APPLICATION OF THE STORM EROSION INDEX (SEI) TO THREE UNIQUE STORMS

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During 2012 and 2013, the State of Florida was impacted by three tropical weather systems (Debby, Isaac, and Sandy) that caused significantly more beach erosion than similar, traditionally classified storms. Here, the storms are reclassified using the more recently developed Storm Erosion Index (SEI) which takes into consideration both the storm tide and storm waves, as well as the storm duration. The SEI has been shown previously to accurately represent the impact of coastal storms at a number of other sites (Miller and Livermont, 2008). When reanalyzed with the SEI, Tropical Storm Debby was found to be more significant in terms of beach erosion potential than any other storm in the record (since 1996), ranking as a "Category 5" storm with a return period of 23.4 years. Hurricane Isaac, which followed closely on the heels of Debby, ranked as a "Category 2" storm with an associated return period of 3 years. A sensitivity analysis performed on the results indicated that the wave steepness threshold used to separate erosion and accretion was particularly important during Isaac, as the conditions throughout the storm remained close to the threshold. While Hurricane Sandy is more known for the devastation it caused in the northeast, it also caused significant beach erosion in the State of Florida. The SEI more accurately reflects the significance of the beach erosion experienced during Sandy, and ranks the storm ahead of all of the other storms in the record (since 1994), including Hurricanes Frances, Gordon, and Jeanne which all made landfall near the area considered. Overall, Sandy registered as a "Category 5" storm in terms of beach erosion potential, with a return period of 40.5 years.

Keywords: coastal storm, beach erosion, erosion index, Florida

INTRODUCTION

Storms are one of the major threats to beaches and coastal infrastructure due to their often sudden impact and extreme power. Erosion frequently occurs during coastal storms, and can be defined as the removal of sand from the dry beach associated with storm induced mechanisms for redistributing sand such as wave action and increased water levels. Three important parameters define the severity of the erosion likely to be caused by a storm. The total water level, which is comprised of both the tide level and the storm surge, dictates how high up on the beach the water will rise, and therefore defines a region of influence. The wave conditions characterize the amount of energy available to move sediment and whether the sediment will move on or offshore. Finally, the storm duration dictates how long the beach is subjected to the storm conditions, and thus regulates how much erosion will occur. Traditional measures of storm intensity consider stage frequency analyses of individual parameters such as water level, storm surge, or wave height alone. More recently, several indices have been developed that combine some or all of these parameters; however, none of these has been widely adopted, and most are intended for use with either hurricanes or northeasters, not both.

In the United States, tropical systems are typically classified based on their meteorological properties such as barometric pressure, maximum wind speed, and storm surge potential. These properties are well-understood for warm-core cyclones and allow for a fairly simple classification system. The Saffir-Simpson hurricane scale (http://www.aoml.noaa.gov/general/lib/laescae.html), categorizes a storm based on its damage potential, and labels each storm with a number from 1 to 5 for easy interpretation by the public and comparison between storms. This classification is based on wind speed, with categories 1 to 5 defined as storms with wind speeds of 33 to 43 m/s, 43 to 50 m/s, 50 to 56 m/s, 56 to 67 m/s, and >67 m/s, respectively. Traditionally, non-tropical storms have been more difficult to categorize. Northeasters are a specific type of non-tropical storm common along the US East Coast. For these storms, there is no direct relationship between wind speed and the amount of damage potential (Herrington and Miller 2010); therefore, they cannot be classified in the same manner as hurricanes. Dolan and Davis (1992) developed one of the first indices specific to northeasters, which takes into account the wave energy and the duration of the storm. The Storm Intensity Index developed by Kriebel et al. (1996) additionally takes into account the storm surge. Table 1 compares the parameters used in these two winter storm indices with the Saffir-Simpson scale.

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Table 1. Storm damage indices, the type of storm it was developed for, and the parameters used to calculate it.

Index	Type of Storm	Parameters Used
Saffir-Simpson Scale	Hurricanes	Sustained wind speed
Dolan and Davis Scale	Northeasters	Wave height and storm duration
Kriebel Index	Northeasters	Storm surge, wave height, and storm duration

More recently, Miller and Livermont (2008) adapted and applied an index originally investigated by Miller (2001) to predict coastal damage based on the relationship between the storm wave heights and water levels and the duration of the event. The Storm Erosion Index (SEI) is a physically based parameter that includes the major factors that contribute to beach erosion during both tropical and non-tropical storms and was developed to work for both northeasters and hurricanes. The SEI provides a common base for comparing the two types of storms. Miller and Livermont (2008) showed that storm severity as ranked by traditional methods (cumulative energy, breaking wave height, and total water level) differed from the ranking by the SEI, and that the SEI was more closely correlated to the observed shoreline change than traditional indices. Miller and Livermont applied the SEI to data sets collected along both the east (Wildwood, NJ and Daytona Beach, FL) and west (Clatsop Plains, OR and Torrey Pines, CA) coasts of the United States; and the east coast (Narrowneck, QLD) of Australia.

