# Developing High-Resolution Channel to Basin-Scale Unstructured Grid Hydrodynamic Models for Tide/Storm Predictions in the US East and Gulf of Mexico Coasts

María Teresa Contreras Vargas[1], Joannes Westerink[2], Damrongsak Wirasaet[1], William Pringle[1], Edward Myers[3], Saeed Moghimi[4], Sergey Vinogradov[4], and Andre Van der Westhuysen[5]

[1]University of Notre Dame
[2]Univ Notre Dame
[3]NOAA
[4]NOAA National Ocean Service
[5]NOAA/NWS

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**Abstract**

The current technology used by the Extratropical Surge and Tide Operational Forecast System (ESTOFS) on the East of the US and Gulf of Mexico coasts uses a sub-optimal unstructured grid, that over-resolves some straight portions of the coastline, under-resolves complex estuaries and coastal features, and employs roughly uniform resolution depending on the different water depths. The ESTOFS model is very efficient in terms of computational run time because it was designed for operational use, but accuracy is sub-optimal as the details of the complex inland water bodies is not captured with the 200 m minimum mesh resolution. ADCIRC is a robust high-fidelity depth-integrated model, widely used for the coastal community, including ESTOFS, for tides, storm surge, and wave-induced coastal setup. ADCIRC is a continuous-Galerkin based finite element unstructured grid framework that allows using meshes with a heterogeneous resolution to better represent the complexity of the ocean, shelf and nearshore regions. Recent advances on mesh generation tools now allow generating replicable high-resolution grids in times much shorter than the hand-edited processes used to develop the current version of ESTOFS. This opens the opportunity to study the effect of the different resolutions to represent topo-bathymetric and far inland water body features, in order to reduce the computational cost and improve the accuracy of the models. Thus, the objective of this research is to develop an ADCIRC-based model to accurately and efficiently simulate the dynamics of the ocean and riverine system in the Atlantic coast of the US and Gulf of Mexico for tide/storm predictions. The new ADCIRC-based model will incorporate a representation of the riverine system far up to the point where the ocean has no effect on water levels, efficiently use the resolution to reduce the minimum grid-size from 250 m to 50 m, with no significant increase in the number of nodes, and will combine pseudo-quadrilateral elements to efficiently represent narrow channels. This new generation of ESTOFS will represent a significant enhancement of the current technology for tides and storm surge prediction, but also will set up the required conditions for future approaches focused on coupling inland hydrology to the coastal modeling.

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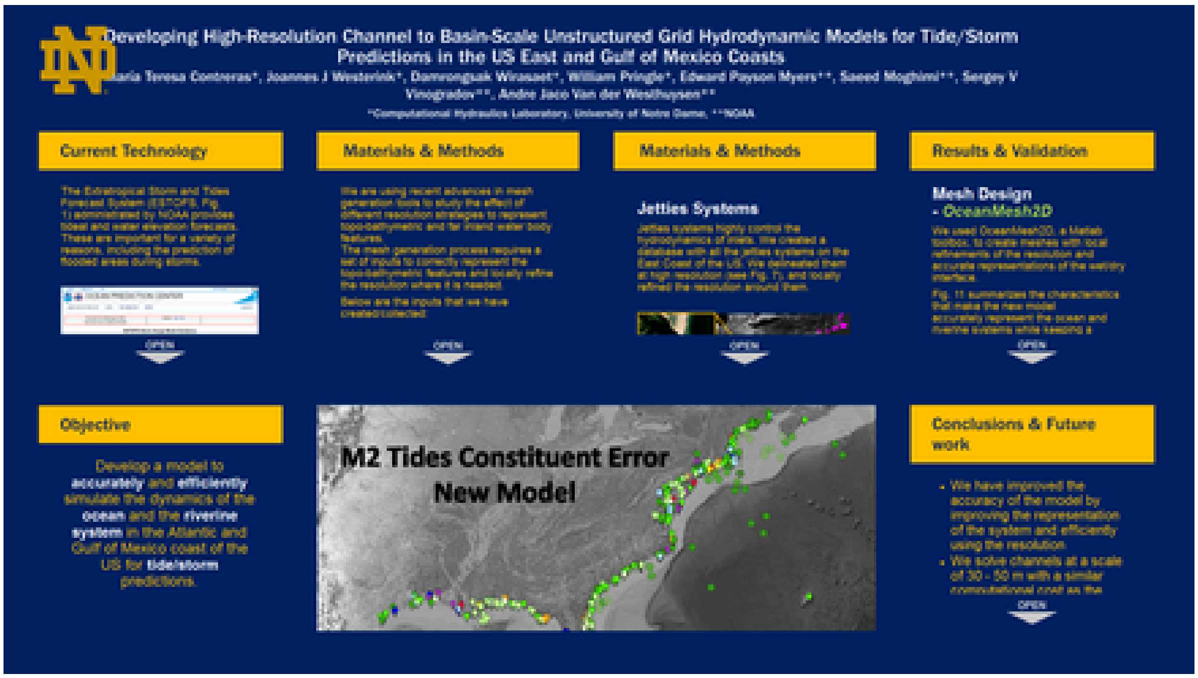


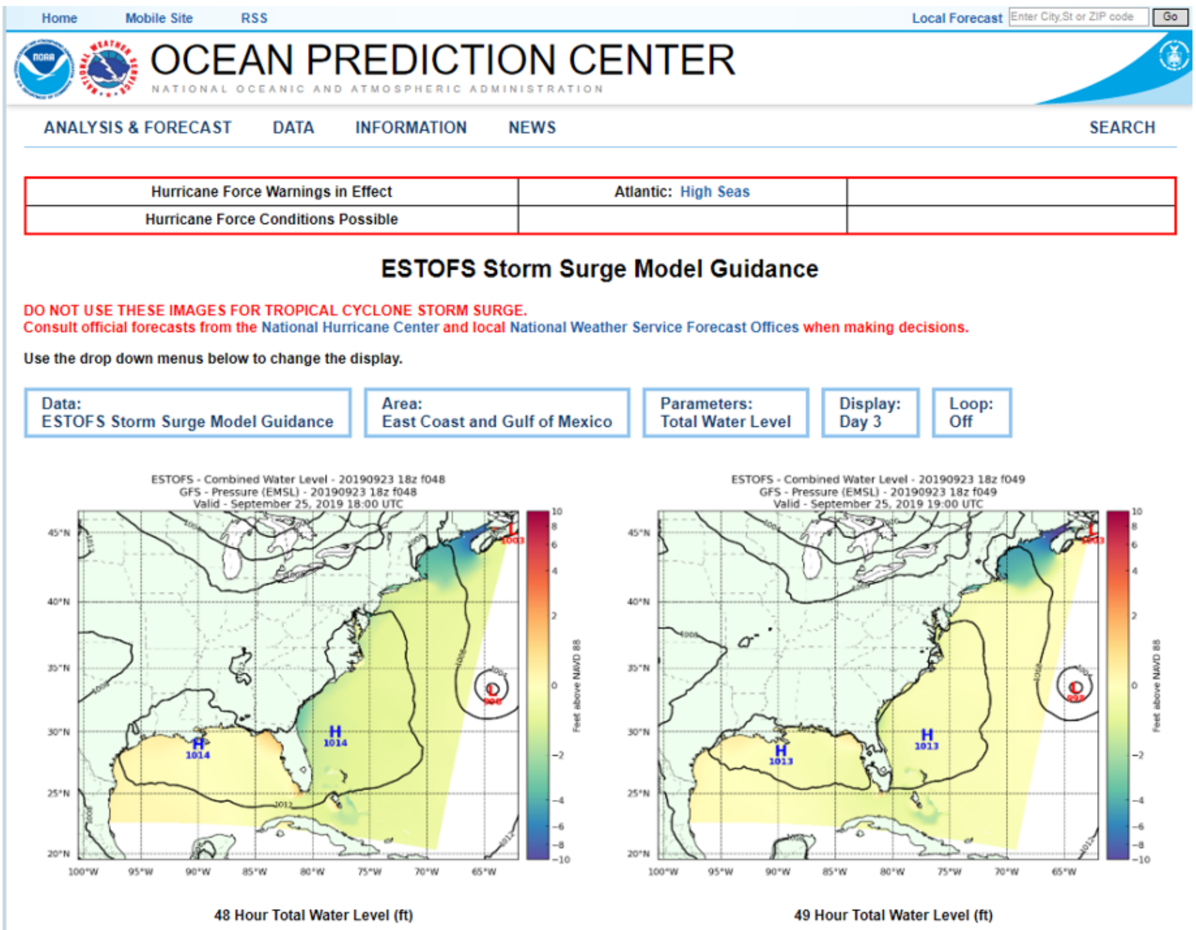

María Teresa Contreras*, Joannes J Westerink*, Damrongsak Wirasaet*, William Pringle*, Edward Payson Myers**, Saeed Moghimi**, Sergey V Vinogradov**, Andre Jaco Van der Westhuysen**

