HAGEN, LSU

DHS Coastal Resilience Center

Research Project:

Annual Project Performance Report

Covers reporting period January 1, 2016 – June 30, 2016

1. **Project Title:** Development of an optimized tide and hurricane storm surge model for the northern Gulf of Mexico (MS, AL, FL) for use with the ADCIRC Surge Guidance System.

2. **Principal Investigator / Institution:** Scott C. Hagen, Professor. Louisiana State University, Department of Civil & Environmental Engineering / Center for Computation & Technology / Center for Coastal Resiliency.

3. **Other Research Participants/Partners:** Stephen C. Medeiros, Research Assistant Professor. University of Central Florida, Civil, Environmental & Construction Engineering Department, Coastal Hydroscience, Analysis, Modeling and Predictive Simulations Lab.

4. **Short Project Description:** This study will develop a semi-automated mesh de-refinement method designed to optimize a research grade tide, wind-wave, and hurricane storm surge model so that it can be used in real-time surge guidance operations. The resulting model will be capable of producing accurate predictions within the ADCIRC Surge Guidance System (ASGS) forecast time frames and will include advanced terrain analysis and lidar-based surface roughness parameterizations.

5. **Abstract:** This project will advance state-of-the-art model development by introducing novel terrain analysis techniques and lidar-based surface roughness parameterization at the regional scale. These advanced techniques will also be used to develop intelligent, stable, and semi- automated mesh de-refinement methods for optimizing a research grade (i.e., high resolution) storm surge model to reduce computational time to the point where it can be run within reasonable real-time forecast time frames (e.g., ~1-2 hrs). We will use a protocol based on emphasizing hydraulically significant embankment or valley features to optimize a research grade model of the MS, AL, and FL Panhandle. Since the purpose of ASGS is the provision of real-time hazard guidance, we will emphasize the accurate capture of the timing and magnitude of maximum water levels. This will be achieved by employing mesh development techniques such as: running preliminary simulations to define active floodplain and removing unnecessary elements (relevant because the research grade model was developed to accommodate up to two meters of sea level rise); employing

accelerated element relaxation moving outward from significant vertical features; and enforcing stricter criteria for vertical feature inclusion (especially for channels). Objective error metrics will be used to assess model performance. The final outcome/deliverable will be an accurate, optimized hurricane storm surge model of the northern Gulf of Mexico (MS, AL, & FL Panhandle) that is suitable for use with the ASGS including improved surface roughness parameterization from our lidar-based technique. In addition, this high resolution ADCIRC+SWAN model will serve as a benchmark for validating future versions that may incorporate less resolution or smaller regional focus.

6. **End users:**
    - Jerrick Saquibal, Northwest Florida Water Management District. Provided preliminary guidance as to the needs of his district during kick-off phone call with Dr. Medeiros. Follow up call to show preliminary model results to be scheduled in performance period 2. Expects high resolution surge forecasts for the Florida Panhandle and Big Bend regions, and looks forward to value-added lidar products.
    - NOAA Gulf of Mexico Sentinel Site Cooperative (GOMSSC). Provided preliminary guidance on role of surge forecasts in GOMSSC mission. Facilitated Dr. Medeiros presentation on topographic characterization of coastal salt marshes at GOMSSC monthly conference call. Expects to invite LSU-UCF personnel to demonstrate surge modeling and value-added lidar products at future GOMSSC workshops and meetings. We plan to elevate the role of the GOMSSC as an end-user as a result of our successful initial engagements.

7. **Explanation of Changes:**

    There have been no major changes to the approved workplan. Minor changes to increase end-user engagement, and documentation thereof, were implemented as a result of DHS comments.

8. **Unanticipated Problems:**

    The administrative tasks associated with implementing the SUMREX program were much more complex than anticipated. Issues regarding payment of travel funds and stipend resulted in Dr. Medeiros spending an inordinate amount of time on this, thus delaying the research milestone associated with submission of a journal paper on the lidar surface roughness parameterization. Also, due to delays in the issuance of Performance Period 2 funds, Dr. Medeiros temporarily funded the SUMREX program from his research balance account in order to mitigate the financial burden on the student from UPRM. All issues are now resolved and we expect the process to go much smoother in summer 2017.

9. Project Outcomes:

Our primary goal is to develop an accurate, optimized hurricane storm surge model of the NGOM that is suitable for use with the ASGS and CERA that includes improved surface roughness parameterization from our lidar-based evaluation technique. This will enable the ASGS to provide emergency management personnel in the region with the highest resolution, most accurate real-time storm surge forecasts for threatening tropical cyclones. In turn, this will facilitate more efficient evacuation and better prediction of post-storm emergency resource needs. These research outcomes have corresponding Research Milestones shown in the table below. The submission and subsequent publication of the surface roughness parameterization and mesh optimization methods in high-impact journals serve to validate the research pathways and document their acceptance by successful peer review. By achieving these milestones, the incorporation of this optimized model into ASGS will be justifiable by any measure and DHS S&T will have independent documentation in support of it. The incorporation of the optimized model into ASGS is also the best, most readily adoptable means for conveying the model results to the public in a meaningful way. The following sections details the progress we have made towards achieving these outcomes.

