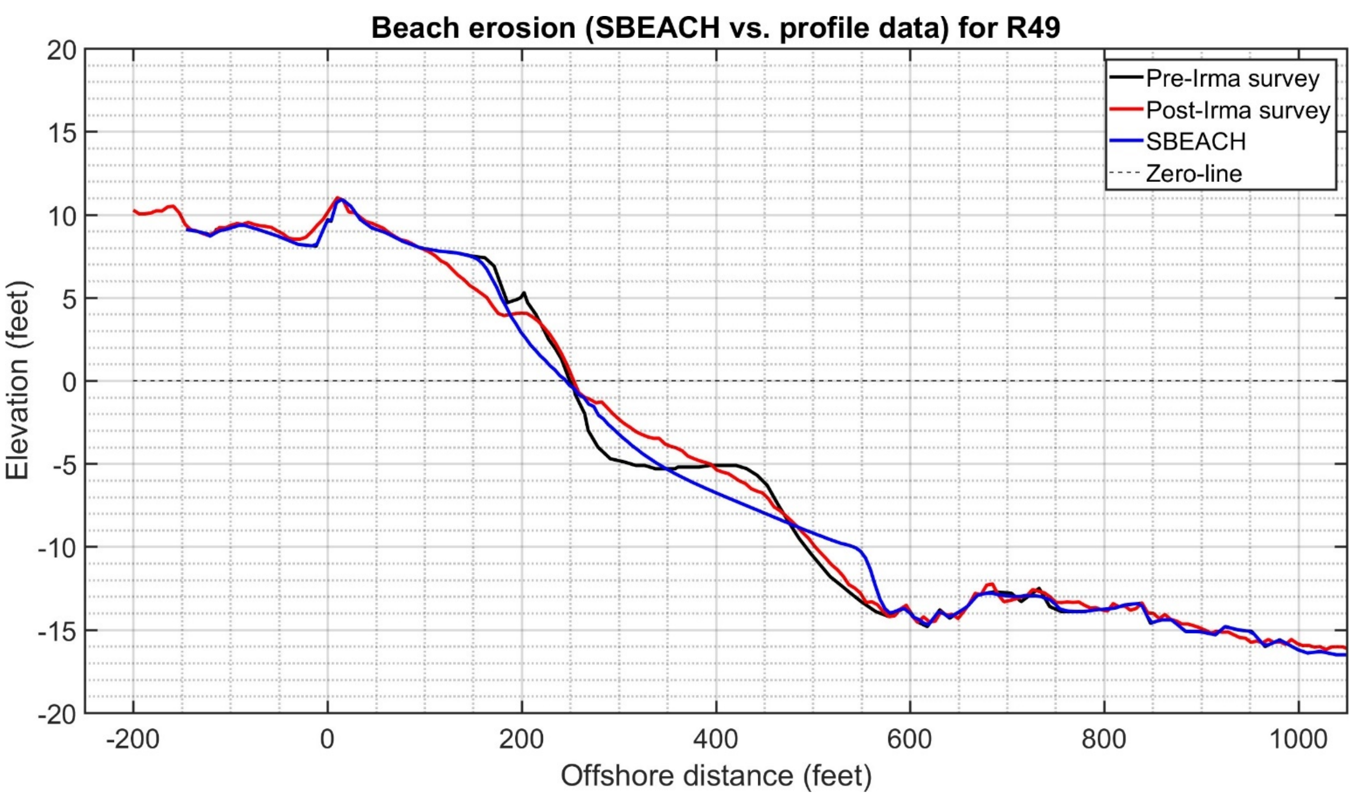
Beach erosion (SBEACH vs. profile data) for R49
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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-5
-10
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-200
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400
600
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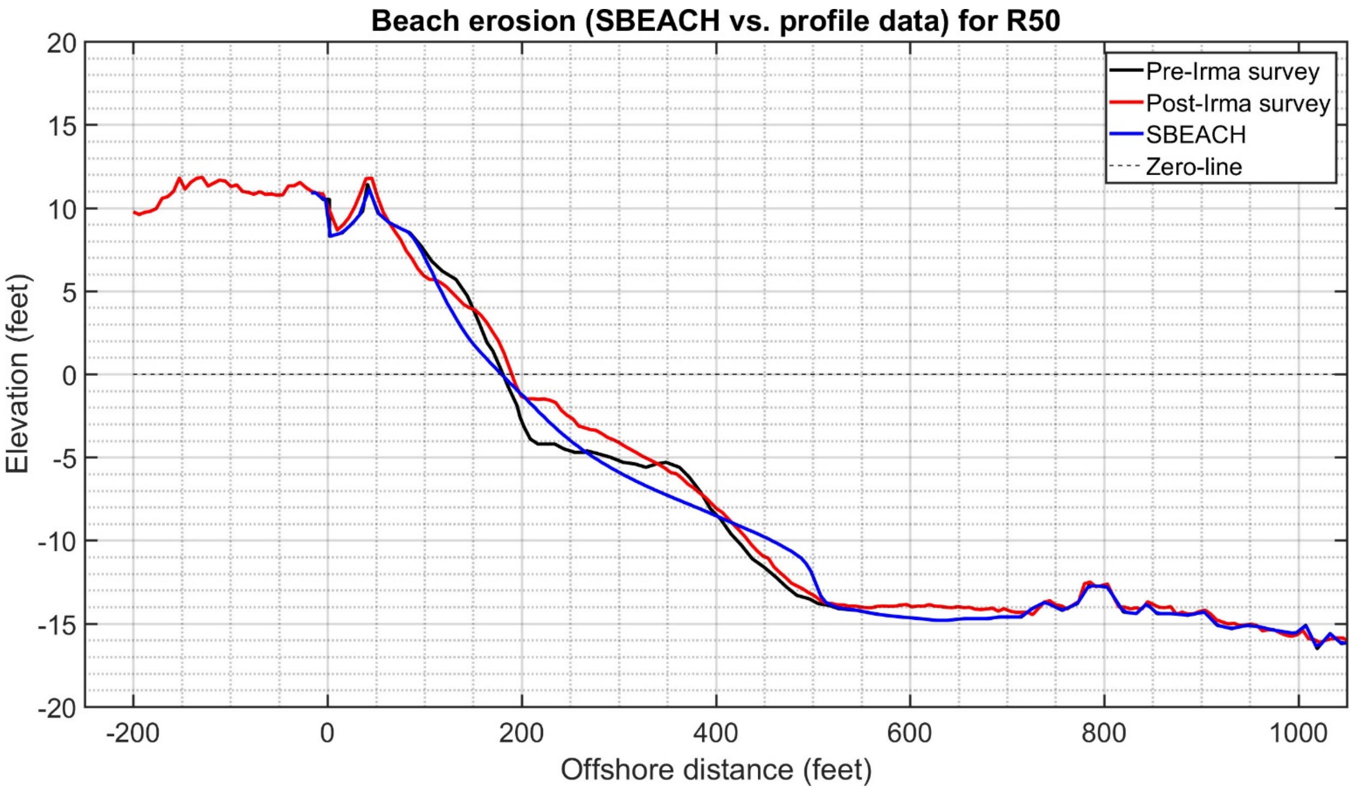
Beach erosion (SBEACH vs. profile data) for R50
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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-5
-10
-15
-20
-200
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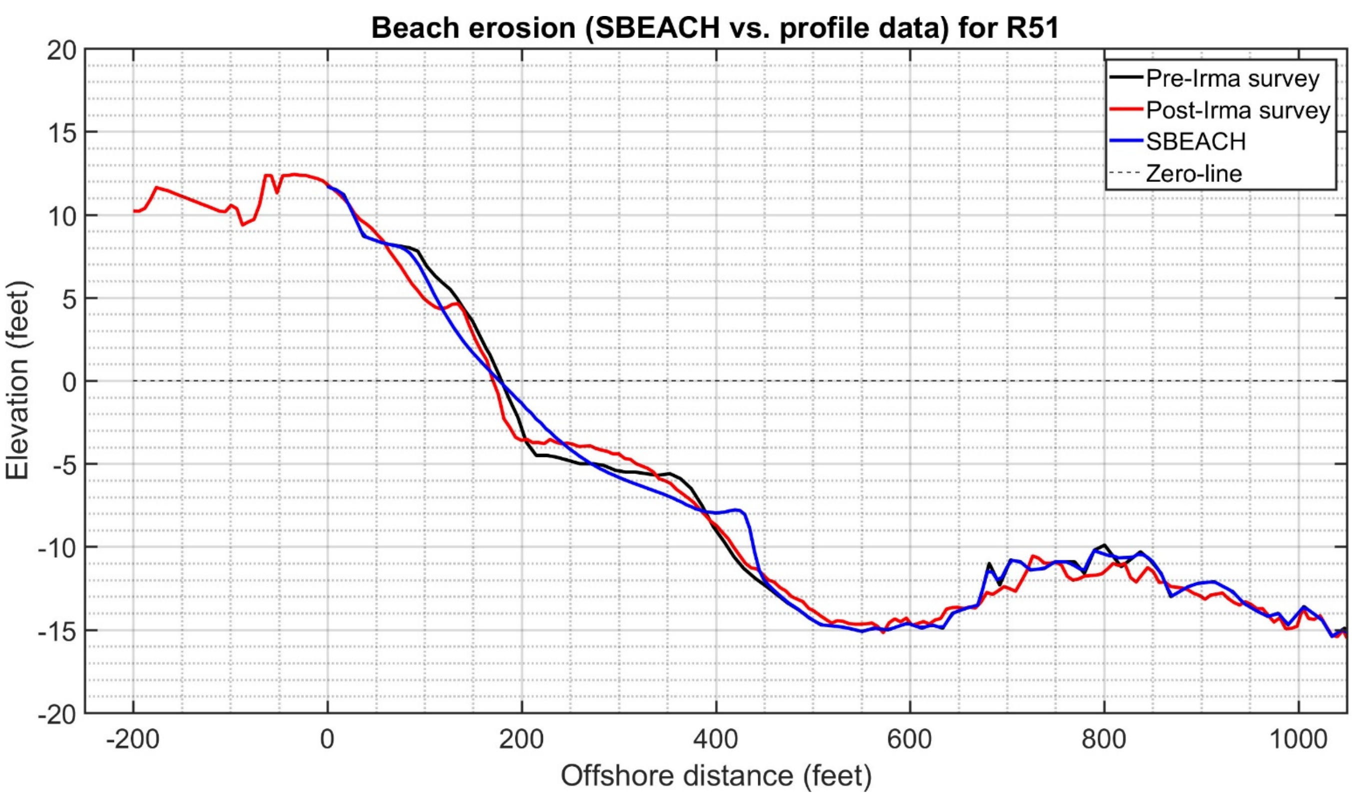
Beach erosion (SBEACH vs. profile data) for R51
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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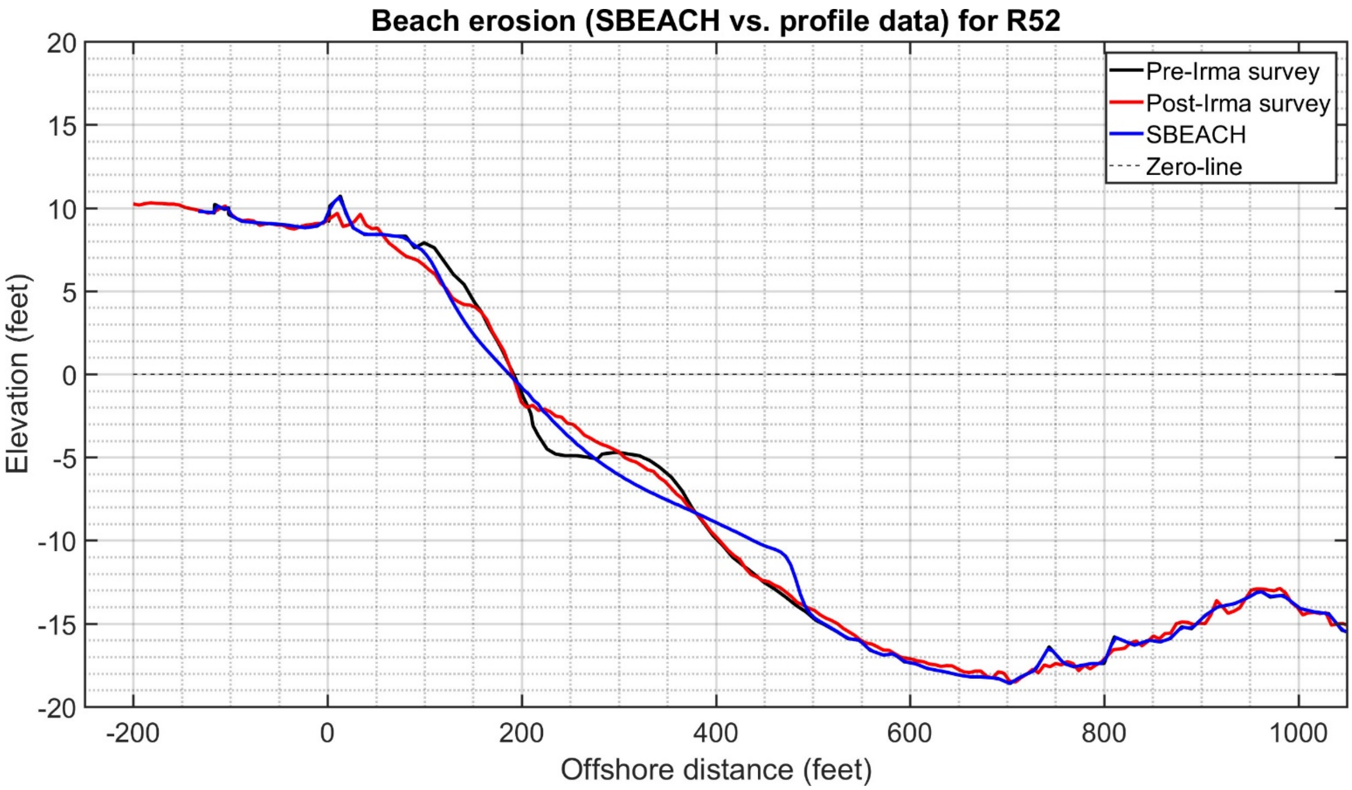
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Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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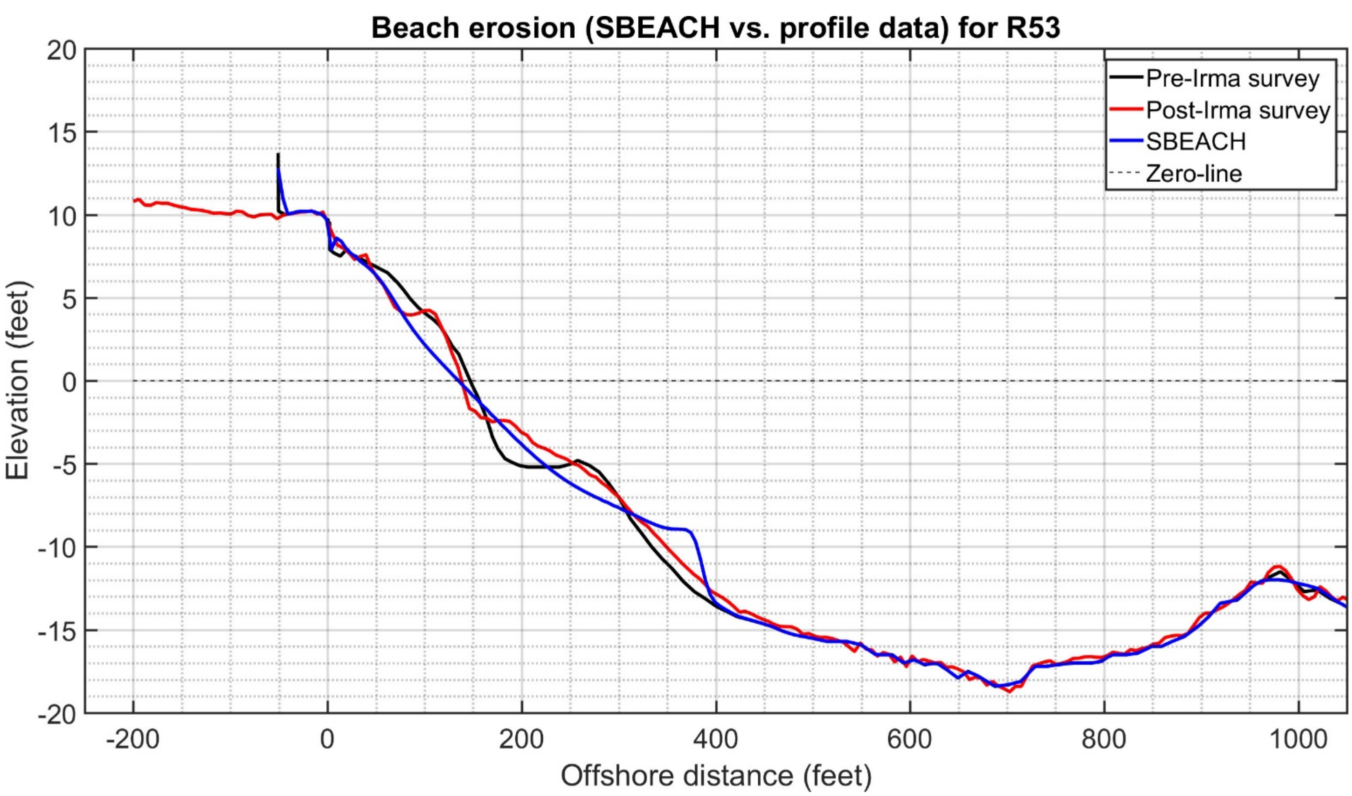
Beach erosion (SBEACH vs. profile data) for R53
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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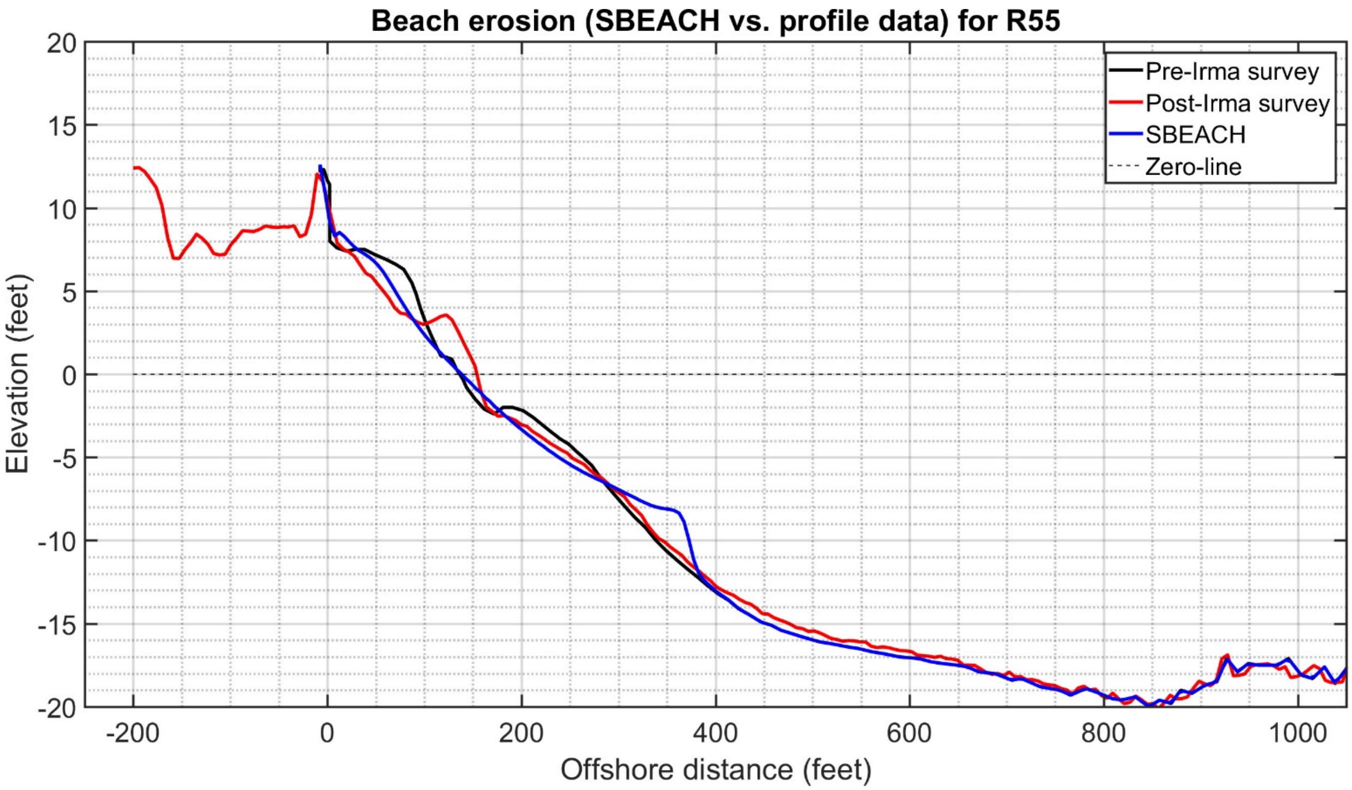
Beach erosion (SBEACH vs. profile data) for R55
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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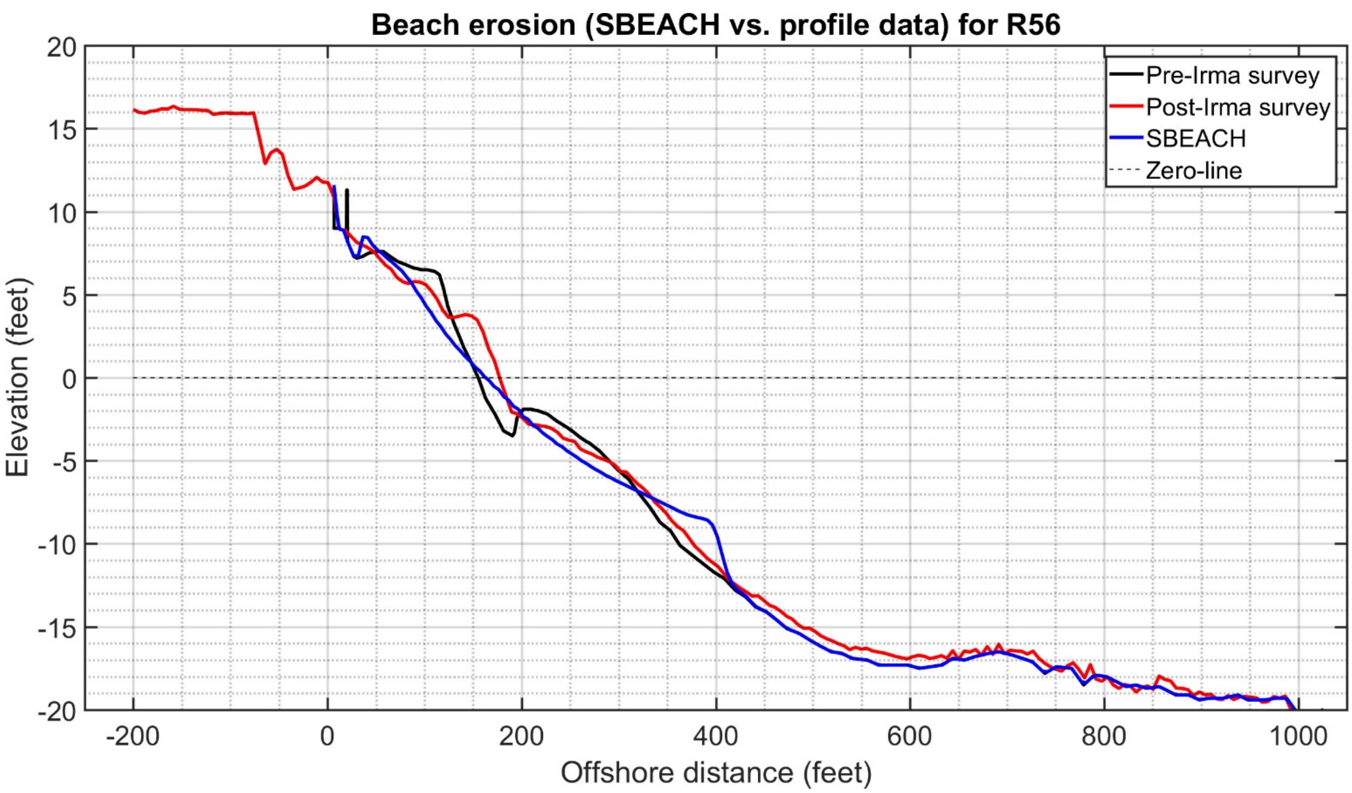
Beach erosion (SBEACH vs. profile data) for R56
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
20
15
10
5
0
-5
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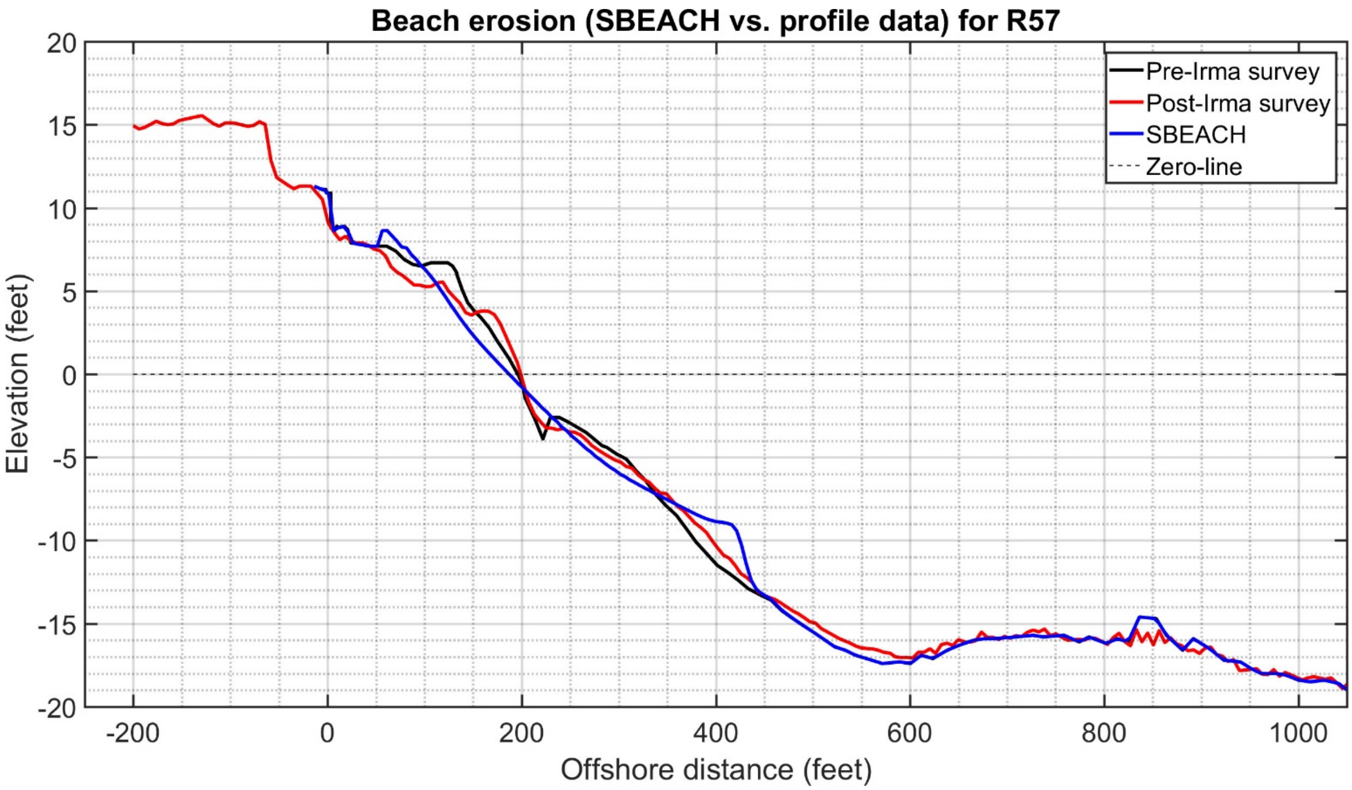
Beach erosion (SBEACH vs. profile data) for R57
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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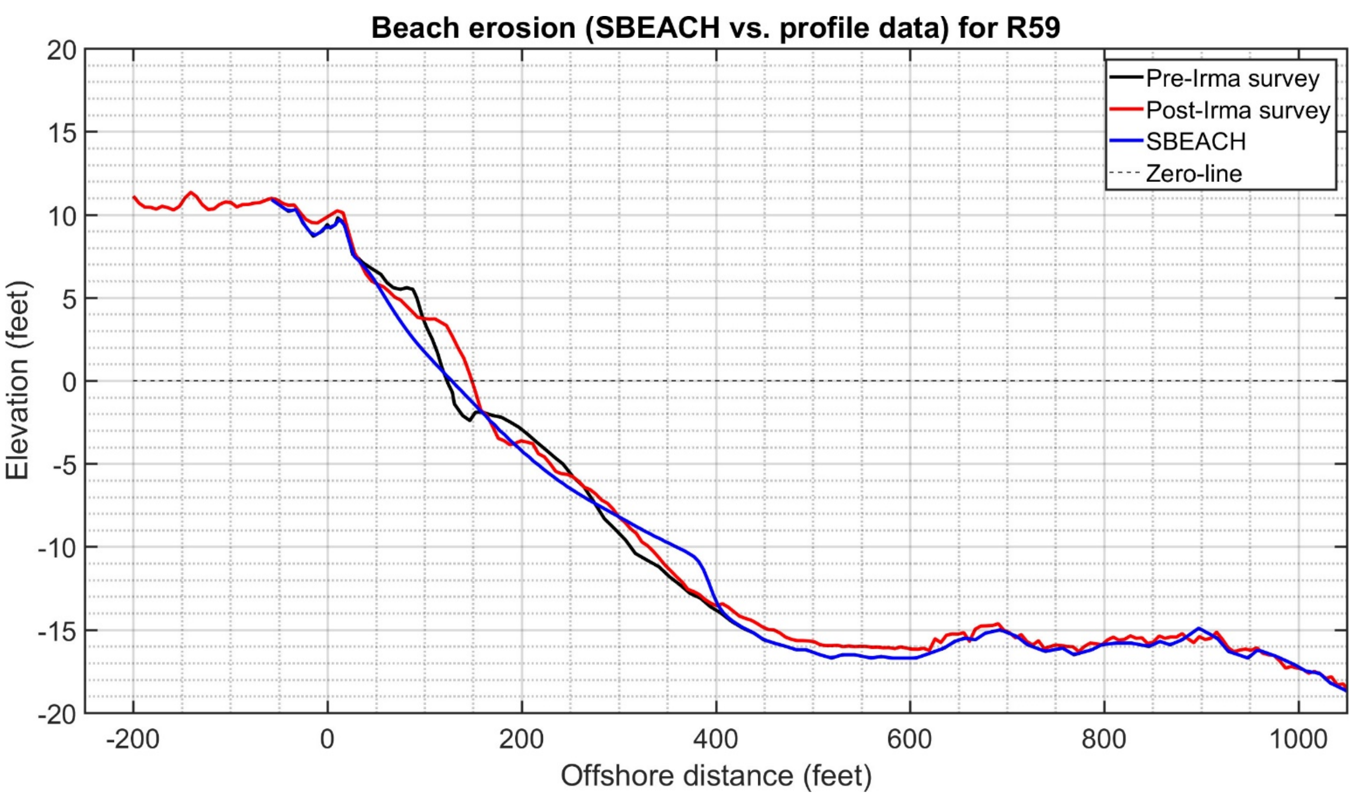
Beach erosion (SBEACH vs. profile data) for R59
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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15
10
5
0
-5
-10
-15
-20
-200
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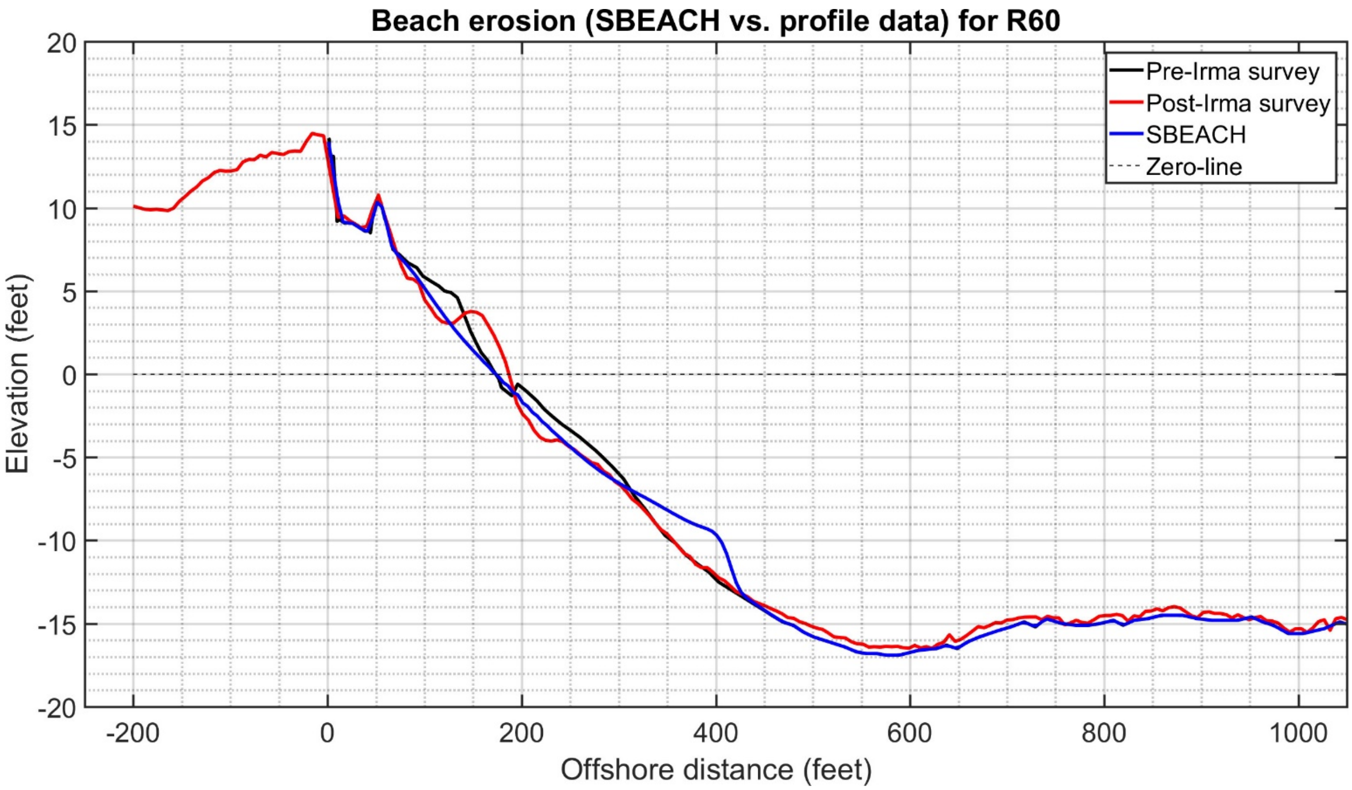
Beach erosion (SBEACH vs. profile data) for R60
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
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15
10
5
0
-5
-10
-15
-20
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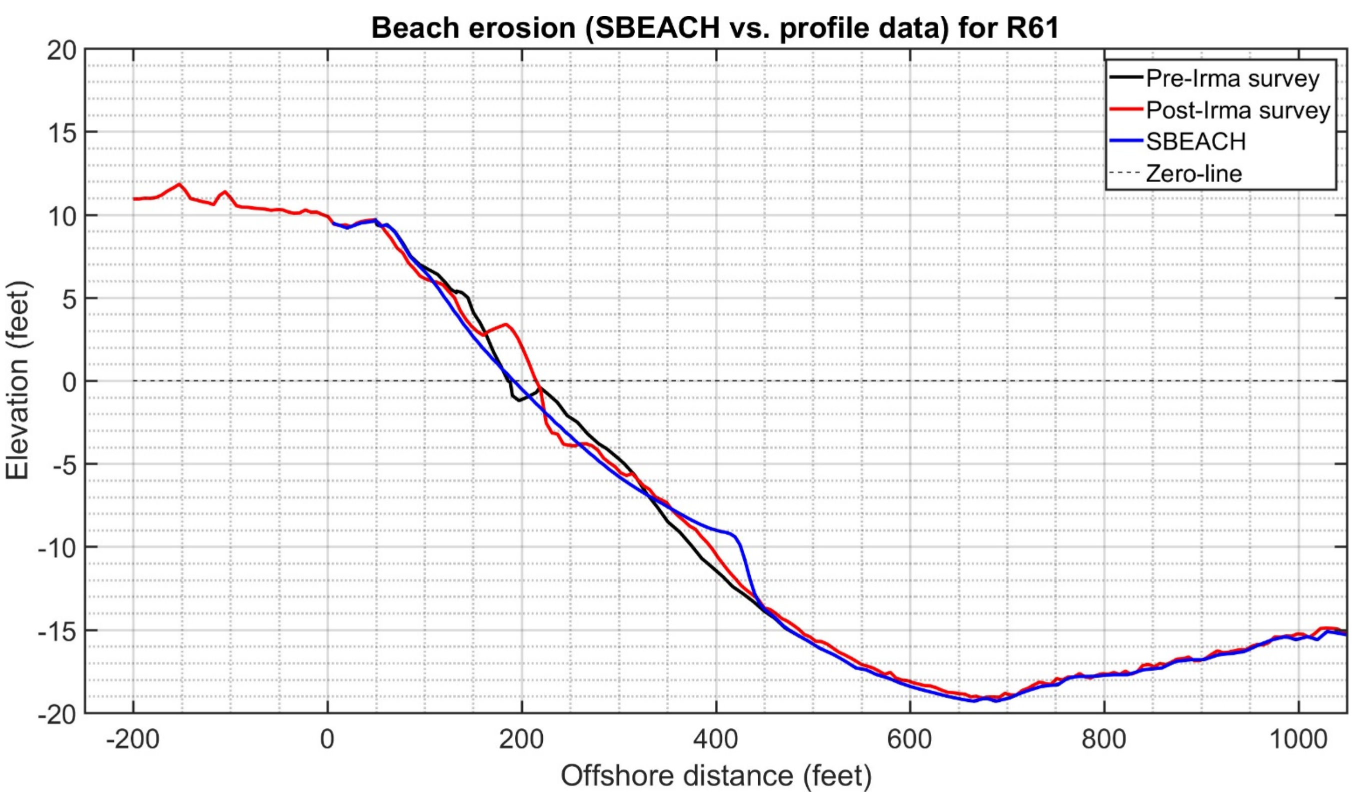
0
200
400
600
800
1000
Offshore distance (feet)


