Unstructured Finite Element Mesh Decimation for Real-Time Hurricane Storm Surge Forecasting

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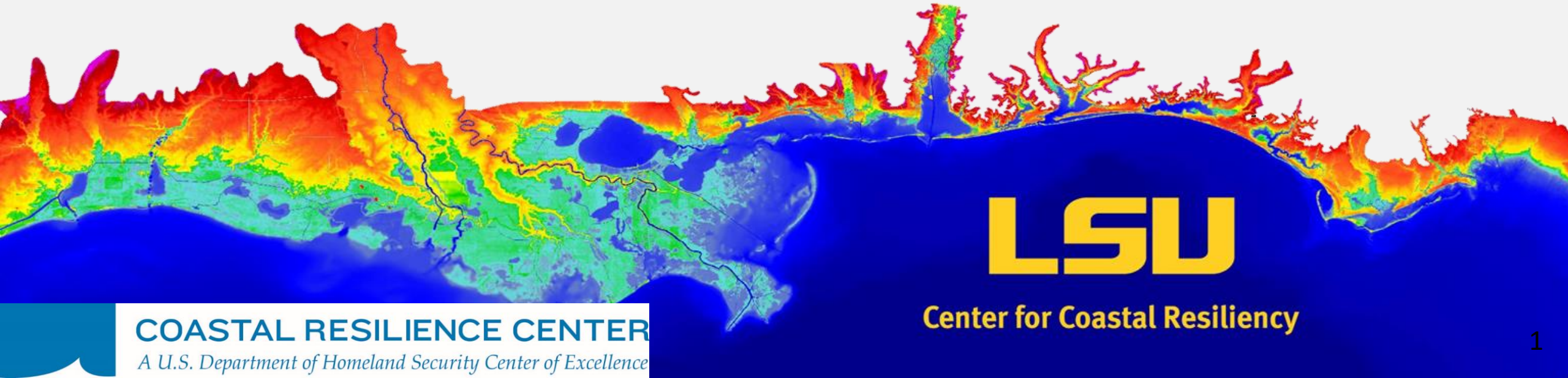
Wednesday, July 31, 2019



COASTAL RESILIENCE CENTER
A U.S. Department of Homeland Security Center of Excellence

Motivation – Provide real-time decision support

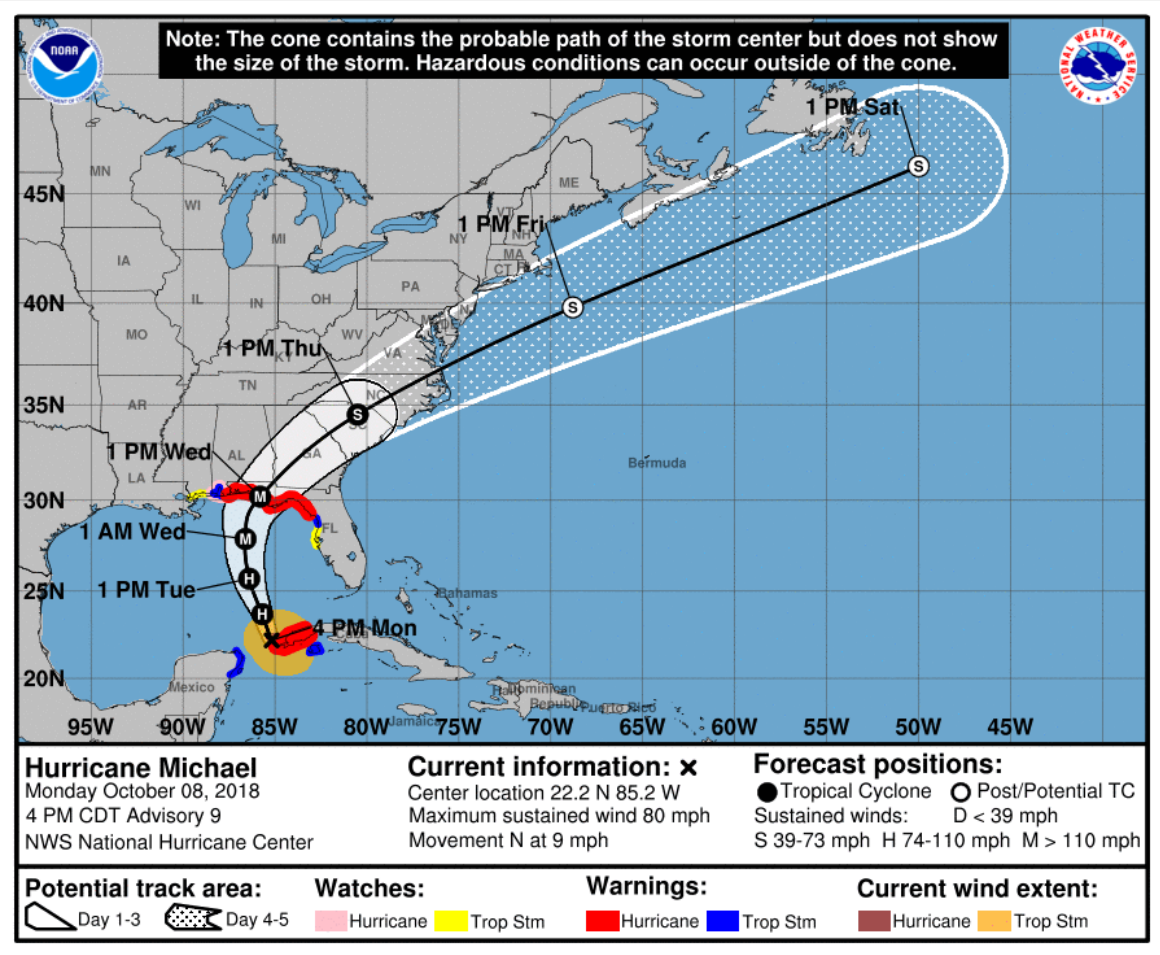
Emergency mangers are interested in…

When will the water rise?

What height will it get?

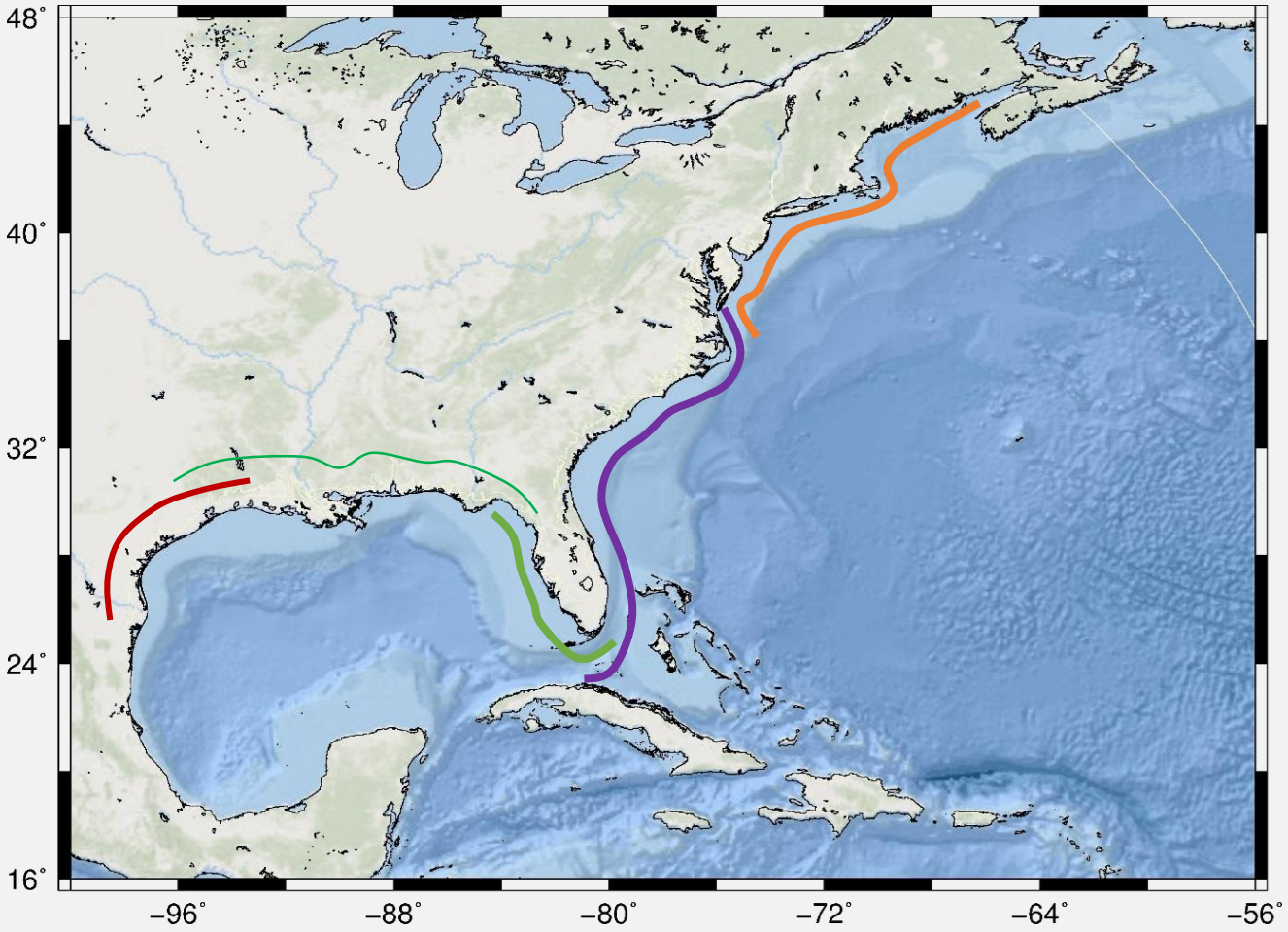
How long will it stay?

Who will be impacted?

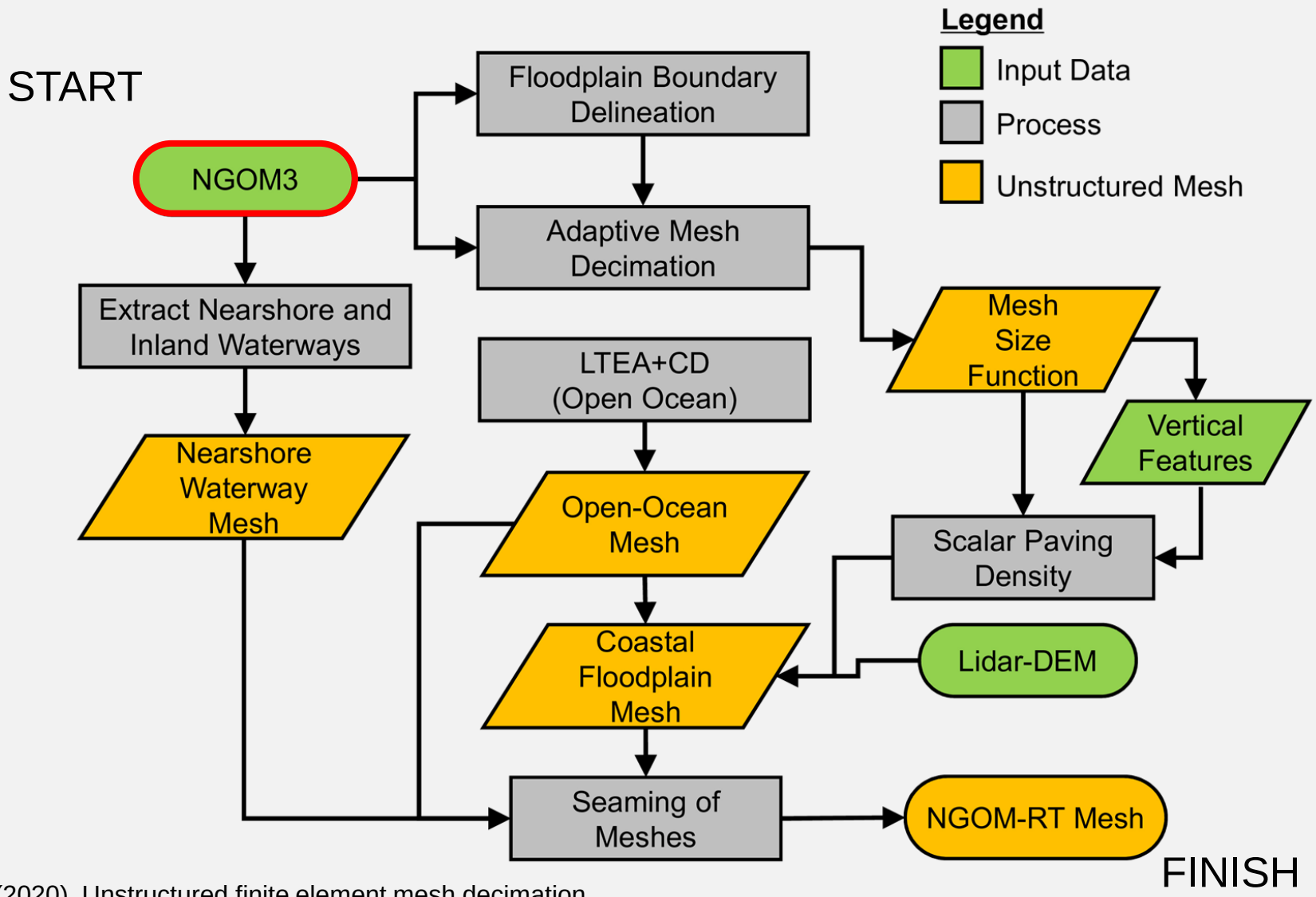


ADCIRC Prediction System Mesh Database

- Coarse Resolution Mesh
  - HSOFS (1.8 million vertices)
- Fine Resolution Meshes for the U.S. Gulf and Atlantic coasts
  - Each 3-4 million vertices
  1. Western Gulf
  2. Northern Gulf
  3. Eastern Gulf
  4. South and Central Atlantic
  5. Northern Atlantic

