Slides in support of NOAA JTTI project

Joannes Westerink[1], Dam Wirasaet[1], William Pringle[1*], Guoming Ling[1], Mindo Choi[1],
Sergey Vinogradov[2], Saeed Moghimi[2], Edward Myers[2],
Andre van der Westhuysen[3], Ali Abdolali[3]

[1]University of Notre Dame, [1*]Joint University of Notre Dame & Argonne National Laboratory,
[3]CSDL NOS NOAA,[7]NCEP NWS NOAA

1. Shoreline and bathy/topo data bases as a foundation for mesh development

Issues to overcome

- Problem: High resolution LiDar based bathymetric/topographic data bases misalign with US Medium shoreline data bases

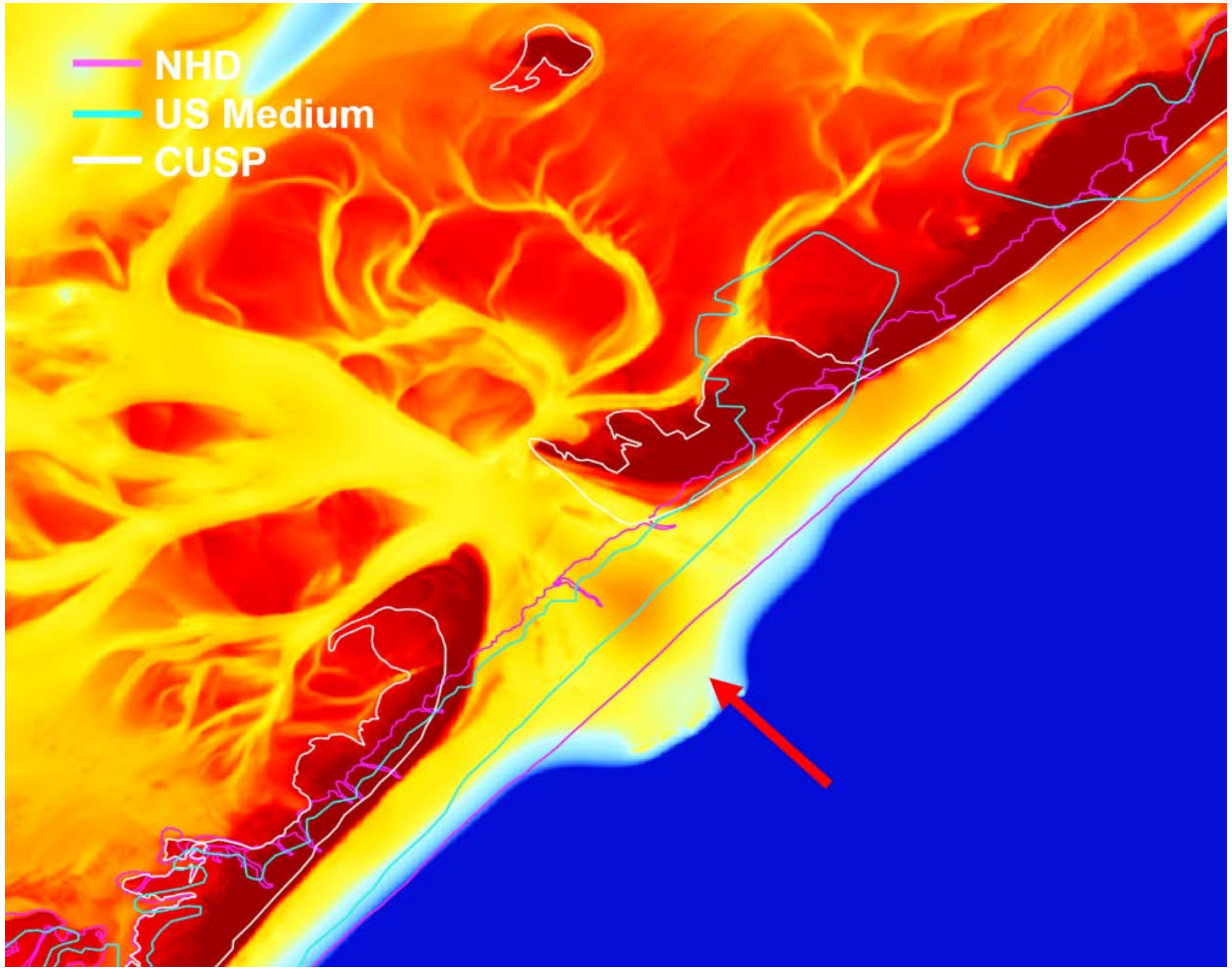
  Solution: Merge CUSP, NHD, and US Medium shorelines into continuous data base

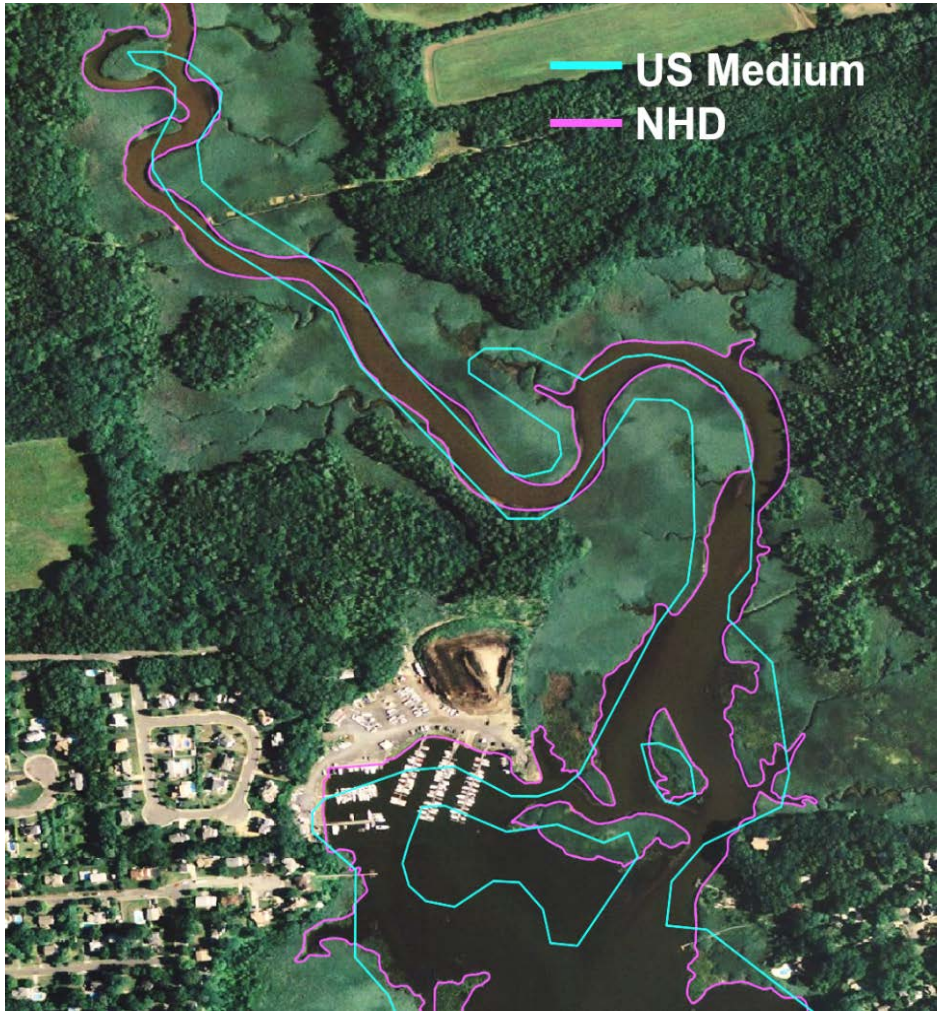
- Problem: NOAA CRM's do not support meshes down to targeted 30 m resolution

  Solution: Apply hierarchal approach using SRTM, Gebco2019, CONED, NCEI, NOAA local 10 m, USACE JALBTX, and USACE Dredging channel surveys

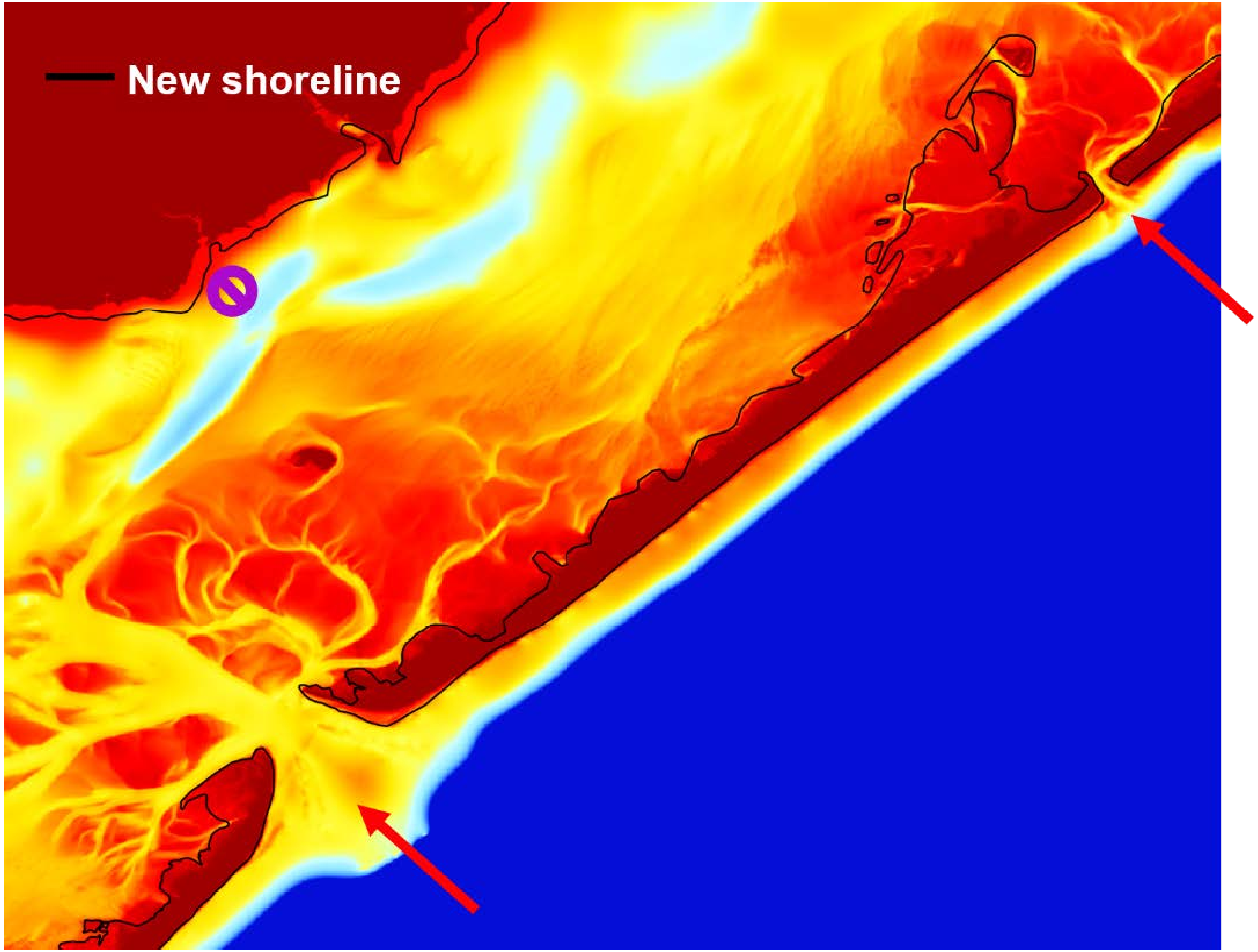
- Problem: Inland high resolution data bases do not match with SRTM as this overestimates inland topography; lack access to statewide Lidar surveys

Misalignments of US Medium shoreline is an impediment to accurate meshes

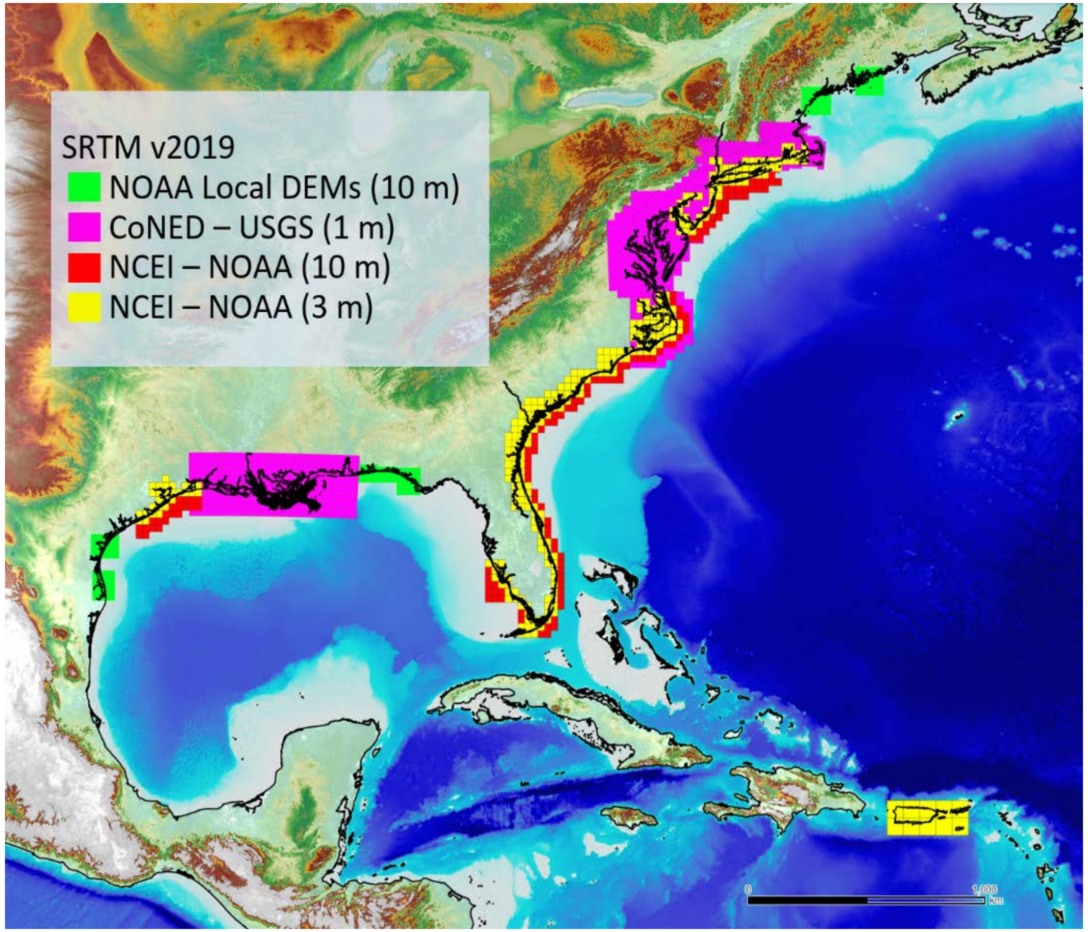


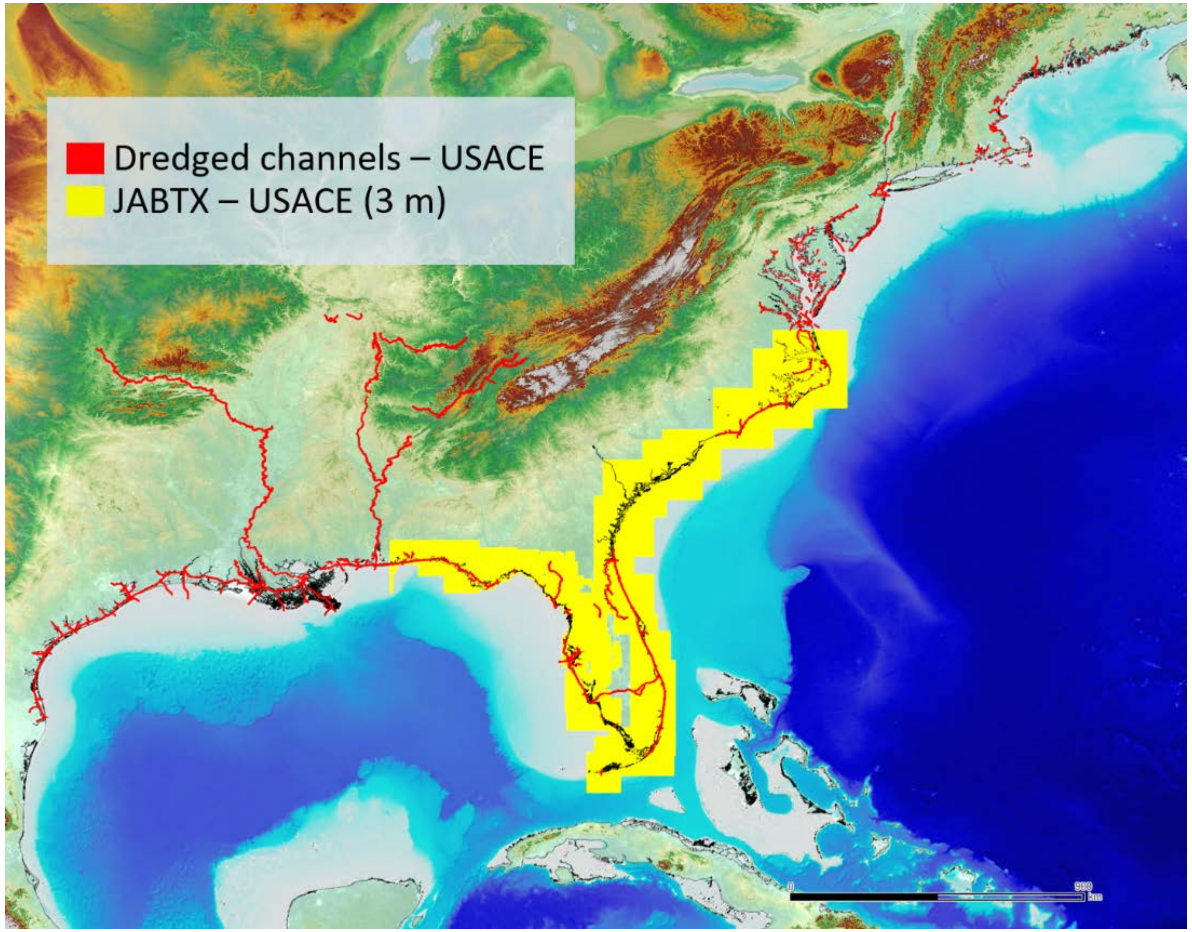


Merged CUSP, NHD, and US Medium shorelines supports meshes to 10 m res



Bathy/topo databases applied



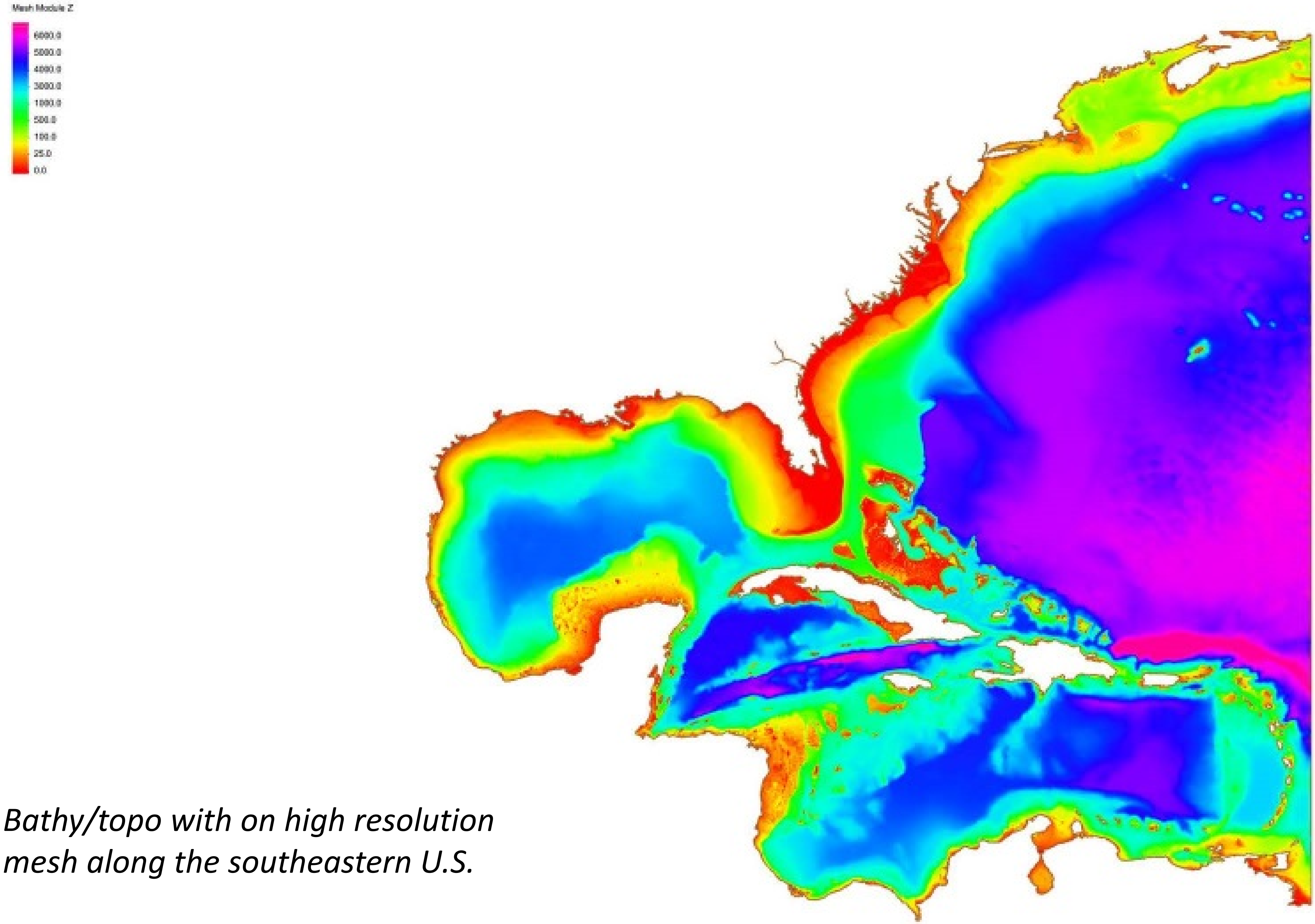


2. High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts

Approach

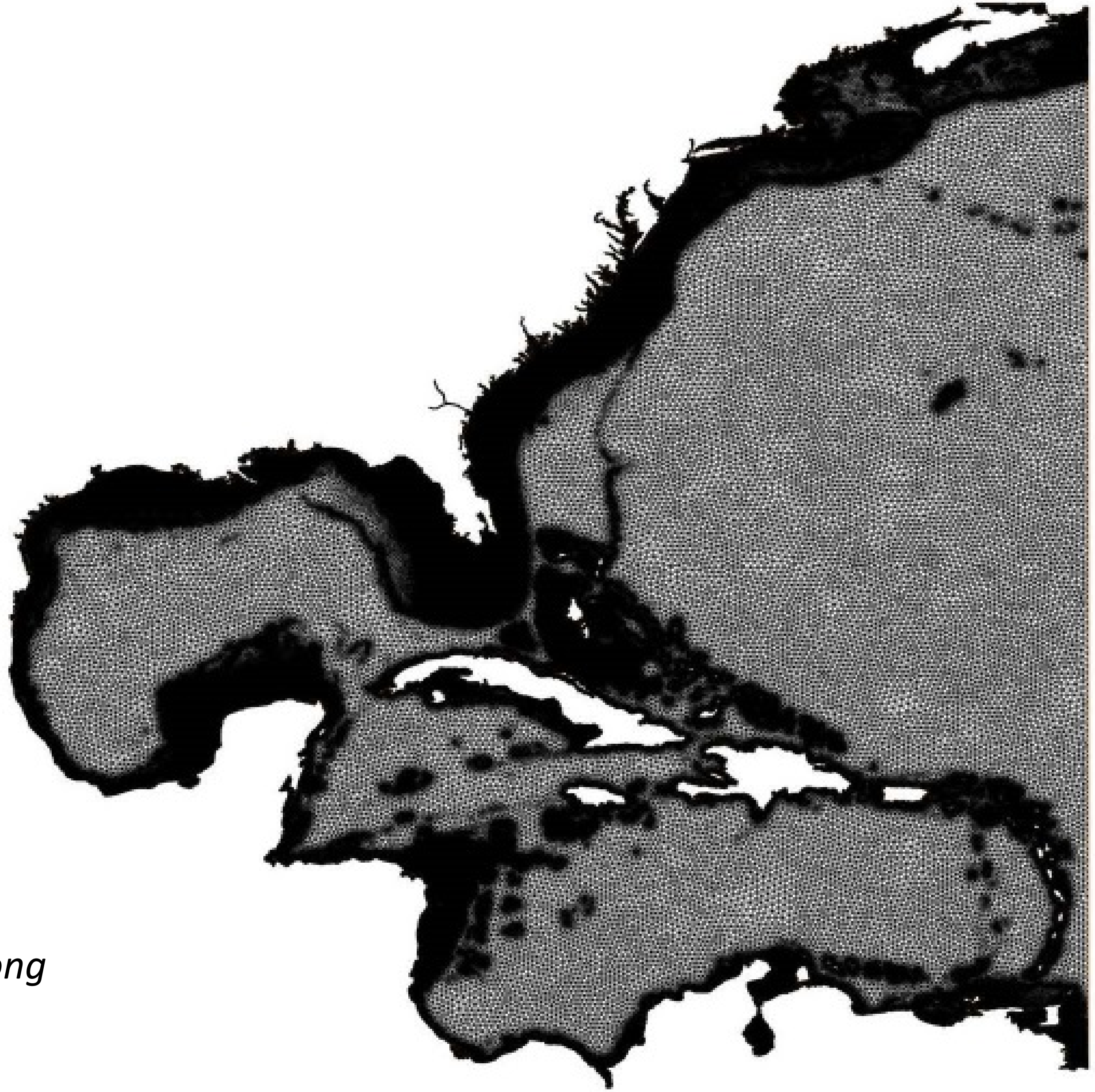
- Apply OceanMesh2D used to generate *water side* with high resolution shoreline
- Parameters control resolution to target mesh size depending on shoreline complexity, feature size, wavelength, topographic length scale, channel and inland feature width, element shape, and element size transition rates.
- Mesh2D used to generate *floodplain/dry land side* of the mesh to seamlessly mate at the wet/dry interface.

