HYDRODYNAMICS AND BEACH EROSION

DURING STORMS ON DELAWARE BEACHES

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Degree in Civil Engineering with Distinction

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ABSTRACT

Coastal erosion is a major concern worldwide, but especially in places like Delaware where activities on the shoreline account for a large portion of the local economy. When waves and surge from large storms reach the coast, they erode dunes and berms. Data on the processes associated with erosion are scarce but are needed to determine how the beach profile changes throughout the storm. Knowledge of the erosive processes and timing is required to improve predictive models and enhance mitigation strategies. The goal of this research project is to quantify hydrodynamic and morphodynamic processes occurring during storm events and use these data to understand the timing and severity of beach erosion.

Chapter 1

INTRODUCTION

Coastal erosion is a major concern worldwide, but especially in places like Delaware where activities on the shoreline account for a large portion of the local economy. When waves and surge from large storms reach the coast, they erode dunes and berms. Data on the processes associated with erosion are scarce but are needed to determine how the beach profile changes throughout the storm. Most data on related to coastal storms causing erosion, only show information relating to before and after the storm rather than being able to show what is occurring during the storm.

The primary goal of this research project is to develop self-logging low cost sensors for intra-storm sampling, quantify beach profile changes throughout the storm and relate the timing and magnitude of erosion to the hydrodynamic forcing. This research project also aims to develop a system of devices that is easily transported and deployable for storms, such as Nor’ Easters, where there is little warning before the storm hits.

Chapter 2

EQUIPMENT

As this research project developed many tests were conducted to determine the best suited low-cost devices that would be able to collect accurate data that could be analyzed. Specifically, we focused on researching, buying and developing devices that would collect data on the fluid velocity, wave height, water depth and bed level change. It was also important that all of the devices used for the research deployments had internal dataloggers, so that we could download data after the storm. Also, most deployments took place over 2-3 days, so sensor batteries needed to be able to sustain for the entirety of the deployment.

2.1 Leica GPS

The first component to the data collection is obtaining a beach profile using a real time kinematic GPS unit before the storm hits to have a base profile to compare all subsequent morphodynamic data. We used a Leica GPS Rover to measure the beach profile both before and after the storm. For our cross-shore deployments, we walked the GPS on a cart built from a golf bag carrier (Figure 1). Whereas, for our alongshore deployments we used the GPS to identify the location for each of the stations and to reference their locations on future deployments. On all deployments we took as many profiles of the beach as possible during the calms in storm conditions, as the equipment cannot get wet. Having more data on the beach profiles changing throughout the storm, lets us see exactly where berms were being eroded, and whether they started to accrete as the storm subsided.

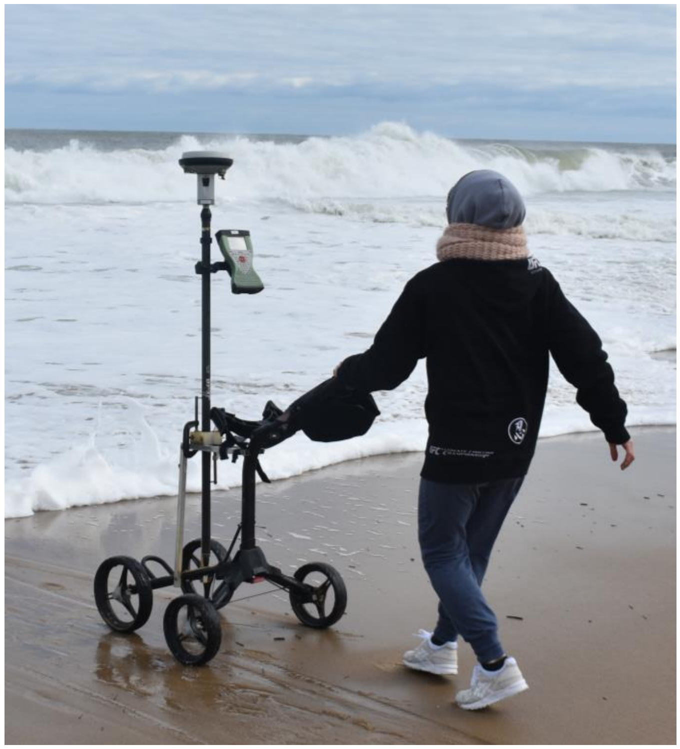

Figure 1 Leica GPS Rover on cart collecting beach profile data

2.2 Electro-Magnetic Current Meters

One of the primary devices that we used at each station was a JFE Advantech electro-magnetic current meter (Figure 2) that measures the horizontal components of water velocity . In order to correlate the devices at each of the stations, we made sure to align the sensors perpendicular to the shore where orientation is identified on the external temperature gage (Figure 2). We also made sure to place each of the JFEs at the same height above the bed (10 cm) as it existed before the storm. Figure 3 shows the setup we used to deploy the JFE sensors.

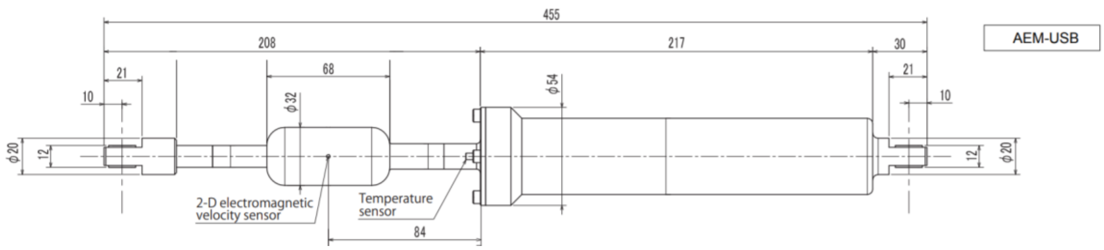

Figure 2 JFE Advantech Co., Ltd Instrument Drawing

Figure 3 Setup of JFE on pole mount

The JFE software allowed us to program the device and set the start time before going into the field. The JFE devices sampled the velocity at a rate of 5 Hz.

2.3 Depth Logger

The RBRsolo was the depth logger that we selected to use for this research experiment, due to the compactness of the device as well as accuracy. The RBRsolo is a “single depth channel logger” that takes into account the amount of pressure above it relative to the water density. The RBR data are essential because we use them to determine when the JFE was submerged in water and thus reading accurate velocity data, compared to when it was in the air reading useless data. We used a combination of RBRsolos and RBR D waves, as they both offer different frequencies for data collection. We set the RBR D wave to collect data at a frequency of 16 Hz, whereas the RBRsolo collects at 2 Hz.

