BACKGROUNDER

THE UNIVERSITY OF RHODE ISLAND
GRADUATE SCHOOL OF OCEANOGRAPHY

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Elevation Mapping as a Tool for Building Resilient Coastal Communities

A Methods Backgrounder

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On October 29, 2012, Hurricane Sandy hit the east coast of the United States, battering coastal towns with heavy winds and a storm surge of up to 14 feet in some areas. The storm displaced more than 23,000 people and decimated critical infrastructure, ranging from public transportation to electrical lines. With over $68 billion in damage, only Hurricane Katrina was more costly in U.S. history.[1]

Although Hurricane Sandy was downgraded to a tropical storm by the time it hit the Atlantic coast, the storm was an important reminder of the scope of natural hazard risks for residents, businesses, and natural and cultural resources in highly populated coastal areas. Coastal zones are exceptionally vulnerable to the effects of storms and sea level rise because of their low elevation and high density of development. Along the mid-Atlantic U.S. coast, these risks are amplified by the adjacent shallow continental shelf and the observed "hot spot" of sea level rise.[2] Studies have shown that sea level rise rates increased nearly four times faster between 1980 and 2009 along a roughly 1,000 km stretch of coastline north of Cape Hatteras, as compared to global rates.[3]

Given these vulnerabilities, scientists and managers from government, academic, and non-governmental organizations are working together to integrate scientific data into local and regional plans that account for projected effects of climate change and enable development of comprehensive coastal storm response strategies to help protect public safety, property, and natural environments. An important component of these plans is the establishment of baseline data on coastal elevations. The collection of elevation data along shorelines is essential not only for examining damage from past storms but also to prepare for future storms.

WHAT ARE ELEVATION DATA?

Elevation data are used to create elevation models and maps, research and management tools that illustrate and help to predict changes to natural landscape features. Each elevation datum, composed of three-dimensional points, can be collected in the field by a variety of methods. Scientists use these data points to create digital elevation models (DEMs) or surfaces that can then be shown on maps as simple contour lines (three-dimensional renderings of a site), or be used to create thematic maps (Figs. 1 a & b).

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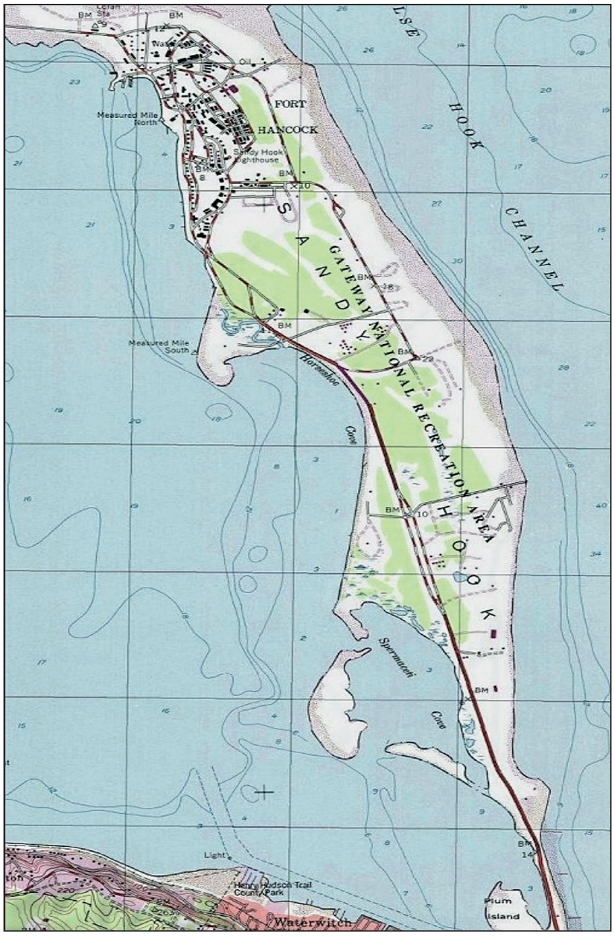

