# Beach and dune impacts due to Hurricane Florence in Dare County, North Carolina

*By*

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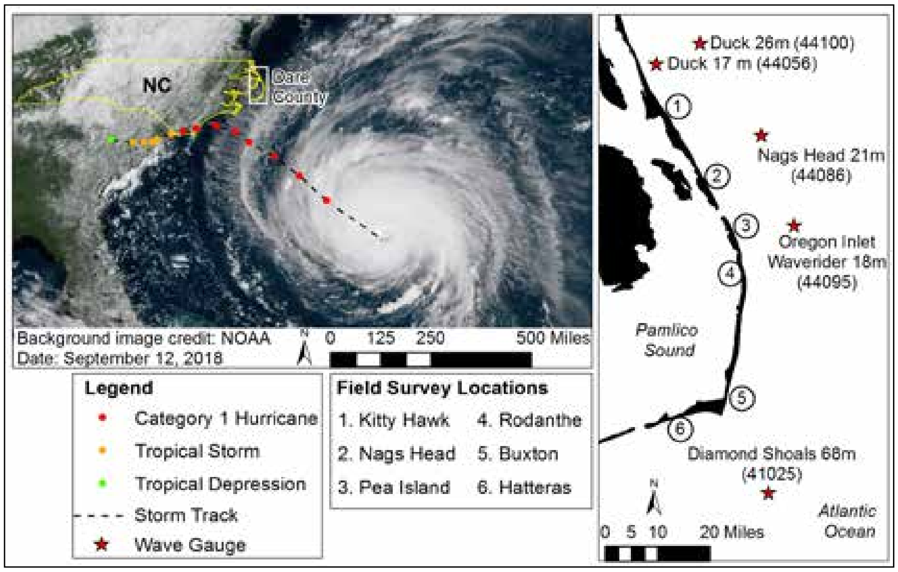



**Figure 1. Track of Hurricane Florence and location of study area. Locations of field surveys are shown in the right panel along with locations of the wave gauges nearest to Dare County with available storm data.**

Rapid-response surveys are an essential part of post-hurricane research and assessment. Fast deployment of research teams enables documentation and quantification of storm impacts on beaches, dunes, and infrastructure (e.g. ALS 2012, NJDEP 2015, the Federal Emergency Management Agency's Mitigation Assessment Team reports [FEMA 2019], and others). Such surveys have long included beach profiles and photographic documentation of damage. In recent years, advances in technology have enabled real-time kinematic GPS surveys with sub-centimeter accuracy to improve beach profile data. The use of unmanned aerial systems (UAS) enables photo and video capture of larger areas with limited access, and can also provide topographic data if ground control is surveyed. Damage photographs taken with a location-enabled smartphone can now be geographically referenced effortlessly. These techniques were used in the field campaign described in this paper.

Less than two weeks after Hurricane Florence made landfall in North Carolina (NC), a team of researchers from NC State University traveled to Dare County to investigate the storm's effects on beaches and dunes. Using available post-storm imagery and prior knowledge of vulnerabilities in the system, the team identified several locations to visit in the towns of Kitty Hawk, Nags Head, Rodanthe, Buxton, and Hatteras, as well as a number of locations within the Pea Island National Wildlife Refuge (Figure 1). Data collected included topographic profiles, still imagery and video from unmanned aerial systems, sediment samples, and geo-located photography. This Coastal Observations piece presents some of the data and photos collected; the full report is available online (Sciaudone *et al.* 2019), and data collected will be made available to interested researchers upon request.

## HURRICANE FLORENCE

Hurricane Florence originated as a tropical wave on 30 August 2018 and progressed to a tropical depression near Cape Verde on 31 August. By 1 September, it had become a tropical storm. As it was moving through the Atlantic Ocean, the storm intensified rapidly, reaching a Category 4 on the Saffir-Simpson scale. By 13 September it was downgraded to a Category 1 hurricane, making landfall on 14 September near Wrightsville Beach (NWS 2019) (Figure 1).

