DIETRICH, NCSU

DHS Coastal Resilience Center

Research Project:

Annual Project Performance Report

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

1. **Project Title:**

   Improving the Efficiency of Wave and Surge Models via Adaptive Mesh Resolution

2. **Principal Investigator / Institution:**

   Joel Casey Dietrich, Assistant Professor, North Carolina State University

3. **Other Research Participants/Partners:**

   Clint Dawson, Professor, University of Texas at Austin

4. **Short Project Description:**

   Coastal communities rely on predictions of waves and flooding caused by storms. These predictions are used during the storm to make decisions about resource deployment and evacuation, and these predictions are also used between storms for design and to establish insurance rates for local homeowners. Computational models are essential for making these predictions, but they can be costly. A typical prediction can require hundreds or even thousands of computational cores in a supercomputer, and several hours of wall-clock time. In this project, we will improve the performance of a widely-used, predictive model. Its representation of the coastal environment will adapt during the storm, to better utilize the computing resources and ultimately provide a faster prediction. This speed-up will benefit coastal communities, including emergency management personnel, who will have more time to make decisions during the storm event. It will also benefit long-range planners, such as flood mappers, who will be able to consider larger, more-accurate models in the same amount of time.

5. **Abstract:**

   Storm-induced waves and flooding can be predicted using computational models such as the ADCIRC+SWAN modeling system, which has been used by DHS and its constituent agencies for mapping of floodplain flood risk and forecasting of storm surge and inundation. This modeling system has been shown to be efficient in parallel computing environments. It is implemented on static meshes and with a static parallelization, and thus it does not evolve as a storm approaches and inundates a coastal region. This implementation can be inefficient when large portions of the mesh remain dry during the simulation.

In this project, we will optimize the parallel implementation of ADCIRC by using a large-scale adaptivity, in which a mesh will be refined by incorporating entire portions of another, higher-resolution mesh. Instead of subdividing an individual element, we will increase resolution by adding elements from a pre-existing mesh that has been well-validated. This procedure will leverage the existing suites of meshes for the same geographic region. The adapted mesh will be rebalanced among the computational cores so that geographic regions with increased resolution will not be concentrated on a disproportionally-small number of cores, and so that the time spent on inactive regions is minimized. These technologies will decrease the computational cost and better utilize the available resources.

This project will develop technologies to improve the efficiency of ADCIRC+SWAN simulations, thus allowing for more model runs in ensemble-based design applications, and for faster simulations in time-sensitive applications such as operational forecasting. These outcomes will increase the accuracy of flood risk products used in building design and the establishment of flood insurance rates, and thus lessen the impact of a disaster. These outcomes will also improve the communication and understanding of potential hazards.

6. End Users:

The proposed enhancements to efficiency will benefit all model users, including several DHS agencies with missions related to coastal flooding. In its development of Flood Insurance Rate Maps (FIRMs), FEMA will benefit because the probabilistic guidance requires a large number of deterministic simulations, and the approach described in this project will require fewer computational resources. For example, if a flood mapping study would see an efficiency gain of, say, 10 percent, then the study could be completed in a shorter time. Alternatively, that efficiency gain could be reinvested into increasing the mesh resolution and/or considering a larger suite of storms, and thus increasing the accuracy of the model results. Several stakeholders at FEMA have agreed to participate as transition partners. The project will also help to speed the delivery of projected flood inundation levels associated with coastal storms, thereby assisting FEMA as well as state and local emergency managers to plan for coastal evacuations and deployment of resources and personnel. In addition, the Coast Guard will benefit from faster guidance about waves and surge and therefore be able to make operational decisions about the possible relocation of assets in advance of an oncoming storm. The project personnel will continue to work with the transition team to identify additional end-users in these and other DHS constituent agencies.

With the Texas State Operations Center, the project personnel will work with **Gordon Wells** and **Teresa Howard** to transition the analysis products that are used for guidance by the emergency management leadership. They have worked with forecast guidance for the Texas coastline in previous seasons, and are supportive of the proposed work to improve the speed of the forecasts. This partnership is important because it will connect the products with end users at the state and local levels.

The proposed work will also benefit ADCIRC model users at other federal agencies. The USACE Engineer Research and Development Center, the NOAA NCEP and the NOAA West Gulf River Forecast Center have agreed to participate as transition partners. In some cases, and especially for partners who are focused on operational modeling with ADCIRC,

these activities will take the form of guidance about development with the goal of transitioning products to their work in the long term.

