
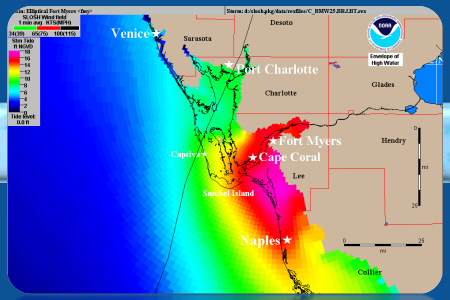

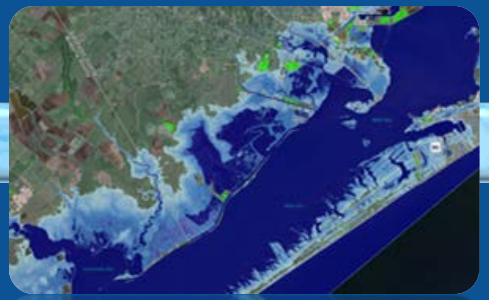

Development of Operational Storm Surge Guidance to Support Total Water Predictions

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2. ERT, Inc.
3. AECOM
4. Riverside Technology, Inc.
5. University Corporation for Atmospheric Research

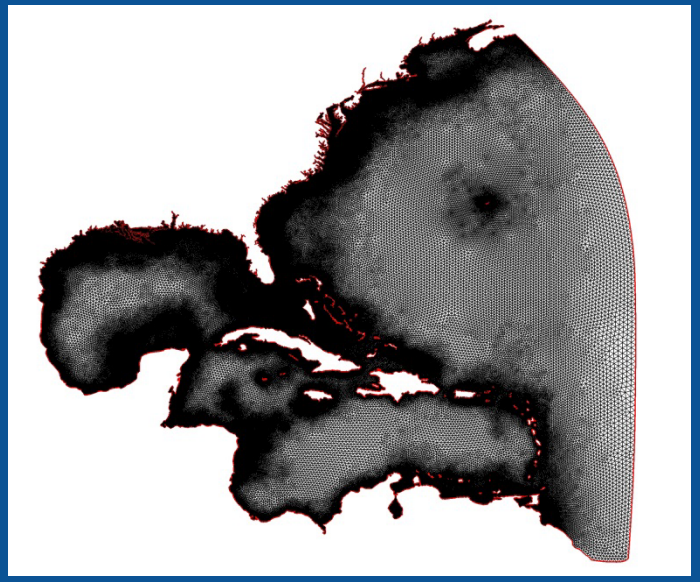
NOAA Storm Surge Roadmap: Tiered Model Approach

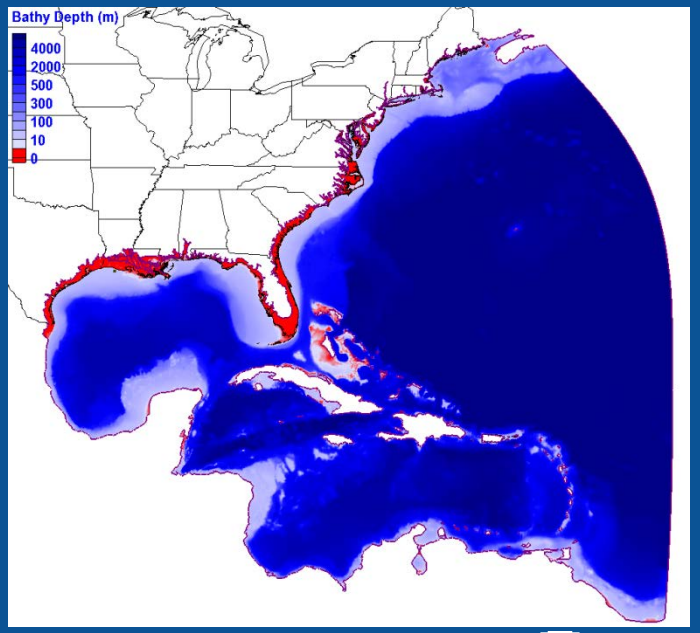
Plan leverages following models for different time frames:

- Longer Lead Time (Greater Uncertainty): SLOSH
  - Efficient numerical scheme, simplified physics
  - Used to address uncertainties, particularly in the wind forecast, by combing numerous quick simulations to form guidance on potential surge impact
- Near or After Landfall (Less Uncertainty): ADCIRC
  - Nonlinear physics, complex finite element numerical scheme, coupling
  - Used to predict details of a specific storm prediction

Model Design

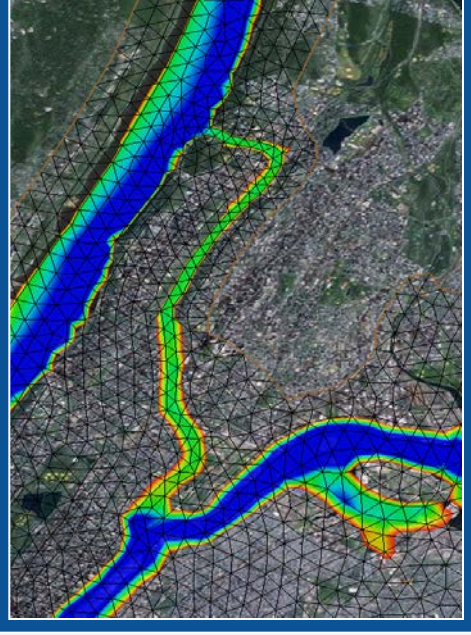
- Use ADCIRC to provide a large scale East Coast unstructured domain with local resolution down to 200 m and apply nonlinear shallow water eqns
- For tropical cyclones, provide 5 member ensemble surge+tide guidance
  - National Hurricane Center will initiate runs on demand near/at landfall
- For extratropical storms, force with Numerical Weather Prediction (NWP) model 4 times per day to compute tide with surge



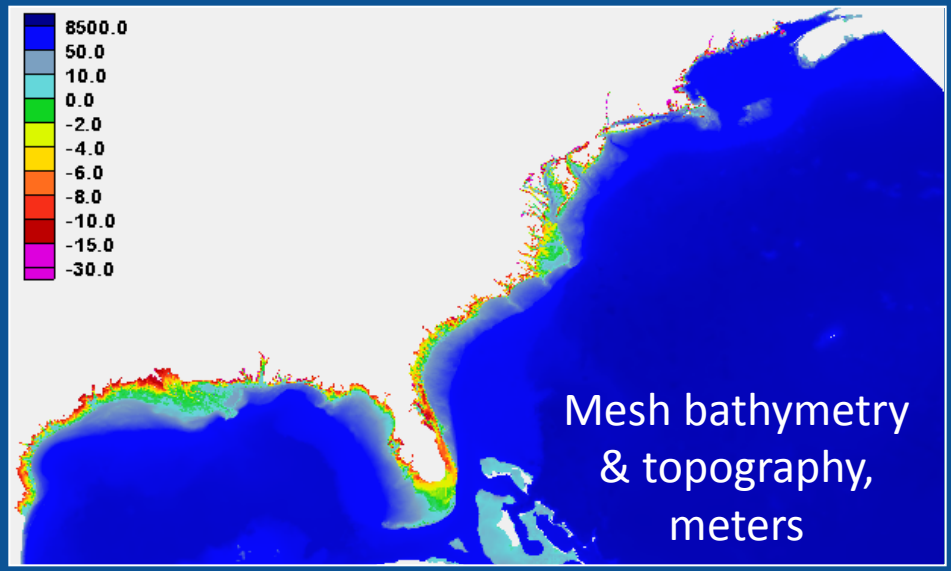


ADCIRC Mesh

- 1,813,443 nodes
  - Typical coastal node spacing 400-500 m but reaching down to less than 200 m
- Extends inland to at least the 10 m contour and includes major population centers
  - Covers rivers with 200 m width, including Atchafalaya, Mississippi, St. John's, Waccamaw, Tar, Potomac, Hudson, and Connecticut rivers
- Bathymetry from latest NOS hydrographic surveys
- Topography from latest lidar & USGS NED (400 GB of topo data)