The RBRs also have software that allows for programing prior to deployment, in order to save the batteries for when the storm is occurring. Also, due to the RBRs being in the swash zone, we covered the open end of the RBRs with a thin mesh to prevent sediment from getting into the devices. Similar, to how we placed the JFEs at a distance from the bed level, we placed the RBRs at the bed level attached to the main pipe that devices are deployed on. The location of the RBR can be seen in Figure 3.

2.4 GoPro with Time Lapse Controller

In order to collect a visual representation of what was occurring during the storms, we selected a GoPro in combination with a time lapse controller. Having the GoPro videos and pictures can help identify anomalies in the data by showing a visual of what was occurring around that time period. The scheduler allows it to be programmed to turn on and off at set increments and then take a photo and or video. The scheduler used for this research project was a CamDo Blink.

The CamDo blink has the capabilities to create its own WiFi that then allows it to be programmed via a webpage. The webpage can be accessed both via a phone or a computer. The Blink gets plugged into the back of the GoPro, and then the Blink's enabling remove gets plugged into the port labeled "port 1" on the right side of the

Blink. The button on the remote activates the WiFi, which causes the center of the Blink to light up and flash blue every couple of minutes. The WiFi will turn off after fifteen minutes, at this time the light will blink cyan then turn off. The GoPro is powered using a Voltaic cell, which also powers the Blink through the GoPro. The set up of the GoPro and scheduler is shown in Figure 4

Figure 4 GoPro and CamDo Blink setup

For this research project we set up a schedule for each day, so that the camera would only capture footage during daylight hours. For some of the test deployments we set the scheduler to turn on and take a one-minute video every 15 minutes. For the test deployments, we also had a motor attached the GoPro mount that would rotate the GoPro 360 degrees while it took the video. This allowed us to get a full video of the whole beach during this time. However, during the course of the deployment, the motor got off schedule compared to the CamDo Blink scheduler. This lead to the option of doing just the CamDo Blink Scheduler without the motor. Figure 5 shows the original layout of the GoPro in its encasement with the motor.

Figure 5 GoPro encasement with motor attachment

For the deployments for the two Nor' Easter storms, we instead just left the encasement with the GoPro and programmed it to take a photo every five minutes during daylight times. The webpage where you input the information for the schedule, including the days of the weeks it should run, time frame, time between photos, and mode is shown in Figure 6. For deployments, we would create a separate schedule for each day that we planned to leave it out, each schedule would run during daylight hours.

Figure 6 Example of the CamDo Blink webpage with schedule

2.5 Ultrasonic Sensor

For this project we selected to use an ultrasonic sensor to be able to determine the relative wave heights in relation to a fixed object by utilizing high frequency sound waves. Ultrasonic devices are also referred to as Acoustic Distance Measurements (ADM). The U-GAGE T30U was selected as the best ADM for this project because maximum and minimum limits can be set, and it is waterproof. The U-GAGE, however, does not have an internal data logger nor a battery, which is why a box to house the electrical components was needed. The bottom of the U-GAGE fits in the cut-out of the electronic box, which has a water tight seal, then has all electrical components inside the box to store the data and power the device (Figure 7).

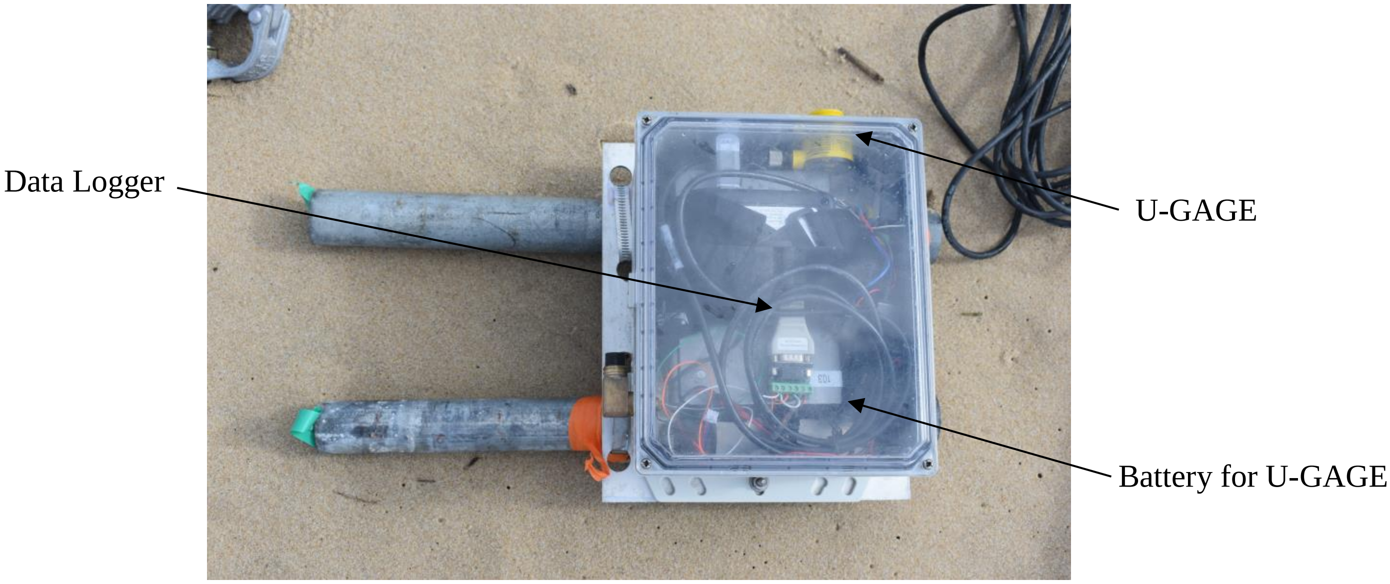

Figure 7   U-GAGE ADM sensor setup within waterproof encasement

Chapter 3

FIELD SETUP

One of the biggest portions to this research was the organization and layout for each of the stations. Being able to assemble the stations and attach the devices in a timely manner was a big part of how we designed them. All of the stations used 10 or 12 foot long vertical pipes, that were inserted into the ground about 7 or 8 feet respectively. In order to escalate the setup process we utilized a water pump to be make the hole for the pipe. However, the water pump requires a system of hoses to transport the water from the ocean to the water jet to the output hose. This was a difficult process as the intake hose was lower than the output hose, which was farther up on the beach.

At each station we used a system of pipes and scaffold clamps as shown in Figure 8. Each station was designed to hold a JFE and RBR, with a select few stations having an Ultrasonic sensor. We designed the stations to have one vertical pipe and one horizontal pipe with a diagonal support arm, which used both swivel and double couplers as seen in the setup.

