Announcement M13AS00014: Hurricane Sandy Coastal Recovery and Resiliency - Resource Identification, Delineation and Management Practices

Agreement: M14AC00006 Massachusetts Geological Survey/University of Massachusetts; Sand Resource Assessment at Critical Beaches on the Massachusetts Coast

Lead Agency:

Massachusetts Geological Survey/University of Massachusetts

Recipient point of contact information - Principal Investigators

Dr. Stephen Mabee
Massachusetts Geological Survey
University of Massachusetts
Amherst, MA 01003
(413) 545-4814 (Office)
(413) 545-1200 (FAX)
sbmabee@geo.umass.edu

Dr. Jonathan D. Woodruff
Geosciences Department
University of Massachusetts
Amherst, MA 01003
(413) 577-3831 (Office)
(413) 545-1200 (FAX)
woodruff@geo.umass.edu

Technical Report

Authors

Nicholas L. Venti, Ph.D.
Massachusetts Geological Survey
University of Massachusetts
Amherst, MA 01003
(413) 545-2538 (Office)
(413) 545-1200 (FAX)
nventi@geo.umass.edu

Stephen B. Mabee, Ph.D., P.G.
Massachusetts Geological Survey
University of Massachusetts
Amherst, MA 01003
(413) 545-4814 (Office)
(413) 545-1200 (Fax)
sbmabee@geo.umass.edu

Jonathan D. Woodruff, Ph.D.
Geosciences Department
University of Massachusetts
Amherst, MA 01003
(413) 545-4814 (Office)
(413) 545-1200 (Fax)
woodruff@geo.umass.edu

Contributors

Zachary D. Stromer
Douglass Beach
Margot Mansfield

Melanie Koerth
Justin Healey
Sabina Gessay

Paul Southard
Jennifer Jurnack
Hannah Baranes

Abstract

Topographic profiles and grain size analyses were completed for 18 public beaches along the Massachusetts coast that are threatened by erosion, have important infrastructure that is at risk or are in communities with no active coastal management plan. The purpose of this work was to fully characterize the beaches so that beach-compatible material can be identified in off-shore borrow areas. A total of 234 topographic profiles (winter and summer combined) surveyed normal to the beaches plus 889 sediment samples and 86 pebble counts (winter and summer combined) were collected and analyzed for the following beaches: 1) Barges Beach, Gosnold, East and Horseneck Beaches, Westport, Low and Miacomet Beaches, Nantucket, Surf Beach, Falmouth, Town Beach, Oak Bluffs (also referred to as Pay and Inkwell beaches) and Sylvia State Beach, Oak Bluffs and Edgartown during August/September 2014 and March, 2015; and, 2) Humarock Beach, Scituate, Nahant Beach, Nahant, Nantasket Beach, Hull, Peggotty Beach, Scituate, Plum Island, Newbury and Newburyport, Long Beach, Plymouth (referred to as Plymouth), Revere Beach, Revere, Long Beach, Rockport (referred to as Rockport), Fieldston/Brant Rock Beach, Marshfield (collectively referred to as Marshfield hereafter) and Salisbury Beach, Salisbury during August/September, 2015 and March, 2016. Sediment samples/pebble counts were collected at low tide, mid tide, and high tide positions, the berm crest and dune, if present. Between 2 and 10 profiles were surveyed at each beach, depending on the length of the beach, using a Topcon GTS 210 total station and/or a real time kinematic Trimble R8 Global Navigation Satellite System (GNSS) connected to the cellular network. Spacing between profiles ranged from 80 to 600 meters.

Results indicate that increased wave activity during winter strips sand from the intertidal zone. At cobble (till- and moraine-dominated) beaches (Horseneck, East, Barges, Town, Humarock, as well as parts of Nantasket, Peggotty, Marshfield and Plymouth) removal of a summer veneer of sand reveals larger grains below but little appreciable change in profile, whereas at finer-grained sandy beaches (outwash-dominated or extensive barrier beaches) significant loss of berm was observed (Low, Miacomet, Salisbury, and Plum Island). Less berm loss is noted as the deposits become progressively coarser (e.g., Sylvia, Oak Bluffs-Edgartown; Surf, Falmouth). Results of this work will be used to help determine which beaches can or will be nourished with sand from an offsite source.

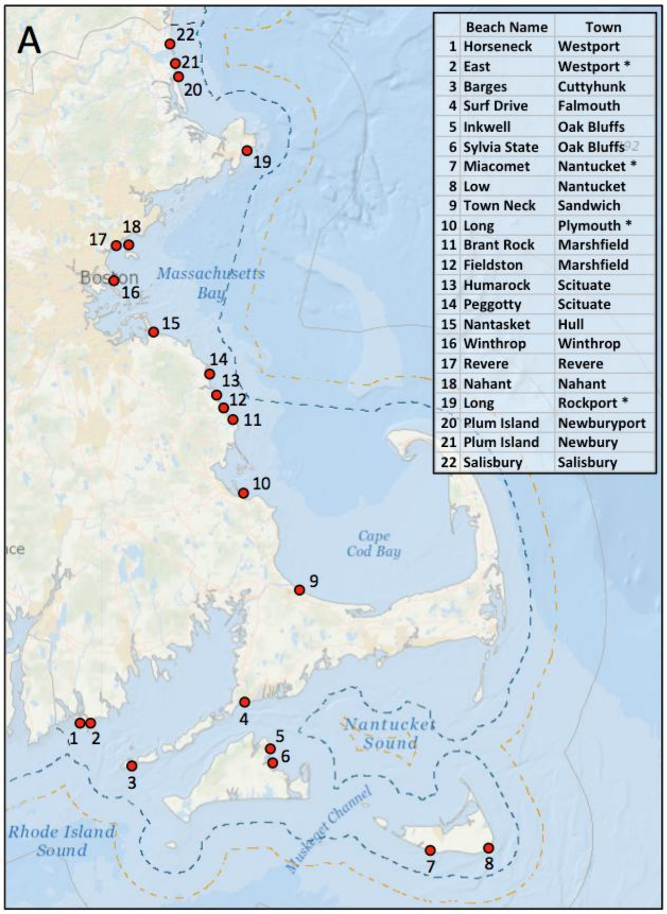
A second objective of this work was to core backbarrier ponds at selected sites to obtain a record of overwash deposits corresponding to intense past storms and provide an estimate of the frequency of major events. Coring was completed at Miacomet Pond, Nantucket, East Beach, Westport, Bartlett Pond, Plymouth, Cambourne Pond, Rockport and a marsh behind Short Beach in Winthrop. However, only Bartlett Pond yielded a usable record suitable for analysis. Work on the core from Bartlett Pond reveals continuous long-term overwash deposits going back as far as 1000 years ago. Analysis of the Bartlett Pond cores show several major storm events that can be linked directly to historic storm events back to 1723. Furthermore, these large events appear to be associated with extra-tropical cyclones (sometimes called nor'easters), not tropical cyclones (hurricanes). This is in contrast to the south-facing shores of Massachusetts (and NYC) where large storm tides are dominated by tropical cyclones. These results point to the importance of considering all the differences in coastal conditions (tidal ranges, different storm populations, etc.) in assessing the return period of flood events. Furthermore, information gained from these historic and sedimentary records also seem to suggest an underassessment of the recurrence

interval of large flood events in the Boston area. Results emphasize the value in combining sedimentological, modeled and historical records of early historical floods for improving these assessments.

