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Assessing the Impact of Hurricanes Irene and Sandy on the Morphology and Modern Sediment Thickness on the Inner Continental Shelf Offshore of Fire Island, New York

Open-File Report 2015–1238

U.S. Department of the Interior
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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 2016

Suggested citation:
Schwab, W.C., Baldwin, W.E., and Denny, J.F., 2016, Assessing the impact of Hurricanes Irene and Sandy on the morphology and modern sediment thickness on the inner continental shelf offshore of Fire Island, New York: U.S. Geological Survey Open-File Report 2015–1238, 15 p., http://dx.doi.org/10.3133/ofr20151238.

ISSN 2331-1258 (online)

Acknowledgments

The authors thank the captain and crew of the motor vessel *Scarlett Isabella* and the research vessel *Shearwater* for their cooperation during the marine geophysical data acquisition. William Danforth, Charles Worley, Eric Moore, Seth Ackerman, and Alex Nichols, all with the U.S. Geological Survey, provided technical support at sea. Andrea Toran of the U.S. Geological Survey was extremely helpful in the publication of this report. The authors thank John Warner and David Foster of the U.S. Geological Survey for their helpful reviews of this manuscript.

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Figures

Conversion Factors

International System of Units to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Velocity	
meter per second (m/s)	3.281	foot per second (ft/s)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Depth, as referred to in this report, refers to distance below the vertical datum.

Abbreviations

GIS	geographic information system
NOAA	National Oceanic and Atmospheric Administration
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

Assessing the Impact of Hurricanes Irene and Sandy on the Morphology and Modern Sediment Thickness on the Inner Continental Shelf Offshore of Fire Island, New York

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Abstract

This report documents the changes in seabed morphology and modern sediment thickness detected on the inner continental shelf offshore of Fire Island, New York, before and after Hurricanes Irene and Sandy made landfall. Comparison of acoustic backscatter imagery, seismic-reflection profiles, and bathymetry collected in 2011 and in 2014 show that sedimentary structures and depositional patterns moved alongshore to the southwest in water depths up to 30 meters during the 3-year period. The measured lateral offset distances range between about 1 and 450 meters with a mean of 20 meters. The mean distances computed indicate that change tended to decrease with increasing water depth. Comparison of isopach maps of modern sediment thickness show that a series of shoreface-attached sand ridges, which are the dominant sedimentary structures offshore of Fire Island, migrated toward the southwest because of erosion of the ridge crests and northeast-facing flanks as well as deposition on the southwest-facing flanks and in troughs between individual ridges. Statistics computed suggest that the modern sediment volume across the about 81 square kilometers of common sea floor mapped in both surveys decreased by 2.8 million cubic meters, which is a mean change of –0.03 meters, which is smaller than the resolution limit of the mapping systems used.

Introduction

Hurricane Sandy, the largest storm on historical record in the Atlantic basin (Blake and others, 2013), made landfall in southern Long Island, New York, and surrounding areas in October 2012 (Hapke and others, 2013). Before this strong storm event, starting in 1996, the U.S. Geological Survey (USGS) had long been involved in research in the region to evaluate the influence of the regional geologic framework on coastal evolution and formulate a conceptual model of sediment flux in the coastal ocean (Schwab and others, 2000, 2013, 2014). In May 2011, the USGS conducted a high-resolution marine geophysical survey of the lower shoreface and inner continental shelf offshore of Fire Island (fig. 1), a barrier island on the southern side of Long Island, using interferometric sonar and seismic-reflection techniques (Schwab, Denny, and Baldwin, 2014). Ultimately, the 2011 survey served to document conditions on the inner continental shelf at Fire Island approximately 6 months before the passage of Hurricane Sandy. The USGS conducted additional surveys in 2014, initially in January and February, to document conditions after the storm in cooperation with the U.S. Army Corps of Engineers (USACE), which served to resurvey the 2011 study area using a high-resolution multibeam echosounder. In October 2014, another survey focused on a series of shoreface-attached sand ridges offshore of western Fire Island, using a high-resolution seismic-reflection profiler (fig. 1). The objectives of the 2014 surveys were to determine the impact of Hurricane Sandy on the inner continental shelf morphology and modern sediment distribution and to broaden the baseline geospatial framework for sediment transport and coastal change model development (U.S. Geological Survey, undated).

This report documents the changes in seabed morphology and modern sediment thickness measured between the mapping investigations from the 2011 (Schwab, Baldwin, and Denny, 2014) and 2014 surveys. Hurricane Sandy produced sustained winds of 25.1 meters per second (m/s) and wave heights as sizeable as 9.7 meters (m), measurements about 25 and 50 percent higher, respectively, than most other large storms during the previous 17 years (Goff and others, 2015; National Oceanic and Atmospheric Administration, undated a). The single exception was Hurricane Irene (August 2011), which impacted the area shortly after the 2011 survey (Schwab, Baldwin, and Denny, 2014) and produced sustained winds of 19.2 m/s and significant wave heights of 7.9 m (Goff and others, 2015; National Oceanic and Atmospheric Administration, undated b). Although Hurricane Sandy was a larger storm event and likely had the greatest impact to the sea floor, Hurricane Irene is also likely to have contributed to the changes to the sea floor revealed by the analyses presented in this report.

Geologic Setting

The southern shore of Long Island west of Southampton, N.Y., consists of reworked glacial outwash associated with the Wisconsinan Laurentide glacial advance (Stone and Borns, 1986) and includes shallow back-barrier bays, marshes, and low-relief, sandy barrier islands (Leatherman and Allen, 1985). Located within this barrier-island system is Fire Island, a 0.5-kilometer (km)-wide, 50-km-long barrier island that is bound by two tidal inlets, Moriches Inlet to the east and Fire Island Inlet to the west (fig. 1), that are managed as navigation channels.

