Towards Dynamic Multi-Physics and Multi-Scale Modeling of the Coastal Ocean and Floodplain

Joannes Westerink[1], Dam Wirasaet[1], Rick Luettich[2], Clint Dawson[3], Andrew Kennedy[1], William Pringle[1], Maria Teresa Contreras-Vargas[1], Guoming Ling[1], Mindo Choi[1], Coleman Blakely[1], Dylan Wood[1], Brian Joyce[1,4], Steven Brus[1,5], Aaron Donahue[1,6], Casey Dietrich[1,7], Ethan Kubatko[1,8], Keith Roberts[1,9], Eric Bohm[9], Laxmikant Kale[10], Eric Bohm[10], Justin Szaday[10], Sam White[10]
Eirik Valseth[3], Younghun Kang[8]

[1]University of Notre Dame, [2]University of North Carolina at Chapel Hill, [3]University of Texas at Austin, [4]Berkshire Hathaway, [5]LANL, [6]LLNL, [7]North Carolina State University, [8]Ohio State University , [9]University of San Paolo, [10]University of Illinois at Urbana-Champaign

Charm ++ Workshop
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The hydrodynamics of the coastal ocean and floodplain

Understanding coastal sustainability and risk means understanding water levels, currents, and wind waves from the shelf to the inland floodplain


Coastal flooding


Wave forces


Sinking deltas


Wetland degradation


Coastal dead zones


Marine larval transport

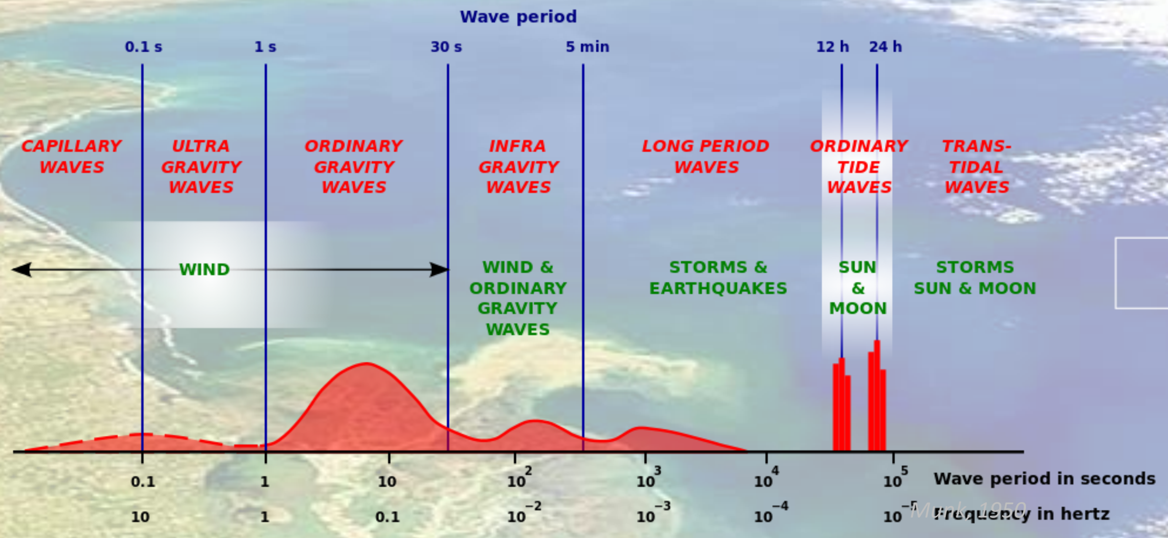
Evolution of coastal ocean hydrodynamics models – the recent past

