Bathymetry and Resolution: Keys to Develop a Channel-to-Ocean Basin-Scale Hydrodynamic Model for the US East and Gulf of Mexico Coasts

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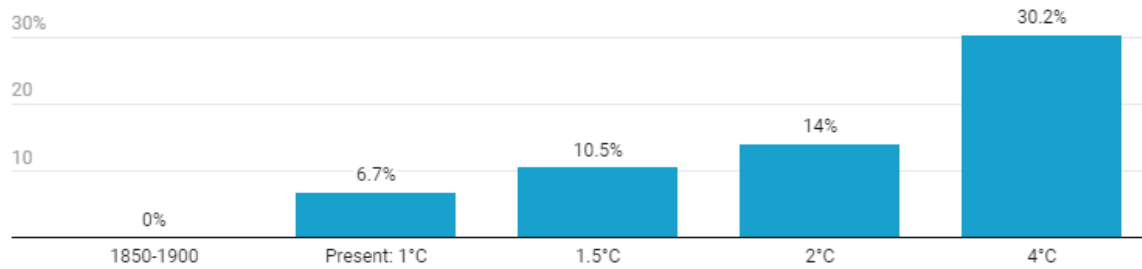
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AGU 2021, New Orleans, LA.

Motivation – Global Warming

Clausius-Clapeyron relation: With every 1 degree Celsius (1.8 F) increase in temperature, there can be about 7% more moisture in the air.
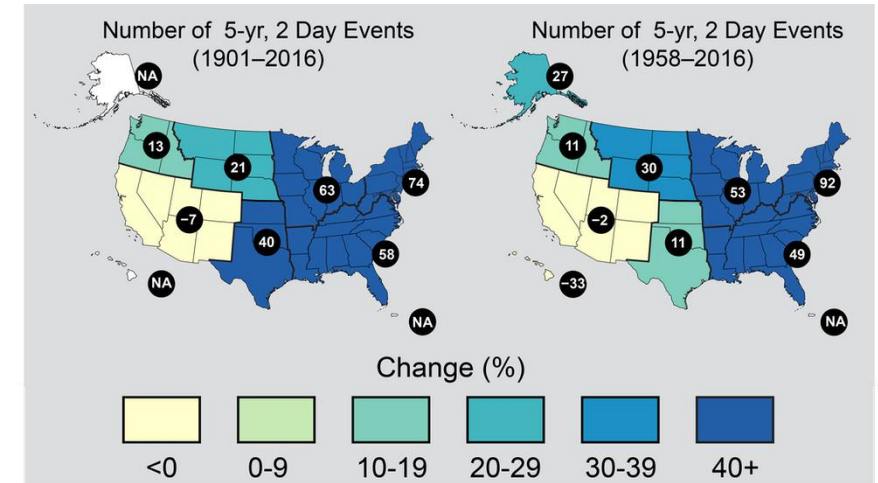
Intensity of rainfall is expected to increase as the climate warms

A small bit of added moisture can lead to a lot more rain:

IPCC 6th Assessment Report (2021)

4th National Climate Change Assessment (2018)

Hurricane Ida 2021

USGS Mississippi River at Belle Chase, LA

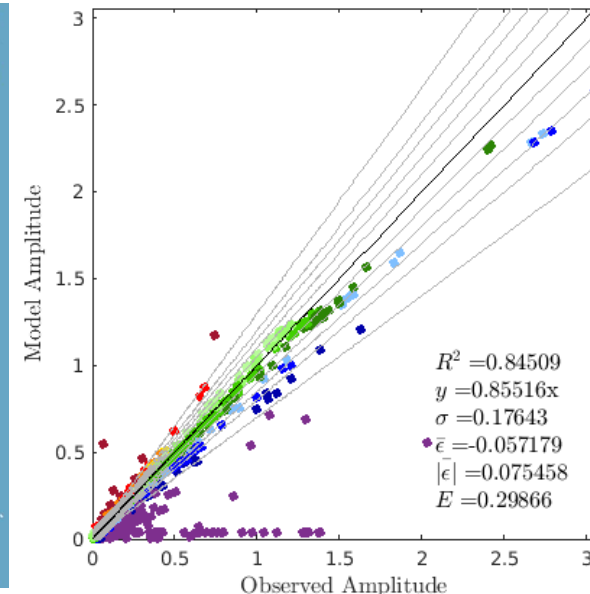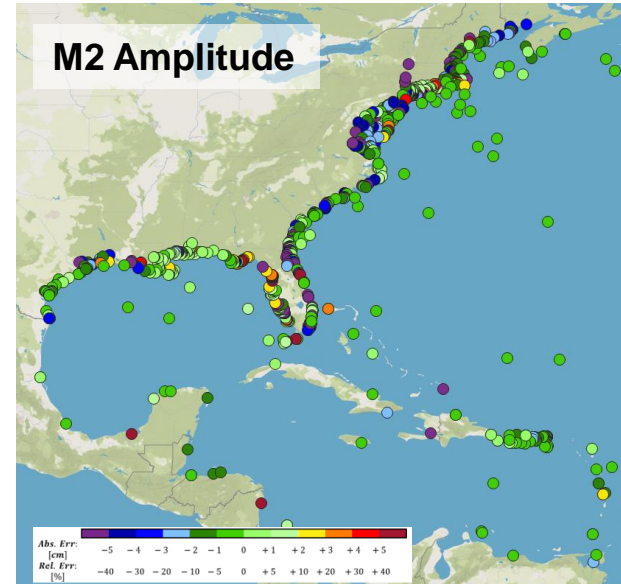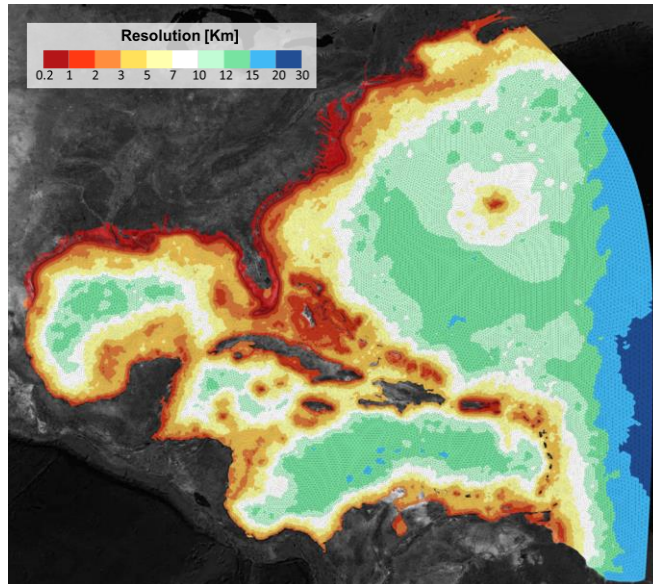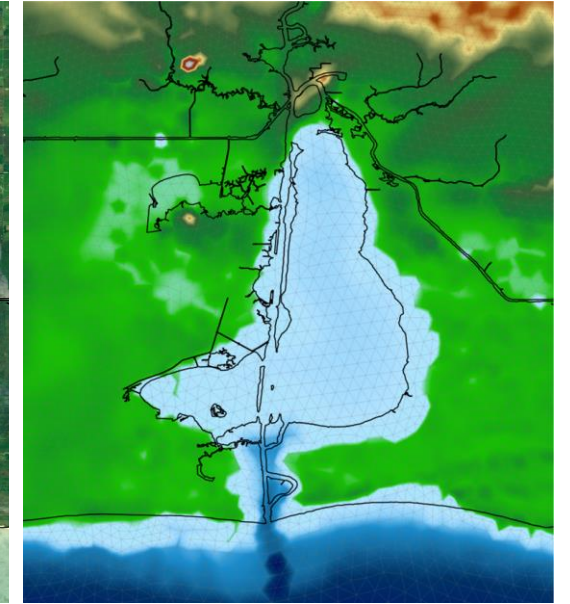**NWS Eastern Region** @NWSEastern

Observed rainfall totals for the last 48 hours ending 9 am Thursday September 2nd. Rainfall rates at some locations were 2.5-3.5 inches per hour. Newark NJ received 3.24" from 8-9 pm & Central Park saw 3.15" from 9-10 pm, both all time records for highest 1-hour rainfall totals

Traducir Tweet

Motivation – Current ESTOFS

- 250 m resolution ESTOFS model
- Sub-optimal grids: linear variation of resolution
- Highly simplified river network
- Poor definitions of inland waterbodies: source of instabilities and inaccuracy

Calcasieu Lake, LA

Resolution [Km]
0.2 1 2 3 5 7 10 12 15 20 30

M2 Amplitude

Abs. Err. [cm] −5 −4 −3 −2 −1 0 +1 +2 +3 +4 +5
Rel. Err. [%] −40 −30 −20 −10 −5 0 +5 +10 +20 +30 +40

$R^2 = 0.84509$
$y = 0.85516x$
$\sigma = 0.17643$
$\bar{\epsilon} = -0.057179$
$|\bar{\epsilon}| = 0.075458$
$E = 0.29866$

St Johns River, FL

Objective

Develop methodologies/tools to create models that efficiently and accurately resolve the hydrodynamics of both, ocean basins and riverine systems.

