PROJECT REPORT

Storm Impacts Research: Using SENCER-Model Courses to Address Policy

Michelle Ritchie
Werth Center for Coastal and Marine Studies, Southern Connecticut State University

James F. Tait
Werth Center for Coastal and Marine Studies, Southern Connecticut State University

Abstract
Hurricane Irene and Superstorm Sandy caused severe damage to the Connecticut shoreline in 2011 and 2012 respectively. The close temporal succession of the two storms has intensified concerns about rising sea levels and storm intensification attributable to climate change. In response, students at Southern Connecticut State University who have taken a SENCER model course, "Science and the Connecticut Coast," as well as students from similarly constructed courses that teach environmental science "through" issues of civic consequence, are conducting research on coastal vulnerability with the goal of impacting policy recommendations that could increase the state's coastal resilience in the face of future storms. The results of these studies suggest that the presence of a wide buffering beach was the most common factor in reducing storm wave damage, and that the characteristics of the storm surge inundation pattern were unexpected. Among the recommendations stemming from this research are that management of beach sand become a priority for the state, that management of beach sand be prioritized according to locality and benefit, that the state provide a mechanism for towns to reclaim eroded beach sands that provide a buffer to storm waves, and, finally, that coastal emergency plans include accurate storm tide inundation maps that are accessible to the public.

Introduction
According to the National Council Population Report (NOAA 2013), the Connecticut shoreline has the fifth highest (non-freshwater) coastal population density in the United States and is one of the most intensively developed shorelines in the country. The ratio of the value of total insured coastal county property/km of linear shoreline length for Connecticut is $3.69 billion/km, second only to New York State (AIRWorldwide 2013). In the face of climate change and sea level rise, shoreline properties in Connecticut face increased risk of damage caused by hurricanes and other large storms. This is due in part to poorly informed policies that fail to recognize the regional beach dynamics of Connecticut's formerly glaciated, fetch-limited shoreline (Tait and Ferrand 2014).

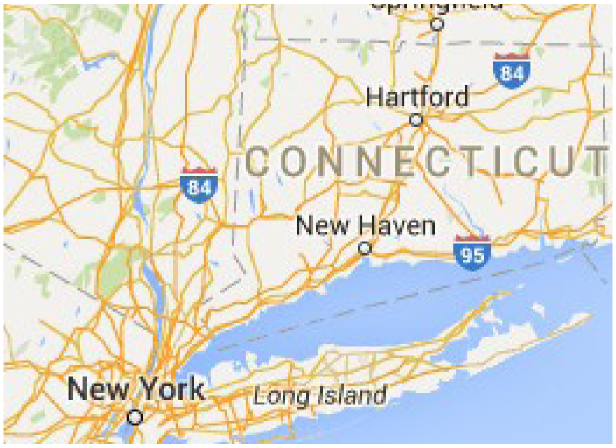

FIGURE 1. Long Island and Connecticut. *(Figure courtesy of Google Maps.)*

In particular, along many parts of the Connecticut shore, communities depend on the presence of sandy beaches to shelter coastal structures and infrastructure from storm damage. While the shoreline is periodically exposed periodically to erosive storm waves, the moderately large, long period swells that rebuild beaches are typically absent due to the sheltering effect of Long Island (Figure 1). As a result, Connecticut's beaches are chronically erosive.

By connecting students with a multifaceted understanding of Connecticut shorelines and providing hands-on experience with storm damage, the class becomes a site of learning, both inside and outside the university walls. From statistics and coastal processes, to teamwork and presentation skills, SENCER courses in what is now the Department of the Environment, Geography and Marine Sciences at Southern Connecticut State University have become a departure point for students to both conduct coastal research and apply that research to coastal policy analysis.[1] After learning important concepts and field and laboratory techniques in formal courses, highly motivated students go on to conduct research as fellows of the Werth Center for Coastal and Marine Studies. It is interesting to note that the students involved in this research are not necessarily science majors but have developed an interest in science as a result of their experiences in these interdisciplinary science courses. Two such courses, "Science and the Connecticut Coast" and "Coastal Processes and Environments," allow students to experience and understand various coastal environments, their origins, and the processes that shape them, as well as associated environmental issues. Although the focus of this article is research on storm impacts, department coursework and research at the Werth Center also focus on water quality monitoring and coastal sediment pollution by heavy metals.

