Sea Level Rise and Storm Surge

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Geospatial Data for Preparation, Recovery and Assessing Future Threats

Keeping History Above Water
Newport RI
April, 2016

Nigel Shaw
National Park Service
nigel_shaw@nps.gov

Geospatial Data for Assessing Threats, Preparation and Recovery

- Accuracy & Uncertainty
  - Error in Geospatial Data
- Key Geospatial Data
  - Elevation
  - Bathymetry
  - Inundation
    - Measurements
    - Models
    - Products
  - Also nice to have: Features & Imagery
- Hx Sandy
  - STLI/ELIS & GATE
  - ICT priorities & Mapping Needs
  - Post Hx Sandy: Planning & Reconstruction

- Elevation Data – NED/Lidar/RTK
  - RTK projects
  - Other related projects
- The Long View

Accuracy and Uncertainty

- Know your data = trust your data

- Error in Geospatial Data
  - What

  - Where

Figure 5. 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.

Attribute Error

In field data, such as features mapped with GPS

What feature is this man standing beside?

Unexploded Ordinance found at Sandy Hook!

In interpreted data, such as from aerial photography

Would these unexpected features be correctly interpreted?

Boats at Forsythe National Wildlife Refuge were washed away from a nearby marina

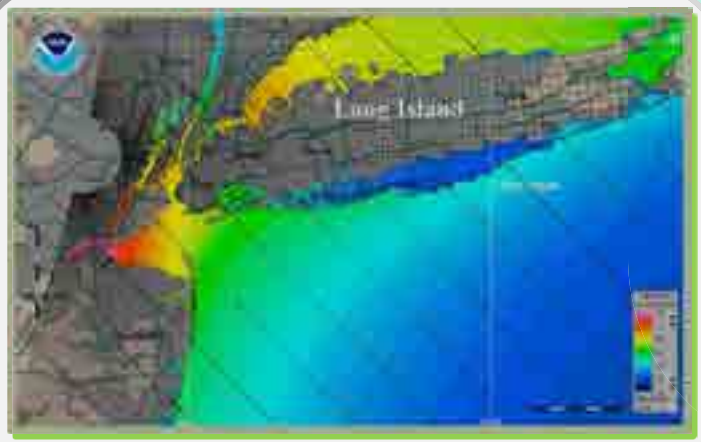
Credit: USFWS

House pushed into the marsh on Staten Island

Credit: Adrees Laif, Reuters

Errors in model output

- **Models cannot accommodate all the parameters of reality**
  - SLOSH does not model waves on top of the surge or account for normal river flow and rain flooding, although these are in development*
- **Models are highly dependent on input data**
  - SLOSH surge heights are variously measured as correct to within 5**-20%***. Error is largely attributed to the difficulty of establishing & predicting meteorological inputs.



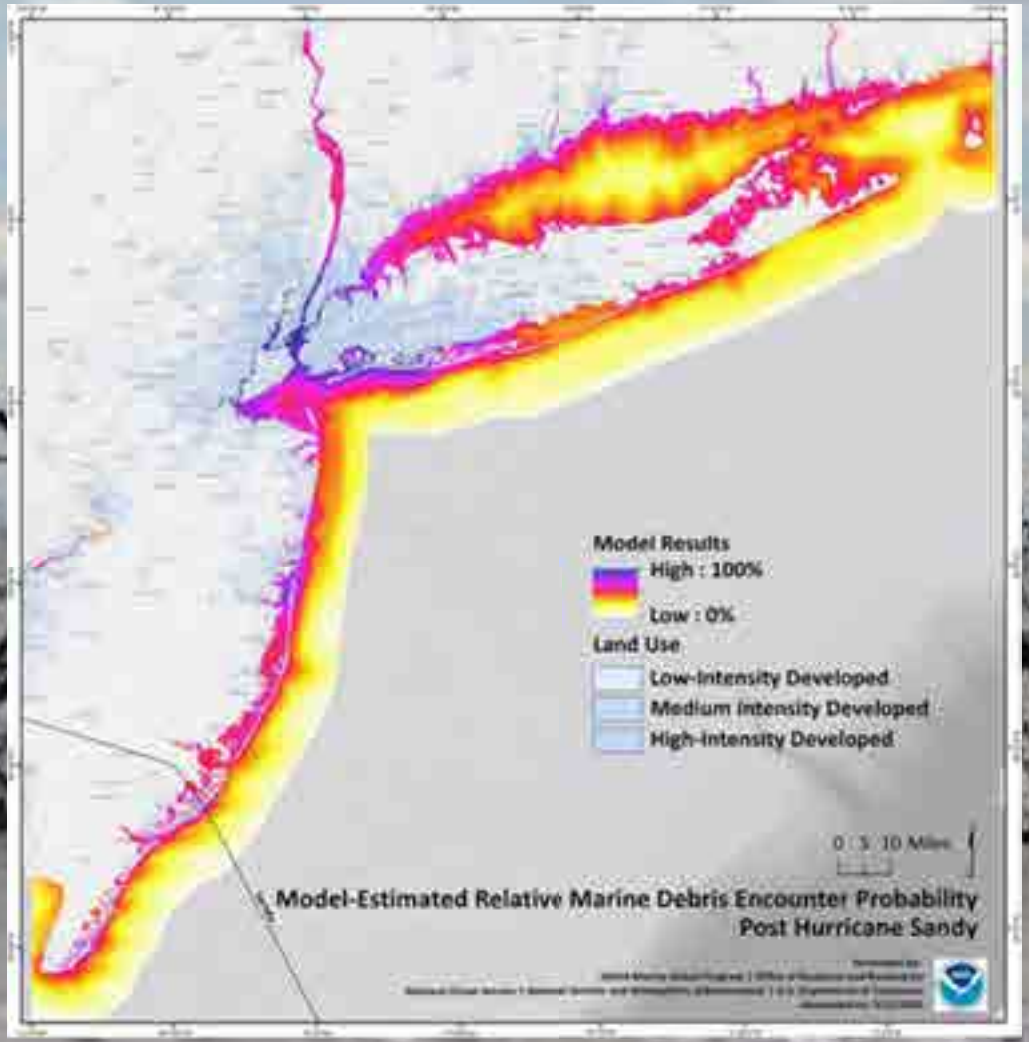
* Sea, Lake, and Overland Surges from Hurricanes (SLOSH) http://www.nhc.noaa.gov/surge/slosh.php

**National Weather Digest, Vol 33, #1, August 2009 (specifically, page 6 of this publication) http://slosh.nws.noaa.gov/sloshPub/pubs/Vol-33-Nu1-Glahn.pdf

***SLOSH model overview on NWS website. http://slosh.nws.noaa.gov/sloshPub/index.php#sloshDsp

Errors in model output

This has been declared a Severe Marine Debris Event



Pixel Value/Placement

(Plus/minus 30 cm Vertical!)

LiDAR-derived DEM
Vertical accuracy
95% confidence: +- 0.30m

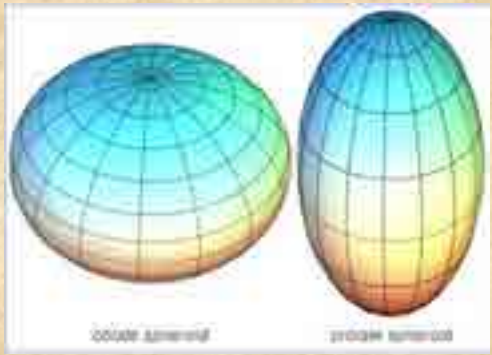
(Pixels move AND change value!)

Satellite Imagery

- Georeferenced, Terrain Corrected
  - swaps around which other pixels they are beside
- Radiometrically corrected to eliminate atmospheric attenuation & resampled
  - changes pixel values

(Details about processing levels of all Landsat data products can be found on http://landsat.usgs.gov/Landsat_Processing_Details.php)

Data Error - Locational



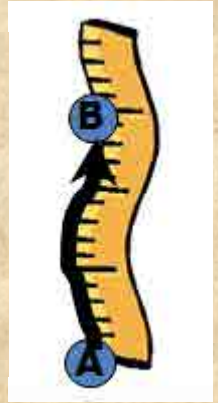
- Getting the datum right
  - On what shape are you measuring distance?
  - Where are you measuring *from*?

Horizontal

- A geodetic datum is a coordinate system with a set of reference points, used to locate places on the earth. Each starts with a spheroid as a base from which it defines X, Y horizontal coordinates. Different spheroids result in different XY coordinates for a given location.
- Geospatial data layers in different datums will not register with each other since they use different spheroids. Sometimes this is obvious, as when a stable and the horse within it have their locations reported in two different datum. Other times it isn't so obvious, and especially with large raster datasets that do not have a strong relationship to familiar landscape features. The data inputs to models, such as DEM, and model outputs, such as the storm surge heights from SLOSH, are data layers for which this is the case.

Vertical

- The vertical datum is equally important when Z values are involved. An easy way to think of this is that the vertical datum defines the surface from which a height is measured. Sea level (or mean sea level) is a common reference for a vertical datum. It uses the midpoint between mean low and mean high tide at a particular location as the "standard sea level" from which rise or surge is measured. All your data must be in the same vertical datum, such as NVGD88.