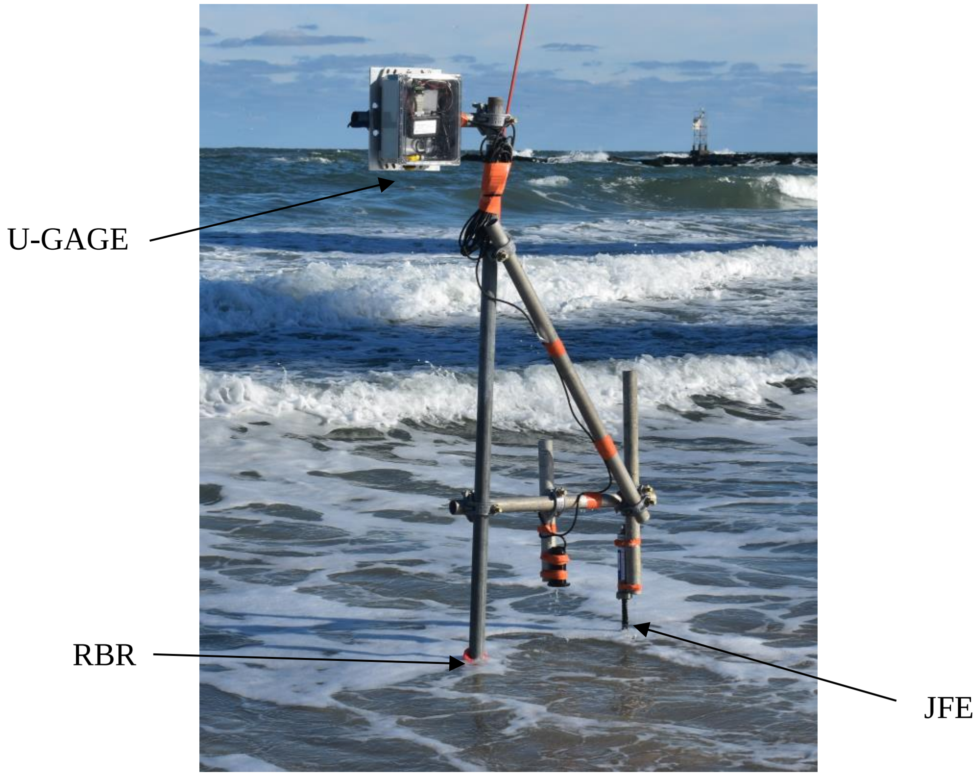

Figure 8 Deployment Pipe Setup with Devices

Figure 9 shows a close view of the internal setup of the ADM device in relation to where the JFE is attached. Also, for safety purposes, as well as assuring the data are not lost, we secured the wires for the ADM with cable tape.

Figure 9 Pipe setup with JFE and ADM

Chapter 4

TEST DEPLOYMENTS

In order to test the system of devices for Nor' Easter storms, a series of test deployments were conducted. Test deployments were done during days of high wave and wind conditions, in order to best simulate conditions during a Nor' Easter. The test deployments allowed us to gather valuable insight on how to improve the system before we would actually have to deploy it for a big storm. It also allowed us to alleviate any small issues, in order to avoid any of the problems persisting during Nor' Easter Storms. The test deployments were conducted at Delaware Seashore State Park, which is similar to Bethany Beach where the actual deployments during Nor' Easters would be located. Delaware Seashore State Park is just north of Bethany Beach, located at the Indian River Inlet, which can be seen in Figure 10.

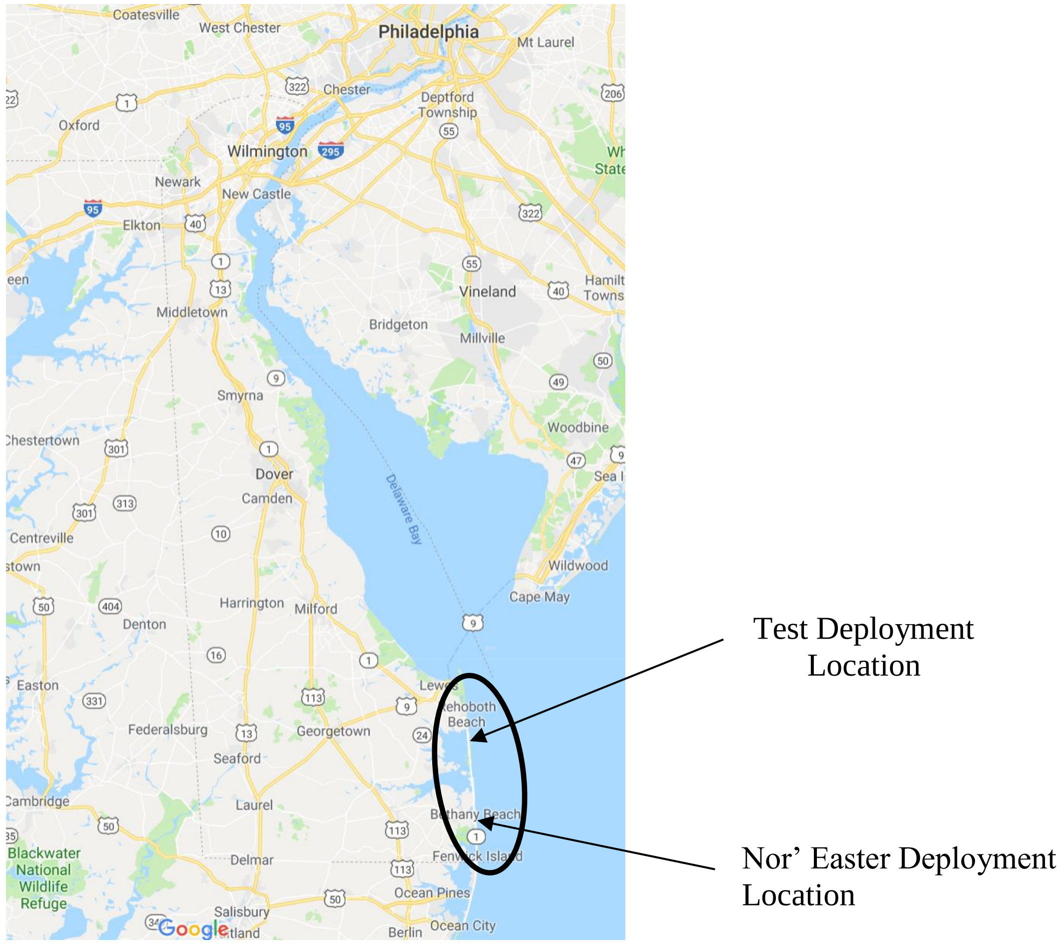

Figure 10 Location of the test deployments is approximately 6.5 miles north of the Nor' Easter deployment location

After conducting two test deployments in November of 2017, the focus was put on improving the systems of devices over analyzing the data. The test deployments showed flaws and strengths in the system we had, as well as prepared us for the Nor' Easters that normally occur from January until March.

