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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Abstract

Coastal interfaces blend processes dominated by upland region hydrology and ocean hydrodynamics (tides, winds, waves, baroclinic fluctuations, among others). These areas tend to be vulnerable to flooding, a matter of concern considering that around 40% of the world's population lives within 100 km of the ocean. Specifically, The US East and Gulf of Mexico Coasts are heavily affected by extratropical storms every year with catastrophic consequences. Models that integrate the dynamics of both oceans and river networks are needed in order to better improve flood forecast systems in coastal areas. Due to their spatial and temporal scale differences, traditional models solve river and ocean hydrodynamics independently. As a first step toward unifying coastal interface modeling, we designed an ADCIRC-based model that uses unstructured, highly variable-sized triangular meshes that can accurately represent both ocean basins and inland river networks. This meshing technique allows for incorporating features that control the dynamics of the nearshore area, such as barrier islands, jetties, and dredged channels. We analyze how mesh design impacts water level estimations in the deep ocean as well as inland rivers. Accuracy in the deep ocean is sensitive primarily to bathymetry in areas with high energy dissipation, whereas water level prediction within river networks depends on both bathymetry and resolution. While a minimum resolution in the order of a hundred meters is enough to accurately predict water level for most rivers with tidal influence, smaller tributaries require resolutions down to tens of meters. Future research will use these findings to build precipitation and rainfall-runoff into the model for a more comprehensive understanding of the coastal interface hydrodynamics.

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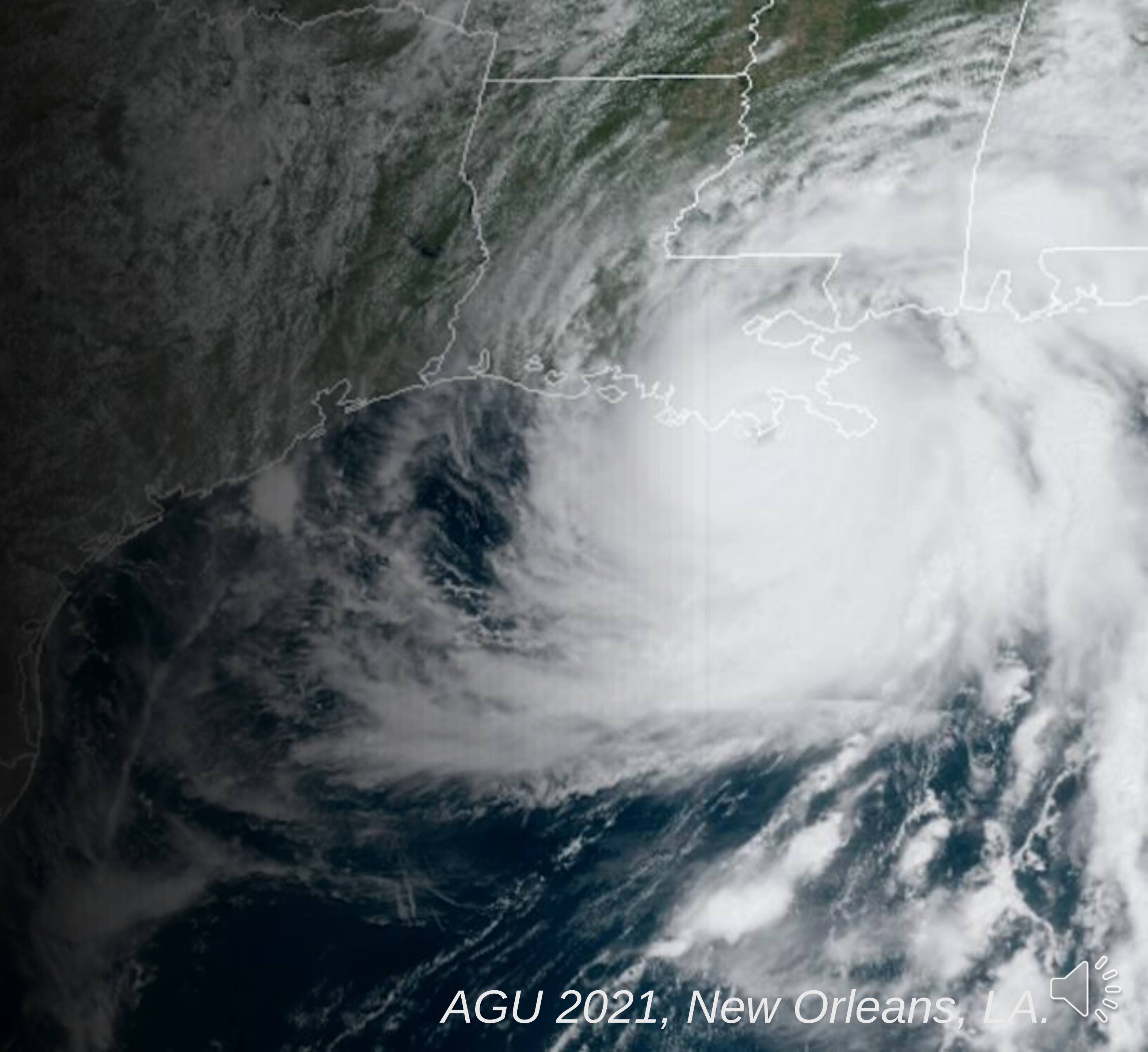
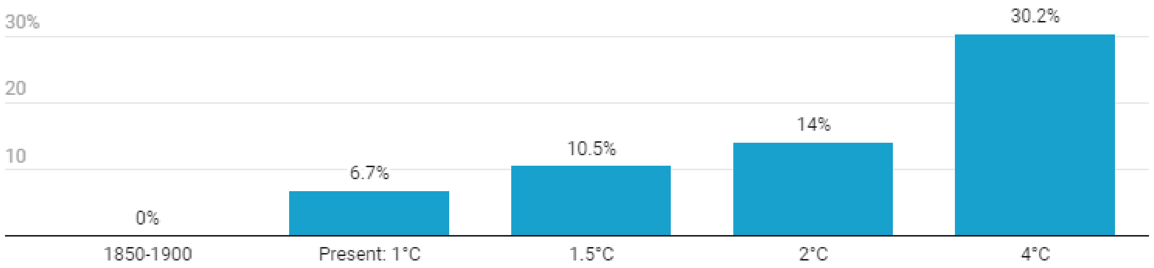


AGU 2021, New Orleans, LA.

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.

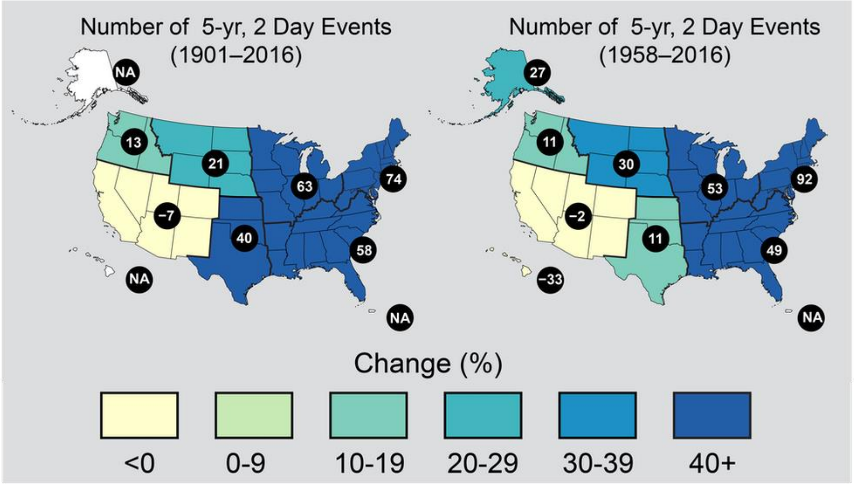
A small bit of added moisture can lead to a lot more rain:



Compared to the 1850-1900 average. 1° Celsius increase = 1.8° Fahrenheit increase.

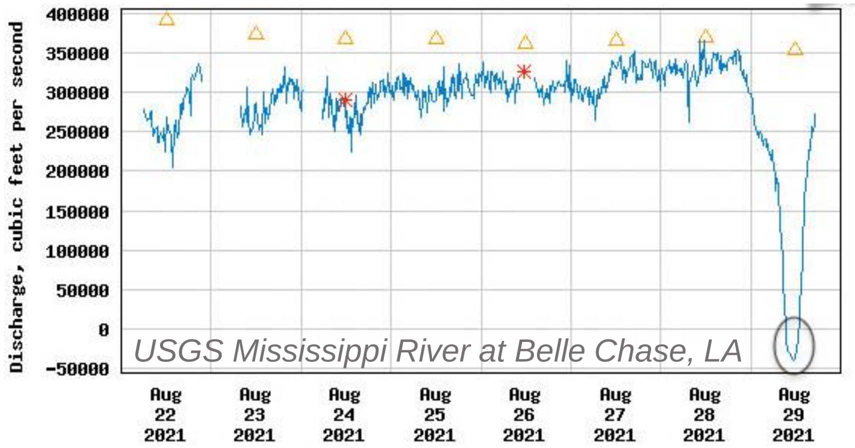
IPCC 6th Assessment Report (2021)

Intensity of rainfall is expected to increase as the climate warms



4th National Climate Change Assessment (2018)