Errors in Databased Content

John Fitzgerald Kennedy National Historic Site
Brookline, MA

Ellis Island and Statue of Liberty
New York Harbor

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Locational Error in Field Data

Some things are tough to map without a GPS, or even with one

Old Inlet Dock at Fire Island NS

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Key Geospatial Data

- Elevation
- Sea Levels, Rise & Surge
- Bathymetry
- Inundation
- Features
- Imagery

Additional Data –Related Considerations	Storm Surge	SLR
Meteorology of Specific Storms	x	
Tidal regime	x	
How future storms will alter the type, shape and character of the coastline	x	x
How the climate will change	x	x
How much sea level will rise	x	x
How vegetation will change	x	x

Key Geospatial Data - Elevation

What's out there

- National Elevation Dataset (NED)
  - Contours (1:24k)
  - Seamless raster elevation of US with continuous update
  - Resolution varies depending on source data: 1/9 arc second – 2 arc second.
  - RMSE for CONUS 1/3 arc second NED overall, as measured against 25,310 NGS benchmarks, was 1.55 as of April, 2013 (an improvement from 2.44 as measured 10 years previously)
  - Check the USGS National Map Viewer for current details of a specific area: http://viewer.nationalmap.gov/viewer/

TNM Elevation Tools:

- Spot elevation
- Profile tool
- Quick profile tool
- Bulk point query

Brown - 1 m extent
Orange - 1/9 arc second extent
(All of New England has 1/3 arc second NED coverage)

What's out there – Lidar

- Lidar Participation
  - Use the USGS 2012 lidar specifications w/quality levels 5 – 139 cm. (vertical accuracy). Hans Karl Heidemann.
    - http://pubs.usgs.gov/tm/11b4/
  - See also the Guidelines for Digital Elevations Data (NDEP), 2004, but designed to be technology-independent http://www.ndep.gov/TechSubComm.html
  - Participate in the annual 3DEP (3D Data Acquisition Partnership) for Lidar in which USGS coordinates lidar investments for critical mass.
    - http://nationalmap.gov/3dep/

Blue – NPS>0.7
Green – NPS 0.36-0.35
Brown – NPS unknown

What's out there - Lidar

- Civilian Elevation Sites (Lidar and more)
  - National Digital Elevation Program (Coordination)
    - http://www.ndep.gov/
  - US Interagency Elevation Inventory (data discovery, incl to state & local repositories)
    - https://coast.noaa.gov/inventory/https://coast.noaa.gov/inventory/
  - OpenTopography (NSF-funded with international holdings, includes Radar topo)
    - http://www.opentopography.org/
  - Digital Coast (NOAA, data viewer for coastal zone data of all sorts.
    - https://coast.noaa.gov/dataviewer/#
  - TNM Lidar holdings that are souce data for NED
    - http://viewer.nationalmap.gov/datasets/
  - Best Fed Site: (opinion) USGS EarthExplorer now includes CLICK (Ctr for Lidar Coordination & Knowledge) for current Lidar holdings of all types for all federal gov't agencies (many co-funded with state/local gov't)
    - http://lidar.cr.usgs.gov
    - http://earthexplorer.usgs.gov/

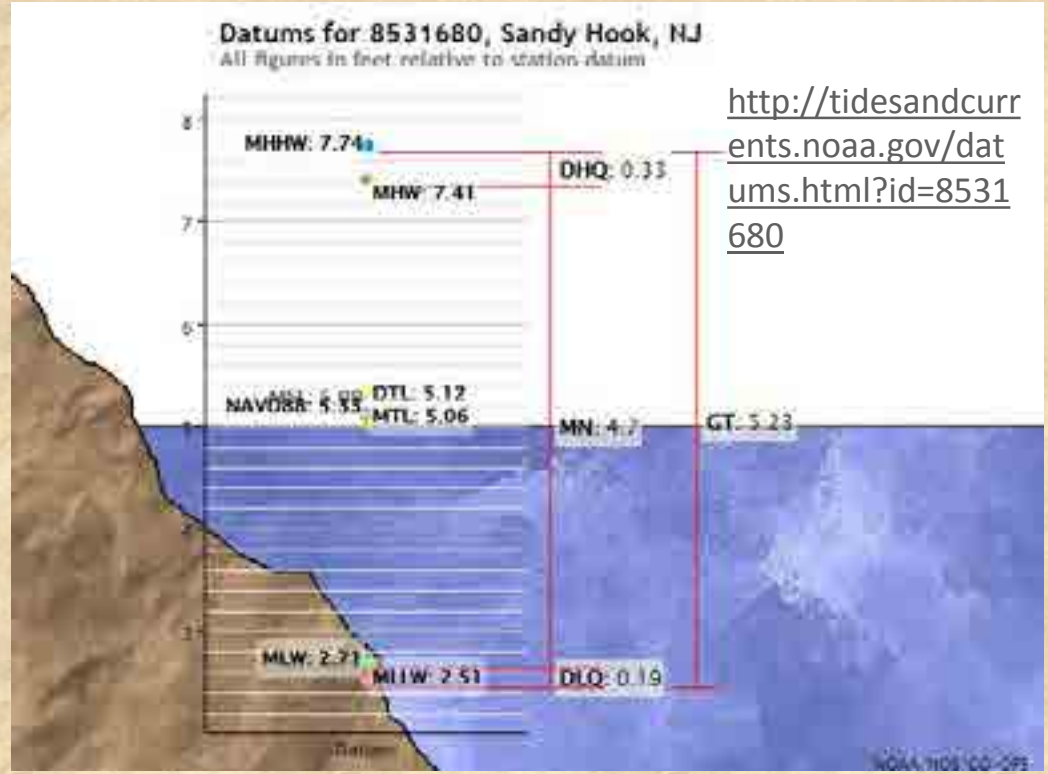
Blue – NPS>0.7
Green – NPS 0.36-0.35
Brown – NPS unknown

What's out there/possible

- RTK GPS for elevation
  - Nail down local geodetic benchmarks and other points with up to cm or even mm accuracy.
  - Develop local dense high resolution coverage for small areas.
  - Technology continues to come down in price and complexity, but this is still high end work involving professional technical skills.
  - Recreational and Mapping grade GPS are also improving but are not yet of the quality to improve on lidar. (e.g. phone, Garmin, and non-RTK/survey grade Trimble, Ashtec and similar)
  - The football of accuracy

Sea Levels & Tide Gauges

Tide gauges **measure sea level** through complex instruments located along our coasts, recording information about the precise patterns of rising and falling tides up and down the coasts . Sensors continuously record long-period water levels relative to a stable height reference surface such as the geoid. Measurements are provided in all major relevant vertical datum. The information is essential for establishing "sea level" (including calibrating altimeter readings in the open ocean), creating accurate elevation maps and making predictions about storm impacts in specific locations.



http://tidesandcurrents.noaa.gov/datums.html?id=8531680

Hurricane Sandy damaged or destroyed 73 tide gauges on the U.S. east coast, leaving researchers with critical information gaps. Replacement of these gauges is necessary for accurate measurement of the vulnerability of coastal resources to inundation (rising water from sea level rise and storm surges).

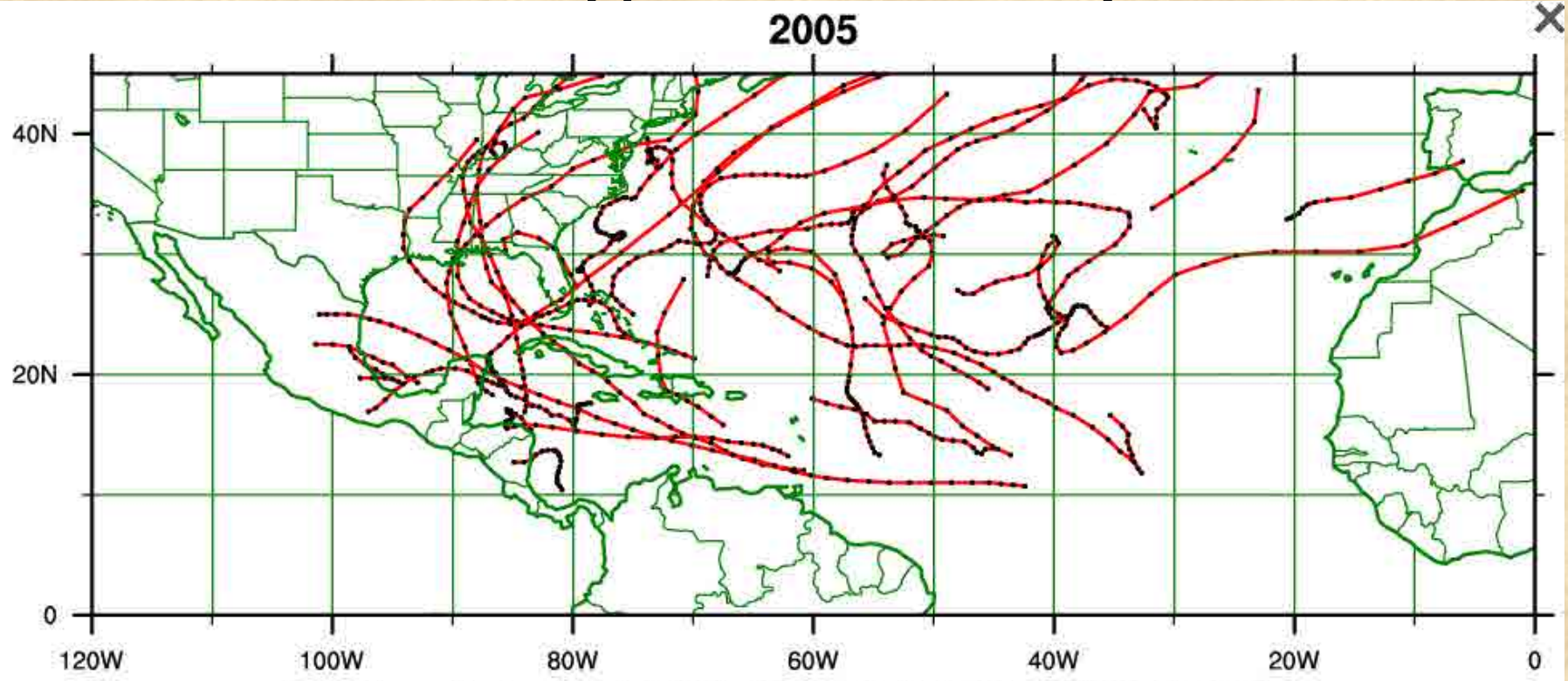
Sea Level Rise Scenarios

Sea Level Rise “data” input to inundation models is simply the selected scenario. The most commonly used are the IPCC scenarios associated with different levels of carbon emissions that result in predicted SLR of 60 cm, 1 m and 2 m.

Storm Surge Model Inputs

Meteorological inputs to storm surge models is extensive and complex and a primary driver of the results, along with geomorphology. Parameters include storm track, intensity, forward speed, size (~diameter), angle of approach and central air pressure. Further complicating matters is that storm characteristics are highly dynamic and difficult to predict. For example, the average errors in track and intensity can mean the difference between a Cat 1 storm in Pensacola and a Cat 3 storm in New Orleans!

Storm Surge Model Inputs p.2



Tropical storm and hurricane tracks (120W-GM) in 2005. Contributed by Carl Schreck (CICS-NC, NOAA-NCDC).

Figure 2 of 5

IBTrACS is a source for tropical cyclone track data from all major sources, maintained by Nat'l Ctr on Atmospheric Research. The World Meteorological Organization sanctions one "answer" per storm.

