BLANTON – UNC/RENCI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: A multi-tiered ADCIRC-based storm surge and wave prediction system

Principal Investigator Name/Institution: Brian Blanton, Renaissance Computing Institute, UNC-Chapel Hill

Co-Principal Investigators and Other Partners/Institutions:

- 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, Master's student, UNC-Chapel Hill, Department of Marine Sciences. (100%, as of May 1, 2017)

Project Start and End Dates: 1/1/2016 – 6/30-2018

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 education and training of end-users interested in using these state-of-the-art models and tools.

Summary Abstract: This project enhances and extends a multi-tiered, ADCIRC-based storm surge and wave prediction system covering the US East Coast with highest resolution in North Carolina (NC). The overall objective is to provide real-time guidance information for active tropical cyclones impacting US coastal waters. The primary computational tool is the ADCIRC storm surge, tide, and wind wave model, in both its direct application and as it is used within the ADCIRC Surge Guidance System (ASGS). ASGS provides fully dynamic, deterministic, highly accurate ADCIRC-based storm surge and wave predictions ~1-2 hrs following the release of meteorological forecasts.

PROJECT NARRATIVE:

1. Research Need:

Our research and application activities in this project directly address many of the goals of Mission 5, which is to *Strengthen National Preparedness and Resilience*. Over the course of the previous DHS/CHC and CRC projects, we have extended the reach of ADCIRC-based coastal hazards assessment capabilities by improving the model's physics, output product and format options,

web-based accessibility, and techniques that can "accelerate" the availability of ADCIRC results. These extensions and enhancements are essential in aiding decision makers in both pre- and post-disaster efforts and will continue to leverage experiences with end users such as coastal emergency managers, FEMA coastal risk groups, and the US Coast Guard (Goals 5.1-5.4). This project forms the core of CRC modeling activities that are advancing the awareness of, and familiarity with, ADCIRC-based research and applications in North Carolina, with broad applicability to other states and regions, as well as other hazards. This CRC project will *advance* these efforts and provide DHS and the ADCIRC community with new capabilities for both real-time decision-making information and educational tools (Goals 5.1, 5.3). A better understanding of storm impacts on coastal environments is essential to reducing risks, both now and in the future (Goals 5.2, 5.3). This includes better, more accurate, and more timely predictions (Goal 5.3) of natural hazards to enhance pre- and post-storm emergency response activities (Goal 5.3). Our education and end-user training activities such as the ADCIRC Boot Camp and Users Group Meeting enable users to develop information for decision-makers and thus enhance preparedness (Goal 5.1) to storm surge hazards and risks.

2. History:

From the outset, this project has built upon prior work in the DHS CHC, with two main threads of activity: **operation** of the ADCIRC Surge Guidance System (ASGS) for computing real-time storm surge predictions; and **research** into statistical approaches for storm surge estimation and hurricane track probabilities.

The development, application, and operation of the ASGS by J. Fleming of Seahorse Coastal Consulting (SCC) has continued, attracting more users that need to provide real-time storm surge results to end users and decision makers further down the line. The ASGS-related activities included the holding of the ADCIRC Boot Camp and Users Group meetings. These events are one of the key transition points for users of ADCIRC and ASGS to get up to date on recent advances, learn about the research and applications of other users, and to educate and train new users (the primary target of the Boot Camps).

The 2017 Atlantic Hurricane season proved to be very active, with Hurricanes Harvey, Irma, and Maria causing substantial damage and losses in the southeast US and Caribbean Islands. The ASGS system provided high-resolution guidance information to end-users, including the US Coast Guard, FEMA, local emergency management groups, and the National Hurricane Center. We have seen large growth in the accesses to the nc-cera.renci.org website, which has motivated a major investment in new hardware to support the ASGS/CERA system (noted below in the leveraging section) and performance analyses of the web site infrastructure. We are now better prepared, with more robust hardware and software, for the 2018 season.

