Island Beach State Park Breach Analysis

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Executive Summary

The new, high-resolution, hydrodynamic model for the Barnegat Bay estuary developed and validated by Stevens' researchers was utilized to investigate possible breaching of Island Beach State Park during Hurricane Sandy. The Stevens Barnegat Bay Inundation Model (SBIMS) has a constant 100m resolution and is nested within the three dimensional Stevens NYHOPS model at its offshore open boundary, providing a link to upstream river flows and downstream to oceanic tidal and storm surge influences, and forced by local meteorology (surface wind and barometric pressure). Wetting and drying of land features in the model's external time step is as low as 0.1 sec in its 2D barotropic mode. This mode provides for the dynamic prediction of depth integrated flood elevations and velocities across land features during inundation events.

SBIMS was calibrated using the NYHOPS hindcast of Hurricane Sandy. The hindcast utilized Sandy over ocean wind field and atmospheric pressure data, offshore wave and tidal boundary forcing, atmospheric heat fluxes, interior streamflow data and was validated against observed water levels and measured high water marks. A comparison against 6 water level time series measured by USGS tide gauges located in the Barnegat Bay verified that the model is able to capture the spatial and temporal variation of water levels in the Bay observed during Hurricane Sandy. A comparison against the verified high water marks found that the model is capable of hincasting overland water elevation to within 0.63ft (one standard deviation) at 71% of the total water marks measured (Blumberg, et. al., 2014).

The SBIMS was employed to analyze possible breaching during Hurricane Sandy. Observations and the model hindcast determined that the central and southern portion of Barnegat Bay slowly filled with water as the Hurricane approached New Jersey. Strong north-northeast winds prior to landfall pushed water south in the Bay, increasing the water elevations in the southern Bay. The peak water level in the southern Bay occurred within minutes of to the time Sandy made landfall. Peak water levels in the central and northern portions of the Bay; however, lagged those in the south by 4 to 7 hours. After landfall the strong southerly wind field associated with Sandy pushed the excess water in the southern Bay north at approximately 5 mph.

The timing of peak water levels in the Bay west of Island Beach Park corresponds to the time of observed flooding in the communities located along the west side of the Bay. At this time, the water elevation on the ocean side of Island Beach State Park were 2ft lower than the water elevation in the Bay. This clearly indicates that the flooding experienced in Berkley Township was a result of the surge moving north in the Bay and not from the breaching or overwashing of Island Beach State Park. At no time does the SBIMS hindcast of Hurricane Sandy show any evidence of overwash or breaching in the Park.

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Introduction

Communities along the Barnegat Bay were significantly impacted by Hurricane Sandy along both the Atlantic Ocean and Bay shorelines. Sandy was a harsh reminder of the vulnerability of low lying coastlines to significant inundation damage from coastal storms. The Barnegat Bay estuary (Figure 1) is a shallow, sheltered lagoon system that includes, from north to south, the waters of Barnegat Bay proper, Manahawkin Bay, and Little Egg Harbor. For the purposes of this document, Barnegat Bay is used to refer to the whole estuary. The total receiving water area of approximately 117 square miles connects to the Atlantic Ocean through the Little Egg Harbor Inlet in the south, the Barnegat Inlet at its midst, and the Manasquan Inlet through the Point Pleasant canal in the north. The estuary drains an approximately five times larger watershed (660 square miles). Spring tidal ranges in the Bay vary from 3.4ft at Little Egg Inlet to 2.7ft inside the Barnegat Inlet, to as small as 0.35ft at Oyster Creek. Maximum water elevations of greater than 6ft above the tide have been measured in the Bay during significant coastal storm events. The low lying land elevations and population density along the Bayshore make Barnegat Bay communities extremely vulnerable to significant inundation.

In an effort to understand specific vulnerabilities and flood mitigation options within the Barnegat Bay, we have leveraged existing model-based flood zone mapping and risk assessment work to quantify the effectiveness of specific short-term and long-term flood protection measures within the Barnegat Bay. We have developed and validated a new, high-resolution hydrodynamic model for the Barnegat Bay estuary; including its vast intertidal areas. The model is nested to Stevens' existing three-dimensional New York Harbor Observing and Prediction System (NYHOPS) model providing a link to upstream river flows and downstream to oceanic tidal and storm surge influences, and forced by local meteorology (surface wind and barometric pressure). The new hydrodynamic model has been used to study flood pathways during Sandy as well as evaluate the reduction in inundation due to short-term (floodwalls in breach locations) and long-term (inlet surge barriers) flood mitigation. For this investigation, the calibrated and validated model has been refocused to analyze the potential overwash and breaching of Island Beach State Park along the eastern edge of central Ocean County.

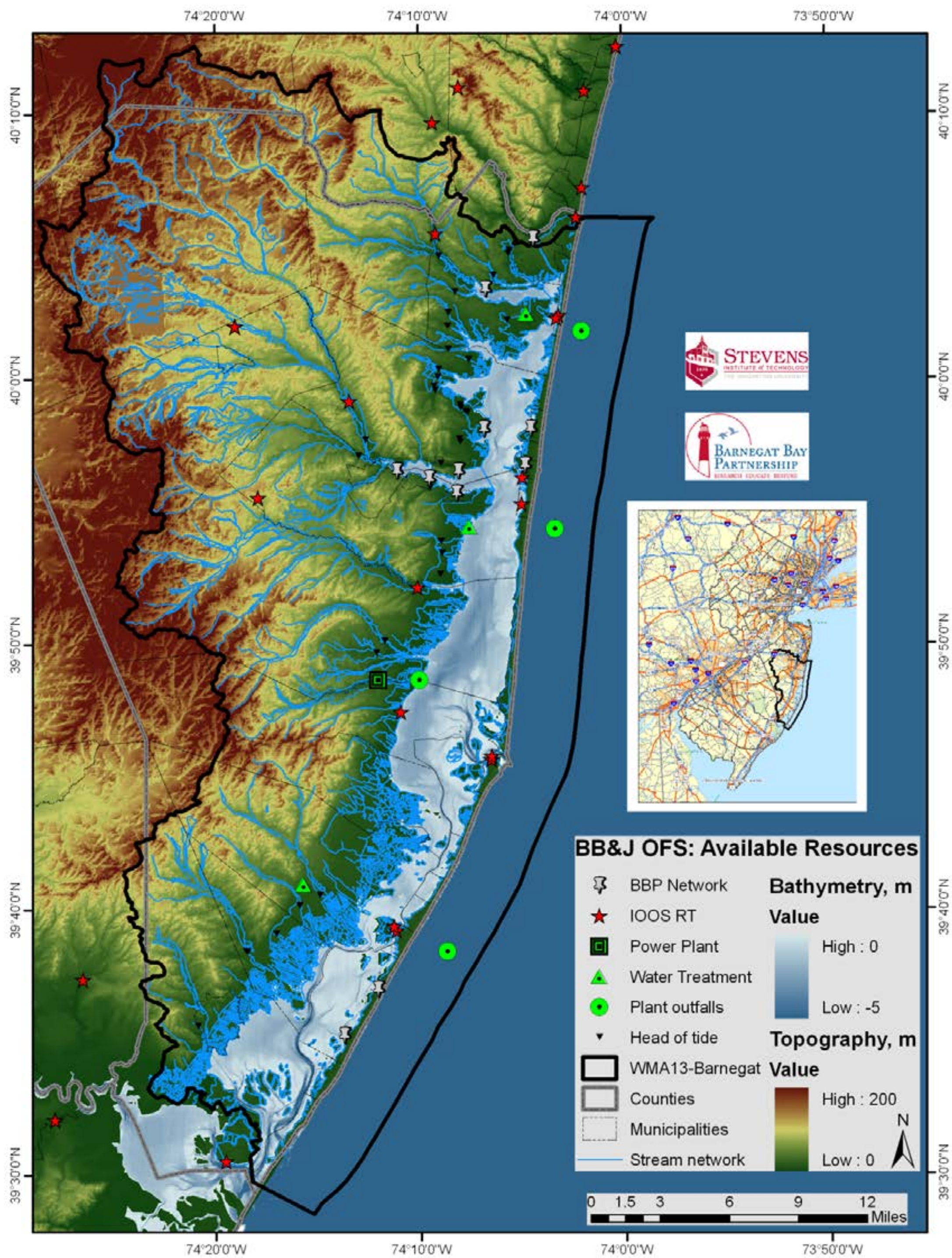


Figure 1. The Barnegat Bay estuary, its watershed surface hydrology and major point sources.

