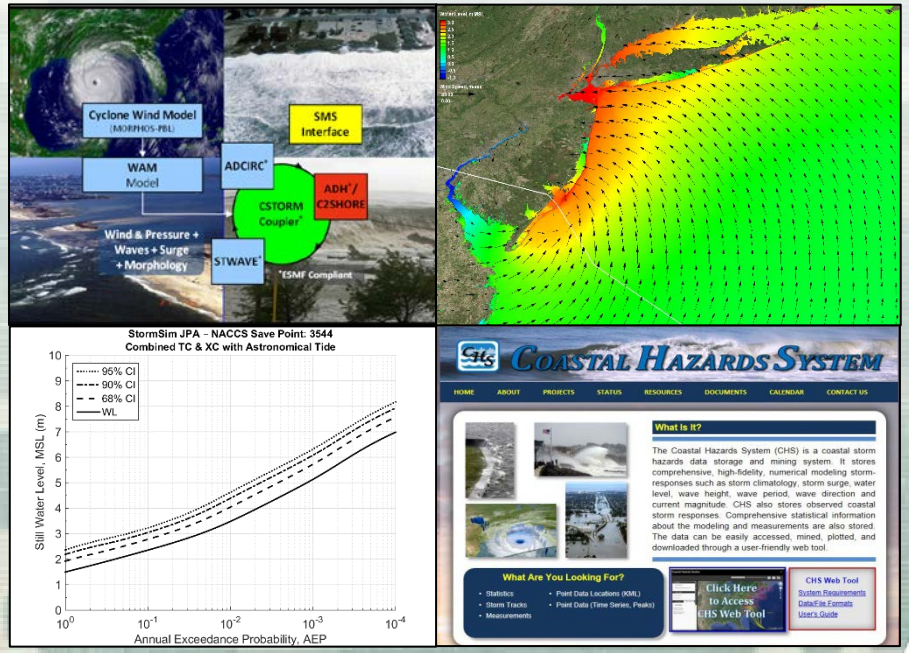
# North Atlantic Coast Comprehensive Study

## Storm Selection and Numerical Modeling

## An Overview

***Computing the Joint Probability of Storm Forcing Parameters from Maine to Virginia***



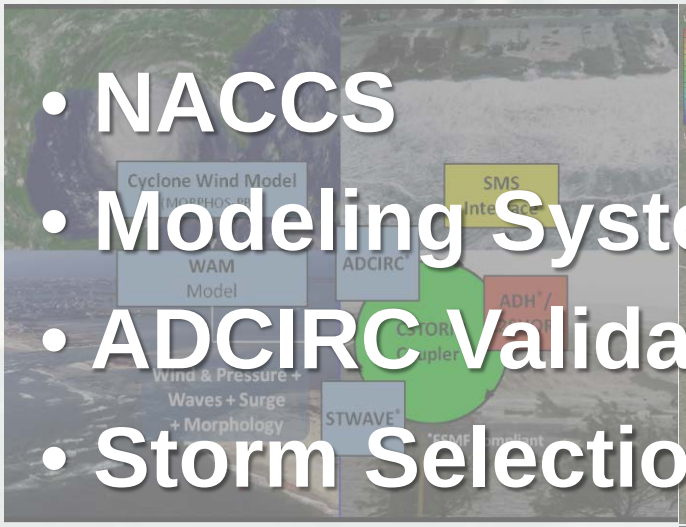

**Mary Cialone, Norberto Nadal-Caraballo, and Chris Massey**

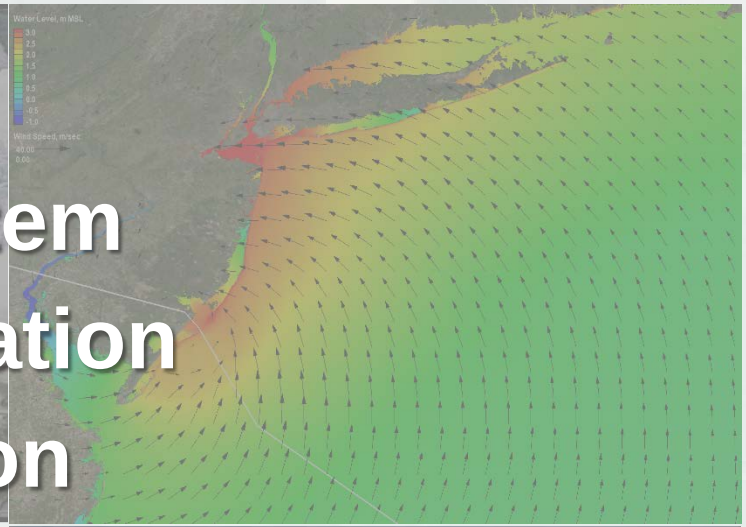
Numerical Modeling & Statistics Team Lead for NACCS

***U.S. Army Corps of Engineers***
*Engineer Research & Development Center*
*Coastal & Hydraulics Laboratory*

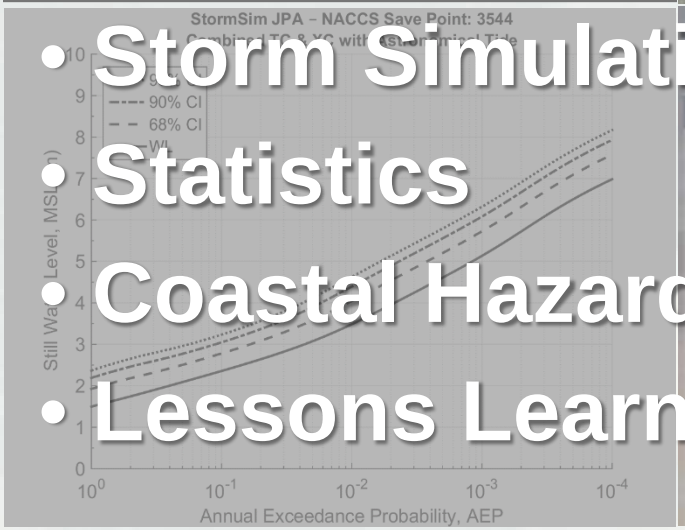
***Coastal Hazards Symposium***
***12 November 2015***

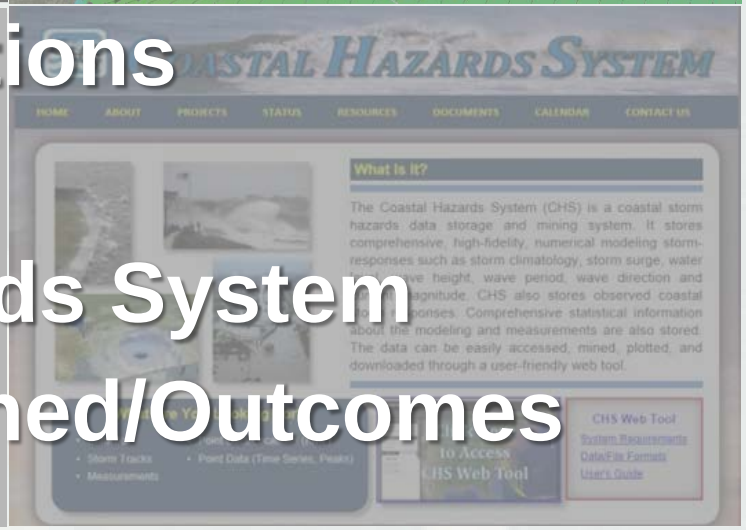
# Topics




- NACCS
- Modeling System
- ADCIRC Validation
- Storm Selection
- Storm Simulations
- Statistics
- Coastal Hazards System
- Lessons Learned/Outcomes

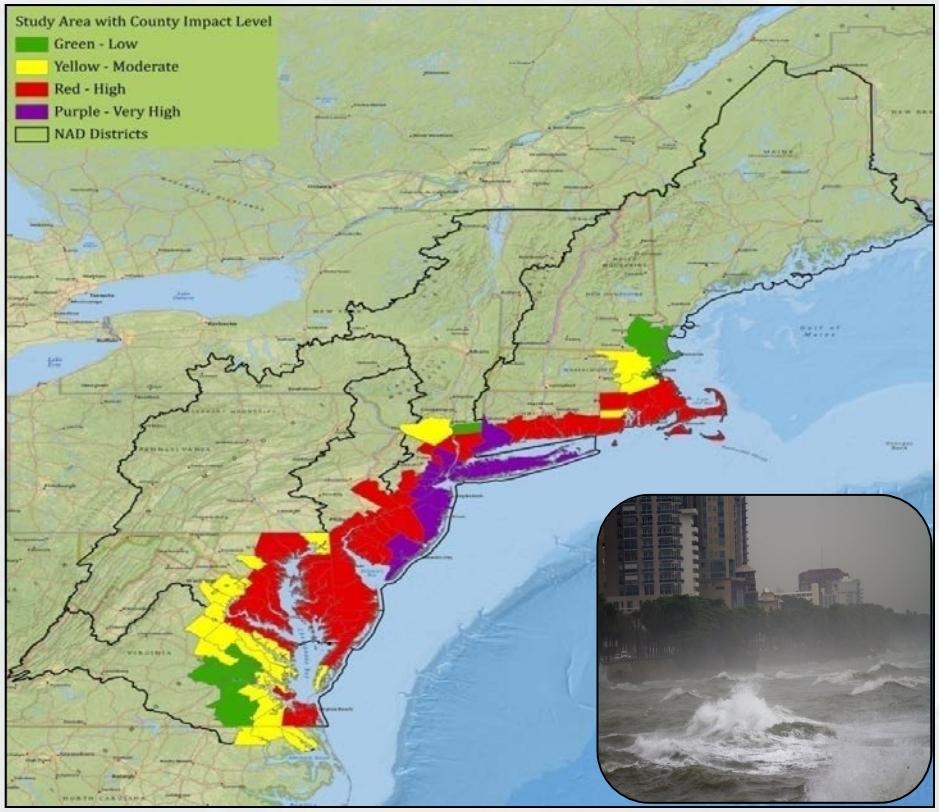


# After Sandy…

- Address **flood hazard** of vulnerable coastal populations
- Develop a **risk-reduction** framework consistent with U.S. Government (USACE/NOAA) Rebuilding Principles

