



# 36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

*The State of the Art and Science of Coastal Engineering*

## USACE Preparation and Response to 2017 Hurricanes Harvey, Irma, and Maria

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*US Army Corps of Engineers*



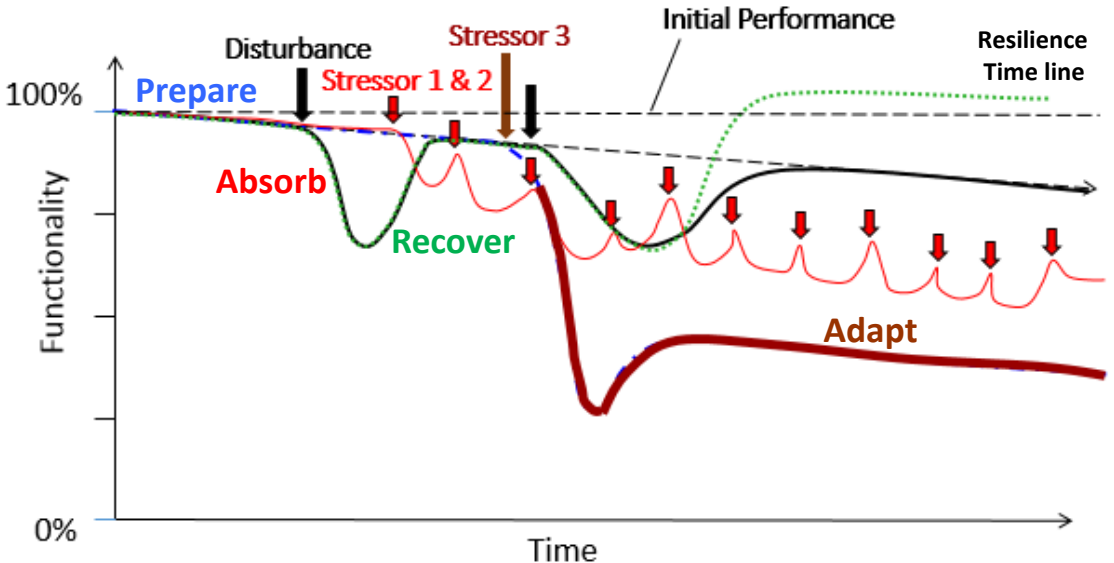
# Outline

- USACE Principles of Resilience
- Impacts of Hurricanes Harvey, Irma, Maria
- USACE products applied in support of Emergency Management
  - Preparations, Responses, and Recovery Efforts
- R&D Successes/Opportunities for Flood Hazard Mitigation



# USACE's Principles of Resilience

**Resilience:** the ability of a *system* to **Prepare (and Plan) for, Resist or Absorb Damages, Recover from,** and more successfully **Adapt** to function as desired through short- and long-term disturbances *(National Research Council 2012)*



Presidential Executive Order 13653, Preparing the U.S. for Impacts of Climate Change (NOV 2013)



“Resilience means the ability to **anticipate, prepare for, withstand, respond to,** and **recover** rapidly from disruptions, and **adapt** to changing conditions ”



## Engineering Infrastructure



## Environmental Infrastructure



## Community Infrastructure



# 2017 Hurricanes *Harvey*, *Irma*, *Maria*

## Significant impacts

**Harvey, Cat 4: Aug 24-29 (162 hrs TS warning)**

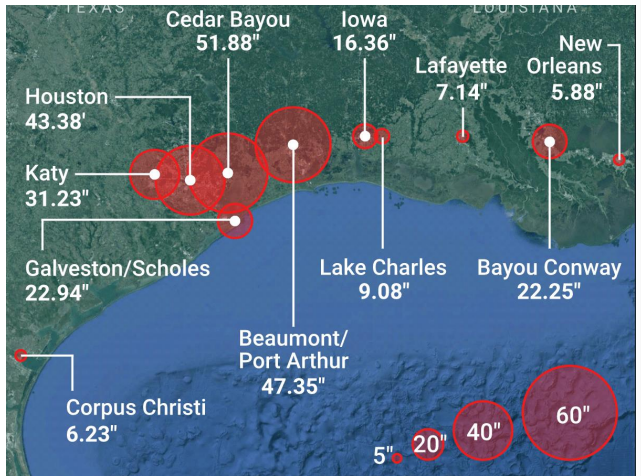
- Slow-moving storm with rapid intensification
- 148 mph winds (Rockport); Pressure 937 mb
- **Max: 60.58" (154 cm) rain (record breaking)**
- Flood water rescues; displaced homeowners
- 89 deaths
- \$180B in damages

*Addicks Reservoir Opened to avoid failure & flooding of neighborhoods*

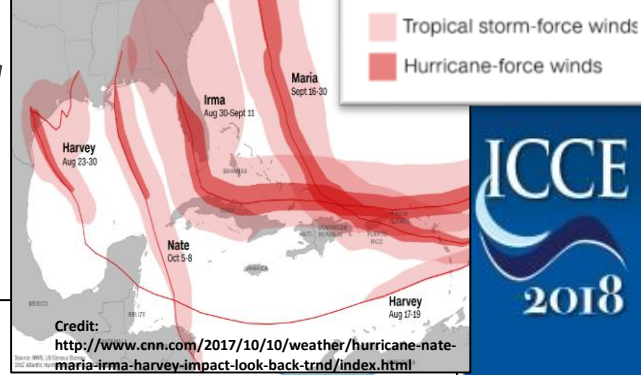


Credit: D. Sternitzky-Di Napoli, *Houston Chronicle*, Sep 2, 2017

Source: <http://www.cnn.com/2017/10/10/weather/hurricane-nate-maria-irma-harvey-impact-look-back-trnd/index.html>