Hurricane Ida 2021



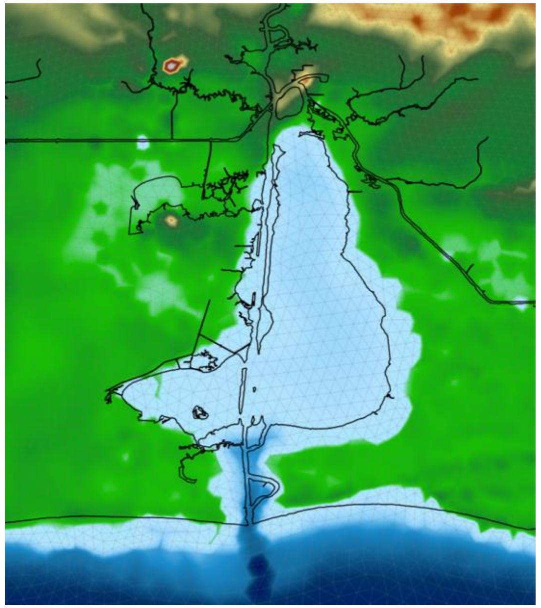
NWS Eastern Region
@NWSEastern

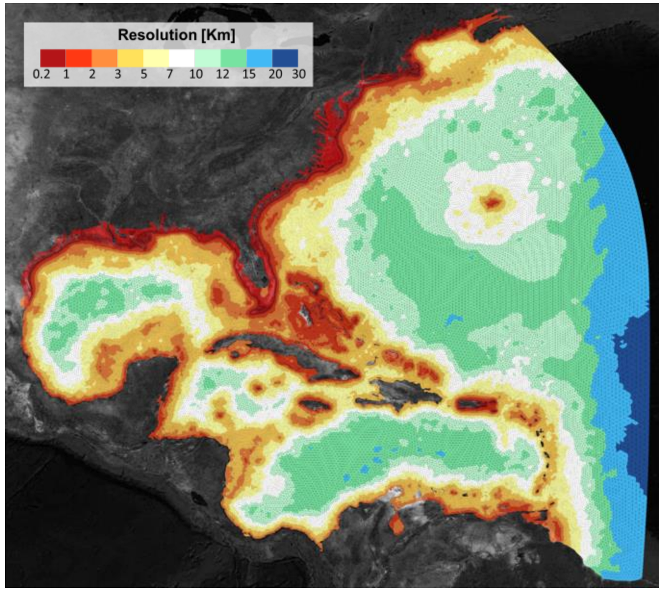
Observed rainfall totals for the last 48 hours ending 9 am Thursday September 2nd. Rainfall rates at some locations were 2.5-3.5 inches per hour. Newark NJ received 3.24" from 8-9 pm & Central Park saw 3.15" from 9-10 pm, both all time records for highest 1-hour rainfall totals

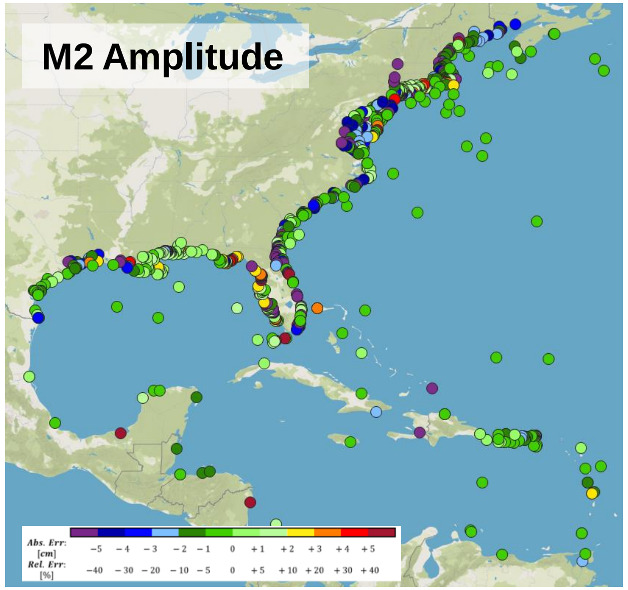
Traducir Tweet

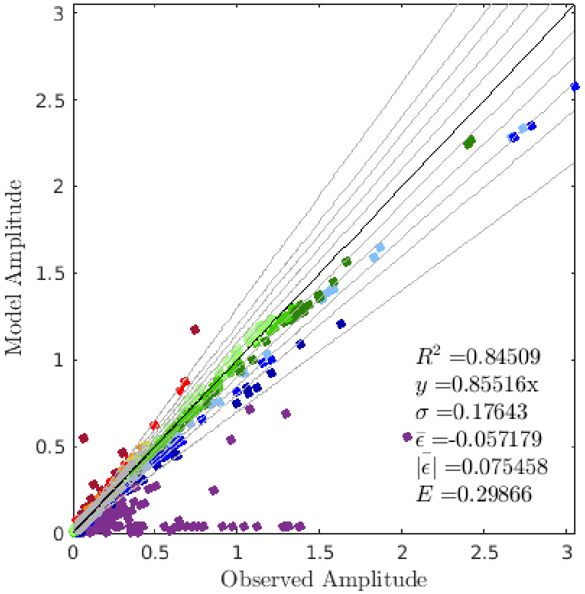
Motivation – Current ESTOFS

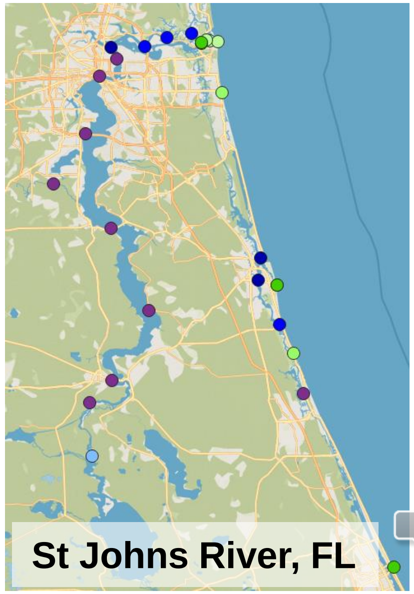
- 250 m resolution ESTOFS model
- Sub-optimal grids: linear variation of resolution
- Highly simplified river network
- Poor definitions of inland waterbodies: source of instabilities and inaccuracy











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

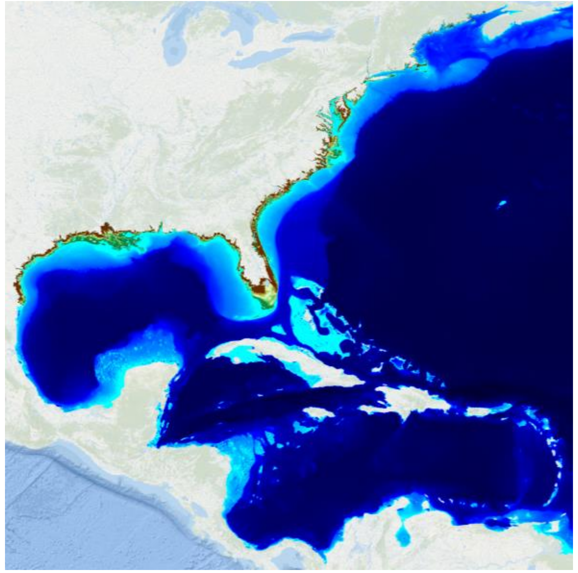
Efficient distribution of resolution for operational purposes

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

Key to incorporate additional physical forcing in future research

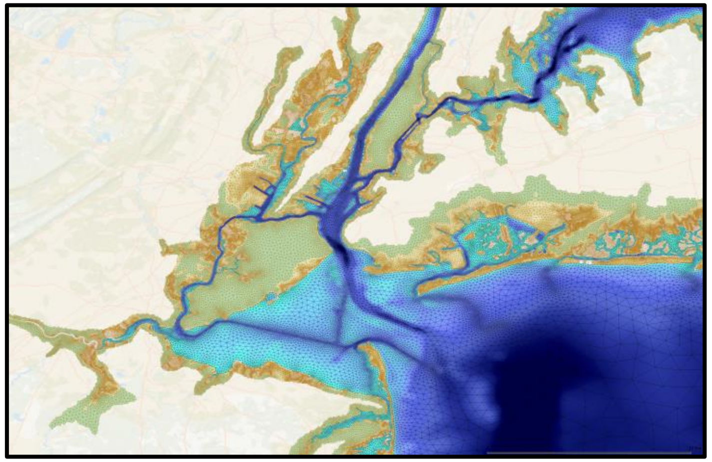
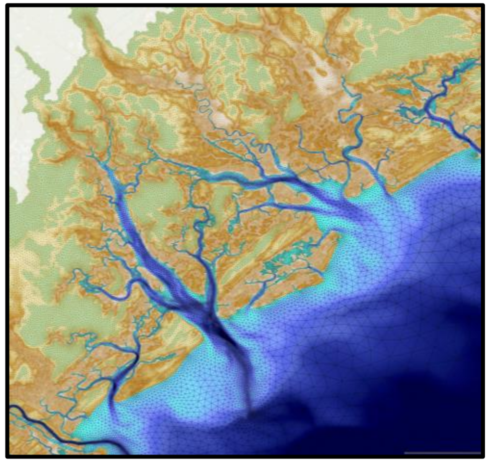
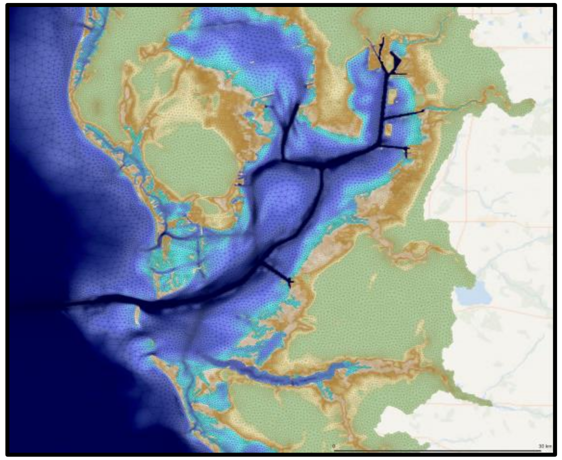
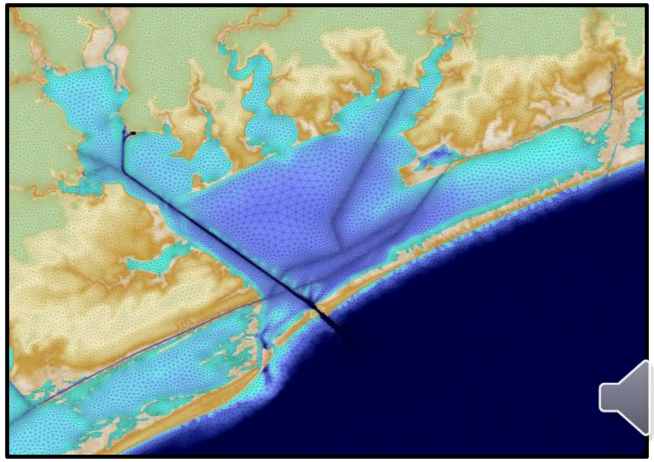
Mesh implementation