Resolve the complexity of the nearshore region

Increase the heterogeneity of the systems to resolve

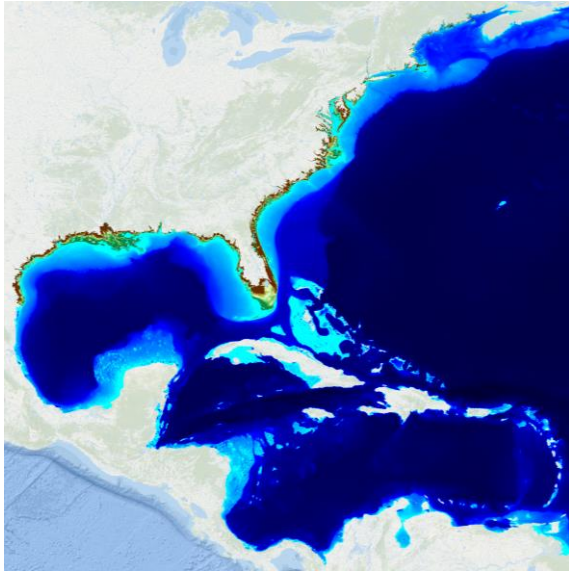Efficient distribution of resolution for operational purposes

Study case: East and Gulf of Mexico Coast of the US

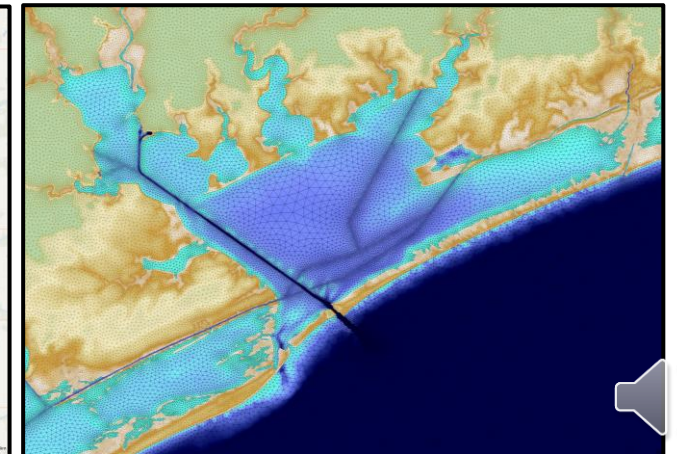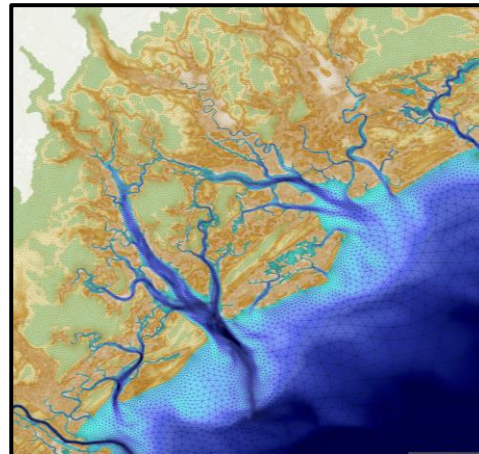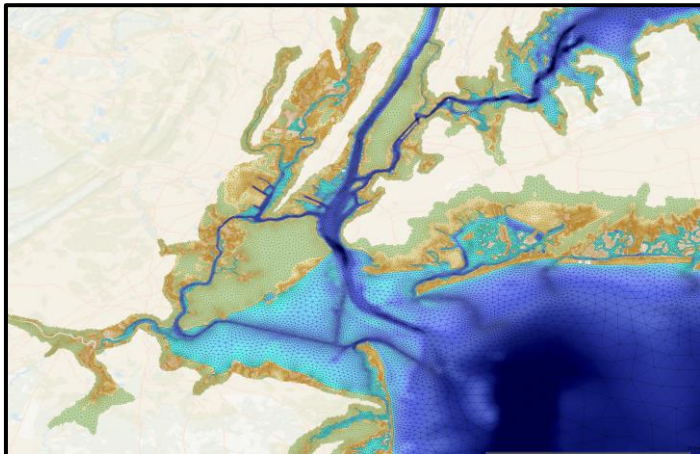Key to incorporate additional physical forcing in future research

Mesh implementation

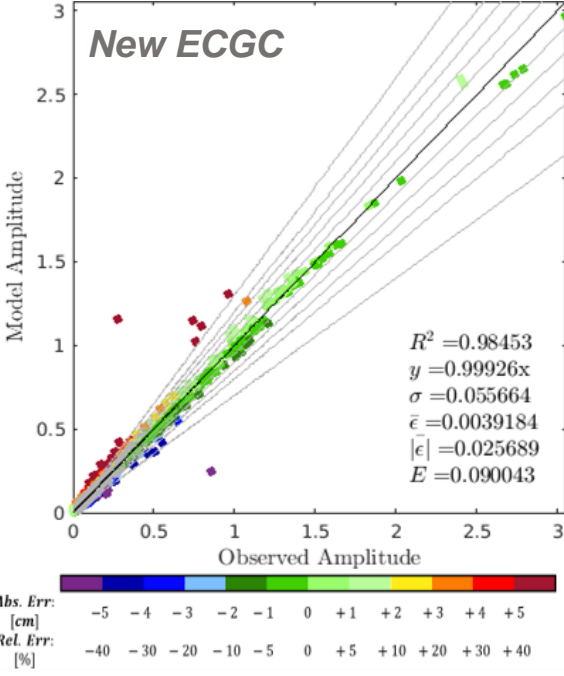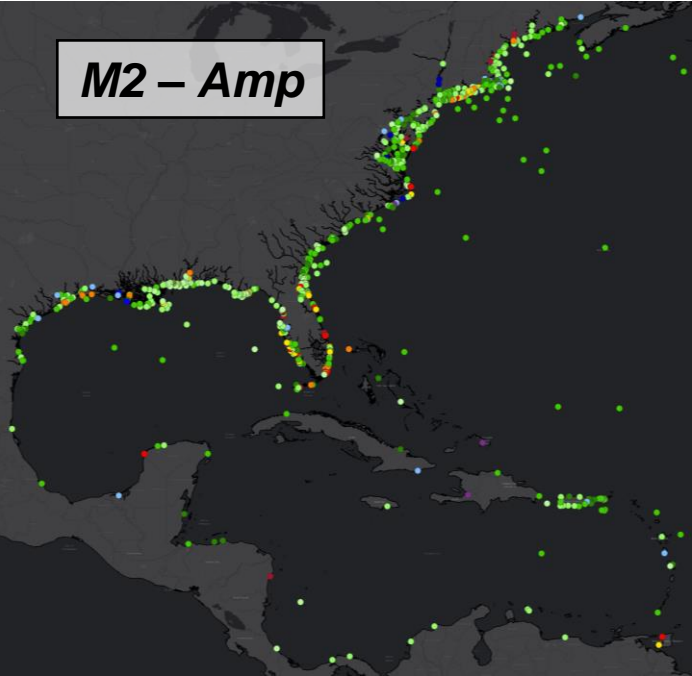**Basin-to-channel East and Gulf of Mexico Coasts of the US**

- Two regional models: 30 and 120 m minimum resolution

- Model solve the deep ocean (North Atlantic) and intercoastal complex features, including inland river network

- Model 120 m is a good balance between accuracy and efficiency

- Model 30 m for design studies

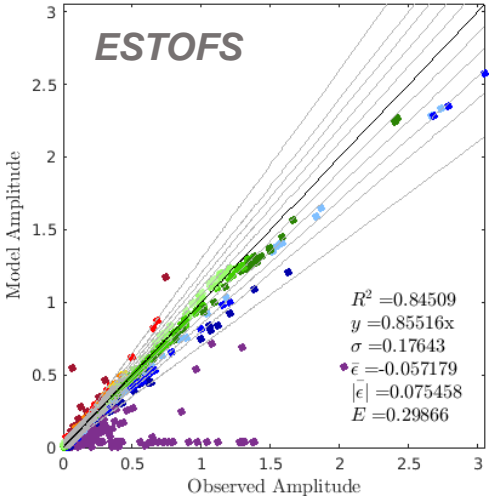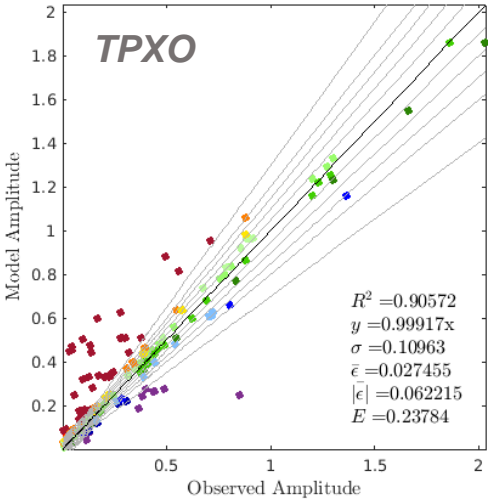|	Model 30 m	Model 120 m
Min. Res	30 m	120 m
Max. Res	24 Km	24 Km
Nodes	21.5 M	6.0 M
Elements	43.0 M	11.8 M