The most progress has been made on Phase 1 of the effort to transform a research grade ADCIRC model to one that is optimized for runtime. To examine the potential reduction in wall-clock time two Hurricane Katrina simulations were performed using the two-dimensional depth-integrated version of ADCIRC [*Luettich and Westerink*, 2004]. The first simulation employs the original *NGOM3* unstructured mesh that contains 5,492,562 computational nodes. Details on the development and validation of the *NGOM3* model can be found in *Bilskie et al.* [2016]. The bathymetry and topography of the *NGOM3* mesh for the northern Gulf of Mexico (NGOM) is shown in Figure 1A.

The *NGOM3_FPL* unstructured mesh was employed for the second simulation. This mesh contains 4,441,392 computational nodes, a reduction of 1,051,170 nodes (19%). The *NGOM3_FPL* mesh was generated by removing mesh nodes and elements at the northern and most upland areas across Louisiana, Mississippi, Alabama, and Florida. The maximum envelope of water (MEOW) derived from 86 synthetic storm forced simulations using the *NGOM3* model under 2 m of sea level rise was utilized. Mesh nodes that were outside the computed MEOW were removed as well as their respective elements. The model boundary and topography and bathymetry of the *NGOM3_FPL* mesh is shown in Figure 1B.

The *NGOM3* and *NGOM3_FPL* unstructured meshes were employed in a simulation forced by Hurricane Katrina wind and pressure. The simulations were performed on the LONI Queenbee2 HPC across 400 computational cores (includes 2 dedicated writer cores). The Hurricane Katrina model was setup to run for 5.0 days with a 0.5 day ramp using a time step of 1.0 seconds (implicit mode). The maximum simulated

water surface from the *NGOM3* and *NGOM3*_FPL simulation is shown in Figure 2A and B, respectively. Both simulations resulted in an equivalent solution.

The *NGOM3* Katrina model simulation resulted in a wall clock of 288 min (57.6 min/day of simulation) and the *NGOM3_FPL* resulted in 232 min (46.4 min/day of simulation), a reduction of 56 min (19.4%) in wall clock (Table 1). For this example, the reduction in wall clock scales linearly with the reduction in computational nodes. This is because the nodes that were removed were generally never wetted; however, more research is required to understand the reduction in wall clock given a reduction in computational nodes.

This initial model comparison yields promising results and will assist in the further development of a forecast-grade model for the NGOM coast. Of course, more research and experimentation is necessary to transition the *NGOM3* unstructured mesh to a forecast-grade model.

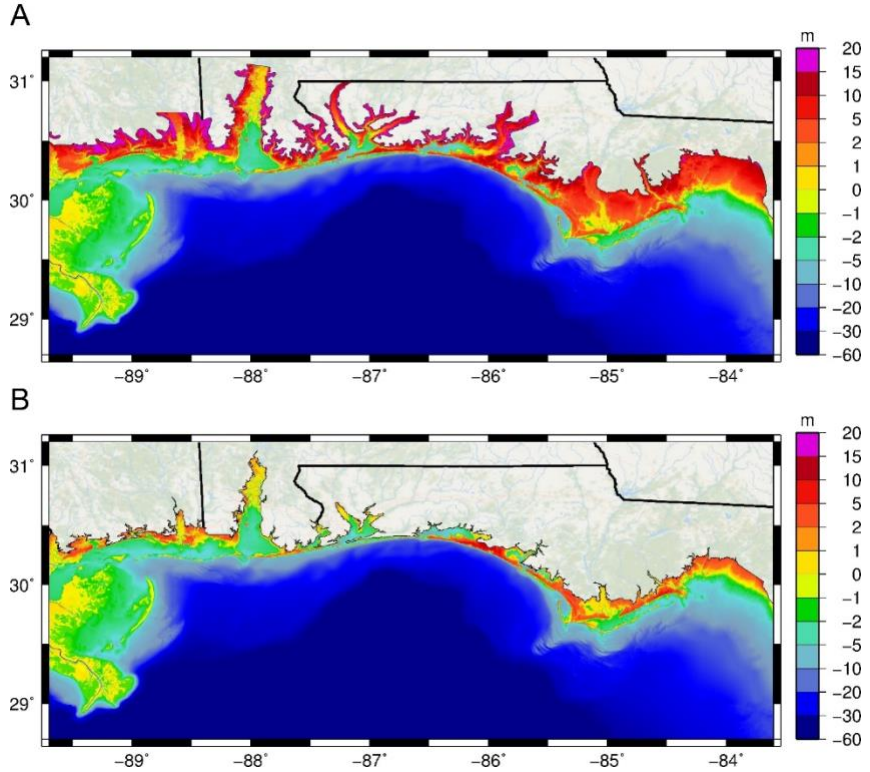

Figure 1. Research-grade NGOM3 model topography and bathymetry (m, NAVD88) for the (A) original model and (B) the *NGOM3_FPL* mesh.