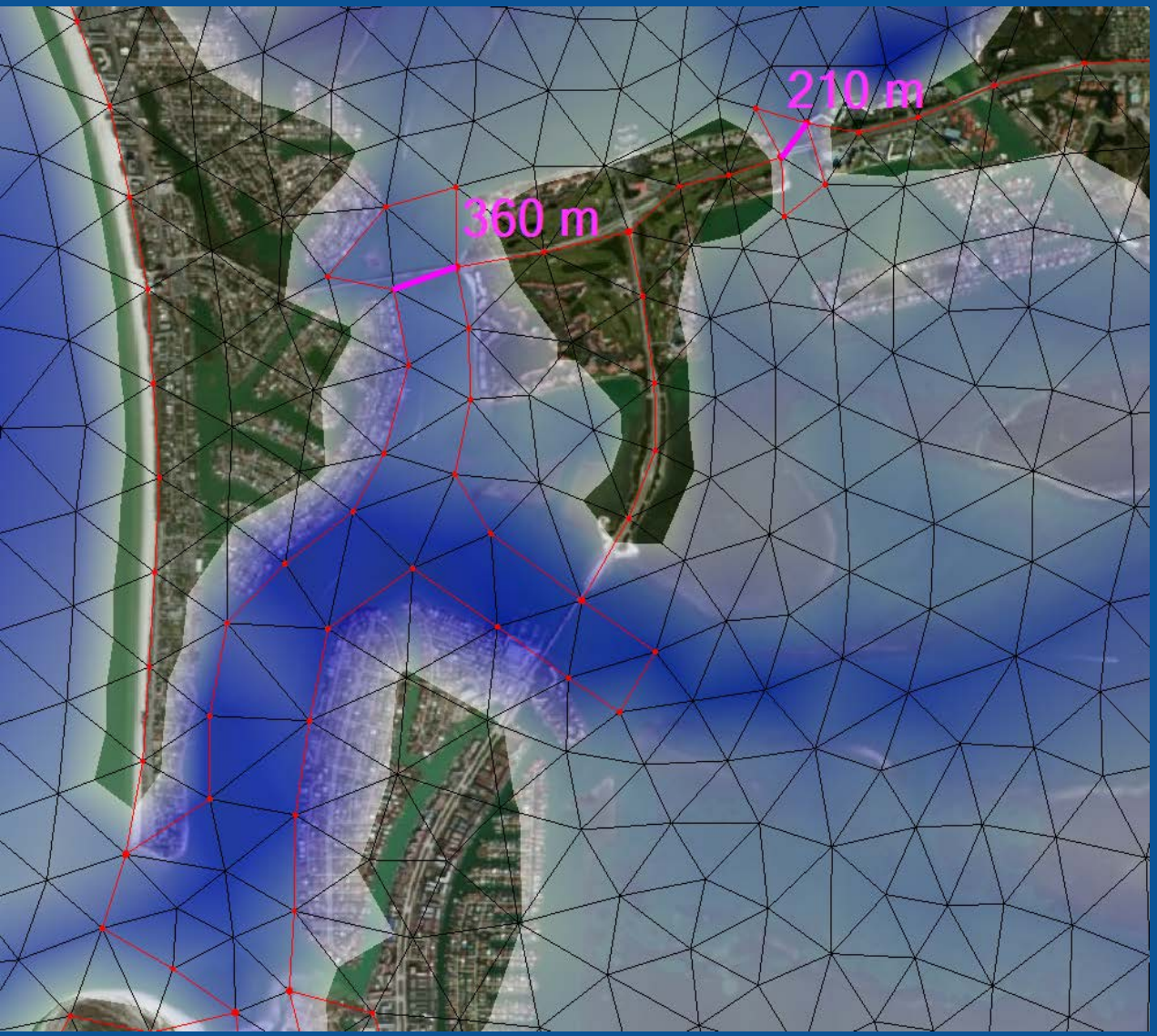


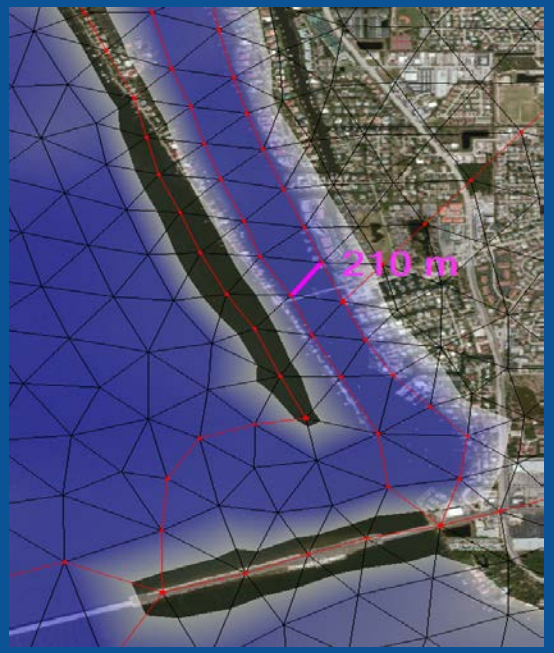
Hudson, Harlem, and East Rivers, NY



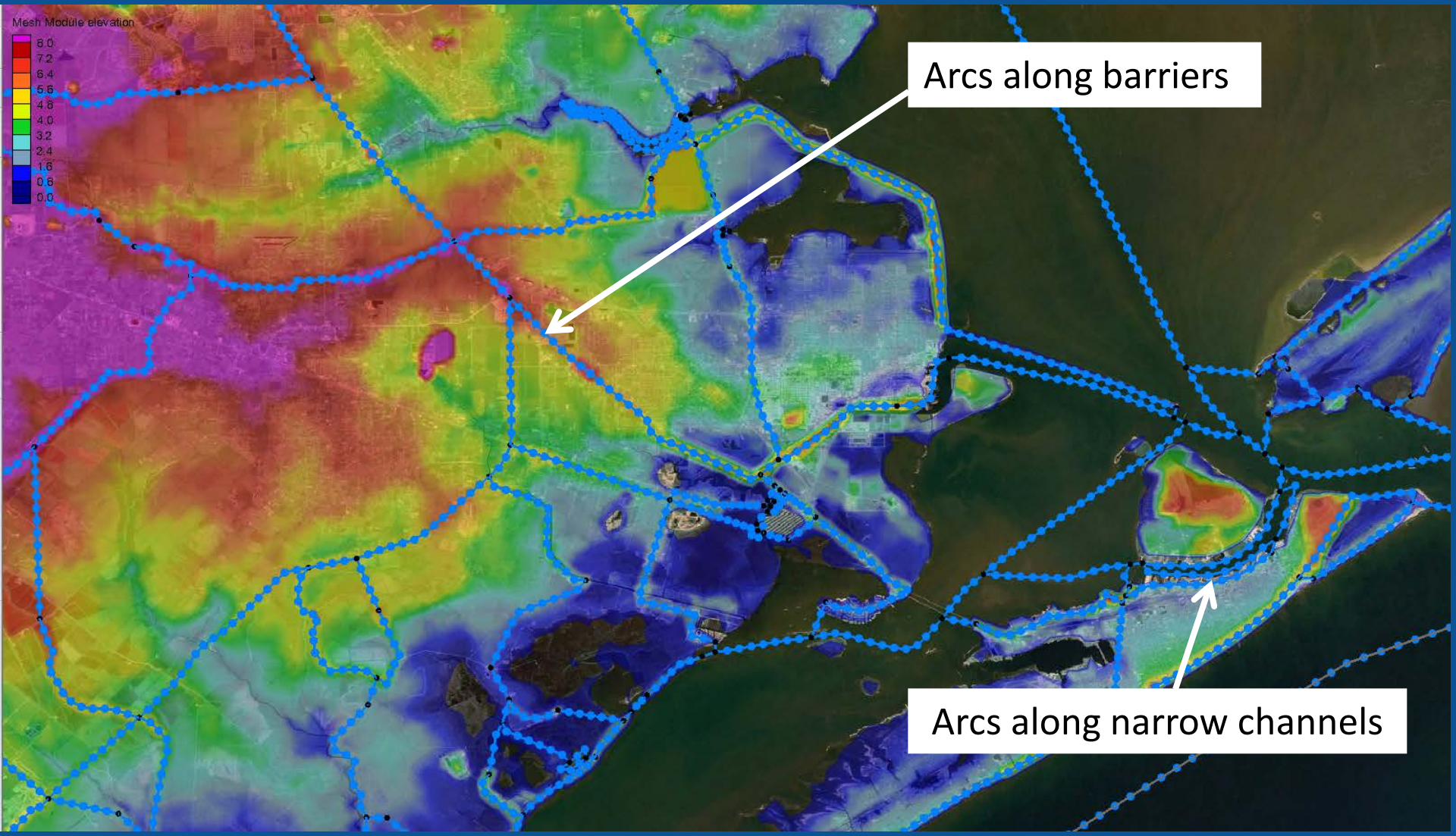
Mesh bathymetry & topography, meters

Narrow Channels

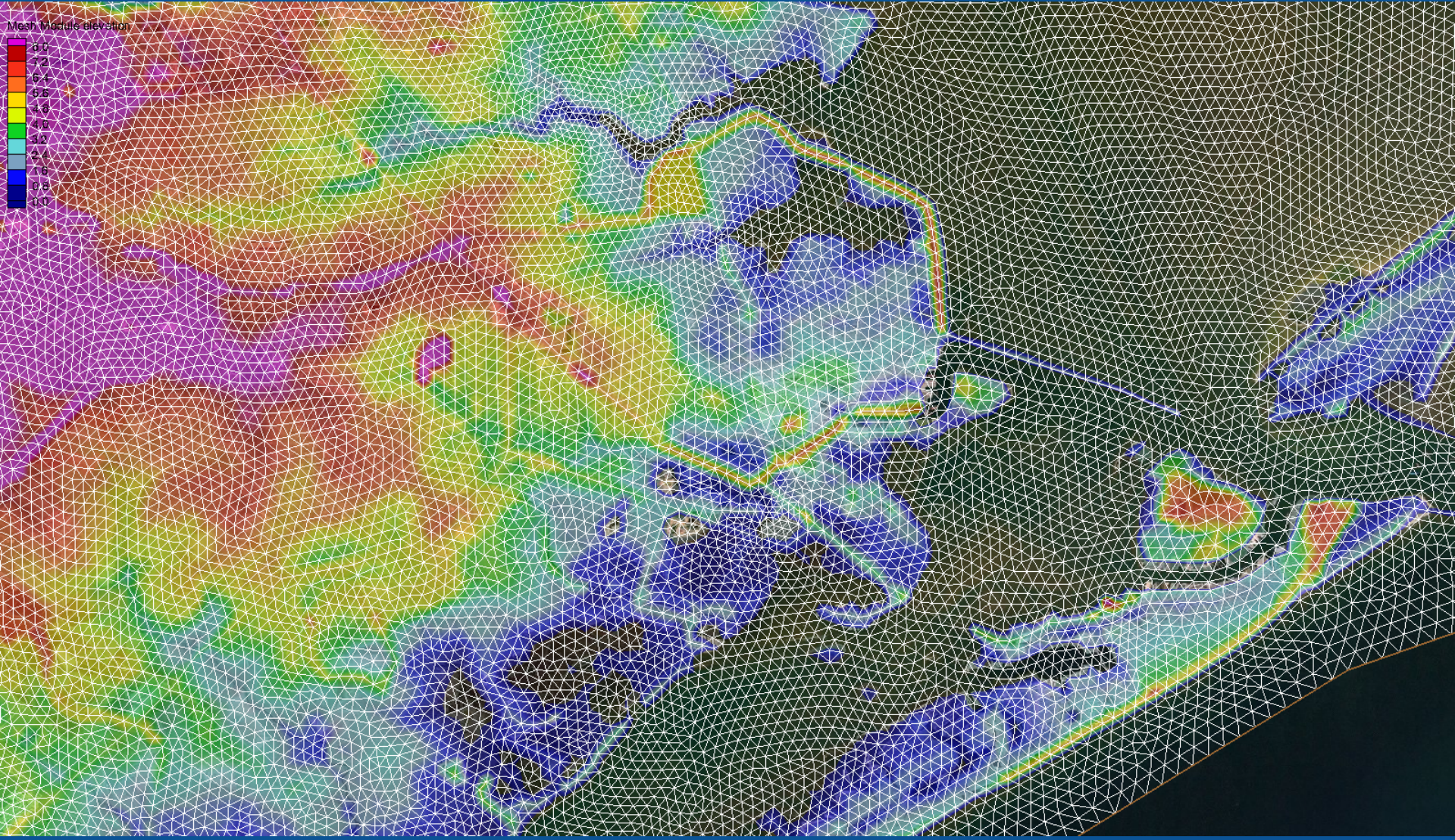




- Offsetting nodes along channel avoids distortion of smaller features
- In rare cases, distort channel geometry



Mesh Samples - TX



Mesh Samples - TX

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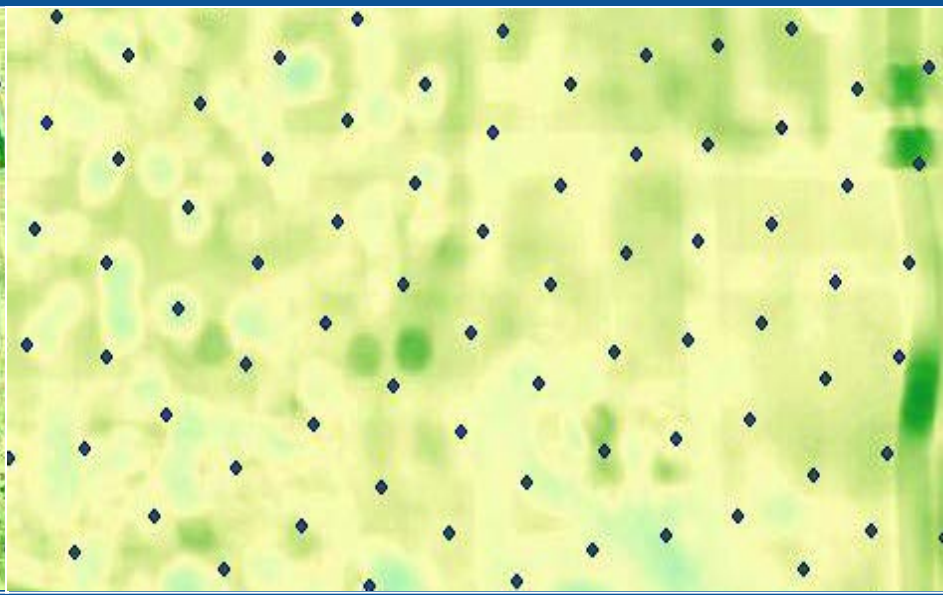
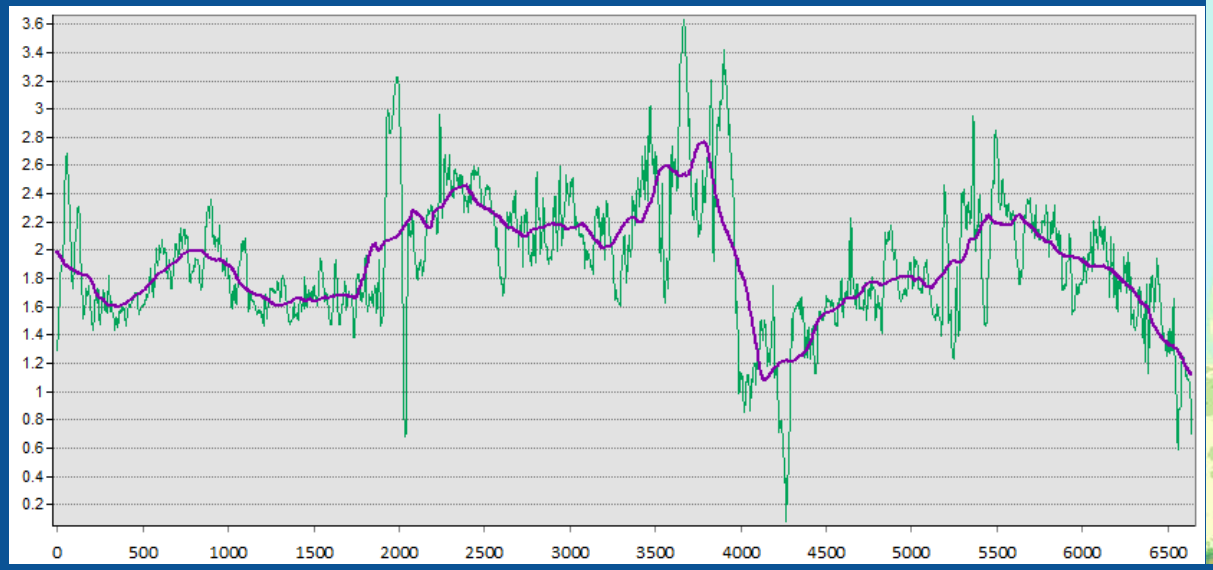
Elevation Assignment - General