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

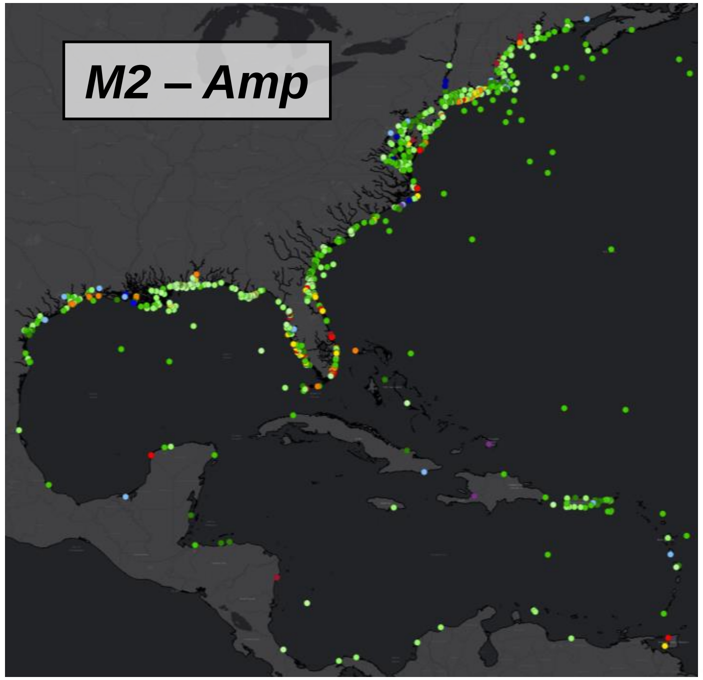
	Model 30 m	**_Model 120 m_**
Min. Res	$30\ m$	$120\ m$
Max. Res	$24\ Km$	$24\ Km$
Nodes	$21.5\ M$	$6.0\ M$
Elements	$43.0\ M$	$11.8\ M$

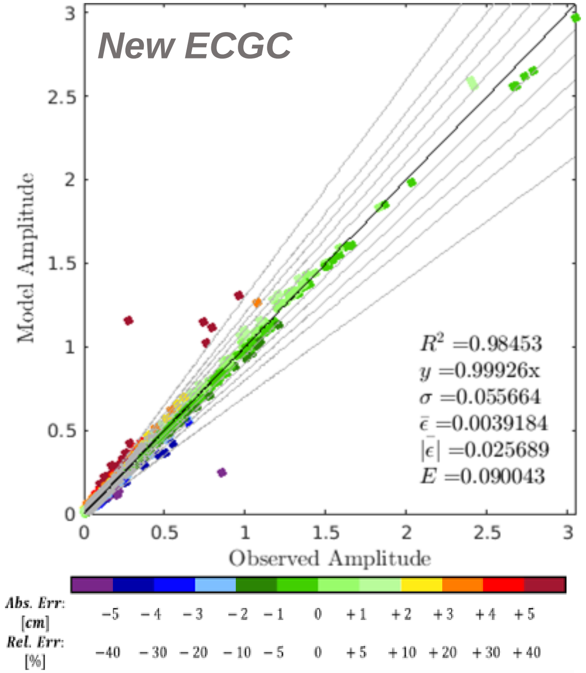





Mesh validation - Tides

Tidal analysis for amplitude and phase of 8 major constituents

Comparison of results against ~800 tidal gauges





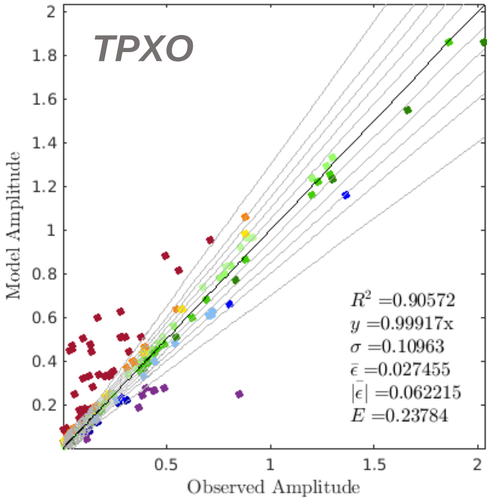
Amplitude

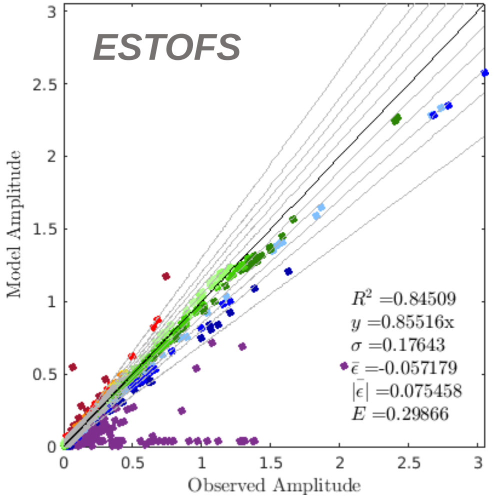
	$M2$	$S2$	$K1$	$O1$
R^2 [−]	0.994	0.966	0.847	0.933
σ [cm]	3.332	1.294	1.573	1.029
$\bar{\epsilon}$ [cm]	0.191	0.259	0.051	0.053
$\|\epsilon\|$ [cm]	2.231	0.856	1.157	0.681
E [−]	0.054	0.131	0.151	0.116

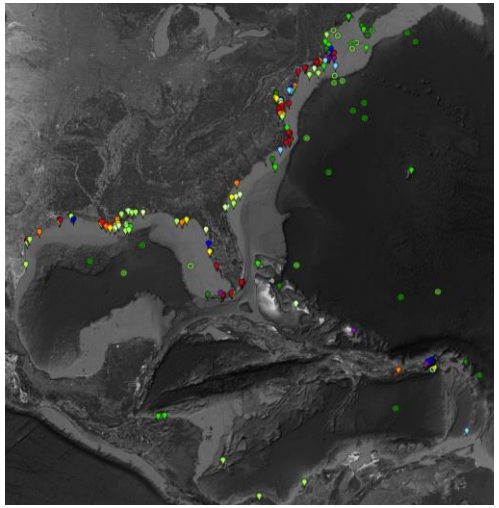
Phase

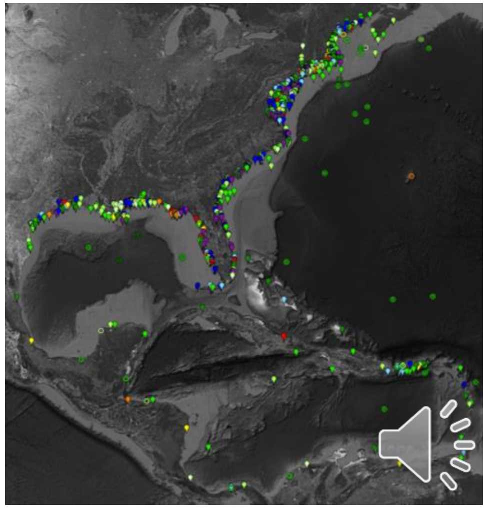
	$M2$	$S2$	$K1$	$O1$
R^2 [−]	0.976	0.943	0.974	0.980
σ	15.903°	21.930°	13.871°	12.863°
$\bar{\epsilon}$	-7.005°	-7.281°	-2.075°	-4.338°
$\|\epsilon\|$	10.177°	13.185°	7.892°	8.840°
E[−]	0.106	0.1450	0.074	0.071