Complete reviews of the major inner continental shelf sedimentary sequences offshore of Fire Island are provided by Schwab, Denny, and Baldwin (2014) and Schwab, Baldwin, Denny, and others (2014). The shallow geologic framework south of Fire Island primarily composes Pleistocene glaciofluvial outwash deposits that are exposed over much of the inner continental shelf (figs. 2 and 3). The upper surface of the outwash is incised by paleochannels (fig. 3) that are filled with a transgressive sequence composing reworked outwash and, in places, caps of lower Holocene muddy estuarine sediment. Where modern sandy deposits unconformably overlie portions of the Pleistocene and lower Holocene units, they clearly define a regional unconformity (termed the Holocene transgressive unconformity) that is interpreted to be a product of Holocene marine transgression (fig. 3). The modern sandy sediments (fig. 2) are derived through erosion of the older sedimentary deposits exposed at the sea floor as the transgression continues (Schwab, Baldwin, Denny, and others, 2014).

Methods

Data Acquisition and Processing

The study area (fig. 1) was surveyed in May 2011 aboard the motor vessel *Scarlett Isabella* using an interferometric sonar to acquire bathymetric and acoustic backscatter data and a chirp seismic-reflection profiler to define the subsurface stratigraphy and structure. The survey area extends about 50 kilometers (km) alongshore and about 8 km offshore in water depths ranging from approximately

8 to 32 meters (m), covering approximately 336 square kilometers (km^2). A full description of the acquisition and processing of these data is provided in Schwab, Denny, and Baldwin (2014).

The study area offshore of Fire Island was resurveyed in January to February 2014 (fig. 1) aboard the research vessel *Shearwater* using a multibeam echosounder to acquire bathymetric (fig. 2*A*) and backscatter data (fig. 4). Details of the acquisition and processing of these data are described in (Denny and others, 2015).

An area about 86 km^2 of prominent shoreface-attached sand ridges offshore of western Fire Island was resurveyed in October 2014 (fig. 1) using the same high-resolution seismic-reflection system used in 2011 to reassess subsurface stratigraphy and structure. The methodology used for data collection, navigation, and processing of seismic-reflection data was identical to that used in the 2011 survey (Schwab, Denny, and Baldwin, 2014). Survey line spacing varied from approximately 75 to 300 m.

Change Analysis

The acoustic backscatter data from the 2011 (Schwab, Baldwin, and Denny, 2014) and 2014 surveys (Denny and others, 2015) were compared to assess morphologic changes before and after major storms on the inner continental shelf. This analysis involved identifying discrete sea-floor features common to both datasets, but perhaps in different locations, by manually digitizing within a geographic information system (GIS) sharp transitions between high and low backscatter along their margins, indicating variation in sediment texture and (or) structure (fig. 4). The digitized transitions for each survey period were stored in a GIS feature class. Additional lines were then digitized between common feature boundaries at roughly perpendicular angles and equal intervals along the lengths of the lines to evaluate lateral offset distances between the locations before and after these major storms (figs. 5 and 6). Basic spatial and statistical analyses were used to assess variability in the magnitude of boundary movements with respect to water depth. Depth contours produced from the bathymetric data from the 2014 survey (fig. 2*B*) were used to spatially query the lateral offset distance lines contained within the areal bounds for four 5-m depth intervals (10 to 14.9 m, 15 to 19.9 m, 20 to 24.9 m, and 25 to 29.9 m). Minimum, maximum, mean, and standard deviation statistics were produced for the lateral offset distance line subsets from each depth interval (fig. 4*C*).

Changes in modern sediment thickness on the inner continental shelf before and after major storms were evaluated by comparing isopachs produced from interpretations of the seismic-reflection data from the 2011 (Schwab, Baldwin, and Denny, 2014) and 2014 surveys (fig. 2). Sediment thicknesses were mapped following the methods described by Schwab, Denny, and Baldwin (2014), in which along-track two-way travel times between the sea floor and the Holocene transgressive unconformity horizon were converted to thicknesses, assuming an internal seismic velocity of 1,500 m/s. The computed along-track sediment thickness values were then interpolated using the natural neighbors algorithm of ArcGIS Spatial Analyst to create 50-meter-per-pixel-gridded isopachs for each survey. The isopach from the 2011 survey (Schwab, Baldwin, and Denny, 2014) was then subtracted from the isopach from the 2014 survey using the raster calculator of ArcGIS Spatial Analyst, yielding a 50-meter-per-pixel-difference grid to illustrate areal patterns of accretion and erosion during the 3-year period within the area common to the two surveys (fig. 7). A vertical resolution of 20 centimeters (cm) is assumed for the sediment volume calculations because of a conservative estimate of the vertical resolution limits of the subbottom profiling system used. However, the change in sediment thickness shown in figure 7 was created using a less conservative vertical resolution of 10 cm to better illustrate net sediment flux.

A comparison of the swath bathymetric surfaces from the 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 (Denny and others, 2015) surveys also clearly identifies geomorphic changes in places (fig. 5*B*), but quantifying that change at the regional scale is not possible because of the vertical resolution limitations of the swath bathymetric systems used. Although the interferometric sonar data from the 2011 survey and the multibeam echosounder data from the 2014 survey show decreased signal-to-noise ratio in the far range, the interferometric sonar data from the 2011 survey show additional data loss in the far range because of interference from the ship's hull and errors introduced because of a lack of sound velocity profiles needed to accurately correct refraction artifacts present in the data (Schwab, Denny, and Baldwin, 2014).

Mapping Results

The patterns apparent in the backscatter data from the 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 (Denny and others, 2015) surveys illustrate the primary sea-floor morphologies on the inner continental shelf, including sorted bedforms offshore of eastern Fire Island, a gravelly lag deposit offshore of central Fire Island, and a field of shoreface-attached sand ridges offshore of western Fire Island (fig. 4). Schwab and others (2013, 2014) provided detailed interpretations of these backscatter patterns, including how some are indicative of net southwestward sediment flux. The analysis of the sharp backscatter transitions in this report, which indicate minor variation in sediment texture and (or) structure, identified in the 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 (Denny and others, 2015) surveys measures lateral offset distances ranging between about 1 and 450 m (with a mean of 20 m) during the 3-year period (fig. 4*C*) and depicts a dominantly southwestward movement of the transitions (figs. 5 and 6). Mean distances computed for changes within the aerial extents of four 5-m-depth intervals indicate that change occurred in water depths up to about 30 meters and tended to decrease with increasing water depth (fig. 4*C*). The greatest change was detected in the area of a borrow pit (last excavated in 2009 for a beach nourishment project) in water depths of about 15 m where comparison of backscatter imagery shows that the southwest-facing flank of a shoreface-attached sand ridge migrated about 450 m southwest toward the borrow pit (fig. 5*A*). A comparison of the bathymetric data from the 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 (Denny and others, 2015) surveys also shows deflation of this ridge flank (fig. 5*B*).

