RESIO, UNF

DHS Coastal Resilience Center

Research Project

Annual Project Performance Report

1. **Project Title:** The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency

2. **Principal Investigator / Institution:** Don Resio / University of North Florida

3. **Other Research Participants/Partners:** ARCADIS, Jackson State University

4. **Short Project Description:** Rising sea level, climate variability, and growing coastal populations increasingly threaten immense investments in critical coastal infrastructure within the US. This threat greatly impacts the commercial and military value of coastal cities such as New York, New Orleans, Norfolk/Hampton Roads and many others. Natural coastal areas are also essential to maintaining healthy ecosystems and provide much needed food and recreation and can contribute nature-based coastal protection in many areas. Decisions affecting coastal utilization must be based on accurate quantification of factors affecting this balance to maximize coastal resilience. A well-known example of an inaccurate assumption is the treatment of coastal and inland/riverine flooding at though they do not interact. This project will develop a methodology for incorporating these interactions in a statistically and physically appropriate manner into FEMA's operational coastal modeling systems.

5. **Abstract:** This project will develop a method for including rainfall-runoff effects into FEMA-JPM studies, and evaluate the potential impacts of incorporating these effects into improved estimates of flooding hazards. There are two parallel efforts the project will be undertaking: 1) an improved understanding of the statistics of river/tributary discharges in terms of both antecedent conditions and the conditional probabilities of rainfall patterns and magnitudes given a tropical cyclone in a particular area and 2) a physics-based coupling of major tributaries into the ADCIRC model, including antecedent and rainfall effects during a surge event. The goal is to develop a model that is ready to be transitioned into realistic JPM applications in areas where rainfall, hydrologic flows and surges are expected to interact strongly.

6. **End users:** 1) FEMA Regions 2, 3, 4, 5 and 6 are contributing technical oversight and guidance on user needs related to Risk Map applications and expect to obtain more accurate actuarial representations of flooding risks. 2) USACE-ERDC is coordinating on the exploration of different approaches and which can be applied to planning and design of Corps projects in areas affected by combined hydrologic-

coastal flooding. 3) NOAA is coordinating on hydrologic modeling and coupling with coastal surges which will enable improved predictions in areas affected by flooding from these combined mechanisms. 4) USGS has expressed an interest in using outputs from this to develop realistic scenarios for Coast Guard guidance during and after disasters. 5) NGA has expressed an interest in incorporating our research into their maritime mission. However, the USGS and Coast Guard contacts have not been involved in the project to date.

7. **Explanation of Changes:** The only change in our initial work plan is a minor 6 weeks slowdown in the production of a report on rainfall patterns associated with tropical events affecting the Norfolk areas. The radar data which was already available to us and was adequate for categorizing many hurricanes in the Gulf of Mexico did not include sufficient storms in the Norfolk/Hampton Roads area to provide a good characterization of rainfall patterns for tropical events at that site. We downloaded available National Weather Service station data for the area and have almost completed our analyses.

8. **Unanticipated Problems:** As noted above, we had a slight slowdown due to the lack of time coverage in our radar data and have addressed this problem.

9. **Project Outcomes:** This project will play a significant role in meeting DHS Goal 1.3: Manage Risks to Critical Infrastructure, Key Leaders and Events," with its emphasis on the first of these, *critical infrastructure.* In particular, the need to understand and prioritize risks to critical infrastructure, i.e. to ensure critical infrastructure resilience needs to understand the areas most threatened in various hazard scenarios will be of great concern in coastal areas in the future. Many hurricanes have wreaked havoc on inland areas far beyond either the effects of coastal flooding or inland flooding considered independently. Improved tools provided by this project will significantly reduce the existing information gap with regard to the coupled flooding of mechanisms combined. Under DHS Goal 5.1: Mitigate Hazards, this project will work with multidisciplinary teams to prepare for, protect against, respond to and mitigate a natural disaster in coastal areas. We plan to transition our modeling system to operational applications and utilize students in exercises to examine the impacts of these new results in areas within the selected test area, Norfolk/Hampton Roads. These exercises will help convert our understanding of increased hazards related to combined hydrologic and coastal flooding to improved quantification of risks in these areas along with potential impacts on societal functions and ecosystems. Such conceptual development will help planners properly locate critical infrastructure to avoid serious flooding. Since lost infrastructure is a major problem in post-disaster recovery, exploitation of such information is expected to reduce post storm recovery time (DHS Goal 5.4).

10. Research Activity and Milestone Progress:

Research Activities and Milestones: Progress to Date

Reporting Period 1/1/2016 – 6/30/2016			
Research Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Obtain radar rainfall data set for statistical analysis of patterns of rainfall relative to hurricane tracks and other parameters	June 2016	90%	We found out we needed a longer period of data and are still downloading some of the NWS hourly rainfall data. Completion is expected by August 2016
Develop and test initial methodology for coupling rivers/tributaries and rainfall into ADCIRC in different characteristic geographic areas.	June 2016	30%	Several conference calls and one on-site meeting have been completed. This effort will still be completed by the due date for the report on this topic.
Interaction with JSU and user groups to develop a firm framework for effective user review of project accomplishments and future directions.	June 2016	40%	We have identified end users groups in FEMA HQ (incl the Coastal Working Group of private sector flood risk practitioners they engage with), in FEMA Regions I, II, II, IV and VI where risk of combined tropical/hurricane storm surge and precipitation is major element of flood risk assessments. User groups in US Coast Guard, USACE, NOAA and NGA also have been identified. Work is underway to identify and enlist an individual in each of these groups to comprise an end-user group that we will interact with. Completion of this activity is expected by 31 Aug.
Research Milestone			
Provide brief report on preliminary analyses of rainfall patterns in hurricanes.	June 2016	90%	We had to revise the length of record that we were examining and will complete this report by 15 August.
Progress reports on research activities 2 and 3.	June 2016	10%	Progress report on standing-up of and composition of the end user group, and initial engagement activities with them, including

			distribution of project reports is expected for Sep 30.