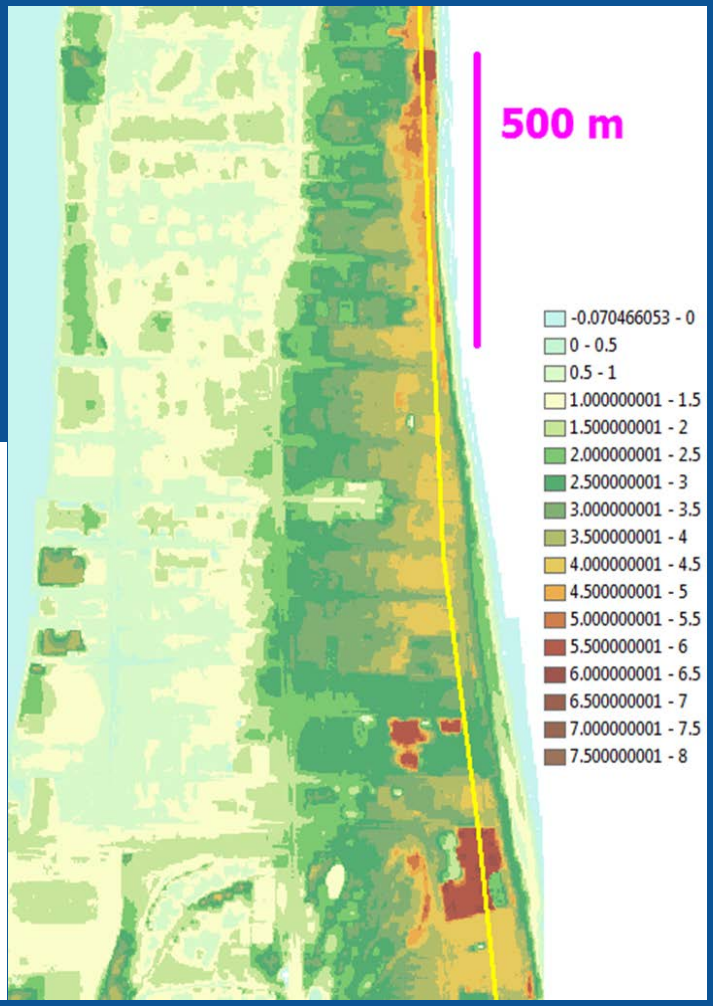
- Assign elevations using smoothed raster for smoother mesh elevations
- Raster smoothed to local mean of circular window of varying size
- ~600 m node spacing, 150 m smoothing window



Elevation Assignment - Ridges

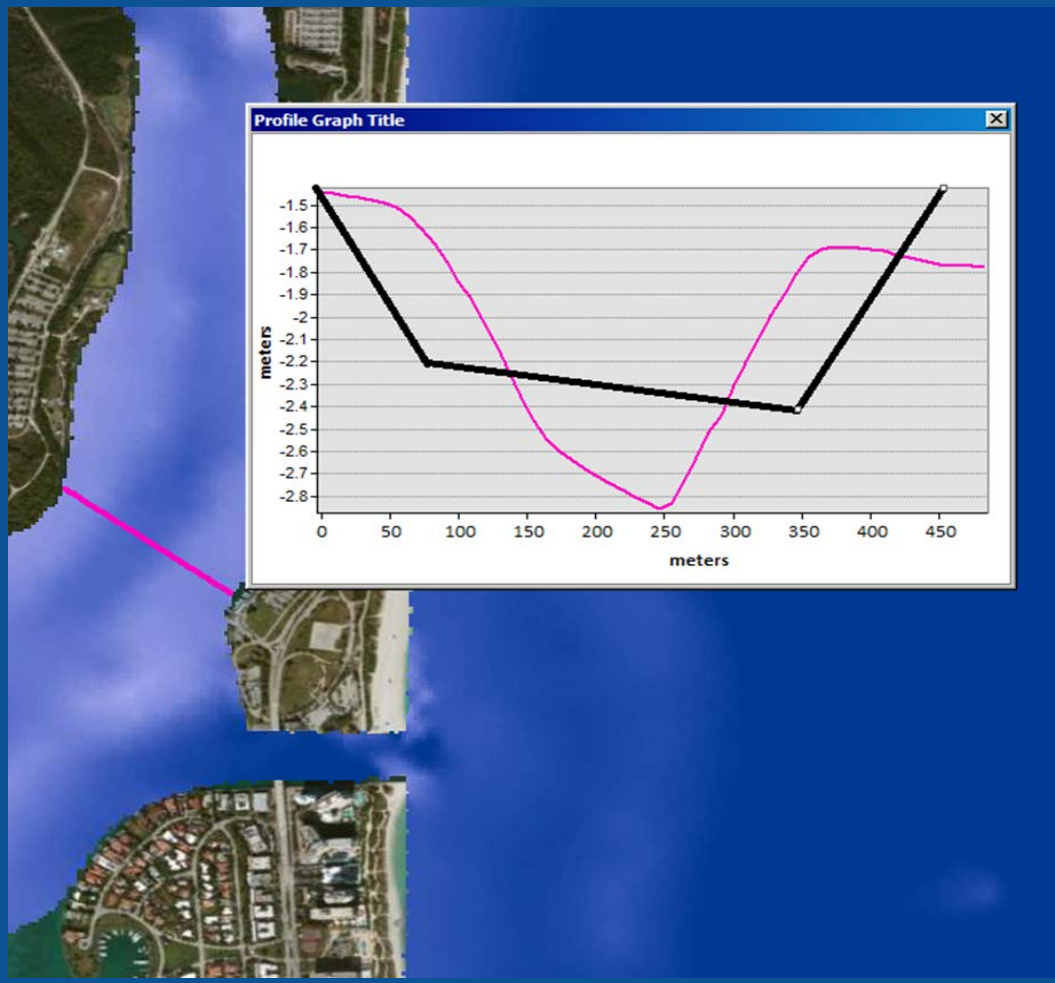
- Long, narrow crests like dunes frequently have variable elevation
- Smooth elevation using moving average (~150 m)
- Smoothed crest drops “noisiness”, broadly represents flow barrier





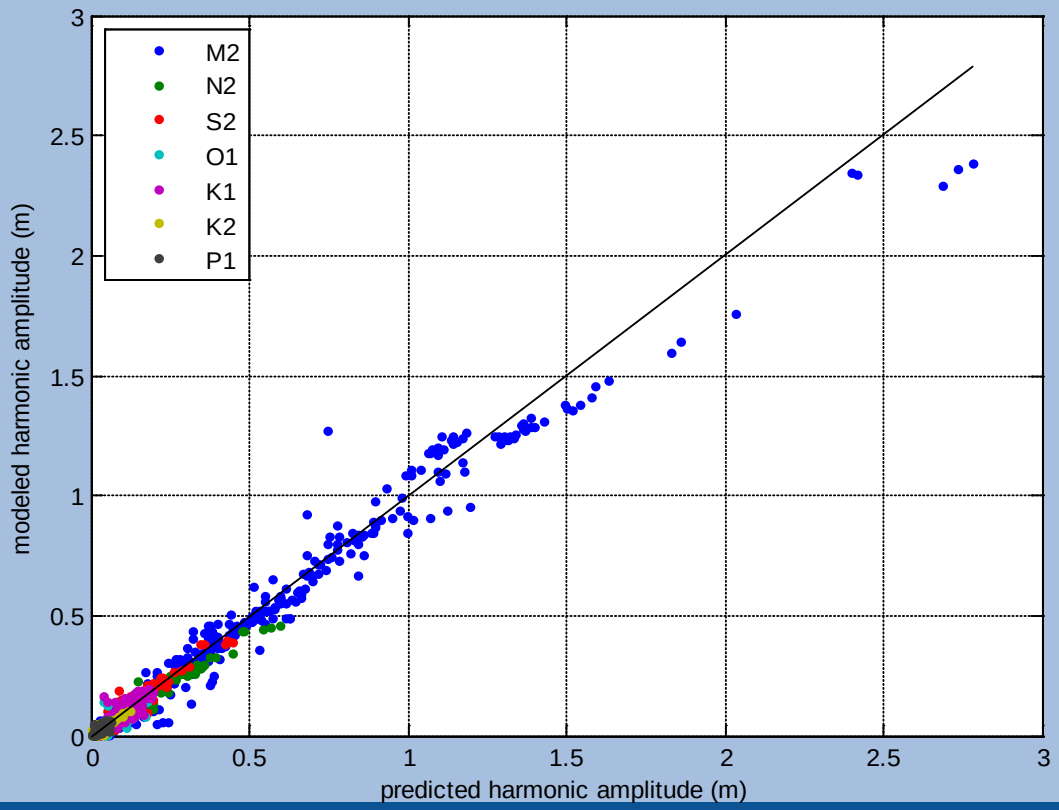
Elevation Assignment - Channels

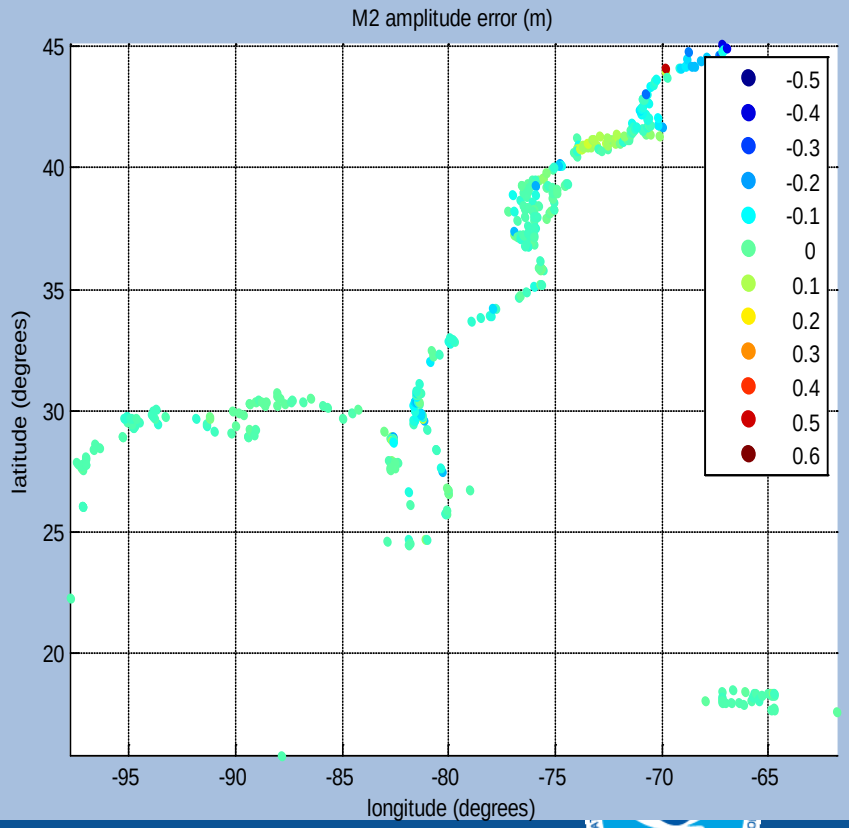
- Channel elevation assignment done using bathymetric data from EC2012 mesh
- Bathymetric data pulled from underlying dataset using mean values, then manually reviewed to verify their accuracy
- Goal is to maintain roughly equivalent representative cross-sectional areas



Tidal Validation Results

- Most error in Gulf of Main due to advection being disabled for stability
- Other errors are generally sheltered waters far from the open coast (e.g. Delaware River)