Comparison with TPXO and ESTOFS



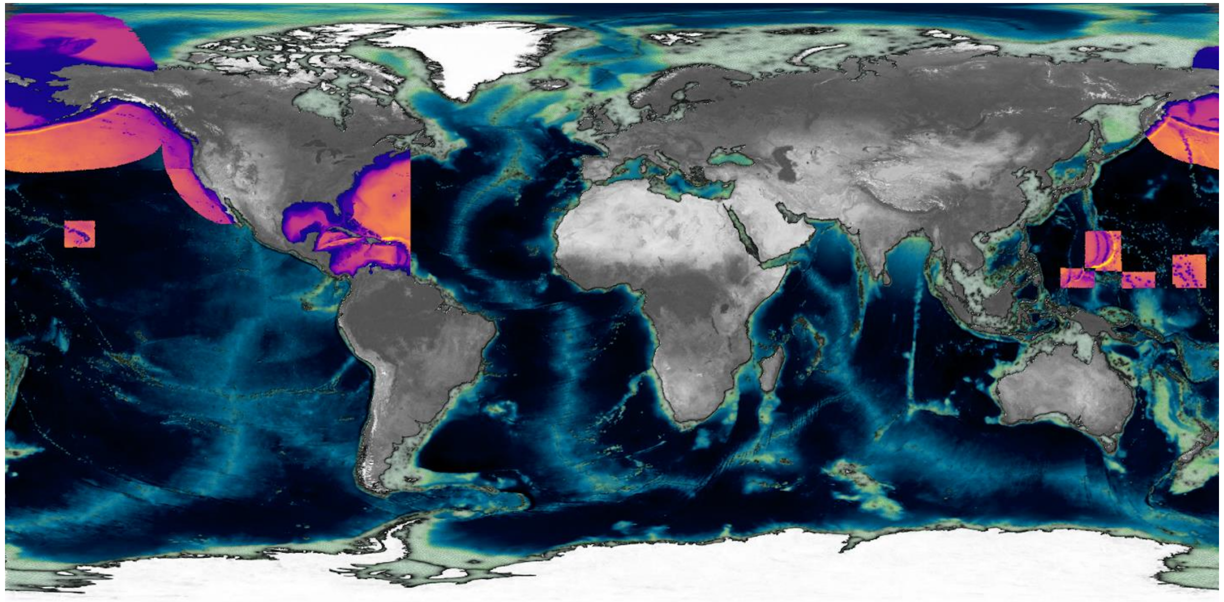




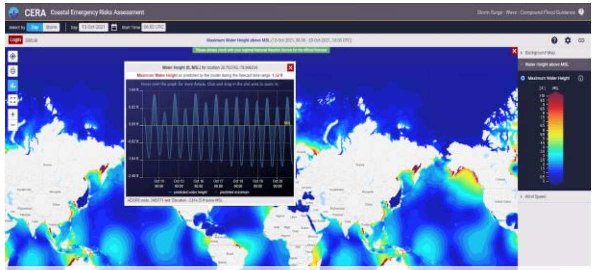


Bonus: NOAA Operational Global Model

Global shell + HR inserts:



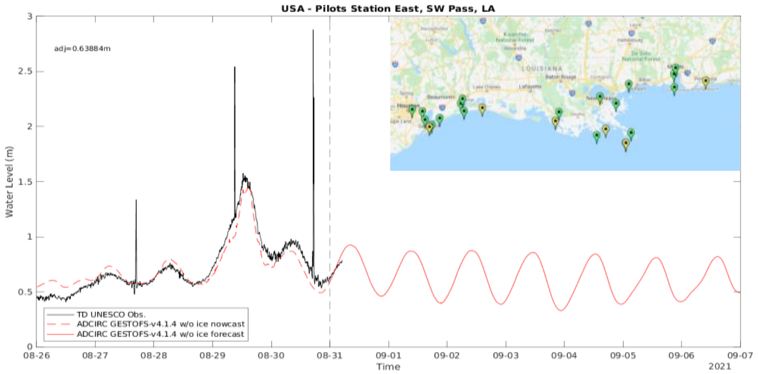
8 M nodes mesh, 6 sec timestep
Forecast 4 times a day for 7 days
Parallel system at ND for a prototype of v3.0
Colleting global statistics