In this study, three tropical storms in Florida were evaluated using the SEI. Though it never reached hurricane status according to the Saffir-Simpson Scale, Tropical Storm Debby lingered in the Gulf of Mexico and impacted beaches in Pinellas County, Florida from June 24 to 26, 2012. The three days of high waves and elevated water levels allowed for severe beach erosion. The Tampa Bay Times reported that a University of South Florida professor of geology said Debby caused the most widespread beach erosion in the 11 years she has been studying the area (Phillips 2012). About two months after Debby, Hurricane Isaac impacted the area on August 28. Slow moving yet destructive Isaac was classified as a Category 1 storm and caused further erosion on the beaches already weakened by Debby (Miller and Wehof 2012). Two months later, beginning on October 26, the focus shifted to the east coast of Florida as Hurricane Sandy generated an extended period of storm surge and damaging waves, in spite of the fact that the Category 1 storm remained well offshore. Water level measurements at the Lake Worth Pier were more than one foot above the predicted water level for four days, while wave heights offshore were sustained over 7 meters for 40 hours and over 5 meters for 63 hours (Miller and Wehof 2013). While Sandy received much more publicity for the devastation it caused in the northeast, the storm also caused significant erosion to the beaches on the east coast of Florida (Broward County 2013). In each case, the amount of observed damage, primarily in the form of beach erosion, was found to far exceed that which was expected based on past experiences with tropical storms and Category 1 hurricanes. At the request of the Jacksonville District of the Corps of Engineers, the storm climatology for the central west coast and south-central east coast of Florida was reevaluated in terms of the SEI to provide a more relevant estimation of the beach erosion potential associated with each storm.

METHODS

Development of the SEI

The method used in the calculation of the SEI has its foundations in the beach profile response that occurs from increased water levels. The well-known Bruun Rule (Bruun 1962) describes the beach response to a uniform increase in water level S,

$$\Delta y = -S \frac{W_*}{(h_* + B)} \quad (1)$$

Where (h_*+B) represents the vertical extent of the active profile and Δy is the resulting horizontal recession.

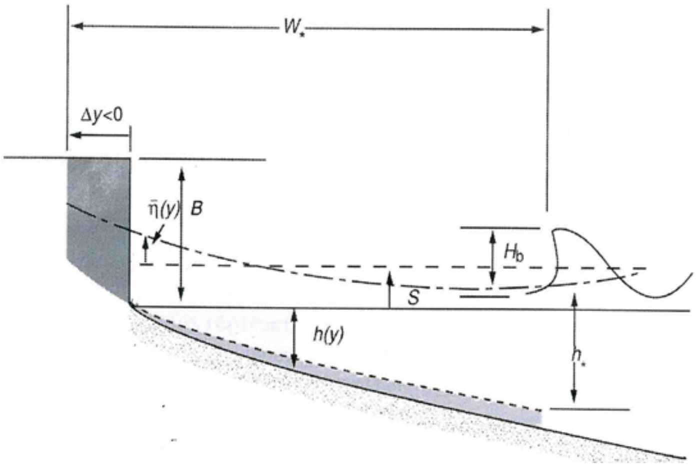

Figure 1: Variables used in the derivation and calculation of the IEI. Figure from Dean and Dalrymple, 2002.

Dean and Dalrymple (2002) presented a modification to the Bruun Rule which describes the shoreline change caused by the combination of waves (due to setup) and storm surge, as shown in Figure 1. As depicted in the figure, the total water level increase across the surfzone consists of a cross-shore uniform component *S*, and the wave setup η, which varies with the distance from shore (*y*). The resulting shoreline change, Δ*y*, can be derived through the application of conservation of volume and equilibrium beach profile concepts,

$$\Delta y = -W_* \left[\frac{0.068 H_b + S}{B + 1.28 H_b} \right] \quad (2)$$

Where H_b is the breaking wave height, W_* is the width of the active surfzone, and *B* is the berm height. In the present analysis, W_* is approximated as the distance to the breakpoint. If the assumption of an equilibrium beach profile is applied, W_* can be calculated directly from the 2/3 relationship proposed by Dean (1977),

$$h = A W_*^{2/3} \quad (3)$$

In Equation 3, *A* is the sediment scale parameter (Moore 1982) which is related to the median sediment size. On a natural beach, each of the parameters in Equation 2, with the exception of the berm height, varies on the short timescale associated with the waves. Here, the time varying shoreline change is used to define an index representing the Instantaneous Erosion Intensity, IEI,

$$IEI(t_i) = W_*(t_i) \left[\frac{0.068 H_b(t_i) + S(t_i)}{B + 1.28 H_b(t_i)} \right] \quad (4)$$

The IEI represents a time varying equilibrium shoreline change, and is a physically based measurement of the instantaneous intensity of a storm. The negative sign in Equation 3 is simply dropped as a matter of convenience. The maximum value of the IEI during a storm can be used define a Peak Erosion Intensity (PEI), which represents the erosion potential of the storm at its apex. While both the PEI and the IEI are useful measures of the instantaneous intensity of a storm, they do not include the effect of storm duration. The persistence of the given wave conditions and water levels has a significant effect on the total erosion potential. Summing the IEI values over the storm duration t_d, defines the Storm Erosion Index, SEI,

$$SEI = \sum_{t_d} IEI(t_i) = \sum_{t_d} W_*(t_i) \left[\frac{0.068 H_b(t_i) + S(t_i)}{B + 1.28 H_b(t_i)} \right] \quad (5)$$

Here, the storm duration is defined as the period of time during which the wave height or water level exceeds the mean plus two standard deviations. Conditions that fall below the defined threshold for more than 24 consecutive hours are considered to represent two separate storms. To compare events of different timescales, the SEI can be divided by the storm duration to arrive at the average erosion intensity during a storm (Miller and Livermont 2008).