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



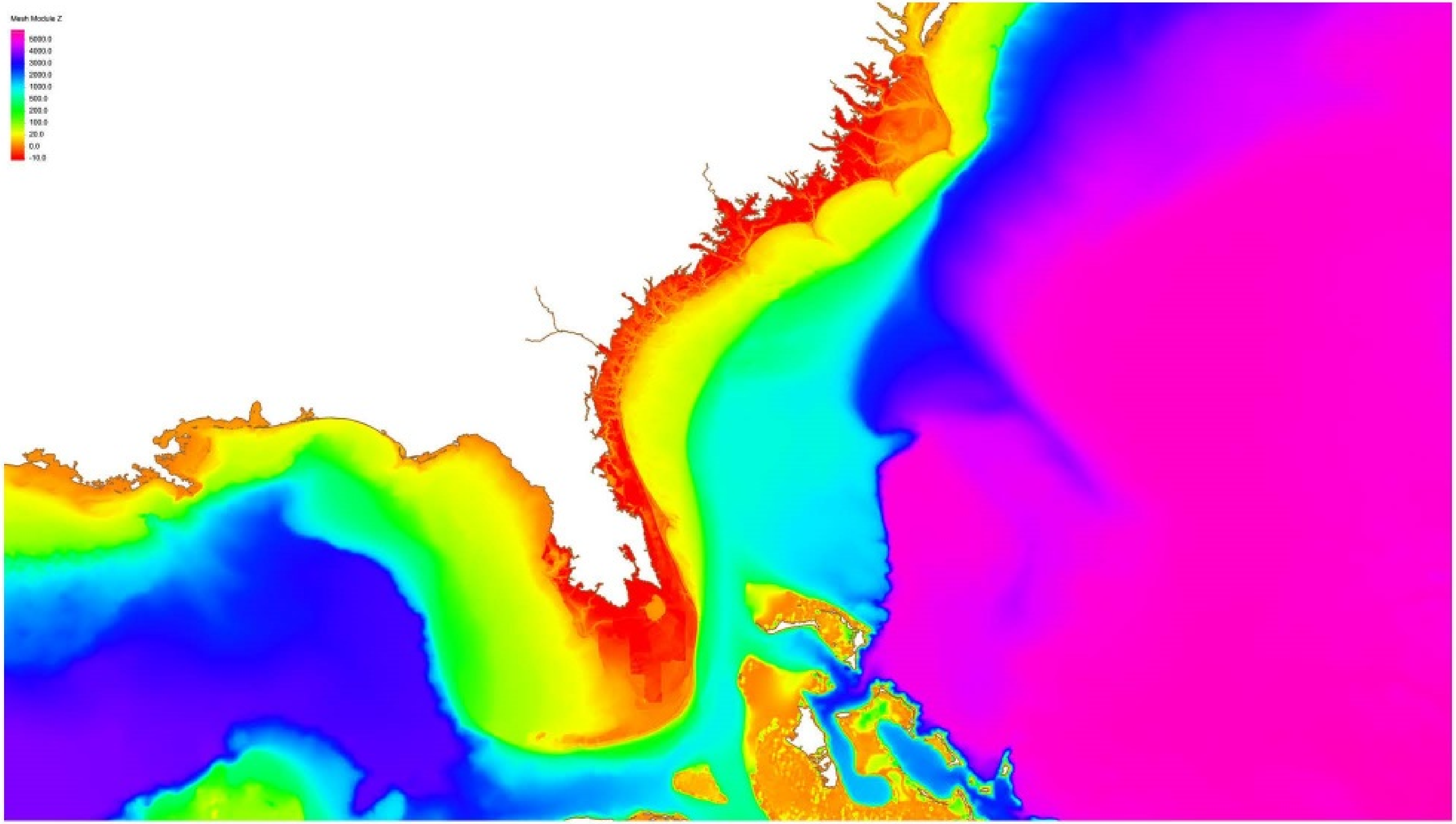
Bathy/topo with on high resolution mesh along the southeastern U.S.

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



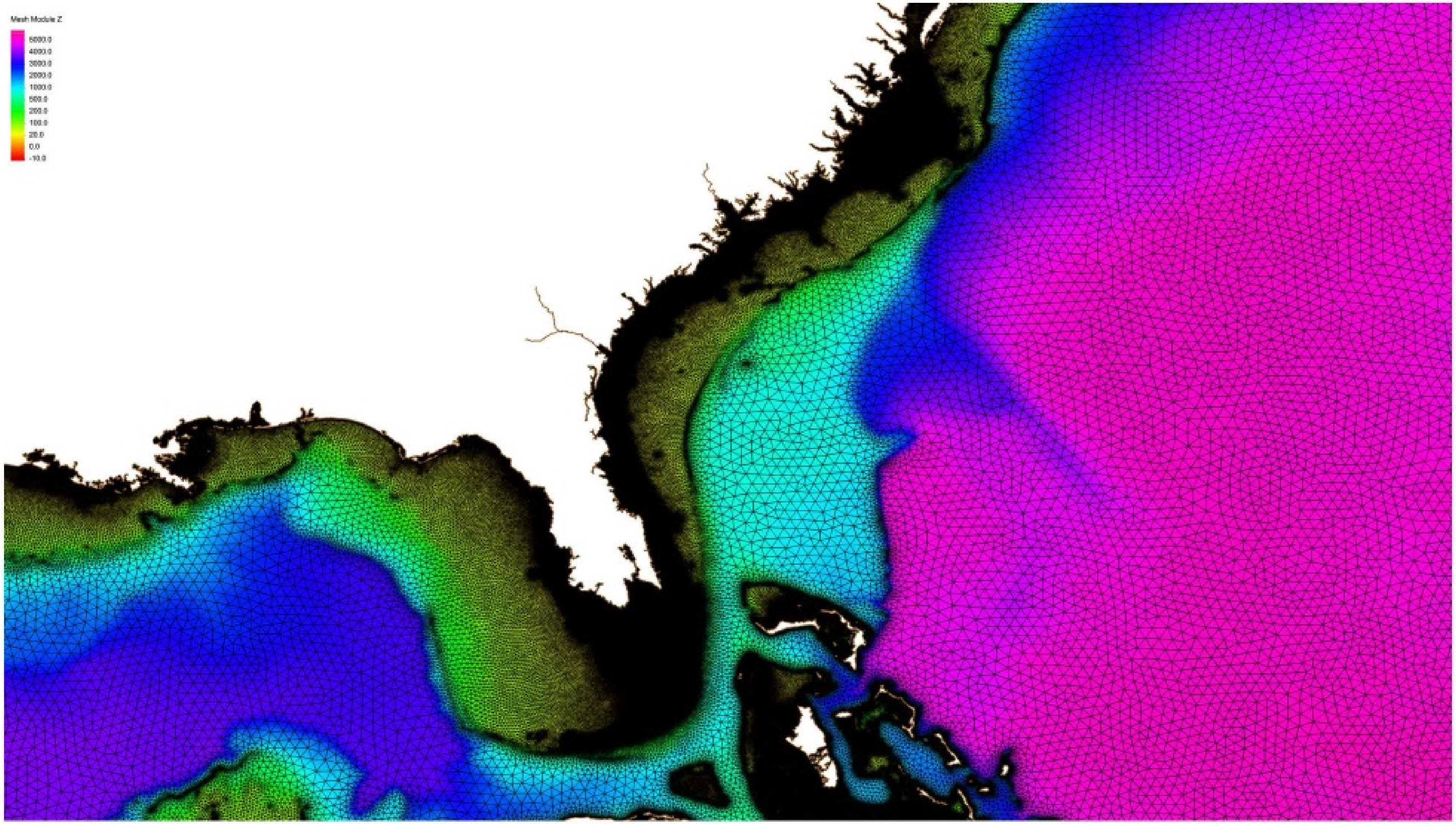
Mesh with high resolution along the southeastern U.S.

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



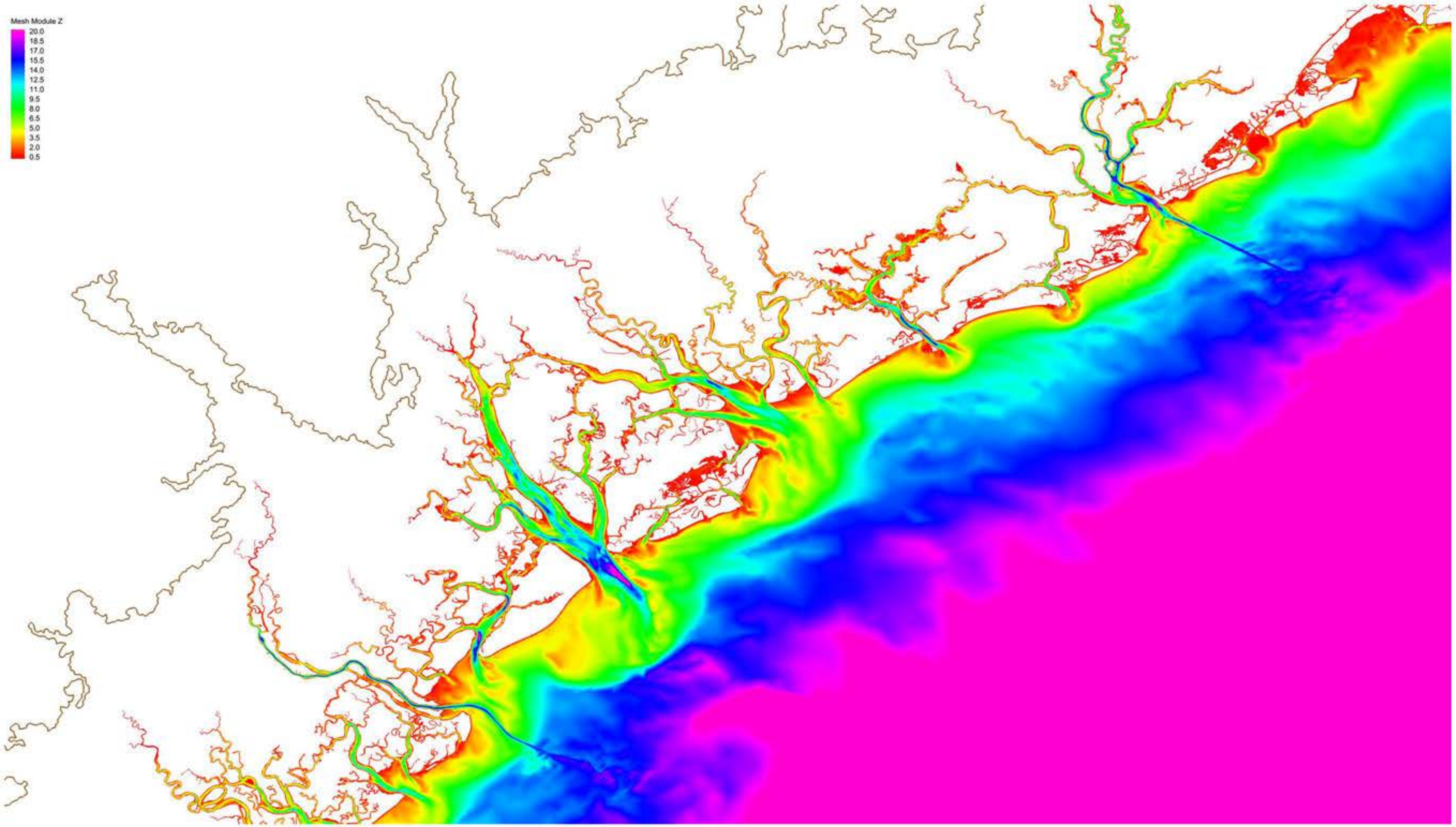
High resolution portion of mesh along the southeastern U.S. – bathy/topo

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



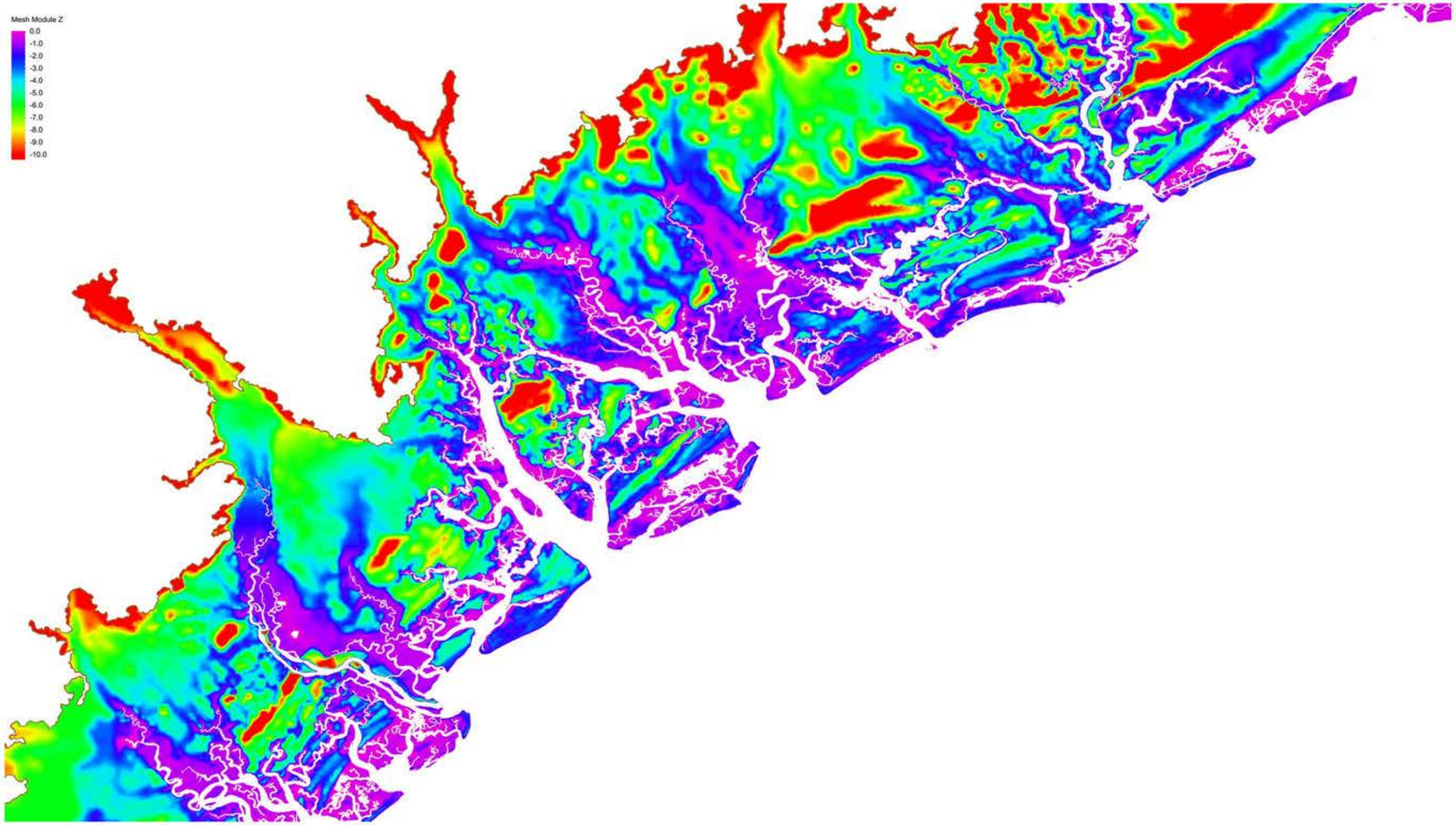
High resolution portion of mesh along the southeastern U.S. – bathy/topo

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



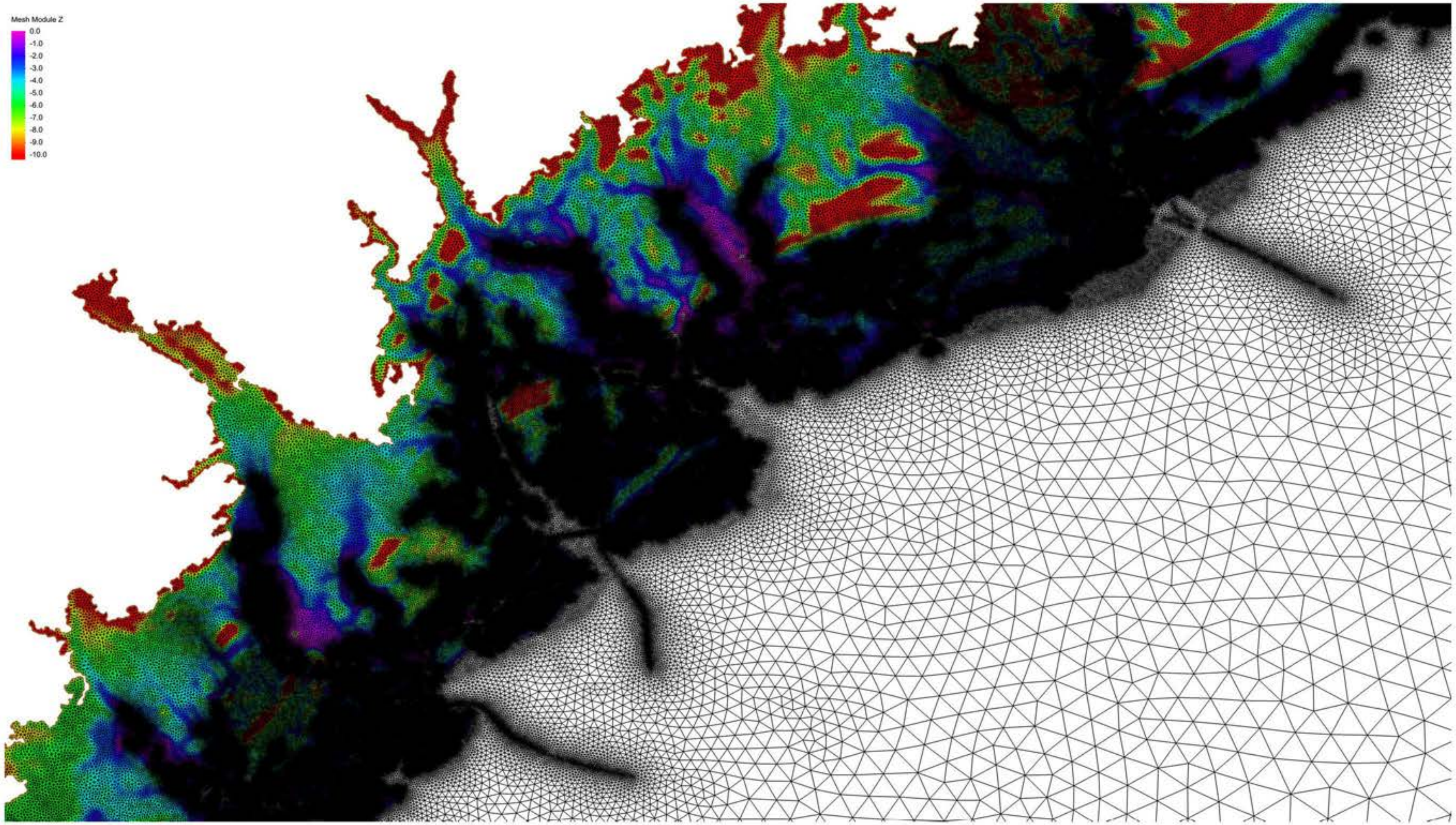
Mesh details along the South Carolina coast – ocean side bathymetry only

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



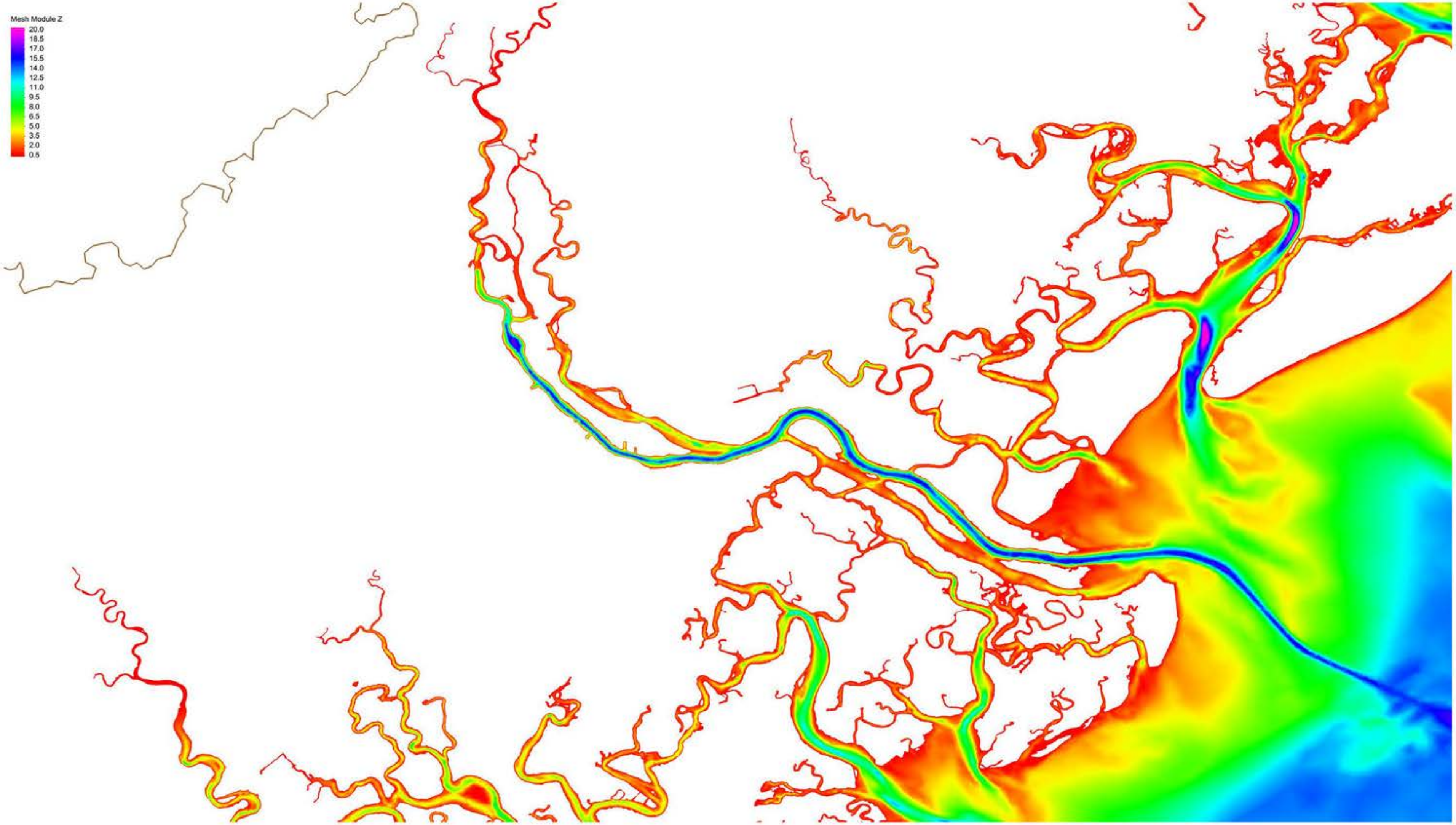
Mesh details along the South Carolina coast – land side topography only

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



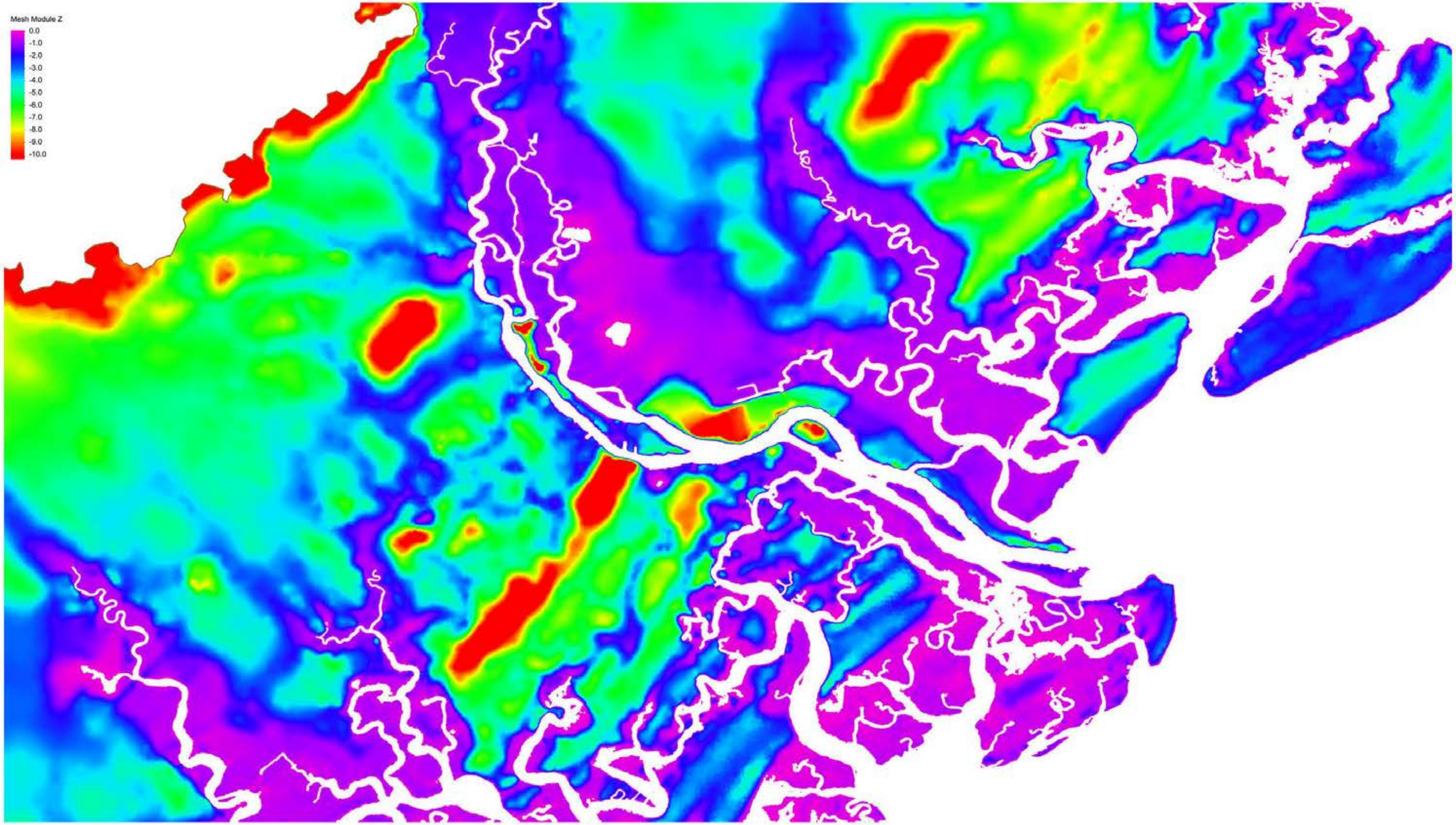
Mesh details along the South Carolina coast – land side topography with mesh