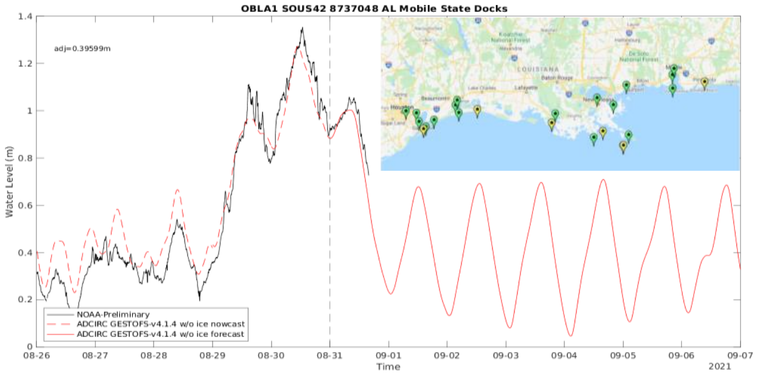


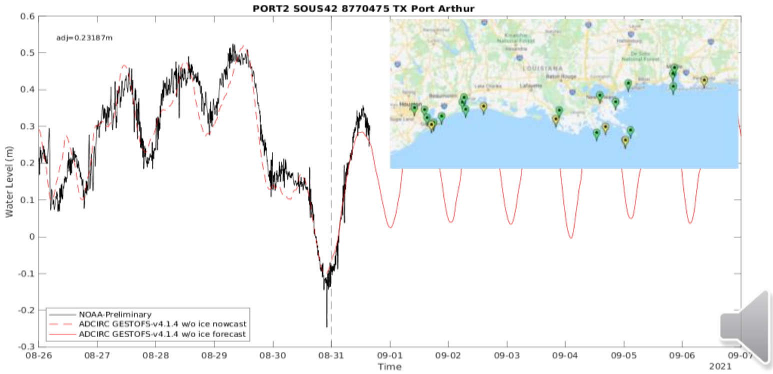
https://cera.coastalrisk.live/

https://gm-ling.github.io/GESTOFS-develop/

Hurricane Ida 2021







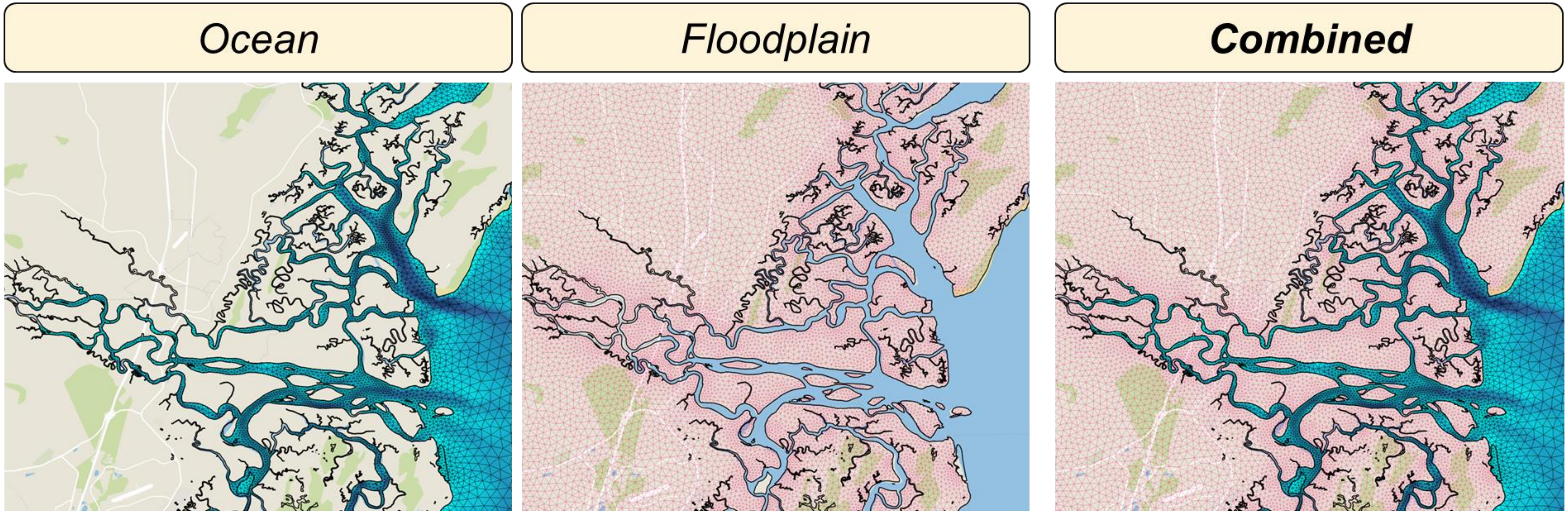
Key N°1: Wet/dry separation

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



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

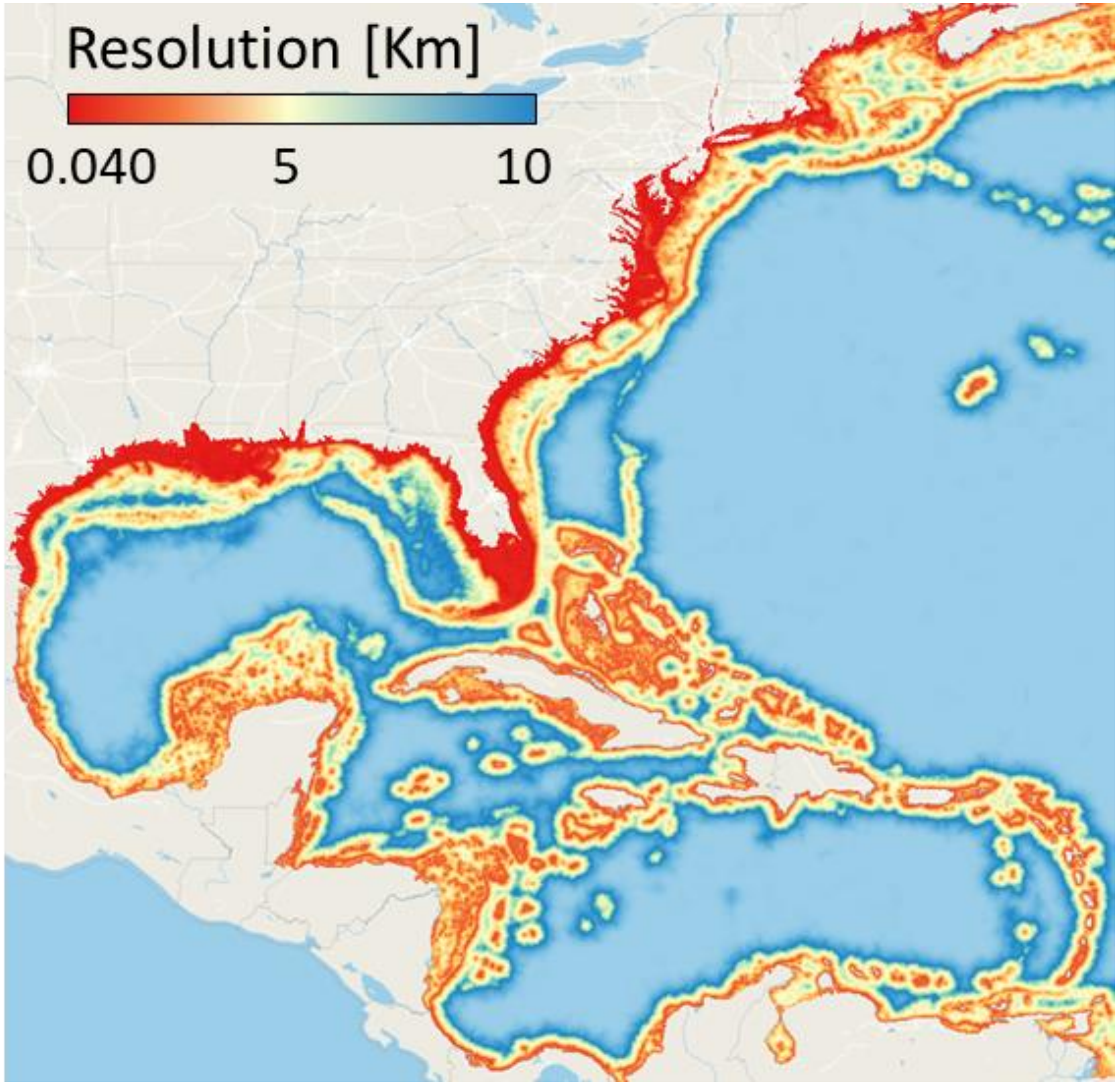
Shoreline

2) Floodplain

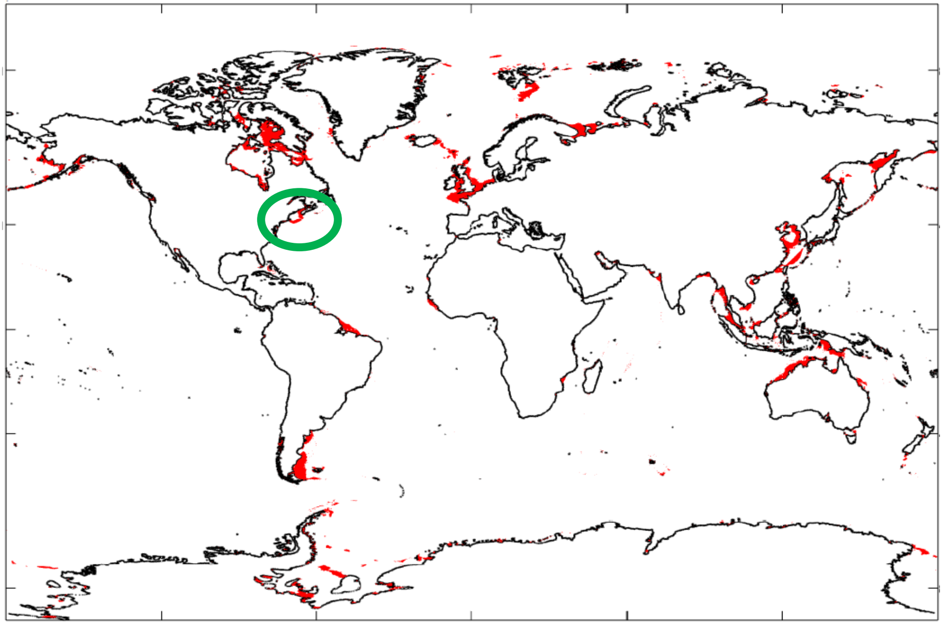
Mesh-2D

- OceanMesh2D edge function
- Max elevation 10 m approx.

Key N°2: Resolution distribution



High-dissipation areas – Gulf of Maine

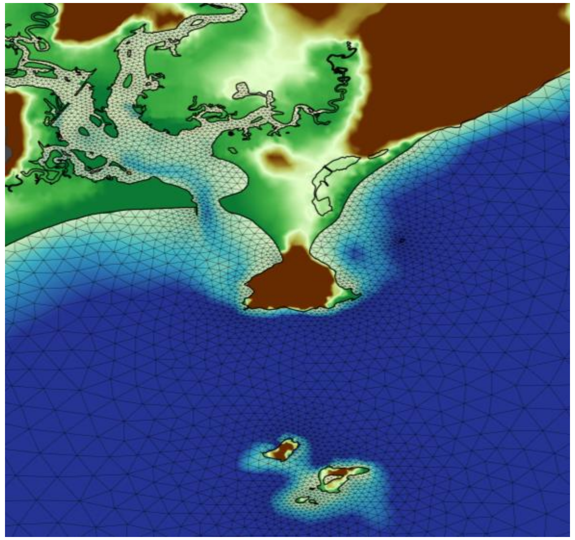


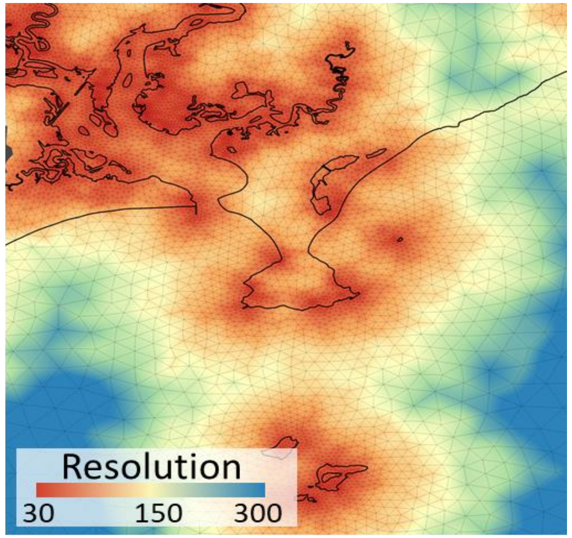
Bathymetric gradients

- 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

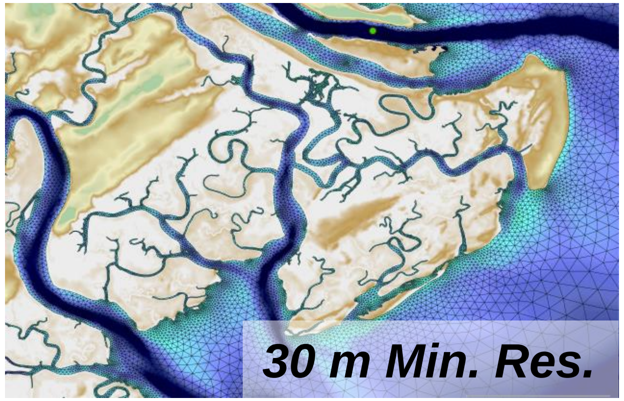
Feature Size – Expansion grade

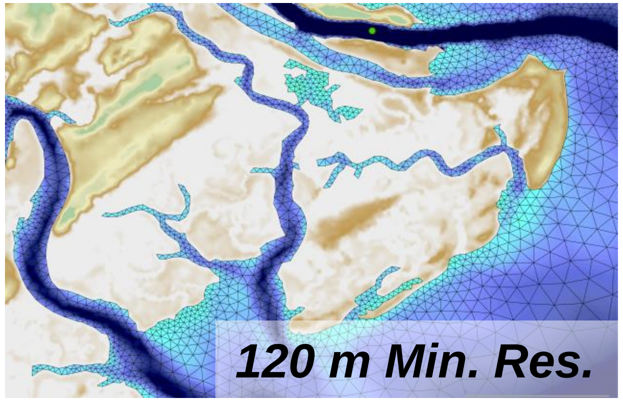




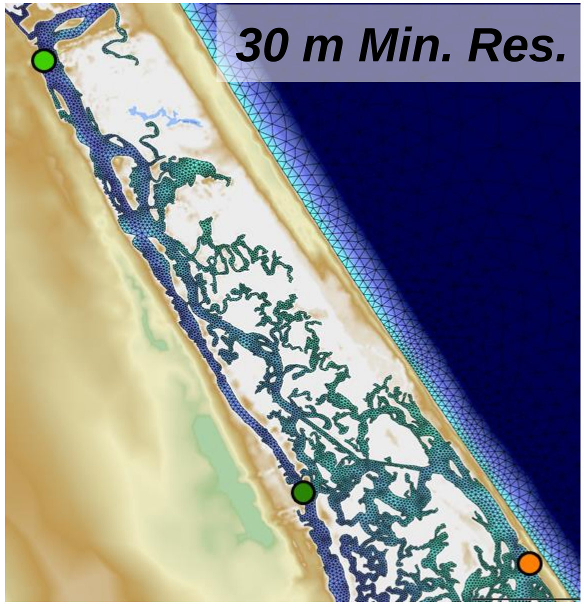
- Estimation of medial axis and feature width
- Nodal distribution based on shoreline complexity
- Prioritization of channels, islands, and shoreline geometry
- Increment of element size offshore
- Crucial for efficiency on distribution of resolution

