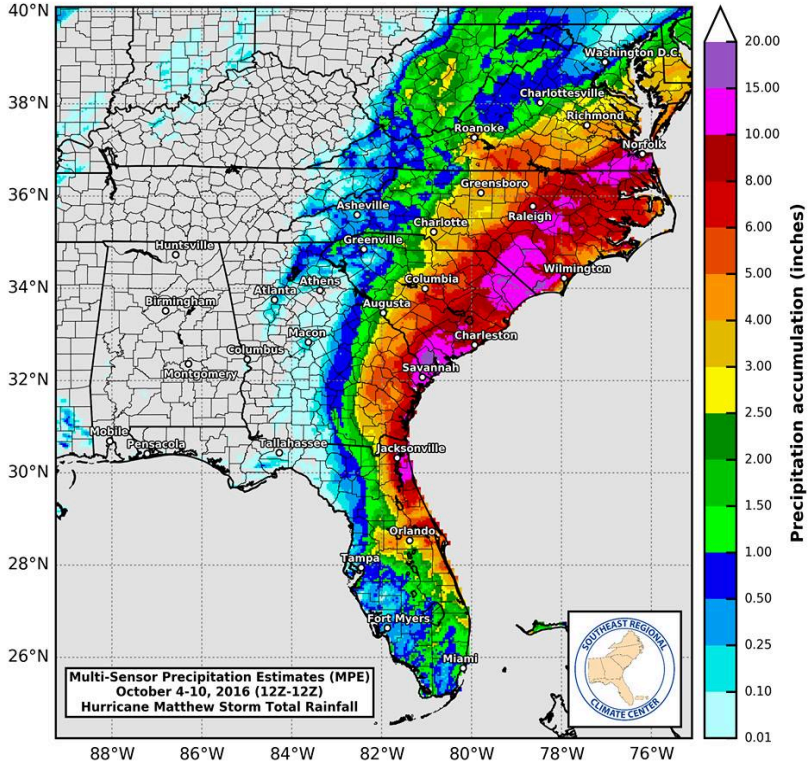
The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency

Donald T. Resio – University of North Florida (don.resio@unf.edu)
Bruce A. Ebersole – Jackson State University (bruce.a.ebersole@jsums.edu)
John Atkinson – Arcadis, Inc. (john.atkinson@arcadis.com)

End User Engagement

Bruce Ebersole (JSUM PI and lead stakeholder Group coordinator) has formed an end-user committee to provide review, feedback and recommendations on the work in progress.

FEMA HQ
FEMA Region I
FEMA Region II
FEMA Region III
FEMA Region IV
FEMA Region VI
US Coast Guard
USACE
NOAA



End User Engagement

- **Direct calls with Stakeholder Group (SG) members**
- **Semi-annual progress reports sent to SG (first sent in July).**
- **Bruce Ebersole is facilitating communications with the SC**
- **Interaction rate will increase in second 12-months of project, possibly including webinars and on-site meetings**

Knowledge Gap Addressed by Project

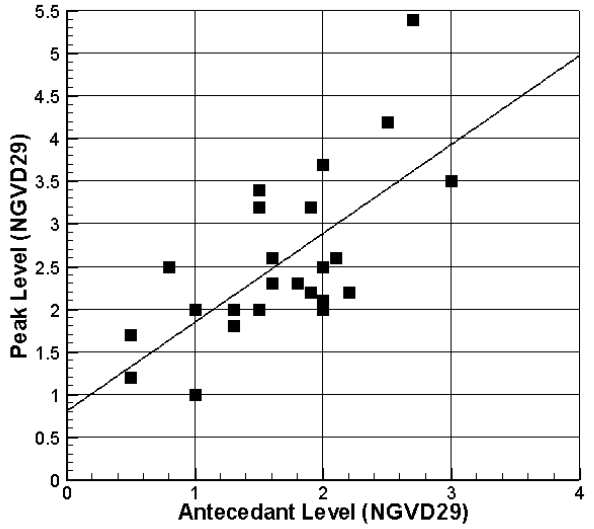
- **FEMA flood modeling and statistical methods currently treat stream and rainfall-induced flooding separately from coastal flooding, which leads to a swath of land between the two approaches that is under-estimated**
- **Statistical methods and modeling methods have to be updated to explore the following goals:**
  - **A coupled modeling system that is defensible and accurate for all critical processes affecting flooding in coastal areas and is adaptable to all coastal areas within the U.S.**
  - **A statistical methodology that is capable of incorporating additional sources of variation in inundation levels, while preserving an overall efficiency that allows the coupled modeling system to be applied effectively to all coastal areas within the U.S.**

