The University of Texas at Austin
Oden Institute for Computational Engineering and Sciences

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DEVELOPMENT OF A COMBINED STORM SURGE AND RIVER RUNOFF MODEL FOR THE TEXAS COAST

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Outline

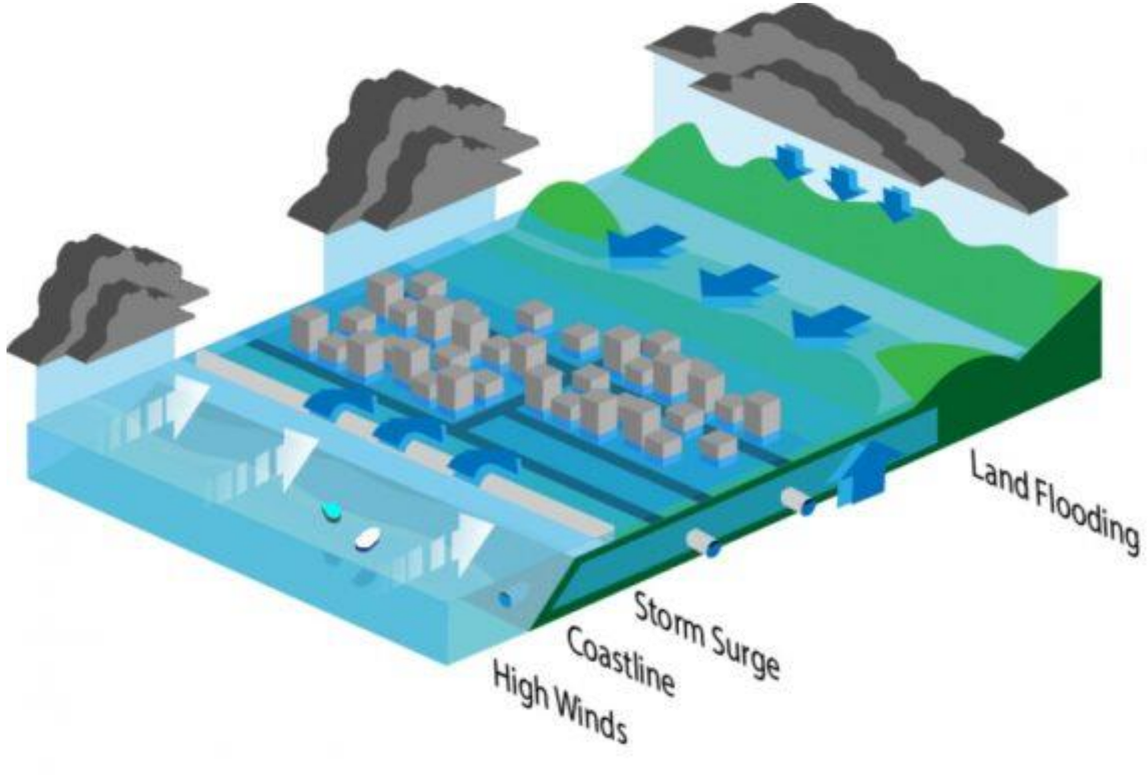
- Motivation and Background
- Mathematical Model
- Development of ADCIRC model/mesh
- Results
- Concluding Remarks

Background

Source: https://www.weather.gov/hgx/projects_ike08_bolivar2

- Storm surge from tropical cyclones (hurricanes) can lead to extensive material and human damages
- Texas and the other gulf states are particularly vulnerable due to the frequency of storms in the Gulf of Mexico
- 1000s of deaths and billions in damage since record keeping began in 1829

Background



- Recent storms are accompanied by heavy rains

-> “Compound flooding” :

- Interaction between two or more sources of floodwaters
- Example: Hurricane Harvey (2017) - (minor) storm surge in Galveston Bay blocked drainage of rainfall runoff and amplified inundation

Source:http://sites.utexas.edu/climatesecurity/2020/03/25/
flooding-from-all-directions-how-compound-flooding-threatens-urban-areas-in-oceania/

Motivation

- Develop ADCIRC models that cover the Texas coastal area with very high resolution:
  - Rivers
  - Floodplains
  - Ocean
- Identify past hurricane events
- Data collection and processing of inputs to the model, including:
  - Meteorology
  - River flows
- Perform computations for each identified event:
  - Storm surge only
  - River flooding only
  - Compound
- Post process results to identify the transitional zones between the 3 types of floods

(2D) Shallow Water Equations

The Shallow Water Equations

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (Hu)}{\partial x} + \frac{\partial (Hv)}{\partial y} = 0$$

$$\frac{\partial (Hu)}{\partial t} + \frac{\partial (Hu^2 + \frac{1}{2}g(H^2 - h_b^2))}{\partial x} + \frac{\partial (Huv)}{\partial y} = g\zeta \frac{\partial h_b}{\partial x} + F_x$$

$$\frac{\partial (Hv)}{\partial t} + \frac{\partial (Huv)}{\partial x} + \frac{\partial (Hv^2 + \frac{1}{2}g(H^2 - h_b^2))}{\partial y} = g\zeta \frac{\partial h_b}{\partial y} + F_y$$

where
u, v = depth-averaged horizontal velocities
F_x, F_y = external forcing, including: bottom friction, winds/pressure, Coriolis, waves ...

Advanced Circulation Computer Model (ADCIRC)

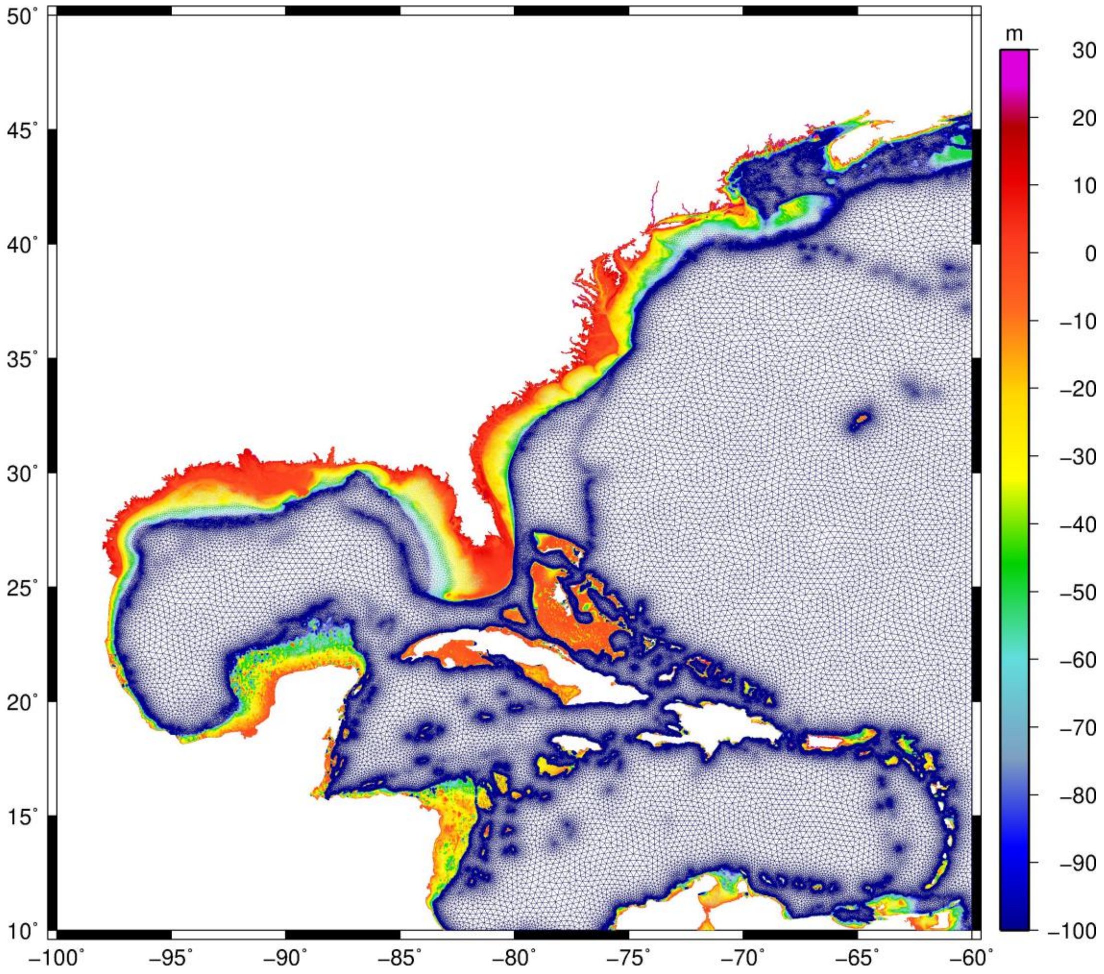
- Developed for tidal flows by Luettich and Westerink in the early 1990's based on earlier work by Lynch, Gray and Kinnmark[1]
- Parallelized in mid 1990's (MPI parallelization)
- First applied to hurricanes for a hindcast study of Hurricane Betsy (1968) for the US Army Corps of Engineers to develop a flood protection system in New Orleans
- Hurricane Katrina (2005) led to extensive post-Katrina development and validation
- Used for FEMA flood insurance studies
- Used for hurricane protection studies in response to Katrina, Sandy, and Ike
- Now used operationally for hurricane forecasting

[1] R. A. Luettich, J. J. Westerink, and N. W. Scheffner. "ADCIRC: an advanced three-dimensional circulation model for shelves, coasts, and estuaries. Report 1, Theory and methodology of ADCIRC-2DD1 and ADCIRC-3DL". In: *Coastal Engineering Research Center (US)* (1992).