Beach erosion (SBEACH vs. profile data) for R61
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
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-15
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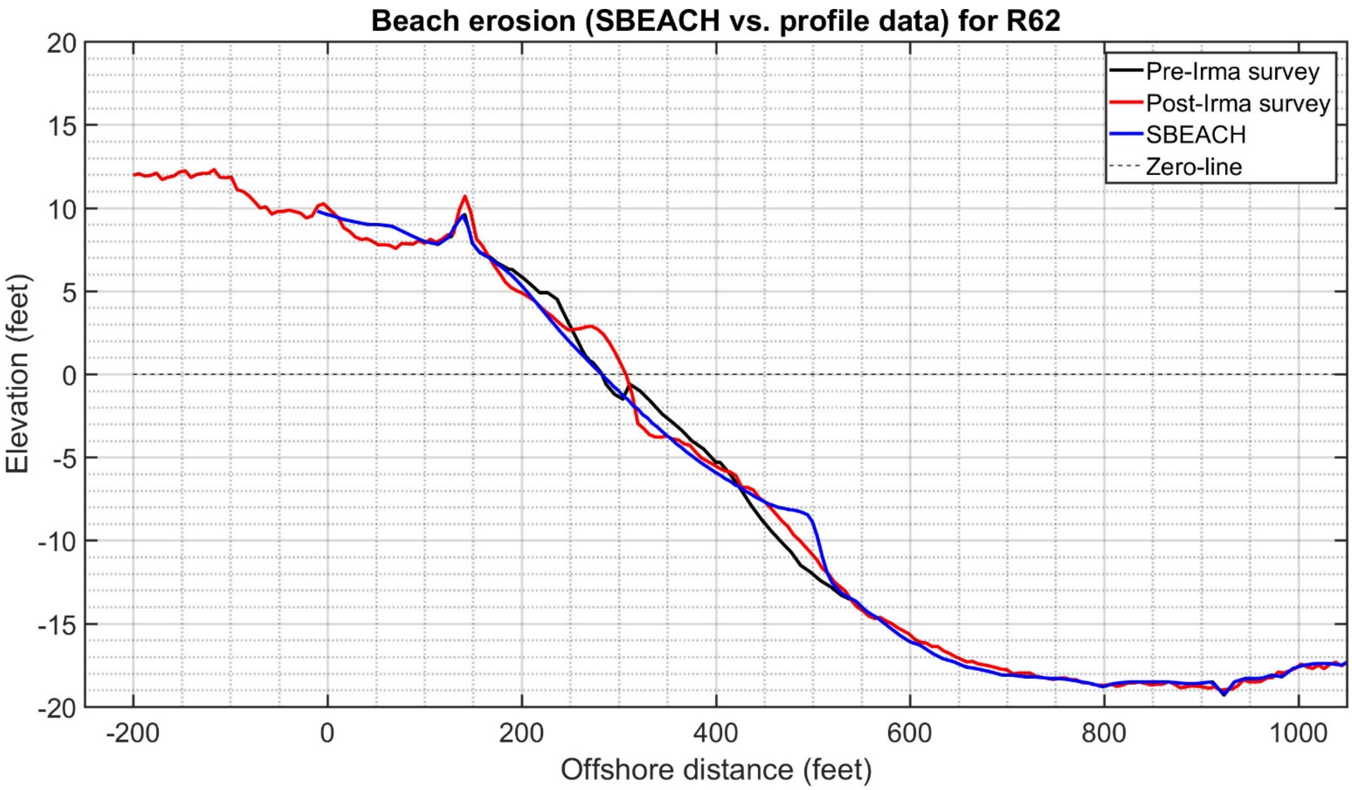
200
400
600
800
1000
Offshore distance (feet)