Mesh validation - Tides

Tidal analysis for amplitude and phase of 8 major constituents
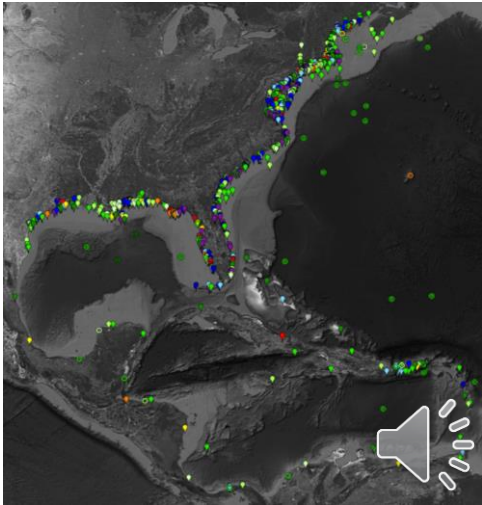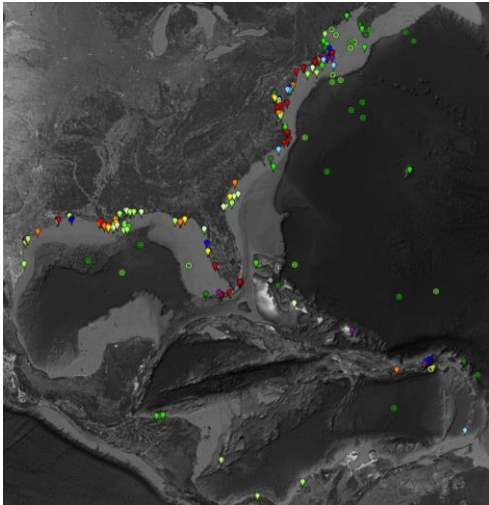
Comparison of results against ~800 tidal gauges

M2 – Amp

New ECGC

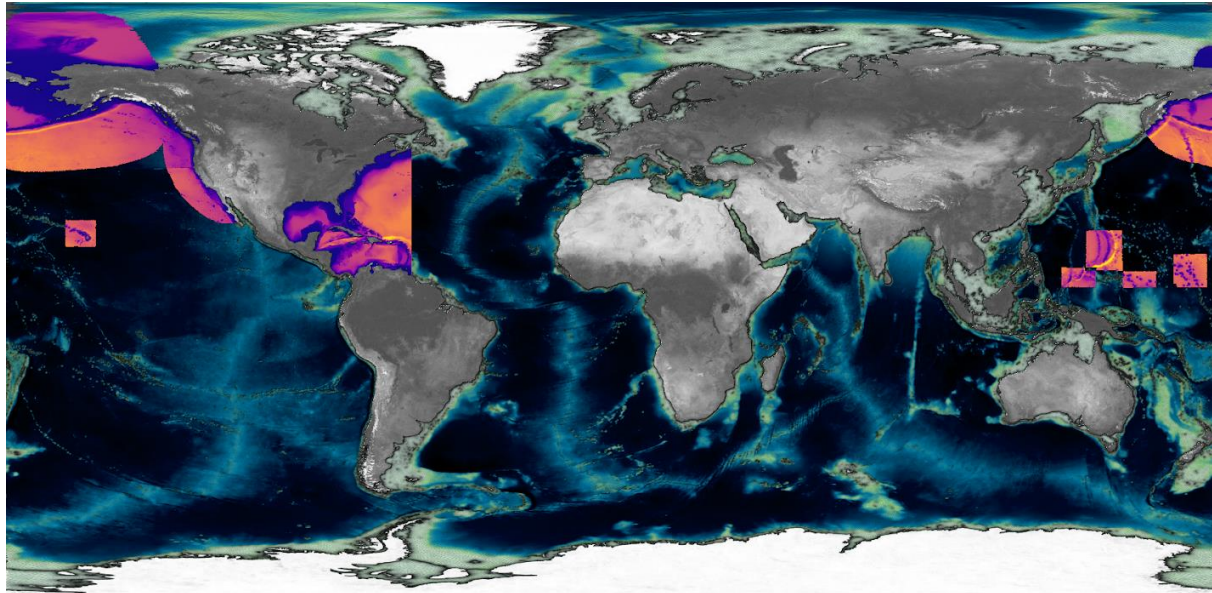$R^2 = 0.98453$
$y = 0.99926x$
$\sigma = 0.055664$
$\bar{\epsilon} = 0.0039184$
$|\bar{\epsilon}| = 0.025689$
$E = 0.090043$

Abs. Err. [cm]: −5 −4 −3 −2 −1 0 +1 +2 +3 +4 +5
Rel. Err. [%]: −40 −30 −20 −10 −5 0 +5 +10 +20 +30 +40

Comparison with TPXO and ESTOFS

TPXO

$R^2 = 0.90572$
$y = 0.99917x$
$\sigma = 0.10963$
$\bar{\epsilon} = 0.027455$
$|\bar{\epsilon}| = 0.062215$
$E = 0.23784$

ESTOFS

$R^2 = 0.84509$
$y = 0.85516x$
$\sigma = 0.17643$
$\bar{\epsilon} = -0.057179$
$|\bar{\epsilon}| = 0.075458$
$E = 0.29866$

Amplitude

	M2	S2	K1	O1
$R^2\ [-]$	0.994	0.966	0.847	0.933
$\sigma\ [cm]$	3.332	1.294	1.573	1.029
$\bar{\epsilon}\ [cm]$	0.191	0.259	0.051	0.053
$|\epsilon|\ [cm]$	2.231	0.856	1.157	0.681
$E\ [-]$	0.054	0.131	0.151	0.116

Phase

	M2	S2	K1	O1
$R^2\ [-]$	0.976	0.943	0.974	0.980
σ	15.903°	21.930°	13.871°	12.863°
$\bar{\epsilon}$	-7.005°	-7.281°	-2.075°	-4.338°
$|\epsilon|$	10.177°	13.185°	7.892°	8.840°
$E\ [-]$	0.106	0.1450	0.074	0.071

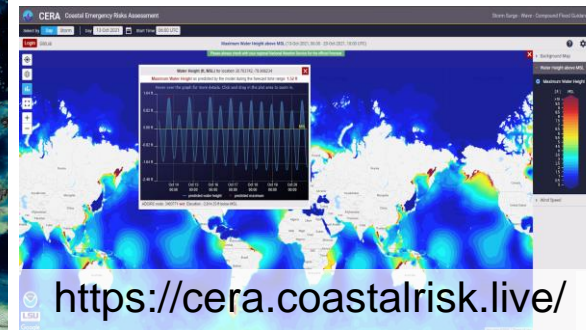# Bonus: NOAA Operational Global Model

Global shell + HR inserts:

8 M nodes mesh, 6 sec timestep

Forecast 4 times a day for 7 days

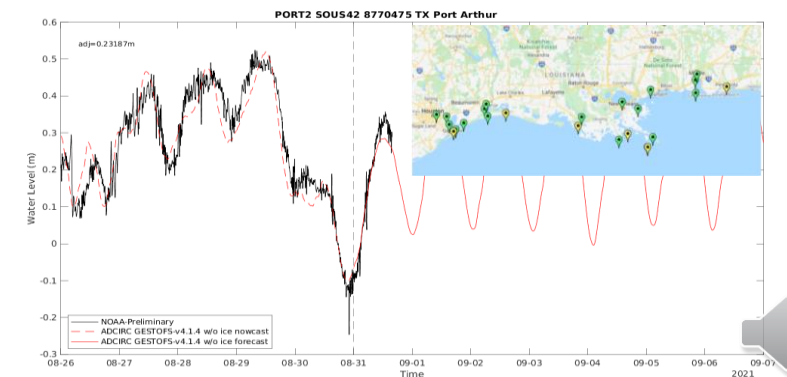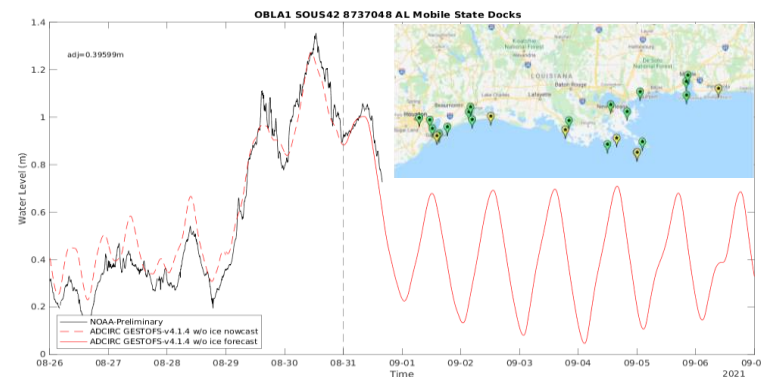Parallel system at ND for a prototype of v3.0

