BLANTON, UNC

DHS Coastal Resilience Center

Research Project:

Annual Project Performance Report

Covers reporting period July 1, 2016 – June 30, 2017

1. **Project Title:** A multi-tiered ADCIRC-based storm surge and wave prediction system
2. **Principal Investigator / Institution:** Brian Blanton, Renaissance Computing Institute, UNC-Chapel Hill
3. **Other Research Participants/Partners:**
    - Rick Luettich, Institute of Marine Sciences, UNC-Chapel Hill, co-PI
    - Jason Fleming, Seahorse Coastal Consulting, ASGS developer, ADCIRC Bootcamp organizer
    - Crystal Fulcher, Institute of Marine Sciences, UNC-Chapel Hill, ADCIRC grid development
    - Jess Smith, Masters student, UNC-Chapel Hill, Department of Marine Sciences. (100%, as of May 1, 2017)

4. **Short Project Description ("elevator speech"):** Decision makers need critical and helpful information delivered on time and in formats that are easily understandable. This is particularly true with dangerous and destructive natural hazards such as hurricanes and the resulting wind, storm surge, and wave impacts. Late and/or incomprehensible information is useless. This DHS CRC project is about reducing the time needed to deliver hazard information to end users by using advanced models for storm surge, very high-performance computing resources, and statistical methods that can provide early guidance information in a matter of minutes as opposed to hours.
5. **Abstract:** We will enhance and extend a multi-tiered, ADCIRC-based storm surge and wave prediction system covering the US East Coast with highest resolution in North Carolina (NC) and southern Chesapeake Bay coastal waters. The system has two main components: (i) the ADCIRC Surge Guidance System (ASGS) that provides fully dynamic, deterministic, highly accurate ADCIRC-based storm surge and wave predictions ~1-2 hours following the release of meteorological forecasts and (ii) ADCIRC-Lite, which utilizes a response surface method (Taflanidis et al, 2013, Rapid assessment of wave and surge risk during landfalling hurricanes: Probabilistic approach, Journal of Waterway, Port, Coastal, and Ocean Engineering, 139**,** 171–182.) with a pre-computed database of ADCIRC surge and wave solutions to provide rapid (e.g., within minutes) probabilistic or deterministic surge and wave predictions for hurricanes using either forecast meteorological input or end user specified storm parameters. A graphical interface will facilitate user interaction and provide an important tool for risk assessment, education and outreach. Additional components to this project include conducting both the ADCIRC Annual User Group meeting and the ADCIRC BootCamp, and a hurricane track generator for probabilistic storm surge analysis.

6. **End users:** US Coast Guard, will provide essential usability feedback on project outcomes. USCG uses ADCIRC-based information routinely, but generally do not have the resources to either run the model or create derived products themselves. Instead, they rely on the products generated by ASGS and accessed through the nc-cera.renci.org website, not the ASGS output itself. We will hold several WebEx meetings with USCG to demonstrate the project activities, particularly for ADCIRC_Lite. We will specifically request feedback as to the user interface and general functionality. We will then update the application.

   NOAA, Coast Survey Development Lab, Silver Spring, MD, leads the ADCIRC-related efforts for NOAA. CSDL uses ASGS to run ADCIRC operationally, and will be providing ADCIRC output to the National Hurricane Center during active tropical cyclone events in the western Atlantic. CSDL has provided their new comprehensive coastal grid for us to use in the operational ASGS system. As we work with this grid, we will provide feedback to CSDL

   FEMA HQ, advisors on federal level coastal hazards and risk. Both are acquainted with ADCIRC, primarily from the federal NFIP perspective. One was previously in Region 4, and oversaw most of the technical aspects of the recent coastal Flood Insurance Study that RENCI conducted (with the State, Dewberry and Davis, Applied Research Associates, and US ACE). With our FEMA end users, we will be particularly interested in how they view ADCIRC_Lite as a potential outreach and education tool. Thus, being able to extend ADCIRC_Lite to more areas will be critical. We will invite FEMA to participate in the WebEx meetings to get a "multi-user" perspective on our project.