Hurricane Sandy moved up the Atlantic coast in late October 2012, interacting with a strong short-wave, mid-latitude cyclone along the way. The combined storms created an extremely large and very low-pressure superstorm with intense winds on the northern side of the cyclone (Grumm and Evanego 2012). These winds, with attendant surge and storm waves, hit the coastal town of East Haven, Connecticut on October 29, 2012. The impacts of Sandy are convolved with those of Hurricane Irene, which had devastated the area just one year earlier in August 2011. While people were still recovering from Irene, Sandy intensified and and spatially extended the damages that already existed. In records of storm damage maintained by the town, specific damages were sometimes not even attributed to a particular storm, a clear indication of the overlapping impact of the two storms (Tait and Ferrand 2014). Superstorm Sandy was generally classified as more intense in terms of maximum storm surge, maximum wind speeds, diameter, and barometric pressure (Fischetti 2012). Prevailing conditions in Connecticut, however, served to moderate the storm's impact relative to Irene. The storm's direction shifted west, sending the eye into New Jersey, so that winds along the Connecticut shoreline blew alongshore rather than onshore, which reduced the magnitude of the surge in the East Haven area. Sandy's forward speed accelerated from approximately 15 mph to 29 mph, so that the storm arrived in the East Haven area earlier than it would have otherwise. According to records from the NOAA New Haven CT tide gauge, Sandy arrived in East Haven at 8:06 p.m., just two hours

1 Southern Connecticut State University (SCSU) has developed three courses that have been selected as SENCER Models: "Computer Ethics", 2006; "Science on the Connecticut Coast", 2007; Pollinators: A Case Study of Systems Thinking and Sustainability", 2014. Since 2004, thirty-two faculty members from SCSU, encompassing twelve departments and three of its schools, have attended Summer Institutes, incorporated SENCER ideals into existing courses and programs, and created new courses. For this work, SCSU received the 2015 William Bennett Team Award for Extraordinary Contributions to Citizen Science from the National Center for Science and Civic Engagement.

FIGURE 2. Cosey Beach. *(Photo courtesy of the Connecticut Department of Energy & Environmental Protection.)*

after a spring low tide, resulting in a storm tide of 8.9 ft (2.7 m) relative to mean sea level, just 7.9 in (20 cm) higher than Irene. If not for these factors, the storm surge would have been higher and would have occurred nearer to a spring high tide, as was previously anticipated. Nevertheless, storm surge inundation, high winds and storm waves caused considerable damage (Figure 2).

To better understand the risk posed to structures and infrastructure, students who had gained research experience in SENCER courses investigated the various controls on wave damage and patterns of inundation in order to assess vulnerability to future storms. The shoreline characteristics investigated with respect to wave impacts included the elevations of houses and roads, beach width and beach erosion patterns, the presence or absence of sea walls, and the amount and types of damage sustained. Spatial patterns of inundation were examined using flood debris deposits, Light Detection and Ranging (LIDAR) data, and Geographic Information Systems (GIS) mapping technology.

Research Activities

Methodology for these studies involved quantitative field observations followed by quantitative laboratory and geospatial analysis. Students were prepared by their classroom experiences to conduct rigorous fieldwork, gather reliable data, analyze the data carefully, and make reasonable interpretations. Collectively, the data constitute a detailed look at various characteristics of the East Haven coastline that contribute to the town's vulnerability to wave damage and to inundation during large storms. Research activities included construction of coastal road elevation maps, measuring beach profiles and erosion patterns, a house-by-house wave damage assessment, and an inundation map series that included the actual inundation pattern and patterns for other potential scenarios. It should be noted that the research performed by the students has been used in the town of East Haven's report to FEMA and will be used by the Town Engineering office for future risk assessment.

Wave Damages

Coastal road elevation maps

A series of road elevation maps were generated. Students used a CST/Berger 300-R total station to gather elevation data. The total station uses a modulated infrared laser beam and prism reflector to obtain highly accurate XYZ coordinates, which must then be assigned a coordinate system that includes a known elevation. Previously existing town engineering benchmarks served as points of known elevation. The locations of surveyed elevation points were recorded using geographic positioning technology (GPS) approximately every twenty feet or at every noticeable change in road elevation, whichever came first, in the centermost part of the road. Data were then visualized using ArcGIS by importing point locations and displaying them as XY point values. Spot elevations were then manually input into a new corresponding float point field. Elevation rasters of the same width as the roads were then created using spline and inverse distance weighting interpolation.