Colleting global statistics

https://cera.coastalrisk.live/

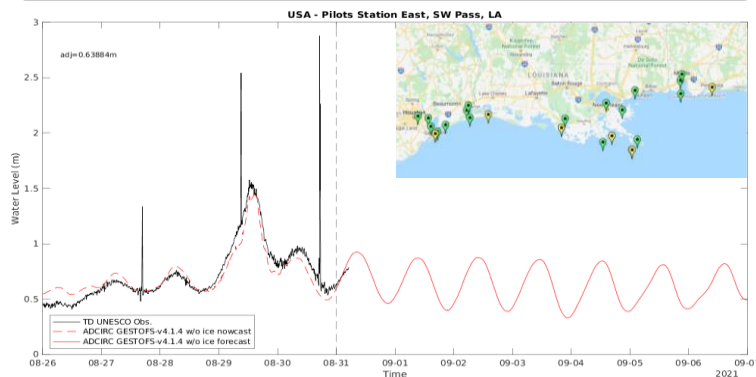https://gm-ling.github.io/GESTOFS-develop/
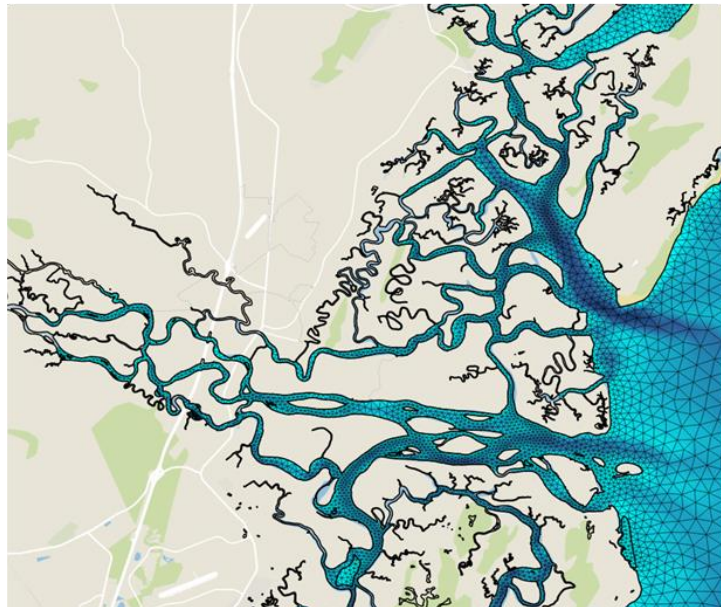
Hurricane Ida 2021

Key N°1: Wet/dry separation

Aligning nodes along the ocean/floodplain interface allows for representing the smallest scale features in the model.
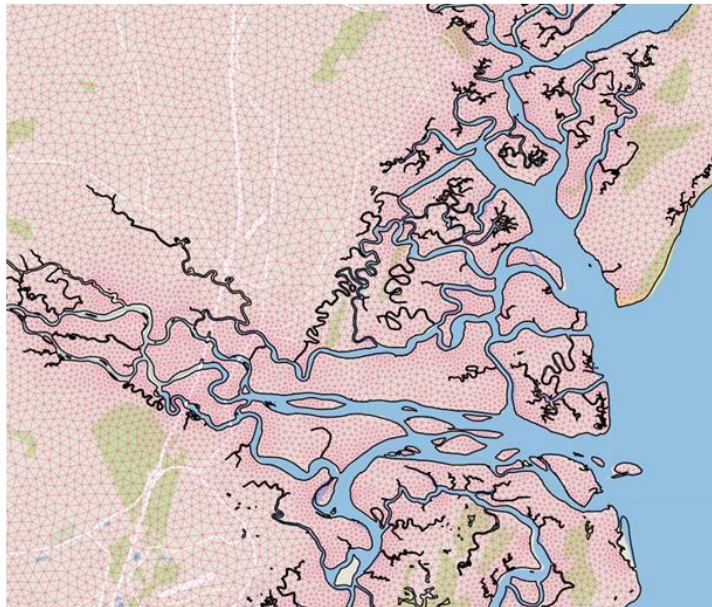
Clear hydraulic connectivity of small channels

Incorporation of barrier islands and small islands
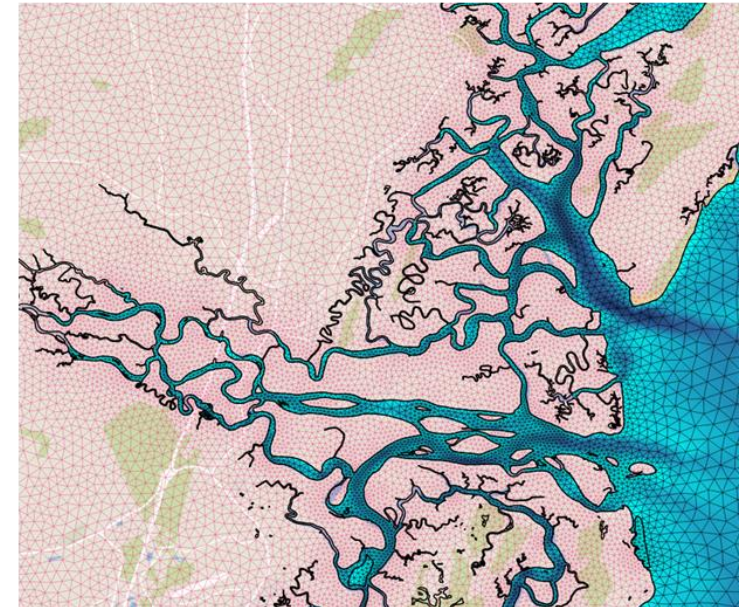
Provides more stability