Hurricane Sandy Characteristics and Impacts

Sandy formed as a tropical depression southwest of Jamaica on October 22, 2012. Sandy strengthened to a Category 3 hurricane as it moved northward across Cuba and into the Bahamas before taking a more northeastward track off the eastern seaboard of the United States as a Category 1 hurricane (Figure 2). Although weaker, the size of the storm greatly increased with tropical force winds reaching the eastern seaboard 250 miles from the center of the storm (Figure 3). In the early morning hours of October 29th, Hurricane Sandy encountered an anomalous blocking high pressure system over the North Atlantic that steered the hurricane toward the Mid-Atlantic coast. As Sandy moved over the Gulf Stream it briefly strengthened to a Category 2 hurricane just 12 hours before landfall. Moving over the cooler waters of the continental shelf east of New Jersey, Sandy quickly weakened and began transitioning into an extratropical storm. Hurricane Sandy retained its unusual large wind field until it made landfall on Brigantine Island at 8pm EDT on October 29th.

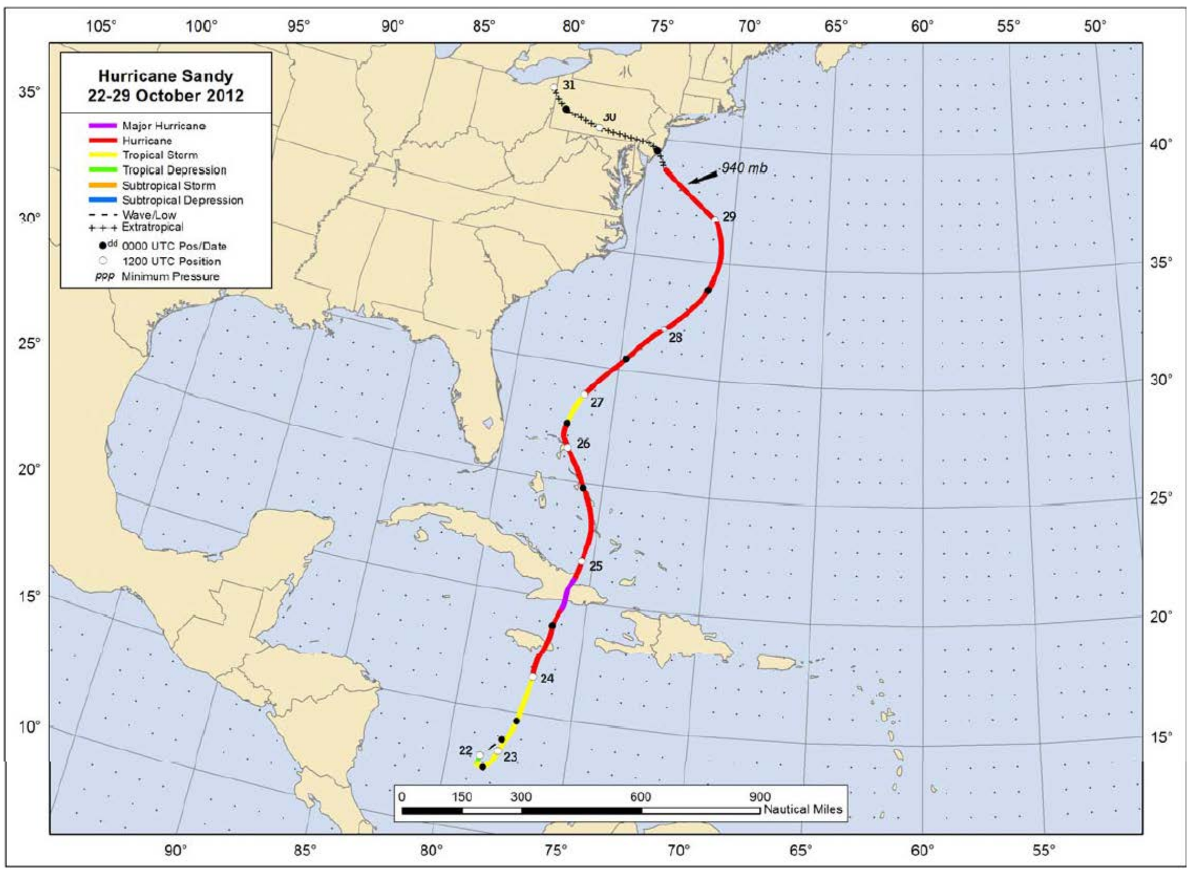


Figure 2. Hurricane Sandy track and intensity (NOAA Hurricane Research Division).

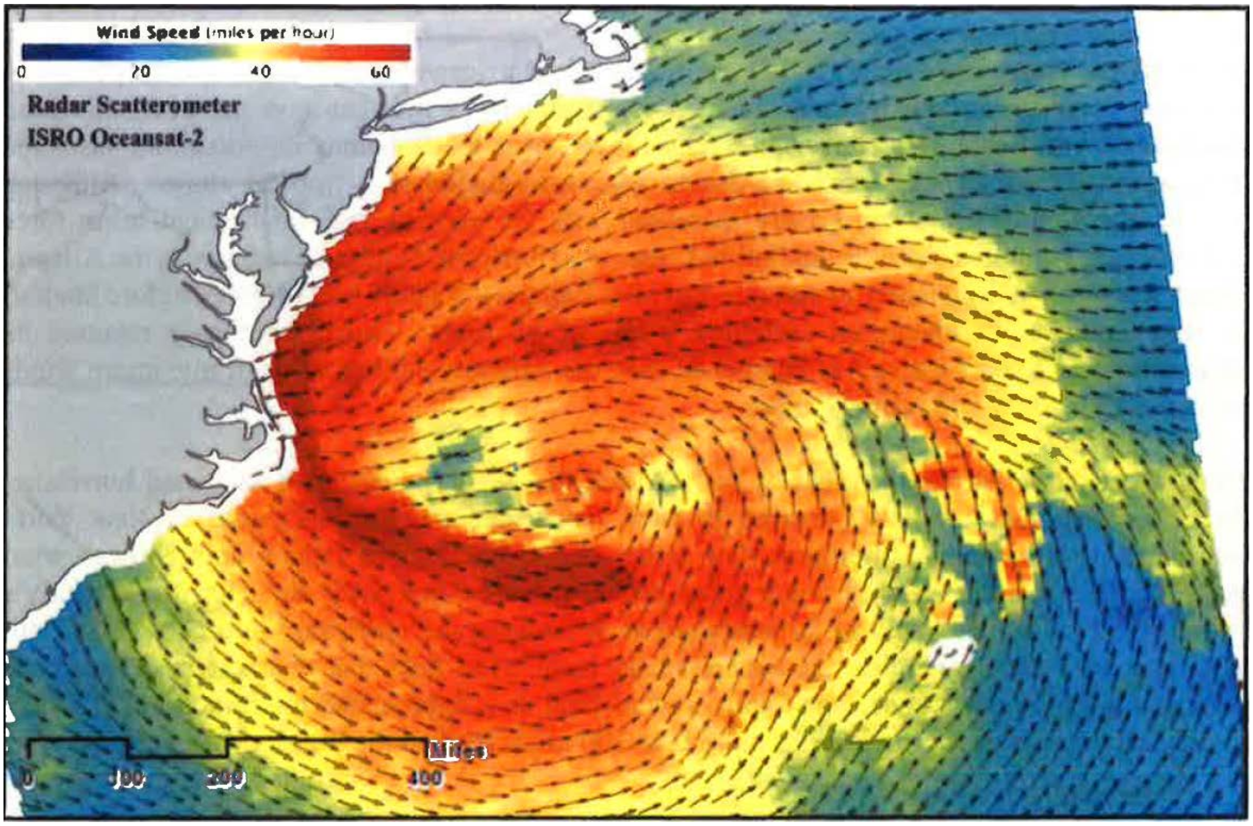


Figure 3. Hurricane Sandy track showing extent of tropical storm force winds (NASA).