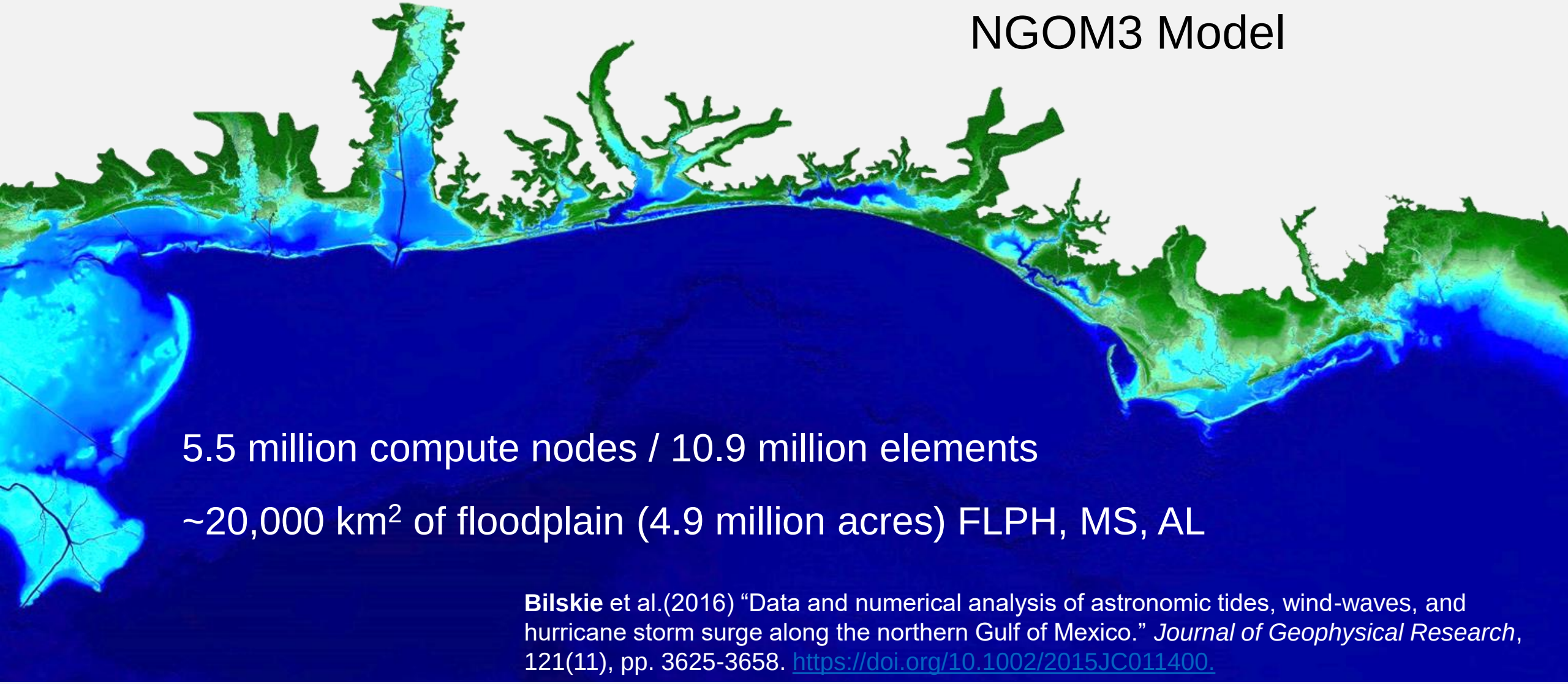


Mesh Design Around Real-Time Forecasting



Bilskie, Hagen & Medeiros (2020), Unstructured finite element mesh decimation for real-time Hurricane storm surge forecasting, *Coastal Engineering*, 156, 103622. https://doi.org/10.1016/j.coastaleng.2019.103622.

Research-Grade Unstructured Mesh

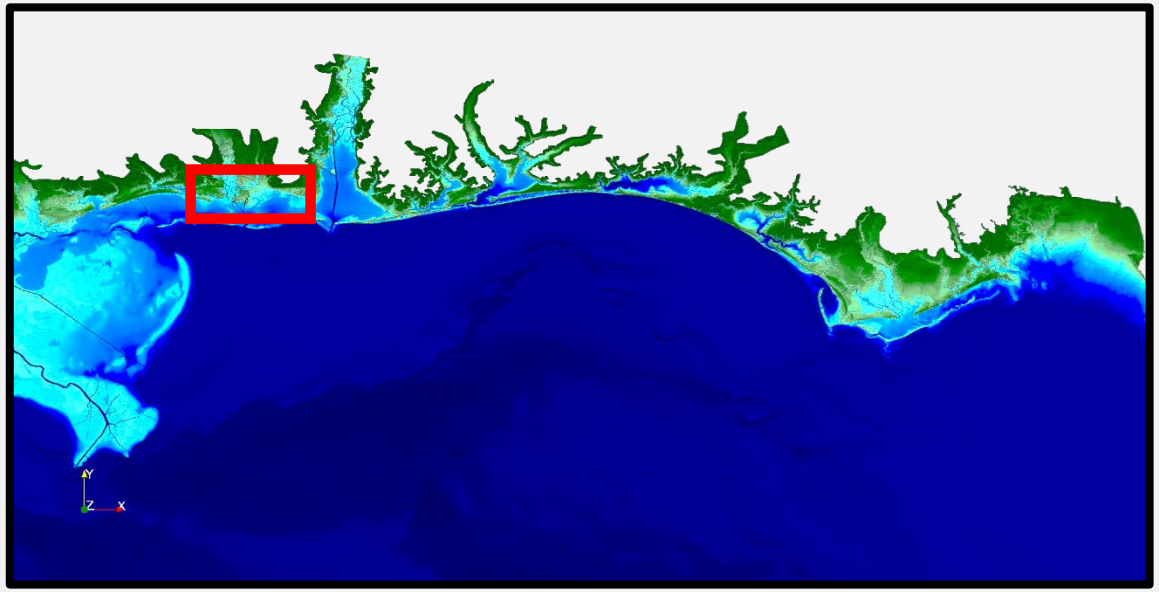


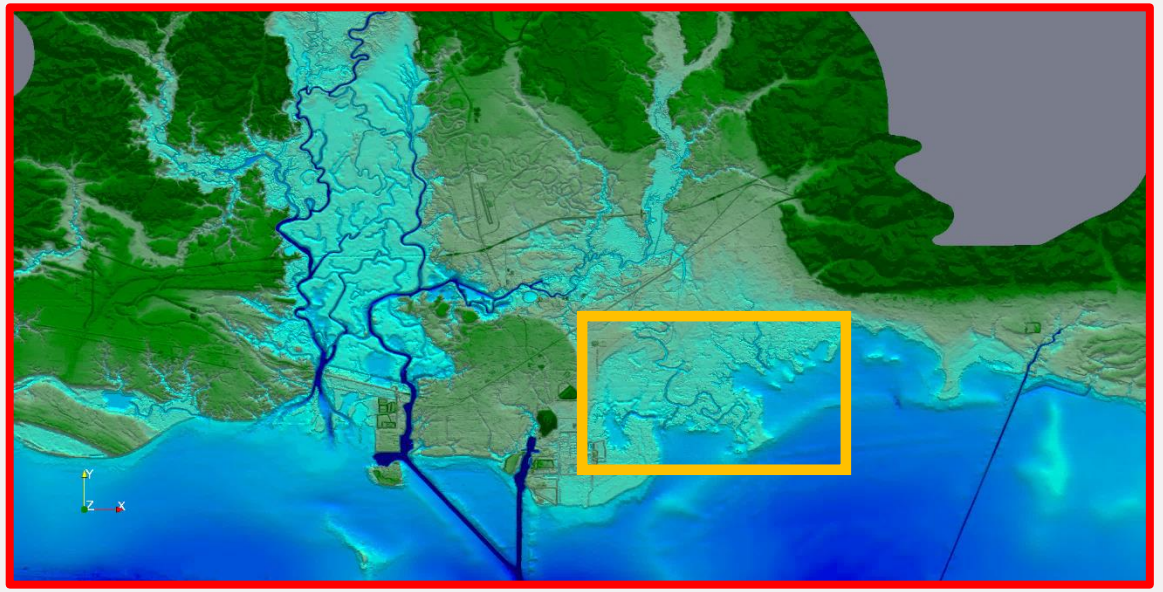
5.5 million compute nodes / 10.9 million elements

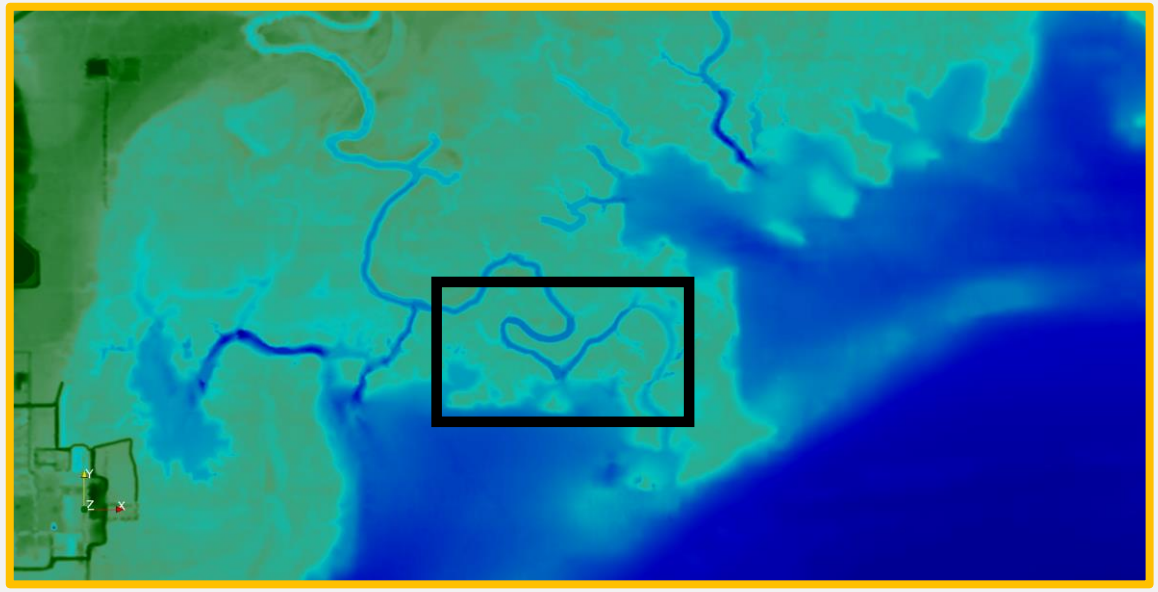
~20,000 km^2 of floodplain (4.9 million acres) FLPH, MS, AL

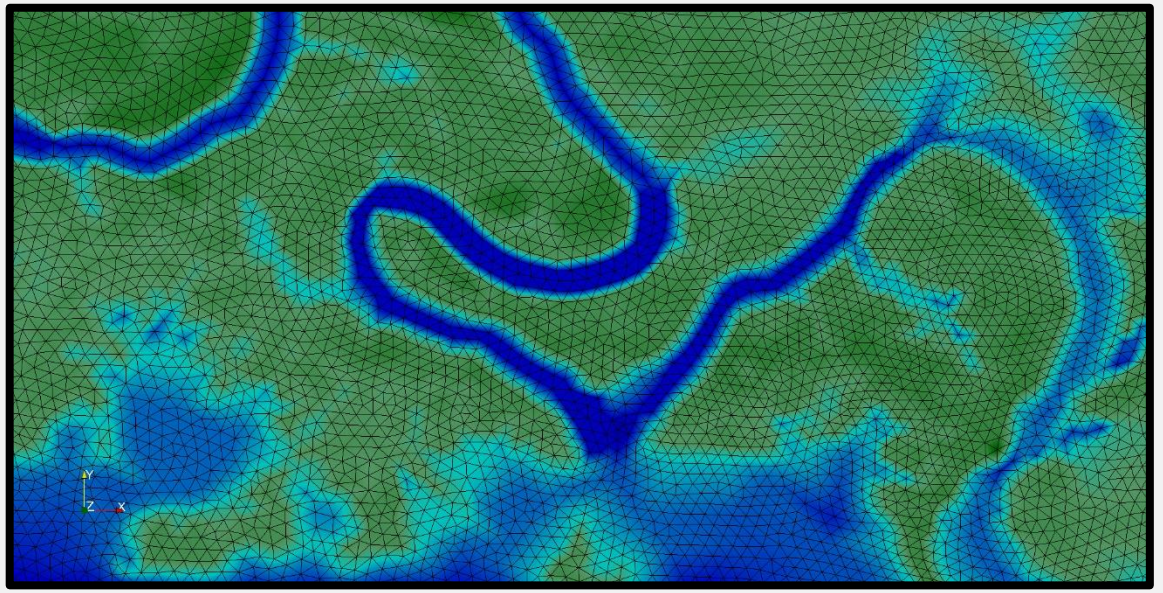
Bilskie et al.(2016) “Data and numerical analysis of astronomic tides, wind-waves, and hurricane storm surge along the northern Gulf of Mexico.” *Journal of Geophysical Research*, 121(11), pp. 3625-3658. https://doi.org/10.1002/2015JC011400.