The comparison of modern sediment thickness mapped from the seismic-reflection data from the 2011 (Schwab, Baldwin, and Denny, 2014) and 2014 surveys closely agrees with results from the backscatter analysis, also illustrating what we interpret to be a net southwesterly migration of the shoreface-attached sand ridges. The isopach difference grid indicates a general pattern consisting of erosion on the northeast-facing ridge flanks and crests of the sand ridges and deposition on the southwest-facing ridge flanks and in the troughs adjacent to the southwest-facing ridge flanks (fig. 7). Statistics computed for the difference grid suggest that the modern sediment volume across the 81 km^2 of common sea floor mapped in both surveys decreased by 2.8 million cubic meters, which is a mean thickness change of –0.03 m (below the resolution limit of the seismic-reflection systems used for mapping in this report). The largest magnitude change in sediment thickness (accretion of about 1.3 m) was observed in the same area where the largest magnitude morphologic change was observed in the backscatter analysis, which is along the eastern margin of the borrow pit area (fig. 5).

Discussion

The results of comparative analyses of change from the data for the periods before and after Hurricanes Irene and Sandy (2011 and 2014 survey data) and by Schwab, Baldwin, and Denny (2014) and Schwab and others (2014) for the 15-year period before the 2011 survey generally agree in the sediment migration direction and the erosion and accretion patterns; a similar analysis was performed for the 15-year period before Hurricanes Irene and Sandy based on data from a survey in 1996–97 and the 2011 survey. Morphologic analyses on backscatter data for the 15-year period and the 3-year period before and after Hurricanes Irene and Sandy indicate predominantly southwestward movement of the sediment distribution patterns, bedforms, and sedimentary structures. The only significantly contrasting observations made from the two analysis periods occurred along the southwestern margins of shoreface-attached sand ridges in water depths less than about 15 m.

During the earlier analysis period, Schwab and others (2013, fig. 8) noted that erosional scarps defining the seaward margins of the ridges had predominantly migrated landward during the 15-year period; in places these scarps define the seaward extent of the toe of the shoreface. From 2011 to 2014, the margins were mostly observed to have moved seaward (fig. 5), but landward motion was also detected at discrete locations along the lengths of the margins. No comparison could be drawn between average bedform movement statistics for the two analysis periods because resolution differences between the backscatter acquired with the towed sidescan in 1996-97 and interferometric sonars in 2011 and 2014 precluded those analyses from being conducted for the 1996–97 to 2011 analysis period (Schwab and others, 2013). However, Goff and others (2015) also presented results comparing the 2011 data (Schwab, Baldwin, and Denny, 2014) with data from two smaller areas surveyed offshore of eastern and western Fire Island after Hurricane Sandy in January 2013. The backscatter analysis results presented in Goff and others (2015) agree well with the comparison of data from the 2011 and 2014 surveys in this report, indicating predominantly western or southwestern bedform migration and a general decrease in the magnitude of change relative to water depth. The measured lateral offset distances of 40 to 75 m in 15-m depths and 0 to 20 m in 20-m water depths in Goff and others (2015) are comparable to the values from the comparison of the data from the 2011 and 2014 surveys over the larger survey area (fig. 4*C*).

The comparison of modern sediment thickness isopachs interpreted from the 1996–97 and 2011 seismic-reflection data (Schwab, Baldwin, and Denny, 2014) was conducted identically to the one presented in this report for the data from the 2011 and 2014 surveys. Calculations of the differences for both analysis periods indicate net southwesterly migration of the shoreface-attached sand ridges, generally showing erosion on the eastern flanks and crests of the ridges and deposition on the western flanks and in the troughs (fig. 7). Results from the 1996–97 and 2011 analysis period indicated substantial accretion along the lower shoreface of western Fire Island, and statistics computed on the difference grid suggested that the modern sediment volume across the about 274 km^2 of common sea floor mapped in both surveys increased by 20.2 million cubic meters during the 15-year period, a mean thickness change of +0.07 m (Schwab, Baldwin, and Denny, 2014). These results suggest that some portion of the predominantly southwestward alongshore net sediment flux is directed shoreward and that erosion of the Pleistocene outwash and lower Holocene channel-fill deposits exposed at the sea floor continues to yield the modern sediment required to balance the coastal sediment budget (Schwab and others, 2013) and maintain the shoreface-attached sand ridges (Schwab, Baldwin, and Denny, 2014).

The observation of net accretion of the modern sediment in the 15-year period between 1996–97 and 2011 (Schwab, Baldwin, and Denny, 2014) and net erosion in the 3-year period between 2011 and

2014 allows speculation as to the dynamics of this shoreface-attached ridge system. During the 15-year period, the sand ridges are maintained by erosion of the Pleistocene glaciofluvial and lower Holocene channel-fill deposits exposed at the sea floor while migrating toward the southwest (Schwab, Baldwin, and Denny, 2014; Schwab, Baldwin, Denny, and others, 2014). The combined impacts of Hurricanes Irene and Sandy caused erosion of the sand ridges, with sediment transported in a general southwesterly direction. Surveys of the shoreface and subaerial components of Fire Island indicate that the eroded sediment was not transferred to the shoreface or adjacent barrier island (Hapke and others, 2013) and thus was transported southwest out of the study area and (or) distributed in a veneer over the glaciofluvial and lower Holocene channel-fill deposits beyond the resolution detected by the seismic-reflection techniques, which is about 20 cm.