Introduction

The following is the technical report for Agreement M14AC00006: Massachusetts Geological Survey/University of Massachusetts – Sand Resource Assessment at Critical Beaches on the Massachusetts Coast. This project has two objectives:

1. Objective 1 is to fully characterize 18 public beaches in Massachusetts that are threatened by erosion or have important infrastructure that is at risk (Figure 1). This characterization includes surveying winter and summer beach profiles and collecting samples for grain size analysis so that beach-compatible material can be identified in off-shore borrow areas. This objective complies with the "sand resources needs assessment" goal of the Marine Minerals Program (MMP). Beach nourishment cannot proceed without an understanding of the existing beach profile and sediment characteristics.
2. Objective 2 provides a better understanding of the frequency of major erosion and overwash events at selected beaches by coring and dating the individual storm event layers within overwash fans. If a substantial investment is planned to nourish a beach it seems prudent to have some understanding of the frequency of overwash events before the investment is made. This objective addresses directly MMP's goal concerning coastal restoration and resiliency.



	Beach Name	Town
1	Horseneck	Westport
2	East	Westport *
3	Barges	Cuttyhunk
4	Surf Drive	Falmouth
5	Inkwell	Oak Bluffs
6	Sylvia State	Oak Bluffs
7	Miacomet	Nantucket *
8	Low	Nantucket
9	Town Neck	Sandwich
10	Long	Plymouth *
11	Brant Rock	Marshfield
12	Fieldston	Marshfield
13	Humarock	Scituate
14	Peggotty	Scituate
15	Nantasket	Hull
16	Winthrop	Winthrop
17	Revere	Revere
18	Nahant	Nahant
19	Long	Rockport *
20	Plum Island	Newburyport
21	Plum Island	Newbury
22	Salisbury	Salisbury

Figure 1. Location of beaches examined in this study. Note: Winthrop (16) and Town Neck (9) in Sandwich are not part of this study. In addition, for the purposes of this study, Brant Rock (11) and Fieldston (12) beaches are lumped as one beach called Marshfield and beaches 20 and 21 are also lumped as one beach (Plum Island) for the purposes of this study giving a total of 18 beaches. Inkwell Beach is synonymous with Town Beach, Oak Bluffs (5); Long Beach, Rockport is referred to as Rockport and Long Beach, Plymouth is referred to as Plymouth to avoid confusion.

Background and Relevance of This Project

Coastal communities in Massachusetts are vulnerable to erosion and relative sea level rise. Extensive development and armoring of shorelines, largely prior to coastal management regulations, have contributed to a severe reduction in the natural supply of sediment to beach systems, resulting in shoreline erosion and loss of dunes—which magnifies the vulnerability of the natural and built environment to coastal storms now and in the future. With accelerated rates of sea level rise and more frequent and intense storms, low-lying coastal areas are increasingly vulnerable to erosion, flooding, and inundation (Woodruff et al., 2013).

Nourishment has significant appeal over armoring approaches that interrupt natural sediment transport. Massachusetts sediment assets, within its nearshore navigation channels and offshore ocean areas, as well as adjacent federal waters, offer great potential for addressing the sediment deficit on beaches. While marine sediments are routinely extracted for beach nourishment and shoreline stabilization projects in other areas of the United States and across the globe, Massachusetts experience has been limited primarily to the beneficial re-use of compatible dredged material and nourishment using upland sources.

The Commonwealth of Massachusetts is now proactively promoting beach nourishment throughout the state. For example, the importance of this issue was recognized by the Coastal Hazards Commission, which was mandated by the state legislature to develop recommendations for addressing coastal hazards issues in Massachusetts. In 2007, the Commission recommended that Massachusetts should ***implement a program of regional sand management through policies, regulations, and activities that promote nourishment as the preferred alternative for coastal hazard protection*** (see www.mass.gov/czm/chc for background, more information, and the full list of recommendations). The 2011 Massachusetts Climate Change Adaptation Report also explicitly promotes the use of soft engineering approaches that supply sediment to resource areas, such as beaches and dunes, to manage the risk to existing coastal development while minimizing adverse impacts to coastal processes (see www.mass.gov/environment/cca for the complete report). In addition, the scope for updating CZM's 2009 Ocean Management Plan includes ***a task to identify appropriate locations for offshore sand resource areas for use as sources of sand for beach nourishment projects***.

Currently, there is an urgent need to assess the viability of nourishing threatened public beaches in the state. In order to advance the analysis and assessment regarding the potential use of offshore sand resources as a beach-nourishment and erosion-management tool, the stage needs to be set with a comprehensive characterization of the shoreline vulnerability and beach nourishment needs. The beach characterization work presented in this technical report focuses on characterizing publicly owned beaches with a history of storm damage. These beaches also have threatened infrastructure and no active management plan for considering the beneficial use of clean, compatible sediments from off-shore sources.

Beach characterizations are designed to provide critical data for informed determinations regarding the volume of sediment that will be required to nourish public beaches currently in the greatest need of protection. An accurate assessment for the viability of any future beach nourishment project therefore requires detailed grain size statistics of the native beach material. Further, the needed fill volume for a beach is dictated by a beaches' slope and equilibrium profile extending off-shore to the depth beyond which changes in bottom elevation are minimal over seasonal-to-annual time scales (i.e. the depth of closure, Nicholls et al., 1998). The grain size distribution of a native beach is one of the primary parameters dictating this equilibrium profile (Dean, 2002), and in turn the volume of sand required to produce a desired extension in beach width. Currently grain size statistics for beaches at greatest risk along the Massachusetts coast are either limited or non-existent, thus placing significant restrictions with respect to assessing the volume of sediment required for their nourishment.

Grain size characterizations of native beach material are also vital to any environmental impact assessment for future nourishment, and critical for assessing potential use conflicts when initially evaluating the overall viability of a project. For example, rocky substrate is commonly viewed as critical habitat for native benthic flora and fauna, which presents a potential roadblock when seeking borrow material to nourish gravel and cobble beaches. Indeed, two of the most recent nourishment projects in the state were rejected due to local concerns on impacts to local benthic habitats. This included a nourishment project on the island of Nantucket that required 2.6 million cubic yards of material from an off-shore borrow site and the nourishment of a beach in the city of Winthrop.

Further, the process often most detrimental to a barrier beach is periods of extreme coastal inundation (Sallenger, 2000). The reoccurrence frequency of extreme coastal flooding must therefore be considered when making any long-term decisions on any nourishment project. Sediments along and behind a barrier beach provide critical information regarding past periods of extreme inundation (e.g. Boldt et al., 2010; Brandon et al., 2013; Donnelly and Woodruff, 2007; Mann et al., 2009; Toomey et al., 2013; Wallace et al., 2014; Woodruff et al., 2013; Woodruff et al., 2008a; Woodruff et al., 2008b, and abstracts by Brandon et al., 2013a; Brandon et al., 2013b). This project uses techniques employed in these past studies to provide regional assessments on the long-term reoccurrence frequency of extreme inundation along Massachusetts coastline.

Methods

All Massachusetts beaches included in this study were selected through close collaboration with the Massachusetts Office of Coastal Zone Management. All fieldwork was performed with permission of local and state authorities, and scheduled based on guidance from the Massachusetts Department of Fish and Wildlife and Department of Conservation and Recreation to avoid endangered nesting shorebirds.