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



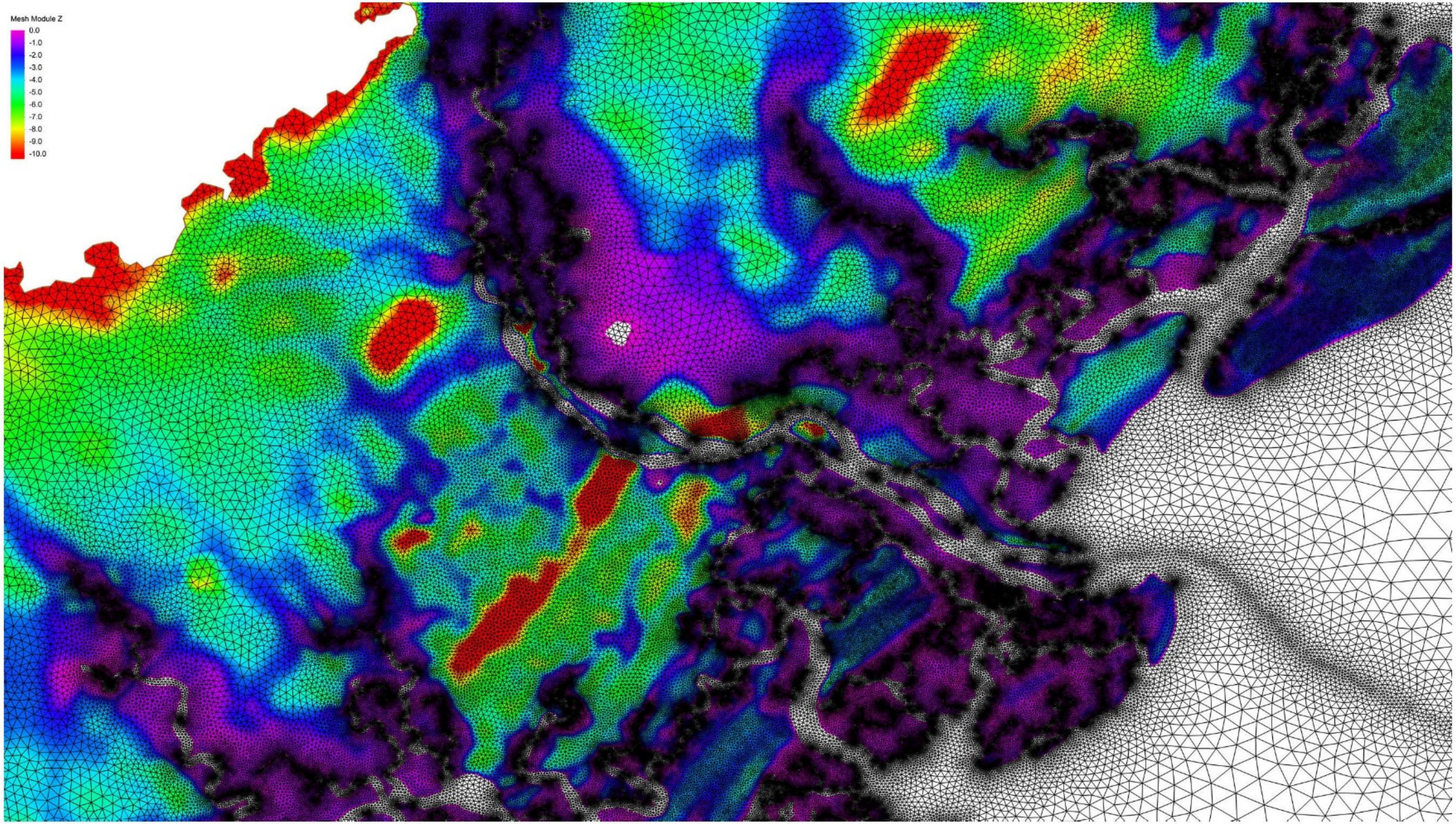
Further zoom of mesh along the South Carolina coast – ocean side bathymetry only

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



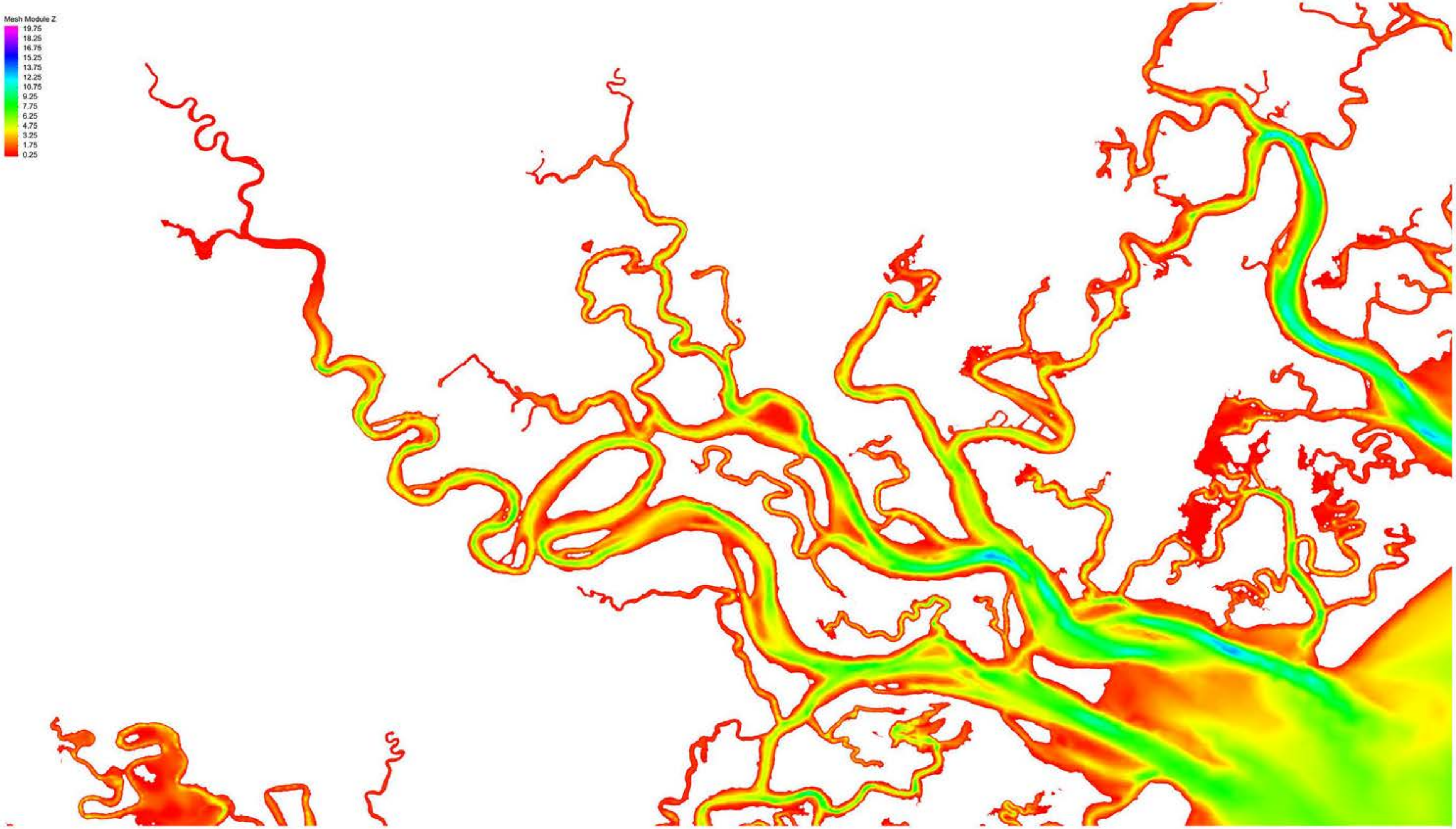
Further zoom of mesh along the South Carolina coast – land side topography only

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



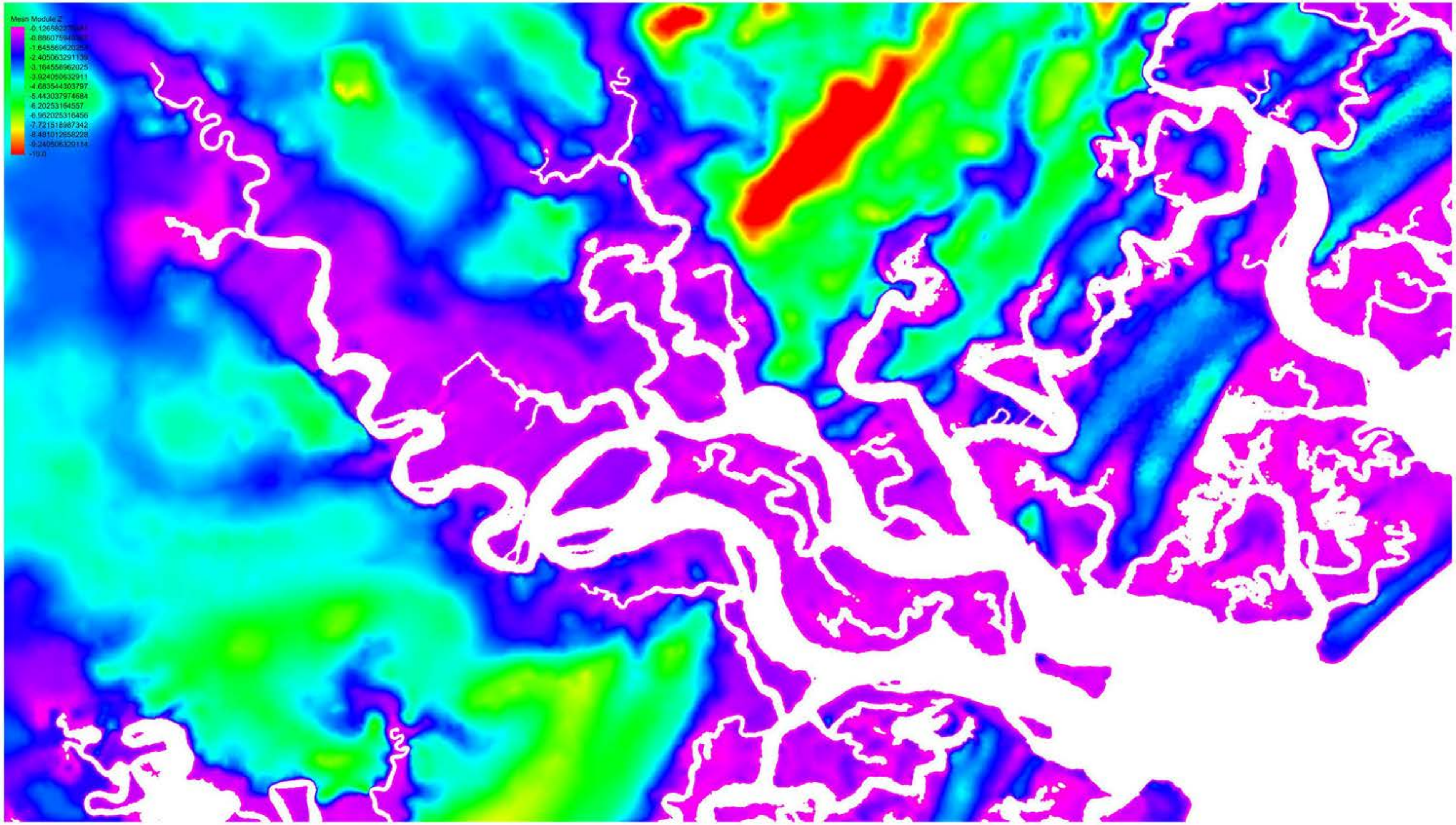
Further zoom of mesh along the South Carolina coast – land side topography with mesh

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



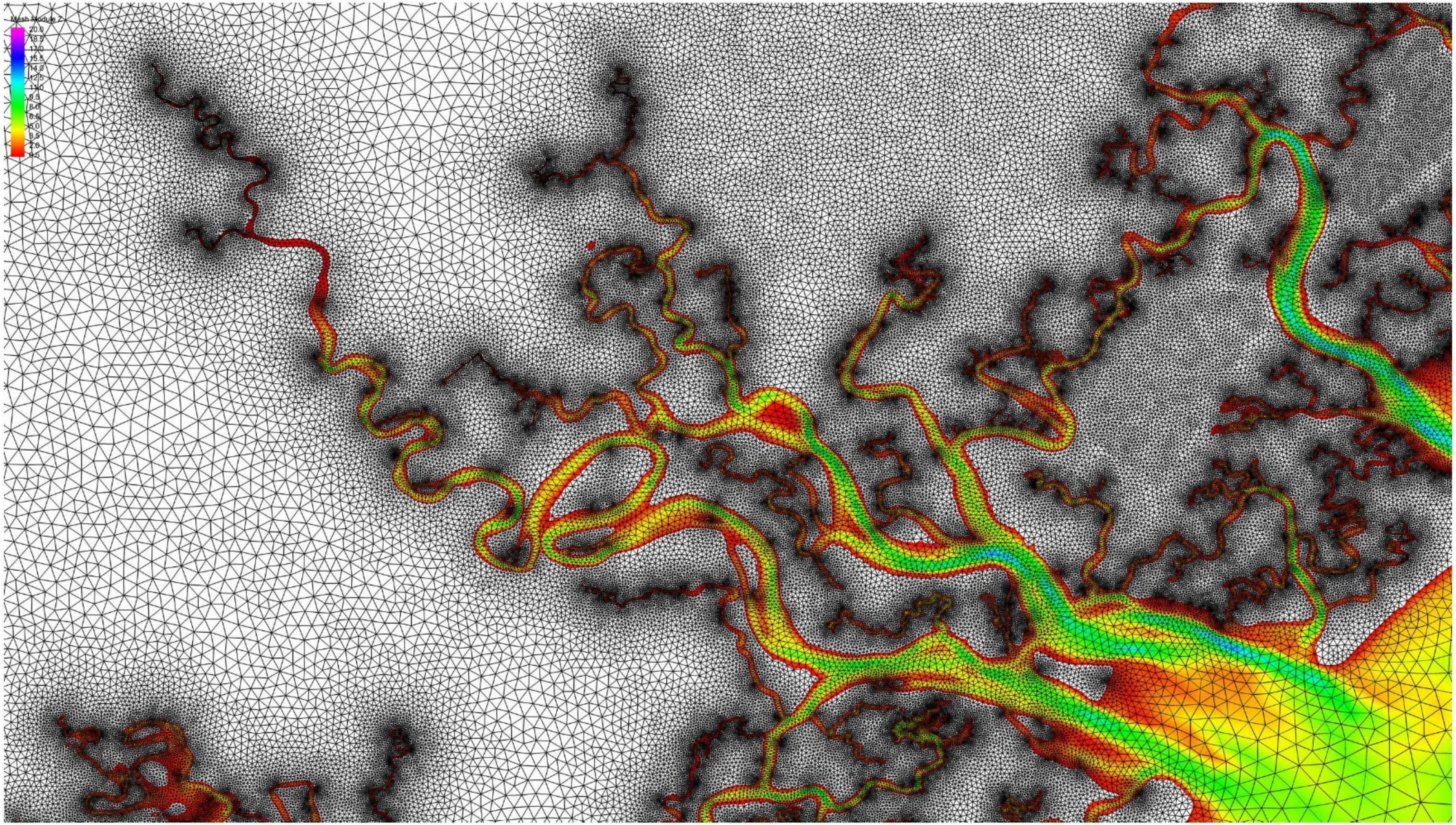
Inlet scale zoom of mesh along the South Carolina coast – ocean side bathymetry only

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts



Inlet scale zoom of mesh along the South Carolina coast – land side topography only

High resolution optimal meshes for the U.S. East and Gulf of Mexico coasts

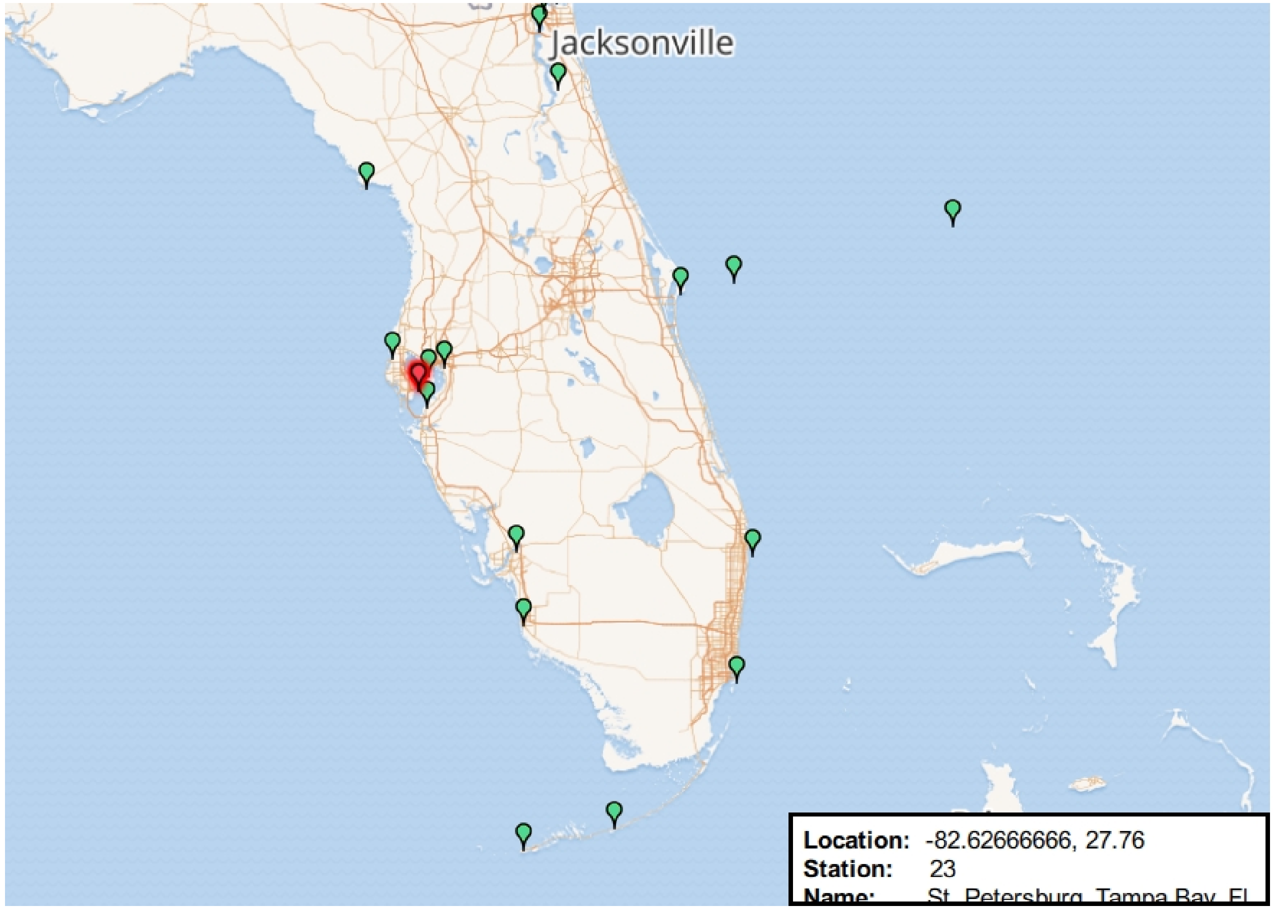


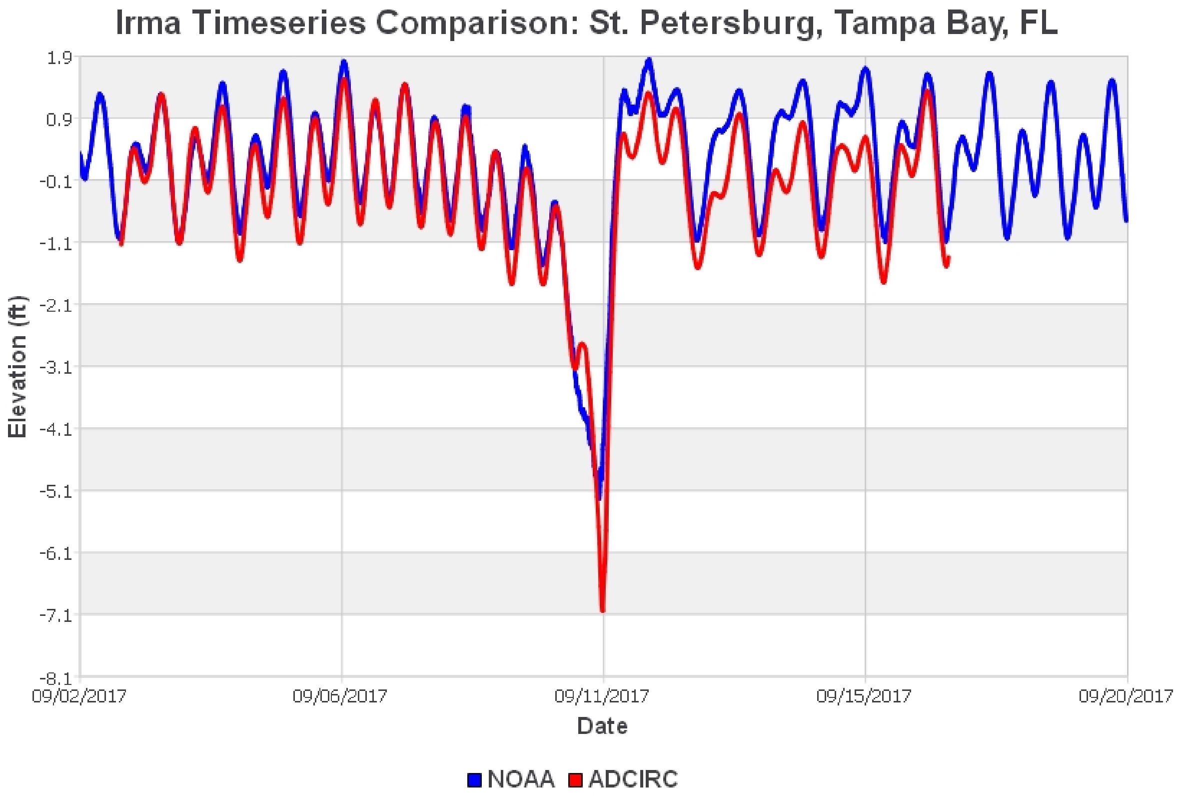
Inlet scale zoom of mesh along the South Carolina coast – ocean side bathymetry with mesh

3. Hindcast of Hurricane Irma using ADCIRC+SWAN

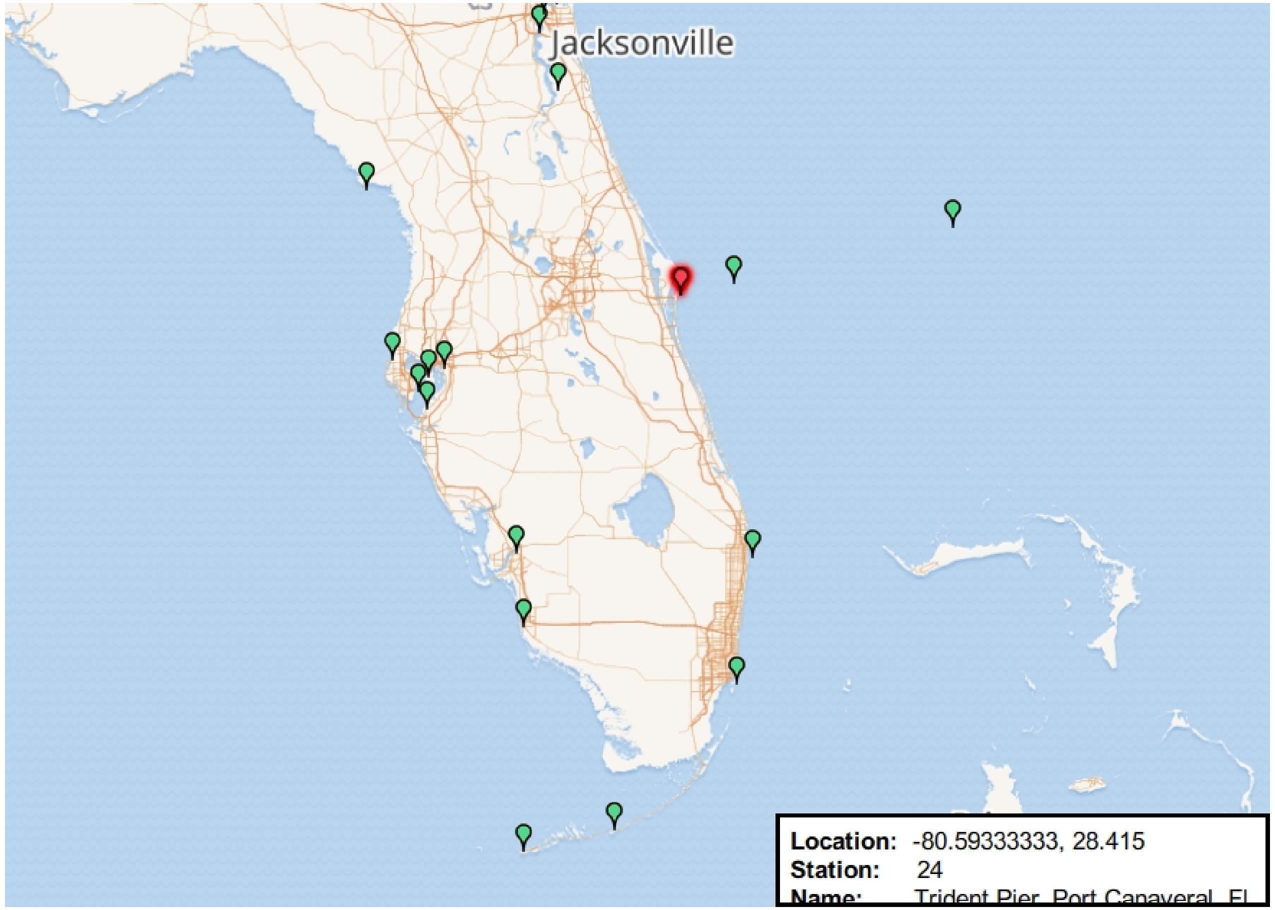
- Tidal forcing functions: Tides at boundary (TPXO8), SAL, internal tidal dissipation using annually averaged ocean climatology
- Atmospheric winds and pressure: Oceanweather Inc. hindcast for winds and atmospheric pressure
- Circulation model: ADCIRC run in 2D barotropic mode
- Waves: SWAN integrally coupled to ADCIRC run on identical unstructured finite element mesh