Storm Rankings

Two different approaches were used to evaluate the severity of individual storms. The first is a simple categorization procedure designed to mimic the well-known and easily understood Saffir-Simpson hurricane intensity scale. The categorization procedure provides a site-specific relative measure of the strength of each storm and scales the storms from 1 through 5, consistent with the Saffir-Simpson scale. At each site, the storm with smallest value of SEI is assigned to Category 1, while the storm with the largest is assigned to Category 5. Linear interpolation is used to assign categories to all of the storms in between according to,

$$Cat = 5\times\left(\frac{SEI - SEI_{\min}}{SEI_{\max} - SEI_{\min}}\right) \tag{6}$$

The value that is obtained from Equation 6 is rounded up to the next whole integer to arrive at a final categorization. While Equation 6 is presented in terms of the SEI, the approach can also be used to categorize storms based on the PEI.

Extreme value analysis (EVA) is a statistical method to examine extreme deviations from the median of a probability distribution. Here, the peaks over threshold (POT) approach was utilized to evaluate the return periods associated with each of the observed storms. The POT method sets a certain threshold and fits the exceedances of this threshold to a Generalized Pareto Distribution (GPD). Holmes and Moriarty (1999) found that the results of a peak-over-threshold extreme value analysis using the GPD were particularly significant for geophysical phenomena such as floods. The POT approach has advantages over other EVA methods in that it utilizes all of the extremes in a dataset rather than limiting the analysis to a single event per year.

Storm Season Rankings

While the approaches outlined above are useful for ranking individual storms, it is often of interest to know the cumulative impact of a series of storms. The approach taken here is to sum the SEI values associated with individual storms over a storm season. Although the definition of storm season is somewhat arbitrary, we have chosen it to coincide with hurricane season, with an individual storm year beginning on June 1 and ending on the following May 31.

DATA

All data used in this study are from publicly accessible data sources. In order to be able to place the storms in the correct historical context, wave height and water level records with at least 10 years of data were sought. Along the west coast of Florida, the nearest water level station meeting the criteria was the National Ocean Service (NOS) tide gauge at Clearwater Beach (8726724). Several potential sources of wave data for the Gulf of Mexico exist. The National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC) West Tampa buoy (42306) was selected due to its proximity to the location of the observed erosion, and the length and quality of its record. The offshore wave data were shoaled and refracted using linear wave theory to obtain the breaking wave heights required for the SEI. While the majority of the data at buoy 42036 are directional, waves without directional data were assumed to approach from due west for the purposes of the refraction calculation.

For the analysis of Sandy's impacts on the east coast, water level data were obtained from the NOS tide gauge at Trident Pier (8721604). Two NDBC wave buoys were used in the analysis of Sandy because the closer of the two buoys (41009) was damaged during Sandy and went offline, and is also missing data from 2004, when Hurricanes Frances and Jeanne made landfall in the study area. Buoy 41010 is located much further offshore and is not directional; however it remained operational during critical periods of the analysis. Since 41010 was never directional, wave directions were assumed consistent with those reported by 41009. For the shoaling and refraction calculations, waves were assumed to approach from the monthly most common direction as reported in the NDBC climatological summary for buoy 41009 when directional information was unavailable.

Prior to calculating IEI values, the waves undergo two screening processes. The first screening process eliminates waves directed offshore from the analysis. The second screening process removes potentially accretional waves from the analysis. A limiting wave steepness of 0.025 is used to separate erosional ($H_o/L_o > 0.025$) and accretional ($H_o/L_o < 0.025$) conditions according to Johnson (1949). A map of the wave and tide gauge locations as well as the counties within the study area is shown in Figure 2. Combining the datasets gives a record that extends back to 1996 for the west coast and to 1994 for the east coast.

SOURCE	RECORD LENGTH	GAPS	DIRECTIONAL
NDBC 42036	1994-2012	Yes	Yes
NOS 8726724	1996-2012	No	NA
NDBC 41010	1988-2012	Yes	No
NDBC 41009	1988-2012	Yes	Some
NOS 8721604	1994-2012	No	NA

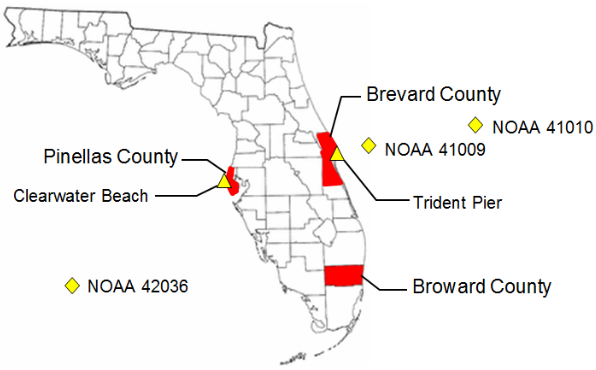

Figure 2. Map of the data source locations and notable counties in Florida. Triangles are tide gauges and diamonds are wave gauges. The table above summarizes the data record at each gauge.