**\*Not final totals**

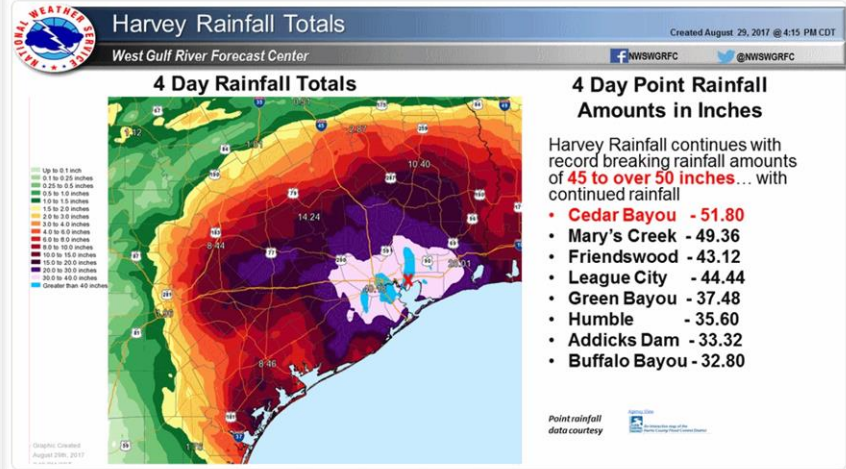


**NWS @NWS**

#Harvey in perspective. So much rain has fallen, we've had to update the color charts on our graphics in order to effectively map it.

**NWSWGRC @NWSWGRC**

Updated #Harvey rainfall totals...Record breaking rainfall amount at Cedar Bayou 51.80" #txflood #txwx #Harvey



4:23 PM - 29 Aug 2017 **\*Not final totals** Unprecedented Rainfall!!!

64 Retweets 22 Likes



# 2017 Hurricanes *Harvey*, *Irma*, *Maria*

## Significant impacts

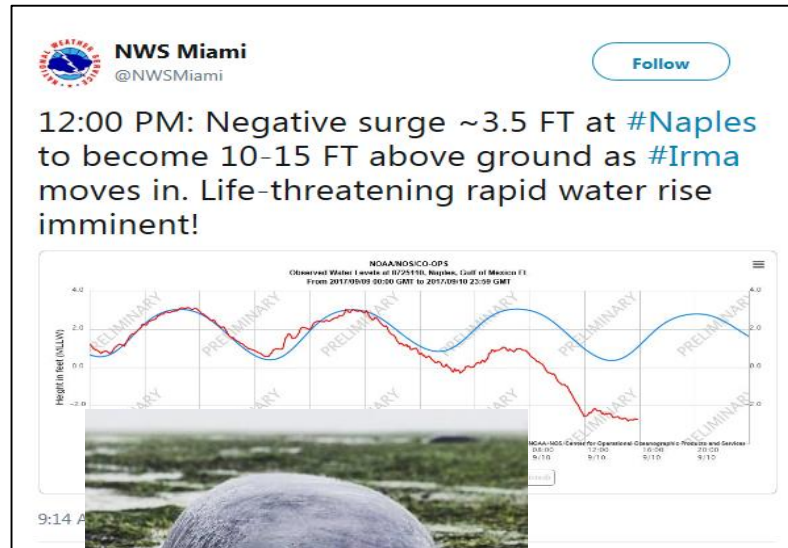
### *Irma*: 6-13 Sep

- Powerful Hurricane (Cat 5); Path of destruction
- 185 mph (83 m/sec) winds for 37 hrs;  $P_{\min} = 914$  mb
- Two Cat 4+ storms hit U.S. mainland in same year (first time in 100 yrs)
- Negative surge -3.5 ft (-1 m) rebounded to +10-15 ft (+3-4.5 m), Naples, FL
- 61 deaths
- \$150-200B in damages

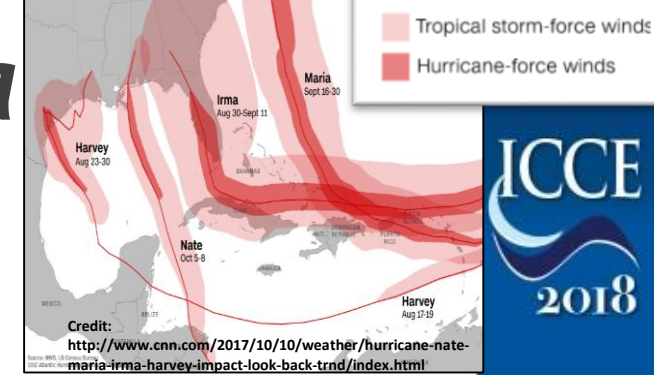
Jacksonville, FL, 9/11/17



Credit: <https://s.w-x.co/wu/jax-flooding-sheriff-9.11.17-835px.png>



Credit:  
<https://www.ecowatch.com/hurricane-irma-manatees-2483963072.html>

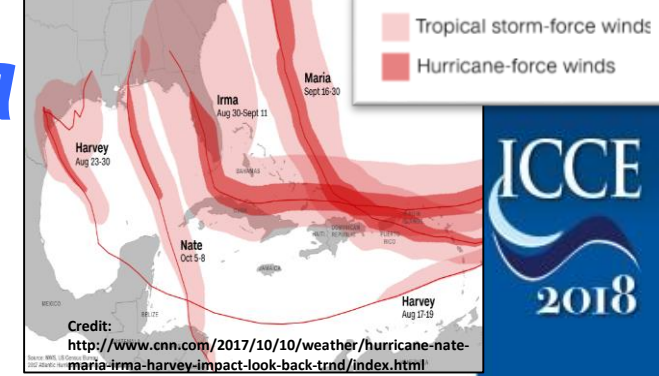


# 2017 Hurricanes *Harvey*, *Irma*, *Maria*

## Significant impacts

*Maria*: 17-20 Sep 2017

- Cat 5 Hurricane, 175 mph (78 m/sec) winds; 908 mB (Top 10)
- 18<sup>th</sup>: Dominica (Cat 5) after *Irma* & *Jose* (worst natural disaster in recorded history)
- 20<sup>th</sup>: Direct Hit to Puerto Rico (30+ hrs); 30 in (76 cm) of rain in one day
- Catastrophe/Humanitarian Crisis: Destroyed infrastructure, lack of resources, locality
- Compounded by 2/3 power loss and 1/3 water loss from *Irma* 2 weeks prior
- \$5-95B in damages
- 55+ deaths