Summary

Hurricane Sandy made landfall in southern Long Island, New York, and surrounding areas in October 2012. The U.S. Geological Survey has been involved in research in the region since the mid-1990s to evaluate the influence of the regional geologic framework on coastal evolution and formulate a conceptual model of sediment flux in the coastal ocean. In May 2011, the USGS conducted a high-resolution marine geophysical survey of the lower shoreface and inner continental shelf offshore of Fire Island, a barrier island on the southern side of Long Island, using interferometric sonar and seismic-reflection techniques. The 2011 survey served to document conditions on the inner continental shelf offshore of Fire Island approximately 6 months before the passage of Hurricane Sandy. Additional geophysical surveys in 2014 document conditions after the storm and serve to determine the impact of Hurricane Sandy on the inner continental shelf morphology and modern sediment distribution and to broaden the baseline geospatial framework for sediment transport and coastal change model development.

This report documents the changes in seabed morphology and modern sediment thickness measured between the mapping investigations from the 2011 and 2014 surveys and compares these changes with those detected from mapping surveys conducted in 1996–97 and 2011. Hurricane Sandy produced sustained winds of 25.1 meters per second and wave heights as sizeable as 9.7 meters (m), measurements about 25 and 50 percent higher, respectively, than most other large storms during the previous 17 years, with the exception of Hurricane Irene (August 2011), which impacted the area shortly after the 2011 survey and produced sustained winds of 19.2 meters per second and wave heights of 7.9 m.

Morphologic analyses on backscatter data for the periods from 1996–97 to 2011 and from 2011 to 2014 indicate predominantly southwestward movement of the sediment distribution patterns, bedforms, and sedimentary structures. The only significantly contrasting observations made from the two analysis periods occurred along the southwestern margins of shoreface-attached sand ridges in water depths less than about 15 m.

From 1996–97 to 2011, erosional scarps defining the seaward margins of the ridges had predominantly migrated landward; in places these scarps define the seaward extent of the toe of the shoreface. From 2011 to 2014, the margins were mostly observed to have moved seaward, but landward motion was also detected at discrete locations along the lengths of the margins. Analysis of backscatter transitions indicates predominantly western or southwestern bedform migration and a general decrease in the magnitude of change relative to water depth. The measured lateral offset distances of backscatter transitions identified in the 2011 and 2014 surveys ranges between about 1 and 450 m (with a mean of

20 m) during the 3-year period before and after Hurricane Sandy, and depicts a dominantly southwestward movement of the transitions. Mean distances computed for changes indicate that change occurred in water depths as large as about 30 m and tended to decrease with increasing water depth.

Calculations of the differences for the periods from 1996–97 to 2011 and from 2011 to 2014 indicate net southwesterly migration of the shoreface-attached sand ridges, generally showing erosion on the eastern flanks and crests of the ridges and deposition on the western flanks and in the troughs between them. For 1996–97 to 2011, analysis indicated substantial accretion along the lower shoreface and adjacent inner continental shelf offshore of western Fire Island, and statistics computed on the difference grid suggested that the modern sediment volume across the about 274 square kilometers of common sea floor mapped increased by 20.2 million cubic meters during the 15-year period, a mean thickness change of +0.07 m. These results suggest that some part of the predominantly southwestward alongshore net sediment flux is directed shoreward and that erosion of the Pleistocene outwash and lower Holocene channel-fill deposits exposed at the sea floor continues to yield the modern sediment required to balance the coastal sediment budget and maintain the shoreface-attached sand ridges.

The combined impacts of Hurricanes Irene and Sandy caused erosion of the sand ridges, with sediment transported in a general southwesterly direction. For the period from 2011 to 2014, analysis indicated substantial erosion on the inner continental shelf, and statistics computed on the difference grid suggested that the modern sediment volume across the 81 square kilometers of common sea floor mapped in both surveys decreased by 2.8 million cubic meters, which is a mean thickness change of –0.03 m. Surveys of the shoreface and subaerial components of Fire Island indicate that the eroded sediment was not transferred to the shoreface or adjacent barrier island and thus was transported southwest out of the study area and (or) distributed in a veneer over the glaciofluvial and lower Holocene channel-fill deposits beyond the resolution detected by the seismic-reflection techniques, which is about 20 centimeters.

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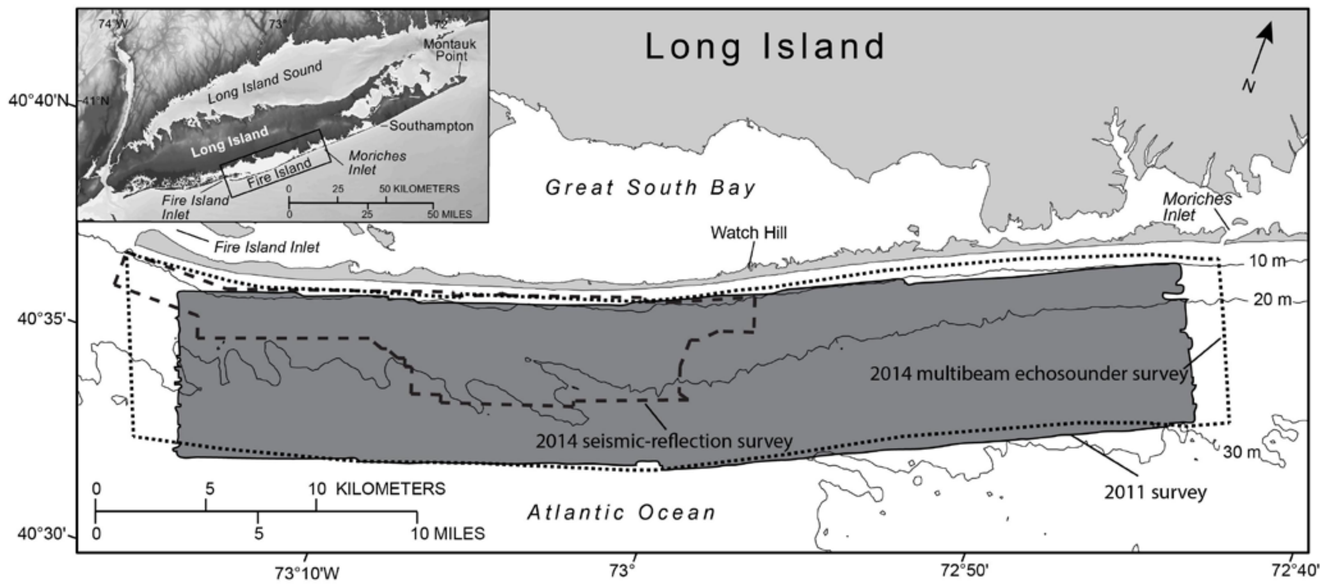