New Compound Flooding Mesh

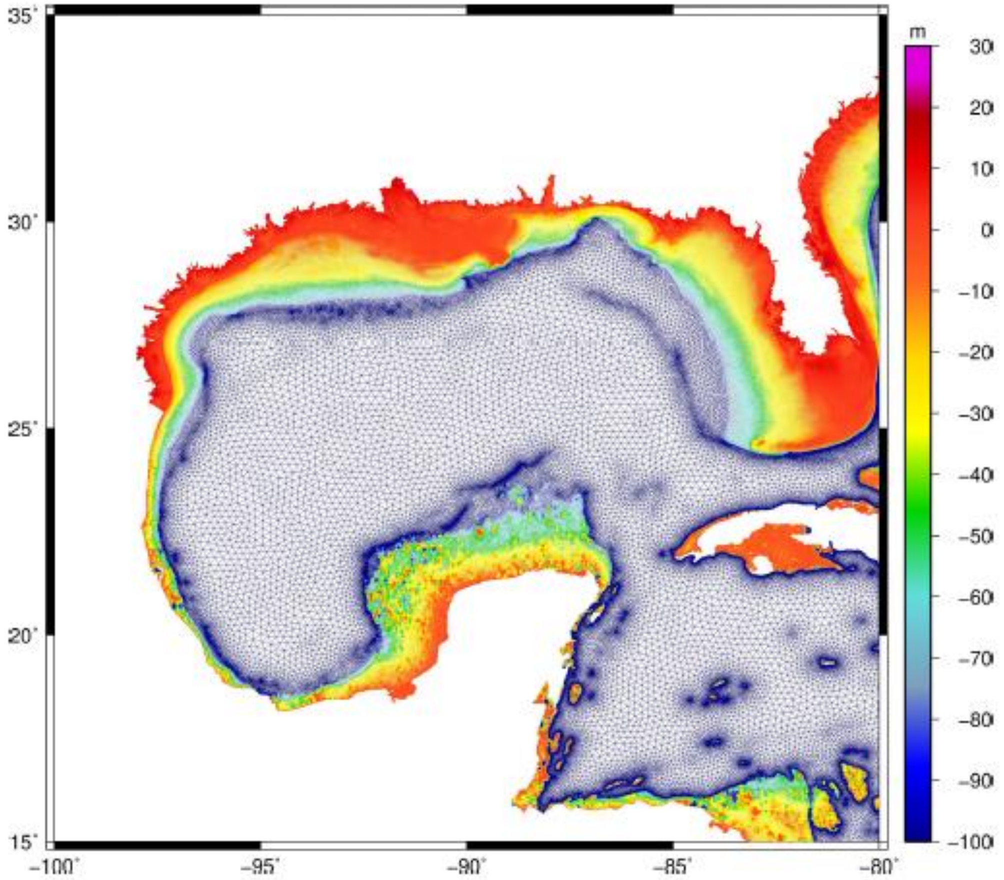
- The validation of the new mesh for tidal flows and past hurricanes is detailed in recent work by Contreras *et al.*
- 12 day Hurricane Ike (2008) with OWI winds will serve as basis for current validation
- Run-time: (10,024 processors): 4 hours 45 minutes
- We "cut" out Texas and Louisiana from the mesh by reducing floodplain and river resolution in all other areas.
- Cut 30m mesh: $7,454,386$ nodes, $14,791,198$ elements. Run-time (2,048 processors) 2 hours
- Stress testing the mesh led to an extension of the floodplains

New Compound Flooding Mesh

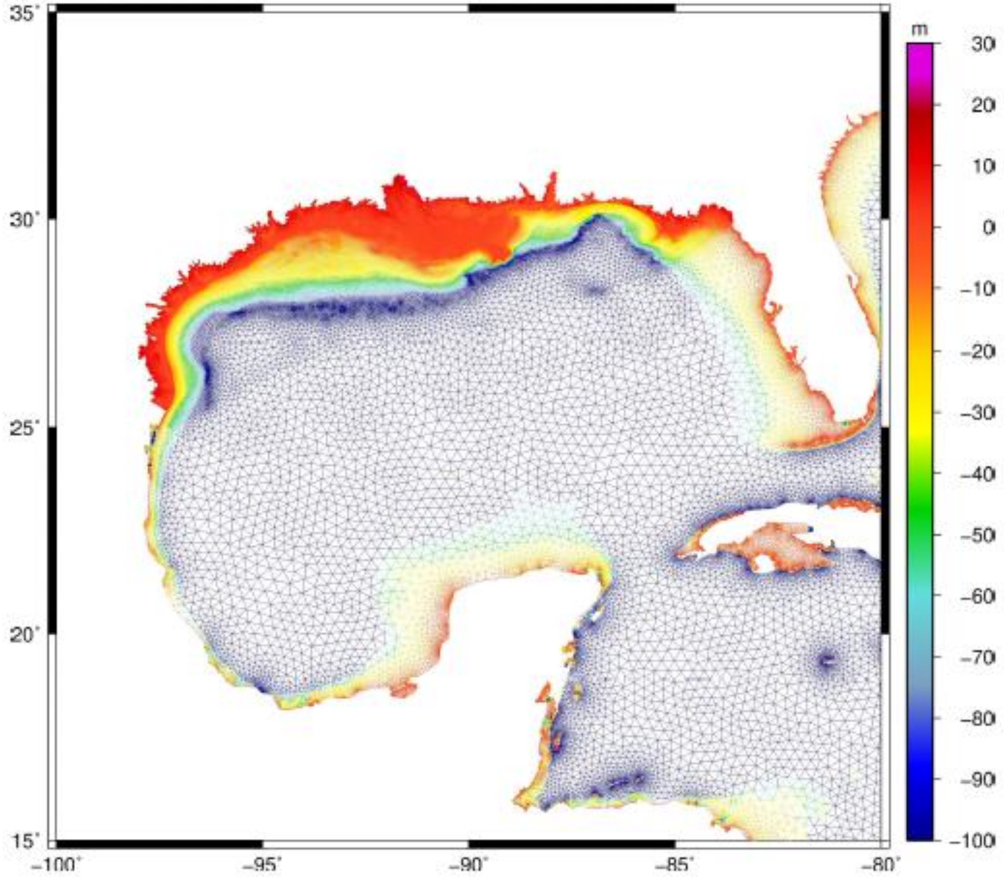


- Extreme resolution of the Texas coast (rivers and floodplains)
- 8 million nodes, 16 million triangular finite elements
- Validated for storm surge during past hurricanes (focus on Ike 2008)
- Flooding from rain induced runoff is modeled using river flows from major watersheds
- “30m mesh” on the left