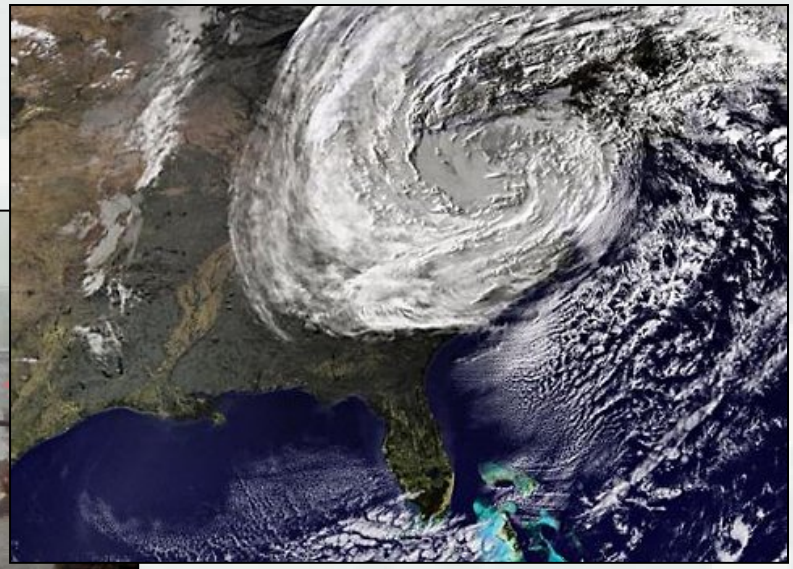
*collaboration, systems approach, risk awareness communicated*



# NACCS Goals

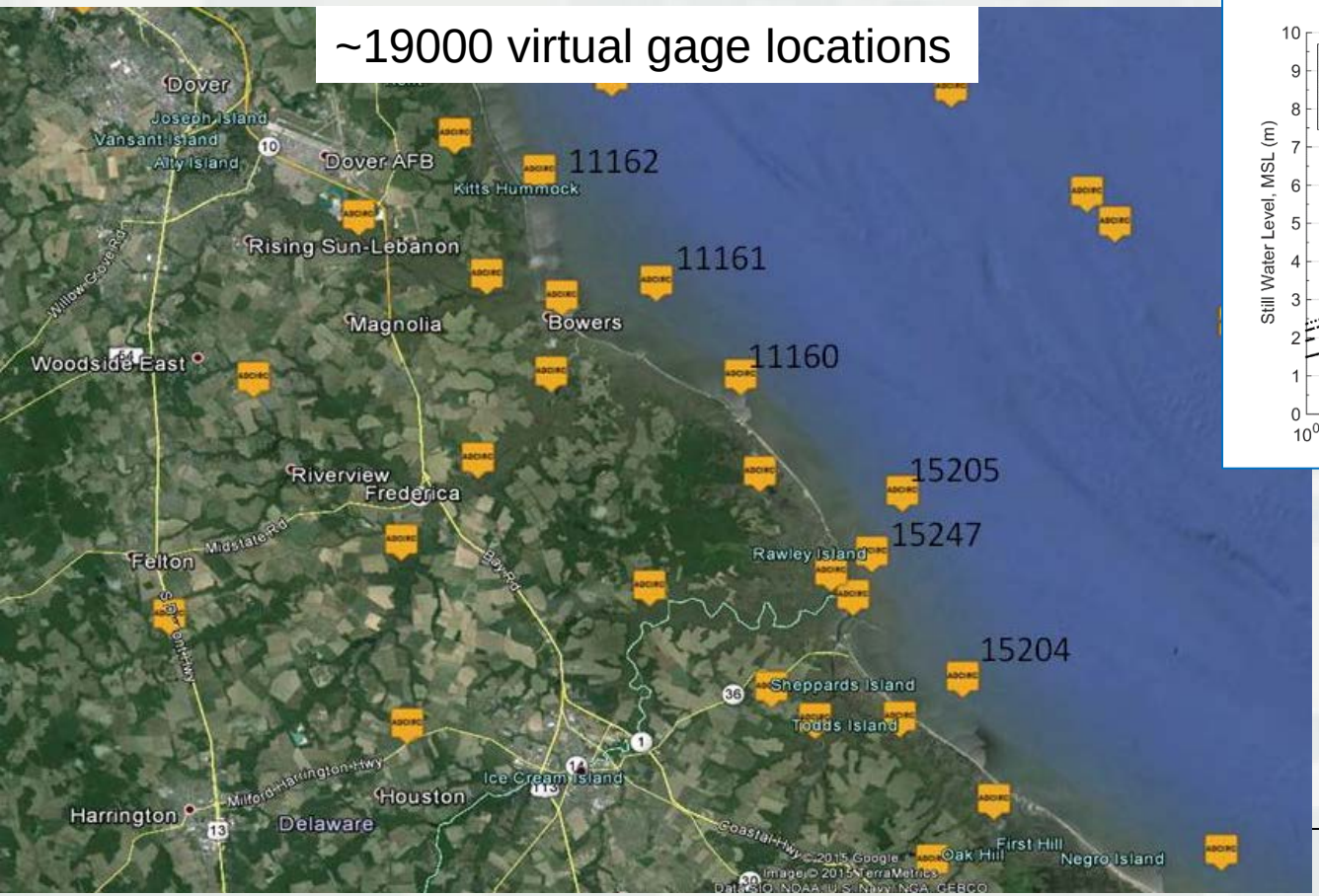
- Develop a method to quantify **resilience of coastal communities**

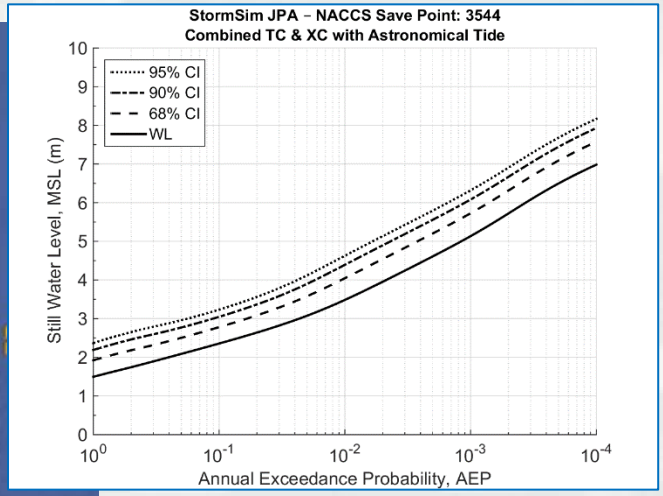
- Promote **coastal resilient communities** with sustainable and robust coastal landscape systems, considering future sea level rise and climate change scenarios, to reduce risk to vulnerable population, property, ecosystems, and infrastructure



# NACCS Numerical Modeling & Statistical Analysis Goal

compute statistics of coastal storm forcing parameters for the entire North Atlantic Coast