Figure 1. Map showing the 2011 (shaded in dark gray) and 2014 (multibeam ecosounder survey outlined by dotted line and seismic-reflection survey outlined by dashed line) surveys offshore of Fire Island, New York. Inset map shows location of study area (outlined in black). Bathymetric contours are in meters (m) below the North American Vertical Datum of 1988 (NAVD 88). Figure modified from Schwab, Baldwin, and Denny (2014).

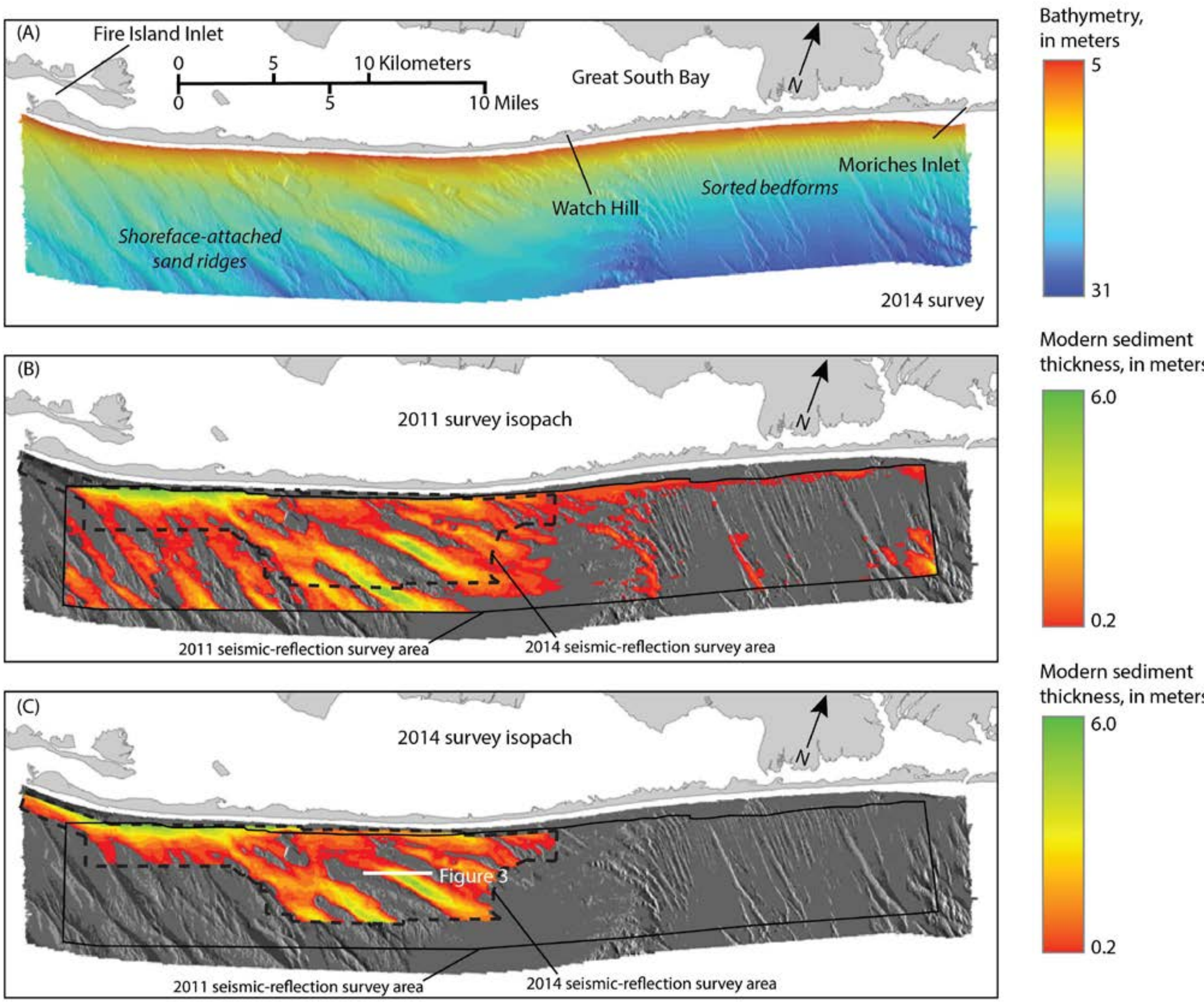

Figure 2. *A*, Map showing the interpolated bathymetric surface generated from multibeam echosounder data collected offshore of Fire Island, New York, in January 2014 (Denny and others, 2015). Bathymetry is in meters (m) below the North American Vertical Datum of 1988 (NAVD 88). *B* and *C*, Maps illustrating isopachs of thickness of modern sediments derived from seismic-reflection data collected in 2011 (Schwab, Baldwin, and Denny, 2014) and 2014, respectively. These isopachs are overlain on the sun-illuminated bathymetric surface derived from the bathymetric surface shown in *A*. West of Watch Hill, the modern sand deposit is organized into a series of shoreface-attached sand ridges oriented obliquely to the shoreline. The Pleistocene glacial outwash units from which the modern sands were reworked are exposed in the troughs between the ridges and across other portions of the Inner Continental Shelf where the modern deposit is absent. The presence of sorted bedforms on the Inner Continental Shelf east of Watch Hill is indicative of this active erosion of the glacial outwash units (Schwab, Baldwin, Denny, and others, 2014).

