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

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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

• What is ADCIRC
• Resource Requirements
• Recent Applications of ADCIRC
  – Coastal Hazards/FEMA
  – Forecasting
  – Validation Studies
ADCIRC (http://www.adcirc.org)

• Computer model for storm surge, tides, and wind waves

• Origination in early-1990’s via USACE funding
  – Rick Lueettich (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](http://www.adcirc.org))

- 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
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

\[ \vec{F} = m \vec{a} \]

Forces include:
- atmospheric winds and pressure,
- waves,
- tides

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

Turn into a set of
algebraic equations

\[ Ax = b \]

Run models on Computers

Turn into a Computer Code to solve Linear Algebra Problem
ADCIRC Surge/Inundation

Governing Equations:

- Mass Conservation
- Newton’s 2\textsuperscript{nd} Law of Motion: \( F = M \times a \)
- 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

- 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.
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

• 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
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
Coastal Flood Insurance Study Process

Primary objective: Determine the Base Flood Elevation (BFE)

- Storm Surge and Wave Modeling (ADCIRC+statistics)
- Overland Wave Hazard Modeling (WHAFIS)
- Map Drawing

2-4 Years
FEMA FIS project ADCIRC Grids

- 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

• 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:

- 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

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

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

- 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

Characterize regional historical record with a set of probabilistic hurricanes
Surge/Wave Responses

Compute surge/wave response to each synthetic hurricane
Statistical Flood Levels

- Values used in drawing FIRMs

1% Water Level

0.2% Water Level
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

- 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)

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

Hurricane Irene
August 25 – 29, 2011
ADCIRC Surge Guidance System (ASGS)

- 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

Significant Waves

Total Water Level

Hurricane Irene (2011)

http://nc-cera.renci.org
ADCIRC Surge Guidance System (ASGS)

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

• 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

• 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

1% Water Level

Present day

100cm Scenario
North Carolina Sea Level Rise Impacts Study

Difference from Straight Bathtub approach
Output Formats

• 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

• 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

• 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