*Computational Hydraulics Laboratory, University of Notre Dame, **NOAA

PRESENTED AT:

# CURRENT TECHNOLOGY

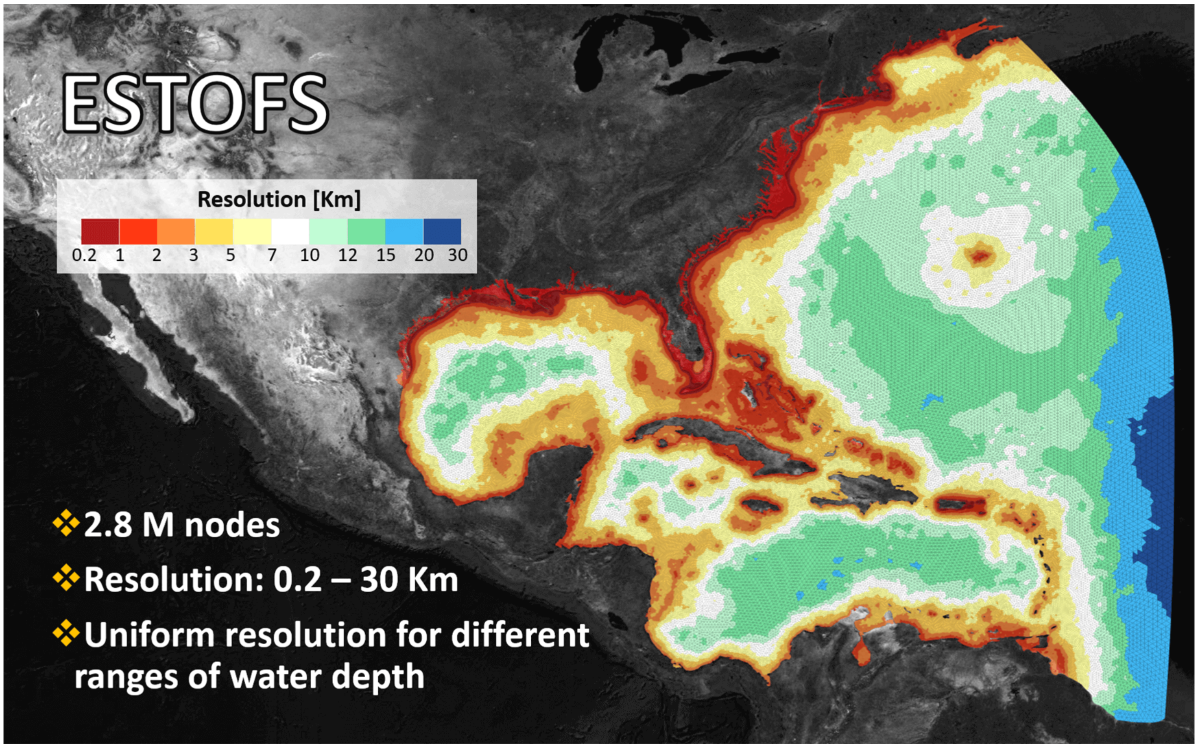
The Extratropical Storm and Tides Forecast System (ESTOFS, Fig. 1) administrated by NOAA provides tideal and water elevation forecasts. These are important for a variety of reasons, including the prediction of flooded areas during storms.




(https://ocean.weather.gov/Loops/ocean_guidance.php?model=ESTOFS&area=Atlantic&plot=surge&day=3&loop=0)

ESTOFS is an ocean numerical model that computes tides and storm forcings (Coriolis, winds, atmospheric pressure, among others) on an unstructured mesh. The current mesh was designed with the objective of keeping a low computational cost for operational purposes.

Thus, the current operational version of ESTOFS uses a sub-optimal unstructured mesh that over-resolves some straight portions of the coastline but under-resolves complex estuaries and coastal features (see Fig.2).


ESTOFS
Resolution [Km]
0.2 1 2 3 5 7 10 12 15 20 30
❖2.8 M nodes
❖Resolution: 0.2 – 30 Km
❖Uniform resolution for different ranges of water depth

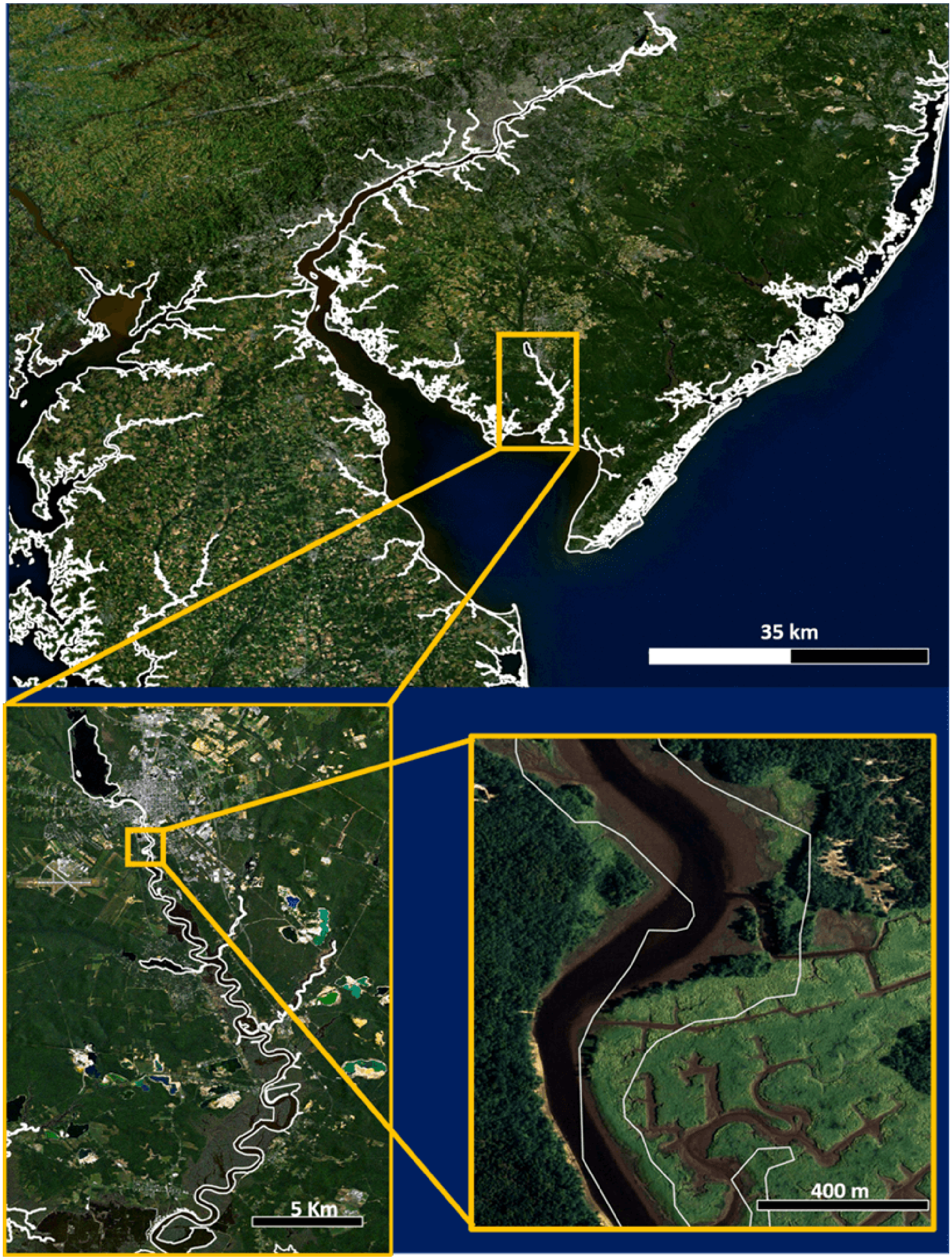
# MATERIALS & METHODS

We are using recent advances in mesh generation tools to study the effect of different resolution strategies to represent topo-bathymetric and far inland water body features.
The mesh generation process requires a set of inputs to correctly represent the topo-bathymetric features and locally refine the resolution where it is needed.