4.1 Pipe Improvements

The series of tests revealed areas where we could improve our system in order to retrieve better data. One specific complication we recognized through the tests was that the horizontal arm coming off the main pipe allowed caused the pipe to rotate in the sand under waves and windy conditions. Therefore, the alignment of all the devices shifted from their original orientation which caused us to be unaware of the orientation of the JFE velocity. Figure 11 shows the original orientation of the pipe compared to how it was after the test deployment.

Figure 11 The image on the left shows the original orientation of the pipe, whereas the image on the right is after the pipe rotated 90 degrees clockwise due to the wind.

In order to combat the rotation issue, four thin metal plates were welded onto the outside of the pipe at about 1.5 feet from the bottom. However, after the second test deployment it was determined that the welds were not strong enough to sustain the force of rotation, so they broke off the pipes. The solution to this issue was to plasma cut slits into the pipe to then insert the plates about an inch into the pipe and then weld around the plate. This would allow for there to be less stress on the welds, since a portion of the plate would be inside the pipe. We also staggered the plates as to create a greater surface area to resist the rotation force. Figure 12 depicts the fins we installed on the pipes after the second test deployment.

Figure 12 The second fin design for the pipes to resist rotation

4.2 GoPro Reliability Issues

During one of the test deployments, the GoPro failed to turn back on in the morning after it turned off the previous night. Despite the CamDo blink having the correct schedule programmed, it failed to follow the planned schedule for unknown reasons. In order to ensure that the camera would turn back on every subsequent day, we decided it was best to create a schedule for each day separately, compared to setting one schedule and then selecting for it to run Monday through Sunday. In later deployments, it was found that this resolved the problem a majority of the time, but still sometimes the GoPro would randomly, or what seemed to be randomly, not turn back on as it was scheduled to. The lack of reliability of the Blink system will require an alternative in future deployments.

4.3 ADM Boxes

The boxes that held all the electronics for the ADM device, including both the battery and Madgetech data logger, were not water tight as reported by the manufacturer allowing some water to leak in and corrode the battery. In order to create a waterproof seal so that no water could leak in, new containment boxes were purchased to house the devices.

After resolving the complications from the test deployments, the system of devices was ready to be deployed for Nor’ Easter storms.

Chapter 5

NOR’ EASTER RILEY

Nor’ Easter Riley was the first Nor’ Easter storm where we were able to test our system of devices . In order to collect the most amount of data we decided to install our devices on March 2nd around 2pm in order to install them as close to low tide as possible. Installing during low tide allows for the pipes and devices to be installed farther seaward. For this storm we set up the seven sites perpendicular to the shore line (Figure 13). The sites were labeled A through G, with A being the farthest seaward, and F being the farthest inland. Labeling the stations allowed us to keep track of the data collected at each station and to draw correlations between each of the stations.

Figure 13 Layout of the Stations for Nor’ Easter Riley

5.1 Beach Profiles

Throughout the storm, beach profiles were taken along the site locations (Figure 14). The additional markers on figure 12 were from marking location with stakes so that we could collect additional elevation data. The additional data points that we surveyed can be seen in figure 15. The day after we deployed is when the most erosion of the beach occurred, specifically the berm was eroded. On the second day of the storm, the beach profile continued to erode but at a slower rate compared to the initial portion of the storm. On March 5th when the devices were removed a final profile was collected. In this final survey the sediment started to accrete where there once existed a berm.

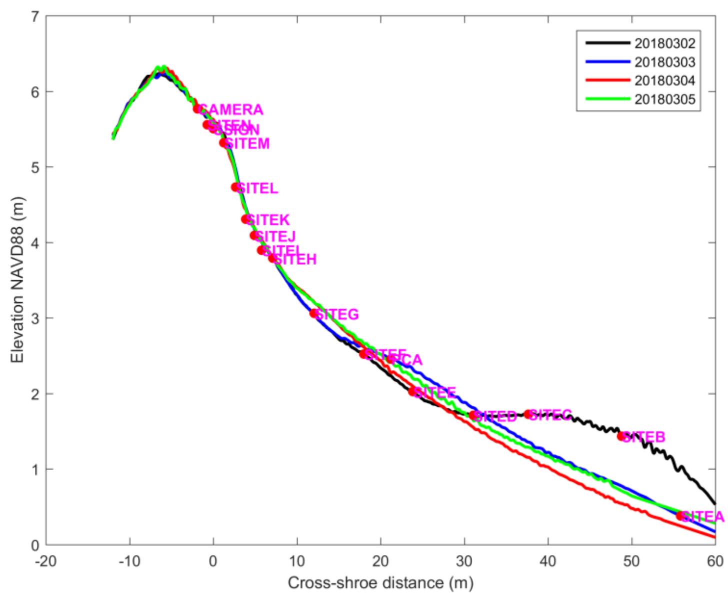

Figure 14 Beach Profile throughout the course of Riley

Figure 15 Surveying additional Data points with Leica GPS

Throughout the course of the storm, the pipe at Site A was significantly warped and fell over (Figure 16). The entire beach eroded approximately 0.75 meters at site A, and the waves were breaking right on the pipe at that location which was shown by the GoPro images, which lead to the collapse of site A.

Figure 16 Station A after day one of Nor' Easter Riley

5.2 Wave Conditions

In order to have quantitative data to match the large wave conditions that the GoPro showed during the storm we utilized information from the National Ocean and Atmospheric Administration's (NOAA) buoy station N44009. The buoy is located off the coast of Cape May, NJ, but was the closest NOAA buoy to our site. We also utilized a buoy off the coast of Bethany Beach under the control of the US Army Corps of Engineers station DE003. By looking at the wave data at the beginning of March, it is evident where Nor Easter' Riley hit because of the spike in wave heights (Figure17). This quantitative data aligns with the photographs taken by the GoPro around the corresponding time of the spike in wave height (Figure18).