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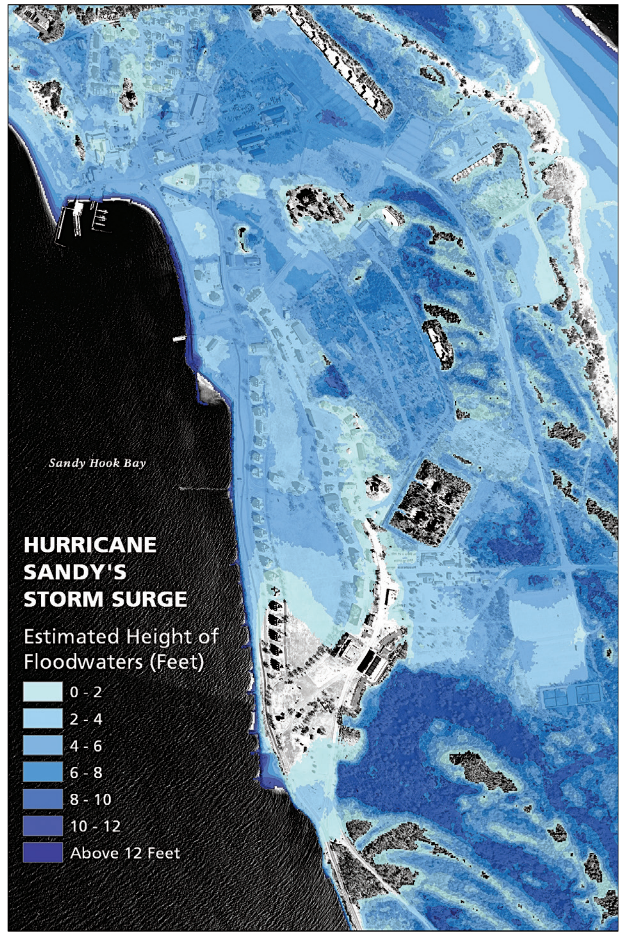

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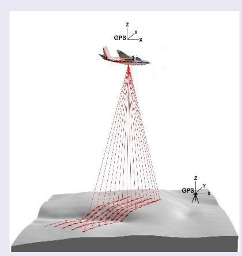
Figure 1. A. Contour map of southern Sandy Hook Bay on the New Jersey coast. The curved contour lines join points of equal elevation. Map courtesy of the United States Geological Survey. B. Inundation of the Fort Hancock area at Gateway National Recreation Area (GATE), NJ, as a result of Hurricane Sandy storm surge. The powerful storm resulted in several feet of flooding and damage across the Sandy Hook peninsula. Map courtesy of GATE GIS URI Branch

TECHNIQUES USED FOR ELEVATION MAPPING

Characteristics	RTK-GPS	LiDAR
	 Retrieved from http://maxwell-land-surveying.com/land-surveyor-services/boundary-surveying.	 Retrieved from http://forsys.cfr.washington.edu/JFSP06/lidar_technology.htm
Full name	**Real Time Kinematic and Global Positioning System[4]**	**Light Detection and Ranging**
Collection techniques/ equipment	Two mobile GPS receivers, one serving as a base station and the other as a 'rover' for collecting data (Figure 3)	Laser attached to an airplane or helicopter points toward a land feature to measure the amount of time it takes for the light pulses to return to the source
Data output	Height data used to create profiles of coastal areas	Based on return time, the relative distance or elevation of the feature or point can be measured
Accuracy	Vertical: 2–5 cm; Horizontal: 1–3 cm	Up to 1 m
Benefits	Real-time results More accurate than LiDAR Useful when collecting elevation data over a small area	Covers a wide area in a short amount of time
Limitations	Difficult to access rocky terrain with handheld or vehicle-mounted GPS receivers	Inaccuracies require correctional techniques Expensive

The three-dimensional nature of a digital elevation model provides land managers with a visualization of coastal features. These models, or DEMs, have multiple functions and can be used to:

- determine water flow or the location of a specific area (such as a wetland, school, or hospital) relative to sea level;
- track and predict inundation of areas most vulnerable to long-term changes in sea level and short-term flooding during storms;
- inform planning processes for land use, engineering, and landscaping;
- identify natural and cultural resources that are vulnerable to rising seas and storm surge.

Figure 2. A park ranger uses a survey monument (beneath the center tripod leg), or benchmark, to position an RTK-GPS instrument. These monuments serve as stable reference points when collecting elevation data. Inset: Example of an embedded NPS survey monument, several inches in diameter. Photos courtesy of Michael Bradley, University of Rhode Island Environmental Data Center

HOW ARE ELEVATION DATA COLLECTED?

