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Northeast Florida: A New Hotspot for Hurricane Damage?

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Abstract

Until recent Hurricanes Matthew and Irma struck northeast Florida, Hurricane Dora had been the first and only hurricane-strength storm in recorded history to strike the region. The area had gradually become regarded as a safe spot as storms at that latitude generally curved away from Jacksonville and northeast Florida and turned north to make landfall in the Carolinas. Unknown to most, Vilano Beach had been experiencing steady yet chronic beach erosion and was already in a highly vulnerable state in many places when the recent storms struck. The cause of the ongoing background erosion continues to be a source of contention among residents and some experts. This paper presents pre-storm historic beach conditions, the potential causes and progression of erosional events surrounding Hurricanes Matthew and Irma at three locations in northeast Florida, and an assessment of protection measures implemented by homeowners. Observations made during field investigations show that bulkheads constructed to protect single or multiple houses exacerbate erosion at the ends of the bulkheads. This results in both failure of the bulkheads as well as increased erosion for neighboring properties.

Introduction

On October 6, 2016 and then again on September 11, 2017 the coast of northeast Florida, specifically Vilano Beach, made national headlines due to severe beach and dune erosion as a result of Hurricanes Matthew and Irma, respectively. This area of Florida had been thought of as “immune” to major landfalling hurricanes as most storms at this latitude generally curved away from northeast Florida and track towards the Carolinas. The only direct hurricane impact in this area was from Hurricane Dora in 1964. The tracks of the three storms are shown in Fig. 1.

Although the two recent hurricanes did not make direct landfall in northeast Florida, there was considerable damage to the coastline. This raised questions of why Vilano Beach was so heavily impacted by the storms. Several different theories have emerged, including 1) long-term sea level rise and moderate, yet persistent, storm attack, coupled with a lack of beach nourishment as compared to efforts north of Vilano Beach (USACE, 2019), and 2) dredging of the large ebb shoal of St. Augustine Inlet between 2001 and 2005, which removed approximately 7.3 million cubic yards of sand. Although the ebb shoal is supposedly located net-downdrift (south) of Vilano Beach, dredging purportedly denied the northern shoreline of sand during times when transport was directed towards the north, e.g. during summer months and southerly storm events, and allowed greater penetration of waves from the south to attack this shoreline, (Olsen Associates, Inc. 2009, 2010).

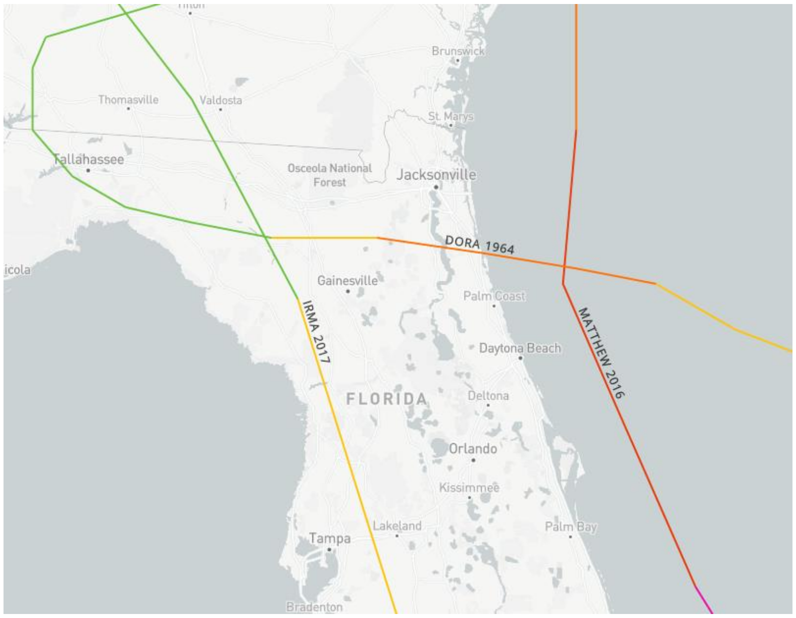


Figure 1. Tracks for Hurricanes Dora, Matthew, and Irma (adapted from NOAA, 2020).

