Large-Scale Storm Tide Modeling in the Mid-Atlantic Bight during Hurricane Sandy

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Abstract
Hurricane Sandy inflicted heavy damage in New York City and along the New Jersey coast as the second-costliest storm in history. A large-scale, unstructured grid storm tide model, SELFE, was used to hindcast water level variation during Hurricane Sandy in the mid-Atlantic portion of the U.S. East Coast. The comparisons of modeled storm tide with the NOAA gauge stations from Montauk, NY, Long Island Sound, encompassing New York Harbor, Atlantic City, NJ, to Duck, NC, were in good agreement, with overall root-mean-square error of the order of 15-20 cm. It was found that there were two storm-induced surges converging in New York City, one from New York Harbor in the South and the other from Long Island Sound in the East, resulting in an explosive setup at the Kings Point near the east end of the East River. The wind wave contribution to the peak of the water level at the Battery in NYC is about 14% from the coupled surge and wave model results.

Introduction
On October 30, 2012, around 00:30 GMT, Hurricane Sandy made landfall near Brigantine, NJ, which caused enormous damage to residential properties, community infrastructure, and human life in the U.S. East Coast. The storm surge created some of the most devastating impacts, including flooding in New York City’s subway tunnels, LaGuardia and Kennedy airports, damage to the New Jersey transit system, and the coastal shoreline (NOAA, 2012). An abnormal storm tide with disastrous water levels occurred in New Jersey, New York City, and a portion of the Long Island Sound. The NOS tide gauges records show water level at The Battery, NY, Bergen Point, NY, Sandy Hook, NJ, Bridgeport, CT, at 9:00, 9:53, 8:01, 5.82 feet above mean higher high water, respectively (NOAA, 2012). The purpose of this study is to accurately simulate storm tide driven by Hurricane Sandy in the mid-Atlantic Bight and evaluate the model results by NOAA tidal gauge observations. The 2D model of the unstructured grid SELFE model was used. It implements the semi-implicit and Eulerian-Lagrangian scheme, which is not restricted by the CFL condition, and thus allows the large time step and robust computations (Zhang and Baptista, 2008). The wind and pressure fields were provided by WeatherFlow Inc. using a 3-km atmospheric model RAMS (Regional Atmospheric Modeling System), NOAA’s 4-km NAM (North American Mesoscale) model, and 32-km NARR (North American Regional Reanalysis) model.

Study Sites
U.S. East Coast

Tidal Forcing Open Boundary
- From Key West, Florida to Nova Scotia in Canada at around 62°W; 1500 km away from the coast
- 4 semidiurnal constituents (M2, N2, K2, and K1) and 4 diurnal constituents (O1, P1, K1, and Q1) at 134 nodes
- Flux Boundary
  - Major river discharge at 7 nodes

Wind Forcing
- NOAA’s NARR (North American Regional Reanalysis) and NAM (North American Mesoscale) wind with 3-hour temporal resolution
- RAMS (Regional Atmospheric Modeling System) hourly model wind with 3.4 km spatial resolution provided by WeatherFlow Inc.

SELFE Model Set Up
- Model domain: 207,096 nodes and 392,013 elements unstructured horizontal grid built by SMS 10. Spatial resolutions from 0.5 km at the grid’s open boundary to 50 m in the Hudson River near New York Harbor
- Wind field: high resolution hourly wind field from REMS covering latitude 33.0000°N to 42.9727°N and longitude from 78.0000°W to 68.0286°W with square elements of 2.6 ft arc-seconds (which is 4 km north-south by 3.4 km east-west)
- Parallelized computations using MPI and global coordinates for large-scale calculations

Tidal Calibration
- Bottom friction: Manning’s n=0.025 for the majority of the model domain except: (1) n=0.010 for the Hudson River, New York Harbor, and Raritan Bay, and (2) n=0.045 for the East River for its entrance and junction with the Hudson River (Blumberg, 1999)
- Tides were calibrated at 14 NOAA gauge stations: Montauk, NY, Newport, RI, New London, CT, New Haven, CT, Bridgeport, CT, Kings Point, NY, The Battery, NY, Bergen Point, NY, Sandy Hook, NJ, Atlantic City, NJ, Cape May, NJ, CBBT, VA, Sewells Point, VA and Duck, NC

Storm Tide Hindcast for the U.S. East Coast

Method

Simulation Period
1 10/15/2012 00:00:00 GMT - 10/24/2012 00:00:00 GMT
2 10/24/2012 00:00:00 GMT - 10/31/2012 00:00:00 GMT

Model Run
- Spin-up with NARR model wind and pressure fields

Results

Storm Tide Simulation and Data Comparisons

Conclusion
- The SELFE model produced reasonable results for large-scale storm tide simulation during Hurricane Sandy over the mid-Atlantic portion of the U.S. East Coast with overall root-mean-square error of 15-20 cm
- The storm tide results driven by RAMS wind were better possibly due to its hourly temporal frequency and 3.4 km spatial resolutions. This could be significant considering the coastal watersheds are sensitive to the swift change winds during Hurricane events
- There were two storm surges induced: one from New York Harbor and the other from Long Island Sound, which converged along the East River, resulting in a super-tide setup at Kings Point
- The performance of SELFE is about 144 times of real time on the 64 processors cluster with MPI parallel programming (i.e., 7-day run is completed within 1 hour)
- Future work: during hurricane events, there are many processes at play which are not included in the current model such as precipitation, storm water drainage, and the effect of wind wave. These are the goals for the future development and further improvements.

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References