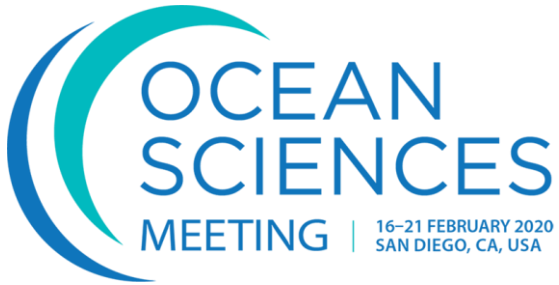
Coupled hydrological-hydrodynamic large-scale simulation

Wei Huang, Y. Joseph Zhang, Fei Ye, Haocheng Yu, Karinna Nunez
Virginia Institute of Marine Science

Saeed Moghimi, and Edward Myers
NOAA National Ocean Service



Overview

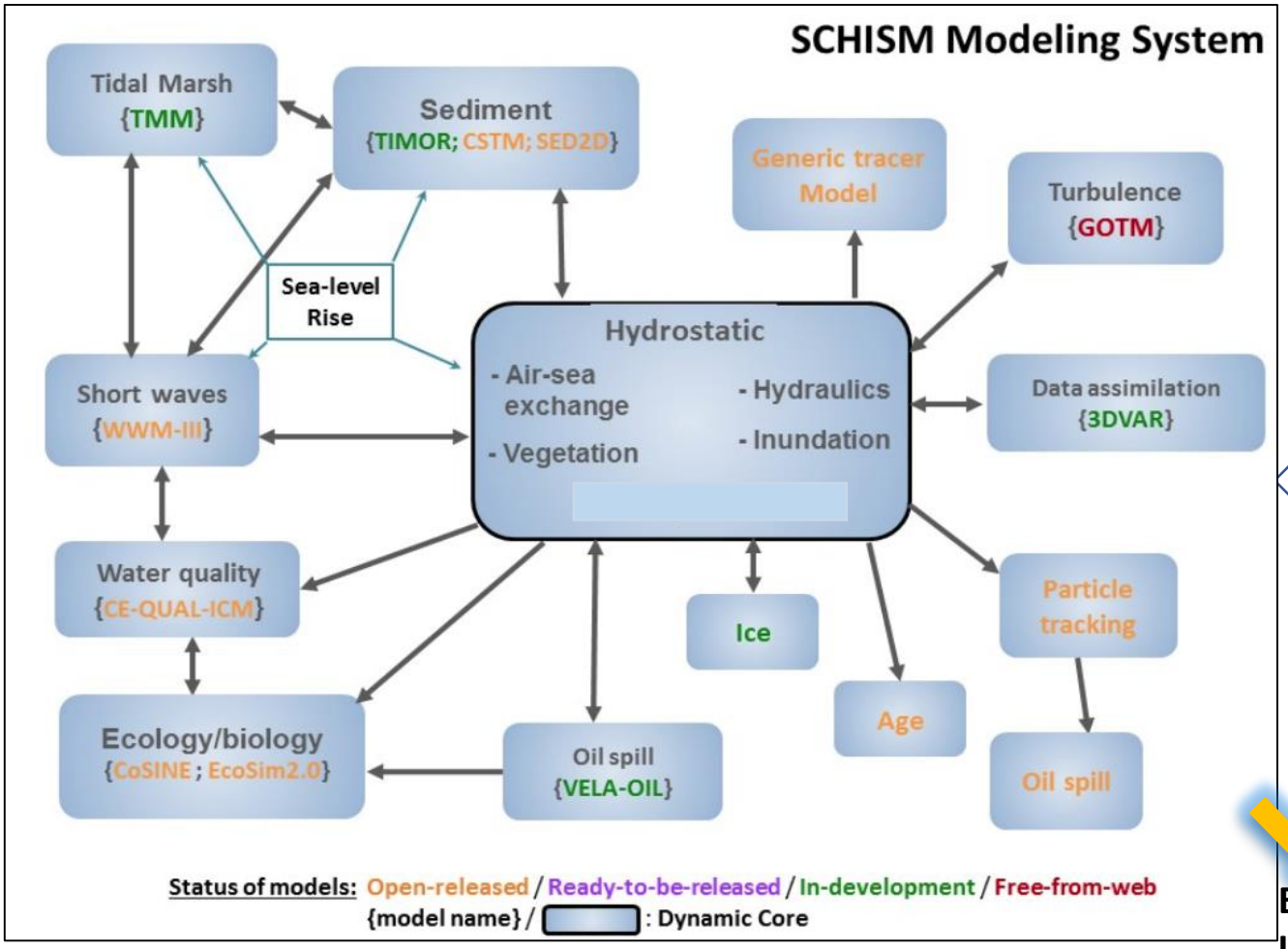
- SCHISM 3D modeling system
- Model setup for Hurricane Irene: coupling to NWM
- Grid generation
- Challenges and success: bathymetry, bathymetry, bathymetry….
- Summary

*Publications:

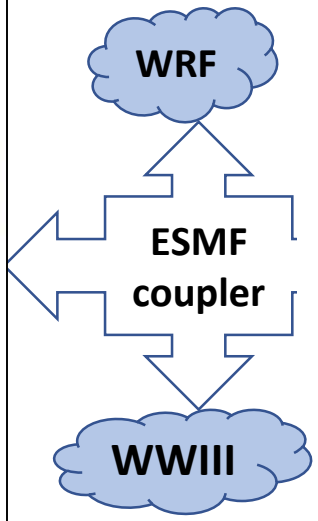
1. Zhang et al. (in press) Simulating compound flooding events in a hurricane, Ocean Dynamics.
2. Ye et al. (2020) Simulating storm surge and compound flooding events with a creek-to-ocean model: importance of baroclinic effects, Ocean Modelling, 145.

SCHISM: Semi-implicit Cross-scale Hydroscience Integrated System Model

- Solves 3D Navier-Stokes equations in hydrostatic form with Boussinesq approximation
- Galerkin finite-element and finite-volume approach: generic unstructured grids
- Semi-implicit time stepping: no mode splitting → large time step and no splitting errors
- Eulerian-Lagrangian method (ELM) for momentum advection → efficiency & robustness



- Mixed grids (tri-quads)
- Flexible LSC^2 vertical grid
- Higher-order, monotone transport: TVD^2; WENO3;
- Higher-order momentum advection (ELM with ELAD)
- ESMF ready



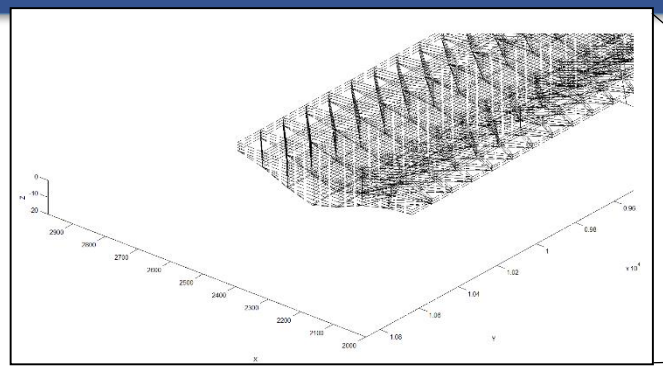
SCHISM offers the capability of multi-scale physics/biology and the following technological advantages:

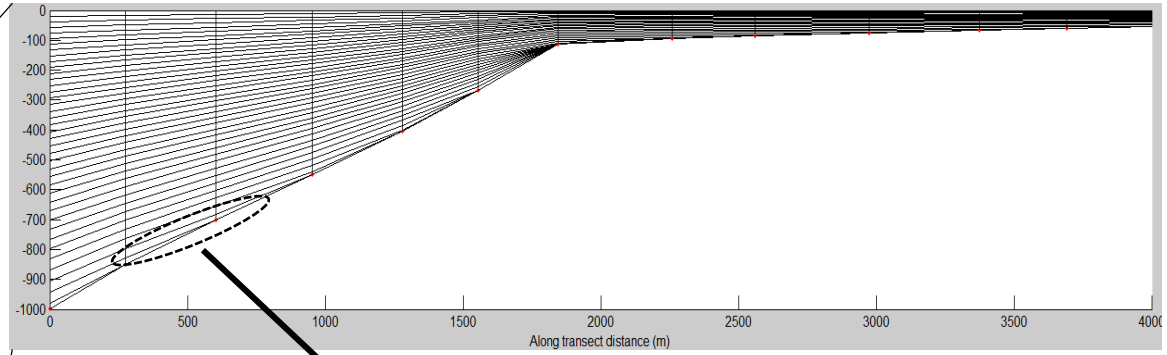
- Unsmoothed bathymetry
- Polymorphism
- Resolution on demand (skew elements)
- Robust seamless creek-to-ocean, Summit-to-Sea capability

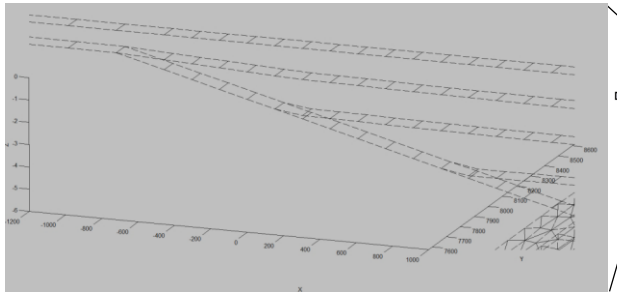
ELCIRC-sub (street-level inundation)