# Hurricane Harvey

## GSSHA - Reservoir Release Operations & Flooding Alternatives

### USACE Galveston District

POC: Aaron Byrd

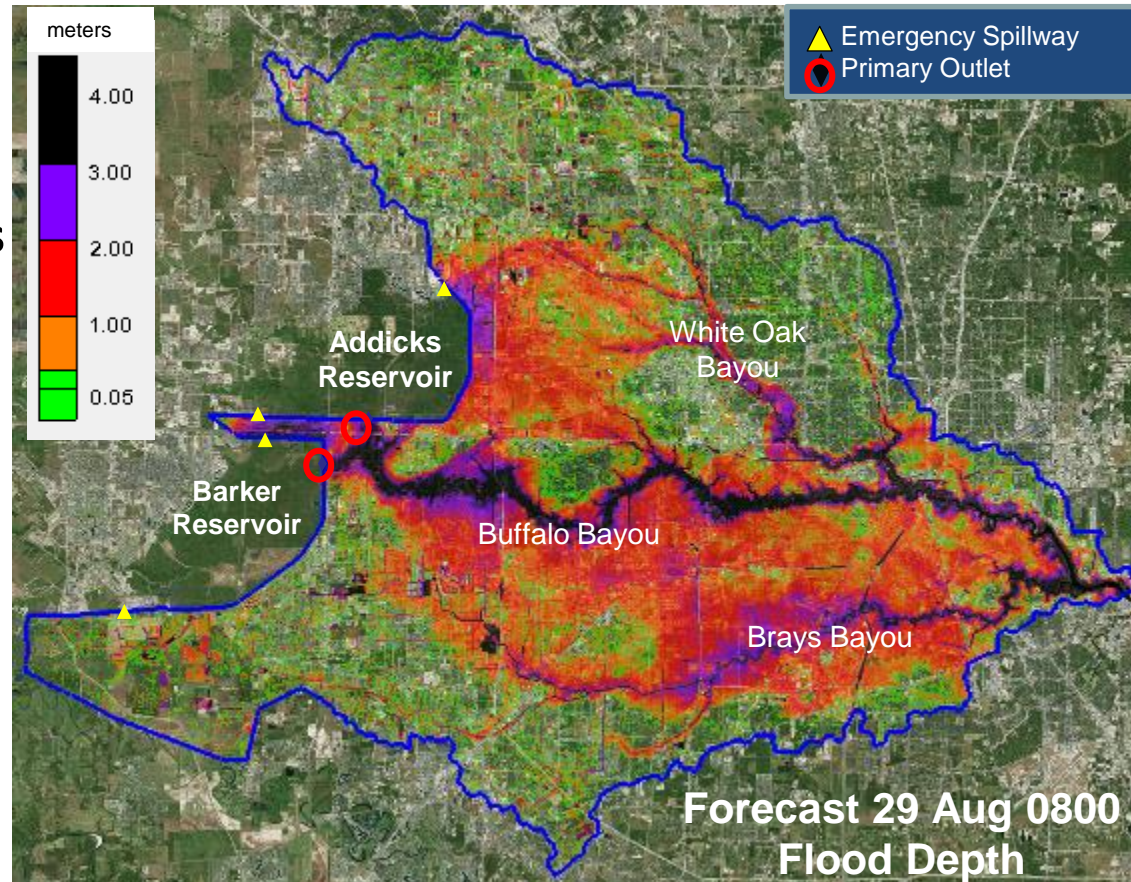


*Gridded Surface-Subsurface Hydrologic Model: 2D physics-based watershed model*



**Results can be used for reservoir releases (when/if) and evacuation (when/where)**

- Forecast Floodwaters
- Aid Emergency Managers
- Each Rainfall Forecast  
GSSHA
- Surfacewater Hydrology
- Two Domains



- 0.05 m – 0.3 m  
Minor flooding begins, cars still passable
- 0.3 m – 1.0 m  
Cars not passable, high trucks ok
- 1.0 m – 2.0 m  
High trucks not ok, emergency vehicles ok
- 2.0 m – 3.0 m (Areas unreachable)  
Emergency vehicles not ok
- 3.0m+, First floor underwater