Beach profiles and erosion measures

Students also collected data on beach erosion (or stability) by measuring the difference in beach profiles over time. Profiles were measured and re-measured at fixed geographic locations. Over the past 3.5 years, beach profiles were measured along East Haven beaches to better understand longer-term erosion or accretion patterns. Where possible, profile measurements were spaced along the beach approximately 200 m apart. Profile locations were recorded and measured from the seaward-most edge of coastal structures, or from the edge of the beach, to maximum wading depth. These measurements were then plotted using Microsoft Excel to reveal spatial patterns of erosion over time. Calculated variables included the width of the beach to the mean higher high water (MHHW) intercept and the volume of beach sand under the profile and above the mean lower low water elevation. Volumetric measurements were given units of m3 per unit length of shoreline. This allowed total volume of sand calculations for specified reaches of beach.

Structural damage assessment

In addition to empirical quantitative research, one student conducted door-to-door interviews at each house along the East Haven coastline to determine the nature of wave damage to each structure. A set of questions was asked at each home including the cost of structural damage that occurred, what type of damages occurred, whether or not a sea wall was present, and whether or not the structures were raised at the time. A map was creating using Google Earth to show the structural damages pattern. Structures were put into one of the following categories: severe damages requiring demolition, severe damages, moderate damages, minor damages, and no damages.

Inundation

Inundation map series

Immediately following the flooding that accompanied the storm surge of Superstorm Sandy, debris lines in the town of East Haven associated with the peak storm surge were located and photographed, and addresses were noted. Blue dots were spray painted to represent the upper boundaries of the debris line. These point locations were then recorded using GPS and their elevations were measured using laser-based surveying technology (total station) (Figure 3). An average elevation for the flood line point locations was then calculated along with a measure of variability (standard deviation). The average elevation for the flood debris was then compared with the peak storm surge water elevation measured at the nearby (~ 4 km) New Haven, CT tide gauge. The difference between the tide gauge elevation and the elevation determined by averaging debris elevations was just 1.5 cm, allowing a high level of confidence in the data collected.

Flood line locations and elevations were then visualized using Geographic Information Systems (GIS), resulting in a series of maps: (1) storm surge inundation of Superstorm Sandy, (2) storm surge inundation of Superstorm Sandy had it come at high tide instead of a couple of hours after low tide, and (3) storm surge inundation projections based on IPCC (2014) estimated sea level rise. This map series was created in ArcGIS utilizing high-resolution LIDAR imagery and 2010 USGS orthophotography. LIDAR imagery elevation information was extracted and displayed using a semi-transparent teal blue color to signify all areas that had been inundated during Superstorm Sandy (elevations at or below 8.9 ft (2.7 m)). A second semi-transparent layer displayed with purple color was added to signify the hypothetical Sandy at high tide storm tide elevation (elevations from 8.9 ft (2.7m) to 12 ft (3.7m)), as was originally predicted. Representation of these two scenarios were then overlain on USGS orthophotography. All remaining elevations were given

FIGURE 3. Data collection using laser-based surveying technology. *(Photo courtesy of Isabel Chenowet.)*

FIGURE 4. Cosey Beach during Hurricane Irene. Note collapsing house on left and wave splash overtopping house in center. *(Photo courtesy of James Tait.)*

FIGURE 5. A coastal road elevation map. *(Figure courtesy of Michelle Ritchie.)*

no color to signify locations free from inundation. Flood debris point locations were then added and displayed as XY point values. These values matched up exceedingly well with the upper boundaries of the storm tide inundation determined from the LIDAR data.

Results

Wave Damages

While the presence of seawalls and raised structures all influenced the degree of wave damage, they were not the primary determinants. For structures that were raised, elevation on pilings often proved effective. However, in some cases, the magnitude of elevation was insufficient relative to peak surge elevation. In other cases, minor damages occurred to fences or stairs to elevated decks. In general, however, few structures were elevated before Sandy. Seawalls were frequently overtopped, deflected energy onto adjacent structures, or increased the elevation of wave splash (Figure 4). When the coastal road elevation maps (Figure 5), the damage assessment map (Figure 6), and beach profile measurements (Figure 7) were compared, it became apparent that beach dimensions and road elevation played the largest role in determining the severity of wave damage. In particular, older cottages which were not elevated and lacked structural robustness sustained only minor damages if they were sufficiently far back on the beach profile, i.e., had a broad protective beach. This was the case even if road elevation was relatively low. In other areas, road elevation played a key role. The central