Research has focused on statistical approaches for storm surge prediction using pre-existing ADCIRC data sets and for developing probabilistic hurricane tracks based on prior errors in hurricane track and intensity predictions. Regarding storm surge predictions, the original concept was to use the large dataset of ADCIRC simulations for the recent coastal flood insurance study in North Carolina and implement the response surface method detailed in Taflanidis et al (2013)♣. We implemented this method and developed a web-based "dashboard" (Figure 1) for accessing the approach (http://dashboards.renci.org:3000). We have noted in prior progress reports that the appropriate sampling of the hurricane parameter distributions is critical to the effective use of a response surface approach, and that the random sampling of the landfall location in the North Carolina FEMA dataset causes significant interpolation issues. As a result, we computed a new data set with even distribution sampling, but on a coarser ADCIRC grid, resulting in a dataset with about 10,000 simulations.

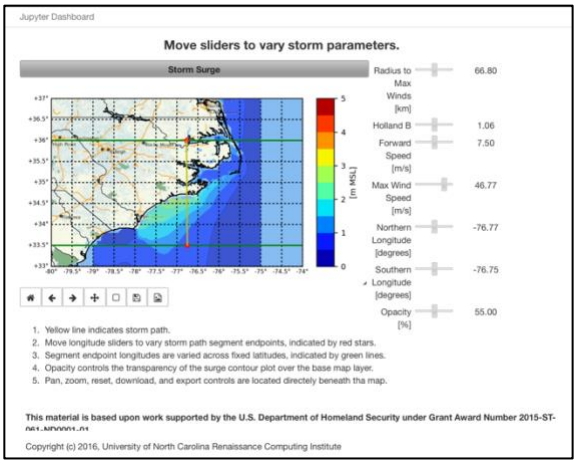

Figure 1: ADCIRC_Lite Dashboard

The hurricane track probability research has focused on development of tracks that represent uncertainty in the near-term evolution of the storm. Led by a Master's student Jessica Smith, tools have been developed that generate a suite of storm tracks, given a forecast from the NHC, that could be used in the ASGS system to provide its ensemble members. Ms. Smith's Master's thesis will be submitted to the Journal of Marine Science and Engineering Special Issue on Coastal Hazards Related to Water, guest edited by Rick Luettich.

One of the main conferences in the coastal hazards community is the American Meteorological Society's Annual Meeting, typically in January or February. This project participated in the AMS's 16th Symposium on the Coastal Environment, with the following research and applications presentations:

- Probabilistic Track Generation for Hurricane Storm Surge Estimates. **Jessica L Smith**, Univ. of North Carolina, Chapel Hill, NC; and B. Blanton and R. Luettich.
- Assimilation of Observed Water Levels into Storm Surge Model Predictions. **Taylor Asher**, Univ. of North Carolina, Chapel Hill, NC; and R. Luettich, J. G. Fleming, and B. Blanton.
- The ADCIRC Surge Guidance System for Coastal Zone Decision Support. **Jason G. Fleming**, Seahorse Coastal Consulting, Morehead City, NC; and R. Luettich, M. E. Agnew, C. Kaiser, N. Dill, and Z. Cobell.

Finally, as the 2018 Atlantic Hurricane season approached, we spent the last six months of the Y3 period preparing for an active tropical season. In addition to the ASGS training activities at the 2018 Boot Camp, we have: 1) deployed ASGS onto different computer systems that will help

♣ 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.)

increase computing capacity if needed; and 2) installed and configured 4 new computer servers at RENCI to support CERA-related activities.

3. Results:

The ASGS-related aspects of this project have several important results and outcomes. Most prominently is the impact that ASGS-driven storm surge and wave guidance products have had on decision-makers. Over the past 3 years, J. Fleming has conducted training classes, hands-on tutorials, and similar engagements with end-users and decision makers who use ADCIRC/ASGS/CERA-related products. The ADCIRC Boot Camps have attracted increasing numbers of participants over the past three years. Course offerings have also been extended into areas such as ADCIRC grid development and visualization approaches and tools, and ASGS for emergency managers and decision makers (which focuses more on how to interpret the graphical output of the system, as opposed to running the ASGS software itself).