This paper will explore the erosional damages and shoreline behavior along Vilano Beach since the early 1970s, along with the dredging activities that have occurred at St. Augustine Inlet. Understanding the extent of prior damages, contributions of both natural and anthropogenic activity, and estimating future damages to Vilano Beach are especially important because a major roadway, Coastal Highway A1A, serves as the only access to the communities along 28 km of coastline north of the city of St. Augustine. In addition, Coastal Highway A1A is a hurricane evacuation route. The highway, which is already subjected to regular flooding in some areas, cannot be moved landward because it runs along the federally protected Guana River Wildlife Management Area and the Guana Tolomato Matanzas National Estuarine Research Reserve (GTM-NERR).

Geographic Setting

Vilano Beach in St. Johns County, FL is located on the northeast coast of Florida. The east coast of Florida is barrier-island and tidal-inlet system. In this geographic area, which is considered the southern end of the Georgia Bight, barrier island morphology is influenced by tidal and wave energies. Tidal range is typically less than two meters, except in the spring when tides can be larger (Davis, 1997). Vilano Beach is located on San Pablo Island just north of the St. Augustine Inlet and to the East of the Tolomato River. Fig. 2 provides the regional location of Vilano Beach, and displays the critically eroding section of shoreline reaching from Florida Department of Natural Resources (FDEP) survey Range-Monument R-100 to R-122.

The elevation of the dunes/bluffs along Vilano Beach are approximately 6 m NAVD88. Mean Sea Level (MSL) is nominally -0.21 m NAVD88 and Mean High Water (MHW) is +0.71 m NAVD88. Prior to hurricanes Matthew and Irma, the width of the dunes was approximately 46 m (USACE, 2019). The dunes themselves are predominantly composed of wind-blown silica sands

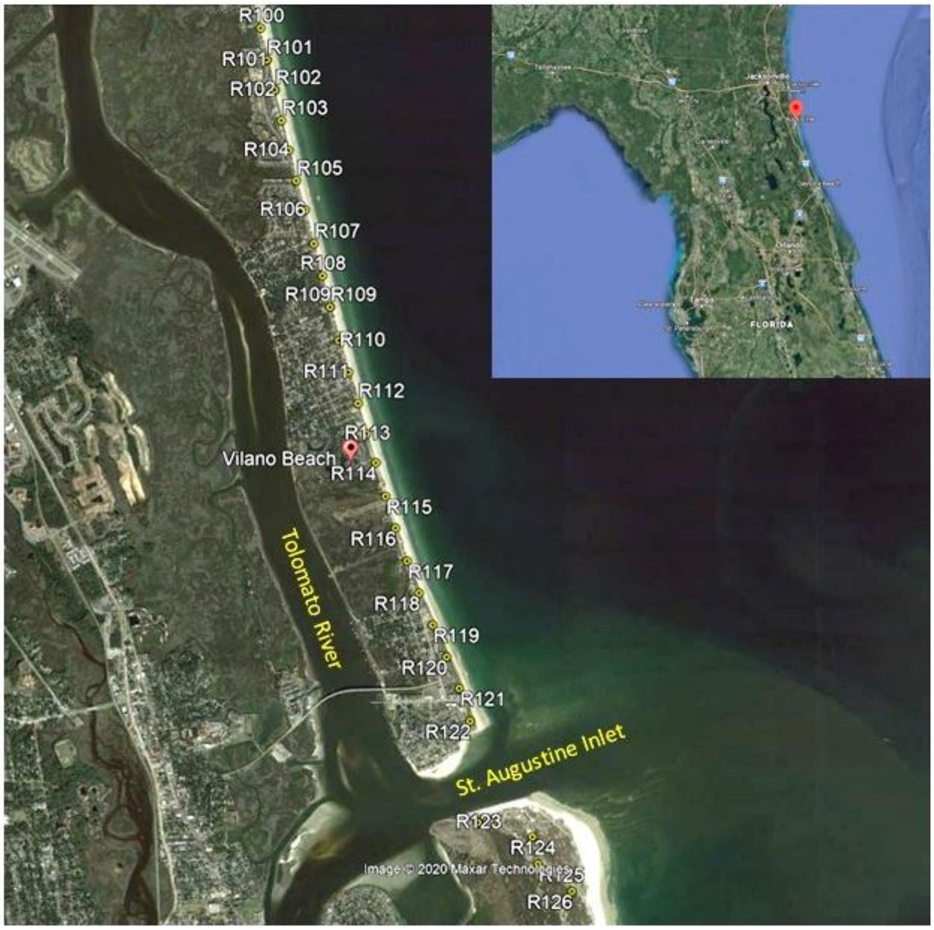


Figure 2. Critically eroding section of Vilano Beach, Florida, and regional location (insert). Locations of Florida Department of Natural Resources (FDEP) survey Range-Monuments R-100 to R-122 are indicated (adapted from Google Earth 2020).