11. Transition Activity and Milestone Progress:

Transition Activities and Milestones: Progress to Date

Reporting Period 1/1/2016 – 6/30/2016			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Establishment of effective coordination between the project team and end users involved in this project.	June 2016	75%	A 4-person standing committee has been identified, comprised of the FEMA HQ lead for the FEMA Coastal Working Group (which reflects an end user community), two project team members who are former USACE employees and both have extensive flood risk experience and experience working with FEMA on flood risk studies, and a fourth member who is a current USACE employee who works in coastal flood risk research and applications community and who represents USACE end user groups. Formalization of the committee is underway. Expect to complete formalization by 15 Aug. Coordination will commence at that time.
Transition Milestone			
Establish a standing committee for coordination between the project team and end users involved in this project.	June 2016	75%	Expect to complete formalization of the standing committee by 15 Aug.

12. Interactions with education projects: Amanda Tritinger, a UNF PhD student funded under this project, attended the CES in Los Vegas and participated in the pre- and post-conference meetings to document her experience and how she benefited from it. The project PI (Don Resio) travelled to Mississippi in April to meet with the JSU Educational Project leaders on this project Robert Whalin, Tom Richardson and Bruce Ebersole. UNF also coordinated a SUMREX visit from a LSU PhD candidate, Rudy Bartels, to come to Jacksonville and work on an internship with Dr. Resio starting in July 2016.

13. Publications:

1. Irish, J.L., Weiss, R. and D.T. Resio,” Physical Characteristics of Coastal Hazards and Risks”, Chapter 25, Springer Handbook of Ocean Engineering, Springer Dordrecht Heidelberg London New York, M. Dhanak and N. Xiros (Eds.), 549 – 562.

2. Resio, D.T., Tumeo, M.A., and J.L. Irish, “Statistical Characterization of Hazards and Risk in Coastal Areas,” Chapter 26, Springer Handbook of Ocean Engineering, Springer Dordrecht Heidelberg London New York, M. Dhanak and N. Xiros (Eds.), 567 – 593.

A. Progress Report: Obtain radar rainfall data set for statistical analysis of patterns of rainfall relative to hurricane tracks and other parameters and preliminary analysis of patterns

All of hourly rainfall data for sites in Virginia and North Carolina have been downloaded for the period 1951-2015 for 11 stations, with most stations reasonably complete over this entire interval. Hurricane track information from HURDAT is also available over this interval through 2013. Norfolk and Elizabeth City are being used as the two selected sites to develop analytical methods for describing the temporal rainfall patterns relative to the hurricane location. Preliminary analysis of these stations shows a clear tendency for rainfall to precede the passage of the hurricane eye and suggest that hurricane size is an important parameter to consider in estimates of hurricane-related rainfall.

Very fine scale radar data has been downloaded and is available for detailed analysis from 2000 – 2009. Along the US Gulf coast these data indicate a rain-shield pattern that occurs before the storm crosses the coast with rainfall diminishing after landfall; however significant exceptions occur in cases where storms slow down at the coast and/or move parallel to the coast west-to-east after landfall. The radar information shows that the rainfall pattern varies substantially from storm to storm, but the slower moving larger storms produce more rainfall than moderate-speed and fast-moving storms.

A hopeful development is the potential for collaboration found in a May 18-19 meeting at the NOAA National Water Center (NWC) in Tuscaloosa, Alabama, where a new initiative was announced, centered on integrated water prediction and the development of a new National Water Model (NWM) at the NWC. This model was described as being “open-source” and a general finite-difference code which could be made available to collaborating groups. Such a model could offer substantial benefits over the presently available “closed-source” HEC models which are being considered for application in the coupled surge-stream flow modeling system on this project.

B. Progress Report: Test methodology for including a range of riverine flows within ADCIRC surge simulations.

A common tool for simulating storm surge in probabilistic flood studies is the ADCIRC model. For ADCIRC models that include rivers, the probabilistic studies (such as JPM-OS used by FEMA) have included a single riverine flow rate for all hurricane surge simulations. Typically, an average value observed during hurricane season is used. Regardless, it is known that the magnitude of the downstream discharge and the stage of the river vary significantly through hurricane season. Moreover, the stage and discharge have meaningful impact on the propagation of surge up river and the extent of inundation adjacent to the river during a hurricane event. The additional water mass associated with the river's discharge can also increase surge and flooding within coastal bays. Thus, it is important to understand the degree of this interaction and the spatial extent to which it occurs both above and below the river mouth. Specifically, this study will quantify the interaction and test several methodologies to include the effect within future probabilistic studies, and identify hurdles to implementation and guidance for deploying an operational approach.

In an operational setting, ADCIRC is considered too expensive to run each JPM-OS synthetic storm multiple times for different antecedent river flows. Thus, a method is required to include the effect of the river either empirically or with use of a more efficient model such as HEC-RAS to evaluate the flooding potential up riverine regions. To this end, we are using an ADCIRC model and a HEC-RAS model to experiment with coupling.