Two hours prior to landfall sustained easterly winds of 35 knots, gusting to 60 knots were measured at Sandy Hook, NJ. The large wind field generated an extreme storm surge (abnormal rise of water above the predicted astronomical tide generated by a storm) north of the eye at landfall. Measured water levels ranged from +6.3ft NAVD88 at Atlantic City to +11.3ft NAVD88 at The Battery in New York City. NOAA has determined that the recurrence interval of such extreme water levels ranges from 30 years to >200 years, respectively (USACE, 2013). Hurricane Sandy's large diameter winds also resulted in long fetch lengths over the Mid-Atlantic and subsequent generation of extreme wave heights. Wave heights in excess of 32ft were measured 14 miles east of Sea Bright by NOAA Buoy 44065 located at the entrance to NY Harbor.

Following landfall, Sandy moved west-northwestward into Pennsylvania by October 30th. As Sandy moved across southern New Jersey, the strong east-northeast wind field that battered the NJ coast north of Brigantine abruptly shifted to a 40 knot southerly wind field (Figure 4). The northern portion of the Barnegat Bay that initially experienced a set-down in water levels at the time of landfall, experienced a significant increase in water level as the center of the storm moved inland.

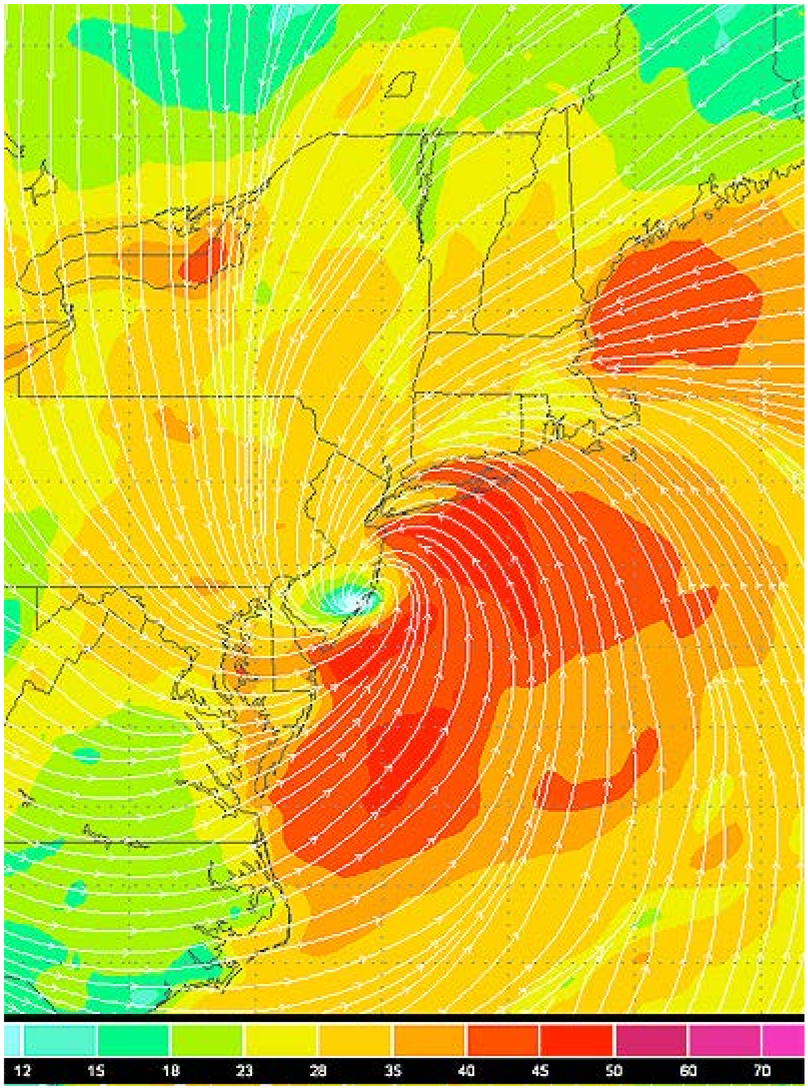


Figure 4. Sandy wind field at landfall showing strong southerly winds to the southeast of the eye.

Sandy caused unprecedented damage to New Jersey's housing, businesses, and infrastructure. Initial FEMA assessments suggest that approximately 71,800 structures in New Jersey were affected by Sandy. Of these, approximately 500 were destroyed and another 5,000 suffered major damage (>50% of the value of the property). The NJ Department of Community Affairs estimated that 40,500 primary residences and over 15,600 rental units in NJ sustained severe or major damage (NJDCA, 2013). In Ocean County alone, immediate post-Sandy FEMA estimates suggest that 22,200 homes were affected, 16,000 suffered minor damage, 1,180 were majorly damaged and 420 were destroyed; representing 56% of all damaged structures in NJ. A majority of the structures affected in the County were inundated by flood waters from the Barnegat Bay.

Barnegat Bay Inundation Modeling System

Details of the Stevens Barnegat Bay Inundation Model can be found in (Bruno *et al* 2006, Fan *et al* 2006, Georgas *et al* 2009a, Georgas 2010, Blumberg *et al*, 2014). SBIMS is a high-resolution model of the Barnegat Bay that is nested to the larger New York Bight sECOM model (NYHOPS), which is itself nested to an even larger Northwest Atlantic sECOM model (SNAP, Figure 5). The large models provide the external tide, current, wave, and atmospheric forcing that is required to run the nested Bay model. The parent model is well documented, is in use by almost 3000 research groups around the world, and is run operationally as part of NOAA's Integrated Ocean Observing System (Figure 6). The Barnegat Bay Inundation Model (BBIMS) has a constant 100m resolution and is nested within the three dimensional NYHOPS model at its offshore open boundary. The grid and bathymetry is shown in Figure 7. A Digital Elevation Model (DEM) based on LiDAR elevation measurements obtained in 2010 by FEMA provides the topography of the surrounding ground elevations. The wetting and drying model's external time step is as low as 0.1 sec in its 2D barotropic mode.