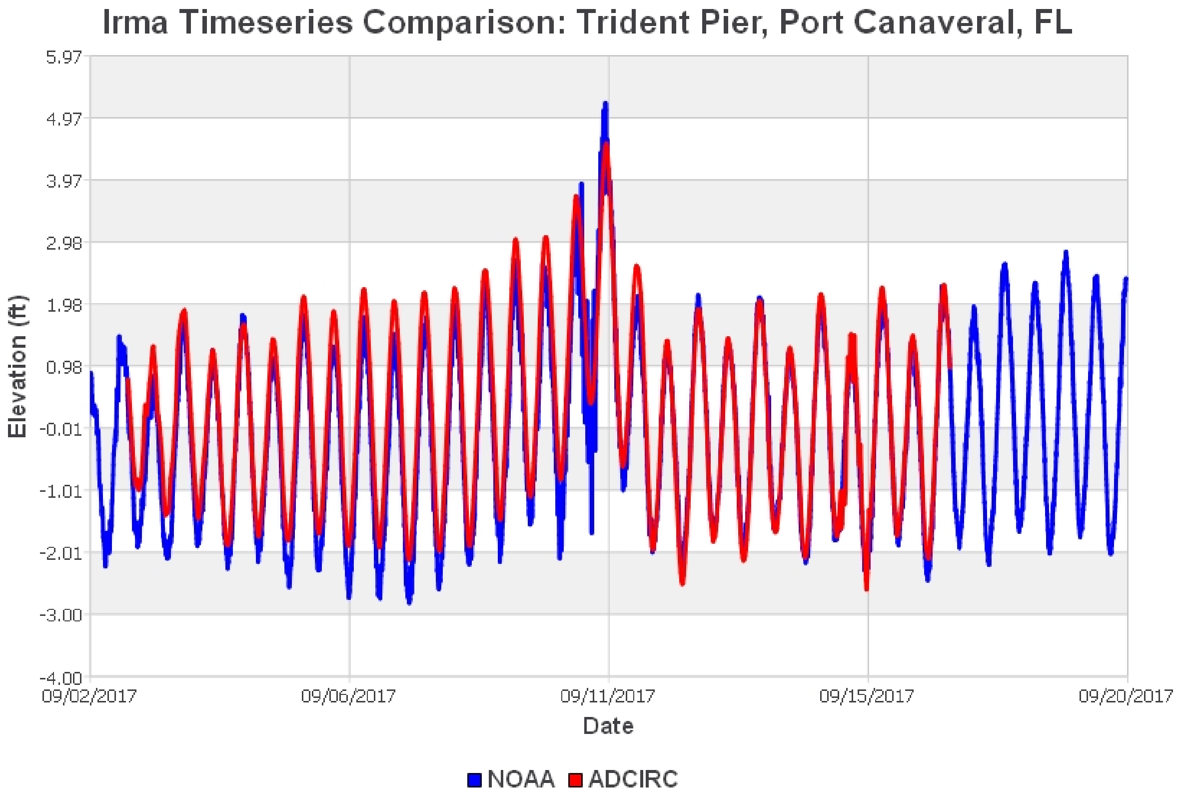
ADCIRC+SWAN hindcast of Hurricane Irma - validation



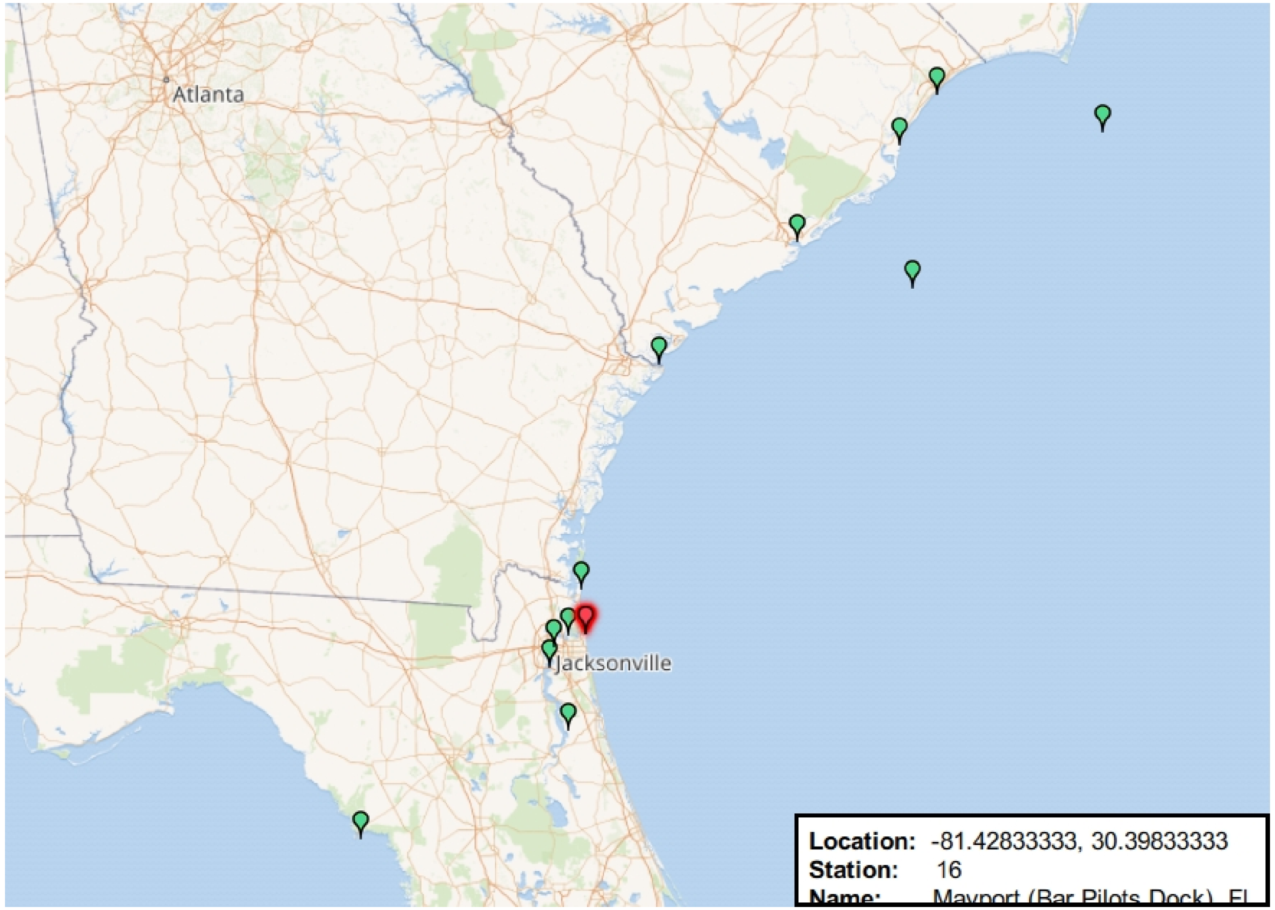


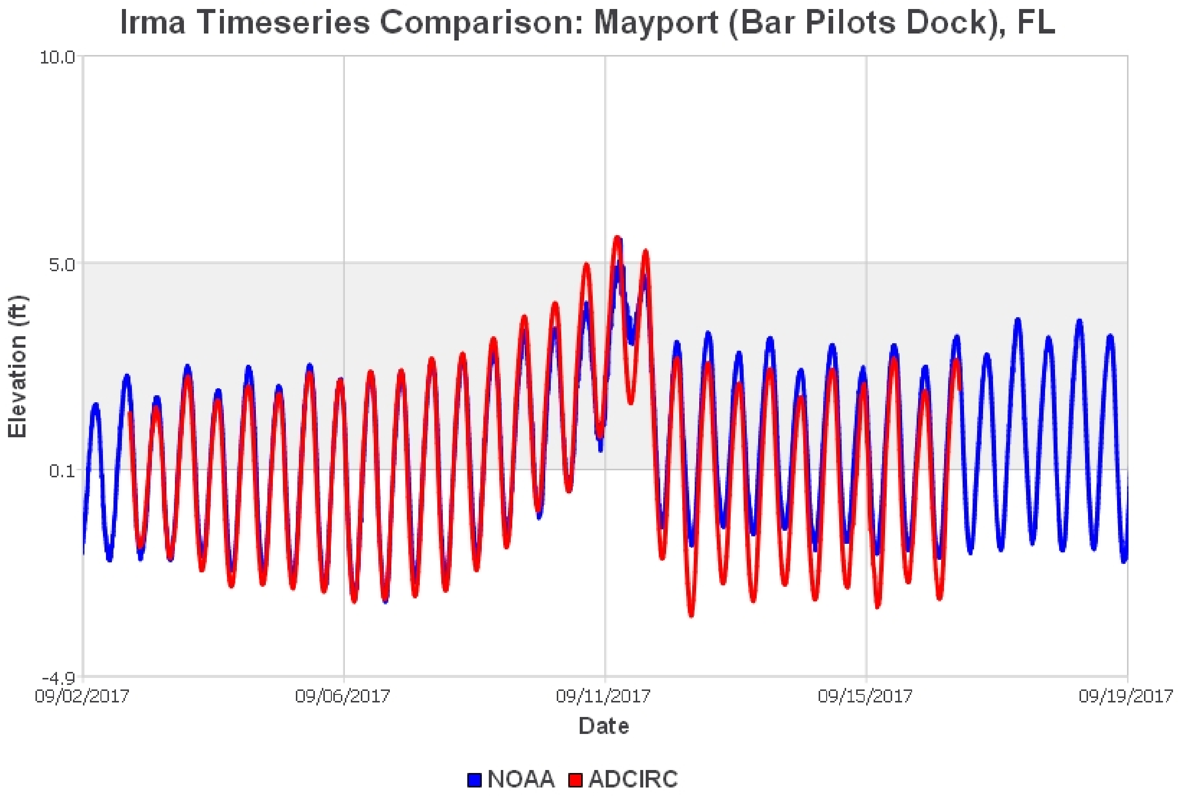
ADCIRC+SWAN hindcast of Hurricane Irma - validation



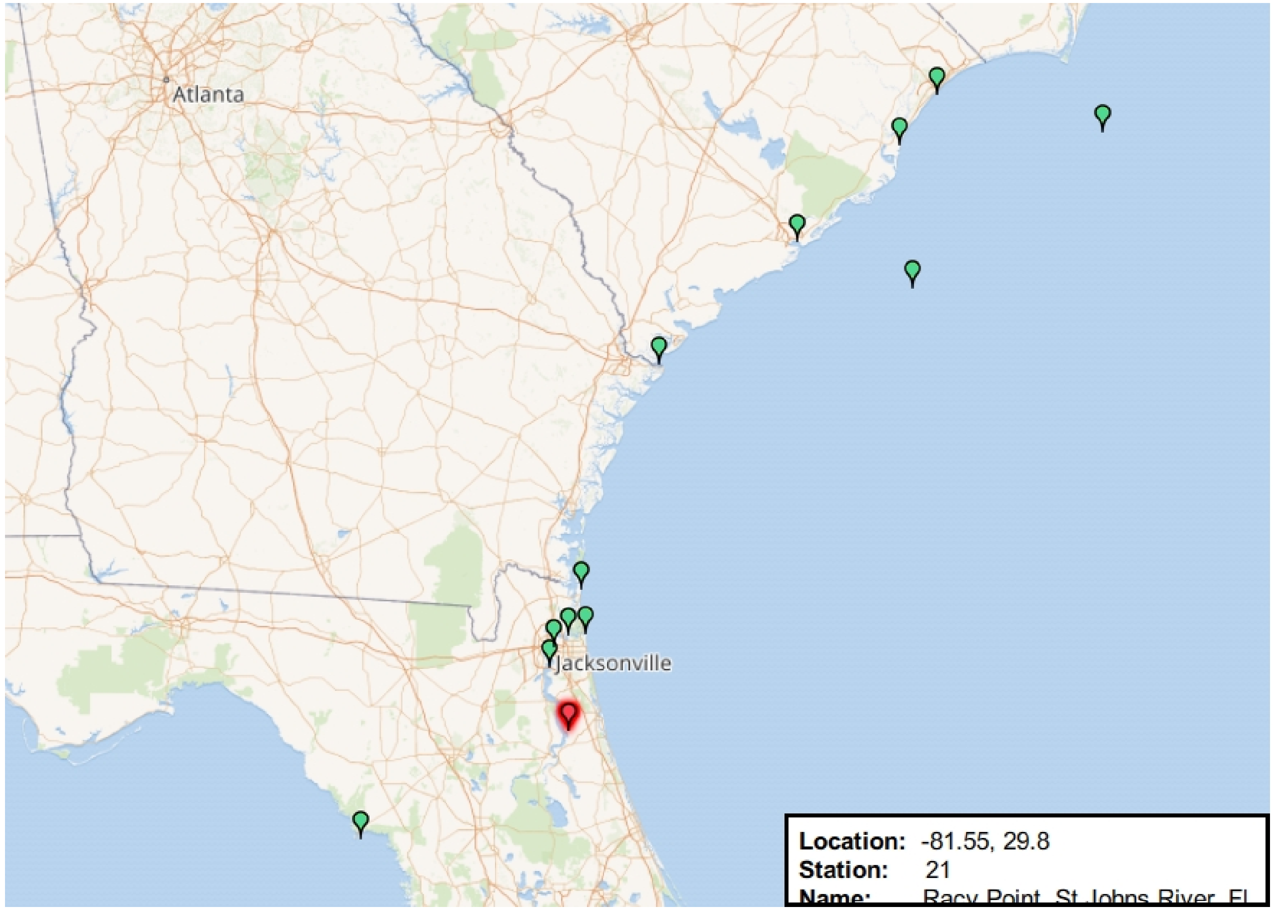


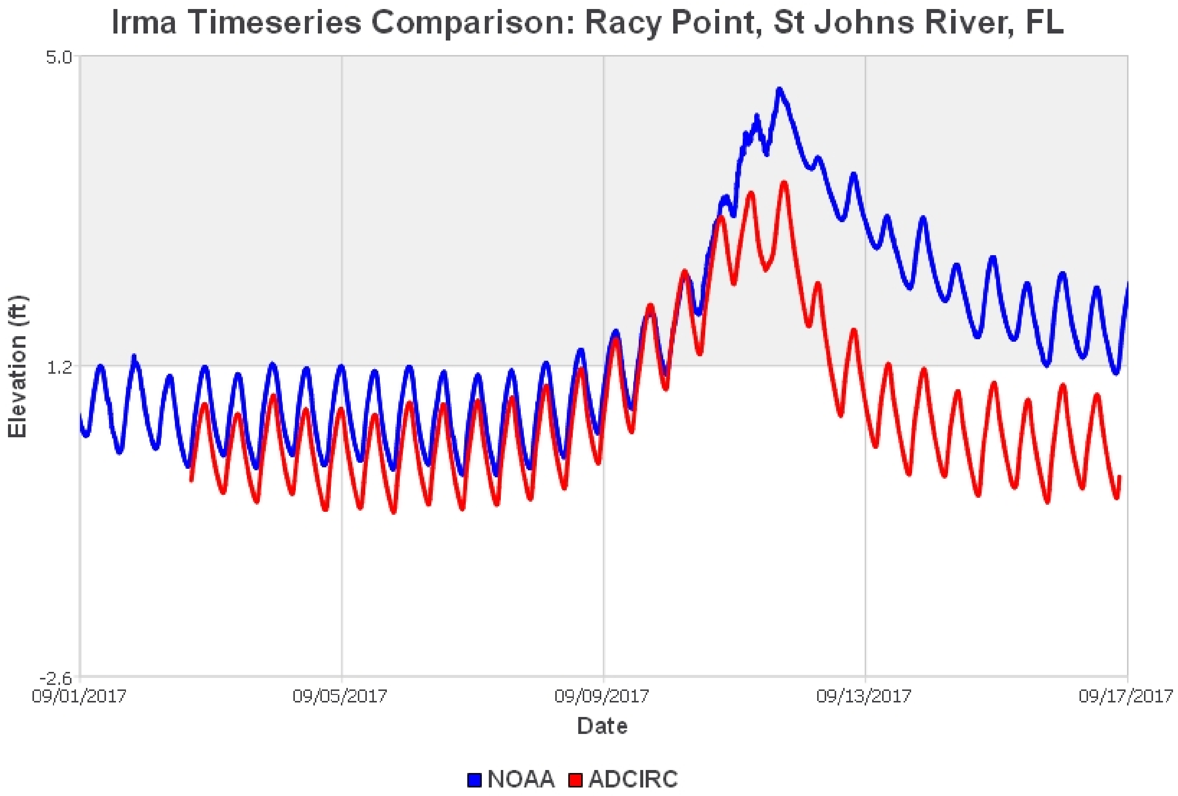
ADCIRC+SWAN hindcast of Hurricane Irma - validation



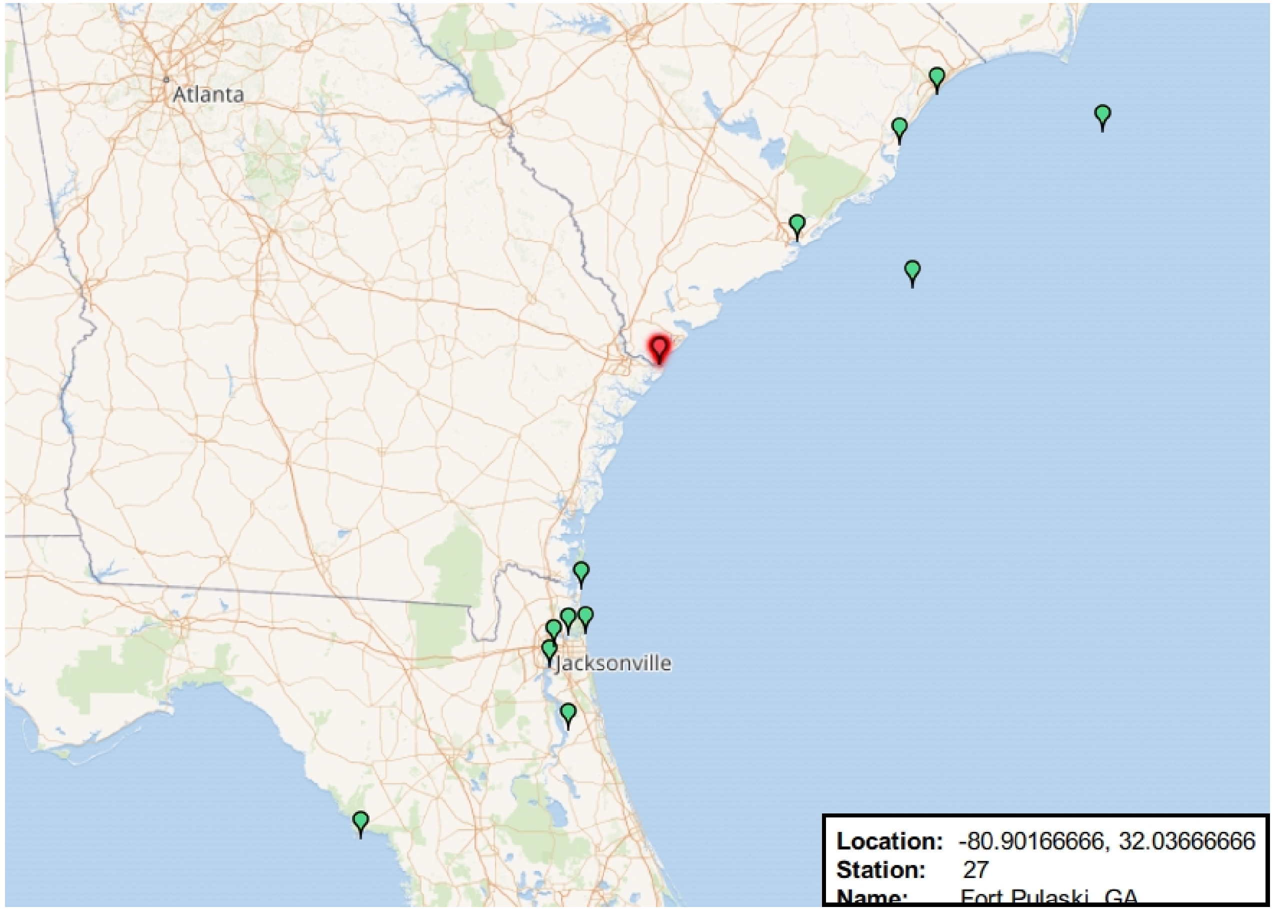


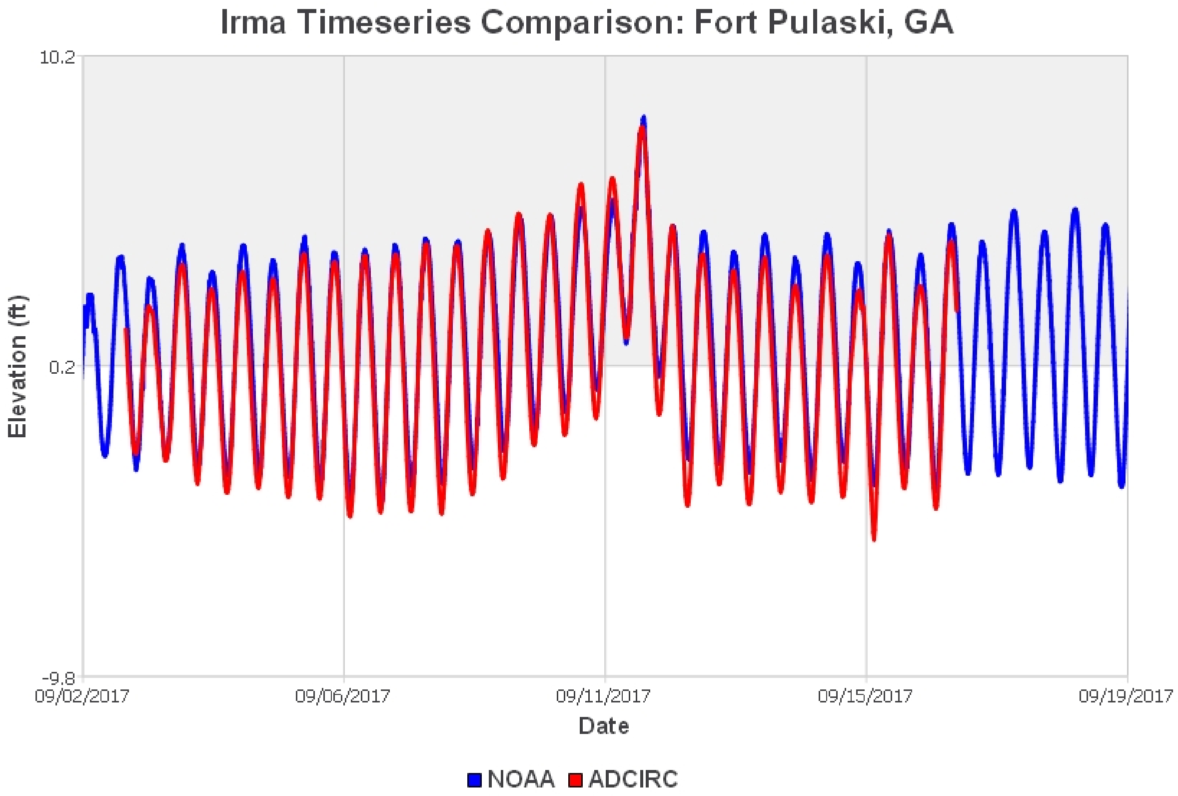
ADCIRC+SWAN hindcast of Hurricane Irma - validation



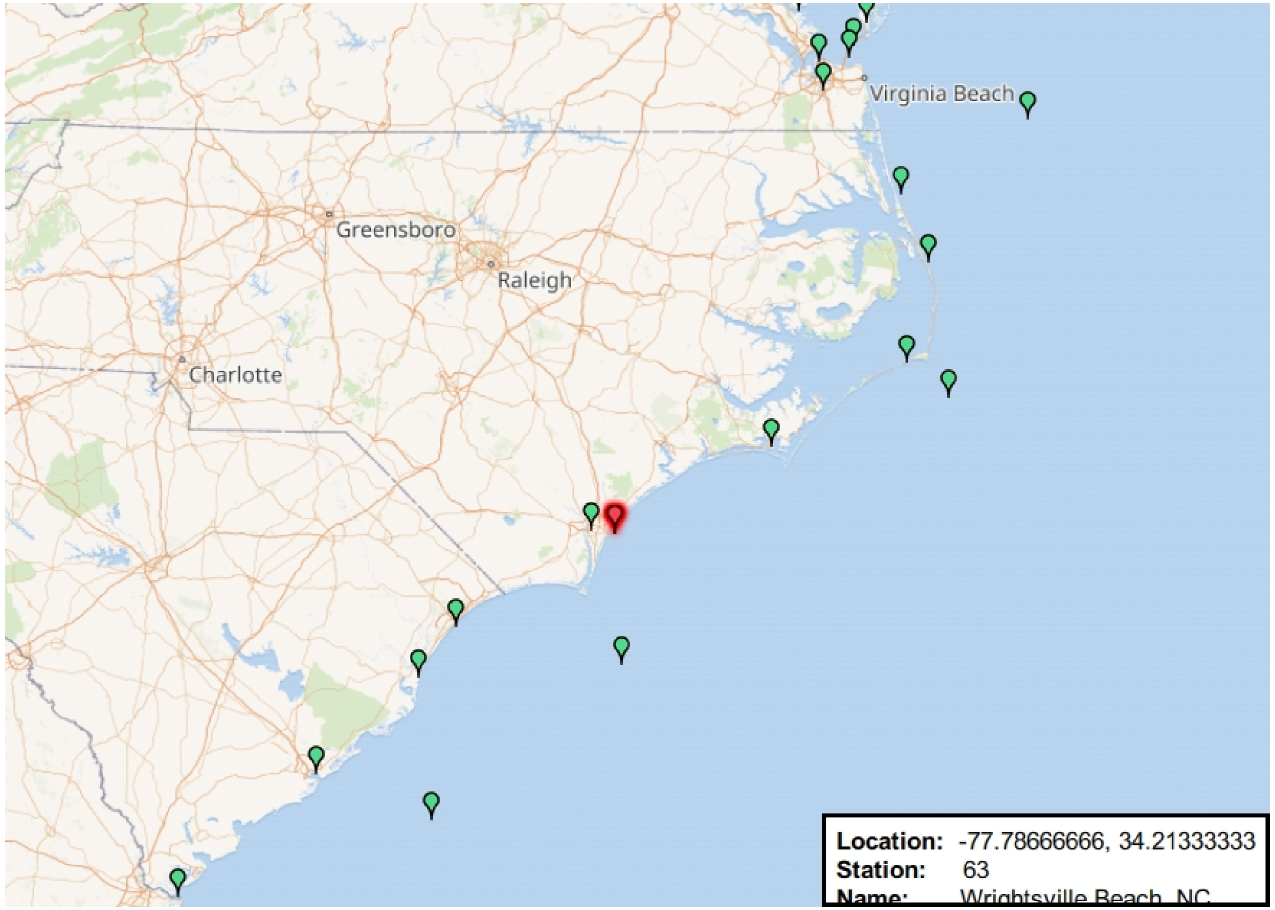


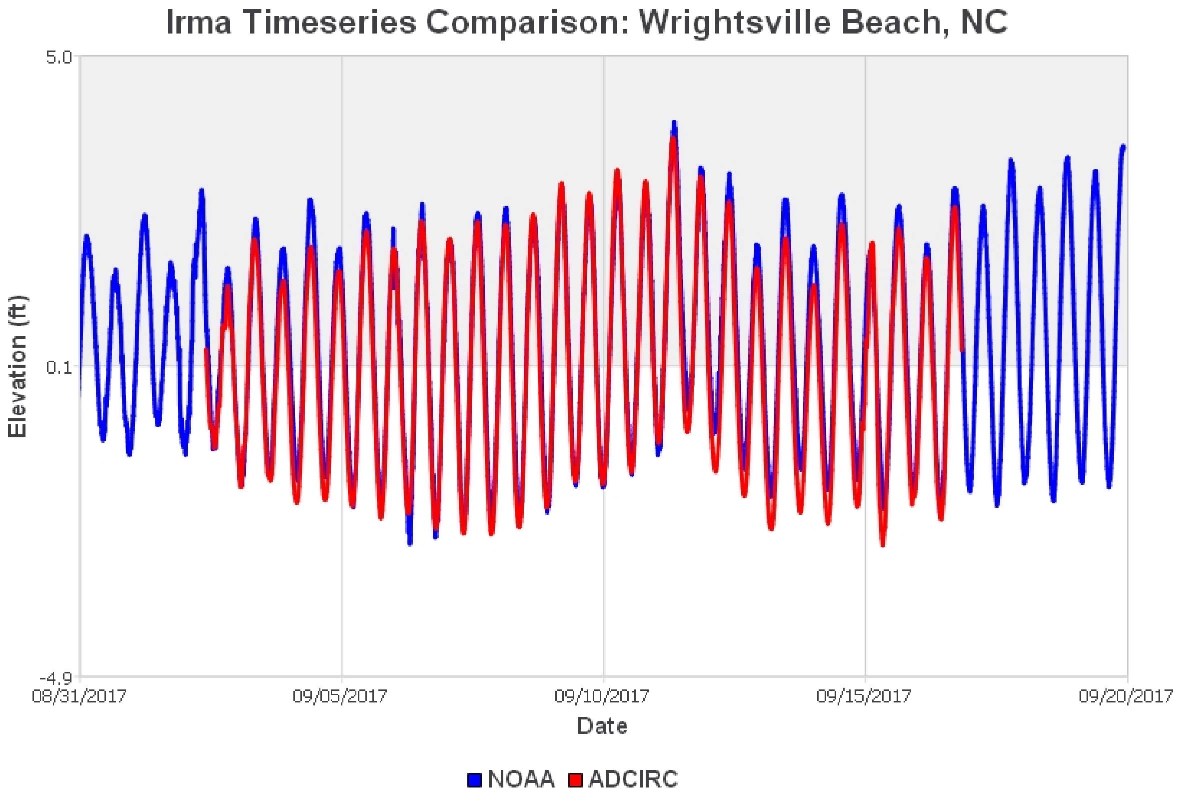
ADCIRC+SWAN hindcast of Hurricane Irma - validation