Beach erosion (SBEACH vs. profile data) for R62
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
0
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-20
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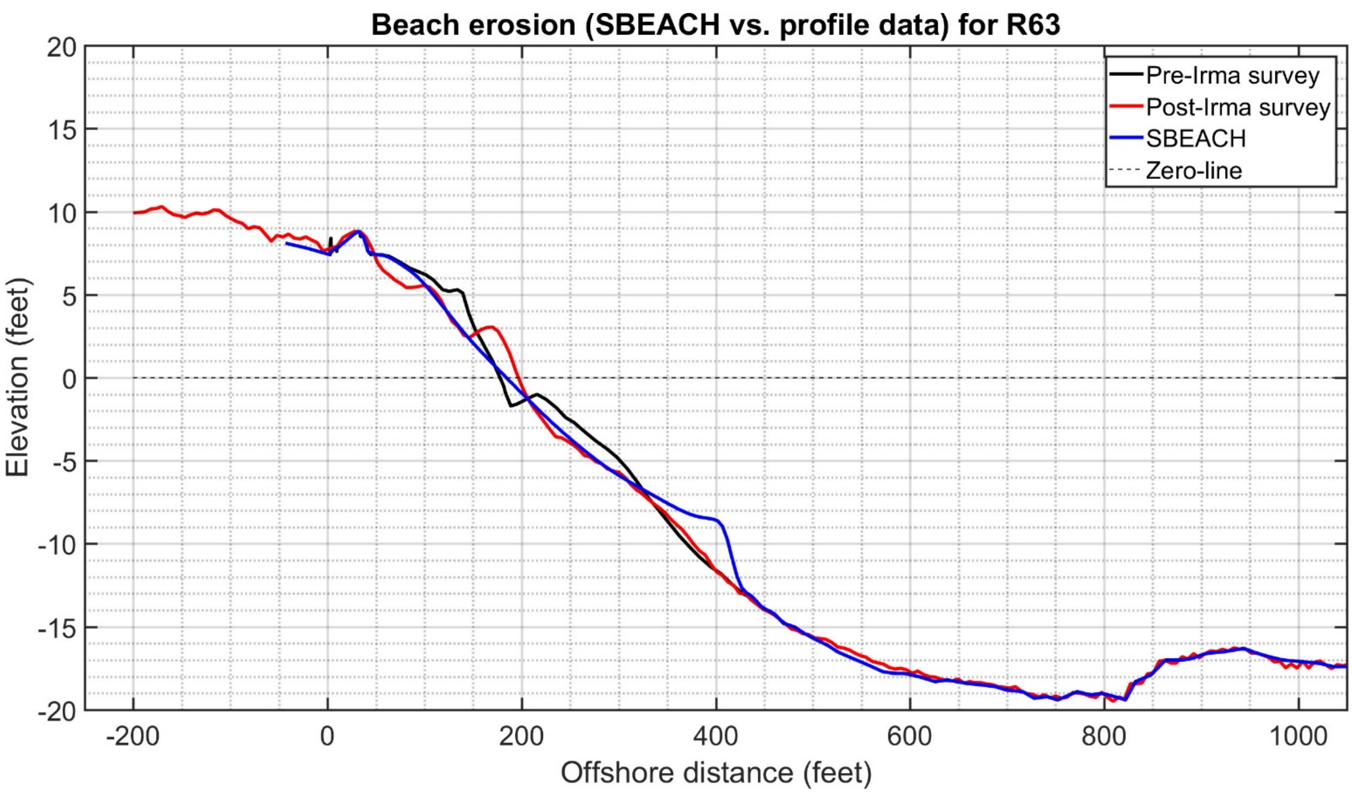
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R63
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
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15
10
5
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-5
-10
-15
-20
-200
0
200
400
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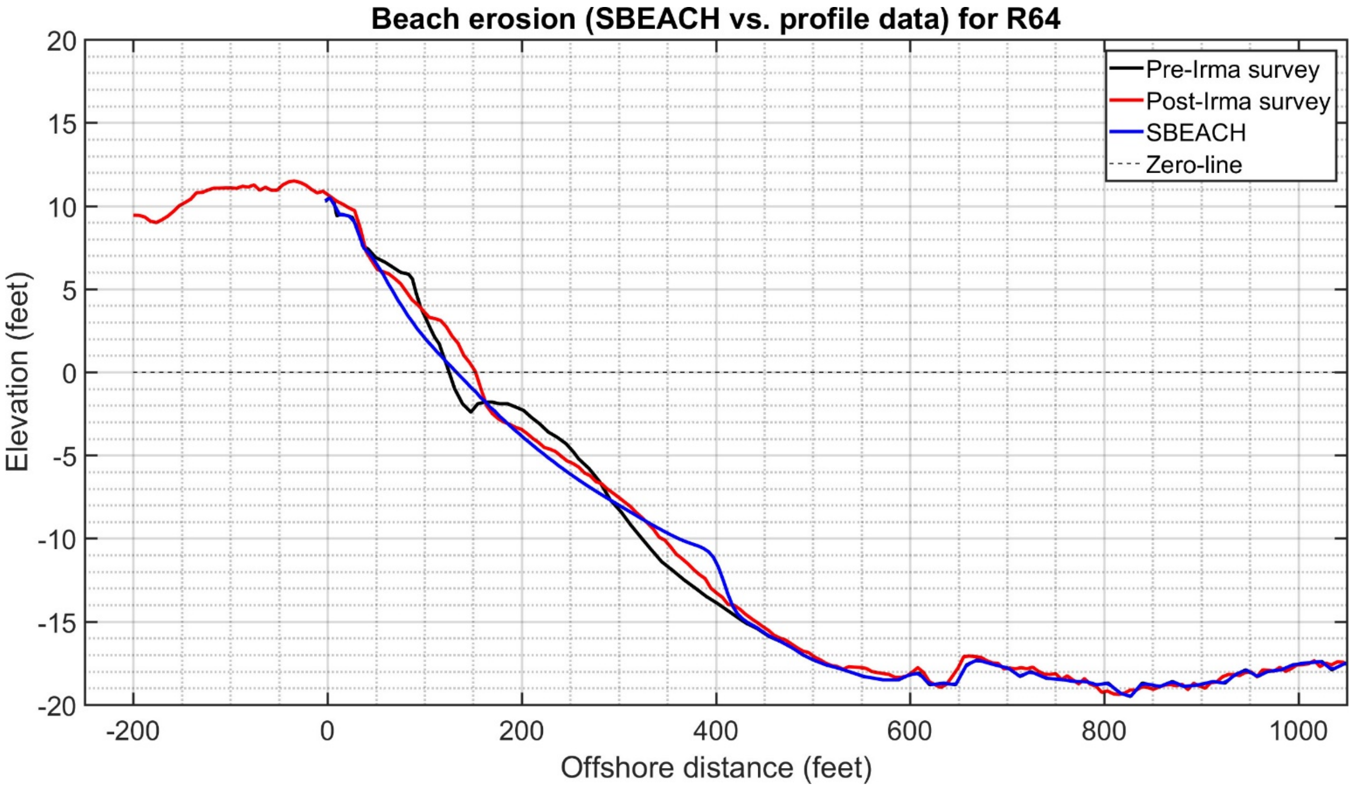
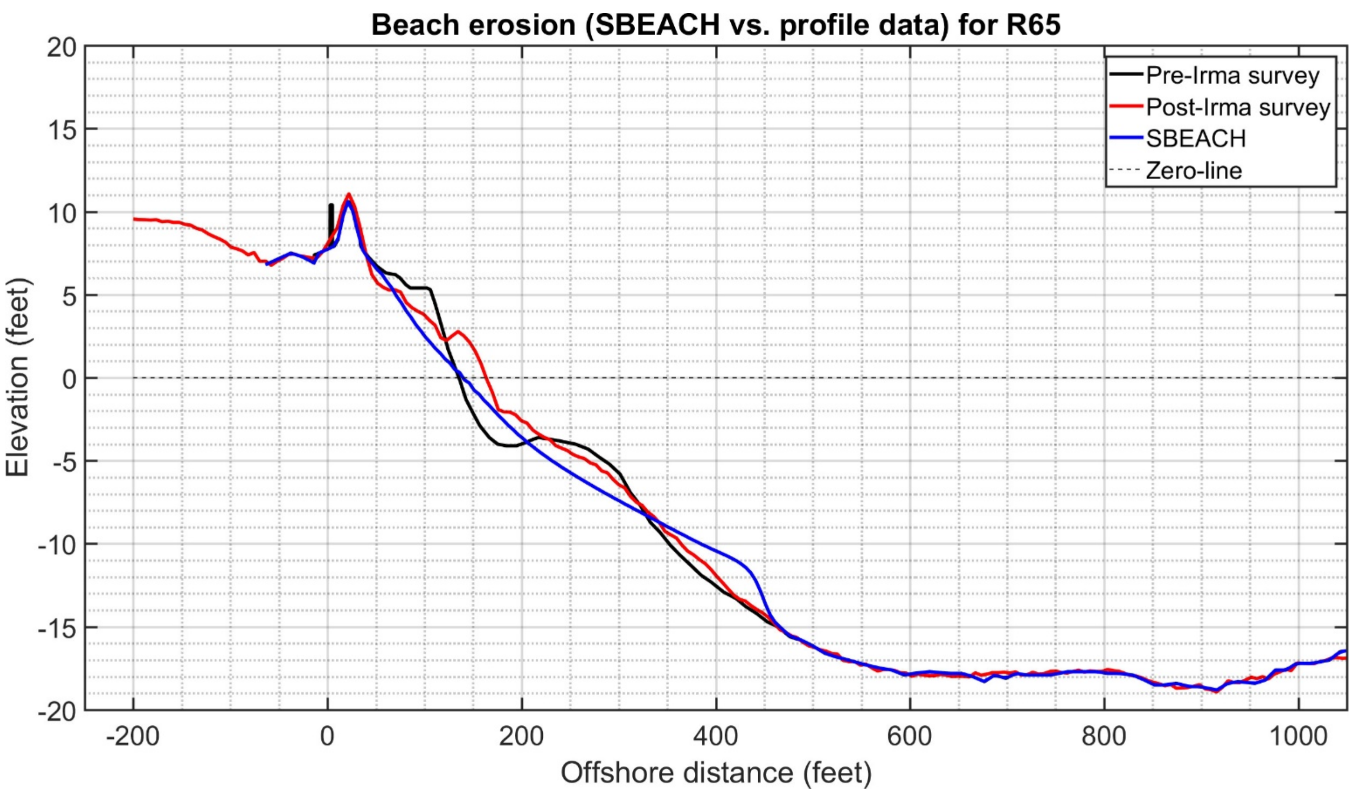
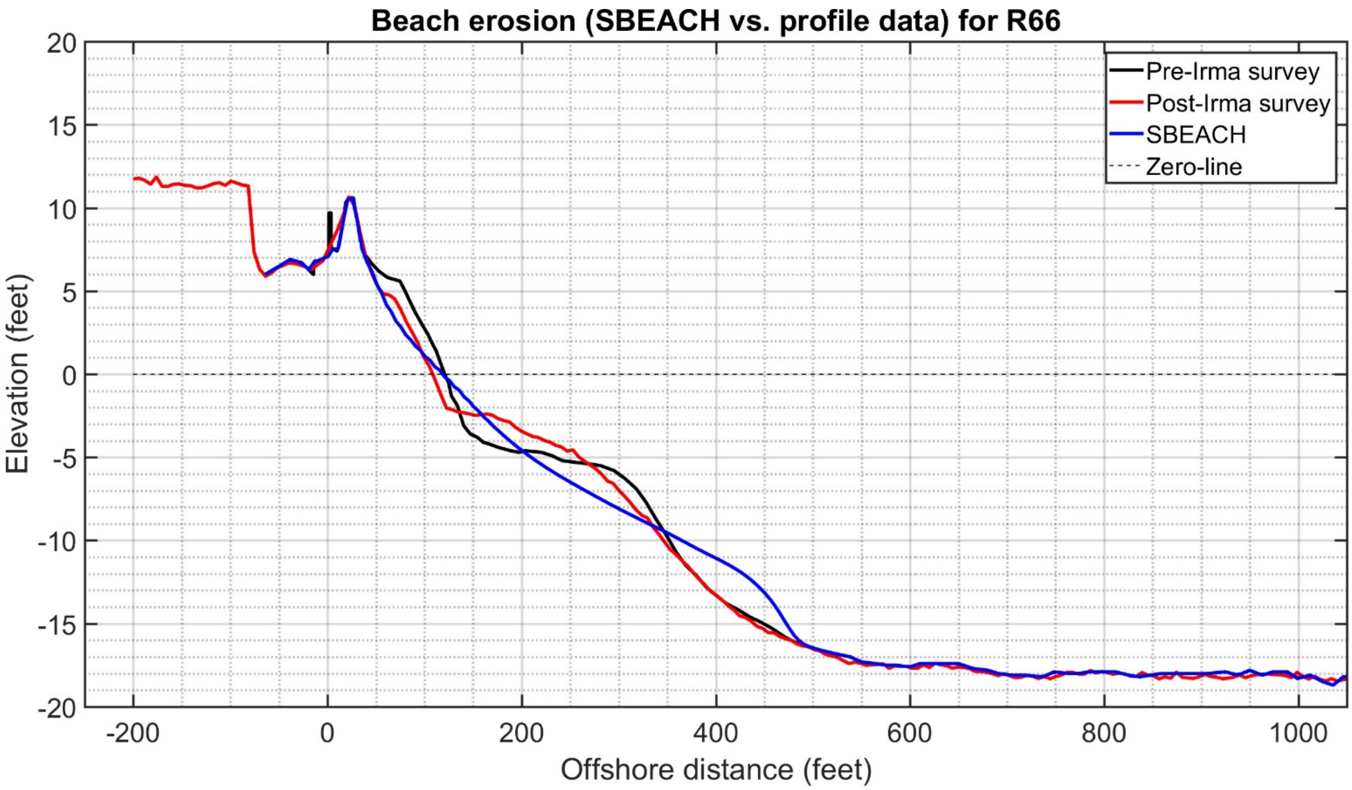

