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Applications of the ADCIRC Storm Surge, Tide, and Wind-Wave Model

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Homeland Security
Science and Technology

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

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RESEARCH ENGAGEMENT INNOVATION

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Applications of the ADCIRC Storm Surge, Tide, and Wind-wave Model

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Hampton Roads Sea Level Rise/Flooding Adaptation Forum

Storm Surge Modeling Tools for Planning and Response

January 23, 2015

Overview

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- What is ADCIRC
- Resource Requirements
- Recent Applications of ADCIRC
  - Coastal Hazards/FEMA
  - Forecasting
  - Validation Studies

ADCIRC (http://www.adcirc.org)

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- Computer model for storm surge, tides, and wind waves
- Origination in early-1990's via USACE funding
  - Rick Luettich (University of North Carolina at Chapel Hill)
  - Joannes Westerink (University of Notre Dame)
- Continual development by community of software, numerical, and storm surge experts

ADCIRC (http://www.adcirc.org)

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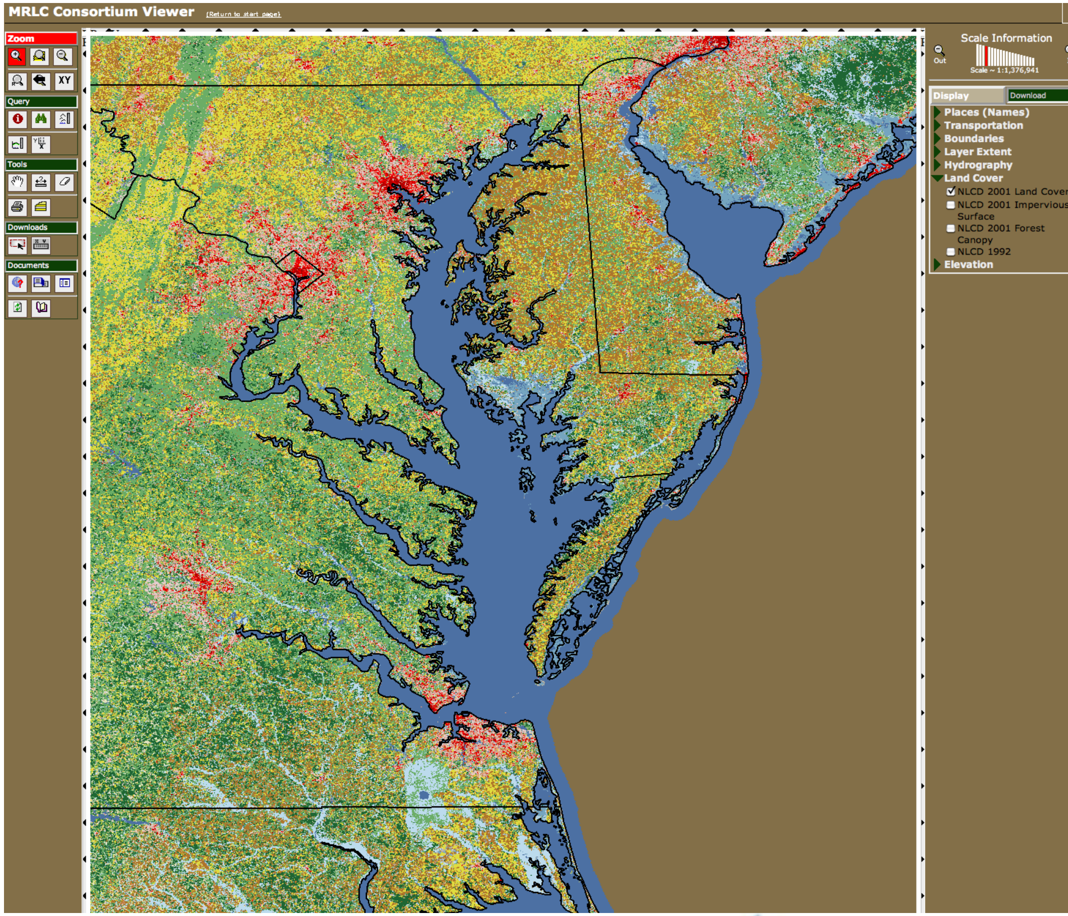
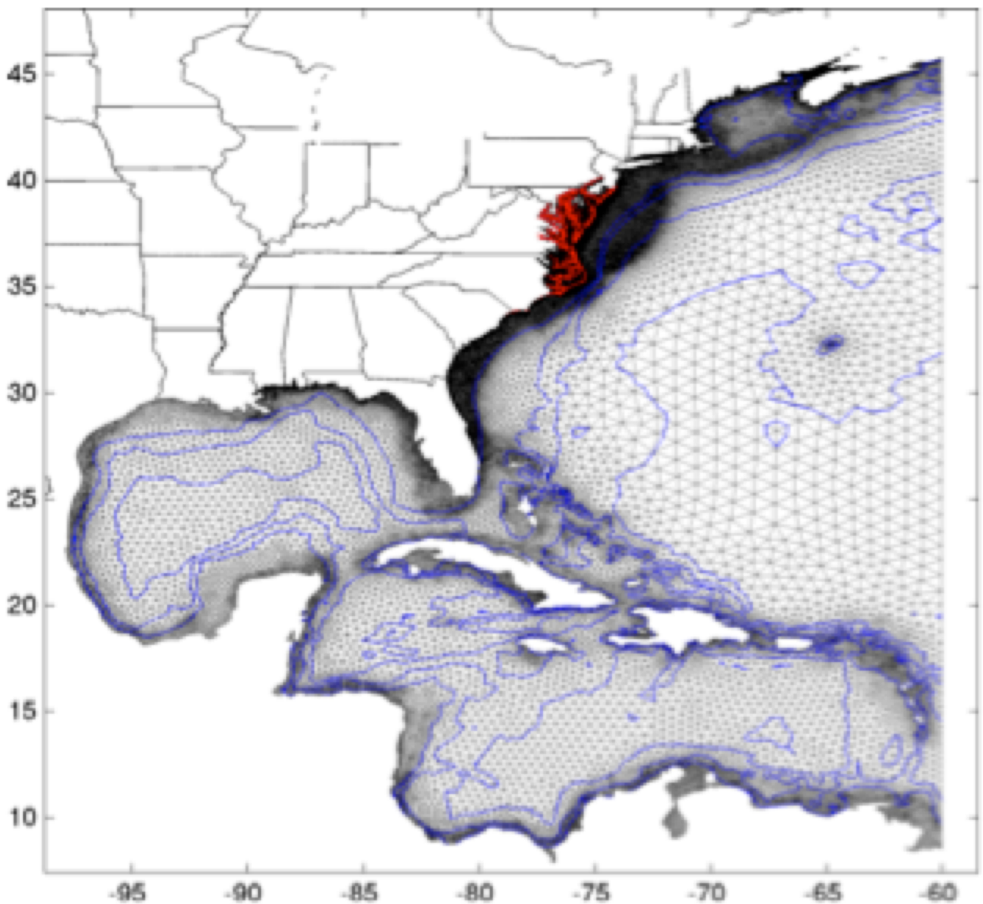
- Triangular Finite Elements
- Efficient Parallel implementation
- Local Topography and Bathymetry
- Critical Hydraulic Structures and Raised Features
  – block and convey flow (levees, roadways, channels)
- Local land roughness
- Formally coupled to the finite element version of SWAN (*Simulating WAves Nearshore*)
- Effects of breaking short waves

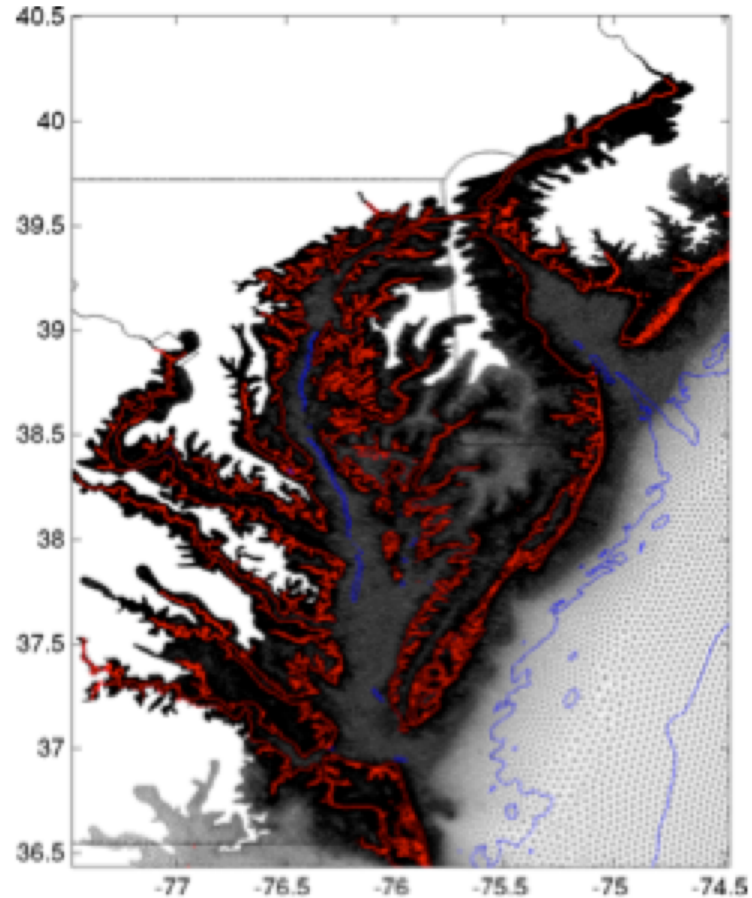
National Land Cover Database



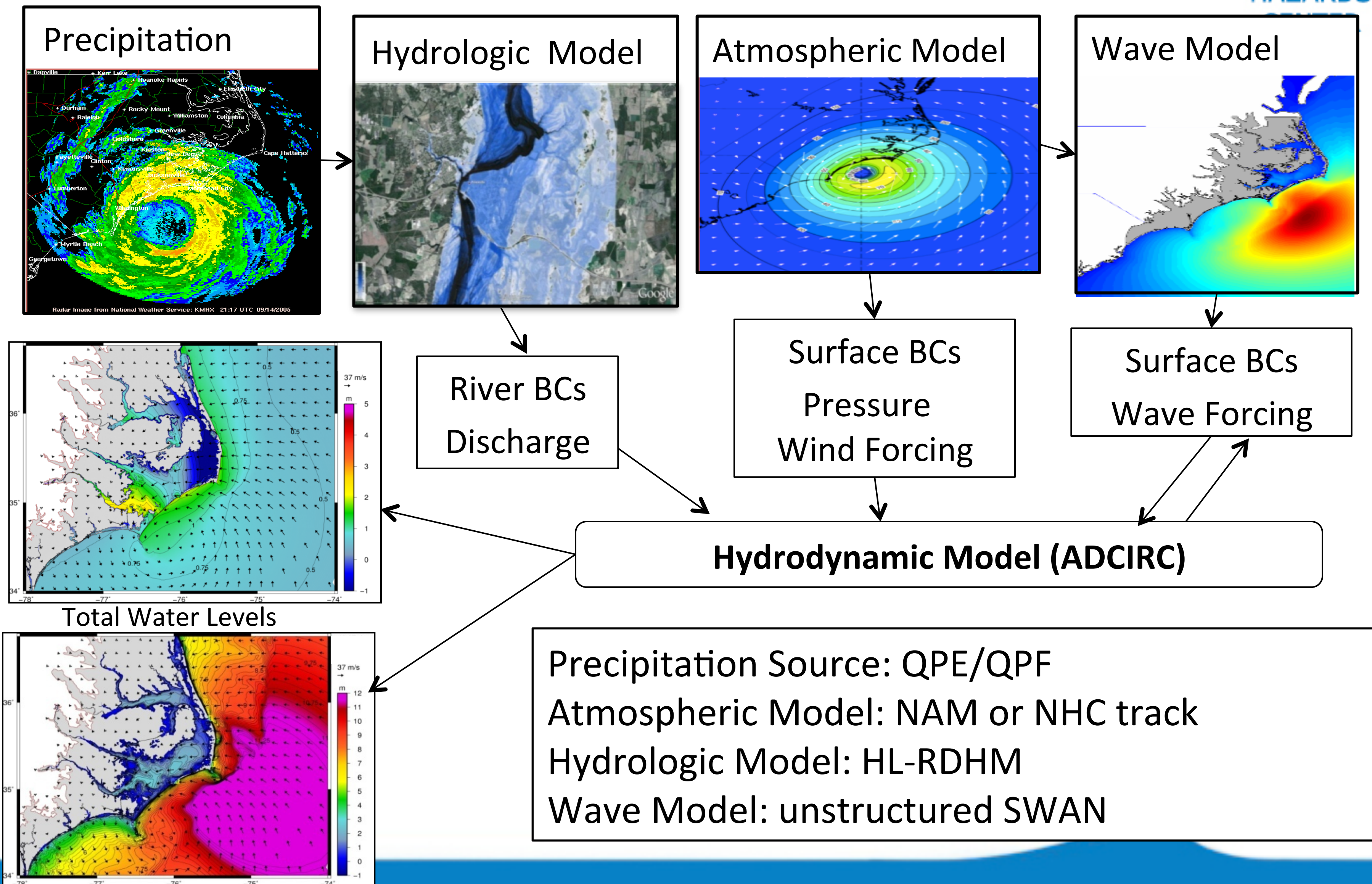
ADCIRC (http://www.adcirc.org)