Dynamic ADCIRC & SWAN Coupling

CFSv2 Global Atmospheric Model

ADCIRC 2D SWE

SWAN Wave Energy Density



Evolution of coastal ocean hydrodynamics models – the recent past

Dynamic ADCIRC & SWAN Coupling

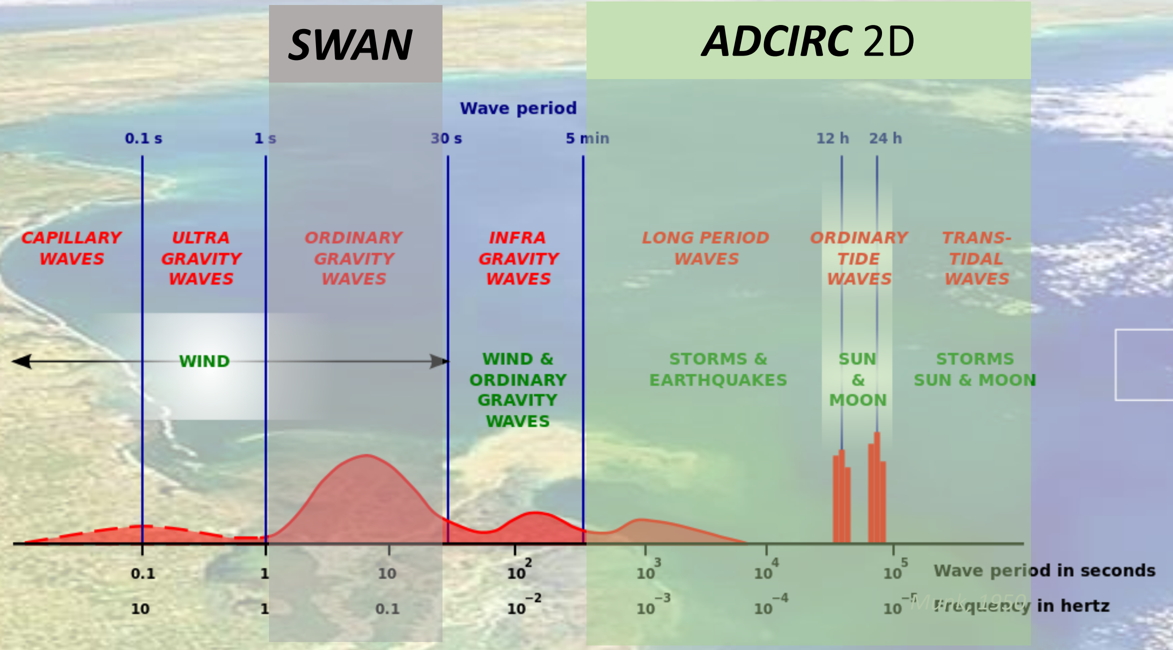
CFSv2 Global Atmospheric Model

ADCIRC 2D SWE

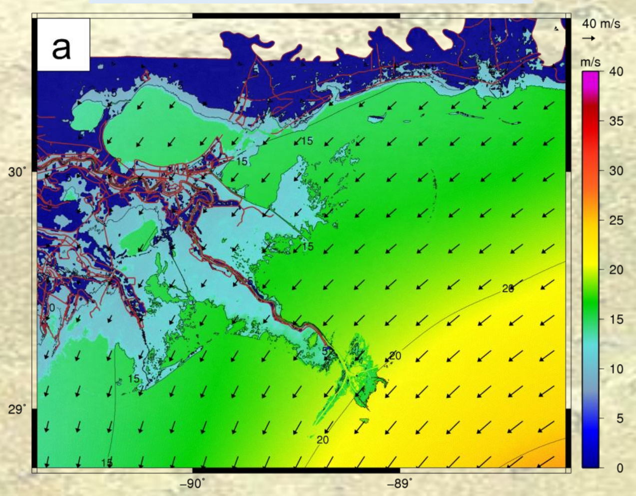
SWAN Wave Energy Density

SWAN

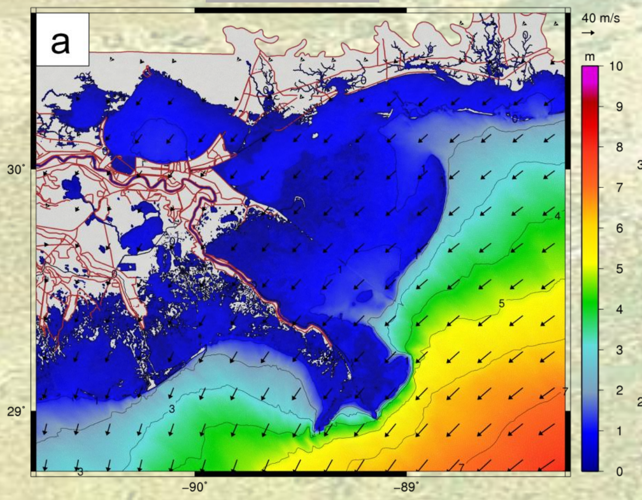
ADCIRC 2D



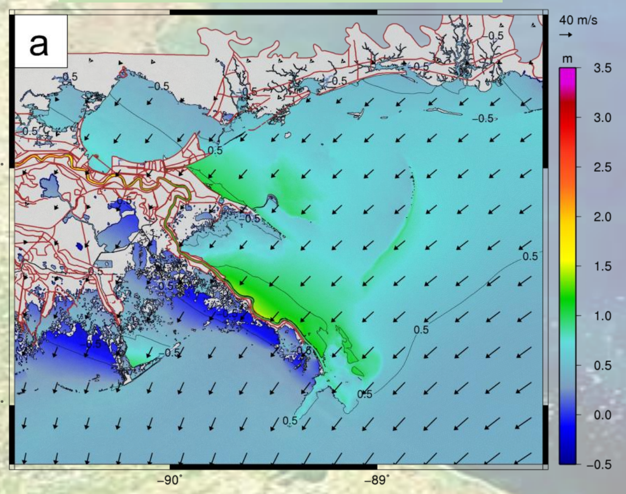
CFSv2



SWAN



ADCIRC 2D

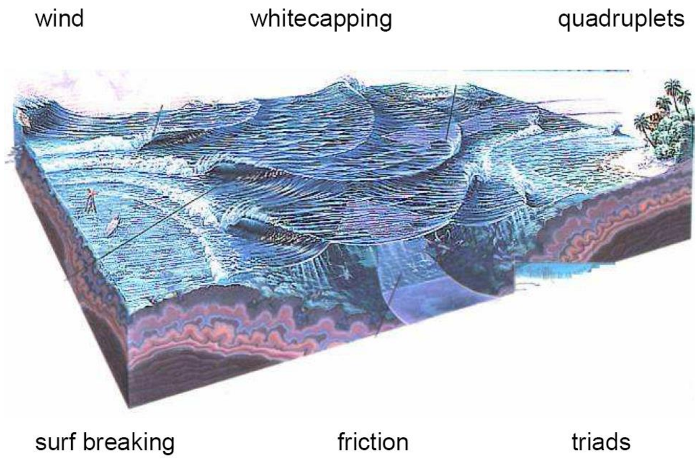


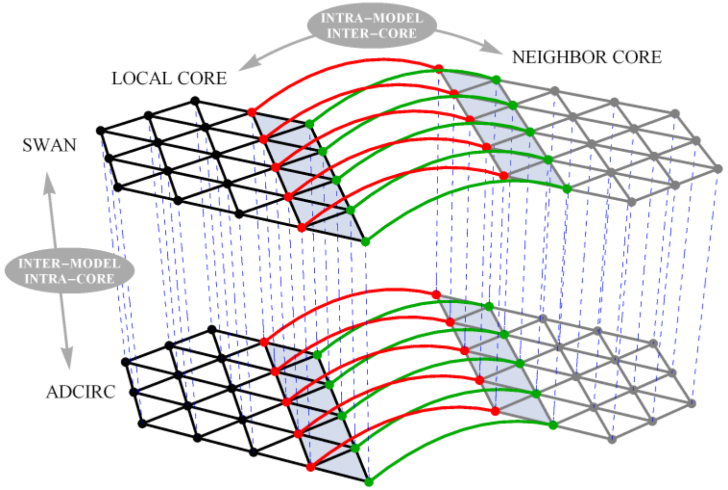
ADCIRC+SWAN: Coastal ocean circulation and wave models – the past

- ADCIRC solves the shallow water equations in 2D and 3D
- ADCIRC applies Galerkin FEM using highly unstructured linear finite element grids over large ocean domains
- ADCIRC usage highlights in U.S.
  - USACE: Design Metropolitan New Orleans levees post Katrina; Post Sandy flood risk study along East and Texas coasts
  - NOAA: Extra-tropical real time forecasting models (ESTOFS and new global G-ESTOFS)
  - FEMA: Flood Insurance Studies for U.S. Gulf, East and Great Lakes coasts
  - NRC: Nuclear power station risk evaluation