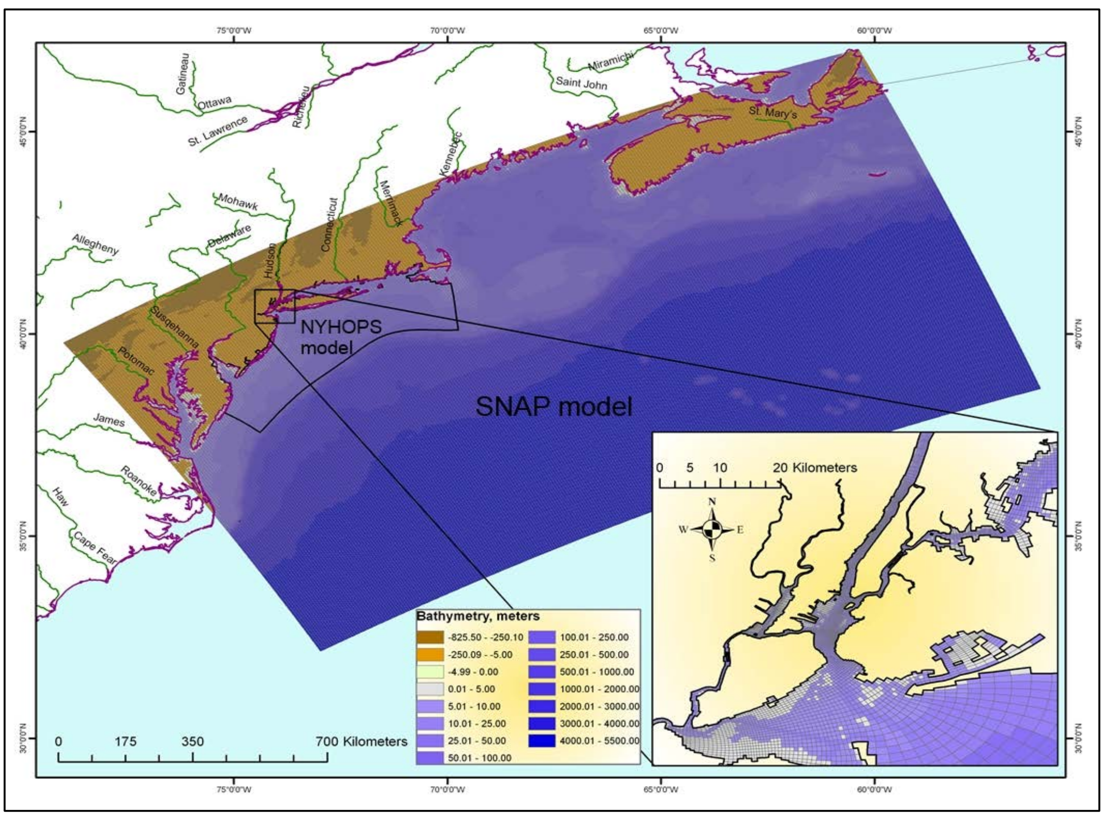


Figure 5. Stevens Northwest Atlantic Prediction (SNAP) model domain, showing the New York Harbor Observing and Prediction System (NYHOPS) model nested within it. The Barnegat Bay Inundation Model is itself nested within NYHOPS.

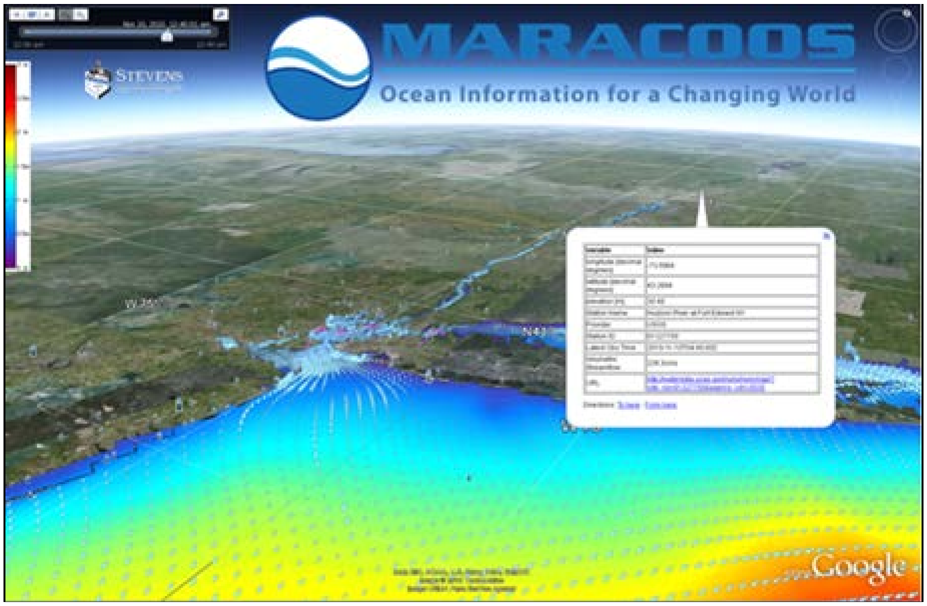


Figure 6. Google interface for NYHOPS model forecasts.

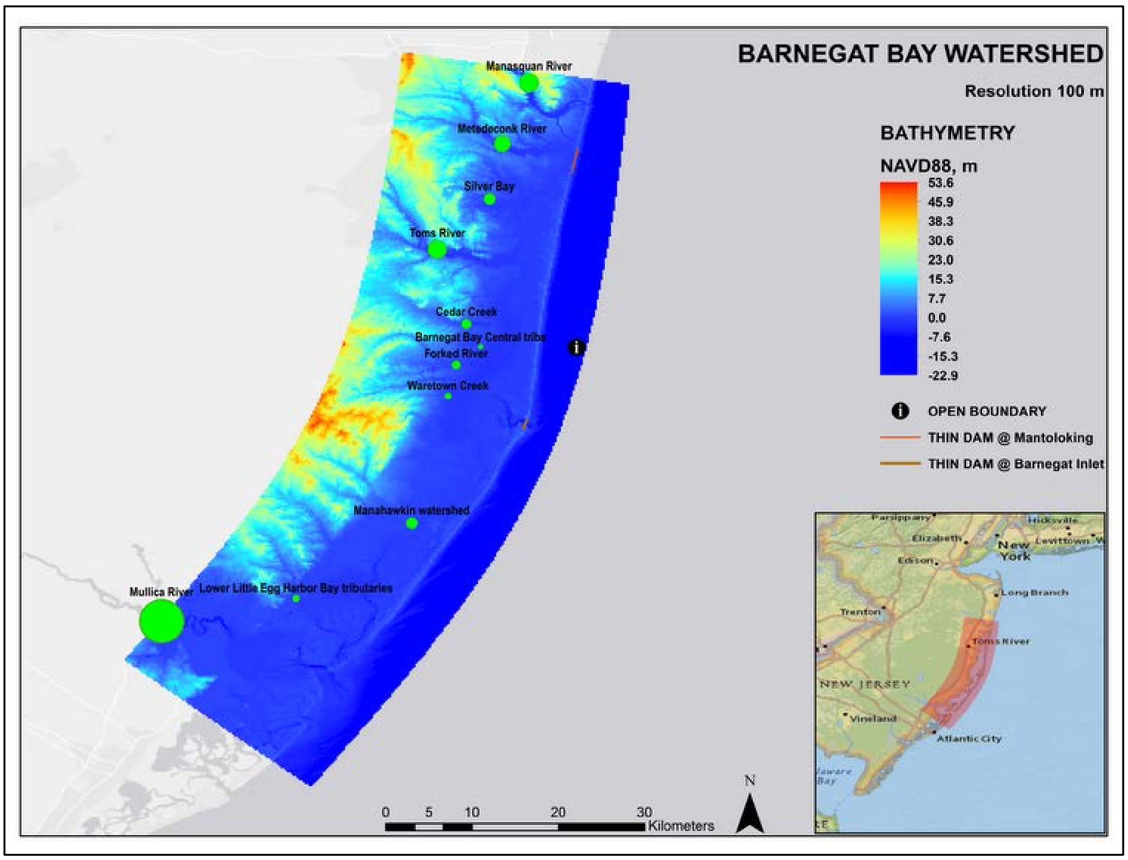


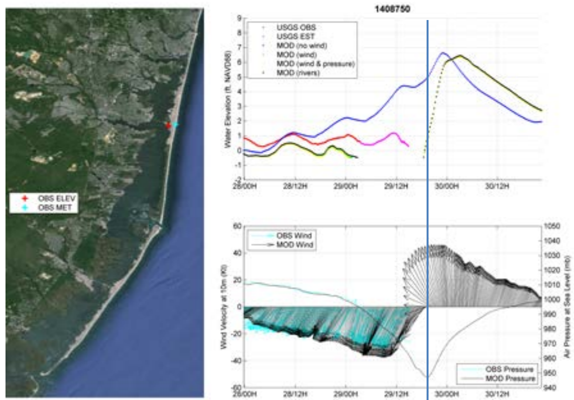
Figure 7. Barnegat Bay Inundation Model. Bathymetry, resolution, open boundary, and significant river discharges as modeled in this work.