The project personnel will also work closely to transition the project outcomes to the ADCIRC modeling community. These transition activities will connect with **Jason Fleming** and **Carola Kaiser**, who are key members of the Coastal Emergency Risks Assessment (CERA) group. They operate the forecasting systems for regions along the U.S. Gulf and Atlantic coasts, and they visualize and communicate the forecast guidance via a Google Maps application. Dr. Fleming also manages the software repository for the development of ADCIRC. The project personnel will work with these partners to ensure that the new modeling technologies can be incorporated within the forecasting system and the release version of ADCIRC.

During this project year, the research team facilitated the transfer of research products to these transition partners via two methods:

A. Progress reports via videoconference, during which the research team shared interim results from our activities, and our transition partners provided guidance about future directions. Their feedback and suggestions are valuable as we move our research products into something useful for production.

B. We are working with Jason Fleming to transition a static load balancing into the ADCIRC version used for forecasting in North Carolina, so it can benefit from a gain in efficiency. The latest development version of ADCIRC was modified so its static domain decomposition will account for the relative costs of dry and wet computational points. Preliminary tests, even with this most-basic of changes, have shown a speed-up of 10-20 percent compared to the existing release version of ADCIRC. We continue to work on more-sophisticated methods that will offer enhanced efficiency gains.

Thus, we are working with our transition partners, and information is flowing in both directions. They have identified some future directions for our research, and we are sharing our technologies with them. The project technologies will be shared as they become available, and our transition partners will be trained and then test the technologies for applications ranging from operational forecasting to engineering design. The technologies developed in this project will also be released to the ADCIRC modeling community. This work will require the development of extensive documentation and example files, which will be hosted online, and the integration of the software into the release version of ADCIRC.

7. Unanticipated Problems:

This project has not had any unanticipated problems or challenges.

8. Project Impact:

This project is developing technologies to improve the efficiencies of the ADCIRC modeling system in parallel computing environments. It is developing automated routines for an adaptive, multi-resolution approach to employ high-resolution, unstructured meshes for storm surge applications, and it is developing automated routines for the efficient re-

balancing of the computational workload via parallelized domain decomposition. These routines better utilize the available computing resources by ensuring that every core is busy during the entire simulation. These routines will be shared (with extensive documentation and examples) with the ADCIRC modeling community, including the ASGS for operational forecasting.

These technologies will decrease the time required for an ADCIRC simulation, thus allowing for more model simulations in ensemble-based design applications, and for faster simulations in time-sensitive applications such as operational forecasting. These outcomes will increase the accuracy of flood risk products used in building design, land use planning and the establishment of flood insurance rates, and thus lessen the impact of a disaster. These outcomes will also improve the communication and understanding of potential hazards to individuals, community officials, the insurance industry, and government agencies.

The project has progressed in two key areas. First, we have focused on code modifications to ADCIRC to improve its load balancing. A new routine was added to its source code to perform the domain decomposition at the start of the simulation, so each computational core is now responsible for developing its own set of input files. This new routine can also be called periodically during the simulation, to re-perform the domain decomposition, and thus re-balance the workload among the cores. Preliminary results are promising. We have been able to tie the re-balancing to the workload, so the code will re-balance only when it needs to do so. In our initial tests, the efficiency gain is about 25 percent. This speed-up is significant because it will lead to shorter simulations in real-time forecasting, and thus more time for the guidance in each forecast cycle to be interpreted by end users. We are working now to further improve the re-balancing by implementing a new library that will allow for computational points to be migrated between neighboring sub-domains, instead of starting each decomposition from scratch. This implementation should provide further speed-ups in the wall-clock time.

Second, we are developing techniques to map solutions between meshes with varying levels of resolution. By using the interpolation techniques within the Earth System Modeling Framework (ESMF), the solution from one mesh (e.g. a coarser mesh) is mapped onto a different (e.g. finer) mesh, in a way that is fast and conservative. The simulation may start with the coarser mesh, then add resolution in regions near where the storm is projected to make landfall, and then continue on this finer mesh until new information becomes available. The results from the coarser mesh will be used to hot-start the continued simulation on the finer mesh. During the first half of this year of the project, we developed a prototype framework and tested it on meshes with no flood plains. We developed an automated tool called ADCIrpolate to map the results between meshes, and we performed initial testing of the system by using results from a coarser mesh to hot-start a simulation on a finer mesh of the East Coast of the U.S. The comparison of the results has shown a near-identical match between simulations on interpolated meshes and fine-scale meshes. Furthermore, the solution obtained through the interpolation was computed in about 60 percent of the time needed to compute a fine-mesh solution. Next, we extended the algorithm to account for wetting and

drying. The wetting and drying logic when interpolating from one mesh to another is challenging, but we have an initial algorithm that works for some simpler test cases. The next step is to test the algorithm on realistic meshes with hurricane force winds. This is a necessary step toward a multi-resolution adaptivity during storm forecasts.