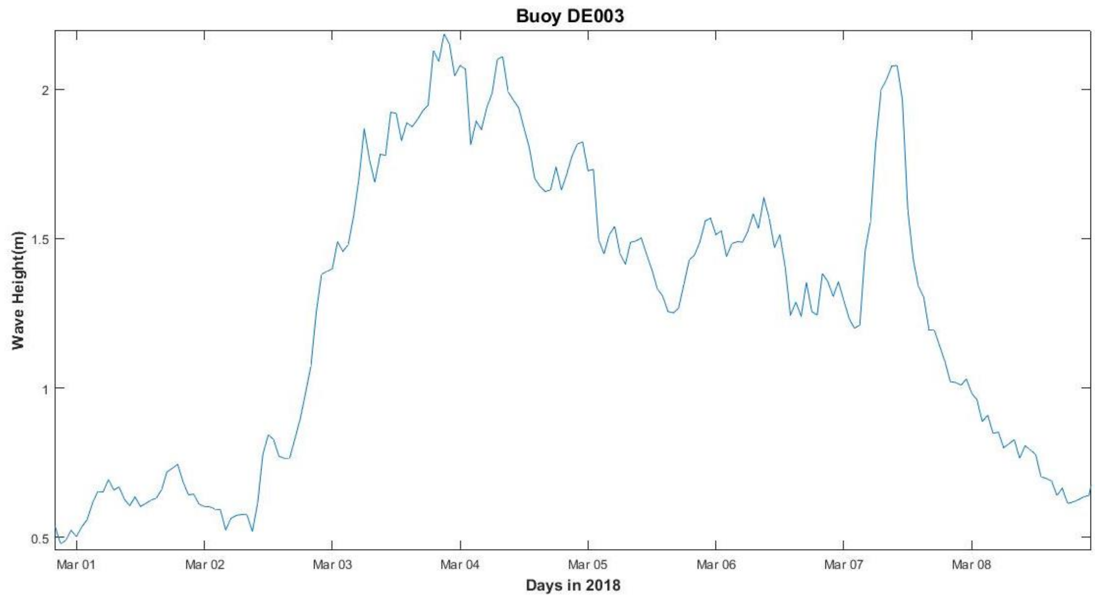

Figure 17 Wave height data collected from buoy DE003 showing the spike in wave heights as Nor' Easter Riley hit the coast of Delaware.

Figure 18 Wave conditions during Nor' Easter Riley

5.3 Data Analysis

Due to the fact that data were collected during a large Nor' Easter, there was a lot more data processing that needed to be done, as there was more noise due to the storm conditions (Figure 19). Some things that were different from the test deploy data were the extreme values collected, as well as taking into account that not all the device data represented wave conditions, as the devices shaking on poles also played a role.

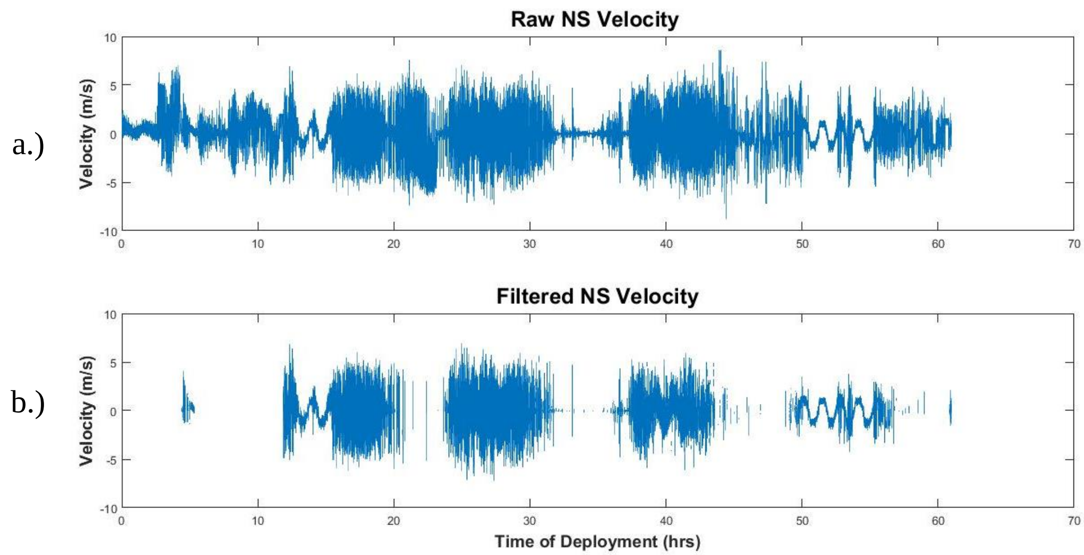

Figure 19 In the top figure (a) it shows the JFE North-South velocity data as it is outputted from the device. Whereas in the bottom figure (b) it shows the same data but with the low frequency pass filter on it as well as removing the data recorded while the JFE was not submerged.

The filter removed some of the extraneous data and outliers, that most likely resulted from the device being jolted rather than from actual wave velocities. However, there is still an excess of data that is not accurately representing the wave conditions throughout the storm.

5.3.1 RBR Data Cleaning

After the RBR depth data were downloaded, we had to adjust the atmospheric pressure due the fact that when it is originally programed it is given a base atmospheric pressure. However, we had to account for the differences in atmospheric pressure throughout the course of the storm by using data from a Delaware Environmental Observing System located on the Bethany Beach Boardwalk. We then used the corrected RBR data to eliminate the JFE data during the periods of time when the RBR indicated a depth of less than 15 cm. The cutoff value was 15 cm because the JFE was placed at 10 cm above the bed level, and then 5 cm was added to be conservative. Therefore, if the RBR read at least 15 cm as the depth, it was probable that the JFE was submerged.

5.3.2 ADM Data

The ADM reads the distance from the sensor to the waves or base water level depending on the conditions. Despite setting the maximum limit on the ADM using the teach function, it still sometimes outputted higher than the maximum. In order to remove these sections of data, we set threshold values for each of the ADMs based on what value they were specifically taught, then ran a function to remove all data points above the threshold value. In order to better comprehend the ADM data, we used the GPS data that gives an elevation in relation to NAVD88, to translate the distance data into a NAVD88 elevation point. While the data get covered by the noise sometimes, it also still shows valuable information. The combination of the JFE and ADM data for site B clearly shows the overall elevation increased drastically from a combination of the tide coming in and from the storm (Figure 20).

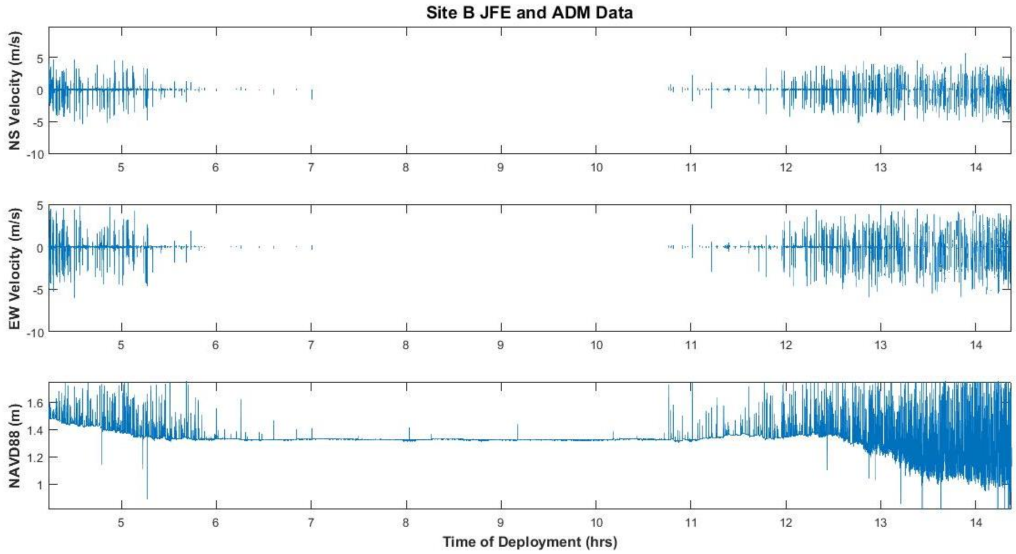

Figure 20 Data collected at site B from the ADM and JFE, showing the clear differentiation of when the tide comes in and the JFE becomes submerged and recording velocities as well as the ADM showing wave activity.