Some Mesh Details

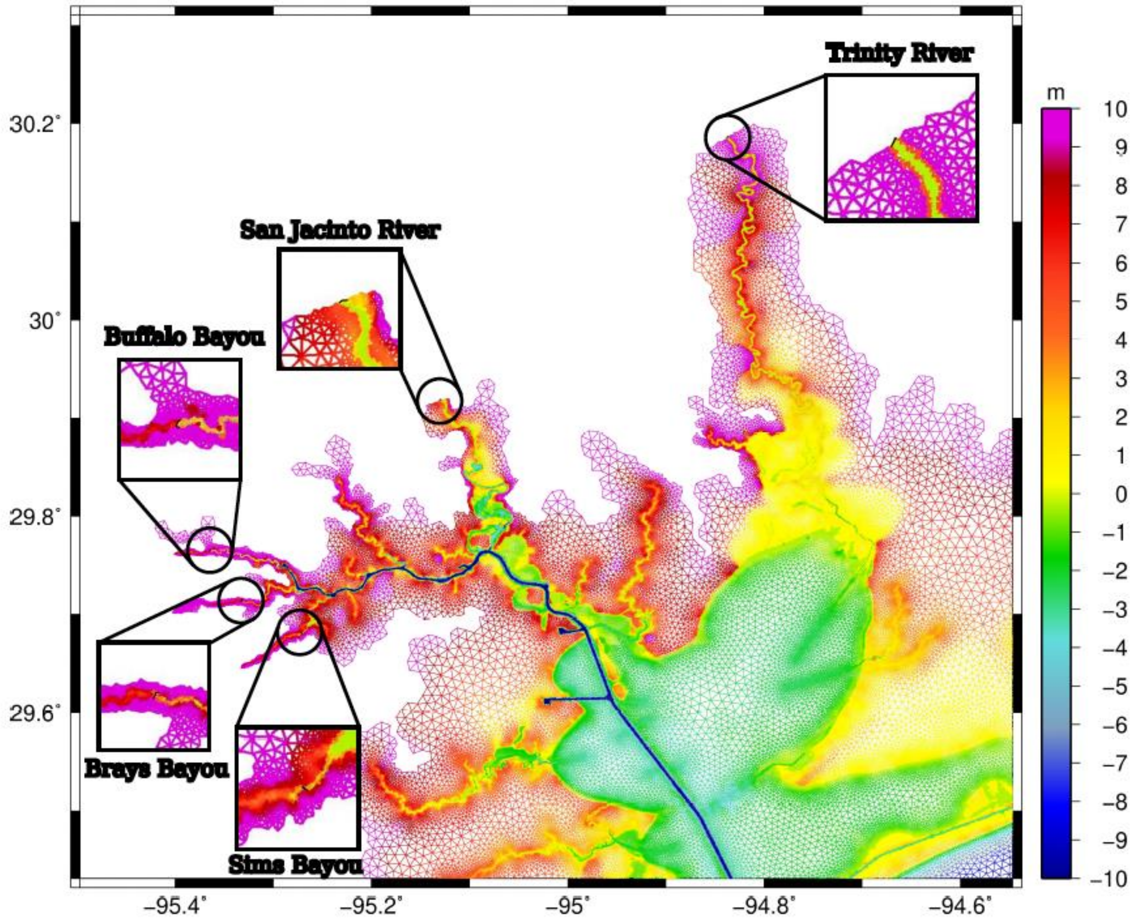


Original mesh

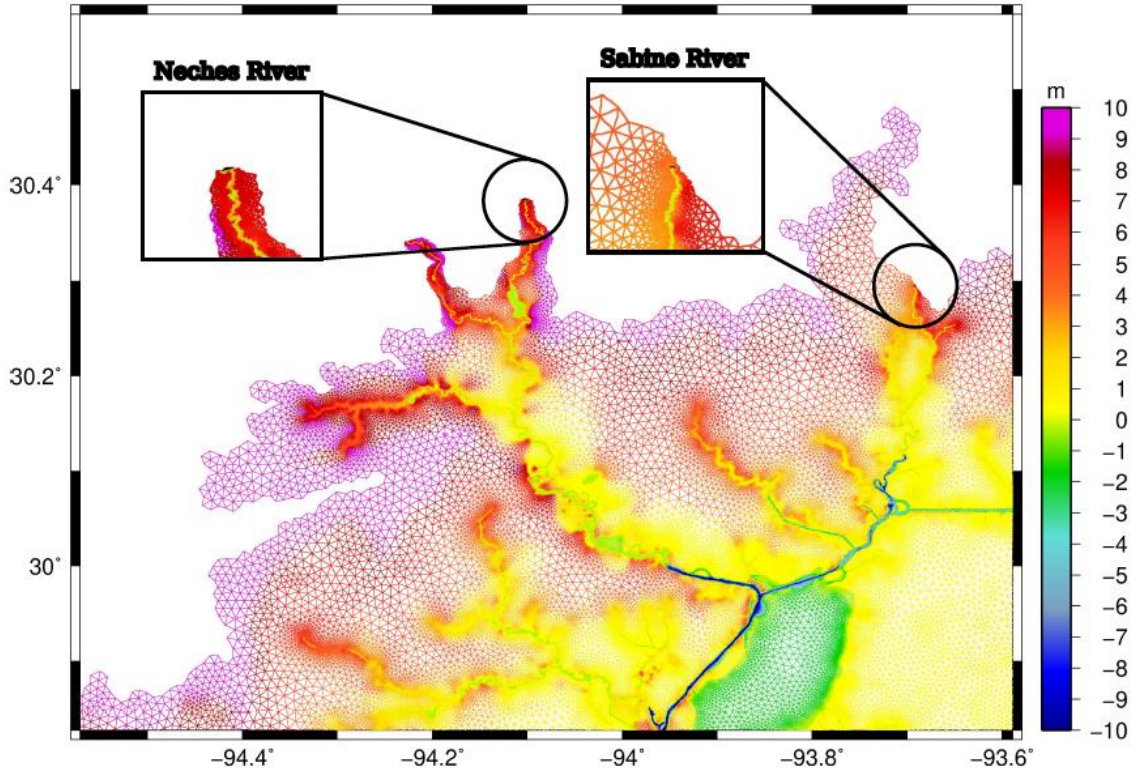


"cut" mesh

Some Mesh Details

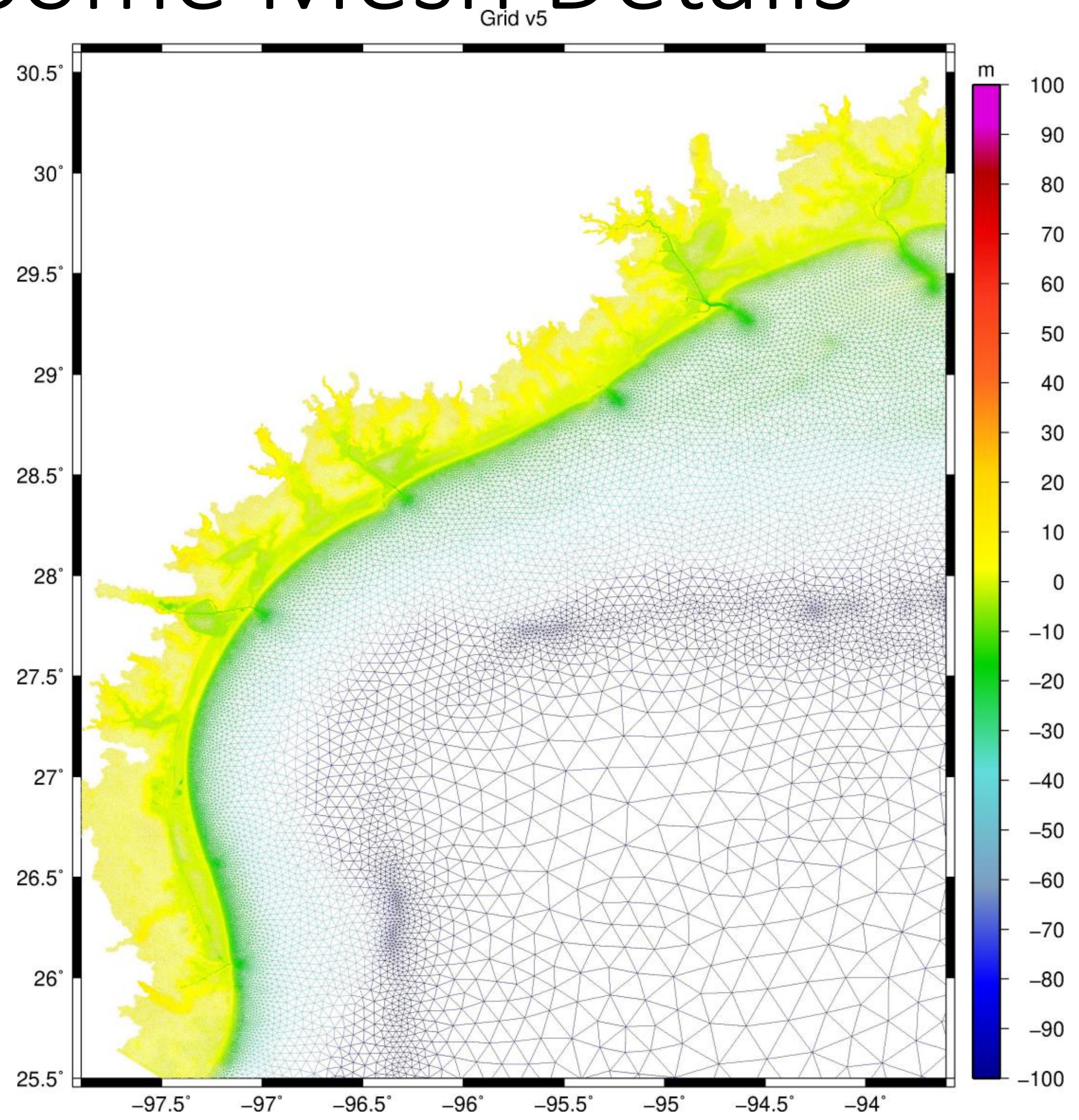


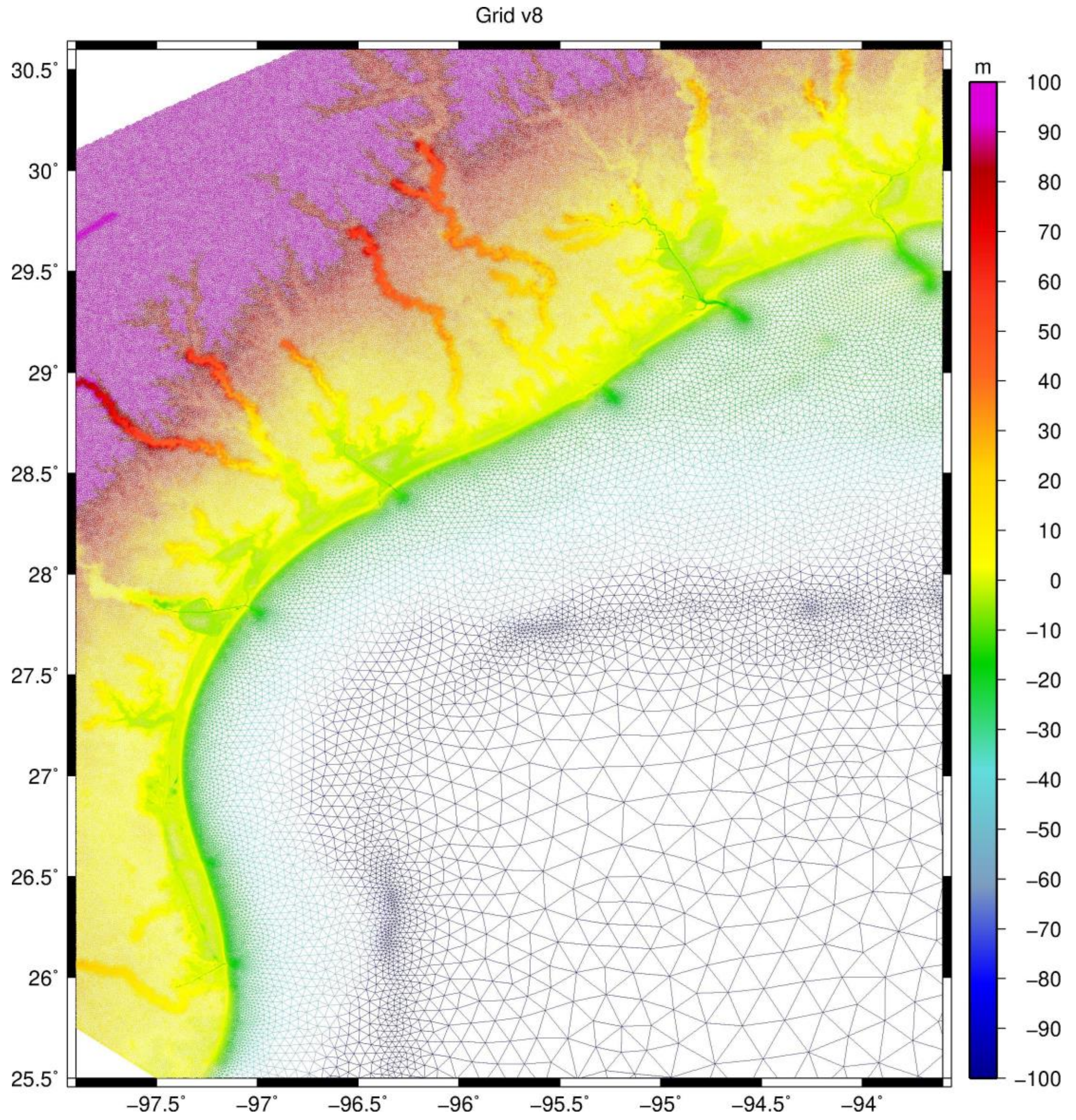
(a) Houston-Galveston



(b) Beaumont

Some Mesh Details

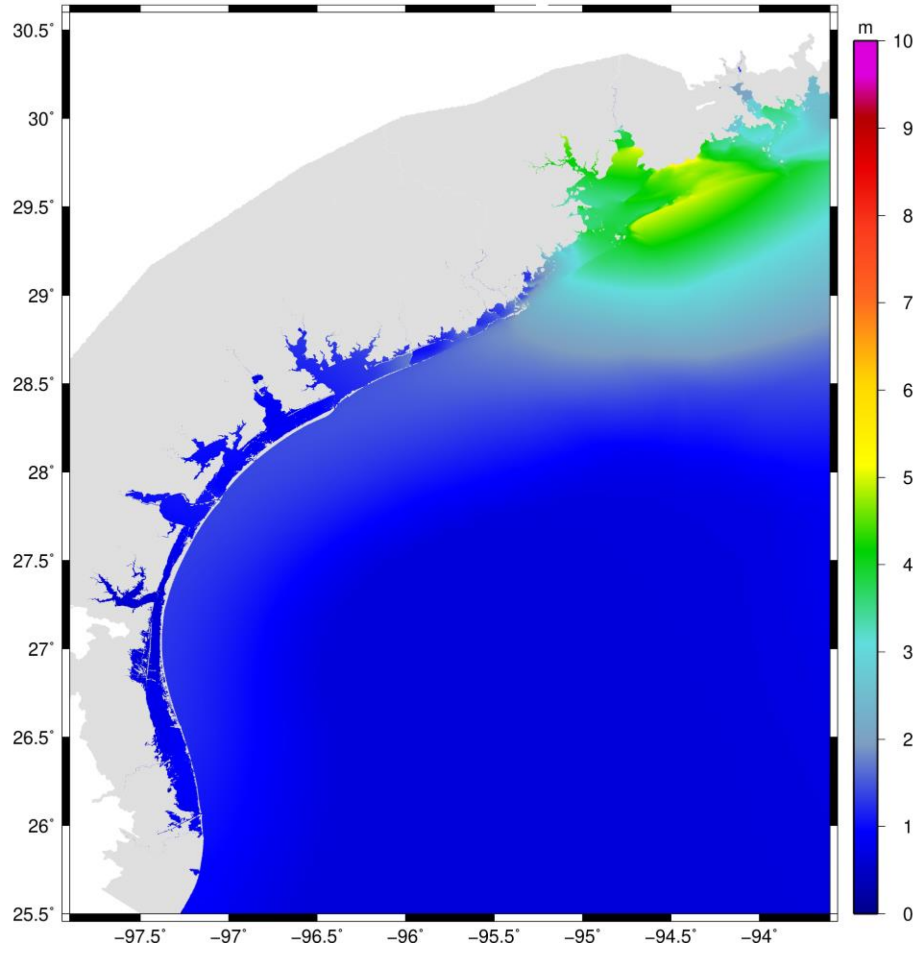




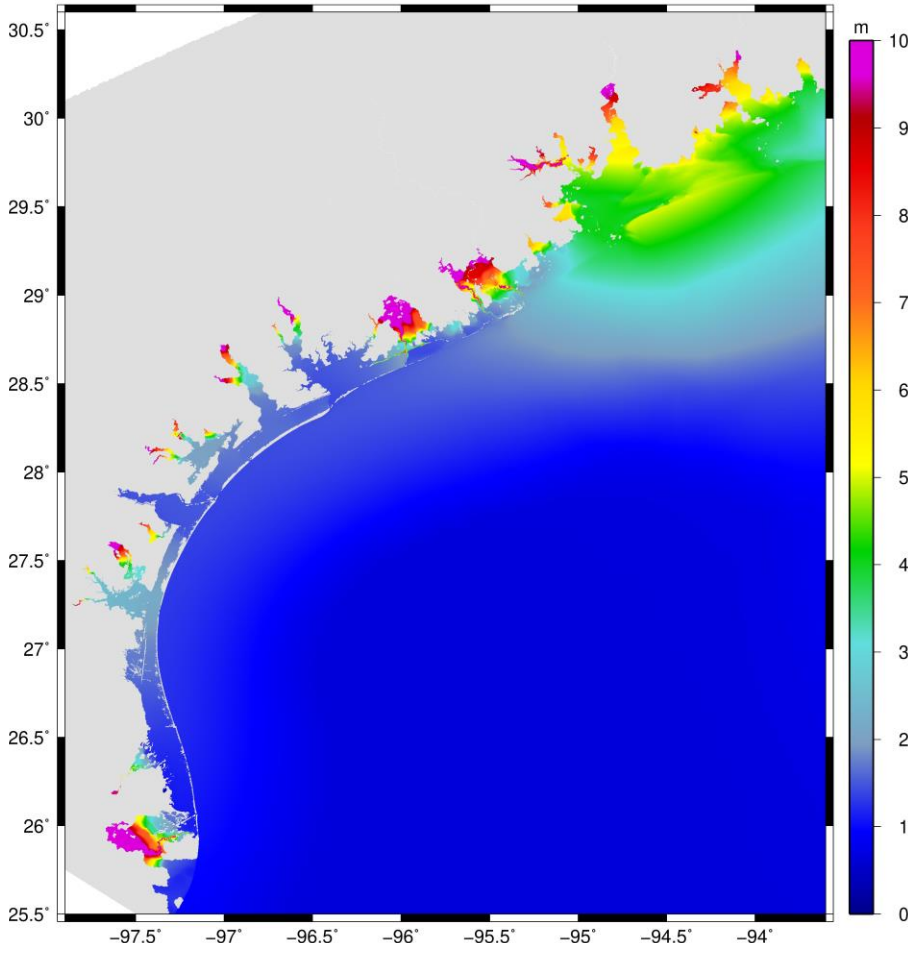
Boundary Conditions

- **Open boundary condition**: nodes on the boundary specifying time-dependent water elevation, such as tides
- **Zero-flux boundary condition**: used for land and islands
- **Normal flux boundary condition**: nodes on the boundary or inside the domain specifying time-dependent flow rates, i.e., rivers:
    - 45 rivers in Texas are added as normal flux boundary conditions, including major ones like Sabine, Neches, Trinity, etc.
    - Most of the data obtained from USGS time series records and converted to ADCIRC format
    - Missing data is handled using trend analysis of gauges as well as TxRR model results provided by TWDB and interpolation in time