Hurricane Florence was the wettest tropical cyclone on record in the Carolinas with 34 inches of total rainfall measured at Swansboro, NC, and 106 mph wind gusts reported at Cape Lookout (NWS 2019). Although most of the wind and flooding damage occurred along Carteret, Onslow, Pender and New Hanover counties, severe impacts were felt all along the North Carolina coast, extending to Dare County in the northeastern part of the state. Hurricane Florence's winds and waves caused beach and dune erosion and forced temporary closure of NC Highway 12 on Hatteras Island. Additionally, northern Dare County was impacted by beach and dune erosion, including along a beach nourishment project conducted in 2017 in the towns of Kill Devil Hills, Kitty Hawk, Southern Shores, and Duck.

Waves were measured at a variety of gauges along the NC Outer Banks (OBX) (Figure 1). Figure 2 shows significant wave height and dominant wave period measured at the wave gauges; impacts from Hurricane Florence in NC were primarily observed between 13 and 15 September. The largest significant wave heights ranged from just under 30 ft offshore at the Diamond Shoals gauge to approximately 15-16 ft at the Duck gauges, with maximum wave heights of 23 ft and 25 ft at the Oregon Inlet Waverider and Nags Head gauges, respectively. Dominant wave periods observed during the storm ranged from approximately 14-16 seconds at all gauges.

## FIELD METHODS

The NC State research team traveling to the OBX was a collaboration between the Civil, Construction, and Environmental Engineering (CCEE) department, the Institute for Transportation Research and Education (ITRE), and the Center for Geospatial Analytics. Post-storm imagery available from NOAA (https://storms.ngs.noaa.gov/storms/florence/) was examined to plan the field visits. The team traveled to the site 26-28 September 2018. Data collected included topographic ground surveys, UAS still and video imagery, sediment samples, and geo-located photos.