   Coastal Engineer, FEMA Region 4, Atlanta, GA, is knowledgeable of ADCIRC, having previously been a coastal engineer for Dewberry and Davis. Dewberry is the prime contractor for FEMA-related activities for the State of North Carolina, and ther stakeholder worked extensively on the coastal extra-tropical statistical problem for the comprehensive sea level rise impacts study recently completed. See above.

   USACE, MVN District, user of ADCIRC products for operational decision making for New Orleans area. They are well acquainted with ADCIRC and ASGS, and will provide end-user critiques of product usefulness, accessibility, and confidence. They typically engage with the UNC ADCIRC group during active tropical events that pose a threat to the New Orleans region. During those periods, we work extensively with him to ensure that the ASGS systems are producing needed output in a timely manner. They frequently advise us as to functionality feedback, and we expect this to continue over the next Atlantic hurricane seasons, as well as interactions during the ADCIRC users group meetings.

7. **Unanticipated Problems:** As noted in the previous Annual Report, response surface methods are fundamentally interpolation methods. As such, the results are very sensitive to the input data. In our case, (the FEMA NC storm surge simulation database), the statistical distributions of dynamic hurricane parameters (radius to maximum winds, central pressure, etc.) are evenly sampled. However, the landfalling location is randomly drawn from a uniform distribution. For the intended purposes of the FEMA coastal flood insurance study, this is appropriate because, for larger storms that contribute more to low-frequency water levels (such as the 1% or 0.5% annual exceedance levels), the storms' radii are large enough to fill in unevenness in landfall location. However, for general interpolation problems, where it is necessary to compute a weighted response from a set of "nearest" neighbors, the interpolated results can be unexpected. For example, if the nearest neighbor set contains storms whose landfall location is to the left of the storm being predicted, the resulting water level will have unphysical higher water to the left of the storm. An example of this behavior is shown in Figure 1. The majority of the high water is to the left of the track (yellow line), which is not consistent with our expectations based on the mechanics of storm surge and hurricanes.

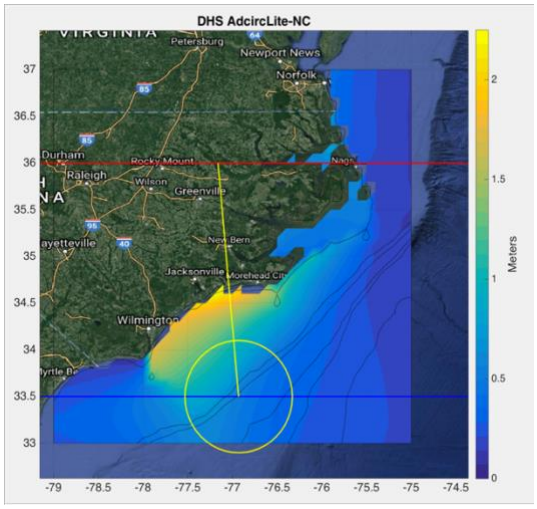


Figure 1. Example of interpolation behavior due to unevenly spaced parameter sampling.

We noted in the prior Y1 report that the remedy appears to be enforcing an even sampling of the landfalling locations. This cannot be done with the existing NC FEMA dataset, because of the sensitivity of storm surge to details of the coastline. We have thus abandoned the NC FEMA dataset and have computed a suitable set of training storms. To do this, we evenly sampled the primary dynamic hurricane parameters (central pressure, maximum wind speed, etc.) and then spaced this set of storm tracks at an along-coast distance increment proportional to the radius to maximum winds. This track set is shown in Figure 2. The track shape is determined by fitting Bezier curves from the starting location at (-70, 24) degrees to the landfall locations, constrained by the landfall orientation angle. Variations in the along-track central pressure are determined by analyzing historical storms and their pressures relative to landfall time. This analysis is summarized in Figure 3. Since the radius to maximum winds is correlated with the central pressure, this serves to provide realistic along-track variation in both parameters. Landfalling angle varies between -80 and 40 degrees (clockwise from true north). Storm surge for each track (a total of 5544 tracks) was computed on a coarse ADCIRC