5.3.3 JFE data

Through the data cleaning process it was found that there were some unexplainable wave motions in the JFE velocities for some of the sites. It appears as though a symmetrical wave with the same period and magnitude took place from 39 to 41 hours after deployment for site D (Figure 21). However, the surrounding sites do not show any similar type wave motion over the course of the same two hours. The movement of waves inland can be traced from site B to site F, as the wave passes each site there is a peak in velocity (Figure 22). The peak drops at each site as the wave loses energy and velocity.

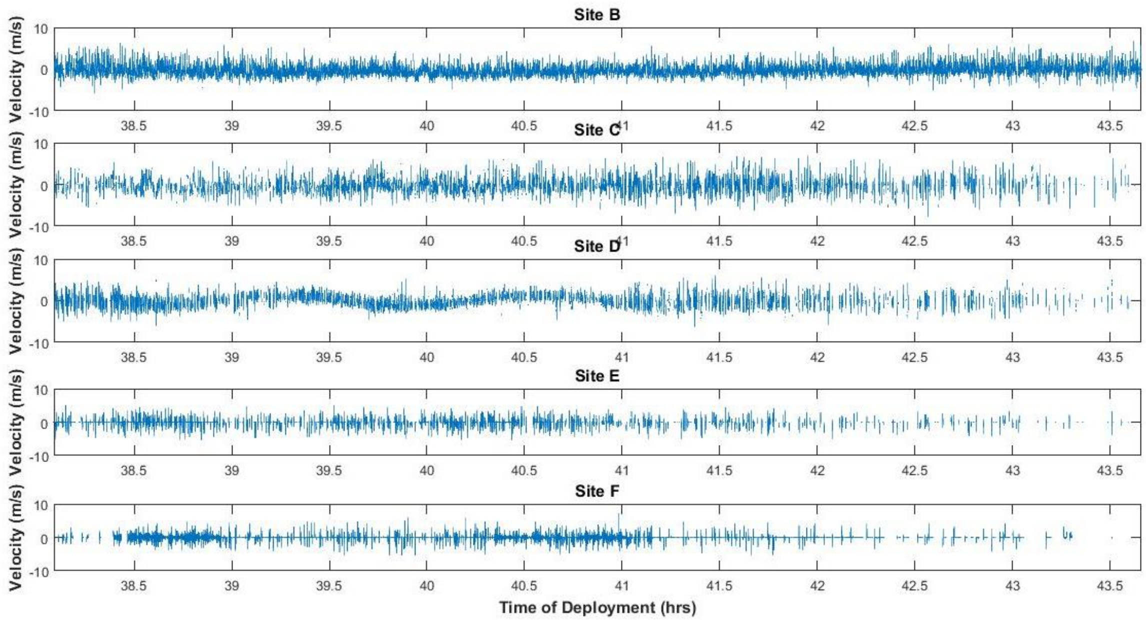

Figure 21 NS velocity data from sites B through F, as there is a unique pattern occurring at site D. The other sites seem to show somewhat consistent data throughout this time frame.

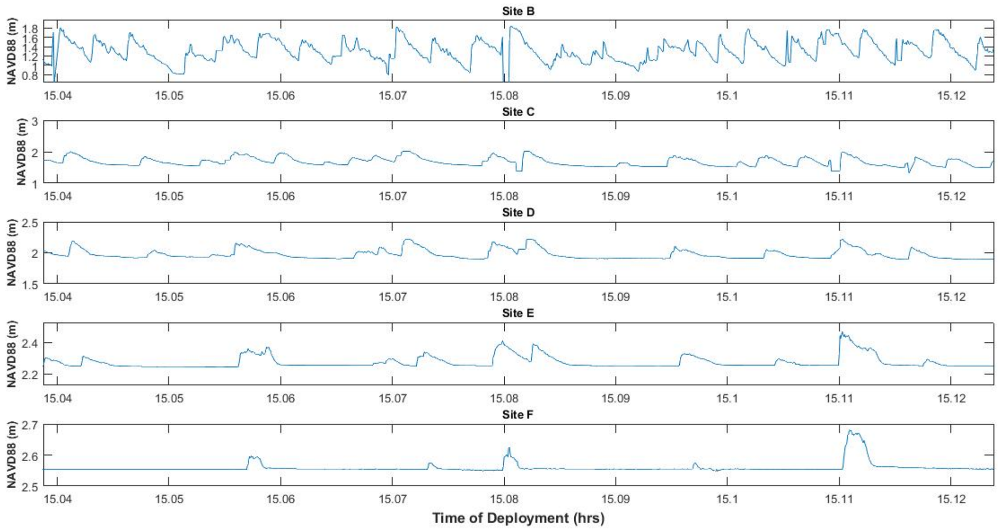

Figure 22 ADM data, relative to the NAVD88, at site B showing the movement of the wave inland, starting at site B until it barely reaches site F.

Chapter 6

NOR' EASTER TOBY

Based off of the data collected during Nor' Easter Riley, we made slight alterations to our deployment scheme for the next storm, Toby. For Nor' Easter Toby we decided to add an additional site. The additional site that we added just had an RBR on it, which was put the farthest from the water, to collect data for the atmospheric pressure.

We deployed the data collection systems in a similar matter to the layout of Nor' Easter Riley. We slightly adjusted the location on Bethany Beach (Figure 23). We started collecting data on March 19th around 6pm and collected the devices on March 23rd at 6am.