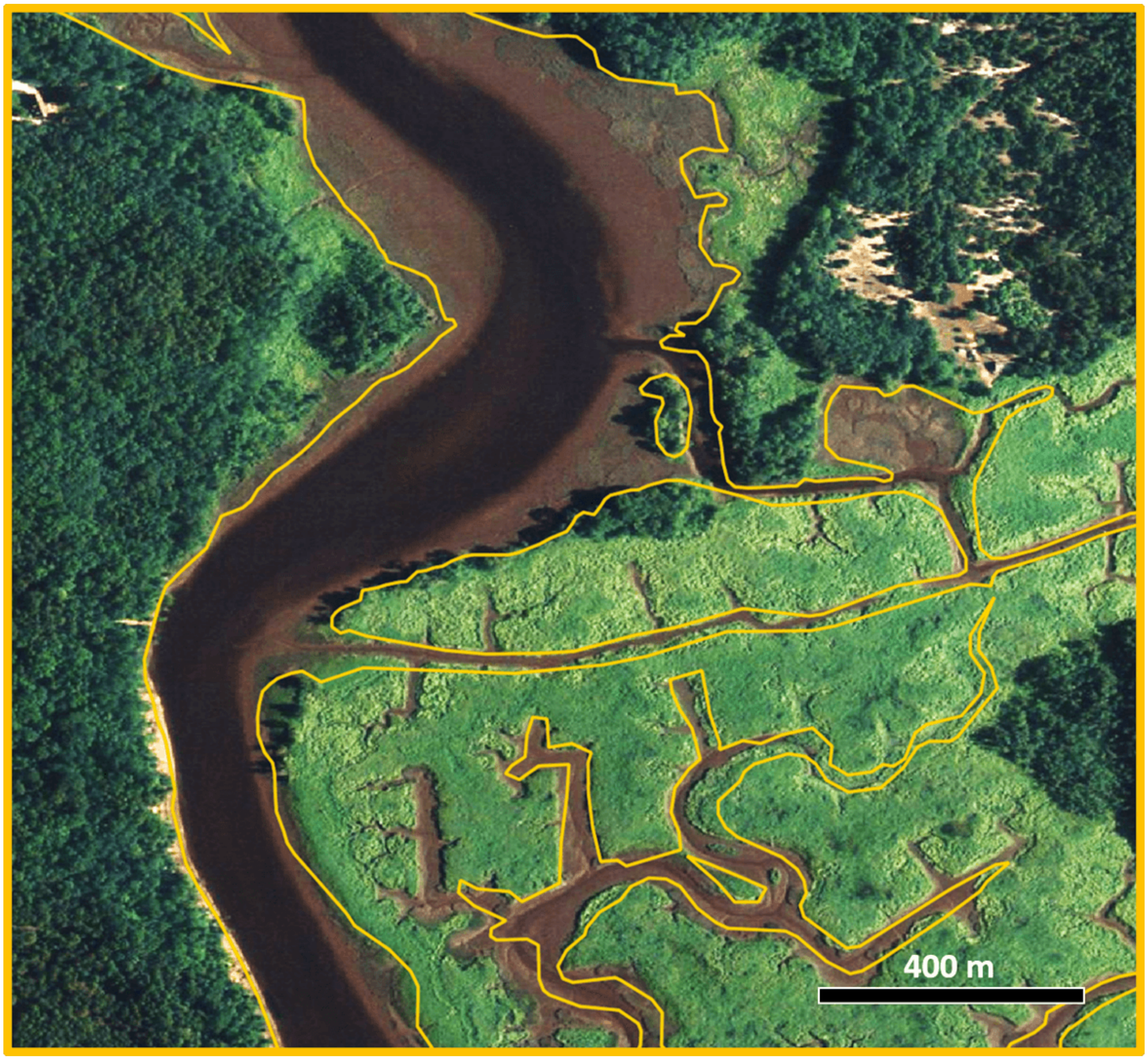
Below are the inputs that we have created/collected:

## Shoreline

The current data available to represent the wet/dry interface is the US medium resolution shoreline. It covers the entire country; however, its resolution is not sufficient to represent inland features on the order of tens of meters (see Fig. 3).

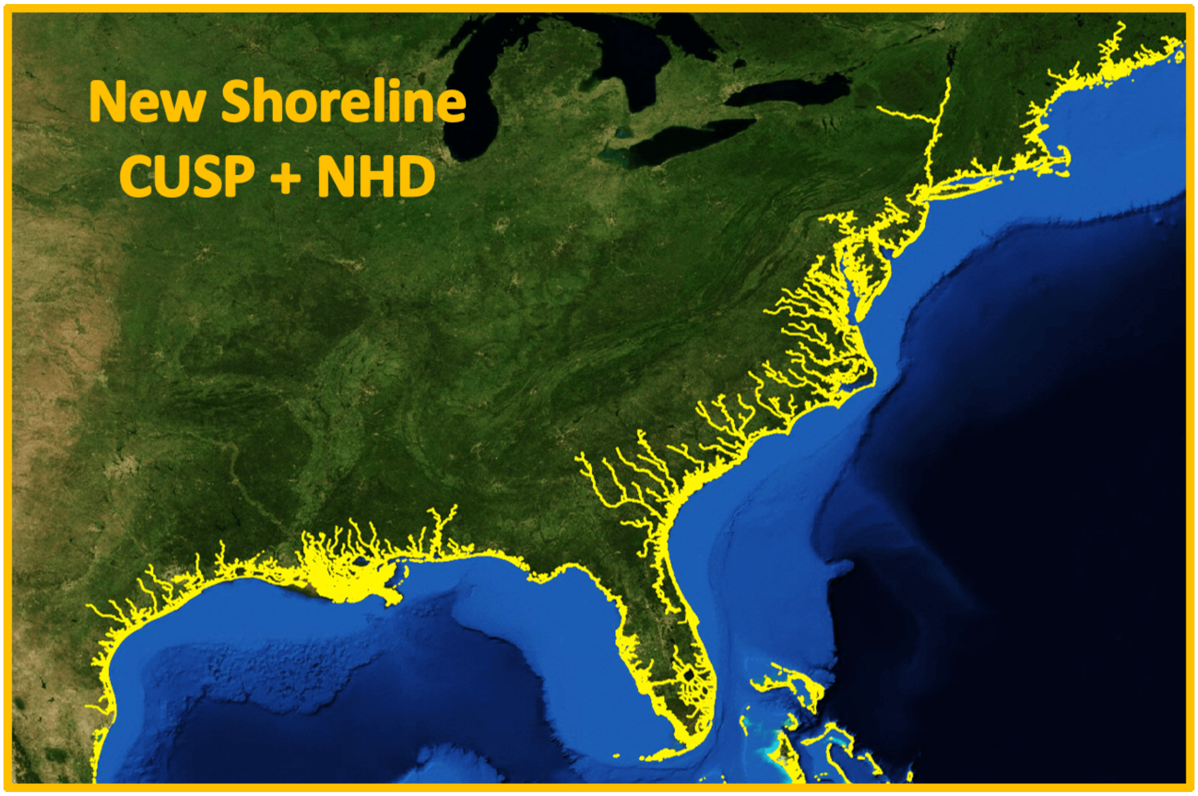

35 km
5 Km
400 m

Another ongoing project, the Continually Updated Shoreline Product (CUSP), represents the wet/dry interface nearshore much more accurately (see Fig. 4). However, the database is segmented and it does not cover all the East Coast of the US.