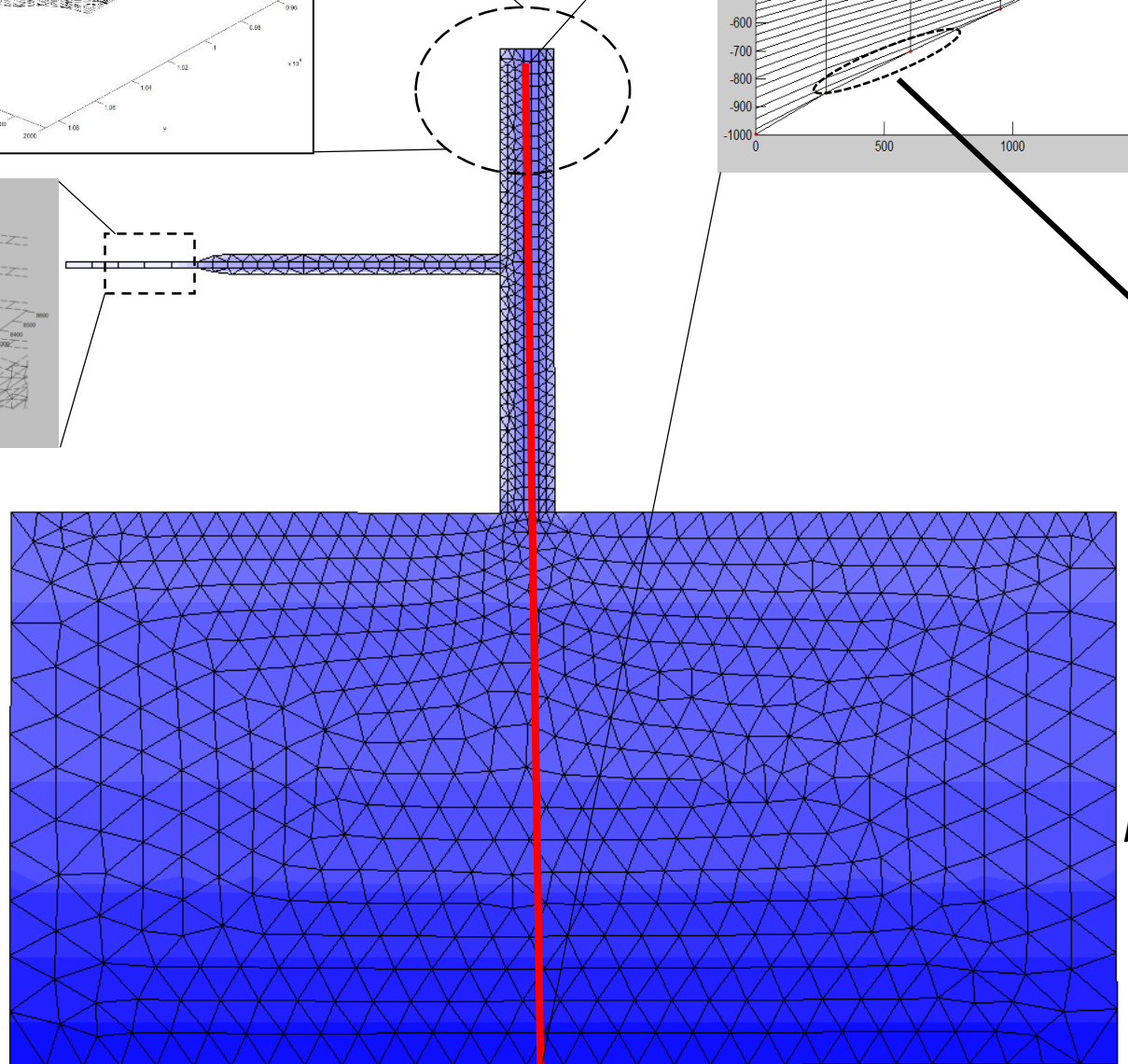
… the goal is to minimize grid nesting as much as possible

Polymorphism

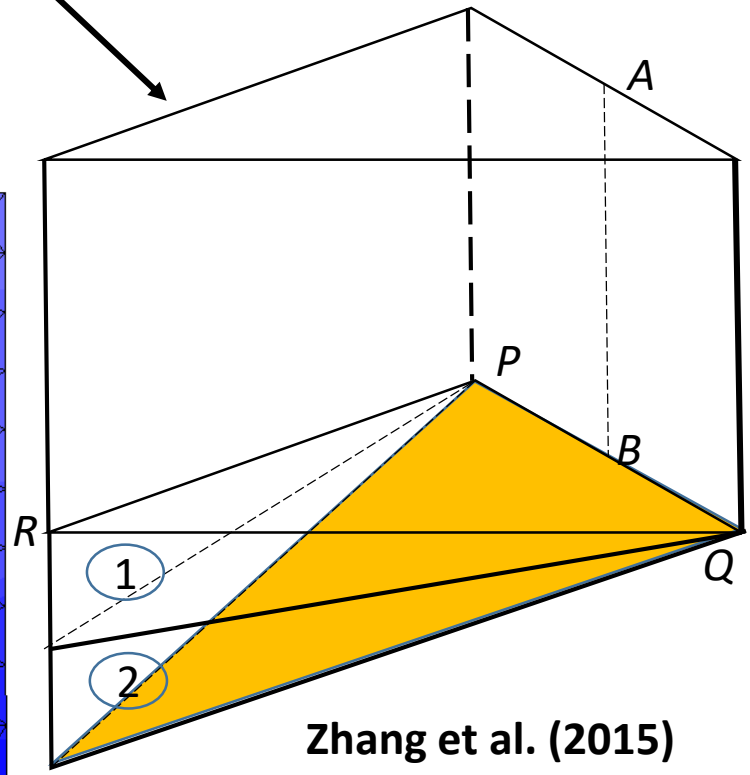






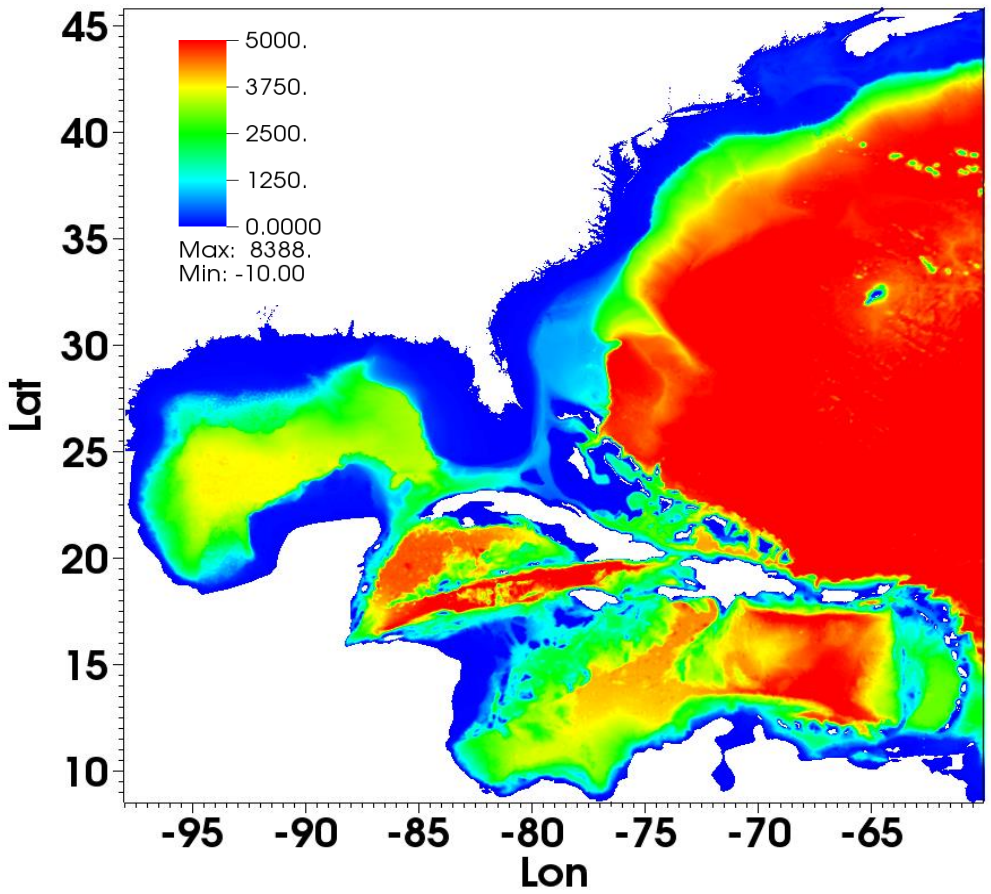


- A single grid mimics 1D/2DV/2DH/3D cells
- Efficiency and flexibility
- Shaved cells for bottom controlled processes
- As a result, the underlying bathymetry can be accurately represented, including steep slopes



Zhang et al. (2015)