RESULTS

West Coast of Florida

The SEI was applied to help evaluate the intensity of Tropical Storm Debby which made landfall near Steinhatchee, Florida on June 26, 2012 and caused severe beach erosion in Pinellas County. Previous storms that impacted the area, such as Hurricane Frances, had higher wind speeds but passed more quickly (Phillips 2012). While the wind damage experienced during these storms was much more significant, the observed beach erosion was less. Similar observations were made when Hurricane Andrew, a fast-moving Category 4 storm impacted south Florida in 1992. While the winds associated with the storm resulted in wide-spread damage to structures, the beach erosion was less severe than might have been expected due to the speed at which the storm impacted the coast. The severe beach erosion caused by Debby resulted from the fact that the storm stalled in the Gulf of Mexico and generated an extended period of elevated waves and water levels. Although Debby never achieved hurricane status according to the Saffir-Simpson scale, the erosional potential of Debby based on the SEI was ranked higher than that of any other storm since 1994. If the proposed categorization based on the SEI is used, Debby is considered a Category 5 storm. More objectively, a return period calculated by fitting the SEI data to a generalized pareto distribution (GPD), using a peaks over threshold (POT) approach suggests that a storm like Debby has a return period of 23.4 years.

Table 2: West Coast of Florida SEI results and return periods.

Date	Storm	SEI	T_r [years]	Category
24-Jun-2012	Debby	1694	23.4	5
26-Sep-1998	Georges	1105	10.4	4
02-Sep-1998	Earl	1045	9.3	4
07-Oct-1996	Josephine	831	6.2	3

28-Aug-2012	Isaac	550	3.0	2

Individually, Hurricane Isaac was much less significant than Tropical Strom Debby according to the SEI. Isaac only registered as a Category 2 storm, with a return period of 3.0 years suggesting the storm generated conditions fairly typical for the area. It should be noted that in the case of Isaac, this conclusion is heavily dependent on the steepness threshold used to separate accreting and eroding waves. During Isaac the waves measured in excess of 3 m for a full 48 hours; however, during a significant portion of this time the calculated wave steepness was just under the 0.025 threshold. This results in some large waves being excluded from the SEI calculation. The 0.025 threshold was selected based on its use in the literature and to be consistent with other applications of the SEI; however, as the dividing line between erosion and accretion is far from certain, more analysis needs to be done to establish the sensitivity of the results to the chosen erosion/accretion threshold. A preliminary sensitivity analysis performed during the current study showed that lowering the steepness threshold to 0.02 recasts Isaac as a Category 4 storm, with a return period closer to 10 yrs.

To assess the cumulative impacts of the two successive storms relative to the historical record, the SEI was accumulated over the period from June 1st to May 31st of the following year for each year in the record. The data were then normalized by the highest yearly total. The results are shown in Figure 3, where the 2012-2013 storm season was found to be the second most severe in the record. (Note the 2012-2013 data represents only a partial storm year through November 2012). Only the 1998-1999 storm season which included Hurricane's Earl and Georges ranks higher. The second parameter presented in the graph which is not discussed in detail here is the Accumulated Storm Wave Energy (ASWE). The ASWE is an index similar to NOAA's Accumulated Cyclone Energy scale for comparing hurricane seasons, where the energy calculation is based on wave height rather than wind speed squared.

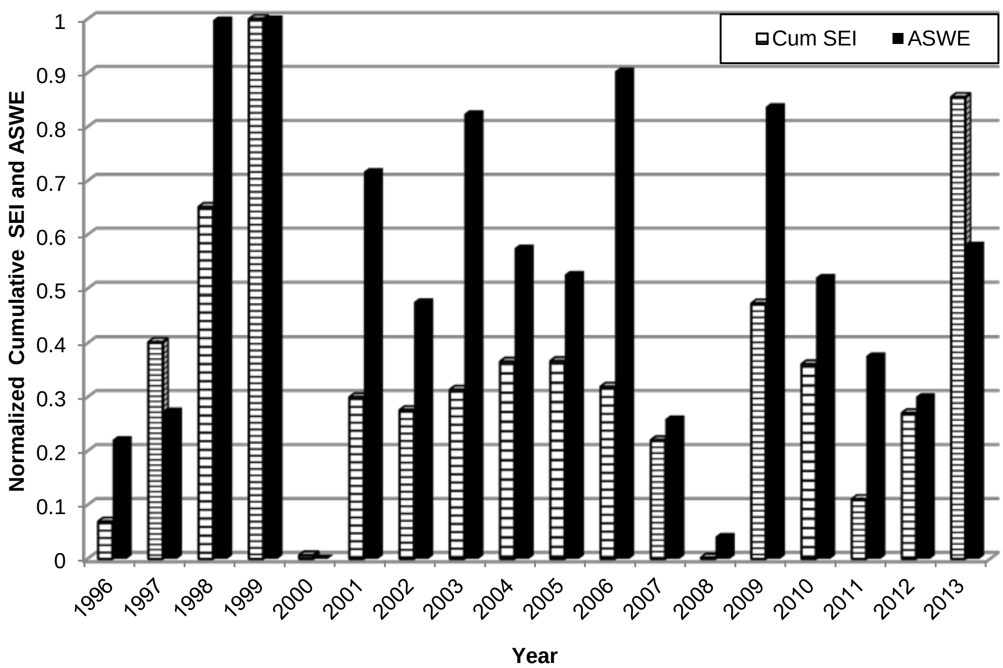

Figure 3. The annual cumulative SEI and Accumulated Storm Wave Energy (ASWE) for the coast off Tampa, Florida. Annual accumulations were made from June 1 to May 31 to represent a storm year.