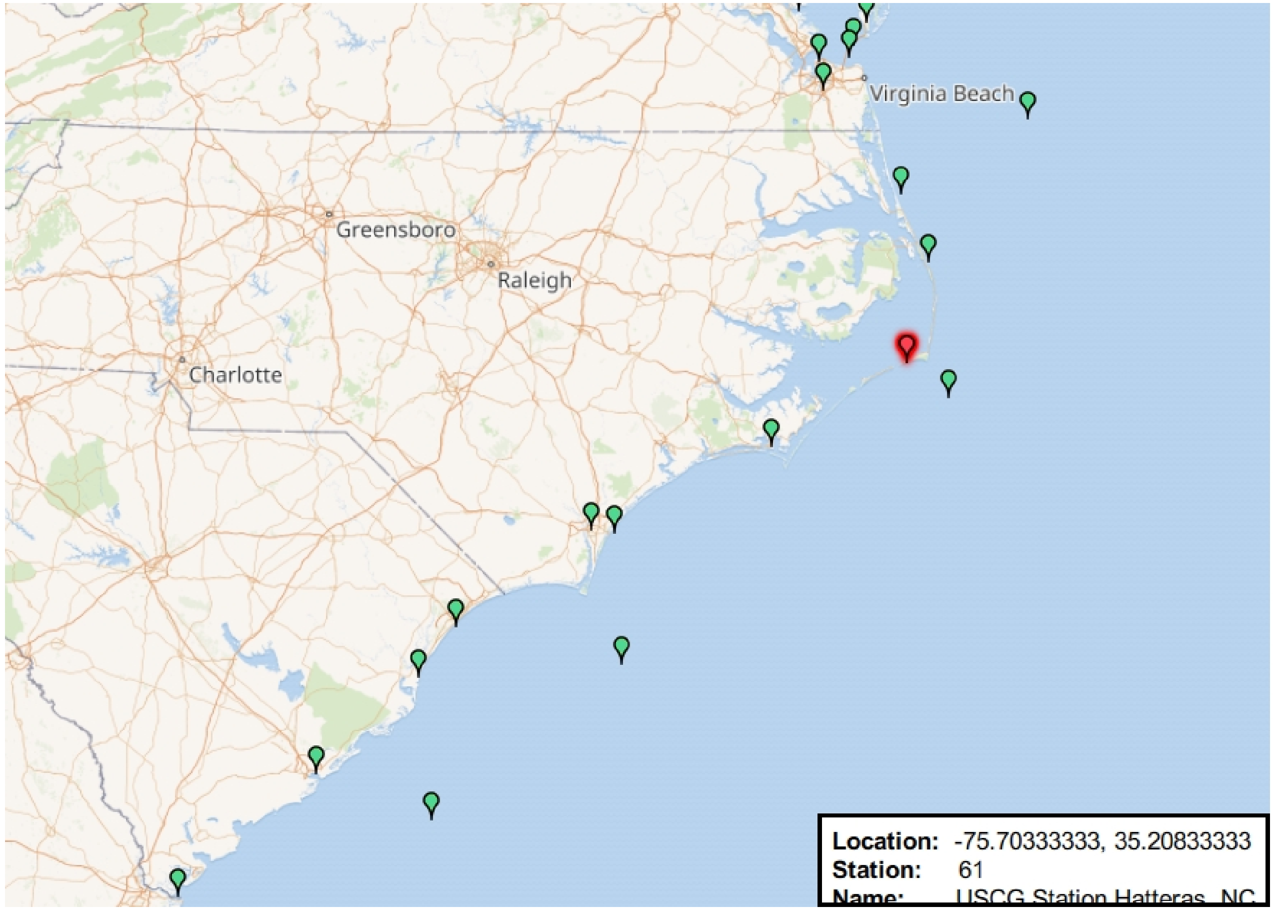


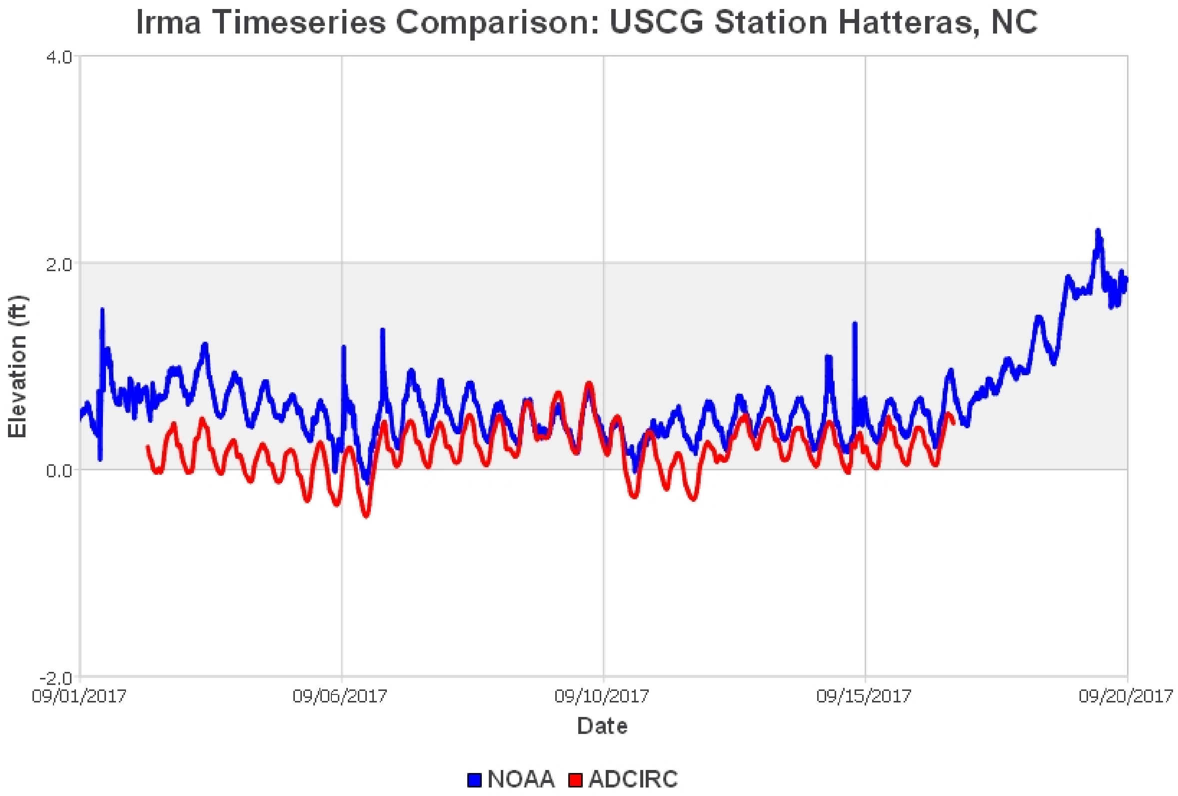
ADCIRC+SWAN hindcast of Hurricane Irma - validation



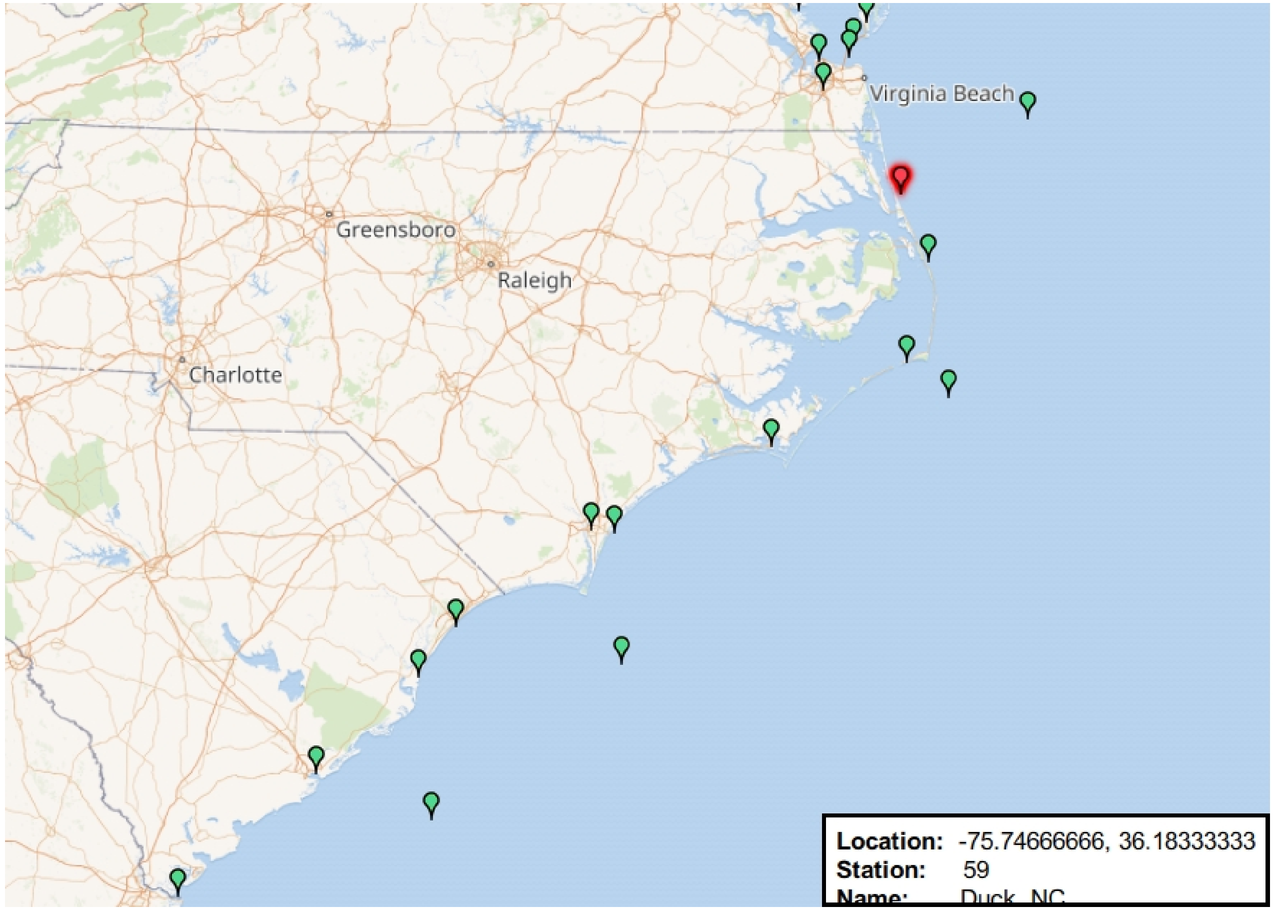


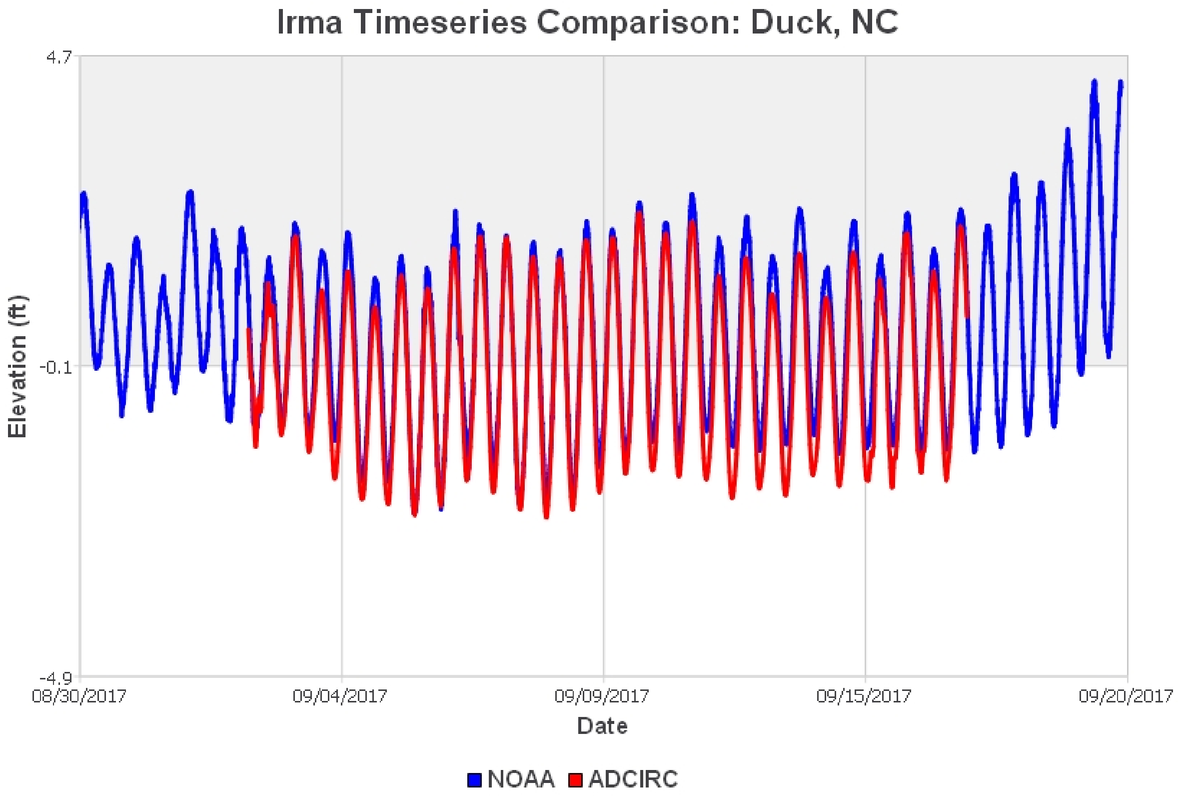
ADCIRC+SWAN hindcast of Hurricane Irma - validation



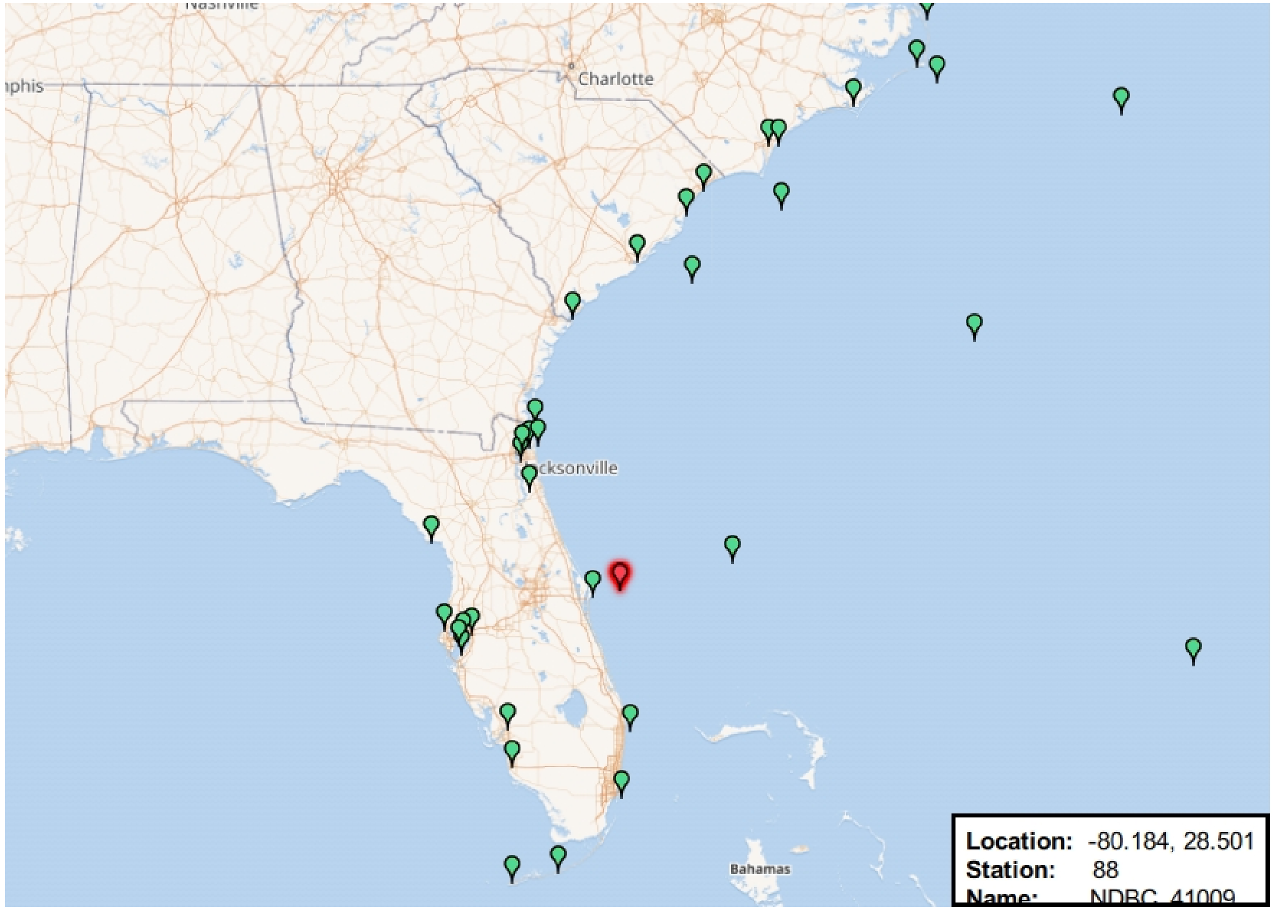


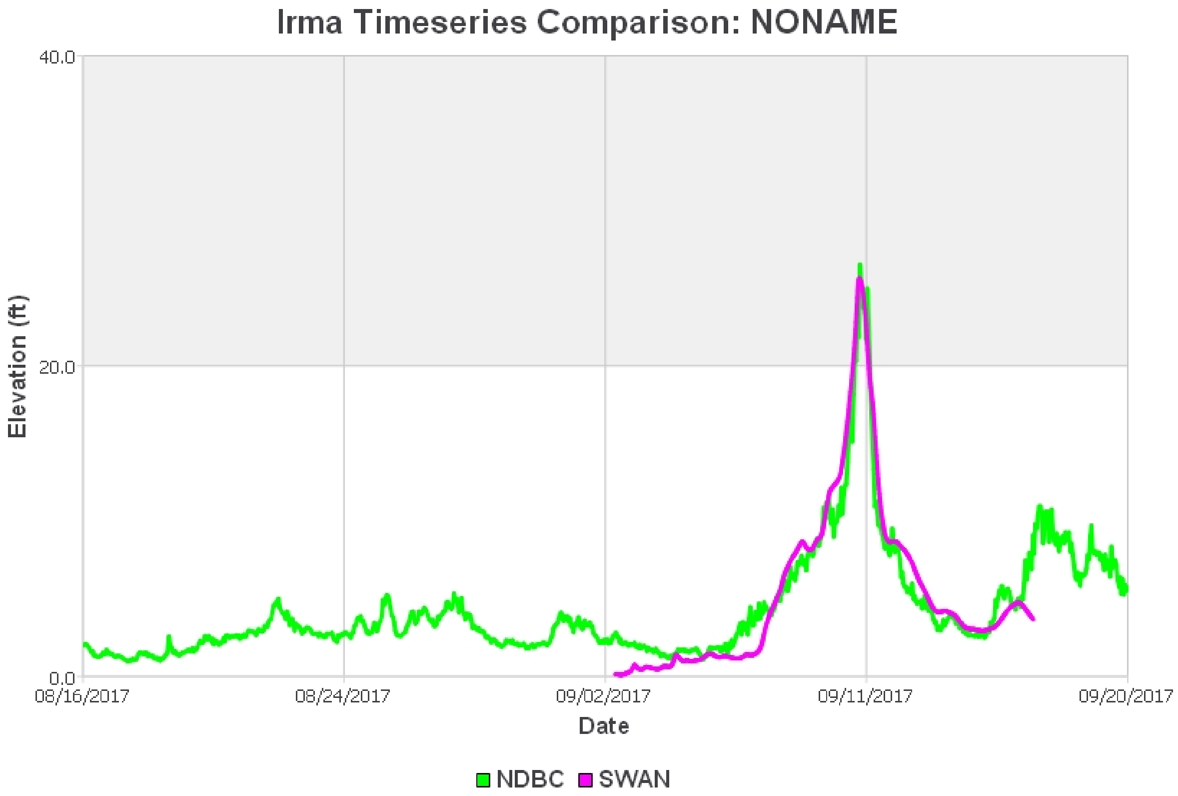
ADCIRC+SWAN hindcast of Hurricane Irma - validation



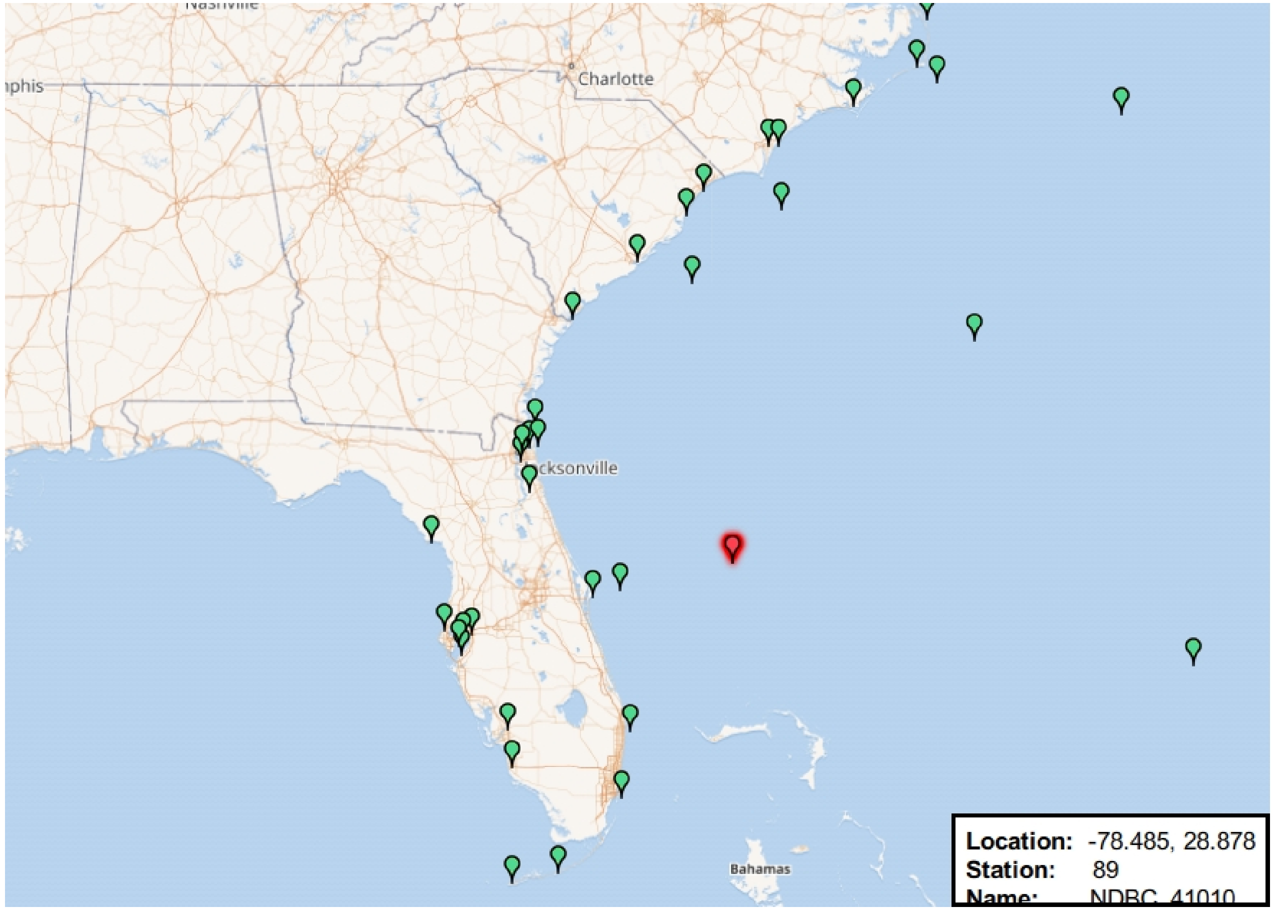


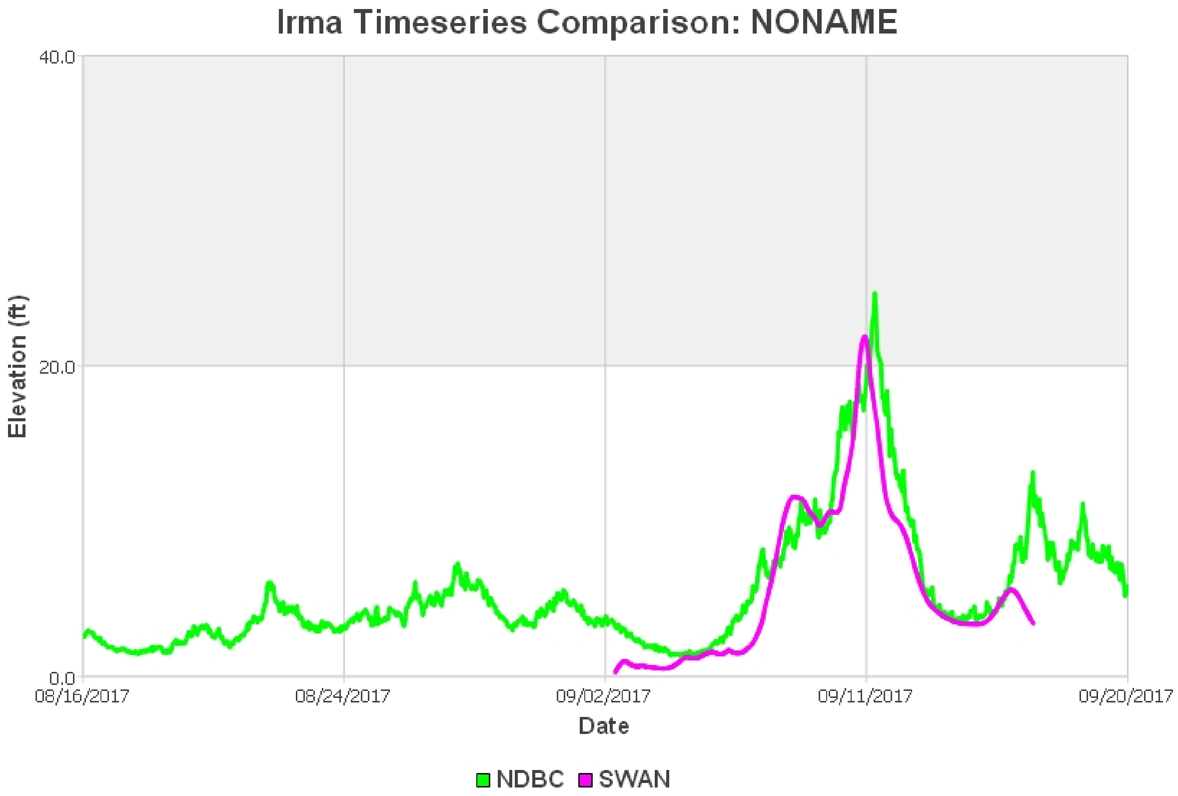
ADCIRC+SWAN hindcast of Hurricane Irma - validation