Model setup: seamless creek-to-ocean



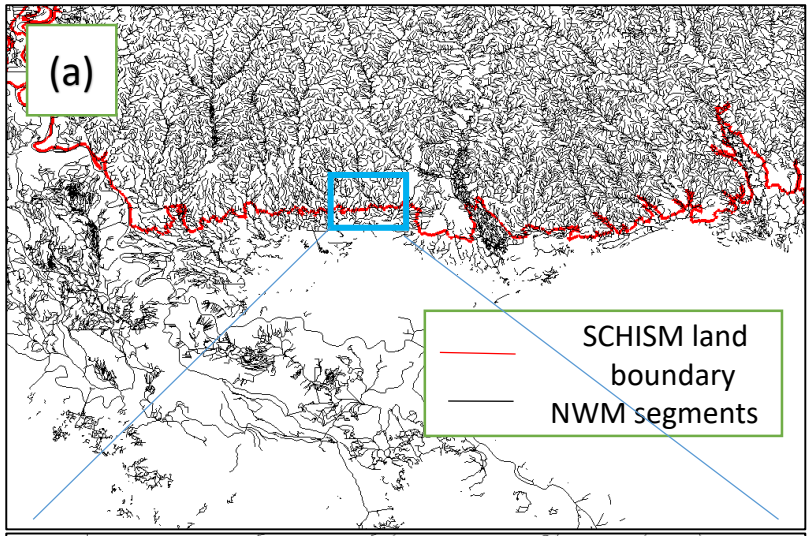
- *Non-smoothed bathymetry*
- *Explicitly representing NWM segments in the horizontal grid*
- *Grid resolution: 2~7 km in the ocean; 50-200 m in the main channels; down to <20m in small streams*
- *Terrain following vertical grid with varying number of layers (LSC^2): 19 on average*
- *3rd order transport scheme based on WENO*
- *Ocean boundary forced by HYCOM*
- *Initialized from HYCOM (with approximated salinity/temperature field inside the estuaries)*
- *Atmospheric forcing from ECWMF (ERA & ERA-HiRes)*
- *Freshwater inflow inside Delaware Bay from NWM*
- *Simulation period: 2011-7-27 ~ 2011-9-10 (50 days)*
- *Time step: 150 seconds*

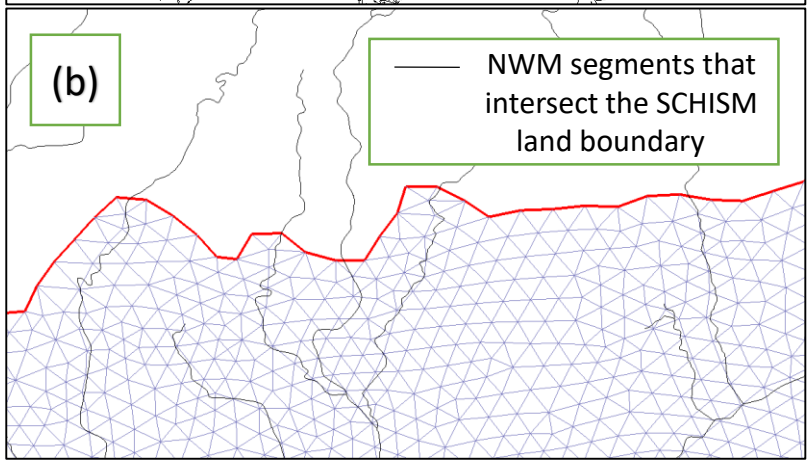
Two major configurations

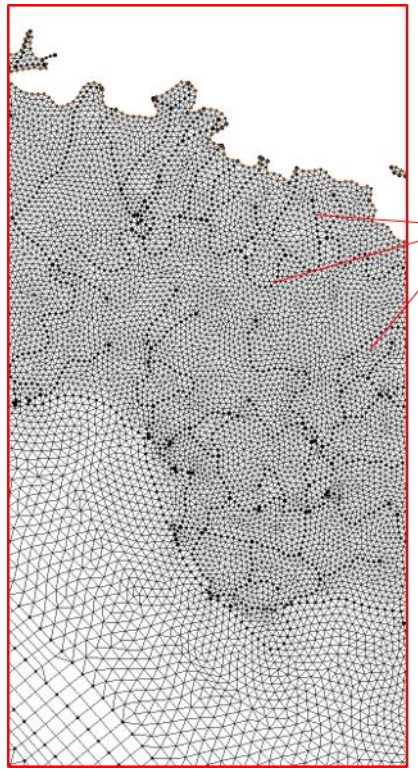
1. *Delaware Bay (3D baroclinic): 759K nodes and 1,478K elements. 80x Real Time on 1440 cores of Pleiades (NASA) (cf. Saeed's talk).*
2. *East coast + Gulf of Mexico: 2.2 mil nodes*
   - *The 2D model runs approximately 300 times faster than real time and can be efficiently conducted using as few as 500 cores*
   - *Working on 3D model*

Coupling with NWM

- One-way coupling at the moment, from NWM to SCHISM
- The intersection points between NWM Segments and the SCHISM land boundary are determined.
- NWM flows are directly injected at the intersection points; SCHISM handles routing inside its own domain