($d_{50} \cong 0.17$ mm) derived from weathering of the Appalachian Mountains in the Carolinas and Georgia. The sediments were transported via longshore transport processes starting approximately 30 Ma and ending approximately 3 Ma (Hine, 2013). However, it is quite evident that coarse shell content ($d_{50} \cong 0.6$ - 1.6 mm) is prevalent between the upper beach face (+4.6 m NAVD88) and MSL (PBS&J, 2009). This has been confirmed by recent work of students at the University of North Florida along more than 6.8 km of undeveloped, pristine beach within the GTM-NERR located only 4.9 km to the north of the study area, where the dune elevation is commonly +9 m NAVD88, and the upper beach face sediments have very high, coarse shell content.

Timeline

To investigate the potential causes of increased hurricane-induced damage to Vilano Beach, it is helpful to examine the timeline of the perceived major contributors to the evolution of this section of shoreline, i.e. 1) long-term erosion stress due to moderate storms and sea level rise, and 2) dredging activities at St. Augustine Inlet. Included are timelines of erosion indicators, i.e. beach profile evolution at three separate locations in Vilano Beach, as well as the associated changes in the distance from the local R-monument to the Mean High Water (MHW) elevation at each location.

As noted, prior to Matthew and Irma, Vilano Beach had been chronically eroding along much of its shoreline. As shown in Fig. 3, the historic shoreline changes from R-102 to R-118 can be subdivided into three time-series: 1) the long-term average from 1972 through 2015 (red), 2) just before, during, and after dredging of the ebb shoal at St. Augustine Inlet between 1999-2007 (blue), and 3) after dredging but before Matthew and Irma struck from 2007-2015 (purple). Mean erosion rates for this stretch of shoreline were -1.58 ft/yr, -3.51 ft/yr, and -0.18 ft/yr for the 1972-

2015, 1999-2007, and 2007-2015 time periods respectively. However, between 1972 and 1999 (not shown) the mean erosion rate was -0.89 ft/yr. The notably higher erosion rate between 1999 and 2007 does coincide with dredging of the inlet shoal, which could possibly have exacerbated the already chronic erosion problem. However, it also coincides with the 2004 hurricane season in which Frances and then Jeanne inflicted severe erosion along much of Florida's east coast. However, since 2007 the erosion rate had abated to less than historic levels before the Matthew and Irma hurricane events.

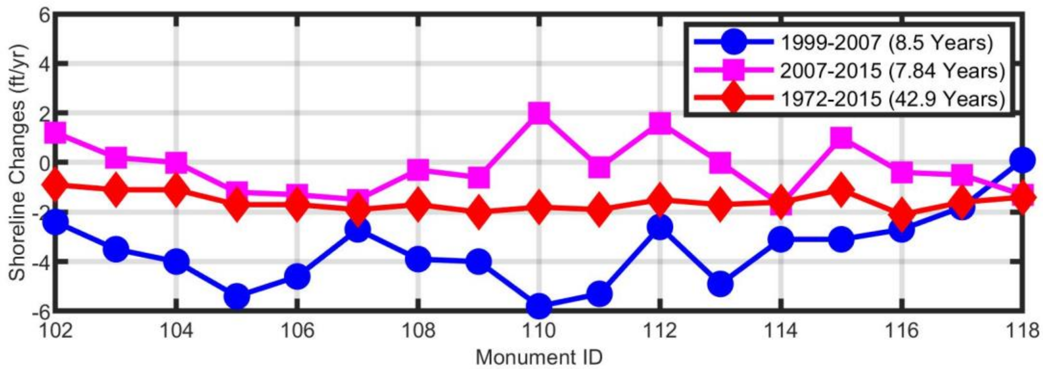
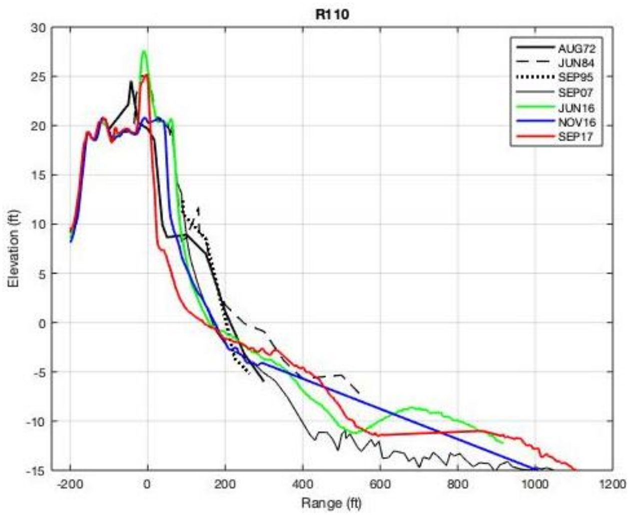