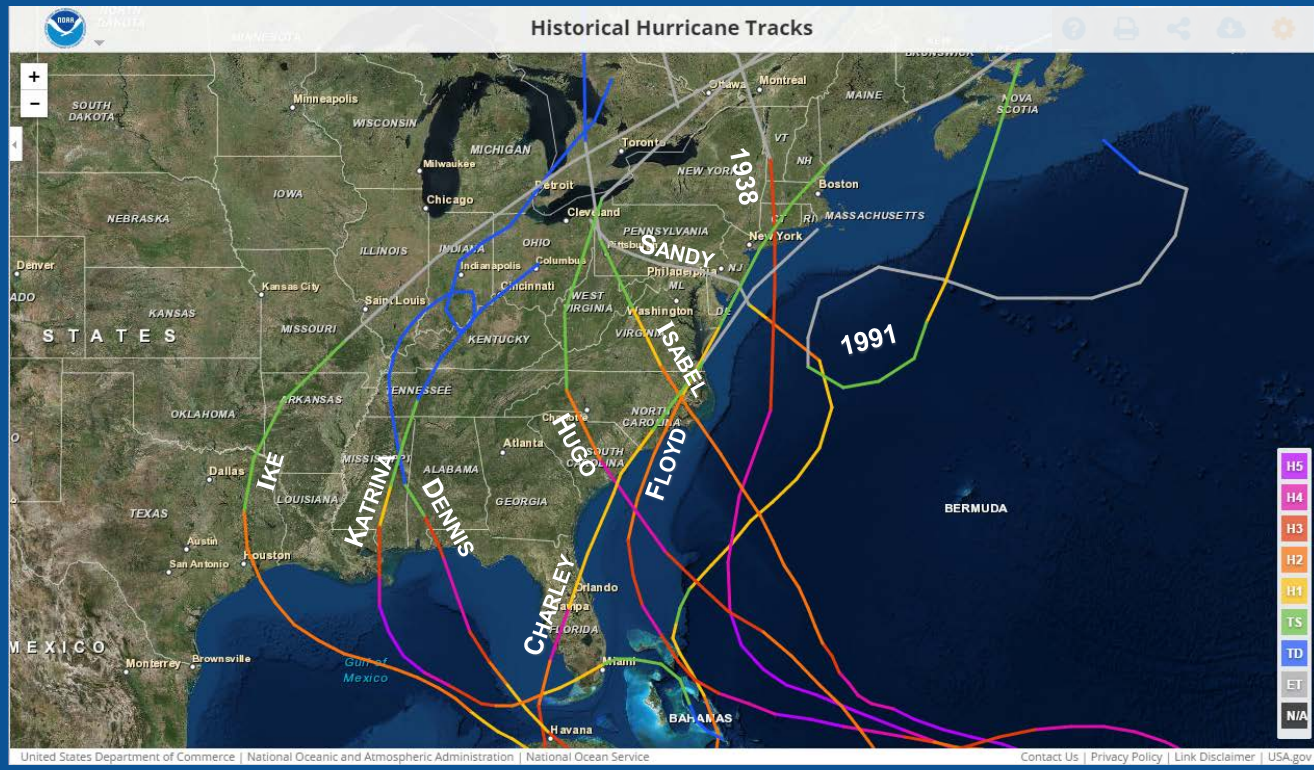


Tropical Cyclone Validation

- Used best available weather forcing to isolate surge model grid performance
  - Weather forcing typically from Oceanweather (OWI) winds from FEMA studies; Sandy uses HWRF, Floyd uses H*WIND
- Storm hindcasts then repeated with operational forcing
  - Dynamic asymmetric Holland model in ADCIRC using Best Track input parameters
  - Also include Ivan (2004), Donna (1960), Andrew (1992), Rita (2005), Wilma (2005), Allen (1980)

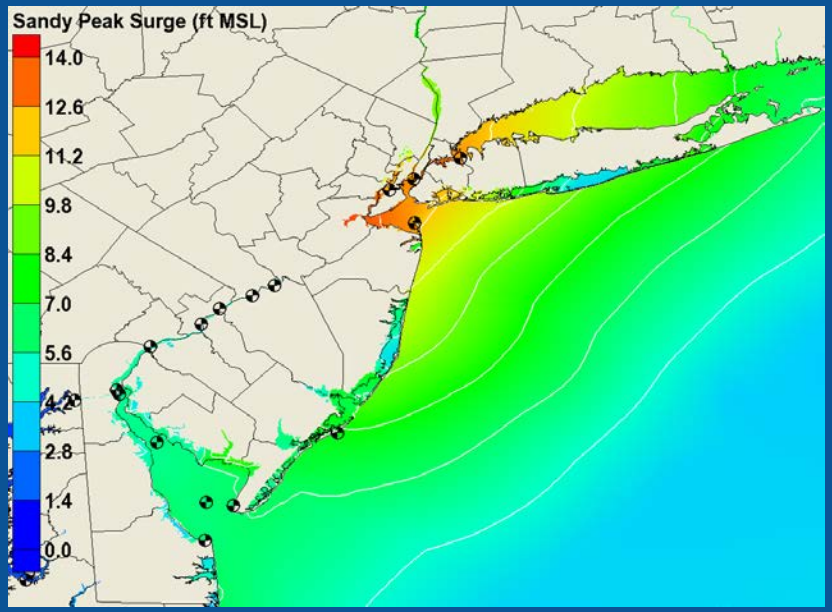
Grid Validation: Hindcast Storms

Year	Storm
1938	Long Island Express
2012	Sandy
1991	Halloween Nor'easter
2003	Isabel
1989	Hugo
1999	Floyd
2004	Charley
2005	Dennis
2005	Katrina
2008	Ike

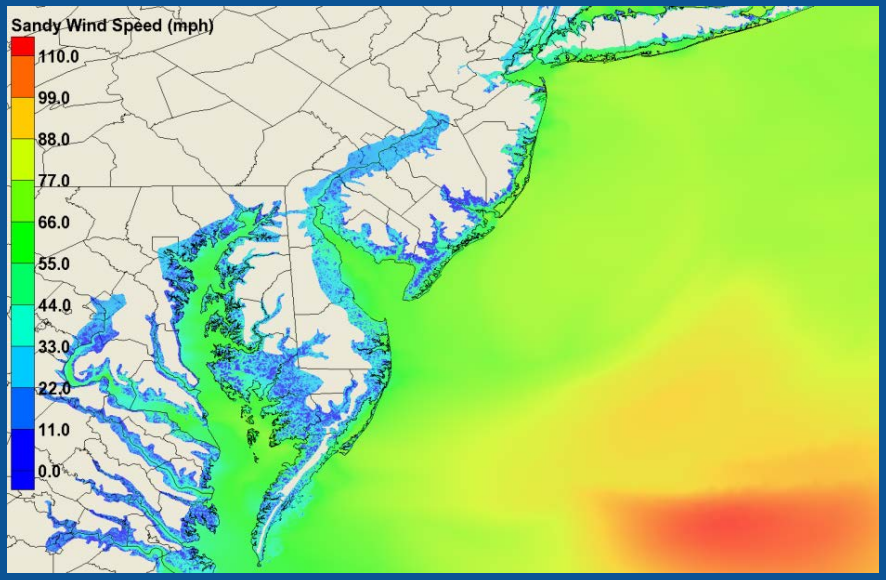


Hindcast Validation – 2012 Sandy

- Met. data from HWRF
- Surge good, mean water level slightly low

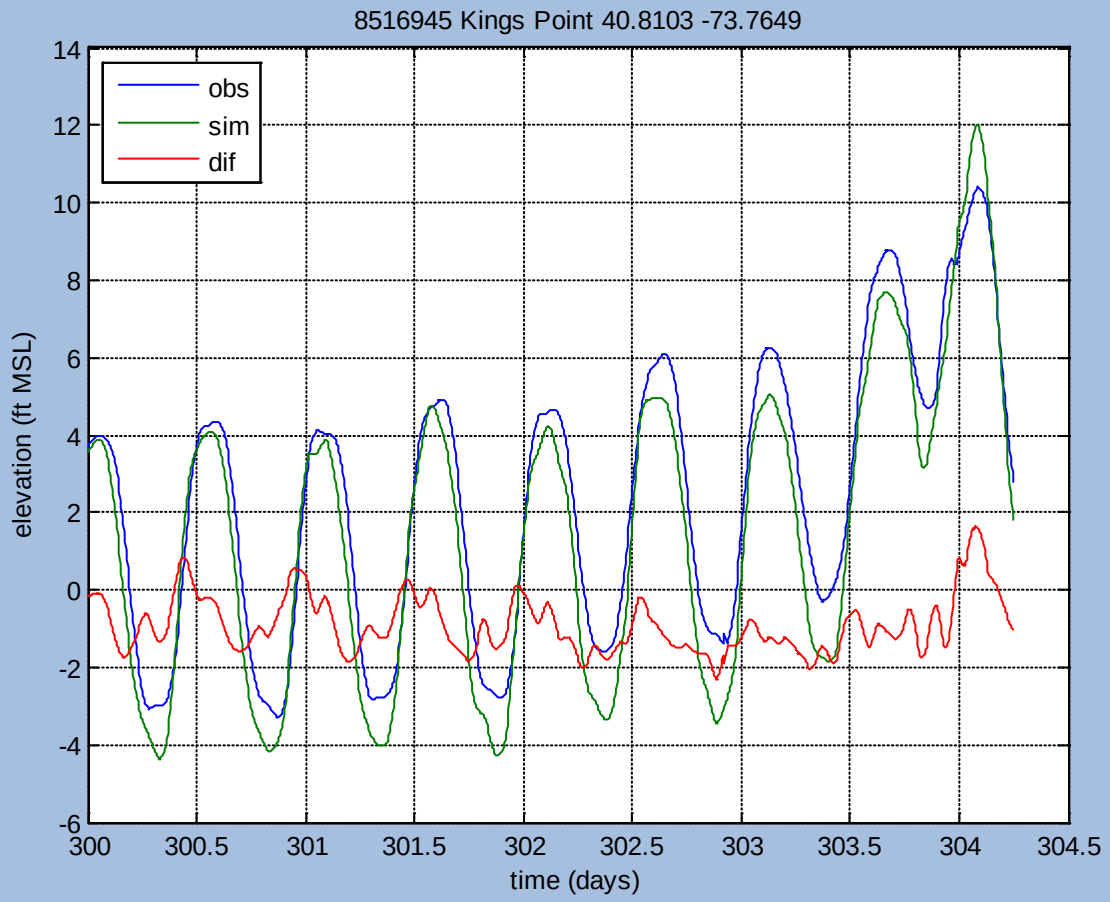


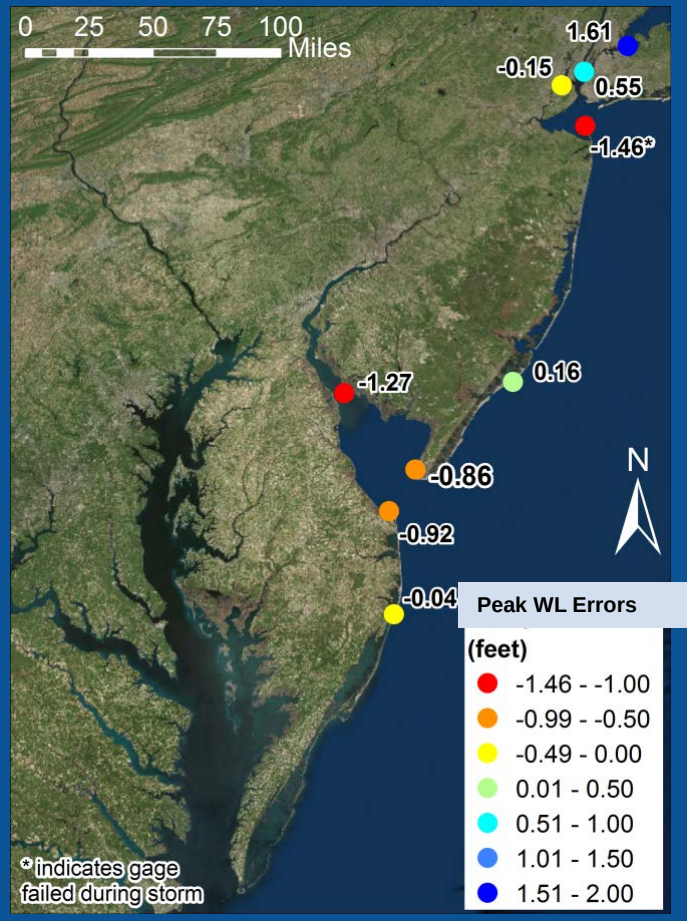
Peak surge (ft)