Triangular Finite Elements





ADCIRC Surge Guidance System (ASGS)



Precipitation Source: QPE/QPF
Atmospheric Model: NAM or NHC track
Hydrologic Model: HL-RDHM
Wave Model: unstructured SWAN

Generic Model Development Process

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$\vec{F} = m\vec{a}$

Forces include:
atmospheric winds
and pressure, waves, tides

Formulate problem using
Partial Differential Equations
for shallow-water rotating
fluid
[GWCE]

Turn in to a set of
algebraic equations

$Ax = b$

Turn into a Computer Code to
solve Linear Algebra Problem

Run models on
Computers

ADCIRC Surge/Inundation

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Governing Equations:

Mass Conservation

Newton's 2nd Law of Motion: **F** = M x **a**

+ Assumptions & Averaging

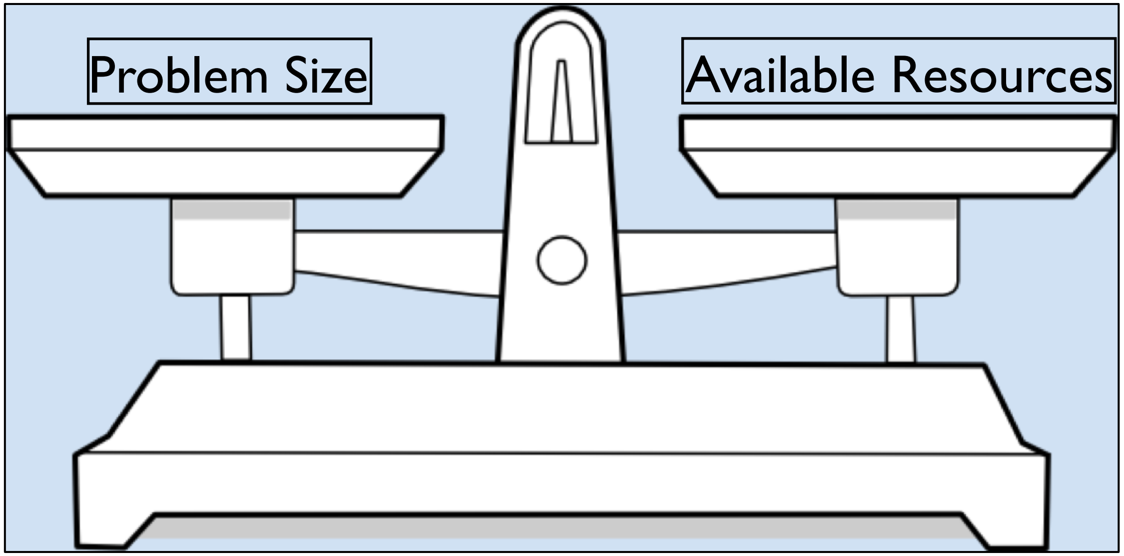
Shallow Water Equations (2D or 3D)

Solve for: (timescales > 10 minutes)

- water surface elevations
- currents
- wind-wave energy spectra

Resource Requirements

Balance must be found between



1) Project Resolution
   - per-simulation resource costs
2) Resources Available (read $$$$$)
   - Storage Requirements (permanent, temporary)
3) Project "schedule"

- VERY difficult to meet all three requirements.
- Generally, only TWO of these can be met. One MUST be redefined.

Resource Requirements

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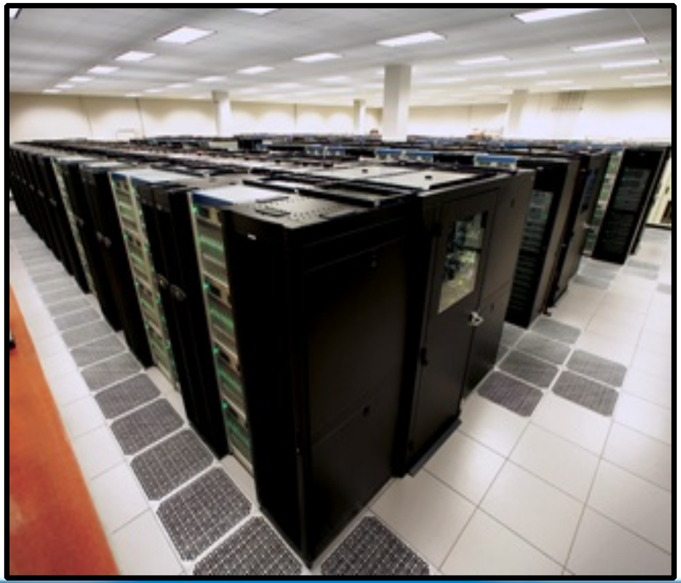
- ADCIRC can certainly run on local computers, including multi-core desktops
  - Limits resolution/number of model nodes

- High resolution models require significant and reliable computing resources

- Typically use high performance computing at:
  - RENCI/UNC – North Carolina
  - LSU & USACE/ERDC – Louisiana
  - UND – Puerto Rico & US VI
  - UT – Texas
  - CUNY – NY



Resource Requirements

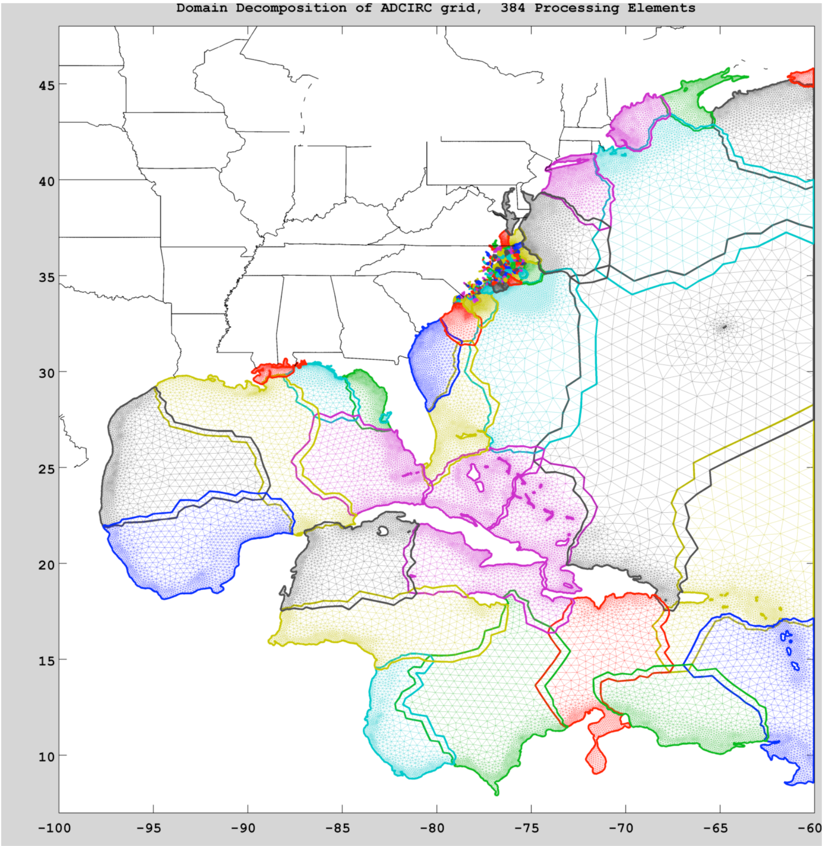
- Generally, Problems are Large!

- A high-resolution (very accurate) ADCIRC simulation is generally too large to fit on one CPU processor of a typical computer.

- Solution is to split the problem into smaller chunks

- Run in parallel mode on hundreds to thousands of processors

- Example of decomposition into 384 CPUs. Each colored piece runs on a separate processor. Information shared by adjacent subdomains.



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Recent Applications of ADCIRC

- Flood protection system engineering and design
- FEMA Coastal Flood Insurance Studies
- Forecasting and prediction systems
- North Carolina Sea Level Rise Impacts Study

Coastal Flood Protection System Design

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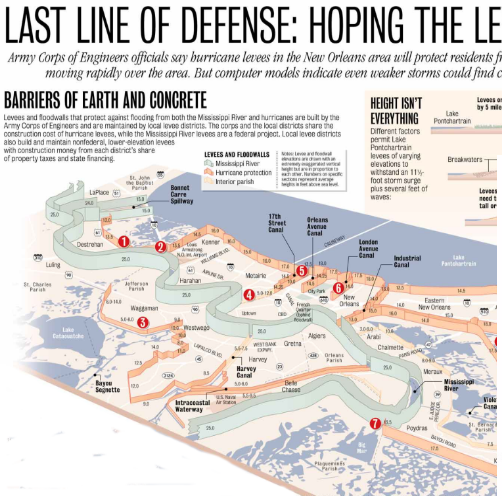
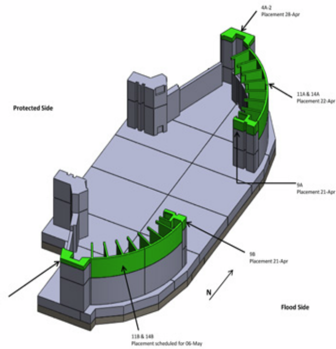
- New Orleans
  - $14.5 Billion Hurricane Storm Damage Risk Reduction System
- New York City
  - Mayor Blumberg's $20B plan to increase NYC capacity to withstand future extreme weather events, area following Hurricane Sandy
  - ADCIRC used to evaluate flood mitigation design alternatives
- Galveston, Tx
  - Ike Dike and associated structures





Artist's rendering of flood gate

ADCIRC in Coastal Hazard Assessments

FEMA National Flood Insurance Program

- All coastal states from NY to TX
- Updated Flood Insurance Rate Maps recently completed or in final stages in most states
- Most studies performed by USACE or private sector, with academic partners

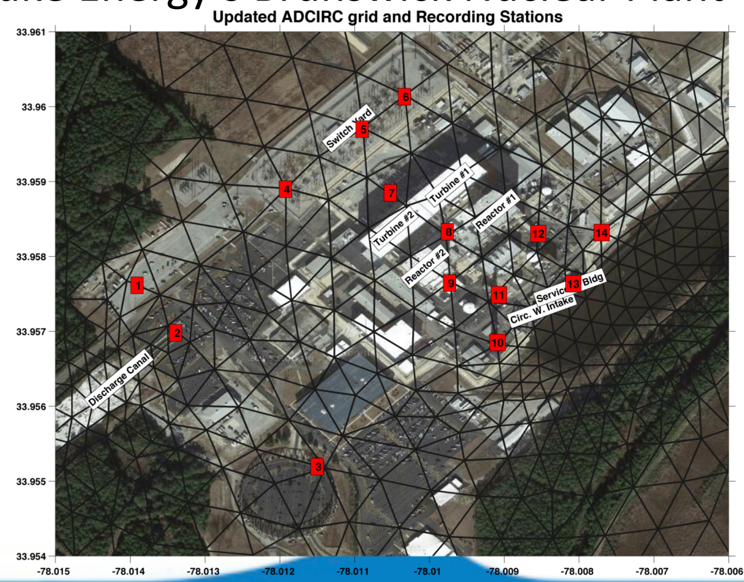
Nuclear Regulatory Commission and Energy Companies