Mesh Representation in Pascagoula, MS

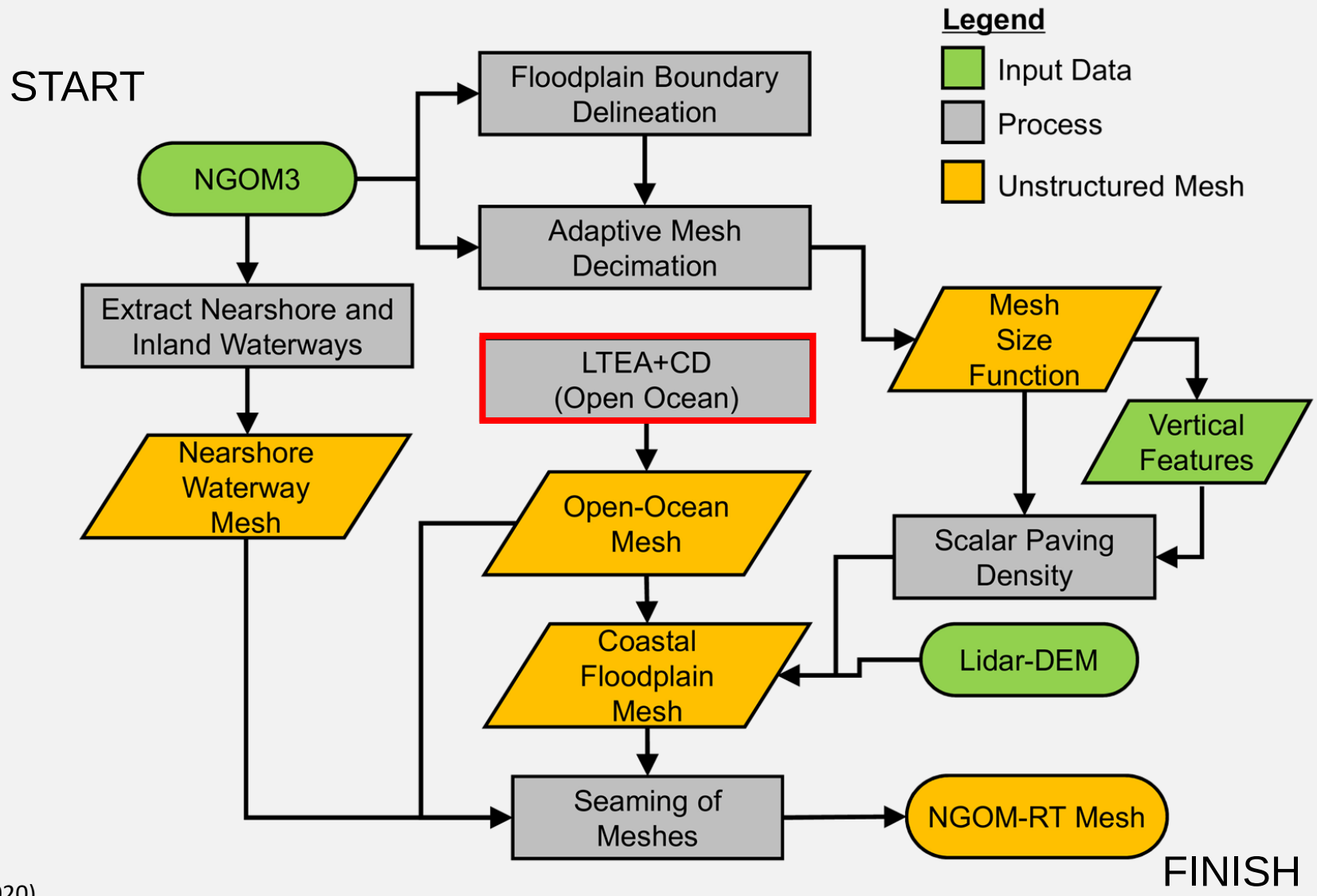






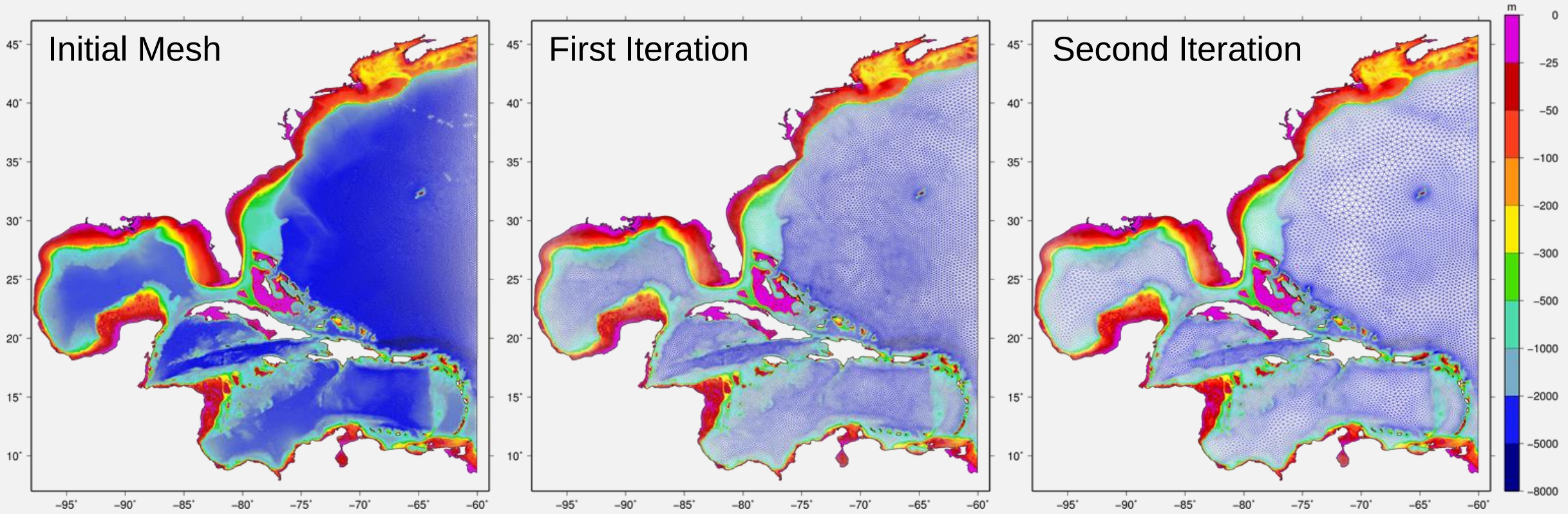


Mesh Design Around Real-Time Forecasting



Bilskie, Hagen & Medeiros (2020)

Localized truncation error (LTEA)

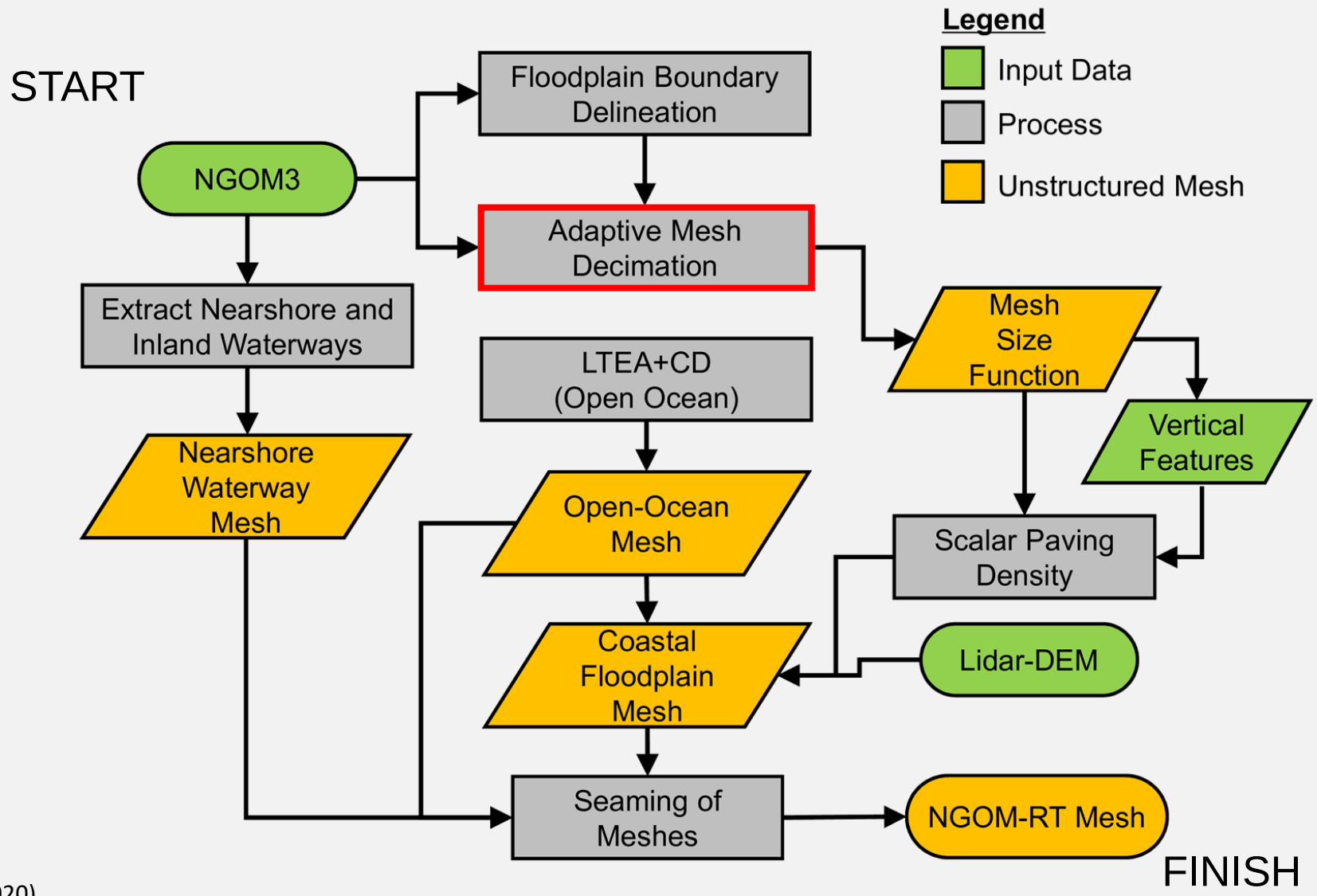


$$\hat{\tau}^{+}_{ME} = \frac{\Delta^6}{1440} \underbrace{[\omega(i\hat{v}_0 - \hat{u}_0) + (\tau\hat{v})_0 + i(\tau\hat{u})_0 - i(f\hat{v})_0 + (f\hat{u})_0)]^6}_{\text{derivative term}}$$

PyLTEA – An open-source Python-based LTEA tool will be available “shortly” via github. Stay tuned!

Parrish, D. M., and S. C. Hagen (2007), *International Journal of Computational Fluid Dynamics*.

Mesh Design Around Real-Time Forecasting



Bilskie, Hagen & Medeiros (2020)

Mesh decimation

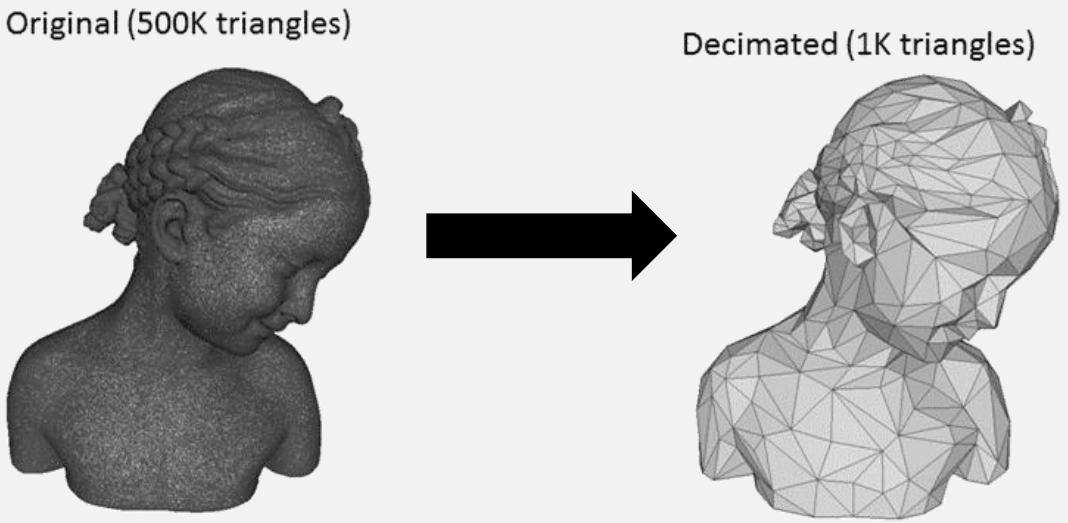
To improve run-times, it is desirable to reduce the number of mesh nodes and elements while preserving desirable geometric features.