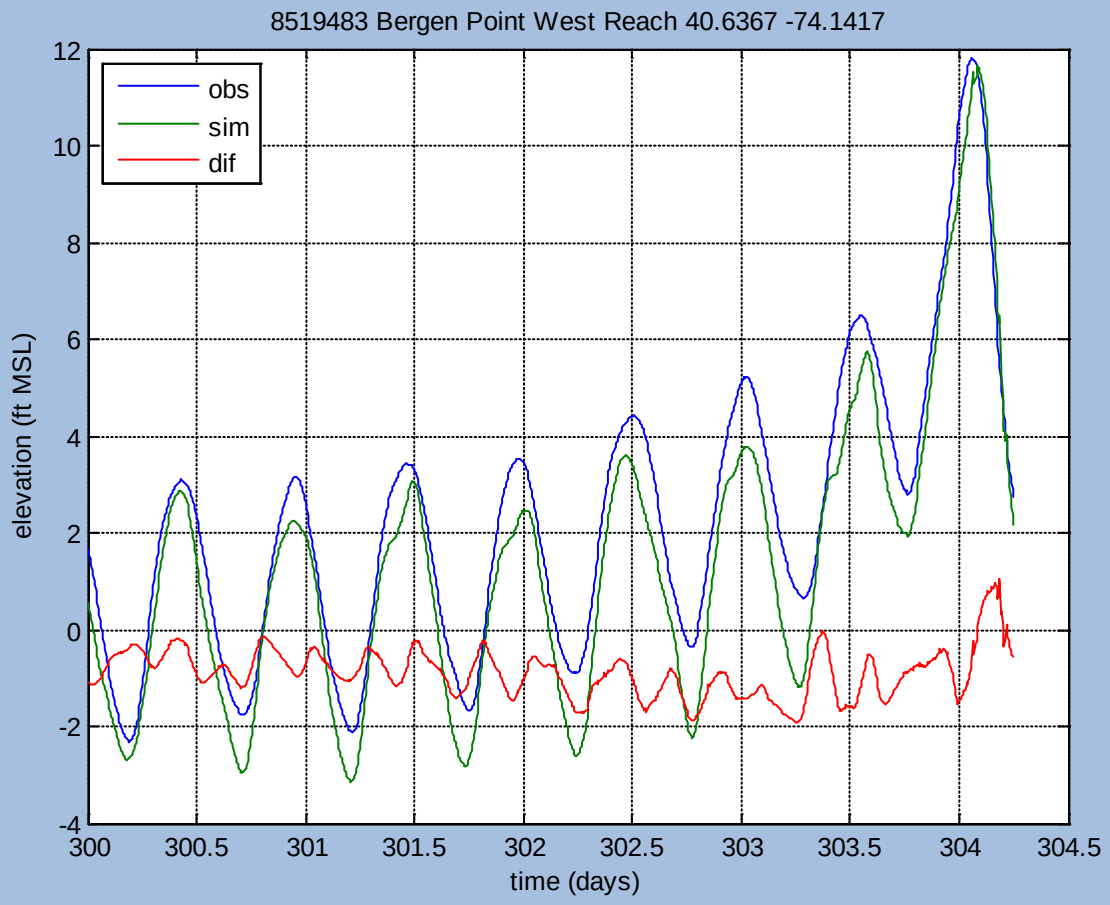
Peak wind speed (mph)