Beach erosion (SBEACH vs. profile data) for R64
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
20
15
10
5
0
-5
-10
-15
-20
-200
0
200
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R65
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
20
15
10
5
0
-5
-10
-15
-20
-200
0
200
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R66
Pre-Irma survey
Post-Irma survey
SBEACH
Zero-line
Elevation (feet)
Offshore distance (feet)
20
15
10
5
0
-5
-10
-15
-20
-200
0
200
400
600
800
1000

APPENDIX B

Recommended SBEACH Input Values for Broward County

Final SBEACH Input Settings – 15- and 25-year storm erosions in Broward County:

For all storm tide hydrographs, use 15- and 25-year hydrographs without wave setup and adjusted proportionally to peak elevation shown for each range monumentation segment shown below, and the storm duration for all cases is 36 hours. All elevations listed below are relative to NAVD. All wave input depth values are set as deep water with no wave randomization. All storm time steps are set at 5 minutes. Water temperature is 27 degrees centigrade. Grid cell width is 5 feet.

Parameter	Value
Transport rate coefficient ($m^4\ N^{-1}$)	1.0×10^{-6}
Overwash transport parameter (unitless)	0.005
Coefficient for slope-dependent term ($m^2\ s^{-1}$)	0.002
Transport rate decay coefficient (m^{-1})	0.5
Landward surf zone depth (feet)	1.0
Effective grain size (D_{50}) (mm)	0.375
Maximum slope prior to avalanching (°)	30
Water temperature (°C)	27
Constant wave height (feet)	12
Constant wave period (seconds)	10
15-year hydrograph peak elevation (feet)	5.3
25-year hydrograph peak elevation (feet)	6.3

APPENDIX C

Adjusted 15- and 25-Year Hydrograph Tables for Broward County

Broward County – Adjusted 15-Year Hydrograph (feet, NAVD) for SBEACH:

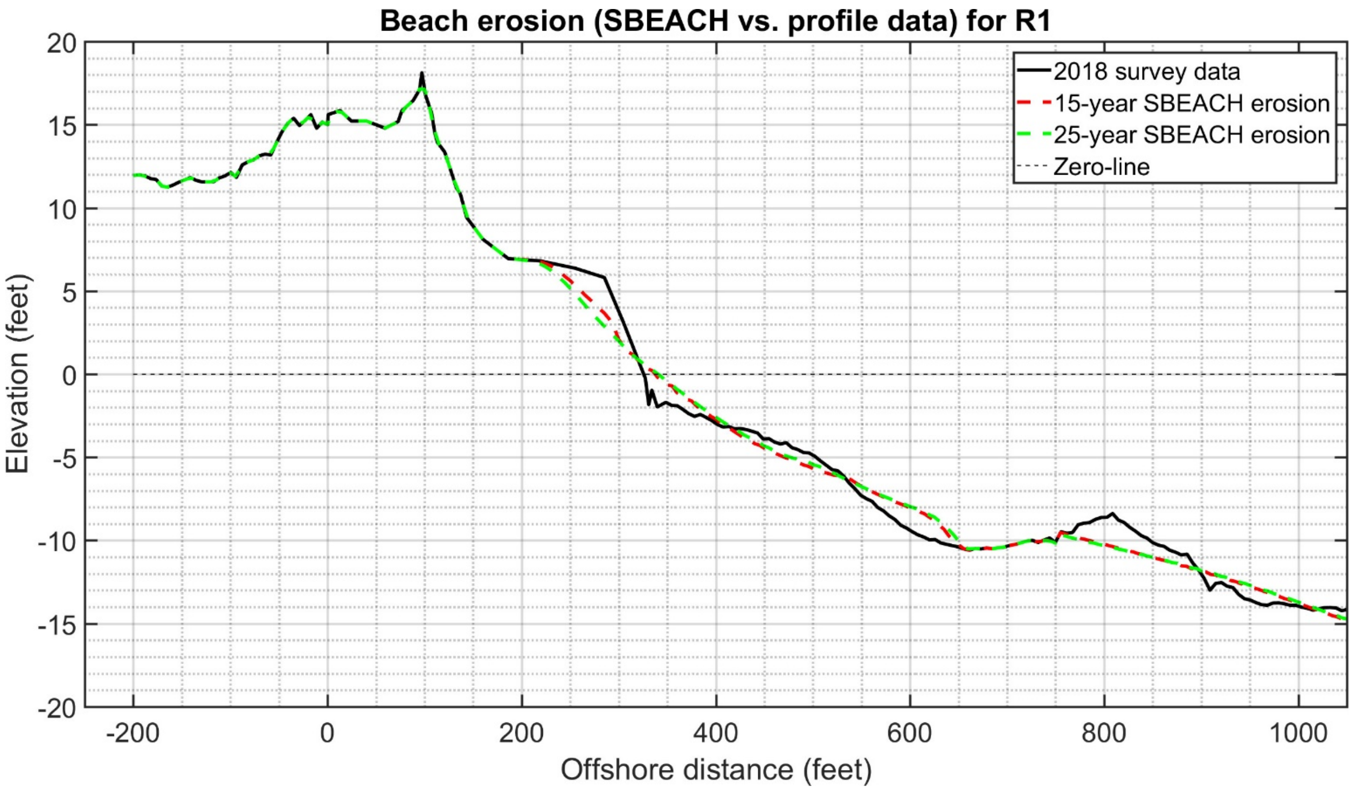
Time (hour)	Water level (feet, NAVD)
0	-1.95
1	-1.35
2	-0.73
3	-0.14
4	0.23
5	0.28
6	0.02
7	-0.45
8	-1.01
9	-1.46
10	1.65
11	-1.49
12	-1.38
13	-0.91
14	-0.16
15	0.69
16	1.45
17	1.95
18	2.16
19	1.90
20	1.57
21	0.37
22	-0.68
23	-1.22
24	-1.78
25	-1.84
26	-1.42
27	-0.89
28	-0.44
29	-0.24
30	-0.35
31	-0.76
32	-1.38
33	-2.05
34	-2.63
35	-2.95
36	-2.96

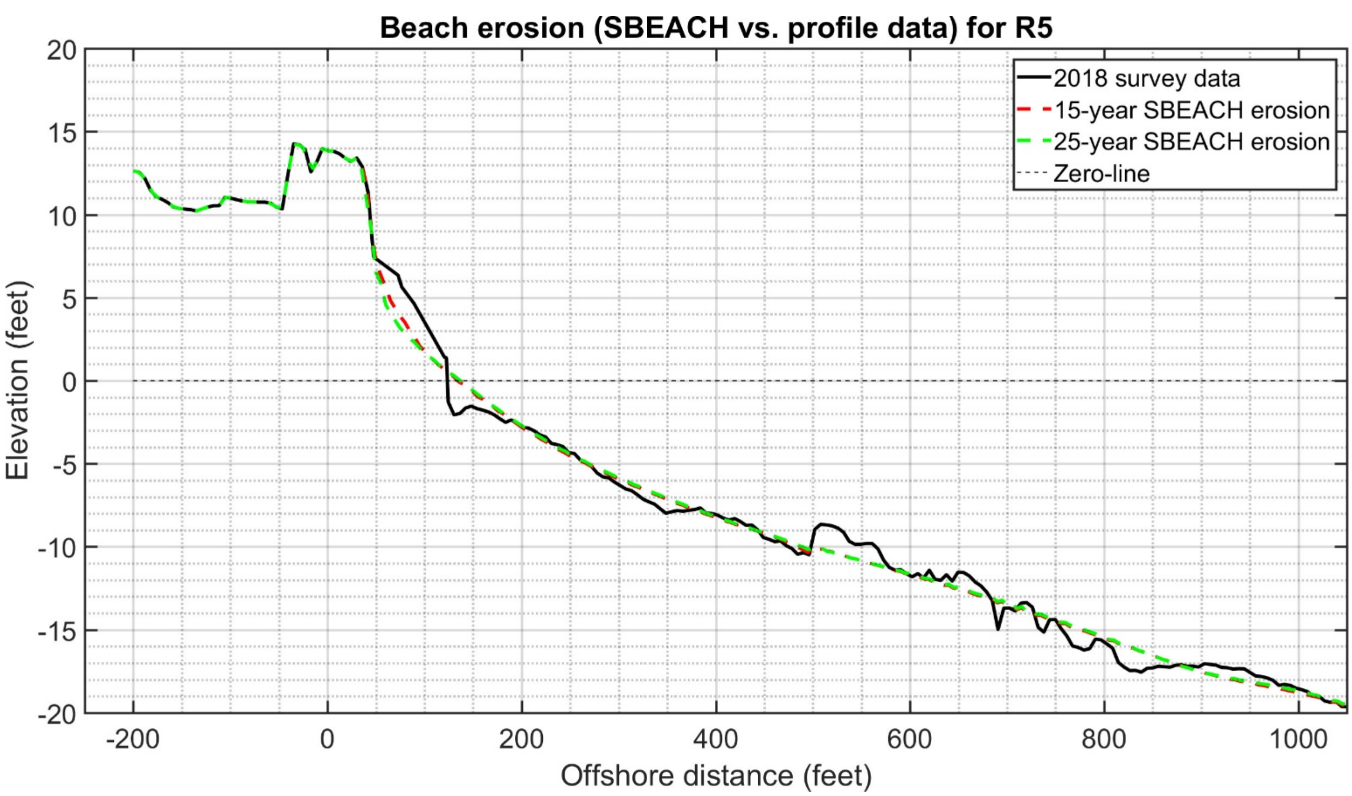
Broward County – Adjusted 25-Year Hydrograph (feet, NAVD) for SBEACH:

Time (hour)	Water level (feet, NAVD)
0	-0.69
1	-0.19
2	0.54
3	0.90
4	1.11
5	0.96
6	0.62
7	0.15
8	-0.27
9	-0.46
10	-0.72
11	-0.60
12	-0.18
13	0.49
14	1.22
15	1.93
16	2.50
17	2.87
18	3.04
19	2.90
20	1.58
21	-0.72
22	-1.24
23	-1.16
24	-0.89
25	-0.31
26	0.32
27	0.85
28	1.11
29	1.07
30	0.71
31	0.13
32	-0.52
33	-1.06
34	-1.38
35	-1.39
36	-1.08

