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Numerical modeling of salt marsh morphological change induced by Hurricane Sandy

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ABSTRACT

The salt marshes of Jamaica Bay serve as a recreational outlet for New York City residents, mitigate wave impacts during coastal storms, and provide habitat for critical wildlife species. Hurricanes have been recognized as one of the critical drivers of coastal wetland morphology due to their effects on hydrodynamics and sediment transport, deposition, and erosion processes. In this study, the Delft3D modeling suite was utilized to examine the effects of Hurricane Sandy (2012) on salt marsh morphology in Jamaica Bay. Observed marsh elevation change and accretion from rod Surface Elevation Tables and feldspar Marker Horizons (SET-MH) and hydrodynamic measurements during Hurricane Sandy were used to calibrate and validate the wind-waves-surge-sediment transport-morphology coupled model. The model results agreed well with *in situ* field measurements. The validated model was then used to detect salt marsh morphological change due to Sandy across Jamaica Bay. Model results indicate that the island-wide morphological changes in the bay's salt marshes due to Sandy were in the range of −30 mm (erosion) to +15 mm (deposition), and spatially complex and heterogeneous. The storm generated paired deposition and erosion patches at local scales. Salt marshes inside the west section of the bay showed erosion overall while marshes inside the east section showed deposition from Sandy. The net sediment amount that Sandy brought into the bay is only about 1% of the total amount of reworked sediment within the bay during the storm. Numerical experiments show that waves and vegetation played a critical role in sediment transport and associated wetland morphological change in Jamaica Bay. Furthermore, without the protection of vegetation, the marsh islands of Jamaica Bay would experience both more erosion and less accretion in coastal storms.

1. Introduction

The Jamaica Bay Estuary (JBE) is located in Brooklyn and Queens, New York City (NYC) on the western end of the south shore of Long Island (Fig. 1). It covers about 107 km^2 and opens into the Atlantic Ocean via Rockaway Inlet on the southwest. JBE is an estuary with diverse habitats, including open water, coastal shoals, bars and mudflats, high and intertidal salt marshes, and upland areas. It provides critical ecological and economic value. Historically, JBE was known for an abundance and diversity of shellfish as well as an important nursery and feeding ground for many species of birds and fish because of its extensive marsh islands, tidal creeks, mudflats, and brackish water (Hartig et al., 2002; Rafferty et al., 2011). However, anthropogenic activities have altered the estuary. For example, natural flow of water and sediment into the bay has been affected by "urbanization" – residential, commercial and transportation development, channel dredging, marsh ditching and filling, bulk-heading, storm water runoff diversion, and sewage treatment plant operations (Kolker, 2005; Benotti et al., 2007; Swanson et al., 2016; Swanson and Wilson, 2008; Talke et al., 2014; Wigand et al., 2014). JBE experienced a conversion of more than 40% of the vegetated saltmarsh islands to intertidal and subtidal mudflats since 1974 (Hartig et al., 2002). It was predicted that without restoration and protection actions, salt marshes in JBE would disappear by 2024 (Steinberg et al., 2004). However, the U.S. Army Corps of Engineers together with state and local partners has begun rebuilding some badly eroded marsh islands (restored 62.7 ha thus far, see a summary at http://www.nan.usace.army.mil/Missions/Environmental/Environmental-Restoration/Elders-Point-Jamaica-Bay-Salt-Marsh-Islands/). Previous studies found that