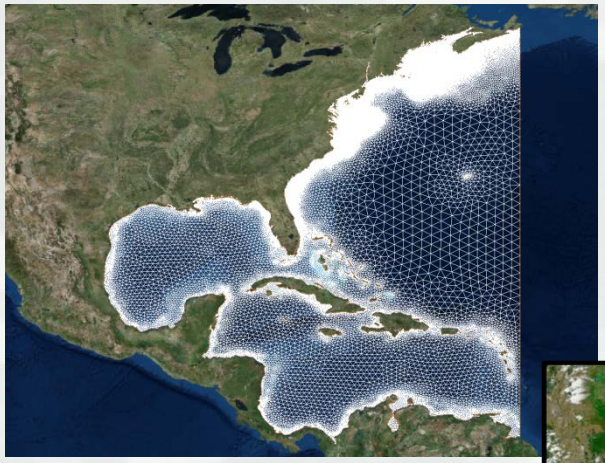


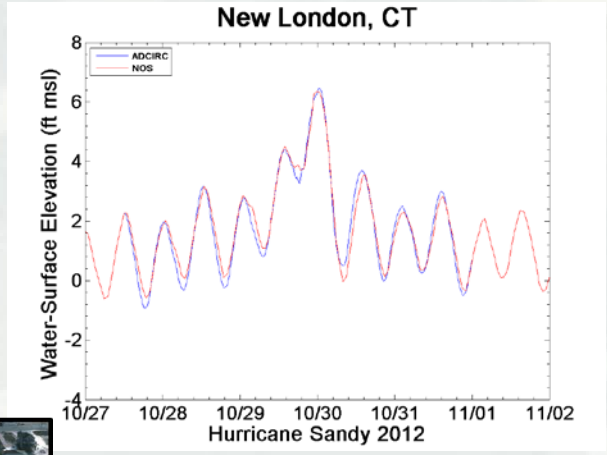



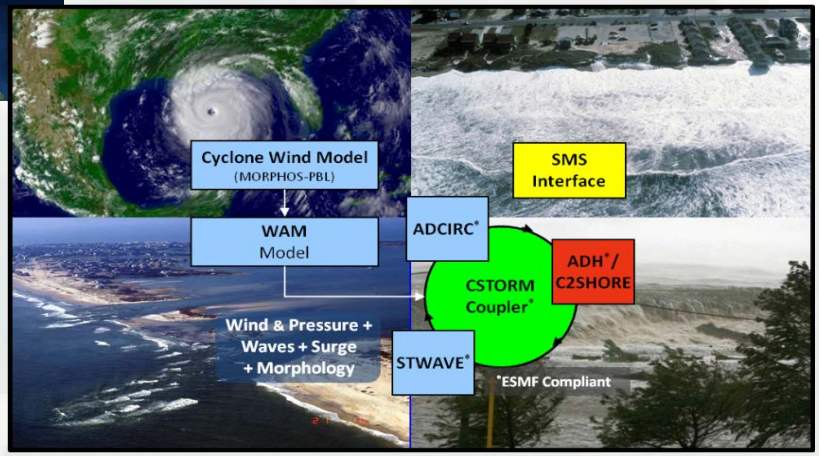

BUILDING STRONG®

# CSTORM-MS
## High Fidelity Modeling

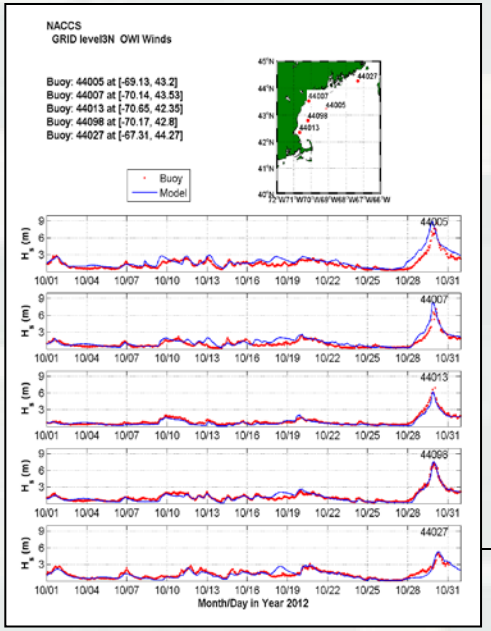
## ADCIRC



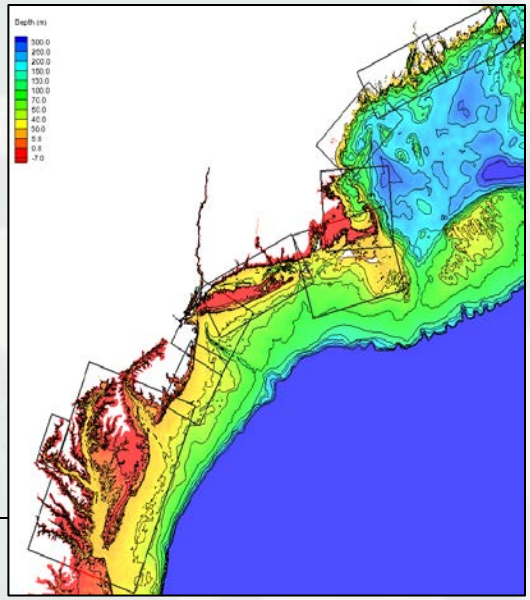



## WAM




## STWAVE

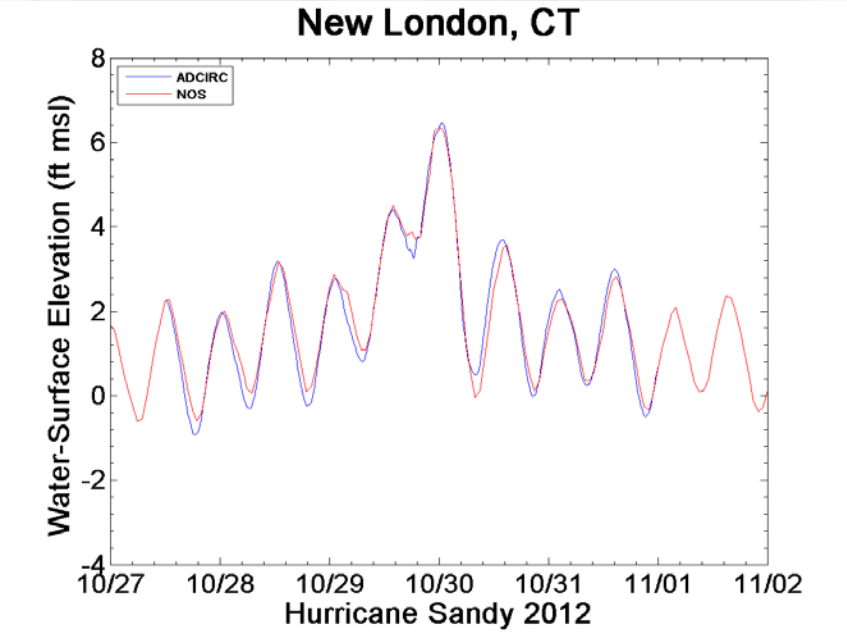


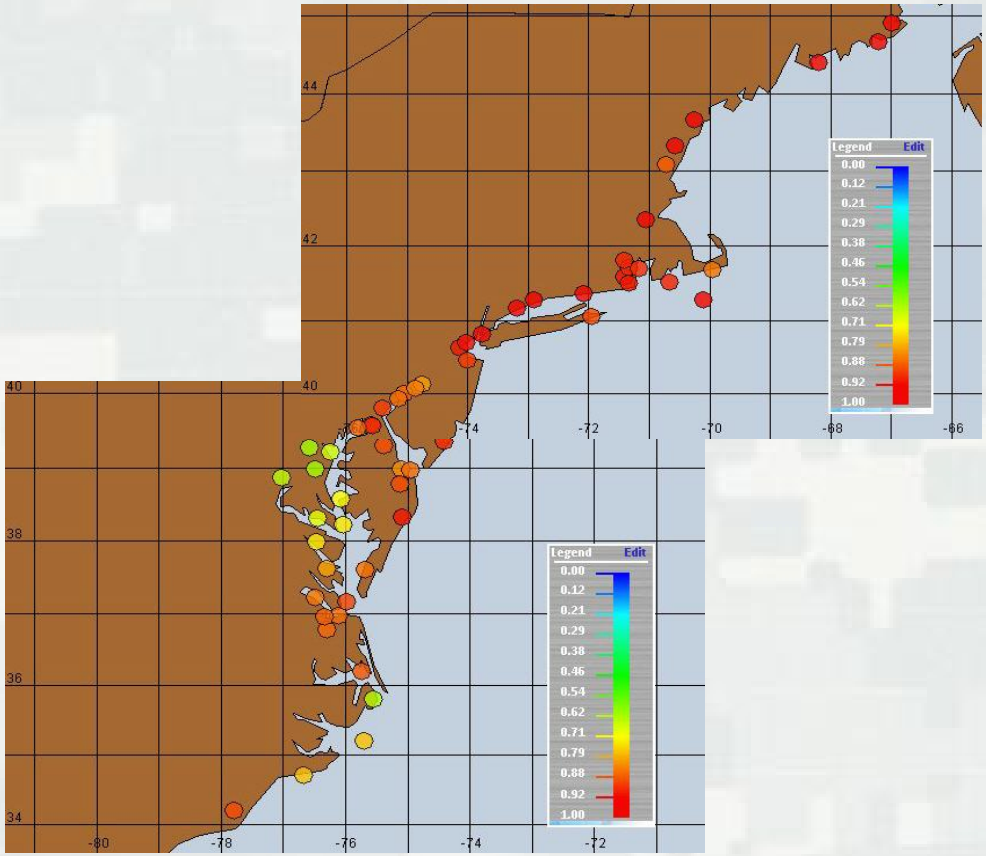
**CSTORM-MS: Coastal STORM Modeling System**

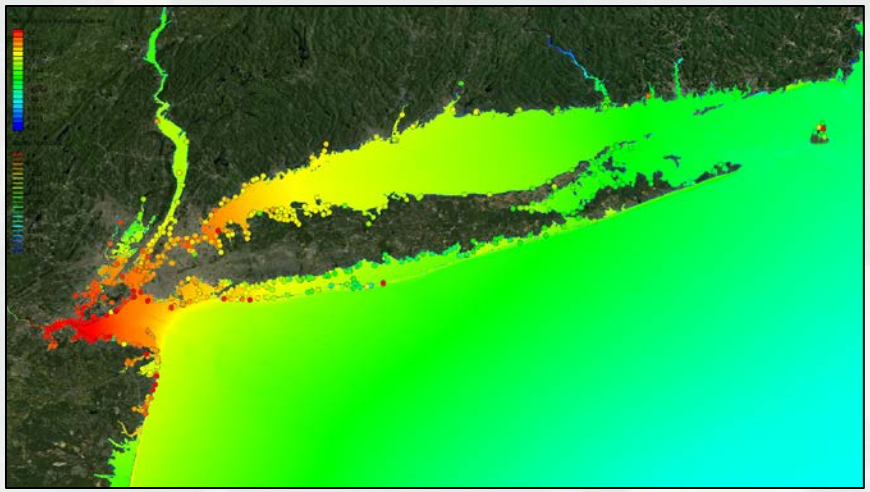
**WAM: WAve Prediction Model**
**STWAVE: STeady-State Spectral WAVE model**
**ADCIRC: ADvance CIRCulation Model**

