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Hazard assessment of storm events for The Battery, New York

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ABSTRACT

The environmental and socio-economic importance of coastal areas is widely recognized, but at present these areas face severe weaknesses and high-risk situations. The increased demand and growing human occupation of coastal zones have greatly contributed to exacerbating such weaknesses. Today, throughout the world, in all countries with coastal regions, episodes of waves overtopping and coastal flooding are frequent. These episodes are usually responsible for property losses and often put human lives at risk. The floods are caused by coastal storms primarily due to the action of very strong winds. The propagation of these storms towards the coast induces high water levels. It is expected that climate change phenomena will contribute to the intensification of coastal storms. In this context, an estimation of coastal flooding hazards is of paramount importance for the planning and management of coastal zones. Consequently, carrying out a series of storm scenarios and analyzing their impacts through numerical modeling is of prime interest to coastal decision-makers. Firstly, throughout this work, historical storm tracks and intensities are characterized for the northeastern region of United States coast, in terms of probability of occurrence. Secondly, several storm events with high potential of occurrence are generated using a specific tool of DelftDashboard interface for Delft3D software. Hydrodynamic models are then used to generate ensemble simulations to assess storms' effects on coastal water levels. For the United States' northeastern coast, a highly refined regional domain is considered surrounding the area of The Battery, New York, situated in New York Harbor. Based on statistical data of numerical modeling results, a review of the impact of coastal storms to different locations within the study area is performed.

1. Introduction

Coastal zones are of major importance due to their intrinsic environmental and socio-economic characteristics, mainly related with their high demographic densities (residents and tourists during the bathing season) and natural resources. These areas are affected by natural disasters mainly caused by weather events, including coastal storms that can induce storm surges. A storm surge is an irregular rise in sea level generated by a tropical cyclone's wind, waves, and low atmospheric pressure. Storm tides are also induced when the combination of astronomic high tides and the storm surge occurs, causing high elevations of the water surface (FEMA, 2003).

Tropical storms and wind storms, constituting about 38% of the total natural disasters, are responsible for 19% of deaths, 39% of overall losses and 72% of global insured losses (Kron, 2012). Such events can cause or worsen various risk situations, such as episodes of overtopping of coastal defenses, coastal flooding with local water surface elevation anomalies reaching up to several meters (Kron, 2012), coastal erosion and loss of territory, resulting in countless damages including loss of property and human lives.

Variations of storm surge heights depend on numerous factors, such as the tropical storm category, forward speed, radius of maximum winds (RMW), proximity of the storm trajectory to the coastal zone, bathymetry, coastal geomorphology and shape of the coastline (Nott, 2006). However, the storm's forward speed can be considered one of the most important factors presenting a greater influence than the wind intensity or the RMW (Rego and Li, 2009). Fast moving storms cause higher surges over open coast and lower surges in protected estuaries, while slower moving storms usually result in greater flooding in estuaries and smaller values of flooding along the coast.

Thus, numerical modeling systems are essential for a detailed forecast of the possible impacts of coastal storms in terms of water levels, flood area and wind speed. Such studies should allow for the

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identification of the most vulnerable areas and assist in proper planning and management of existing coastal resources in the long term. In the future, such scenarios may worsen due to climate change occurrences, considering the possible rise in sea level (Klemas, 2009), as well as coastal storms with greater frequency and intensity (Weisse et al., 2012).

Tropical cyclones usually form between 5° and 30°N latitude, usually moving toward the west. This 5°N formation is required in order to produce a minimum of Coriolis force required for the development of a tropical cyclone (Landsea and Goldenberg, 2004). In the North Atlantic Basin, tropical storms occur with a certain seasonality (mainly concentrated between August and September) and usually affect the Eastern United States and Canada (between 1 and 2 storms every year) and occasionally also Western Europe (one storm in 1 or 2 years) (Hart and Evans, 2001; Keim et al., 2004). In the case of the Eastern United States, the Atlantic “hurricane season” runs from June 1st to November 30th (Landsea and Goldenberg, 2004). When reaching 30°N latitude, the tropical cyclones often move northwest affecting the Eastern United States and Canada.

As the tropical cyclone develops, it reaches a point where it transitions from a tropical system to an extratropical system. A tropical transition is referred to as a tropical cyclone that moves over colder water and into strong shear at high latitudes (Hart and Evans, 2001). The term ‘extratropical’ is used to indicate that a cyclone has lost its “tropical” characteristics; it implies both polarward displacement of the cyclone and the conversion of the cyclone's primary energy source from the release of latent heat of condensation to baroclinic (NHC, 2015). The cyclone's source of energy becomes baroclinic, meaning that it results from the temperature contrast between cold and warm air masses. It should be noted that cyclones can become extratropical and still retain winds of hurricane (64 knots) or tropical storm (33 knots) force. The probability of cyclone's transitioning is during the months of September and October, when transiting 50% of all Atlantic tropical cyclones (Hart and Evans, 2001).