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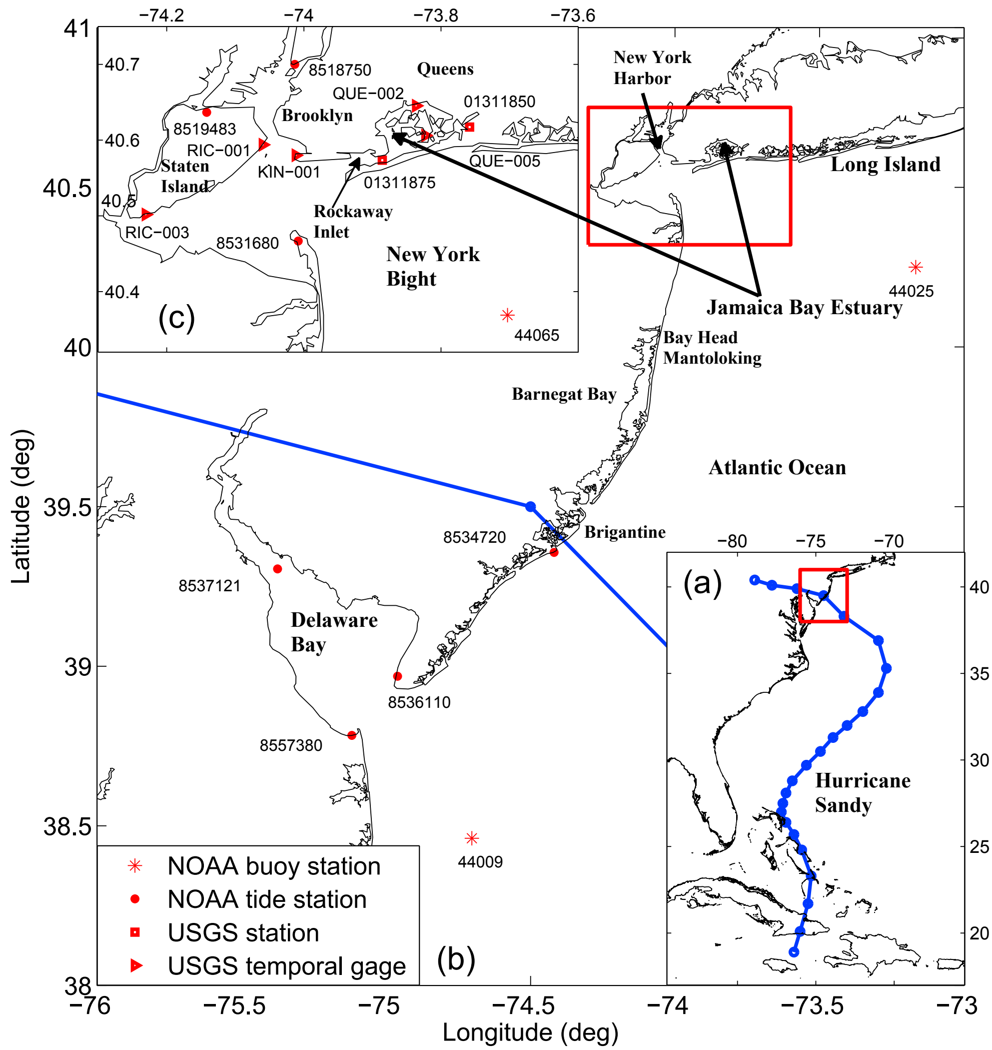

Fig. 1. Locations of (a) the track of Hurricane Sandy (2012) (blue line with dots), (b) Jamaica Bay relative to Long Island, and (c) observation stations (red symbols) in a local map. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

possible contributors to marsh loss in JBE include: (a) nutrient overloading from sewage treatment plants, (b) increased inundation due to dredging-induced increases in tidal range, (c) insufficient sediment supply from marine and riverine sources, and (d) sediment trapping in channels, rather than deposition on marsh island surfaces (Hartig et al., 2002; Rafferty et al., 2011; Swanson and Wilson, 2008; Wigand et al., 2014).

Large-scale storm events may be an important component in sediment transport processes and marsh surface accumulation especially for coasts under sediment-poor, sand-starved and low energy conditions (Goodbred and Hine, 1995; Cahoon, 2006). Hurricane Sandy (2012) provides a critical opportunity for studying the effects of hurricanes on sedimentation, erosion and morphologic changes in the salt marshes of JBE. A recent analysis indicated that Hurricane Sandy caused the largest storm tide at New York (NY) Harbor (Fig. 1) back to at least 1700 and has a return period of about 260 years (Orton et al., 2016). Hurricane Sandy made landfall at 23:30 UTC near Brigantine, New Jersey (NJ), approximately 130 km southwest of JBE (Fig. 1), on October 29, 2012 with maximum sustained winds of 130 km/h and a central pressure of 945 mbar, delivering hurricane-force winds and record-setting storm tides, e.g., 3.4 m above 2012 mean sea level at The Battery in NY Harbor (National Oceanic and Atmospheric Administration/National Ocean Service Station 8518750) (https://tidesandcurrents.noaa.gov/stationhome.html?id=8518750) in Fig. 1 (Brandon et al., 2014). The peak surge coincided with high tide in Jamaica Bay. Within JBE, two freshwater ponds (the East and West Ponds, see Fig. 3) were breached by Hurricane Sandy's storm tide and waves and inundated with saltwater (American Littoral Society, 2012).

Tropical cyclones (e.g., hurricanes) are among the most important driving forces that can rapidly reshape coastal landscapes and affect estuary resilience and sustainability (Cahoon et al., 1995; Nyman et al., 1995; Cahoon, 2006). A single hurricane deposit may be the equivalent of over a century of non-storm-surge sedimentation in Coastal Louisiana wetlands (Williams and Flanagan, 2009). However, no field observations on sediment deposition and erosion due to Hurricane Sandy were reported for wetlands along NJ and NY coasts. Nevertheless, evidence of Hurricane Sandy induced sediment deposition and erosion has been provided for other types of coastal systems. For example, deposition (5–20 cm) associated with Hurricane Sandy was found from four cores extracted from Seguine Pond (also known as Wolfe's Pond) on the southern coast of Staten Island, along Raritan Bay near the southern-most point of New York State (Brandon et al., 2014). Based on acoustic and LiDAR bathymetric data, Miselis et al. (2016) found that within the estuary near Mantoloking, north of Barnegat Bay, the storm resulted in $\sim$250 km^3 of deposition and $\sim$50 km^3 of erosion within the bay with measurable changes of $\pm$35 cm, not widespread, but rather very localized. Smallegan et al. (2016) used Xbeach to simulate the morphology of a sandy barrier island with a buried seawall at Bay Head, NJ, during