The geographic location selected for testing is the Neches River in eastern Texas. Both a HEC-RAS model and an ADCIRC mesh of the region already exists and flow rate data is available. The Neches River drains into Lake Sabine at the border between Texas and Louisiana. Surge enters Lake Sabine through Sabine Inlet and can propagate some distance up the river. The distance of propagation up river depends upon the magnitude of the surge, the directionality of wind and wave setup within Lake Sabine, and on the magnitude of the discharge flowing down the Neches. The ADCIRC mesh has been modified to include a larger reach of the Neches River which required significant additional resolution. The mesh resolution has been increased to allow for three "wet" elements across the channel which required elements as small as 20m for a long distance inland. Figure 1 and Figure 2 demonstrate the original and modified geometry in the ADCIRC model and Figure 3 and Figure 4 demonstrate the level of mesh resolution in the two models.

We are using a range of flow conditions to determine the sensitivity of surge and flooding to the flow in the river. The flow scenarios are no flow, the 2 year flow, the 25 year flow, and the 100 year flow. The hurricane scenarios are representative 100-yr synthetic storms from the FEMA storm suites for Texas and Louisiana and Hurricane Ike. Figure 5 indicates seven synthetic storms that generate the 100 year surge at the mouth of the Neches. Of these storms, LA-218, TX-151, and TX-128 were chosen because they span a range of storm track angles and landfall locations. For simulations of the synthetic storms, no tidal forcing is included (as consistent with FEMA operational methodology in Texas). For the Hurricane Ike simulations, a 36 day tidal spin up is included using the eight most dominant tidal constituents. Figure 6 and Figure 7 provide contour plots of maximum surge elevation for the no river flow and 100-year river flow respectively using synthetic storm LA-218. Figure 8 is a contour plot of the difference between the two scenarios from which the spatial extent of the river's influence on surge can be clearly identified.

The coupling between models has been limited to sharing results from one model as a boundary condition in the other. ADCIRC simulations use a flow boundary at the upper end of the Neches River while HEC-RAS simulations are being performed using the surge from the ADCIRC model to supply a downstream stage boundary condition. Testing is underway to identify the appropriate location for establishing the lower boundary in HEC-RAS and the upper boundary in ADCIRC.

Summary of Lessons Learned to Date

General

- Surge can propagate very far upstream, on the order of miles.
- Inclusion of riverine flow can increase stage in the river by several feet.
- Details of surge/river interaction learned from testing at the Neches may not apply to all river systems. Presence of hydraulic features such as salinity barriers and flood control dams will need to be considered for some rivers.
- Coastal morphology at the river mouth (barrier islands, back bay, delta, or open coast) will alter the surge response.
- Spatial extent and magnitude of surge/river interaction will be specific to each river bathy/topo.
- Guidance is to perform sensitivity testing at each river location of interest to evaluate.
- Operational methodology will need to be tailored to each river location.

ADCIRC

- In an operational mode, it will be challenging to provide adequate resolution in the ADCIRC mesh to capture smaller river systems. As the finite element size is reduced, the time step also must decrease to maintain numerical stability which can become impractical. Node spacing of 20m is a practical lower limit, which results in a crude representation of the river bathymetry.

- It will be important to limit the upstream extent of river representation in ADCIRC. Site specific empiricism for estimating the surge/river interaction or reliance on HEC-RAS are recommended.
- Setting the initial condition for a sloping water surface up a river can be challenging and can induce instability if done poorly. Several approaches are being explored to solve this issue and create a robust operational method.

HEC-RAS

- While HEC-RAS is a well-used model, the source code is not available. This limits true coupling in the sense that HEC-RAS must be operated through its stand-alone GUI.
- It may be worth considering an alternative to HEC-RAS such as the open source hydrology/routing model being developed at Sandia Labs. Access to source code would allow for dynamic coupling with ADCIRC (following the SWAN paradigm).
- Alternately, future research may be pursued to define one-dimensional flow elements within ADCIRC to get around the resolution limitation mentioned above.
- HEC-RAS does allow for batch processing, which will be efficient during operational mode as long as all of the ADCIRC surge results are pre-processed and available as input to HEC-RAS.