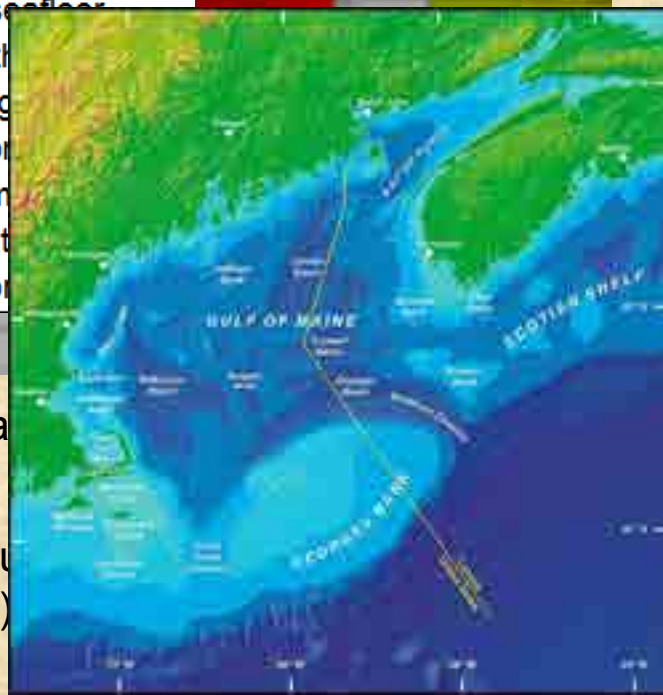
https://climatedataguide.ucar.edu/climate-data/ibtracs-tropical-cyclone-best-track-data

Key Geospatial Data - Bathymetry

Comparison of Shallow Water Mapping Technologies, GOMMI 2009

prime advantages	Trade-offs/thresholds	bathymetry
Ability to acquire dense sounding data w/ few tracklines, and simultaneously acquire backscatter imagery using same sensor. Multibeam has c to acquire conti data over wide a	* Much more complex and expensive relative to single beam, but benefits in cost per unit effort and resolution can well outweigh the disadvantages. * Swath widths shorten in s * Multibeam backscatter im and detail in sidescan imag corrected for distortion from motion (e.g. role, pitch, and	* Yes *Primary purpose. *Excellent high-resolution bathymetry.

limits/disadvantages of technolo	Primary products
requires support vehicle, etc. *Multibeam is less efficient in sh (< 30 m). Time intensive and co water due to limitations on swath width. Swath width is only 3-5 x water depth. Narrow swath=more tracklines, time, cost. *Surveying in < 5 m, particularly tough. * Rigorous groundtruthing needed to verify the accuracy of substrate classifications b/c	*Seafloor morphology/shape of the seafloor/se topography. Bath * Surficial geolog classification fro backscatter is im **Classify format structural enviro

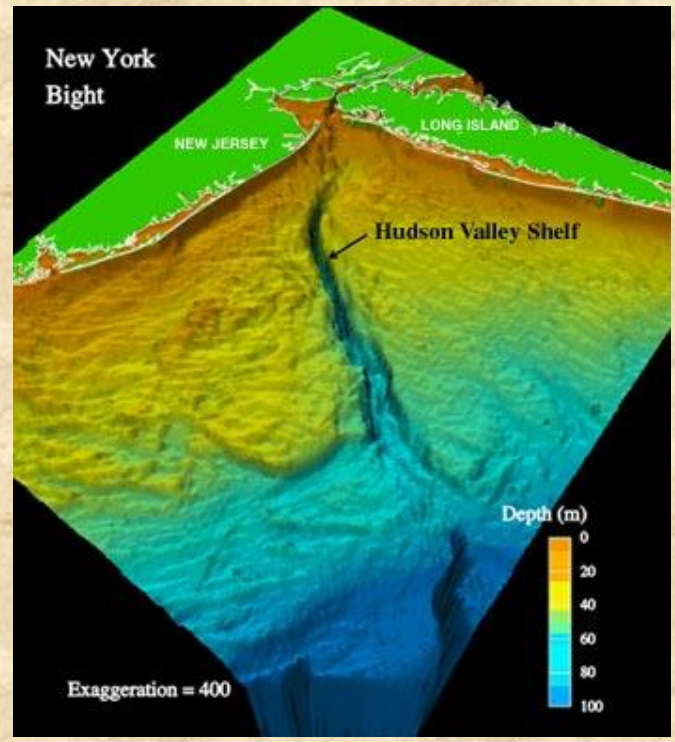


Technologies: side-scan sonar, multibeam & single beam sona interferometric, topo-bathy lidar, AUV platforms & more.

Fields: dis/advantages, trade-offs/thresholds, data types & produ technical complexity of data, suitability for conditions (e.g. depth) costs, more information

Key Geospatial Data - Bathymetry

NOAA's National Centers for Environmental Education
http://maps.ngdc.noaa.gov/viewers/bathymetry/



Key Geospatial Data - Inundation

Measurements

USGS sensors deployed pre-Sandy
High water marks

Models

SLOSH, ADCIRC, SWAN, CHAMP

NHC products for storm preparation

MOMs, MEOWs, P Surge

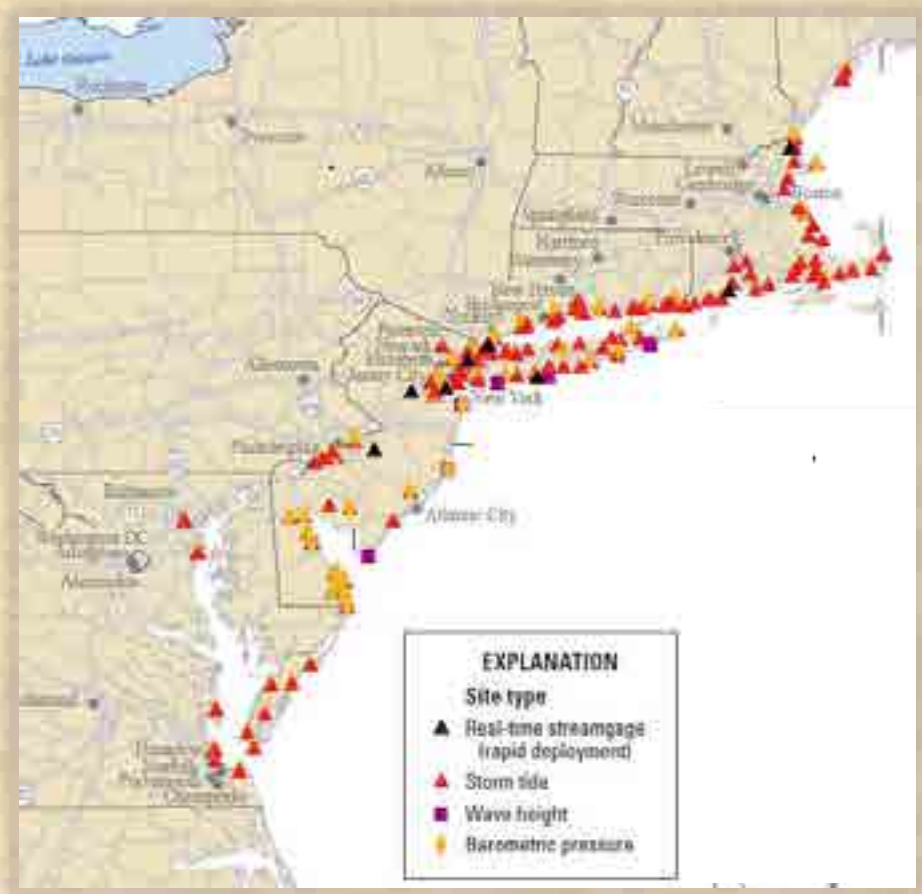
FEMA products for planning & construction

FIRMs, BFE/ABFE

Key Geospatial Data – Inundation Measurements

USGS deployed a temporary monitoring network of water-level and barometric pressure sensors at 224 locations along the Atlantic coast from Virginia to Maine to continuously record the timing, areal extent, and magnitude of hurricane storm tide and coastal flooding generated by Hx Sandy. These records were greatly supplemented by an extensive post-flood high-water mark (HWM) flagging and surveying campaign from November to December 2012 involving more than 950 HWMs.

The resulting data constitute an extensive collection of continuous water-level records documenting a single, landfall hurricane and can be used to evaluate the performance of storm-tide models for maximum and incremental water level and flood extent, and for site-specific effects of storm tide.



Locations of storm-tide sensors deployed for Hurricane Sandy, October 2012.

Data available in tab-delineated, ASCII format by site for each sensor by using a USGS interactive storm-tide mapper at *http://water.usgs.gov/floods/events/2012/sandy/sandymapper.html*.

Inundation Models - SLOSH

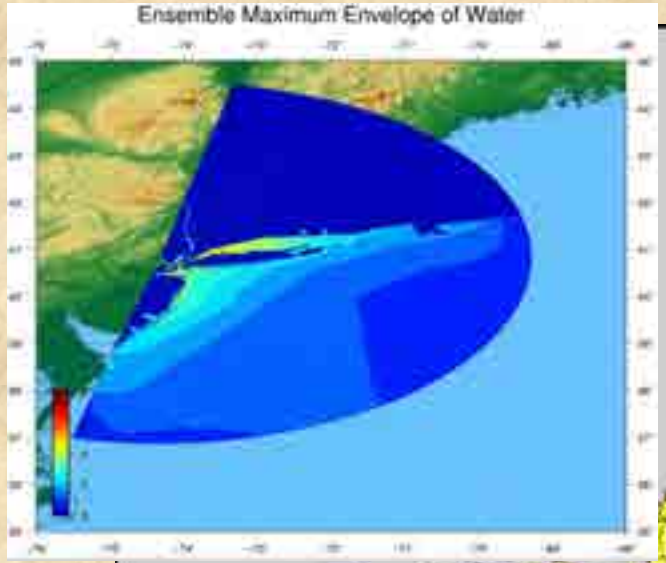
- Sea, Lake, and Overland Surge Height: http://www.nhc.noaa.gov/surge
  estimate storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes. Developed by NWS. Primary model for FEMA, NOAA, USACE.

