11D.4 PROBABILISTIC STORM SURGE HEIGHTS FOR THE US USING FULL STOCHASTIC EVENTS

Shangyao Nong*, Jeffrey McCollum, Liming Xu, Michael Scheffler, and Hosam Ali
FM Global, Norwood, MA

1. INTRODUCTION

Storm surge flooding associated with tropical cyclones can cause significant causalities and property damage along the gulf and eastern coastlines of the USA. The 1900 hurricane that struck Galveston, TX was responsible for over 8000 deaths (Blake et al., 2007). In 2005, Hurricane Katrina generated over 9.1 m (mean sea level) storm surge (NIST 2006) along segments of the Mississippi coastline and is estimated to be the costliest hurricane affecting the US coastline (Blake et al., 2007). Hurricane Ike in 2008 caused considerable storm surge along the Louisiana and Texas coastline while it was in the middle of the Gulf of Mexico (Berg 2009). As population and commercial activities grow in coastal regions, it is anticipated that the property and causality losses due to storm surge will increase.

Historical storm surge data are insufficient to evaluate storm surge risk because of the short periods of record and limited geographic coverage. An ideal approach for risk quantification is to operate a high-resolution numerical storm surge model with hundreds of thousands synthetic landfalling hurricane events for the entire coastline. Since 2005 after the occurrence of Hurricane Katrina, several studies have been performed to re-evaluate increased storm surge flood risk. These studies use very detailed storm surge models, for example ADCIRC (*Ad*vanced *Circ*ulation Model, Luettich et al. (1992)), to cover a limited segment of the coastline. Because of ADCIRC's demanding computing resources even for a small geographical area, the studies had to specify carefully a small number of synthetic events based on available historical tropical cyclones.

In this paper, we employ an alternate approach. We use a synthetic hurricane data set for the entire gulf and eastern US coastline coupled with a fast-to-run numerical storm surge model to understand the characteristics of storm surge flood frequencies. The storm surge flood frequency distributions generated with this approach provide insight into the distribution of storm surge flooding along the entire US coastline with adequate accuracy for engineering applications.

* *Corresponding author address:* Shangyao Nong, FM Global, 1151 Boston-Providence Turnpike, Norwood, MA 02062 USA; e-mail: shangyao.nong@fmglobal.com.

2. METHODOLOGY

2.1 Surge calculations

Since our approach requires tens of thousands of tidal storm surge computations, we needed a computationally efficient storm surge model. We chose the SLOSH (Sea, Lake and Overland Surges from Hurricanes) model (Jelesnianski et al., 1992) because it provides the level of detail needed for our investigation. SLOSH is configured for 35 overlapping basins covering the Gulf and east coasts. Currently, NHC and emergency management officials use SLOSH to provide primary guidance for coastal evacuation planning and the basins are continually modified and updated since their original configuration.

The SLOSH model solves 2D shallow water equations in an orthogonal curvilinear, polar coordinate grid system. Each grid element has values for land elevation, water depth, and potential vertical barriers that can impede storm surge flooding. The grid elements range in size from 0.25 km^2 to tens of km^2. The model has sub-grid features such as one-dimensional flow for rivers and streams, barriers and cuts between barriers, and channel flow. Customary surface friction coefficients are also included to account for trees and mangroves for the computation of overland flood elevations. However, SLOSH's large grid size coupled with the underlying assumption of long wave approximation to the Navier-Stokes equations precludes calculations of breaking waves/wave run-up, astronomical tide, or river flow associated with precipitation. More details about the model can be found in NWS 48 (Jelesnianski et al. 1992).

The wind fields and storm surge heights from SLOSH have been evaluated in several studies (Houston and Powell, 1994; Houston et al., 1999; NWS 48; Jarvinen and Lawrence, 1985). These studies conclude that SLOSH's wind fields are in general similar to the HRD (Hurricane Research Division of NOAA) observational-based wind fields, and SLOSH surge heights are generally within ±20% of the observed ones. Recently, the National Institute of Standards and Technology evaluated the physical performance of structures for hurricanes Katrina and Rita (NIST 2006). As part of the evaluation, comparisons between SLOSH- and ADCIRC-predicted flood elevations and field observations demonstrated that SLOSH estimates aligned closely with actual flood elevations. In our evaluation of SLOSH, we have collected 718 high water marks from 14 historical hurricanes, and calculated the maximum surge heights at the same locations where the high water marks were observed. Our comparisons confirmed the documented performance of SLOSH and provided the validation needed to confidently use SLOSH to evaluate storm surge risk along coastal regions.

2.2 Synthetic hurricane set

The synthetic landfall hurricane set was obtained from WindRiskTech, LLC (http://www.windrisktech.com/). A detailed technical discussion is provided in Emanuel et al. (2006). Unlike widely used historic-track-based methodologies, the methodology adopted here has the following features:

(1) genesis locations of synthetic events are based on kernel-smooth historical genesis locations to ensure an accurate estimate of the space-time distribution of storm generation;
(2) moving directions of synthetic tracks depend on perturbations to observed atmospheric flow, rather than on the directions derived from the sparse historical tracks data; and
(3) intensities of synthetic events are calculated using a coupled ocean-atmosphere numerical model instead of using incomplete observed historical storm intensity data.

The set used in this paper has 16,500 synthetic landfalling hurricanes. Each synthetic hurricane event contains a track at 2-hour intervals with date and time, 1-min maximum sustained wind, central pressure, and radius of maximum wind at each track point.