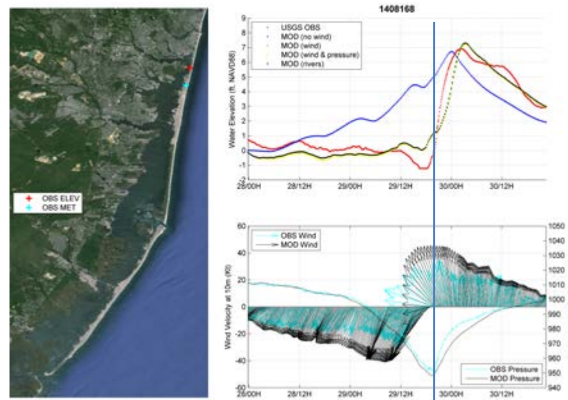
Hurricane Sandy Model Simulation

Water level time series recorded by USGS coastal tide gauges in the Barnegat Bay were used to validate the SBIMS. The USGS operates 8 real-time tide gauges in the Barnegat Bay. Two of the gauges, one in Waretown and one in Seaside Heights were destroyed during Sandy. Verified data from the six gauges that survived were used to validate the model. Meteorological data from the closest available weather station to each gauge was used to validate the atmospheric forcing. The location of each tide gauge is indicated by the light blue squares on Figure 8.

To determine the importance of varying physical forcing in the model, (including winds, air pressure, and breaches) a comparison between observed and forecast water levels was conducted at each validation point in the model domain. Each validation plot presents the water level time series in the upper right and the atmospheric time series in the lower right. Each water level plot shows the observed water levels (red dots) at the tide gauge, the predicted water level without wind forcing over the bay (blue dots), the predicted water level with wind forcing (green dots), and the predicted water level with both wind and local atmospheric pressure forcing variation (black dots). Each atmospheric plot shows the modeled (black) and observed (aqua) wind vector and atmospheric pressure. The arrows on the wind vectors point in the direction toward which the wind is blowing (i.e., an arrow pointing directly up is a wind blowing from south to north).

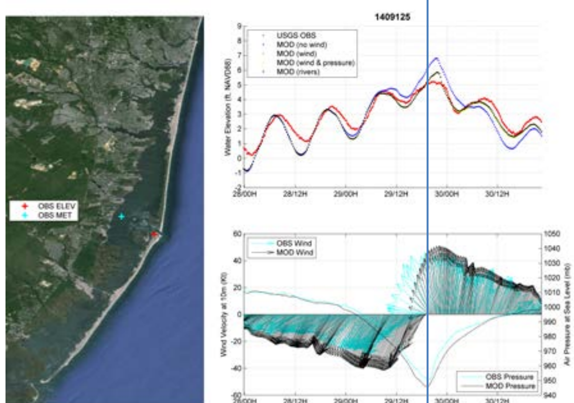
Figure 8. Location of operational (light blue squares) and non-operational (red squares) USGS tide gauges used for model validation.

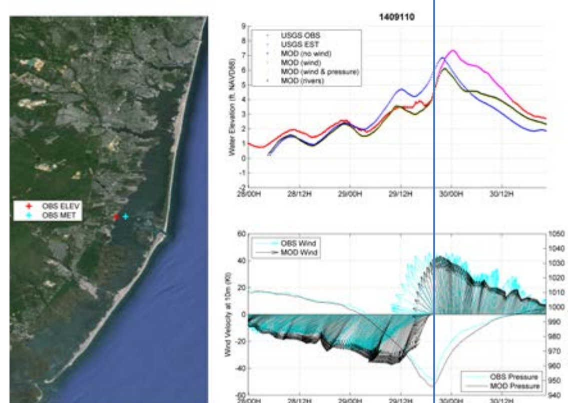




(e)

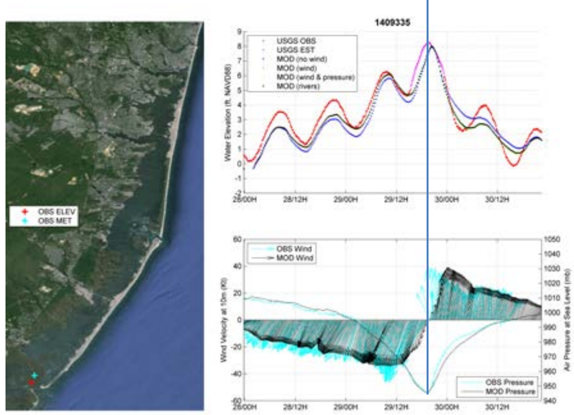
(f)

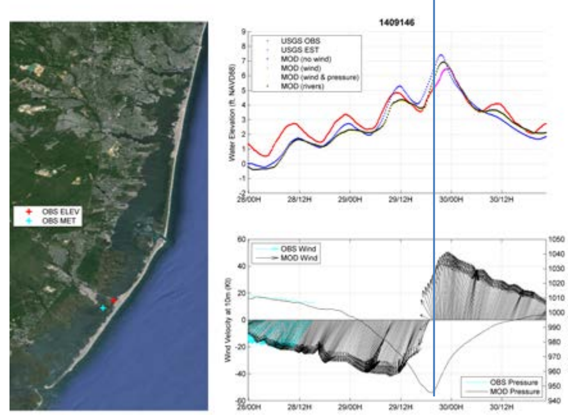




(c)

(d)





(a)

(b)

Figure 9. Comparison of observations (after USGS corrections; pink) and model predictions.

The validation results are presented from south (a) to north (f) in Figures 9. A quick look at the observed water level shows that the southern portion of the Bay, south of Barnegat Inlet, experienced a longer duration surge event than the northern portion of the Bay. Data and model results for the southernmost tide gauge, located at the Rutgers Marine Field Station in Tuckerton, NJ, is presented in panel (a). The observations show that water began to enter the southern portion of the Bay starting on October 28th. The bay gradually filled with water on each incoming tide as Sandy approached the coast. Recorded water elevations reach 6ft NAVD88 during the morning high tide on October 29th and only receded about a foot prior to the peak surge that occurred during the next tidal cycle. After landfall, the southern portion of the Bay began to drain but remained above the astronomic tide elevations until the morning low tide on October 30th.

The model water elevation prediction with and without surface wind forcing both track the observed water level well prior to landfall but underestimate the elevations by approximately 1ft. The skill of the model increases greatly on October 29th. Prior to and at landfall, the model water level prediction that includes both wind and air pressure surface forcing match the observed water level almost exactly. The model predicts a peak water level of 8ft NAVD 88 at Tuckerton, exceeding the recorded peak by 2ft (Figure 9a). Based on the model prediction, it appears the peak water level in the southern Bay occurred within minutes of to the time Sandy made landfall.

Observed and predicted water levels at Long Beach Island (LBI) are shown in panel (b). The observations at LBI also show a gradual increase in water elevation prior to landfall, similar to the data recorded at Tuckerton. The model predictions with and without wind forcing again show a trend similar to the observations but under predict the observed water levels prior to landfall. The model predictions that include wind and pressure forcing at the surface again show the greatest skill in predicting the peak water elevations. The peak water level at LBI also exceeded the elevation at which the gauge could accurately measure water levels. The model predicts a peak water elevation of approximately 7ft NAVD88 at LBI, but occurring after the time Sandy made landfall, a fact that is consistent among all back-bay stations (b, d, e, f) away from the inlets, especially in the upper bay (e and f).