Research Approach

- Re-examine fundamental assumptions within statistical methodologies, particular with respect to effects of natural structure on probabilities(JP submitted to Natural Hazards)
- Quantify relationships between Tropical Cyclones (TCs) and rainfall patterns affecting flooding in coastal areas
- Develop statistical framework for estimating probabilities of coastal inundation that maintains accuracy standards and overall efficiency in terms of numbers of simulations required
- Investigate options for model coupling that provide the following:
  - ability of river models to account for surge
  - ability of surge models to account for river flow & stage
  - accurate coupled model system that reproduces important physics
  - system that is stable & computationally efficient

Research Work and Accomplishments (Rain Patterns & Statistics)

- **Completed analysis of rainfall patterns and statistical framework for combining rainfall, tides, river/stream discharge and antecedent conditions into a statistically robust, defensible methodology, efficient and adaptable to multiple locations (Report completed 1/31/2017)**

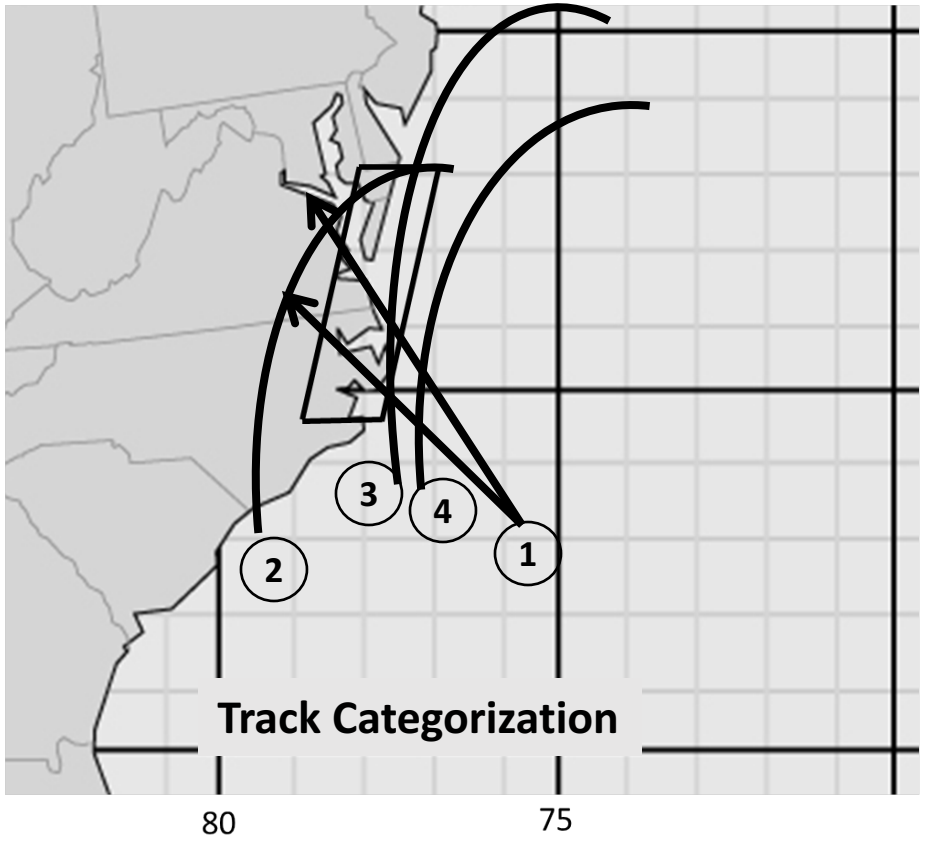


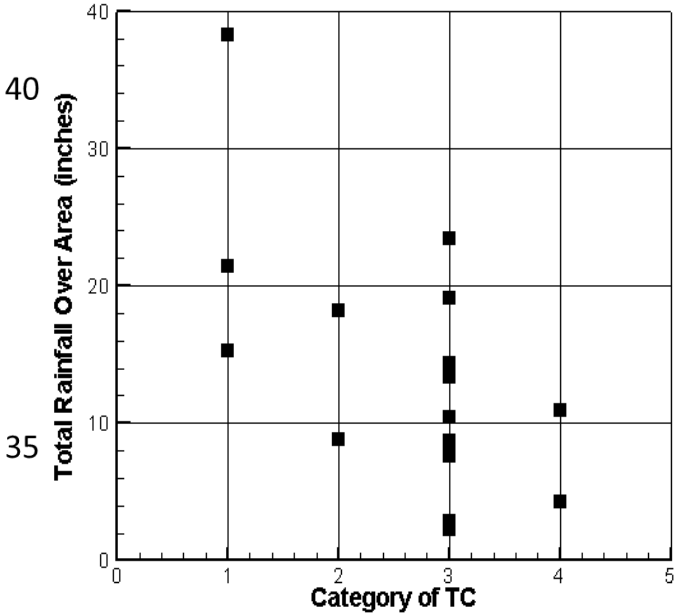
- **Findings to date:**
  - **Rainfall offshore is influenced primarily by Sea Surface Temperature (SST) and Storm Size**
  - **Timing of rainfall with the point of closest proximity of storm center to Norfolk suggests that the onshore rainfall slightly lags the storm passage, but is mainly concentrated in a 24-hour interval centered on the point of closest approach in hurricanes in the Norfolk/Hampton Roads area**
  - **Storm track is the primary discriminator of both the duration and intensity of rainfall in storms**
  - **Response Function (RF) method is much more adaptable than Bayesian Quadrature (BQ) for incorporation of spatially inhomogeneous processes into statistical framework**

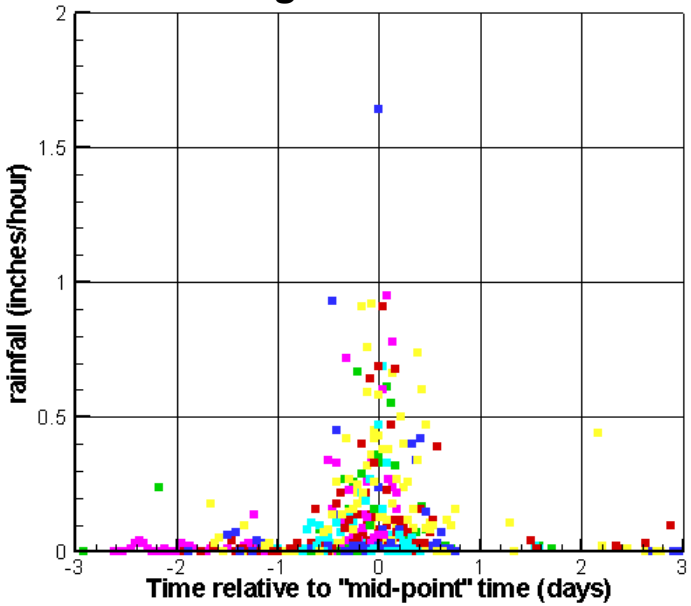
Research Work and Accomplishments 1

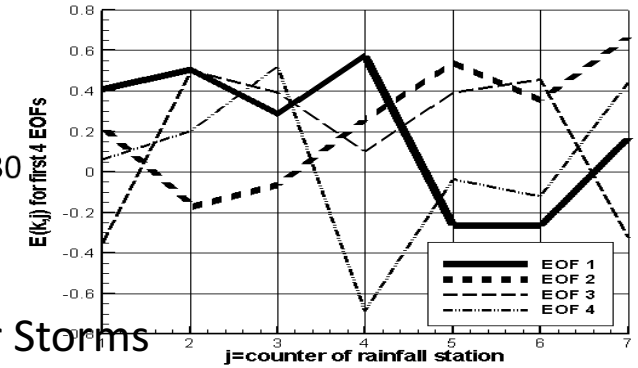
Rainfall from all 17 "major" storms in the Norfolk area

1 – Surge and high rainfall
2 – Little surge and moderate rainfall
3 – Moderate surge and high rainfall
4 – Little surge and little rainfall