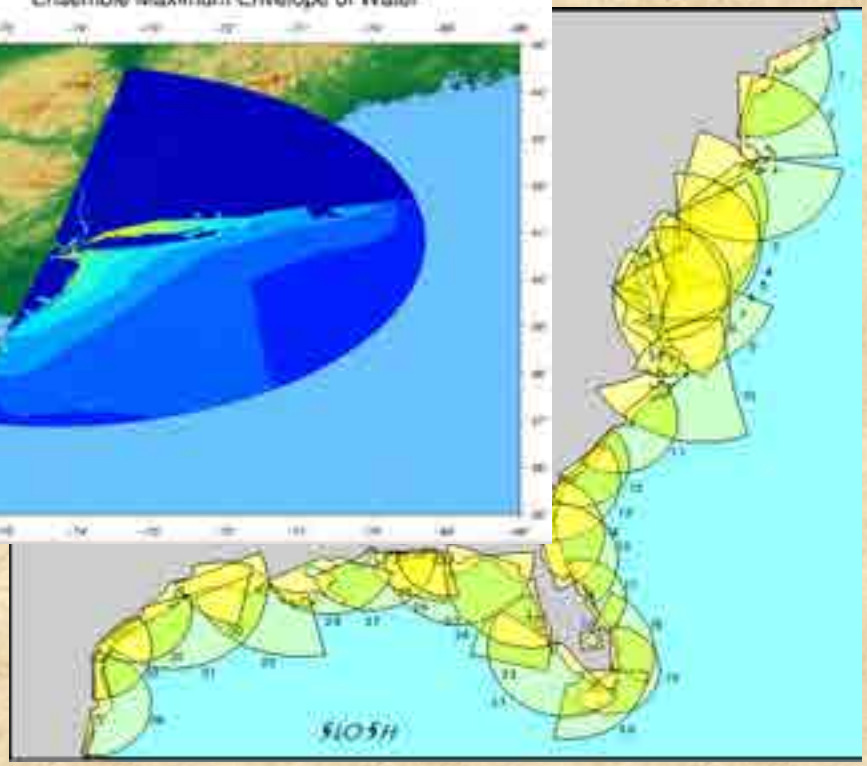
Try SLOSH at home!

- Computationally efficient (fast)
- Resolves flow through barriers, gaps & passes and inland inundation
- Resolves overtopping of barrier systems, levees and roads
- Resolves coastal reflections of surge

Inputs:

- Bathymetry for shape & character of coastline and for width & slope of the continental shelf.
  - NWS provides SLOSH basins, varying resolutions, updates
- Meteorological data (storm specific) for intensity, forward speed, size (~diameter), angle of approach, central air pressure. (NOTE:"There is more inaccuracy in the input wind parameters to surge models than in the models themselves." – SLOSH Disclaimer. (see model error, above)
- Land elevation data Lidar-derived DEM (see Elevation sources, above)





Inundation Models – SLOSH, p.2

Modeling Approaches

Deterministic Single simulation using a perfect forecast for a specific event.

Probabilistic Incorporate statistics of past forecast performances to generate an ensemble of runs.

Composite Incorporate statistics of hypothetical storms to generate several thousands of runs under different conditions.

SLOSH Products

Maximum Envelope of Water

Max of the MEOWs

*

P-Surge

Inundation Models - ADCIRC

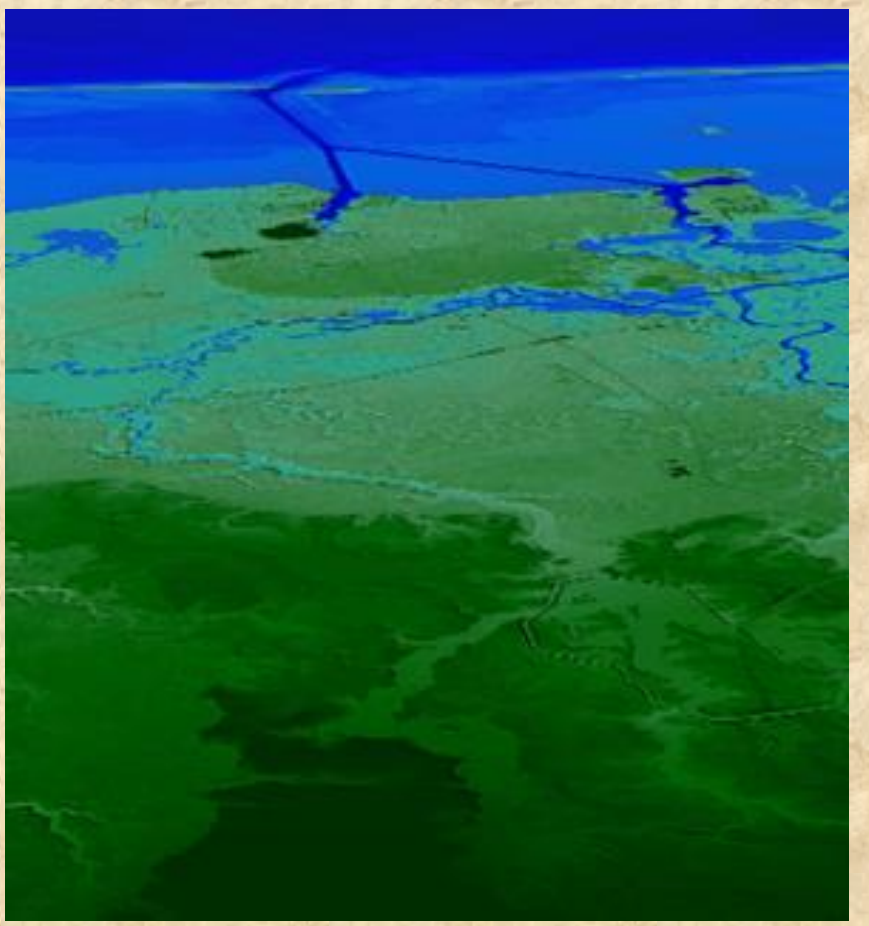
- Advance Circulation http://adcirc.org/

Predict storm surge, flooding, model tides, wind driven circulation & more. Developed at University of North Carolina. More complex than SLOSH. Widely used.

➢Inputs: bathymetry, topography, boundary information, tidal characteristics, nodal attributes (often based on land use data), river inflow, meteorological forcing input, wave radiation stress forcing, and others depending on the geographical area of interest

➢Products: time varying & spatially varying water surface elevation, water velocity, wind velocity, & atmospheric pressure, 2D or 3D as specified in the input.

ADCIRC Bootcamp in May: http://www.eventbrite.com/e/2016-adcirc-users-group-meeting-and-adcirc-boot-camp-registration-21381005162



Inundation Models – Wave Action

Simulating Waves Nearshore – SWAN

http://swanmodel.sourceforge.net/

Delft University of Technology

What it models:

- Wave propagation in time and space, shoaling, refraction, frequency shifting
- Wave generation by wind
- Three- and four-wave interactions
- Whitecapping, bottom friction & depth-induced breaking
- Dissipation due to aquatic vegetation, turbulent flow and viscous fluid mud
- Propagation from laboratory up to global scales
- Wave-induced set-up
- Transmission through and reflection against obstacles
- Diffraction

Coastal Hazard Analysis Modeling Program – CHAMP*

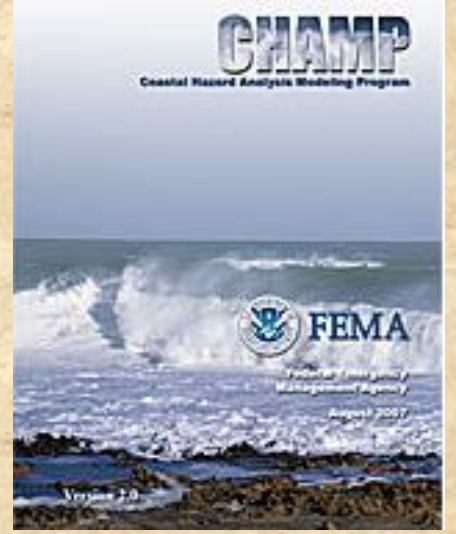
http://www.fema.gov/media-library/assets/documents/11551

FEMA

What it models:
(for 2%, 1% or 0.2% SWEL)

- Storm-induced erosion
- Wave height & period
- Wave runup

*CHAMPS now incorporates WHAFIS (Wave Height Analysis for Flood Insurance)

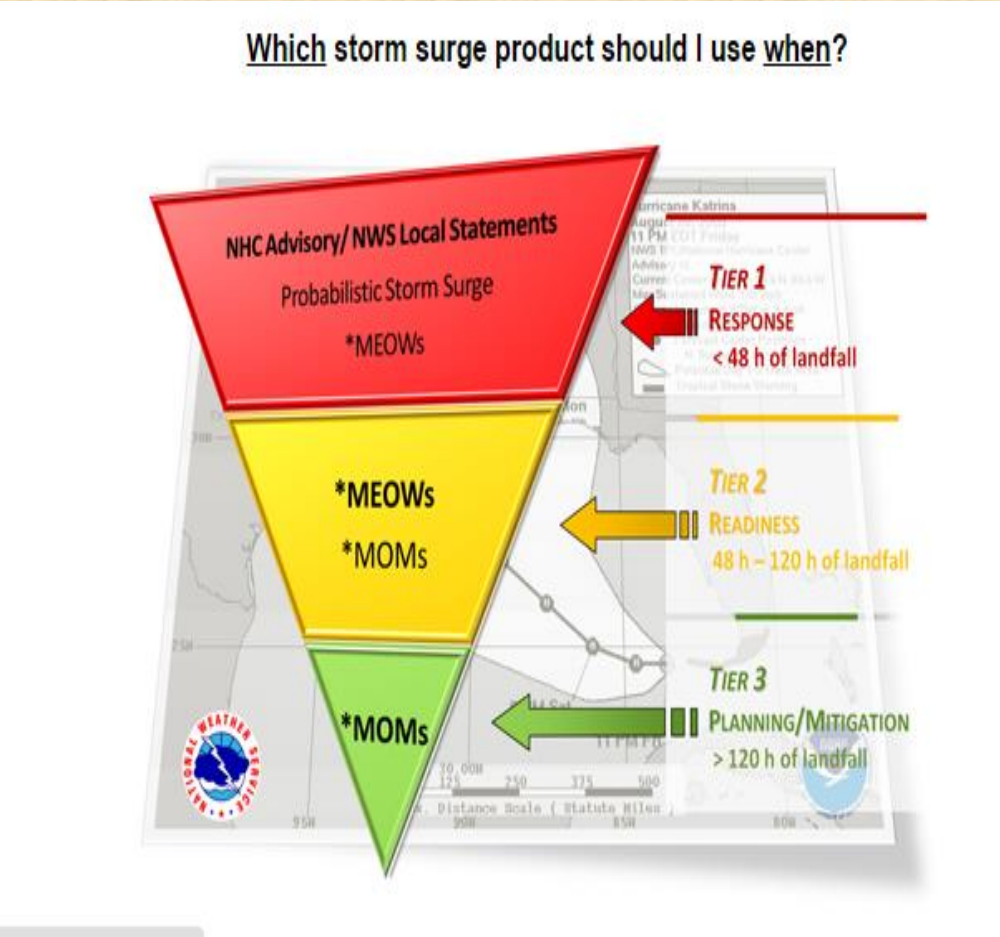


The National Hurricane Center's Inundation

NWS, NOAA

Storm-specific advisories based on SLOSH and other analyses

- Predicted storm surge for specific events is highly dependent on meteorological input, hence the NHC "decision wedge" ⟹
- MEOWs and MOMs both provide regional worst case storm surge estimates
- Average errors in storm track and intensity can mean the difference between a Cat 1 in Pensacola or a Cat 3 in New Orleans.
- Probabilistic Storm Surge accommodates uncertainties
- Hurricane Local Statements address local conditions w/in 48 hrs
- Coastal areas susceptible to storm floods (not storm specific)