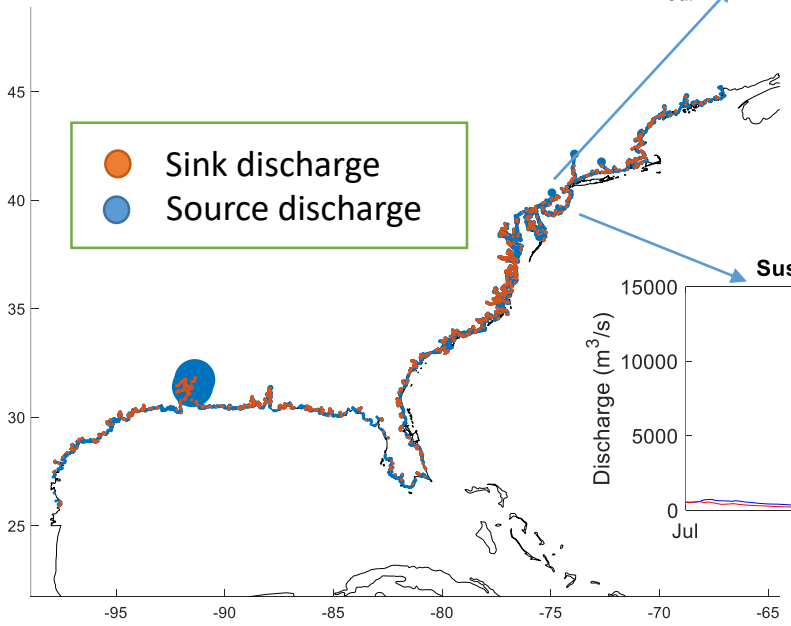


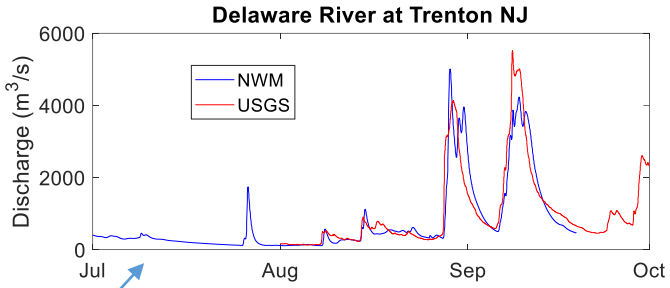


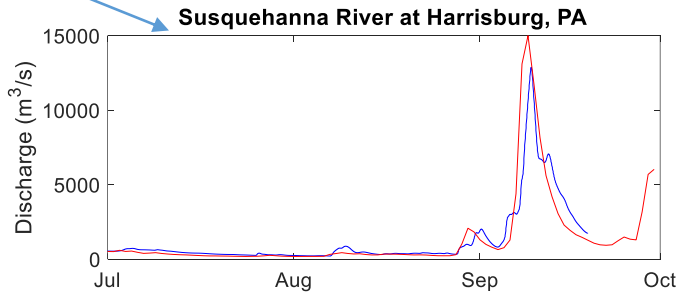


NWM segments

Total source elements: 6835
Total sink elements: 1348

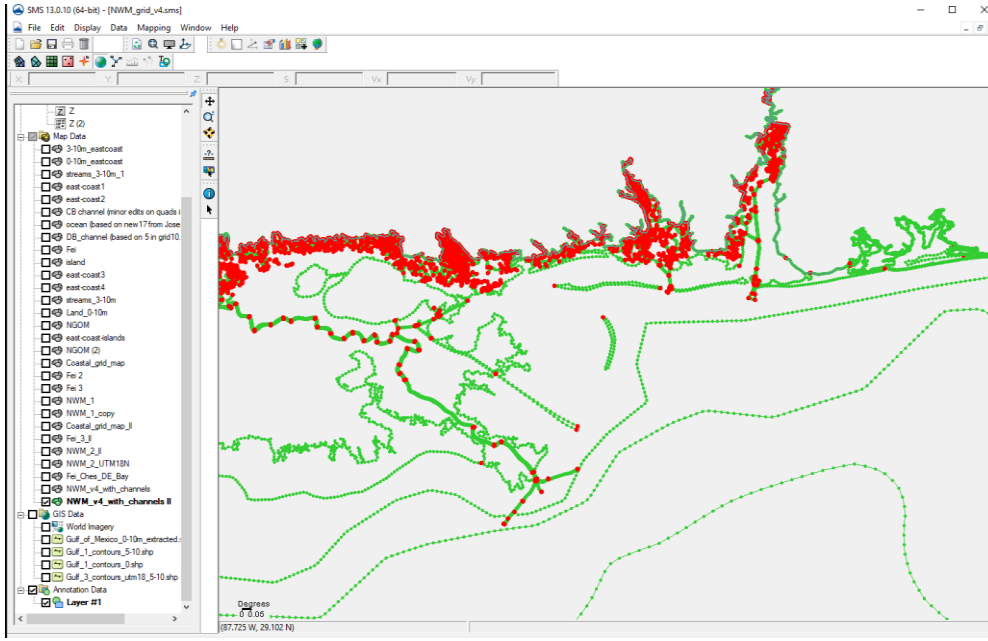


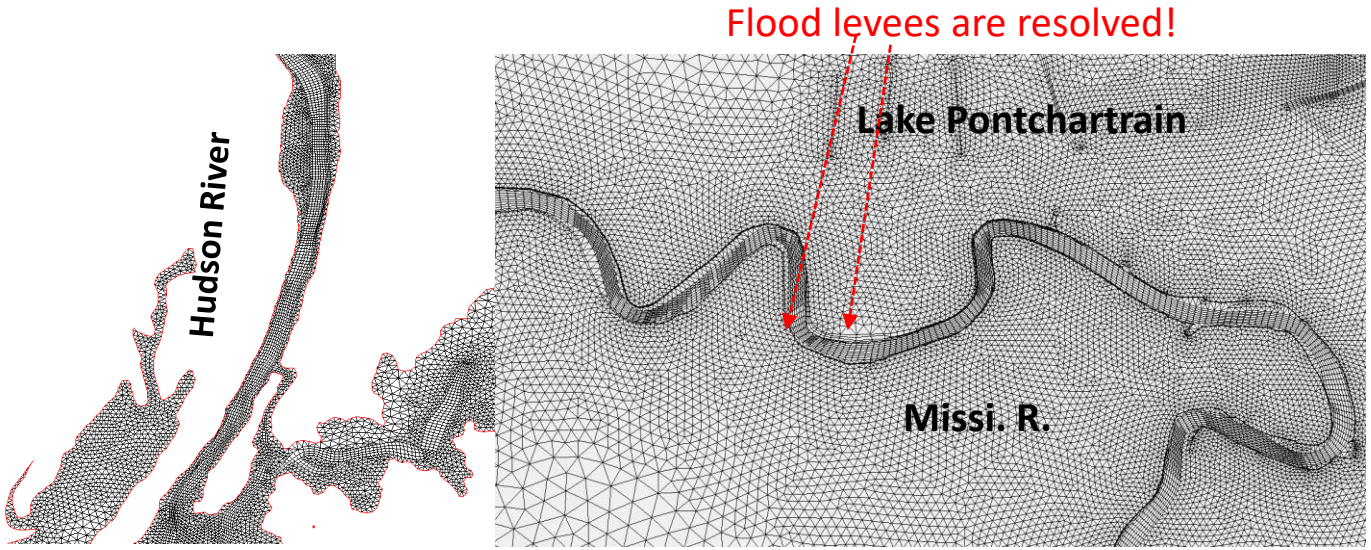


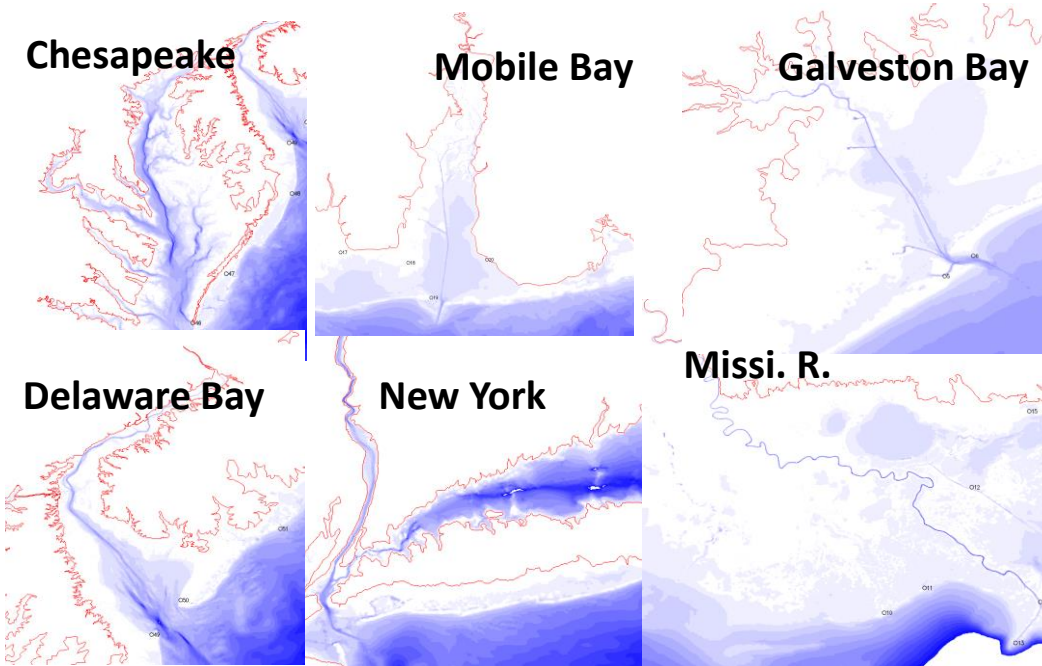


Grid Generation

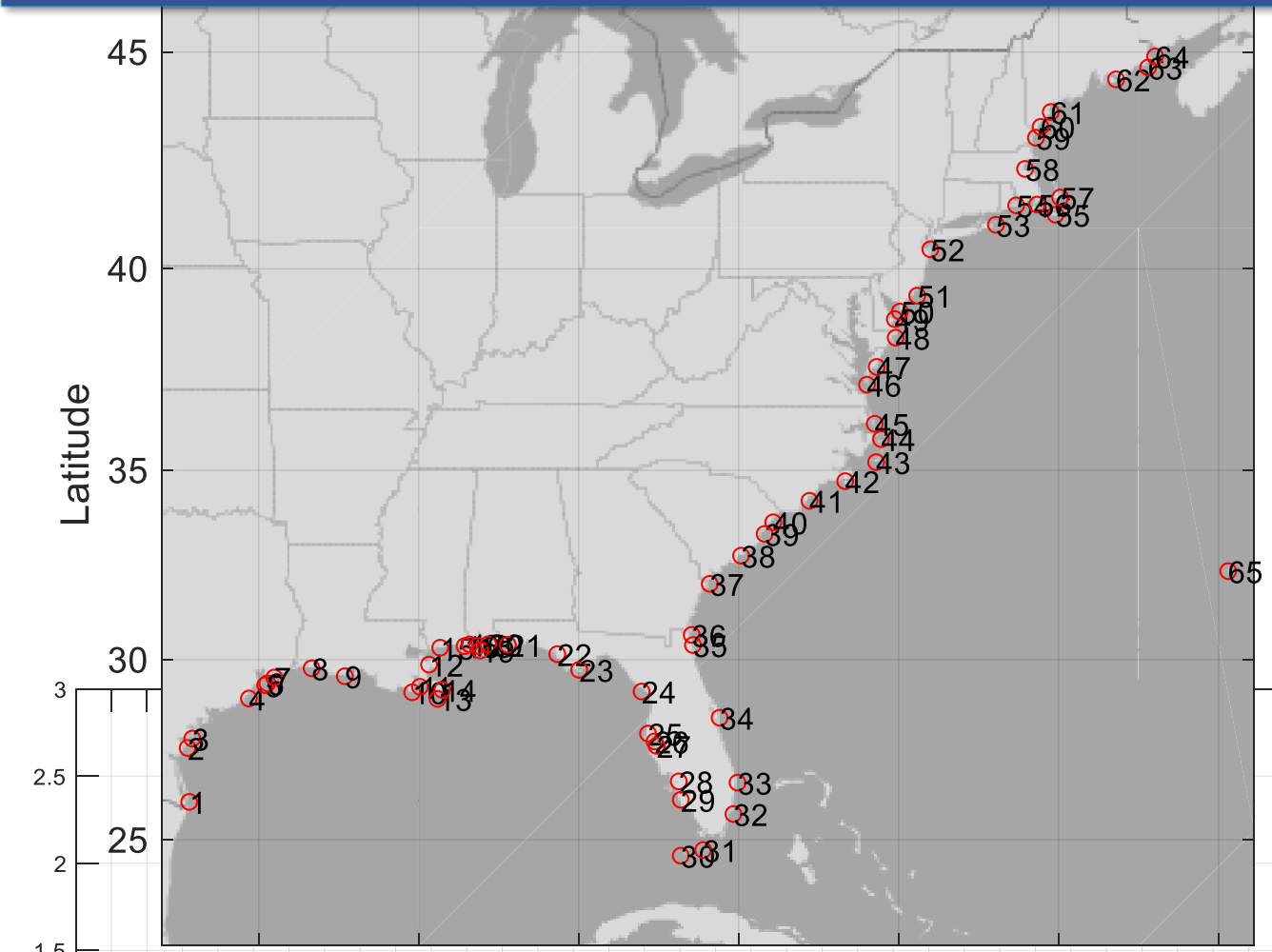
- DEM preparation: >300 tiles
- Major steps with SMS
  - Resolve all major channels
  - Patches are great way to resolve channels
- NWM segments are explicitly incorporated
  - Use GIS tools to clean up first
  - Robustness of the model greatly helps: did not bother to clean up skew elements
- Highly flexible to incorporate any small features: important for model skill locally