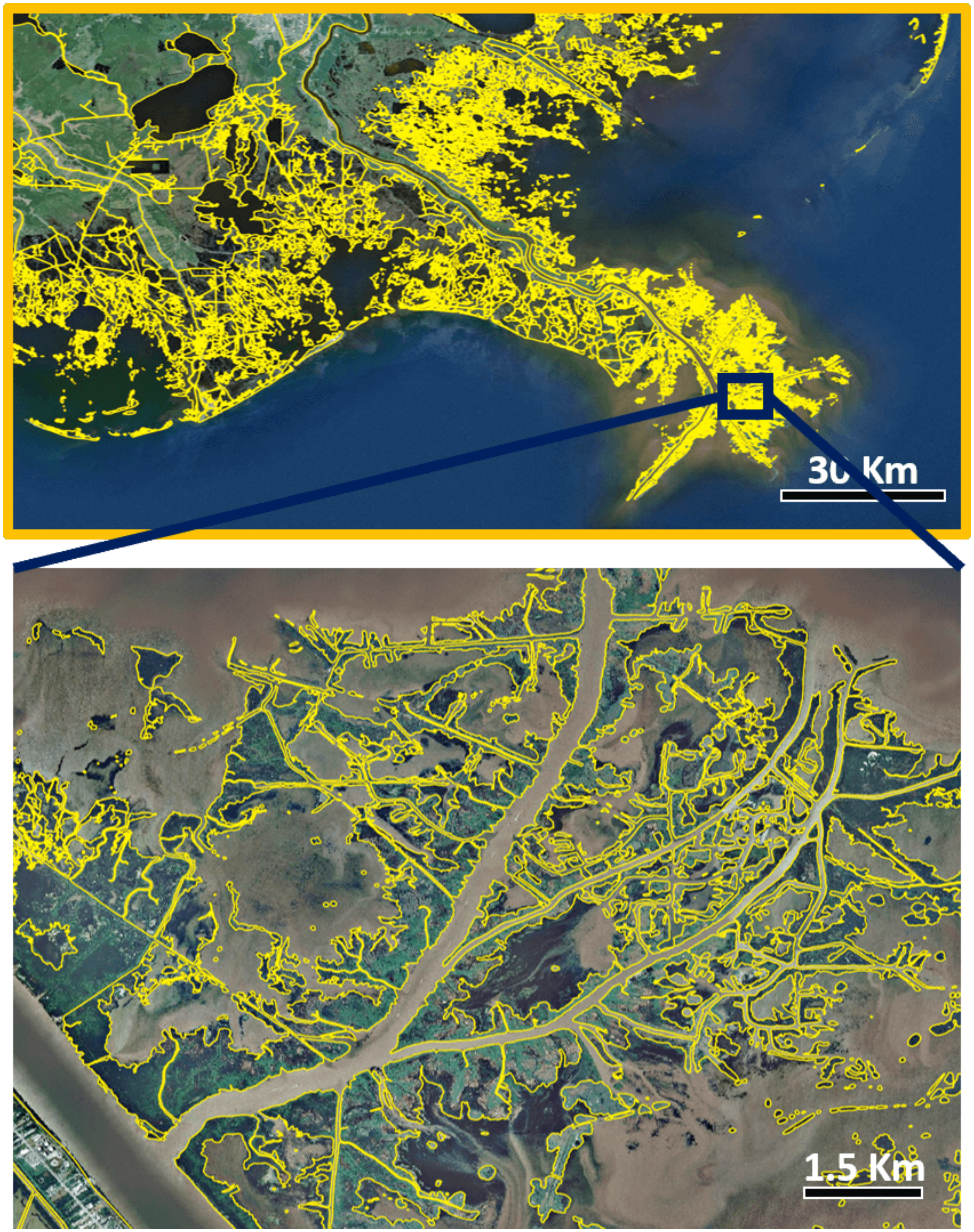



Since we want to incorporate the riverine system, we use the National Hydrographic Database (NHD), a delineation of the river boundaries across the country.

We coupled CUSP and the NHD to have a representation of the wet/dry interface. This new database covers all the US East Coast and the Gulf of Mexico (see Fig. 5).



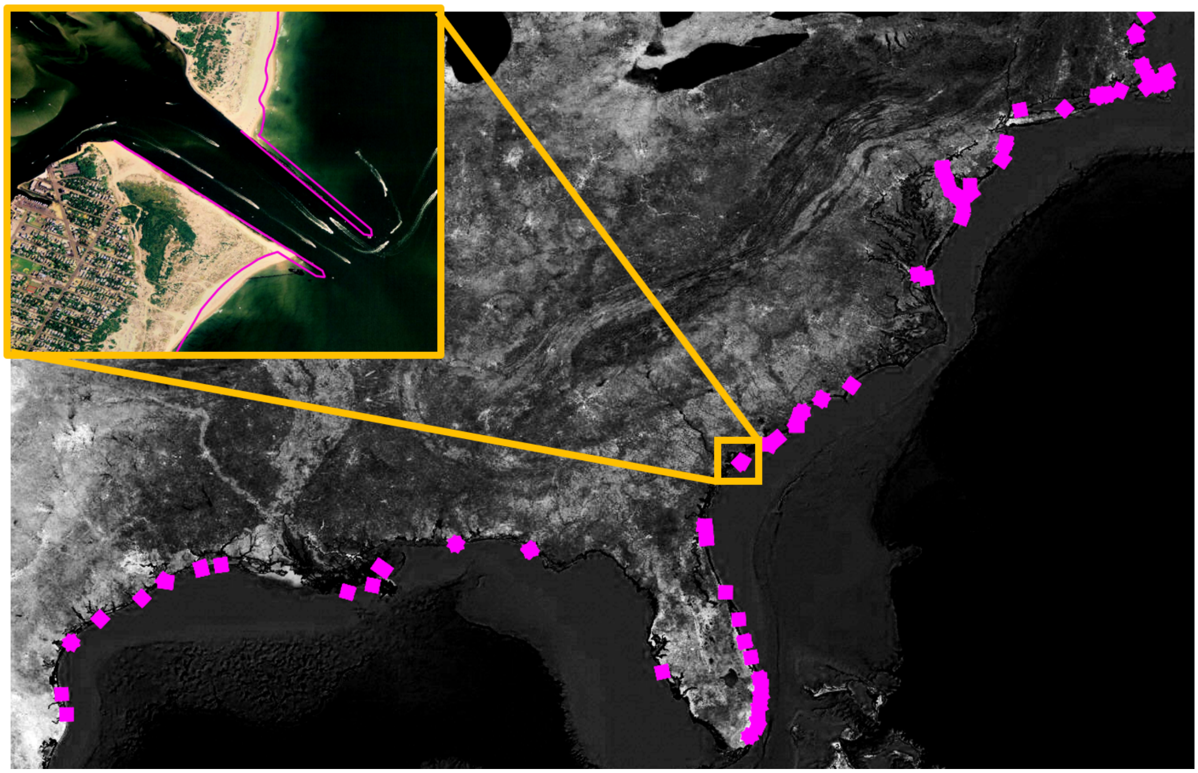

Aforementioned new shoreline has sufficient resolution to represent channels on the order of a couple of meters (see Fig.6) and incorporates the delineation of river boundaries in all the nearshore region over 20 masl.