Stress Test of the Model

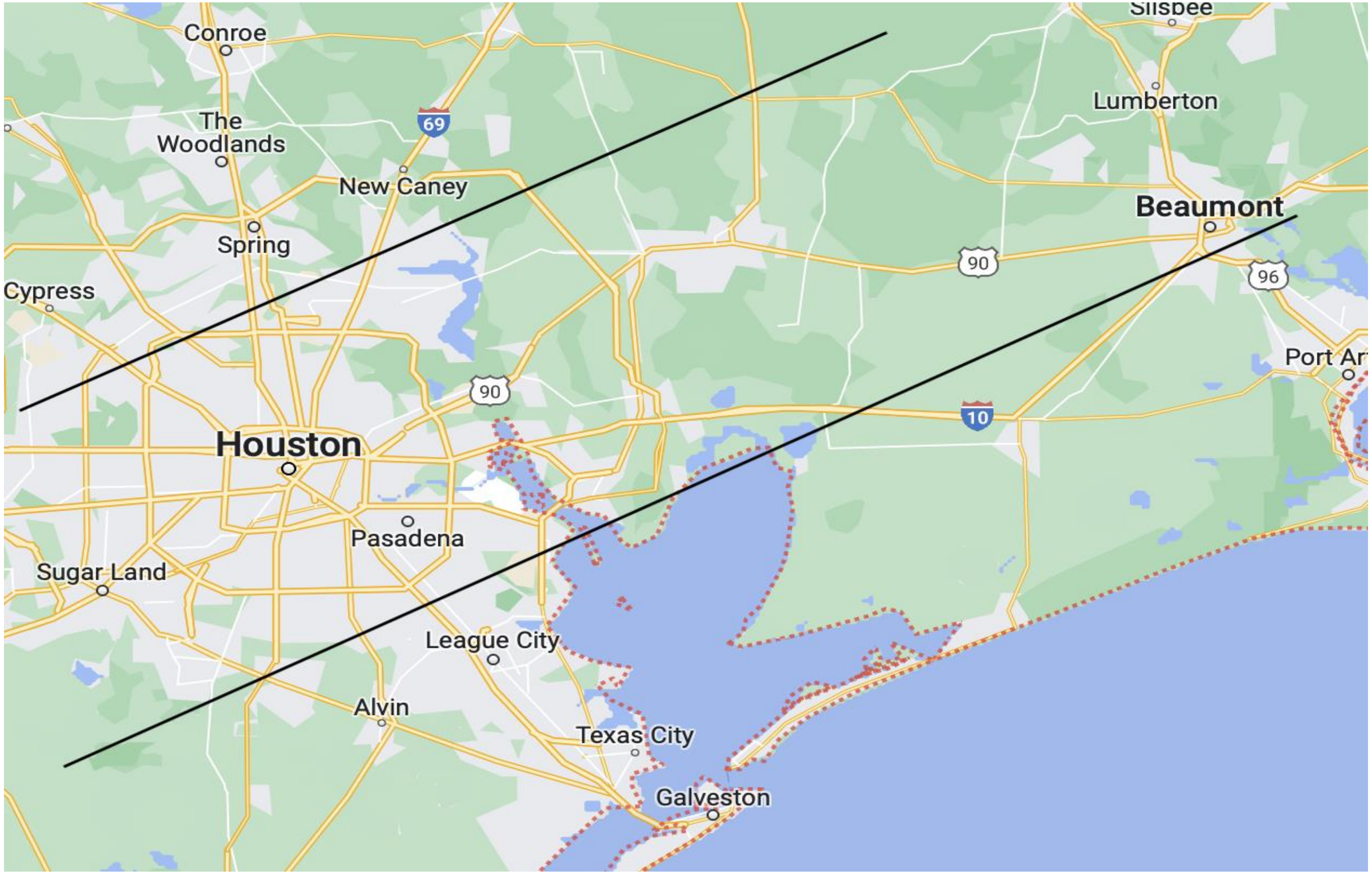


Hurricane Ike surge

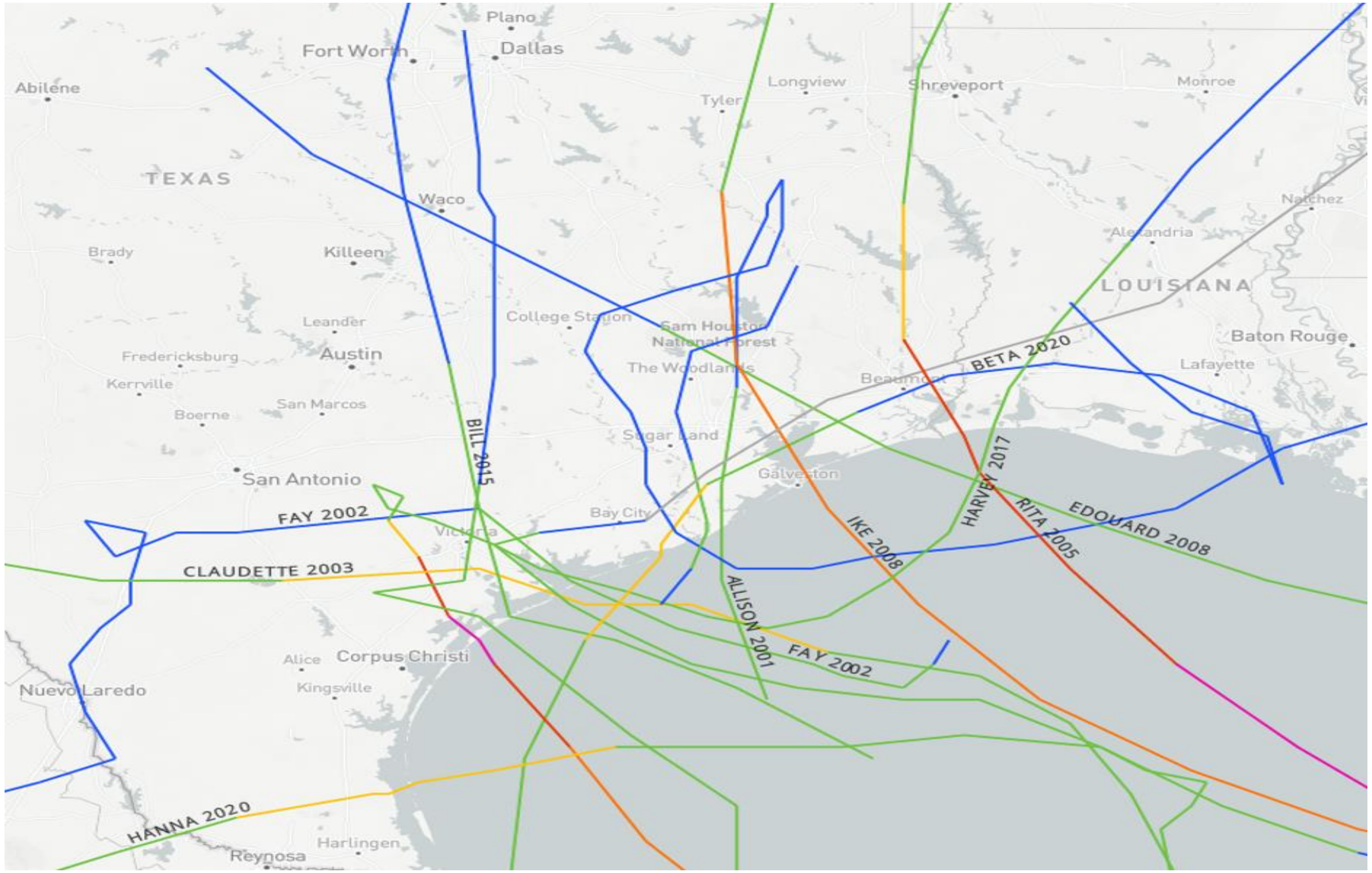


Hurricane Ike surge + 500,000cfs in all rivers (breaks old mesh)

“Goal”


Silsbee
Conroe
Lumberton
69
The Woodlands
New Caney
Beaumont
Spring
90
96
Cypress
Port Ar
90
10
Houston
Pasadena
Sugar Land
League City
Alvin
Texas City
Galveston

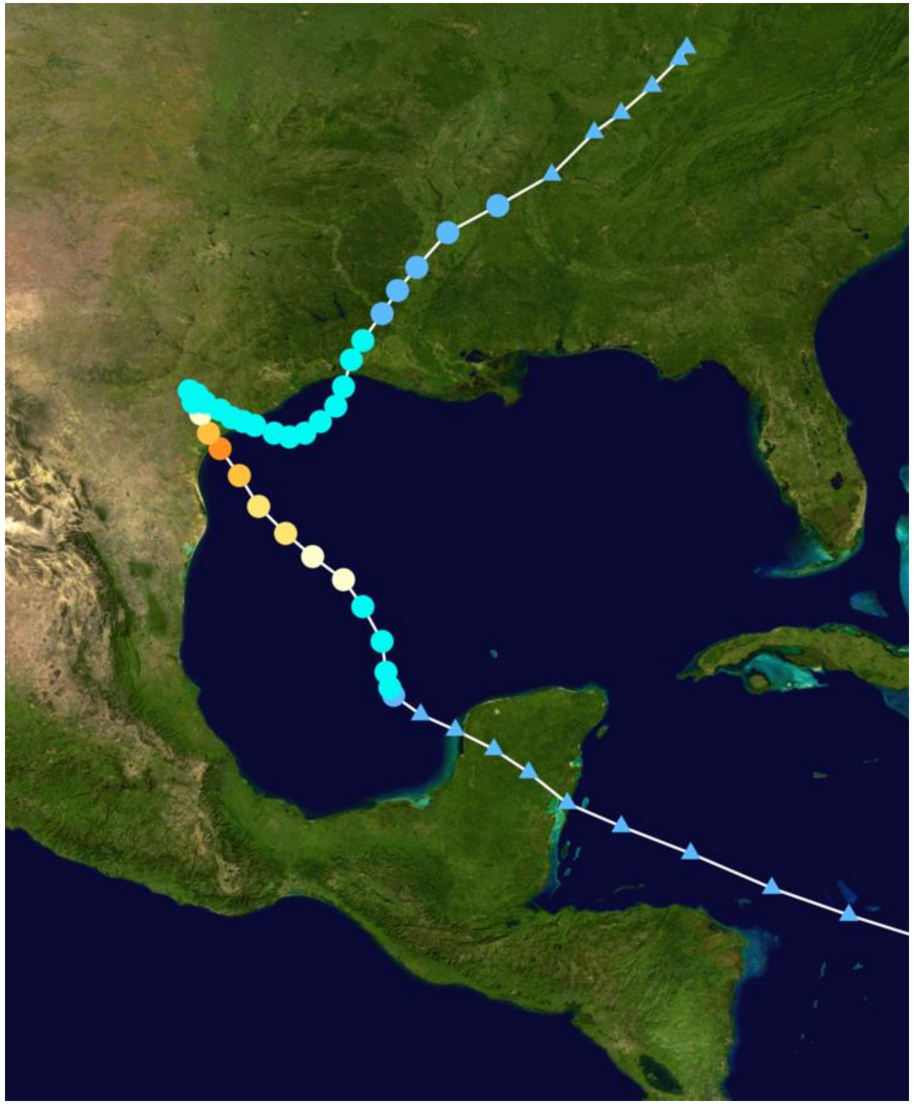
Selected Past events



Tracks of 14 historic hurricanes

Results – Hurricane Harvey (2017)