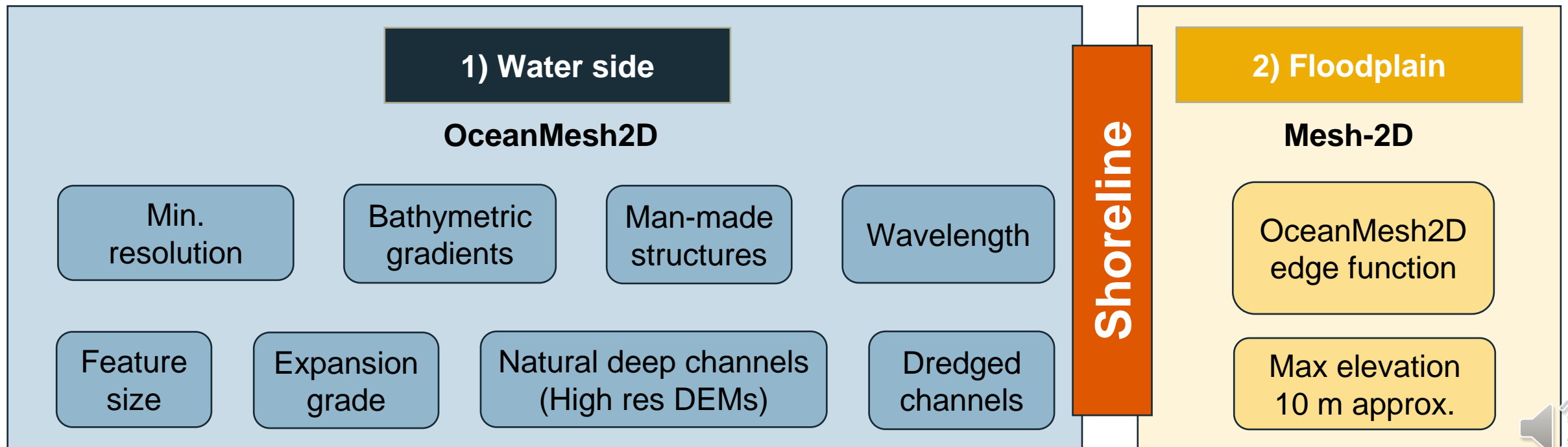| Ocean	Floodplain	Combined

Key N°2: Resolution distribution

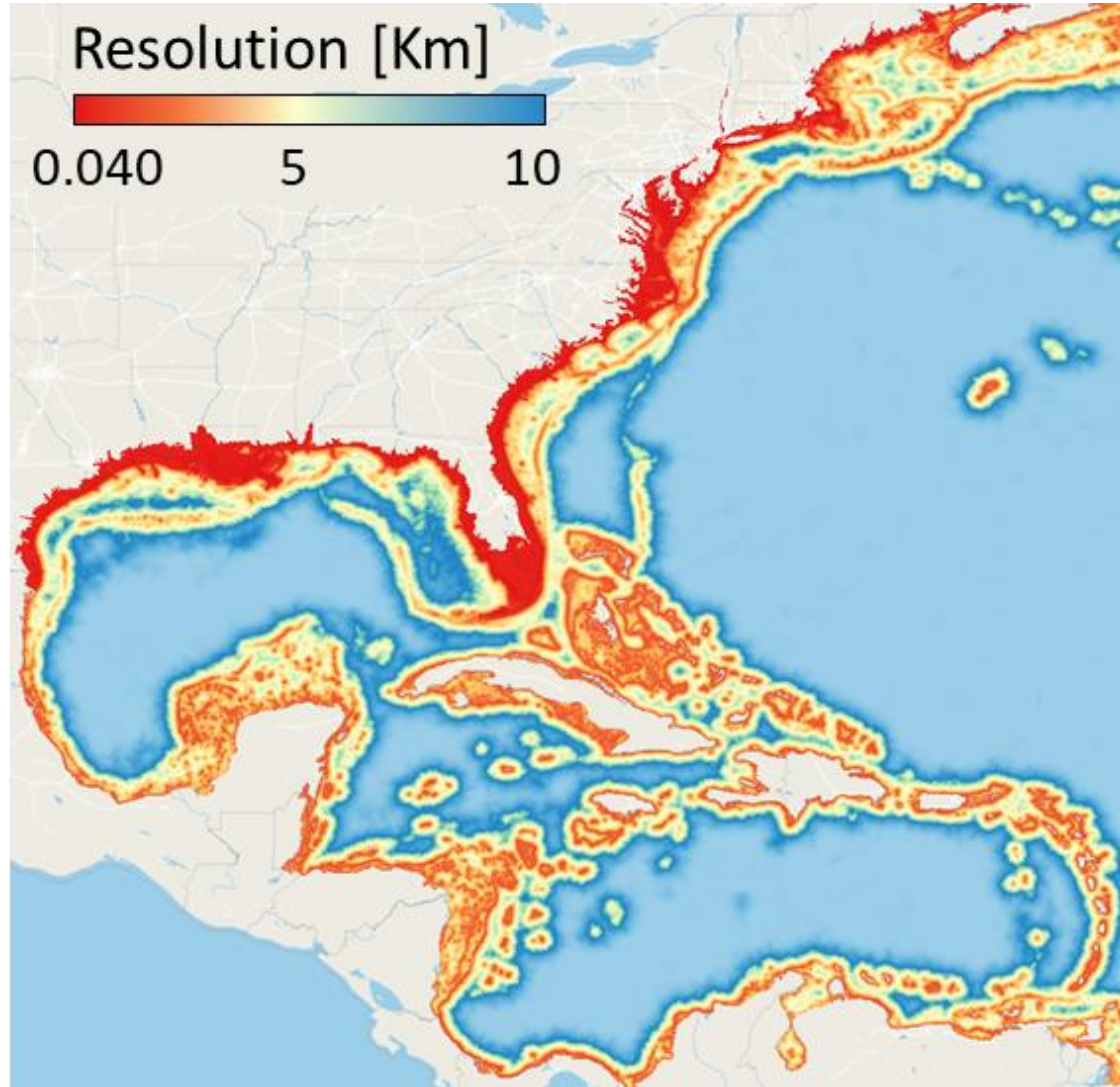## Parametrization of nodal distribution based on topo-bathymetric features and their geometry

Balance between accuracy and efficiency
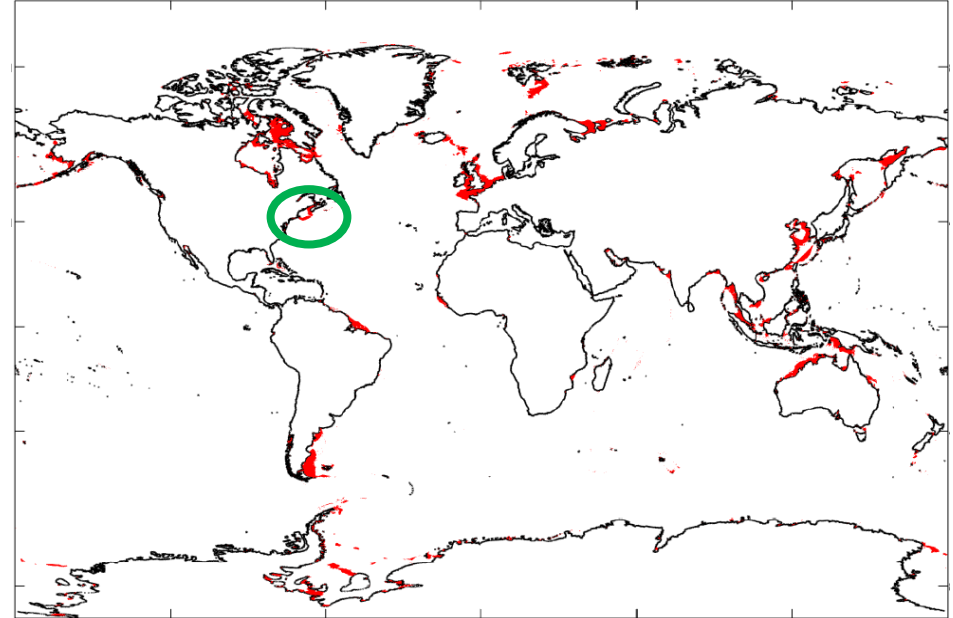
Prioritization of the complex nearshore region

Meet computational cost constraint for operational systems

1) Water side

OceanMesh2D

- Min. resolution
- Bathymetric gradients
- Man-made structures
- Wavelength
- Feature size
- Expansion grade
- Natural deep channels (High res DEMs)
- Dredged channels

Shoreline

2) Floodplain

Mesh-2D

- OceanMesh2D edge function
- Max elevation 10 m approx.

Key N°2: Resolution distribution

Resolution [Km]
0.040   5   10

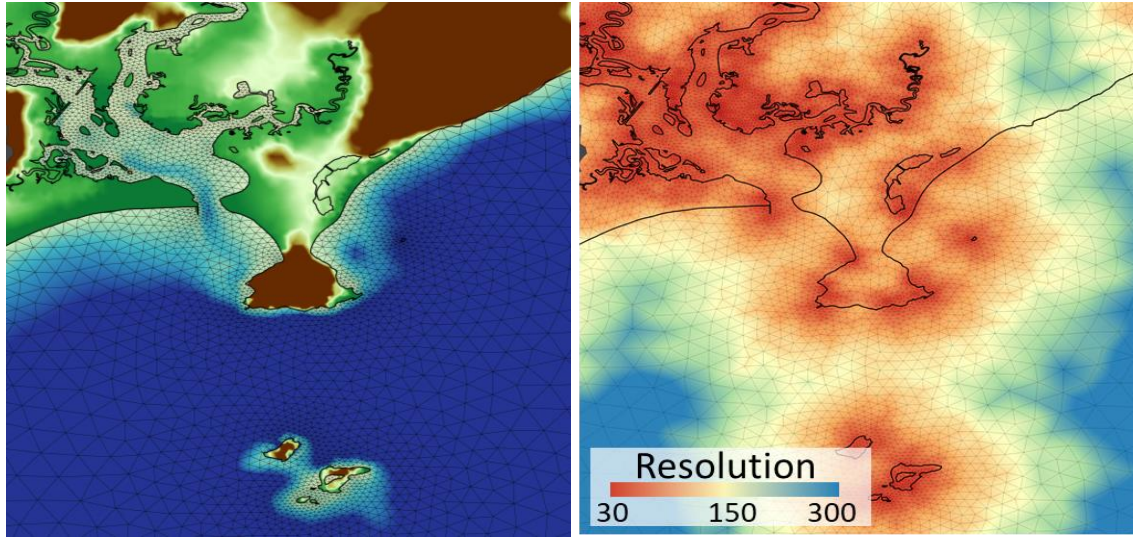**High-dissipation areas – Gulf of Maine**

Bathymetric gradients

➢ Continental shelf break, submarine ridges, and rough bathymetry

➢ Change on wave celerity due to quick change of water depth
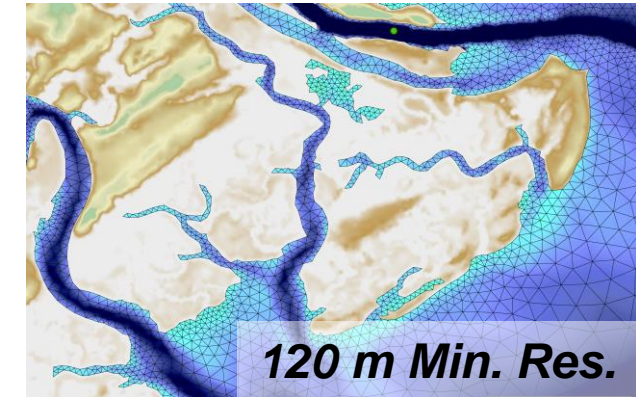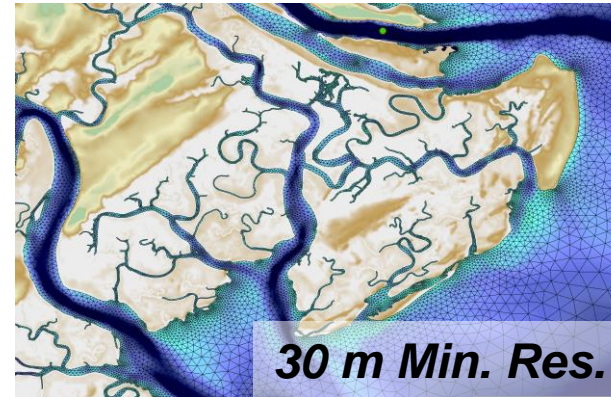
➢ Mechanism of internal tides generation