The observed erosion in Pinellas County supports the high SEI ranking of Tropical Storm Debby. Figure 4 is a photo showing some of the severe erosion that occurred during the storm; this photo represents what was observed at many of the Pinellas County beaches. In some locations, buried seawalls became exposed and scoured due to the storm event. Most of the beach profiles surveyed (at R-monuments established by the State of Florida) experienced sand loss in the dune, on the dry beach, and in the nearshore zone, with sand accumulation observed on the nearshore bar. An example profile is given in Figure 5. The change in shoreline position, as measured by the mean high tide line, for the surveyed profiles is given in Figure 6. Over all of the beaches in Pinellas County, more than 800,000 cubic meters of sand were displaced from the dune and dry beach, with up to 10.5 meters of shoreline retreat (Wang and Roberts 2012).

Figure 4: Dune scarping and erosion in Pinellas County immediately after Tropical Storm Debby. Photo by Hilary Stockdon, USGS, 2012.

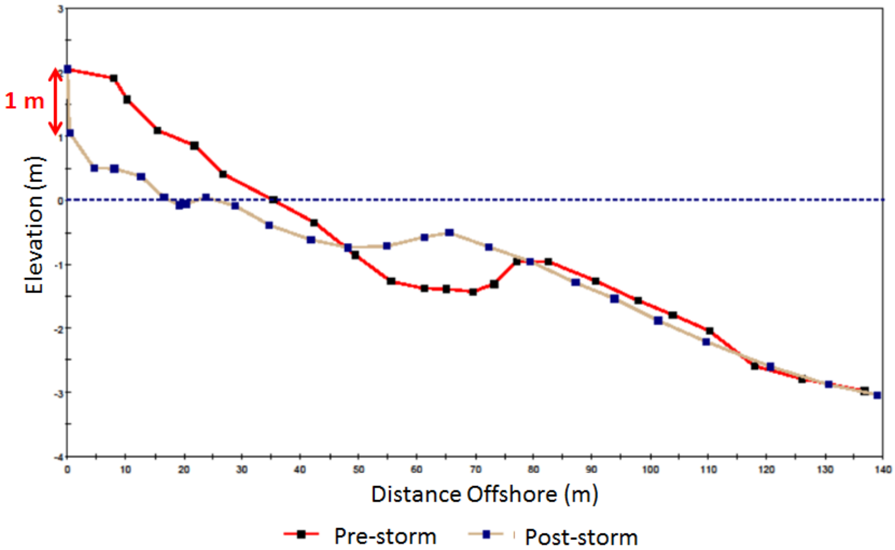

Figure 5. Beach profile change from before and after Tropical Storm Debby. There was about more than one meter of erosion in some areas of the dry beach, with deposition into an offshore bar. Adapted from Wang and Roberts 2012.

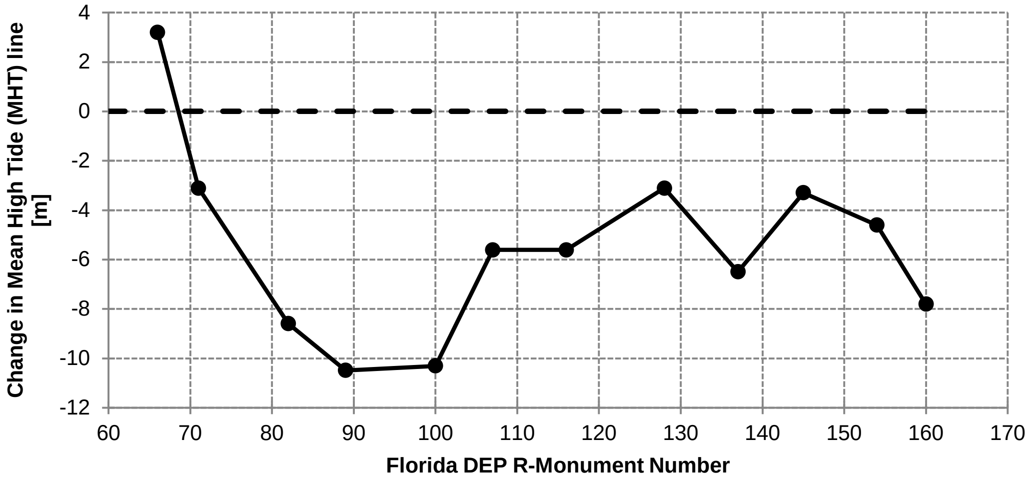

Figure 6. The change in the mean high tide (MHT) line along beach profiles at State of Florida R-monuments. Negative change indicates erosion while positive change indicates accretion.