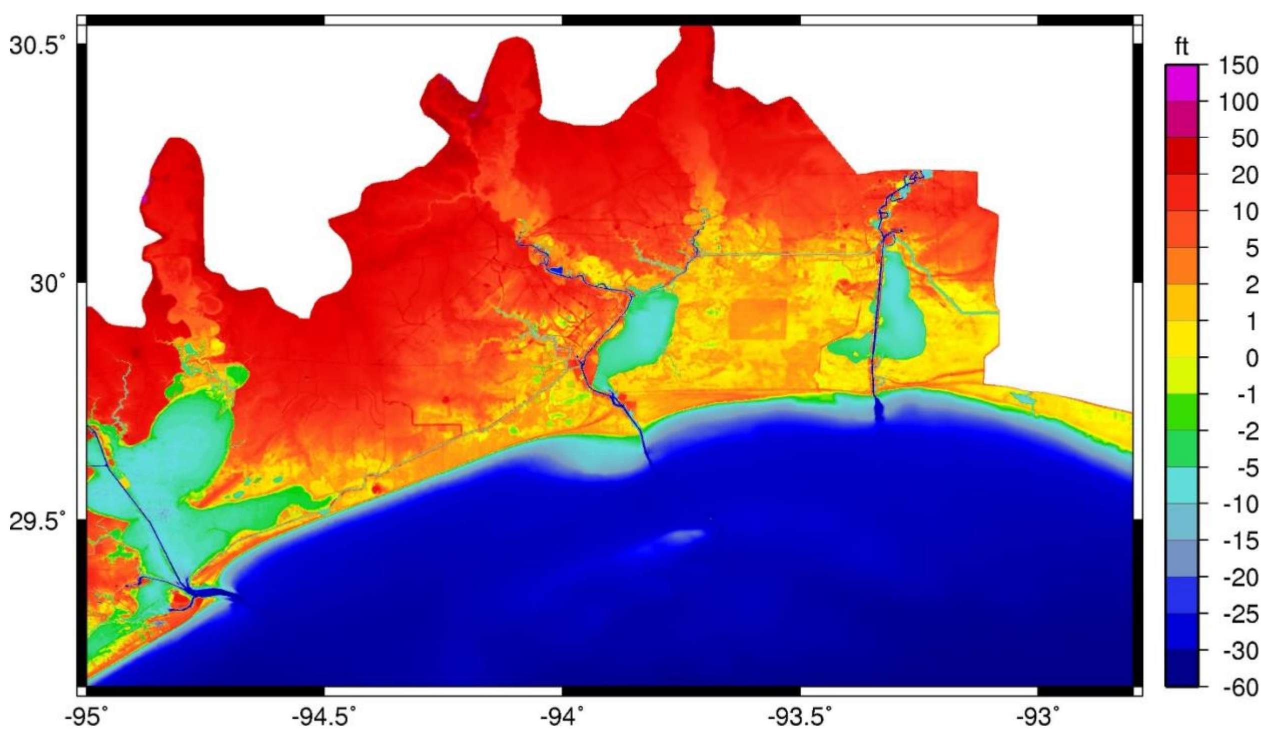

Figure 1. Modified ADCIRC mesh of Texas including expanded Neches River.