# Hurricane Harvey

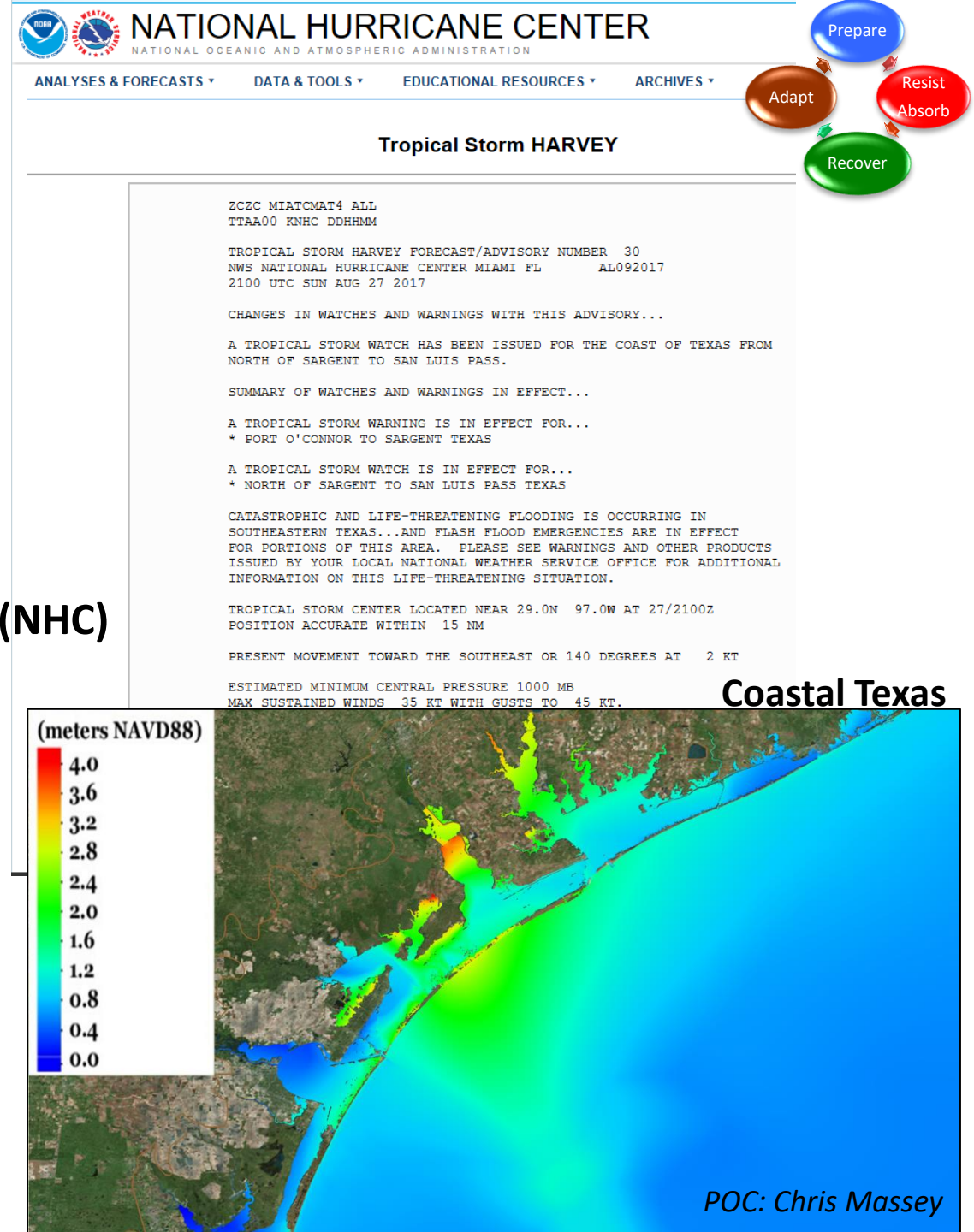
## ADCIRC Storm Surge Modeling

### USACE Galveston District

- USACE Texas Coast, HiFi Modeling Study (**Prepare**)
- Advanced Circulation (ADCIRC) Model storm surge simulations
- Harvey Simulation Period: 25-29 Aug 2017
- Advisory 16-37 from the National Hurricane Center (NHC)
- Forced with tides, wind, & pressure data derived from NHC Advisories by Seahorse Engineering

#### Products:

- Water level time series at 10 key locations and maximum water level envelopes
- Used by the Galveston District to provide surge forecasts to emergency managers for decision-making

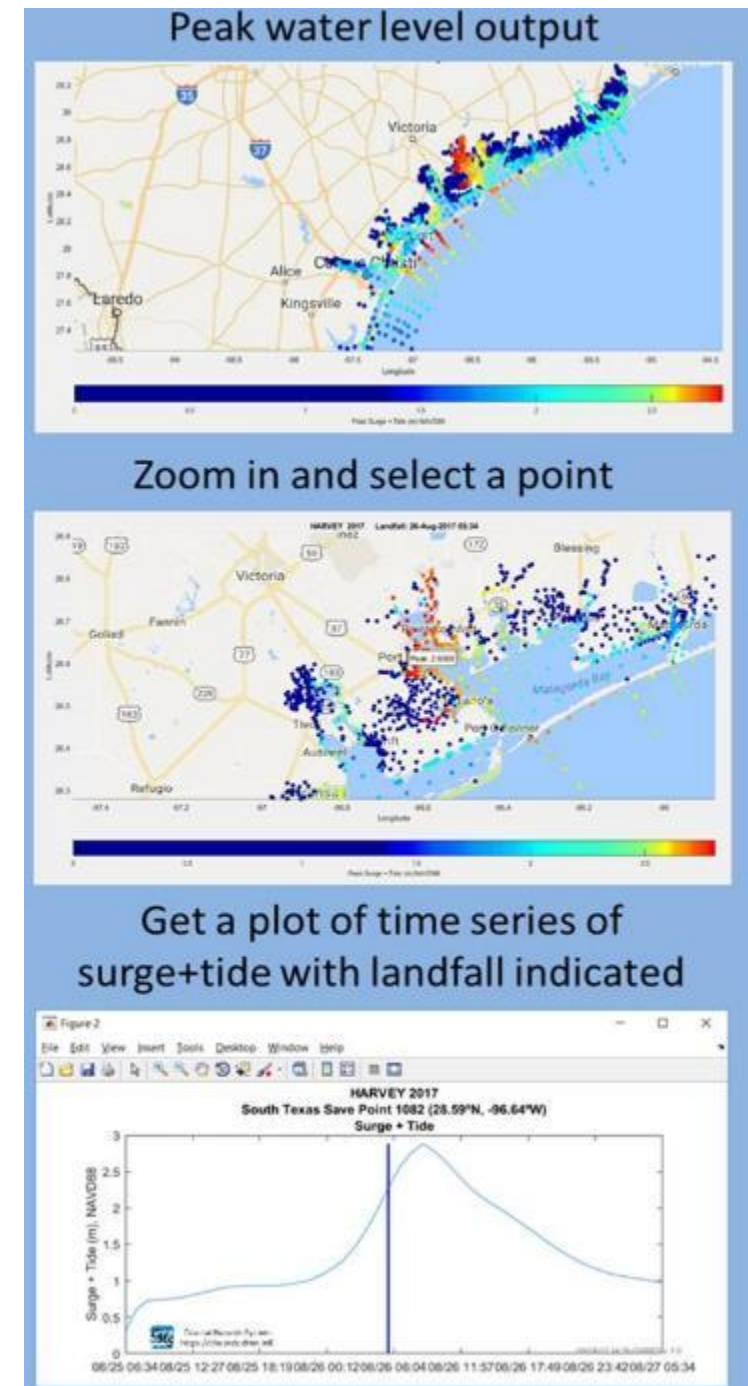




# Hurricane Harvey Coastal Hazards System (CHS) & Storm-Sim Coastal Hazards Rapid Prediction System (StormSim-CHRPS) for USACE Galveston District