- Coastal nuclear power plant storm surge/wave hazard assessments

Sea Level Rise

- North Carolina Sea Level Rise Impacts Study

Duke Energy's Brunswick Nuclear Plant



Coastal Flood Insurance Study Process

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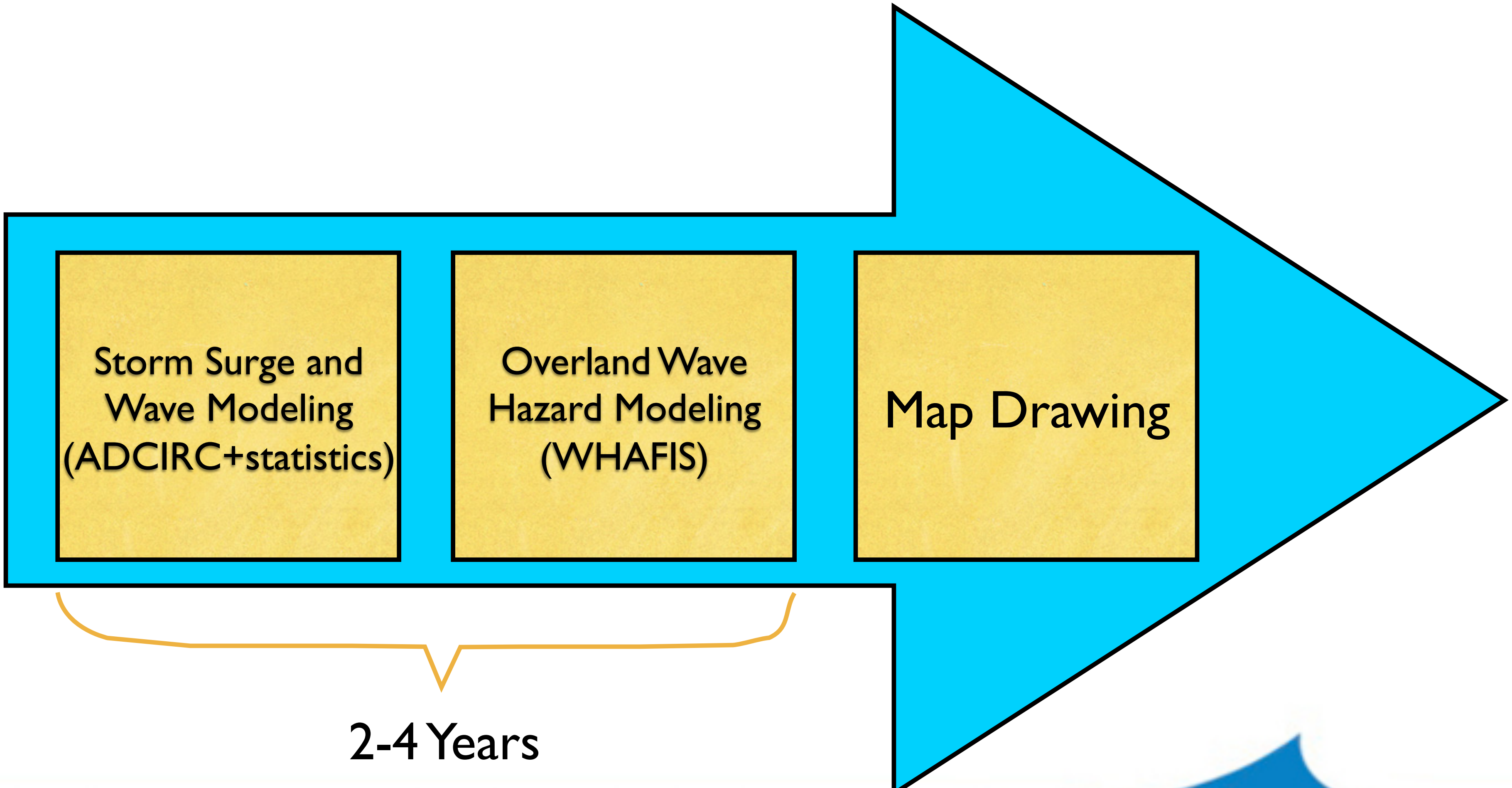
Primary objective: Determine the Base Flood Elevation (BFE)



FEMA FIS project ADCIRC Grids

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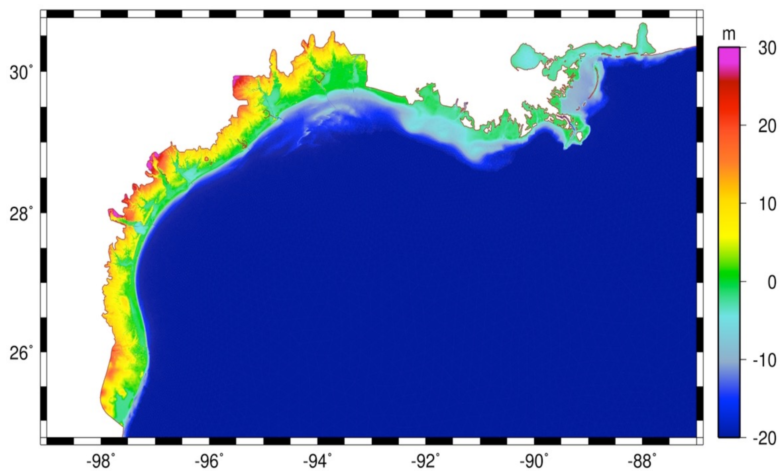
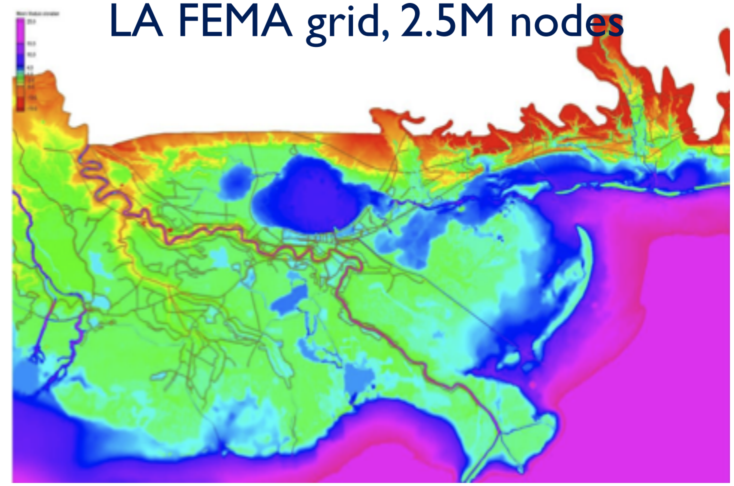
- All FEMA projects from Tx to NY

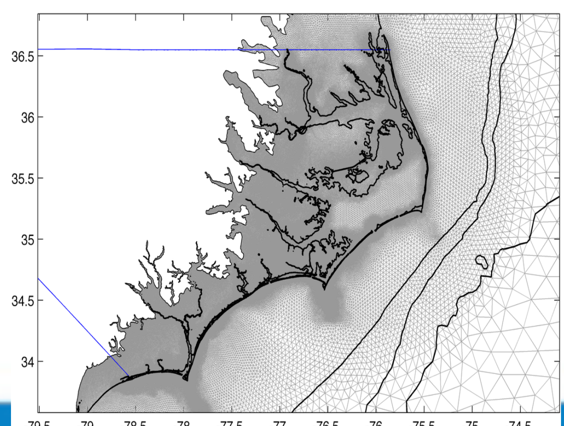
Texas FEMA grid, 10M nodes



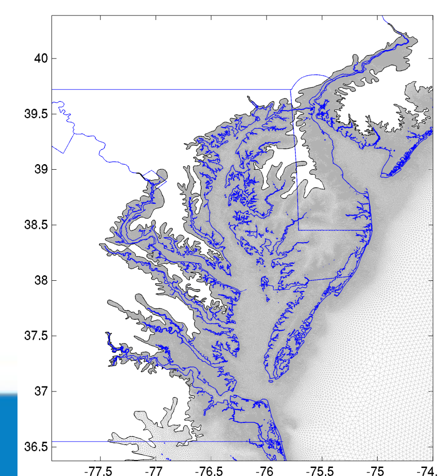
LA FEMA grid, 2.5M nodes



North Carolina FEMA grid, .6M nodes



Region 3 FEMA grid, 1.8M nodes



ADCIRC Validation Studies

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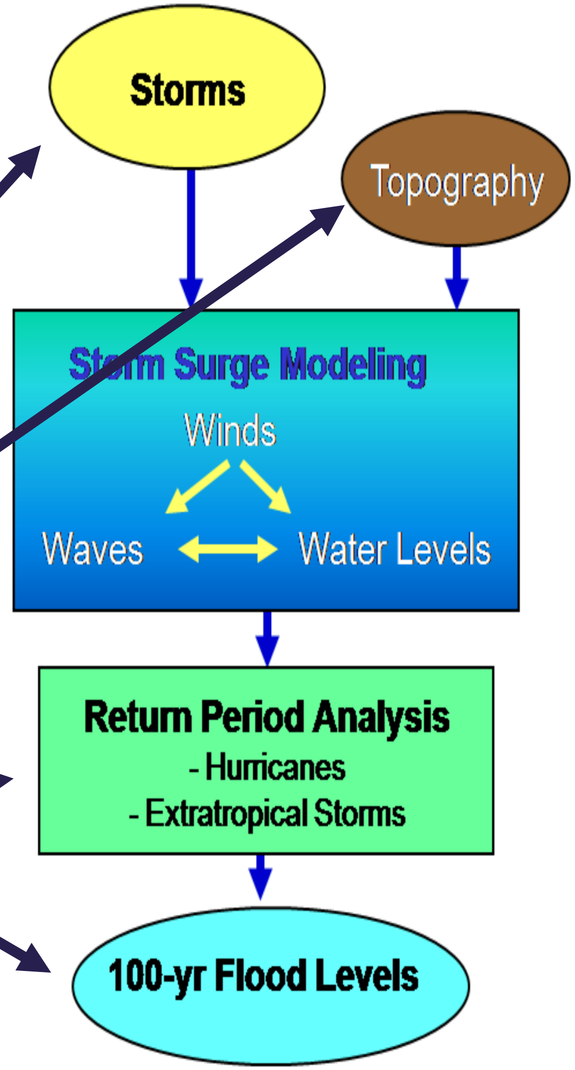
- Scientific, Research-based
- Associated with FEMA Coastal FIS
  - TX, LA, MS, several in FL, GA, SC, NC, Region 3, Region 2
- Results published in peer-reviewed, science literature
  - Comprehensive list @ www.adcirc.org
- Validated many recent hurricanes and extra-tropical storms
  - Betsy, Emily, Fran, Gustav, Ike, Rita, Irene, Isabel, Katrina, Ophelia

Region 3 MAP Modernization Project

- 2010-2013
- Collaboration among:
  - FEMA, US Army Corps of Engineers, Industry (Arcadis, Applied Research Associates, Ocean Weather, Dewberry), Academic (UNC)
- Study Objectives:
  - Develop statistical models (e.g., Joint Probability Method) for storm populations
  - Develop detailed, high-res grid for region
  - Compute storm surge response to probable storms
  - Compute statistical water level surfaces for mapping