Federal Emergency Management Agency's Inundation

DHS

FEMA starts with field reconnaissance (shoreline type, condition, presence of protection structures, buildings, vegetation, esp. marsh grass type, density & height). Next they use inundation models (SLOSH, ADCIRC) to delineate stillwater elevation (SWEL) for storm surge events of the 10%, 2%, 1% and 0.2% annual chance magnitudes. The third step adds runup, wave action and related variables on top of the SWEL. The last step is to compare the final water elevations, with waves, to the land elevation data and identify Special Flood Hazard Areas (SFHA) and other flood zones based on these Base Flood Elevations (BFE).

Annual chance magnitude	Common name	Annual likelihood	Frequency	Calculation
0.2 %	"500 year flood"	The flood with a 0.2% chance of being equaled or exceeded every year.	There is a 100% chance of such a flood during any 500 year span.	0.2 * 500 = 100
1%	"100 year flood" or "base flood"	The flood with a 1% chance of being equaled or exceeded every year.	There is a 100% chance of such a flood during any 100 year span.	1 * 100 = 100
2%	"50 year flood"	The flood with a 2% chance of being equaled or exceeded every year.	There is a 100% chance of such a flood during any 50 year span.	2 * 50 = 100
10%	"10 year flood"	The flood with a 10% chance of being equaled or exceeded every year.	There is a 100% chance of such a flood during any 10 year span.	10 * 10 = 100

Federal Emergency Management Agency's Inundation

(p.2)

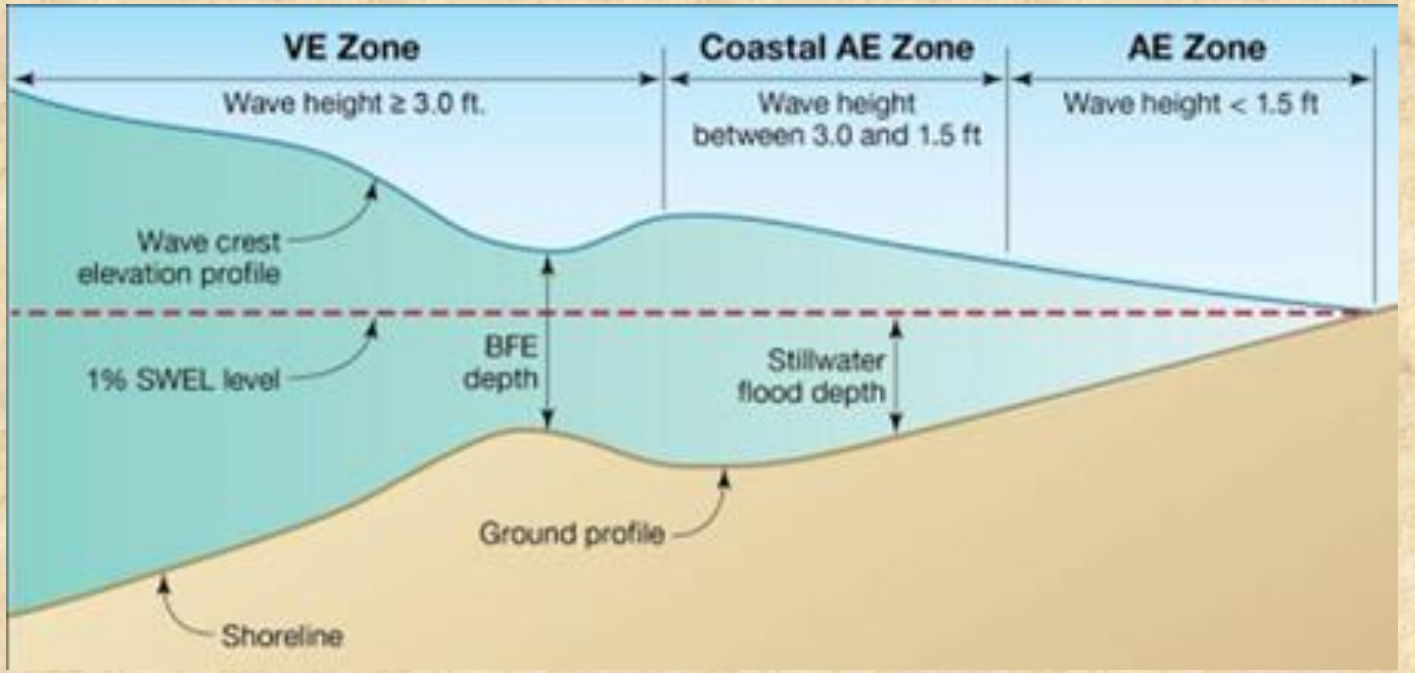
The Zones

- **Special Flood Hazard Area (SFHA)** = 100 year flood areas (1% annual chance of flood) and includes all 'A' and 'VE' FIRM Zones: A, AO, AH, A1-A30, AE, A99, AR, AR/AE, AR/AO, AR/A1-A30, AR/A, V, VE, and V1-V30.
- **Moderate flood hazard areas**, labeled Zone B or Zone X (shaded) are also shown on the FIRM, and are the areas between the limits of the base flood and the 0.2-percent-annual-chance (or 500-year) flood.
- **Minimal flood hazard areas**, which are the areas outside the SFHA and higher than the elevation of the 0.2-percent-annual-chance flood, are labeled Zone C or Zone X (unshaded).
- **Regarding Updates**
  - Not unusual to see a several foot increase in BFEs and a large landward shift in the VE zones with new flood study using updated data (e.g. longer storm history with big events, more refined strom surge grid), better models, and better topo.
  - Not unusual to have an AE Zone adjacent to or encircled by a VE Zone of the same whole-foot elevation. It just means that the wave height component of the total flood elevation dropped below the 3' threshold of the VE Zone. Probably due to a small change in topo (sub-foot), so the SWEL is reduced to < the 4'minimum for 3' waves.

Federal Emergency Management Agency's Inundation

(p.3)

- Within the SFHA



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Inundation

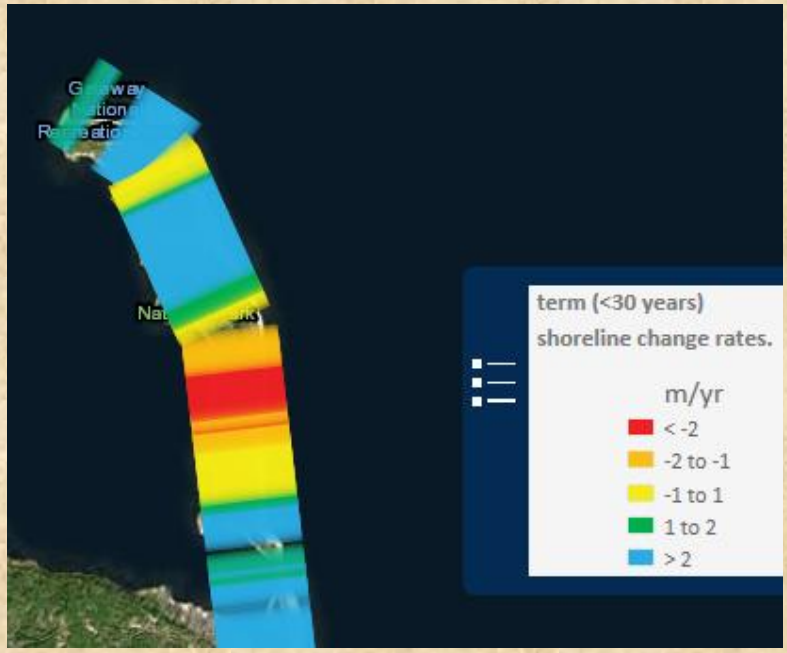
A NOAA online inundation tool (not geospatial):

- The data input for this tool is 6-minute water level data time series and the tabulated times and heights of the high tides over a user specified time period, relative to a desired tidal datum or user-specified datum.
- The data output of this tool provides summary statistics, which includes the number of occurrences of inundation above the threshold (events) and length of duration of inundation of each events above the threshold elevation for a specified time period.
- http://tidesandcurrents.noaa.gov/inundation/

Inundation

A USGS online tool:

- Sea Level Rise
  - Coastal Vulnerability Index
  - Shoreline Change Forecasts
- Shoreline Change
  - Long term change rates
  - Short term change rates
  - Historical shoreline positions
- Extreme Storms
  - Coastal change hazards
  - Beach morphology
- Nor'easters
  - Erosion probabilities and related content
- http://marine.usgs.gov/coastalchangehazardsportal/



Additional Geospatial Data Considerations

Imagery from both before and after a storm event

This photo, taken just after Hurricane Sandy, shows Fire Island's dunes blown back onto the inner barrier in overwash fans.

Ground Features

- resources of special interest
- general context

Infrastructure

- utilities
- power / communication systems
- access / transportation

Potential Danger Zones

Geospatial Data for Assessing Threats, Preparation and Recovery

- Accuracy & Uncertainty
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    - Products
  - Also nice to have: Features & Imagery
- **Hx Sandy**
  - **STLI/ELIS & GATE**
  - **ICT priorities & Mapping Needs**
  - **Post Hx Sandy:Planning & Reconstructio**
- Elevation Data – NED/Lidar/RTK
  - RTK projects
  - Other related projects
- The Long View

Hx Sandy

Recovery, Reconstruction, Planning & Mitigation

- What we used and how
- What we wished for
- Geospatial data products

First Priorities: Safety, community assistance, identify access impediments and safety concerns, prevent further damage, remove or stabilize hazmat, stabilize structures, re-establish access to critical areas.