POCs: Norberto Nadal-Caraballo, Amanda Lewis, Fatima Diop

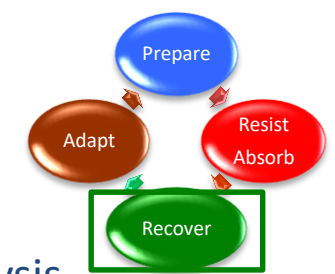
- Coastal Hazards System (CHS) archives HiFi Model Results
- CHRPS provides rapid estimates of surge in minutes via queries of CHS archive
- Utilized NHC Advisory Track forecasts with “what-if” adjustments for potential landfall
  - e.g., landfall path shifted north to Port Arthur
- Estimates potential water levels from Harvey
- Entire hydrograph within minutes/not hrs
- **Used to prepare emergency operations**



# Hurricane Harvey

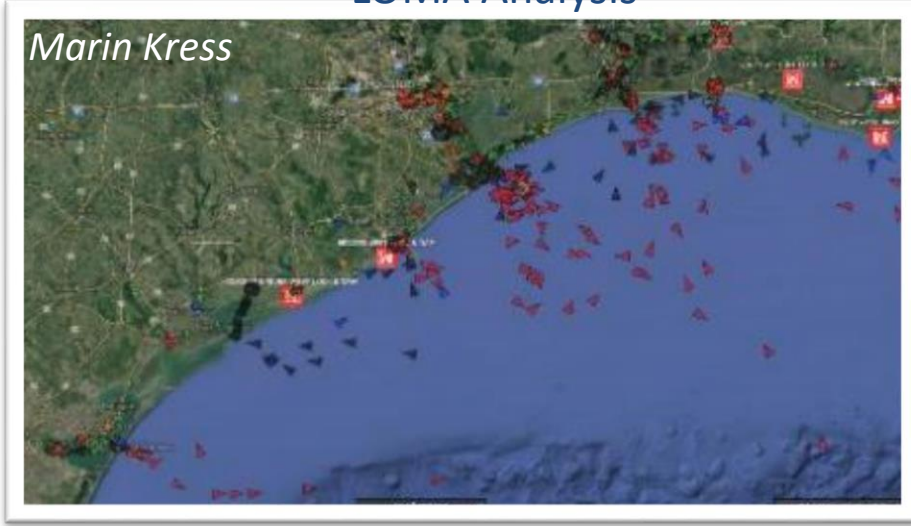
## LOMA Applications for Vessel Locations & Port Operations

### USACE Galveston and Mobile Districts



POCs: Brian Tetreault, Katherine Touzinsky, Kenneth N. Mitchell, Patricia Dijoseph,

- Lock Operations Management Application (LOMA) used to provide vessel location to USACE Districts and anticipate navigation needs via analysis of Automated Information System (AIS) data
- **Used to locate lost vessels, track dredging vessels, and plan for port operations (dredging/re-opening/supplies)**

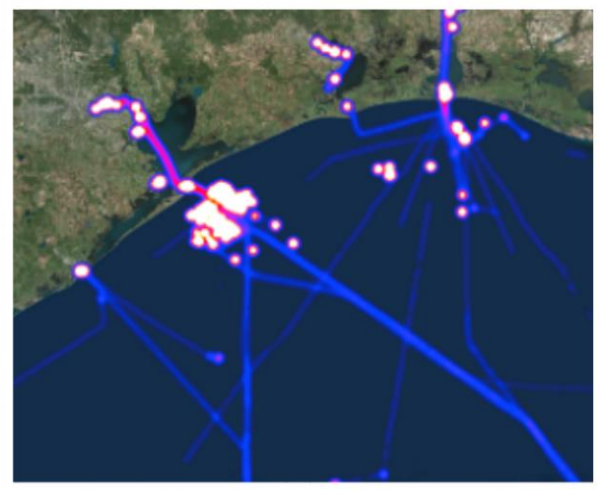
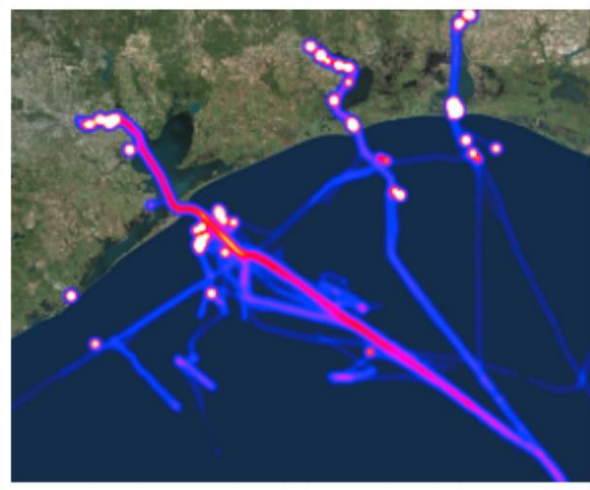
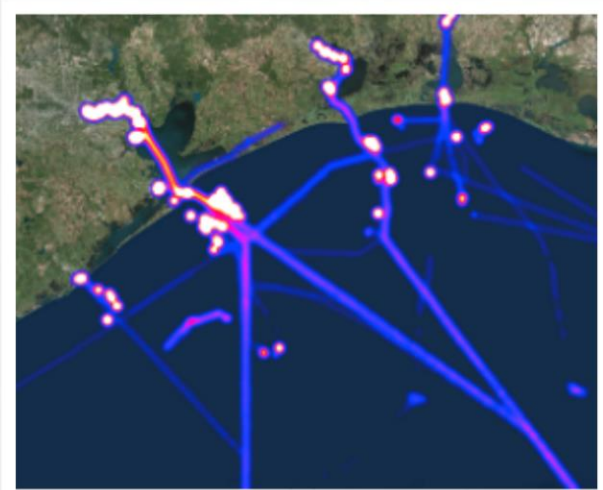