Key N°2: Resolution distribution

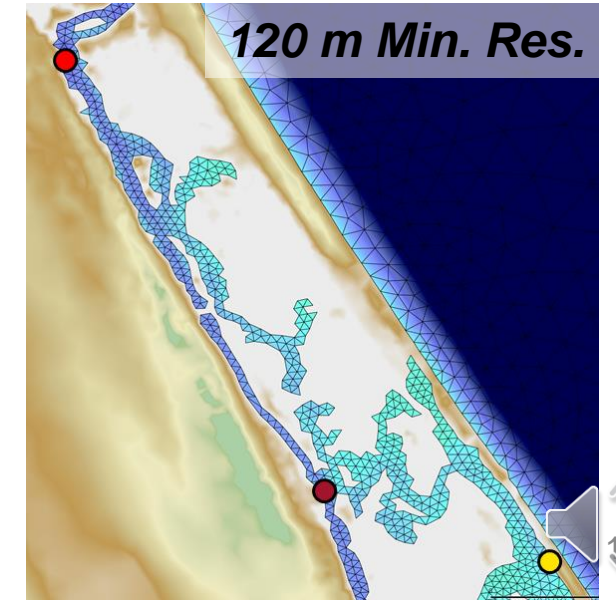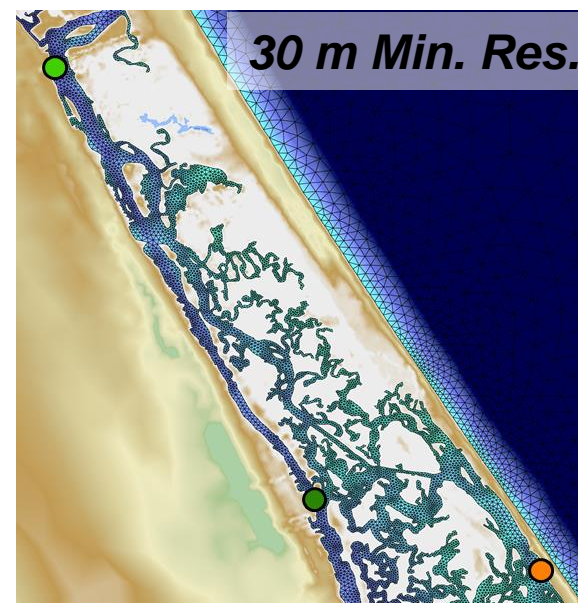**Feature Size – Expansion grade**

Resolution
30   150   300

➤ Estimation of medial axis and feature width

➤ Nodal distribution based on shoreline complexity

➤ Prioritization of channels, islands, and shoreline geometry

➤ Increment of element size offshore

➤ Crucial for efficiency on distribution of resolution
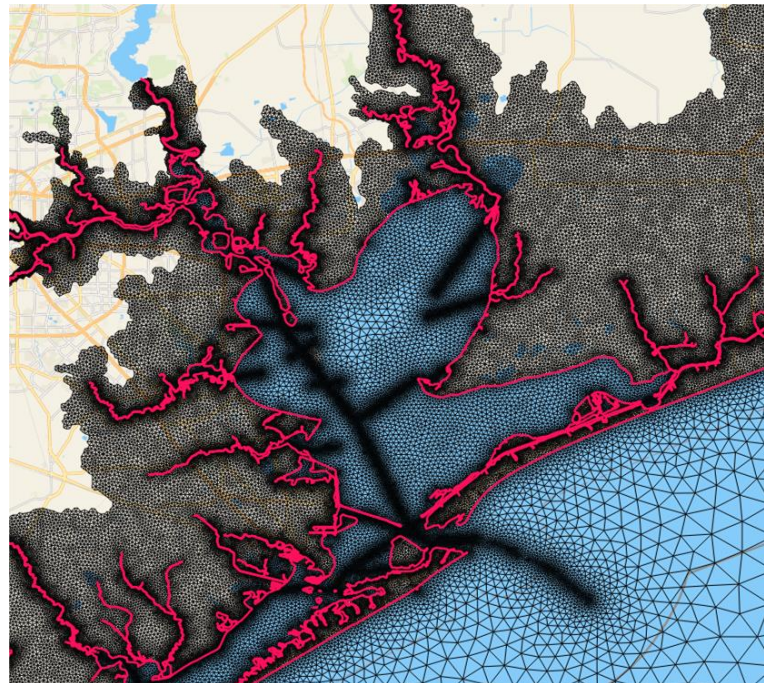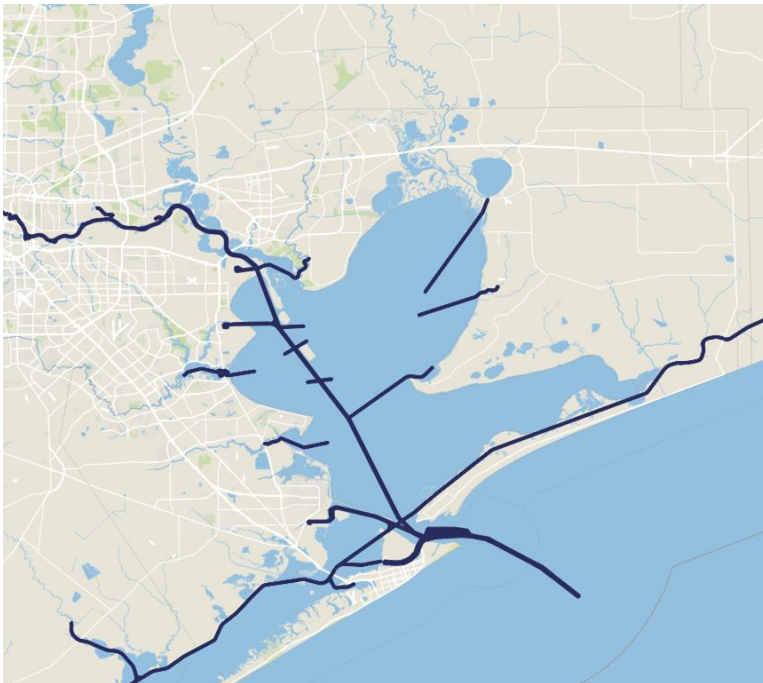
Complex channel network

30 m Min. Res.

120 m Min. Res.

Complexity of intertidal zone

30 m Min. Res.

120 m Min. Res.

Key N°2: Resolution distribution
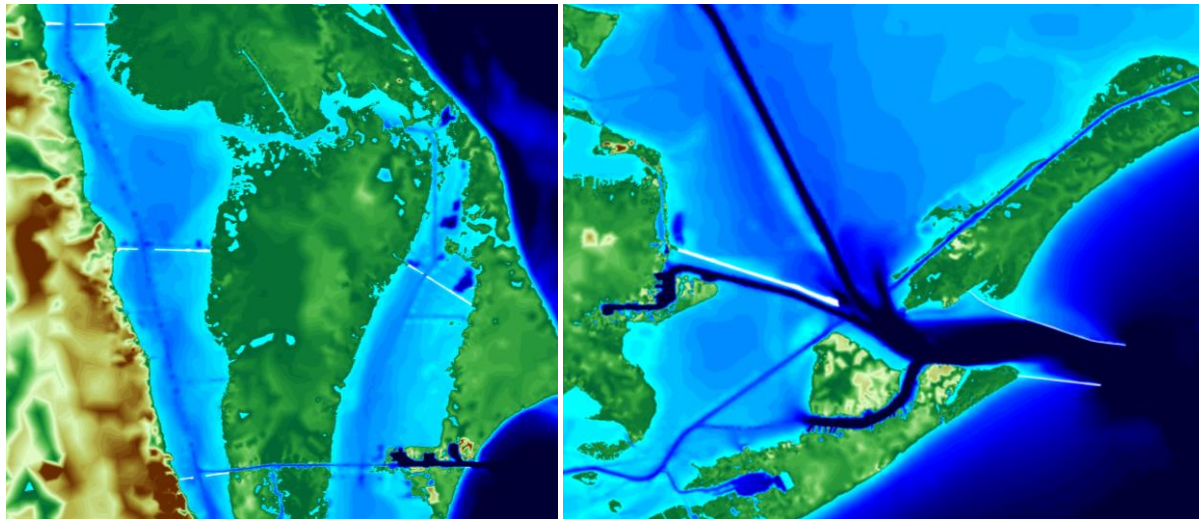
Natural deep and dredged channels

➤ Deep narrow channels that require higher definition to properly capture the water depth

➤ Crucial to preserve the conveyance

➤ Dredged channels based on USACE database, and natural channels derived from DEMs