Elevation data are typically collected in one of three ways:

- Real Time Kinematic Global Positioning System (RTK-GPS) technology;
- Light Detection and Ranging (LiDAR) involving laser sensors attached to airplanes;
- aerial photography.

Researchers must also use land-based reference points, referred to as benchmarks, to collect elevation data (Fig. 2). Benchmarks, installed in the ground, improve the accuracy of elevation data through a process called differential correction. Since each benchmark's elevational position is known to a high level of accuracy, scientists can use this known position to detect and correct slight errors in elevation measurements obtained by GPS. The amount of error measured in the ground surveys can be extrapolated to unmeasured sites, thus defining the accuracy of future GPS measurements. Benchmarks can be damaged or moved during significant storm events, and it is critical to replace them in order for researchers to continue monitoring elevation change.

HOW ARE ELEVATION MAPS USED?

Elevation data from storm-prone coastal areas can be used to model the changes in natural and built environments as a result of storms and to predict the effects of future storms and sea level rise in those areas. The following are some examples of how these data are used:

- Modeling inundation scenarios: Many models used by coastal managers incorporate elevation mapping to assess risk and damage from inundation at coastal sites. For example, the Coastal Vulnerability Index (CVI) was developed and used at the Cape Cod National Seashore to classify the vulnerability of shoreline segments to future sea level rise (Fig. 3).[6] In addition to classifying vulnerability, elevation data can contribute to the formation of predictive inundation maps that forecast storm damage and sea level rise. DEMs demonstrate how sea level rise will change coastal

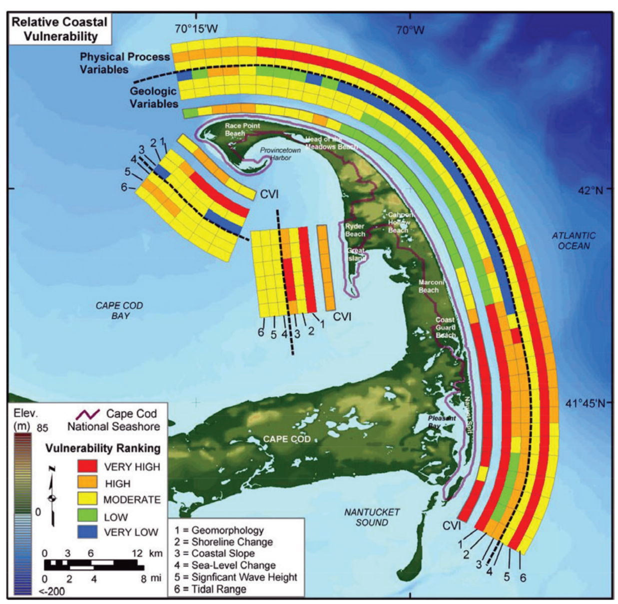


Figure 3. Relative Coastal Vulnerability, Cape Cod National Seashore. Rankings from data regarding geological coastal structure and how water inundation may affect shorelines. Warmer colors represent high risk, cooler colors low risk. Color bar closest to the coast represents the overall coastal vulnerability index, bars 1–6 represent geologic variables, as noted in the figure. Hammar-Klose, E.S., E.A. Pendleton, E.R. Thieler, and S.J. Williams, 2003, Coastal Vulnerability Assessment of Cape Cod National Seashore to Sea-Level Rise: U.S. Geological Survey Open-File Report 02-233, accessed August 13, 2014, at http://pubs.usgs.gov/of/2002/of02-233/index.html.