Figure 3. Mean erosion rates (ft/yr) in southern Vilano beach during most erosive period from 1999-2007 (blue), most accretive/stable period from 2007-2015 (purple), and long-term average from 1972-2015 (adapted from USACE, 2017).

Finally, to complete the timeline of events, it is noted that construction of a major beach nourishment project was initiated by the U.S. Army Corps of Engineers in October of 2020 and completed in January of 2021. The borrow area for the project was the *flood* shoal of St. Augustine Inlet.

Study Sites

Three distinctive sites have been selected to further illustrate the pre-storm historic beach conditions, and progression of events surrounding Matthew and Irma. The site at R-110 (Fig. 4) was first selected due to its close proximity to the now well-known, slab-on-grade house that actually fell off the bluff during Irma and, as indicated in Fig. 3, is where one of the highest pre-storm erosion rates was observed. The other two sites at R-105 (Fig. 5) and R-113 (Fig. 6) were selected because they too had been experiencing some of the highest pre-storm erosion rates. For each of the three sites, both selected historic and pre-and-post-storm beach profiles are presented, as well as aerial photographs that bracketed the two storm events.



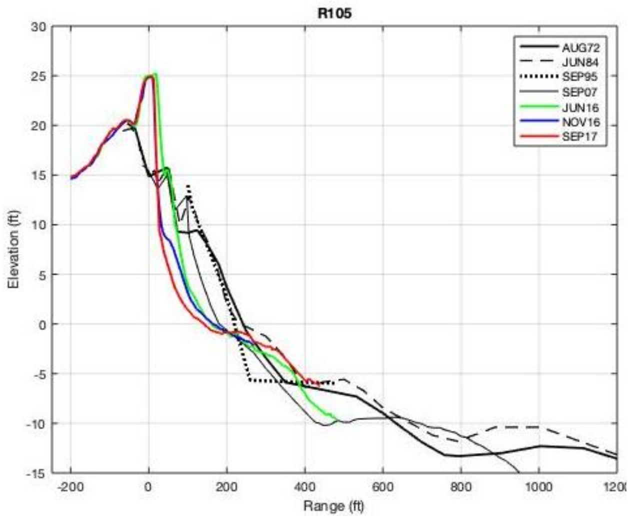
a) Historic (black) and pre-and-post hurricane profiles (color).

c) Post Hurricane Matthew (March 2017).

b) Aerial photo of houses adjacent to R-110 pre hurricanes (November 2015).

d) Post Hurricane Irma (September 2017).

Figure 4. Historic and pre-and-post-storm beach profiles at R-110, and pre-storm, post-Matthew, and post-Irma aerial photographs (photos adapted from Google Earth, 2020; profile data adapted from USACE, 2017).



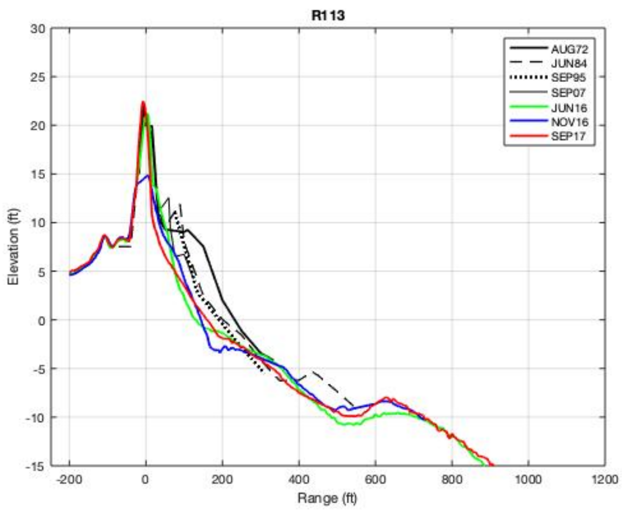
a) Historic (black) and pre-and-post hurricane profiles (color).

c) Post Hurricane Matthew (March 2017).

b) Aerial photo of dune cross-over adjacent to R-105 pre hurricanes (November 2015).

d) Post Hurricane Irma (September 2017).