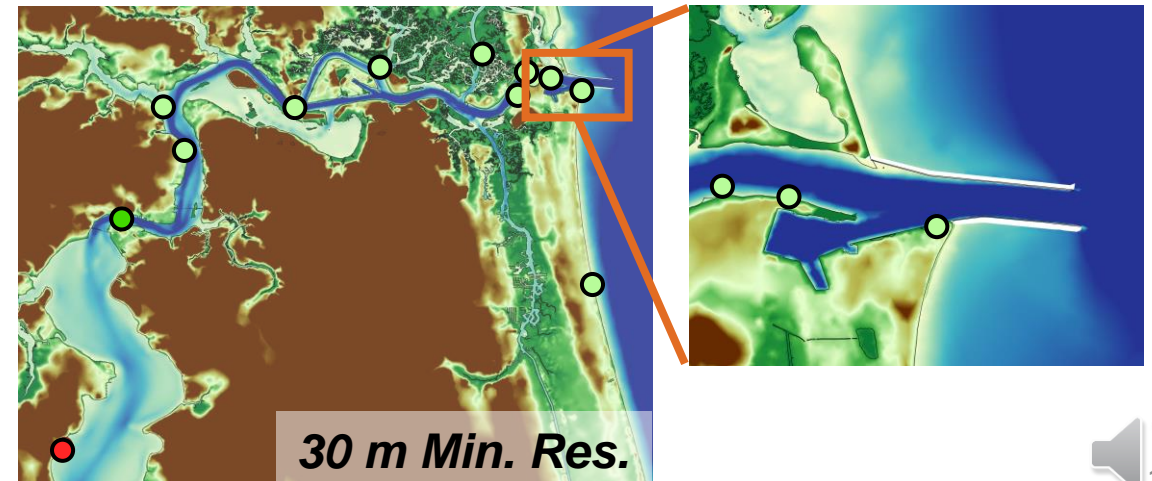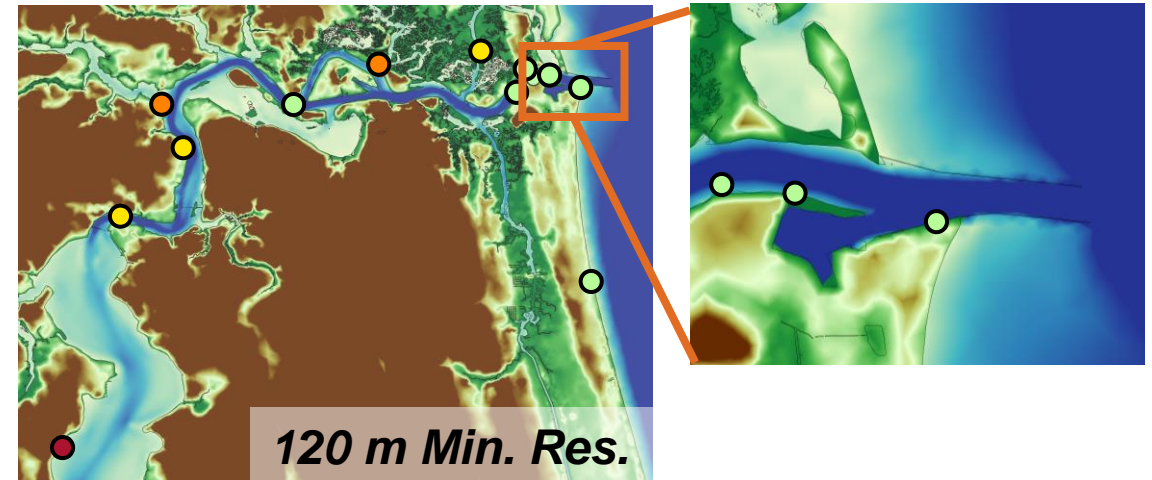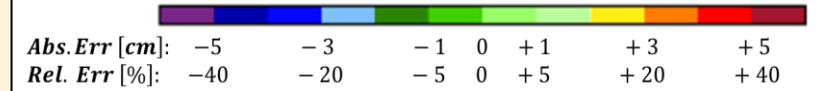➤ Adjustment of resolution and bathymetry

Key N°2B: Man-made structures

Jetty systems

- Creation of a dataset with 116 jetties

- Adjust shoreline and local element size function so they can be included in the minimum resolution of the model

- Only implemented for resolutions ~tens of meters.
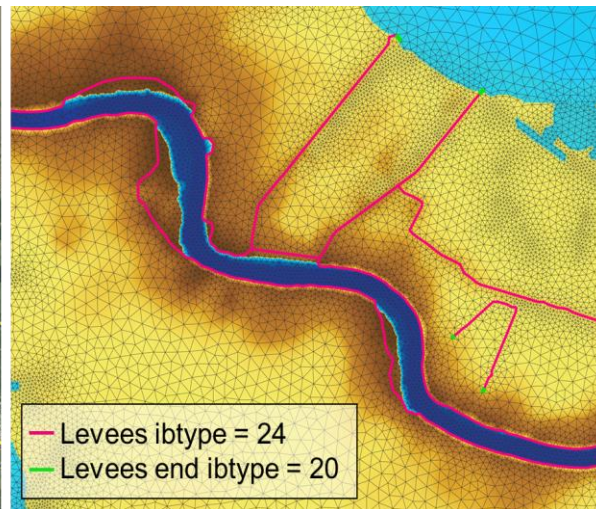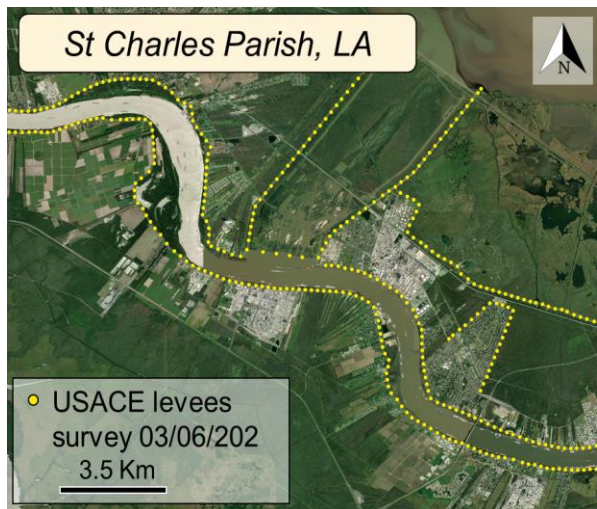
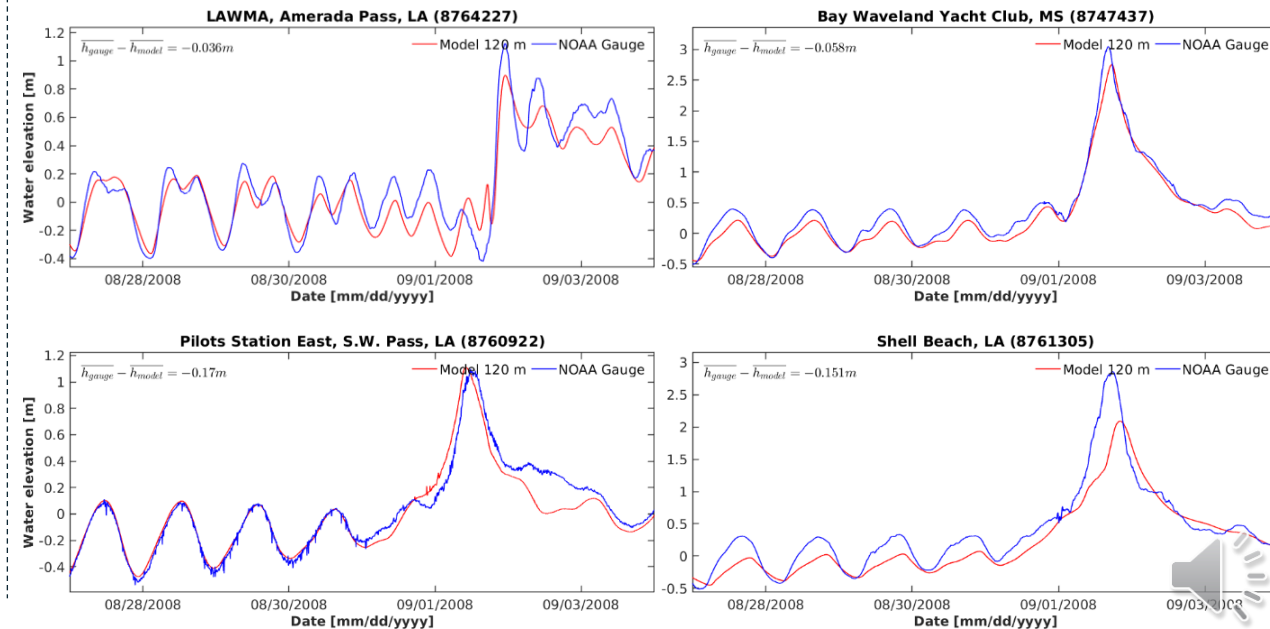- Open land boundary conditions
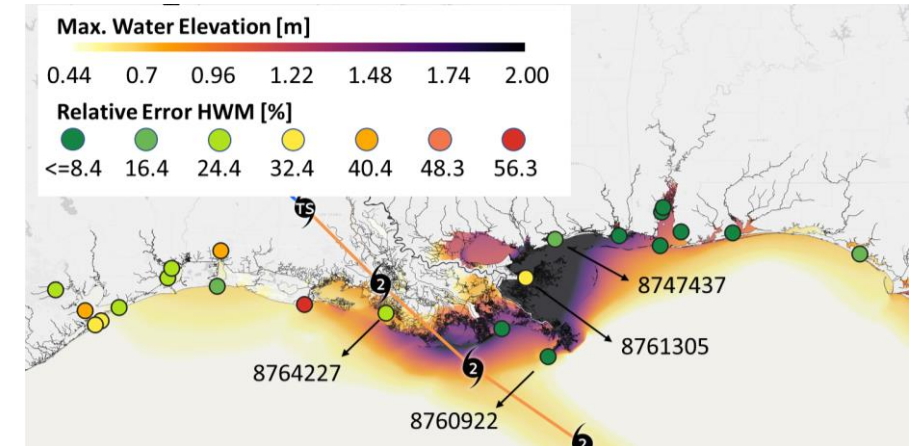
M_2 tidal constituent

| Abs. Err [cm]: | −5 | −3 | −1 | 0 | +1 | +3 | +5 |
| Rel. Err [%]: | −40 | −20 | −5 | 0 | +5 | +20 | +40 |

120 m Min. Res.