30 Km
1.5 Km

# MATERIALS & METHODS

## Jetties Systems

Jetties systems highly control the hydrodynamics of inlets. We created a database with all the jetties systems on the East Coast of the US. We delineated them at high resolution (see Fig. 7), and locally refined the resolution around them.

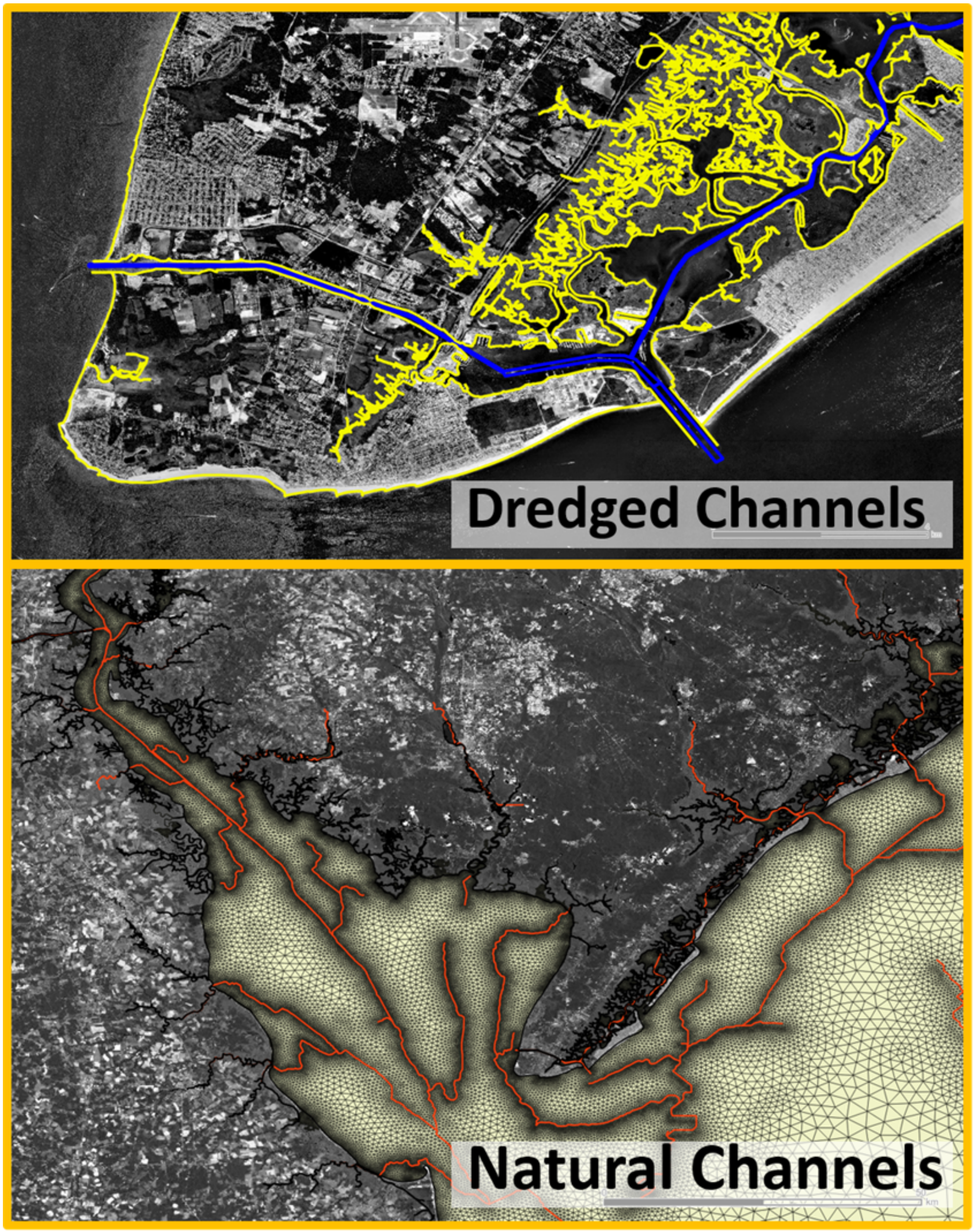


## Dredged and natural deep channels

Representing deeper channels in the shallow waters is critical to solving the conveyance among the different riverine systems.

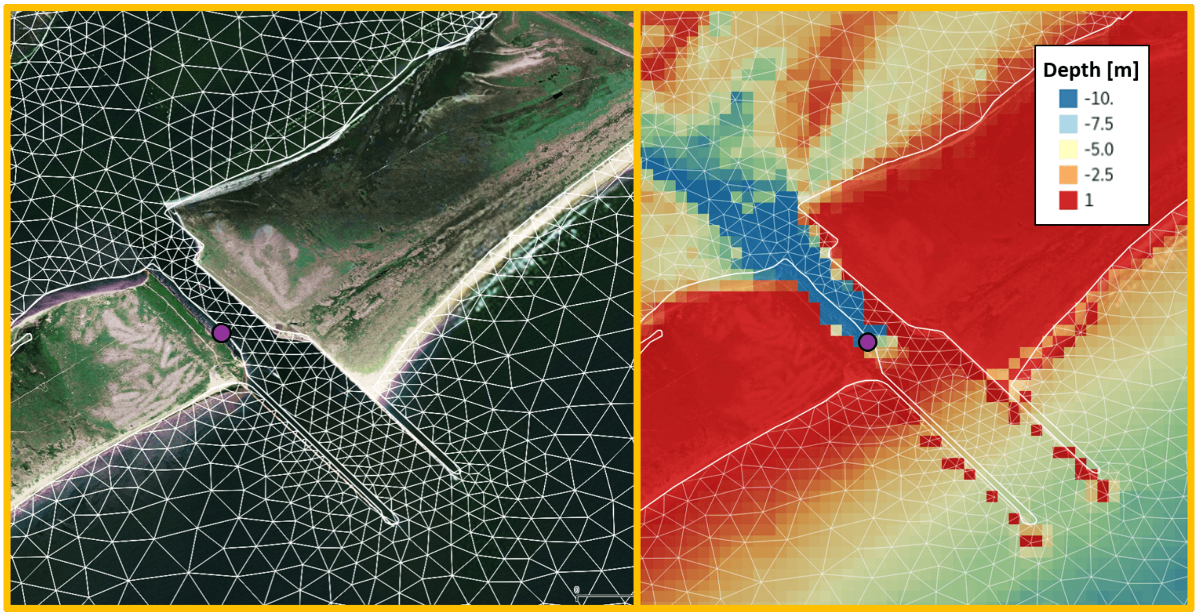
We used the Dredged Channels Database of the USACE to determine the correct water depth maintained in these areas, and to increase the resolution along the channels (See Fig. 8 on the top).

Additionally, natural deep shelf channels require extra resolution to correctly represent the connectivity of the systems. We extracted the river network from high-resolution DEMs, and used those flow paths to determine areas where high-resolution is required (see Fig. 8, bottom).