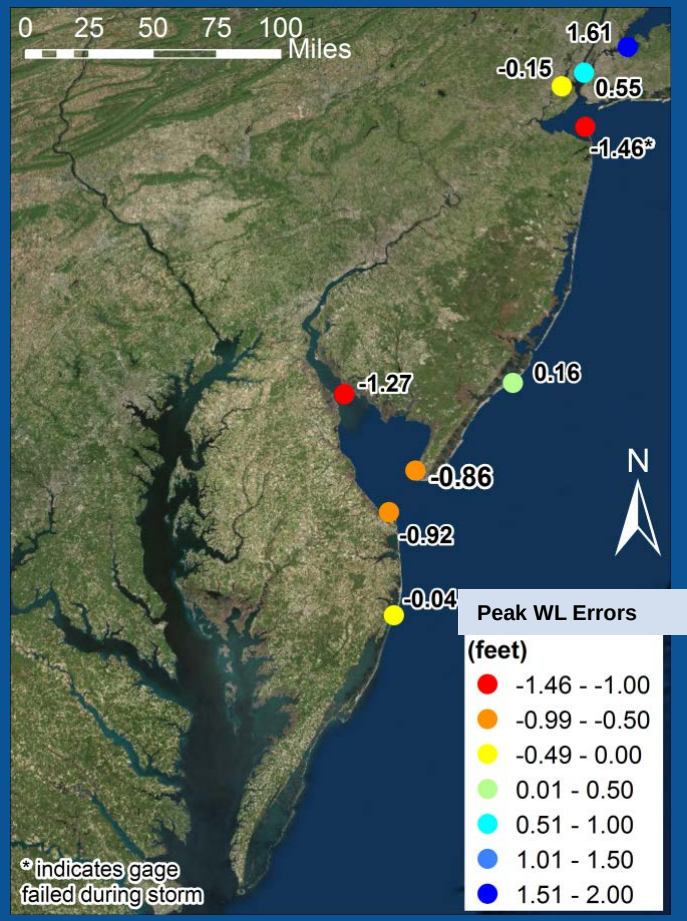
Hindcast Validation – 2012 Sandy



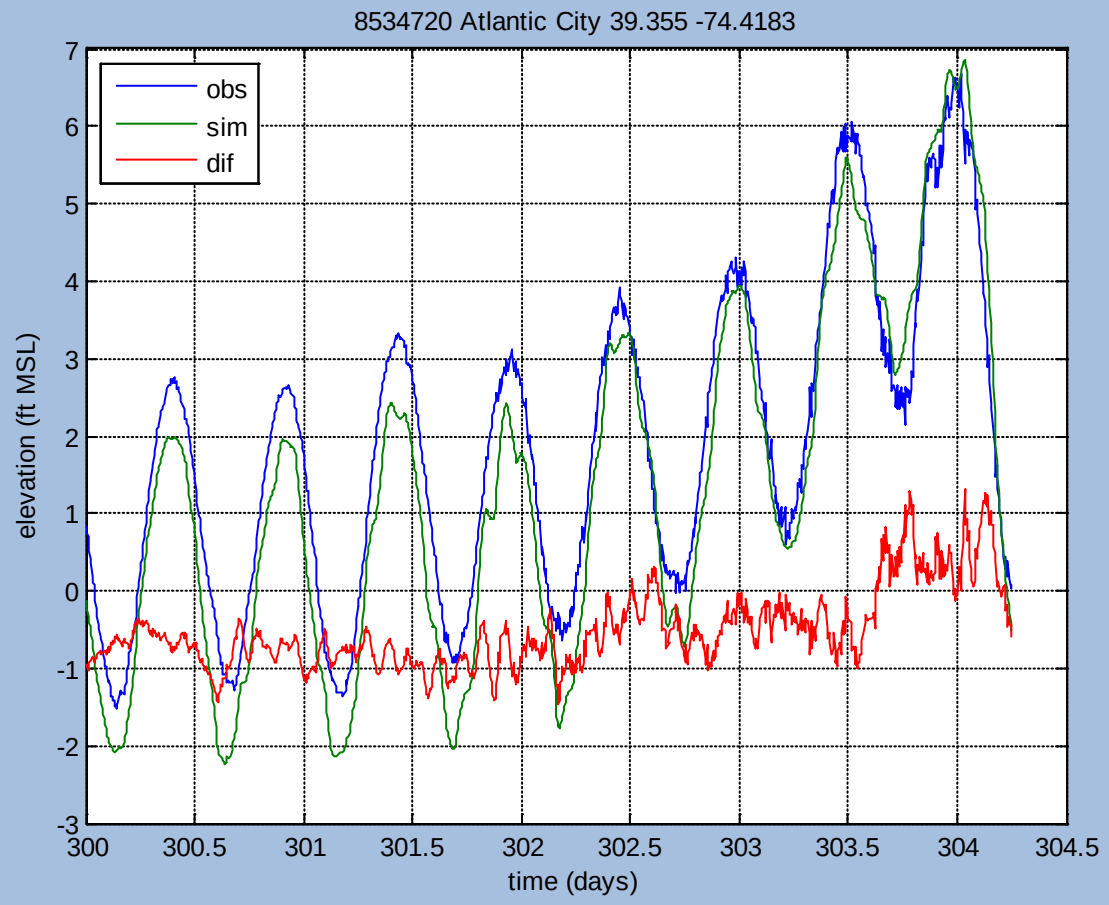


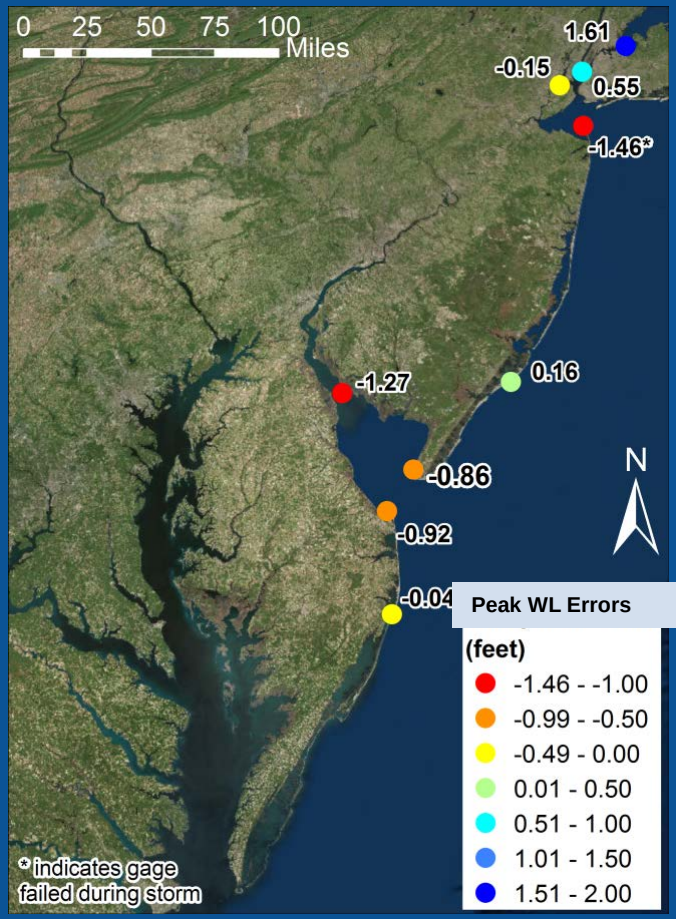
Hindcast Validation – 2012 Sandy



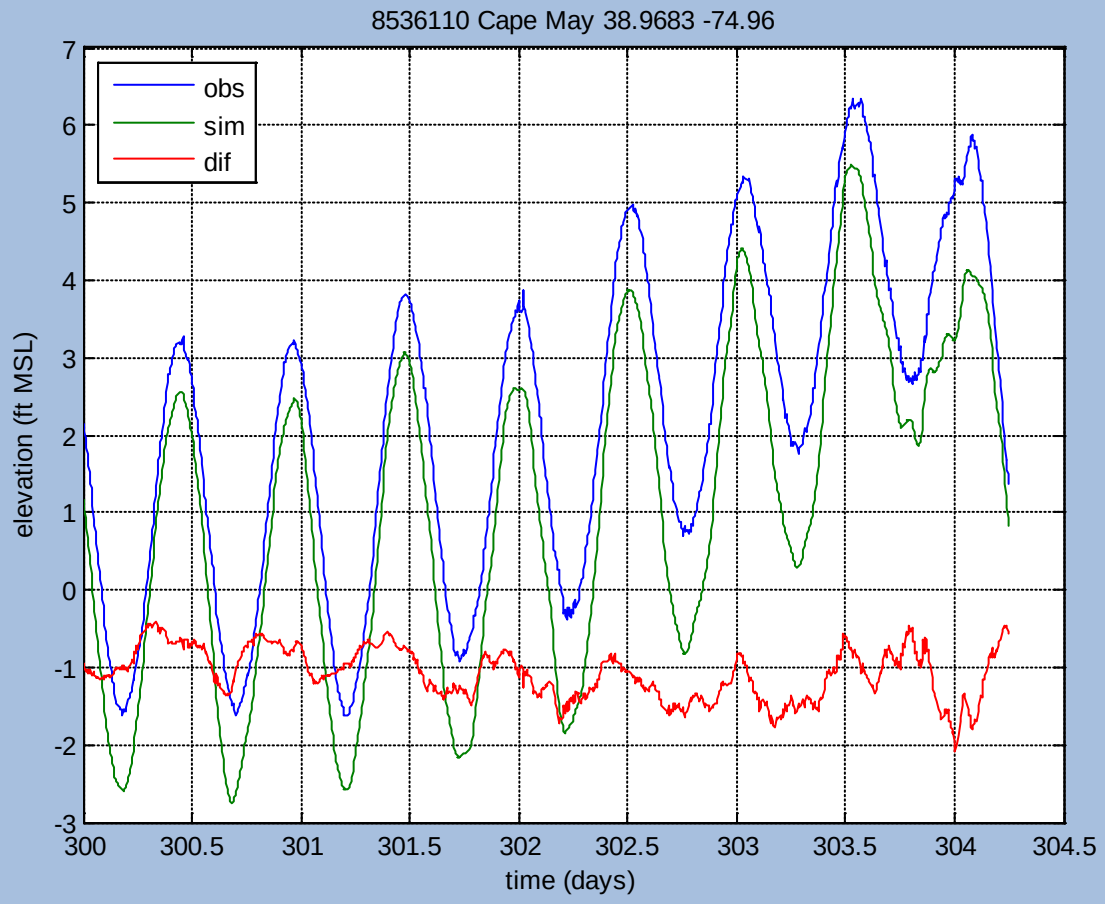


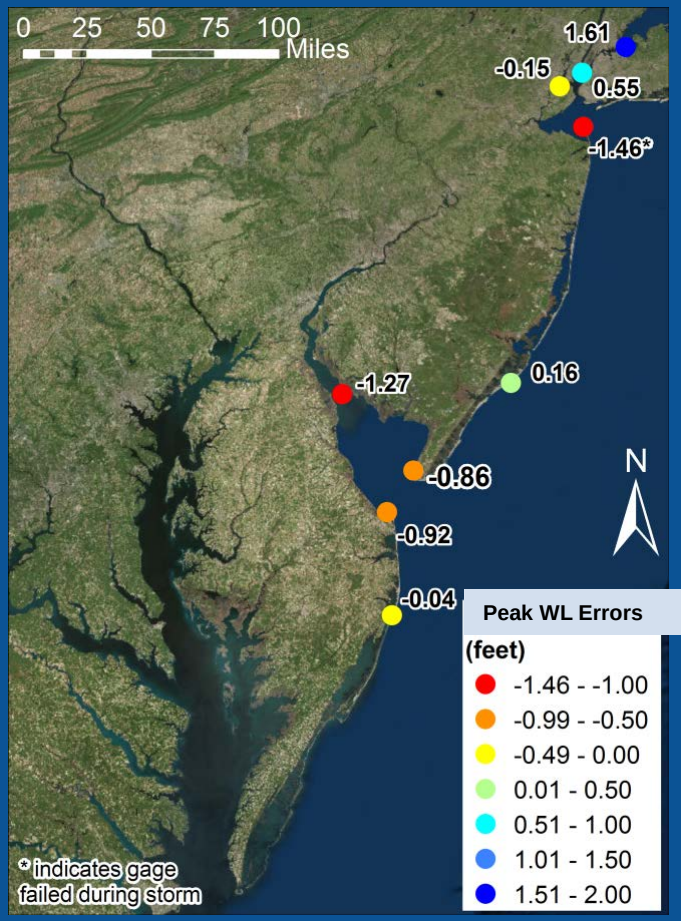
Hindcast Validation – 2012 Sandy





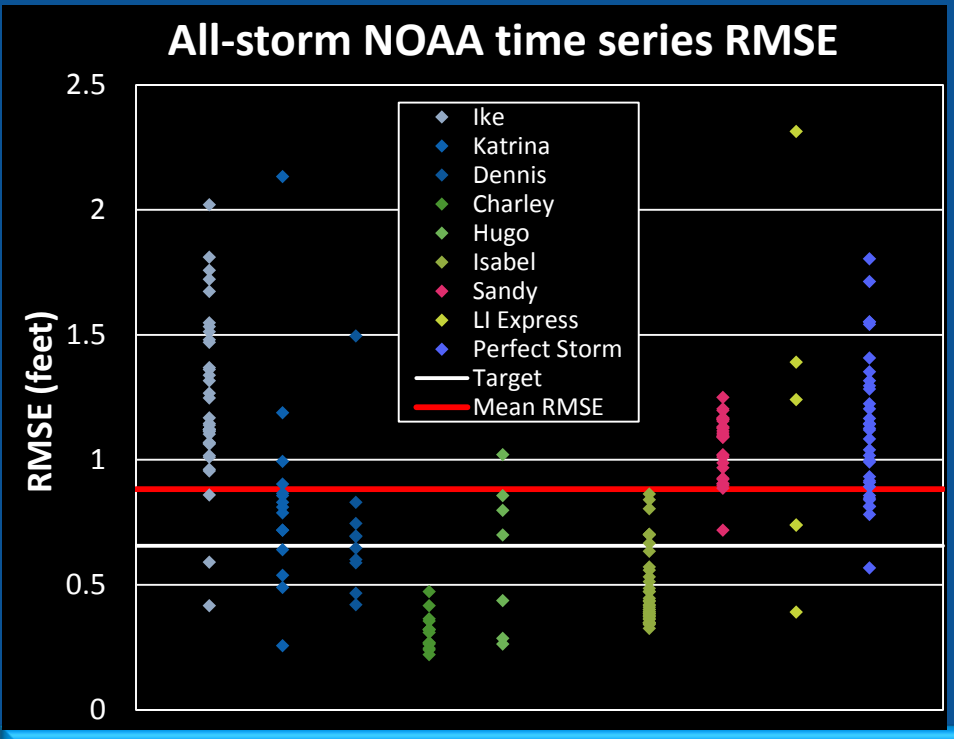
Hindcast Validation – 2012 Sandy

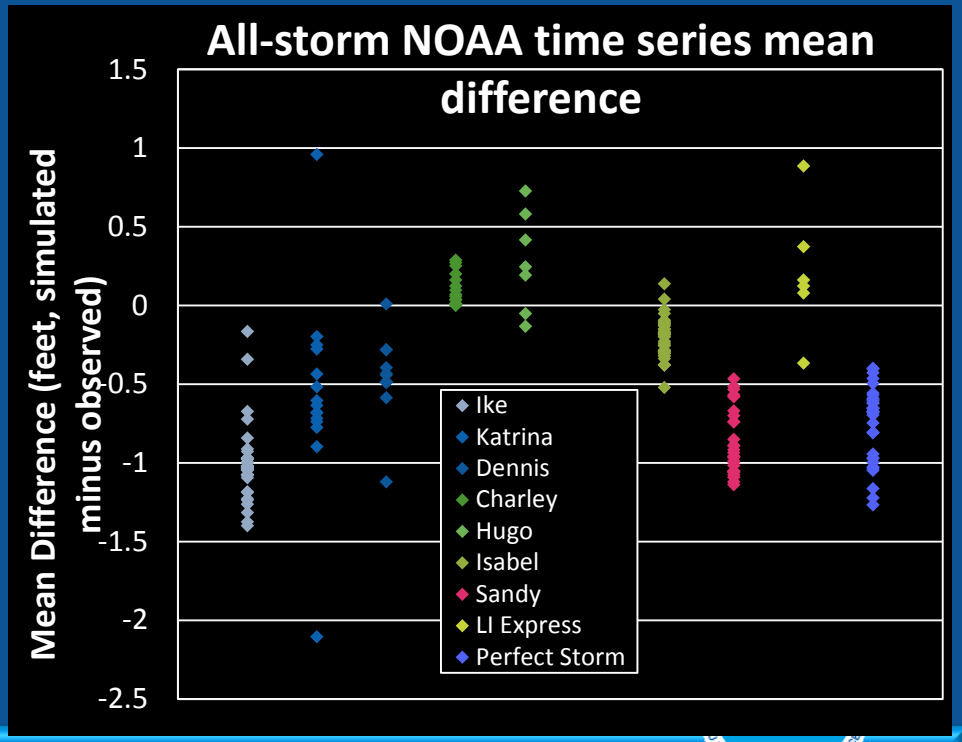




Grid Hindcast Validation – Model Skill Summary at NOAA Tide Gauges

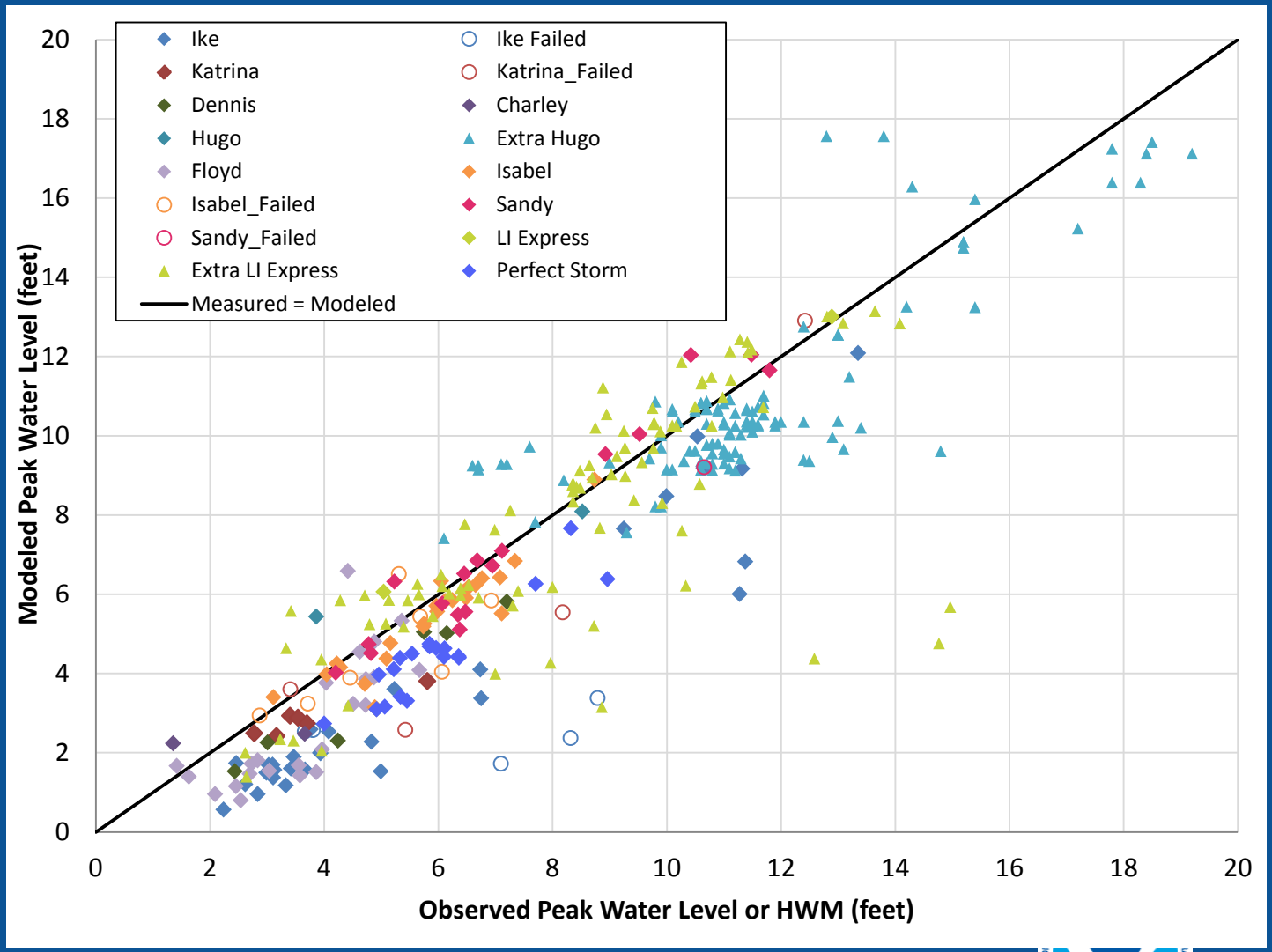
- RMSE 0.85 ft
- Steric effect, wave setup not included
  - Low bias in most storms
- Error summary
  - Difference in mean water levels is biggest contributor to error
  - Surge errors in Ike and Perfect Storm largest





Hindcast Validation – High Water Marks

- NOAA gage HWM error
  - 90% within +/-2 ft
  - Low bias overall
  - Mean -1.1 ft
  - Mean absolute 1.2 ft
- All HWM error
  - 90% within +/-2.5 ft
  - Low bias overall
  - Mean -0.80 ft
  - Mean absolute 1.3 ft