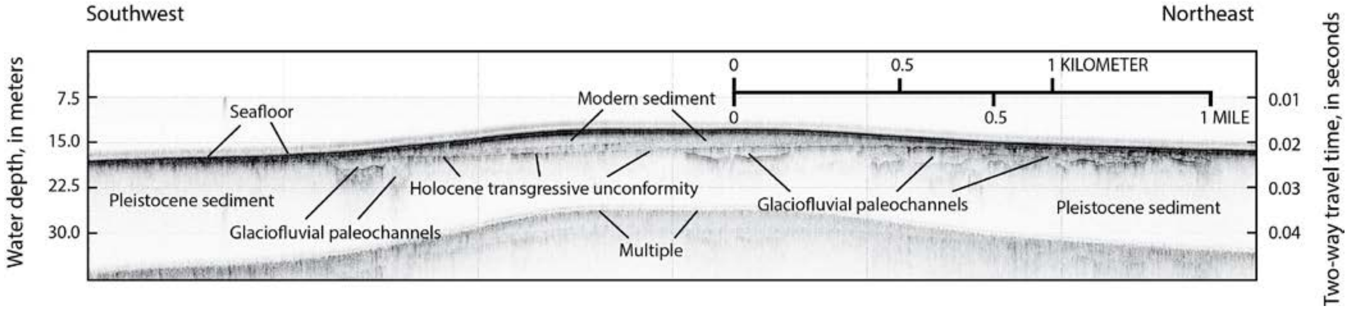

Figure 3. High-resolution chirp seismic-reflection profile illustrating the stratigraphic features and geometries discussed in this report. Location of the profile is shown in figure 2*C*. Approximate water depth in meters was converted from two-way travel time assuming a seismic velocity of 1,500 meters per second.

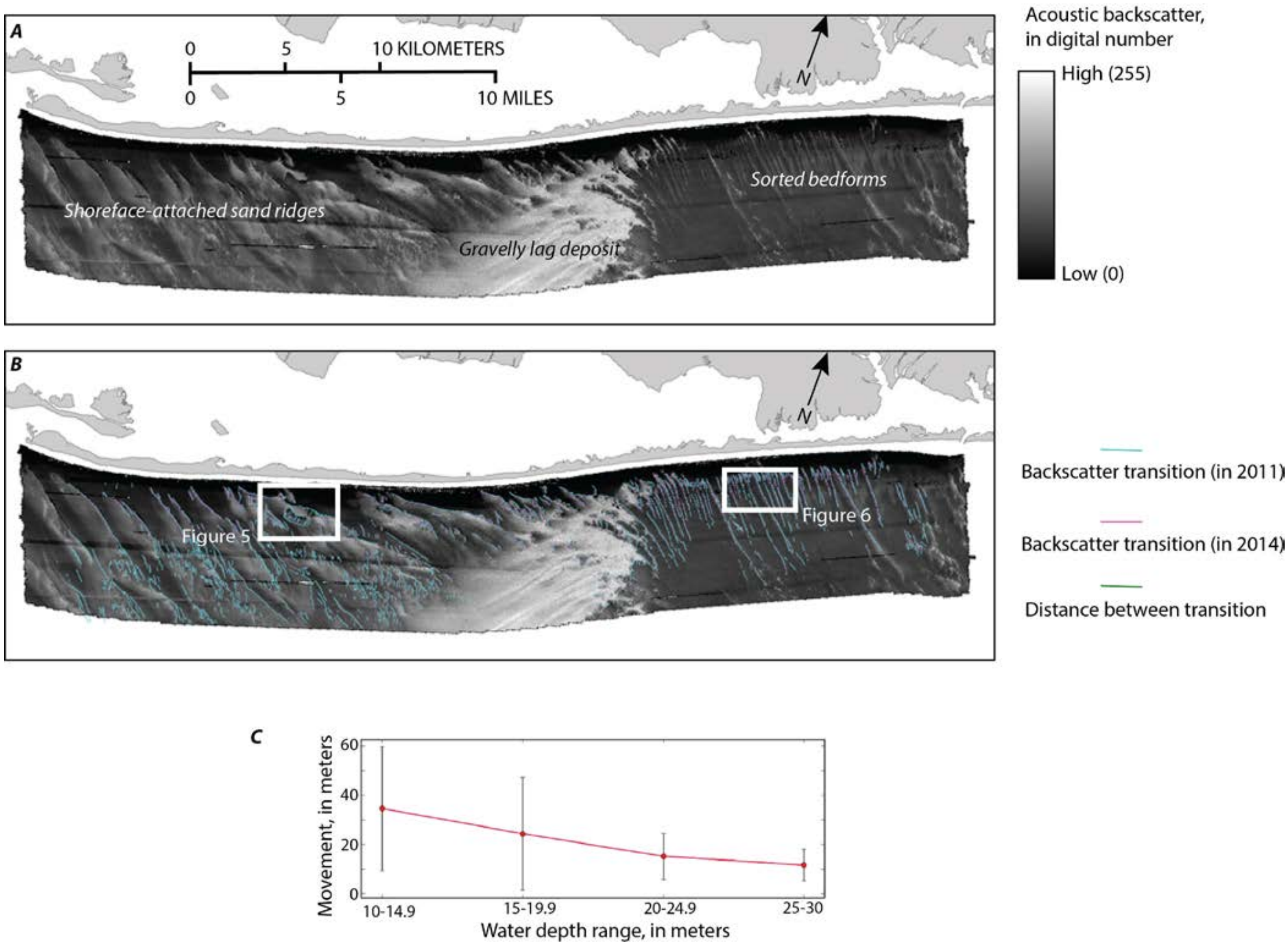

Figure 4. Maps showing *A*, acoustic backscatter data collected using the multibeam echosounder in 2014 (Denny and others, 2015) and *B*, transitions and distances between areas of high- and low-backscatter margins of common sea-floor features digitized from 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 backscatter data. *C*, Graph illustrating the mean movement (in meters) of backscatter transitions within four depth intervals between 2011 and 2014. Vertical bars indicate one standard deviation of mean value.