Beaches were surveyed along transects perpendicular to the shore following Massachusetts Office of Coastal Zone Management (CZM) beach nourishment guidelines (MassDEP, 2007). Spacing of transects was designed to capture full variability within these field areas and ranges from less than 100 meters in small field areas to approximately 800 meters between transects in large areas (Table 1). Transects for each beach were initially laid out in the office on the most recent orthophoto images available from MassGIS and equally spaced along the beach providing between 2 and 10 transects per beach. Transect heads were identified in the field using the orthophotos as a guide and then adjusted as needed depending on access and other obstacles or moved to capture beach characteristics. Once transect heads were identified and marked in the field, each transect head was located using a Trimble GeoExplorer 2008 series GPS unit to obtain UTM coordinates (UTM Zone 19T). Flags were set out from the transect head normal to the shore. Spacing of flags were set to capture breaks in slope and changes in surface material

Beach	Town	Coast	Months observed	Surface Material	Length (m)	# Tran-sects	Spacing (m)	# Sam-ples
Horseneck	Westport	south	August-September 2014, March 2015	sand-cobble	700	5	150	44
East	Westport			sand-cobble	400	4	80	34
Barges	Gosnold			sand-boulder	500	5	90	43
Surf	Falmouth			sand-gravel	650	5	150	40
Town	Oak Bluffs			sand-cobble	650	5	120	41
Sylvia	Oak Bl./Edgartn.			sand-gravel	3500	9	350	81
Miacomet	Nantucket			sand	1500	5	350	45
Low	Nantucket			sand	500	5	110	48
Salisbury	Salisbury	east	August-September 2015, March 2016	sand	5500	9	600	90
Plum Island	Newbury(port)			sand	3000	10	300	100
Long	Rockport			sand	900	4	220	24
Long/Nahant	Nahant			sand	2200	6	360	60
Revere	Revere			sand	3800	6	800	50
Nantasket	Hull			sand-cobble	5000	10	600	80
Peggotty	Scituate			sand	200	2	110	20
Humarock	Scituate			sand-cobble	4600	9	500	82
Brant/Fields.	Marshfield			sand-cobble	3000	9	380	54
Long	Plymouth			sand-cobble	4900	9	450	72

Table 1. Summary of surface material, total transect length and average spacing, and number of samples collected at each beach.

along the transect. On slopes, flags were set at the top of the slope, mid slope and at the bottom of the slope. The azimuth of the transect was measured with a Brunton compass so that the transect could be reoccupied in the next season.

In year 1, a TopCon GTS 210 total station and prism were used to survey in the flag positions. A baseline was established for each transect and used to survey the UTM coordinates of each flag. Vertical control was provided by tying the total station into nearby benchmarks in the network of National Geodetic Survey monuments or with local vertical control provided by the town and converted to North American Vertical Datum 1988, if necessary. Horizontal control of the flags is within approximately 1 meter and vertical control within 0.1 meters. In year 2, a Trimble R8 Global Navigation Satellite System, linked to the cellular phone network, was used to survey flag locations. This unit provides direct read out of UTM coordinates (Zone 19T) and elevation in North American Vertical Datum 1988. Horizontal accuracy is within 1 meter and vertical accuracy within 0.1 meters. QA/QC between winter and summer profiles was determined by plotting the profiles in excel and visually comparing the profiles. Any transcription errors were checked against field notes and UTM coordinates in Google earth.

Once data were collected and assembled in a table, the latitude and longitude of each point was calculated using an excel spreadsheet prepared by Steve Dutch, University of Wisconsin-Green Bay dated May 15, 2015. Data used in the conversion included: Datum WGS84, Polar radius 6,356,752.3 meters, Equatorial radius 6,378,137 meters, flattening (f) 0.003353, 1/f = 298.257, UTM Zone 19T, Central meridian -69 degrees, false easting = 500,000, eccentricity = 0.081819, scale factor = 0.9996, mean radius = 6,367,436 meters. The complete method and formulas used to make the UTM to geographic coordinate conversion can be found in Karney, Charles F.F., 2010, Transverse Mercator with an accuracy of a few nanometers, http://geographiclib.sf.net/tm.html Once latitudes and longtitudes were calculated the resulting text files were imported into ArcGIS version 10.03 and converted to shapefiles. In addition, Google Earth KMZ files were also exported from ArcGIS to allow easy viewing of transects on Google Earth images.

Low tide, mid tide, high tide, berm crest and dune positions were identified in the field by a field geologist. Procedures for sampling followed CZM guidelines (MassDEP, 2007). Samples were collected from the top 1 foot of the beach using a shovel. The volume of sample collected depended on the coarseness of the beach material and was collected on the following schedule: a) 100% sand beaches, 1 quart sample bag; b) beaches comprised predominantly of sand but contain a trace to a little very fine to fine gravel, 1 gallon sample bag; c) for beaches comprised of more than 25% gravel and a trace of cobbles, a 2 to 5 gallon bucket was collected; and, d) for beaches comprised of greater than 80% gravel, cobbles or boulders, a pebble count, following the method of Wolman (1954) as described by Kondolf et al. (2003), was performed in the field and no sample was collected (http://onlinelibrary.wiley.com/doi/10.1029/TR035i006p00951/epdf). A minimum of 50 stones were tallied for each pebble count.

The Wolman method uses a gravelometer for tallying different sizes and ranges from 4 mm to greater than 362 mm. The distribution of the varies sizes is determined by randomly selecting the first stone or grain you touch with your finger near the toe of your foot, picking it up and passing the intermediate dimension through the appropriate opening in the gravelometer. These data are then tallied into a cumulative frequency of the number of stones in different size classes and plotted on a grain size distribution curve. If the sampled stones are of the same density, which is assumed, the results obtained are comparable to the distribution by weight. For more information on how to process and plot pebble count data see: http://www.gulfofmaine.org/streambarrierremoval/Stream-Barrier-Removal-Monitoring-Guide-12-19-07.pdf

In this study, the Wolman method was used for this planning-level project in place of ASTM D-422 (Standard Test Method for Particle-Size Analysis of Soils) because of the large volume of sample required for sieving cobble and gravel dominated samples. Traditional grain size analysis (ASTM D-422) should be used for any site-specific projects, consistent with MassDEP's Guide to Best Management Practices for Projects in Massachusetts, Technical Attachments (2007).

Collected samples were returned to the lab and washed to remove salt and organic debris. Samples were washed with a volume of water equal to approximately 12 times the weight of the sample. Once washed samples were dried. Dried samples were then sieved at 4 mm to separate very fine gravel and sand from the coarser material. The coarser material was then sieved at 60 mm to separate gravel from cobbles and then at 256 mm to separate boulders from cobble. At each step the masses were weighed. The plus 4mm material was sieved following ASTM D-422 and using the following meshes: 362mm, 256mm, 180mm, 128mm, 90mm, 60mm, 45mm, 32mm, 25mm, 16mm, 12mm, 9mm, 6mm. Each fraction was weighed and the percent passing determined. The less than 4mm fraction was split to reduce the size to about 25 to 100 grams. The final split was passed through a Retsch Technology Camsizer. This instrument provides high resolution grain size and shape information on particle sizes ranging from 4mm to 0.3 nm. Grain size distribution data are considered reliable if the % difference in sample weights prior to processing and after processing is within 1%. If they are not within 1% the error is investigated by the lab technician and resolved. All data in this study are within 1%.