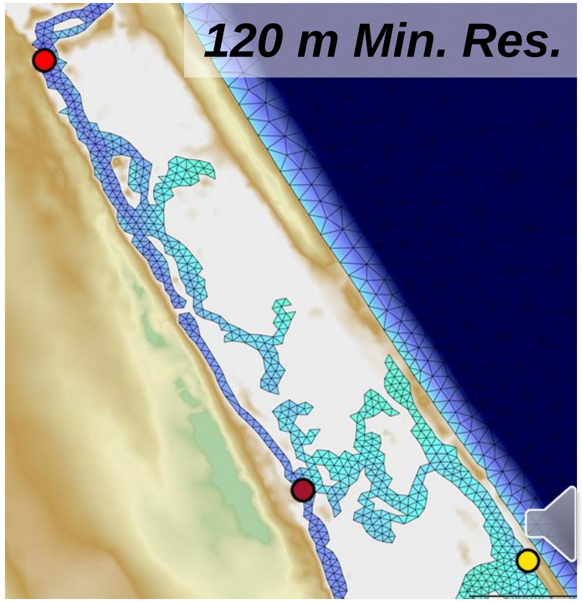
Complex channel network





Complexity of intertidal zone

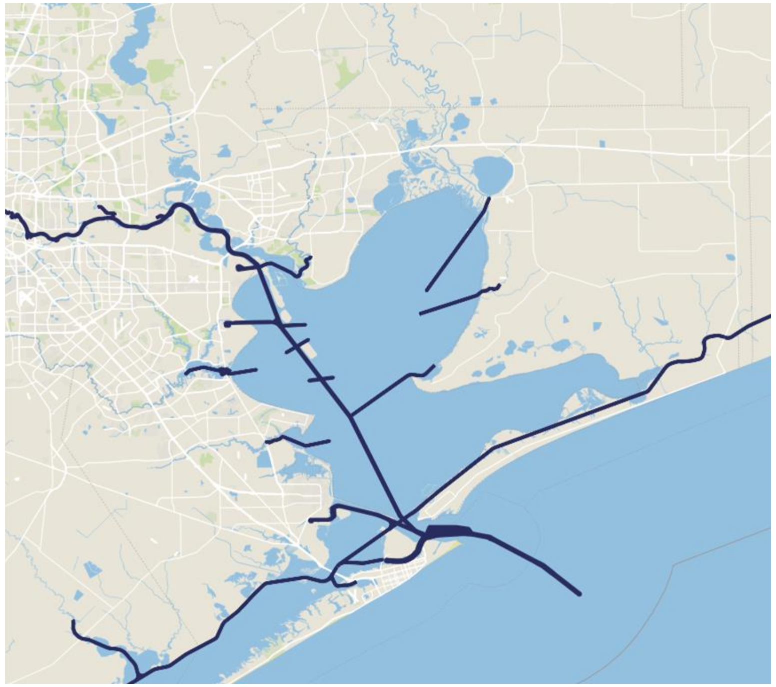


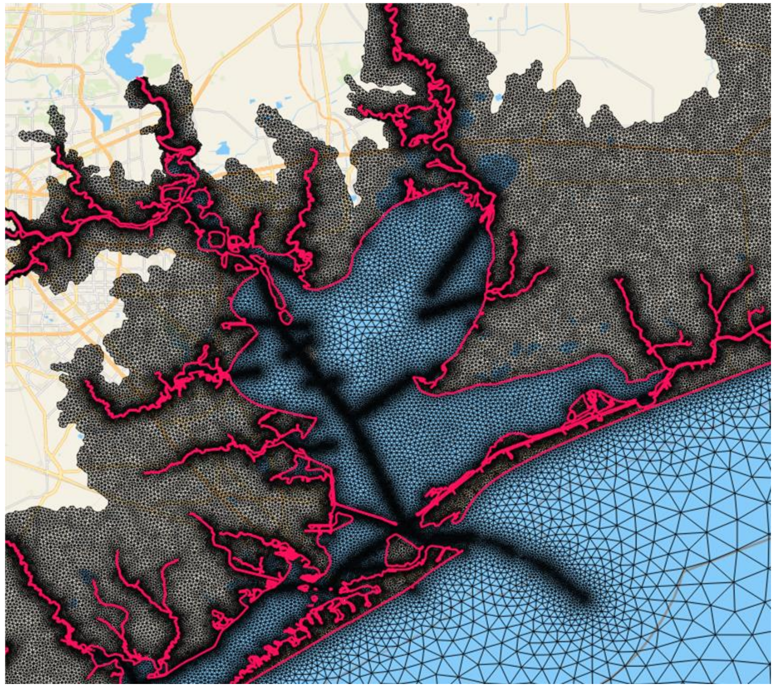


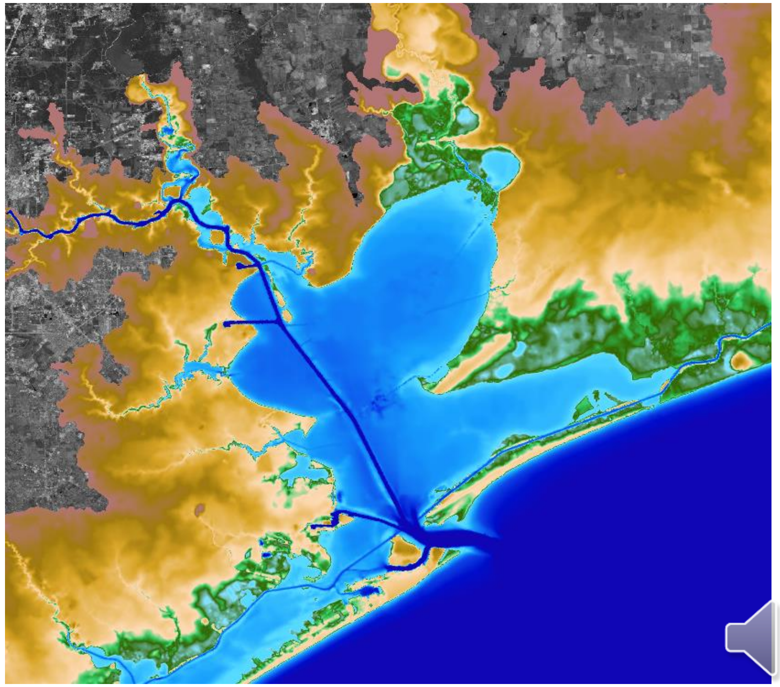
Key N°2: Resolution distribution

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



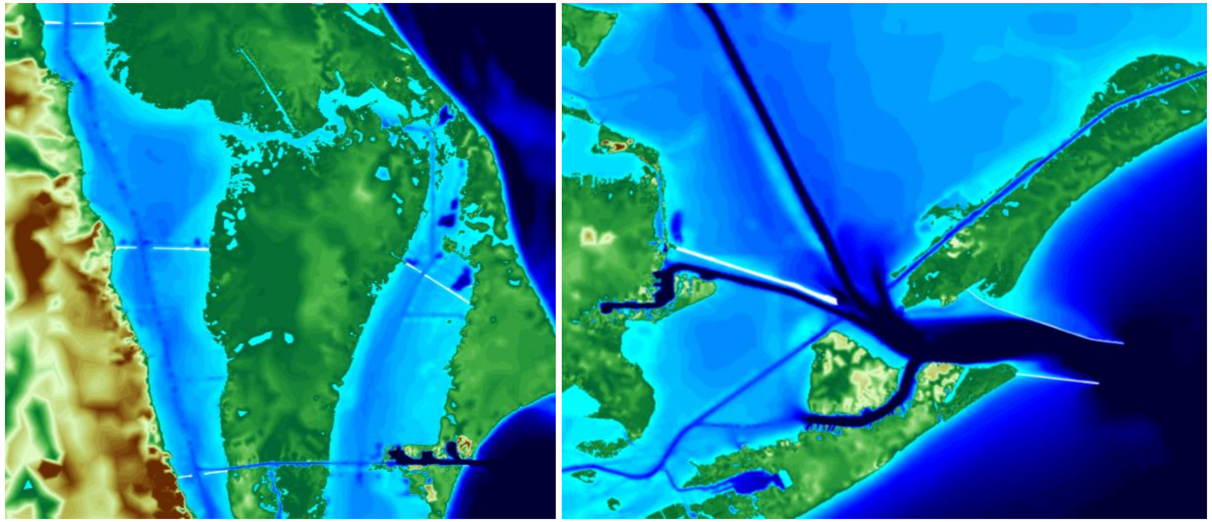




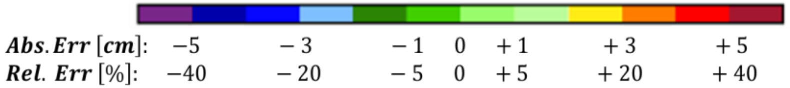
Key N°2B: Man-made structures

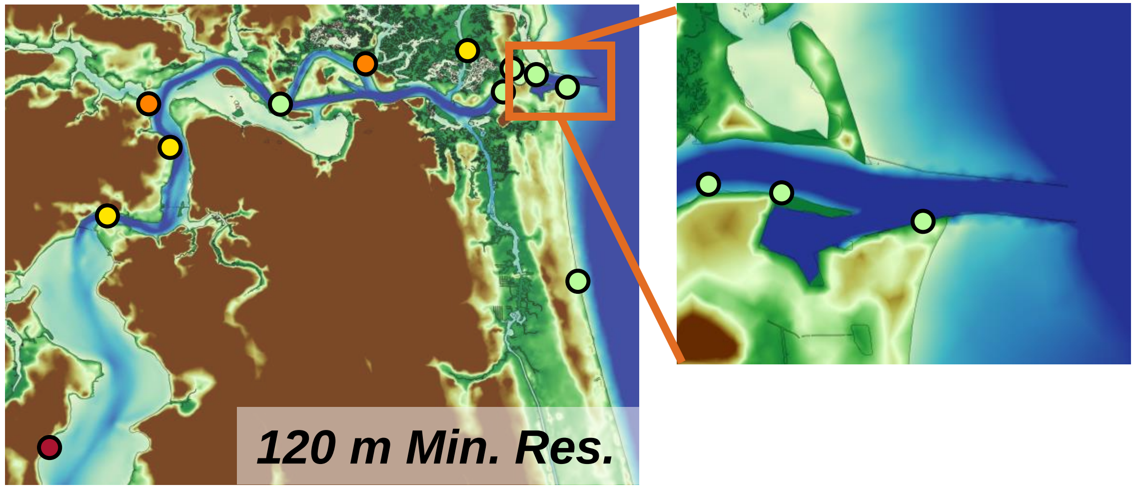
Jetty systems

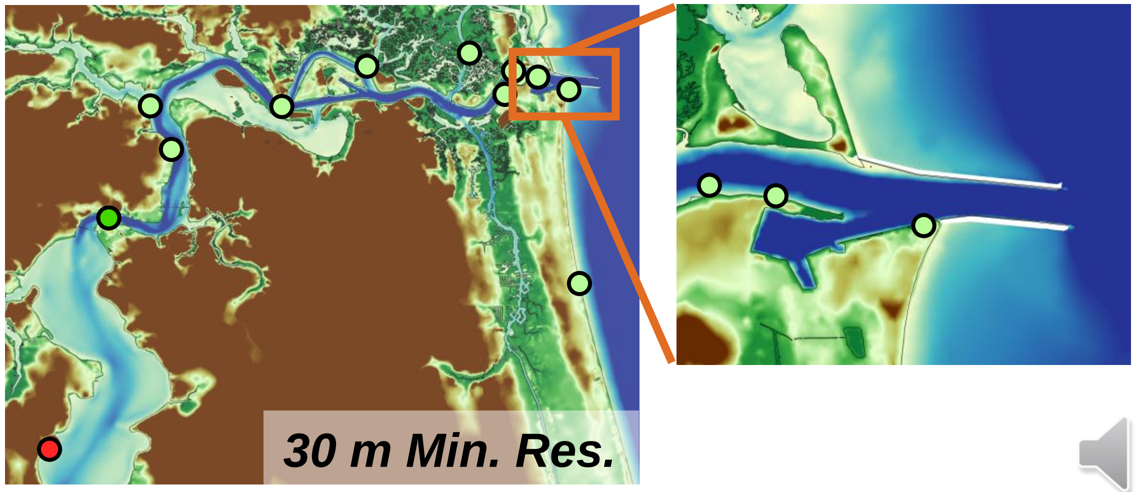
- Creation of a dataset with 116 jetties
- Adjust shoreline and local element size function so they can be included in the minimum resolution of the model