Panels (c) and (d) on Figure 9 show the observed and modeled water levels on the east and west side of the Bay inshore of Barnegat Inlet, respectively. Both tide gauges show the gradual filling of the Bay with water starting on October 28th. At these stations, the model error is reduced to between 0.25 and 0.5ft below the originally recorded water elevations. The model results with no wind forcing over predicts the peak water level in the middle of the Bay. The wind and air pressure forced simulations accurately predict the time and elevation of each high tide but somewhat under predict the observed low tide elevations. The peak water levels, occurring at about the time of landfall, are over predicted by the model at Barnegat Inlet. At the inlet, the model predicts a water elevation of 5.75ft NAVD88 while the observed water elevation peaked at 5.25ft. The USGS estimate that a peak water elevation of 7.33ft NAVD88[1] occurred at midnight on October 30th at Waretown, the western station. At this location, the model predicts a peak water elevation of 6ft NAVD88 at around 22:00 on October 29th. We note that the USGS-estimated and revised data at Waretown (Figure 18d) are quite different from both the originally recorded values and our model results.

The water level observations and prediction in the northern portion of the Bay are shown in panels (e) and (f) of Figure 17. It is immediately obvious from a quick look at the observed water levels that the upper Bay responded very differently than the southern and central portions. The tide gauge at Seaside Heights (e), located 12.5 miles north of Barnegat Inlet was destroyed during Sandy. Prior to its failure, the observed water levels and the fully dynamic model predictions (green dots) show a set-down in water levels in the upper bay in contrast to the observed gradual filling of the central and southern portions of the Bay prior to landfall. The predicted water elevations from the model run without wind forcing forecast a gradual filling of the Bay similar to that observed in the southern portions of the Bay. The difference between with and without wind forcing cases shows the extreme sensitivity of the northern portion of the Bay to the north-northeasterly wind field prior to landfall.

The northern most tide gauge (f) is located just south of the Mantoloking Bridge, the place with the largest breach during Sandy. The observed water levels show a gradual set-down in elevation prior to landfall. A few hours prior to landfall, the water elevations fall below the lower limit of the tide gauge (~ -1ft NAVD88). The water elevations predicted by the wind and pressure forced the model to forecast a near-constant water level prior to landfall followed by a slight rise and then drop in water elevations as the gauge reports a set-down in water elevation. After landfall both the observations and the model show a rapid rise in water elevation, reaching a peak approximately 7 hours after landfall. The rise in water elevations in the northern portion of the Bay is in response to the rapid switch from northerly to southerly winds following landfall; again showing the extreme sensitivity of the northern portion of Barnegat Bay to local wind forcing.

[1] http://nwis.waterdata.usgs.gov/usa/nwis/uv/?cb_00065=on&format=gif_default&period=&begin_date=2012-10-28&end_date=2012-10-30&site_no=01409110

Assessment of Island Beach State Park Breaching

The SBIMS was employed to analyze possible breaching during Hurricane Sandy. The modeling system utilized the same Sandy hindcast over ocean wind field, atmospheric pressure data, and offshore wave and tidal boundary forcing that was used to validate the model. The model simulation spans the time period from midnight EDT on October 28th and midnight EDT October 31st, 2012. The full model domain is shown on the left side of Figure 10. A zoomed in view of the portion of the model centered on Island Beach State Park is shown on the left. The location of the two water level time series plotted in the lower right hand corner are indicated by the blue and red boxes in the upper left hand plot. The blue line is the time series of open ocean water levels and the red line is the predicted water level in the Bay west of the mid-point of Island Beach State Park.

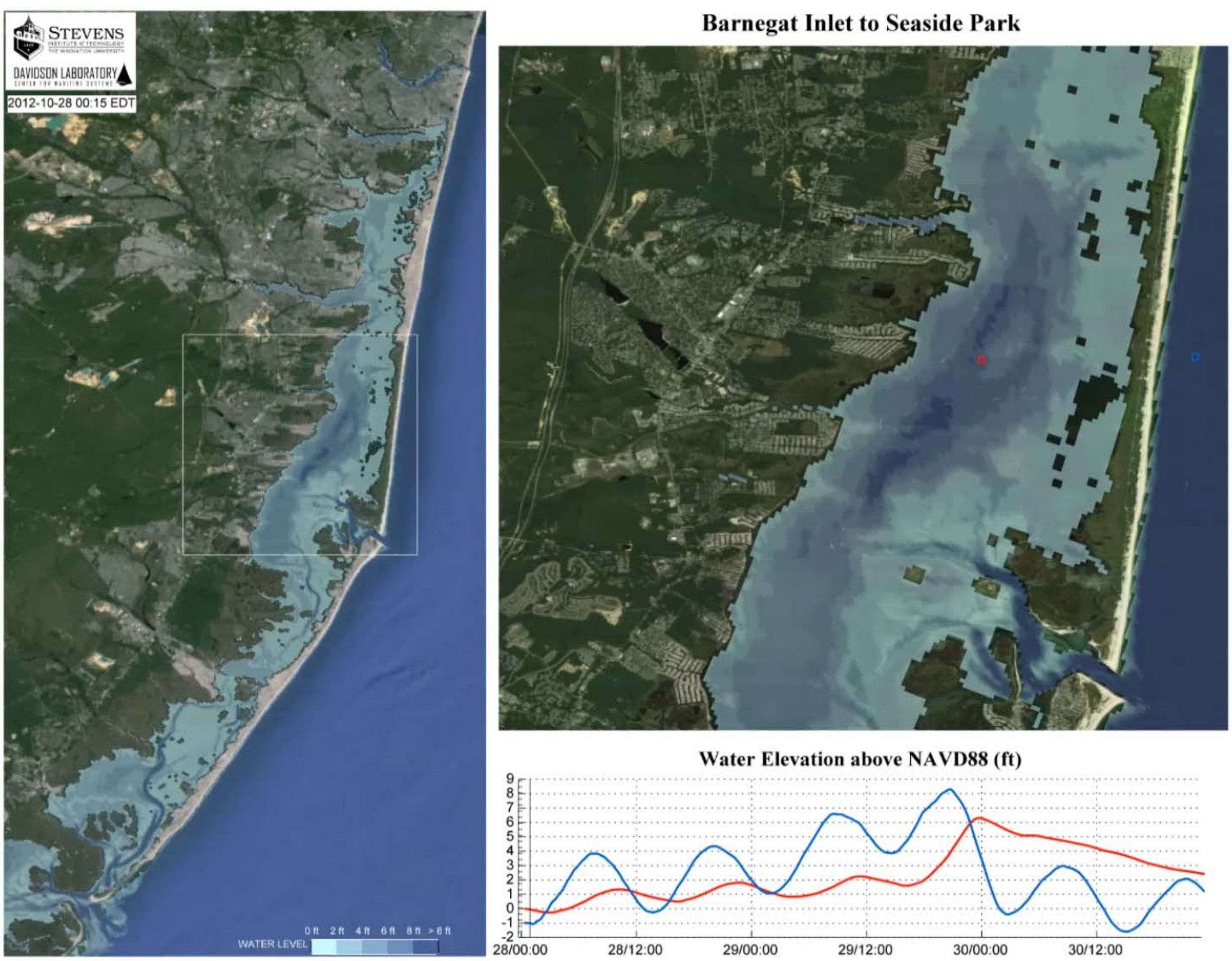


Figure 10. Island Beach State Park Model Domain in SBIMS

The morning high tide prior to Sandy's landfall occurred at 8:00 EDT on the oceanfront and reached an elevation of approximately 6.5 t NAVD88 (Figure 11). Note on the figure that time is indicated in the upper left corner and corresponds to the vertical grey solid line on the time series plot. Water levels in the central Barnegat Bay indicate a slow rise with each tide as the bay filled with water. At 8 AM water was at an elevation of 1.5ft NAVD88. At this time there was minor flooding of the western shoreline of Island Beach State Park.