East Coast of Florida

The SEI was also applied using data from the southeast coast of Florida to assess the erosional potential of Hurricane Sandy, which passed offshore of Florida as a weak Category 1 storm between October 26 and October 28, 2012. The wave heights and water levels during the storm recorded at buoy 41010 and the Trident Pier tide gauge are plotted in Figures 7 and 8, respectively. The waves at the Canaveral East buoy reached a maximum of 9.26 m and were sustained over 7 m for a period of 40 hours, and over 5 m for 63 hours while elevated water levels were observed over a period of 6 days. The persistence of the waves and storm surge during Sandy more closely resembled the typical pattern associated with a Nor'easter than a hurricane. As described above, the combination of elevated water levels and large waves acting over an extended period of time has the potential to cause significant beach erosion.

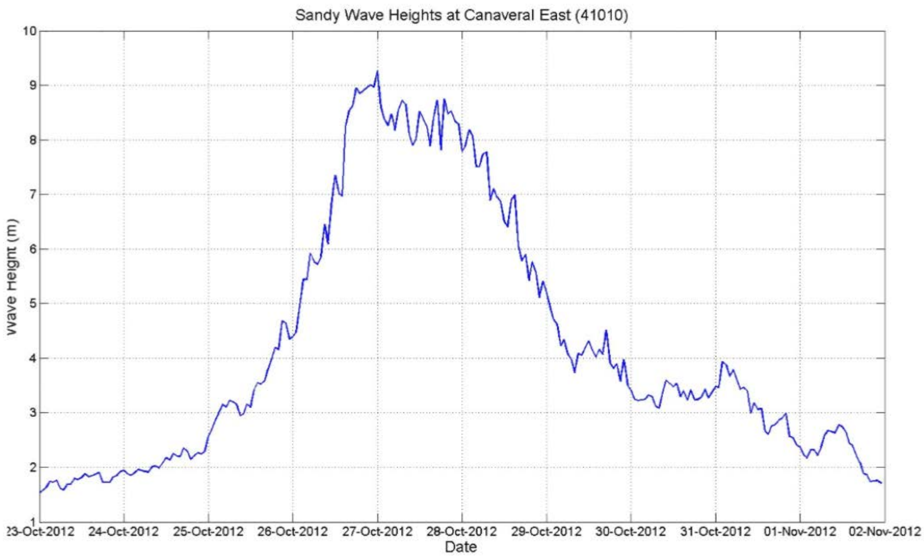

Figure 7. Wave heights measured at NOAA NDBC buoy 41010 (Canaveral East) during Hurricane Sandy.

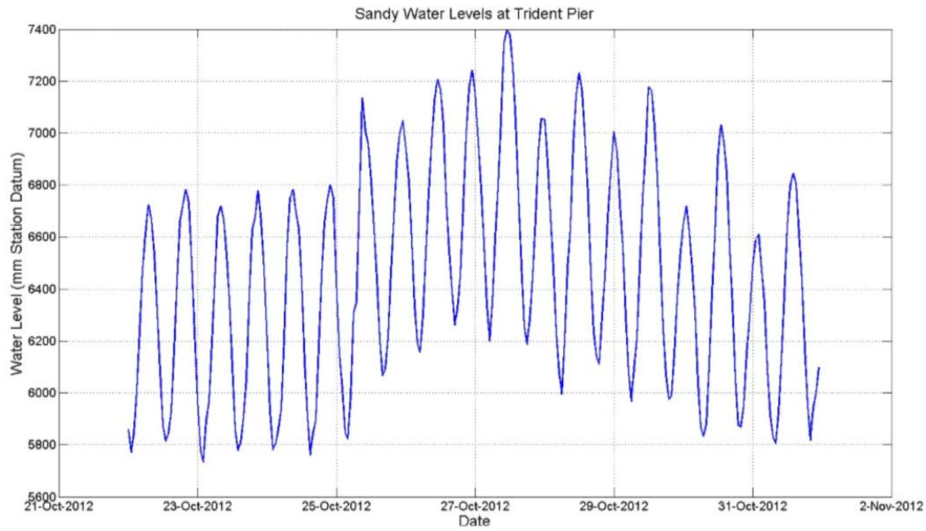

Figure 8. Water levels measured at NOS station 8721604 (Trident Pier) during Hurricane Sandy.

Four sets of SEI results were calculated, representing the combination of two different shoreline orientations with both nearshore and deep-water wave data. The results for the northeast facing shorelines in the northern part of the study area using the nearshore wave data are summarized below in Table 3. Noticeably absent from the table are Hurricanes Frances and Jeanne which made landfall in the study area in 2004. Further investigation revealed that buoy 41009 has a tendency to go offline during major storms, and even though Sandy ranks high on the list, the buoy stopped reporting before the waves had completely subsided. This resulted in the need to reanalyze the storms using the offshore buoy which remained operational throughout the 2004 hurricane season, and throughout Hurricane Sandy. The SEI results obtained using the offshore wave data are summarized in Table 4.

Table 3: East Coast of Florida SEI results and return periods using nearshore wave data.