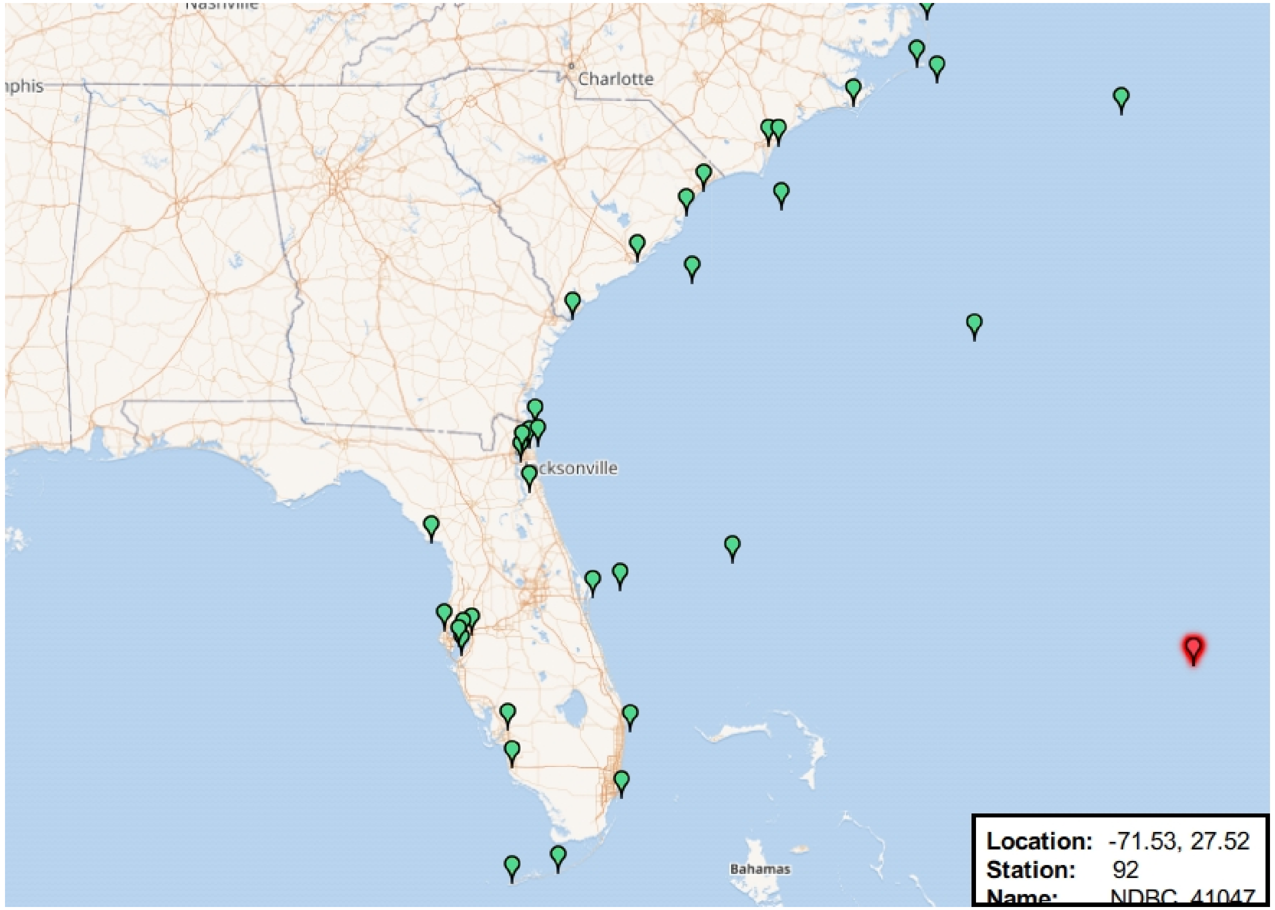


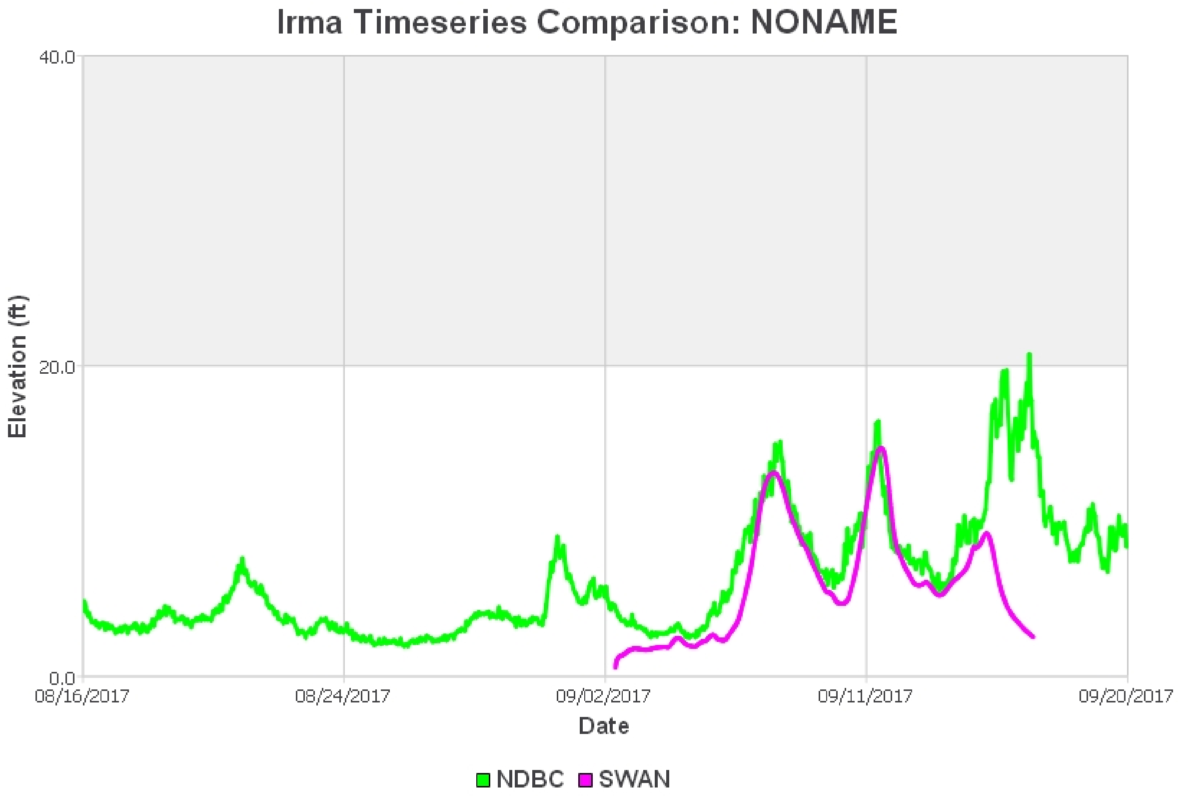
ADCIRC+SWAN hindcast of Hurricane Irma - validation



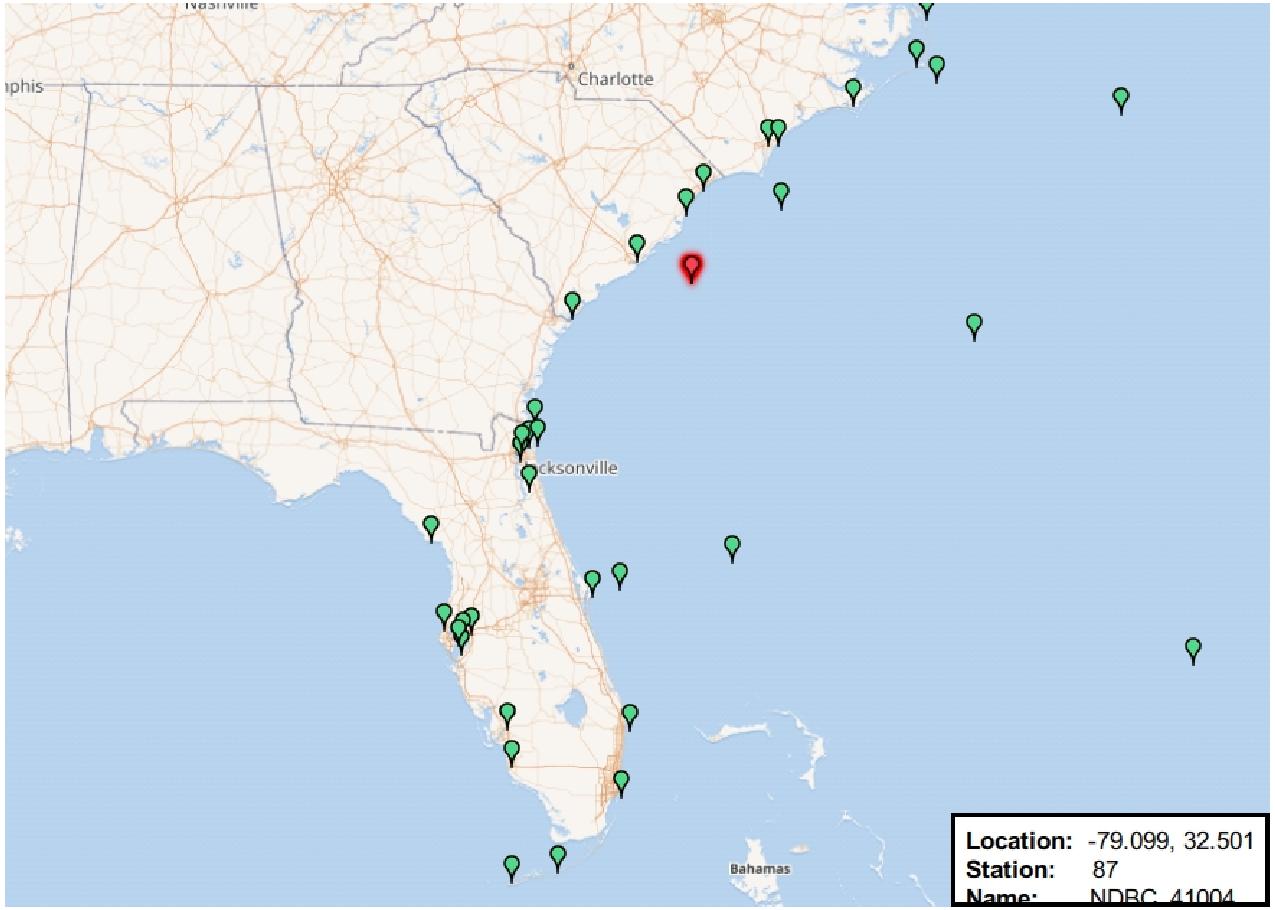


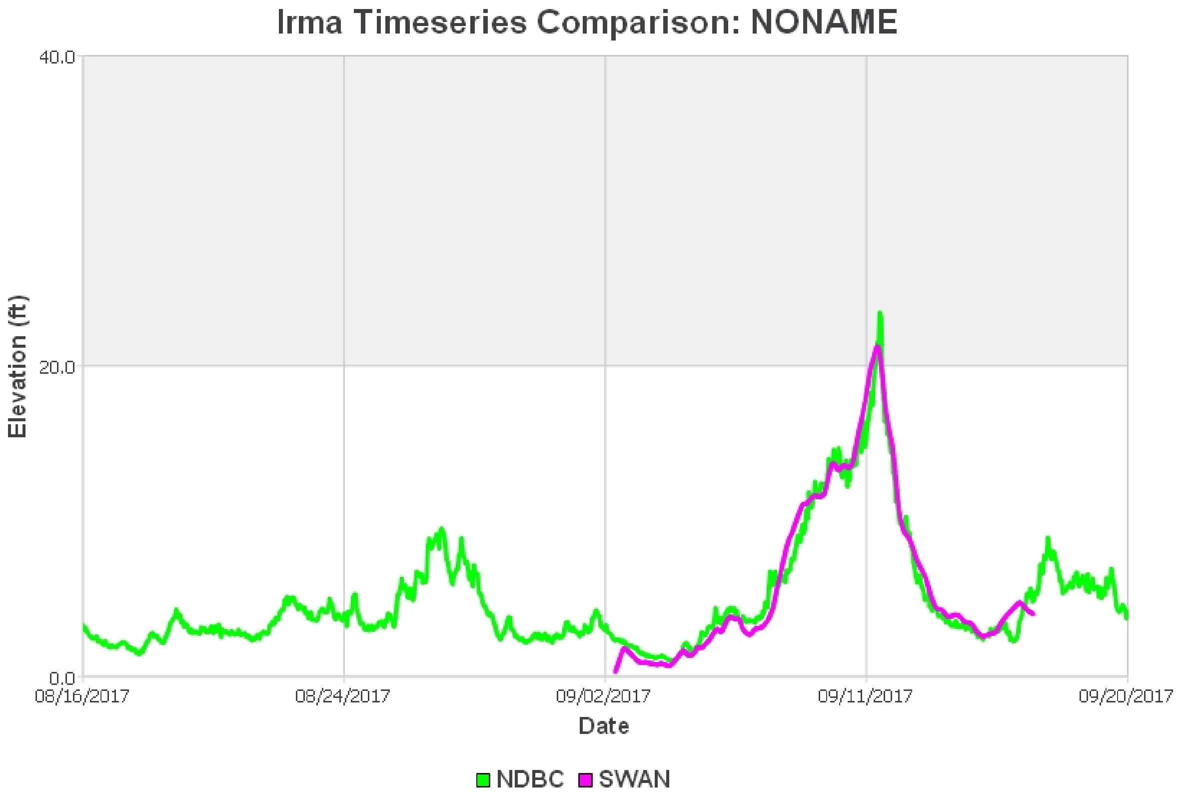
ADCIRC+SWAN hindcast of Hurricane Irma - validation



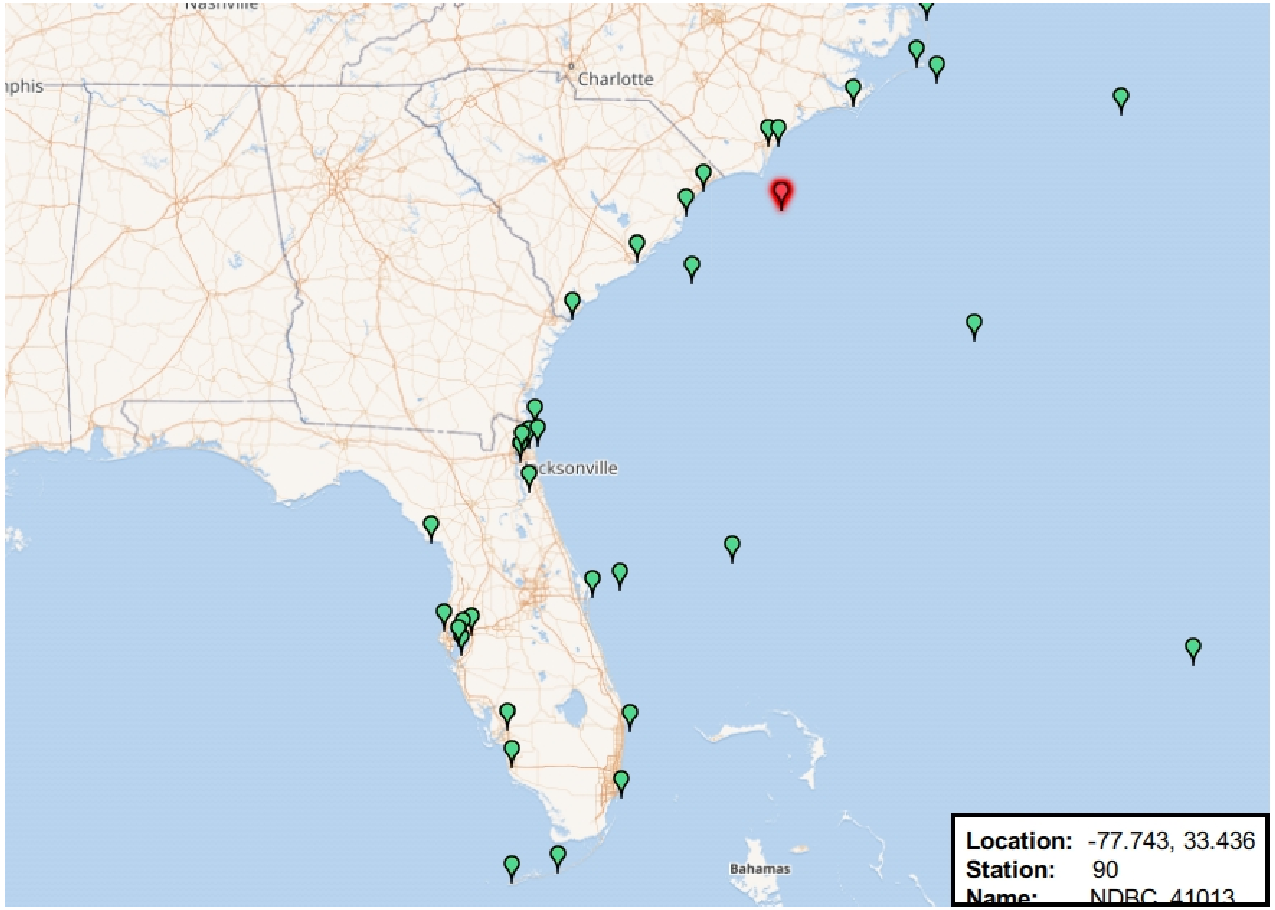


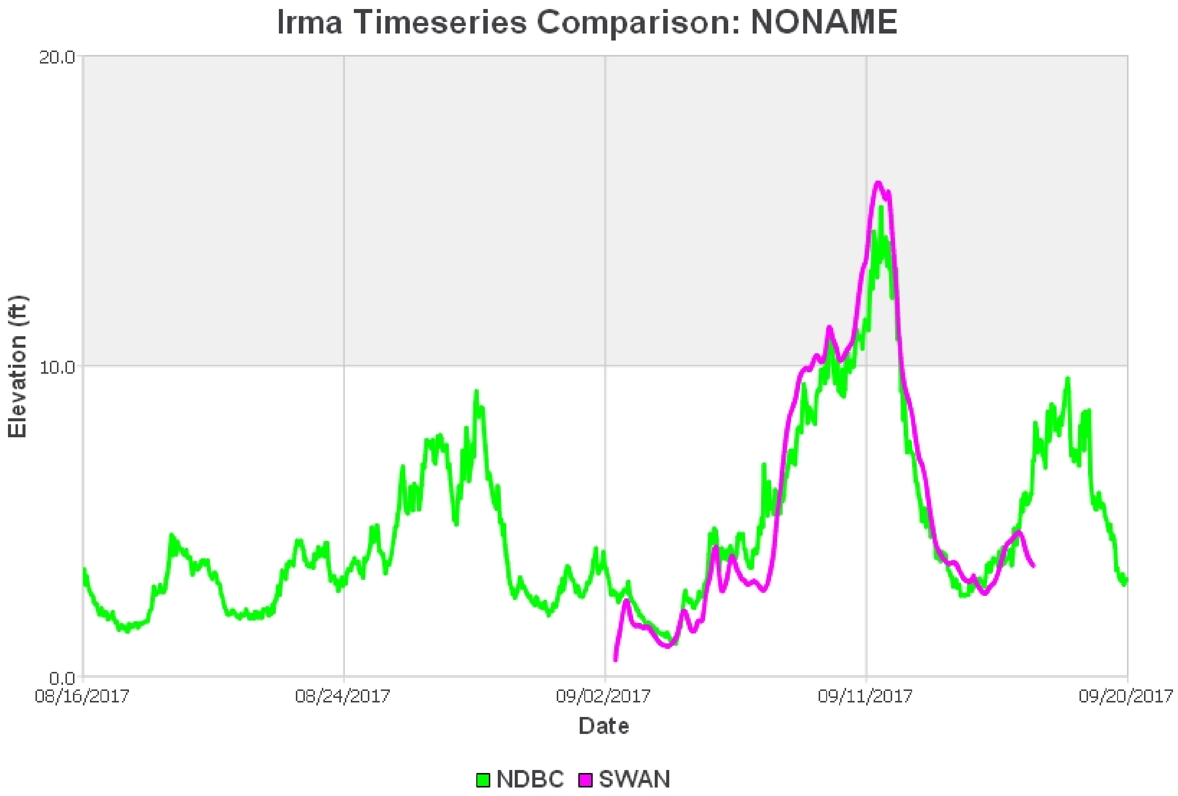
ADCIRC+SWAN hindcast of Hurricane Irma - validation



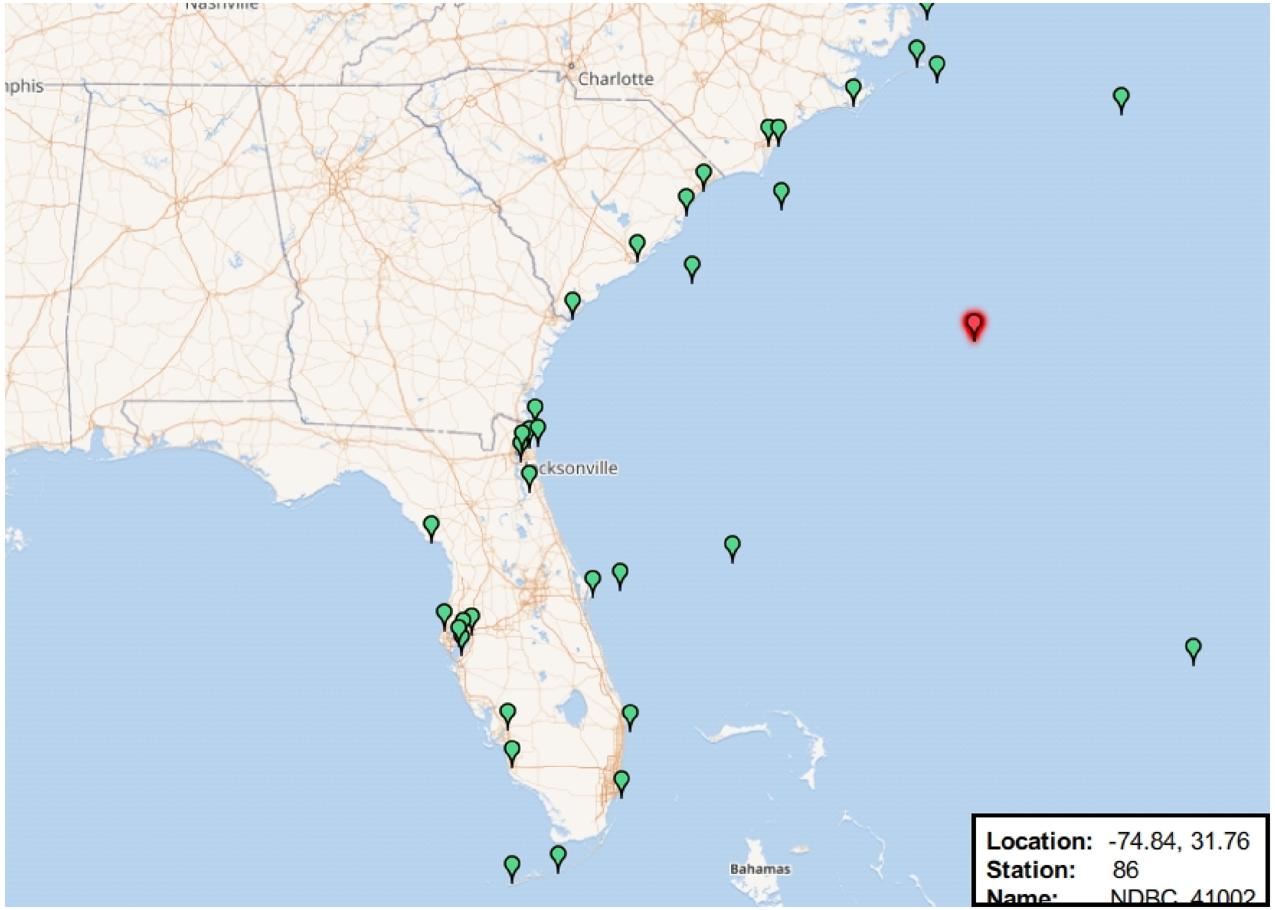


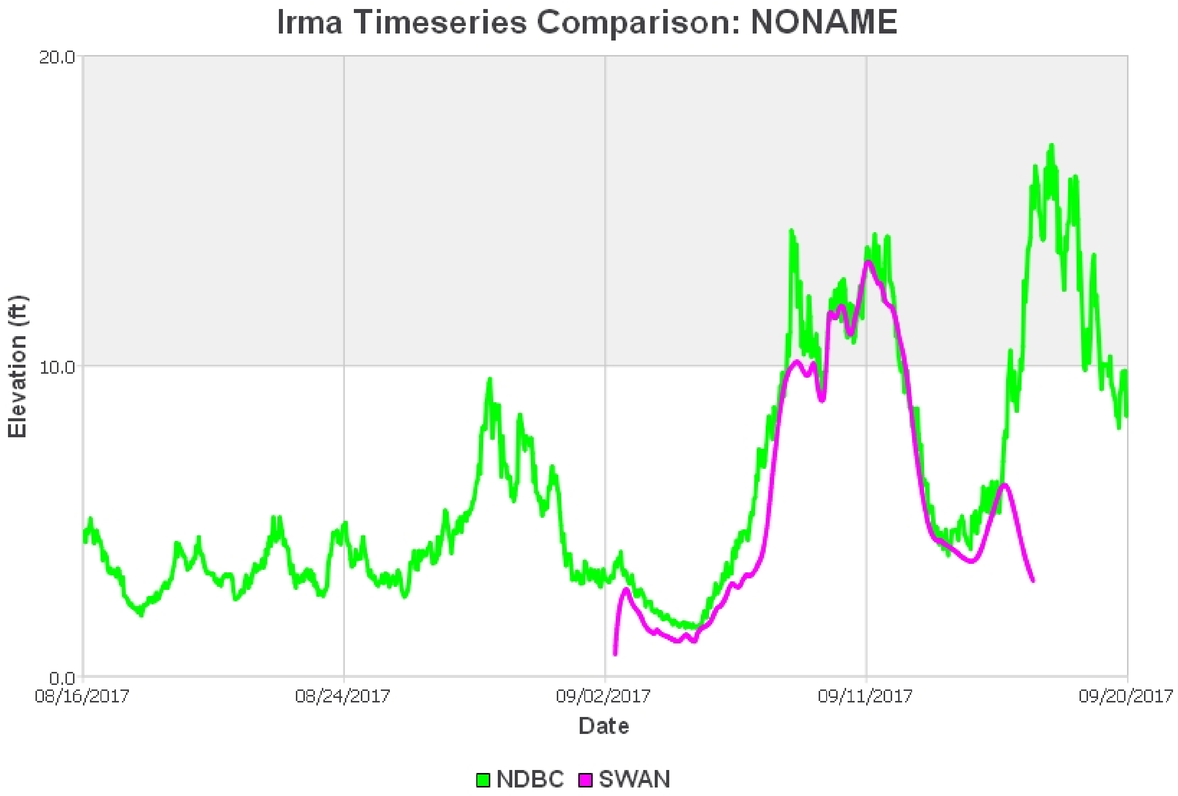
ADCIRC+SWAN hindcast of Hurricane Irma - validation