Figure 5. Historic and pre-and-post-storm beach profiles at R-105, and pre-storm, post-Matthew, and post-Irma aerial photographs (photos adapted from Google Earth, 2020; profile data adapted from USACE, 2017).



a) Historic (black) and pre-and-post hurricane profiles (color).

c) Post Hurricane Matthew (March 2017).

b) Aerial photo of pedestrian bridge adjacent to R-113 pre hurricanes (November 2015).

d) Post Hurricane Irma (September 2017).

Figure 6. Historic and pre-and-post-storm beach profiles at R-113, and pre-storm, post-Matthew, and post-Irma aerial photographs (photos adapted from Google Earth, 2020; profile data adapted from USACE, 2017).

As shown in the beach profile data (Figs. 5a, 6a, and 7a) and based upon all available surveys at each of the three sites, Fig. 7 presents time histories of the distance from each R-monument to the location of MHW (nominally +0.71 m NAVD88). The selected sites were experiencing chronic erosion from 1972 until just prior to Hurricanes Matthew and Irma, with Matthew and Irma then greatly compounding the problem. Aerial data support this conclusion in the sense that the beach width appeared to shrink after each storm.

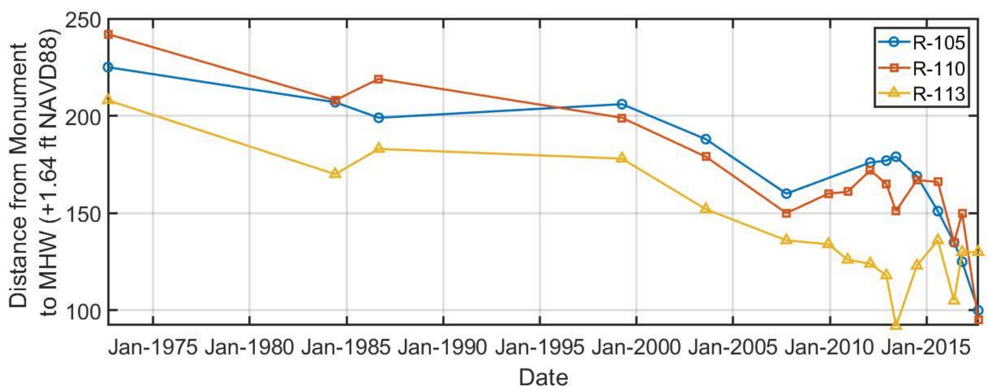


Figure 7. Time histories of the distance from selected R-monuments to mean high water (adapted from USACE, 2017).

Bluff line regression provides further evidence to show that Hurricanes Matthew and Irma accelerated already-occuring chronic erosion. Fig. 8 (below) shows the regression of the bluff line at 4010 Coastal Highway (approximately the location of R-110). Data were generated using Google Earth® historic images from December 1994 through October 2017 by measuring the distance from the centerline of Coastal Highway A1A to the approximate edge of the bluff. As seen in Fig. 8, there has been consistent regression of the edge of the bluff over time at this location, with the rate appearing to accelerate.

Date	Distance (m) Center Line of A1A to Bluff Edge
Dec. 1994	45.95
Jan. 1999	45.16
Jan. 2006	44.58
Jan. 2008	41.26
Dec. 2011	38.65
Jan. 2017	35.72
Oct. 2017	20.45

Figure 8. Edge-of-bluff locations for house in Fig. 4 taken from aerial photographs (Google Earth, 2020) from December 1994 through October 2017.

Anecdotally, the first author of the paper interviewed a former owner of this residence and she remembers in the 1970s having to walk “a couple hundred feet” to get from the house to the beach. As shown in Fig. 7 the distance from the R-110 monument to the mean high-water mark steadily decreased over time at this location, with only slight variation before the hurricanes struck.