Date	Storm	SEI	T_r [years]	Category
15-Nov-1994	Gordon	2867	46.6	5
09-Oct-2011	???	2378	20.3	5
01-Nov-2007	Noel	1701	6.4	4
26-Oct-2012	Sandy	1513	4.6	4

Table 4: East Coast of Florida SEI results and return periods using offshore wave data.

Date	Storm	SEI	T_r [years]	Category
26-Oct-2012	Sandy	2358	40.5	5
05-Sep-2004	Frances	2086	22.8	5
15-Nov-1994	Gordon	1450	6.3	4
26-Sep-2004	Jeanne	1415	5.9	4
11-Mar-1996	Nor’easter	1223	4.1	4

The results using both sets of wave data indicate that Hurricane Sandy was a significant storm as measured by the SEI. When the incomplete nearshore wave data is used, Hurricane Sandy is the storm with the fourth largest storm erosion potential in the historical record with a return period of 4.6 years (using a peaks over threshold (POT) approach). When the more complete offshore data is used, Sandy actually ranks as the most damaging storm, with the two major 2004 storms slightly behind. Using the same peaks over threshold approach, the calculated return period for Sandy using the offshore data is approximately 40.5 years.

The results from the southern part of the study area (from approximately West Palm Beach through Brevard County) where the shoreline is approximately oriented north-south mirror those discussed above. As mentioned previously, this analysis does not account for the presence of the Bahama Banks, so any sheltering provided is not considered. Overall, the ranking of the storms does not change; however minor modification to the nearshore wave field reduce the return period of Sandy and increase the return period of Hurricane Frances slightly, such that both are approximately 25-year storms. As with the west coast Florida data, the normalized annual cumulative SEI was calculated for storm years June 1 through May 31, given in Figure 9. Frances and Jeanne appear in the 2005 year as the stormiest on record, with 2013 including Sandy to be the third most damaging.

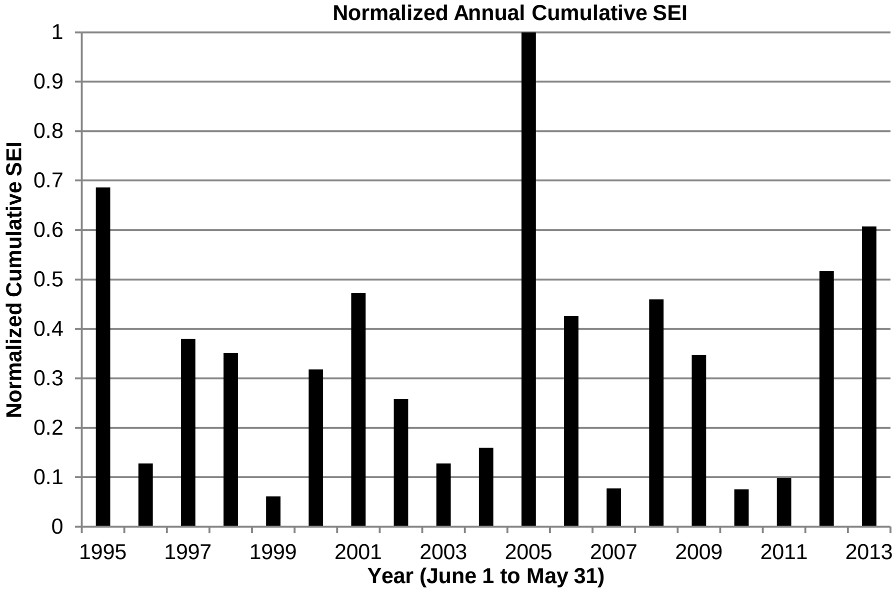

Figure 9. Normalized, annual cumulative SEI for the east coast of Florida. Annual sums are from June 1 to May 31 to incorporate a hurricane season and winter storm year in lieu of a calendar year.

The Jacksonville District of the Corps of Engineers assessed the damage due to Hurricane Sandy in a post-storm aerial inspection from Hillsboro Inlet south to Port Everglades on October 29, 2012. Scarp lines, seawalls, and the base of coconut palms had between 30 and 190 cm of vertical erosion in the 18 km segment of Broward County beach. The high water line receded to within 9 meters of seawalls and residential structures in the area, and significant overwash onto State Road A1A had to be scraped away with bulldozers, with eventual replacement back onto the beach. A total pre- to post-storm erosion due to Hurricane Sandy in the Broward County segment surveyed was approximately 81,400 cubic meters, an average of 4.5 cubic meters lost per meter of beach. An example of an eroded profile at Florida DEP monument R-26 is shown in Figure 10. Figure 11 depicts the volume changes in the vicinity of monument R-26, where erosional profiles have a negative volume change. In all, 20 of the 28 profiles experienced a loss in sand volume due to Hurricane Sandy.