# ADCIRC Validation

- Seven storms
- Time series (133 locations)
- High water marks
- IMEDS



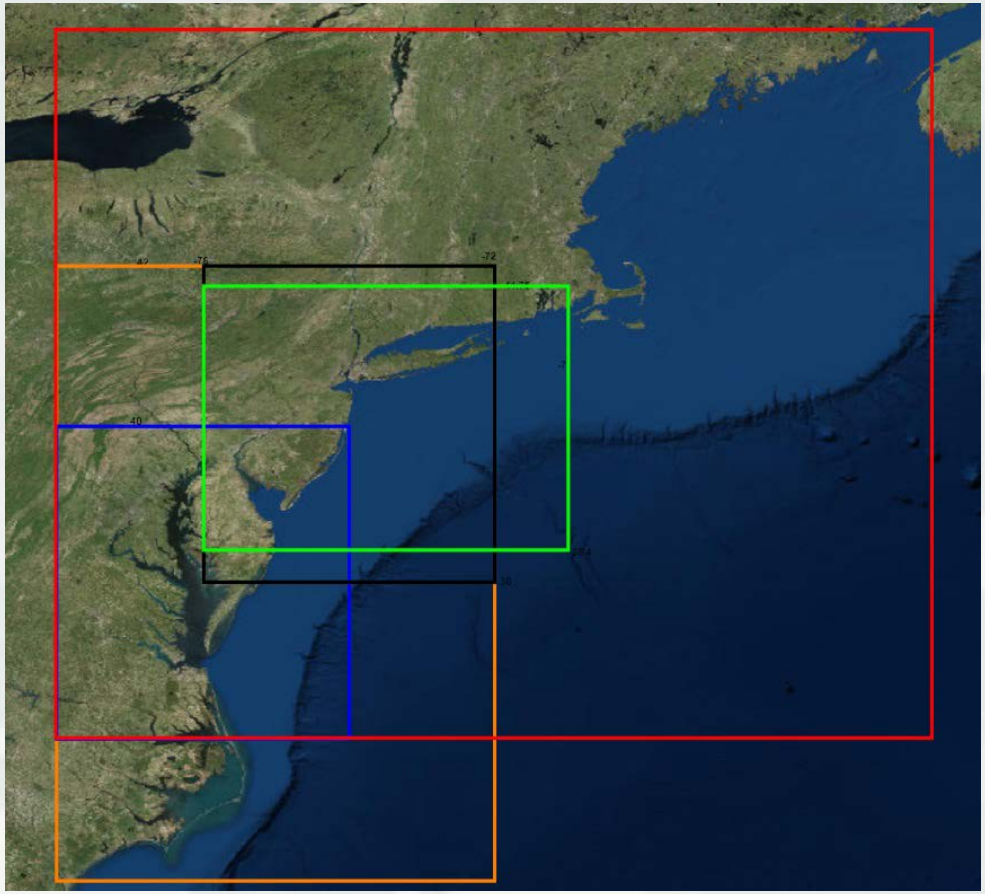



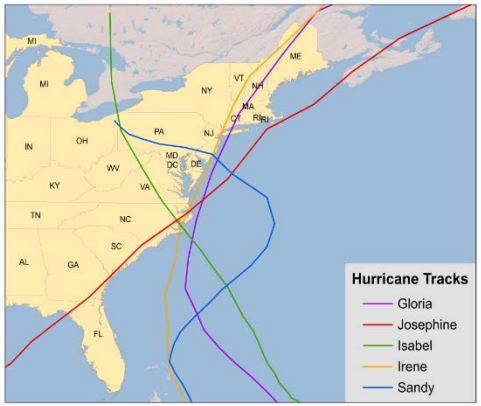
# ADCIRC Validation Storms

(Started with 8 tropical and 12 ETs)

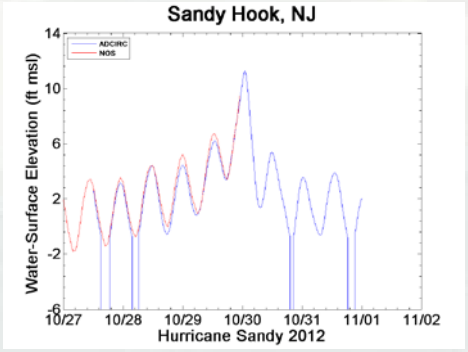
- **Tropical Events**
  - 1985 (Gloria)
  - 1996 (Josephine)
  - 2003 (Isabel)
  - 2011 (Irene)
  - 2012 (Sandy)
- **Extratropical Events**
  - 2 storms from FEMA studies

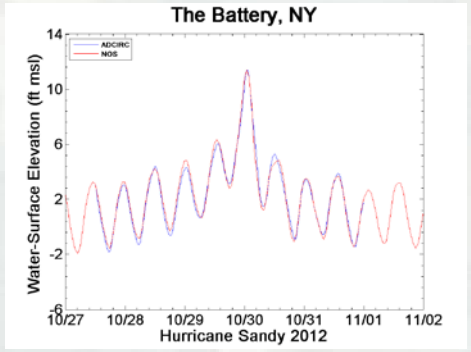


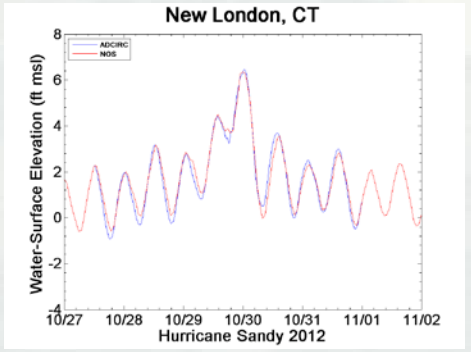
**Extent of the fine resolution winds for FEMA Region II winds (green box), other validation storms (blue, orange, and black boxes), and NACCS fine resolution winds (red box)**