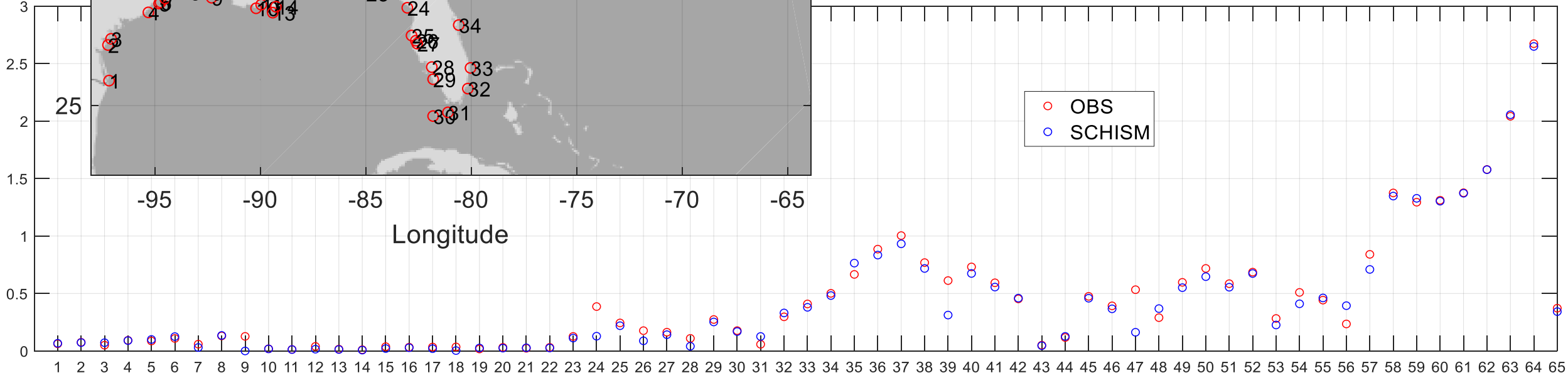


Model results: Harmonic analysis

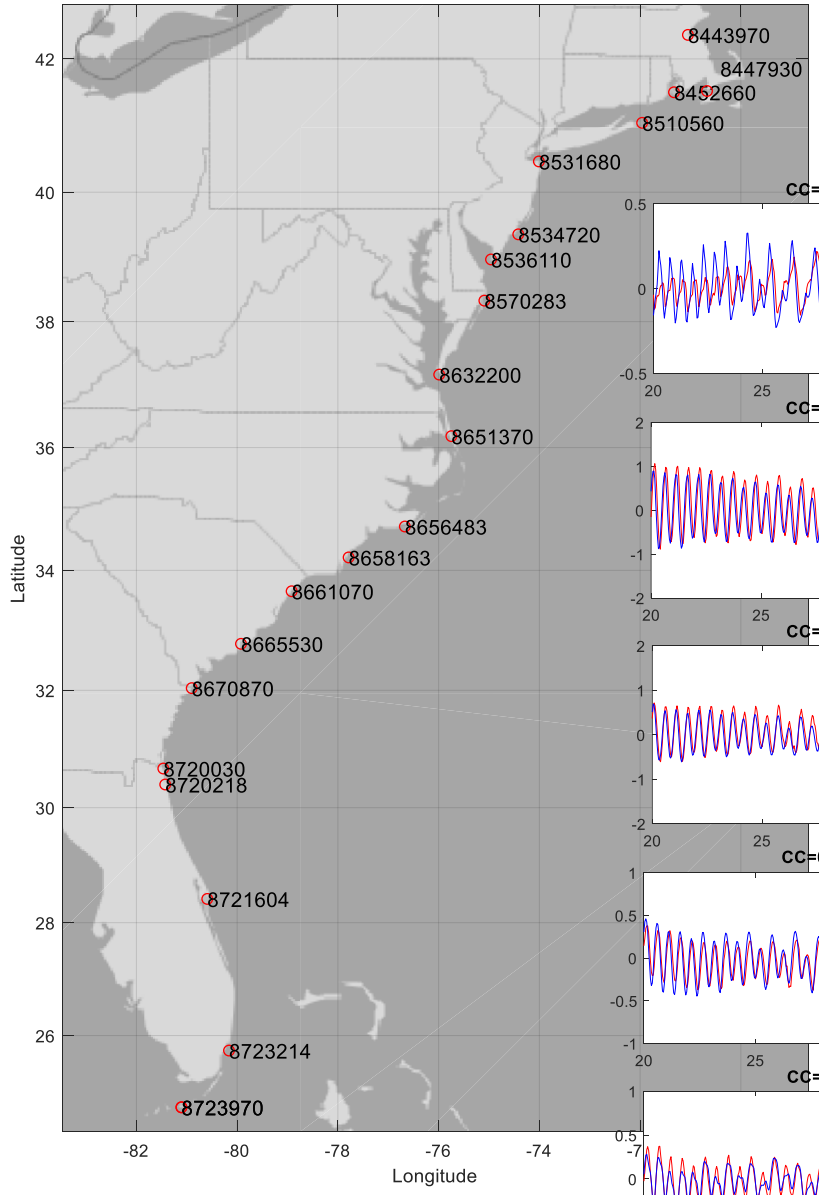


2D barotropic simulation during Hurricane Irene

- **M2 Tidal amplitude**
- Model skill at most stations are good.
- Remaining issues: coarse DEMs, grid resolution at 2 stations in SC and VA.