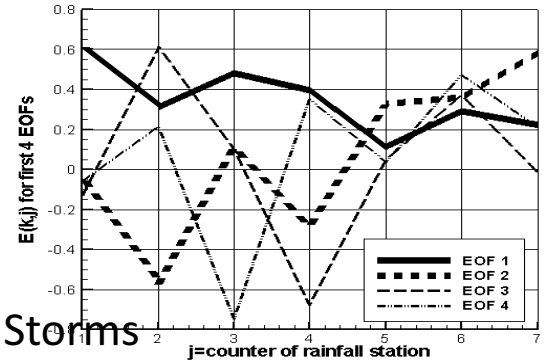








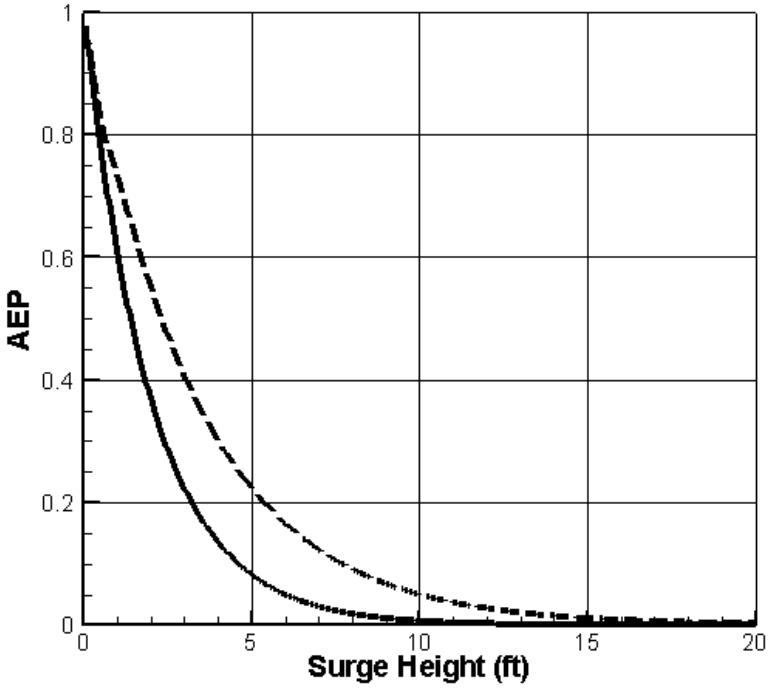
EOFs for Major Storms

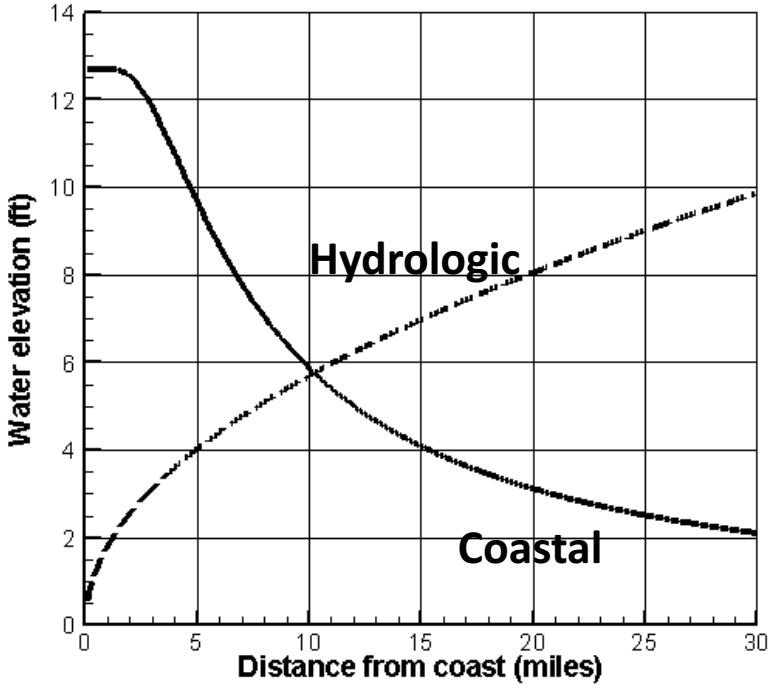


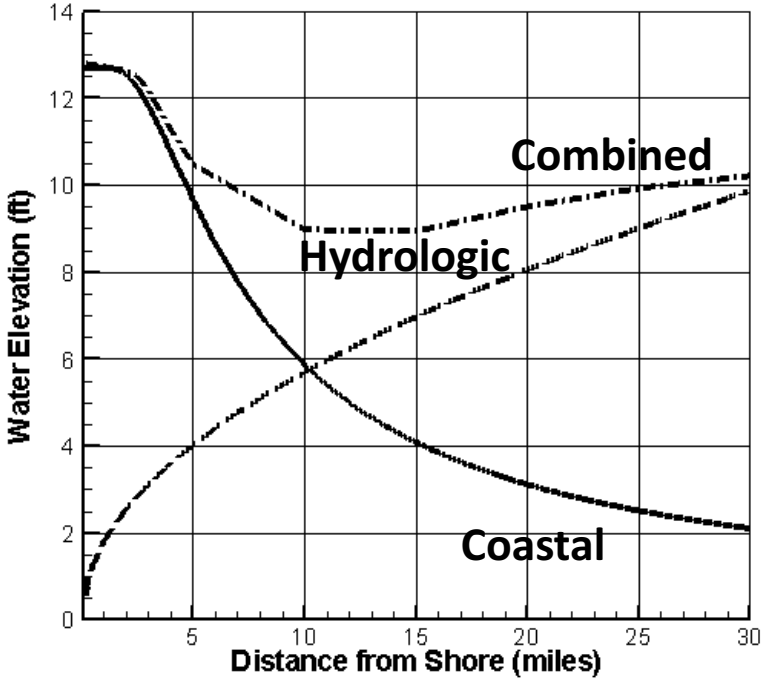
EOFs for Minor Storms

Research Work and Accomplishments 2