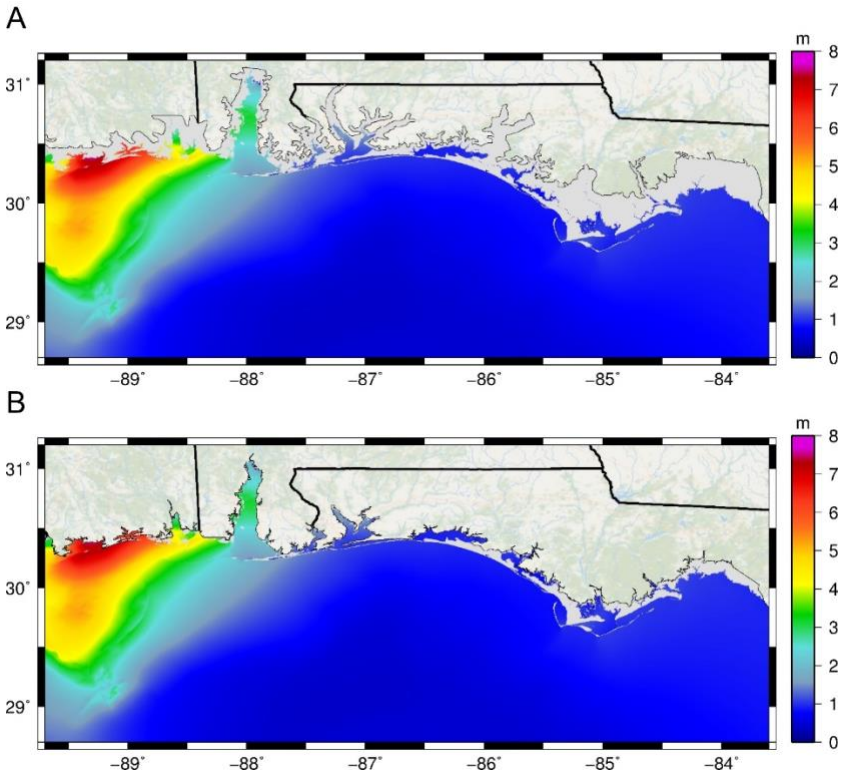

Figure 2. Research-grade NGOM3 simulated maximum water surface elevation from Hurricane Katrina (m, NAVD88) for the (A) original model and (B) the *NGOM3_FPL* mesh.

Table 1. Node count and wall-clock (min) for the full research-grade NGOM3 model and the NGOM3 model with additional floodplain removed.

Model	**Node Count**	**Total Wall Clock (min)**	**Wall Clock (min) per day of simulation**
NGOM3	5492562	288	57.6
NGOM3_FPL	4441392	232	46.4

References

Bilskie, M. V., S. C. Hagen, S. C. Medeiros, A. T. Cox, M. Salisbury, and D. Coggin (2016), Data and numerical analysis of astronomic tides, wind-waves, and hurricane storm surge along the northern Gulf of Mexico, *Journal of Geophysical Research: Oceans*, *121*(5), 3625-3658.

Luettich, R. A., and J. J. Westerink (2004), Formulation and numerical implementations of the 2D/3D ADCIRC finite element model version 44.XX*Rep.*, 12/08/2004.

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
Establish baseline metrics for research grade model performance (accuracy at stations, run time, etc.)	03/31/2016	75%	Diverted resources towards Phase 1 optimization task, Completion expected 09/30/2016
Develop scalable data processing pipeline for lidar-based surface roughness parameterization	06/30/2016	25%	Time devoted to SUMREX startup issues, expected completion 12/31/2016
Phase 1 of optimization procedure: Remove unnecessary floodplain elements and document incremental performance improvements	06/30/2016	100%	Phase 1 reduced 17% of the unnecessary floodplain nodes and resulted in a 25% reduction in wall-clock time on 480 HPC cores. Complete.
Research Milestone			
Submit a manuscript on Regional Scale Lidar Surface Roughness	06/30/2016	50%	Time devoted to SUMREX startup issues, expected completion 12/31/2016