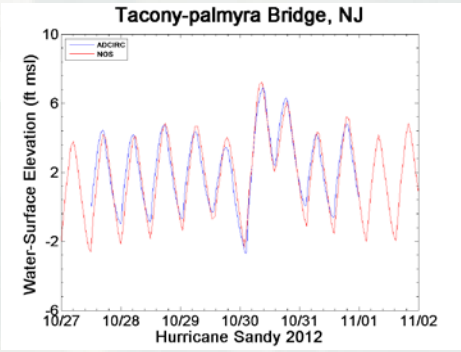


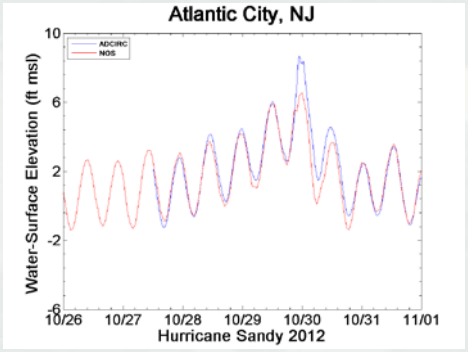
# Sandy



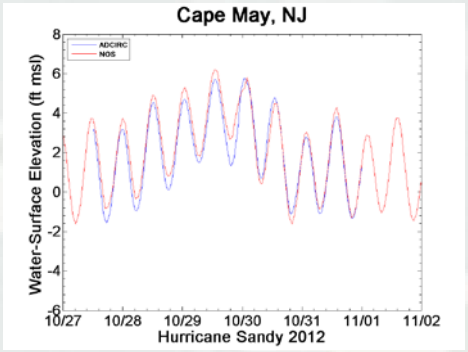



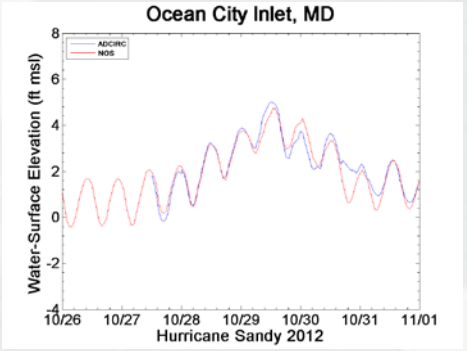



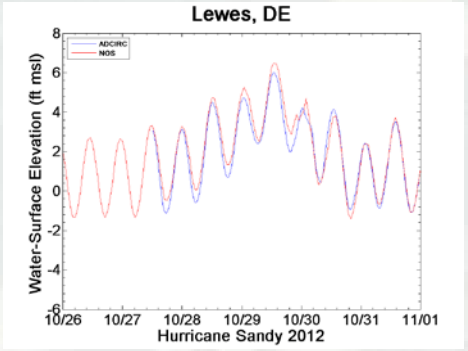







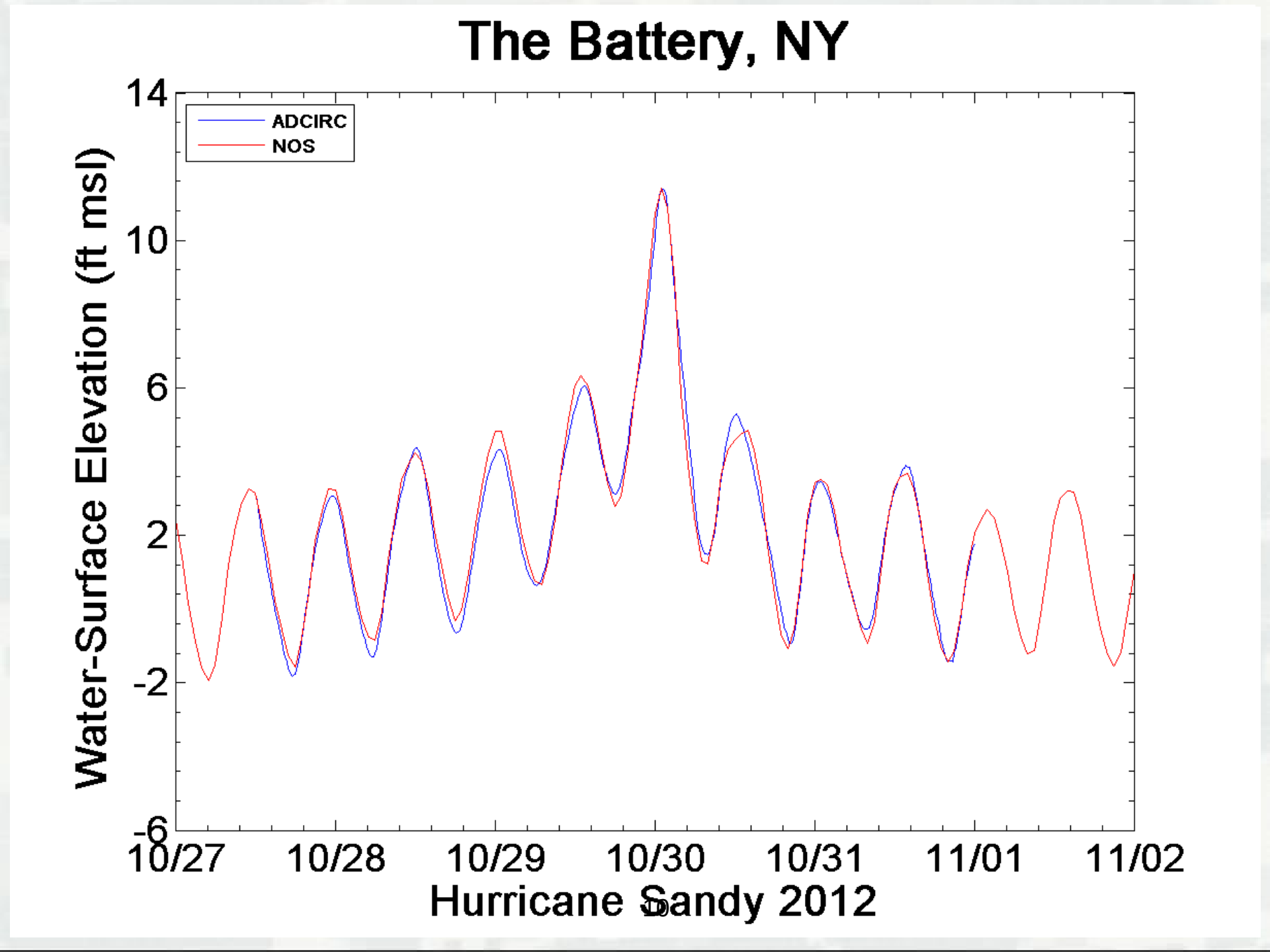



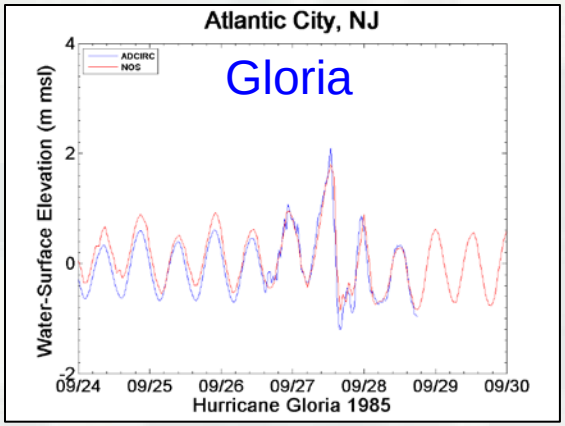

Measurement Location

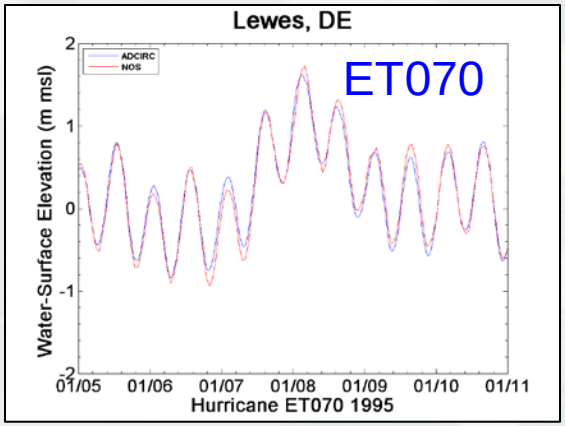
Modeled Water Level

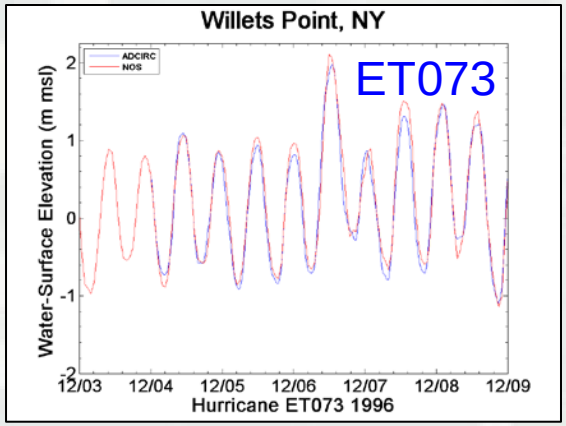
Measured Water Level

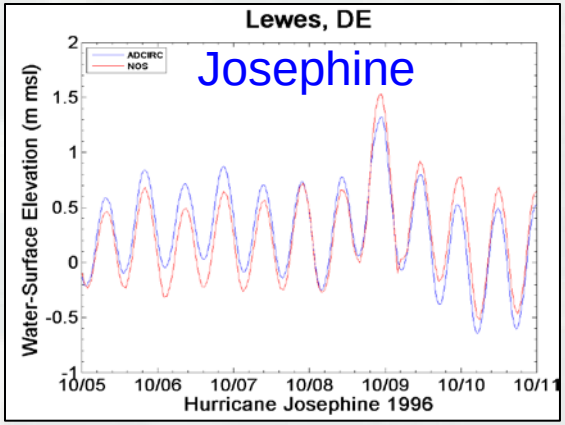

The Battery, NY
ADCIRC
NOS
Water-Surface Elevation (ft msl)
14
10
6
2
-2
-6
10/27
10/28
10/29
10/30
10/31
11/01
11/02
Hurricane Sandy 2012