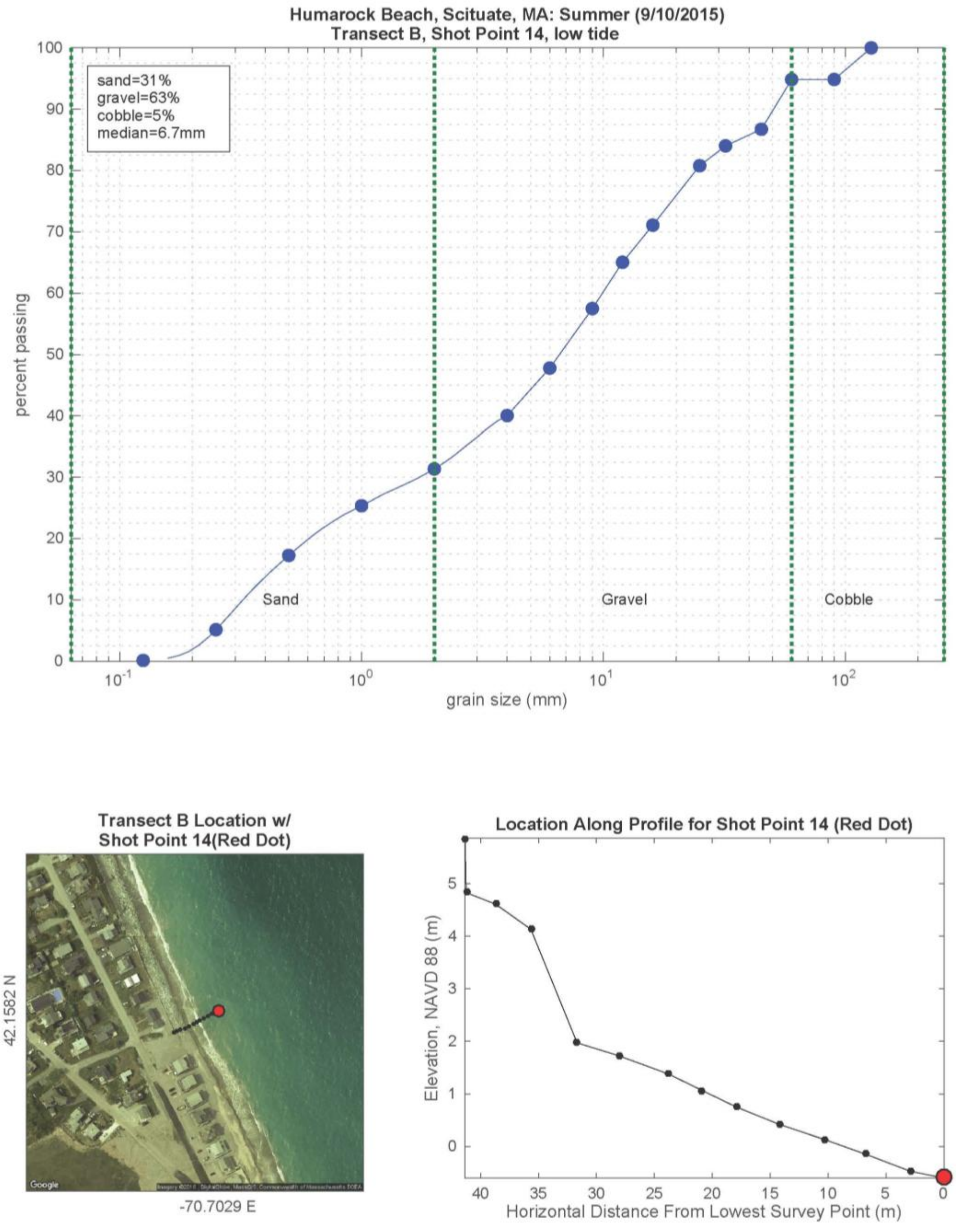
The output from the camsizer provides files in .xle format, which are readable in Excel. Each .xle file in the dataset provides the total mass of the greater than 4mm fraction, total mass of the less than 4mm fraction, percentage of sand fraction, number of splits to reduce size of the less than 4 mm fraction so it can be put into the Camsizer, D_{10}, D_{50}, D_{90} of the less than 4 mm fraction, cumulative distribution, sphericity, symmetry, aspect ratio, proportion (%) of samples with sphericity less than 0.9, proportion (%) of samples with symmetry less than 0.9, proportion (%) of samples with aspect ratio less than 0.9, and number of particle detections.

The camsizer data and sieved plus 4mm fractions were then combined using a script developed in Matlab R2011b (version 7.13.0.564) to produce data tables and plots of grain size versus percent passing. This dataset contains two outputs: 1) a table of data with the grain size, in mm, and the percent passing each grain size; and, 2) a plot showing the cumulative percent passing (percent passing vs. grain size, in mm), a google image showing the transect and location along the transect where the sample was taken including the latitude and longitude of the point, and a profile (cross section) of the beach showing the elevation position of the sample along the transect (Figure 2).

Cores were taken from deposition centers in four back barrier ponds and one marsh. Three cores were acquired from Miacomet Pond on Nantucket, 5 cores at Bartlett Pond behind Whitehorse Beach in Plymouth, 2 cores in Cambourne Pond behind Pebble Beach in Rockport, and a marsh adjacent to Short Beach in Winthrop. Attempts were made to acquire cores in the pond behind East Beach in Westport but too many boulders and cobbles were encountered so the site was abandoned.

Prior to coring bathymetric data was collected in a canoe using a fish finder attached to a hand-held Garmin GPSmap 76S GPS unit. Horizontal accuracy is less than 15 meters. Vertical accuracy with the fish finder is approximately 0.1 meters. The purpose of this bathymetric survey was to locate the best coring locations. Optimal coring sites are those with deep deposition centers that are not in high energy environments and have experienced no human disturbance. Cores were collected using a modified Vohnout/Colinvaux piston corer mounted on a twin canoe coring platform. Typical sediment recovery was 2 to 5 meters. Cores were taken in overlapping ~2 meter sections (ie., D1, D2, etc.). These sections were later cut into 150 cm lengths or less for ease of analysis (ie., 1 of 2, 2 of 2).

Once collected, core sections were transported to the University of Massachusetts and refrigerated until analysis. In the lab, cores were opened and submitted to additional laboratory analyses including X-ray fluorescence (XRF) measurements using a newly acquired Cox Analytical Systems ITRAX XRF core scanner at the University of Massachusetts. The XRF core scanner provides non-destructive, high-resolution (~100 µm) characterization of the bulk elemental composition of sediment and X-radiograph images for cores. This XRF technique has proven to be highly effective by the lead-PI’s lab group in identifying overwash deposition (e.g. Donnelly and Woodruff, 2007; Woodruff et al., 2008a; Woodruff et al., 2009), including event deposits from Hurricane Sandy in backbarrier environments (see published abstracts by Brandon et al., 2013a; Brandon et al., 2013b).



BOEM Hurricane Sandy Relief Project
Massachusetts Geological Survey
UMass-Amherst, Dept. of Geosciences

Figure 2. Example of grain size distribution plot (top) from Transect B, low tide sample in summer 2015 collected at Humarock Beach, Scituate, Massachusetts. Also shown is the location of the sample on the transect (lower left) and location of sample along the beach profile (lower right).