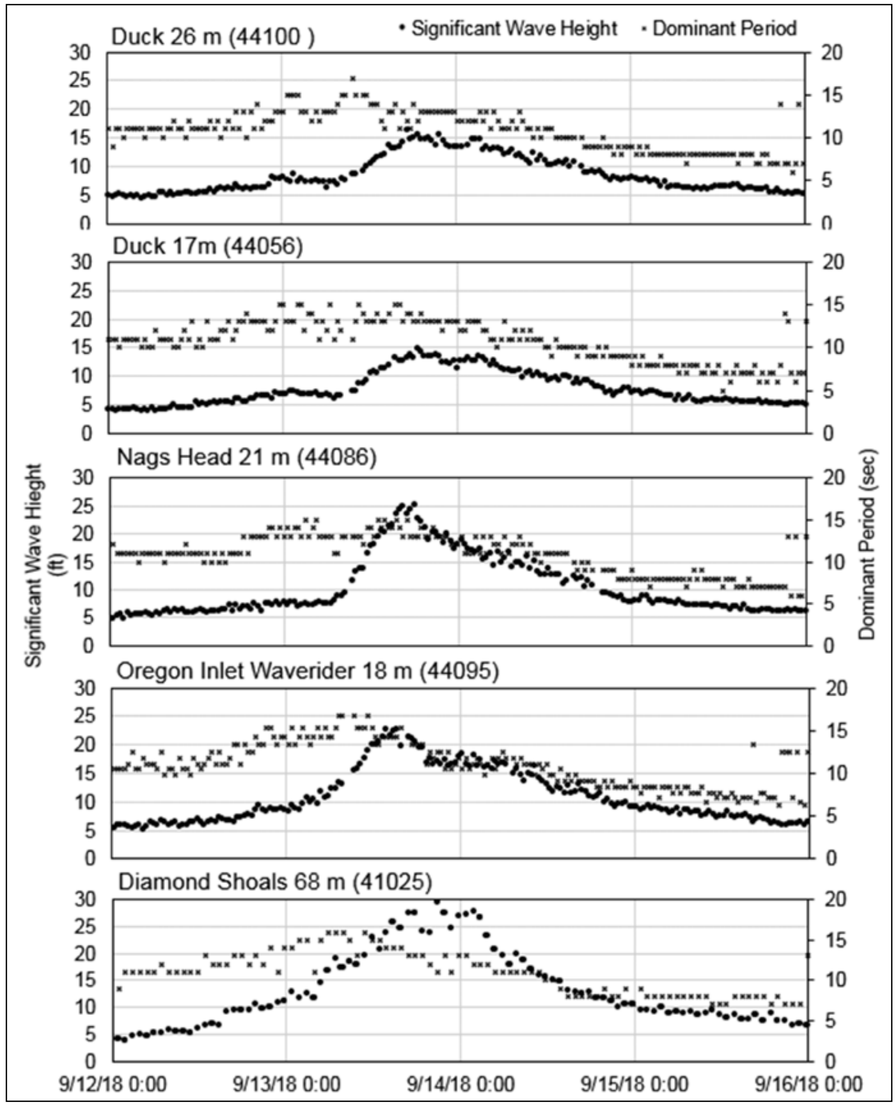



**Figure 2. Significant wave heights and periods measured at OBX gauges during Hurricane Florence (highest waves observed between 13 and 15 September 2018). Times are shown in GMT (4 hours ahead of Eastern Daylight Time, which was local time at landfall).**

**Figure 3. RTK-GPS survey of ground control points for UAS survey.**

### *Topographic ground surveys*

Topographic ground surveys were conducted using a Trimble R10 RTK-GPS system, with a maximum precision of 8 mm horizontal and 15 mm vertical. The team measured cross-shore beach and dune profiles as well as ground control points for the UAS surveys (Figure 3). Ground Control Points (GCPs) were measured at Kitty Hawk and Nags Head (sites 1 and 2 in Figure 1). Cross-shore subaerial profile surveys were conducted at Pea Island, Rodanthe, Buxton, and Hatteras (sites 3-5 in Figure 1). A total of 25 profiles were surveyed at Pea Island and Rodanthe, 2 in Buxton, and 17 in Hatteras.

### *UAS still and video imagery*

Two UAS platforms were used for aerial imaging during this effort: 1) the DJI Inspire 1, a quadcopter capable of vertical takeoff and landing equipped with a three-axis gimbaled camera; and 2) the SenseFly eBee, a traditional fixed wing aircraft that is hand launched and utilized two different camera systems during the field campaign. One sensor is fixed to the airframe body looking straight down, and the second has the ability to shoot lateral oblique photos. The UAS systems were used to map Kitty Hawk approximately 2.5 miles south of the Kitty Hawk pier, directly north of Jennette's pier in Nags Head, and South Nags Head adjacent to the Cape Hatteras National Seashore boundary. Each location was flown by both the Inspire and the eBee, for comparison between techniques and sensor accuracy. The Inspire requires physical ground control points to be set and measured (Figure 3) to reach an acceptable level of accuracy. The eBee is equipped with Real-Time Kinematic GPS, which generates a high enough level of accuracy during flight to eliminate the need for GCPs.

The still imagery was processed using Agisoft Photoscan Professional software that utilizes Structure from Motion (SfM) and Multi-View Stereo (MVS) photogrammetry algorithms. Ground control point measurements were used for processing the Inspire-obtained imagery. The water surface was masked in order to remove artifacts (SfM algorithms do not reconstruct the water surfaces accurately). Orthophotos, Digital Surface Models, point clouds and 3D models were created for all the survey locations. The final reso-

**Figure 4. Transect measurement for sediment sampling in Kitty Hawk.**

**Figure 5. (a) Overwash on NC 12, Hatteras Island, 13 September 2018 as Florence approached the coast, NCDOT photo; (b) Same area as of 14 September 2018, Daniel Pullen Photography, and (c) 27 September 2018 during field visit, A. Gharagozlou photo.**




lution for the orthophotos was below 2 inches per pixel and all the DSMs below 7 inches per pixel. Additionally, wave runup positioning video was captured with the Inspire with additional GCPs to allow the evaluation of experimental processing techniques for determining bathymetry. This extra data collection was only performed at the Kitty Hawk location.