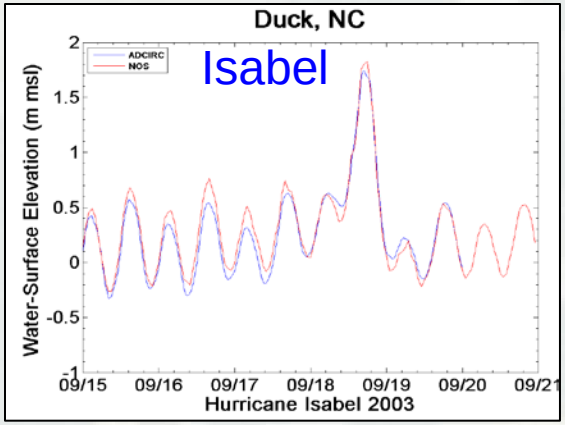
# All Validation Storms

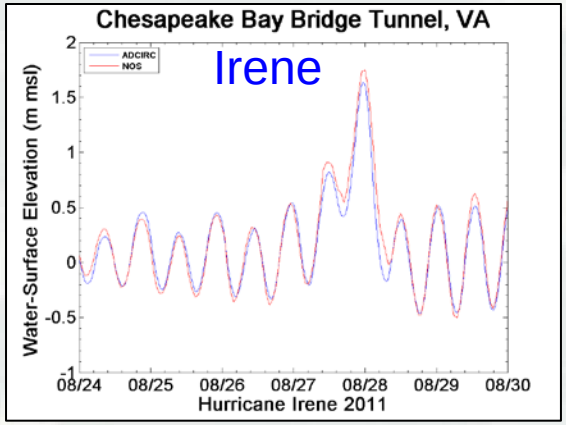


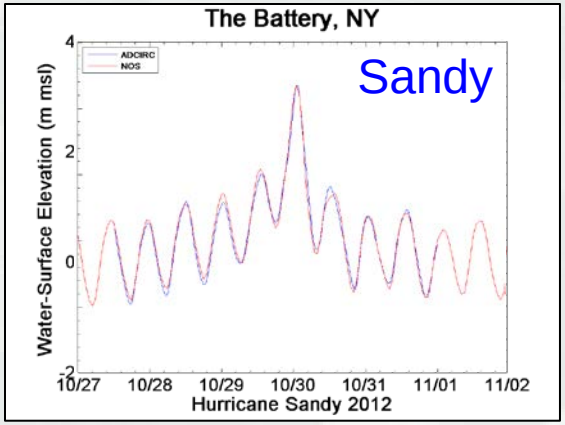



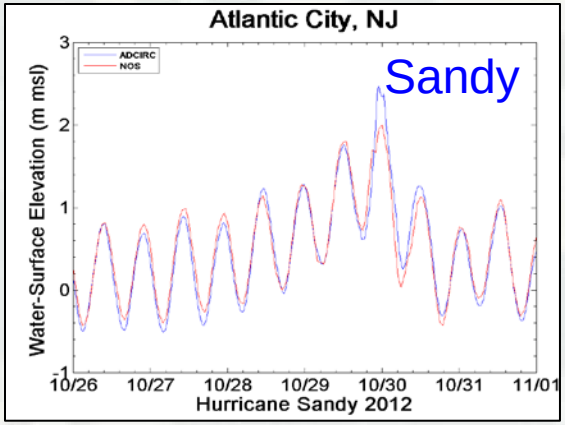



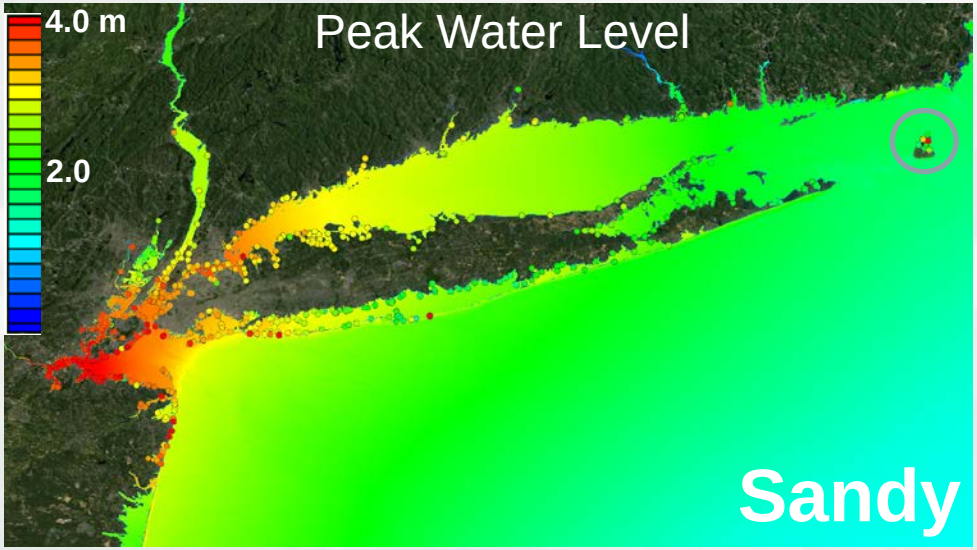



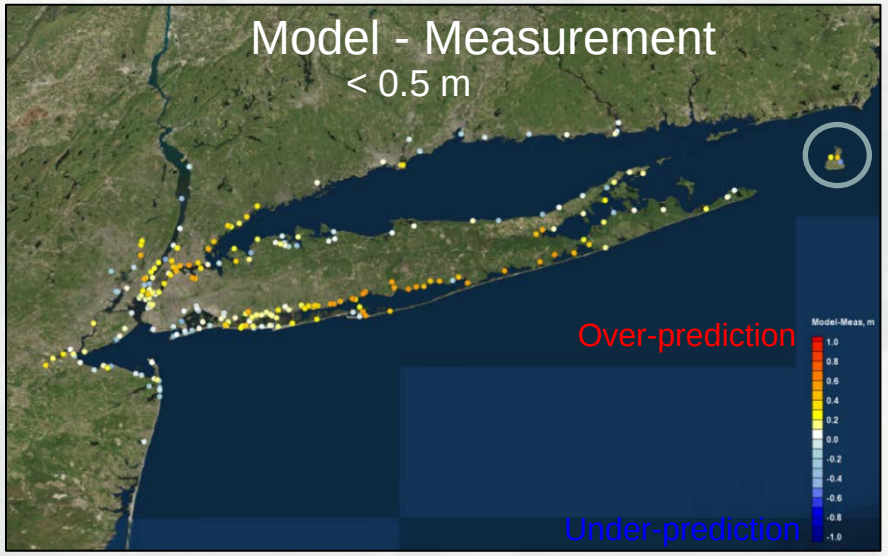




Modeled Water Level

Measured Water Level

# High Water Mark Comparison

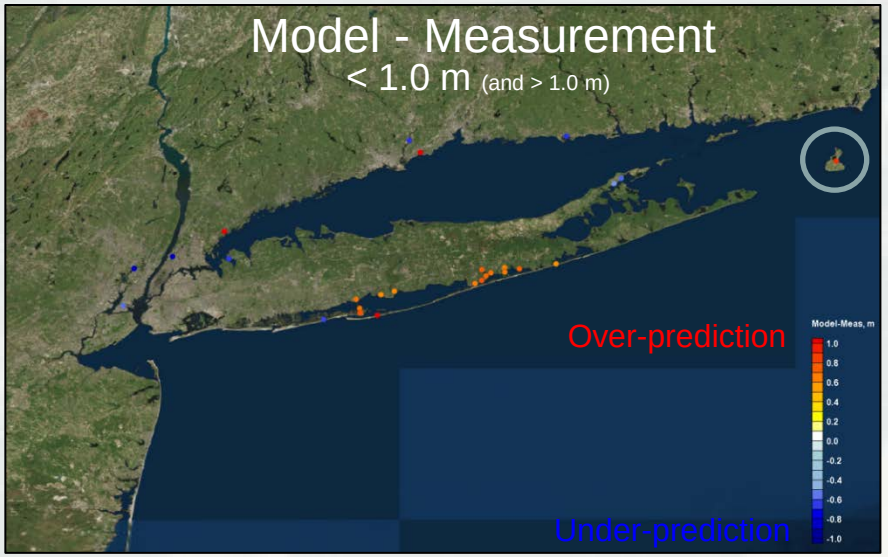



- 314 land locations

Model Results:

- 90% < 0.5 m; Avg=0.2 m
- 8.5% < 1.0 m
- 1.5% > 1.0 m (inaccurate measurement/geometric constrictions)
- Avg = 0.27 m; IPET =0.40 m

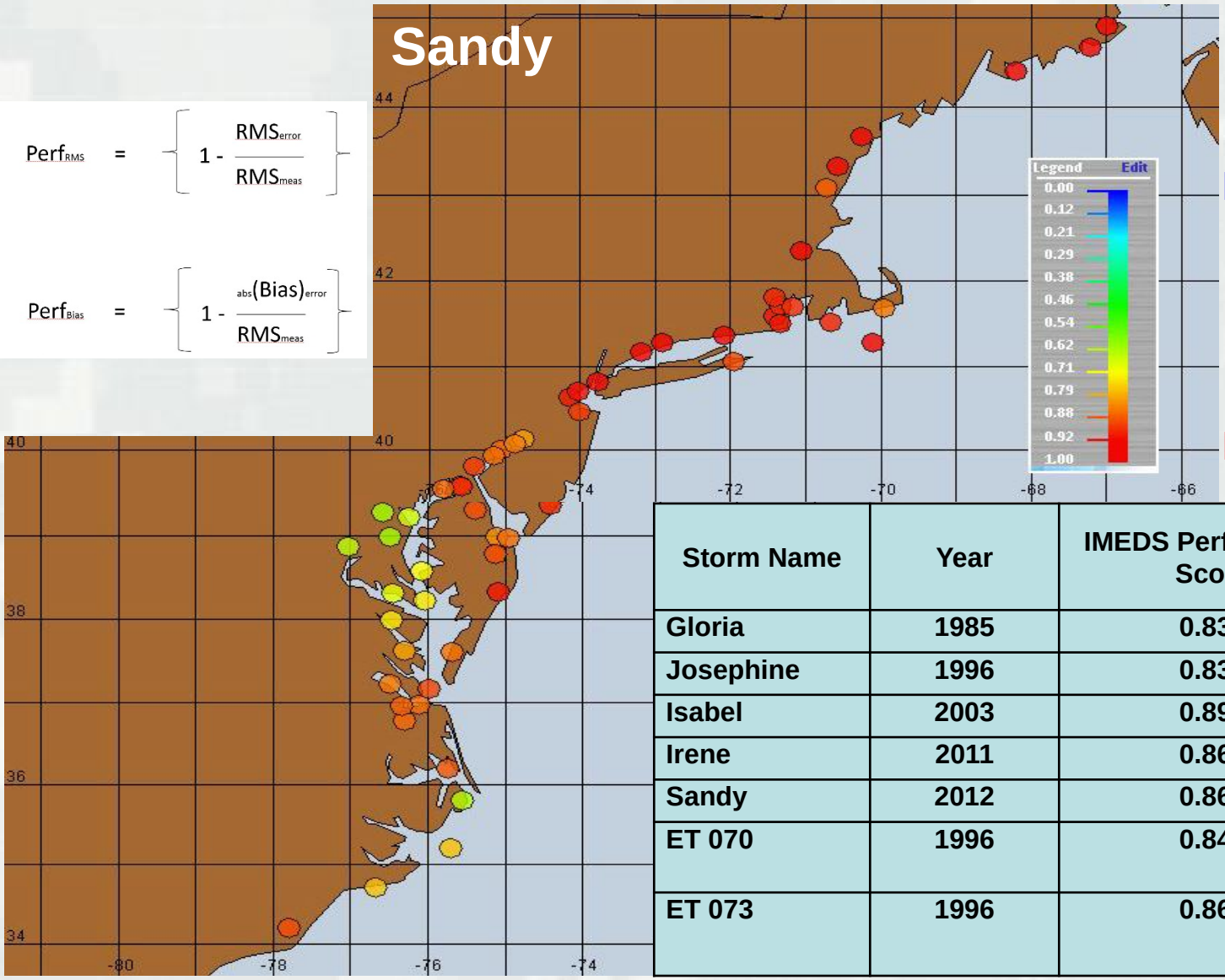


# IMEDS Performance Score

(**I**nteractive **M**odel **E**valuation and **D**iagnostics **S**ystem)

$$Perf_{RMS} = \left\{ 1 - \frac{RMS_{error}}{RMS_{meas}} \right\}$$

$$Perf_{Bias} = \left\{ 1 - \frac{{}_{abs}(Bias)_{error}}{RMS_{meas}} \right\}$$

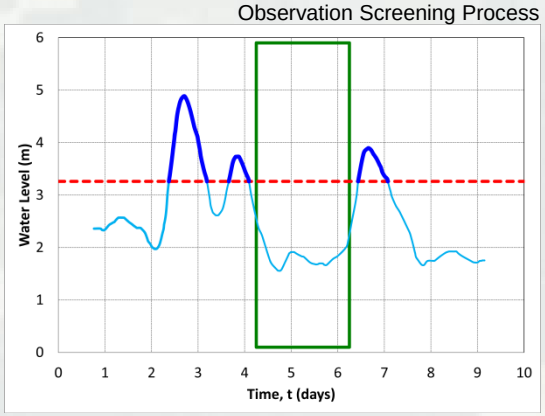



| Storm Name | Year | IMEDS Performance Score | IMEDS Overall Bias (m) |
|---|---|---|---|
| Gloria | 1985 | 0.838 | 0.014 |
| Josephine | 1996 | 0.834 | 0.014 |
| Isabel | 2003 | 0.890 | -0.003 |
| Irene | 2011 | 0.868 | 0.005 |
| Sandy | 2012 | 0.868 | -0.04 |
| ET 070 | 1996 | 0.841 | 0.015 |
| ET 073 | 1996 | 0.862 | -0.004 |

# Storm Selection

## Historical Storms – *applied to extratropical events*

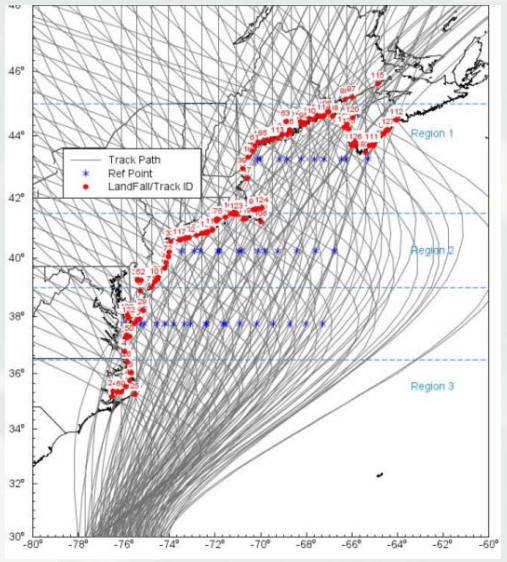
- 23 NOAA water level stations
- 30-yr record or more
- Peak-over-threshold
- 100 storms selected
- Composite Storm Set method (Nadal-Caraballo et al. 2014)




## Synthetic Storms – *applied to tropical events*

- Radius to maximum winds
- Central pressure
- Forward speed
- Track
- Landfall location

**1050 storms**



# NACCS Storm Suite

- 100 Historical Extratropical Storms
- 1050 Synthetic Tropical Storms

**1150 Total Storm Population**

**Model Simulations: 1150 Storms x 3 conditions:**

- Surge and wave only (base)
- Surge and wave and tide
- Surge and wave and tide and sea level change