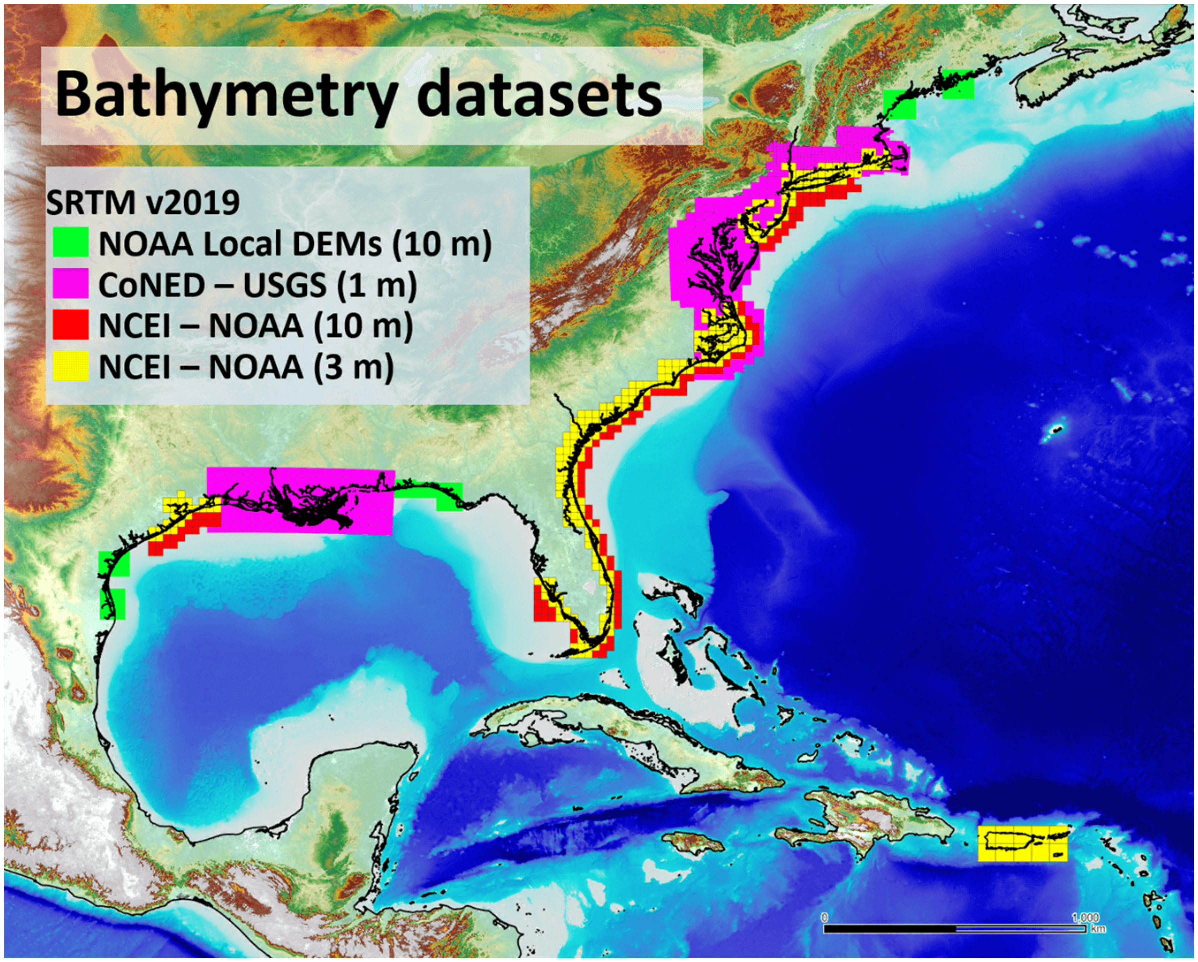



## Bathymetry

Many incorrect tidal computations are a consequence of wrong bathymetry. Fig. 9 shows a clear example of a consistent under-prediction of tides in the station shown in the purple point. On the left, the correct representation of the domain, with a clear definition of the jetties systems. On the right, the bathymetry shows that the channel is only 1 m, which is impossible for a navigation channel like this.




We collected ~1.5 Tb of different bathymetry datasets (see Fig. 10). We use layers of interpolation, prioritizing the newest and highest-resolution sets in areas with overlapping of information.

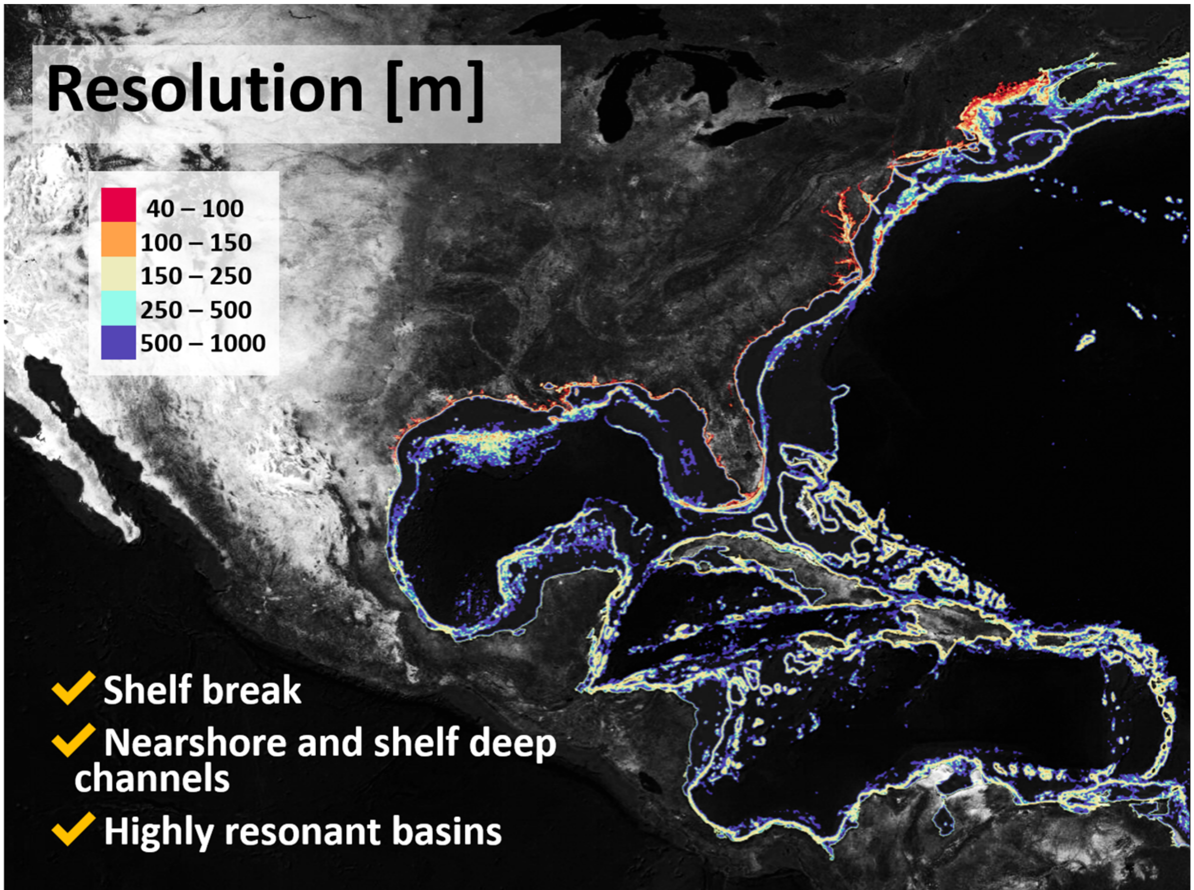

Bathymetry datasets
SRTM v2019
NOAA Local DEMs (10 m)
CoNED – USGS (1 m)
NCEI – NOAA (10 m)
NCEI – NOAA (3 m)
0
1,000
km