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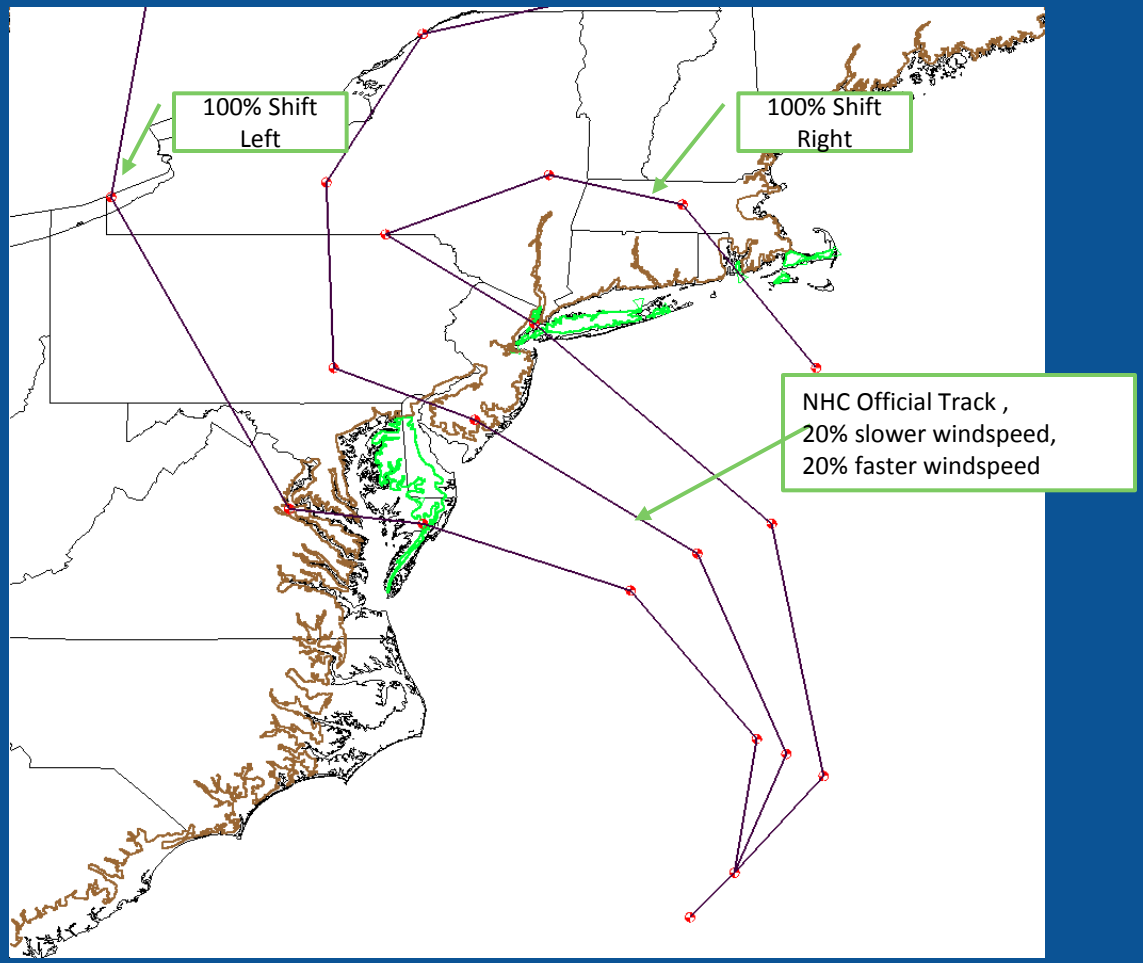
Tropical Cyclone Operational Forcing

- Use NHC official track with ADCIRC's dynamic asymmetric hurricane model
- Perturb track variables to generate ensemble forcing
  - Location (left, right, forward speed)
  - Max wind speed
  - Size
- Model Timing
  - 4.2 day simulation of Sandy takes 39 min on 400 cores

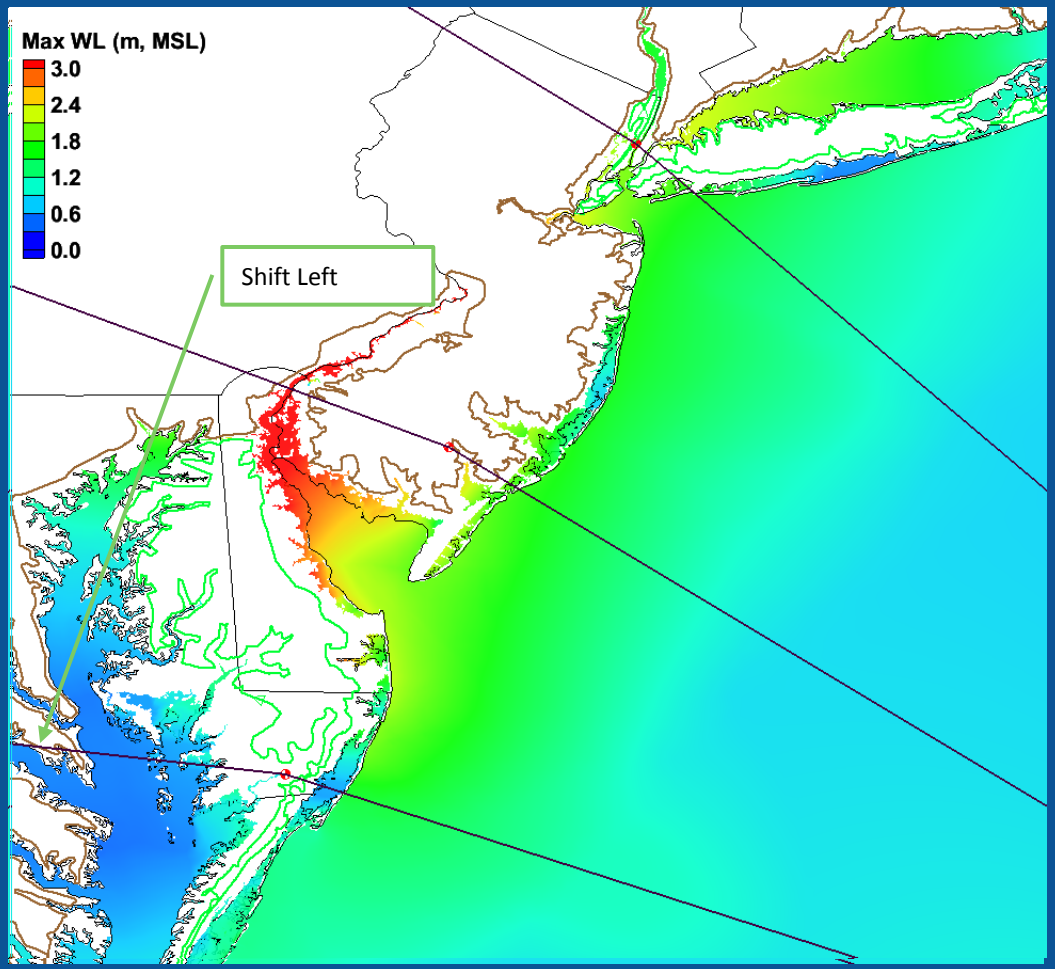
Ensemble Members: Hurricane Sandy

Advisory 26 (2012102818Z)



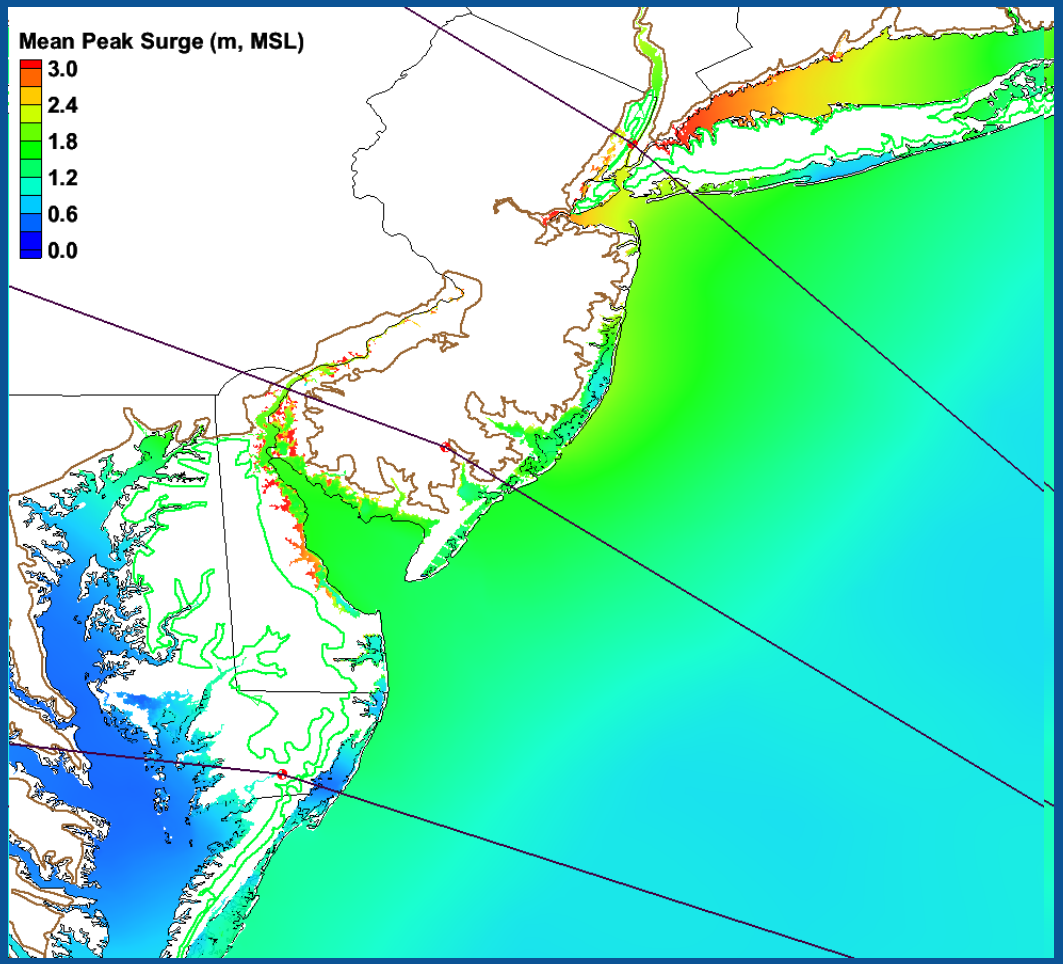
Ensemble Members: Max WL

Advisory 26 (2012102818Z)



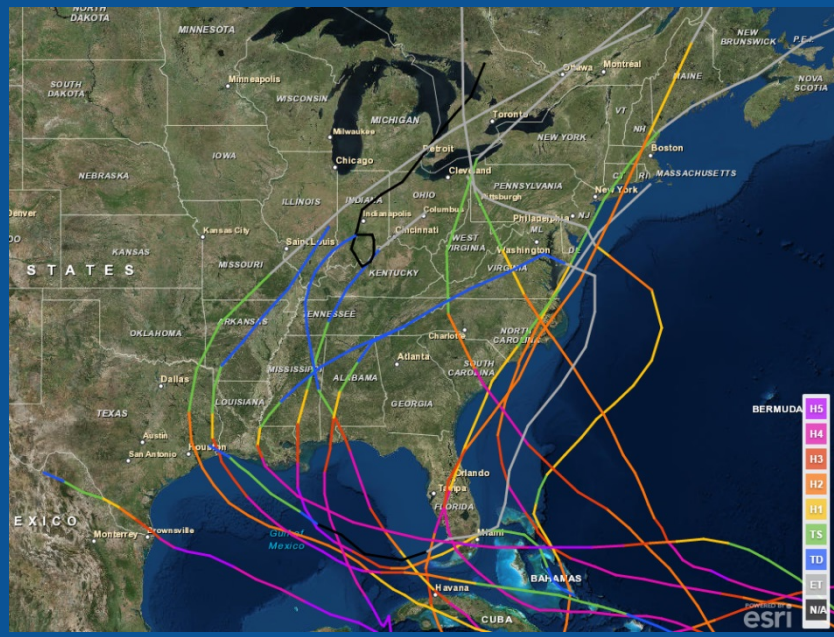
Hurricane Sandy Ensemble: Max, Mean Peak Surge

Advisory 26 (2012102818Z)