### *Sediment sampling*

Sediment samples were obtained at each of the field sites, corresponding to the locations of ground survey and/or UAS data collection. In each of the six locations, two to four sampling transects were selected to represent the cross-shore grading conditions. These transects were sequentially numbered from T1 to T13. Along each transect, three cross-shore sampling stations denoted as S1, S2, and S3 were selected. These notations correspond to the dune crest (where present, S1), mid-beach (S2), and the edge of the shoreline (S3). Distances between the samples along each transect varied from 7 m to 24 m depending on the beach width (Figure 4).

## RESULTS

### *Hatteras and Buxton surveys*

Several locations of erosion and overwash events were observed in post-storm aerial photos where dune removal or overtopping occurred during Florence. Figure 5 shows a comparison of images during (a), immediately post-storm (b), and at the time of the site visit (c), for a location just northeast of the town of Hatteras. High waves on top of elevated water levels eroded the dunes and pushed the sediment onto the road. However, by the time of the survey, sand had been pushed off the road and dunes had been rebuilt. As such, the surveyed profile in this location did not represent the actual post-storm dune elevations but rather the recently reconstructed dunes.

Comparison between the surveyed Hatteras subaerial profiles and the 2016 post-Matthew lidar shows extensive profile lowering of approximately 2-5 feet on the beach at the Hatteras locations (e.g. Figure 6). Two profiles were also surveyed north of Buxton (location 5 in Figure 1), where a known erosion hotspot is located. However, the dune in this location was not impacted by the storm and no sign of overwash was observed at Buxton, likely due to a beach nourishment project which placed 2.6 million cubic yards along 2.9 miles of shoreline at Buxton and was completed in February 2018

(Dare County 2019). The average eroded volume (volume per length alongshore) was computed from the profile comparisons for the post-Florence survey data. Using the 2016 Post-Matthew profiles as a baseline, the average volume loss for 17 profiles at the Hatteras sites (location 6 in Figure 1) was 168 $ft^3/ft$. It is noted that Hurricane Florence is one of a number of storms that have impacted the OBX since Matthew, including Winter Storm Riley in March 2018. Therefore, this volume loss cannot be solely attributed to Florence.

At the two Buxton transects, the surveyed profiles showed an average gain of 385 $ft^3/ft$. This is at least partly attributable to the beach nourishment project, as well as other coastal processes occurring between the post-Matthew lidar survey and the post-Florence field campaign.

***Pea Island surveys***

In general, the impacts observed from Florence were less substantial along Pea Island than in Hatteras, although in some areas, the same type of rebuilding/repair was apparent. For Pea Island, additional data were available to compare with the field surveys, and illustrate the compound impact of both Winter Storm Riley (March 2018) and Hurricane Florence through comparisons with both the 9 February and 18 April 2018 digital terrain models. An example is shown in Figure 7, which illustrates dune erosion due to multiple storm impacts, with minimal time for natural dune recovery. The average volume losses for the Pea Island profiles when compared to the 18 April 2018 terrain model was 31 $ft^3/ft$.