Model Validation

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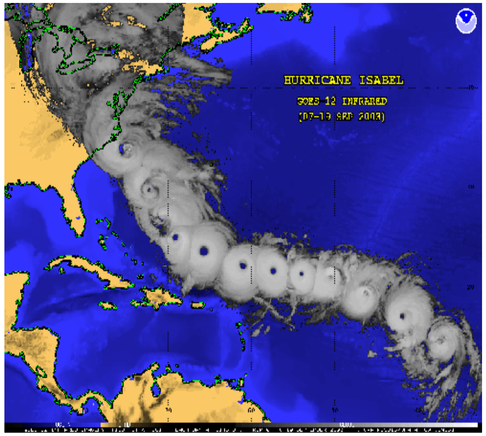
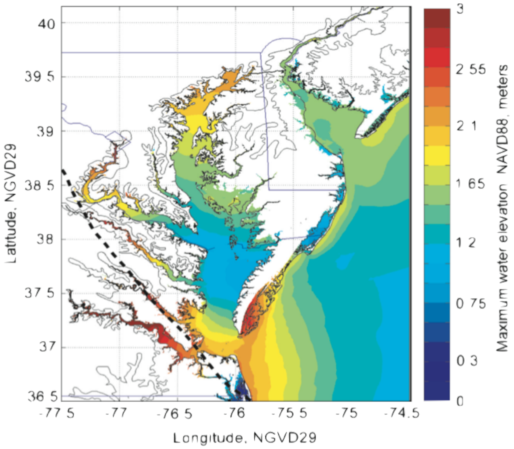
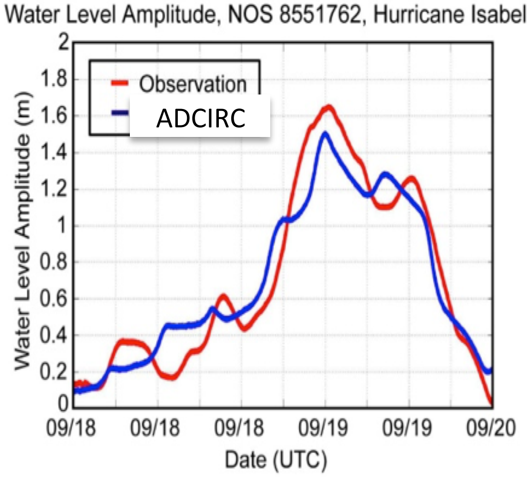
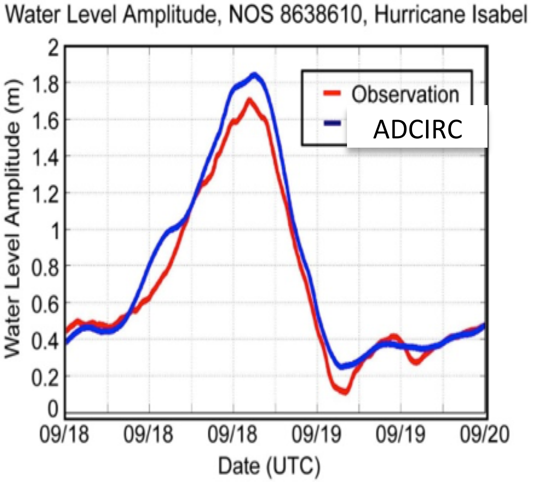
Hurricane Isabel (2003)

- Landfall near Drum Inlet, NC
- 18 Sep 2003
- Cat 2 at landfall (Cat 5 offshore)
- Passed to the west of Ches Bay
- ~$1.7 billion in insured damage
- ~$3.4 billion total damage
- Simulation using analyzed Isabel Winds
- NOAA Tide Gauge Observations





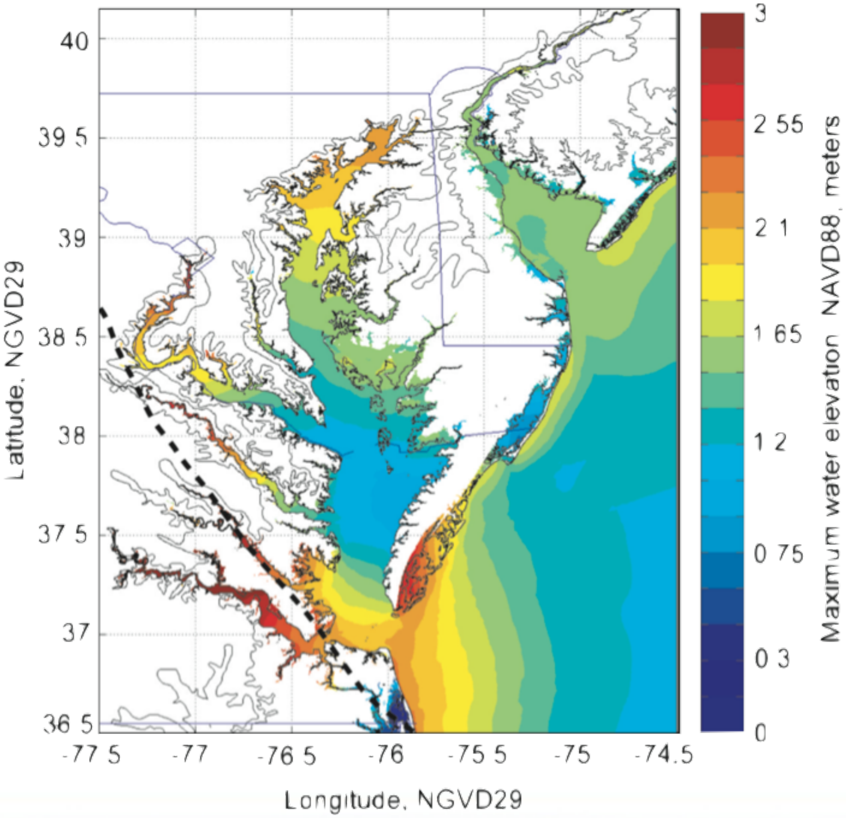




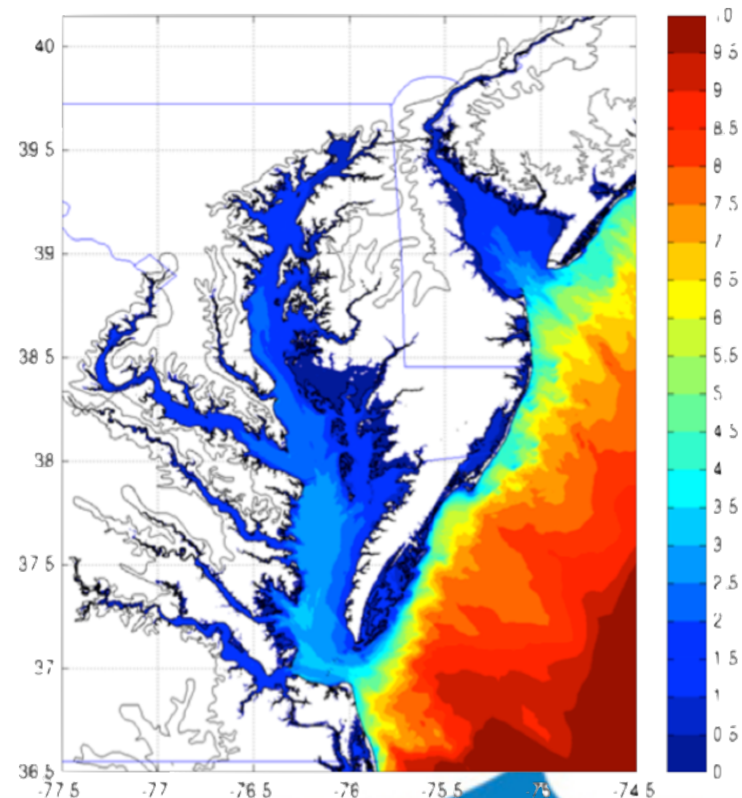
Model Validation

- Hurricane Isabel (2003) Simulations
- Simulation using analyzed Isabel Winds
- Detailed comparison to water level and wave observations