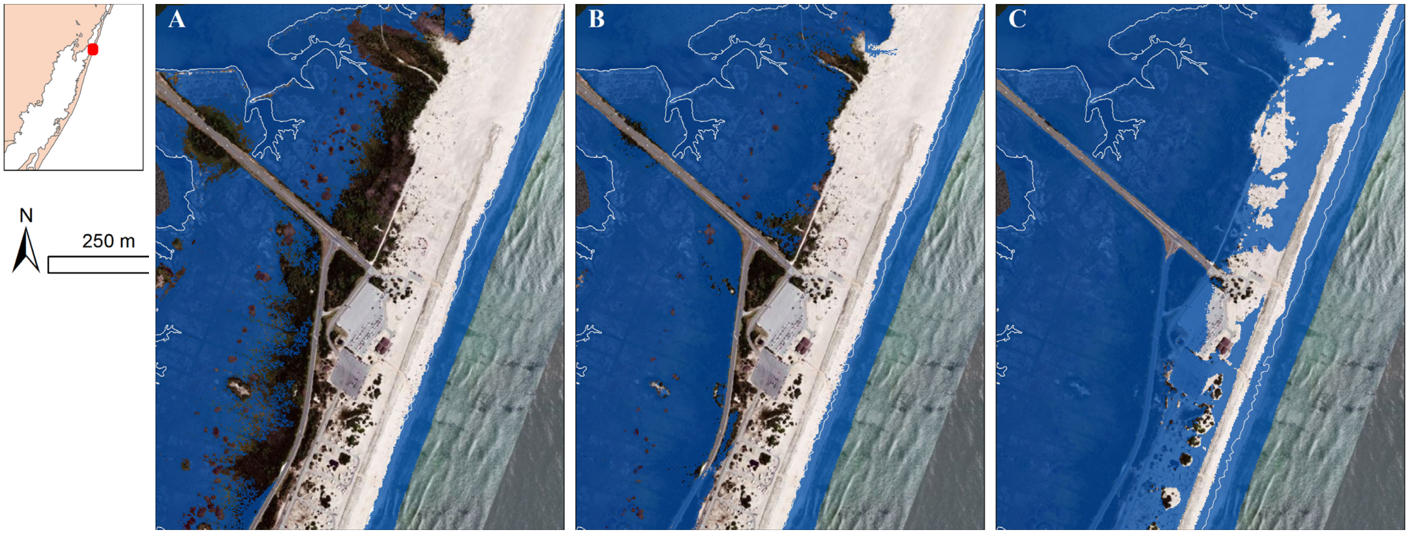


Figure 4. DEMs show how sea level rise will translate to coastal inundation near Verrazano Bridge, Assateague Island, MD. A. With 0.6 meters of sea level rise, the bridge and other coastal features are still above sea level. B. Sea level rise up to one meter would partially cover the shoreline as well as a portion of road near the bridge, as indicated by the blue shading over the southern road segment. C. After two meters of sea level rise, most of the island would be inundated, including a significant portion of the road. Retrieved from Murdukhayeva, *et al.*, 2013: http://dx.doi.org/10.2112/JCOASTRES-D-12-00196.1

features and shorelines, such as along the coast of Assateague Island, MD (Fig. 4). These models provide critical information to local governments for determining protective strategies in coastal zones.

• Measuring changes to shoreline and beach profiles: Beaches are subject to rapid gains or losses in elevation during coastal storms. The Pea Island National Wildlife Refuge, part of the Outer Banks off of North Carolina, was severely damaged by Hurricane Sandy. The U.S. Geological Survey used LiDAR-based elevation data to construct elevation maps comparing the shoreline and beach profile before and after Hurricane Sandy (Fig. 5). Elevation maps showed that the shoreline retreated on both the eastern and western sides of the island, causing sand dunes to be overwashed into salt marshes and roads.[7] These measurements and maps are essential tools for prioritizing steps to repair and protect these sensitive barrier islands and their natural and economic resources.

INFLUENCE OF TIDAL DATA

Creating elevation maps and modeling complex processes are made more difficult by the rise and fall of the tides. Tide data must be considered when creating inundation maps because, when coupled with sea level rise or storm surges, tides can significantly amplify coastal inundation. The combination of local tide data and elevation data will increase the spatial and temporal accuracy of predictive, site-specific models for managers. Scientists at the National Oceanic and Atmospheric Administration have been using long-term tide gauge records to monitor sea levels since the mid-1800s. Hurricane Sandy damaged or destroyed 73 tide gauges on the U.S. east coast,[5] which has hindered the progress of researchers attempting to evaluate and assess post-Sandy damage and future needs. Replacement of these tide gauges and installation of new gauges in areas where there are gaps in tide data are imperative for accurate measurement of inundation, erosion, and vulnerability of coastal resources.

• Monitoring critical coastal habitats: Physical changes to shorelines also have a significant effect on local wildlife, and elevation mapping can help predict population abundance and distribution changes. The National Wildlife Federation has done in-depth analysis of the Pacific Northwest using the Sea Level Affecting Marshes Model (SLAMM), version 5.0, which incorporates USGS elevation data, tidal gauge data, and regional ecosystem data to project future changes to coastal habitats. Among the changes projected was a loss of coastal marsh and tidal flat area, which would reduce spawning grounds for forage fish and Chinook salmon. These organisms, critical to the Pacific Northwest coastal food web, would experience a decrease in population size that could, in turn, shift other populations dependent on them for food, such as Orcas. Additionally, the model predicts a loss in beach area critical for harbor seal pup habitat. Changes to the area would even affect non-local species, such as migratory birds that depend on coastal marshes as a stop-over area.[8] Ultimately, these habitat changes would affect all levels of the ecosystem, indicating the need for adaptation strategies that include strategies to help wildlife cope with a changing shoreline.