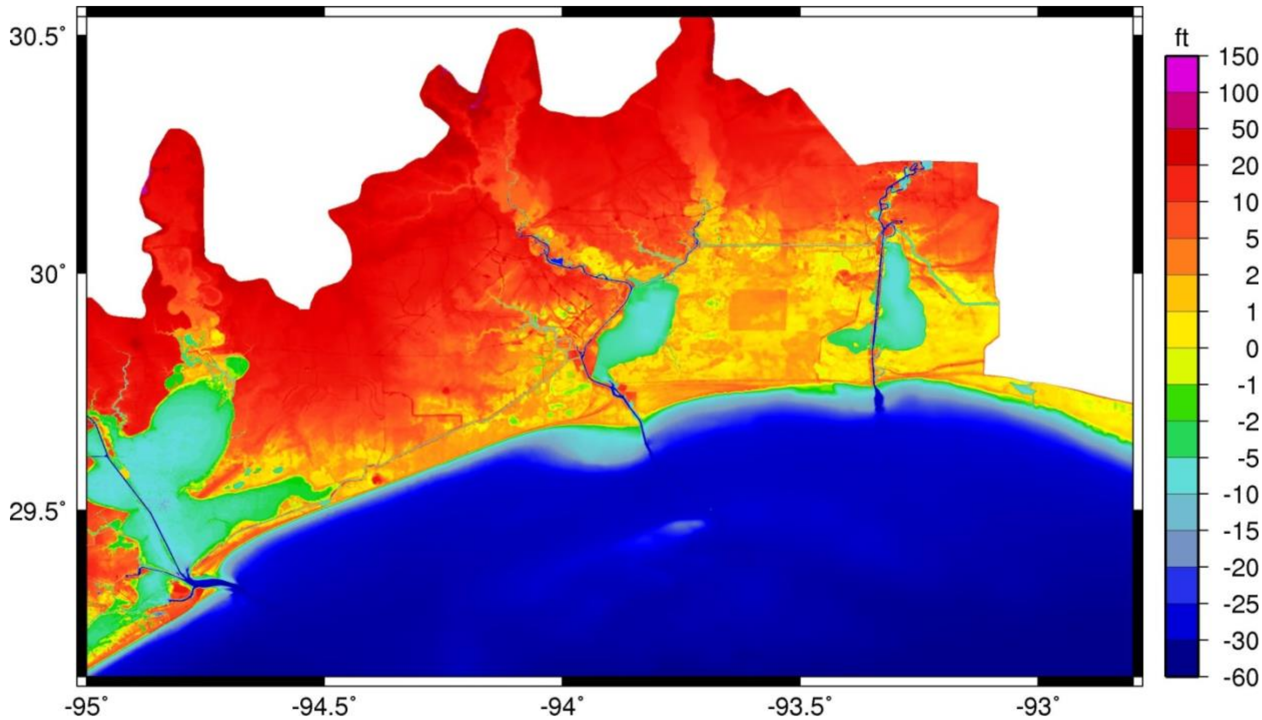

Figure 2. Original ADCIRC Mesh of Texas

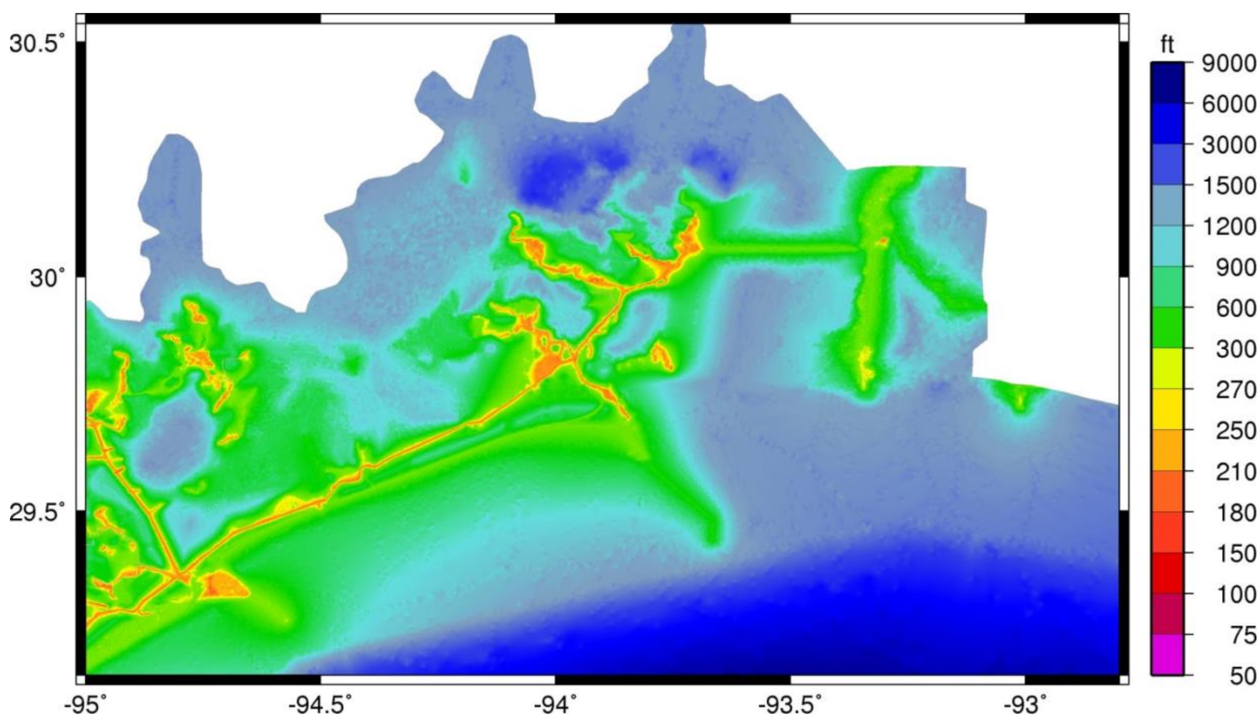

Figure 3. Resolution in the original ADCIRC mesh.

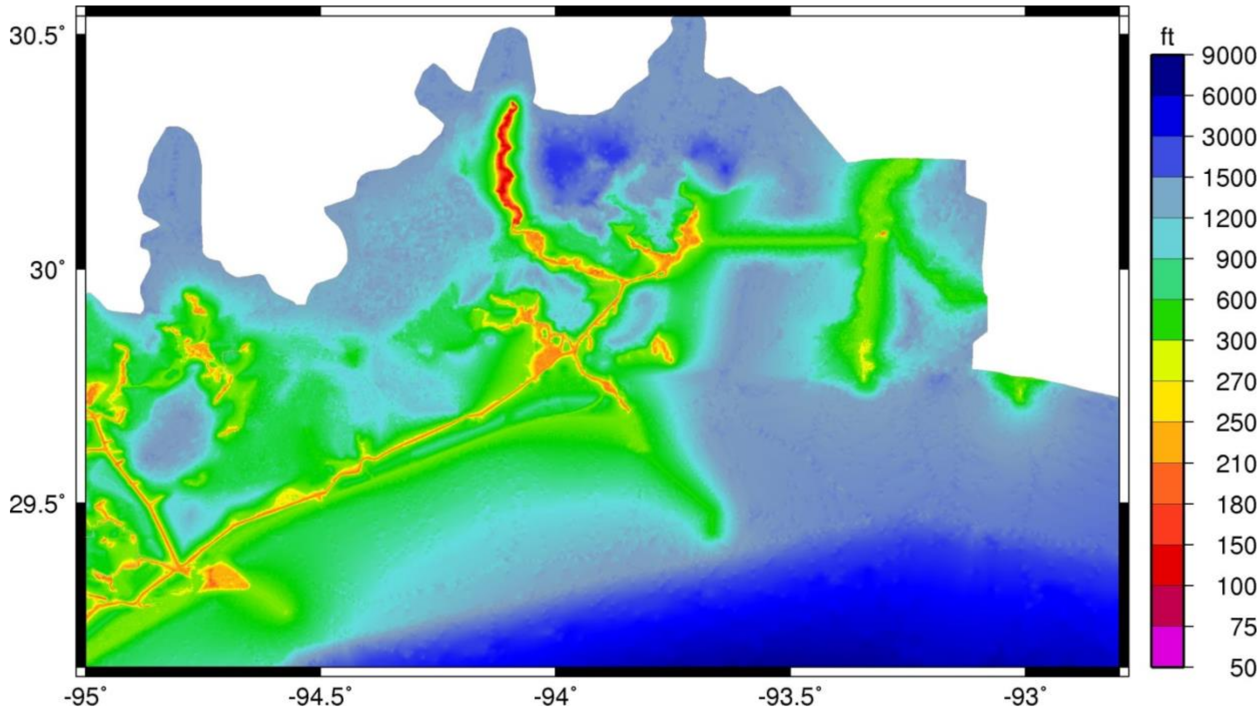

Figure 4. Resolution in the updated ADCIRC mesh.