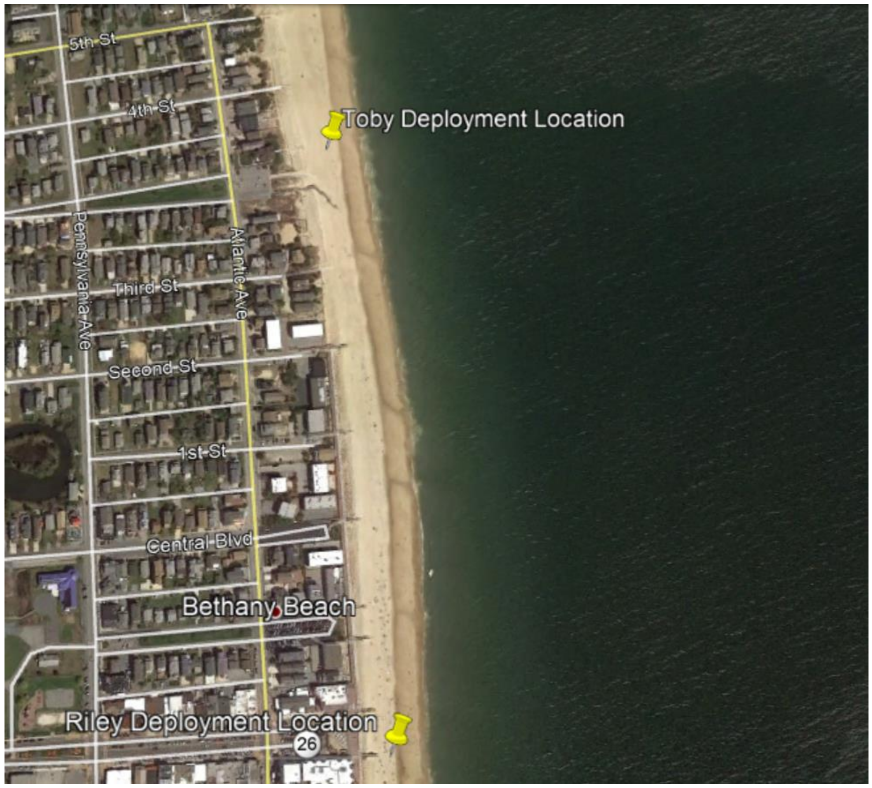

Figure 23 Map of data location for Nor' Easter Riley compared to Toby

6.1 Beach Profiles

For this deployment, we were unable to gather survey data throughout the course of the storm. However, we still were able to see a comparison of before and after the storm (Figure 24).

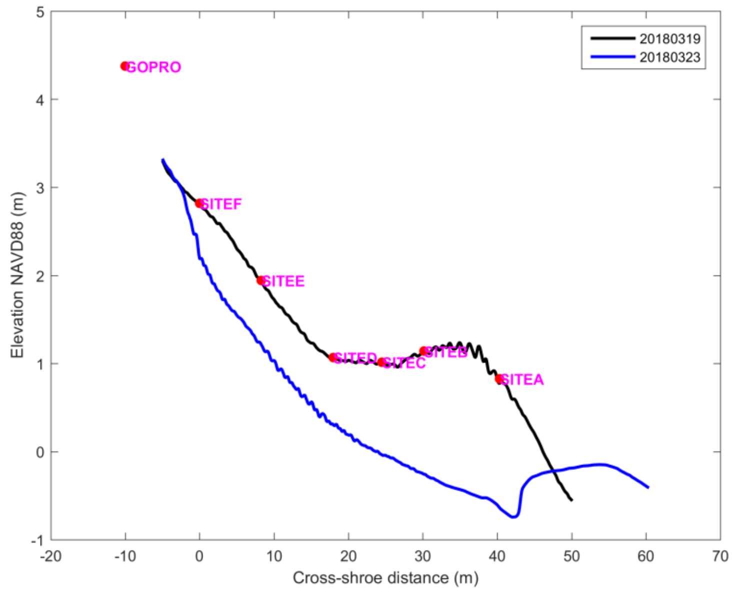

Figure 24 Profile of beach before and after Nor' Easter Toby

The profile shows that berm that existed near sites A-C was completely eroded away throughout the course of the storm. The profile also shows how the original slope of beach gets significantly steeper due to the storm. The post-storm profile also shows the preliminary stages of a berm starting to reform around 40 to 60 meters on Figure 24, which is based off a local coordinate system. This probably started to occur as the storm subsided, with net sediment transport onshore.

6.2 Storm Severity

Nor' Easter Toby had more drastic effects on our testing equipment compared to that of Riley. The storm conditions during Toby caused us to lose the JFE on station A. Also, when looking at the pipes after they were removed from the sand, it was evident that the storm conditions were worse than previous deployments, as it caused deformation of the pipes (Figure 25).

Figure 25 Deformation of the pipes used at each site for Nor' Easter Toby, the pipes with the more drastic curved shape came from sites A through C.

6.3 Wave Conditions

The same two buoy stations were used to retrieve wave height data as for Nor' Easter Riley. When looking at the wave data for the whole-time frame of late February to the end of March, the first and last peak represent the two Nor' Eater storms that we collected data at (Figure 26). With the middle peak representing a third storm, that we were not able to deploy our devices for. The wave conditions for the additional storm were of the same magnitude as for Riley and Toby, but did not last nearly as long. The magnitude of the two Nor' Easters we collected data for appeared to have the peak wave height at a little above 4 m according to the NOAA Buoy 4409 (Figure 26).

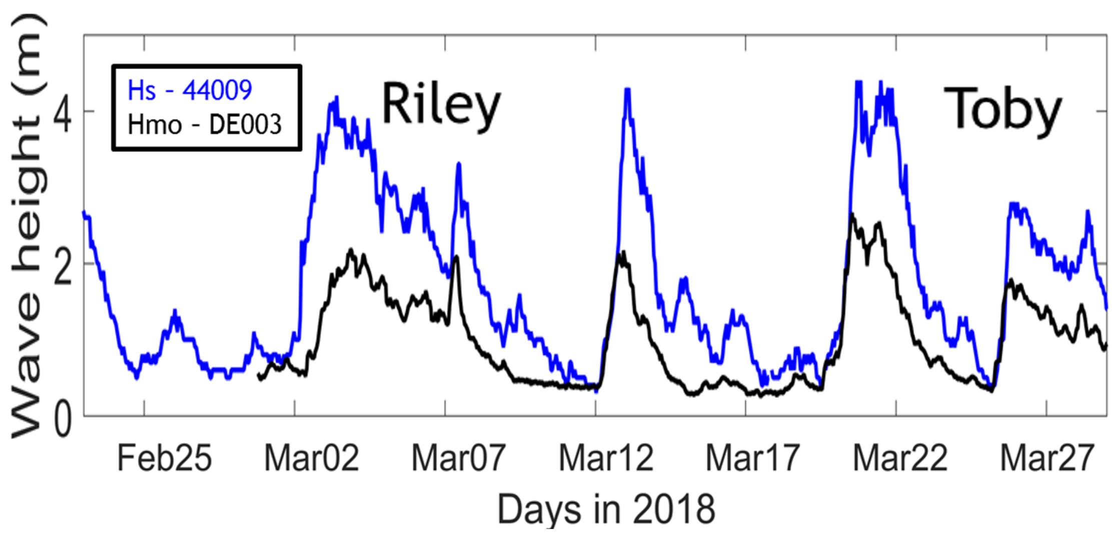

Figure 26 Comparison of how wave heights compared from Nor' Easter Riley to Nor' Easter Toby, despite the fact that our equipment sustained more damage from Nor' Easter Toby.