The XRF scan provides relative abundances of 33 elements. Elements such as lead are used as proxies to look for changes in lithology, onset of industrialization, changes in energy regime and changes in the source of deposition. X-radiographs provide a means of identifying sandy layers within the core at high resolution. The sand layers indicate individual storm events, which when linked with an age model, extend the coastal storm flood record back in time beyond the instrumental and historic record.

Based on the x-radiographs, the best core exhibiting a clearest record of sandy overwash and no disturbance was core BAP6 from Bartlett Pond. Therefore, all additional analyses were performed on core BAP6. BAP6 was subsampled at a minimum of every 3 cm at 1 cm resolution and sieved for coarse percentage (greater than 32 microns and 63 microns). Coarse percentages greater than 63 microns of sandy deposits were analyzed on a Retsch Technology camsizer to determine grain size distribution. Additional subsamples were taken from the core to determine organic content via loss on ignition. These subsamples were dried, weighed and then burned at 550 degrees Celsius for 5 hours, cooled and weighted again. The change from dry weight to burned weight compared to the initial dry weight is the loss on ignition and assumed to be related to the percent organic matter.

Temporal constraints on sediment deposition were determined using radiocarbon, cesium-137 (^{137}Cs), and the onset of industrial heavy metals (such as lead). Bulk heavy metal profiles obtained by the XRF core scans were utilized to identify sediments deposited during the industrial era (e.g. Boldt et al., 2010; Woodruff et al., 2013). The global onset of ^{137}Cs in the sediment record corresponds to 1954, or the start of atmospheric nuclear weapons testing, and the peak in ^{137}Cs dates to 1963, or just prior to the signing of the Nuclear Test Ban Treaty. ^{137}Cs was measured using a Canberra GL2020R Low Energy Germanium Detector. Sediment samples with a dry mass greater than 2 grams were powdered, put in 6 cm diameter plastic jars, and counted for 48-96 hours. ^{137}Cs activities were computed spectroscopically using the 661.7 keV photopeak. In the Northeastern U.S., concentrations of heavy metals increase significantly in sediment between 1850 and 1900, corresponding to the rise of factories during the Industrial Revolution. Depth profiles of lead were employed to identify the depth of this industrial horizon. Lead content was measured in all cores with the ITRAX Core Scanner using a Molybdenum tube and operating at 30 kV and 55 mA for 10 seconds per measurement. Measurements of unsupported ^{210}Pb activity ($t_{1/2}$=22.3 yrs) will provide further temporal constraints over the last 100 yrs (e.g. Woodruff et al., 2013; Toomey et al., 2013).

To extend ages beyond heavy metal and ^{137}Cs derived constraints, radiocarbon dates were obtained at sediment depths of 73.5, 125.5, 223, 289.5 and 482.5 cm. Carbon 14 dates were analyzed at the National Ocean Sciences Accelerator Mass Spectrometry lab at Woods Hole, Massachusetts. The radiocarbon age with 1 sigma uncertainties was converted to calendar age probabilities using the IntCal13 radio- carbon calibration curve. Monte Carlo simulations were employed to derive Bayesian age constraints between chronological controls. For each of the large number of simulations a discrete age is drawn randomly from the sample's obtained probability radiocarbon-derived distribution. A specific age is defined for the 1963 and 1954 ^{137}Cs constraints, and a randomly drawn age between 1850 and 1900 for the heavy metal onset, with probabilities evenly distributed over this 1850 -1900 interval. A date of 2014 was also defined at the top of the core. Random ages were generated at random depths between the radiocarbon, ^{137}Cs, and heavy metal control points such that ages increase monotonically with depth (i.e. no age reversals). The median of all simulations for a particular depth is defined as the most likely age, with bounds presented for 68% and 95% uncertainties. A complete description of the age modeling procedure is described in Brandon, C., Woodruff, J.D., and Donnelly, J.P., 2014, How Unique was Hurricane Sandy? Sedimentary Reconstructions of Extreme Flooding from New York Harbor. Scientific Reports (http://www.geo.umass.edu/faculty/woodruff/Publications_files/Brandon_etal_ScientificReports2014.pdf)

Results

Year 1 - South Coast

Seasonal changes in beach grain size vary with surficial geology (Figure 3). Beaches near till or moraines (East, Horseneck, Barges, Town and Sylvia) are characterized by a mixture of sand, gravel, and cobble, whereas beaches adjacent to glacial outwash (Surf, Miacomet, Low) are cobble free (Table 1). Grain size of berm and dune facies show little change from summer to winter. Cobble armors the high tide/berm facies transition year-round at Barges Beach, East Beach and Horseneck Beach, and fore dunes at Horseneck and Barges Beaches are cobble-veneered (Figure 4). Upper beach facies at Surf Beach, Town Beach and Sylvia State Beach are sandy with gravel interspersed, and berm and dunes at the Nantucket beaches are composed exclusively of sand.

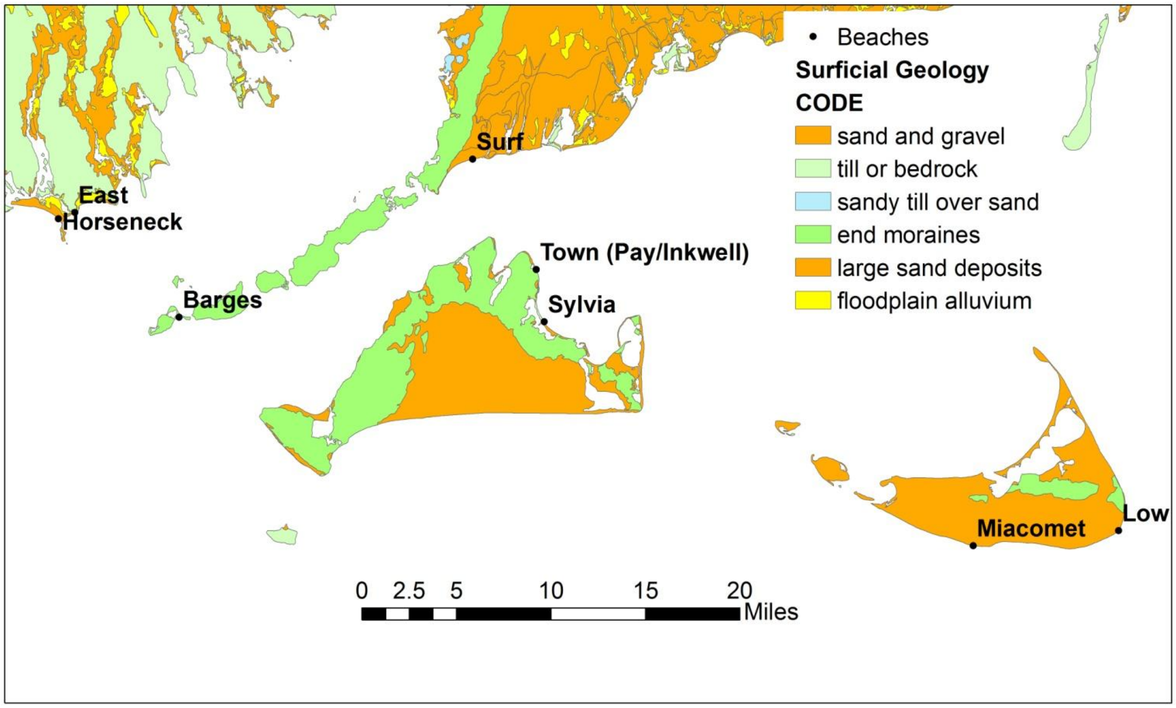


Figure 3. Surficial geology of Massachusetts south coast (Stone and DiGiacomo-Cohen, 2010) showing study sites adjacent to till/moraine and outwash. Figure reproduced from Venti et al. (2015).