- Only implemented for resolutions ~tens of meters.
- Open land boundary conditions



M_2 tidal constituent



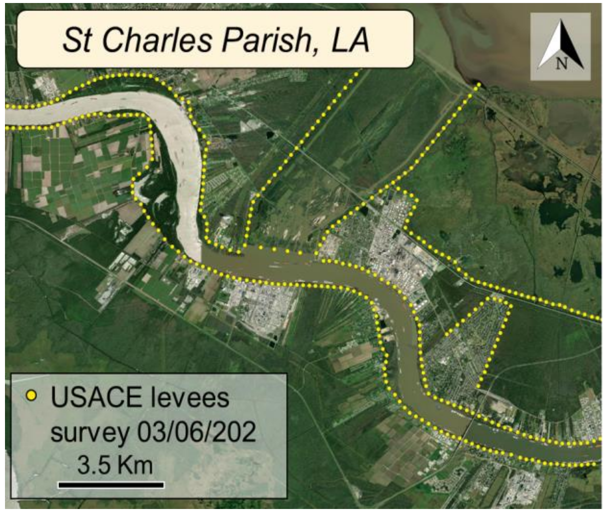


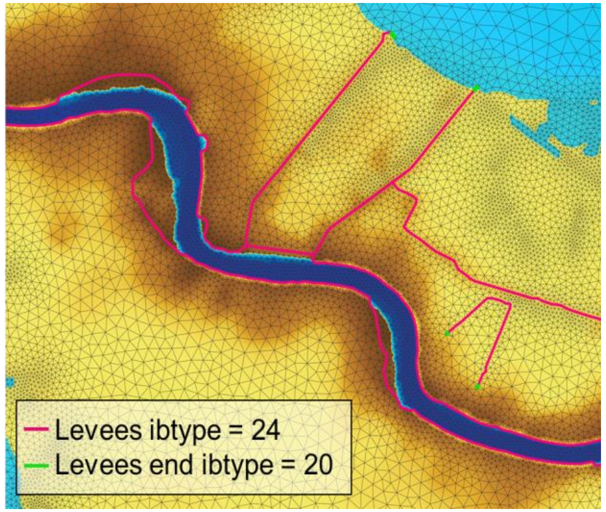


Key N°2B: Man-made structures

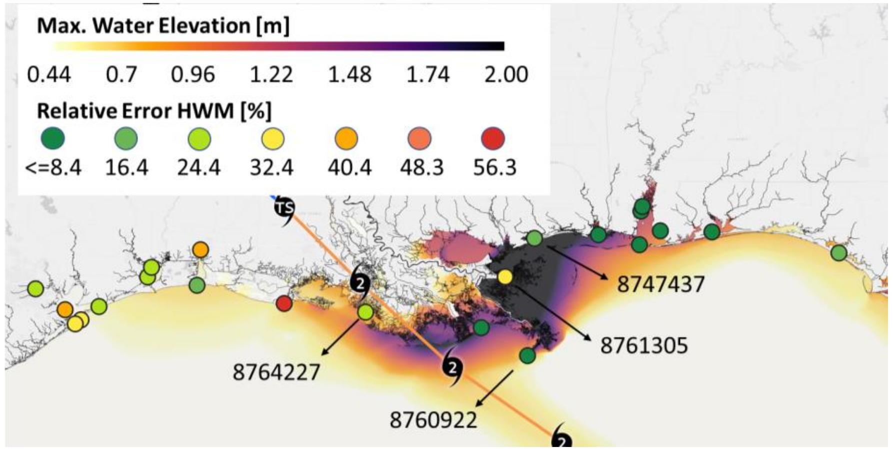
Levees

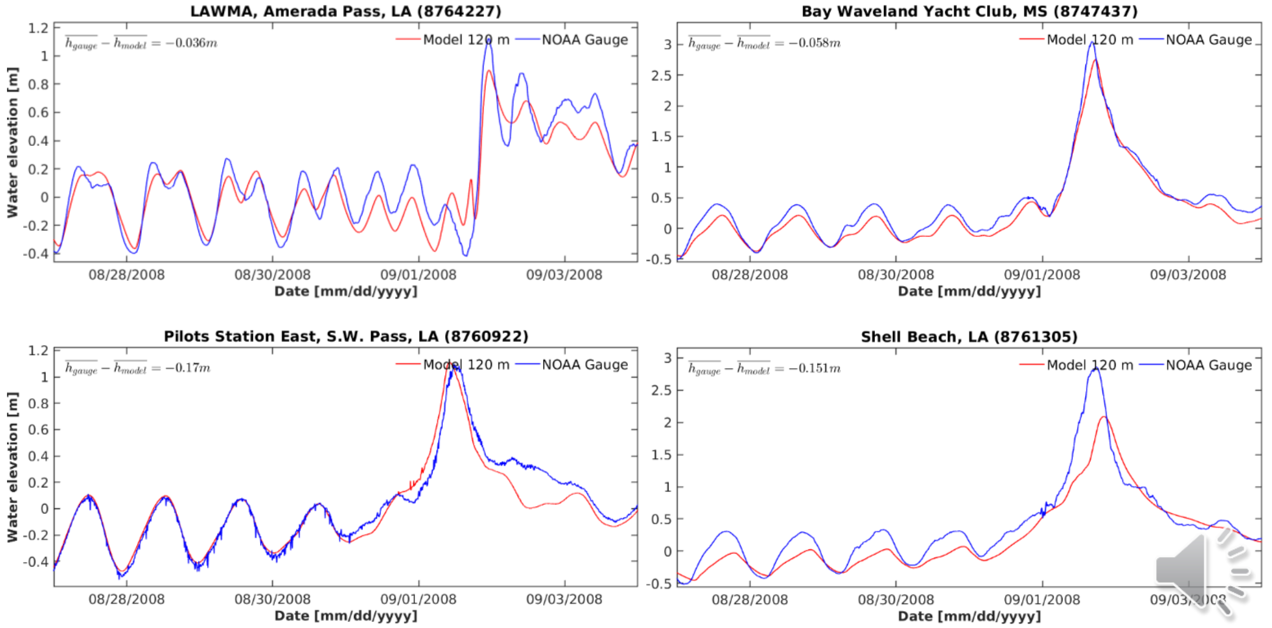
- USACE dataset for federal levees
- Snap the centerlines to the wet/dry interface based on the minimum resolution of the model
- Constraint levees nodes during the floodplain generation
- Weir boundary condition
- Adjustment of bathymetry to ensure clean wet/dry interface