APPENDIX D

Broward County SBEACH 15- and 25-Year Storm Erosion Profiles


Beach erosion (SBEACH vs. profile data) for R1
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
20
15
10
5
0
-5
-10
-15
-20
-200
0
200
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R5
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
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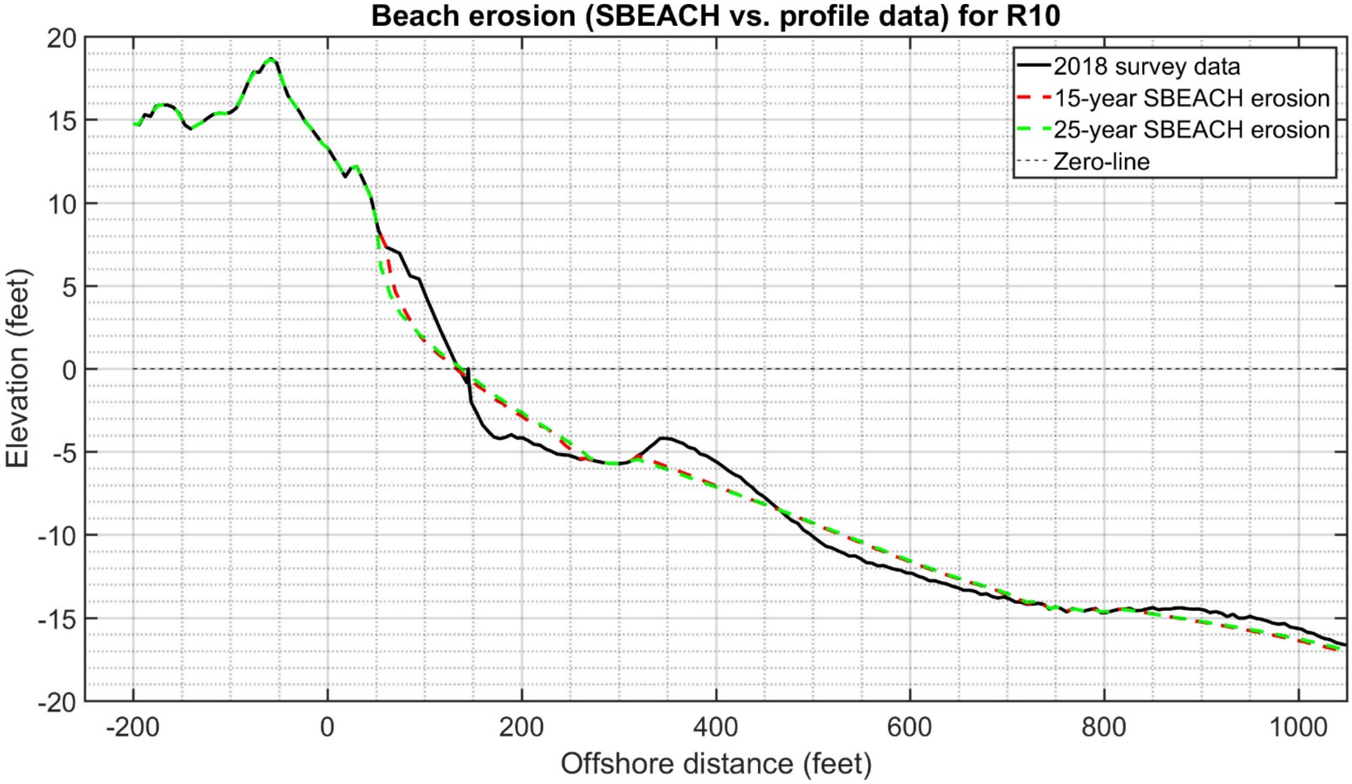
-15
-20
-200
0
200
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R10
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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10
5
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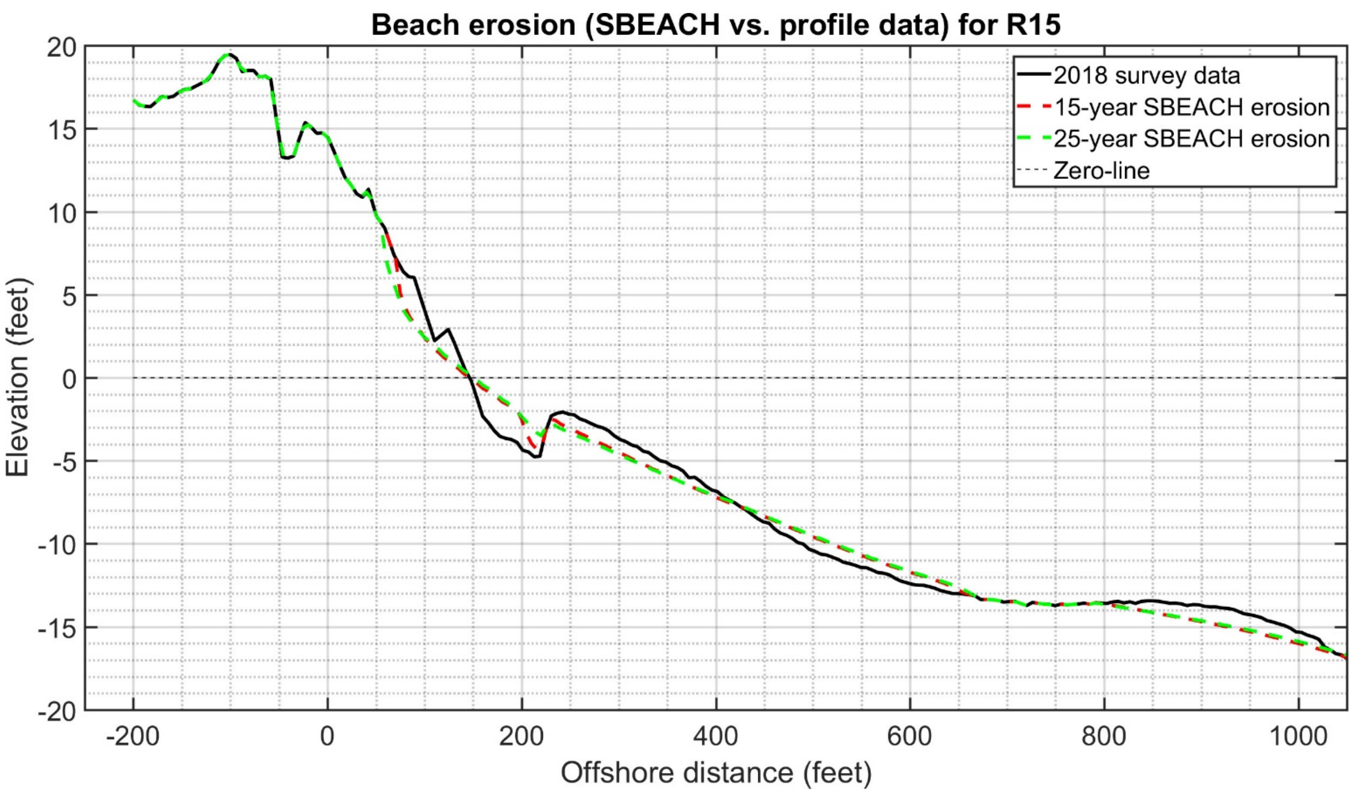
-15
-20
-200
0
200
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R15
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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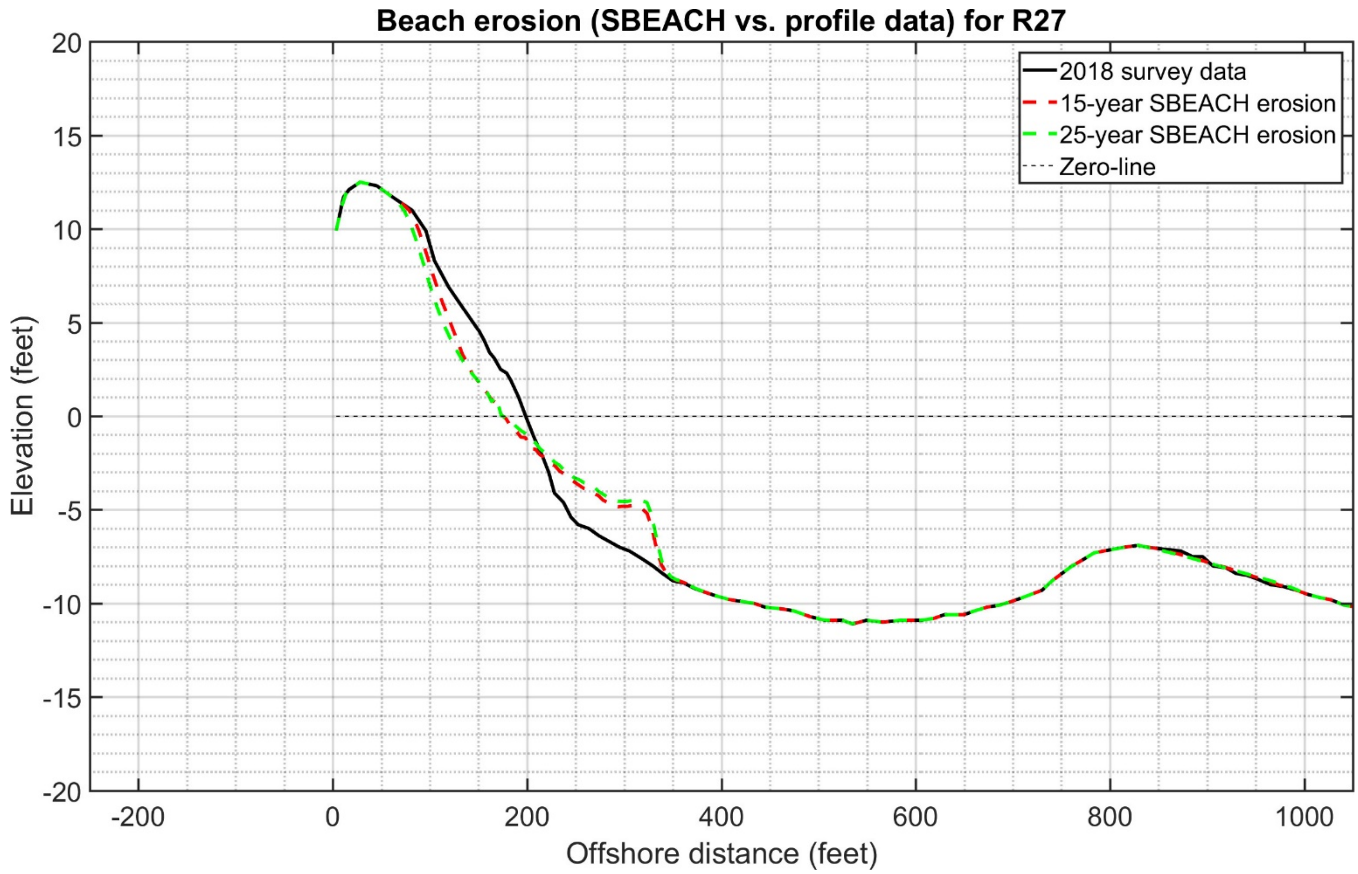
15
10
5
0
-5
-10
-15
-20
-200
0
200
400
600
800
1000