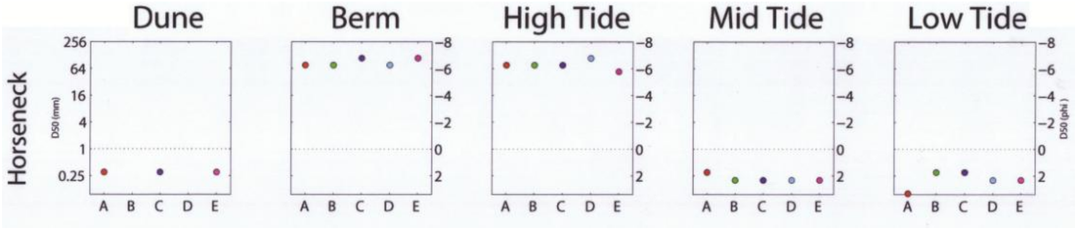


Figure 4. Median grain size at Horseneck Beach, summer 2014. Cobble dominates berm and high tide facies; fine and medium sand characterize low and mid-tide facies (from Venti et al., 2015). Letters are transects, mm on left y-axis, phi scale on right y-axis.

Grain size becomes coarser in the intertidal zone during the winter compared to summer, particularly at the low tide facies (Table 2). Sand or very fine gravel form a veneer at all beaches in the summer but beaches derived from till/moraines (East, Horseneck, Barges, Town) show a significant coarsening in the winter (Table 2). Intertidal zones at beaches derived from distal outwash deposits (Low, Miacomet, Surf) show little to no change in grain size from summer to winter (Table 2).

Table 2: Summary of profile and median grain size changes on south coast beaches in Year 1.

Beach	Range of winter retreat (m)	Average winter retreat (m)	summer low tide grain size (φ)	Winter low tide grain size (φ)	LT Grain size change (φ)
Horseneck	-1 – 4	1	medium sand (1 – 2)	very fine gravel (-2 – -1)	-3
East	-3 – 3	0	coarse sand (0 – 1)	medium gravel (-4 – -3)	-4
Barges	-2 – 5	1.2	medium sand (1 – 2)	fine gravel (-3 – 2)	-4
Surf	0 – 2	1.2	very fine gravel (-2 – -1)	fine gravel (-3 – -2)	-1
Town	0 – 4	2.1	coarse sand (0 – 1)	coarse gravel (-5 – -4)	-5
Sylvia	-5 – 2	-0.7	very fine gravel (-2 – -1)	very fine gravel (-2 – -1)	0
Miacomet	-10 – 20	10	coarse sand (0 – 1)	coarse sand (0 – 1)	0
Low	-10 – 5	0	coarse sand (0 – 1)	coarse sand (0 – 1)	0

Berm and intertidal facies generally migrate landward along the south coast beaches during winter (Table 2). At cobble- and gravel-bearing beaches (Horseneck, East, Barges, Surf, Town, and Sylvia), these facies migrate short distances, <5 m at individual transects, with average landward migration distances between -0.7 and 2.1 meters (Table 2). Seasonal profile variability is more dynamic at beaches that lack these larger, less mobile grains. Facies at Miacomet Beach and Low Beach, composed exclusively of sand, migrate the farthest, up to 20 meters on two transects on Miacomet Beach (Table 2, Figure 5).

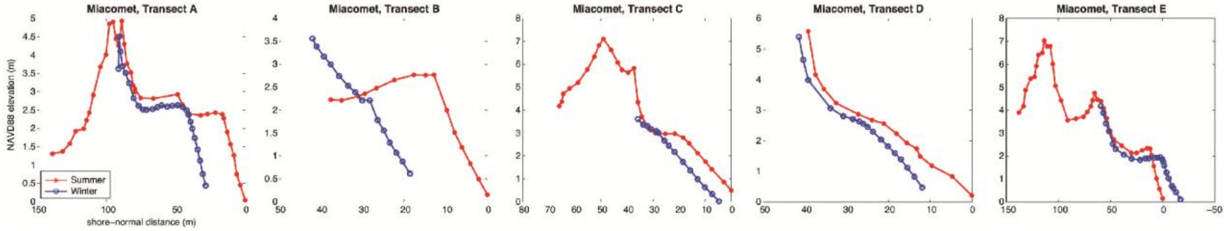


Figure 5. Shore-normal transects at Miacomet Beach illustrate landward retreat of intertidal and berm facies from summer (red) to winter (blue) in an environment lacking gravel and cobble (from Healey et al., 2015).

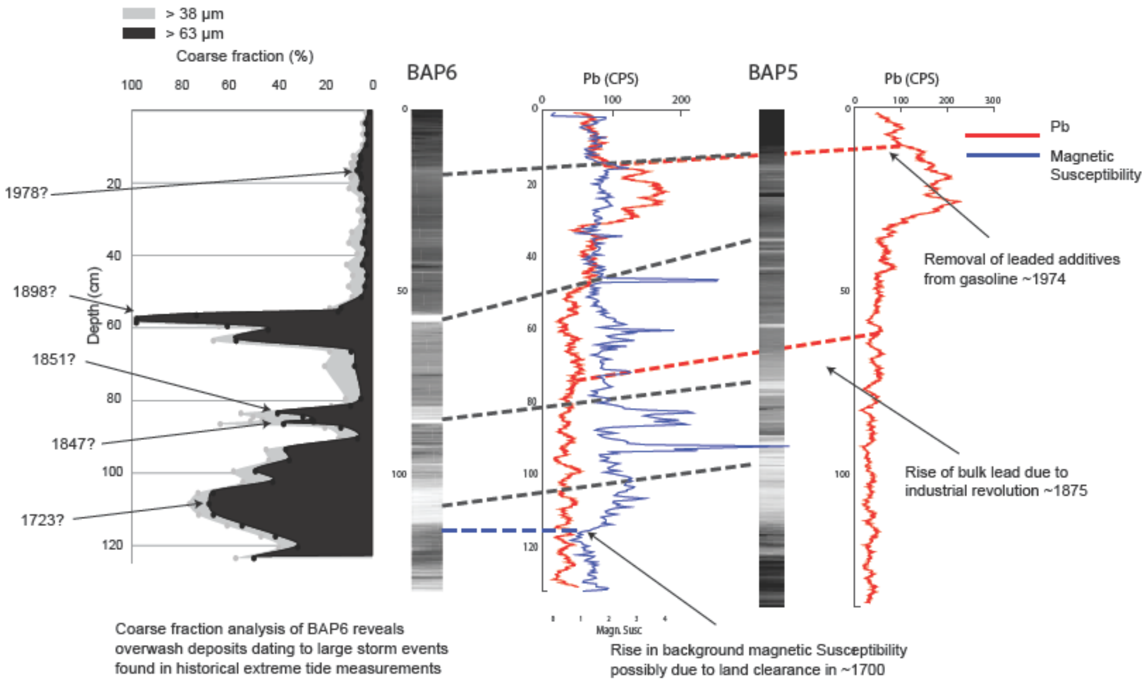
External factors might explain cases that do not fit the patterns described above. For example, Sylvia State Beach showed little change between winter and summer profiles and no change in median grain size. It is understood that sand may have been added to a portion of Sylvia State Reservation in October, 2014, between summer and winter surveys, possibly resulting in the minimal change in profile observed. Similarly, transects C and D at Low Beach showed an enhanced winter profile possibly due to the intersection of southward and eastward directed long-shore transport at that location (Figure 3). In general, grain size and profile results indicate a net loss of finer grains (sand) from beaches during the winter.