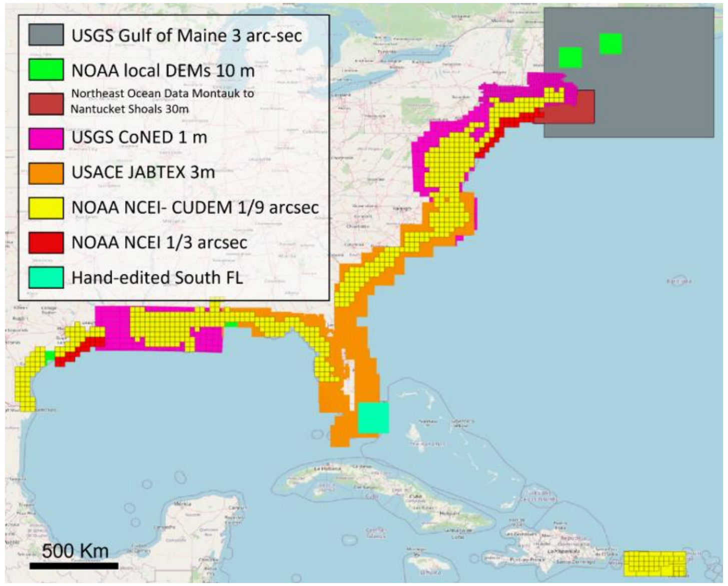
Historical storms - Gustav 2008

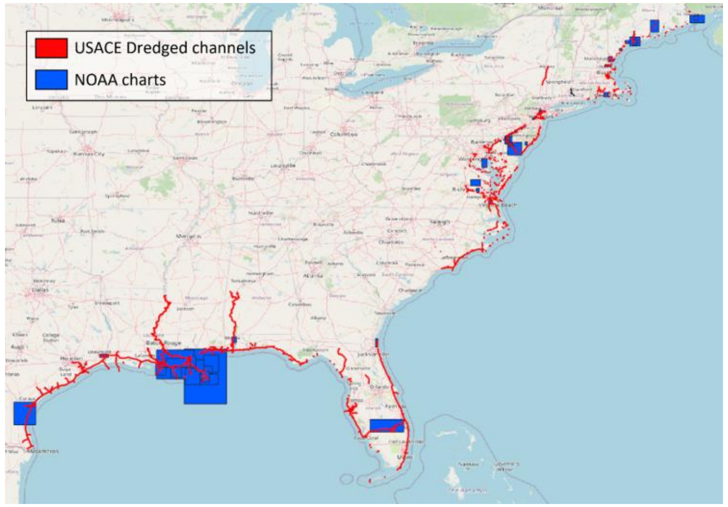




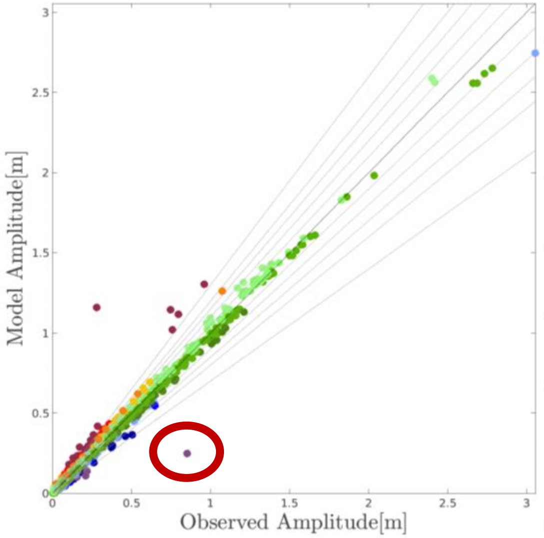
Key N°3: Correct bathymetry

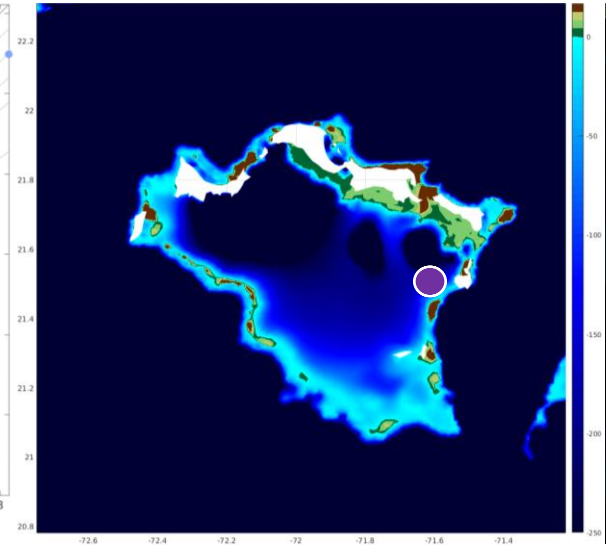
Topo-bathymetric databases





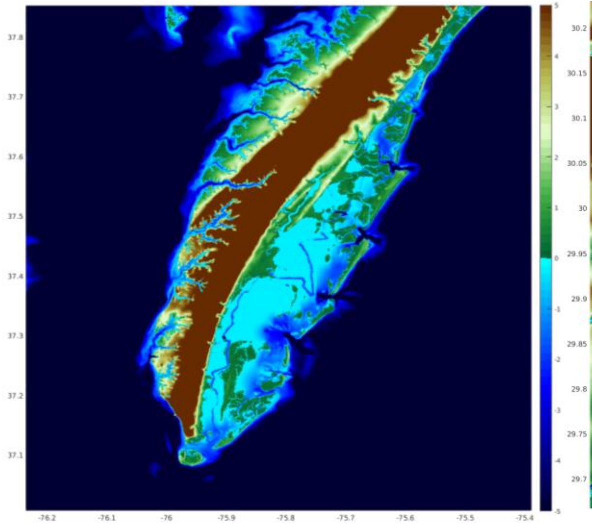
Bathymetric errors

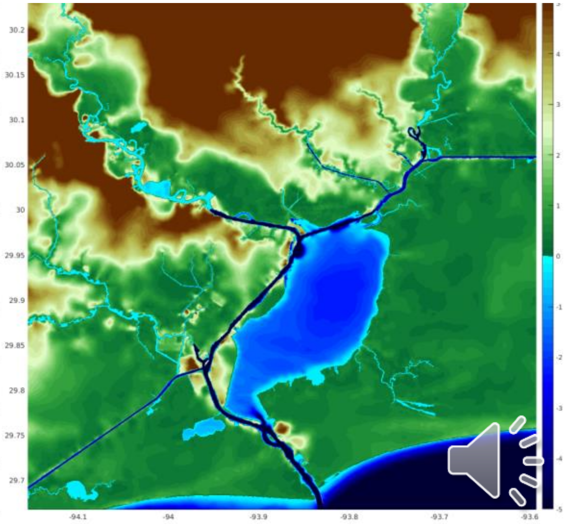




Lack of data

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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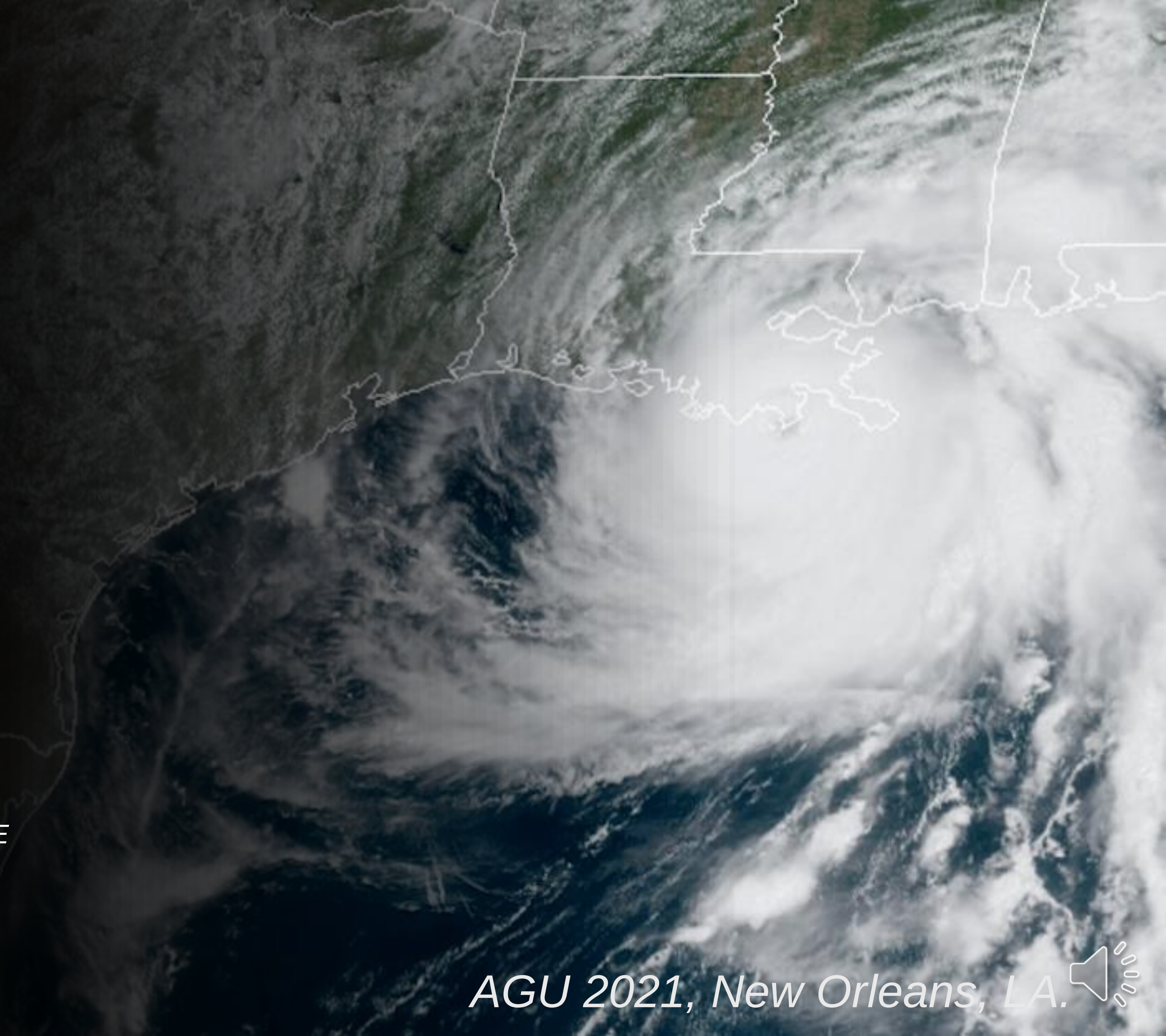

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