Maximum Surge Level



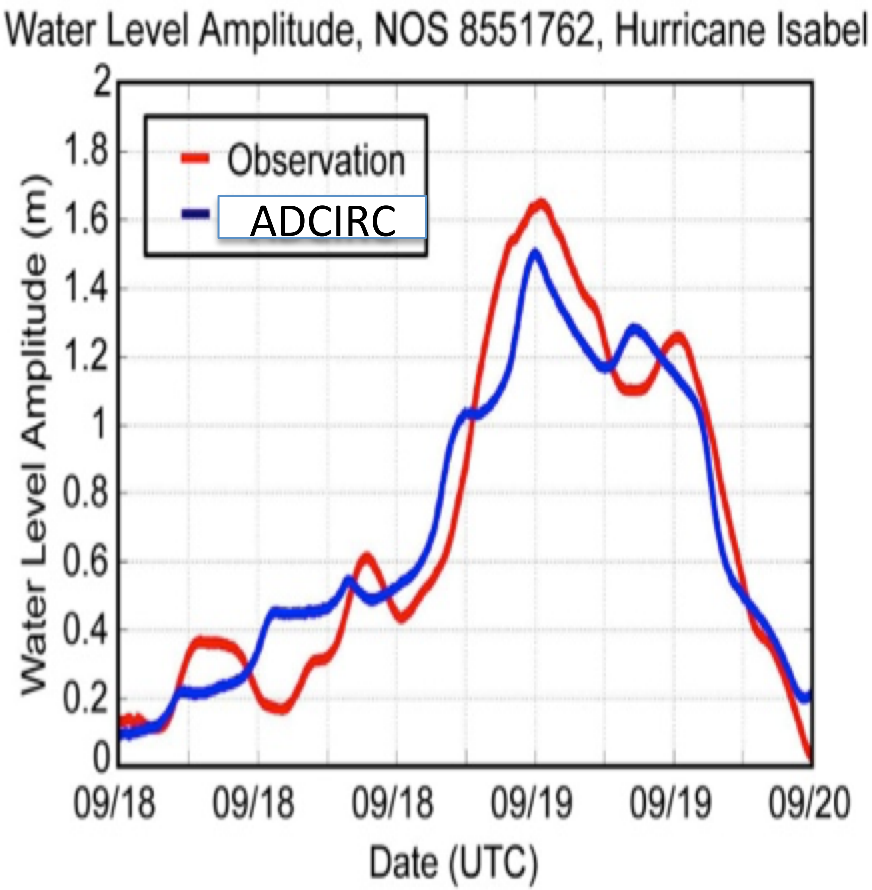
Maximum Significant Wave Height

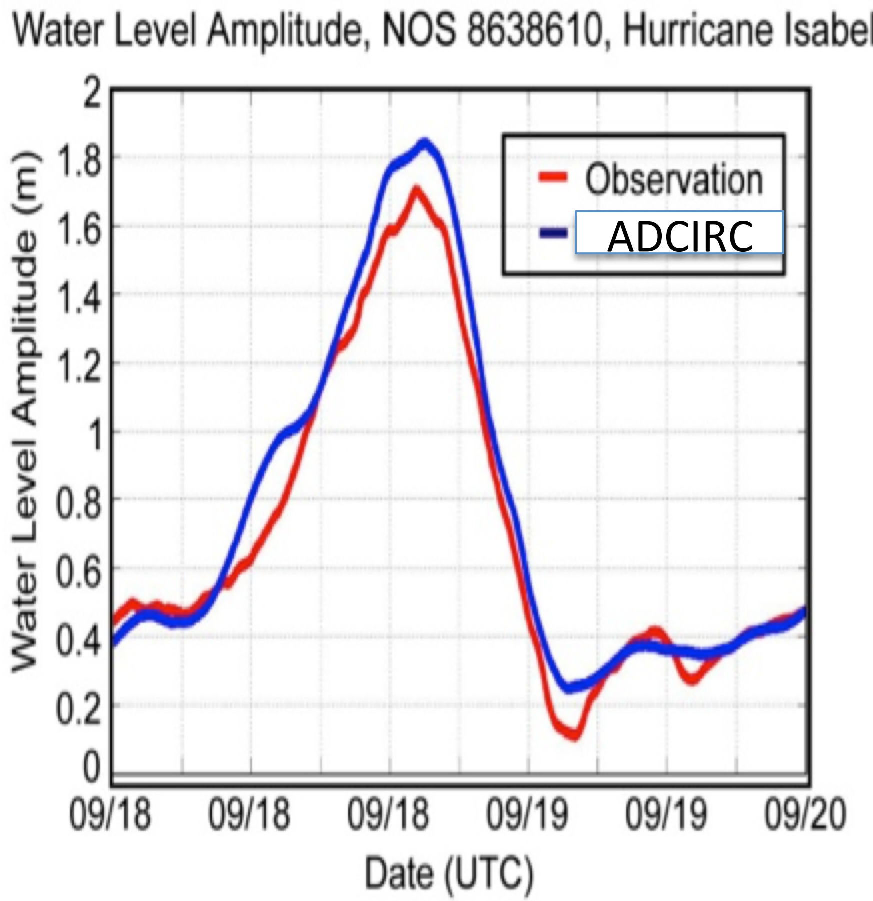


Model Validation

COASTAL HAZARDS CENTER

- Hurricane Isabel (2003) Simulations
- NOAA Tide Gauge Observations





Model Validation

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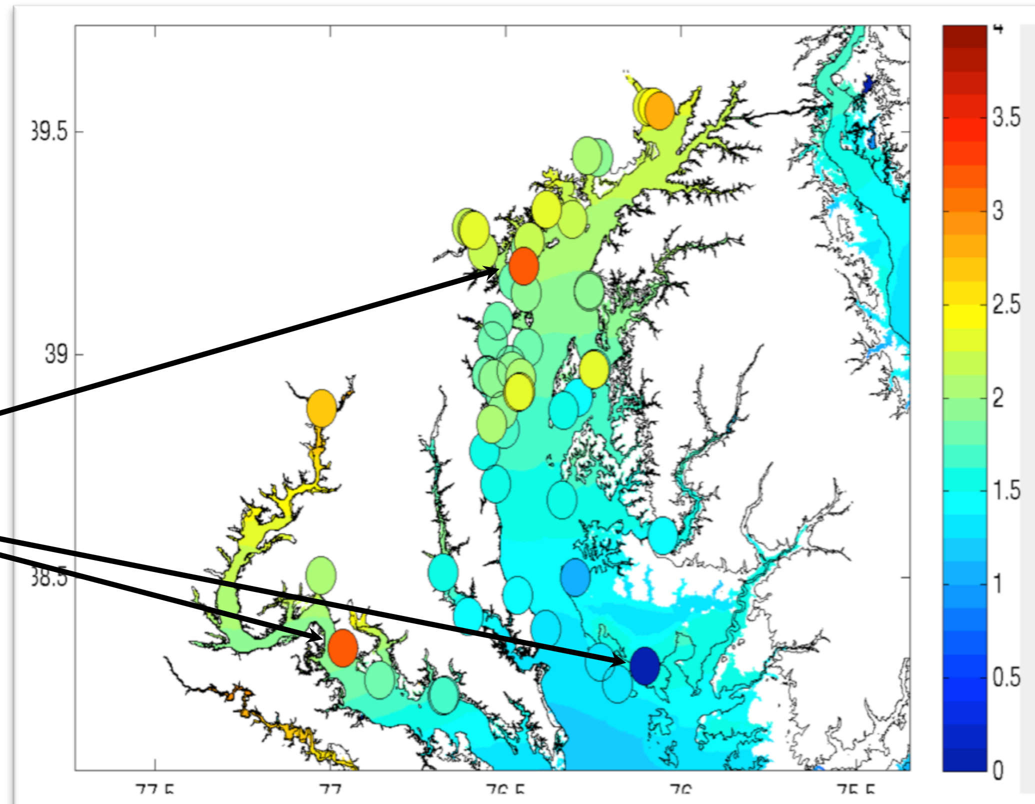
- Hurricane Isabel (2003) Simulations
- High Water Marks recorded by engineering firms post-storm
- Varying levels of data quality
- Suspect Data Quality

Northern Chesapeake Bay High Water Marks



Probabilistic Simulations

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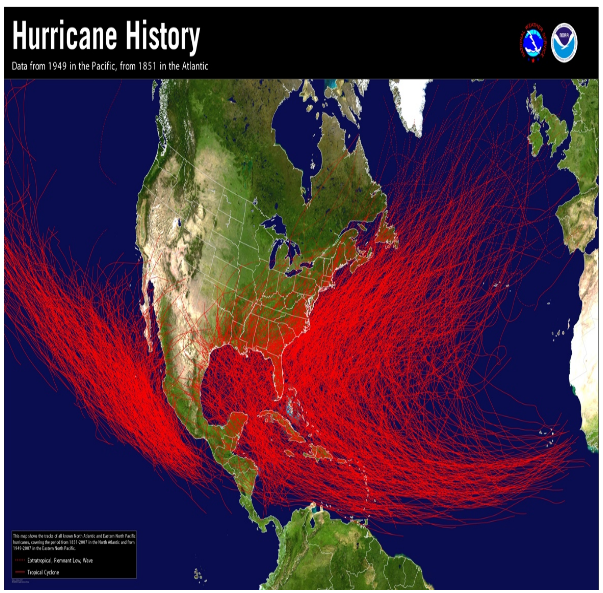
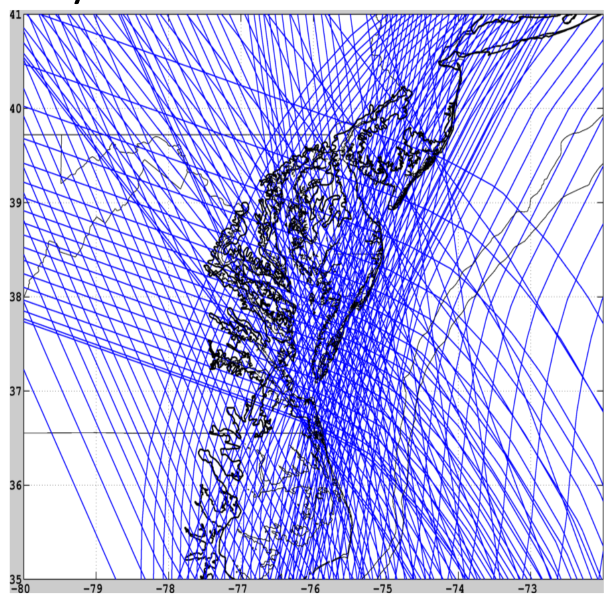
Characterize regional historical record with a set of probabilistic hurricanes