August 1, 2017  
Normal vessel operations

August 25, 2017  
Ports close, vessels exit

September 4, 2017  
Vessels queue in anchorage

Heat Maps  
Vessel AIS  
Signal Density



# Hurricane Harvey

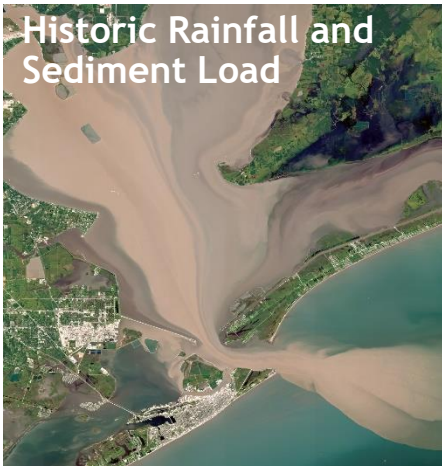
## Galveston District **During Storm** Activity and **Post-Storm Recovery**

### • **Rescue Operations**

USACE worked with numerous State and Federal Partner Agencies. Search and Rescue Teams completed:

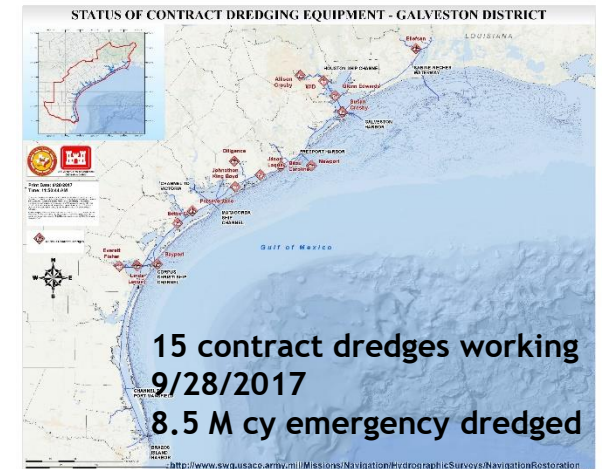
- >21000 Search & Rescue Personnel (State, National, Overseas)
- >34000 People Rescued (>1000 by Air; >33000 by Water)
- >37000 People Evacuated
- >4000 Welfare Checks or Shelter-in-Place on individuals
- >2000 Pets & Animals rescued or evacuated to safety
- Does not include Cajun Navy or Homeland Security team rescues

### • **Navigation Restoration Team**



**24 survey boats: dredging 12 hr/day for 6 weeks**

- 8 Galveston District; 3 New Orleans District
- 4 NOAA; 9 Contractors; 41 Government Surveyors
- \$15B in losses due to Port Closures
- By 9 Sept 2017, surveyed 270 miles (deep draft channels)
- Surveyed 750 miles (shallow draft channels)
- Task: Dredge out; made navigable

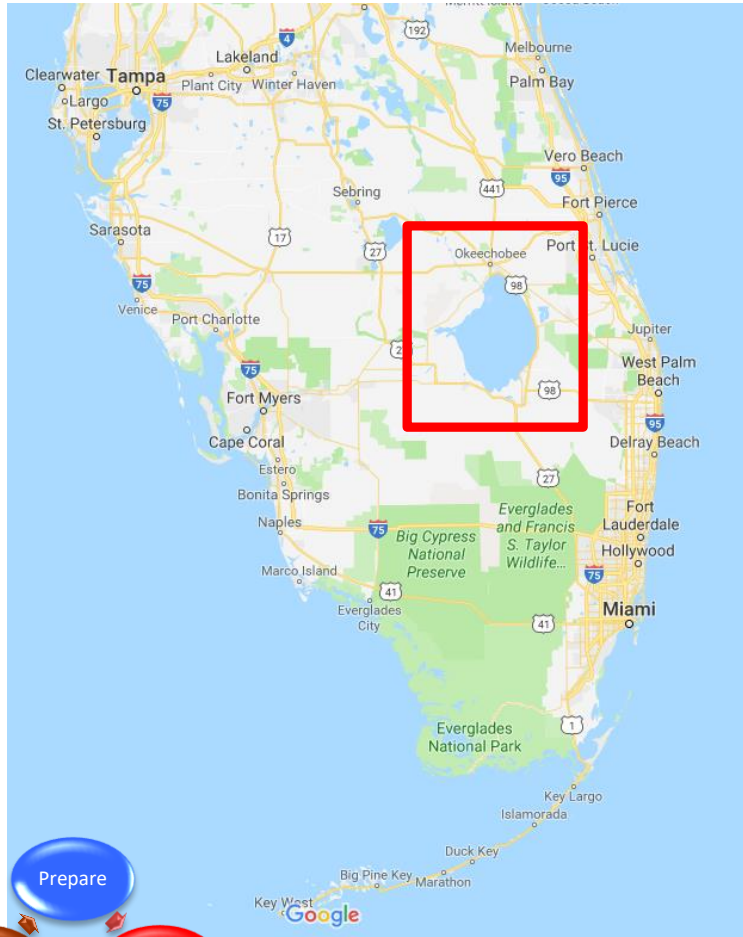


# Hurricane Irma

## Herbert Hoover Dike

### USACE Jacksonville District

- 143-mile Lake Okeechobee earthen dam
- Reduces flooding Impacts to South Florida
- 1920s: Hurricane flooding killed 1000s
- 1930s: USACE built south side levees
- 1947: Congress authorized USACE to build the current 143-mile levee footprint
- Since 2001, USACE invested \$870M to rehabilitate the aging structure