FIGURE 6. Damage assessment map. *(Figure courtesy of Stephanie Cherry.)*

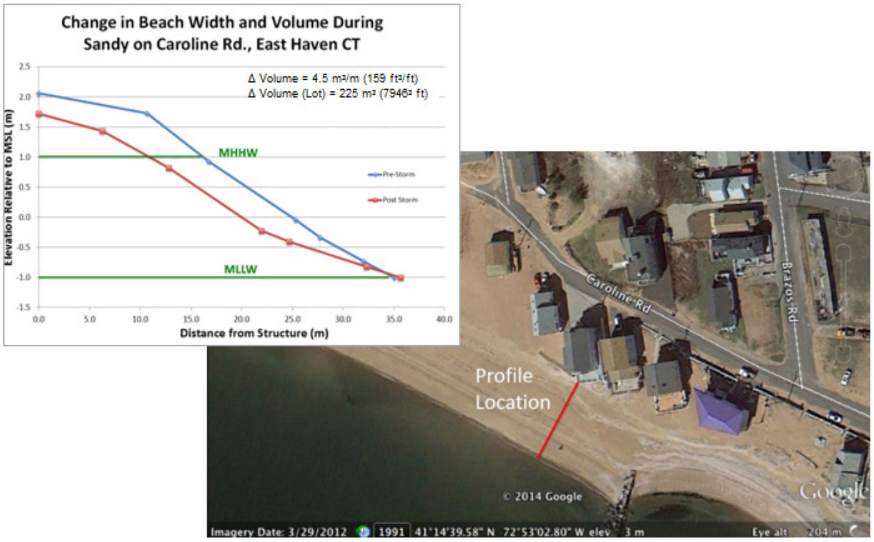

FIGURE 7. Changes in beach profile via volume of sand. *(Figure courtesy of James Tait.)*

FIGURE 8. Map of Superstorm Sandy. *(Figure courtesy of Michelle Ritchie.)*

portion of Cosey Beach Avenue, for example, is the highest part of the road topographically. Damages here were minor to non-existent. In the western portion of Cosey Beach Avenue, houses were the most robustly built, typically had low seawalls, but were at a lower road elevation than those in the central portion, and more importantly, had no buffering beach at high tide (compare Figures 5 and 6).

Inundation

Inundation, while less dramatic than wave damage, also caused considerable damage and collectively may have been more costly. Sandy's peak storm tide in East Haven was 8.9 feet (2.7 m). Mean higher high water in this area is 3.4 feet (1.0 m). On the morning of October 29, Sandy shifted its track westward toward New Jersey and accelerated to nearly twice its forward speed. As a result, the peak surge arrived in the East Haven (New Haven) area just after low tide. Using NOAA water level data for the New Haven station, the storm tide (predicted tide + the storm surge) elevation for the area was calculated and mapped (Figure 8). The storm tide for Sandy arriving at high tide was 12 feet (3.7 m). The areal extent of flooding and the depth of inundation would have been considerably worse. In addition, escape routes that functioned under the actual storm tide elevation might not have been accessible had Sandy's forward speed not changed. The difference between the actual storm tide and the potential storm tide is similar to the rise in sea level (~3 feet). predicted for the end of the century by some climate models. The pathway of flooding was also an issue. In many places along the East Haven coast, salt marshes back areas of housing and other development. In most cases, flood waters moved landward from the marshes in addition to overtopping the beaches. As a result, distance from the shoreline was not a guarantee of safety. In one area, the flooding extended the shoreline of Long Island Sound ~1845 feet (~562 m) landward via marsh flooding.

Policy Discussion

In keeping with the ideals of SENCER courses, this student-driven research has substantially increased the fund of public knowledge of storm impact on the Connecticut coast and provided critical information on which to ground public policy. Now more than ever, students, the general public, and politicians alike have come to realize that climate change is significantly impacting our lives. This is especially measurable in areas like the town of East Haven that were severely impacted by Hurricane Irene and Superstorm Sandy in recent years. In fact, following Hurricane Irene the Connecticut State Legislature authorized the Shoreline Preservation Task Force, a bipartisan group that has made policy recommendations and called for the integration of climate change and sea level rise science into both resource development planning and municipal zoning regulations (Tait and Ferrand 2014).

When assessing coastal vulnerability, it is essential that we look closely at the characteristics of an area to understand how they combine to constitute that area's vulnerability. In the case of East Haven, Connecticut, topographic elevation and the presence of seawalls and raised structures all play roles in determining the severity of wave damage. Data analysis, however, indicates that beach width and height were the primary determinants of the degree of wave damage to coastal structures during Irene and Sandy. With this information, locally proposed policy changes can be made to more easily and economically maintain the buffering capacity of beaches in the face of future storm waves and improve the accuracy of evacuation warnings.