The probabilistic track statistical research has resulted in an improved understanding of the level at which hurricane forecast track error distributions need to be sampled to achieve a specified level of along-shore "accuracy" in a probabilistic assessment of predicted storm surge levels. This work extends that of Davis et al (2011)♦ by including intensity as a variable through the maximum wind speed. The number of tracks needed is a function of several factors, including the time to landfall (longer time to landfall requires more tracks, due to the inherent uncertainty in track direction) and the storm's radius (larger storms need fewer tracks to resolve along-coast spacing). We do not yet have a fully developed expression for estimating the needed number of tracks based on a specific storm's characteristics. That is a future activity. The statistical analysis of the NHC's OFCL (official) forecast error data shows several interesting features. Table 1 reports the mean and standard deviations of the OFCL errors over the 2011-2015 Atlantic hurricane seasons. The error components are the along- and cross-track errors (ATE and CTE) and the error in the forecast maximum wind speed (Vmax), for the usual forecast lead times of 0, 12, 24, 36, 48, 72, 96, and 120 hours. Regarding the spatial error (ATE and CTE), there is an increasingly negative error in both components, indicating that forecast storm centers slide behind and to the left of the verified best-track locations. In other words, the forecast storms are increasingly slower and "to the left" of the true storm centers. This can be more easily seen in Figure 2, which shows the corresponding error ellipses. In this context, the ellipse axes correspond

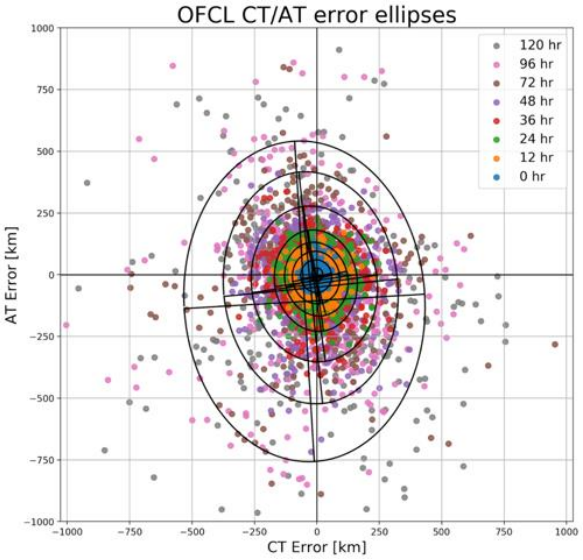

Figure 2. ATE/CTE error ellipses over the period 2011-2015. Major and minor ellipse axes show the variance in the along- and cross-track directions. The center of each ellipse is the mean error for that time level. The color dots are the individual errors for each time level.

♦ Davis et al. (2010). Toward the probabilistic simulation of storm surge and inundation in a limited-resource environment, *Monthly Weather Review*, 138/7, pp. 2953-2974.

to the +/- 1 std dev of the error, which is how the NHC defines their cone of uncertainty. The Vmax data shows that the forecast maximum wind speed error does not have an obvious trend toward *increasing* errors. If anything, its magnitude gets smaller as the lead time increases, although the *variance* does increase in the first 48 hours, then flattens out beyond that. The importance of this is not particularly clear and may not be statistically significant.

Table 1 Forecast errors for NHC OFCL forecasts, over the period 2011-2015.

	Mean			Std. Deviation		
Time	ATE	CTE	Vmax	ATE	CTE	Vmax
[hr]	[km]	[km]	[m/s]	[km]	[km]	[m/s]
0	-0.5	0.4	-0.8	17.9	14.2	1.9
12	-9.6	-3.4	-0.7	44.1	40.3	3.9
24	-20.9	-6.0	-0.7	70.0	61.2	5.6
36	-32.1	-7.2	-0.5	99.7	84.5	7.0
48	-44.5	-11.4	-0.4	140.6	113.6	8.1
72	-72.1	-22.8	-0.6	206.0	180.9	9.7
96	-98.5	-47.0	-0.1	306.0	252.3	10.0
120	-176.8	-65.7	0.5	399.2	352.8	9.5

This dataset consists of storm surge levels for a population of probable hurricanes, with cyclone parameters determined using a joint probability approach to sample distributions of the observed parameters (radius to maximum winds, central pressure deficit, etc). For the FEMA study, the computational load was substantially reduced by randomly sampling the landfall location of the cyclones. 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.

4. End Users and Transition Partners:

End users and decision makers have been substantially involved in the ASGS-related activities led by J. Fleming. Below, we list the key partners, with additional information on these and other contacts provided in an Appendix.