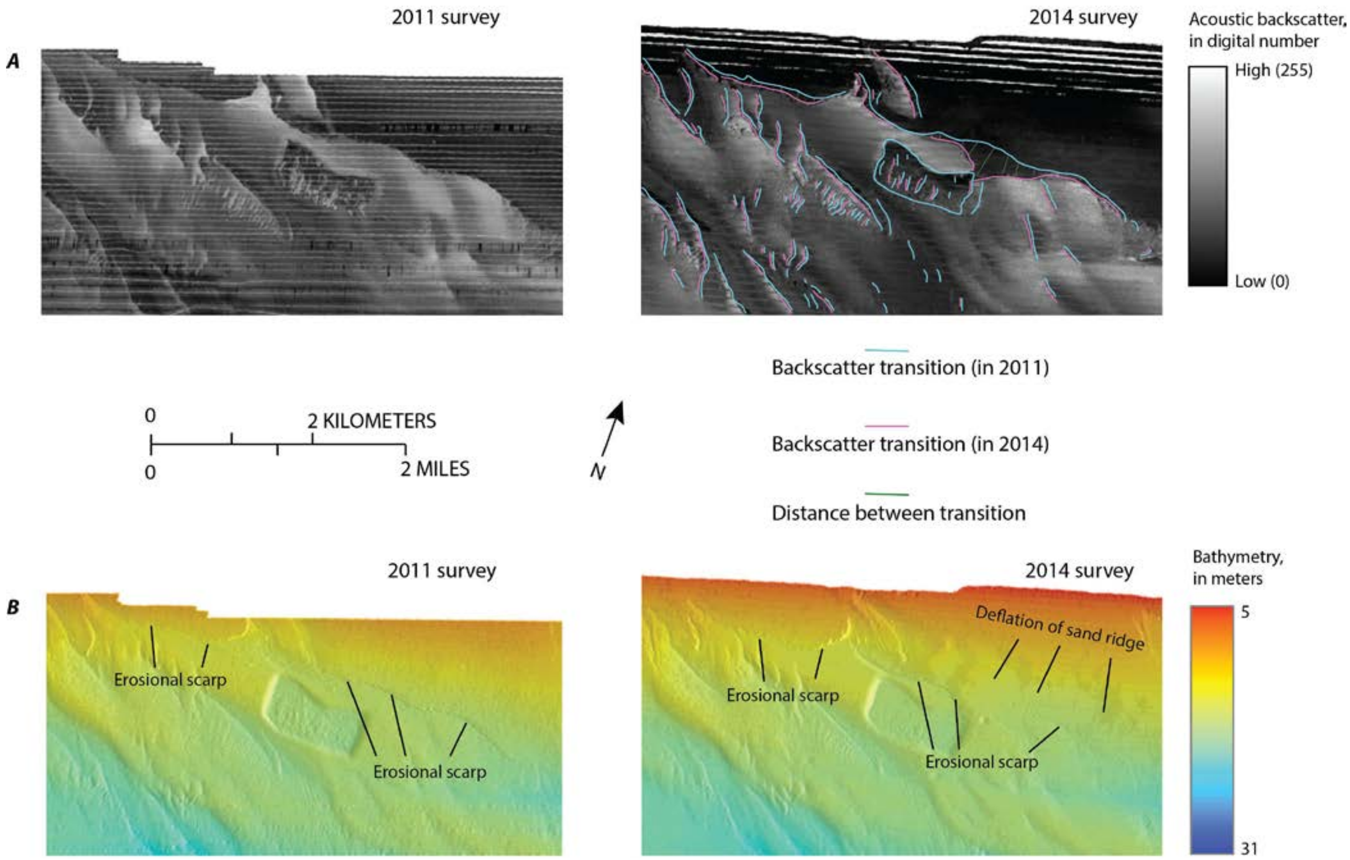

Figure 5. Maps showing *A*, backscatter and *B*, bathymetry collected in 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 (Denny and others, 2015) in the vicinity of a borrow pit offshore of western Fire Island, New York. Location of maps shown on figure 4*B*. *A*, Sharp transitions between areas of high and low backscatter identified along the margins of discrete sediment distribution patterns, bedforms, and sedimentary structures from the 2011 and 2014 surveys are overlain on the backscatter data from the 2014 survey. *B*, Bathymetric data from each survey also illustrates significant change around the borrow pit area.