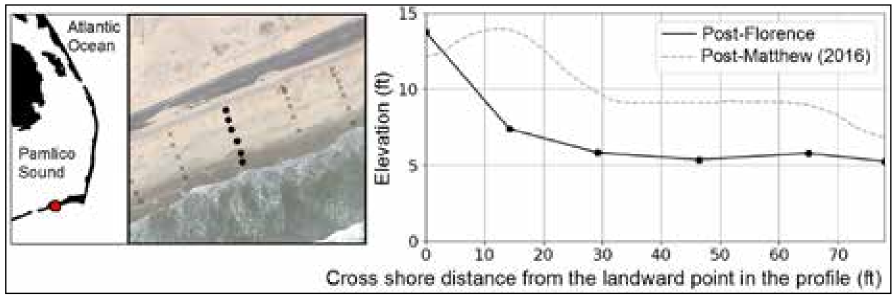
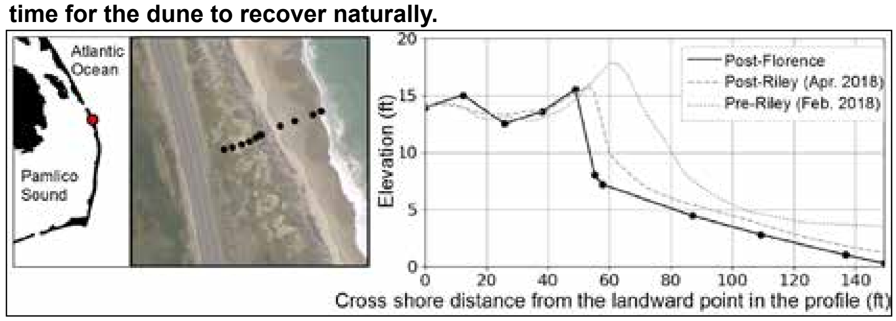



**Figure 6. Hatteras Transect 4. The post-Florence survey shows substantial volume loss at this transect since the 2016 post-Matthew lidar survey. Peaked dune appears to have been rebuilt prior to the field survey.**

**Figure 7. Pea Island Transect 18. Prior to Winter Storm Riley in March 2018, this location had a large primary dune (2 February 2018, dotted line); after Riley, the dune was substantially eroded (18 April, dashed line). The post-Florence survey shows further erosion. Multiple storm impacts did not allow time for the dune to recover naturally.**




***Overwash and impacts to NC 12***

The most noticeable overwash on Hatteras Island impacting Highway 12 was found just north of the Town of Hatteras heading toward Frisco (shown in Figure 5). Post-Florence reconstruction of the dune was apparent by the time of the field campaign, indicated by the discontinuity of dune vegetation and asphalt chunks on the crest of the dune. On the landward side of the road an overwash fan was present, outlined in Figure 8. This fan had sand depths ranging from 60-630 mm, (2.4-24.9 inches) measured with a standard 1 m stick. Sea oats and other beach grasses were knocked down by the overwash and were heading at approximately $270^0$ from north (Figure 9). Although there were other discontinuities in the dune in this area, it was not apparent whether these dunes had been built up pre-storm or post-storm.

In some locations on Hatteras Island, it was determined that what appeared as overwash in the post-storm aerial