Concurrent Concerns: Remove sand and debris, remove portable resources, mold prevention, assess bridges, roads and piers along access routes, assess damage and additional threats to specific resources and structures.

History Below Water

Three quarters of Liberty Island and all of Ellis Island were underwater. Almost all buildings were flooded. The storm had destroyed most of the infrastructure on both islands, including primary and back-up power, HVAC, water, sewer, communications and security systems as well as piers and walkways.

The Statue itself was not damaged, but museum collections as well as nearly every other historic feature on these islands was affected.

NPS Photos

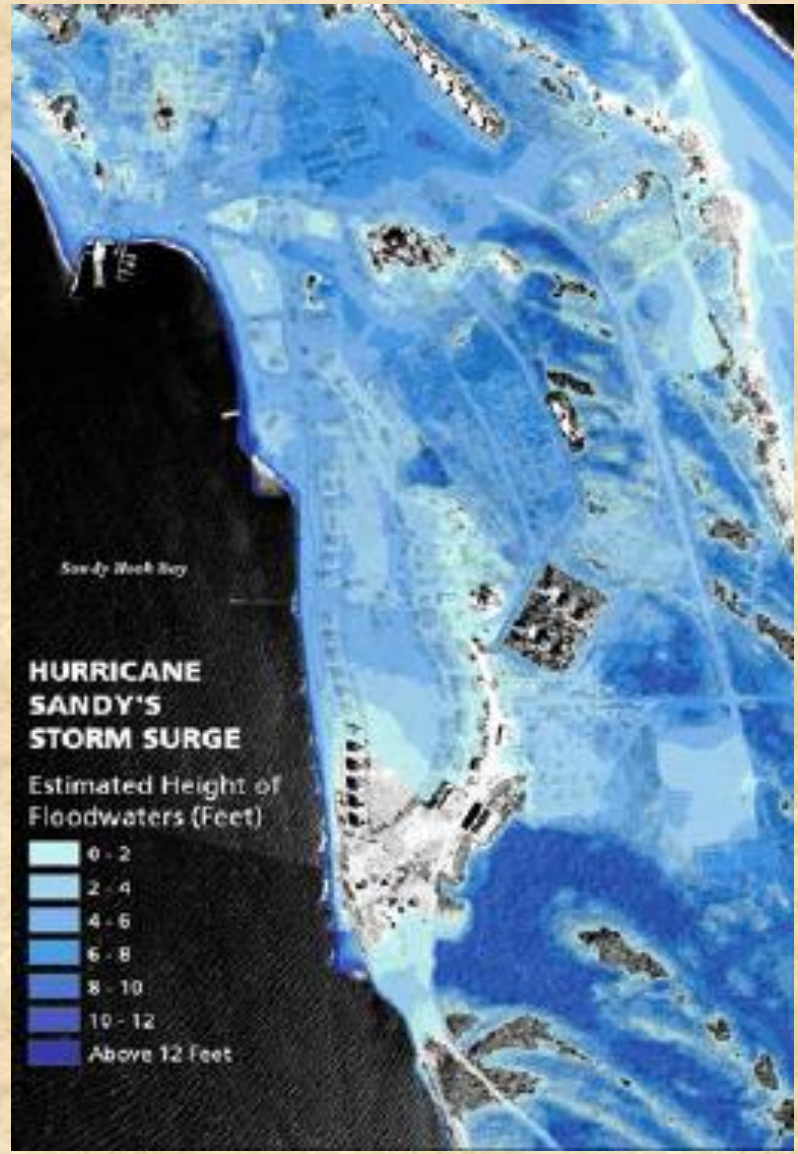
Walkway on Liberty Island

At ELIS, a team of dozens of curators from across the NPS would move over 1 million archival documents and historic artifacts down three flights of stairs by hand for eventual temporary relocation in Maryland.

NPS Photos

Pier at Ellis Island

History Below Water



Credit: Gateway NRA GIS

At Gateway's three units, Jamaica Bay, Staten Island and Sandy Hook, the staff and community were further shaken by traumatic incidents such as the fires in Far Rockaway and the 12+ feet of water on Staten Island.

Maintenance facilities at Fort Hancock, located in the Sandy Hook Unit of Gateway National Recreation Area, were underwater and only accessible by boat after Hurricane Sandy.

CREDIT NATIONAL PARK SERVICE

TRATION

What to do & What's been done

Safety:
Daily and sometimes hourly updated maps identifying areas, routes and structures that are unsafe or need a safety assessment.

Logistics & Local Info for ICT staff:
Housing assignments
Getting around
Where to eat, do laundry, charge phones, etc.

Access:
Routes open/closed with the specific locations and nature of existing impediments and potential impasses.

Work Assignments:
Teams for debris and sand removal, etc.

Damage Assessment Activity:
Areas evaluated and by whom.
Prioritized assignments for the different kinds of evaluation teams.
Coordinating transportation

Resource Status:
Status of specific areas and features.

Team Briefings:
Daily and more maps to accompany team briefings, both general and site specific.

Reporting:
Daily and more maps to inform WASO, etc.

Incident Command Team Geospatial Data Needs

First Priorities: Safety, community assistance, identify access impediments and safety concerns, prevent further damage, remove or stabilize hazmat, stabilize structures, re-establish access to critical areas.

Boardwalk damage at Fire Island

Concurrent Concerns: Remove sand and debris, remove portable resources, mold prevention, assess bridges, roads and piers along access routes, assess damage and additional threats to specific resources and structures.

Work Assignments

Gateway NRA, Sandy Hook Unit

Sand Removal from Visitor Center parking lot

NPS Photo

Resource Assessments

Fire Island National Seashore

Hurricane Sandy not only introduced a lower, wider beach, it also uncovered a bit of history. Filled with coal and headed to Newfoundland, the Bessie White ran aground close to Smith Point County Park in the 1922. Waves carried the remains of the ship west, to its present-day location near Skunk Hollow in the Otis Pike Fire Island High Dune Wilderness. Winter storms occasionally reveal the wreck but for most of the year, the beach keeps this ship a buried treasure.

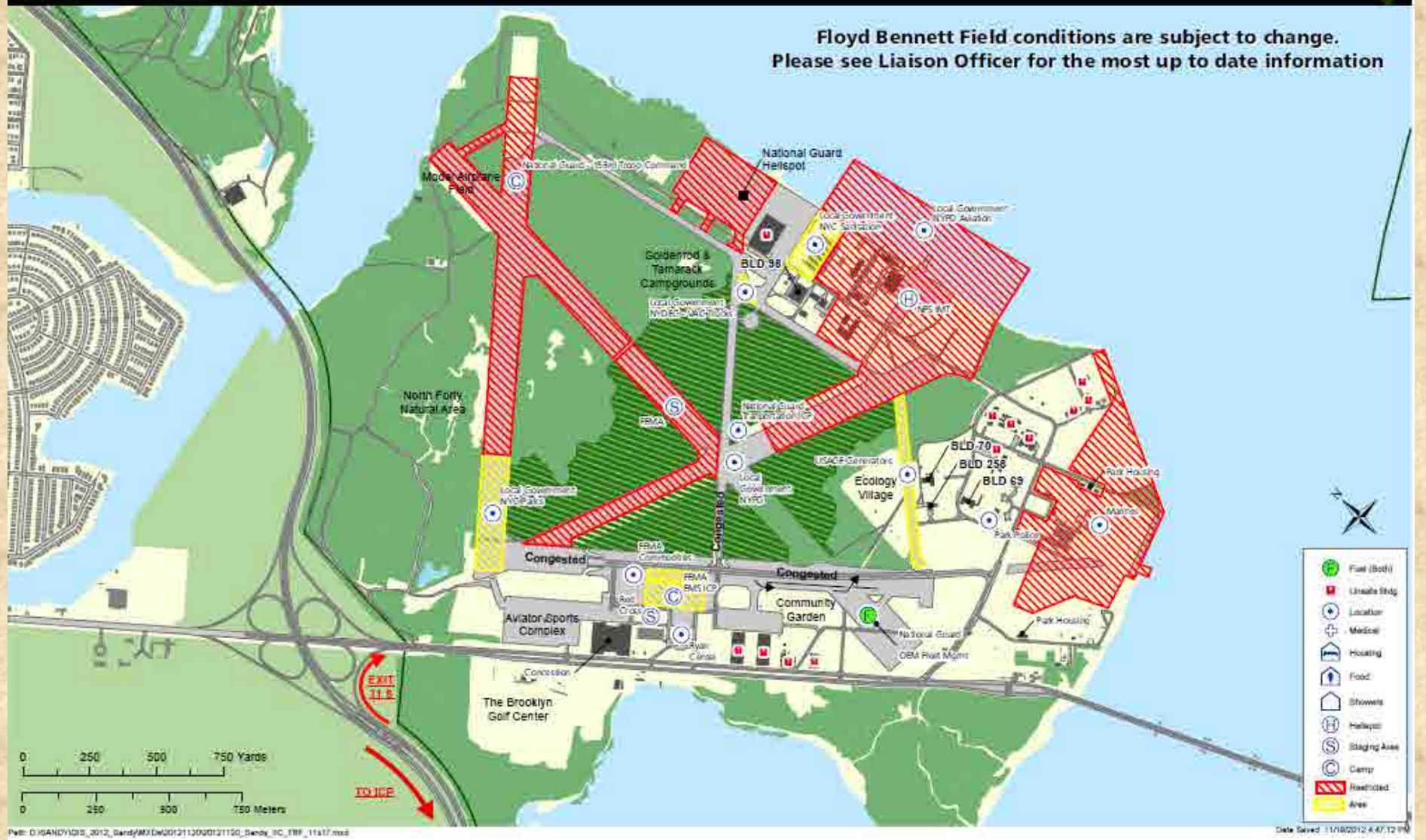
NPS Photos

NPS Photos

Hurricane Sandy DC-WOP-130004
NPS Incident Management Team

II - Gateway Branch, Div. C - Floyd Bennett Field

National Park Service
U.S. Department of the Interior




Hurricane Sandy DC-WOP-130004
NPS Incident Management Team
II - GATEWAY BRANCH, DIV. D - STATEN ISLAND
GREAT KILLS PROGRESSION MAP
National Park Service
U.S. Department of the Interior
Boat removal
Rock shoreline done
Temporary Debris Storage
Beach cleanup
Current as of 11/24/2012
Work Progress
Assessed - Awaiting Stabilization
Assessed - Stabilization in Progress
Assessed - Stabilization Complete
Interagency Staging Area
0 75 150 300 450 600
Meters
Path: X:\GIS_2012_SandyMXDs\20121124_Sandy_ID_Great_Kills_Progression_11x17.mxd
Date Saved: 11/25/2012 1:00:17 PM