Problem: Given: $M = (V, F)$

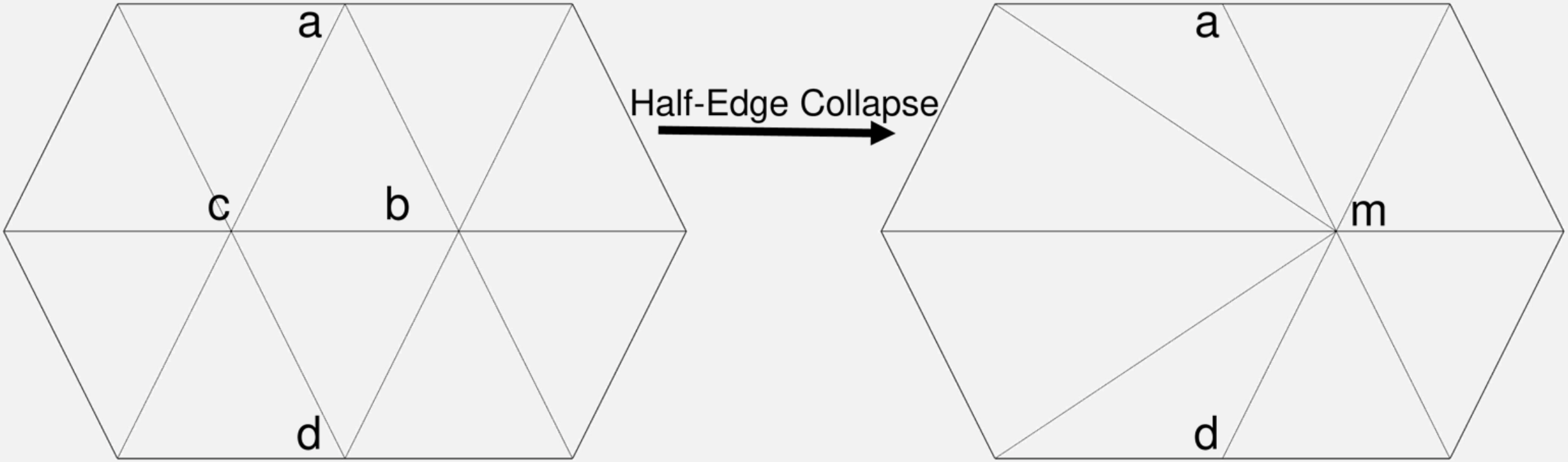
Find: $M' = (V', F')$ such that

$|V'| = n < |V|$ and $||M - M'||$ is minimal, or

$||M - M'|| < e$ and $|V'|$ is minimal

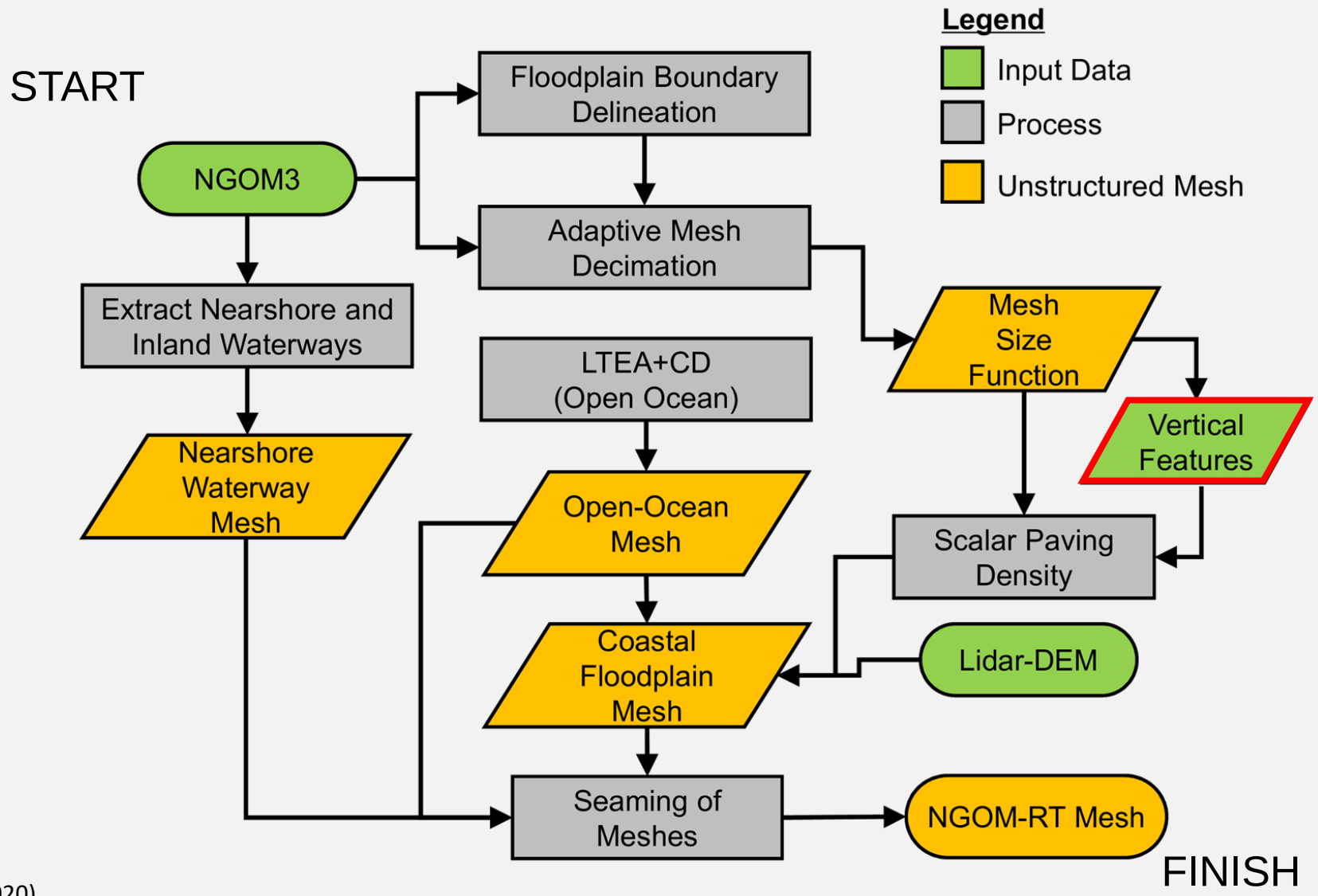


Half-Edge Collapse



Limitation: Edge-collapse does not consider element quality.

Mesh Design Around Real-Time Forecasting



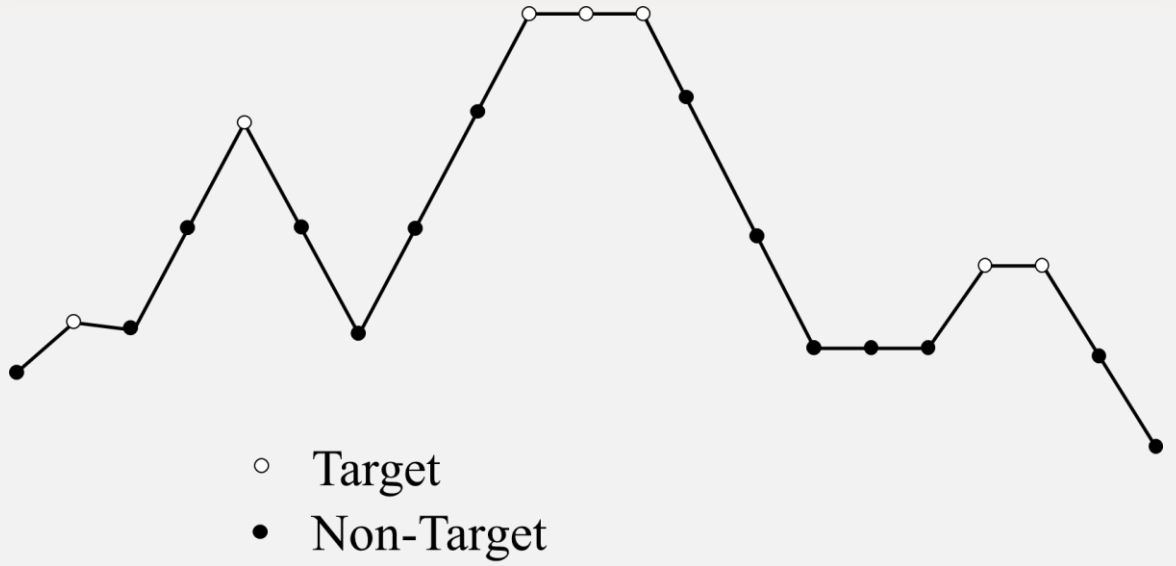
Bilskie, Hagen & Medeiros (2020)

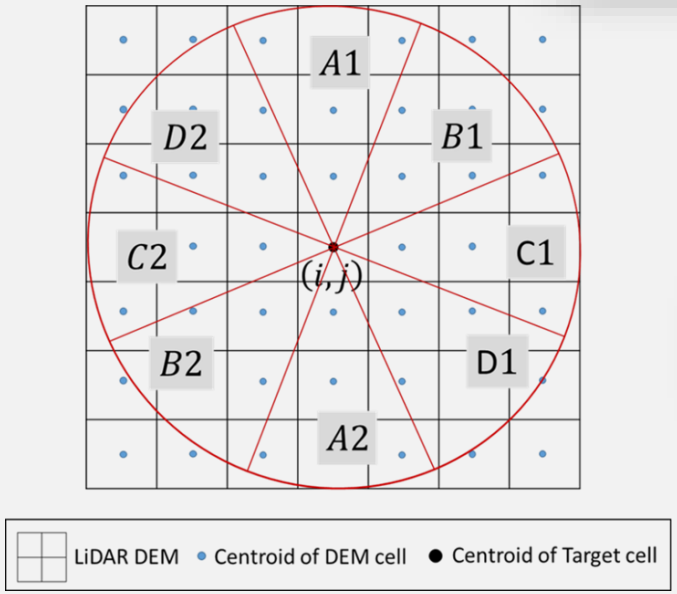

INTERSTATE
10
90
Chevron
Pascagoula
Grand Bay
Z
Y
X

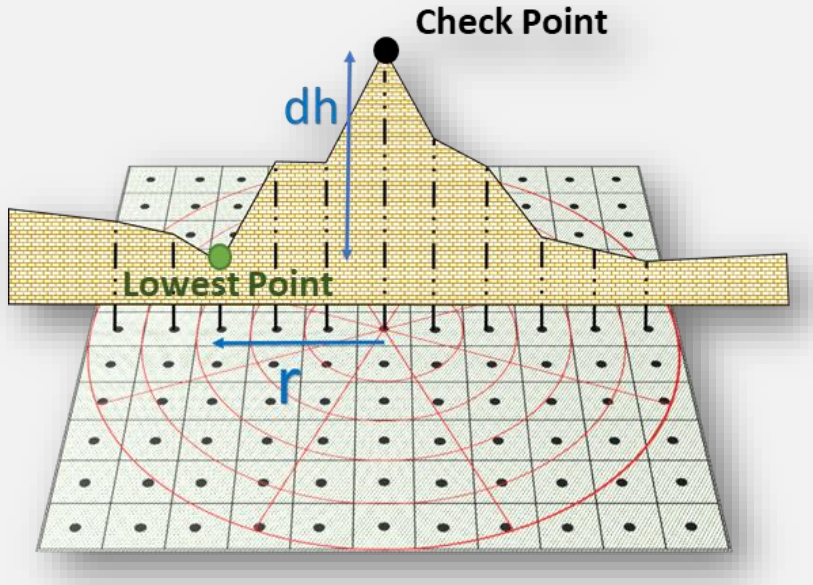
Automated Vertical Feature Detection

VF Algorithm

- Target Recognition (Moving Window)
- Target Delineation (Watershed Boundary)