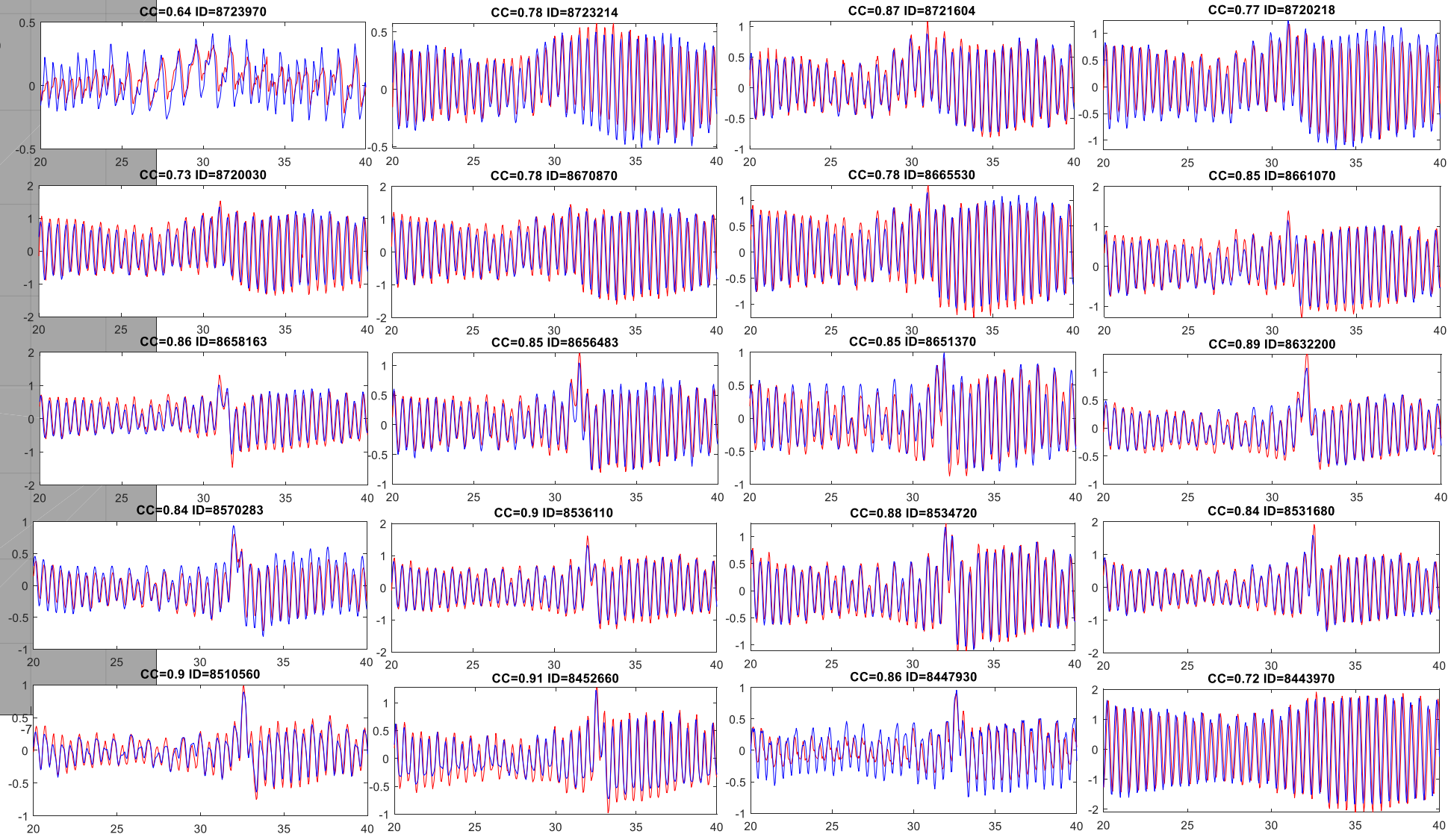


Model results: water elevation for stations of east coast

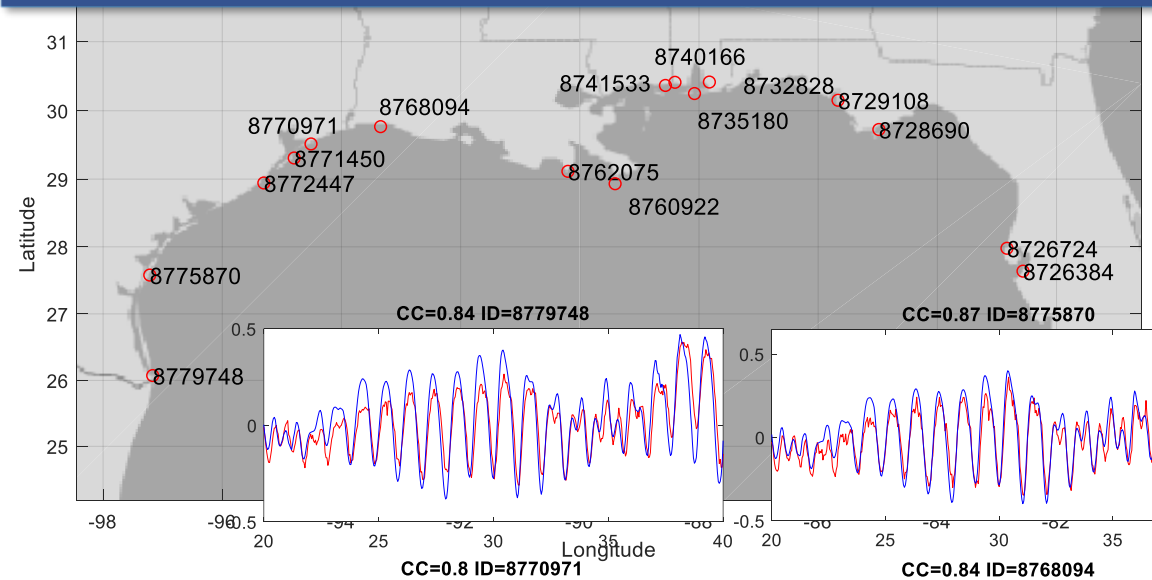


NOAA stations from north to south.
Average correlation coefficient: 0.85

OBS
SCHISM

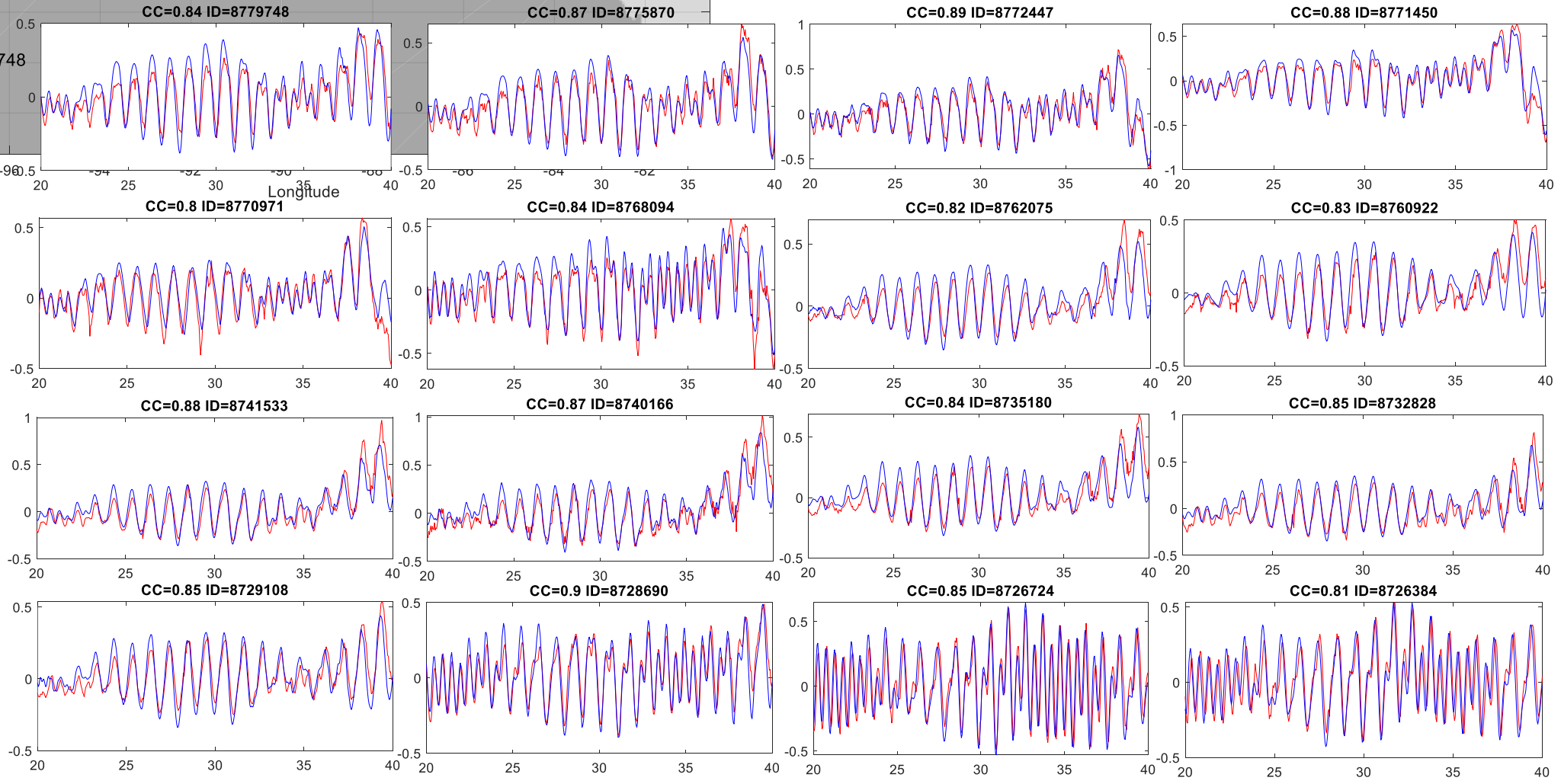


Model results: water elevation for stations of Northern Gulf of Mexico



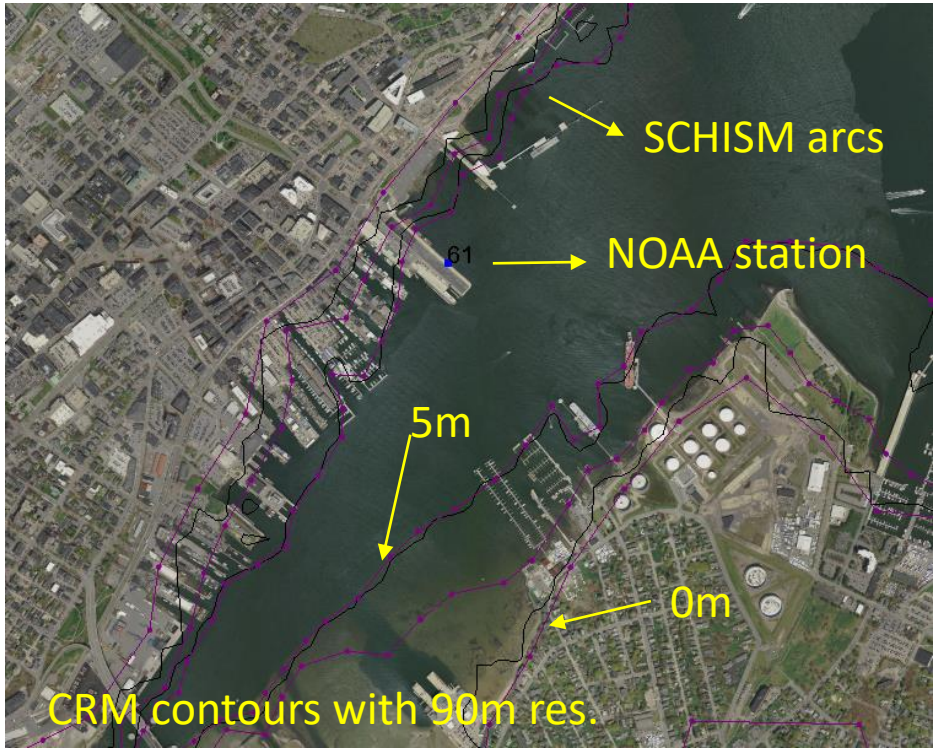
NOAA stations from west to east.
Average correlation coefficient: 0.85

OBS
SCHISM



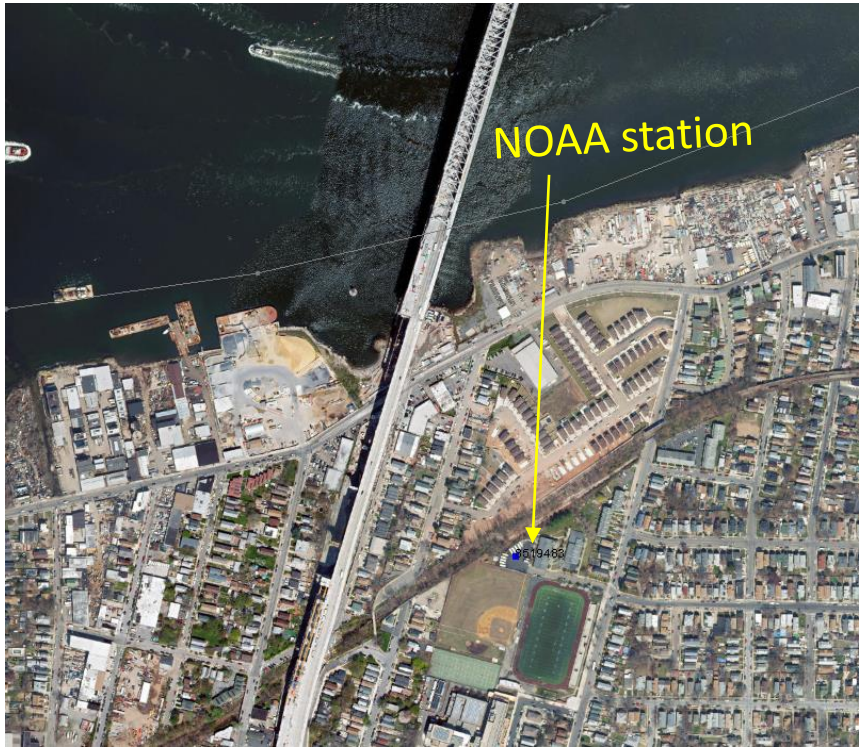
Challenges & issues

Low-resolution DEM



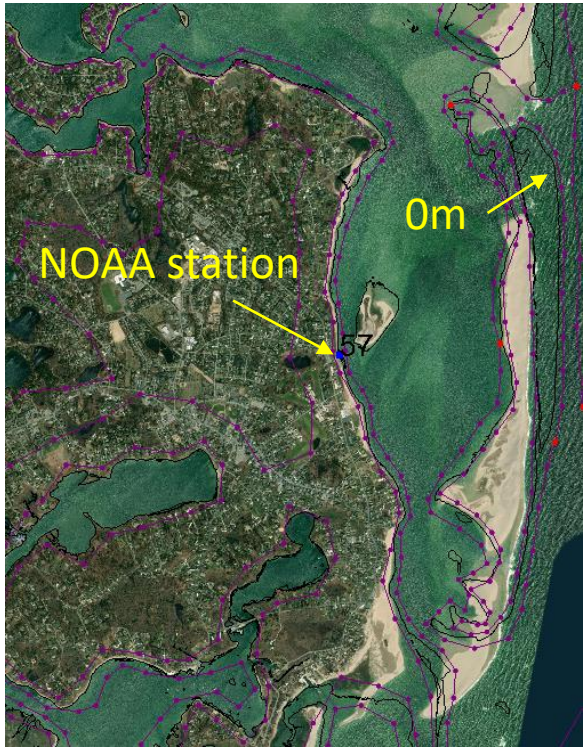
Solution: move the station towards approximate location when post-processing