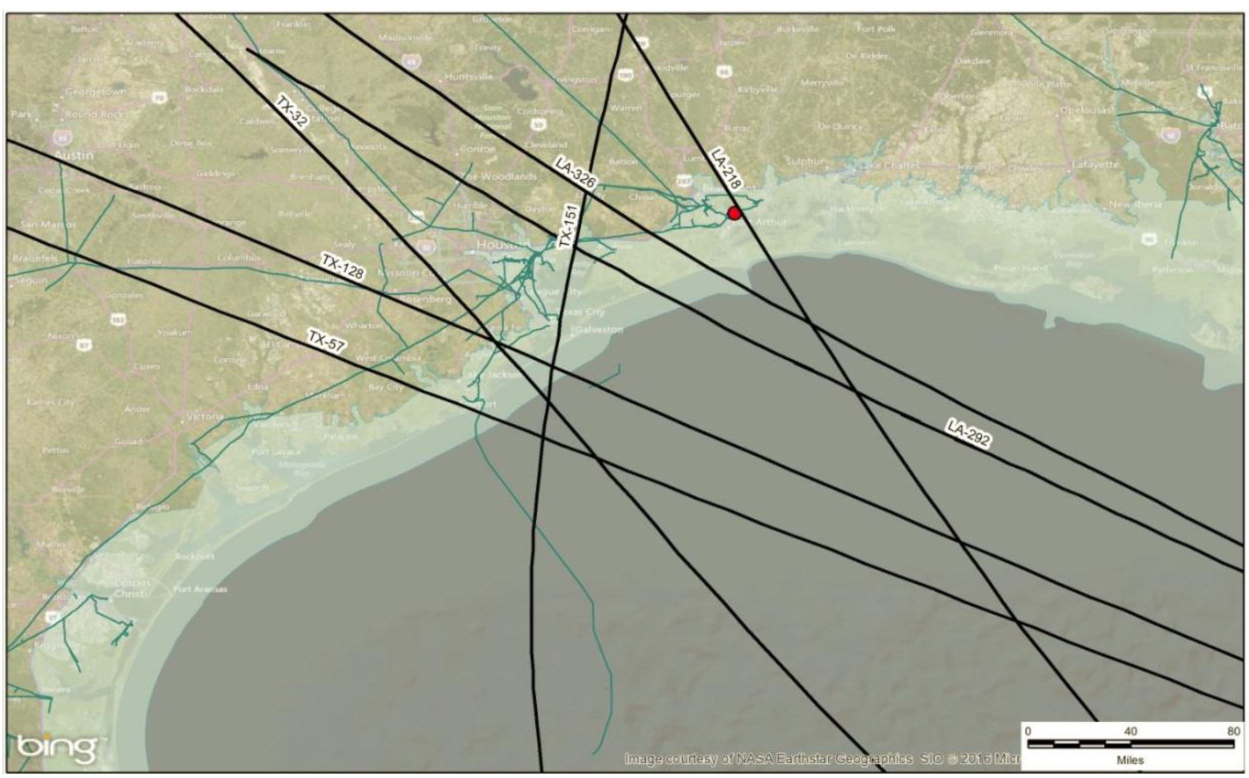

Figure 5. Storms from the synthetic storm suite that generate the 100-yr surge at the mouth of the Neches River.