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
Meet (in-person or virtual) with technical team from Coastal Emergency Risks Assessment (CERA) to establish file format, tiling scheme, and transfer protocols for displaying model results on http://cera.cct.lsu.edu/	03/30/2016	40%	Effort directed at Phase 1 optimization task, the results of which will form the basis for this activity, expect to be complete by 12/31/2016
Coordinate with end users to determine transition goals and plan	03/01/2016	100%	End Users were briefed on project and all requested to be kept informed. CERA interface presented and all users responded positively. All users responded positively to research grade model being evolved into usable product.
Transition Milestone			
Prototype integration of NGOM ADCIRC model output into CERA	06/30/2016	25%	Delays in funding delivery and actual project start, expect to be complete by 12/31/2016
Refined transition goals and plan with end user input	06/30/2016	50%	Initial conversations complete, pivoting to give NGOM SSC greater role, expect to be complete by 12/31/2016

12. Interactions with education projects:

The LSU-UCF Summer Research Experience (SUMREX) was a resounding success. Felix Santiago from UPRM was selected from the applicant pool to participate in the 2016 program. He arrived at UCF on Monday June 13, 2016 and checked into his on-campus apartment (paid for by the project).

Starting Tuesday, June 14, he began his SUMREX program with a pre-test consisting of some basic linear algebra and numerical methods problems designed to assess his level of competence in these topics and gage the need for further explanation on these topics. During the pre-test, he engaged daily with Dr. Talea Mayo for assistance with

the mathematical aspects of the pre-test. The pre-test also required Felix to read a research paper in JGR-Oceans written by the LSU-UCF team, highlighting both concepts he did not understand, as well as concepts that he was interested in. For the remainder of the UCF phase of the SUMREX, Felix worked closely with Dr. Medeiros and his graduate students to learn the SMS software for ADCIRC mesh development. He went through tutorials from past ADCIRC boot camps, working through the examples. He then used that knowledge to expand and add resolution to an existing mesh and run desktop ADCIRC tide simulations in SMS. Also, Dr. Medeiros took Felix into the field at the Merritt Island National Wildlife Refuge to determine Manning's *n* bottom friction coefficients. Dr. Medeiros also taught Felix the method for determining the effective aerodynamic roughness length in the field by measuring the height, canopy width and other dimensions of trees and above-ground obstructions.

On July 5, Felix transitioned to LSU and checked into his project provided housing. He immediately began working with Dr. Hagen's student Matt Bilskie to build on his ADCIRC knowledge by conducting storm surge simulations. Felix attended three virtual trainings entitled "Introduction to Linux" and High Performance Computer (HPC) User Environment Part 1 and Part 2". These trainings were provided by LSU HPC. He simulated several hurricanes using a coarse ADCIRC model on his workstation and on the LSU HPC and documented the difference in run-time. He also learned how to generate presentation and publication quality graphics of storm surge model output using the FigureGen software program (developed by J. Casey Dietrich, NC State University, CRC PI). His work continued by simulating Hurricane Dennis using a high-resolution model of the Florida panhandle and compared the peak storm surge using two different wind-vortex models. He also learned how to spin-up a model in order to hot-start a storm surge simulation. During his final week at LSU, Felix employed the modified mesh he developed at UCF and simulated astronomic tides and hurricane storm surge from Hurricane Sandy. He then compared storm surge results among his modified mesh and the original, pre-modified, mesh. This experience is still underway and we look forward to Felix's final presentation.

13. Publications:

Tahsin, S., **S.C. Medeiros**, A. Singh (2016). "Resilience of coastal wetlands to extreme hydrologic events in Apalachicola Bay." *Geophysical Research Letters,* Vol. 43, doi: 10.1002/2016GL069594.

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)			
Graduate students provided stipends (number)			
Undergraduates who received HS-related degrees			
Graduate students who received HS-related degrees			
Certificates awarded (number)			
Graduates who obtained HS-related employment			
SUMREX program students hosted (number)	1		
Lectures/presentations/seminars at Center partners			
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)			
Journal articles published (number)	1		
Conference presentations made (number)			
Other presentations, interviews, etc. (number)	8		
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)	0		
Accomplished partially (number)	3		
Not accomplished (number)	0		
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 Date	Recipient or Anticipated End Users
ASGS NGOM Forecasts	Web Application	12/31/2017	NGOM SSC, NWFWMD, General Public

Table for Documenting External Funding and Leveraged Support

External Funding			
Title	PI	Total Amount	Source
N/A			
Leveraged Support			
Description			Estimated Annual Value
XSEDE High Performance Computing Allocation (Stampede) – Est. 30% of award to be used on this project			$32,014.40