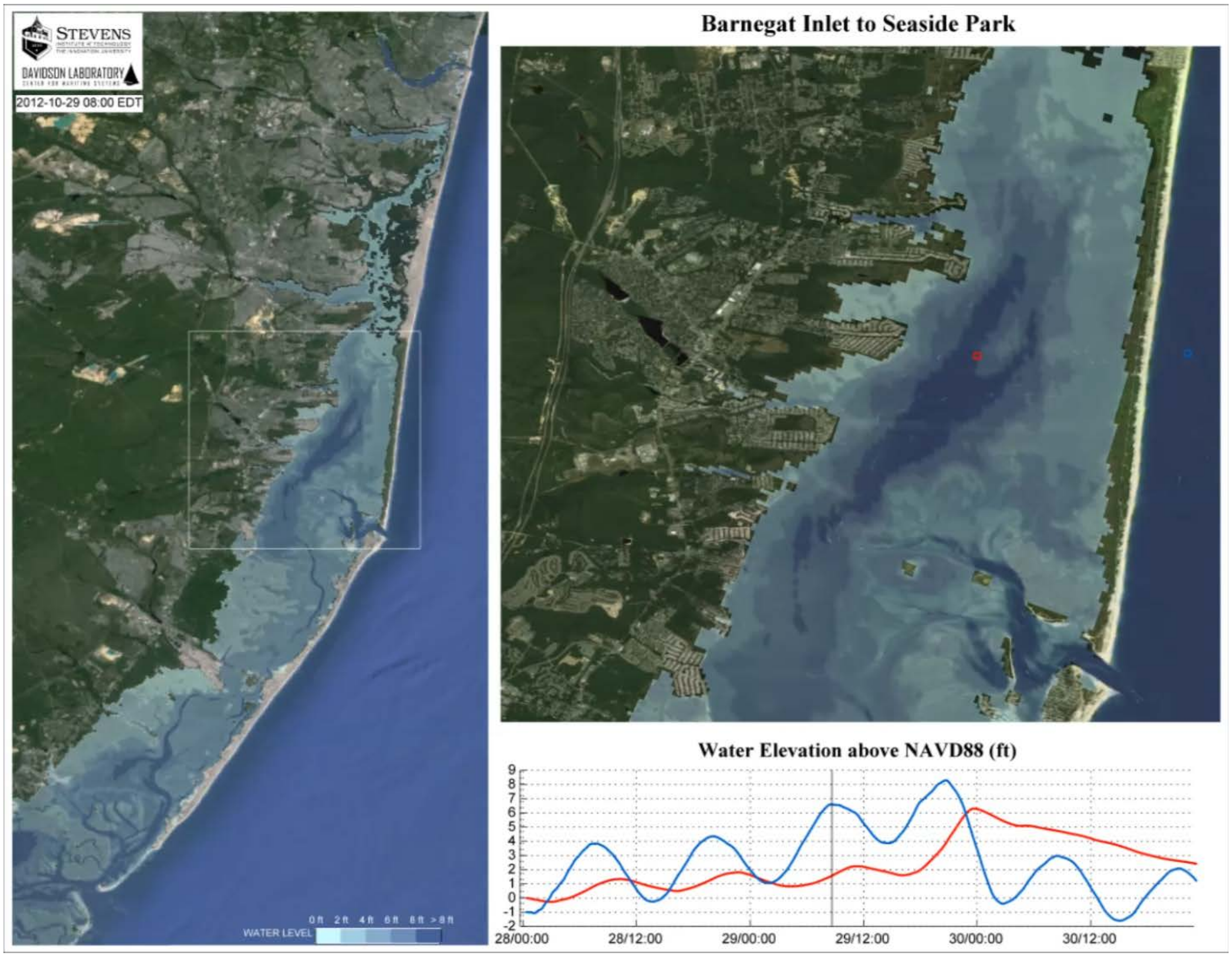


Figure 11. Water levels at morning high tide on October 29, 2012.

Sandy's peak ocean surge coincides with the hurricanes landfall at 20:00 EDT on October 29th. Water levels reach an elevation of 8.25ft NAVD88 on the oceanfront and 4ft NAVD88 in the central Bay west of Island Beach State Park (Figure 12). Looking carefully at the Island Beach inset, there is no evidence of overwash or breaching occurring across the barrier spit. Flooding is evident within the communities immediately adjacent to the bayshore along the western side of the Bay.

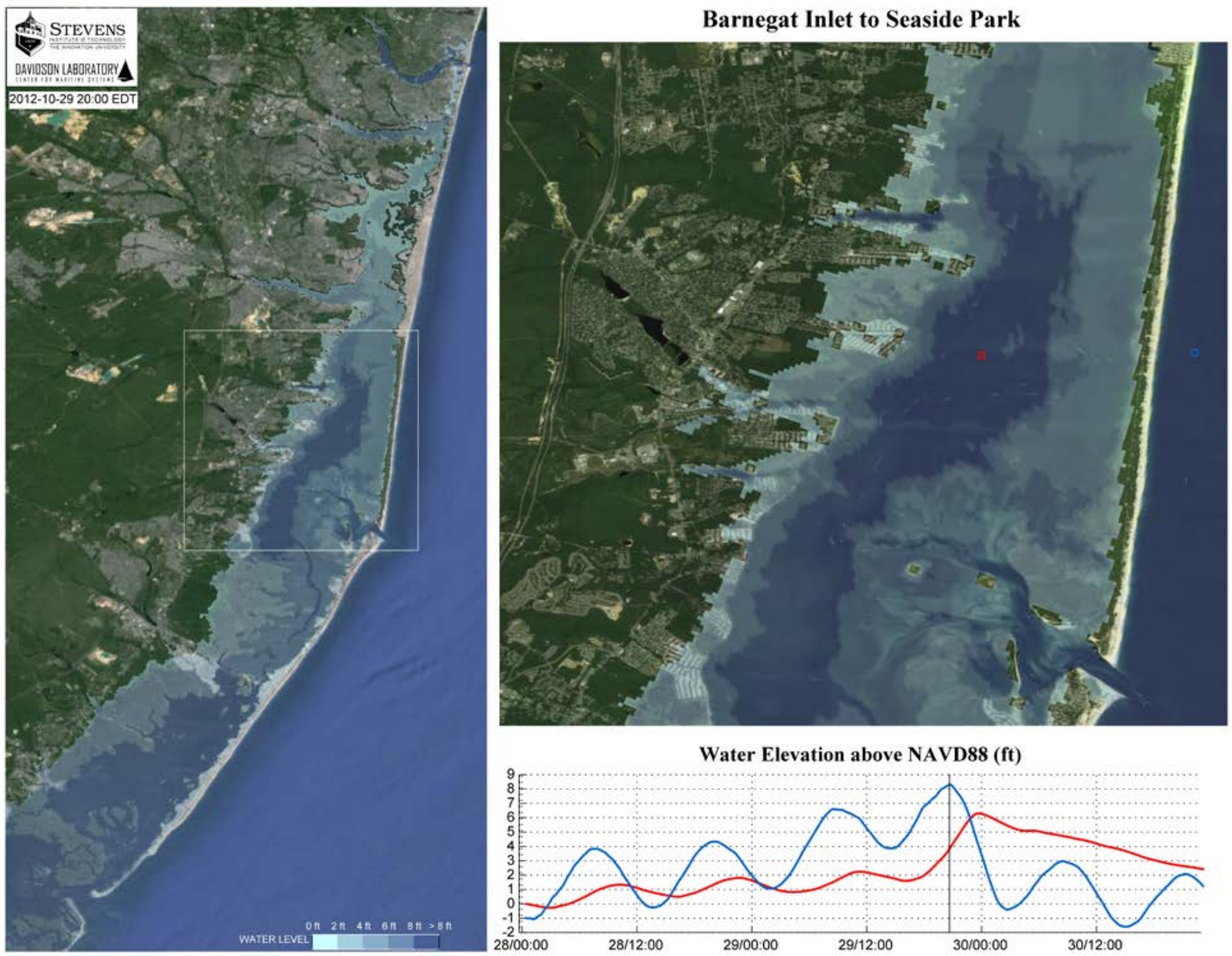


Figure 12. Water levels at time of peak surge on October 29, 2012.