- Costliest hurricane on record (tied with Katrina)
- Maximum storm surge: 8 ft. near Port Aransas
- Rainfall in Houston up to ~50 inches
- Simulation dates: August 17 - September 2, 2017



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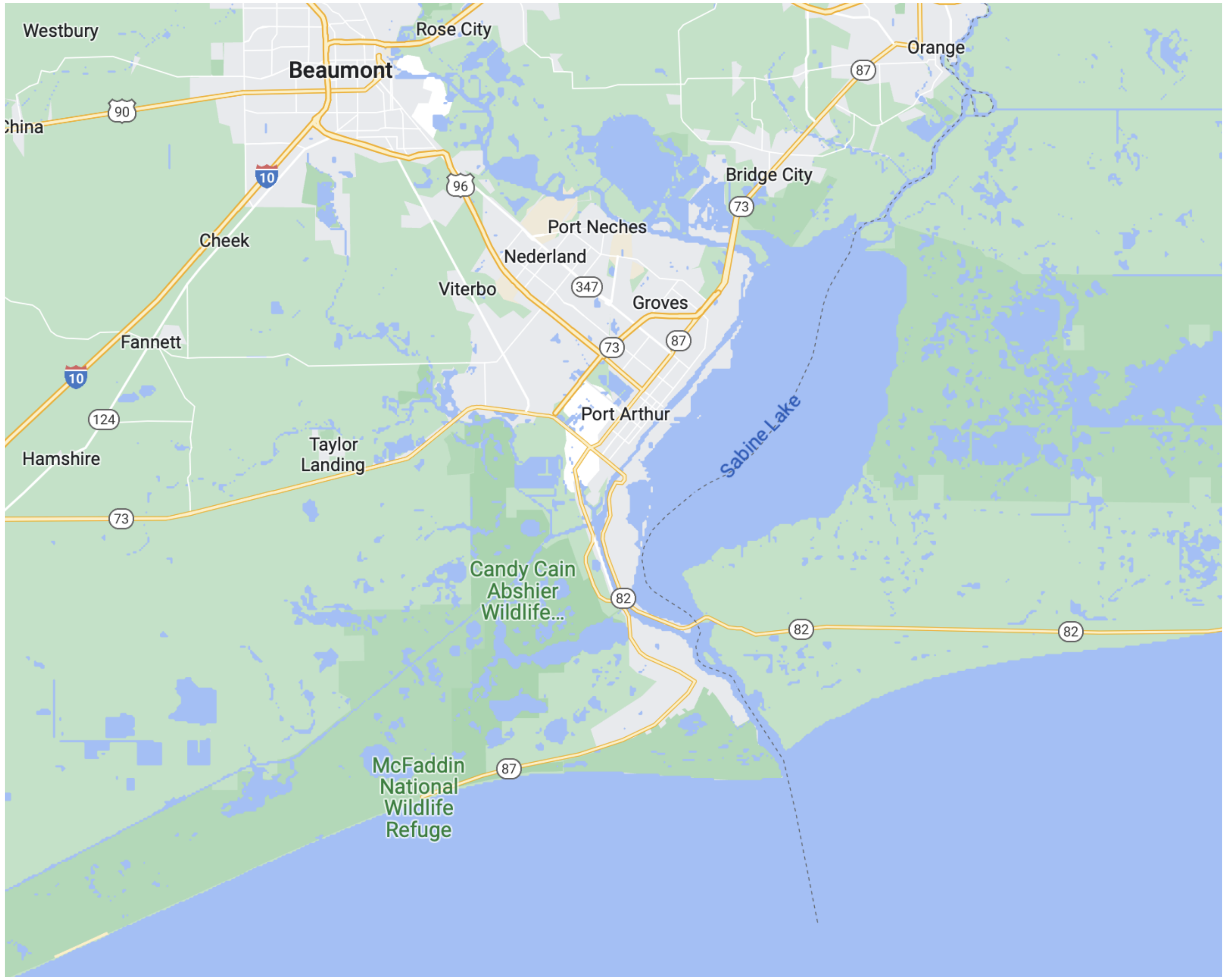

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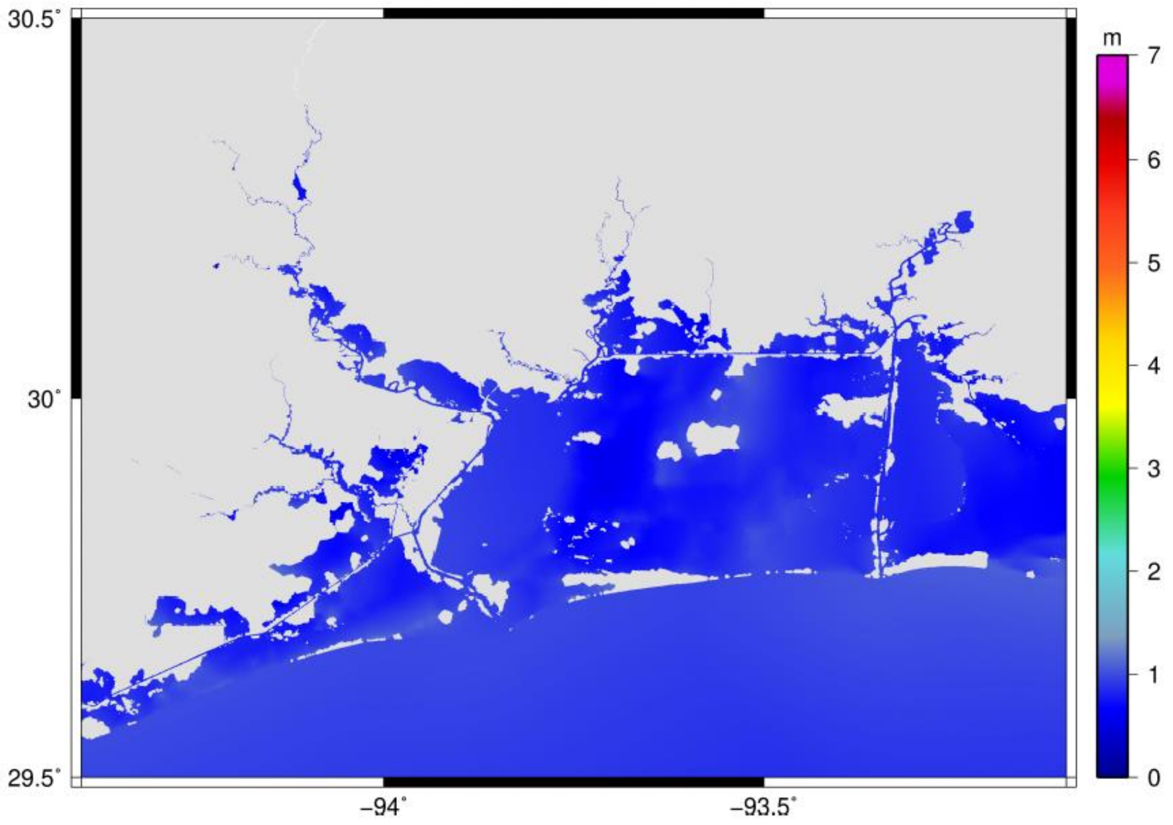
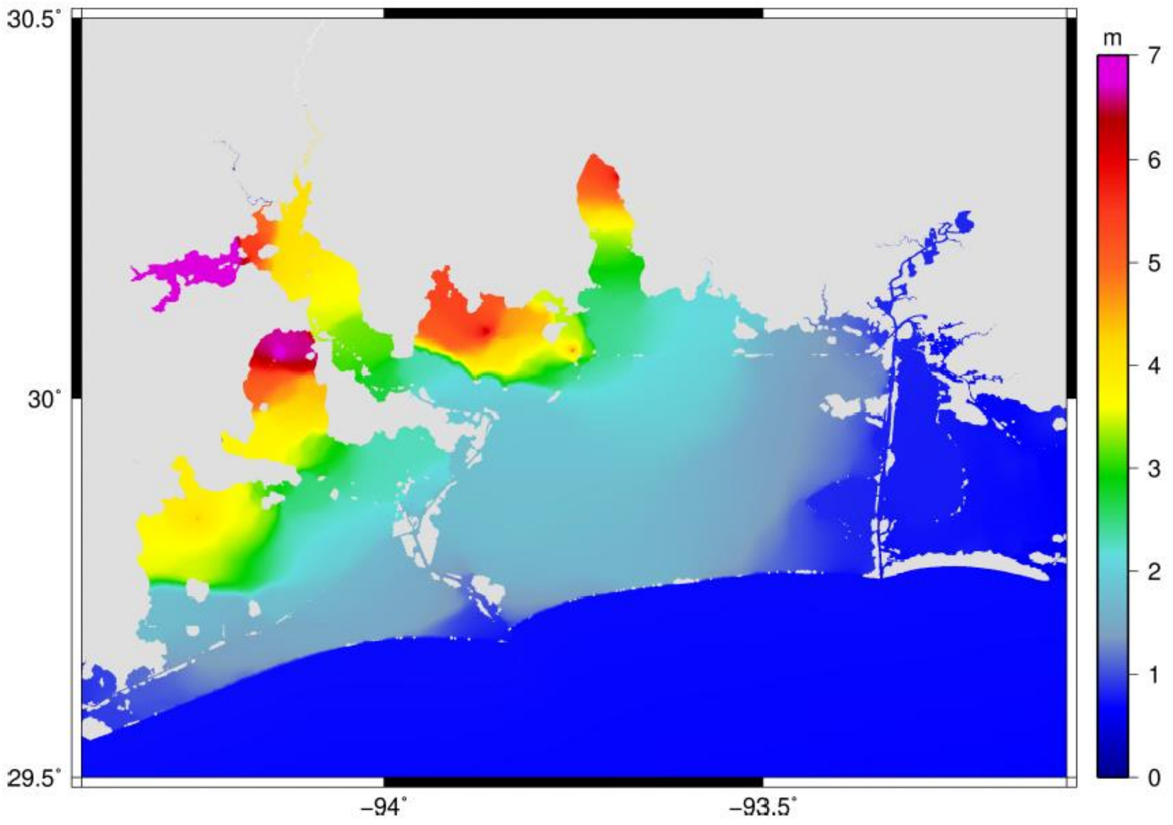
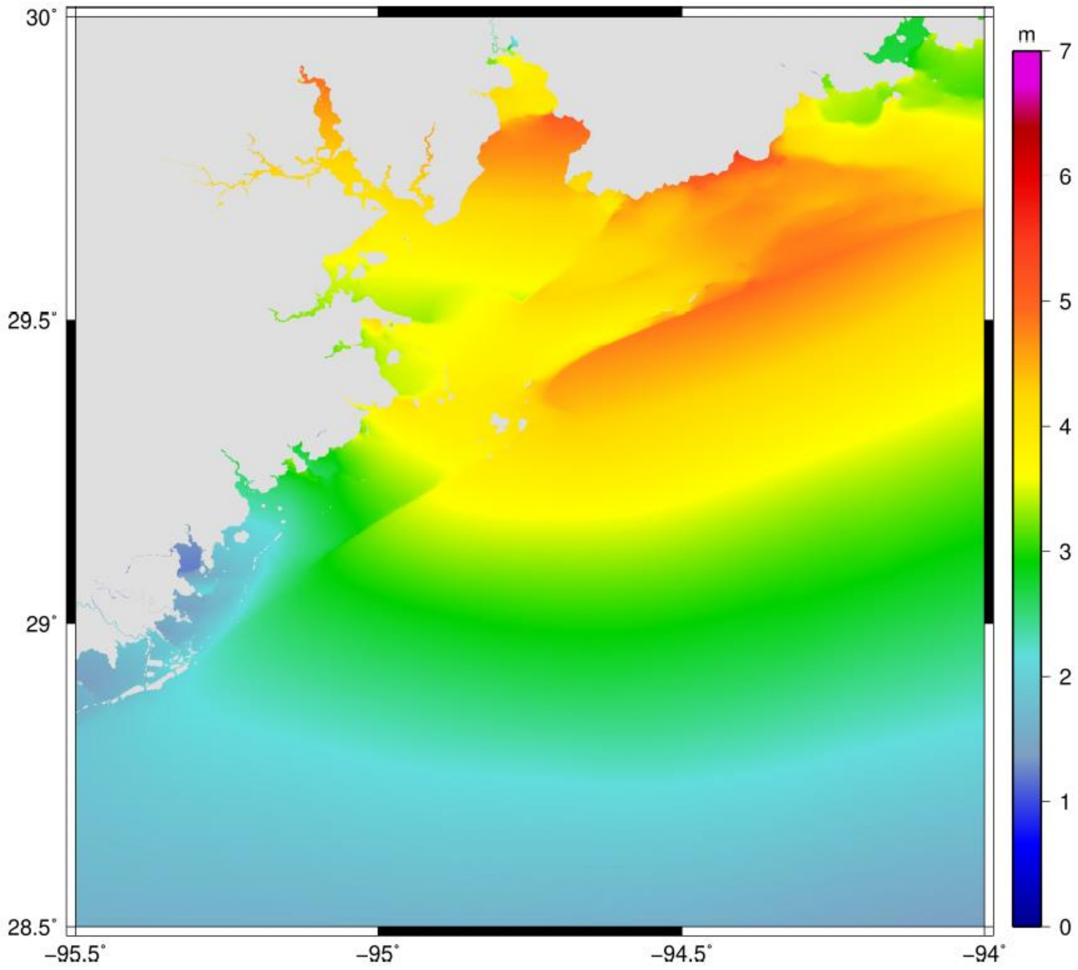