Beach erosion (SBEACH vs. profile data) for R27
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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10
5
0
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-10
-15
-20
-200
0
200
400
600
800
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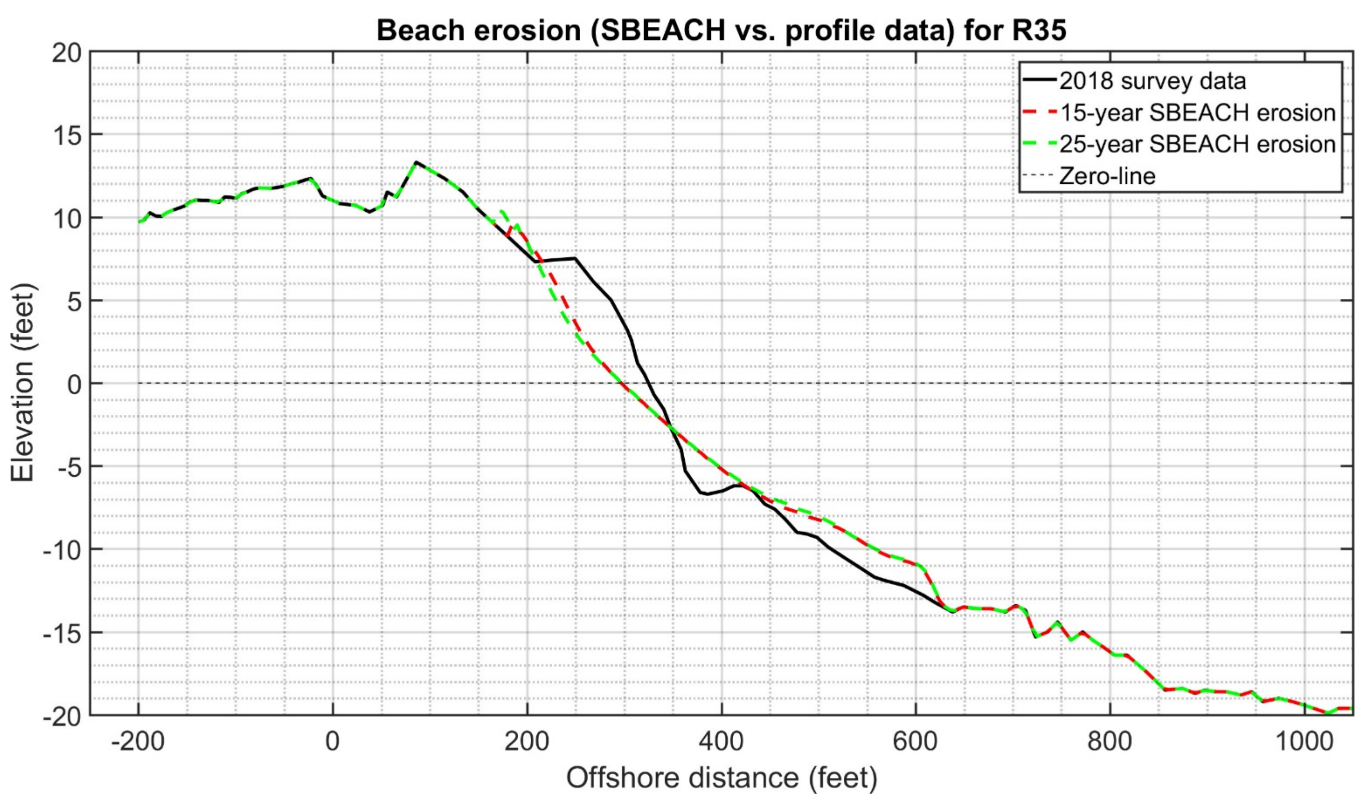
Beach erosion (SBEACH vs. profile data) for R35
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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10
5
0
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-20
-200
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200
400
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800
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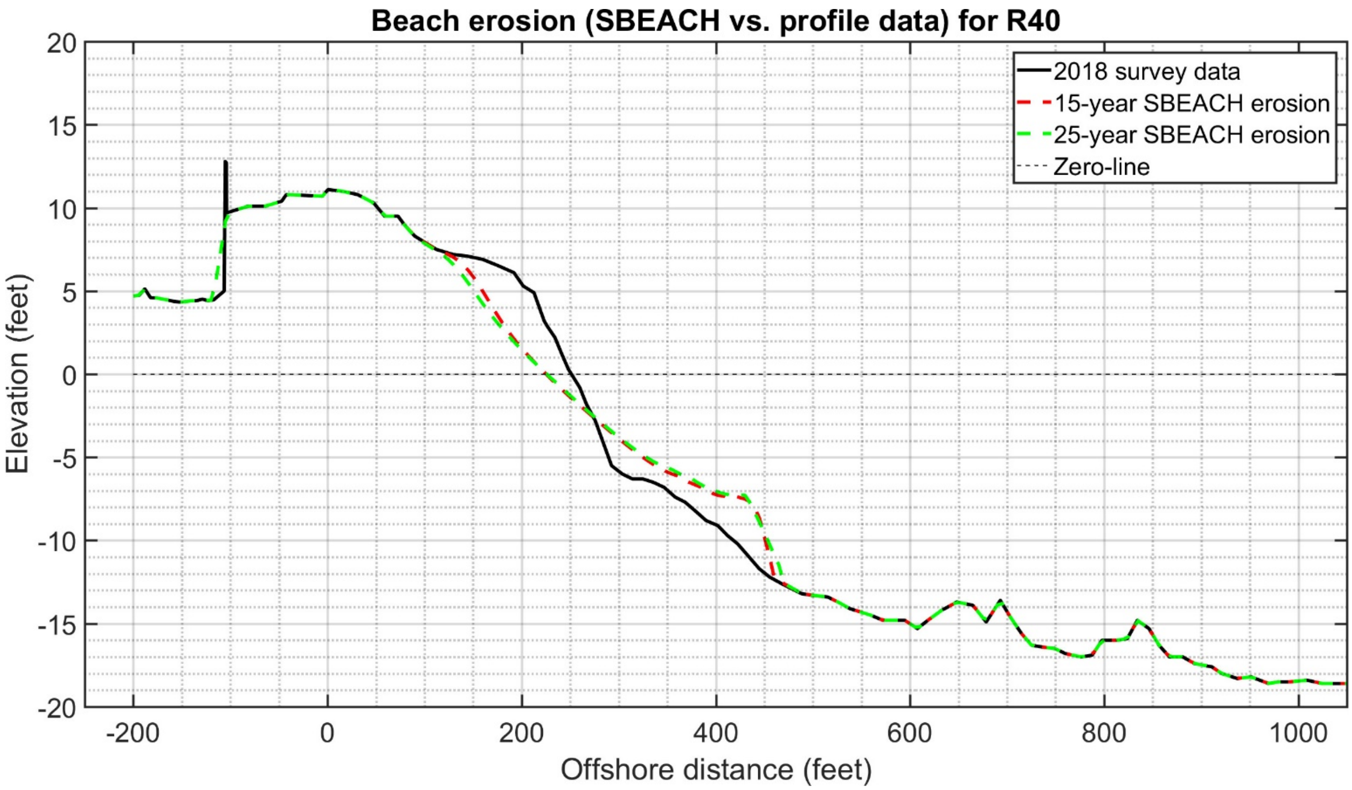
Beach erosion (SBEACH vs. profile data) for R40
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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400
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800
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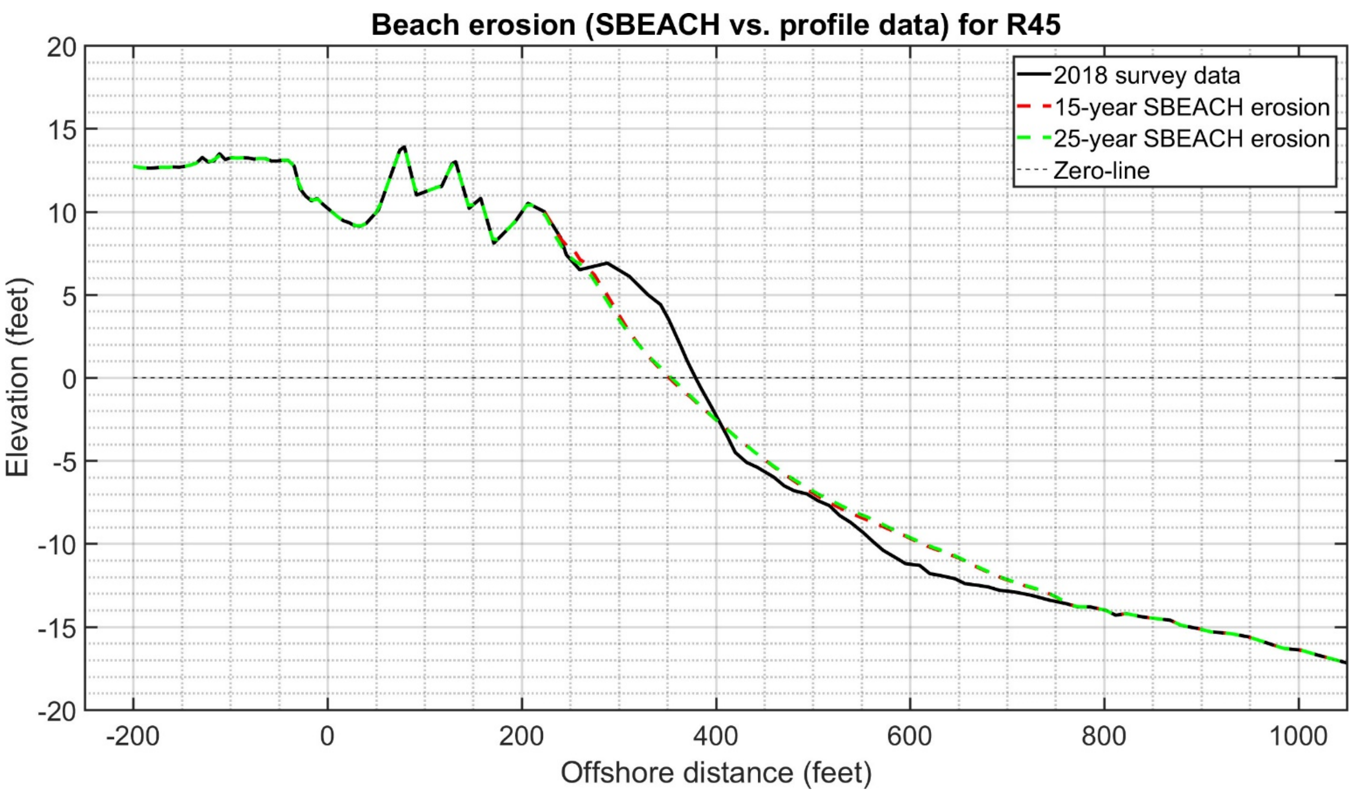
Beach erosion (SBEACH vs. profile data) for R45
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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-20
-200
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400
600
800
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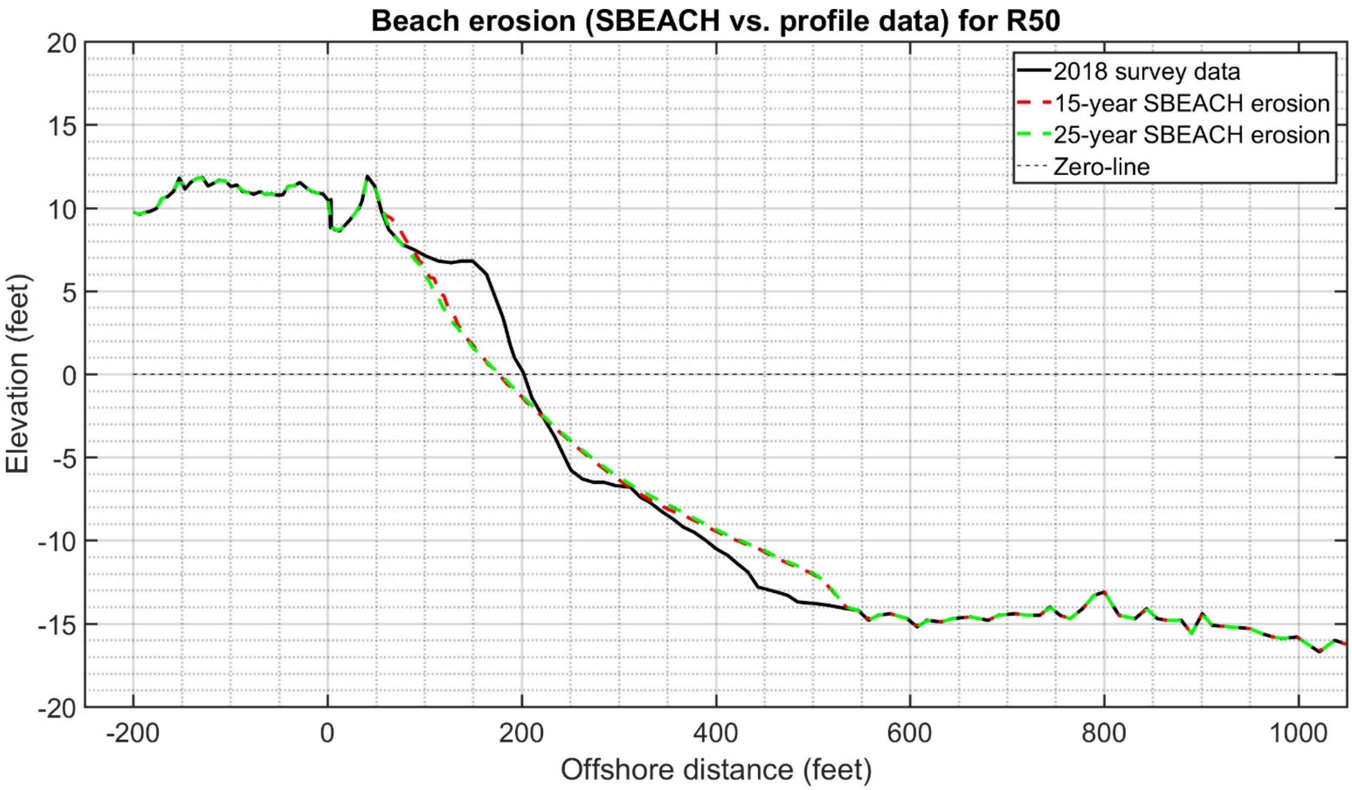
Beach erosion (SBEACH vs. profile data) for R50
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
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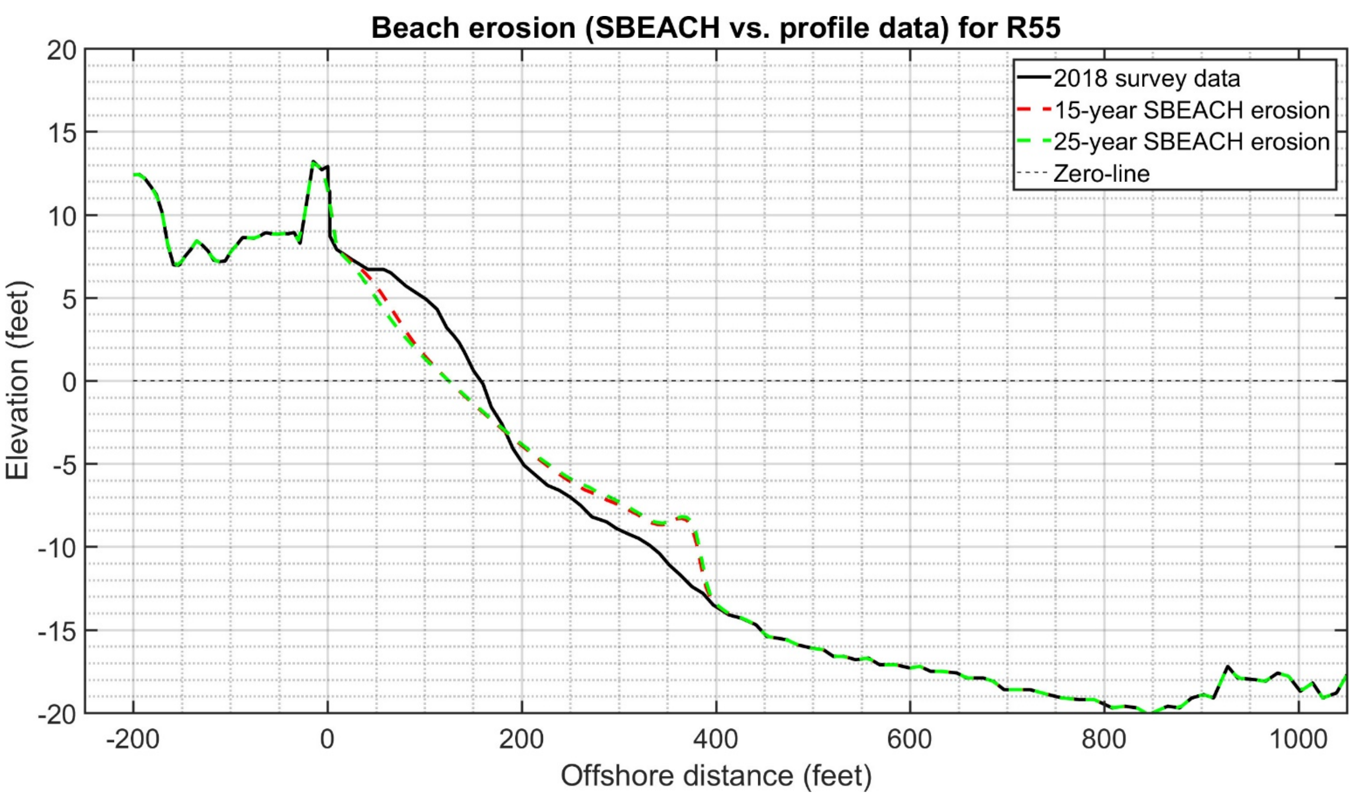