EXAMPLES OF EXPECTED STATISTICAL PRODUCTS FROM THE OVERALL PROJECT



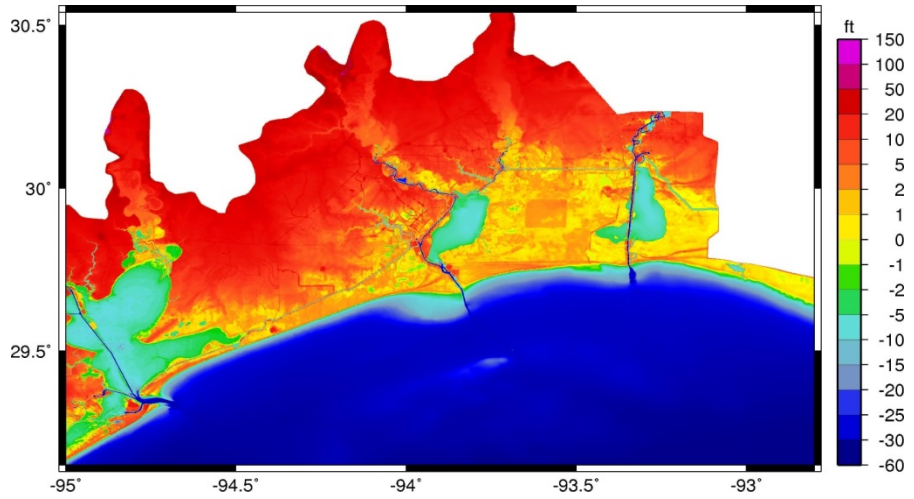




Annual Exceedance Probability for coastal surges and coupled coastal and hydrologic/rainfall flooding

Research Work and Accomplishments (Coupled Modeling)