Station is located in a parking lot



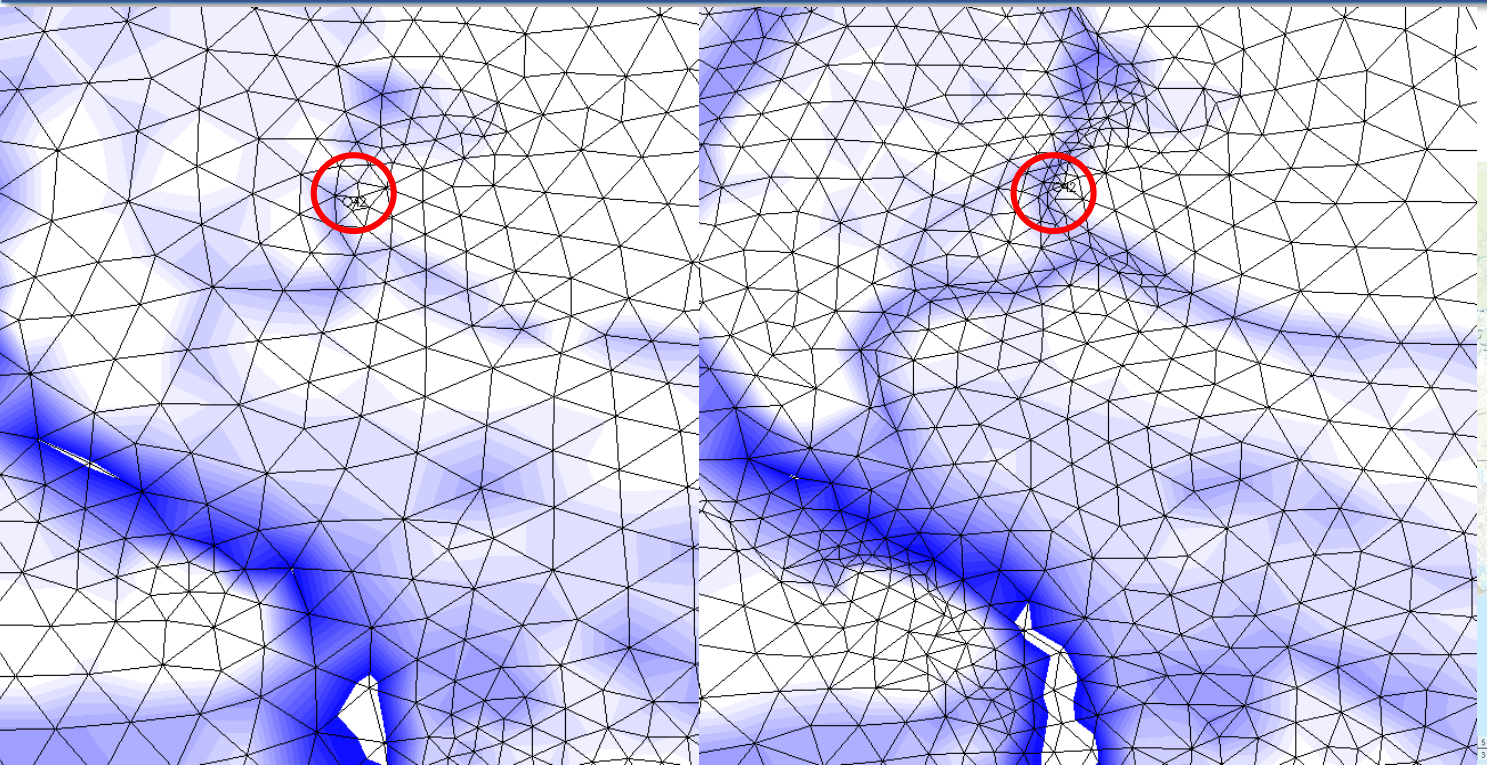
Solution: no solution

Mismatch between the hi-res DEM and imagery/station location

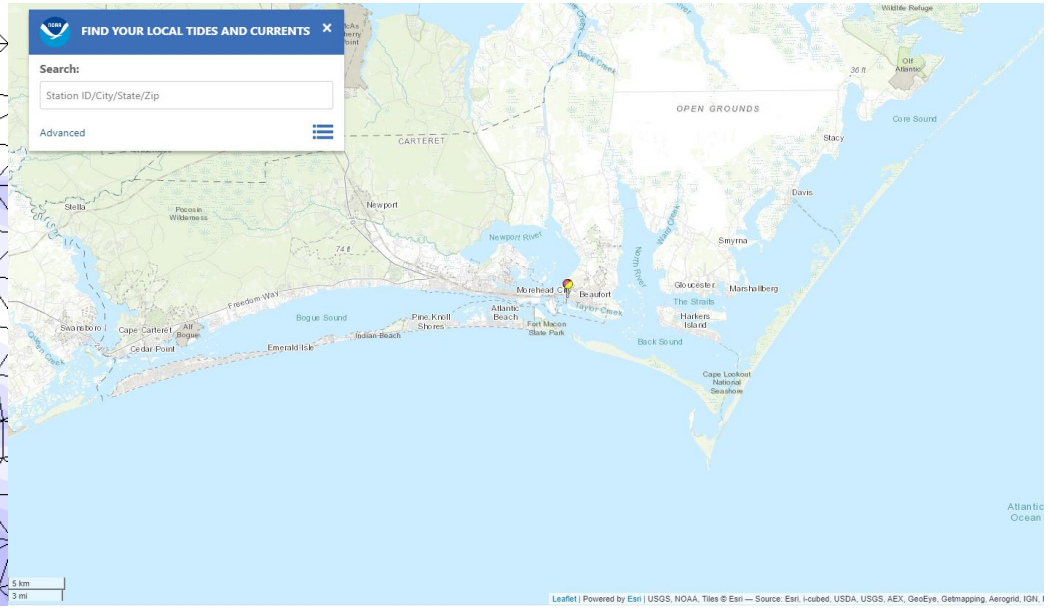


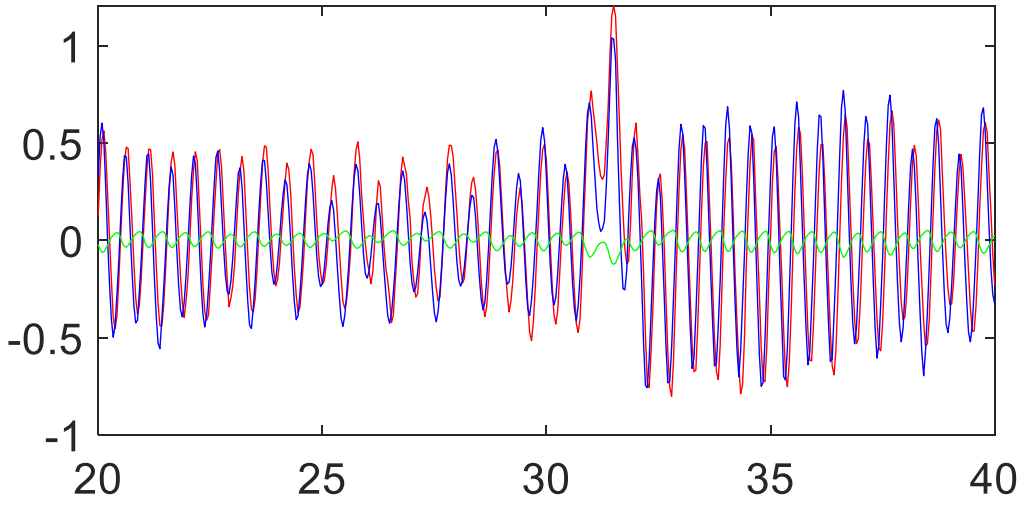
Solution: no solution

Success: importance of resolving bathymetry



NOAA station 8656483 at Beaufort, NC



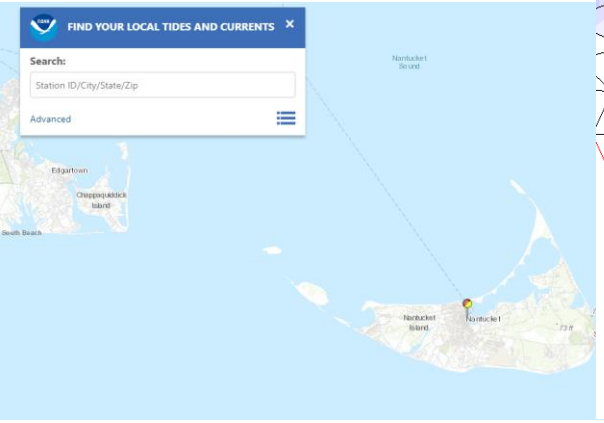


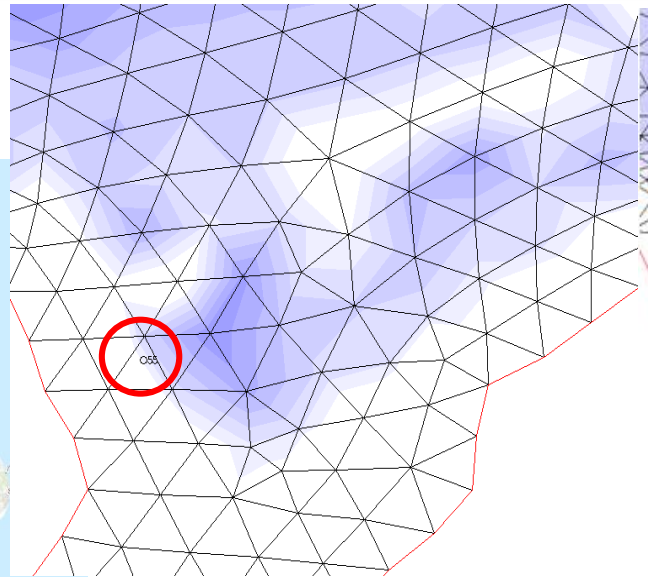
Channels are resolved to allow water transport to upstream

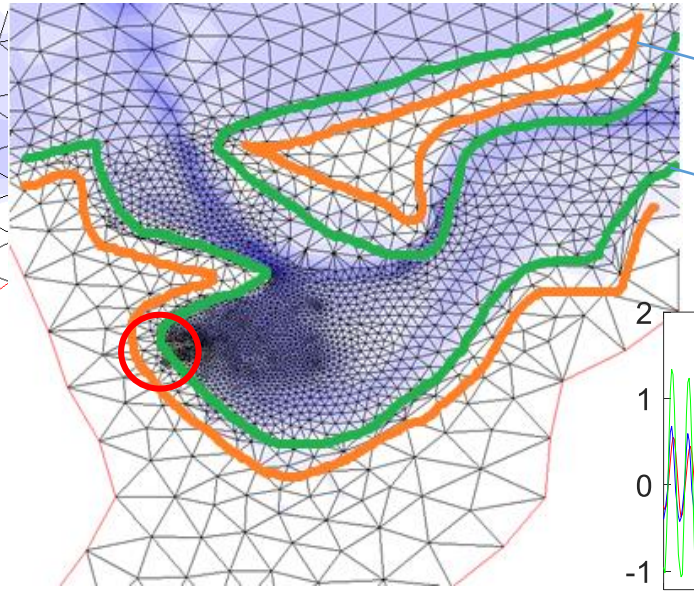
OBS
After resolved
Before resolved

Success: importance of resolving bathymetry

NOAA station 8449130 at Nantucket Island, MA

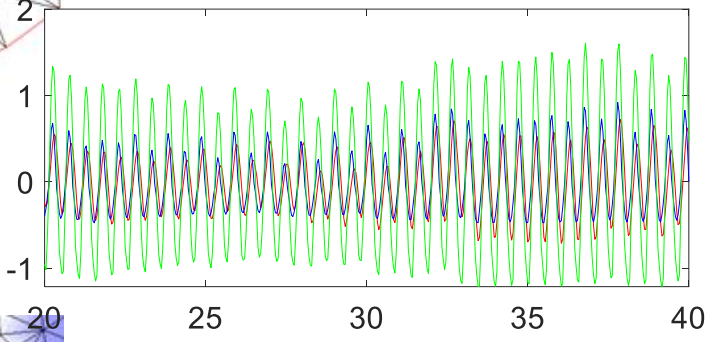




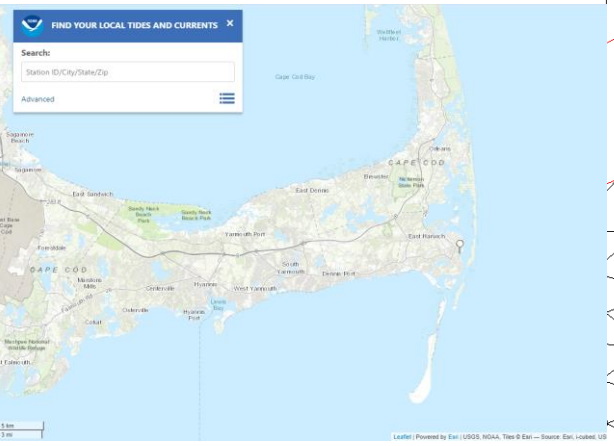


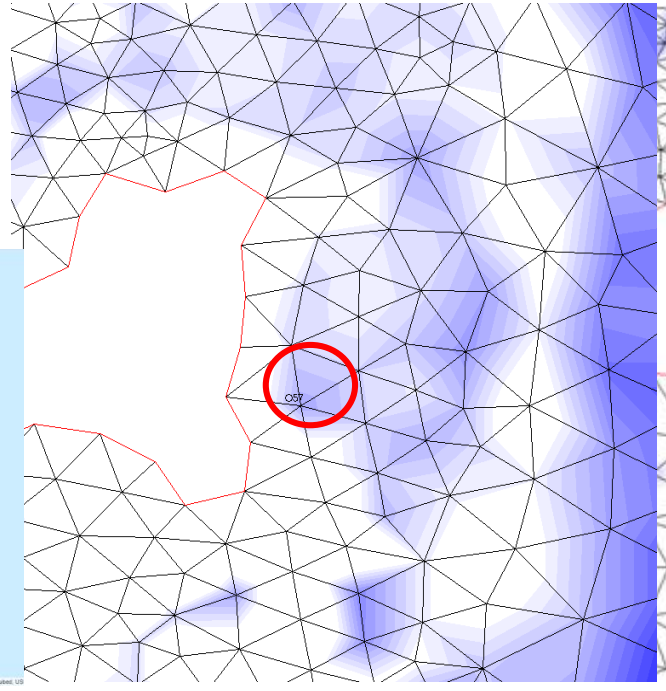
Arcs above 0m resolving the dry area.

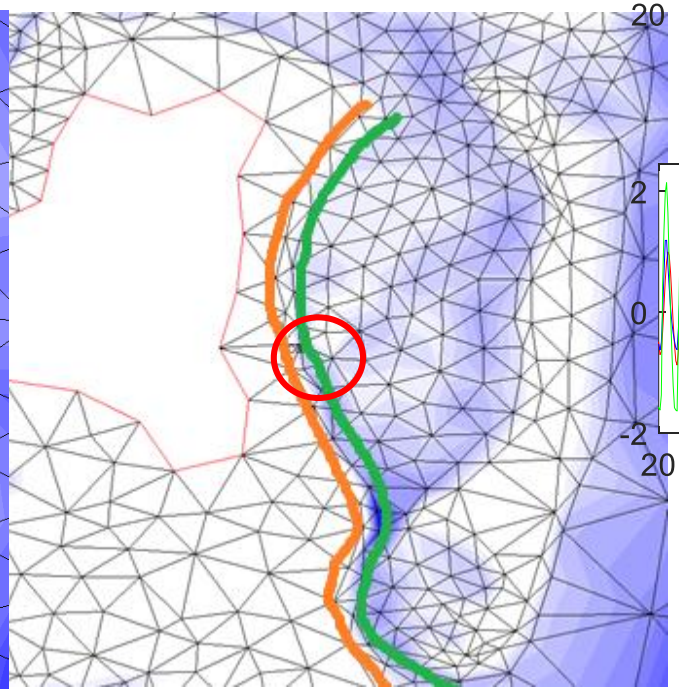
Arcs below 0m resolving the wet area.

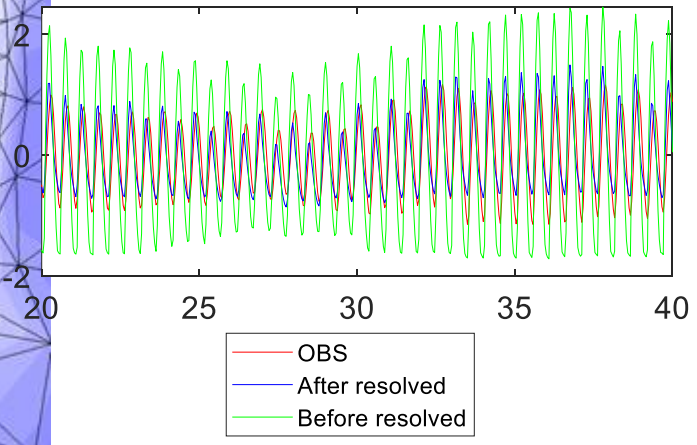


NOAA station 8447435 at Chatham, Lydia Cove, MA









Summary

- During Hurricane Irene (2011), both storm and river induced surges are important
  - The first surge is mostly from ocean but at stations away from the coast, compound flooding from rivers is also important
  - Second and later surges are mostly due to river flooding; this is especially obvious at upstream stations
  - Inflow from National Water Model is reasonably accurate for predicting compound surges
  - Baroclinic adjustment is significant after the storm surge due to Gulf Stream adjustment
  - The direct precipitation is important
- We are applying the same technology to a 3D model for east coast + Gulf of Mexico
  - SCHISM's robust seamless capability enabled by polymorphism makes it efficient
  - 2D results show good model skills, provided that DEMs are accurate
  - It's important to resolve local features to capture the nonlinear transformation of tides
  - Future work: baroclinic model; other hurricane events