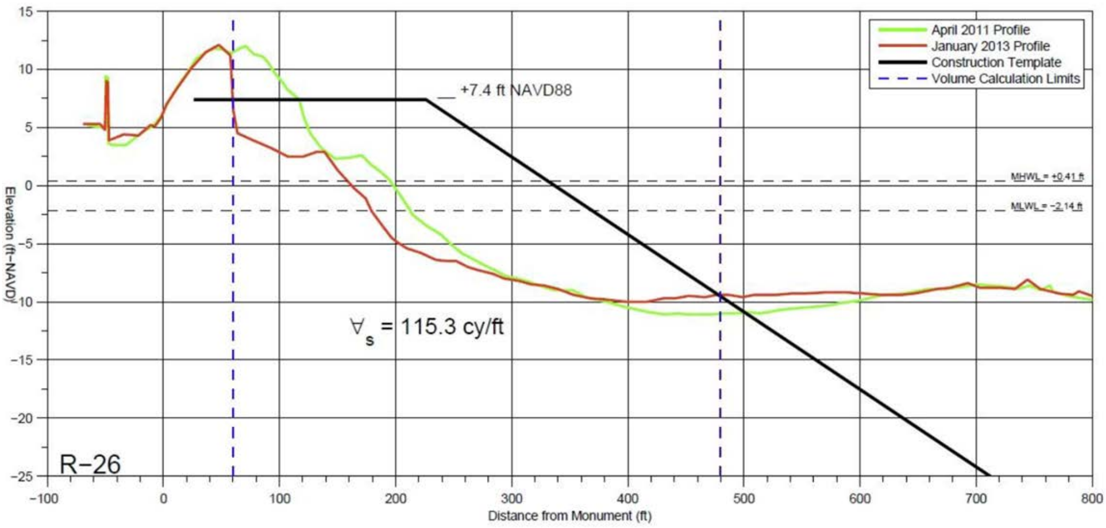

Figure 10. Pre-storm and post-storm profiles at Florida DEP survey monument R-26. Vertical dashed lines identify volume calculation limits.

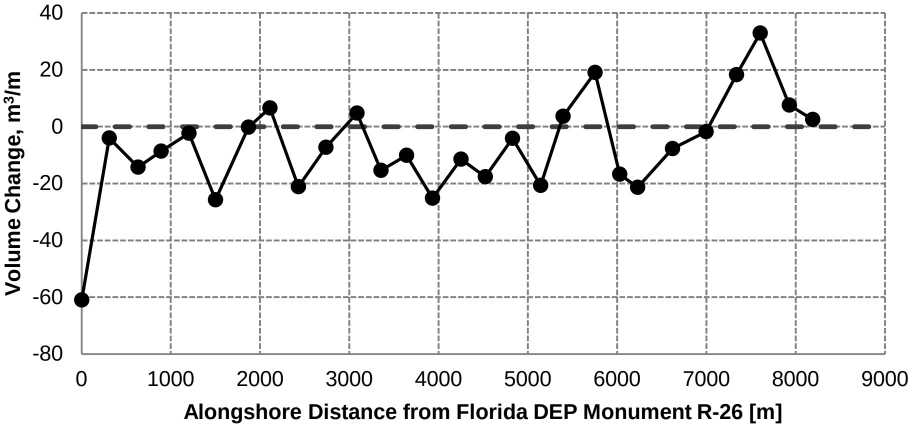

Figure 11. Pre-storm to post-storm volume change in the beach profile at each Florida DEP established survey monument. Monuments are given in alongshore distance from monument R-26, and volume change is given as cubic meters gained (positive, above the dashed line) or lost (negative, below the dashed line) per linear meter of beach.

CONCLUSIONS

The Storm Erosion Index (SEI) was used to evaluate the severity of three storms which caused significant damage in the State of Florida, in spite of the fact that they were only classified as minor storms according to traditional indices. The SEI was first used to represent the beach erosion potential of storms by Miller (2001) and was later improved and shown to be effective by Miller and Livermont (2008). The SEI takes into consideration the storm tide, storm waves, and the storm duration in evaluating the erosion potential of a given storm, and is equally applicable to tropical and extra tropical weather systems.

In 2012, Tropical Storm Debby and Hurricane Isaac caused significant beach erosion along the Gulf Coast of Florida, in spite of only being classified as minor storms according to the Saffir-Simpson scale. The severe beach erosion caused by Debby resulted from the fact that the storm stalled in the Gulf of Mexico and generated an extended period of elevated waves and water levels. Although Debby never achieved hurricane status according to the Saffir-Simpson scale, when evaluated against other historical storms on the basis of SEI, Debby registers as a Category 5 storm with a return period of 23.4 years. Hurricane Isaac, which followed closely on the heels of Debby, ranked as a Category 2 storm with a return period of 3 years. The one-two punch provided by the storms ranks the 2012-2013 season as the second most intense since 1994.

In 2013, Sandy transited the east coast of the United States, and in spite of remaining well offshore of the State of Florida, generated significant beach erosion in the state. Although Sandy was only classified as a Category 1 storm on the Saffir-Simpson scale, waves off the coast of Florida were sustained over 7 m for a period of 40 hours, and over 5 m for 63 hours. The persistence of the waves and storm surge during Sandy heightened the beach erosion potential compared to “traditional” Category 1 hurricanes. The SEI captures the erosion potential of the storm and classifies Sandy as a Category 5 storm, with a return period of 40.5 years.

AKNOWLEDGEMENTS

Jennifer Wehof would like to thank Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution for financial support to attend ICCE 2014 to present this research. The support of the New Jersey Department of Environmental Protection in furthering the development of the SEI is gratefully acknowledged.

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