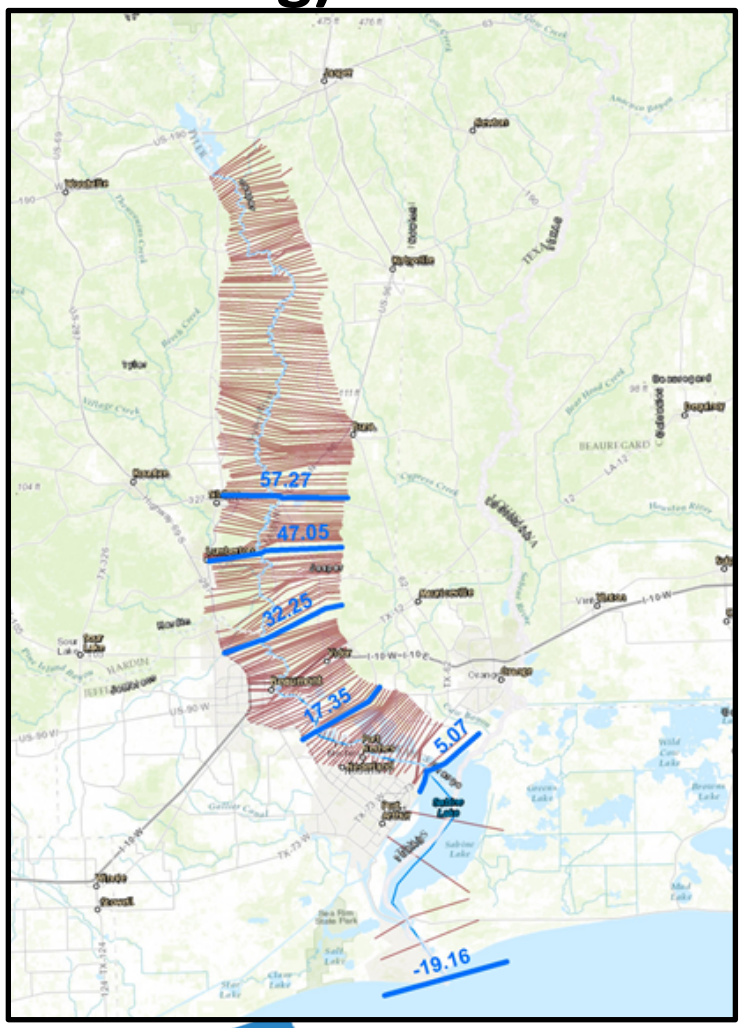
- **Investigated impact of precipitation & river stage on surge (what are we missing in present methodology?)**
- **Uses Neches River (Texas) as test case**
- **Procedure**
  - **Obtain two existing models that include the Neches**
  - **2D surge model from previous TX-FEMA study**
  - **1D riverine model from USACE**
  - **Compare simulations for several events**
  - **Systematically adjust domain overlap and boundary location**
  - **Optimize the "best" coupling process**
  - **Identify the physical conditions that impact the coupling strategy**



Research Work and Accomplishments (Coupled Modeling)

HEC-RAS

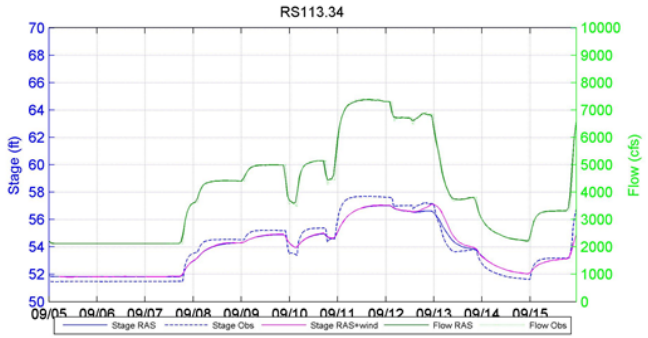
- Well known and respected model to compute stage-flow relationships for rivers and streams
- Can be used in unsteady mode with time varying boundary conditions
- Source code is not publicly available
- Very efficient per storm, but not easily automated
- Existing, calibrated/validated HEC-RAS model of Neches River available from USACE
- USACE model modified and coupled with TX-FEMA ADCIRC model

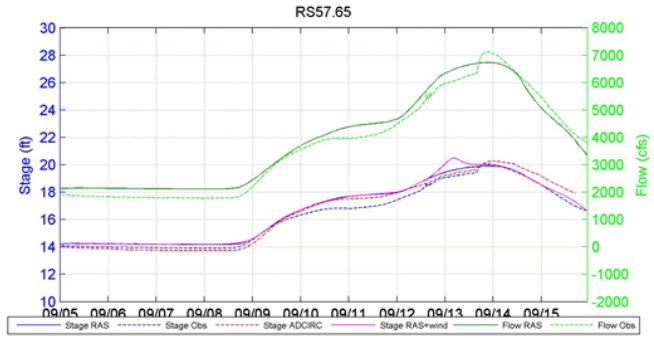


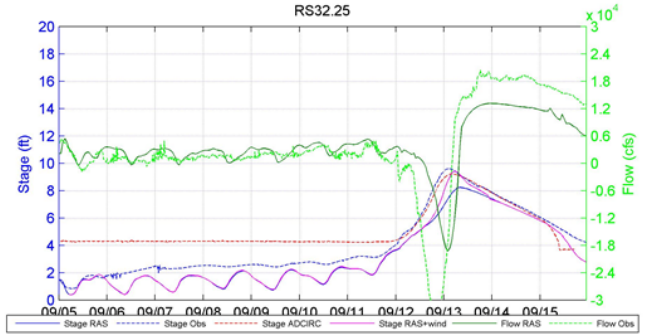
Research Work and Accomplishments (Model Coupling – draft conclusions)