**Total Storms simulated: 3450**

# HPC Resources: 3450 Storm Simulations

Department of Defense Supercomputing Resource Centers (DSRCs)

## USACE


Garnet: Cray XE6

4,716 compute nodes
32 cores/node
150,912 processors

## Air Force


Spirit: SGI Ice X

4,590 compute nodes
16 cores/node
73,440 processors

## Navy


Armstrong: Cray XC30

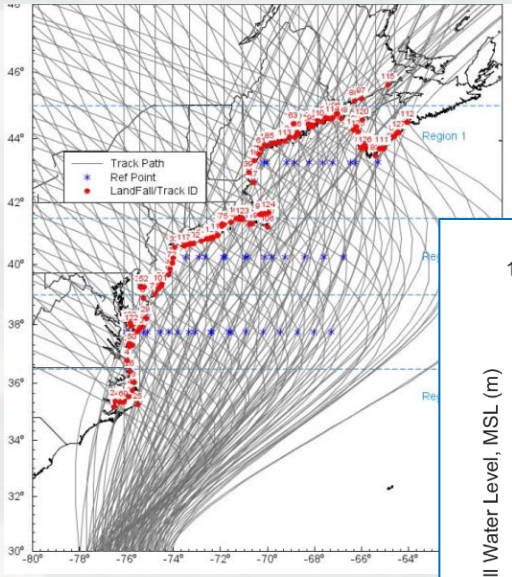
1,347 compute nodes
24 cores/node
32,328 processors

- *100M CPU hours*
- *Largest CW project*
- *40% Garnet and 60% Armstrong*
- *8-month time frame*

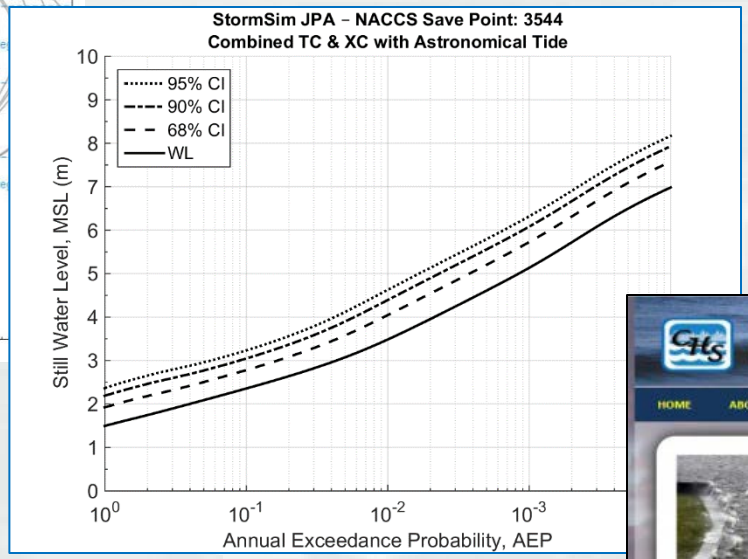
# Statistics and Coastal Hazards System

## State-of-the-art statistical methodology

Joint Probability Method with Optimal Sampling ( JPM-OS)




- USACE – Guidance documents
- FEMA – Flood mapping
- NRC – Regulatory documents



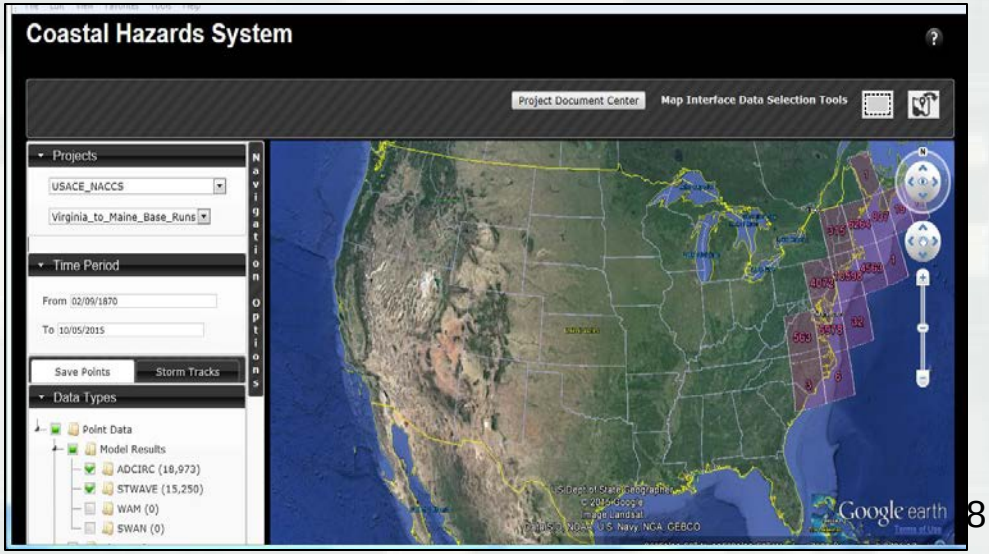

**CHS – Web-Based Tool**

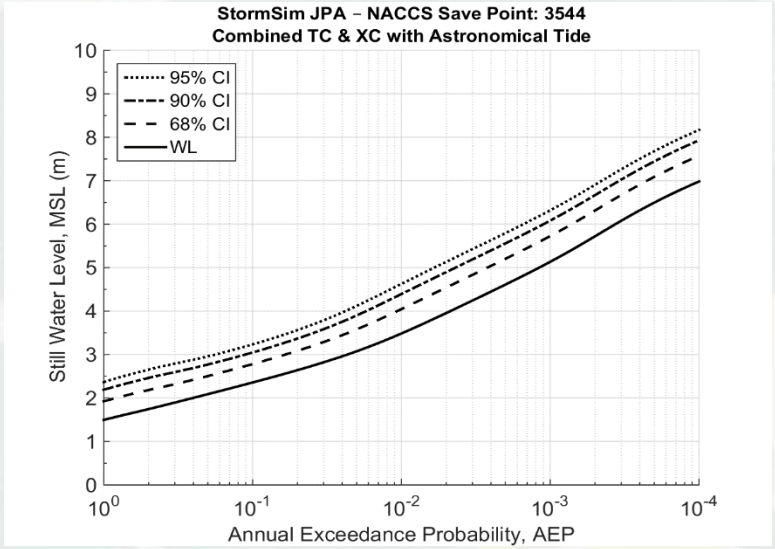
# Data Products

*serve the coastal engineering and management communities 10+ years*

- **Model results – waves, water levels, wind and pressures at ~19000 "virtual gage" locations as well as regionally**
- **Statistics – probability of storm response**
- **Coastal Hazards System - web-based software**

  Improved method of delivery of information; well-vetted; QA/QC; available



# Economies of Scale

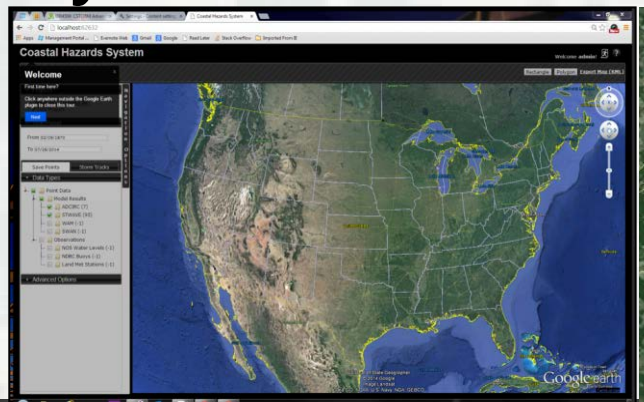
***spatial extent/quantity of reusable data from regional model***

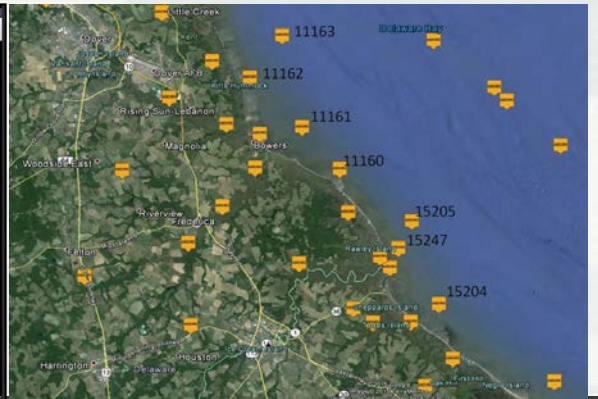
- **Regional model – detailed resolution from Virginia to Maine**
- **Reusable data – new project decisions; input conditions for fine scale modeling**