30 m Min. Res.

Key N°2B: Man-made structures

- USACE dataset for federal levees

- Snap the centerlines to the wet/dry interface based on the minimum resolution of the model

- Constraint levees nodes during the floodplain generation

- Weir boundary condition

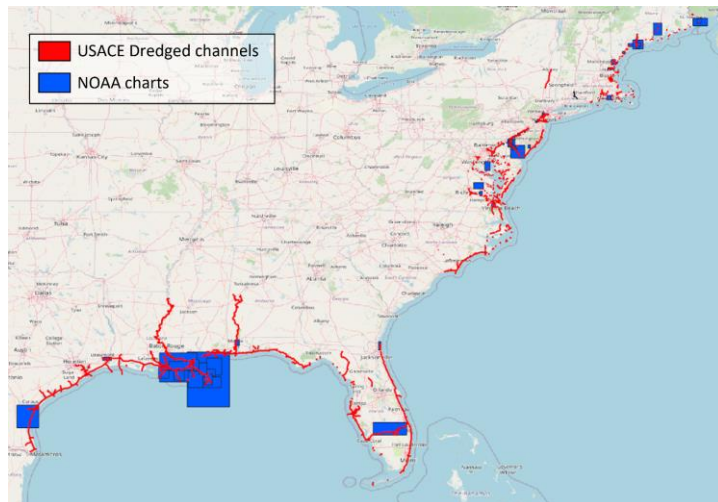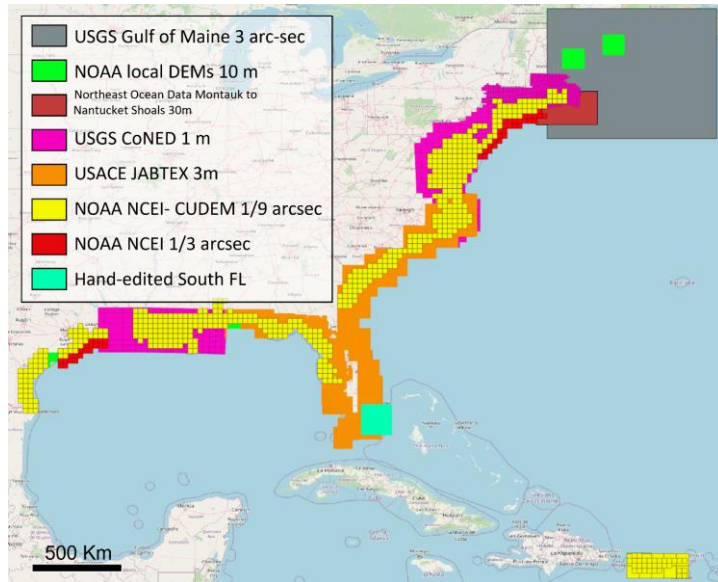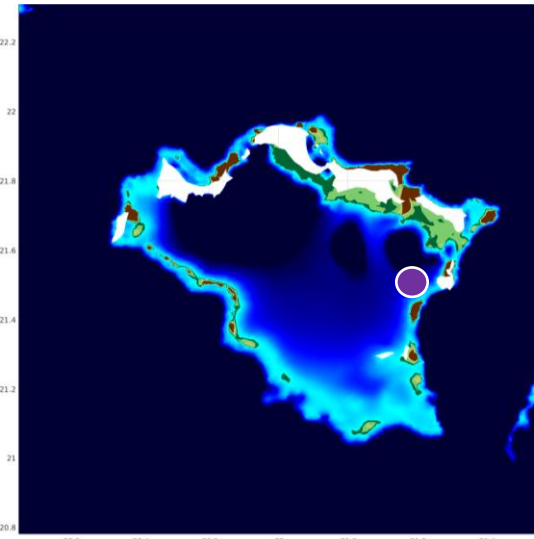- Adjustment of bathymetry to ensure clean wet/dry interface

St Charles Parish, LA

○ USACE levees survey 03/06/202
3.5 Km

— Levees ibtype = 24
— Levees end ibtype = 20

Historical storms - Gustav 2008

Max. Water Elevation [m]
0.44 0.7 0.96 1.22 1.48 1.74 2.00
Relative Error HWM [%]
<=8.4 16.4 24.4 32.4 40.4 48.3 56.3

8747437
8764227
8761305
8760922

LAWMA, Amerada Pass, LA (8764227)
$\overline{h_{gauge}} - \overline{h_{model}} = -0.036m$
— Model 120 m — NOAA Gauge

Bay Waveland Yacht Club, MS (8747437)
$\overline{h_{gauge}} - \overline{h_{model}} = -0.058m$
— Model 120 m — NOAA Gauge

Pilots Station East, S.W. Pass, LA (8760922)
$\overline{h_{gauge}} - \overline{h_{model}} = -0.17m$
— Model 120 m — NOAA Gauge

Shell Beach, LA (8761305)
$\overline{h_{gauge}} - \overline{h_{model}} = -0.151m$
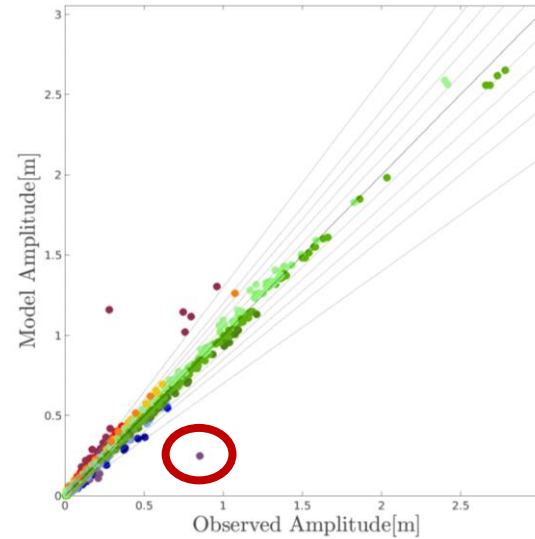— Model 120 m — NOAA Gauge

Key N°3: Correct bathymetry
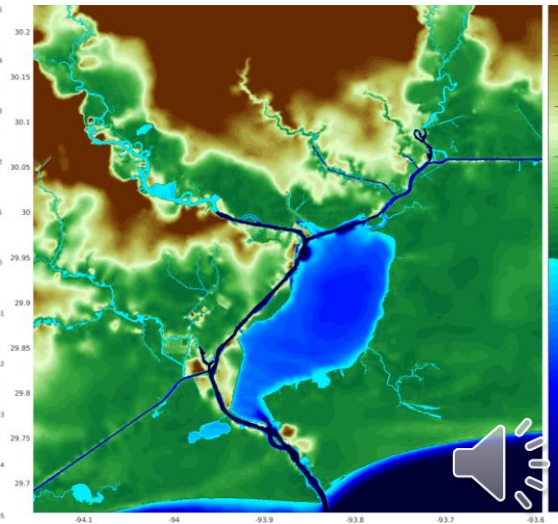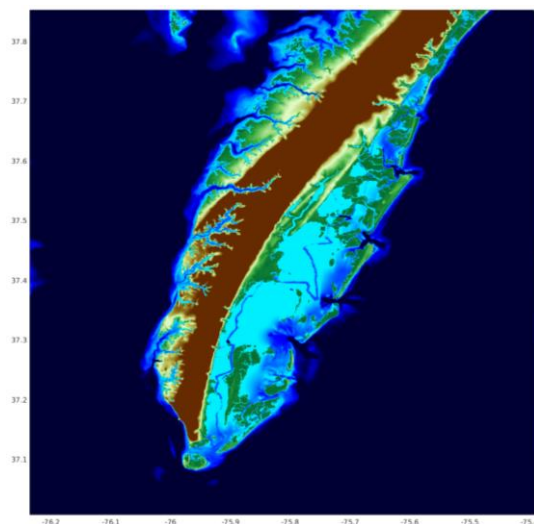

Topo-bathymetric databases

Bathymetric errors

Lack of data

Particularly in upper sections of rivers

Conclusions – future work

- Key for developing efficient channel-to-basin scale hydrodynamics models:
    - Clear wet/dry interface
    - High-resolution only where it is needed
    - Clear conveyance of river network
    - Addition of hydrodynamically relevant man-made structures

- Future work:
    - Incorporate riverine flow inputs from NWM

Thanks for your attention!

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