6.4 Data Analysis

The same data cleaning processes and processing for Nor' Easter Riley was applied to the data collected for Toby.

6.4.1 JFE data

The JFE data from Nor' Easter Toby looked similar to that of Nor' Easter, even the irregular wave pattern. The wave pattern appeared again, but only at Site D. This is also a strange considering that while Site D was showing a wave pattern, there appeared to be more significant noise occurring at Site C, despite the fact that it was pretty constant beforehand. Most likely both the wave pattern and noise are a result of the sensors being dry causing them to output inconsistent data.

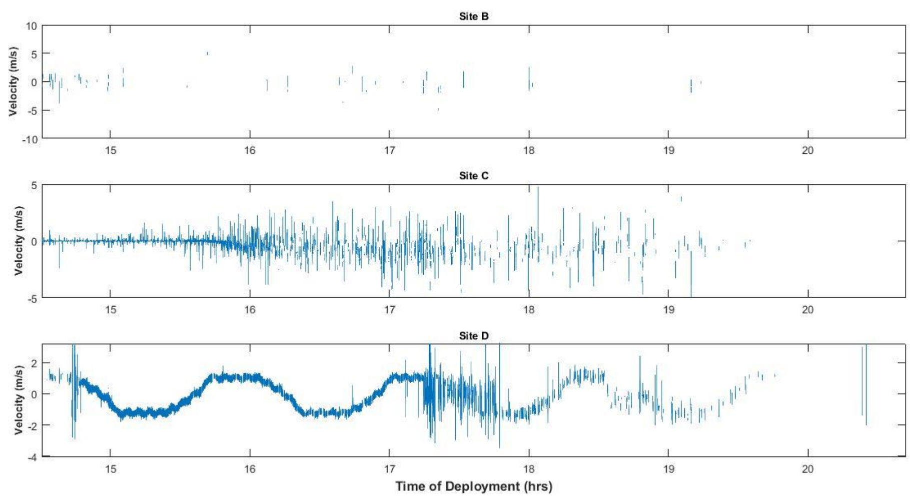

Figure 27 The same type of irregularities from Nor' Easter Riley, were shown in the data collected during Nor' Easter Toby at Site D in the JFE North-South velocity data.

When looking at the JFE compass data throughout the course of the storm, it is evident that site C significantly shifted. While most of the compass data stays relatively constant, while neglecting the noise caused by the sensor being hit by waves, Site C rotates about 60 degrees. This would be constant with the pipe rotating and sliding to be at an angle rather than vertical (Figure 28). Site E and F have significantly less noise in the data, which supports the concept that the noise is due to the winds and waves that cause the poles to vibrate because they are the farthest inland stations. Also, the compass data at all of the sites should have started close to 90 degrees as they were all deployed in the same orientation. The compass data for site B and F could have been effected due to them being deployed on steel pipes unlike the other stations.

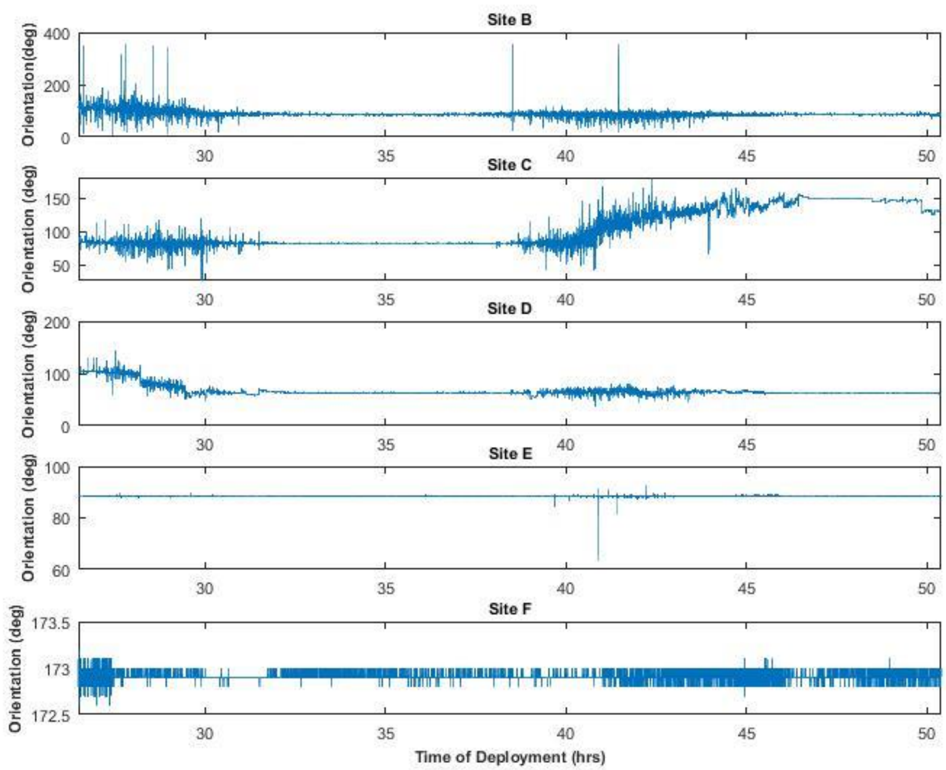

Figure 28 JFE internal compass data throughout the course of the storm, that show how the devices rotated and shifted due to the poles as a result of the storm conditions

Chapter 7

CONCLUSIONS

The goal of this research was to be able to quantify and qualify the conditions that lead to the erosion of beaches during Nor' Eastern storms. Having these data would allow us to understand the hydrodynamics and morphodynamics of what exactly is causing the majority of the erosion. By using our system of devices, we were able to collect data that gave insight as to the wave velocities, wave heights, and bed level changes throughout the storm. Working off of the research we conducted, similar systems of devices can be deployed throughout storms to see if the data we collect is representative of the majority of storms that occur on the coast of Delaware. In addition to the development of devices that can record information on the frequency that the pipes are moving can help to remove errors in the wave data. Adding more devices that can measure the bed level changes throughout the storm instead of relying on the GPS surveys, would benefit this research.

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