Emanuel et al. (2006) have compared the 1-min sustained winds between synthetic and historical storms, and have illustrated that synthetic events are able to "mimic" real hurricanes. We have used a wind-pressure relationship from Knaff and Zehr (2007) to convert 1-min maximum sustained winds to central pressures for all the synthetic events needed for SLOSH calculations which require the central pressure. Furthermore, we have developed a regression equation for radius of maximum wind as a function of latitude and 1-min maximum sustained winds based on a satellite-based data set from Kossin et al. (2007). We have used the equation to calculate radii of maximum winds based on the latitudes and 1-min maximum sustained winds for every synthetic event.

In summary new values for central pressures and radii of maximum winds were derived using 1-min maximum sustained winds and the new values were used for storm surge height calculations. We calculated the statistics of the new values for central pressure and radii of maximum winds and found that the statistics from synthetic hurricane events are in general similar to those from historical hurricanes.

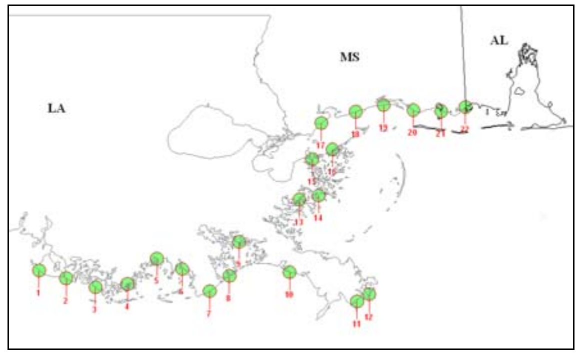

Figure 1. Twenty-two coastal locations used to compare current FEMA elevations, draft FEMA elevations and calculated elevations.

3. SURGE RESULTS

In calculations of the frequencies of maximum surge heights, every synthetic event was assumed to have the same probability of annual occurrence. For every SLOSH grid, we ranked the individual maximum storm surges and derived the exceedance frequency curves of storm surge height. Here we present results at twenty-two coastal locations shown in Figure 1 along Louisiana and Mississippi.

We compared our preliminary results with current and draft FEMA values. Current FEMA values were developed using the Joint Probability Method (Myers, 1975; Ho and Myers, 1975) along most of the east coast and a variety of models for the Gulf coast. FEMA draft values along the Louisiana and Mississippi coastline were developed using ADCIRC and the Joint Probability Method with Optimal Sampling (Resio, 2007). The draft values are undergoing FEMA's review process prior to being issued as final results.

Figure 2 shows current FEMA elevations (blue color), and new draft FEMA elevations (red color), and our elevations (green color) at 100-year return periods. Figure 3 shows the comparison of storm surge elevations at 500-year return periods. All elevations use NGVD29 vertical datum. Both figures show that FEMA has increased their estimation of storm surge elevations for many coastal locations, especially at Locations 17, 18, and 19 which suffered high surge in the 2005 Hurricane Katrina. Surge elevations calculated in this study generally agree with the new FEMA values.

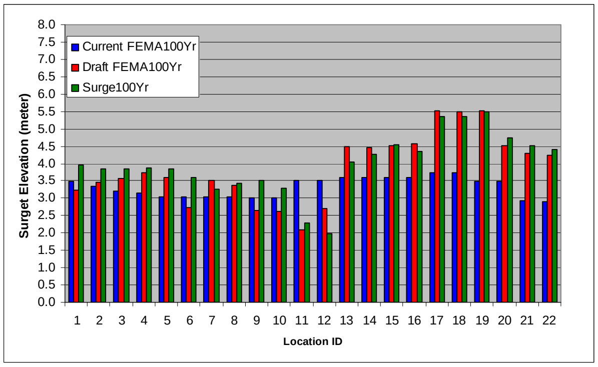

Figure 2. Storm surge elevations (relative to NGVD29 vertical datum) for current FEMA values (blue), draft FEMA values (red), and this study (green) at 100-year return period.

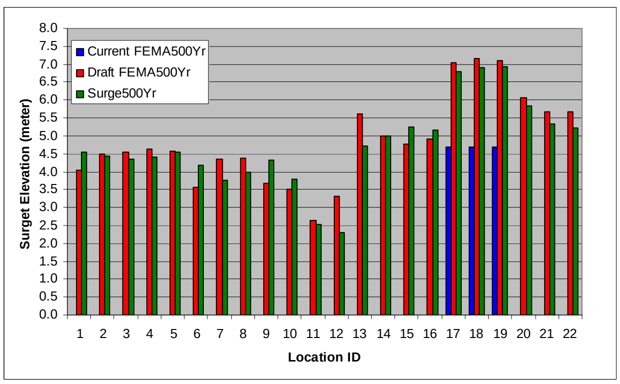

Figure 3. Storm surge elevations (relative to NGVD29 vertical datum) for current FEMA values (blue), draft FEMA values (red), and this study (green) at 500-year return period.

4. CONCLUSIONS

We have proposed and implemented an approach to evaluate the storm surge risk along the entire Gulf and eastern US coastal regions. The approach uses a physics-based and full coastline stochastic event set with tens of thousands of synthetic hurricanes instead of an event set with limited number of historic or synthetic hurricanes restricted to a geographic area. To reduce the computational burden, we have chosen SLOSH: a proven, relatively simple yet physics-based numerical storm surge model to compute the storm surge elevations. Our analyses indicate that the full coverage coastal physics-based approach produces similar results to those produced by very detailed area-specific studies.

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