Assessment of Protection Measures

Prior to Hurricane Matthew, for an individual beachfront homeowner to obtain a permit from FDEP to construct a seawall, the structure firstly had to be within 20 ft of the existing bluff-line, and secondly it had to be demonstrated that it was threatened with undermining by the 1-in-5-year storm event. This usually required hiring of coastal consultants (to apply the use of numerical beach erosion models) and was an expensive and time-consuming process (Antigua, 2013, personal communication). However, with Matthew’s severe impacts, FDEP could now issue an “emergency” permit for any house that was imminently threatened, as seen in Fig. 9.

Figure 9. Photographs of Vilano Beach both before (left) and after (right) Hurricane Matthew (USGS 2020a).

In response, many homeowners along the beach attempted to protect themselves from further erosion by installing polyvinyl chloride (PVC) sheet pile seawalls. After Hurricane Irma, a field team (consisting of this paper’s co-authors and others) inspected and documented damage in Vilano Beach (Hudyma et al. 2017). Significant erosion was observed in the area, and the PVC retaining structures that had been hastily completed after Matthew appeared to do little to mitigate erosion and, in some cases, exacerbated the issue. One such example is the heavily publicized slab-on-grade house at 4010 A1A that actually fell off the eroding bluff during Irma, as shown in Figure 10. However, this ground-level photograph is somewhat deceiving. It is clearly seen in Figs. 4c&d, that the homeowner just to the north of R-110 did indeed build a seawall after Matthew. However, not only did the presence of the seawall itself exacerbate the “normal” erosion of the bluff along the properties to the south during the storm by disrupting longshore sand transport, but the seawall did not have a sufficient wing-wall lateral embedment. The subsequent breach at its southern end further worsened the bluff erosion at the adjacent house. This phenomenon, and other issues associated with post-Matthew seawall construction practices are discussed below.

Fig. 11 shows seawall failure typical of many such new structures, and it is interesting that the anchored sheet piles exhibited minor distress at the face (parallel to the shoreline) but failure initiated at the wingwalls (perpendicular or sub-perpendicular to the shore line). The faces of

Figure 10. Ground-level photograph of slab-on-grade house at 4010 A1A (adjacent to R-110) destroyed by bluff erosion. However, as shown in Fig. 6d, failure was not due solely to cross-shore erosion processes, but due to downdrift impacts of neighbor's post-Matthew-constructed seawall.

anchored sheet piles were noticeably bowed; below the anchor line the sheet piles bowed outward towards the ocean due to lowering of the dredge line (material being removed from the face of the sheet pile below the anchor line) which resulted in the sheet pile becoming bowed inward towards the dunes above the anchor line. Another important aspect to consider in the orientation of the anchors. Fig. 11 shows the inclined anchors still in place after the material behind the sheet pile wall was removed. Horizontal ties connected to deadman anchors failed because of the loss of supporting soil behind the sheet pile walls.

The initiation of sheet pile failure at the wing walls was due to improper embedment of the sheet piles into the dunes, both in terms of the depth of the sheet pile from the ground surface but also how far the sheet pile extended into the dune. Fig. 12 demonstrates the beginning of the failure of a sheet pile. In the left image in Fig. 12, removal of the dune material coupled with improper depth embedment allowed sand to be removed from behind the sheet pile wall. The removal of the sand from behind the wall resulted in a funnel shaped depression on the soil surface behind the face of the wall (right side image of Fig. 12). This is akin to sand flowing through an hourglass. If the storm had continued, this sheet pile structure would have failed. As noted, Fig. 6d shows the failure of a wingwall from an aerial view, whereas Fig. 11 shows the complete removal of the sheet pile wingwall.

Figure 11. PVC anchored sheet pile failure due to Hurricane Irma.

Figure 12. Initiation of sheet pile failure. Improper depth embedment allowing soil to escape from behind the sheet pile wall (left). Resulting funnel shaped depression on the ground surface (right).

Finally, sheet pile wall construction should be a community effort, not just a single homeowner endevor. A long sheet pile structure which protects a whole community minimizes the number of wingwalls which are succesptible to failure. Anchors should be inclined and anchorage provided below the dredgeline. Deadman anchors should not be used. The depth of sheet pile penetration, in terms of both vertical depth and extent into the dunes, must be based on the worst case scenario, which is the location of the dune and the beach elevation *after* the storm event.