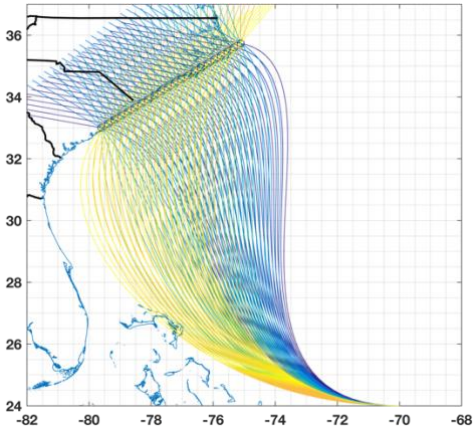


Figure 2. Synthetic hurricane tracks for North Carolina. The line colors serve to visually discriminate the different track paths and do not represent parameter variations.

grid for testing purposes. Figure 4 shows the maximum storm surge across all tracks (maximum of maximums). We are currently modifying the response surface method code to accommodate this larger (in terms of the number of storms) dataset.

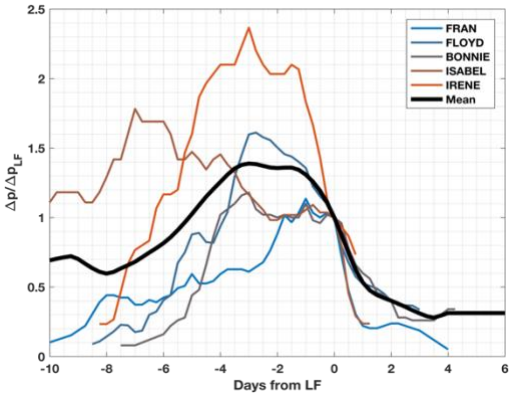


Figure 4. Along-track pressure variation scale relative to the central pressure landfall at t=0.

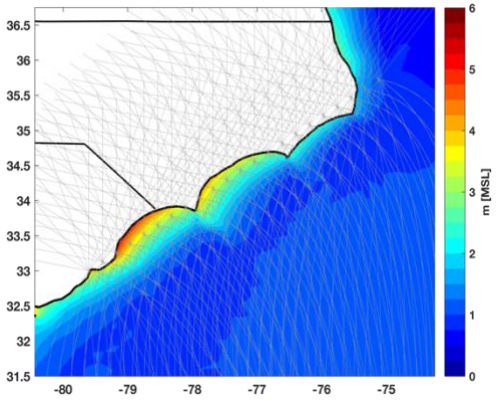


Figure 3. Maximum of maximums across all storms in the new storm population (gray lines), computed on a coarse ADCIRC grid.

Additional changes to the original plan: The original project plan included developing a comprehensive ADCIRC grid for the North Carolina and lower Chesapeake Bay region. However, in collaborating with NOAA's CSDL on this and other projects, we started using a new comprehensive coastal grid that CSDL has developed (HSOFS). This grid provides consistent coastal and near-coast land resolution for the entire eastern US and Gulf of Mexico coasts. We started using this grid during the Hurricane Matthew (2016) event, and have been evaluating this grid's performance for that event. A manuscript is in preparation describing the ASGS forecasting performance during Matthew and the implementation of a water level assimilation scheme.

8. Project Impact:

As detailed above, there are several aspects (or tiers) to this ADCIRC-based CRC project. At the technical/operational level, we continue to develop and extend the ASGS forecasting framework, the primary activity of Seahorse Coastal Consulting. Dr. Fleming has also developed extensive curricula for education and training activities for ADCIRC and ASGS, and these have been used at recent ADCIRC Annual Meetings and BootCamps. Dozens of graduate students, post-docs, and early career professionals attended the 2017 BootCamp in Norwood, MA. This constitutes a broad group of "end-users" of the software and technology developed, maintained, and supported by this project. Many of the students are conducting important research in coastal hazards, risk, and resilience, and whose research activities may have impacts in the near future. We note that one student (Mr. Stephen Kreller of LSU) attended the BootCamp specifically to be better prepared for spending the summer 2017 in residence at RENCI working with Dr. Blanton on his ADCIRC-related research.