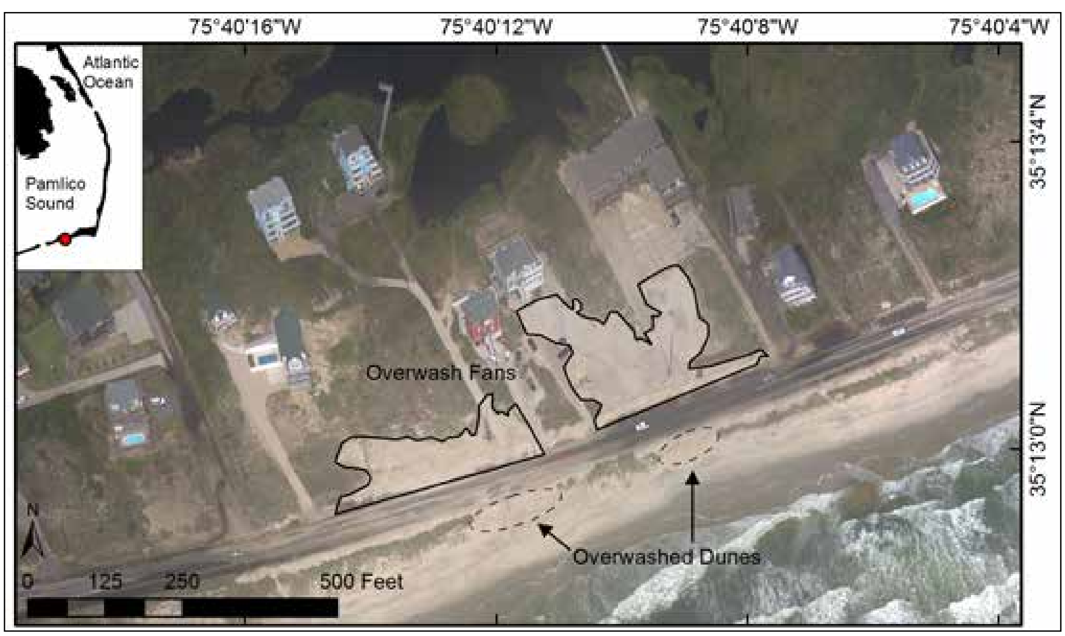



**Figure 8. Post-Florence aerial image of overwashed dunes and corresponding overwash fans on Hatteras Island.**

**Figure 9. Vegetation knocked over by dune overwash during Florence at location shown in Figure 8. J. Woodruff photo.**

**Table 1.**

**Results of grain size analysis by sample type and location, with $D_{10}$, $D_{50}$, and $D_{90}$ expressed in µm. Rows at the top of each section indicate the average for each sample type.**

| Sample type and location | $D_{10}$ | $D_{50}$ | $D_{90}$ |
|---|---|---|---|
| **All S1: Dune** | **243.6 ± 42.9** | **387.5 ± 68.0** | **607.3 ± 125.0** |
| K-S1 (Kitty Hawk) | 271 ± 29.6 | 458.2 ± 49.0 | 753 ± 87.0 |
| J-S1 (Jennette's Pier) | 257.5 ± 15.4 | 404.4 ± 25.4 | 619.7 ± 35.9 |
| N-S1 (South Nags Head) | 207.3 ± 8.3 | 341.1 ± 10.9 | 548.7 ± 46.7 |
| PI-S1 (Pea Isl./Rodanthe) | 256.7 ± 53.3 | 411.5 ± 64.3 | 652.9 ± 111.4 |
| AB-S1 (Buxton) | 274.8 ± 7.9 | 406.6 ± 8.1 | 600.4 ± 48.0 |
| A-S1 (Hatteras) | 197 ± 6.1 | 288.5 ± 18.8 | 420 ± 41.1 |
| **All S2: Berm** | **255.2 ± 52.8** | **395.0 ± 79.6** | **624.6 ± 207.4** |
| K-S2 (Kitty Hawk) | 277.7 ± 32.3 | 434.6 ± 40.9 | 668.9 ± 50.3 |
| J-S2 (Jennette's Pier) | 268.1 ± 81.2 | 402.4 ± 107.3 | 605.4 ± 168.5 |
| N-S2 (South Nags Head) | 244.1 ± 22.5 | 355.1 ± 31.1 | 512.4 ± 43.8 |
| PI-S2 (Pea Isl./Rodanthe) | 257 ± 58.3 | 399.15 ± 79 | 612.65 ± 119.5 |
| AB-S2 (Buxton) | 238 ± 5.6 | 376.8 ± 5.9 | 579.4 ± 6 |
| A-S2 (Hatteras) | 236.1 ± 55 | 388.5 ± 118 | 758.3 ± 452.7 |
| **All S3: Water's Edge** | **255.9 ± 54.0** | **383.7 ± 76.1** | **569.3 ± 110.4** |
| K-S3 (Kitty Hawk) | 333.7 ± 19.8 | 486.3 ± 28.7 | 696.8 ± 42.5 |
| J-S3 (Jennette's Pier) | 236 ± 9.7 | 357.2 ± 9.7 | 535.5 ± 11.9 |
| N-S3 (Nags Head) | 254 ± 33.1 | 374.9 ± 50.9 | 546.8 ± 74.3 |
| PI-S3 (Pea Isl./Rodanthe) | 213.6 ± 42.6 | 329.33 ± 65.1 | 501.33 ± 99.7 |
| AB-S3 (Buxton) | 324.6 ± 0.9 | 467.4 ± 3.0 | 660.6 ± 6.9 |
| A-S3 (Hatteras) | 228.8 ± 33.4 | 356.3 ± 74.9 | 554.1 ± 156.5 |

imagery was actually wind-blown (aeolian) sand transport. Highway impacts observed include covering of pavement with sand either by overwash or aeolian transport. In addition, standing water was observed in many areas caused by ocean overwash and the heavy rainfall associated with Hurricane Florence.