- NWS Morehead City, North Carolina Weather Forecast Office, coordinator for storm surge activities for the entire NWS
- Ignacio Harrouch, Director of Operations, Louisiana Coastal Protection and Restoration Authority (CPRA)
- New Orleans District of US Army Corps of Engineers
- Tom Langan, NC Division of Emergency Management
- Lora Eddy, The Nature Conservancy
- NWS Warning Coordination Meteorologists in Houston and Corpus Christi
- FEMA HQ

- US Coast Guard search-and-rescue (SAROPS)
- NOAA Coast Survey Development Lab
- Gordon Wells, UT Center for Space Research

Organizations that have participated in transition activities include:

- South Florida Water Management District, at their request.
- North Carolina Association of Flood Plain Managers, Atlantic Beach, NC, Apr 2017.
- NC Division of Emergency Management, routine/frequent interactions
- North Carolina Beach Inlet and Waterway Association, Wrightsville Beach, NC, Nov 2017.
- Corpus Christi National Weather Forecast Office, Jan 2018.
- Harte Research Institute (HRI) at Texas A&M, Corpus Christi, TX, Jan 2018.
- Seattle District of the US Army Corps of Engineers, Jun 2018.

Transition of technical and operational outcomes occur routinely by email and listserv activity, as well as by presentations on the state of ASGS at AMS, the ADCIRC Boot Camp and Users Group meetings, and continuous outreach and "marketing" by J. Fleming. He has also traveled extensively to end-user locations to provide training, tutorials, and hands-on activities, and frequently holds virtual meetings with end users, decision makers, scientists and researchers to convey and discuss ASGS results and capabilities. Transition of the probabilistic track research has been primarily through posters and presentations at the AMS annual meetings by Ms. Jessica Smith. We are currently working on turning the research software into more general user-friendly python code to be hosted in GitHub.

As a last example of end user connections, RENCI, IMS, SCC, and CRC PI Dietrich have had many discussions with the North Carolina Department of Emergency Management (NC-DEM) about how ADCIRC products and related CRC-funded activities could be used by them in their flood forecasting framework. NC-DEM is led by John Dorman, with whom RENCI and IMS conducted the recent coastal Flood Insurance Study statistical analysis for updating the North Carolina digital flood insurance rate maps. Tom Landon, the engineering supervisor for the Risk management Section of NC-DEM, has been our primary contact throughout the years. While there has always been much interest on the state's part for leveraging our activities, specific funding mechanisms have not been clear, until recently. The state would like real-time guidance information and ensemble specification beyond what is currently available in the ASGS implementation for North Carolina. They also would like the Enhanced Resolution product (developed at CRC PI Dietrich and his Master's student N. Tull at NCSU) available in real-time. We are currently (July 2018) working through the final stages of this contract, which specifies a per-storm-event cost for ASGS simulations and provides support for implementing the Enhanced Resolution product in the ASGS workflow. In anticipation of this contract for ASGS services, we have installed and tested the ASGS system with the high-resolution North Carolina grid on a commercial High-Performance-Computing (HPC) provider called Penguin Computing. This represents the first commercial contract-for-services for ASGS outputs that will support both CRC and SCC time and effort.

5. Project Impact:

As detailed above, there are several aspects 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 Boot Camps. Dozens of graduate students, post-docs, and early career professionals attended the 2017 and 2018 Boot Camps (Figure 3) in Norwood, MA and College Park, MD. This constitutes a broad group of "end-users" of the software and technology developed, maintained, and supported by DHS via this project.

Figure 3. Dr. J. Fleming (Seahorse Coastal Consulting) conducting a training session at the 2018 ADCIRC Boot Camp.

Coastal decision-makers are using ASGS/ADCIRC results much more frequently, as evidenced by the transition and outreach activities described in the accompanying appendix and below. We highlight a few of these interactions here.