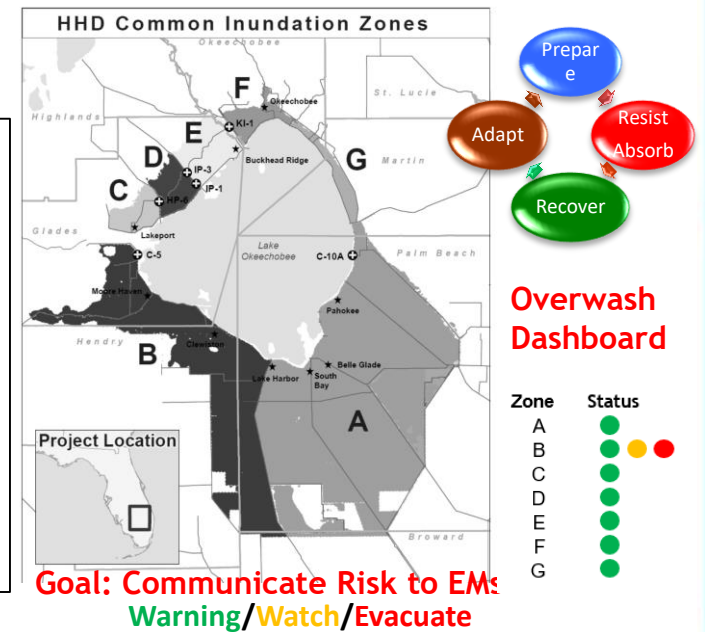
Credit:  
<https://www.google.com/maps/@26.5730277,-81.5990714,8z>



Resilience Cycle

# Prepare ... before the storm

- Used lessons learned from Hurricane Matthew (2016) to prepare
- Jacksonville District (SAJ) coordinated with National Weather Service (NWS) (Miami & Melbourne) and State and Local Emergency Managers (Ems) to develop a **Standard Operating Procedure** (SOP) exclusively for tropical threat to the Lake Okeechobee region (finalized before Irma)
- SOP identifies six milestones related to arrival of tropical storm force winds in order to ensure any flash flood warnings/watches would be issued with appropriate lead time



# Absorb/Resist ... during the storm

- **Implemented SOP**
- Twice daily meetings (SAJ, NWS, EM)
- NWS delivered Meteorological Data to SAJ with each Advisory
  - Applied a surge-only model
  - Deterministic wind forecasts from the best track forecast
- SAJ pre-computed Herbert Hoover Dike Flood Risk
  - Empirical surge calculation
  - STWAVE wave calculation
  - ACES wave run-up calculation → overwash

# Recover and Adapt ... after the storm

What worked/what needs improvement

- Pre-planning/coordination helped during the event
- NWS results varied widely from Advisory to Advisory - needs resolution
- SAJ internal assessment is overly conservative; a higher fidelity modeling system may provide more accurate assessments
- ERDC Coastal Hazard System can provide highly accurate and timely assessments of the risk that include all relevant storm/lake variables



# Hurricane Maria: Inland Flooding Estimates with AutoRoute for US Army South Command



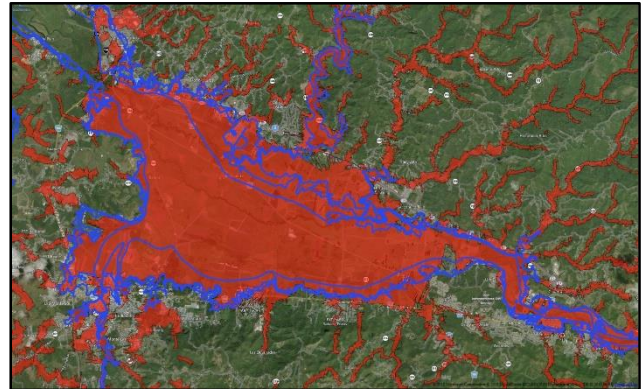
POCs: Mike Follum, Chris Massey, Mark Wahl

- **18 Sept 2017 0915** – Initial contact: need for storm surge/flood inundation potential from Hurricane Maria for the Rio Guanajibo Basin

- *Population 225000*
- *Area 140 sq mi*
- *Plan for floodwall/channel improvement/levees*

- **19 Sept 2017 0830** – Official request for flood inundation maps sent to US Army Reachback Operations Center (UROC)

- **19 Sept 2017 1400** – Initial 100-yr flood inundation maps produced and linked to forecasted storm surge data



Rapid flood inundation maps (red) matched well with FEMA flood maps (blue)