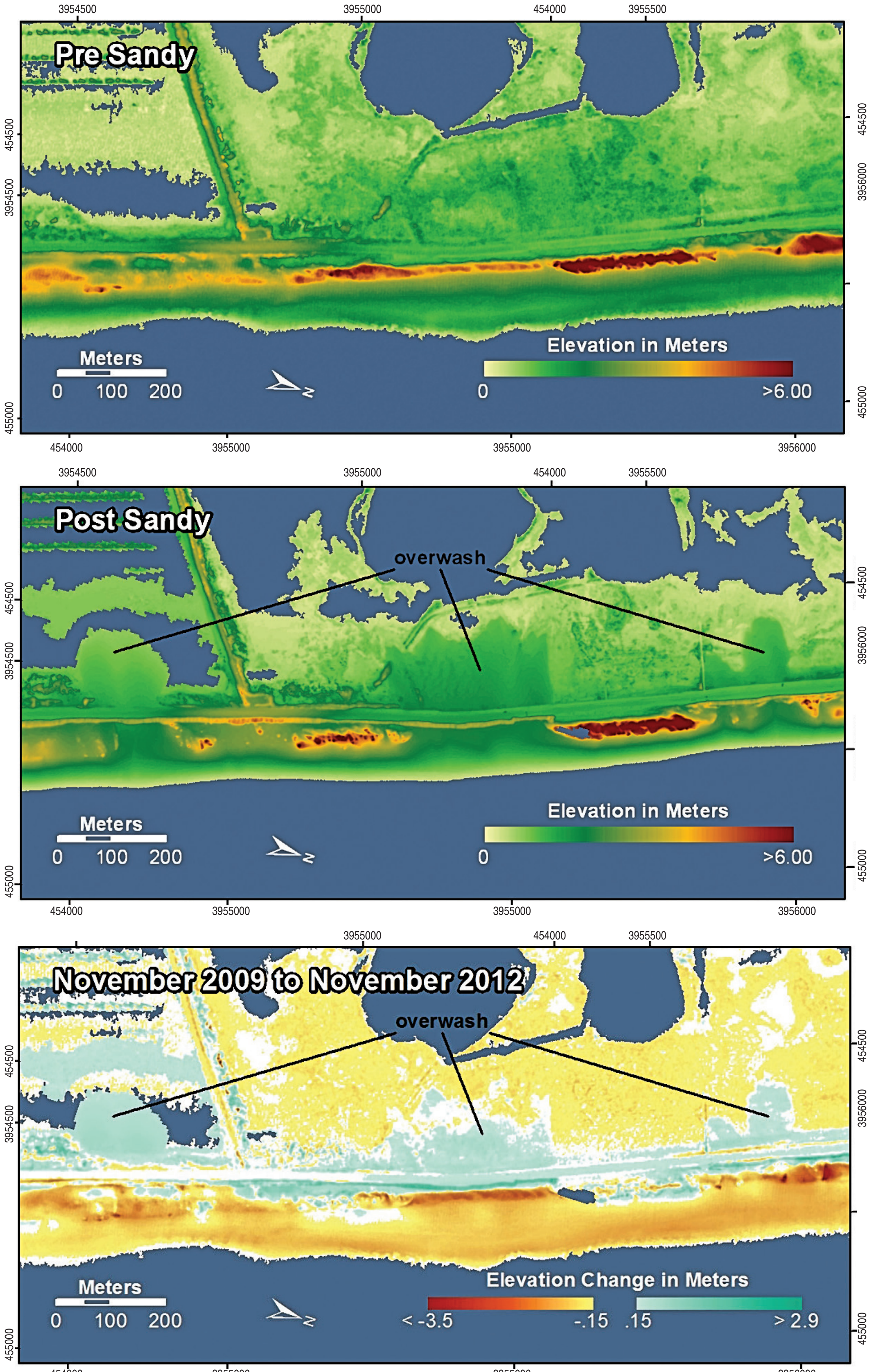


Figure 5. Elevation maps showing the change in shoreline at the Pea Island National Wildlife Refuge, Kinnakeet, NC, before and after Hurricane Sandy. A. Before the storm, the island had a continuous stretch of sand dunes along the shore, depicted by the red band of elevation in the pre-Sandy figure. B. One month after the storm, those sand dunes were destroyed in three places, and sand was overwashed into the central part of the island. C. Overall elevation of the island was reduced adjacent to the ocean and heightened along the main road. Retrieved from http://coastal.er.usgs.gov/hurricanes/sandy/lidar/northcarolina.php