(a) Storm surge only



(b) Storm surge + river flows

Results – Hurricane Ike (2008)



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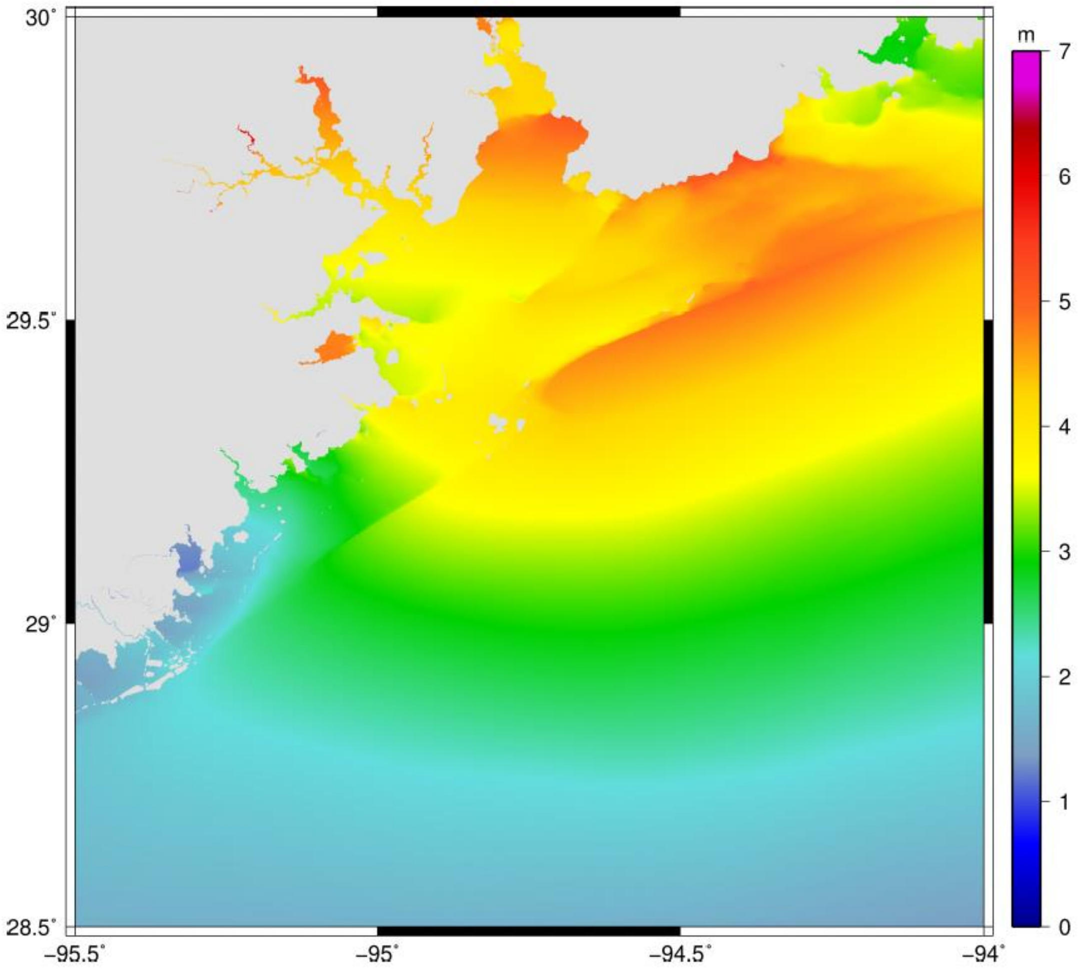
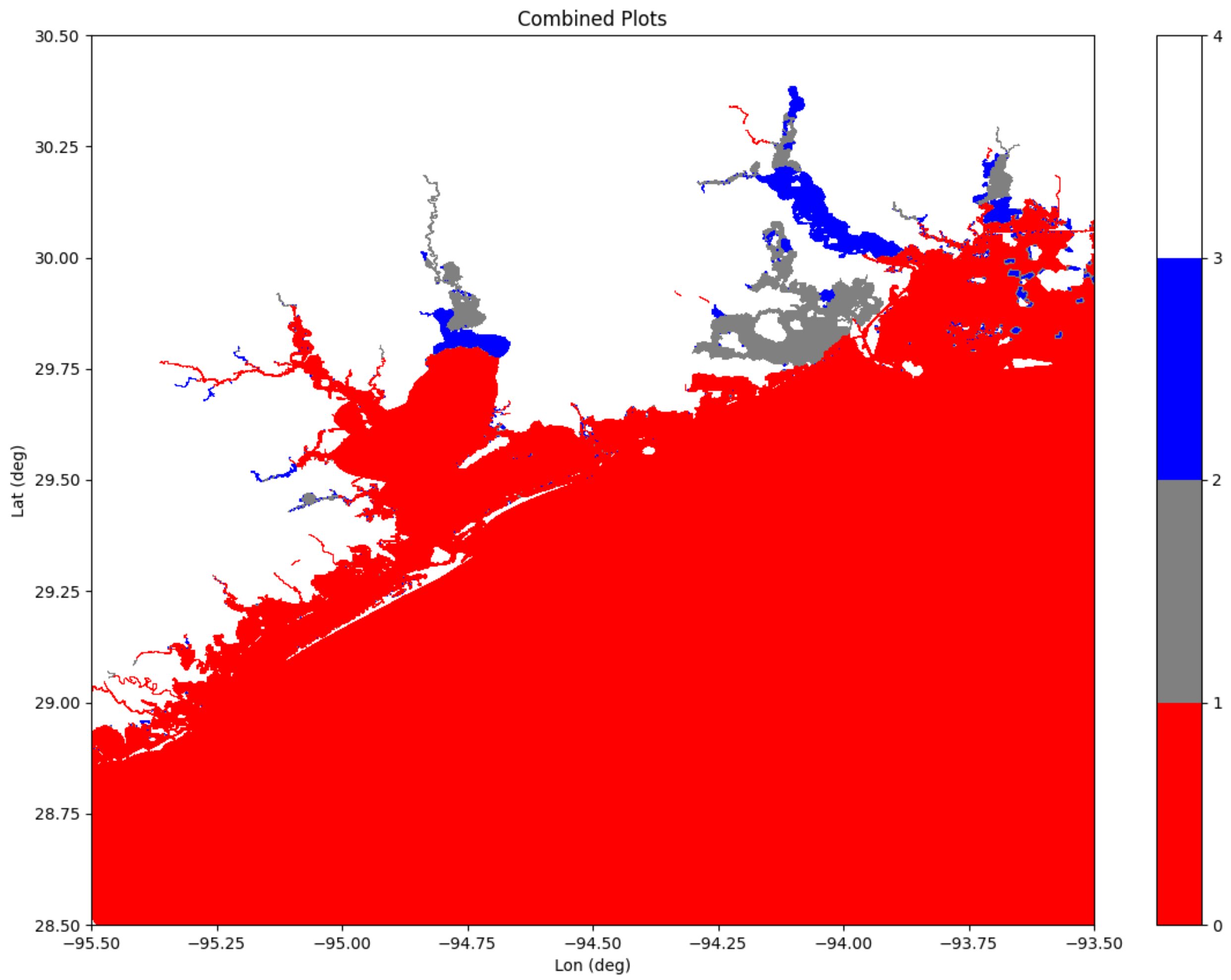
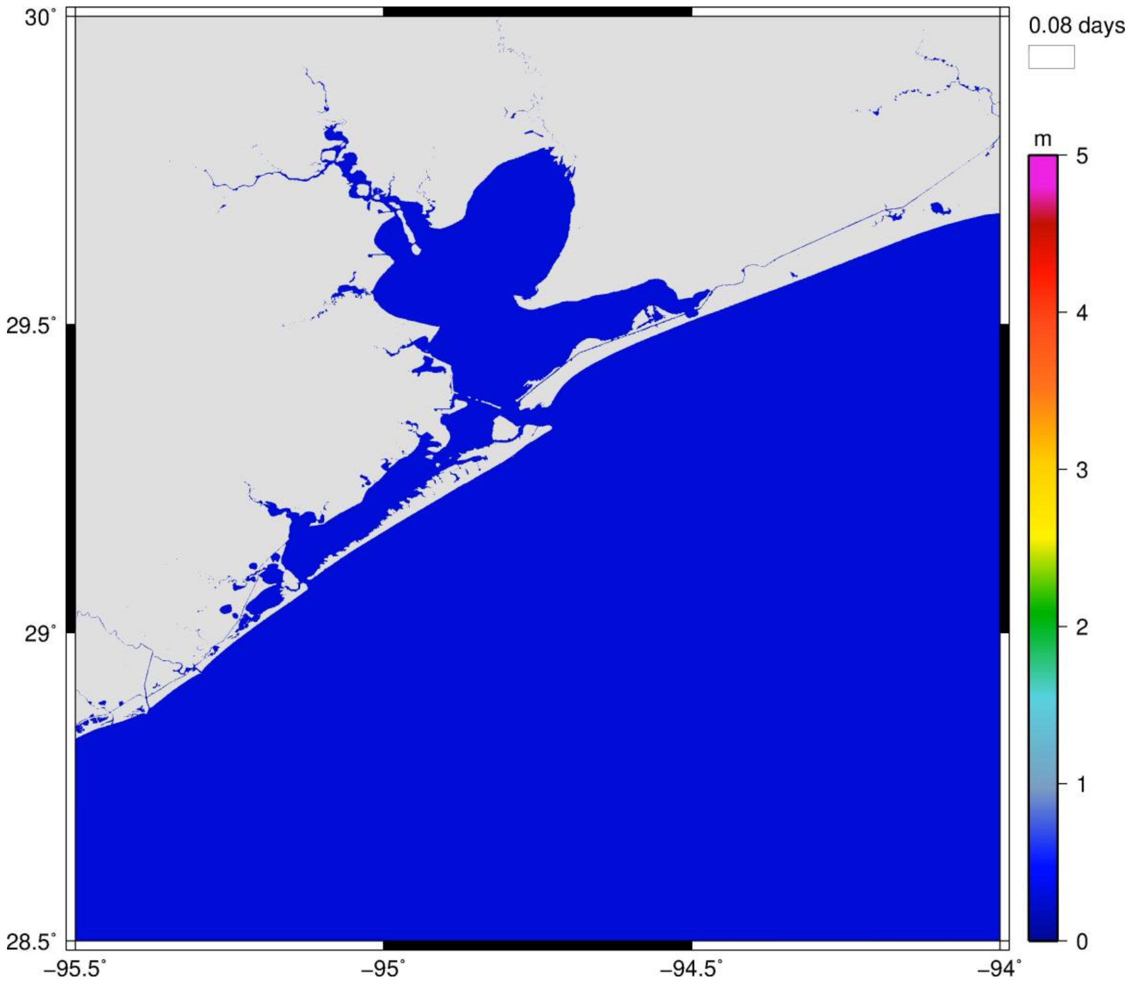


(b) Storm surge + river flows

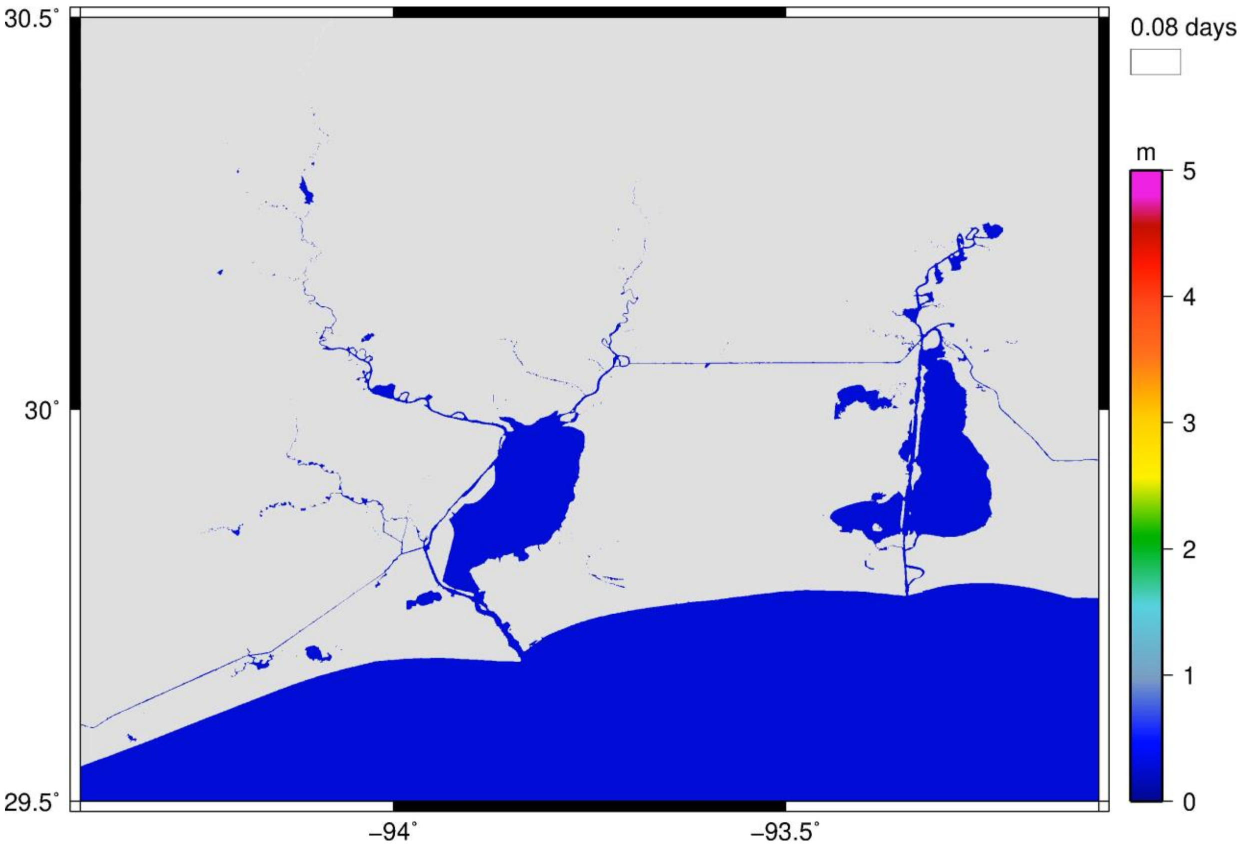
Results – Hurricane Ike (2008)



Results



Hurricane Ike



Hurricane Harvey

Takeaways

- New ADCIRC mesh capable of incorporating riverine runoff in hindcasting and studies
- New ADCIRC mesh (hopefully) to be used for operational forecasting of storm surge and compound flooding
- Currently post-processing the results to ascertain the locations of the transitional zones
- At present state, we have performed ~ 150 hurricane simulations for this project (hundreds more to come using synthetic storms and river flow data)

Acknowledgements

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