A Hint from Mother Nature?

Fig. 13 shows the series of beach profile surveys taken at a location at the southern end of a 6 km stretch of pristine beach in the GTM-NERR (R-66), just north of Vilano Beach. The only notable loss of beach during the hurricanes at this location was the erosion of a small frontal dune that had begun to form between 2011 and 2014. The main dune appeared to receive minimal damage. At this location it has been observed that the upper beach consists mostly of coarse shell material, with median diameters from 0.6-1.6 mm, whereas the dune itself and below the water line are comprised mostly of fine quart sand (0.16-0.2 mm). This shell-based "armor" would appear to be a form of natural protection that formed along this undeveloped beach over time, and it would appear that this protection is both reducing the degree of chronic, long-term erosion, as well as severe erosion during worst-case storm events like Hurricanes Matthew and Irma.

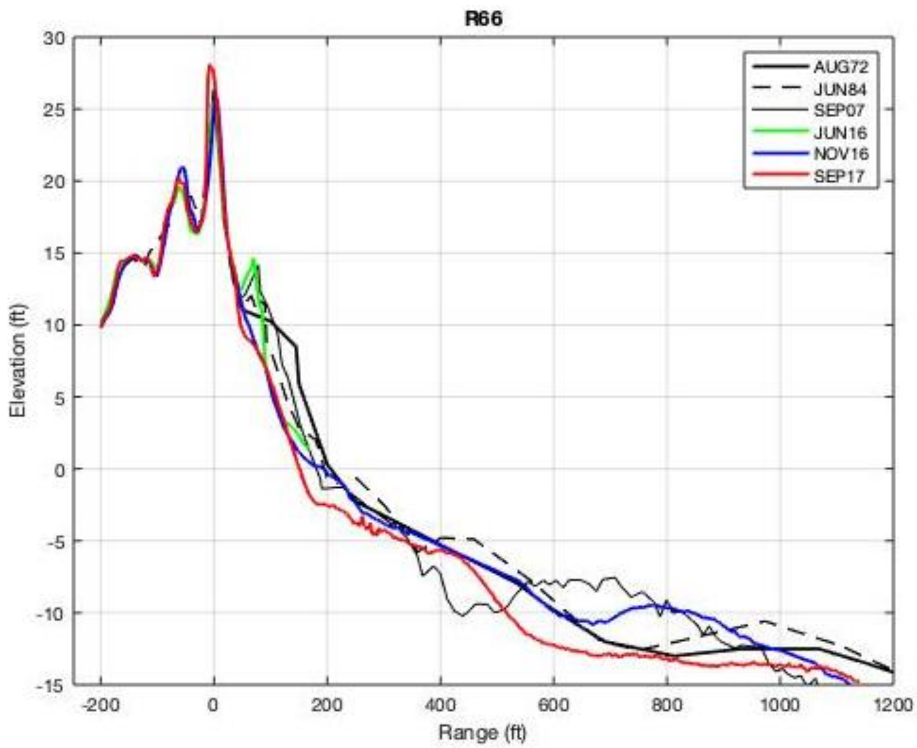


Figure 13. Historic beach profiles (black) and pre-and-post hurricane profiles (color) at the southern end of the pristine, undeveloped shoreline of the GTM-NERR (just north of developed shoreline at Vilano Beach starting at R-70).

Summary and Conclusions

Recent hurricanes, Matthew and Irma, caused considerable damage to northeast Florida beaches and dunes causing many to believe there is a new hotspot for hurricane damage. However, the issues that are causing this are deep-rooted and have been at work for over 50 years. Overall, data suggest that the Vilano Beach shoreline has been gradually, yet chronically eroding for decades before the large-scale storm systems of Hurricanes Matthew and Irma struck. The conditions had slowly deteriorated to the point where damage from even a single moderate storm may be extreme. North of Vilano Beach pristine, undeveloped beaches, received little damage from the hurricanes. This suggests that it may be possible to blame much of this erosion upon past oceanfront-development practices. In addition, data shown here appear to suggest that individual measures like piecemeal bulkheads do little to protect against erosion damage. The bulkheads that were observed along Vilano Beach were poorly designed and ill-conceived. If Vilano Beach is to survive another series of hurricanes like Matthew and Irma, community-wide efforts will be required to protect residents from erosion damage.

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