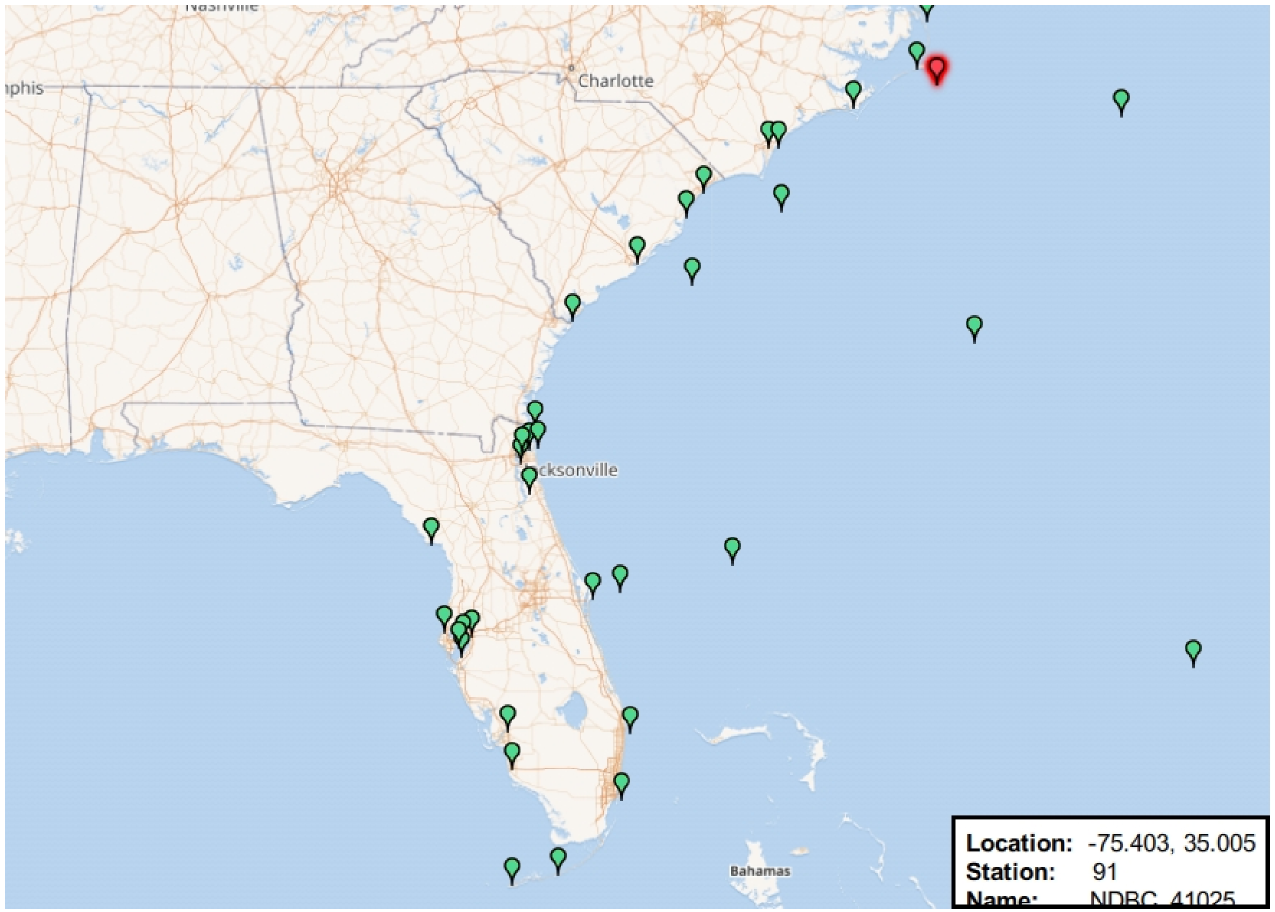


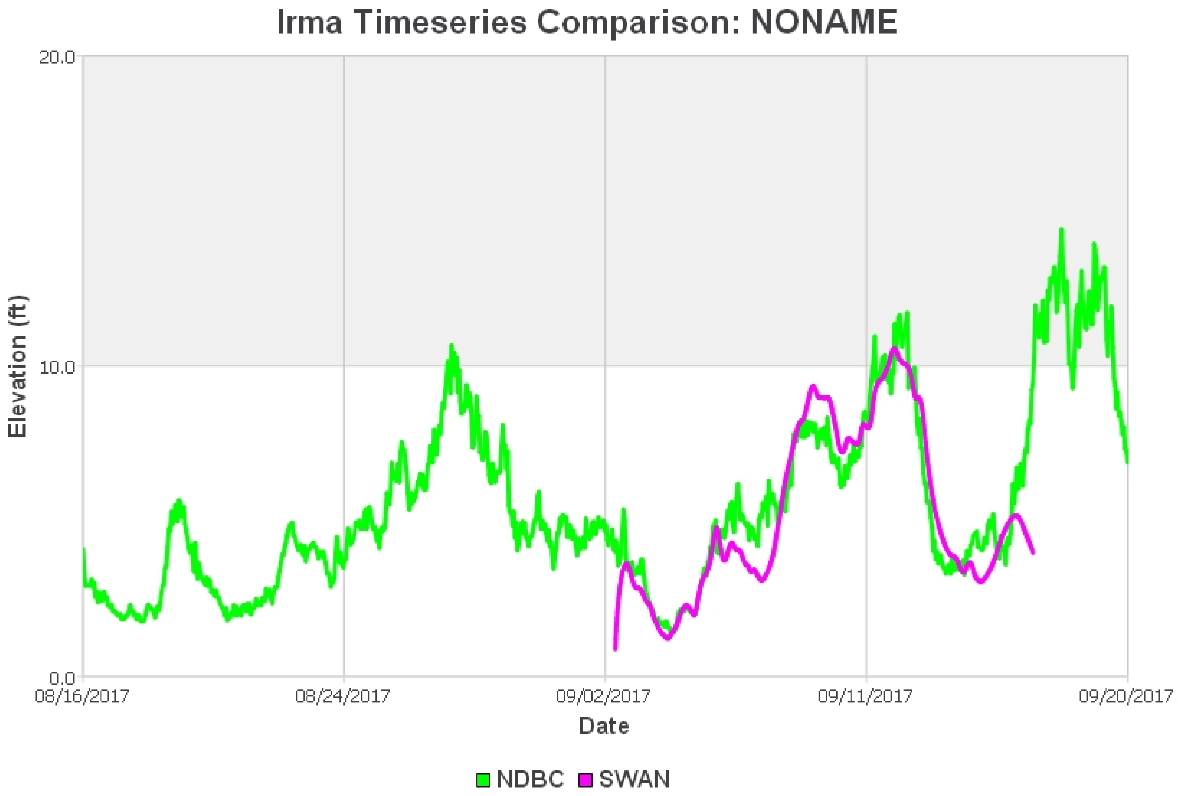
ADCIRC+SWAN hindcast of Hurricane Irma - validation





ADCIRC+SWAN hindcast of Hurricane Irma - validation





ADCIRC+SWAN hindcast of Hurricane Irma - validation

ADCIRC validation

- Excellent tide and surge results, including drawdown in western Florida

Missing Physics in the circulation model

- Baroclinicity impacts base water levels that change pre- to post-storm
- Rainfall affect far upstream locations

SWAN validation

- Excellent hindcasts of significant wave height

4. ADCIRC global tidal model development

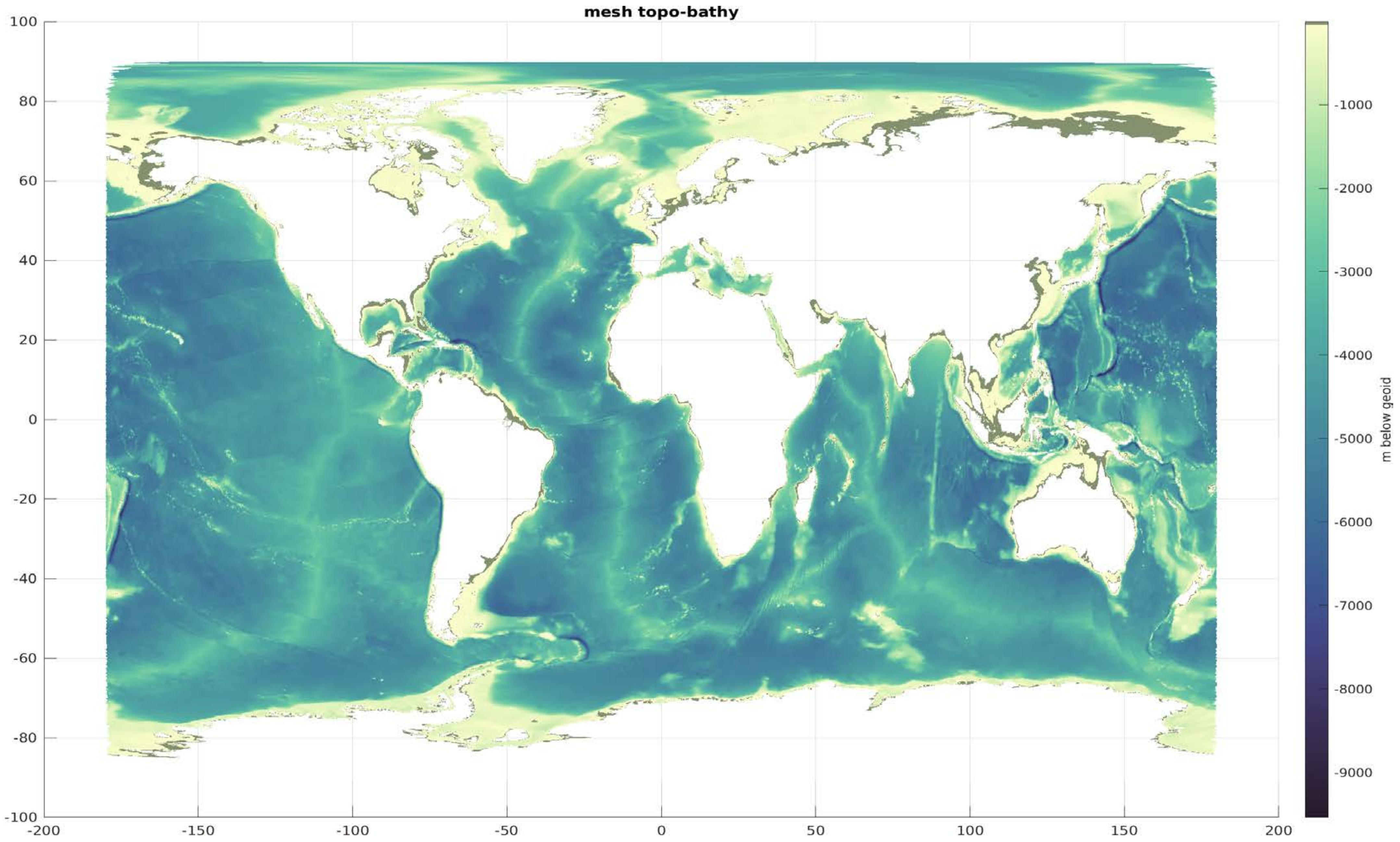
Advantages of a global model

- Global shell to seamlessly insert regional scale models
- Improves robustness and accuracy of tidal, atmospherically, and baroclinicaly forced processes
- Unify and reduce runtime and maintenance costs of running a host a regional models

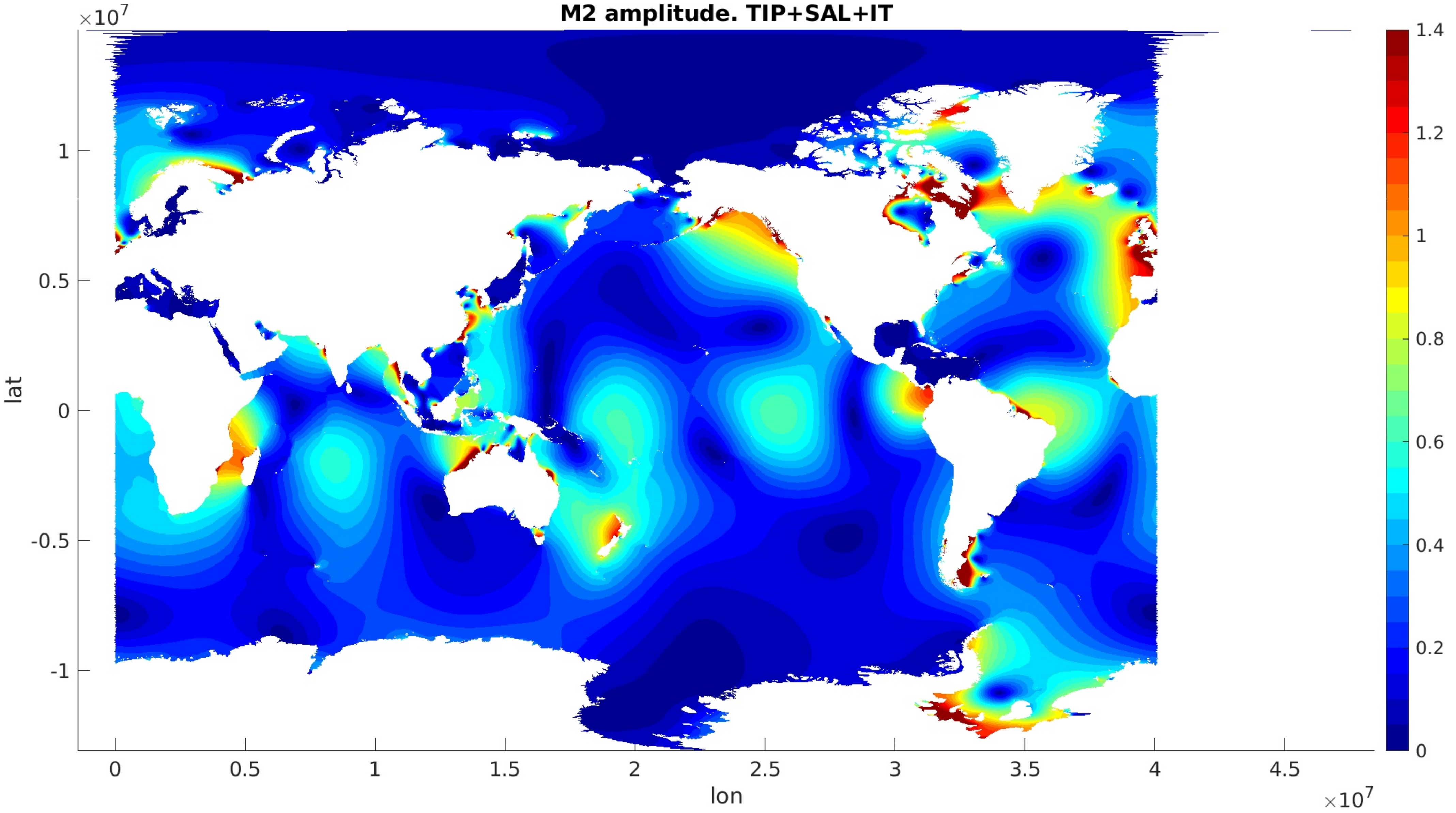
ADCIRC implementation details

- Reformulated ADCIRC's equations and its GWCE algorithm to enable solution on a sphere
- Implemented re-orientation of the spherical axis in order to avoid the singularity at the poles
- All global meshes improve resolution towards the coast, have a maximum resolution of 24 km in the deep ocean, and add resolution where there are steep topographic gradients, down to 2 km nearshore
- Apply Self attraction and load tides and internal tide dissipation model based on average ocean climatology

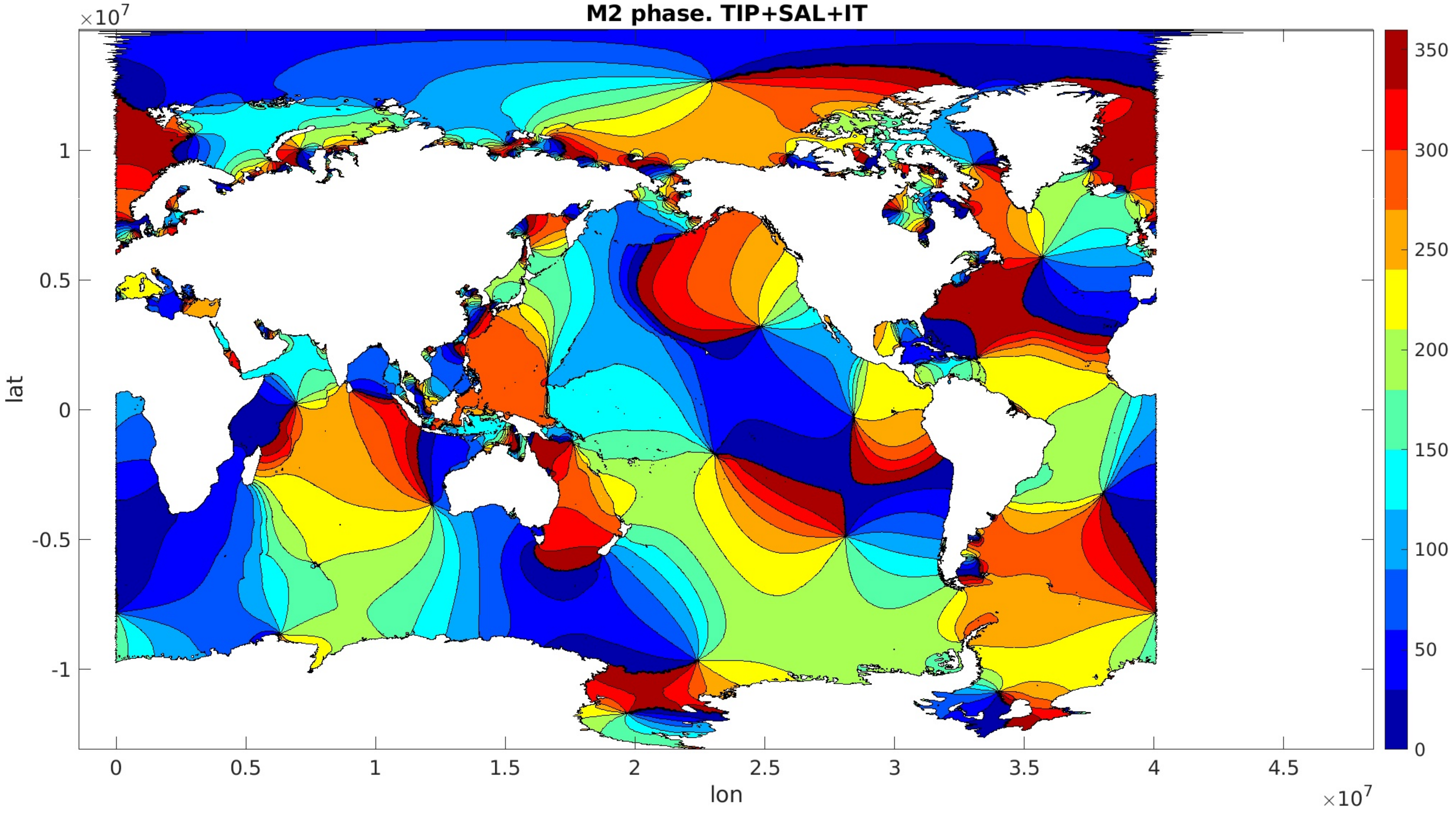
ADCIRC global model bathymetry



ADCIRC global M_2 tide amplitudes (m)



ADCIRC global M_2 tide phases (degrees)



ADCIRC global and other model RMS elevation differences (cm) versus tidal gauges and the TPXO8 Atlas

Model	Deep Ocean		Shelf	
	RMS_{TG}	RMS_{ALT}	RMS_{TG}	RMS_{ALT}
ADCIRC global	2.84	2.1	8.13	7.8
NSWC	4.27	4.41	-	17.4
HIM	8.75	5.25	33.7	22.3
OTIS-GN	7.54	6.76	25.3	18.6
STORMTIDE	8.33	7.76	48.2	27.9
OTIS ERB	5.63	4.65	23.6	24.0
STM-1B	12.69	7.74	30.5	25.8
HYCOM	7.82	7.00	49.0	26.2

ADCIRC global modeling observations

Projections

- All 7 ADCIRC projections lead to identical results

Bathymetry

- Gebco2019 leads to much better results than SRTM or earlier Gebco data sets
- High resolution regional bathy sets in "*tidal dissipation hot spots*" leads to improvements in global results
    - Hudson Bay, Australian Shelf, St. Lawrence/Bay of Fundy, Bering Sea

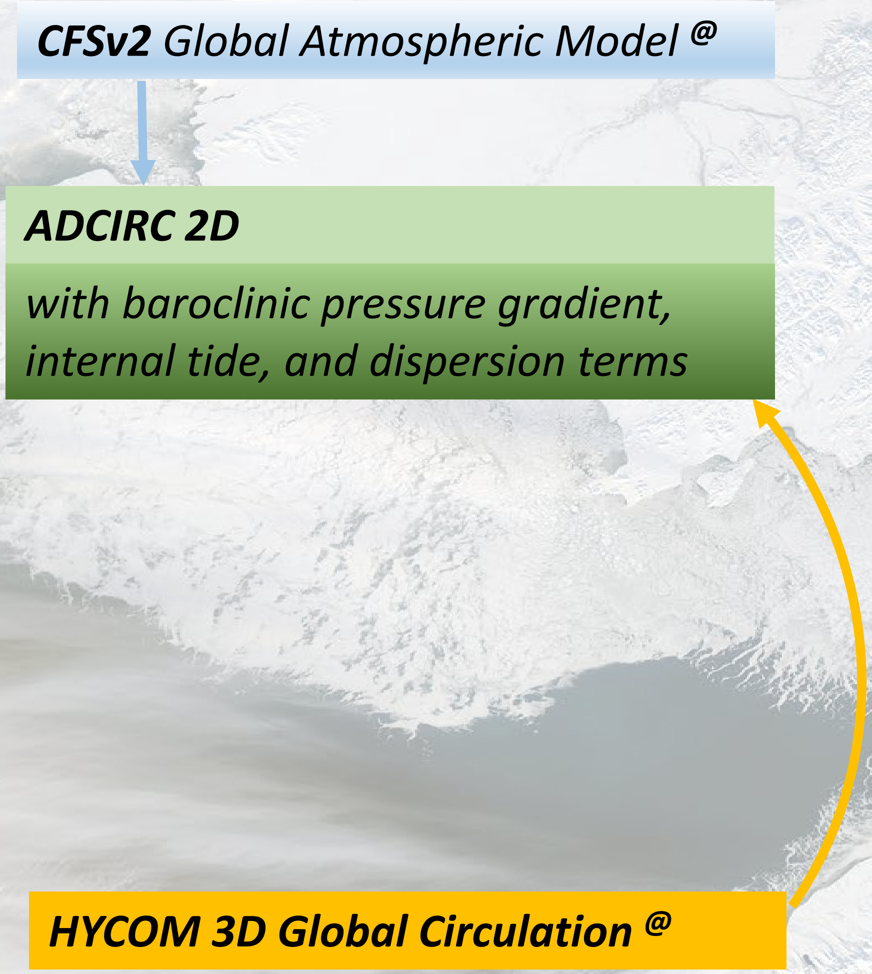
Friction vital in other "dissipation hot spots"

- Yellow Sea

Inner shelf and coastal stations

- Are quite sensitive to inner shelf bathy

5. Baroclinicity as a driver of steric water level fluctuations and ocean currents



- Heterogeneous mode splitting

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u} + f\mathbf{k}\times\boldsymbol{u} = -\nabla\left[\frac{p_s}{\rho_0} + g(\zeta - \zeta_{EQ} - \zeta_{SAL})\right] + \frac{\nabla M}{H} - \frac{\nabla D}{H} - \frac{\nabla B}{H} + \frac{\boldsymbol{\tau}_s}{\rho_0 H} - \frac{\boldsymbol{\tau}_b}{\rho_0 H} - \mathcal{F}_{IT}$$

- Baroclinic pressure gradient (BPG):

$$\nabla B = \int_{-h}^{\zeta}\left(g\nabla\left[\int_{z}^{\zeta}\frac{\rho-\rho_0}{\rho_0}\right]dz\right)dz$$