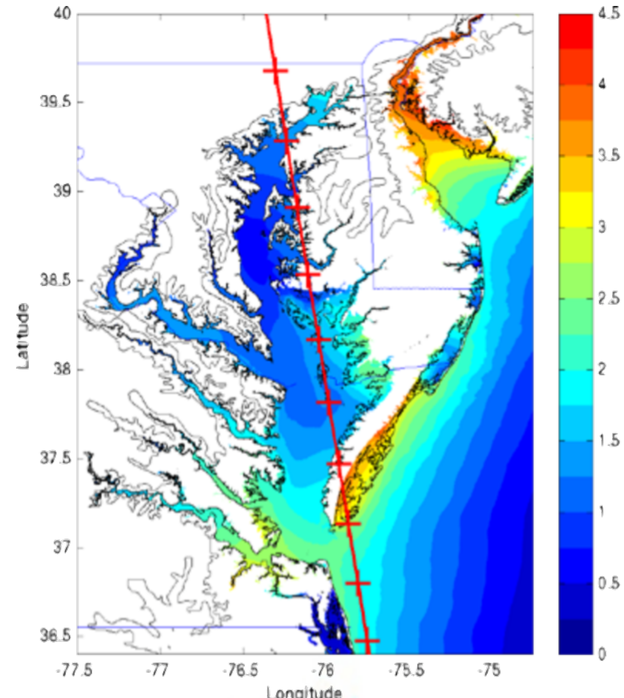
Hurricane History



Synthetic Hurricane Tracks

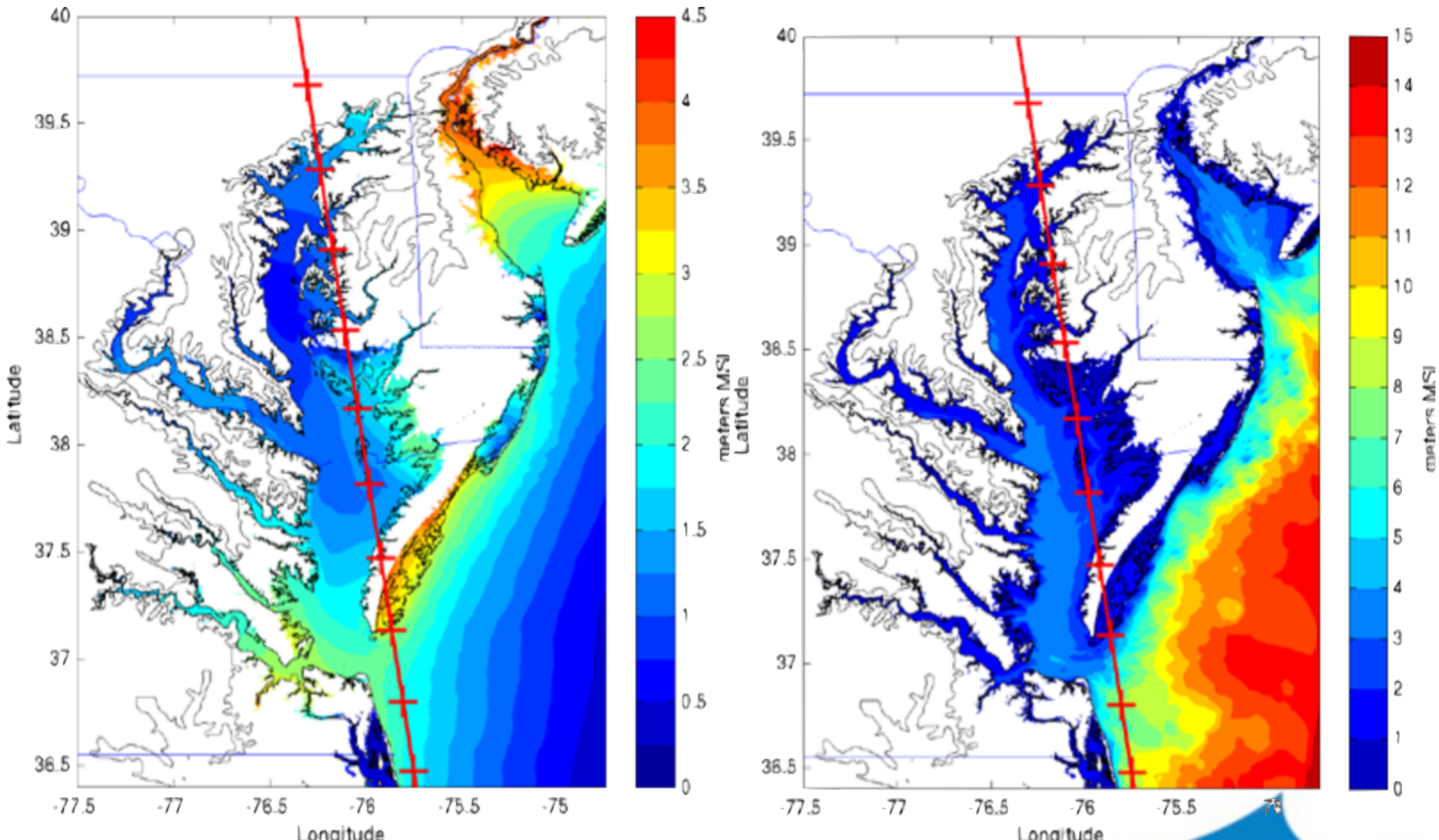


Storm Surge Responses



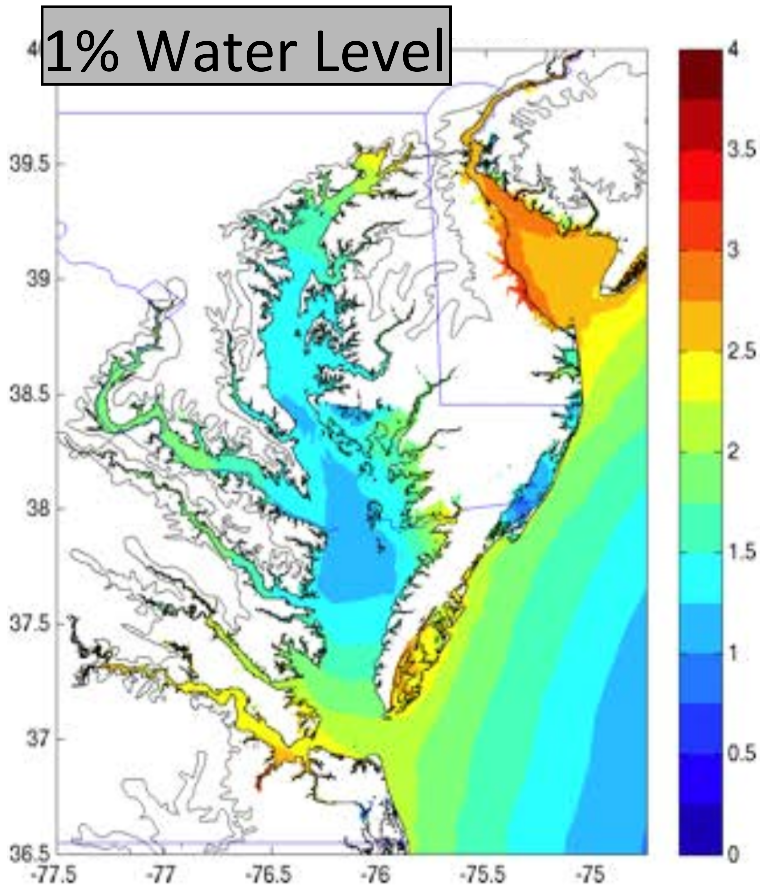
Surge/Wave Responses

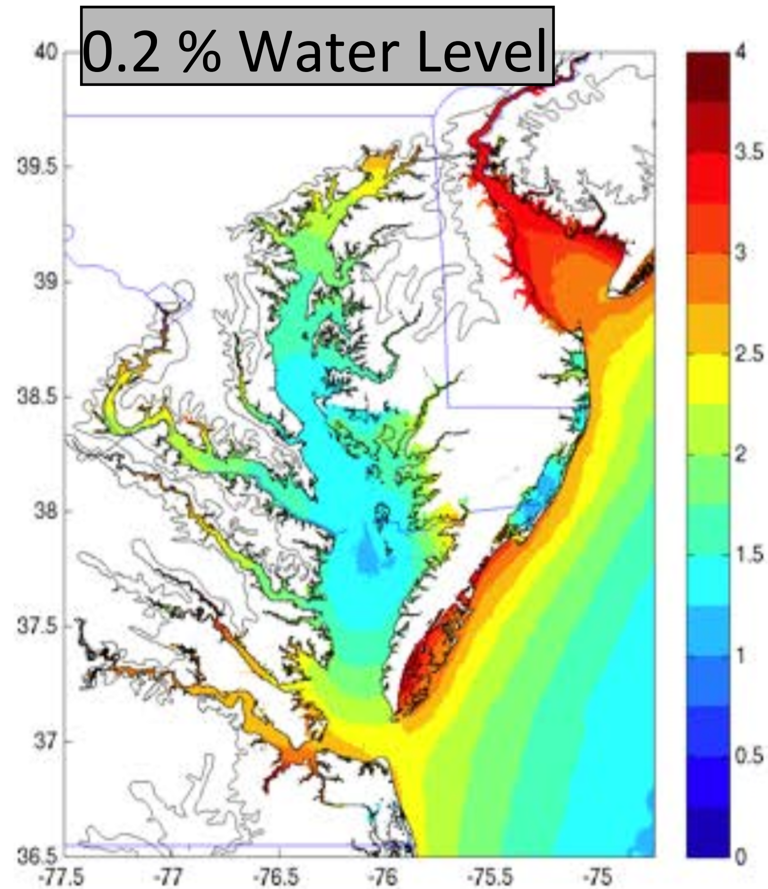
Compute surge/wave response to each synthetic hurricane



Statistical Flood Levels

- Values used in drawing FIRMs





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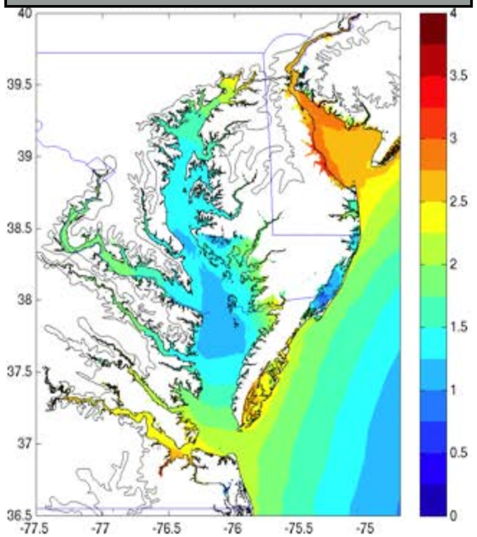
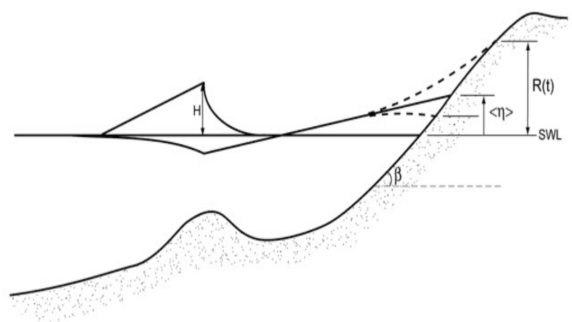
FIRM Development (Map Making)

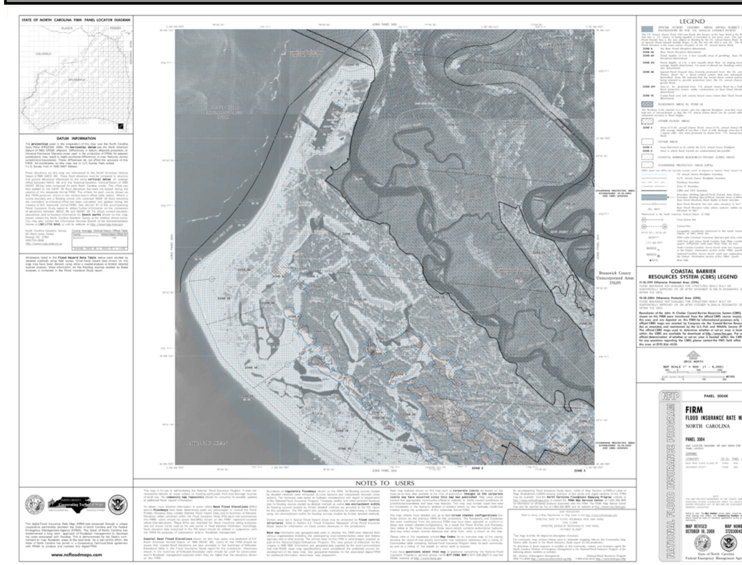
- Performed by Certified Mapping Firms

Flood Statistics	Overland wave analysis	Flood Insurance Rate Map





How far onshore individual waves "run up"



Forecasting with ADCIRC

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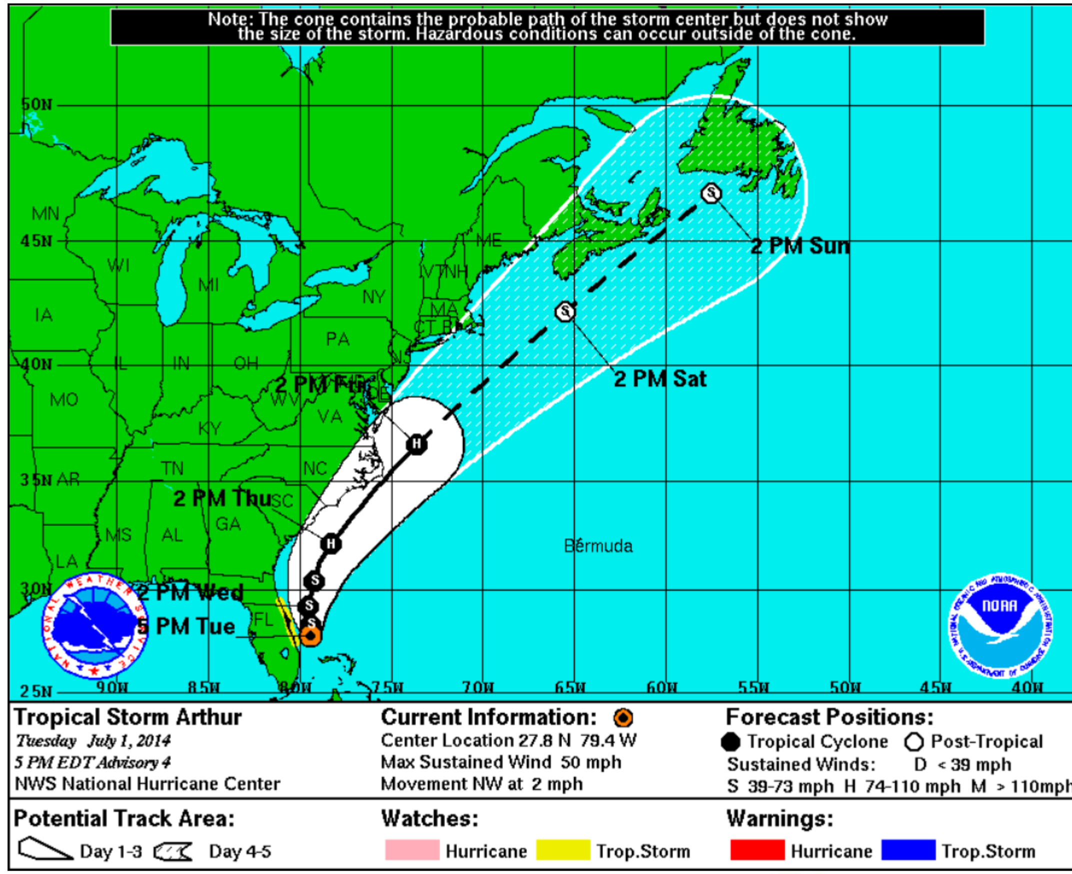
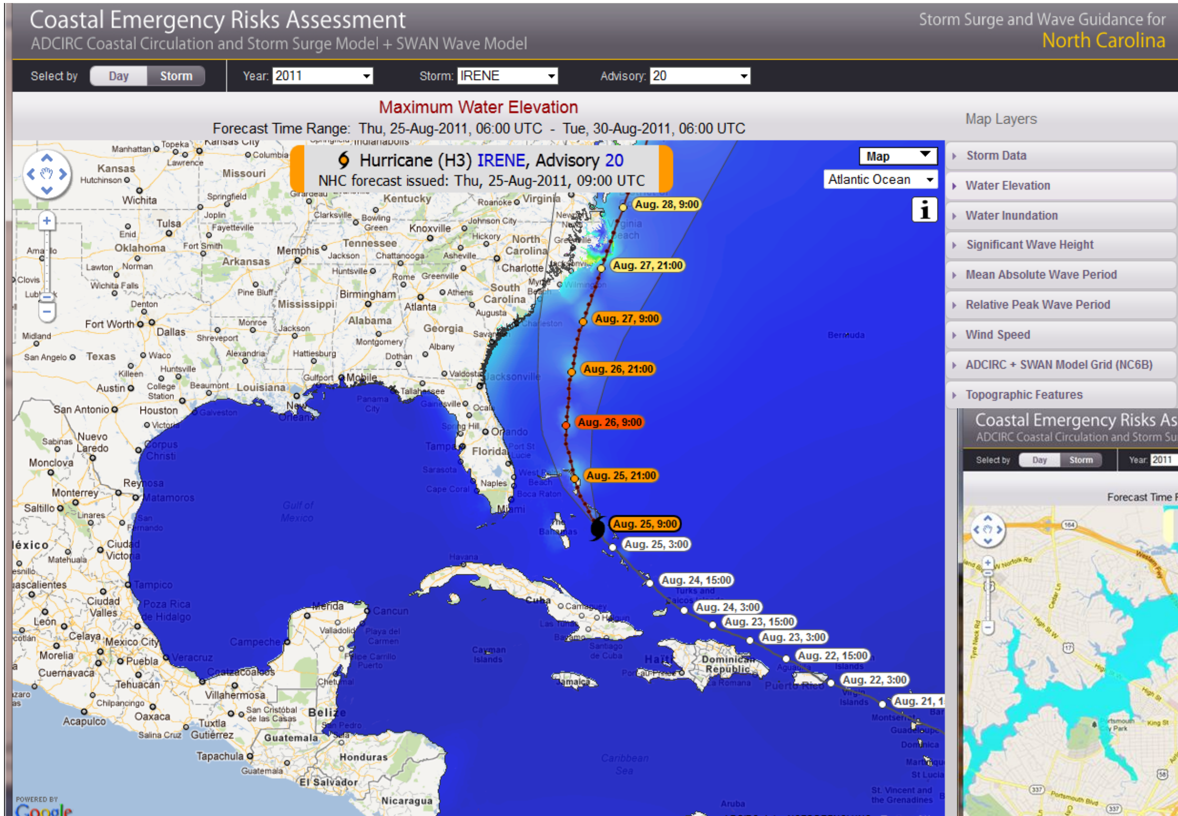
- Part of comprehensive risk reduction
- Nat'l Weather Service (NCEP) runs ADCIRC for ***extra-tropical storms***
- Nat'l Hurricane Center in Miami remains firmly committed to SLOSH for tropical cyclones