This project also maintains the infrastructure at RENCI that hosts the nc-cera-renci.org website and the operational ASGS for North Carolina. This website is routinely used by many end-users, including the USCG, FEMA, NOAA, and USACE. Additionally, during active events that may impact North Carolina, the North Carolina Division of Emergency Management accesses ADCIRC forecast products through the RENCI data servers (http://tds.renci.org:8080/thredds/asgs.html). Now that we have implemented the NOAA HSOFS grid in ASGS at RENCI, we will be able to provide additional guidance for any region threatened by tropical cyclone activity. This may substantially broaden the impact of ADCIRC, ASGS, and DHS's support of these activities.

Although not yet completely implemented, the ensemble track generator has the potential to provide new probabilistic storm surge information that is similar to NOAA's P-Surge information. While running thousands of simulations at high spatial resolution in near-real-time is not feasible, we hope to use the ADCIRC_Lite approach (with the new storm surge database) to make this tractable.

9. Research Activity and Milestone Progress:

Research Activities and Milestones: Progress to Date

Reporting Period 7/1/2016 – 6/30/2017			
Research Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Develop ADCIRC grid for NC and lower Chesapeake Bay by merging existing NC grid with portions of the existing FEMA Region III grid	03/30/2016	50	As noted above, the need for this grid has been superseded by the availability of NOAA CSDL's comprehensive coastal grid (HSOFS).
Test early grids with historical storms and in the ASGS	05/31/2016	75	The intent of this activity was to validate the regional NC/Chesapeake Bay grid. However, since adopting the NOAA HSOFS grid, we have focused
Continue operation of ASGS	Ongoing	100	RENCI continues to support the ASGS by providing computational resources to ASGS.
Develop parameter sampling for new storm surge database	03/31/2017	100	
Research Milestone			
Review of existing probabilistic track generation methods	05/31/2016	100	
Implement the new CSDL HSOFS grid in ASGS	10 /01/2016	100	

Develop new storm population that addresses the above-noted issue with the FEMA dataset.	03/31/2017	100	
Compute storm surge database using coarse ADCIRC grid	05/31/2017	100	
Status report on ASGS system upgrades and initial tests with new grid to NOAA and DHS	05/30/2017	100	ASGS progress/status and preliminary results with the NOAA HSOFS grid were presented at the DHS CRC Annual meeting in Chapel Hill, NC.
Presentation on project's ASGS activities to ADCIRC Annual Meeting	04/1/2017	100	Overview of ASGS updates and capabilities was presented by J. Fleming at the ADCIRC Annual Meeting and BootCamp.

10. Transition Activity and Milestone Progress:

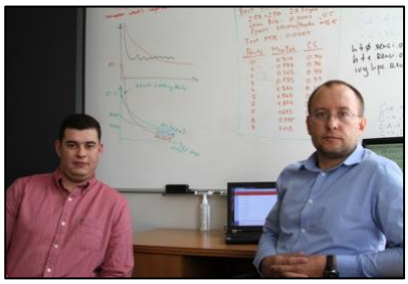
Transition Activities and Milestones: Progress to Date

Reporting Period 7/1/2016 – 6/30/2017			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Attend 2017 American Meteorological Society meeting to present ensemble method development and results	01/31/2017	100	J. Smith presented a poster at the AMS 2017 meeting on her research into probabilistic storm surge simulations.
Develop report on ASGS enhancements and status to ADCIRC user community	03/31/2017		
Prepare for ADCIRC Annual Meeting and BootCamp	05/31/2017	100	
Incorporation of ASGS enhancements into the ASGS software repository. The software repository is the primary way that ASGS software is distributed.	05/15/2017	100	All new features developed by Seahorse Coastal Consulting have been committed to the ASGS repository for use by the community of ASGS users.
Transition Milestone			