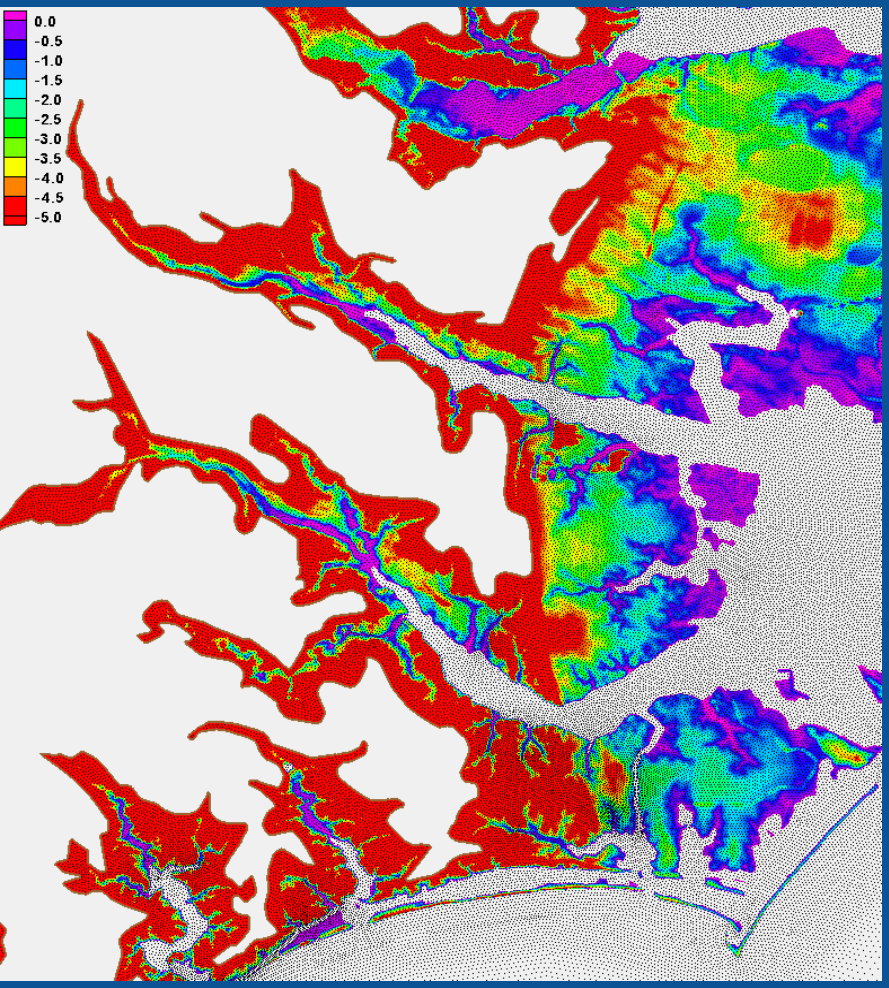
Tropical Cyclone Forcing Validation

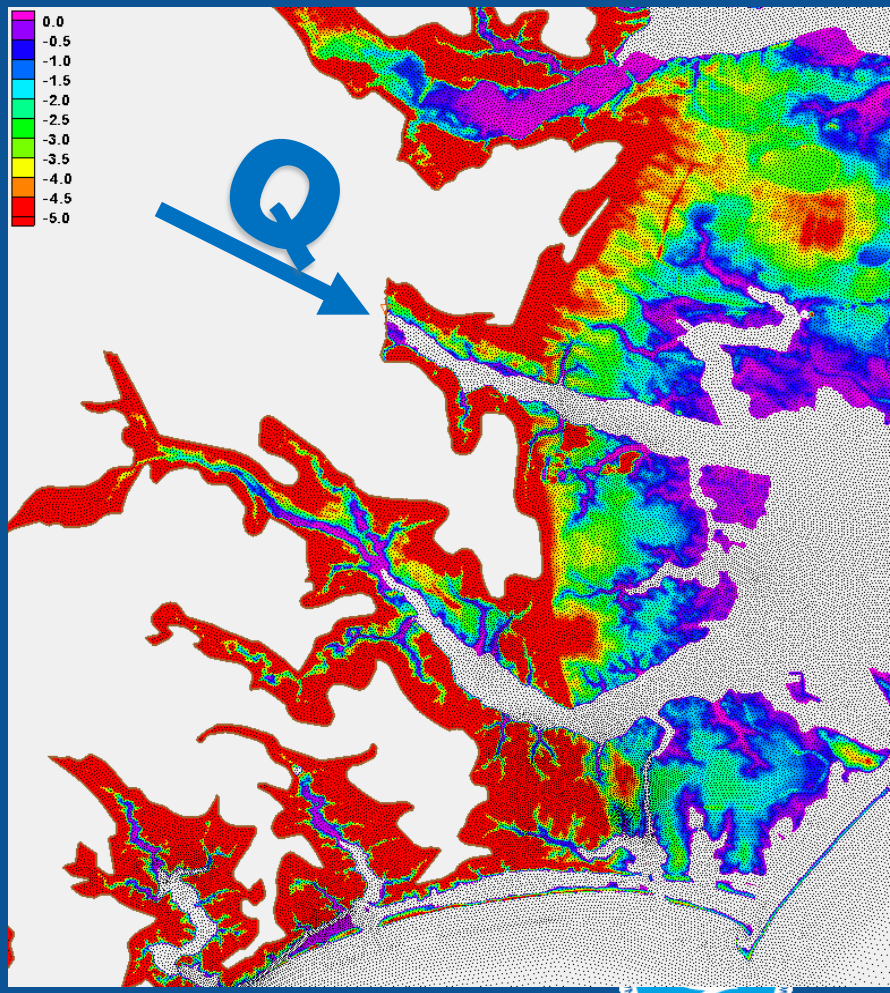
Storm	Gridded Forcing	NHC Track
	Mean RMSD, meters	Mean RMSD, meters
2005 Dennis	0.18	0.21
1999 Floyd	0.21	0.21
1989 Hugo	0.16	0.20
2008 Ike	0.24	0.24
2008 Isabel	0.14	0.25
2005 Katrina	0.19	0.22
2012 Sandy	0.26	0.23[1]
1960 Donna		0.42[2]
2005 Rita		0.23
2005 Wilma		0.27
2004 Ivan		0.23
1992 Andrew		0.11
1980 Allen		0.21



Testing Integrated Water Level Prediction

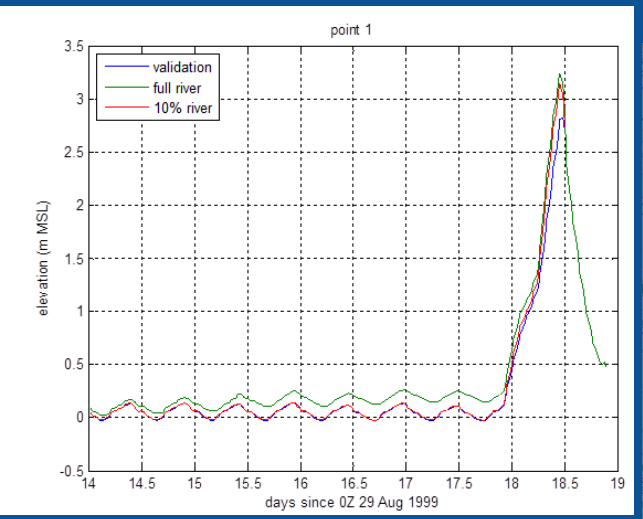
- Mesh changed to test inflow boundary condition in Tar River (NC)

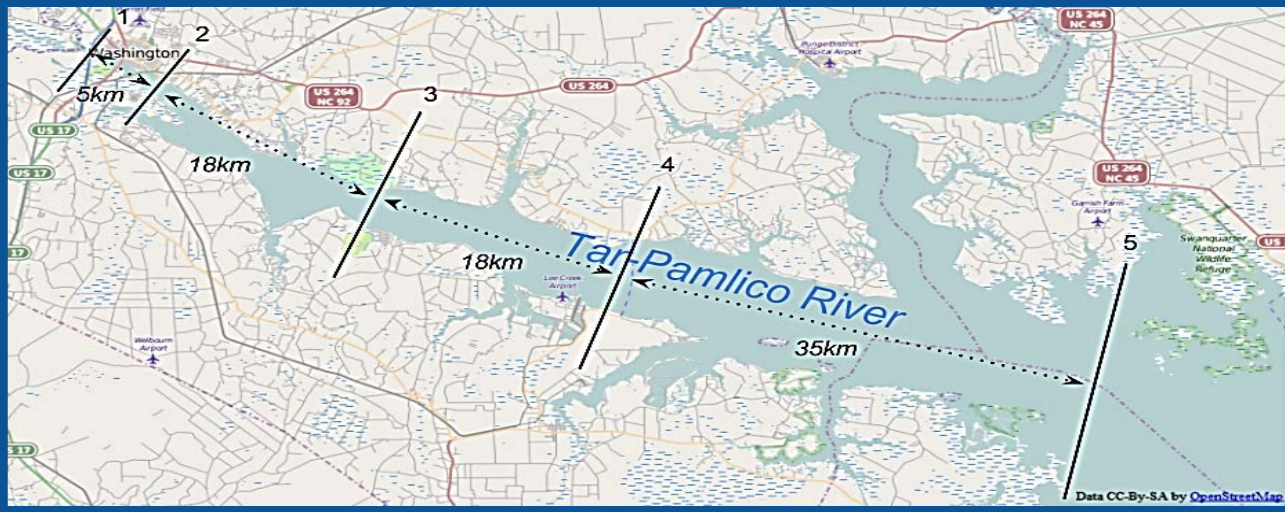


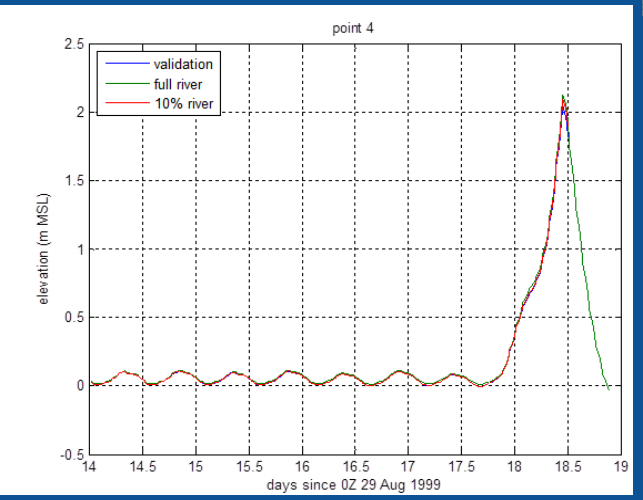


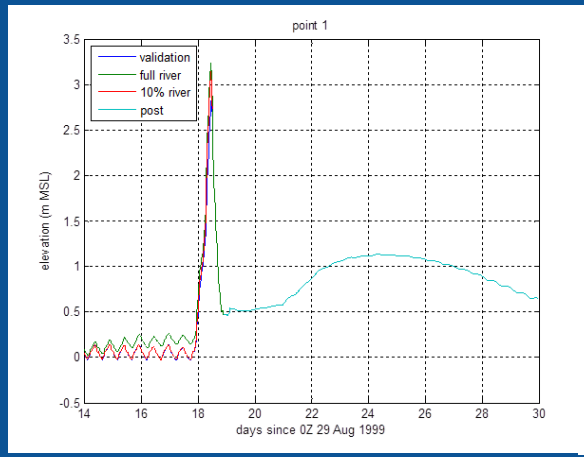
Testing Integrated Water Level Prediction

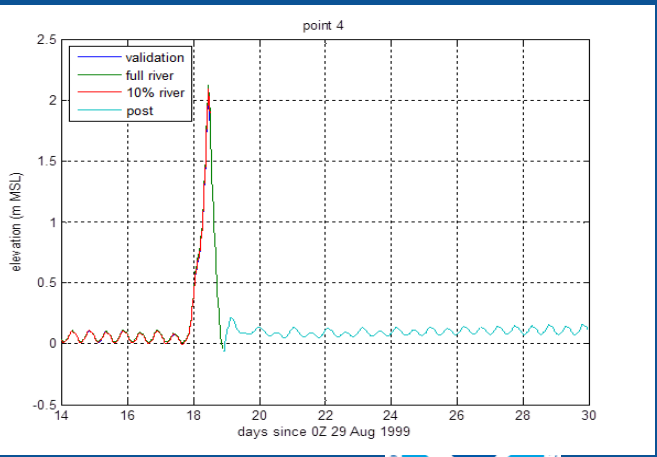
- Floyd (1999) to evaluate coupling strategies in Tar-Pamlico River











Next Steps

- Install ADCIRC on NOAA's Weather and Climate Operational Supercomputing System (WCOSS) for 2016 hurricane season
- Develop and implement bias correction technique to account for steric and other deviations from Mean Sea Level
- Upgrade Extratropical Surge and Tide Operational Forecast System (ESTOFS) using this grid
  - Have tested ADCIRC with multiple operational NWP models: HWRF, GFDL, GFS, NAM, HRRR, ECMWF
- Develop coupling to national hydrologic model to support total water prediction