- **June 2016**, J. Fleming visited the **Texas Department of Emergency Management** (TDEM), National Weather Service (NWS) Regional Operations Center (ROC), and NWS West Gulf River Forecast Center (WGRFC) at the Texas State Operations Center (SOC) in Austin, Texas. TDEM expressed particular interest in the high-resolution model guidance available from ADCIRC/ASGS, and this group uses ADCIRC results more routinely in their decision-making framework more often. CRC PI Clint Dawson also participated in this interaction.
- **November 2017**, J. Fleming held a virtual meeting with **NWS Warning Coordination Meteorologists in Houston and Corpus Christi** including John Metz, MIC Tom Johnstone, and Dan Reilly to review ADCIRC wind and storm surge performance during Harvey. They described their success in validating the guidance after the storm with measured data and their interests in future capabilities.
- **January 2018**, J. Fleming Site visit to **Coast Guard Sector Houston-Galveston** in Houston, Texas to discuss the use and value of ADCIRC model guidance to the Coast Guard in general and Sector Houston-Galveston in particular. One specific outcome of this meeting was that the value of ADCIRC guidance to the US Coast Guard is exclusively focused on consequences for search-and- rescue and oil/chemical spills.

- **April 2018**, J. Fleming and C. Kaiser (a CRC PI and developer of the CERA system) visited with Cristina Lindemer, Rafael Canizares, and Gene Longenecker of **FEMA HQ** to discuss the use of ADCIRC guidance during the 2017 hurricane season and ways to make direct connections between technical ADCIRC experts and FEMA stakeholders in future hurricane seasons.

6. Student involvement and awards:

This project involved two Master's level students in ADCIRC-related research and applications. Mr. Stephen Kreller, a student at LSU of CRC-funded Barry Keim, visited RENCI in the summer of 2017 to learn about the ADCIRC model, how to run it and analyze its output, and how to more generally carry research computations. This was done through SUMREX funding. He returned to LSU and has continued to use ADCIRC in his research into storm surge impacts on the Louisiana coast. Ms. Jessica Smith, a Master's student in the Department of Marine Sciences at UNC-Chapel Hill of Rick Luettich, was supported by this CRC project. She conducted research into computing probabilistic hurricane tracks for potential use in ASGS or other applications where uncertainty in hurricane path/intensity and resulting storm surge needs to be accounted for. During her research, she presented results in the American Meteorological Society's annual meetings, in both 2017 and 2018. She successfully defended her Master's thesis in December 2017, entitled "Probabilistic Hurricane Track Generation for Storm Surge Prediction".

- Smith, J. December 2017. Probabilistic Hurricane Track Generation for Storm Surge Prediction. Master's Thesis, UNC-Chapel Hill, Department of Marine Sciences.
- Smith, J., Blanton. B., and Luettich, R. 2018. Probabilistic Hurricane Track Generation for Storm Surge Prediction. Presented at the American Meteorological Society 2018, Austin, TX.

7. Interactions with education projects:

This project has not directly engaged with CRC Education projects. However, we have worked with several graduate students, and we consider the ADCIRC/ASGS Boot Camp and Users Group meeting venues as critical points of education, outreach, training, and transition. In addition to extending the reach of ADCIRC and ASGS through this project's end users and forums such as the ADCIRC Annual meeting and Boot camps, one key to long-term development and sustainability of these activities is to engage with future researchers and end-users at the educational level. Indeed, this is a core part of the RENCI mission, and RENCI enthusiastically participates in these opportunities with DHS/CRC. In the summer of 2017, RENCI hosted a summer internship in conducting coastal hazards research with ADCIRC. This included in-depth experiences that range from setting up ADCIRC, high-performance computing, and statistical methods for risk assessment. Through the DHS Summer Research Team Program for Minority Serving Institutions, Dr. Anton Bezuglov and undergraduate student Reinaldo Santiago from Benedict College in Columbia, South Carolina, spent the 2016 summer at RENCI. Dr. Bezuglov is a computer scientist with expertise in "expert systems", a branch of artificial intelligence research targeted at emulating the human decision-making process. He and Mr. Santiago were in residence at RENCI to implement an artificial neural network for storm surge prediction using the same ADCIRC storm surge database used for the ADCIRC_Lite response surface research. This

complemented and extended our current knowledge about rapid forecasting methods. Drs. Bezuglov and Blanton have continued to work on machine learning techniques as applied to hurricane-related problems, with a change in focus to hurricane track simulations to be consistent with the probabilistic track research described above. The goal is to conduct enough background research to pursue new funding opportunities.

8. Publications:

- Thomas, A., J. Dietrich, T. Asher, M. Bell, B. Blanton, J. Copeland, A. Cox, C. Dawson, J. Fleming, and R. Luettich (2018). Influence of Storm Timing and Forward Speed on Tides and Storm Surge during Hurricane Matthew (2016). Submitted to *Ocean Modelling.*
- Smith, J. December (2017). Probabilistic Hurricane Track Generation for Storm Surge Prediction. Master's Thesis, UNC-Chapel Hill, Department of Marine Sciences.

9. Tables:

Table 1: Documenting CRC Research Product Delivery
Table 2A: Documenting External Funding
Table 2B: Documenting Leveraged Support
Table 3: Performance Metrics

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
ASGS	Software	ongoing	ADCIRC forecasting and real-time users
ASGS	Training, tutorials	ongoing	ADCIRC/ASGS operators, end-users/decision-makers

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
Real Time ADCIRC Model Guidance for Louisiana CPRA (cooperative Contract to SCC)	J. Fleming	$45,000	LACPR
Coupling the National Water Model to the Coastal Ocean for Predicting Water Hazards	B. Blanton	$890,000	NOAA/IOOS

Table 2B: Documenting Leveraged Support

This project, as in several DHS-funded projects in the previous Center of Excellence, is based at the Renaissance Computing Institute (RENCI), a long-term partner with Rick Luettich, DHS, FEMA, and Seahorse Coastal Consulting. RENCI has provided substantial cyberinfrastructure resources to previous DHS projects involving ADCIRC, including high-performance computing resources, data storage and data management resources, and data servers for delivering and making available ADCIRC/ASGS output to the end user community. RENCI will continue to provide this level of service and support for this new project at no direct cost. We estimate that, at a minimum, this leverage is $75,000 per year, when considering the level of computation involved, storage requirements for the large volume of data, and the personnel involved in maintaining the compute resources and helping debug ASGS runtime issues when they arise. In this year 3 period, RENCI also purchased the hardware noted above to update the CERA-related servers at RENCI. External contributions to ASGS/SCC are estimated by considering support for Users Group and Boot Camp events, travel support to certain meetings from non-CRC sources, and internal SCC travel funding.

Description	Estimated Total Value
Recurring technical/infrastructure support @ RENCI (computer support, compute/storage resources, hardware installation/support) @ 75,000/yr	$225,000
RENCI hardware investment for CERA website infrastructure	$35,000
External contributions to SCC/ASGS activities	$150,000
Total:	$410,000

Table 3: Performance Metrics:

BLANTON PERFORMANCE METRICS

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17-6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	1	1	1
Graduate students provided stipends (number)	1	1	1
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	1
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	0	1	0
Lectures/presentations/seminars at Center partners (number)	1	0	1
DHS MSI Summer Research Teams hosted (number)	1	0	0
Journal articles submitted (number)	0	0	0
Journal articles published (number)	0	0	0
Conference presentations made (number)	2	2	2
Other presentations, interviews, etc. (number)	0	2	4
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	0
Requests for assistance/advice from other agencies or governments	0	0	0
Total milestones for reporting period (number)	7	7	5
Accomplished fully (number)	2	2	5
Accomplished partially (number)	3	3	0
Not accomplished (number)	2	2	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Complete probabilistic track generator implementation	12/31/2017	100	
Continue operation of ASGS at RENCI	On-going	100	
Test new ASGS features and deployment of the NOAA HSOFS grid at RENCI	12/31/2017	100	
Research Milestones			
Status report on ASGS system upgrades and initial tests with new grid	12/31/2017	100	
Report on probabilistic track generator implementation and initial results (J. Smith's Master's Defense)	12/31/2017	100	
ASGS for NC ready for 2018 Atlantic Hurricane season	01/05/2018	100	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Attend 2018 American Meteorological Society meeting to present ensemble method development and results	Jan 2018	100	
Develop material on ASGS enhancements and status for ADCIRC user community	3/31/2018	100	
Aide NOAA/CSDL in deploying ASGS prior to the 2018 hurricane season	5/31/2018	100	
Transition Milestones			
Report/presentation on ASGS enhancements and features to ADCIRC User's Group and Boot Camps	April 2018	100	
J. Smith's Master's Thesis on probabilistic hurricane track generation	31/12/2018	100	