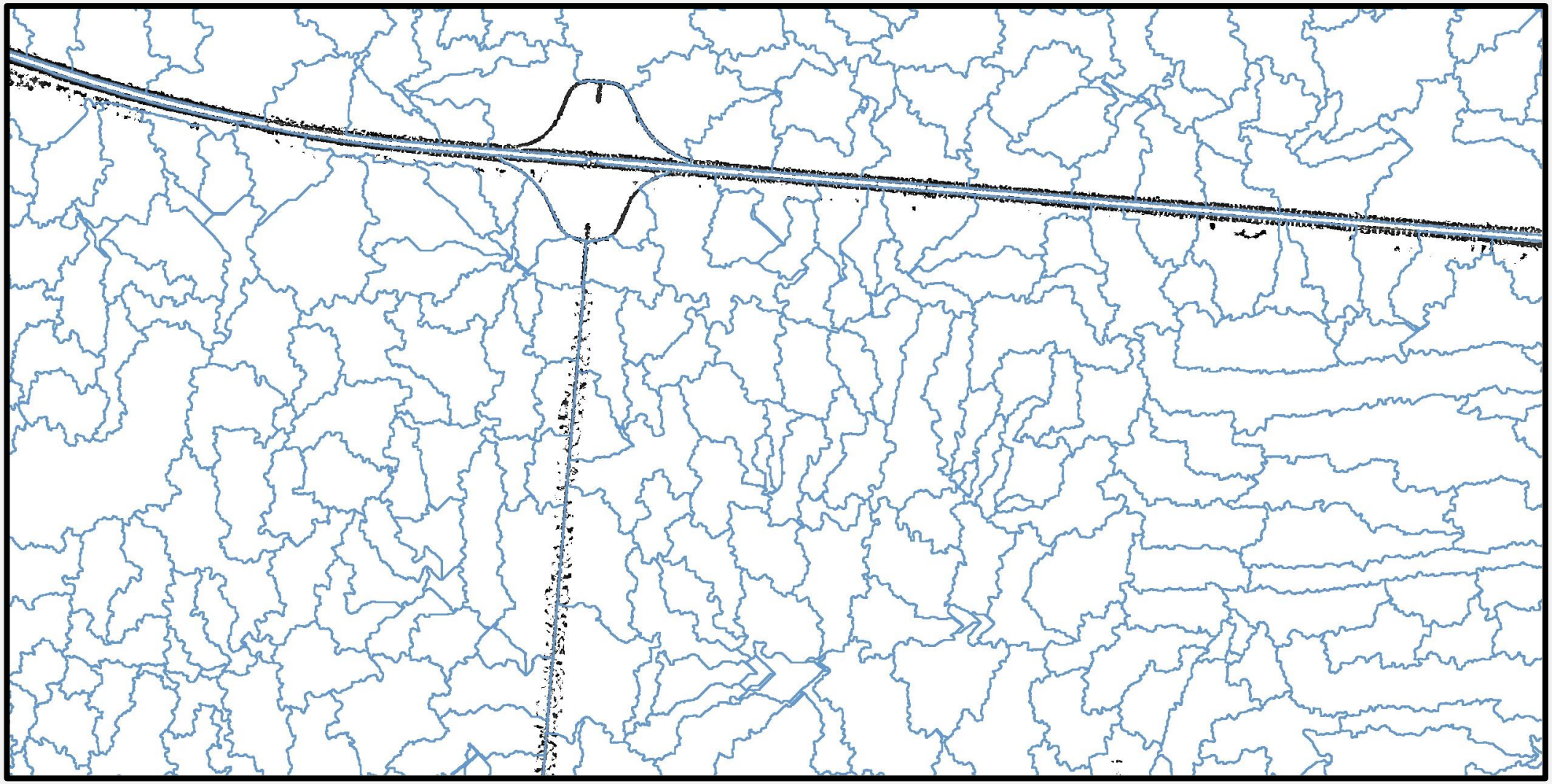




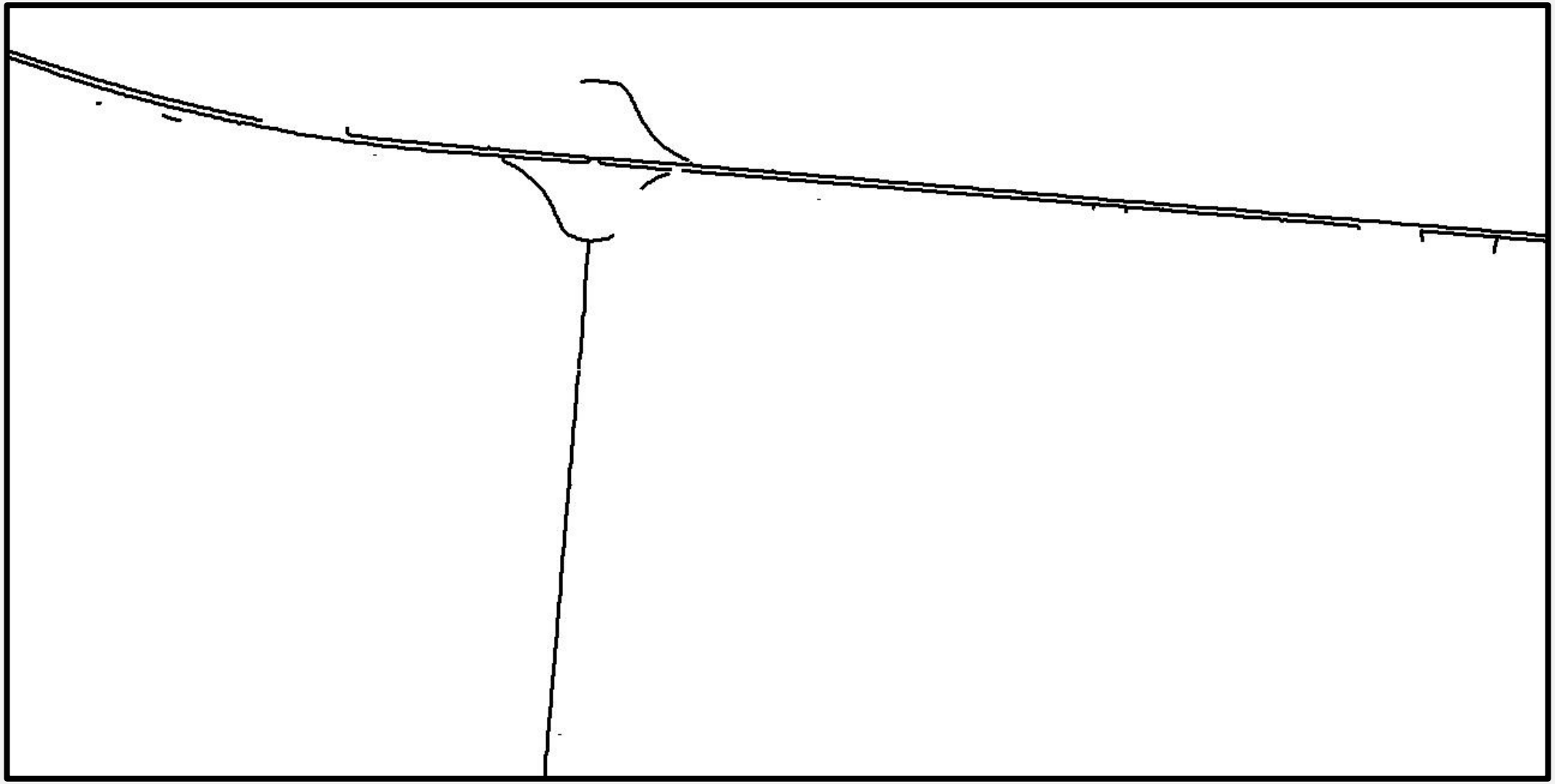
***dh**: a parameter to define if the difference between target points elevation and minimum elevation of a sector is large enough.*