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
Dynamic load balancing for a static ADCIRC simulation	12/2016	100	N/A
Automation of interpolation routines	12/2016	100	N/A
Demonstration of adaptive approach with single target mesh	06/2017	100	N/A
Research Milestone			
Presentation at national conference	12/2016	100	N/A
Presentation at ADCIRC workshop	04/2017	100	N/A
Submission of manuscript about dynamic load balancing	06/2017	25	While we could write-up our progress to date, we are waiting to do so until we implement a new library that will allow more flexibility in the load balancing, and thus allow the consideration of more research questions related to how and when to re-balance. We expect to submit a manuscript on this work during Fall 2017.

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
Integrate dynamic load balancing into release version of ADCIRC	03/2017	25	The dynamic load balancing has been added to a development version based on the ADCIRC repository, but we are still testing and improving these additions. While we will be sharing the code with targeted users, it will not make it into this year's release version of ADCIRC. We will push it into the version released in Spring 2018.
Transition Milestone			
Quarterly progress updates, feedback from transition partners	09/2016 12/2016 03/2017 06/2017	75	We shared progress updates in Aug and Dec 2016, and again in May 2017. We will update again before the end of summer.
Testing of dynamic load balancing with J Fleming and C Kaiser	12/2016	25	We have shared our research progress with our transition partners. As we finalize the dynamic load balancing, we will connect with targeted partners for testing and implementation.
Release of software to transition partners, training with examples	03/2017	25	The documentation of the dynamic load balancing will be finalized and shared widely when the code changes are mature and stable.

11. Interactions with Education Projects:

This project has initiated involvement with the CRC's MSI education partners in several ways. First, PI Dietrich visited Johnson C. Smith University (JCSU) and presented a seminar about current research in storm surge modeling and forecasting. The seminar was on 31 March 2017, and it was attended by a combination of graduate students and faculty members from JCSU. The first half of the seminar was a summary of the last decade of PI Dietrich's research, with a focus on storm surge modeling along the northern Gulf coast, and with an

emphasis on experiences in graduate school and beyond. The second half of the seminar was an introduction to and preliminary results from this CRC project. The seminar was well-received with many questions from the audience. The presentation has been archived on PI Dietrich's institutional web site, and notice of the seminar was shared with CRC leadership.

PI Dietrich will be hosting a visit from JCSU students on 14 June 2017. The JCSU students will visit NC State for a day, meet with PI Dietrich and his graduate students, and learn more about their recent research in modeling of coastal hazards. Because the JCSU students have backgrounds in computer science and engineering, much of the discussion during their visit will be focused on the applications of computational techniques and models into our research program. PI Dietrich has invited several faculty members from inside his department to meet the JCSU students and describe their research, too. Hopefully this interaction will be another building block to connect JCSU students with research at NC State.

Co-PI Dawson hosted a PhD student from Jackson State University (JSU) at UT-Austin during last summer under the CRC SUMREX program. Xuesheng Qian is a PhD candidate in coastal engineering, and he visited UT-Austin to learn the SWAN+ADCIRC wave and surge models. Qian learned how to run the model on the HPC machines at UT Austin, how to use the Surface Water Modeling System to generate/modify finite element meshes and data used in the models, how wind files are generated and used, and worked with Dawson and JSU researcher Bruce Ebersole to run the model for storms in the Texas Gulf Coast area. With this training, Qian will be able to teach other researchers at JSU how to run the model.

12. Publications:

This project does not yet have any articles submitted for publication.

13. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type	Approx. Delivery Date	Recipient or Anticipated End Users
ADCIRC forecast guidance for Texas	Guidance	June-Nov 2017	G Wells and T Howard, Texas State Operations Center

Table 2: Documenting External Funding and Leveraged Support

External Funding			
Title	PI	Total Amount	Source
NA			

Leveraged Support	
Description	Estimated Annual Value
NSF XSEDE allocation of 6.6M CPU-hours combined for supercomputers at UT-Austin and SDSC	$ 282,311.86

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)	3	2
Graduate students provided stipends (number)	3	2
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)	1	0
Lectures/presentations/seminars at Center partners (number)	1	1
DHS MSI Summer Research Teams hosted (number)	0	1
Journal articles submitted (number)	0	0
Journal articles published (number)	0	0
Conference presentations made (number)	2	4
Other presentations, interviews, etc. (number)	1	4
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	1
Requests for assistance/advice from other agencies or governments (number)	0	1
Total milestones for reporting period (number)	6	7
Accomplished fully (number)	6	3
Accomplished partially (number)	0	2
Not accomplished (number)	0	2