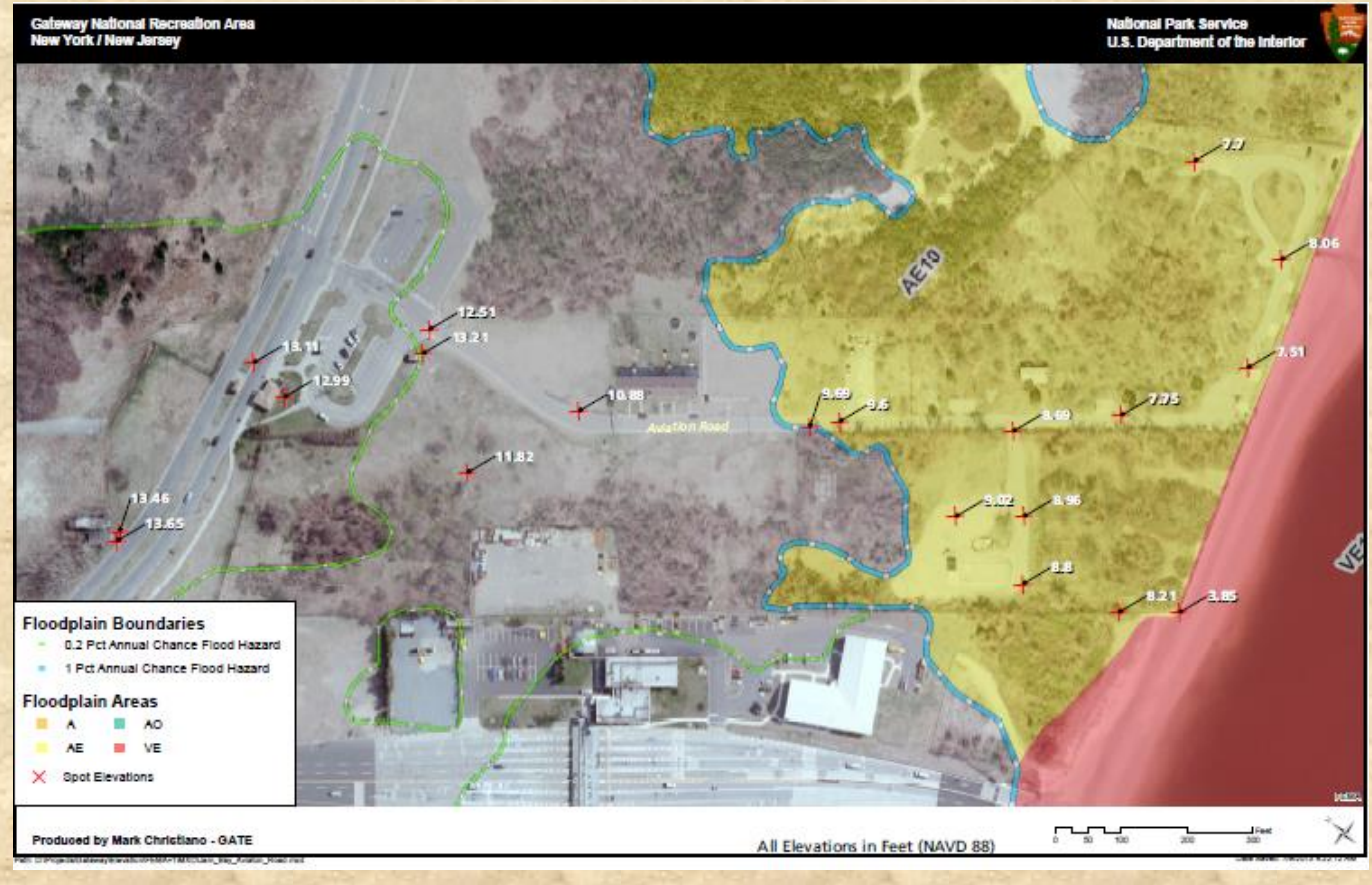
Hx Sandy Planning & Reconstruction Projects

A 2012 web map application displayed pre-Sandy imagery. Park and ICT staff delineated impact areas associated with specific recovery, rehabilitation and mitigation projects. Resulting maps were very helpful when sorting out overlapping project requests.

Park	# PMIS Projects	PMIS Total Cost to Date
AFBG	1	$ 68,170
CACL	1	$ 395,776
FIIS	19	$ 13,728,495
GATE	175	$ 128,511,655
GOIS	4	$ 1,093,844
MORR	4	$ 159,015
SAHI	3	$ 1,031,018
SAPA	2	$ 96,421
STLI	27	$ 48,105,166
TOTAL	**236**	**$ 193,189,560**

Hx Sandy Planning & Reconstruction Projects

Compare FFE and FEMA flood zone for reconstruction requirements



A 2013 project to establish the First Floor Elevations (FFE) for every building at GATE, Statue and Ellis with RTK GPS and total stations by the numbers:

Buildings FFE'd: >500
RTK shots: >1,500
Staff: 8
Days: 5
Cost: $5,354.12

Repeated for FIIS FFE in 2014.

Geospatial Data for Assessing Threats, Preparation and Recovery

- Accuracy & Uncertainty
  - Error in Geospatial Data
- Key Geospatial Data
  - Elevation
  - Bathymetry
  - Inundation
    - Measurements
    - Models
    - Products
  - Also nice to have: Features & Imagery
- **Hx Sandy**
  - **STLI/ELIS & GATE**
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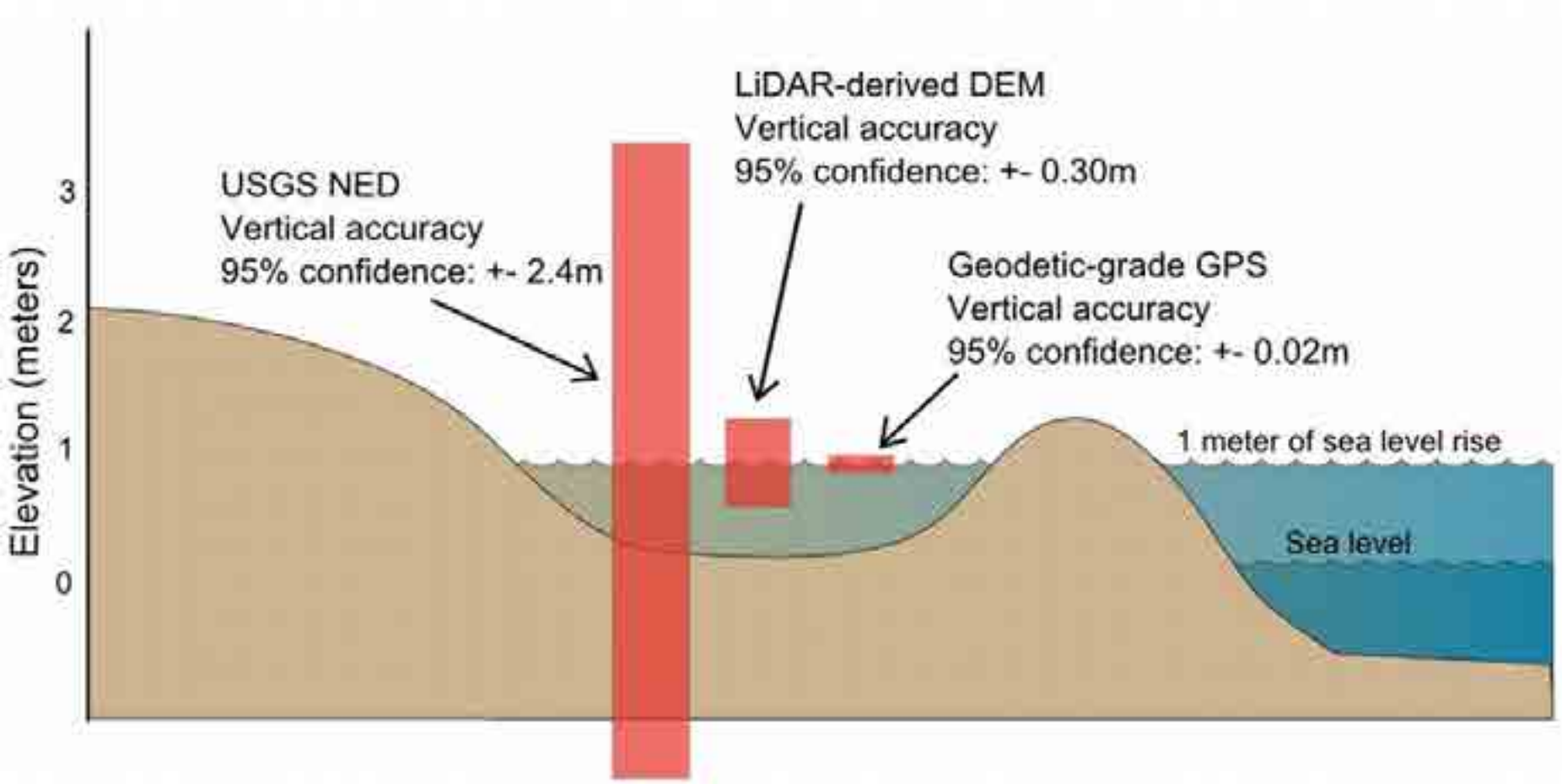
Comparing Elevation Data Sources