  FEMA Comparisons: Union Beach, Port Monmouth, Asharoken, Staten Island

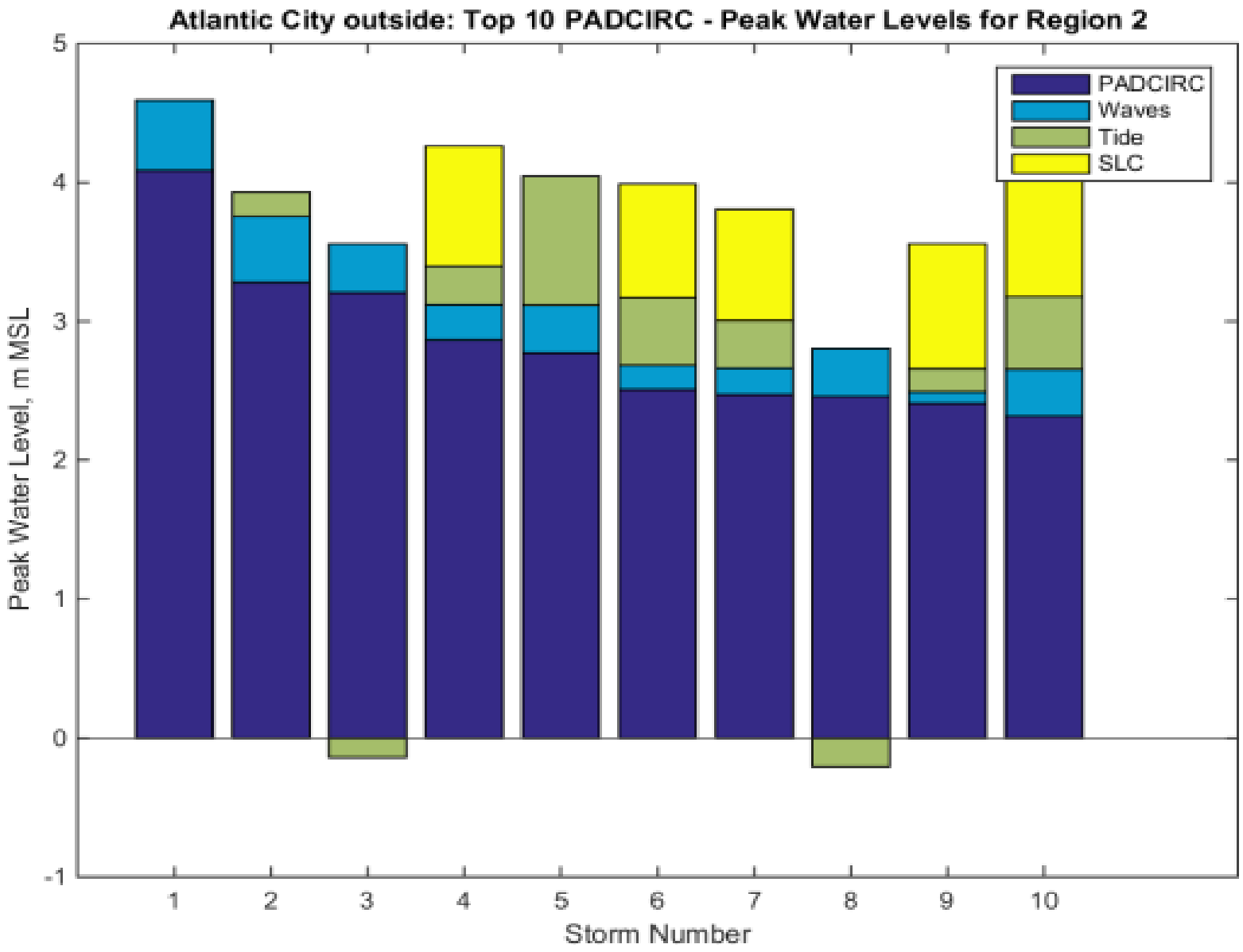
  Feasibility Studies: Hashamomuck, NY; Passaic, NJ; Rahway Tidal, NJ; East Rockaway, NY; Jamaica Bay, NY; Delaware Bay DMU

  Univ of Rhode Island, Virginia Tech, and George Mason University
- **Available to others – Coastal Hazards System accessible to Corps, Federal/State Partners, Coastal Community**
  - **On-line Help**
  - **On-line Tutorials**
  - **Users Guide**



# Sample Analysis

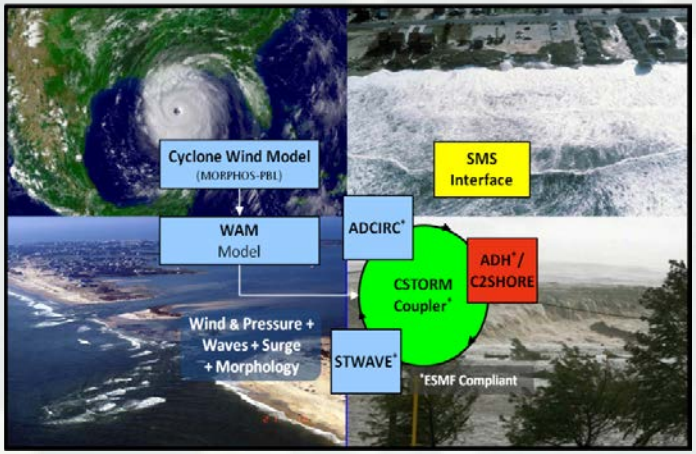


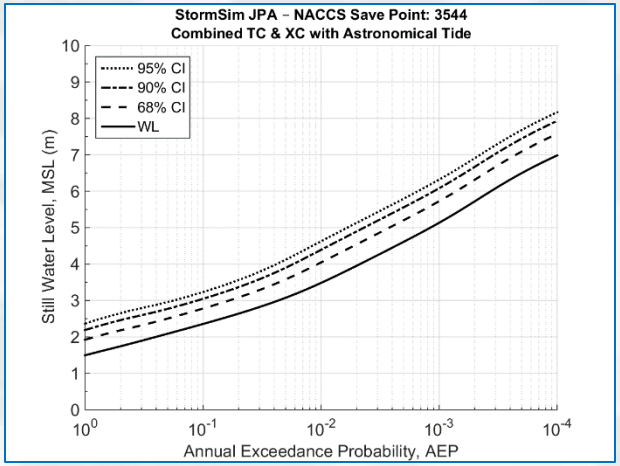
# Relevance

*technical advancements post-Katrina; enterprise modeling and analysis methods; USACE engineering guidance update*

- **CSTORM-MS – high-resolution, highly-skilled physics-based models in a tightly-integrated modeling system; computational leaps in HPC**
- **Statistical analysis – JPM-OS state-of-the-art scientific tools**
- **Incorporated into Corps guidance**

- *Physical representation of land features*
- *Frictional resistance*
- *Wetting/Drying*
- *Coupling*
- *Efficiency*
- *Magnitude*
- *3000+ storms*
- *3M nodes*
- *High level scripting*
- *CPU hours*

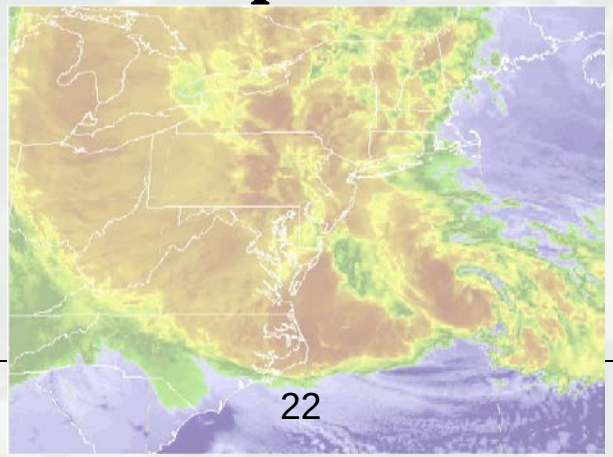


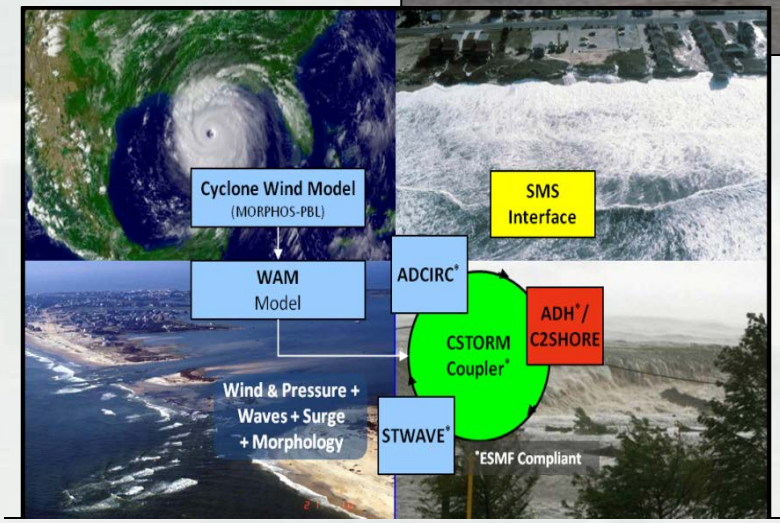
# Summary Outcomes of NACCS

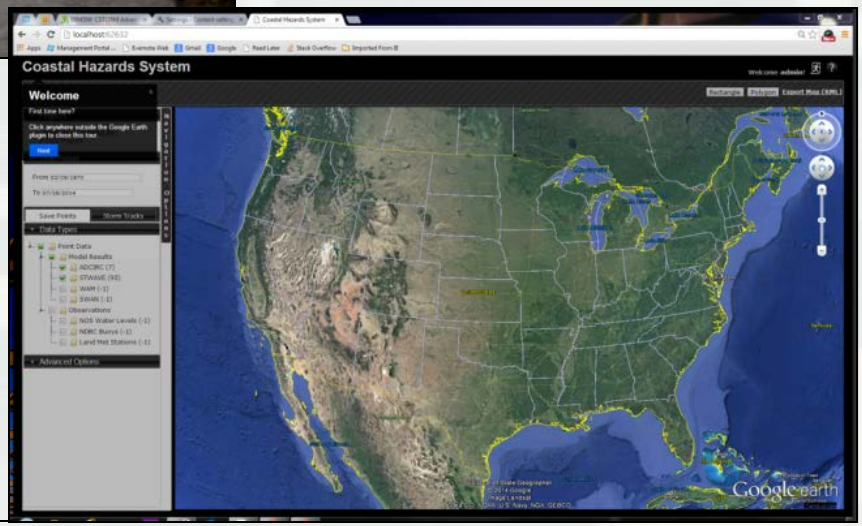
## *Numerical Modeling and Statistical Analysis*

- ***Data Products*: serve the coastal engineering and management communities 10+ years**
- ***Economies of Scale*: spatial extent/quantity of reusable data from regional model**
- ***Relevance*: technical advancements post-Katrina; enterprise modeling and analysis methods; USACE engineering guidance update**



# Questions?


Cyclone Wind Model
(MORPHOS-PBL)
WAM
Model
Wind & Pressure +
Waves + Surge
+ Morphology
SMS
Interface
ADCIRC*
CSTORM
Coupler*
ADH*/
C2SHORE
STWAVE*
*ESMF Compliant


Coastal Hazards System
Welcome
Google earth