Elevation mapping can be used in countless ways to protect coastal communities, from small seaside business to vulnerable marine fish, mammals, and birds. Incorporating this type of data in management, development, and restoration practices helps communities to better prepare for and protect themselves from further damage.

Figure 6. Shoreline changes in the Pacific Northwest are potentially detrimental to local and regional fish and wildlife species (left to right): Chinook salmon, *Oncorhynchus tshawytscha;* Killer whale, *Orcinus orca;* Pacific harbor seal, *Phoca vitulina* (photo credits: NOAA, http://www.nmfs.noaa.gov/pr/species/); and Western snowy plover, *Charadrius nivosus nivosus*. Photot: Kerry Ross, U.S. Fish and Wildlife Service, http://www.fws.gov/arcata/es/birds/wsp/plover.html

Scientific Sources

Christopher Barrow, The Southeast Region (SER - ACTING) (http://www.nps.gov/gis/contacts)

Marcia Berman, Virginia Institute of Marine Science, Center for Coastal Resources Management (http://ccrm.vims.edu/about_us/people/staff/berman_mr.html)

Michael Bradley, University of Rhode Island Environmental Data Center (http://www.edc.uri.edu/about/staff)

Craig Dalby, Columbia Cascades and Pacific Great Basin Clusters Support Office (http://www.nps.gov/gis/contacts)

David A. Hart, University of Wisconsin Sea Grant Institute (http://maps.aqua.wisc.edu/dhart.htm)

Darcee Killpack, Intermountain Regional Office (http://www.nps.gov/gis/contacts)

Nigel Shaw, National Park Service Northeast Region GIS (http://www.nps.gov/gis/contacts/documents/NER_GIS_Fact_Sheet.htm)

Tim Smith, National Park Service GPS Program (http://www.nps.gov/gis/gps/nps_gps_contacts.html)

Sara Stevens, National Park Service Northeast Coastal and Barrier Network (http://science.nature.nps.gov/im/units/ncbn/about.cfm)

Doug Wilder, Midwest Region GIS RTSC (http://www.nps.gov/gis/contacts)

Other Resources

The National Map, U.S. Geological Survey – use freely available elevation data to create maps: http://nationalmap.gov/index.html

U.S. Geological Survey Center for LiDAR Information, Coordination and Knowledge – learn more about LiDAR and view elevation data: http://lidar.cr.usgs.gov/

NOAA Coastal Services Center Digital Coast – visualizing coastal inundation: http://www.csc.noaa.gov/digitalcoast/inundation/visualize

Southern Fried Science #DrownYourTown – step-by-step instructions to use Google Earth to simulate sea level rise: http://www.southernfriedscience.com/?p=15682 and http://drownyourtown.tumblr.com/

Notes

1. http://www.fema.gov/hurricane-sandy
2. Murdukhayeva, A., P. August, M. Bradley, C. LaBash, and N. Shaw. 2013. "Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks." *Journal of Coastal Research.*
3. http://www.nature.com/nclimate/journal/v2/n12/full/nclimate1597.html
4. http://www.channelcoast.org/southwest/survey_techniques/landbased/?link=rtk_gps.html
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6. Hammar-Klose, E.S., E.A. Pendleton, E.R. Thieler, and S.J. Williams. 2003. Coastal vulnerability assessment of Cape Cod National Seashore (CACO) to sea-level rise. Reston, Virginia: U.S. Geological Survey, Open-File Report 02-233, 23 pgs.
7. http://www.fws.gov/peaisland/
8. http://www.nwf.org/pdf/Wildlife/PacificNWSeaLevelRise.pdf

Figure 7. A large post-Sandy breach at the Jamaica Bay unit of Gateway National Recreation Area. Photo by Roland Duhaime, University of Rhode Island Environmental Data Center