### *UAS still and video imagery*

Topographic surfaces were developed from the UAS data and surveyed control points at Kitty Hawk, Jennette's Pier, and Nags Head. Figure 10 shows the point cloud data for Kitty Hawk and South Nags Head, as collected by the DJI Inspire. These data have been processed to develop georeferenced digital surface models (DSM). Figure 11 shows a difference map developed using these data as well as data from a previous site visit in May 2017. The video data collected by the DJI Inspire will be used in future work to test algorithms for extracting wave runup and bathymetric data from the time series (Holman *et al.* 2017, Karanci *et al.* 2019).

### *Sediment samples*

The distribution of grain sizes sampled was variable between all 39 samples taken at 13 transects with a median grain size of 391 ±74 µm, corresponding to medium sand according to the Wentworth scale. The samples were in general poorly sorted and had a unimodal distribution. Table 1 presents the $D_{10}$, $D_{50}$, and $D_{90}$ of each of the sample types (S1, dune; S2, mid-berm; and S3, edge of shore) for each of the sampling areas, as well as the overall values for the sample type.

## SUMMARY AND FUTURE WORK

Findings from the field campaign include:

- As expected due to the storm track, south-facing beaches at Hatteras (location 6 on Figure 1) were the most affected by Hurricane Florence.
- Roadway impacts included sand and standing water on the road as a result of overwash, wind-blown transport, and heavy rainfall associated with the storm.
- Sediment sizes along the study area corresponded to coarse to fine sands with the median grain sizes in the medium sand range.
- Cumulative beach and dune erosion occurred during 2018 caused by a combination of winter storm Riley and Hurricane Florence, with little time for natural dune recovery. This may be a red flag for the upcoming 2019 hurricane season. Community and transportation officials could prepare for the upcoming season by building up dunes as they are able.

The multidisciplinary collaboration allowed for the team to collect a large number of different types of data in a short time and with minimal cost. The data collected during the post-Florence field visit will contribute to a number of ongoing projects and support student research and publications. Post-storm profile data, sediment samples, and assessment of overwash extent and depth will assist students in calibrating and verifying morphological models on Pea Island and Hatteras Island and contribute to publications on their research. Ongoing work with UAS data in Kitty Hawk will incorporate these new data sets and help to evaluate innovative techniques for extracting bathymetric data from UAS video.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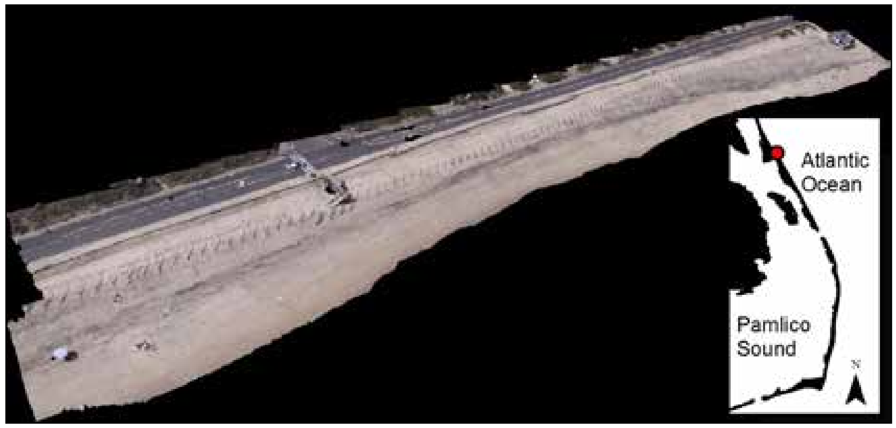
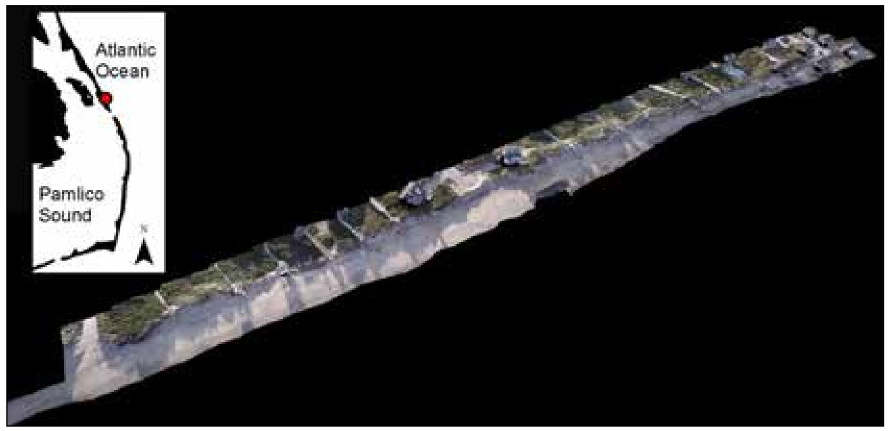