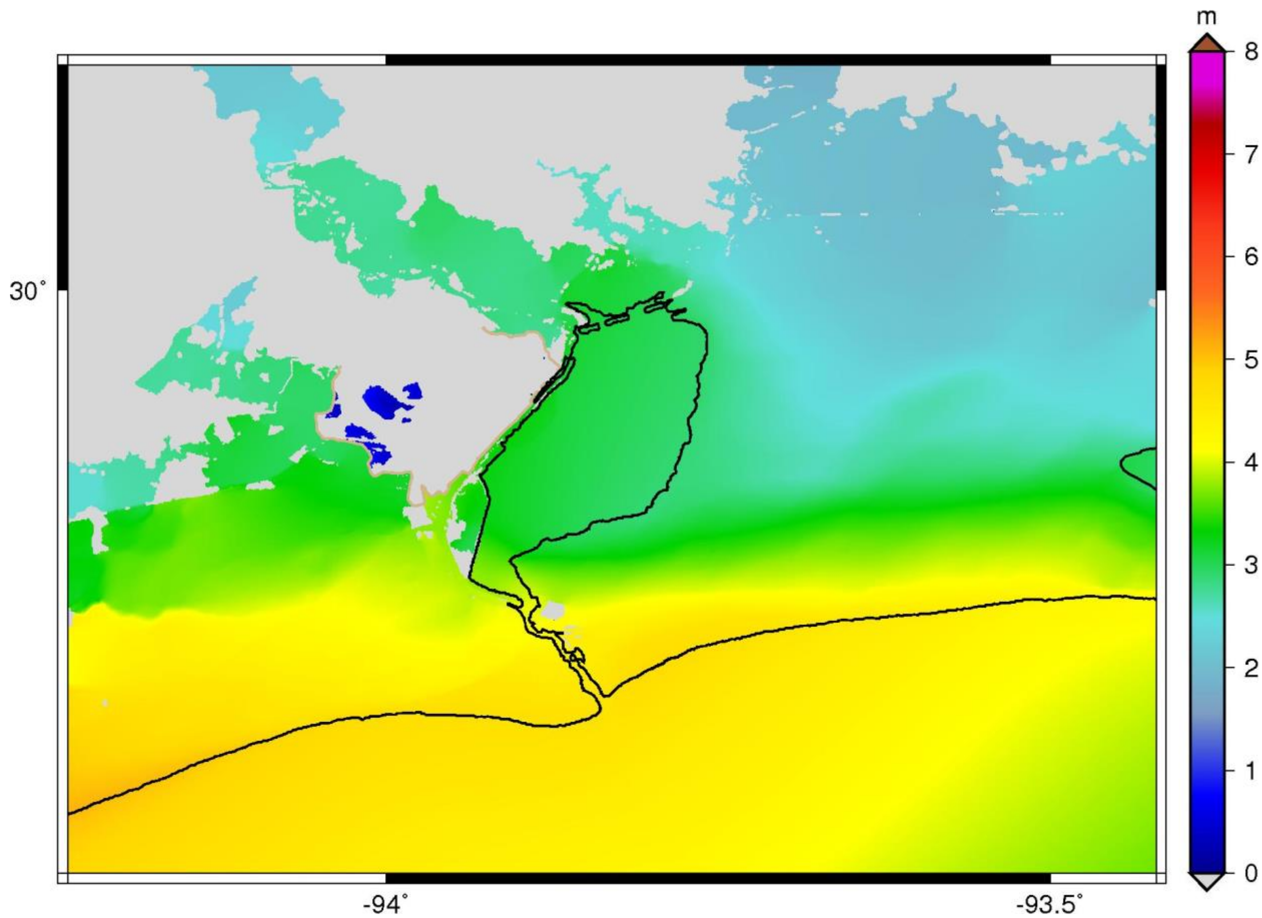

Figure 6. Contours of maximum surge elevation with zero river flow.

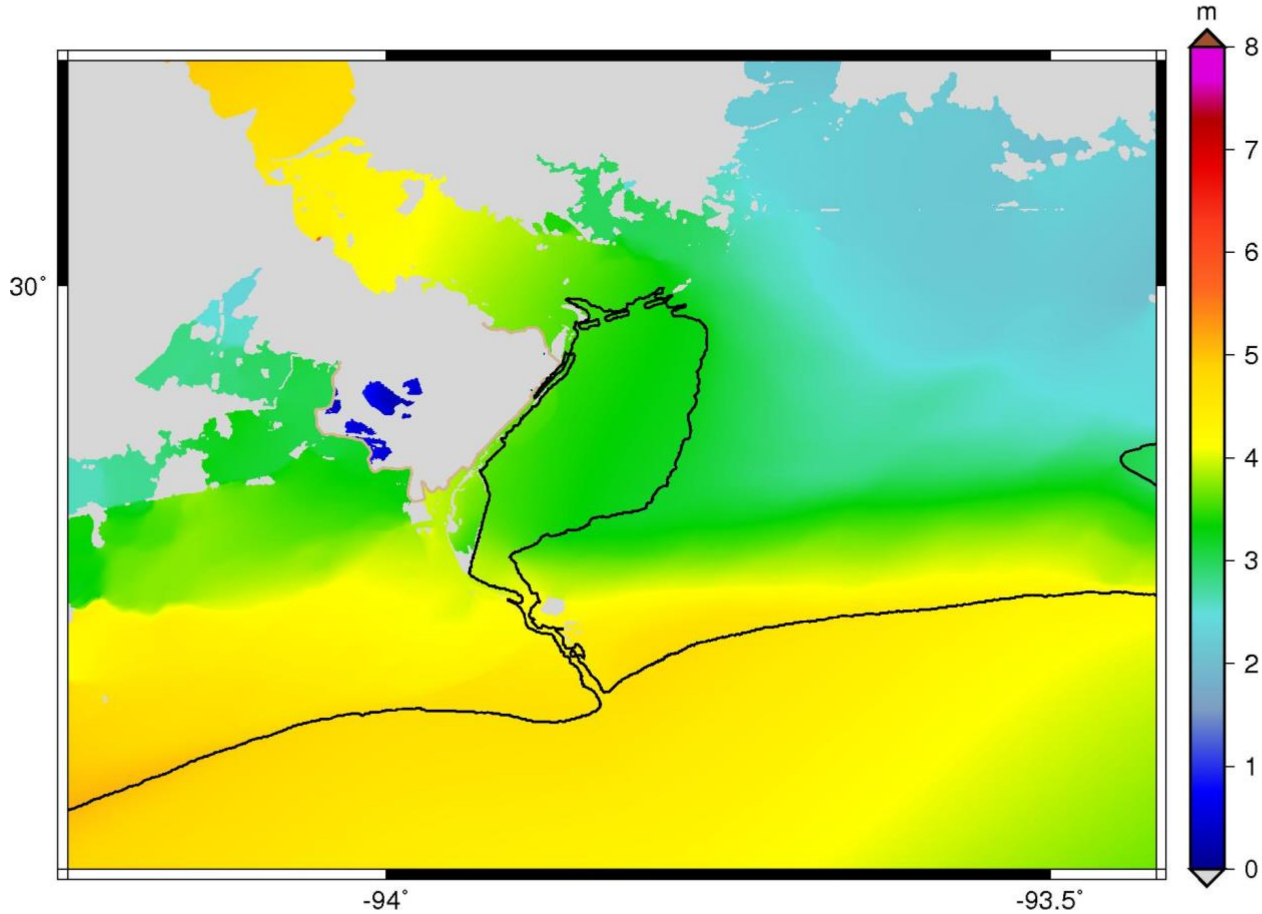

Figure 7. Contours of maximum surge elevation with the 100-year riverine flow (91,000 cfs).