Tropical Storm Arthur (2014)

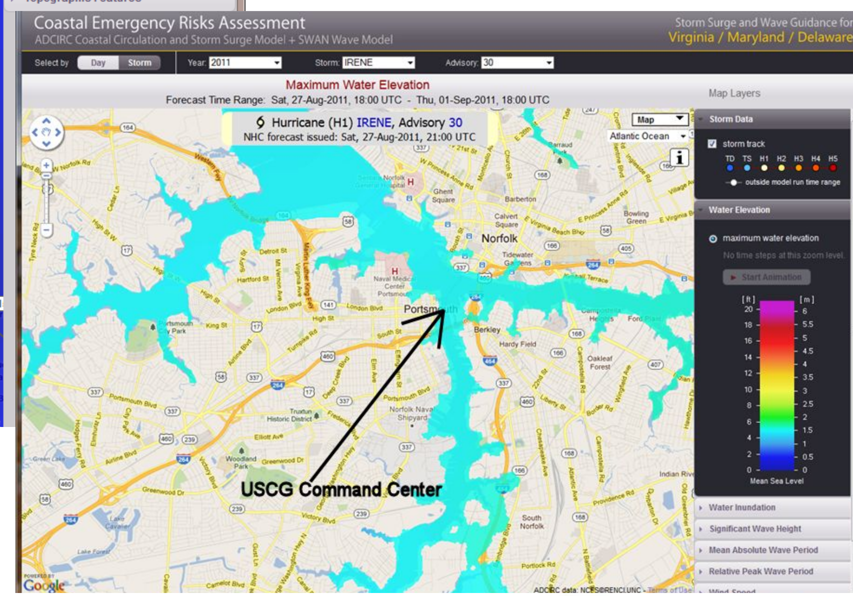


ADCIRC Surge Guidance System (ASGS)



Hurricane Irene

August 25 – 29, 2011



- Balance speed and accuracy
- Low resolution may be much better than nothing!

ADCIRC Surge Guidance System (ASGS)

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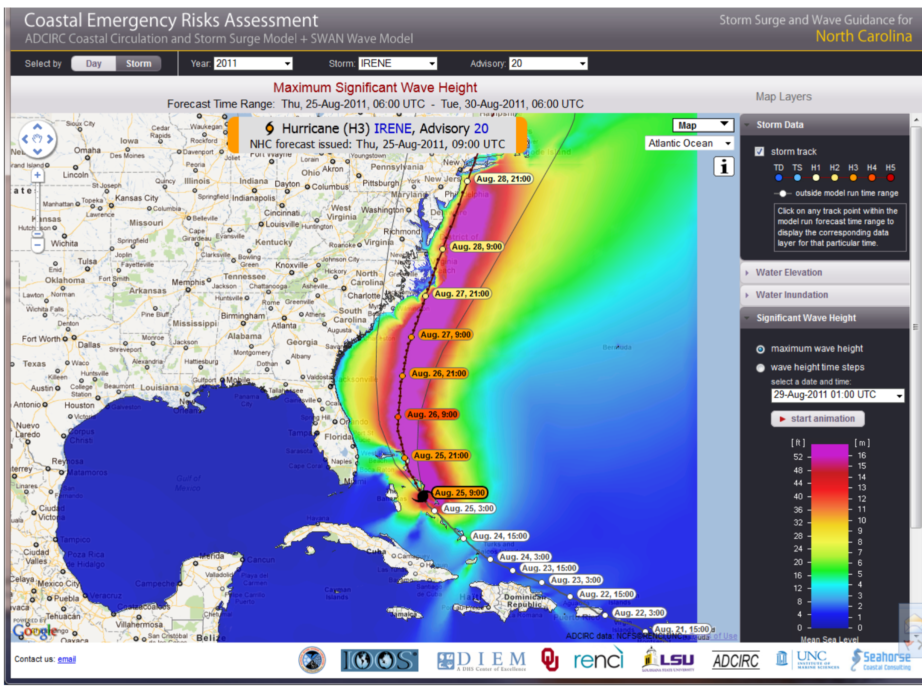
- 2 – 4 x daily, 365 days / year for North Carolina and Lower Virginia
- Includes tides and major rivers
- Run ADCIRC + SWAN for duration of meteorological forecast to generate time sequence of wave, surge and inundation conditions for forecast.
- Post output to community-accessible data servers
- Visualization at CERA website:
  - nc-cera.renci.org; cera.cct.lsu.edu
- AlsorRunning for TX, LA, West FL, NY/NJ

ADCIRC Surge Guidance System (ASGS)

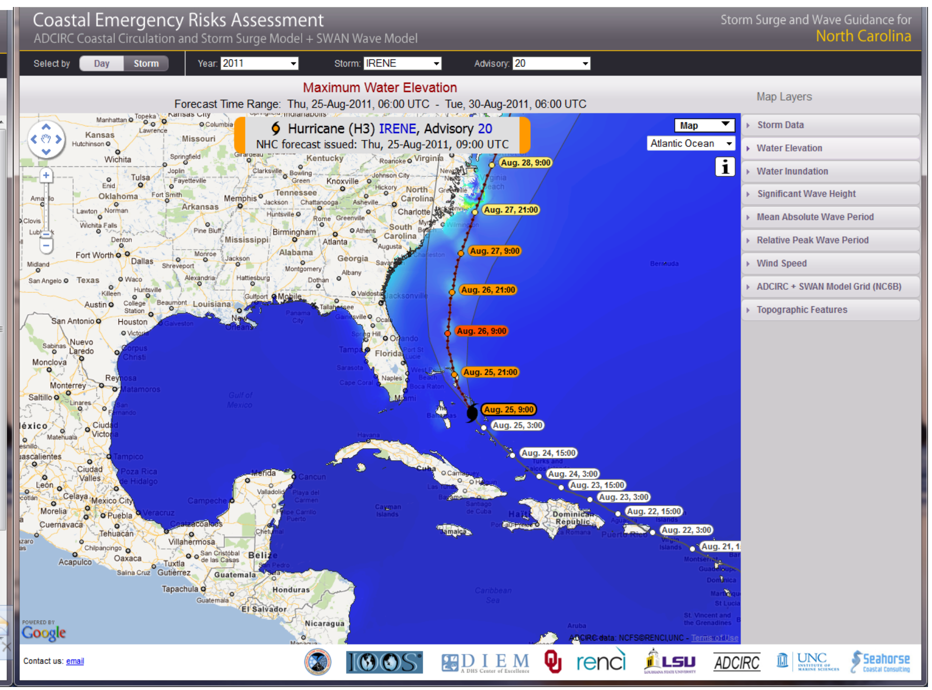
Primary Outputs

http://nc-cera.renci.org

Significant Waves



Total Water Level



Hurricane Irene (2011)

ADCIRC Surge Guidance System (ASGS)

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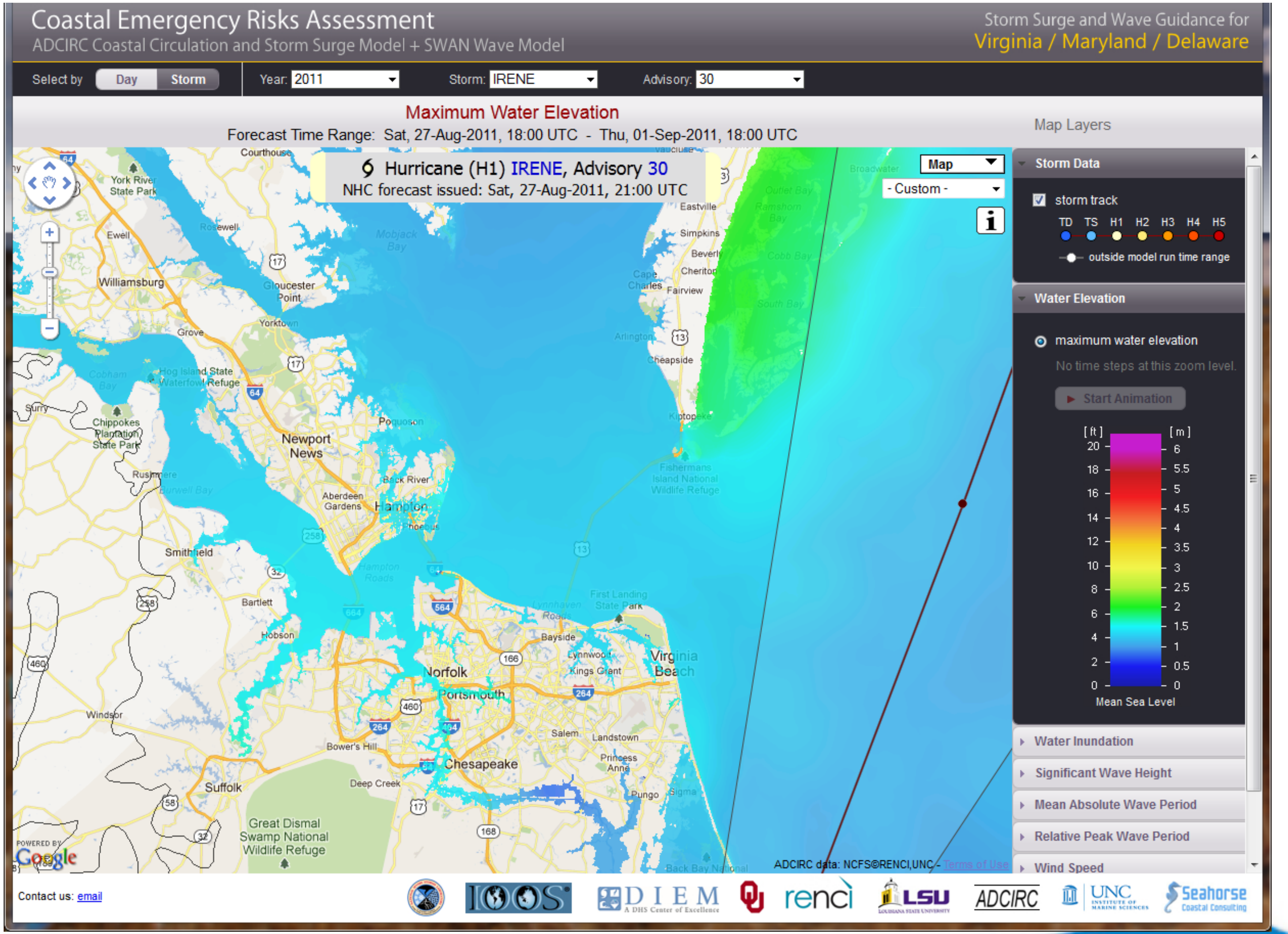
Detail of lower Chesapeake Bay, Hurricane Irene (2011)