Year 2 – East Coast

East-facing beaches showed similar trends as observed on south-facing beaches, however, the changes between summer and winter in Year 2 were not as dramatic as Year 1. The difference may be explained by fewer winter storms in Year 2. Gradients, particularly in upper facies (berms and dunes), were steepened due to incision by wave action. However, in many cases the volume removed appears to be redistributed to lower facies resulting in a change in the profile but not a major change in net sediment volume. In select areas, for example, the mouth of the Merrimack River at Plum Island near Transects A and B and also further south in the bluff at Transect I, there was dramatic loss of sediment. In these cases, the loss of material extended into the dune indicating this magnitude of loss exceeds the expected seasonal cycle. A coarsening of material was observed in many locations between summer and winter indicating winnowing of finer sediment (i.e., sand size material) during the winter season. In addition, the most dramatic change in profile corresponds to sections of beach lacking coarser material (cobble and coarse gravel). In general, the pattern of coarse material associated with neighboring source areas of glacial till is generally consistent with that observed on the south shore. However, this pattern is not as well developed as on the south coast. The east coast beaches exhibit greater heterogeneity in the surficial materials than the more expansive surficial deposits found on the south shore.

Coring Results

The cores from Miacomet Pond on Nantucket and Cambourne Pond in Rockport could not be used for detailed analysis. The Cambourne Pond core was too shallow and was located in too energetic an environment. In other words, the deposits were disturbed by every large storm preventing preservation of any record of historic events. At Miacomet Pond, periodic opening of the barrier beach to flush the system eroded the sediments producing a gap in the sedimentary record; the core is not continuous. Only Bartlett Pond core BAP6 provided the best continuous sediment record (Figure 6).



Removal of leaded additives from gasoline ~1974

Rise of bulk lead due to industrial revolution ~1875

Coarse fraction analysis of BAP6 reveals overwash deposits dating to large storm events found in historical extreme tide measurements

Rise in background magnetic Susceptibility possibly due to land clearance in ~1700

Figure 6. Results of core scans and grain size analyses on cores BAP5 and BAP6 from Bartlett Pond. Grain size analyses on core BAP6 (left) showing sand peaks associated with storm events. Lead and magnetic susceptibility help constrain the age model for each core. Bright sections in core scan represents sandier storm event layers (from Stromer et al., 2015).

Results from Bartlett Pond indicate the pond preserves a 1000-year record of extreme events. Historic coastal flood events recorded in the core, among others, include the Blizzard 1978, the Christmas Storm of 1909, the 1851 Minot Light storm, Benjamin Franklin's eclipse storm of 1743, and a particularly large storm in 1723 recorded by the Reverend Cotton Mather. The data also suggest an increase in extra-tropical events causing large floods north of the Cape prior to 1909. This record of coastal flood events near Boston extends our knowledge of known extreme events back at least 300 years. In addition, analysis of dating, historic records and review of the instrumental tide gauge records on the east-facing shores of Massachusetts indicate that these coastal flood events are dominated by non-tropical cyclone events and generalized extreme value theory (GEV) seems to describe the data reasonably well (Figure 7). However, data from the south-facing shores show that the largest events are predominantly tropical cyclones. Standard GEV analysis fails for the southern facing shore due to the mixture of two different populations of storms (i.e. tropical and extra-tropical), whose flooding behavior is different along southern facing coastlines of New England.

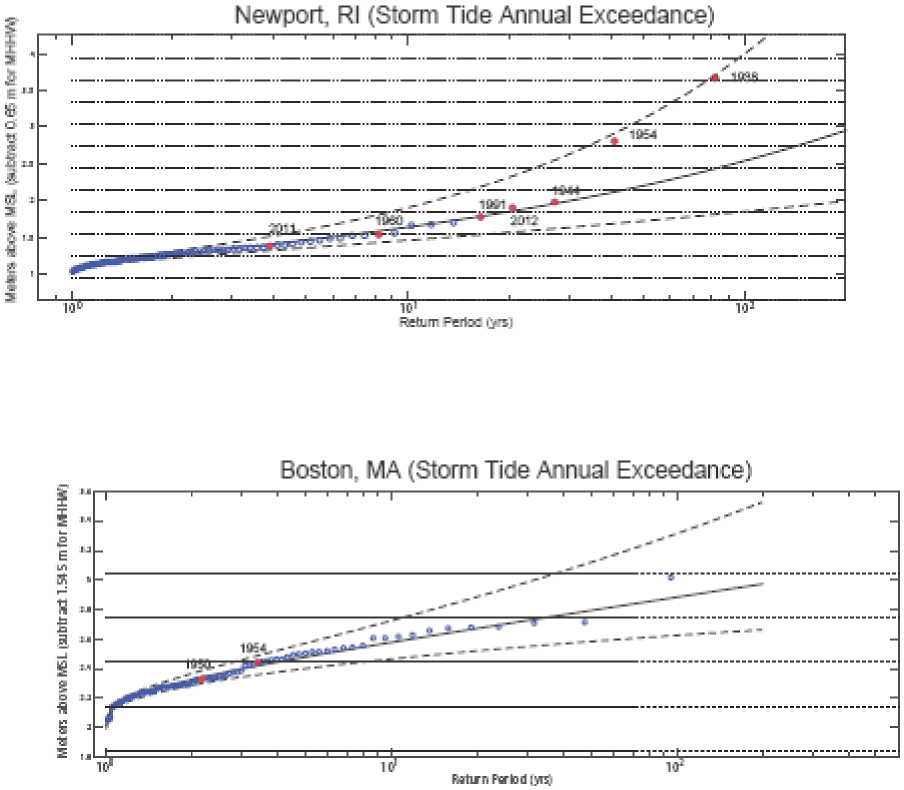


Figure 7. Comparison of storm tide annual exceedance from hourly tide data for Newport, RI (south-facing shores) and Boston (east-facing shores). Blue dots are extra-tropical nor'easters and red dots are tropical cyclones. Curves to the data are fit using the three-parameter Generalized Extreme Value (GEV) function (from Stromer et al., 2015).

Conclusions/Implications

Topographic profiles and grain size analyses performed on sediment samples collected at 18 Massachusetts beaches that are currently experiencing erosion were taken during the summer and winter to evaluate seasonal and spatial variability. This information will be used primarily to match native-beach material with compatible offshore sand resources for beach nourishment projects.