Conduct ADCIRC Annual Meeting and BootCamp	5/31/2017	100	Seahorse Coastal Consulting organized, in conjunction with the host FM Global, the annual meeting and BootCamp, held in Norwood Mass. This was the largest BootCamp to date, attended by dozens of students and early career professionals.
HSOFS grid results in nc-cera.renci.org	10/31/2016	100	HSOFS grid results are posted to the usual nc-cera.renci.org website once the ASGS system posts the output to the data servers.
Present ensemble method results at AMS 2017	01/31/2017	100	
Provide update on ASGS status and enhancements at Annual ADCIRC Users Meeting and BootCamp	04/30/2017	100	
Aide NOAA in deploying ASGS prior to the hurricane season	05/31/2017	100	

11. Interactions with education projects:

While not a direct CRC education project interaction, we note the following. During the 2016 summer (which includes the early part of this Y2 project), the CRC hosted Anton Bezuglov (Associate Professor of Computer Science) and Reinaldo Santiago (rising senior in Computer Engineering) from Benedict College in Columbia South Carolina. This was through the DHS Summer Research Team for Minority Serving Institutions (SRT MSI). Bezuglov and Santiago were in residence at RENCI, where they developed an artificial neural network that uses hurricane parameters and storm surge responses from our FEMA North Carolina coastal flood insurance study to simulate storm surges at coastal locations. The network is an accurate and fast method and is a strong complement to ongoing CRC-funded research at RENCI on response surface methods for storm surge prediction. A manuscript describing the research and results is available in arXiv at this URL: https://arxiv.org/pdf/1609.07378. This summer research led to a follow-on proposal to the DHS SRT MSI program. This project was funded, but due to unforeseen circumstances, Prof Bezuglov was unable to accept the award.



DHS SRT researchers in residence at RENCI, a collaborator with the CRC. Mr. R. Santiago (left) and Prof. A. Bezuglov (Right).

RENCI is also hosting Mr. Stephen Kreller from LSU for the summer 2017 period, as part of the DHS SUMREX program. Mr. Kreller is a master's degree student of Prof Barry Keim (a CRC PI), and he is spending the summer at RENCI working with ADCIRC, including data processing and analysis, model setup and execution, and scientific communication skills.

12. Publications:

Storm Surge Probabilities for Hurricane Events, J. Smith, B. Blanton, R. Luettich, 2017. This is a poster presented at AMS 2017 in Seattle WA (Jan 2017), DHS CRC Annual Meeting in Chapel Hill, NC (Feb 2017), and the annual Hurricane Awareness conference at East Carolina University (May 2017).

13. Tables

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type	Approx. Delivery Date	Recipient or Anticipated End Users
ADCIRC_Lite	Software	Dec 2017	Coast Guard, FEMA, other end-users as approriate
ASGS	Software	ongoing	ADCIRC forecasting and real-time users

Table 2: Documenting External Funding and Leveraged Support

External Funding			
Title	PI	Total Amount	Source
NA			
Leveraged Support			
Description			Estimated Annual Value
RENCI Computing Resources			30,000

14. Metrics

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)
HS-related internships (number)	0	0
Undergraduates provided tuition/fee support (number)	0	0
Undergraduate students provided stipends (number)	0	0
Graduate students provided tuition/fee support (number)	1	1
Graduate students provided stipends (number)	1	1
Undergraduates who received HS-related degrees (number)	0	0
Graduate students who received HS-related degrees (number)	0	0
Graduates who obtained HS-related employment (number)	0	0
SUMREX program students hosted (number)	0	1
Lectures/presentations/seminars at Center partners (number)	1	0
DHS MSI Summer Research Teams hosted (number)	1	0
Journal articles submitted (number)	0	0
Journal articles published (number)	0	0
Conference presentations made (number)	2	2
Other presentations, interviews, etc. (number)	0	2
Patent applications filed (number)	0	0
Patents awarded (number)	0	0
Trademarks/copyrights filed (number)	0	0
Requests for assistance/advice from DHS agencies (number)	0	0
Requests for assistance/advice from other agencies or governments (number)	0	0
Total milestones for reporting period (number)	7	7
Accomplished fully (number)	2	2
Accomplished partially (number)	3	3
Not accomplished (number)	2	2