After landfall, the offshore water levels rapidly fall on the outgoing tide. The water levels in the Bay continue to rise as the water that had been forced to the southern portion of the Bay by the very strong NNE winds prior to landfall is forced up the Bay by the strong southerly winds in the southeast quadrant of the storm. Due to the shifting strong local wind forcing, the upper Bay first emptied to the south, then filled up much faster as the winds shifted, with rates close to 1ft/hr.

Peak water levels in the central Bay occur 4 hours after the peak oceanfront water levels (Figure 13). This peak varied in space and time as the peak in the upper Bay occurred 3 hours later (7 hours after landfall). This indicates that the bay surge propagated at approximately 5 mph up the Bay. At 00:00 EDT on October 30th, the water level in the Bay west of Island Beach State Park peaked at 6.25ft NAVD88. A careful look at the inset of Figure 13 shows that no areas of the Park were overwashed or beached during Sandy. The elevation of the dunes and back beach forest in the DEM is above the peak water elevations reached on either the ocean or bay sides of the barrier spit, virtually eliminating any probability of the type of breaching.

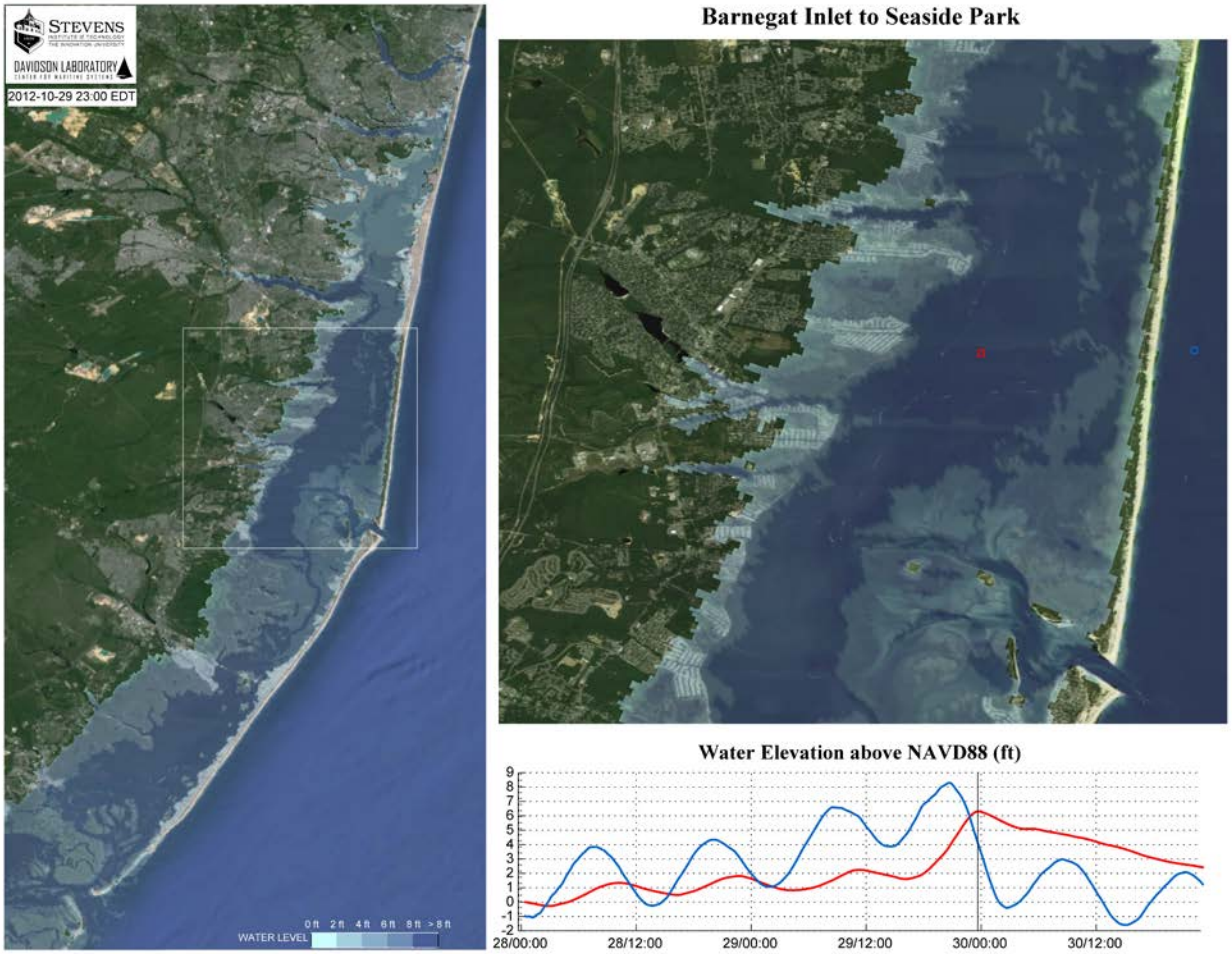


Figure 13. Water levels at time of peak surge in the central Bay on October 30, 2012.

In comparison, the peak ocean water elevations did exceed the oceanfront elevations in the DEM in Mantoloking causing the model to create breaches across the spit in 2 locations.

Wide spread flooding of the communities located along the western side of the bay is evident 4 hours after landfall. This flooding occurred as a result of the northward propagating surge in the bay and not from the breaching of the Park. In fact, had breaches occurred across Island Beach State Park, the breaches would have helped drain the bay as the water elevation in the bay exceeded the ocean water elevations over the duration of the flooding experienced by communities on the west side of the Bay.

Conclusions

The new, high-resolution, hydrodynamic model for the Barnegat Bay has been used to determine if breaching or overwash may have occurred in Island Beach State Park during Hurricane Sandy. Observations and the model hindcast determined that the central and southern portion of Barnegat Bay slowly filled with water as the Hurricane approached New Jersey. Strong north-northeast winds prior to landfall pushed water south in the Bay, increasing the water elevations in the southern Bay. This is evident in the significant drawdown of water levels in Mantoloking prior to landfall.

The peak water level in the southern Bay occurred within minutes of to the time Sandy made landfall. Peak water levels in the central and northern portions of the Bay; however, lagged those in the south by 4 to 7 hours as it took some time for the strong southerly winds in the southeast quadrant of the storm to influence the Bay. The southerly wind field pushed the excess water in the southern Bay north at approximately 5 mph. The timing of peak water levels in the Bay west of Island Beach Park corresponds to the time of observed flooding in the communities located along the west side of the Bay. At this time, water elevation on the ocean side of Island Beach State Park were 2ft lower than the water elevation in the Bay. This clearly indicates that the flooding experienced in Berkley Township was a result of the surge moving north in the Bay and not from the breaching or overwashing of Island Beach State Park. At no time does the SBIMS hindcast of Hurricane Sandy show any evidence of overwash or breaching in the Park.

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