Results suggest that nearly all beaches lose a veneer of sand size particles in the winter but that initial beach grain size distribution and seasonal profile changes are a function of coarseness and proximity to glacial till exposures. Beaches derived from till or moraines are coarser initially, often become coarser in the intertidal zone during winter but show 2.5 meters or less of retreat in the winter. In contrast, beaches comprised exclusively of sand show significant (up to 10 to 20 meters) retreat in winter, depending on location, but no change in grain size with season. Beaches that are comprised of sand but contain more fine gravel and gravel facies fall in between these extremes with some coarsening in the intertidal zone during the winter and some winter retreat. Results indicate that matching native-beach material with offshore sources spans a broad spectrum of grain size distributions that exhibit different seasonal behaviors.

Core BAP6 obtained from Bartlett Pond in Plymouth reveals a continuous long-term sediment record. Analysis of the Bartlett Pond core shows several major storm events that can be linked directly to historic storm events back to 1723. Furthermore, these large events appear more frequent prior to 1909 and are associated with extra-tropical storms, not hurricanes. This is in contrast to the south-facing shores of Massachusetts where storm tides appear to be a mixture of both nor'easters and tropical hurricanes. The implication is that perhaps more attention needs to be paid to understanding the frequency and likelihood of future extra-tropical storm events for Boston and all east-facing shores as these may be the greater flood hazard. This record of coastal flood events near Boston extends our knowledge of known extreme events back at least 300 years. These events suggest an under-assessment of risk of flooding if that risk is based solely on the instrumental record.

References Cited

Bodge, K. R. (2006). Alternative Computation of Dean's Overfill Ratio. Journal of waterway, port, coastal, and ocean engineering, v. 132, no. 2, pp.133-138.

Boldt, K. V., Lane, P., Woodruff, J. D., & Donnelly, J. P., 2010, Calibrating a sedimentary record of overwash from Southeastern New England using modeled historic hurricane surges, Marine Geology, v. 275, no. 1, pp. 127-139.

Brandon, C. M., Woodruff, J. D., Lane, D., & Donnelly, J. P., 2013, Tropical cyclone wind speed constraints from resultant storm surge deposition: A 2500 year reconstruction of hurricane activity from St. Marks, FL., Geochemistry, Geophysics, Geosystems, v. 14, no. 8, pp. 2993- 2008.

Brandon, C., Woodruff, J.D., Donnelly, J.P., 2013a (Oct. 27). How unique was Hurricane Sandy? A Comparison of the inundation deposits and surge heights from Hurricane Sandy and the 1821 Hurricane, Geological Society of America, Annual Meeting Denver, CO, Abstracts with Programs, v. 45, No. 7, p.53.

Brandon, C., Woodruff, J.D., Donnelly, J.P., 2013b (Oct. 29). Using inundation deposits to constrain past storm surges impacting New York City, NY, Geological Society of America Annual Meeting Denver, CO, Abstracts with Programs, v. 45, no. 7, p.580.

Dean, R.G., 2002, Beach nourishment: Theory and practice, Advanced Series on Ocean Engineering, v. 18. River Edge, NJ: World Scientific Publishing, 399p.

Donnelly, J.P. and Woodruff, J.D**.,** 2007, Intense hurricane activity over the past 5,000 years controlled by El Nino and the West African monsoon. Nature, v. 447, p. 465-468.

MassDEP, 2007, Beach nourishment: MassDEP's guide to best management practices for projects in Massachusetts, MassDEP and MA Office of Coastal Zone Management, 32p.

Healey, J., Koerth, M., Gessay, S., Southard, P., Jurnack, J., Beach, D., Mansfield, M., Mabee, S.B., Venti, N.L., Woodruff, J., 2015 (April 23), Seasonal Variability of Massachusetts' Southern Coast: Influence of Grain Size on Berm Resilience, Five College Geology Undergraduate Symposium, Amherst College, April 23, 2015.

Mann, M.E., Woodruff, J.D., Donnelly, J.P., and Zhang, Z., 2009, Atlantic hurricanes and climate over the past 1,500 years. Nature, v. 460, p. 880-883.

Nicholls, R.J., Birkemeier, W.A., and Lee, G., 1998, Evaluation of the depth of closure using data from Duck Harbor, NC, USA, Marine Geology, v. 148, Issue 3-4, pp.179-201.

Sallenger, A.H., Jr., 2000, Storm impact scale for barrier islands, Journal of Coastal Research, v. 16, Issue 3, pp.890-895.

Stauble, D.K., 2005, A review of the role of grain size in beach nourishment projects, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, http://www.fsbpa.com/05Proceedings/02-Don%20Stauble.pdf.

Stone, B.D. and DiGiacomo-Cohen, M.L., 2010, Surficial geologic map of the Pocasset-Provincetown-Cuttyhunk-Nantucket 24-quadrangle area of Cape Cod and islands, southeast Massachusetts: U.S. Geological Survey, Open-File Report OF-2006-1260-E, scale 1:24,000.

Stromer, Z.D, Woodruff, J.D., Donnelly, J.P., 2015 (Nov. 1), The Great Colonial Hurricane of 1635 - Reassessing Extreme Flood Vulnerability for the Southern Coast of Massachusetts, Geological Society of America Annual Meeting, Baltimore, MD, Abstracts with Programs, v. 47, no. 7, p.360.

Toomey, M.R., Donnelly, J.P., Woodruff, J.D., 2013, Reconstructing mid-late Holocene cyclone variability in the Central Pacific using sedimentary records from Taha'a, French Polynesia. Quaternary Science Reviews, v. 77, no. 1, p. 181-189.

Venti, N.L., Gessay, S., Southard, P, Beach, D. Mansfield, M, Mabee, S.B., Woodruff, J.D., 2015, Subtle Modification of Glacially Derived Materials Along Massachusetts' Southern Coast by Passing Summer Storms, Geological Society of America Northeast Section, Abstracts with Programs, v. 47, no., 3, p. 136.

Wallace, D., Woodruff, J.D., Anderson, J., and Donnelly, J.P., 2014, Palaeohurricane reconstructions along the Gulf of Mexico, Caribbean Sea, and western Atlantic Ocean margins. Geological Society London Special Publications, v. 388, doi: 10.1144/SP388.12.

Wolman, M.G., 1954, A method of sampling coarse river-bed material. Transactions of the American Geophysical Union, v. 35, no. 6, pp. 951-956.

Woodruff, J.D., Donnelly, J.P. and Emanuel, K., 2008a, Assessing sedimentary records of paleo-hurricane activity using modeled hurricane climatology. Geochemistry, Geophysics, Geosystems, v. 9, no. 9, p. 1-12.

Woodruff, J.D., Donnelly, J.P., and Okusu, A., 2009, Exploring typhoon variability over the mid-to-late Holocene: evidence of extreme coastal flooding from Kamikoshiki, Japan. Quaternary Science Reviews. v. 28, p. 1774-1785.

Woodruff, J.D., Donnelly, J.P., Mohrig, D. and Geyer, W.R., 2008b, Reconstructing relative flooding intensities responsible for hurricane-induced deposits from Laguna Playa Grande, Vieques, Puerto Rico. Geology, v. 36, p. 391-394.

Woodruff, J.D., Martini, A.M., Naughton, T.N., Elzidani, E.Z., Kekacs, D., MacDonald, D., 2013, Off-river waterbodies on tidal rivers: Human impact on rates of infilling and the accumulation of pollutants. Geomorphology, v. 184, p. 38-50.