For example, direct development of the shoreline should be strongly discouraged. The long-standing assumptions that the Long Island protects the Connecticut coast, or that erosion is random rather than methodical, need to be dispelled. In addition, a managed retreat from the coastline in areas of high vulnerability needs to become part of policy conversations (Tait and Ferrand 2014). Furthermore, less expensive alternatives to current beach nourishment projects, which consist of trucking in sand from other regions, should be explored. One such economical option would be to pull eroded sands back onshore. In general, *regional* planning to make coastal communities more sustainable in the face of future storms needs to be undertaken. Although the State of Connecticut has established an interdisciplinary research, outreach and education center (Connecticut Institute for Resilience and Climate Adaptation) that offers support to local communities, response to Irene and Sandy still largely resides with individual communities.

One improvement to the current system might be a regional sand management plan. At present, beach restoration is discouraged and when replenishment does occur, sand is typically trucked in or shipped in from distant offshore borrow areas or regional quarries. Sand that was originally eroded from the beaches, however, typically accumulates just offshore. Using this sand source to replenish the most vulnerable beach areas according to a system of prioritization would be a significant improvement to the current system. In other areas, where replenishment is cost-prohibitive, prioritizing which assets to protect (i.e., which beaches to replenish), and which beaches should be surrendered to nature, would be another viable and more sensible option.

The results of these studies have been made available to the Engineering Department of the town of East Haven and to the Public Works Department of the town of West Haven to aid in their long-range and emergency planning efforts. Similar work is being done for the State Beach at Hammonasset. Recommendations based on the results of this work will be offered to the State Department of Energy and Environmental Protection as well as to the Environment Committee of the State Legislature.

About the Authors

Michelle Ritchie recently graduated with honors from Southern Connecticut State University with a Bachelor of Arts in Geography and a concentration in Environmental Studies. While at SCSU, she worked as a research assistant at the Werth Center for Coastal and Marine Studies and as an intern at the Office of Sustainability and Recycling Center. She is currently attending Binghamton University in pursuit of a Master of Arts in Geography specializing in Environmental and Resource Management while working as a graduate research assistant at the Hazards and Climate Impacts Research Center. Her research primarily focuses on hazard mitigation, planning and recovery.

James Tait is a professor of marine and environmental sciences in the Department of the Environment, Geography and Marine Sciences at Southern Connecticut State University. He received his Ph.D. from the University of California at Santa Cruz in Earth Science with a specialization in Oceanography and, in particular, Coastal Processes. Since 2011, his research has focused on the coastal impacts of large storms, including Irene and Sandy. Dr. Tait is a SENCER leadership fellow and a co-recipient of the William Bennett Team Award for Outstanding Contributions to Citizen Science. Along with his colleague, Dr. Vincent Breslin, he co-authored a course for the SCSU Honors College on Science and the Connecticut Coast. The course has students conduct scientific studies of storm impacts and coastal pollution in Connecticut. The course became a SENCER Model Course in 2007. Dr. Tait is also co-founder of the Werth Center for Coastal and Marine Studies at SCSU. The Center employs talented students as research assistants working on problems such as coastal vulnerability and resilience, metal pollution of coastal sediments and organisms, microplastics in the marine environment, coastal water quality changes, and response of corals to climate change in Long Island Sound.

References

AIR Worldwide Corporation. 2013. The Coastline at Risk: 2013 Update to the Estimated Insured Value of U.S. Coastal Properties. http://www.air-worldwide.com/Facet-Search/Search-Results/ (accessed January 2, 2016).

Fischetti, M. 2012. Sandy vs. Katrina, and Irene: Monster Hurricanes by the Numbers. Scientific American. Available: http://www.scientificamerican.com/article/sandy-vs-katrina-and-irene/ (accessed January 2, 2016).

Grumm, R.H., and C. Evanego. 2012. "Hurricane Sandy: An Eastern United States Superstorm." NWS State College Case Examples. http://cms.met.psu.edu/sref/severe/2012/30Oct2012.pdf (accessed January 2, 2016).

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Core Writing Team, R.K. Pachauri and L.A. Meyer, eds.) Geneva, Switzerland: IPCC.

National Oceanic and Atmospheric Administration (NOAA). 2013. National Coastal Population Report: Population Trends from 1970 to 2020. http://stateofthecoast.noaa.gov/features/coastal-population-report.pdf (accessed January 2, 2016).

Tait, J., and E.A. Ferrand. 2014. "Observations of the Influence of Regional Beach Dynamics on the Impacts of Storm Waves on the Connecticut Coast during Hurricanes Irene and Sandy." In Learning from the Impacts of Superstorm Sandy, J.B. Bennington and E.C. Farmer, eds., 67–88. London: Academic Press.