Beach erosion (SBEACH vs. profile data) for R55
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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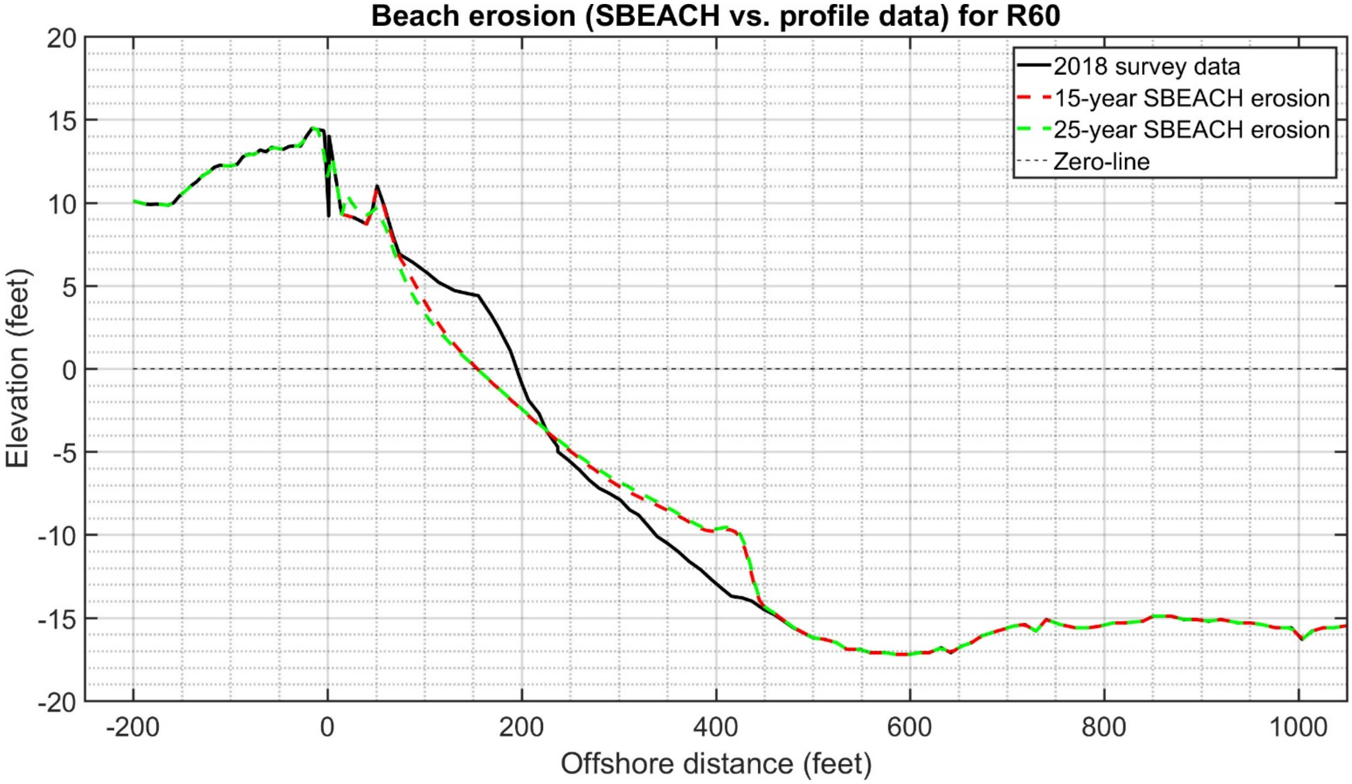
Beach erosion (SBEACH vs. profile data) for R60
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
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-20
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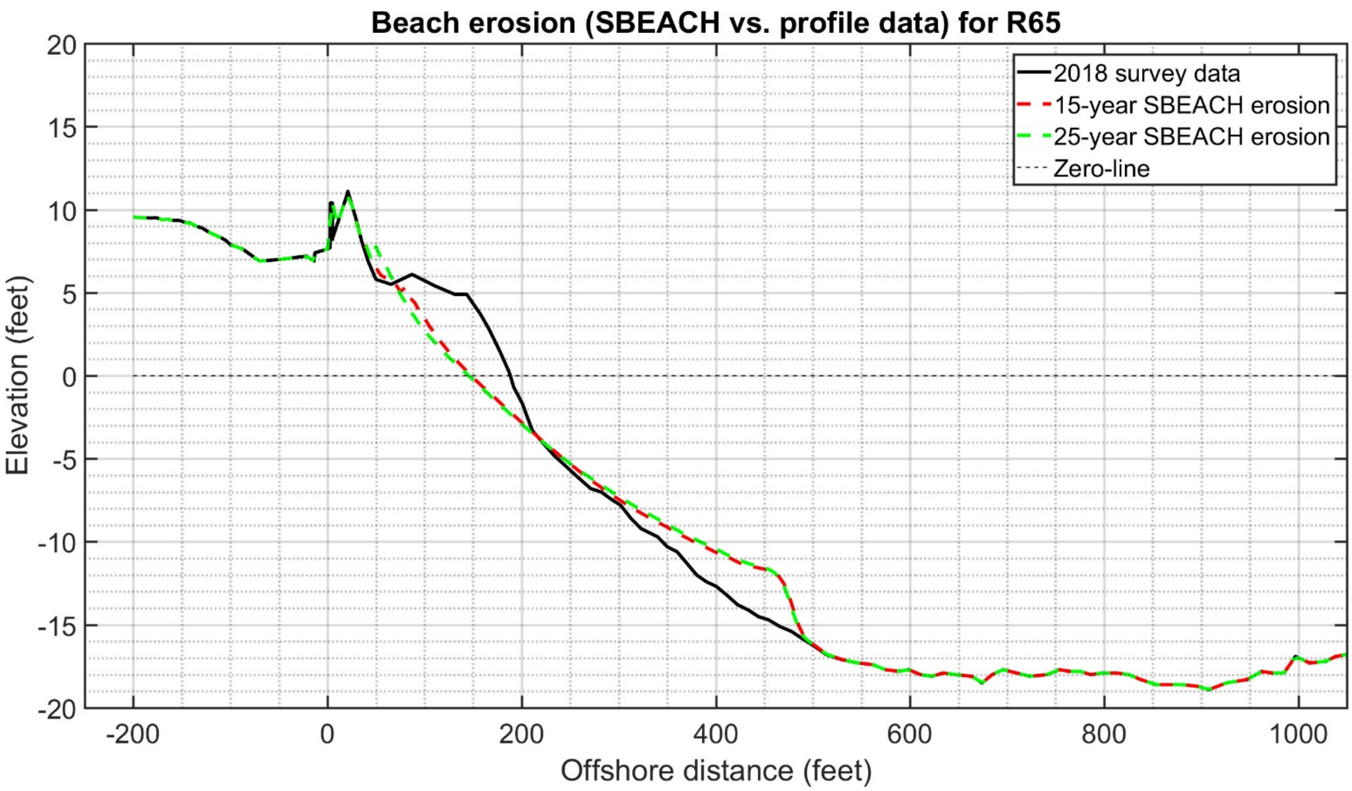
Beach erosion (SBEACH vs. profile data) for R65
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
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-20
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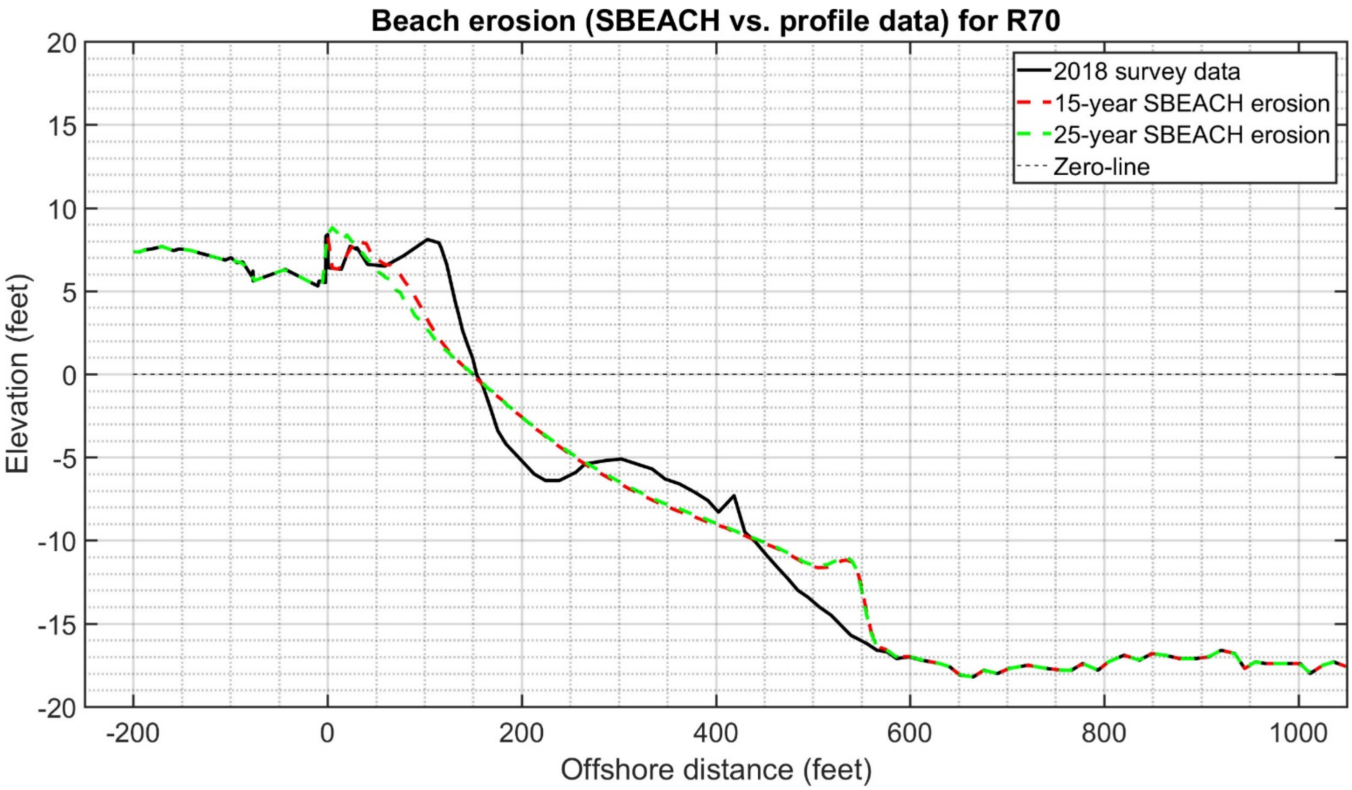
Beach erosion (SBEACH vs. profile data) for R70
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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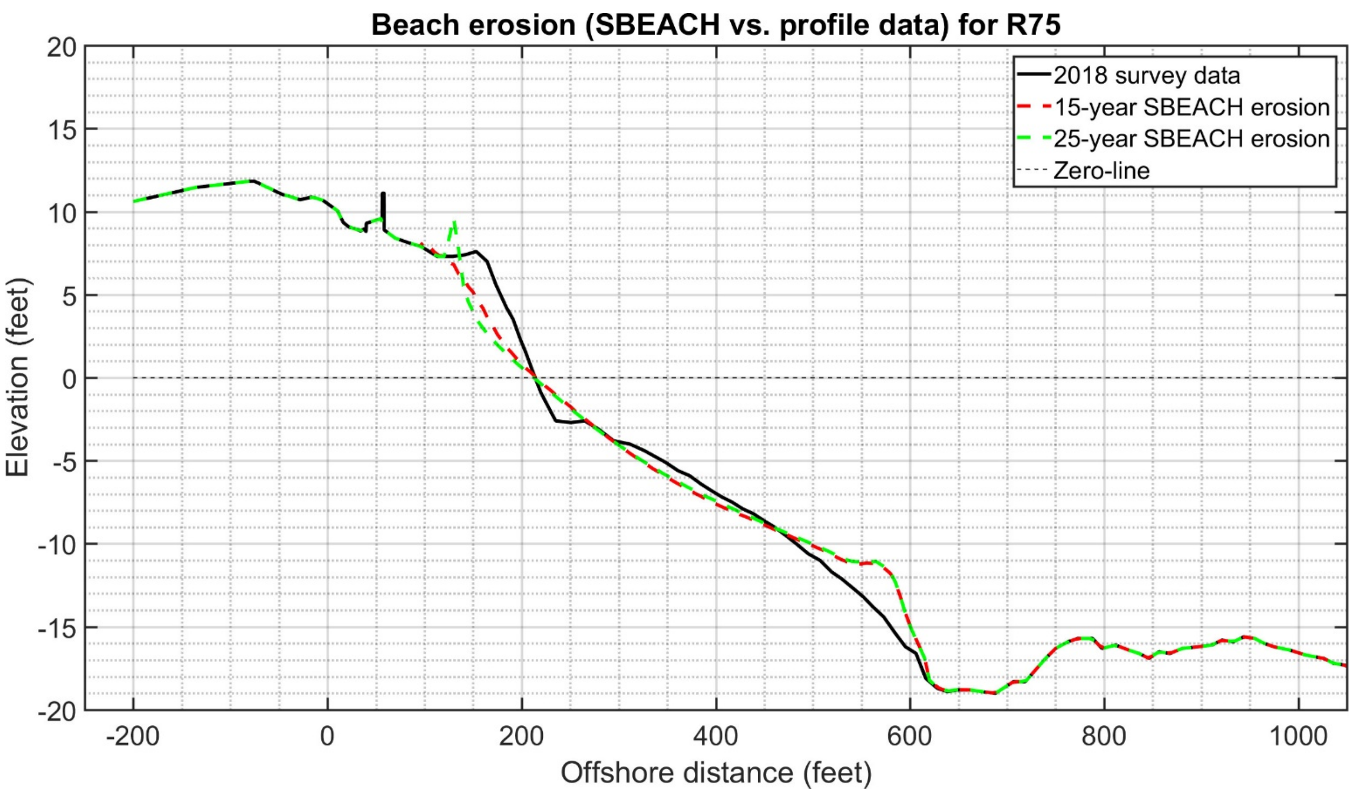
Beach erosion (SBEACH vs. profile data) for R75
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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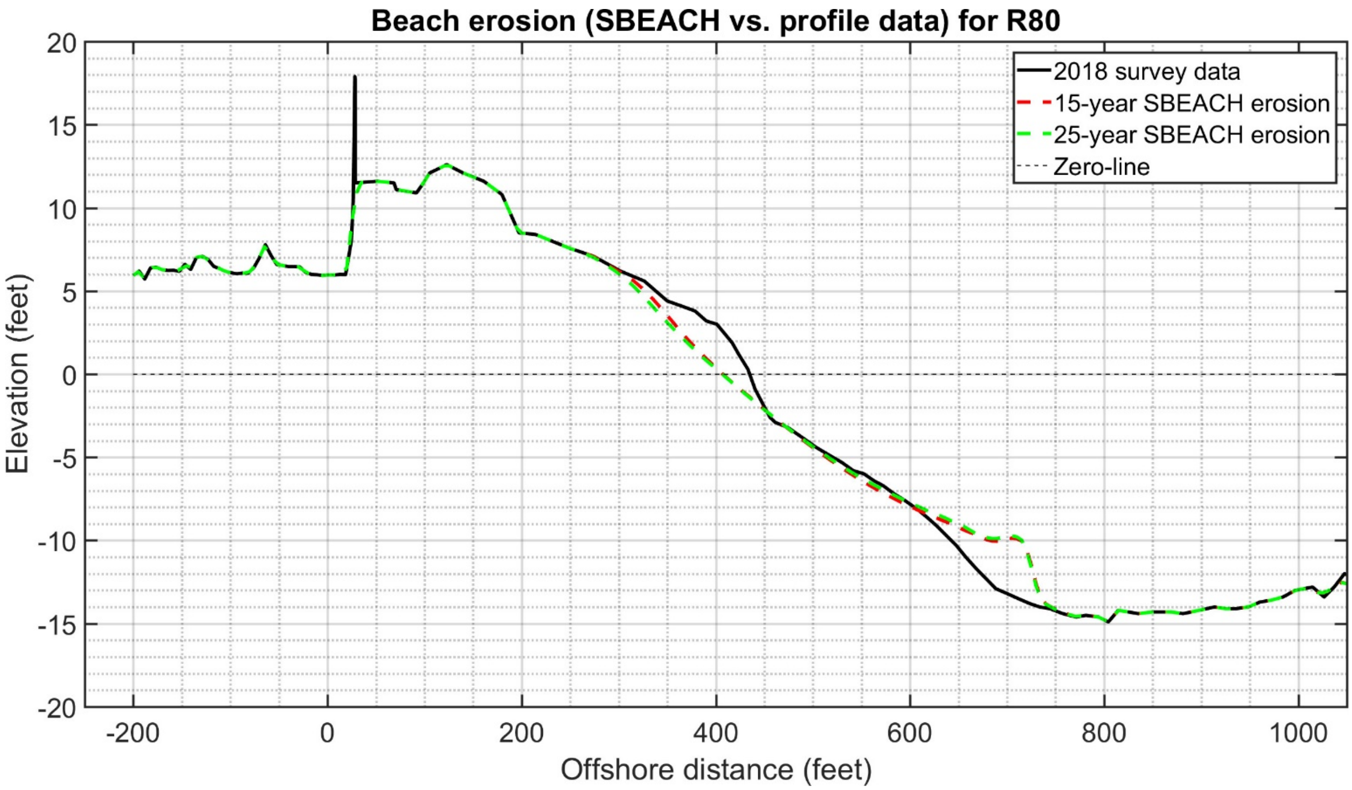
Beach erosion (SBEACH vs. profile data) for R80
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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-200
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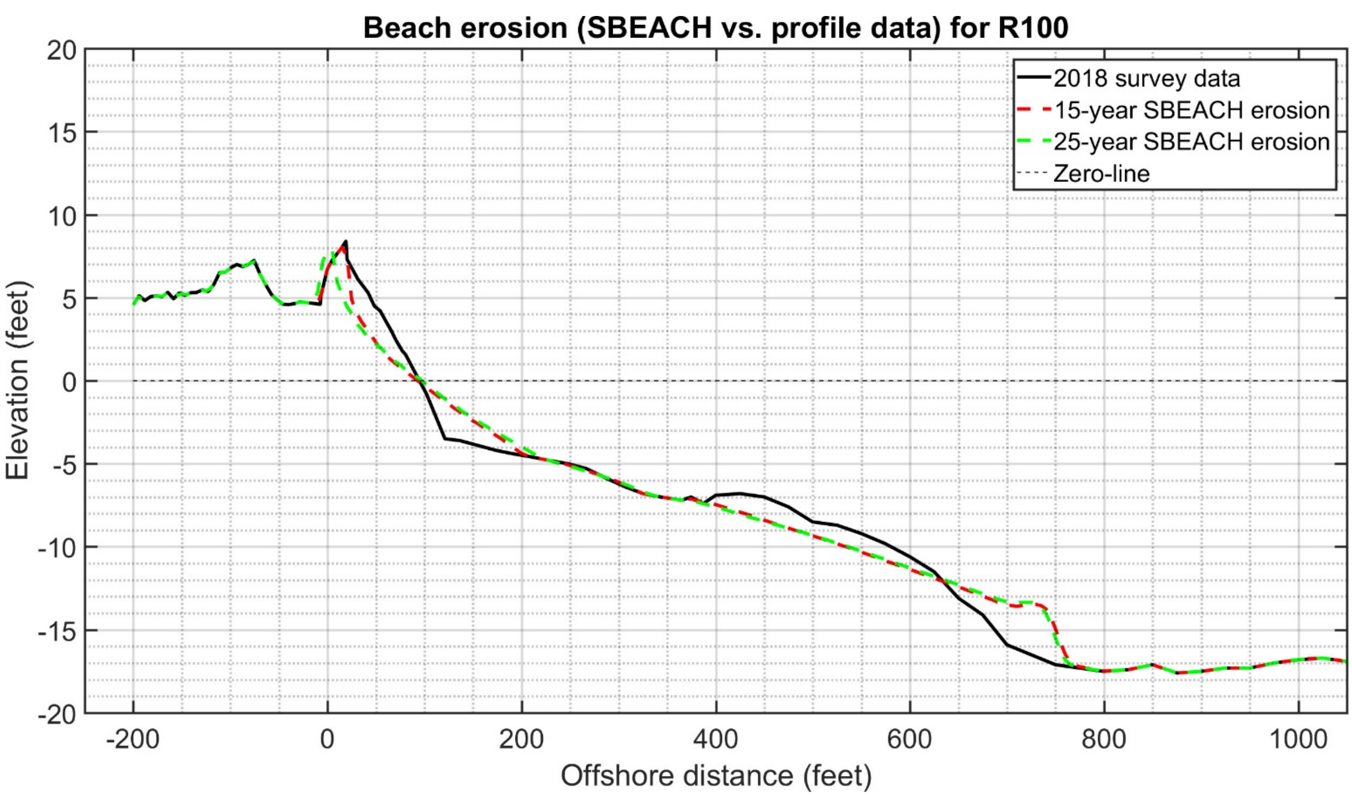
Beach erosion (SBEACH vs. profile data) for R100
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
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-200
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400
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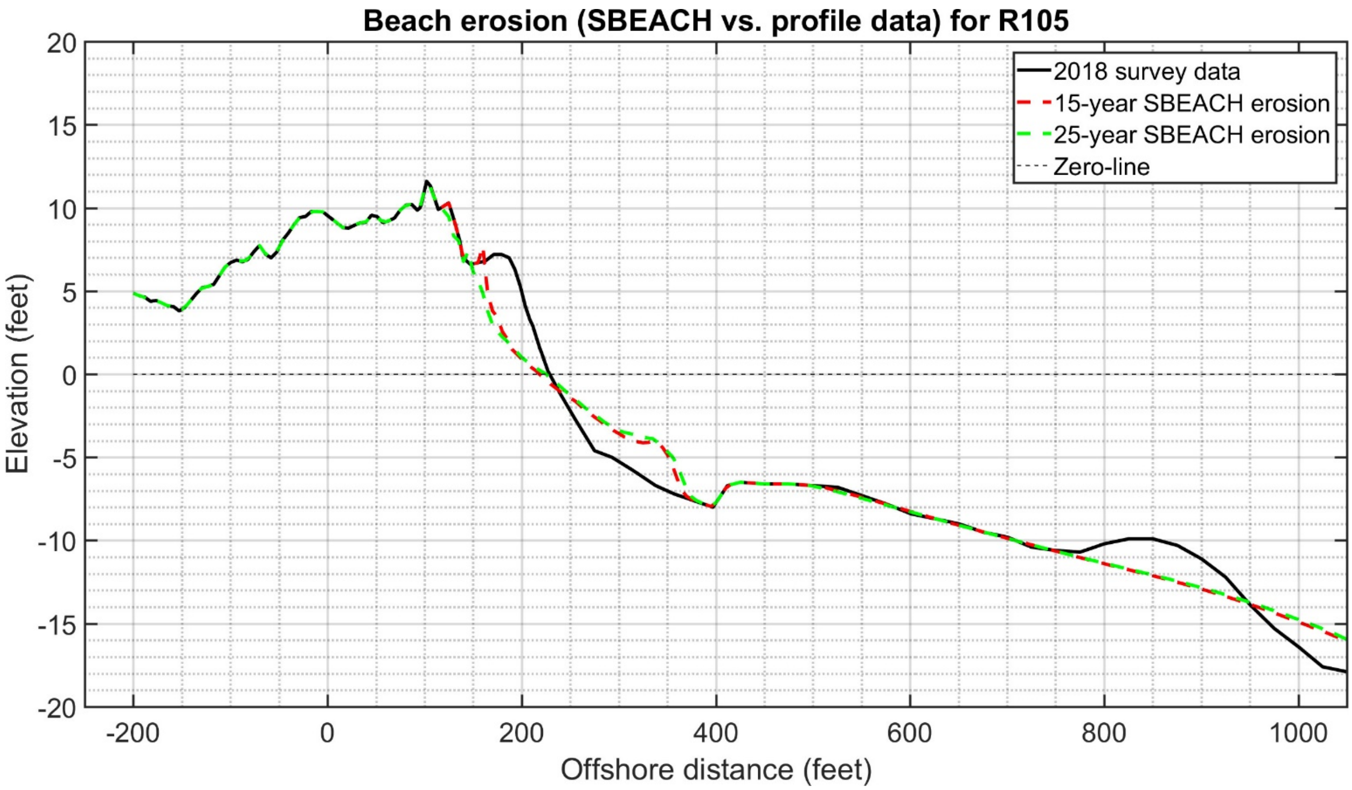