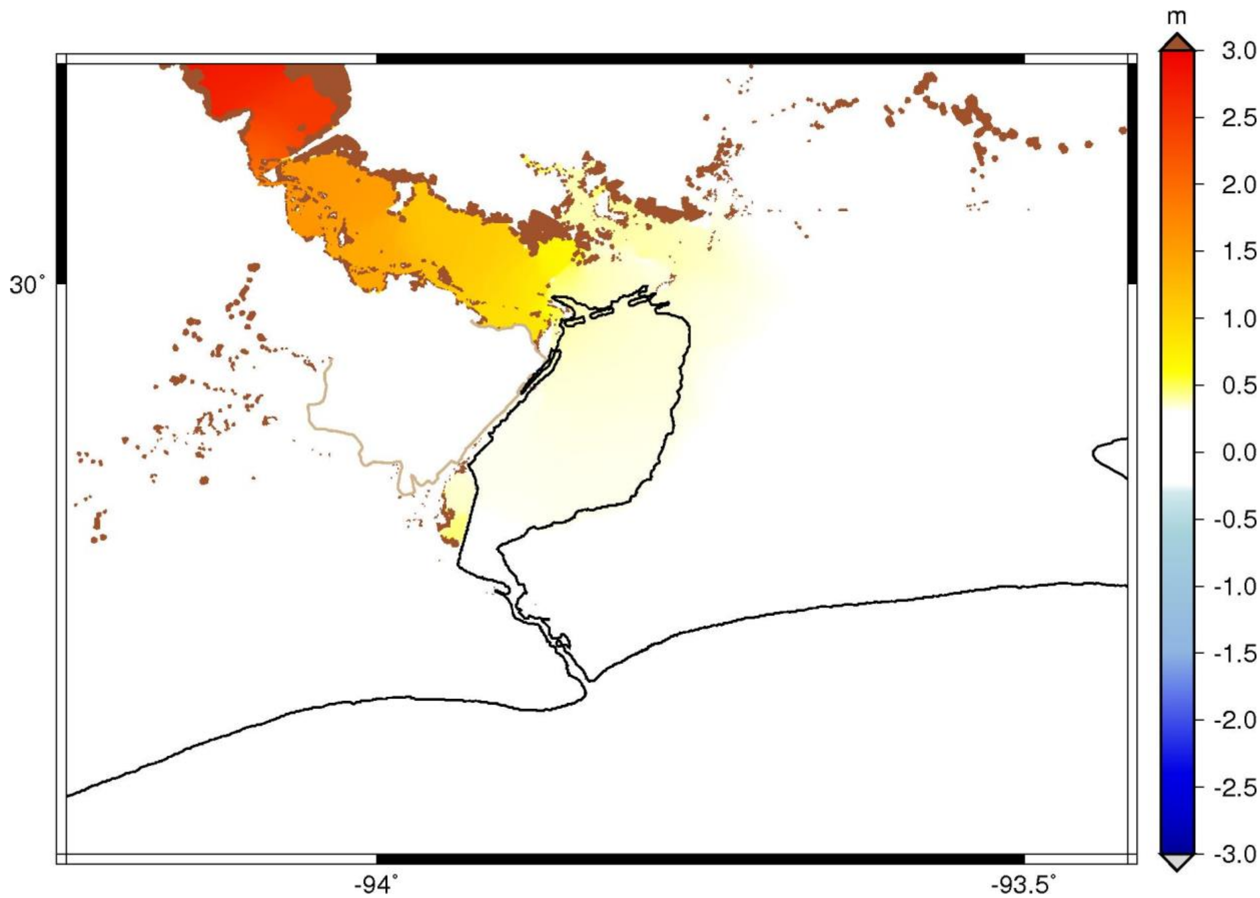

Figure 8. Contours of the surge difference between no riverine flow and the 100-year riverine flow.

14. CRC Performance Metrics:

CRC Performance Metrics			
Metric	**Research**	**Education**	**Center**
Courses/certificates developed, taught, and/or modified		See Table	
Enrollments in Center-supported courses/certificates			
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)	1		
Graduate students provided stipends (number)	1		
Undergraduates who received HS-related degrees			
Graduate students who received HS-related degrees			
Certificates awarded (number)			
Graduates who obtained HS-related employment		2	
SUMREX program students hosted (number)			
Lectures/presentations/seminars at Center partners			
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)			
Journal articles published and Book Chapters (number)	2		
Conference presentations made (number)			
Other presentations, interviews, etc. (number)	1		
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies			
Requests for assistance/advice from other Federal			
Total milestones for reporting period (number)	3		
Accomplished fully (number)	1		
Accomplished partially (number)	2		
Not accomplished (number)			
Product/s delivered to end-user/s (description and	See Table		
External funding received	See Table		
Leveraged support			
Articles on Center-related work published on website			
Coverage in media, blogs (number)			
Social media followers (number)			
Posts to social media accounts (number)			
Events hosted (number)			
Website hits (number)			

Table for Documenting CRC Research Project Product Delivery

Product Name	Product Type	Approx. Delivery	Recipient or Anticipated End
None			

Table for Documenting External Funding and Leveraged Support

External Funding			
Title	PI	Total Amount	Source
Coupled Rainfall-Surge Modeling for the Upper Barataria Basin	Resio	$40,000	Louisiana Water Institute of the Gulf

Leveraged Support	
Description	Estimated Annual
Free office space	$2,000
Portion of university indirect returned to project	$15,000
Reduced rates on high performance computer	$20,000