# Hurricane Maria: Inland Flooding Estimates with AutoRoute for US Army South Command

POCs: Mike Follum, Chris Massey, Mark Wahl



**Note:** FEMA provides the STANDARDS (Flood Inundation Maps)

BUT request for **1st-order estimates** for ALL rivers in < 6 hrs

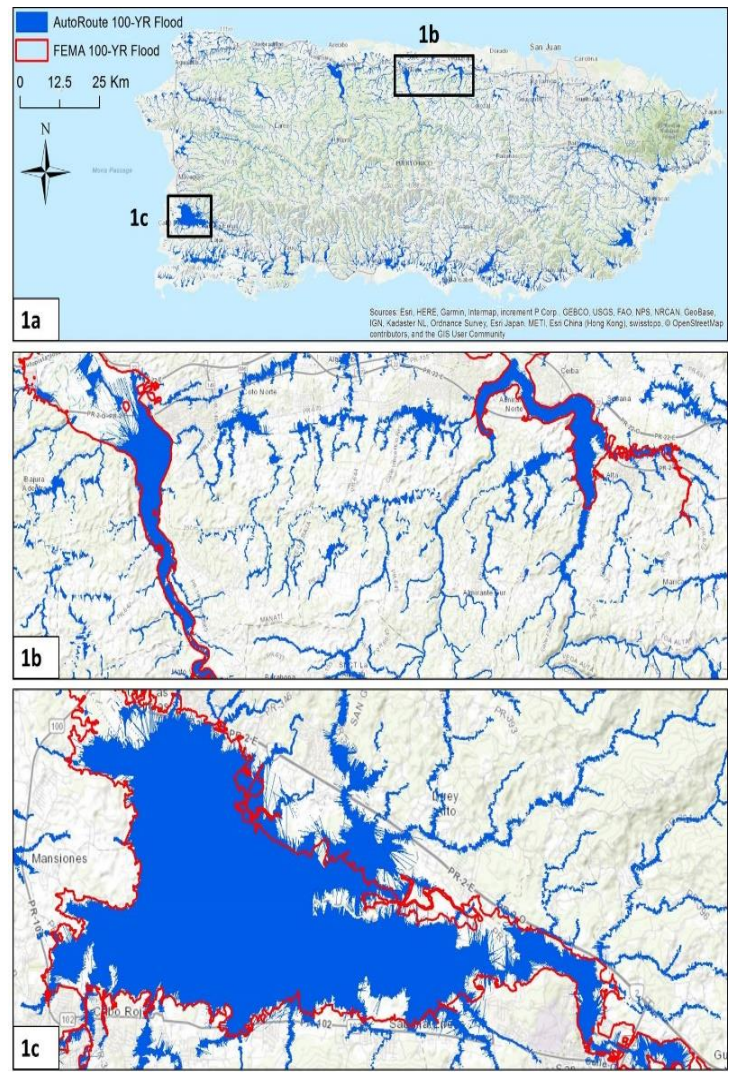
**Input:** Readily-Available, High-Resolution:

- 10-m Elevation Data (NOAA, coastal; TanDEM-X, inland)
- Land Cover (defined hydraulic roughness)
- USGS flow regression equation with 100-yr flow estimates
- Automated Cross-Sections (from DEM)

**Results:**

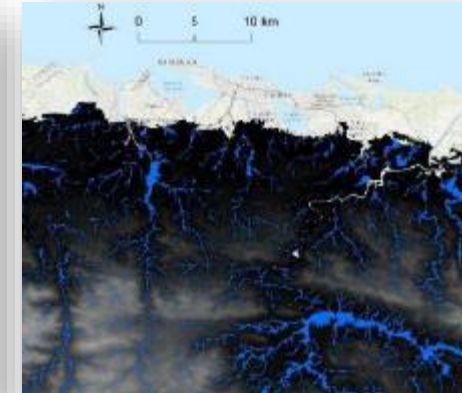
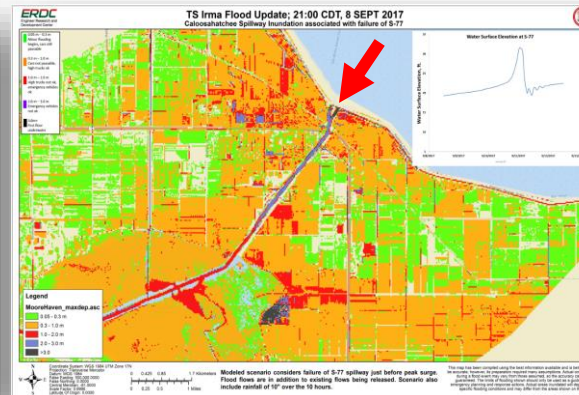
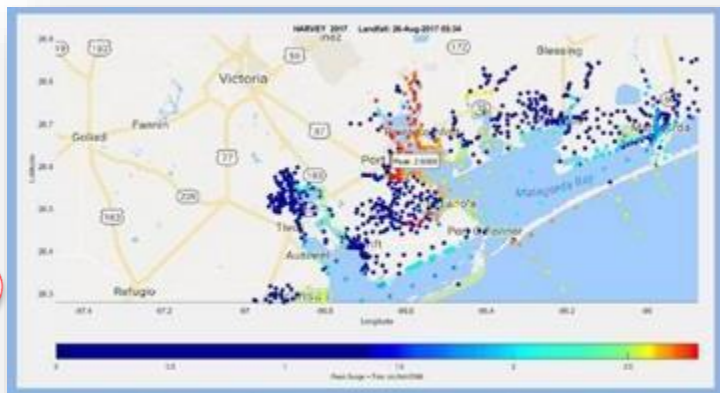
- **First-order inland flow and inundation estimates in < 6 hrs**
- **Used to plan evacuations and emergency operations**

\* Storm surge assumed to affect elevations < 5 m



# Lessons Learned

- Pre-calculated CHS archive and CHRPS tools enabled rapid forecasting of surge magnitude for range of potential landfall locations (South Atlantic/GOM)
- Existing numerical grids from previous studies enabled assessments in hours to days (aids EMs with reservoir operations and community evacuation)
- Range of tools and products facilitated applications in data-poor regions





# Recommended Research Needs

- Prepare: Improve Storm Inundation & Impact Predictions to include coupled coastal/inland models and morphology change (breaching) during storm events
- Prepare for the Next Storms:
  - Complete the Coastal Hazards System (CHS)
  - Develop Emergency Operations Real-Time Response & Recovery
  - Update Engineering Guidance to leverage lessons learned and technological advancements, prior to future storms.
- Prepare/Absorb/Recover: by incorporating Coastal System Resilience in rebuilding efforts including Natural and Nature-based Feature Design Tool