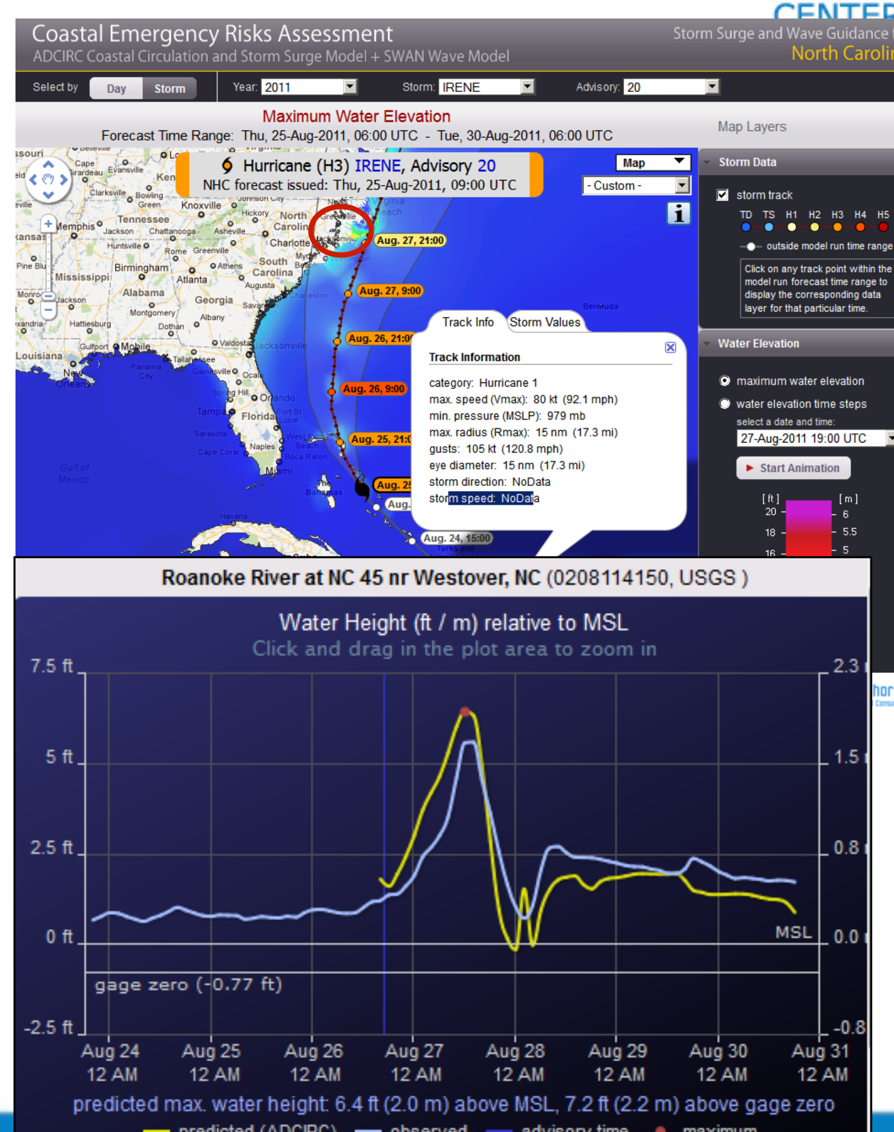


ADCIRC Surge Guidance System (ASGS)

Query Capabilities

- query results for each ADCIRC grid node

- water elevation, inundation
- topography/bathymetry
- wave height
- wave period
- wind speed



North Carolina Sea Level Rise Impacts Study

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- FEMA-funded
- Highly interdisciplinary and collaborative
  - Academic, State of NC, Industry (led by Dewberry)
- Impacts of sea level rise on coastal flood plain statistics
  - Same model and statistical techniques as used in the NC FIS
  - With:
    - Sea Level Rise scenarios of 20, 40, ... 100 cm
    - Various geomorphological changes plausibly caused by increased sea level stand
    - Future storm climatology changes

North Carolina Sea Level Rise Impacts Study

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- Recompute the storm responses and statistics (ADCIRC)
- ~1500 ADCIRC runs
- Probably the only SLR project that recomputed the floodplain based in SLR increments

- NOT the bathtub approach, which assumes that SLR and storm impacts interact only linearly
- This may not be true locally

North Carolina Sea Level Rise Impacts Study

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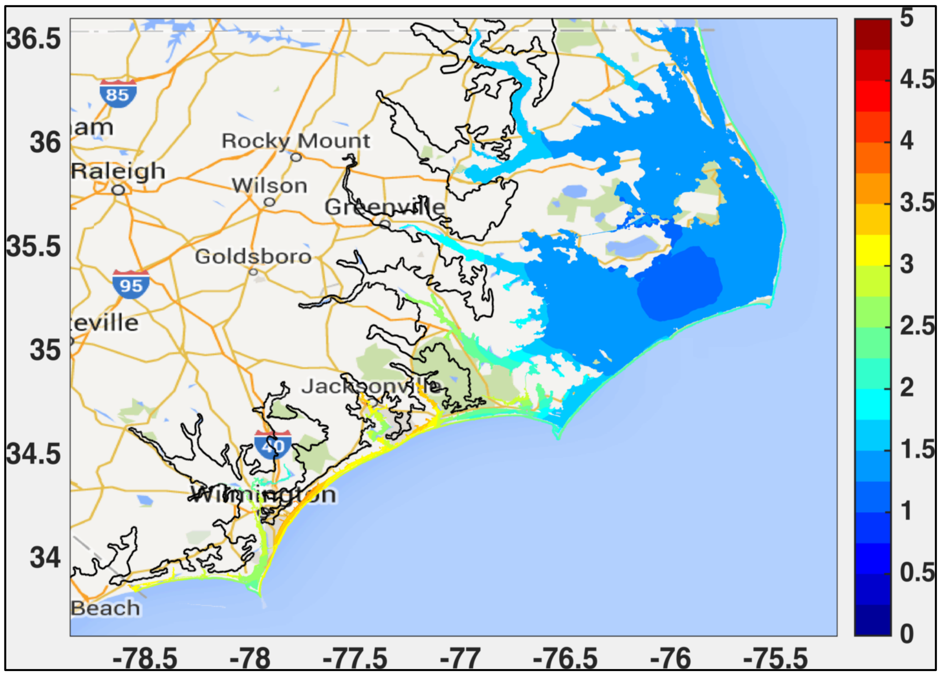
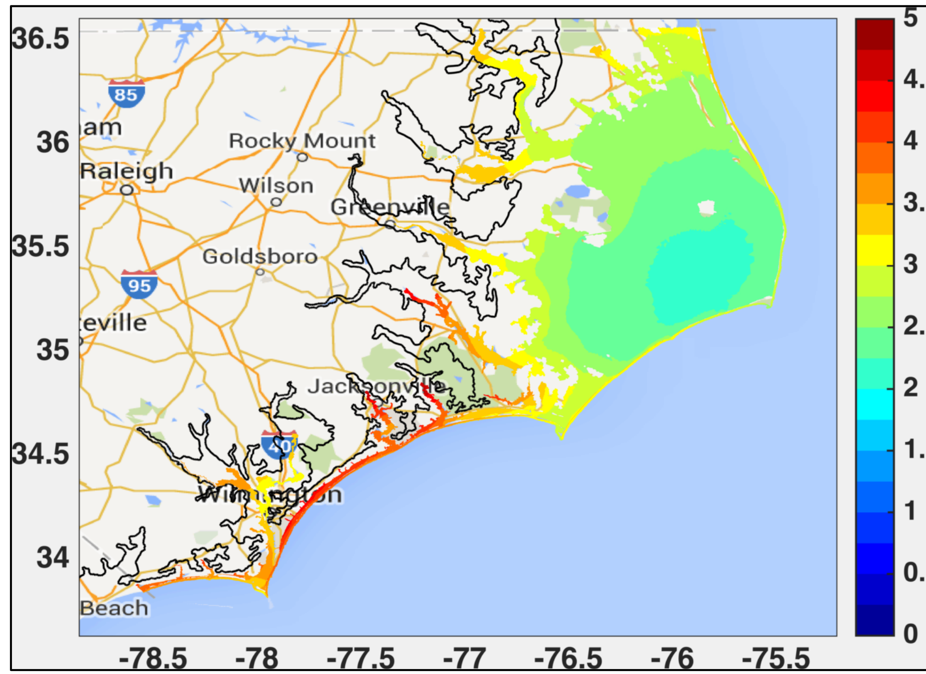
1% Water Level

Present day



100cm Scenario



North Carolina Sea Level Rise Impacts Study

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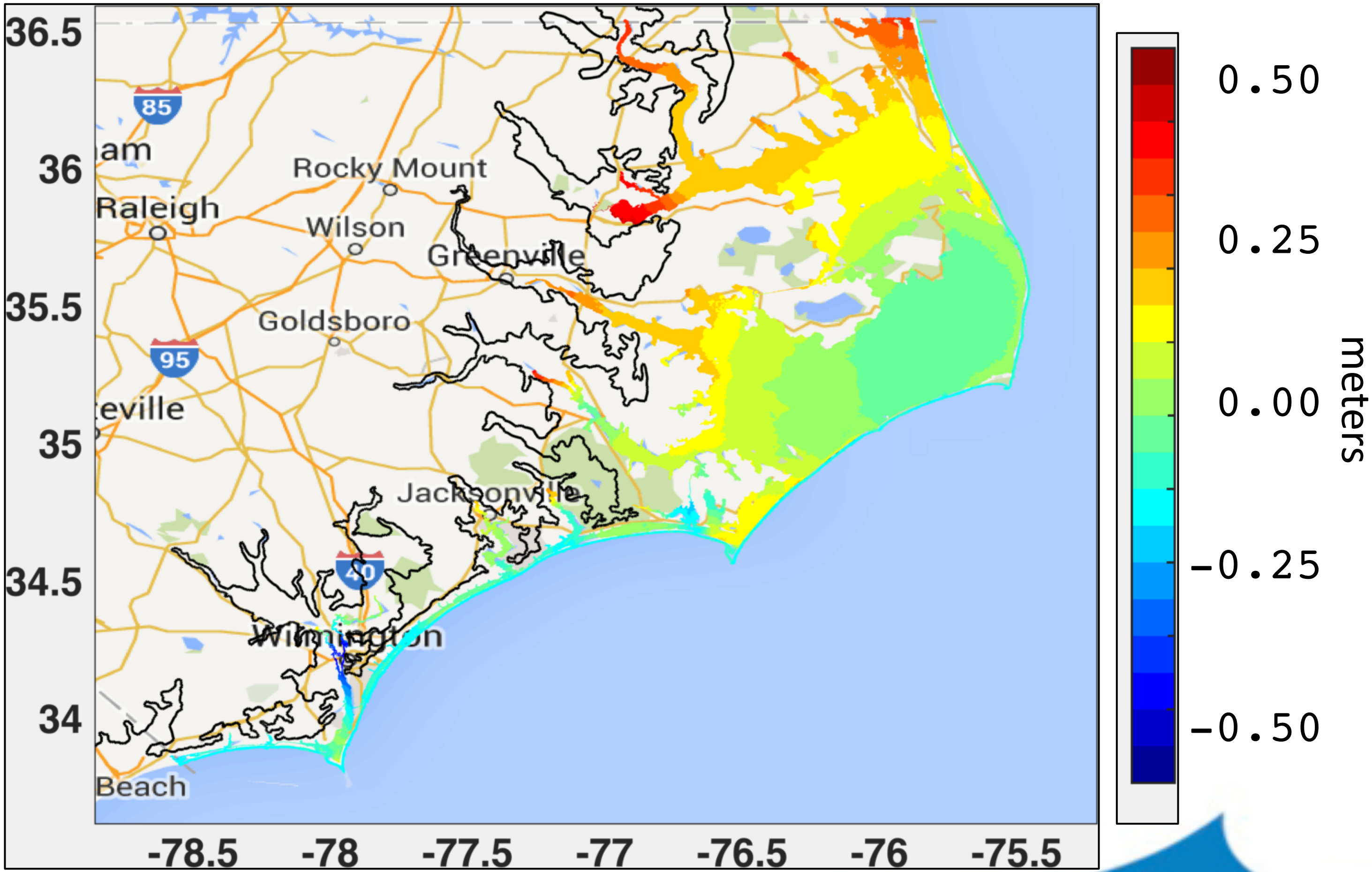
Difference from Straight Bathtub approach



Output Formats

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- Graphics on website (nc-cera.renci.org)
- Shapefiles posted to public data server
- Google Earth kmz files posted to public data server
- Native ADCIRC data in netCDF
- Also have developed applications to help examine storm surge solutions

Conclusions

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- ADCIRC is widely used for a variety of coastal hazards related research and applications
- Triangular grid permits highly configurable grids that capture the full range of important physics and structures (levees, roadways, etc.) Can run on a spectrum of resource capabilities
  - But high-resolution does need relatively large computers
- We are ready and willing to collaborate on applications of ADCIRC

Large User Community

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- From Developers to End-users
- Modelers, Model product/output consumers
- Academic
- Commercial
  - Insurance, Engineering, Consulting
- Federal
  - DHS, Coast Guard, FEMA
  - NOAA/NWS
  - USACE, NAVY

ADCIRC Users Group Meeting

- Annual
- This year in College Park

- ADCIRC User Group Meeting
  - March 30-31
  - Applications, development, etc.

- ADCIRC BootCamp
  - April 1-3
  - Immersive workshop, hands-on