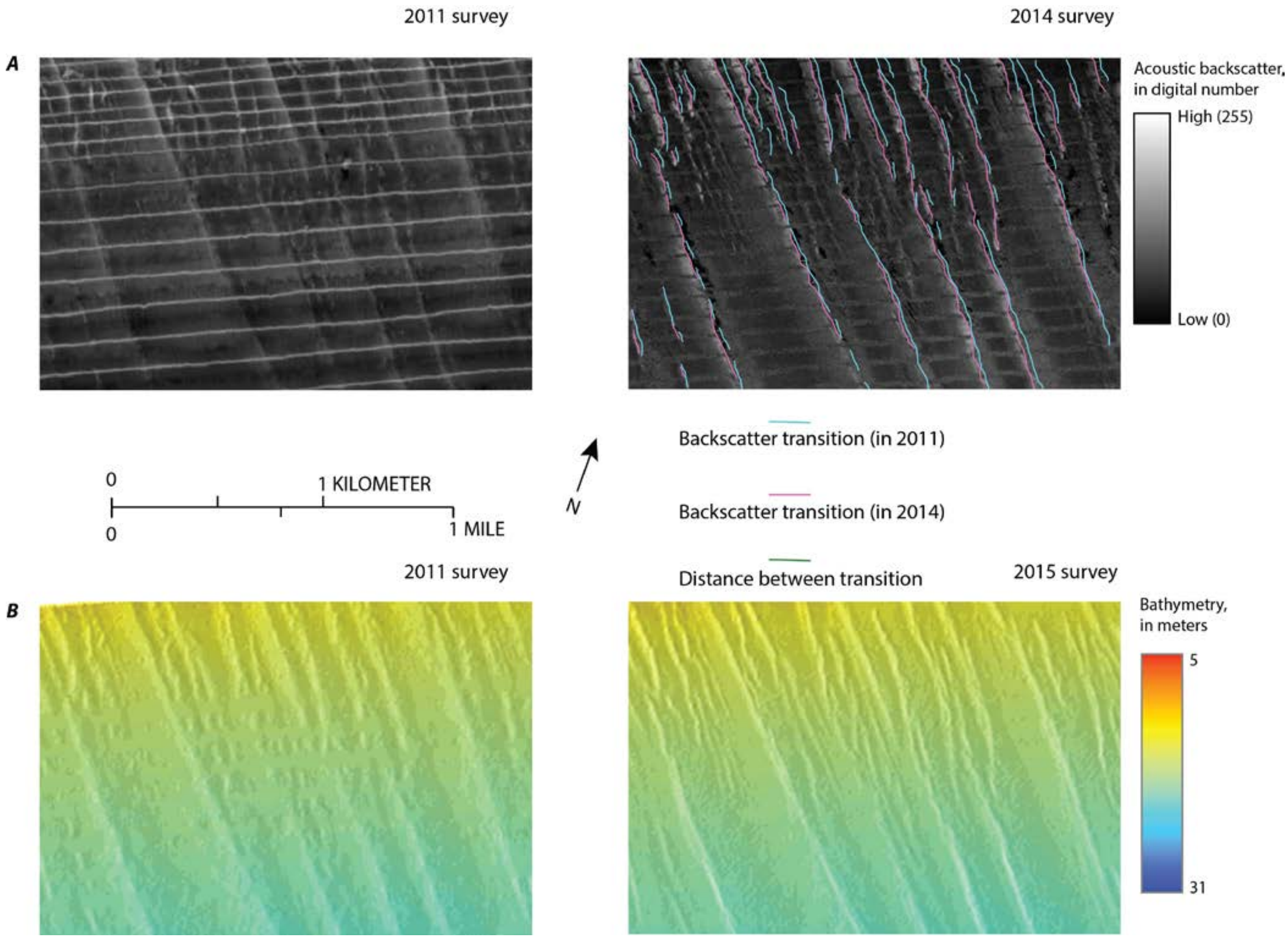

Figure 6. Maps showing *A*, backscatter and *B*, bathymetry collected in 2011 (Schwab, Denny, and Baldwin, 2014) and 2014 (Denny and others, 2015) in an area of sorted bedforms offshore of eastern Fire Island, New York. Location of maps shown on figure 4*B*. *A*, Sharp transitions between high and low backscatter identified along the margins of discrete sediment distribution patterns and sedimentary structures from the 2011 and 2014 surveys are overlain on the backscatter data from the 2014 survey and aid in detecting change. *B*, Coincident bathymetry illustrates that change detection is prohibitive largely because of the subtlety of changes in this area. Change detection is further complicated because of artifacts in the data from the 2011 survey as described in the “Methods” section of this report.

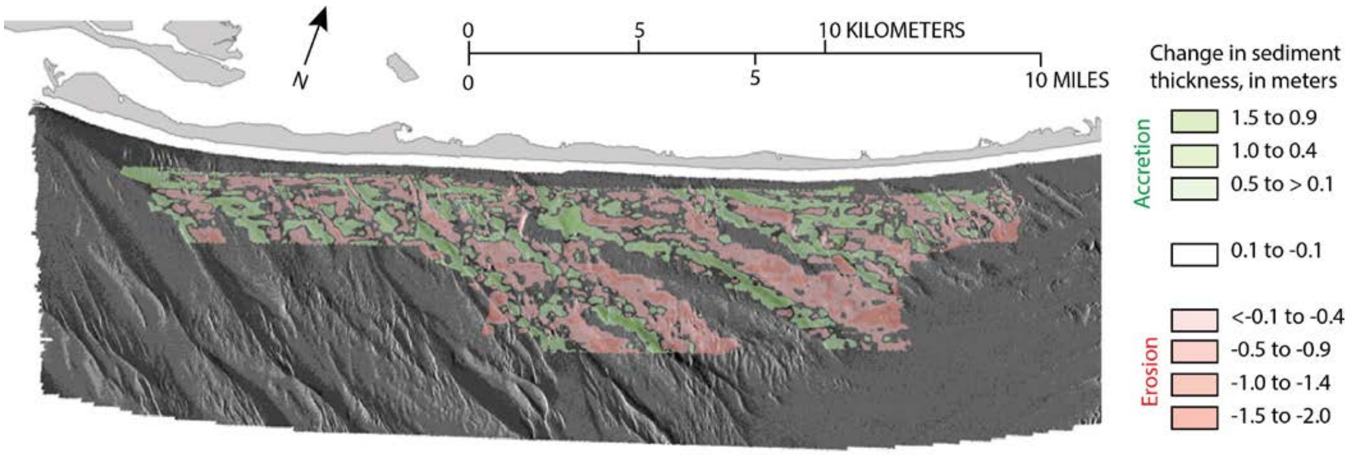

Figure 7. Map showing change in modern sediment thickness in meters between the 2011 (Schwab, Baldwin, and Denny, 2014) and 2014 surveys. A vertical resolution of 20 centimeters (cm) is assumed for the sediment volume calculation because of the resolution limits of the seismic system used. However, the change in sediment thickness is displayed with a less conservative estimate of 10 cm to better illustrate the sediment flux patterns. It is assumed that the majority of this change was a result of Hurricane Sandy.

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Publishing support by:
The Pembroke Publishing Service Center.

Schwab and others—**Impact of Hurricanes Irene and Sandy on Morphology and Modern Sediment Thickness, Inner Continental Shelf, Fire Island, N.Y.**—Open-File Report 2015–1238

ISSN 2331-1258 (online)
http://dx.doi.org/10.3133/ofr20151238