Figure 10. Point cloud data developed from imagery collected by DJI Inspire, visualized at plas.io. Top is Kitty Hawk, bottom is South Nags Head.



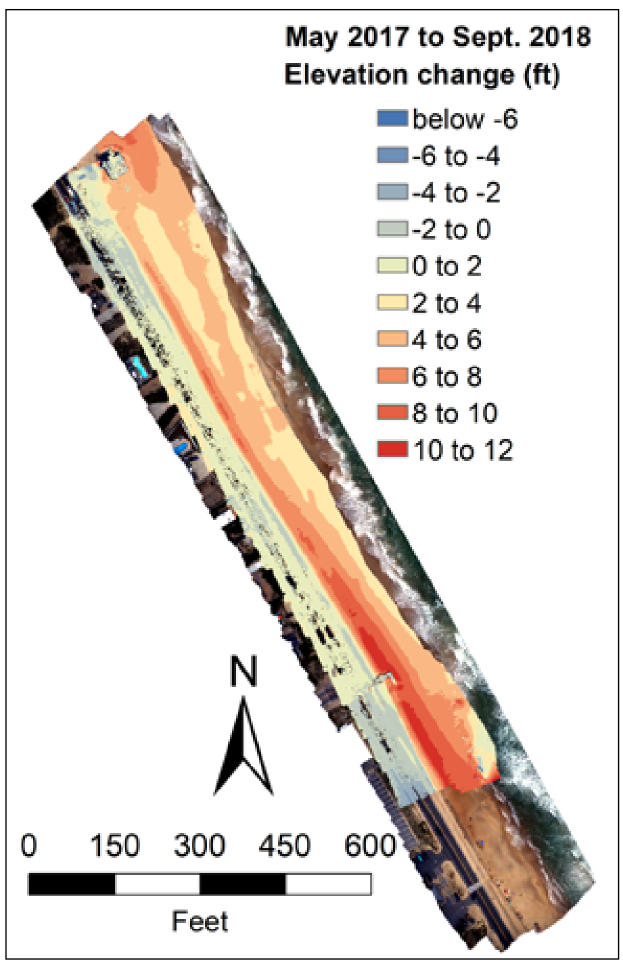




Figure 11. Difference map from UAS surface models showing elevation changes from May 2017 to September 2018 in Kitty Hawk, NC. Elevation increases (darker colors) shown on the beach face reflect beach nourishment which took place during the summer of 2018.