***r**: a parameter to define how wide is the vertical feature*

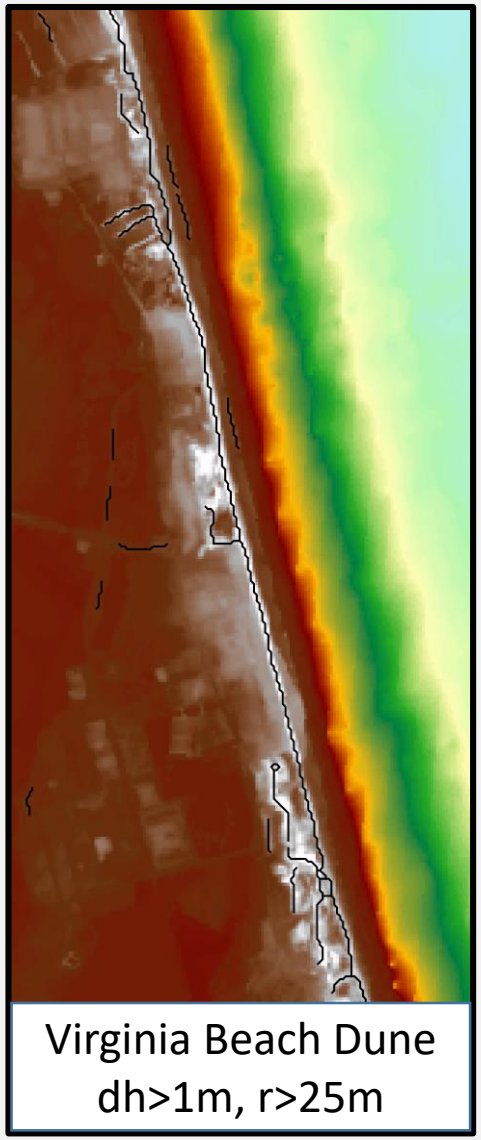
Automated Vertical Feature Detection



Automated Vertical Feature Detection

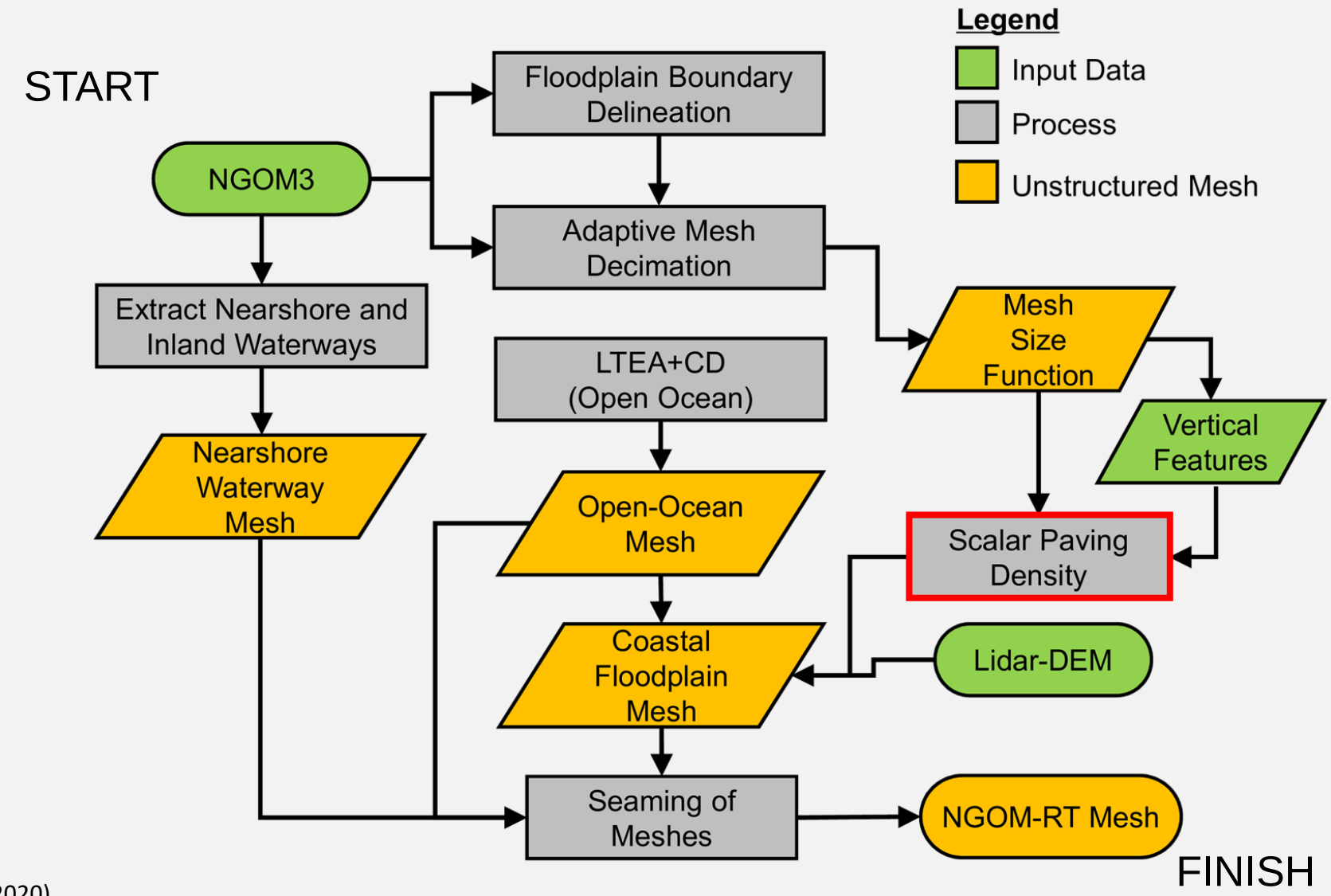


VF Detection for various terrain types



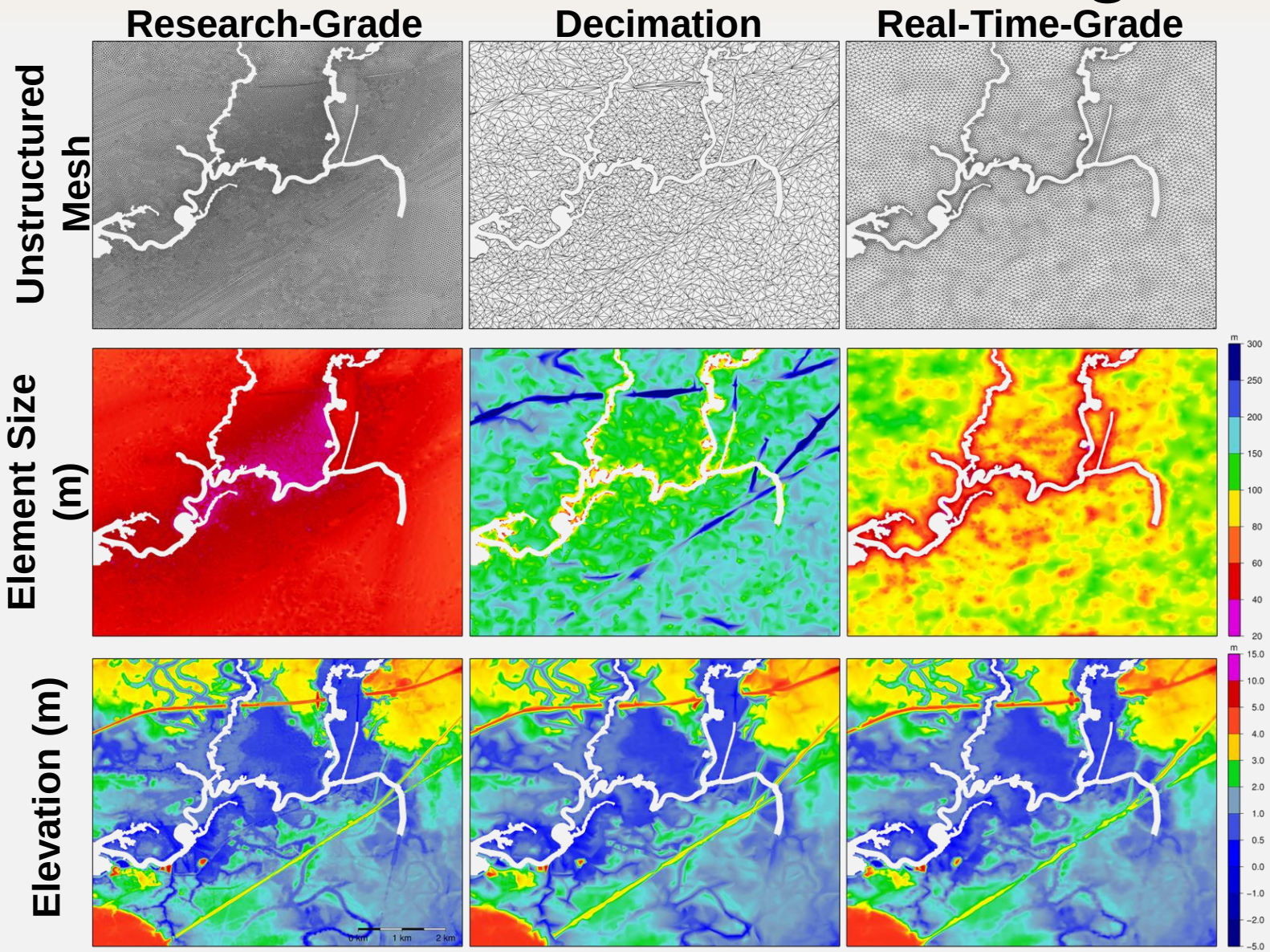
Virginia Beach Dune
dh>1m, r>25m

Mesh Design Around Real-Time Forecasting



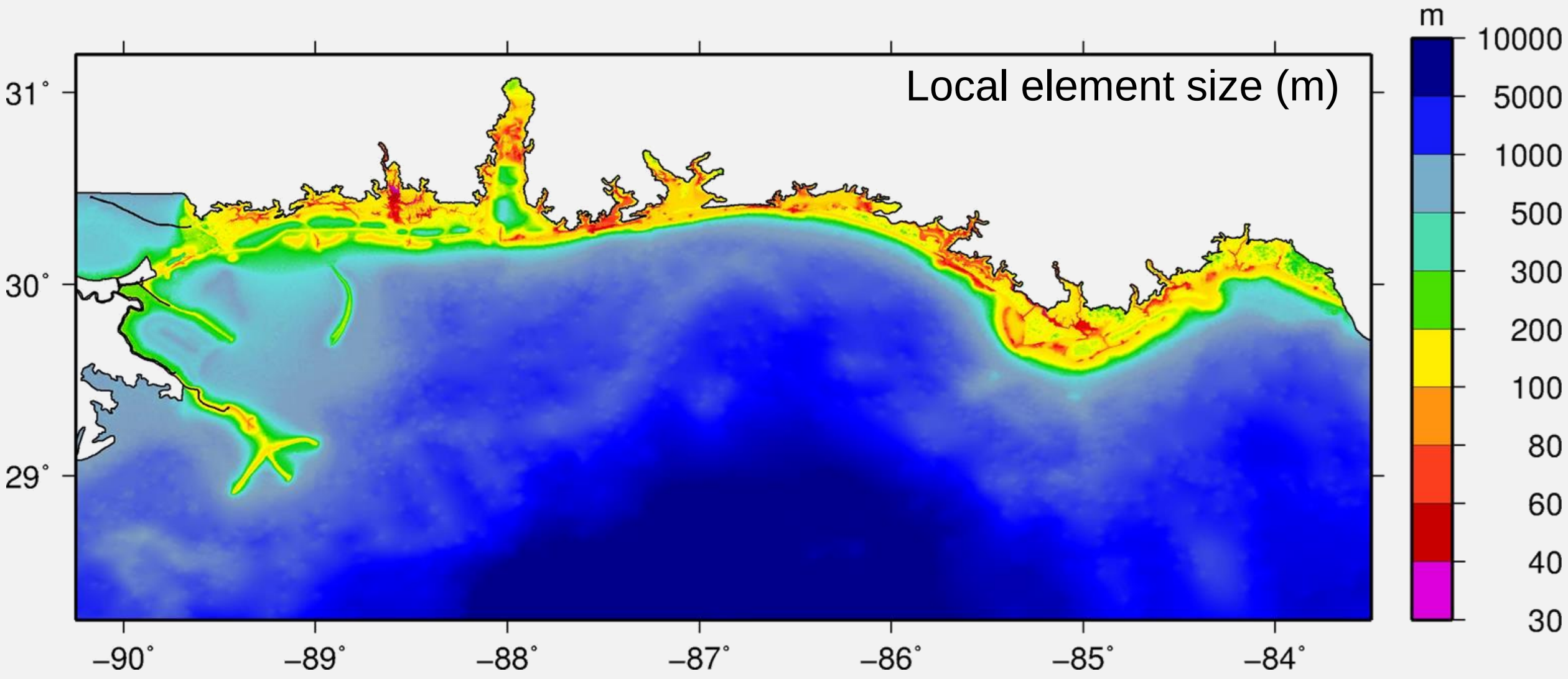
Bilskie, Hagen & Medeiros (2020)

Coastal Inundation Mesh Design

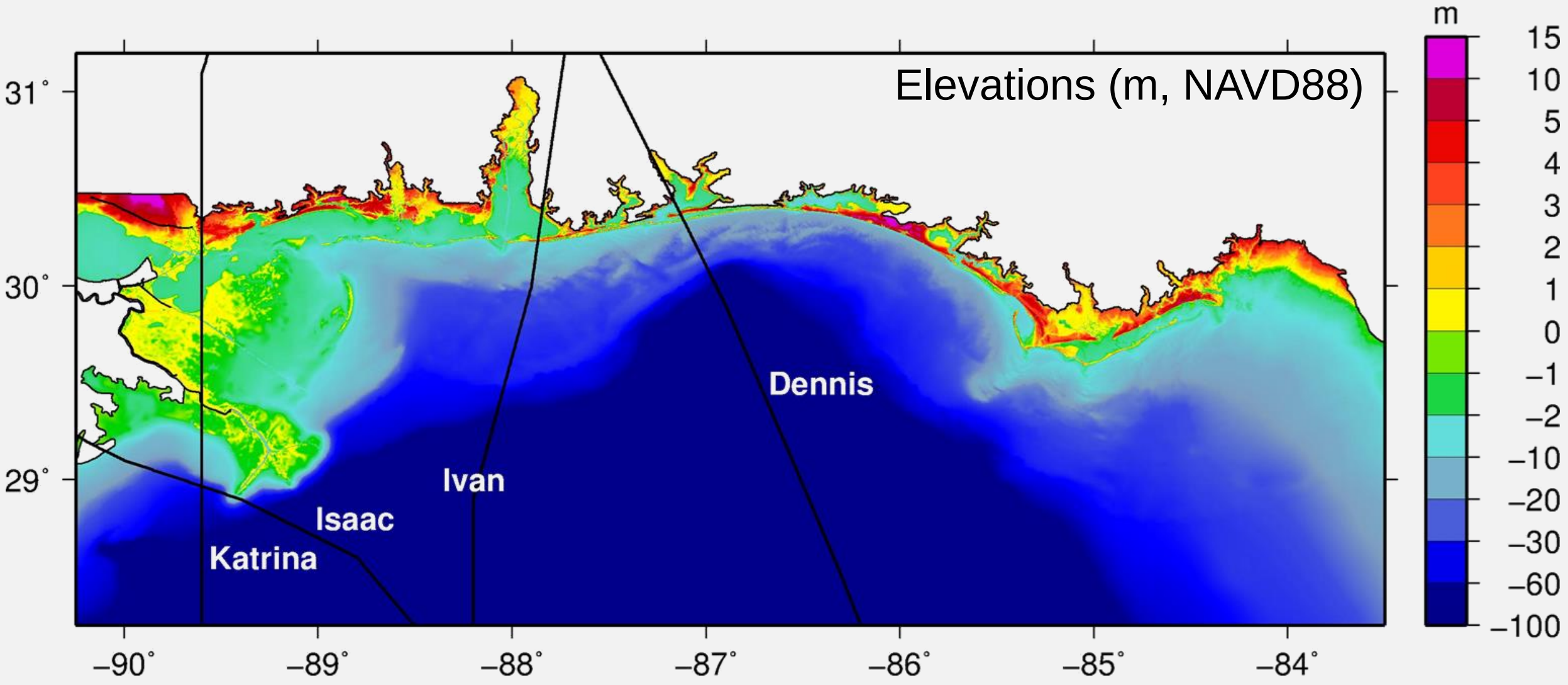


Bilskie, Hagen & Medeiros (2020)