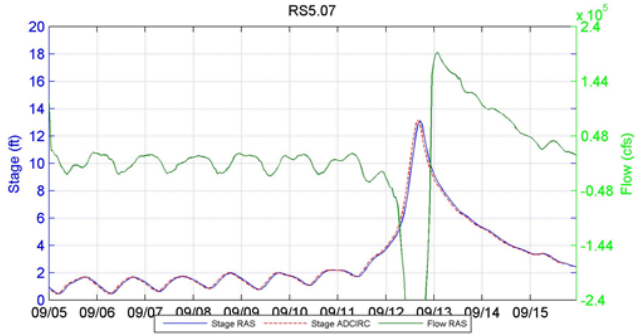
- **One-way coupling appears feasible for coupled simulations (using subdomain+BC)**
- **Automation developed for HEC-RAS using VBA and Matlab calls**
- **Rainfall can be added on ADCIRC sub-domain basis with BC**
- **Timing of flooding in HEC-RAS and ADCIRC in phase in most tests**
- **HEC-RAS has more damping than ADCIRC**
- **HEC-RAS cannot account for effects of Lake Sabine (implications for Hampton Roads and other regions)**
- **HEC-RAS does not account for wind**
- **Other 1D river models may perform better (SOBEK, SWAT)**
- **For all surge conditions, total stage (backwater curve) in river increase with flowrate**
- **For increasing surge, HEC-RAS under predicts total surge by 1 to 2 ft**

Research Work and Accomplishments (Coupled Modeling)









Model Comparison for Hurricane Ike

Educational Efforts

- **Participated in SUMREX Program with Rudy Bartels – PhD student from LSU**
- **Plans in place to give research presentation at LSU and continue work with Rudy Bartels and Professor Barry Keim for a journal publication**
- **UNF PhD student Amanda Tritinger participated in last years CES on behalf of DHS**

Anticipated Project Impact (1)

- **DHS Goal 1.3 – Manage Risks to Coastal Infrastructure, Key Leaders, and Events**: Past events have demonstrated threat posed to inland areas is often underestimated, with damages due to inland flooding comparable to areas at the coast . This project will help remediate this deficiency, thereby enhancing our decision-making capabilities related to resilience.
- **DHS Goal 5.1 – Mitigate Coastal Hazards and Risks:** Multidisciplinary teams will be utilized to develop improved hazard maps in coastal areas that will disperse costs more equitably.
- **DHS Goal 5.3 – Ensure Effective Emergency Response** : This project will provide improved quantitative time-space patterns of event hazards, which will be very valuable to emergency responders.
- **DHS Goal 5.4 – Rapidly Recover from Catastrophic Events**: This project will provide accurate information on the interaction of hazards with critical infrastructure and the patterns of these individual hazards during individual events, as needed for effective post-disaster planning and for minimizing future exposure.

Expected Future Research Work and Accomplishments

- **Develop and test a statistical and modeling framework over the expected range of forcing.**
- **Delineate magnitudes and areas of significant differences and investigate impacts on inundation probabilities**
- **Develop objective methodology for RF approach to storm selection that includes rainfall, hydrologic inputs, and antecedent conditions.**
- **Evaluate performance of the newly released 2D version of HEC-RAS**
- **Compare 2D HEC-RAS performance with SOBEK and/or SWAT for ADCIRC coupling**
- **Deploy coupled system on different river system to see if conclusions are general (possibly lower James River area)**
- **Include precipitation in surge model**
- **Define a "flashiness" parameter for river basins to identify where coupling is more important during precipitation events**

Proposed Follow-on Work

- **Develop test concepts (with stakeholder input) for Norfolk-Hampton Roads coupled surge-rain-hydrologic modeling system**
- **Using existing data from previous FEMA flood map studies in this area, develop a set of sub-domain models for testing.**
- **Investigate the stability and accuracy of 1-way coupling to 2-way coupling**
- **Estimate the areas and significance of impacts of coupled modeling compared to surge-only modeling**
- **Evaluate the modeling system and statistical framework for transition to full-scale applications**
- **Provide recommendations on any needed alterations to the system needed before transition, if any**