Beach erosion (SBEACH vs. profile data) for R105
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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5
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-5
-10
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-20
-200
0
200
400
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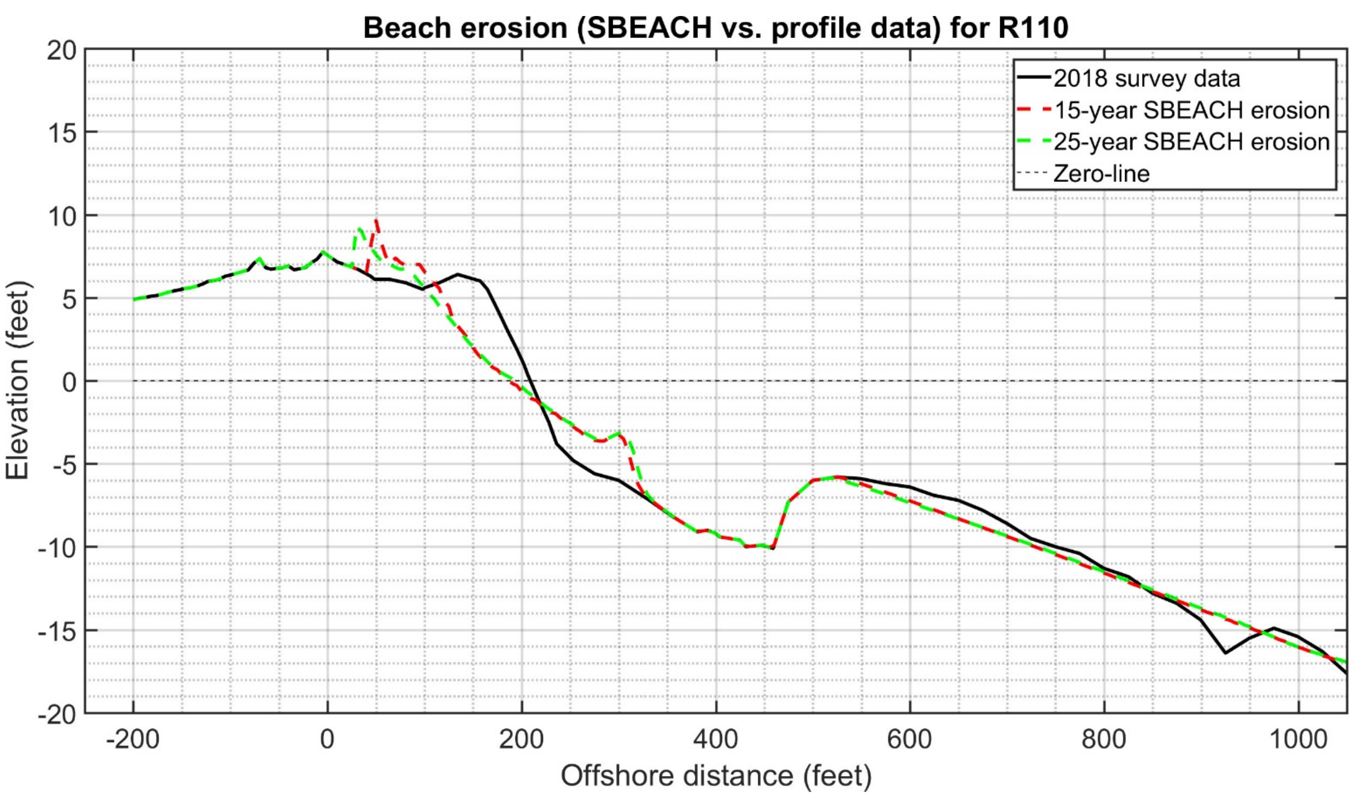
Beach erosion (SBEACH vs. profile data) for R110
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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-20
-200
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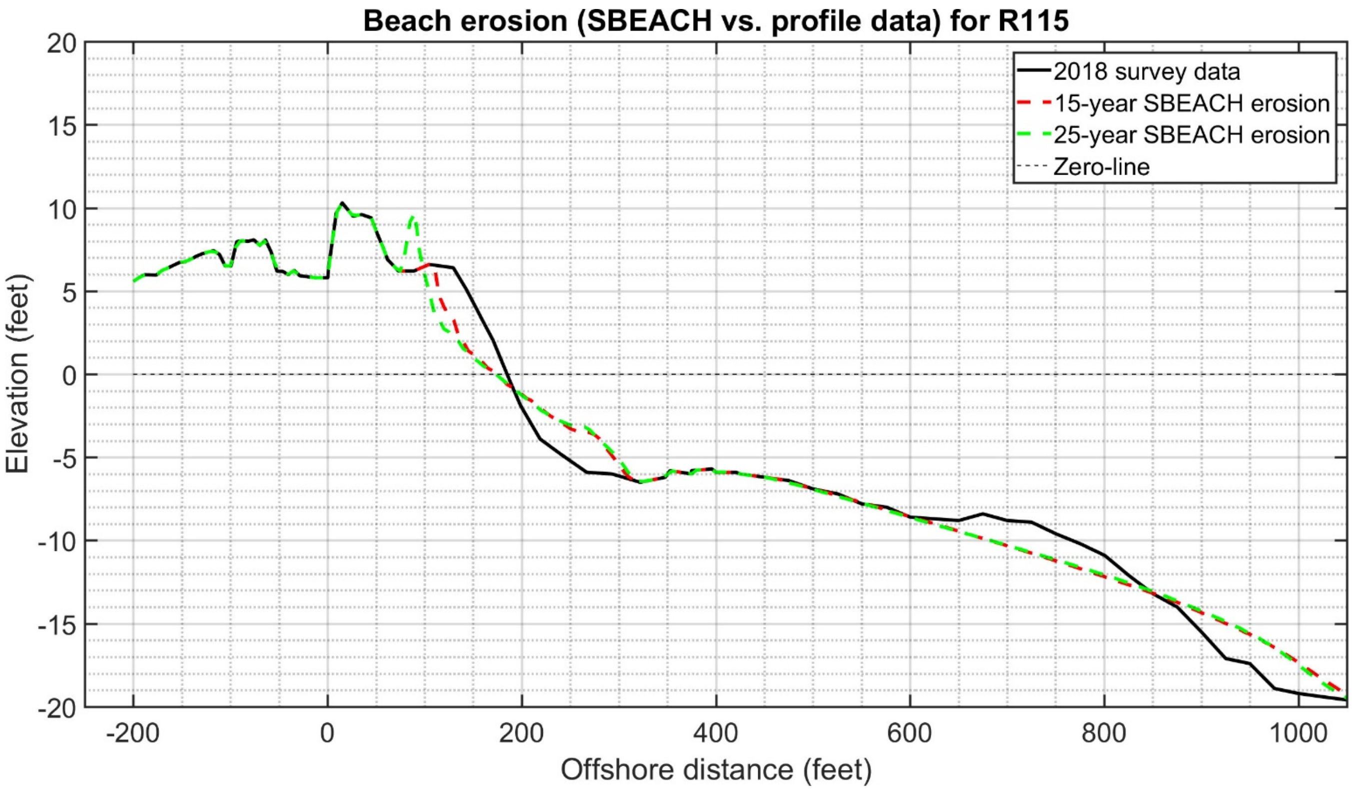
Beach erosion (SBEACH vs. profile data) for R115
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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-200
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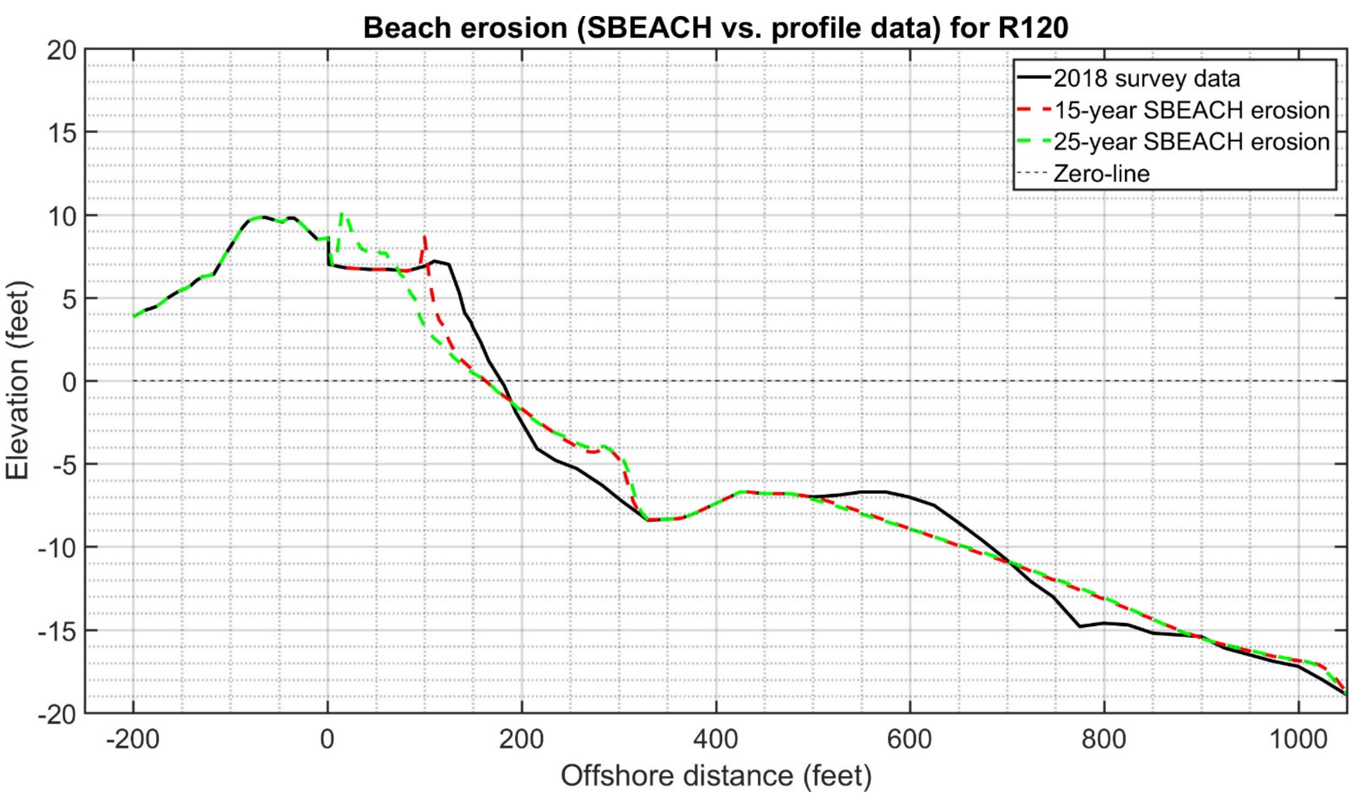
Beach erosion (SBEACH vs. profile data) for R120
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
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-15
-20
-200
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400
600
800
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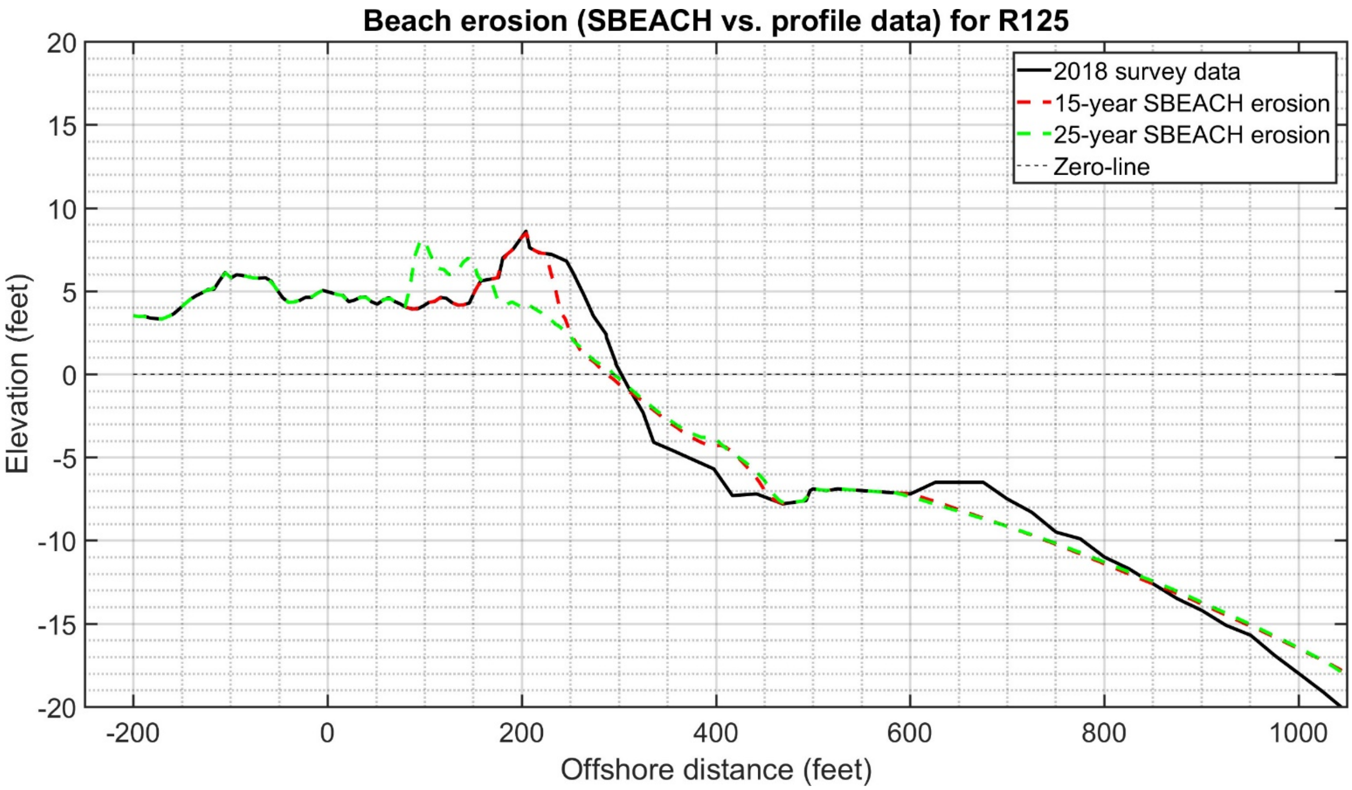
Beach erosion (SBEACH vs. profile data) for R125
2018 survey data
15-year SBEACH erosion
25-year SBEACH erosion
Zero-line
Elevation (feet)
Offshore distance (feet)
20
15
10
5
0
-5
-10
-15
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-200
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200
400
600
800
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