Mapping Elevation for Park Planning and Resource Protection

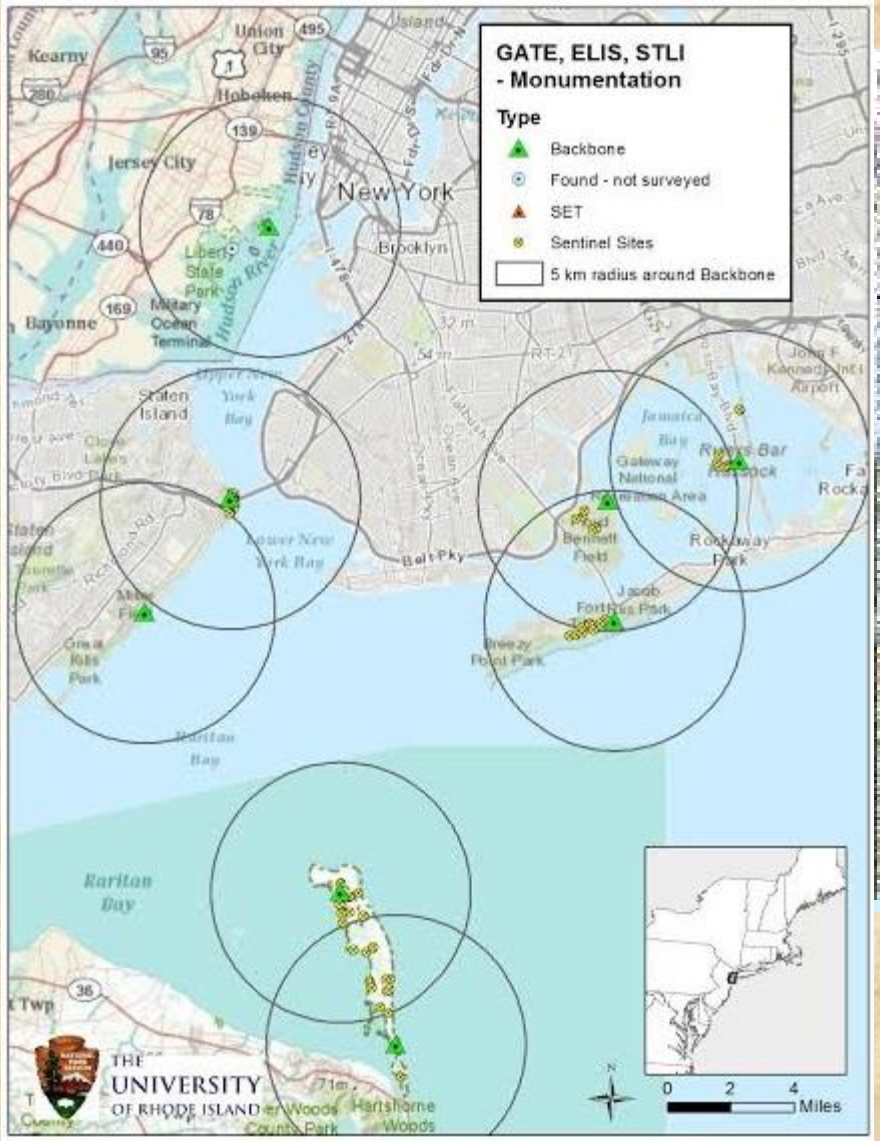
The NPS and the University of Rhode Island are engaged in a series of valuable high resolution elevation mapping projects utilizing RTK GPS:

- "The Backbone" Establish a network of high quality geodetic benchmarks through ten coastal National Parks in the northeast, providing comprehensive coverage at 5 km spacing so future projects can include high res elevation for all features using GPS.

- "Sentinel Sites" Use the Backbone to map an additional 15-20 selected features in each park with nearly as high vertical accuracy to demonstrate the backbone-based mapping process.

- Hx Sandy Sentinel Site Elevation Data Collection for marshes, beaches, dunes, archaeological sites, buildings…you name it!

All the Backbone sites are shared publicly on OPUS, NGS' centralized repository.

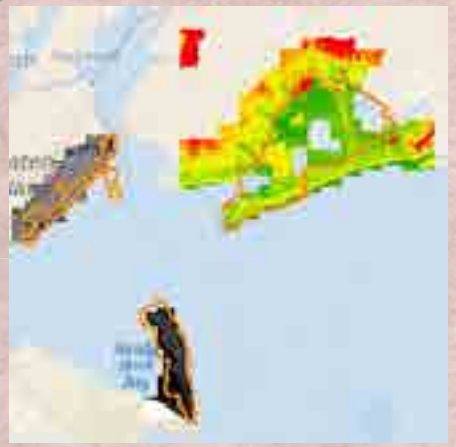


CREDIT ENVIRONMENTAL DATA CENTER, UNIVERSITY OF RHODE ISLAND

All the Backbone sites are shared publicly on OPUS, NGS' centralized repository.

Storm Surge, Sea Level Rise and Web Maps

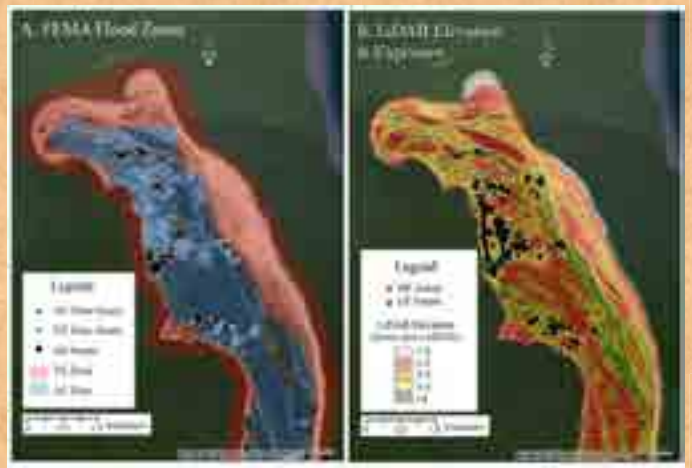
Academic expertise has a central role in collecting, modeling and analyzing data and information on storm surge and sea level rise in National Parks. Among the current projects:



Develop an emergency preparedness and response system to guide spatial data acquisition, analysis and archiving before, during and after extreme storm events. University of Rhode Island. http://www.edc.uri.edu/sandy/home

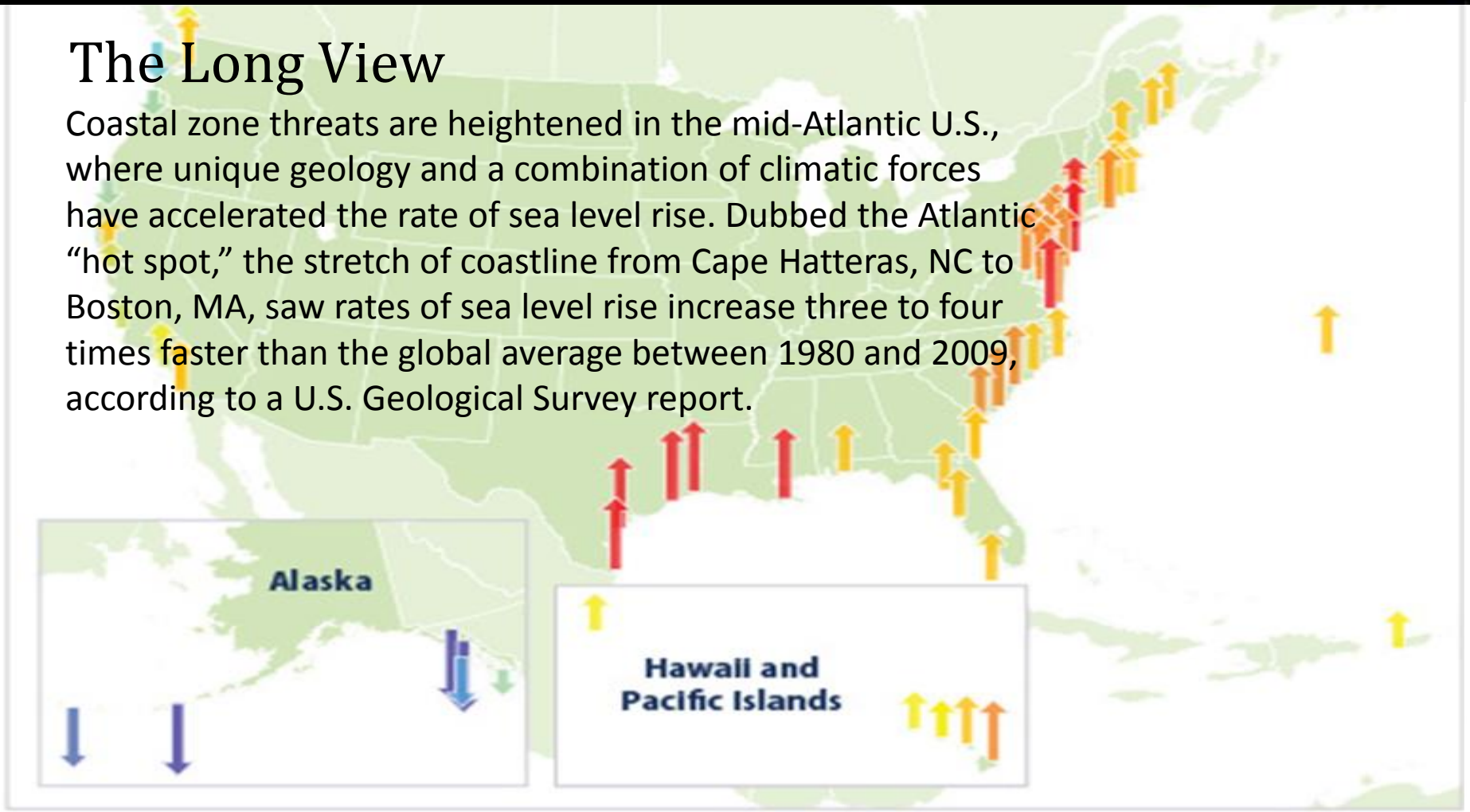
Quantify the dimensions of geomorphological change caused by the storm, including analysis of volumetric and 3D change. Rutgers University.

Evaluate vulnerability of site specific resources and infrastructure to inundation for coastal parks with reference to FEMA Flood Hazard Maps and known exposure.



The Long View

Coastal zone threats are heightened in the mid-Atlantic U.S., where unique geology and a combination of climatic forces have accelerated the rate of sea level rise. Dubbed the Atlantic "hot spot," the stretch of coastline from Cape Hatteras, NC to Boston, MA, saw rates of sea level rise increase three to four times faster than the global average between 1980 and 2009, according to a U.S. Geological Survey report.



1960-2013, Relative sea level change (Inches):

≤ -8	-7.99 to -6	-5.99 to -4	-3.99 to -2	-1.99 to 0	0.01 to 2	2.01 to 4	4.01 to 6	6.01 to 8	> 8

CREDIT U.S. ENVIRONMENTAL PROTECTION AGENCY; DATA SOURCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION