GINIS, URI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title:

Modeling the combined coastal and inland hazards from high-impact hurricanes

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

Short Project Description ("elevator speech"):

This project advances modeling capabilities to assess and predict the impacts of landfalling hurricanes and nor'easters on critical infrastructure and communities in the Northeastern United States. The primary focus is on combined multiple hazard impacts, including coastal flooding due to storm surge and inland flooding due to rainfall. This project will allow DHS and other agencies to better understand the consequences of hazards associated with extreme weather in specific regions and to better prepare coastal communities for future risks.

Abstract:

This project is developing a modeling system to predict the consequences of coastal and inland hazards associated with high-impact landfalling hurricanes and nor'easters with complex storm characteristics in order to prepare coastal communities in the Northeast for future risks. Our modeling approach adds new capabilities to the real-time ADCIRC-SWAN system, such as improved surface wind modeling near the coast and over land, coupling effects of storm surge and waves, inland flooding from rainfall, incorporation of vulnerability data collected from emergency managers, and 3D visualization of hazard impacts. The ADCIRC mesh is highly refined in order to properly resolve the complicated coastal geometry of the New England coast including narrow inlets and salt ponds. The computational domain boundaries over land are reconfigured to allow river inflows from the major rivers for combined inland and coastal flood

modeling. Coupling of the storm surge and wave models include a sea state dependent drag coefficient and air-sea flux budgets. The Precipitation-Runoff Modeling System (PRMS) is applied to simulate rainfall runoff for all major rivers in southern New England. River flows are used as upland boundary inputs for ADCIRC to simulate the effects of rainfall runoff on coastal flooding. The Regional Ocean Modeling System (ROMS) model is used to investigate the effects of 2D vs. 3D on storm surge predictions and environmental impacts of hurricanes on estuarine systems. The prediction system includes 3D visualization and impact assessment tools to provide specific actionable outputs that are relevant to emergency and facility managers. Geographic points representing specific vulnerabilities are indexed directly into multiple nodes of ADCIRC and detailed 3D visualizations of critical infrastructure such as buildings, bridges and wastewater treatment plants allow for rapid impact assessment by the users.

PROJECT NARRATIVE

1. **Research Need**:

This project will assist DHS agencies such as FEMA and USCG to better understand the consequences of simultaneous coastal and inland hazards associated with landfalling hurricanes and nor'easters. Comprehensive ensemble modeling of the combined coastal and inland flooding and wave effects has not been previously considered. FEMA Region 1, a region that experiences infrequent but extremely severe hurricanes, currently lacks high-resolution storm surge models, relying primarily on SLOSH and other low-to-medium-resolution storm surge models for the area. In addition to storm surge, landfalling hurricanes and nor'easters in the Northeastern United States often cause extreme rainfall runoff and floods in coastal rivers, extreme waves during the hurricane often cause severe erosion in beaches and coastal roadways, and strong wave forces can cause damage to coastal and waterfront structures. The New England states of Connecticut, Rhode Island and Massachusetts are especially vulnerable to inland flooding since the rivers are relatively short and high-river discharge can coincide with coastal storm surge during extreme wind and rain events. This project will advance modeling capabilities of combined coastal and inland flooding in order to better prepare coastal communities in the Northeast for future risks from extreme weather. This research meets DHS priorities by strengthening national preparedness and improving the resilience of coastal communities in the face of coastal storm hazards. As such, this research addresses Presidential Policy Directive 8, which calls for increasing our level of National Preparedness by preventing, mitigating, responding to, and recovering from the hazards that pose the greatest risk.

2. **History**:

During the first three years of this project a multi-model framework was built, including state-of-the-art atmosphere, wave, ocean, and hydrology models in the southern New England. Major milestones include new capabilities and improvements to the ADCIRC-SWAN system, such as improved surface wind modeling near the coast and over land, coupling of storm surges and waves, and inland flooding from rainfall. The ADCIRC mesh has been highly refined in order to properly resolve the complicated coastal geometry of the New England coast including narrow inlets and salt ponds. Coupling of the storm surge and wave models include a sea state dependent drag coefficient and air-sea flux budgets. We have developed a new hurricane boundary layer (HBL) model for more accurate prediction of the surface winds near shore and over land during hurricane landfall. The Precipitation-Runoff Modeling System (PRMS) has been configured for several watersheds in Rhode Island and applied to simulate rainfall runoff for all major rivers. We have implemented the Regional Ocean Modeling System (ROMS) model and investigated the effects of 2D vs. 3D configurations on storm surge predictions and explored longer term impacts of hurricanes on estuarine systems. A 3D version of ROMS was used to track water masses of ecological and economic significance, particularly offshore nutrient sources and industrial chemical spills, and to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay after hurricane landfall. The developed multi-model framework includes impact analysis and 3D visualizations of critical infrastructure such as buildings, bridges and wastewater treatment plants to provide specific actionable outputs that are relevant to emergency and facility managers. Our major transition effort involved collaboration with NOAA's National Weather Service Office, the DHS Office of Cyber and Infrastructure Analysis, FEMA Region 1, and Rhode Island Emergency Management Agency (RIEMA) to create a hypothetical high-impact scenario, "Hurricane Rhody" that was used to support a FEMA Integrated Emergency Management Course conducted by the Emergency Management Institute and RIEMA in Cranston, RI June of 2017. More than 160 participants attended the training course from state agencies, municipalities, non-profit organizations and FEMA Region 1.

This project is clearly compute-intensive and the primary challenge has been the availability of adequate computer resources. It has been addressed by our partners at the Coastal Resilience Center who provided access for our team to the computer cluster and data storage at the Renaissance Computing Institute (RENCI) at the University of North Carolina at Chapel Hill.

3. **Results**:

This project has advanced the state-of-the-art in coupled models for simulating the physics of atmosphere/ocean/estuarine/watershed processes during extreme weather events and their impacts on critical infrastructure. Here we briefly summarize our results, including primary outcomes and products. Details of the project activities and results are provided in Appendix.

We implemented the ADCIRC-SWAN modeling system for storm surge predictions in the Southern New England region and made several advancements to improve its performance. The ADCIRC mesh has been highly refined in order to properly resolve the complicated coastal geometry of the New England coast including narrow inlets and salt ponds. The Precipitation-Runoff Modeling System (PRMS) has been configured for several watersheds and major rivers in Rhode Island and applied to simulate rainfall runoff during historic and hypothetical hurricanes in New England. The computational domain boundaries of ADCIRC and PRMS are configured to allow river inflows from the major rivers for combined inland and coastal flood modeling.

We employed the Regional Ocean Modeling System (ROMS) model and investigated the effects of 2D vs. 3D on storm surge predictions. Using ROMS we explored longer term impacts of how tropical cyclones impact estuarine systems. We focused on tracking water masses of ecological and economic significance in Narragansett Bay – particularly offshore nutrient sources and industrial chemical spills. We showed that baroclinic effects are the dominant contributor to the non-tidal storm response and in developing modeling tools that accurately represent the longer term impacts of a tropical cyclone it is not sufficient to rely on vertically integrated storm-surge models. We conducted a modeling study to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay during and after the passage of a hurricane for the purpose of understanding the redistribution of potentially harmful pollutants from locations that are known to contain those contaminants to other, relatively contaminant-free locations.

We investigated the sensitivity of tropical cyclone wave simulations in the open ocean to different spatial resolutions using two wave models, WW3 and SWAN. We found that model errors in maximum wave predictions can be significant with coarser resolutions under a small and fast-moving storm.

We investigated the sea state dependent drag coefficient (C_d) in shallow water under hurricane wind conditions, by extending the approach of Reichl et al. (2014) that was developed for deep water. It is found that as water depth decreases, the sea state dependence of drag coefficient is enhanced. Also, the median value of C_d is gradually reduced at all wind speed with decreasing depth, compared to that in the deep water. In shallow waters, opposing swell can introduce large variability of C_d at lower (10-20m/s) wind speed.

We developed a hurricane boundary layer (HBL) model that utilizes the physical balances in the dynamic equations to determine how the near surface winds respond to local variability in the surface conditions (primarily topography and surface roughness) during hurricane landfall. Parametric wind models commonly used in storm surge modeling are typically too simplistic and are not capable of properly representing the changes in the wind structure when the hurricane moves from sea to land. The HBL model software infrastructure enables to run high-resolution wind simulations in a real time forecast mode.

In parallel with the development of high-resolution hazard models we have been developing innovative impact and visualization methods. While methods for creating aggregate hazard impact models based on statistically derived damage curves are well established (e.g., HAZUS), methods for creating highly granular impact models of individual infrastructure points that take advantage of the high-resolution and time-incremented aspects of the physical models have not been considered in the past. In our approach geographic points representing specific vulnerabilities are indexed directly into multiple nodes of ADCIRC and detailed 3D visualizations of critical infrastructure such as buildings, bridges and wastewater treatment plants allow for rapid impact assessment by the users. We enlisted local facility managers and other decision makers in the development a “concern thresholds database” that includes the concerns of specific facility managers as quantifiable thresholds that tie these concerns back to the hazard models. This allowed us to extend impact modeling to facilities for which there are not existing damage functions (e.g., effects of communications outages resulting from a wind-damaged cell tower).

Our team collaborated with NOAA’s National Weather Service Office, the DHS Office of Cyber and Infrastructure Analysis, FEMA Region 1, and Rhode Island Emergency Management Agency (RIEMA) to create a hypothetical high-impact scenario, “Hurricane Rhody” that was used to support a FEMA Integrated Emergency Management Course (IEMC) conducted by the Emergency Management Institute (EMI) and RIEMA on June 19-22, 2017. The four-day exercise which was attended by more than 160 emergency managers from Rhode Island municipalities, state agencies, and nonprofit organizations focused on the response and identifying key actions taken before, during, and after a hurricane. We developed the training material and 3D impact visualizations for use in the exercise. Outcomes from the course provided RIEMA with an opportunity to enhance overall preparedness, while actively testing modeling outputs during various parts of the course. RIEMA will use the developed materials for further trainings and exercises to update state preparedness to new threat standards.

4. **End Users and Transition Partners**:

Rhode Island Emergency Management Agency (RIEMA) and FEMA Emergency Management Institute (EMI)

1) The URI team provided modeling products and collaborated with Rhode Island Emergency Management Agency (RIEMA) and the Emergency Management Institute (EMI) to conduct an Integrated Emergency Management Course (IEMC) as part of a statewide preparedness exercise on June 19 – 22, 2017. The four-day exercise focused on the response to hurricane scenarios while identifying key actions taken before, during, and after a hurricane. Outcomes from the course provided RIEMA with an opportunity to enhance overall preparedness, while actively testing modeling outputs during various parts of the course. In this effort, the URI team worked closely with Stephen Conard at RIEMA, stakeholders at EMI, and Marilee Orr and a stakeholder at the DHS Office of Cyber and Infrastructure Analysis in developing the impact analysis on critical infrastructures in Rhode Island. Stephen Conard, Training & Exercise Specialist, stated: "The information and modeling provided by URI will be used within RIEMA sponsored trainings and exercises to update the scientific data and modeling used. Also, RIEMA can use this information within the State Emergency Operations Center for catastrophic planning. The information given from URI can also be used in long-term planning to deal with the effects that sea level rise plays on 21 of RI's 39 communities."

2) Graduate student Bobby Witkop received a summer internship from RIEMA and was authorized to interview critical facility managers in Westerly, RI after he underwent background checks. RIEMA's personnel involved in this effort included Peter Gaynor – Director, Mark Bennett- Critical Infrastructure/Key Resources Coordinator, Tom Guethlein - Acting Associate Director of Program Operations at Rhode Island's Department of Human Services, and Tara Chicharro - Internship coordinator. Bobby Witkop created a database of 11 critical facilities in Westerly based on damage assessment from hypothetical Hurricane Rhody.

FEMA Region 1
Hurricane Program Manager implemented the Hurricane Rhody scenario developed by our team into HVX decision support tool administered by FEMA for the Integrated Emergency Management Course on June 19 – 22, 2017.

NOAA NWS, Taunton, MA

Meteorologist-in-Charge, and Hurricane Program Leader used the Hurricane Rhody scenario and output from the URI hurricane boundary layer model wind simulations to develop tropical storm advisories and hazard graphics for the weather briefings during the

Integrated Emergency Management Course on June 19 – 22, 2017.

NOAA/NWS/NCEP Environmental Modeling Center
The URI team conducted an evaluation of the new operational (ST4) version of the WAVEWATCH 3 wave model in hurricane conditions and shared the results with the NCEP wave modeling group and during the WW3 developer meetings (Jessica Meixner) and provided recommendations to adjust/recalibrate the source terms in the WW3 wave action equations.

DHS Office of Cyber and Infrastructure Analysis
Senior Analyst conducted analysis of the impact of Hurricane Rhody on critical infrastructure for the Integrated Emergency Management Course on June 19 – 22, 2017 based on hazard model output provided by the URI team.

RI Flood Mitigation Association
We participated in the RI Flood Mitigation Association Annual Meetings to network with state emergency managers. Presentations of model outputs provided our team with feedback from local end users. These inputs have been incorporated into the model and outputs as feasible.

RI Coastal and Resources Management Council
We coordinated with this state regulatory agency on modeling and visualizations as a tool for planning, response and permitting. Discussions on integrating the models and programs (i.e. Shoreline Change Special Area Management Plan) are underway. This coordination also provides an example of how to link with 33 coastal states as well as NOAA's Office of Coastal Resources Management.

RI Environmental Management Agency
Efforts have been made to transfer technological advances and multi-modeling tools to those relevant RI management agencies that are tasked with protecting RI marine resources. We organized a meeting with RI EMA that included DHS team members Chris Kincaid, David Ullman and Lew Rothstein, along with Jim Boyd, (Coastal Policy Analyst, RI CRMC), David Beutel, (Aquaculture Coordinator, RI CRMC) and Conor McManus (RI DEM, Fisheries Management Section). Also present were Professors Dale Levitt and Scott Rutherford, researchers from Roger Williams University with extensive experience with RI Shellfishing activities, communities, outreach, and research. The outcome of the meeting was the consensus agreement that our DHS-funded modeling tools on the mobilization and transport of hazardous materials from the urban source regions in the north, through the sensitive and valuable fisheries resource regions of the mid-lower estuary, should be developed into planning and training activities.

5. **Project Impact**:
The unique aspect of this project is the employment a multi-model approach to characterizing and improving simulations of hurricane winds, waves, storm surge and inland flooding in coastal regions combined with innovative hazard impact modeling and visualization methods. Below we list specific project's outcomes:

5.1 The project advanced current technologies and capabilities by developing end-to-end model simulations capable of representing extreme hurricane events from the open ocean, onto the shelf, through coastal estuaries and tributaries, and into coastal watersheds based on multiple, independent models that contributed to an ensemble of model solutions for DHS stakeholders in the southern New England region.

5.2 The project conducted detailed assessment of the performance of state-of-the-art coastal circulation, watershed rainfall and river flood models in representing the hurricane and other extreme weather hazards in the Rhode Island region.

5.3 The project conducted detailed assessment of the performance of two ocean surface wave models, WW3 and SWAN under hurricane forcing and communicated the results to operational wave modeling centers.

5.4 The project created a physically plausible hypothetical worst case scenario (low probability, high impact), Hurricane Rhody, by combining multiple hazard impacts, including coastal flooding due to storm surge and inland flooding due to rainfall, based on a combination of historical storm elements.

5.5 The project developed multi-model strategies and methodologies for testing the benefits and unintended consequences of utilizing engineered structures (hurricane barriers) under a range of storm characteristics, and conducted detailed evaluations of the Fox Point Hurricane Barrier in Rhode Island.

5.6 The project transitioned the results from the physical modeling scenarios to DHS end users that helped to inform the impact on infrastructure and losses and the associated challenges in managing multiple threats with limited resources, and used this as a pilot for other emergency preparedness and response trainings.

5.7 The project designed a computationally efficient framework that combines multi-model ensemble output with interactive 3D visualization tools for training and real-time hazard impact analyses. These products are a substantial advancement of the existing tools that will maximize the utility of outputs from complex numerical models. They are produced in forms that are most useful for emergency managers, first responders, and other professionals from all levels of government and the private sector.

5.8 By contributing models and outputs (visualizations and impact scenarios) to RIEMA/FEMA training for their Integrated Emergency Management Course, the trainees of the statewide preparedness exercise are able to envision (and practice) and respond to "exercises that update our materials to current threat standards, instead of slightly outdated, unrealistic thresholds that growth has easily surpassed." (Stephen Conard, RIEMA). These materials are being considered for more trainings and exercises in the state and the Northeast region.

6. **<u>Student involvement and awards</u>**:

1. Involvement in Research

   1) Xuanyu Chen, a PhD student at the Graduate School of Oceanography, focused her work on evaluation and improvements of the wave models WW3 and SWAN in hurricane conditions and investigated the sea state dependent drag coefficient in shallow waters during hurricane landfall.
   2) Catherine Nowakowski, an MS student at the Graduate School of Oceanography, focused her work on advancing modeling of surface winds during hurricane landfall for predicting storm impacts.
   3) Megan Layman, a MO student at the Graduate School of Oceanography, developed an ArcGIS interface for ADCIRC model output and analyzed coastal inundation from historic and hypothetical hurricanes that made landfall in the southern New England and the impact on critical infrastructure using E-911 classifications.
   4) Peter Stempel, a PhD student at the Department of Marine Affairs, focused his work on developing techniques to integrate qualitative data into hazard models and produce 3D visualizations of model outputs.
   5) Robert Witkop, a MS student at the Department of Marine Affairs, developed a methodology to collect qualitative data from emergency managers in a format that could then be integrated with the drivers that can be modeled (e.g., wind, wave, surge, flooding). He served as an intern in RIEMA's critical infrastructure program intern and conducted storm vulnerability analysis for 11 critical facilities in Westerly, RI.
   6) Xiahui Zhou, a PhD student at the Graduate School of Oceanography, conducted a modeling study to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay during and after the passage of a hurricane for the purpose of understanding the redistribution of potentially harmful pollutants from locations that are known to contain those contaminants to other, relatively contaminant-free locations.
   7) Kevin Rosa, a PhD student at the Graduate School of Oceanography, focused his work on impacts of tropical cyclones on estuarine systems. He investigated water masses of ecological and economic significance in Narragansett Bay – particularly offshore nutrient sources and industrial chemical spills during and after the passage of a hurricane.

2. Degrees attained by students

   1) Peter Stempel earned a PhD in Marine Affairs, 2014 – 2018, Dissertation title: *Depicting the consequences of storm surge and sea level rise: risk communication opportunities and ethics.*
   2) Robert "Bobby" Witkop earned a Master of Marine Affairs, 2016 – 2018, Thesis title: *Developing Consequence Thresholds for Storm Impact Models: Case Study of Westerly, Rhode Island*

3. Student awards, publications, posters, presentations, etc.

<u>Student awards:</u>
- Propeller Club Scholarship awarded to Peter Stempel (2017)

- Graduate Student Research and Scholarship Excellence Award in Social Sciences, Arts, and Humanities, awarded to Peter Stempel (2018)
- Best poster award of the URI Graduate Conference awarded to Kevin Rosa (2018)

Student presentations (students indicated by *):

Stempel, P.*, Becker, A., (Accepted). "Effects of localization on perceptions of storm surge risk depicted in model driven semi-realistic visualizations." International Conference on Sustainable Development, NY, NY. September 26-28, 2018.

Chen, X. *, I. Ginis and T. Hara (2018). "Sea-State Dependent Drag Coefficient in Shallow Waters Under Tropical Cyclones", 21st Conference on Air-Sea Interaction, June 18 https://ams.confex.com/ams/23BLT21ASI/meetingapp.cgi/Paper/345222

Chen, X.*, T. Hara, and I. Ginis (2018). "Sea-state dependent air-sea momentum flux in a shallow water under a tropical cyclone", Ocean Sciences Meeting, February 14 https://agu.confex.com/agu/os18/meetingapp.cgi/Paper/303041

Ginis, I., C. Nowakowski*, and K. Gao (2018). "A Hurricane Boundary Layer Model for Simulating Surface Winds during Hurricane Landfall", 33rd Conference on Hurricanes and Tropical Meteorology, April 18, https://ams.confex.com/ams/33HURRICANE/webprogram/Paper339799.html

Ginis, I., D. Ullman, T. Hara, C. Kincaid, K. Rosa*, X. Chen*, B. Thomas, A. Becker, P. Stempel*, R. Witkop*, P. Rubinoff, W. Huang, M. Orr, R. Thomas, R. Thompson, M. Belk, P. Morey, and S. Conard (2018). "Advancing Modeling Capabilities and Impact Analysis Tools to Improve Preparedness for Major Hurricane Hazard Events", 98th AMS Annual Meeting, January 11, https://ams.confex.com/ams/98Annual/webprogram/Paper336049.html

Nowakowski, C.* and I. Ginis I. (2018): Advancing modeling of surface winds during hurricane landfall for predicting storm impacts, DHS Centers of Excellence Summit, May 30-31, 2018 https://cina.gmu.edu/coe-summit-2018/

Witkop, R.*, Becker, A., Stempel, P.*, (2018). "Incorporating facility manager knowledge into storm impact models: A case study of critical facilities in Westerly, Rhode Island," Rhode Island Floodplain Managers Association, Smithfield, RI, April 5.

Rosa, K.*, Kincaid, C. (2018). "Transporting Nutrients Northward from Rhode Island Sound Bottom Water to the Upper Narragansett Bay Euphotic Zone", RI C-AIM/RI NSF EPSCoR Symposium. Kingston, RI, April 9.

Rosa, K., Kincaid, C., Ullman, D., and Ginis, I. (2017). Hurricane Rhody: How does Rhode Island Fare Against Hypothetical Superstorm?. URI Graduate Conference. Kingston, RI. 8 April.

Rosa, K. *, Kincaid, C., Ullman, D., and Ginis, I. (2017). "Baroclinic Model of Narragansett Bay Post-Storm Shelf-Estuary Exchange", Estuary Research Workshop: Limiting Factors Beyond Nitrogen. Narragansett, RI. September 13.

Ginis, I., D. Ullman, T. Hara, C. Kincaid, L. Rothstein, W. Hwang, B. Thomas, X. Chen*, K. Rosa*, A. Becker, P. Stempel*, R. Witkop*, P. Rubinoff (2017). "Developing a mul.-model ensemble system for assessing hurricane hazards and impacts", URI Coastal Resilience Science and Engineering Workshop, December 4.

Ullman, D., I. Ginis, W. Hwang, P. Stempel*, T. Hara, C. Kincaid, L. Rothstein, P. Rubinoff, B. Thomas, X. Chen*, K. Rosa* (2017). "Assessing the Mul-ple Impacts of Extreme Hurricanes in Southern New England", URI Coastal Resilience Science and Engineering Workshop, December 4.

Witkop, R.*, Stempel, P.*, Becker, A., (2017). "Coupling local scale, high resolution, qualitative data to interface with numerical storm models", American Geophysical Union Annual Conference, New Orleans, LA. Dec. 12.

Stempel, P.* (2016). "Data Driven Visualization", Estuarine and Coastal Modeling Conference 2016, Narragansett, RI, June 14-15.

Student publications:

Witkop, R.*, Stempel, P.*, Becker, A.. Incorporating critical facility managers' knowledge into hazard impact models: A case study of Westerly, Rhode Island. *Frontiers in Citizen Science: Reducing Risk and Building Resilience to Natural Hazards. To be submitted.*

Stempel, P.*, Becker, A., (*In Prep*). Visualizations out of context. Implications of using simulation-based 3d hazard visualizations.

Stempel, P.*, Ginis, I., Ullman, D. S., Becker, A., Witkop, R.*, 2018: Real-Time Chronological Hazard Impact Modeling. *Journal of Marine Science and Engineering. To be submitted.*

Spaulding, M. L., Grilli, A., Damon, C., Crean, T., Fugate, G., Oakley, B., & Stempel, P.*, (2016). "Stormtools: Coastal Environmental Risk Index (CERI)." *Journal of Marine Science and Engineering*, 4(3).

Chen, X. *, I. Ginis, T. Hara: Sensitivity of Offshore Tropical Cyclone Wave Simulation to Spatial Resolution in Wave Models, Journal of Marine Science and Engineering, to be submitted.

Other student press

Disaster visualization work of Peter Stempel featured on front page of *Providence Journal*, (Nov. 27, 2016), "Rising seas, rising stakes, R.I. researchers project future flooding." Online at http://www.providencejournal.com/news/20161127/rising-seas-rising-stakes-ri-researchers-project-future-flooding

Peter Stempel featured in URI *Big Thinkers* (2016), "CELS grad student innovates ways to visualize climate change." Online at http://web.uri.edu/cels/cels-grad-student-innovates-ways-to-visualize-climate-change/.

Interactions with education projects:

Our team hosted two undergraduate summer interns from Tougaloo College in 2017. We took advantage of an opportunity presented when Tougaloo College approached us with the need to place students.

This project motivated a new URI-GSO minor (PODS-Proficiency in Ocean Data Science), a 4-course sequence with a capstone internship. The program involves all DHS Faculty PI's, with the fourth, or capstone course covering the multi-model hurricane-surge approach developed on this project. All courses and the PODS minor approved by general education and curriculum affairs committees and URI Faculty Senate.

Results from this research project have been used in class teaching and student's course projects in URI's large general education courses The Ocean Planet, OCG 110, Fall, 2016 and General Oceanography, OCG 301, Fall, 2016 and 2017.

Results from this research project have been used in class teaching and student's course projects at FSU: CWR4201, Hydraulic Engineering I, Fall, 2016, 20 students and a course project for CWR4201, Hydraulic Engineering I, Spring, 2017, 23 students

7. Publications:

Aijaz, S., M. Ghantous, A. Babanin, I. Ginis, B. Thomas. and G. Wake 2017: Nonbreaking wave-induced mixing in upper ocean during tropical cyclones using coupled hurricane-ocean-wave modeling. J. Geophys. Res. Oceans., 122, 3939-3963.

Blair, A., I. Ginis, T. Hara, and E. Ulhorn, 2017: Impact of Langmuir turbulence on upper ocean response to Hurricane Edouard: Model and Observations, J. Geophys. Res., 122, 9712–9724, http://DOI: 10.1002/2017JC012956.

Chen, X., I. Ginis, T. Hara, 2018: Sensitivity of Offshore Tropical Cyclone Wave Simulation to Spatial Resolution in Wave Models, Journal of Marine Science and Engineering, to be submitted.

Gao K, and I. Ginis, 2018: On the characteristics of roll vortices under a moving hurricane boundary layer, J. Atmos. Sci., 75, 2589-2598. https://doi.org/10.1175/JAS-D-17-0363.1

Gao, K., I. Ginis, J.D. Doyle, Y. Jin, 2017: Effect of boundary layer roll vortices on the development of the axisymmetric tropical cyclone J. Atmos. Sci. DOI: 10.1175/JAS-D-16-0222.1

Gao, K. and I. Ginis, 2016: On the Equilibrium-State Roll Vortices and Their Effects in the Hurricane Boundary Layer. J. Atmos. Sci., 73, 1205-1221.

Fei T., Q. Shen, W. Huang, I. Ginis, and Y. Cai, 2017: Characteristics of river flood and storm surge interactions in a tidal river in Rhode Island, USA, Procedia IUTAM, 25, 60-64, DOI: 10.1016/j.piutam.2017.09.009

Fei, T., W. Huang, and I. Ginis, 2017: Hydrological modeling of storm runoff in Taunton river basin by HEC-HMS and PRMS models, Natural Hazards, https://doi.org/10.1007/s11069-017-3121-y.

Fei Teng, Wenrui Huang, Yi Cai, Chunmiao Zheng, Songbing Zou, 2018. Application of PRMS hydrological model to simulate rainfall runoff in Zamaske-Yingluoxia Subbasin of the Heihe River Basin. Journal of Water, Accepted.

Fei T., W. Huang, I. Ginis, D. Ullman, Y. Cai, 2017. Integrated rainfall runoff and river hydrodynamic modeling for flood analysis in Woonasquatucket river basin. J. Frontiers of Civil and Structure Engineering, to be submitted November 2017.

Liu, Q., L. M. Rothstein, Y. Luo, D. S. Ullman, and D. L. Codiga, 2016. Dynamics of the periphery current in Rhode Island Sound, Ocean Modelling, 105, 13-24. DOI: 10.1016/j.ocemod.2016.07.001

Liu, Q., L. M. Rothstein, and Y. Luo, 2016. Dynamics of the Block Island Sound estuarine plume. J. Phys. Ocean., 46, 1633–1656. DOI: 10.1175/JPO-D-15-0099.1

Liu, Q., L. M. Rothstein, and Y. Luo, 2017. A periodic freshwater patch detachment process from the Block Island Sound estuarine plume. J. Geophys. Res. Oceans, 122, 570–586, doi:10.1002/2015JC011546.

Reichl, B. G, D. Wang, T. Hara, I. Ginis, T. Kukulka, 2016: Langmuir turbulence parameterization in tropical cyclone conditions. J. Phys. Oceanogr., 46, 863-886. DOI: 10.1175/JPO-D-15-0106.1

Reichl, B. G., I. Ginis, T. Hara, B. Thomas, T. Kukulka and D. Wang 2016b: Impact of Sea-State-Dependent Langmuir Turbulence on the Ocean Response to a Tropical Cyclone. Mon. Wea. Rev., 144, 4569-4590.

Rosa, K., and C. Kincaid, 2017: Modeling and observations of mixing, circulation and exchange in Narragansett Bay and Rhode Island Sound during Hurricane Floyd, J. Geophys. Res., to be submitted.

Soloviev, A., R. Lukas, M. A. Donelan, B. K. Haus, and I. Ginis, 2017: Is the state of the air-sea interface a factor in rapid intensification and rapid decline of tropical cyclones? J. Geophys. Res., 122, 10174-10183, https://DOI: 10.1002/2017JC013435.

Spaulding, M. L., Grilli, A., Damon, C., Crean, T., Fugate, G., Oakley, B., & Stempel, P.*, 2016: Stormtools: Coastal Environmental Risk Index (CERI) Journal of Marine Science and Engineering, 4(3).

Stempel, P., Becker, A., (In Prep). Visualizations out of context. Implications of using simulation-based 3d hazard visualizations.

Stempel, P., Ginis, I., Ullman, D. S., Becker, A., Witkop, R., 2018: Real-Time Chronological Hazard Impact Modeling. Journal of Marine Science and Engineering. To be submitted.

Sun, Y., C. Chen, R. C. Beardsley, D. Ullman, B. Butman, and H. Lin, 2016. Surface Circulation in Block Island Sound and Adjacent Coastal and Shelf Regions: A FVCOM-CODAR comparison, Progress in Oceanography, 143, 26-45.

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8. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type	Delivery Date	Recipient or End User
Hurricane Rhody scenario	Digital track files and model output	May 2017	NOAA NWS, Taunton FEMA Region 1, Boston
WAVEWATCH III	Hurricane Evaluation Analysis	July 2016	NOAA NCEP
Hurricane Rhody impact analysis	Damage spread sheets	April 2016	EMI, RIEMA
Hurricane Rhody visualizations	3D graphics	May 2017	EMI, RIEMA
Hurricane Rhody Master Scenario List (MSEL)	Digital tables aligning with storm timing	June 2017	EMI, RIEMA
WAVEWATCH III	Analysis of hurricane waves	February 2017	NOAA NCEP

Table 2A: Documenting External Funding

External Funding			
Title	PI	Total Amount	Source
Improving NOAA's HWRF Prediction System through New Advancements in the Ocean Model Component and Air-Sea-Wave Coupling	Ginis	$260,000	NOAA
GFDN operational tropical cyclone model maintenance and support	Ginis	$134,000	Navy

Advancing tropical cyclone models through explicit representation of boundary layer roll vortices	Ginis	$260,000	ONR-Navy
Langmuir turbulence under tropical cyclones	Hara, Ginis	$376,000	NSF
Airflow separations over wind waves and their impact on air-sea momentum flux	Hara	$355,000	NSF
4D physical models of migrating mid-ocean ridges: Implications for shallow mantle flow	Kincaid	$357,000	NSF
Collaborative Research: 3D Dynamics of buoyant diapirs in subduction zones	Kincaid	$442,000	NSF
NOAA/RISG: Quahog Larval Dispersion and Settlement in Narragansett Bay	Kincaid Ullman	$199,000	RI Sea Grant/NOAA
Authentic Data and Visualization Experiences and Necessary Training (ADVENT): An undergraduate model for recruiting students to STEM careers in the U.S. Navy	Pockalny Kincaid	$750,000	ONR-Navy
Rhode Island Sound as a Potential Source of HAB Toxins for Narragansett Bay	Ullman	$140,000	RI Sea Grant
MARACOOS: Preparing for a Changing Mid-Atlantic	Ullman	$75,000	NOAA, Rutgers Subcontract
Optimizing Seaweed and Shellfish Integrated Multi-Trophic Aquaculture: Developing a Spatially Explicit	Humphries, Ullman, Kincaid,	$300,000	NOAA

Ecosystem Model	Thornber		
Summer Undergraduate Research Fellowship in Oceanography (2 students from Tougaloo)	Rubinoff	$12,000	NSF

Table 2B: Documenting Leveraged Support

Description	Estimated Annual Value
Returned Indirect Cost [1]	$10,000
Graduate Student tuition	$30,000
Microsoft Azure Research Award, a one-year grant that allows our project to utilize cloud computing technology.	$20,000
Support for graduate students Peter Stemple and Robert Witkop from URI Coastal Institute and RI Sea Grant	$40,000
Support for graduate students Kevin Rosa and Xuanyu Chen from State Funded TA's.	$40,000

[1] The University of Rhode Island's Coastal Institute (CI) has generously agreed to return 66% of their share of indirect cost return back to the project. The CI obtains 17% of the indirect cost, so roughly 11.3% of indirect cost is being returned to the project.

Table 3: 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)	2	3	3
Graduate students provided stipends (number)	2	3	3
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	0
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	0	2	2
Lectures/presentations/seminars at Center partners (number)	1	3	2
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	2	7	6
Journal articles published (number)	7	8	9
Conference presentations made (number)	15	14	15
Other presentations, interviews, etc. (number)	12	22	17
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	3	5
Requests for assistance/advice from other agencies or governments (number)	5	13	12
Total milestones for reporting period (number)	11	21	19
Accomplished fully (number)	9	17	19
Accomplished partially (number)	2	4	0
Not accomplished (number)	0	0	0

1. Year 3 Research Activity and Milestone Achievement: Use the chart below to show the status of your research activities and milestones as of June 30, 2018. Refer to your Year 3 Workplan to list your research activities and milestones. Explain why any activity or milestone was not completed.

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

Research Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Investigate the impact of wave coupling on simulated coastal ocean flooding. Implemented the URI air-sea coupling module (ASCM) into the ADCIRC/SWAN model.	12/31/2017	100%	
Set up the river flood model and provided time series of flow and water levels at RI rivers as boundary conditions for ADCIRC and tested its performance in historic hurricanes.	12/31/2017	100%	
Simulated the impact of hypothetical Hurricane 'Rhody' on coastal and inland flooding and compared it to the historical events.	12/31/2017	100%	
Refined ADCIRC mesh to provide uniformly high resolution (30 m minimum cell size) over Narragansett Bay and the adjacent southern New England shelf. Continue to work on improvements of the ocean circulation/storm surge and hydrological models and investigate the impact of opening or closing the Fox Point Hurricane Barrier on the magnitude of flooding in the Providence area.	12/31/2017	100%	

Conducted tests of mesh nesting capabilities in ROMS, for use in DHS simulations. Focus on defining benefits of enhanced resolution in the most sensitive regions of the estuary (e.g. Port of Providence, Fox Point Hurricane Barrier, etc.).	11/30/2017	100%	
Developing total storm impacts through multi-model approach: preliminary simulations of after hurricane environmental impacts. Fate/impacts of a) chemical releases from Port of b) mobilized debris.	12/31/2017	a. 100% b. 100%	This activity has been added in the course of the project based on feedback from end users. Summary provided in Appendix
Ran ROMS tests of key differences in 2D versus 3D predictions for transport of chemical fields and debris for Hurricanes Carol and Bob.	11/30/2017	100%	
Improved computational efficiency and software infrastructure of the Hurricane Boundary Layer model	6/30/2018	100%	
Implemented ADCIRC on Microsoft Cloud Computing Platform, Azure.	6/30/2018	100%	
Investigated the role of hurricanes on shelf-estuary exchange in Narragansett Bay using ROMS and observations during Hurricane Floyd.	6/30/2018	100%	
Conducted a modeling study to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay during and after the passage of a hurricane for the purpose of understanding the redistribution of potentially harmful pollutants.	6/30/2018	100%	

Investigated the sensitivity of tropical cyclone wave simulations in the open ocean to different spatial resolutions using WW3 and SWAN.	6/30/2018	100%	
Investigated the sea state dependent drag coefficient in shallow water under hurricane wind conditions.	6/30/2018	100%	
Implemented and tested the Precipitation-Runoff Modeling System (PRMS) in Blackstone River Basin.	6/30/2018	100%	
Collected new data regarding local concerns of facility managers and other decision makers in Rhode Island and integrated as ADCIRC flood model output.	6/30/2018	100%	

Research Milestone			
All research milestones associated with the research activities described above have been achieved. Details are provided in Appendix to this report.		100%	Summary is provided in Appendix.

2. 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
Generated model output in a digital format compatible with FEMA Hazus and other software.	8/01/2017	100%	
Training workshop for DHS, DEM, NOAA/NWS and other end users.	11/31/2017	100%	

Transition the results to end users, and tailor output from our model simulations to the software tools they routinely use.	12/31/2017	100%	
Provided model output to the project led by James Opaluch for examining the variable response of counties, communities, firms and individuals to different hurricane impact scenarios and analysis of the most significant barriers to adoption of hazard mitigation behaviors by different interest groups for different decisions.	8/01/2017	100%	
Transitioned the wave coupling methodology developed during this project to NOAA NCEP/EMC, including wave coupling module for NWS operational models and documentation.	12/31/2017	100%	
Transition Milestones			
Organized Workshop with RIDEM and other end users, October 10, 2017			
Organized a breakout session "Assessing the Impact of Extreme Hurricanes in Rhode Island" at RI Preparedness Conference. August 9, 2017.			
Joint URI-RIEMA presentation at the New England Weather Conference: Ready for Hurricane Rhody? FOXBORO, MA, November 4, 2017 http://www.providencejournal.com/news/20171104/weather-conference-asks-are-we-ready-for-hurricane-rhody			
Three presentations at the URI Coastal Resilience Science and Engineering Workshop, December 4, 2017			
Multiple interviews to state and local media about the project.			
Attended and presented at ADCIRC Week, session: ADCIRC for Decision Makers, College Park, MD, April 11, 2018			
Attended and presented at the DHS Centers of Excellence Summit, Arlington VA, May 30-31, 2018			