# RESULTS & VALIDATION

## **Mesh Design - *OceanMesh2D*** (https://github.com/CHLNDDEV/OceanMesh2D)

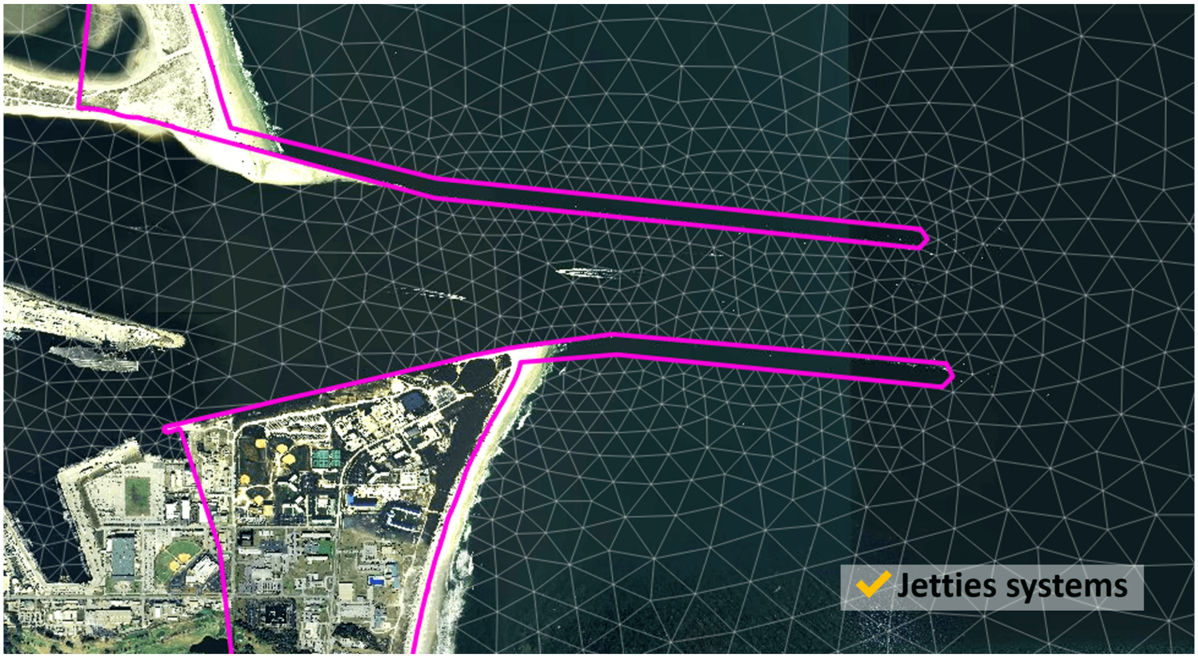
We used OceanMesh2D, a Matlab toolbox, to create meshes with local refinements of the resolution and accurate representations of the wet/dry interface.

Fig. 11 summarizes the characteristics that make the new model accurately represent the ocean and riverine systems while keeping a relatively low computational cost.



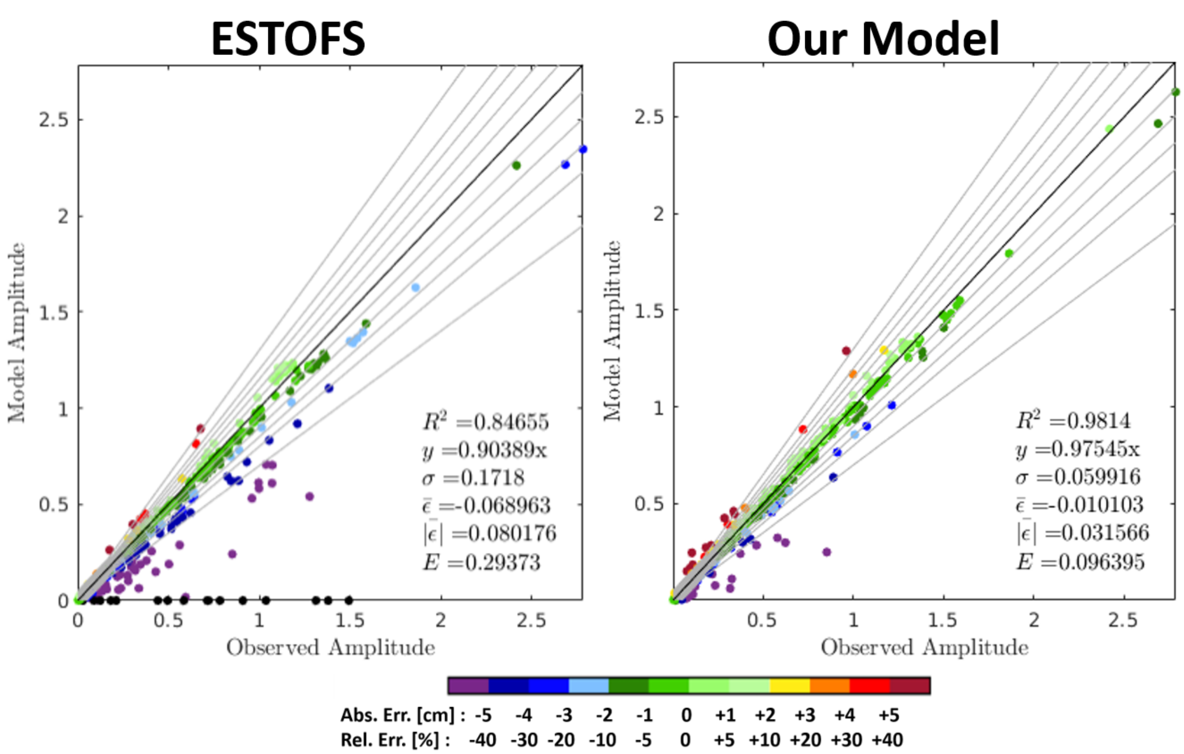
Resolution [m]
40 – 100
100 – 150
150 – 250
250 – 500
500 – 1000
Shelf break
Nearshore and shelf deep channels
Highly resonant basins


5 Km
Inland and shoreline features

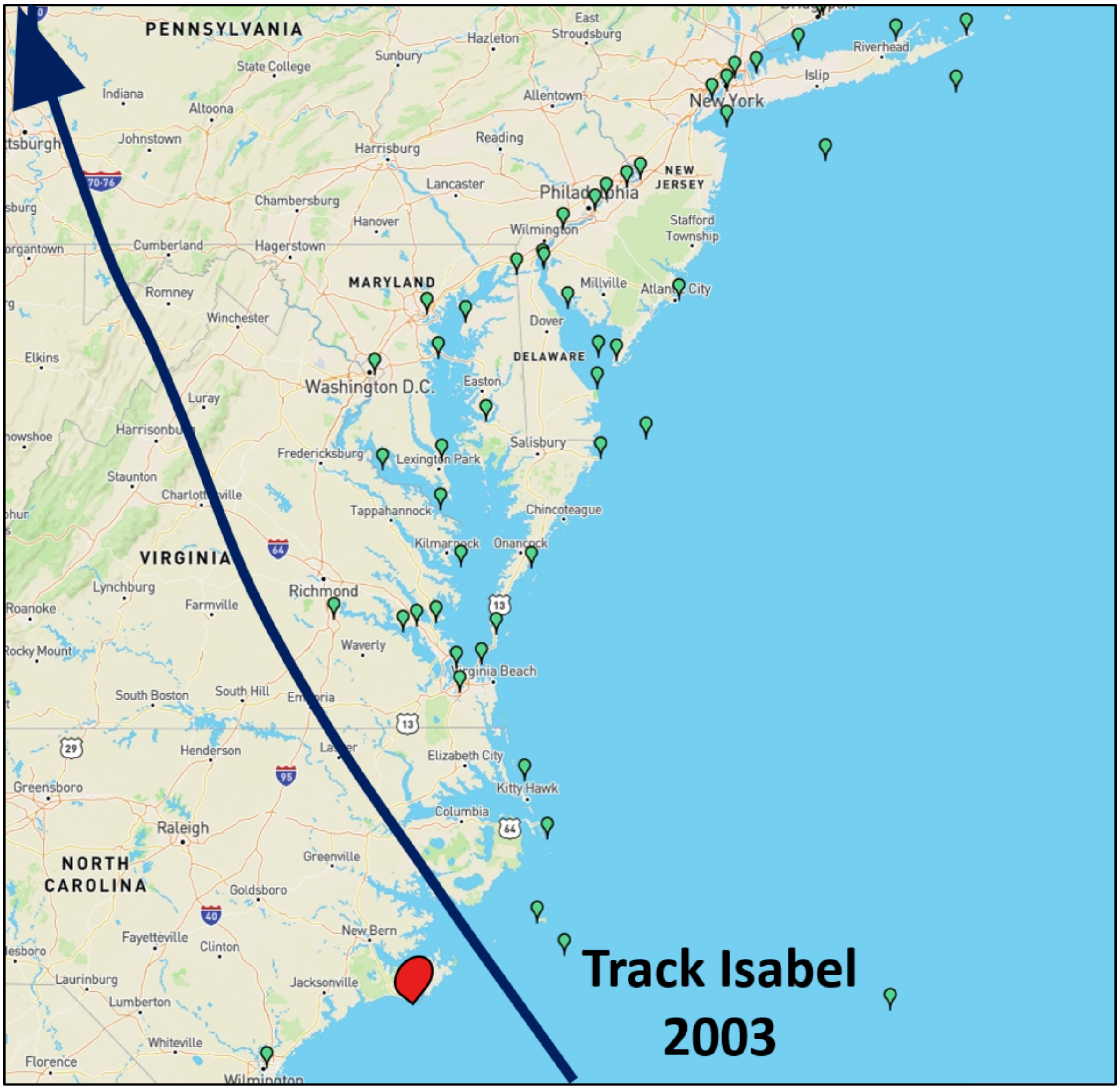

We studied the impact of the different models on tides and water surface elevations during storms.