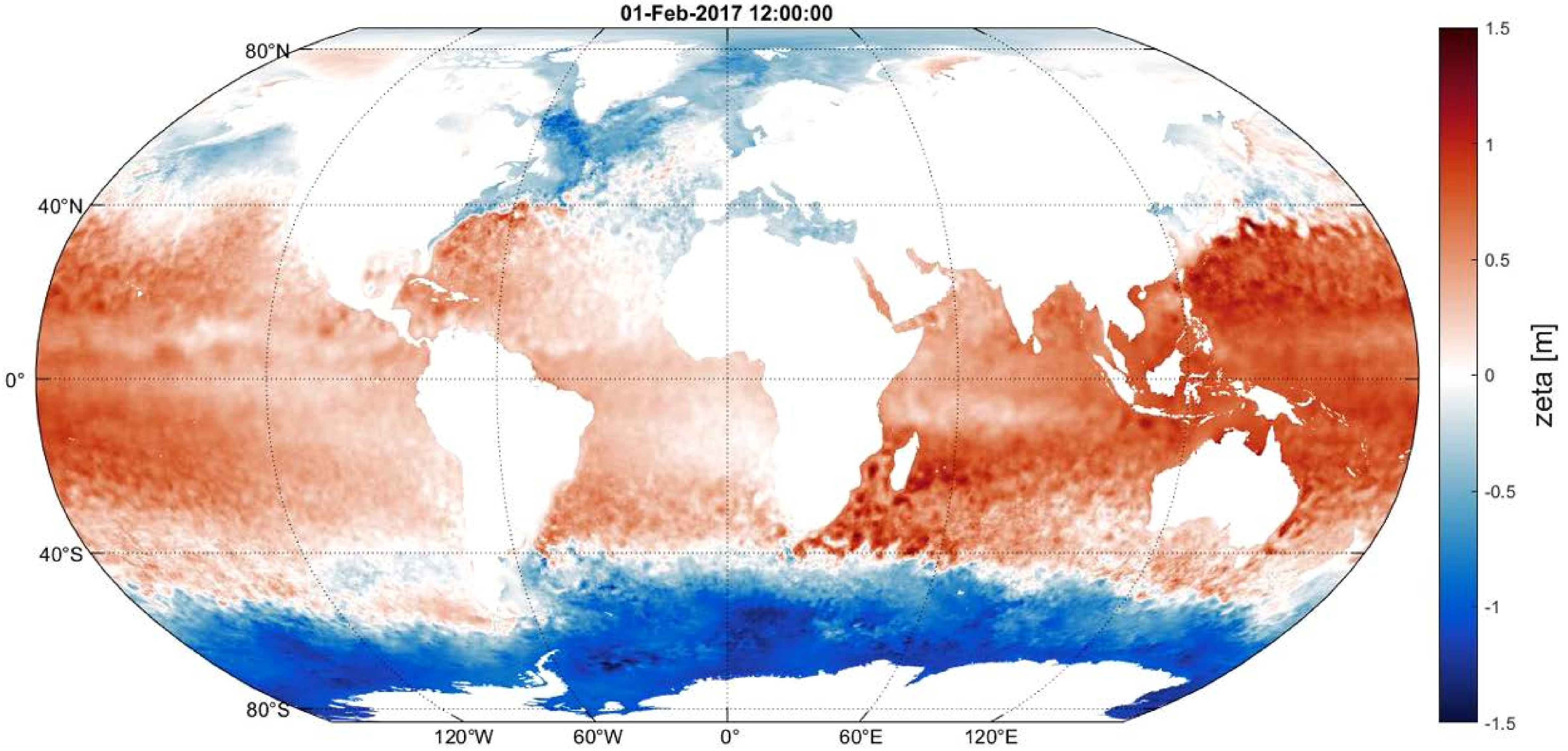
- Momentum Dispersion:

$$\nabla D = \nabla\int_{-h}^{0}\left[(\boldsymbol{v}-\boldsymbol{V})\cdot(\boldsymbol{v}-\boldsymbol{V})\right]dz$$

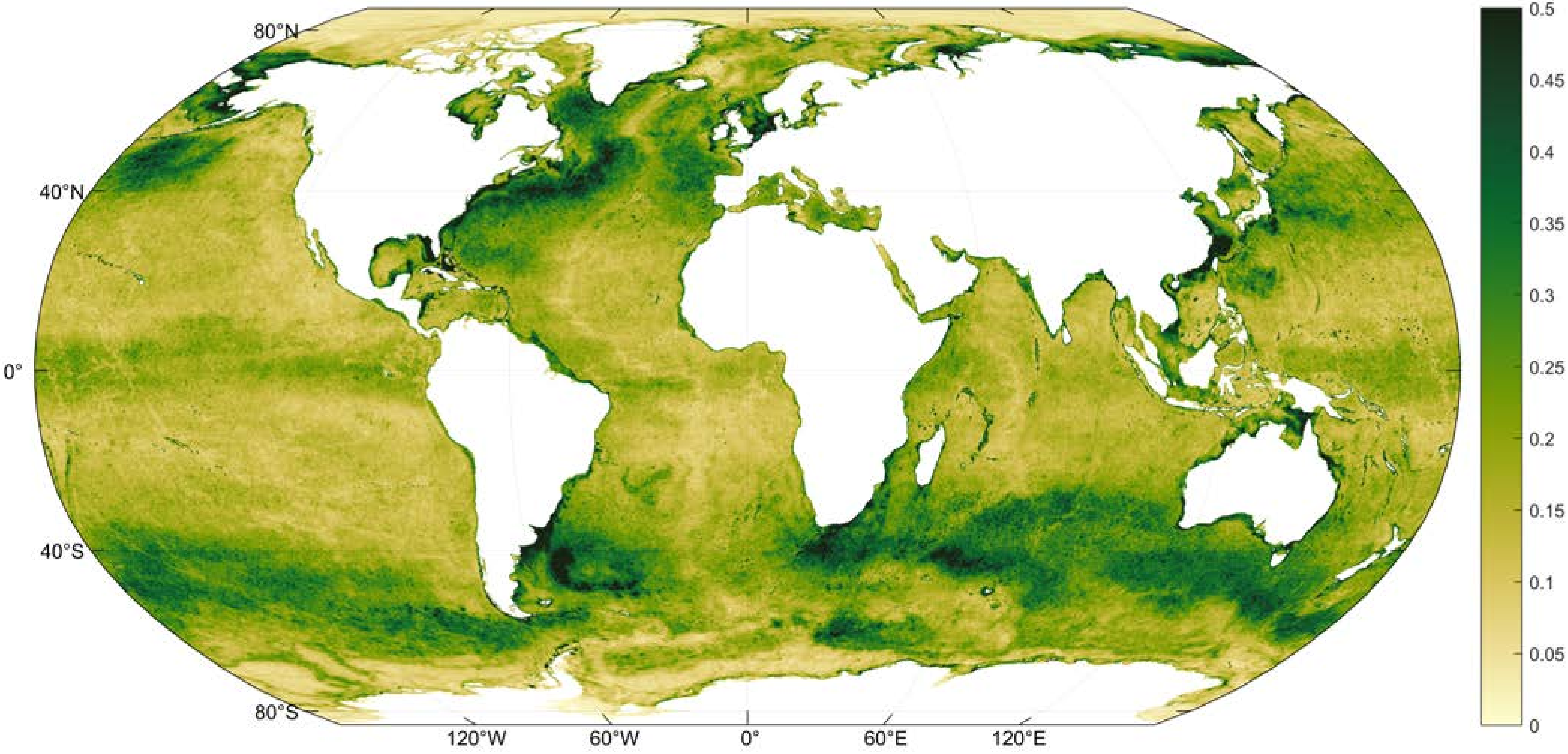
- Internal tide induced barotropic energy conversion:

$$\mathcal{F}_{IT} = C_{IT}\frac{\left[(N_b^2-\omega^2)(\tilde{N}^2-\omega^2)\right]^{1/2}}{\omega}(\nabla h\cdot\boldsymbol{u})\nabla h$$

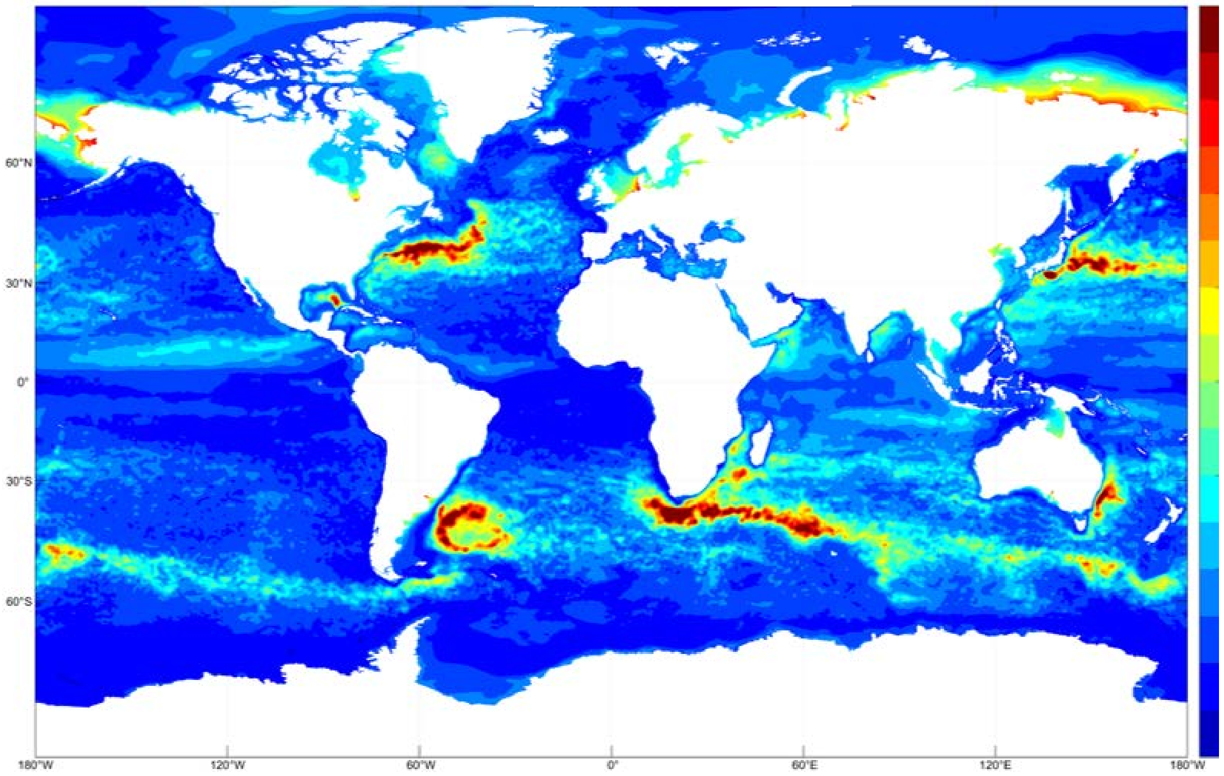
GOFS3.1 forcing of the ADCIRC global model: sea surface elevation



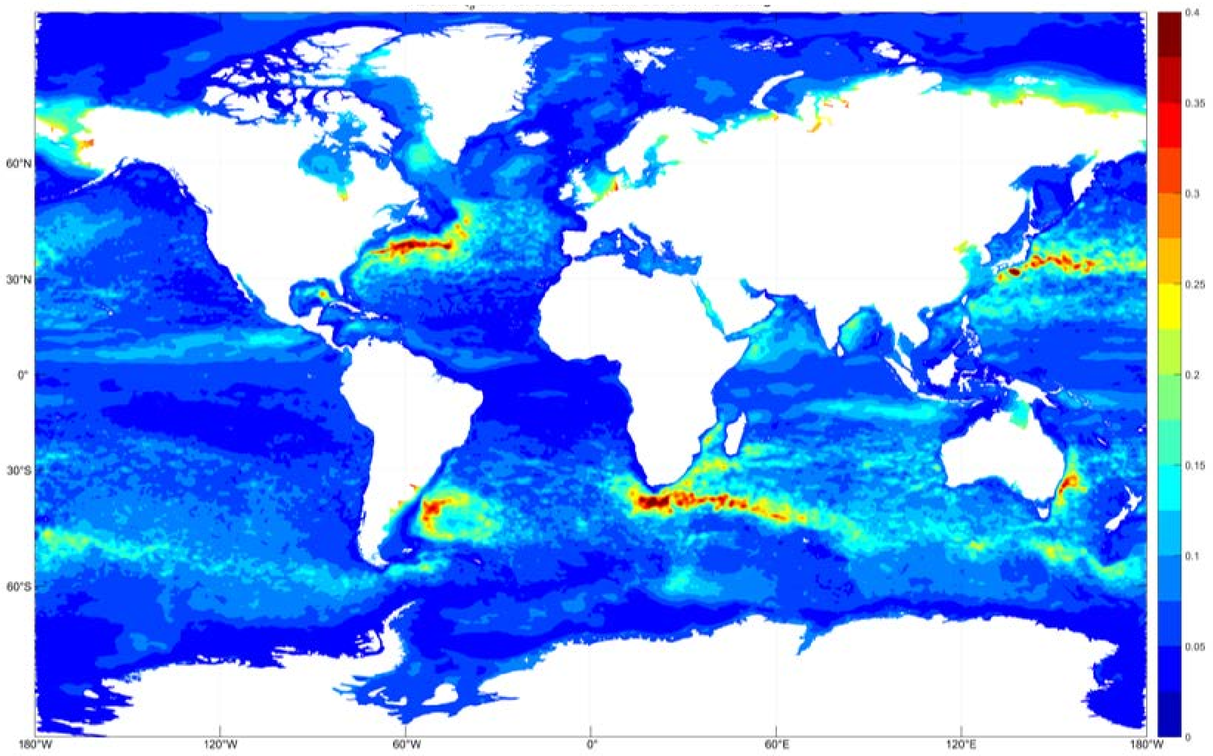
GOFS3.1 forcing of the ADCIRC global model: currents



Comparison of sea surface height RMS variability between GOFS3.1 and ADCIRC forced with GOFS3.1 temperature and density fields

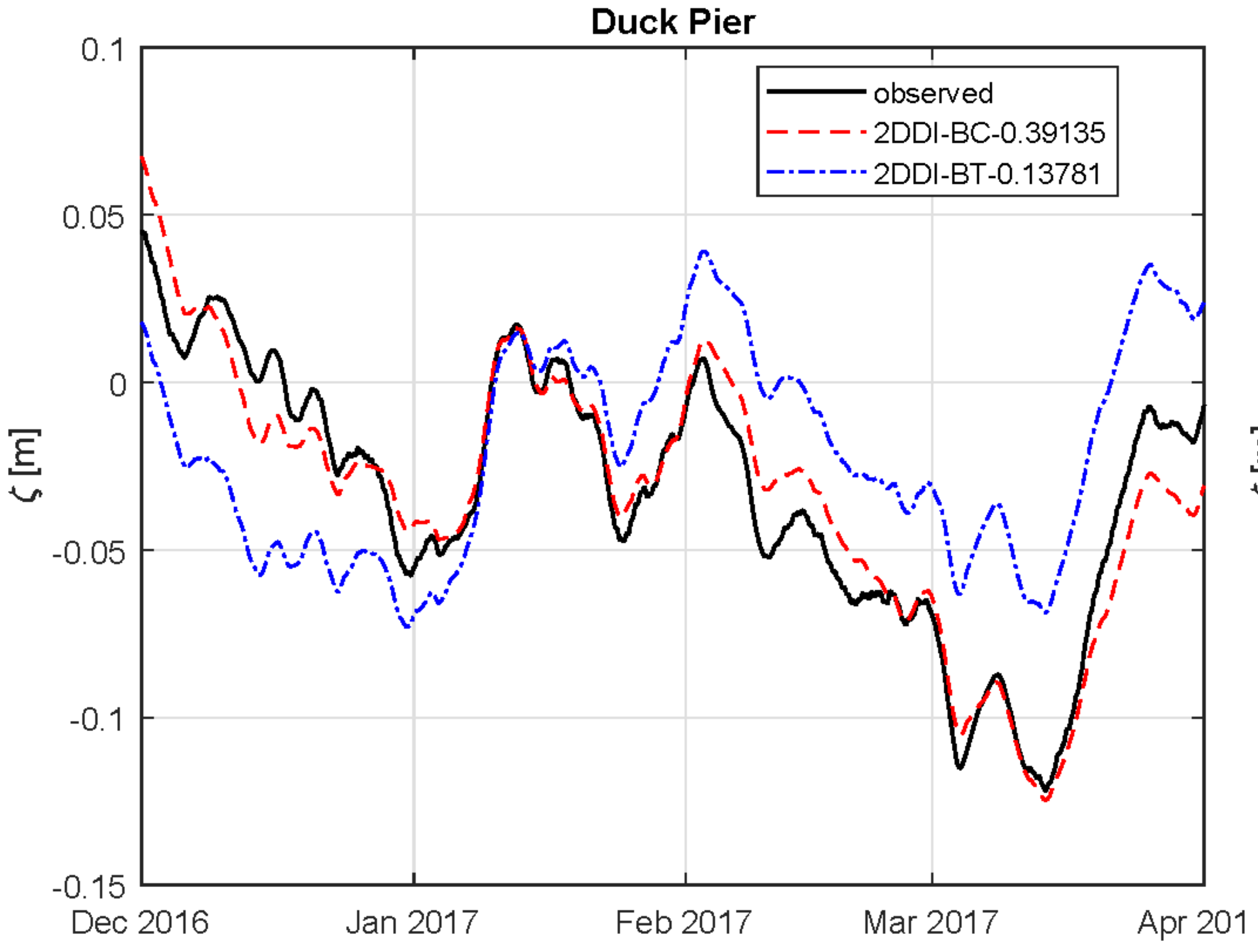


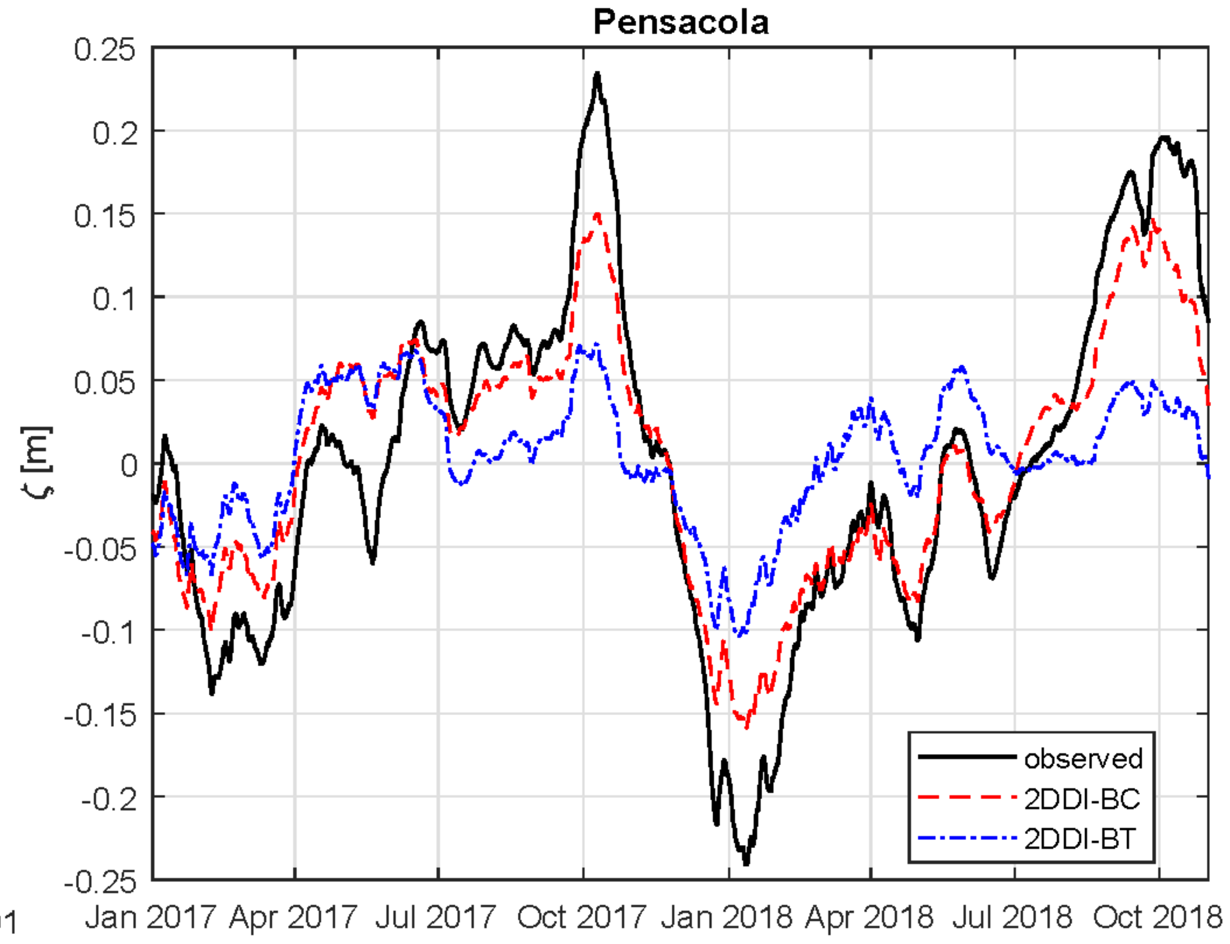
GOFS 3.1



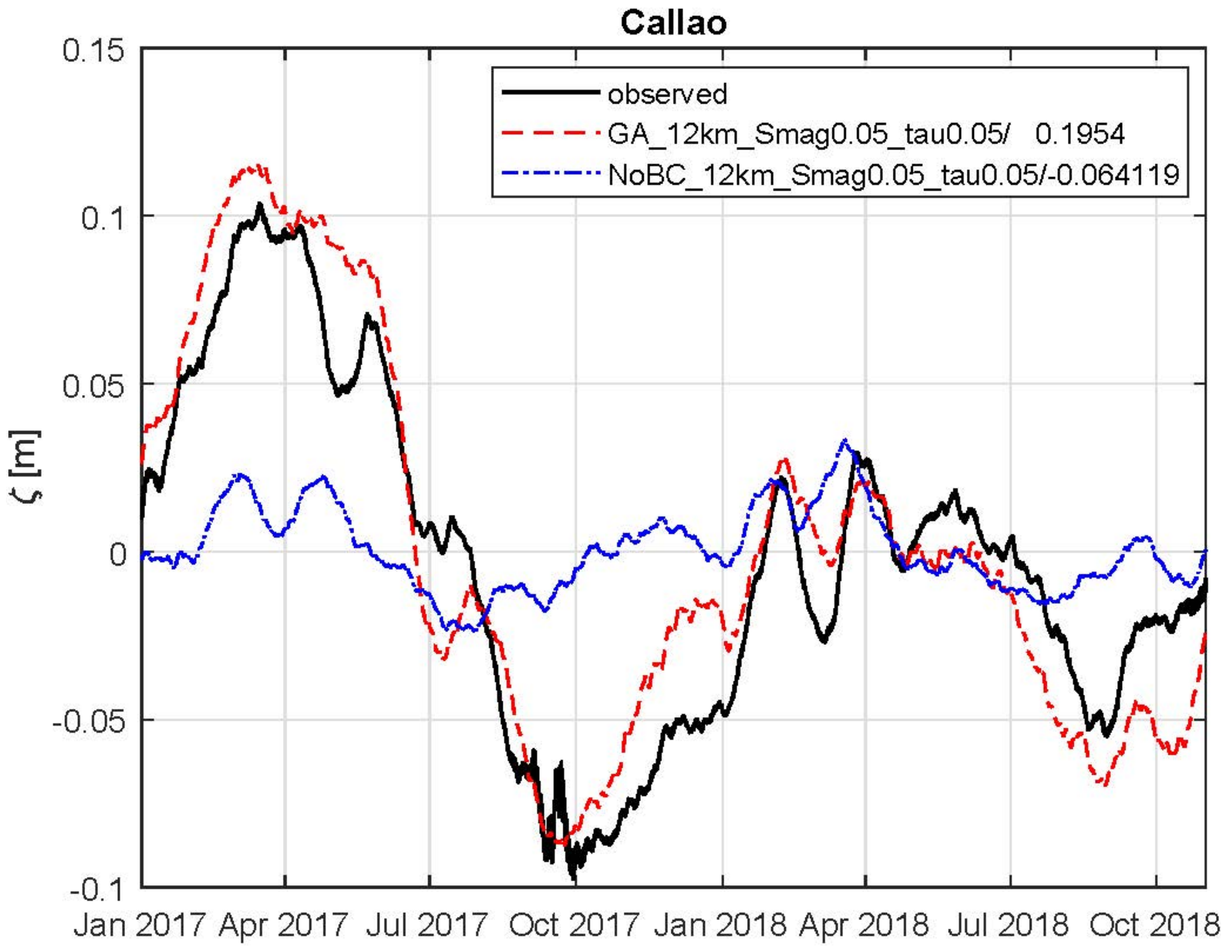
ADCIRC forced with GOFS 3.1 temperature and salinity fields

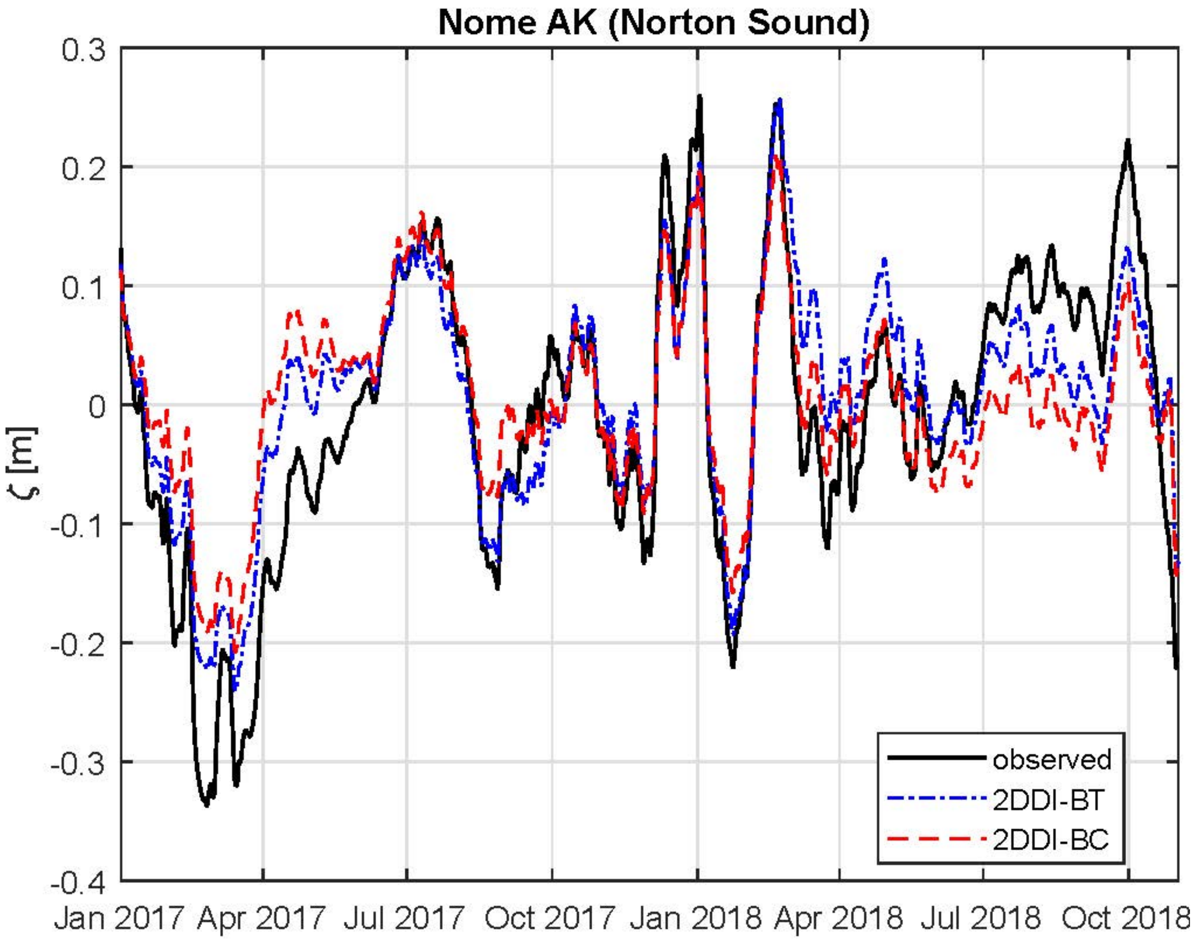
Sample comparison of 30 day averaged water levels – Atlantic Basin





Sample comparison of 30 day averaged water levels – Eastern Pacific





Sample comparison of 30 day averaged water levels – Western Pacific