The sudden change from a tropical to an extratropical cyclone means a sudden change to the structure of the cyclone. Drastic variations of storm speed, direction, and position are a result of this structural change. As the systems become extratropical, rapid fluctuations of a storm's wind field intensity and an outward expansion of storm force is associated. The transformation of tropical cyclones to extratropical cyclones, and vice versa, is in fact a challenging forecasting problem. Results from general circulation models, GCMs, about future tropical cyclone climatology are mixed, but there is a suggestion that extratropical storms could decrease slightly, but that there is still potential for the generation of more intense hurricanes. There is also a strong suggestion that extratropical systems in the North Atlantic Basin have declined overall over the past 50–100 years, but there is an increase in frequency of really powerful storms (Keim et al., 2004). This is certainity an important factor to consider in terms of coastal management and emergency evacuation plans.

The Battery, New York, is located in lower Manhattan. Manhattan is the most populated New York county in the United States. Southern Manhattan alone has a population density greater than the citywide average, containing a population of nearly 200,000 inhabitants. Southern Manhattan's coastal areas are crucial to New York's evolution as a global city. Its waterfront can become a valuable asset, as home for residential and commercial office development; nevertheless, its low-lying coastal edges remain vulnerable to extreme weather. Southern Manhattan contains the fourth largest business district in the United States. It is positioned at the heart of the New York's transportation networks, such as subway lines, heliports, ferry landings, power facilities, and healthcare institutions (Bloomberg, 2013). In 2013, the American Association of Port Authorities, AAPA, ranked the Port of New York/New Jersey as the second busiest port in the United Stated, based on total imports and exports by weight (American Association of Port Authorities, 2014).

The NYC Panel on Climate Change, NPCC, projects that New York City could see up to 0.76 m of sea level rise by the 2050s as well as triple the number of days above 90 °F (NPCC, 2013). The Preliminary Work Maps released by FEMA in June 2013 for the 2020s predict that the flooded area could expand to 153 km^2, encompassing 88,000 buildings. That magnitude of sea level rise can threaten communities residing in low-lying New York areas and make flooding as severe as today's 100-year storm at The Battery up to five times more likely. New York City in collaboration with the Swiss Reinsurance Company has performed an initial loss-modeling, which indicates that due to sea level rise, NYC is 17% more likely in the 2020s to see a storm that causes nineteen billion dollars in damages, as Superstorm Sandy did (Bloomberg, 2013).

The main objective of this work is to study storm surge occurrences in the northeastern United States coast. The ongoing population increase along the coast, verified in the United States' eastern coast, only exacerbates the importance of the effects of eventual coastal flooding resulting from storm surges. This work seeks to identify and analyze the impact of historic tropical systems that affect the western end of the Northern Atlantic Basin. The characteristics and pathways of tropical cyclones will be explored as well as an assessment of their associated weather conditions. The main purpose deals with the use of practical applications with the main objective of generating useful knowledge for advancements in the hydrodynamic modeling of storm surges. Numerical modeling systems are essential for a correct forecasting of the impact of coastal storms. Studying important aspects like the wind speed, water levels and possible flood regions make it possible to define the most vulnerable areas. At present, there are hydrodynamic tools available to allow for the simulation of storms effects, provided that one knows their associated wind and atmospheric characteristics. They can be estimated based on the prediction of the velocity, atmospheric pressures, and trajectory of the storm's center. With this, it is then possible to establish proper planning and management of the coastal areas in the future. It is important to study various scenarios to identify the more susceptible areas and manage existing coastal resources for long term planning.

In the first phase, the historical coastal storms that occurred near the New York coast were collected, using the National Oceanic and Atmospheric Administration (NOAA) database as well as the University of Hawaii Sea Level Center's database. Through a physical viewpoint, a historical hazard analysis can be used as a contribution for further analysis on risk assessment and aid in the development of risk plans. With this work, a better understanding of how tropical systems behave in the North Atlantic Basin, on its westward extremity, will be given. The application of DelftDashboard and Delft3D-FLOW will be explored for the simulation of the effect of storms on the surface elevation of the water along the coast. The creation of numerical tools for storm simulations is possible with the DelftDashboard software based on the grid generation, definition of the corresponding boundary conditions, generation of the trajectory's wind field and the storm's center wind speed. Historical storms affecting the US's northeastern coast (encompassing the Hudson River mouth) will be simulated and results compared to the storms' recorded values.

Consequently, in a second phase, the definition and subsequent simulation of probabilistic ensemble forecasts will be created to assess the vulnerability of the coast to storminess. A methodology will be presented that considers hypothetical scenarios resulting from geographical shifts of the already generated historical tropical systems. By comparing the different possible outcomes, one can