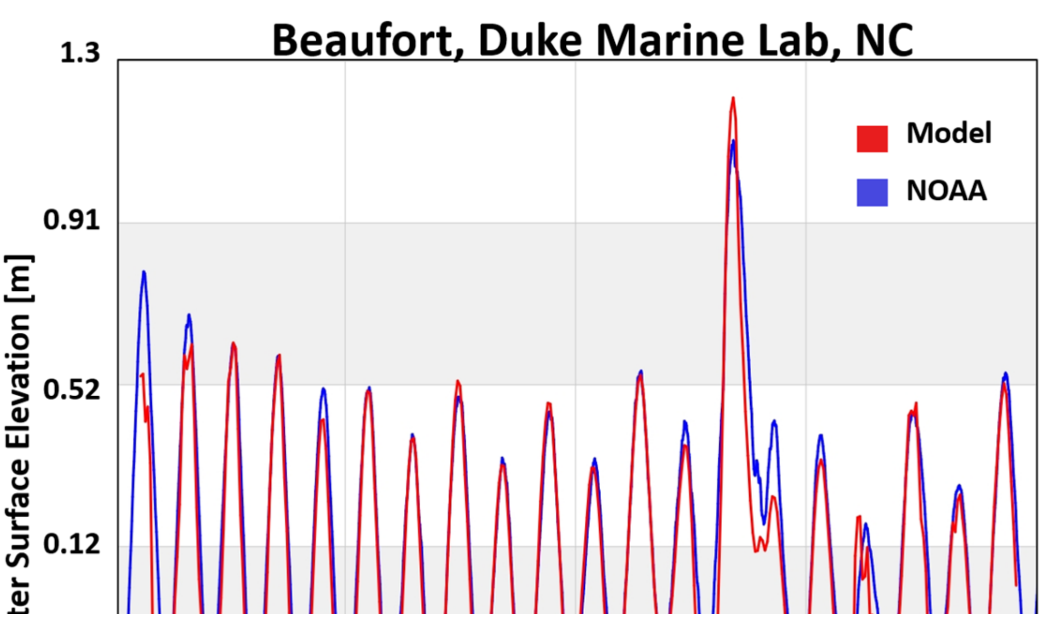
Fig. 12 shows a comparison of the results for the M2 constituent, the largest in the ocean, again ~250 NOAA stations in the deep ocean, shelf, and nearshore.

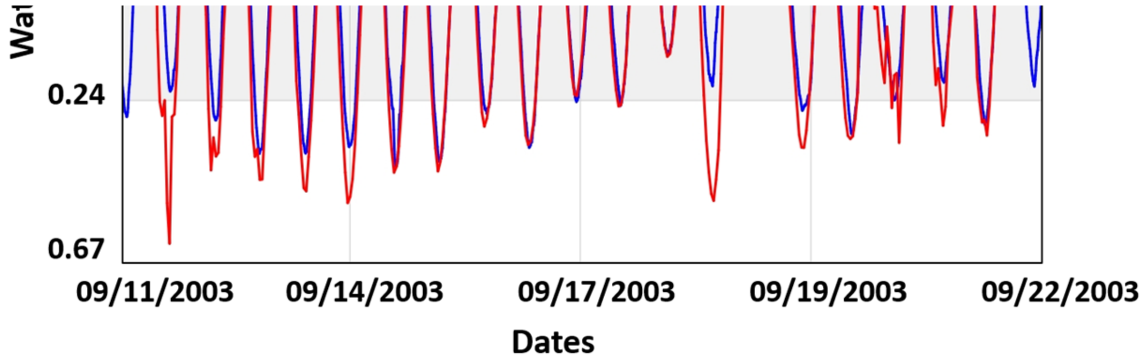


Results for water surface elevation improved as well for a set of storms that includes: Floyd (1999), Isabel (2003), Matthew (2007), Norida (2009), Sandy (2012), Irma (2017), Florence (2018).

Fig. 13 show on top shows the track of Hurricane Isabel. The red dot shows the location of the station whose results for water surface elevation are shown on the bottom.


PENNSYLVANIA
MARYLAND
DELAWARE
NEW JERSEY
VIRGINIA
NORTH CAROLINA
New York
Philadelphia
Washington D.C.
Richmond
Raleigh
Track Isabel
2003


Beaufort, Duke Marine Lab, NC
1.3
0.91
0.52
0.12
ter Surface Elevation [m]
Model
NOAA


Wa
0.24
0.67
09/11/2003
09/14/2003
09/17/2003
09/19/2003
09/22/2003
Dates

## OBJECTIVE

Develop a model to **accurately** and **efficiently** simulate the dynamics of the **ocean** and the **riverine system** in the Atlantic and Gulf of Mexico coast of the US for **tide/storm** predictions.

## CONCLUSIONS & FUTURE WORK

- We have improved the accuracy of the model by improving the representation of the system and efficiently using the resolution
- We solve channels at a scale of 30 - 50 m with a similar computational cost as the current technology.

## Future Work:

- Solve local errors of shoreline, DEMs, and bottom friction.
- Incorporate the floodplain in the Gulf of Maine and Mexico.
- Couple the hydrology into the model to consider floods produced by precipitation and runoff.

Sorry but time is up!

# ABSTRACT

NOAA's Extratropical Surge and Tide Operational Forecast System (ESTOFS) for the US East and Gulf of Mexico coasts spans across the western North Atlantic and applies an unstructured heterogeneous triangular mesh. ESTOFS uses ADCIRC, a robust high-fidelity coastal ocean circulation model, widely used by the coastal community for tides, storm surge, and wave-induced coastal setup. ADCIRC uses a continuous-Galerkin based finite element unstructured mesh framework that allows a highly variably-sized resolution to better represent the complexity of the ocean, shelf and nearshore hydrodynamics, and geometry.

The current operational version of ESTOFS uses a sub-optimal unstructured mesh that over-resolves some straight portions of the coastline but under-resolves complex estuaries and coastal features. While the current ESTOFS model is efficient in terms of computational run time since it was specifically designed for operational use, its accuracy is suboptimal as the details of the complex inland water bodies are not captured with the 200 m minimum mesh resolution. Recent advances in mesh generation tools now allow generating replicable high-resolution (minimum resolution ~50-m) meshes in much shorter times than the hand-edited processes used to develop the current version of ESTOFS. This opens the opportunity to study the effect of different resolution strategies to represent topo-bathymetric and far inland water body features, in order to reduce the computational cost and improve the accuracy of the models. Thus, the objective of this research is to develop an ADCIRC-based model to more accurately and efficiently simulate the dynamics of the coastal ocean and riverine system for the US Atlantic and Gulf of Mexico coasts for tide/storm/wave setup predictions.

The new ADCIRC-based model will incorporate a representation of the riverine system far up to the point where the ocean has no effect on water levels, efficiently reduce the minimum grid-size from 250 m to 30 m with no significant increase in the number of nodes, and will combine pseudo-quadrilateral elements to represent narrow channels. This new generation of ESTOFS will represent a significant enhancement of the current technology for tides, storm surge, and wave setup prediction, but also will set up the required conditions for future approaches focused on coupling inland hydrology to the coastal modeling.

SWITCH TEMPLATE