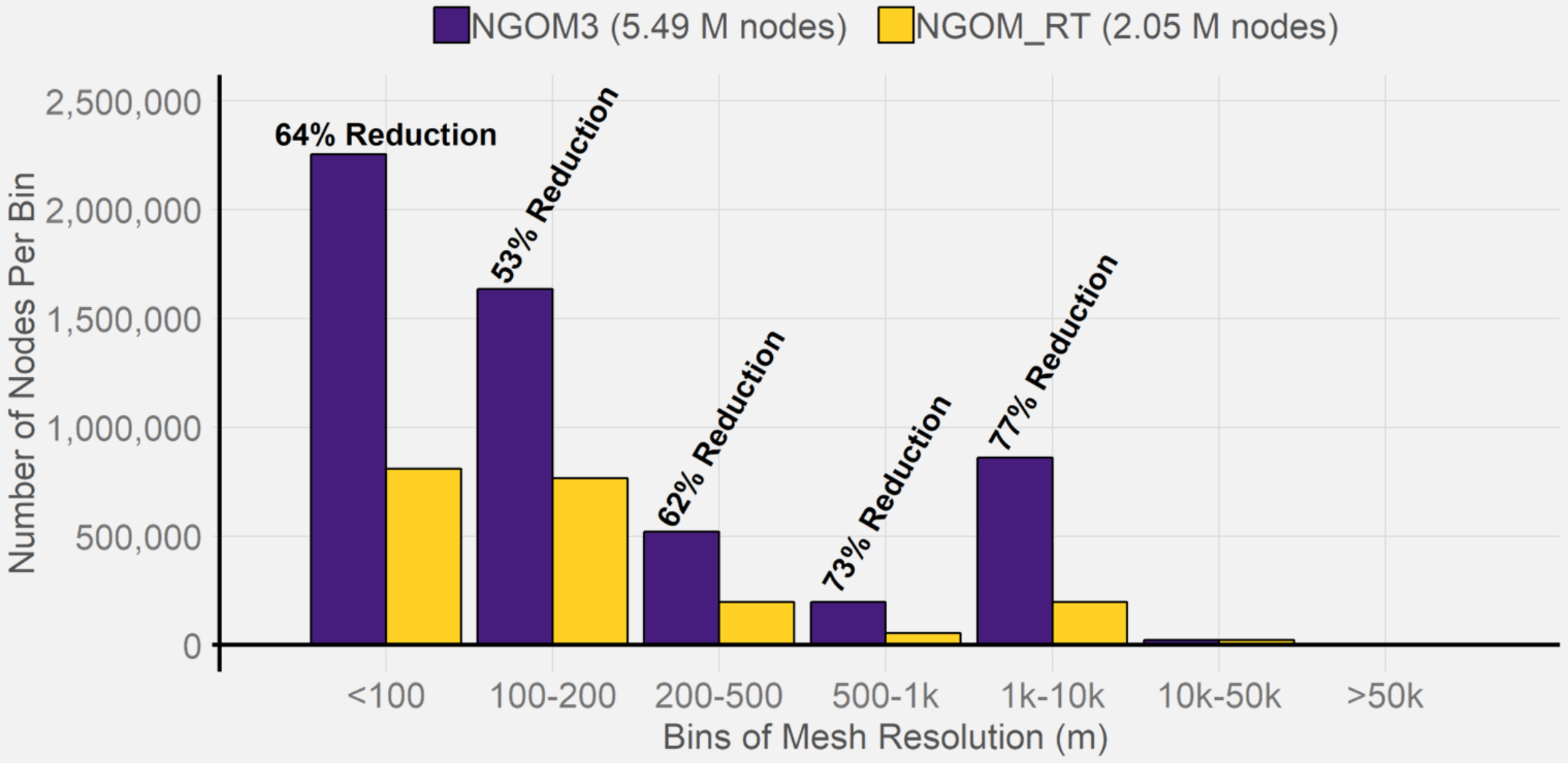
NGOM Real-Time-Grade Mesh



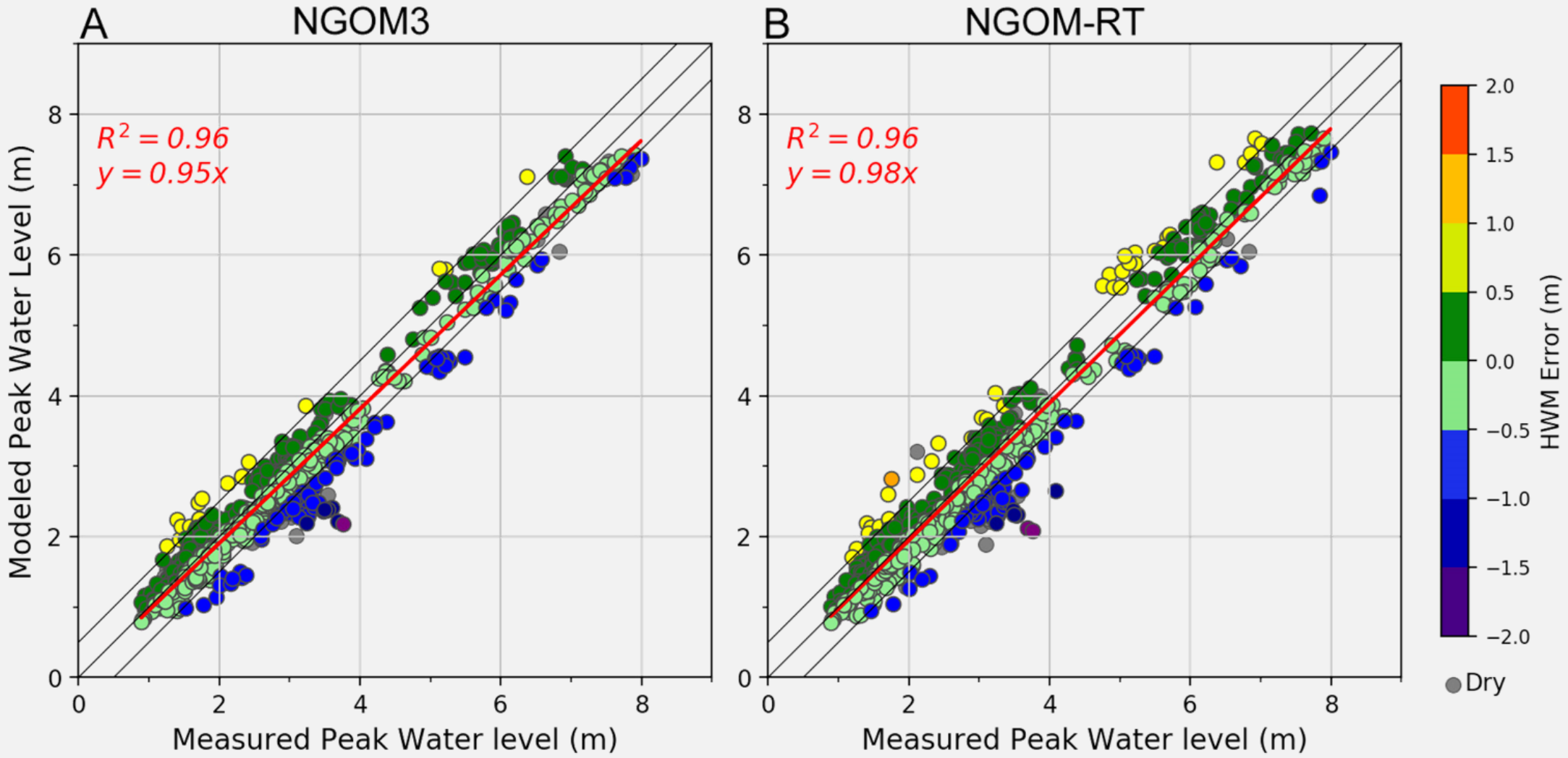
NGOM Real-Time-Grade Mesh



Mesh node reduction

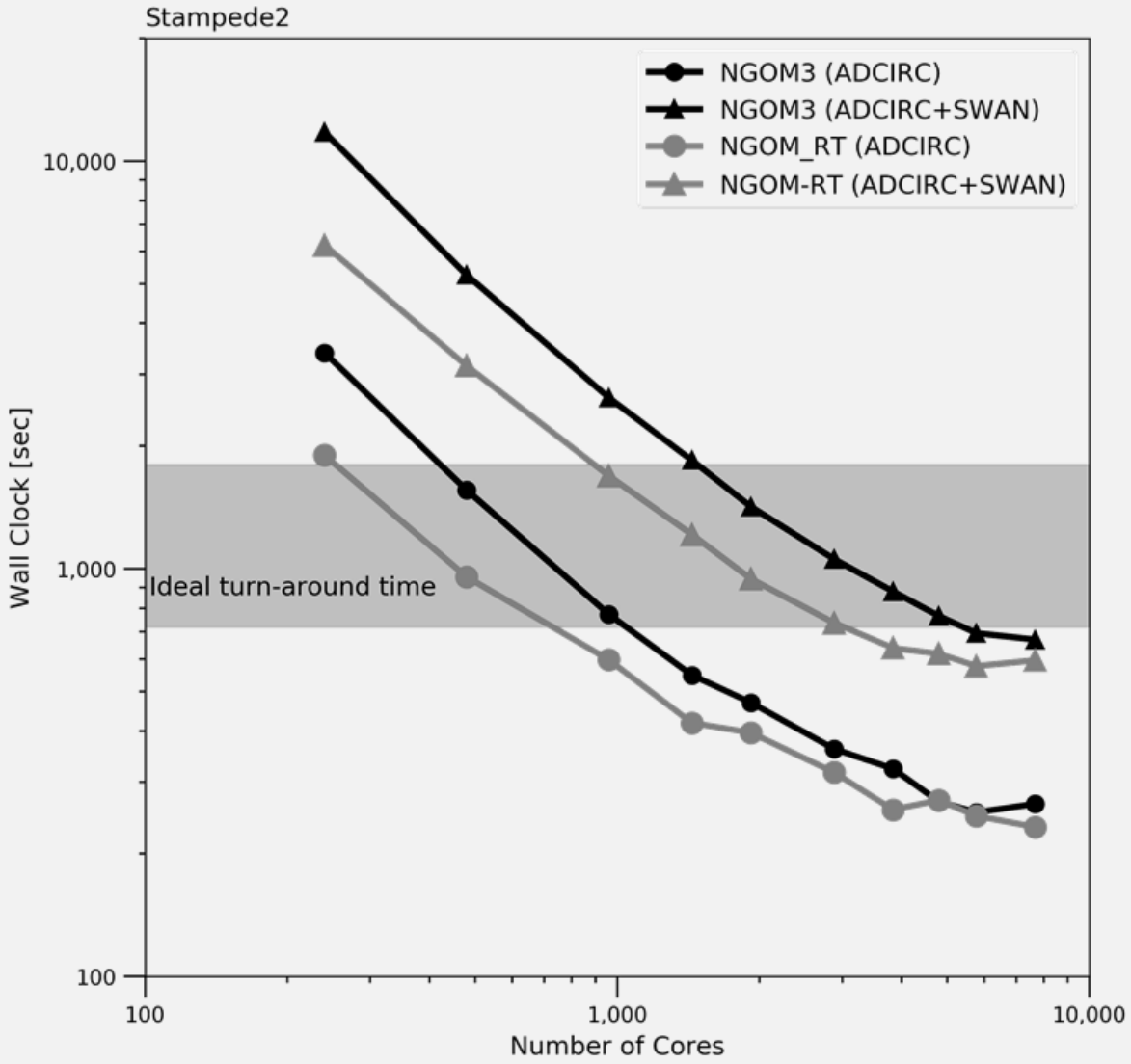


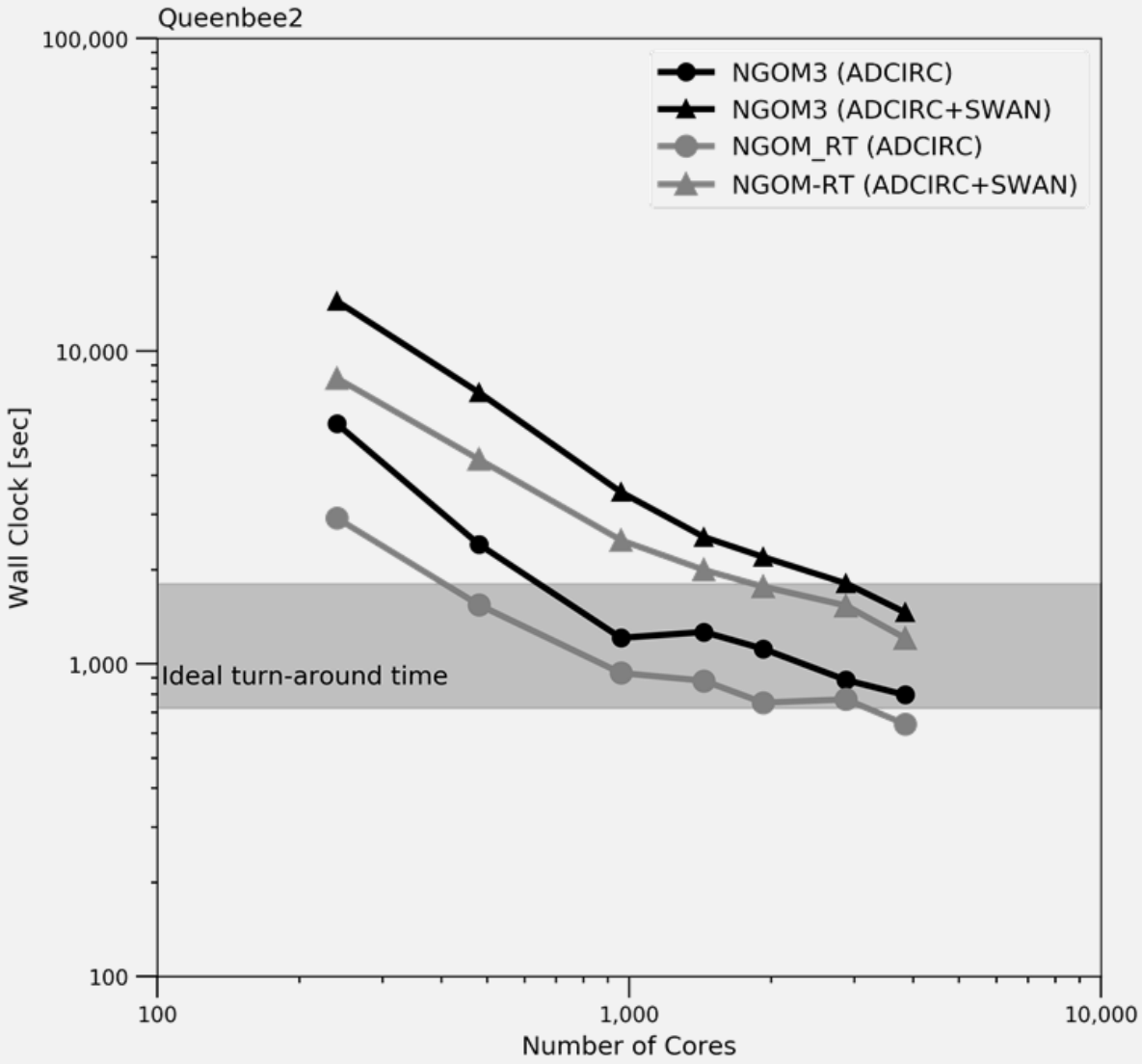
High Water Mark Validation



Bilskie, Hagen & Medeiros (2020)

Run-Time Comparison

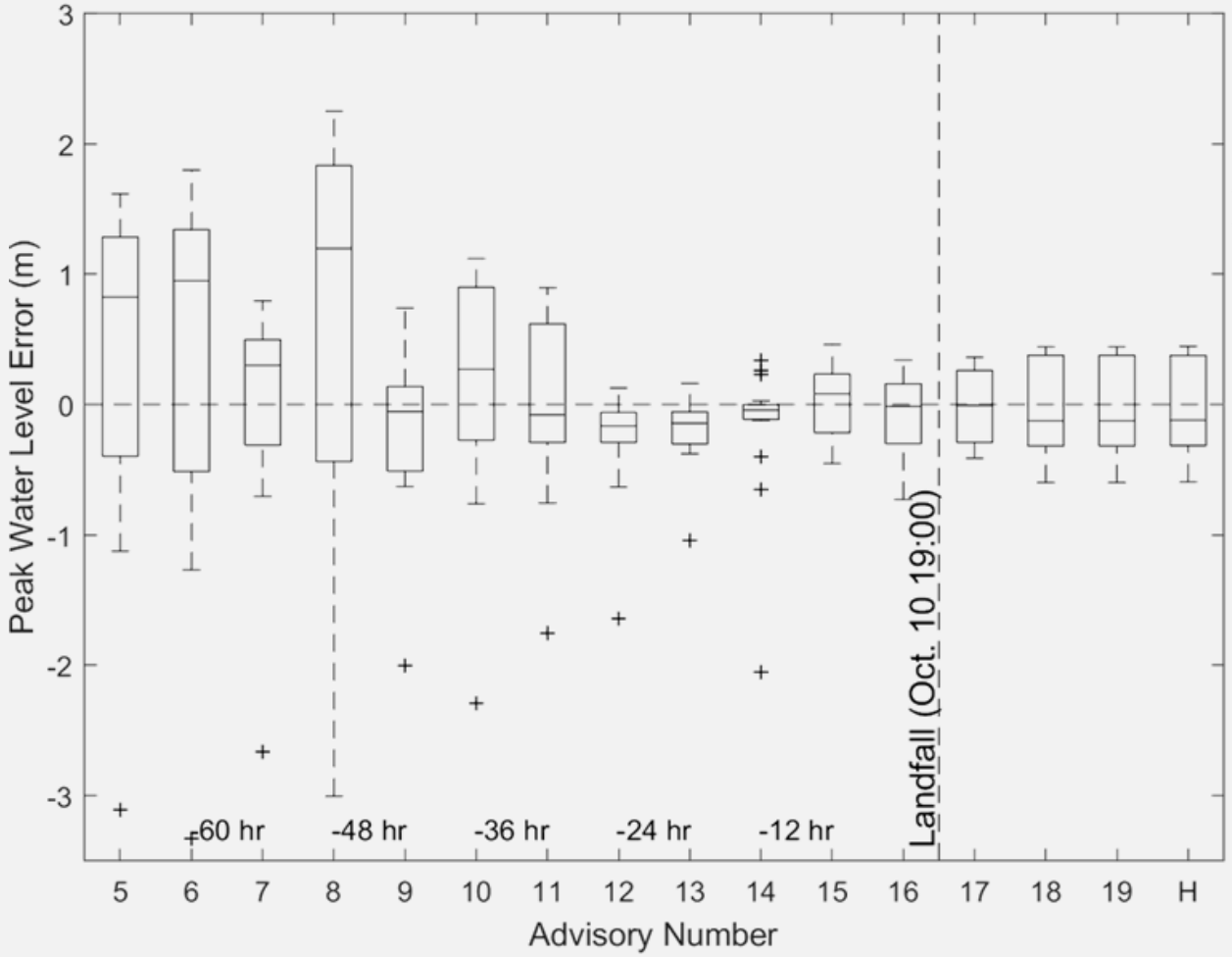


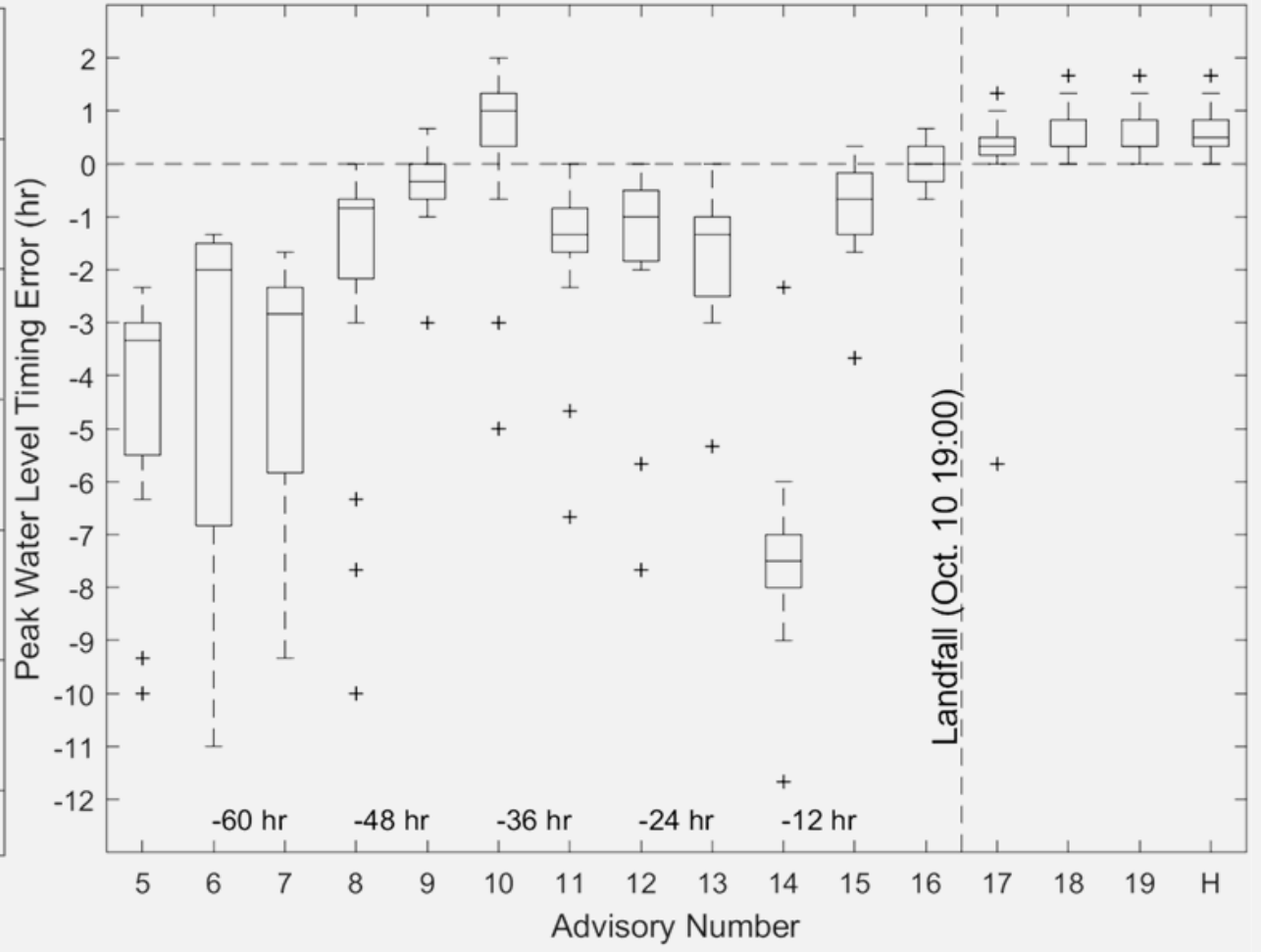


Bilskie, Hagen & Medeiros (2020)

Hurricane Michael (2018) Forecast Error

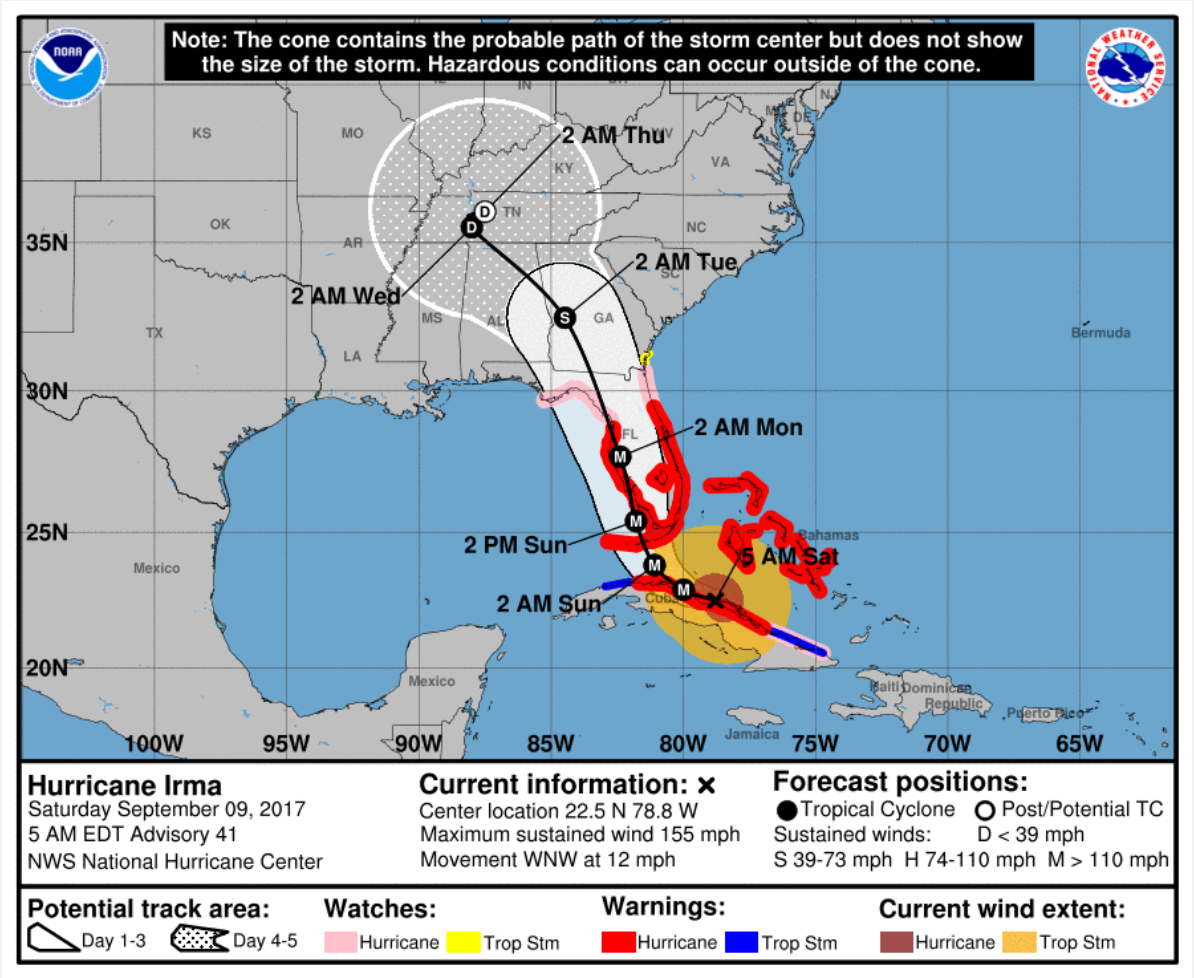
ADCIRC Prediction System Results

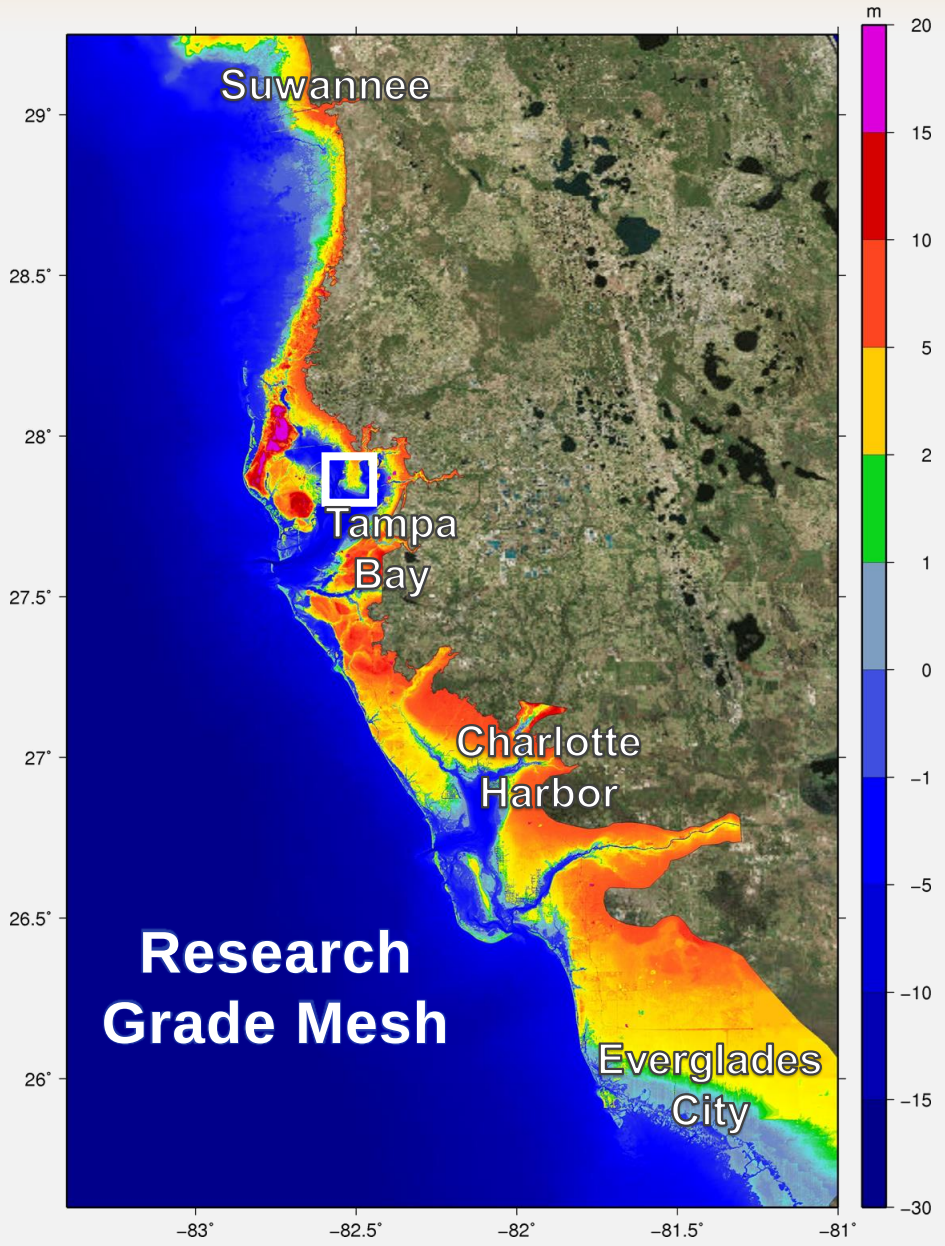




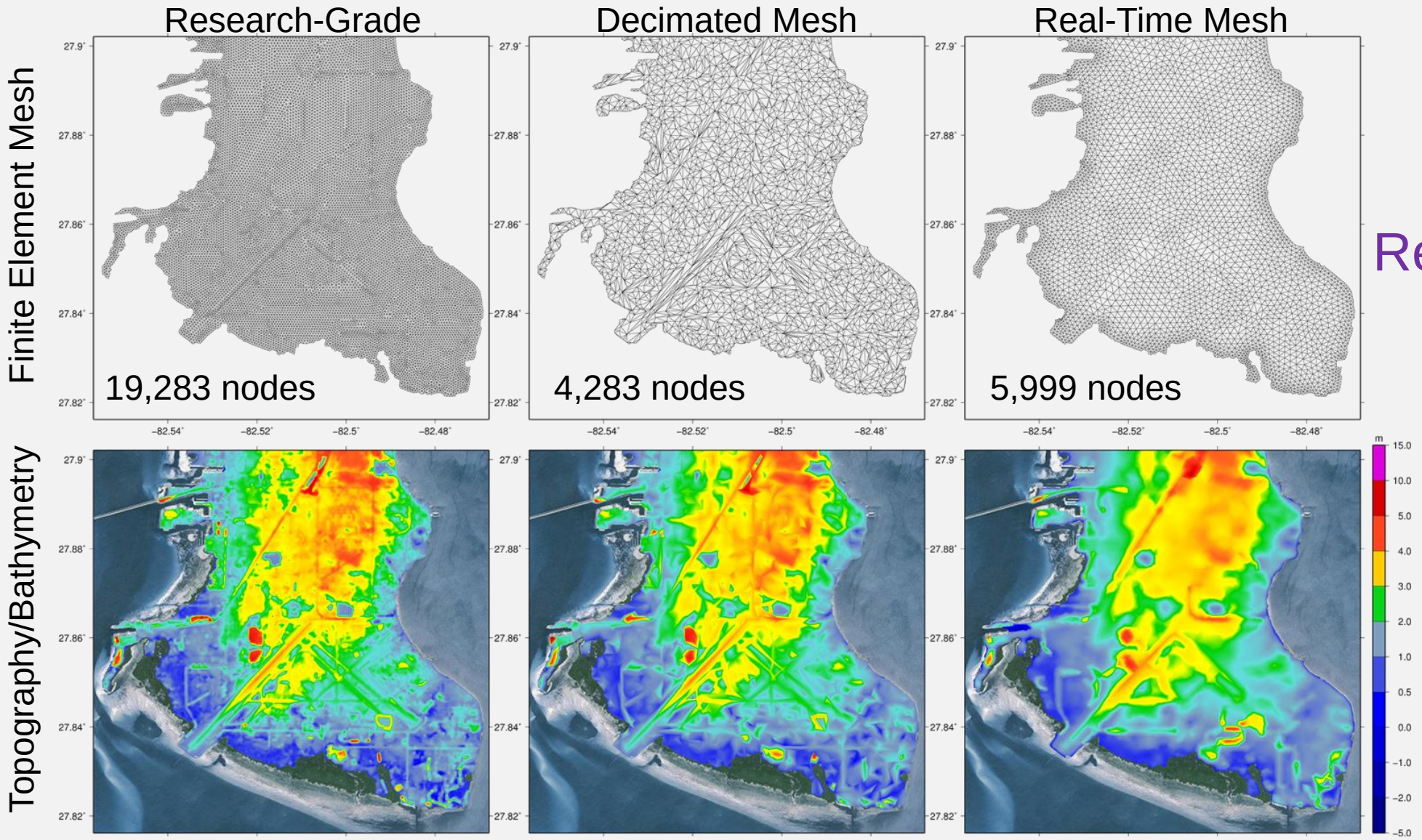
*Error results are currently being updated based on more recent observations.

Transition to the West Coast of Florida





MacDill Air Force Base, FL



69% Reduction!

Conclusions

- Mesh decimation reduced the number of computational points by 64% across the coastal floodplain
- The resulting NGOM-RT mesh preserves the topographic representation of the landscape
- Simulated water levels for both models agree with measurements from four historical hurricanes
- ADCIRC+SWAN simulations with the decimated mesh are 1.5 - 2.0 times faster on 1,000 – 2,000 cores
- The new mesh requires 480-960 cores to perform a 5-day forecast in under two hours
- Forecasted water level is within 0.5 m with a 48-hr lead time

Future Work

- Automated and reproducible approaches to unstructured mesh development across the coastal land margin that stem directly from a high-resolution DEM.
- We have only examined a decimation routine based solely on geometry (topography) using Matlab's "reducepatch" mesh decimation algorithm.
- Customize own decimation routine.
  - How to better define the error? $||M - M'||$
  - Can we customize our mesh decimation routine by considering the SWE directly into the error?
- Long-term: This technology may lead us closer to geometric/physics-informed adaptive mesh refinement (AMR) in real-time?

Acknowledgements

FEMA

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Extreme Science and Engineering Discovery Environment

TACC
TEXAS ADVANCED COMPUTING CENTER

LONI

LSU HPC HIGH PERFORMANCE COMPUTING

The Water Institute of the Gulf RESTORE ACT CENTER OF EXCELLENCE LOUISIANA

We're going on a bear hunt…

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Bilskie, Hagen & Medeiros (2020), Unstructured finite element mesh decimation for real-time Hurricane storm surge forecasting, *Coastal Engineering*, 156, 103622. https://doi.org/10.1016/j.coastaleng.2019.103622.