ADCIRC+SWAN: Coastal ocean circulation and wave models – the past

- SWAN solves the wave action density and is a non-phase resolving wave model with wave energy represented by a spectrum
- SWAN has been implemented as an unstructured grid model with the degrees of freedom at triangle vertices
- ADCIRC and SWAN interact
  - Water levels and currents affect waves
  - Wave breaking forces water level setup and currents

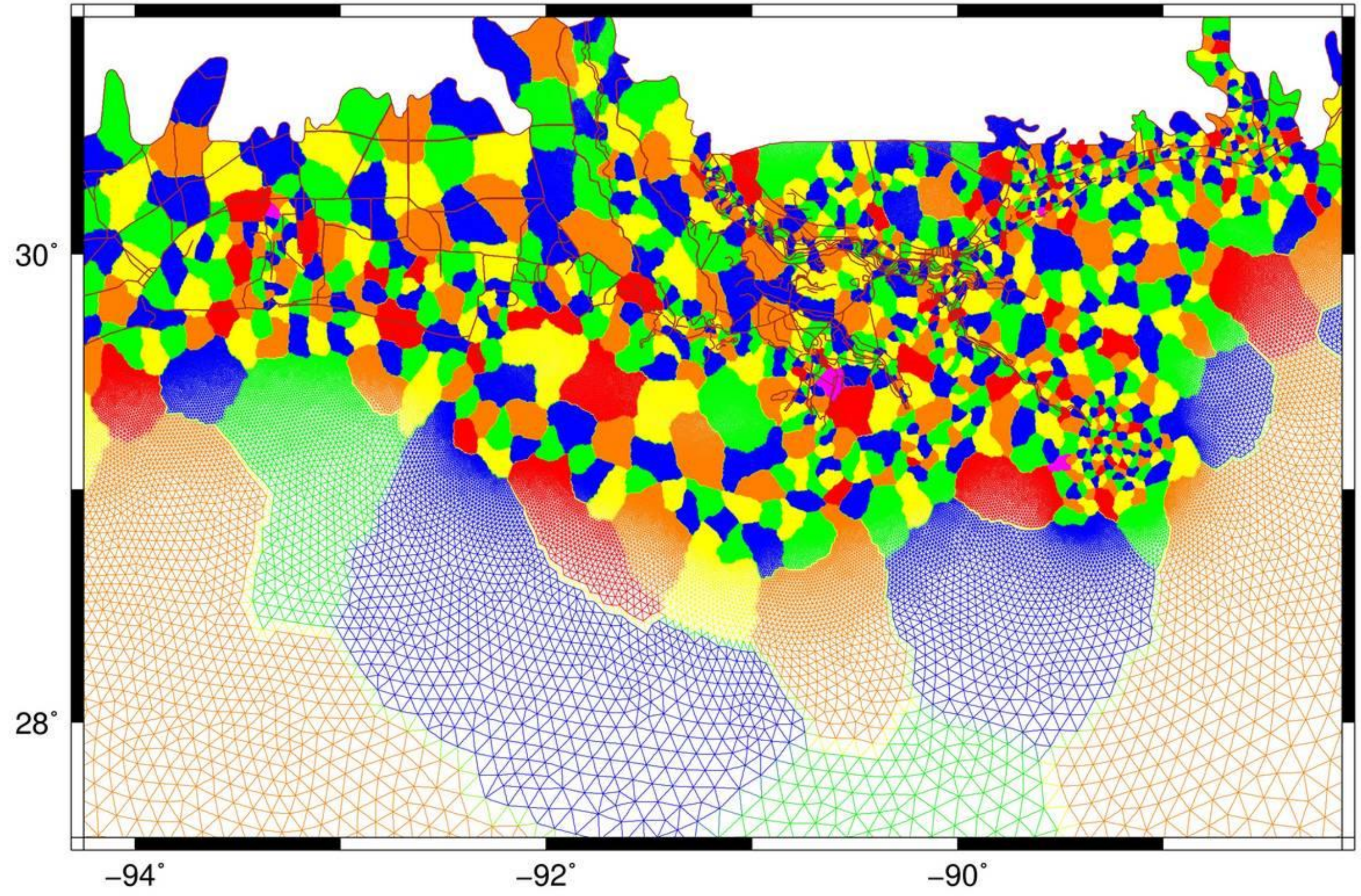




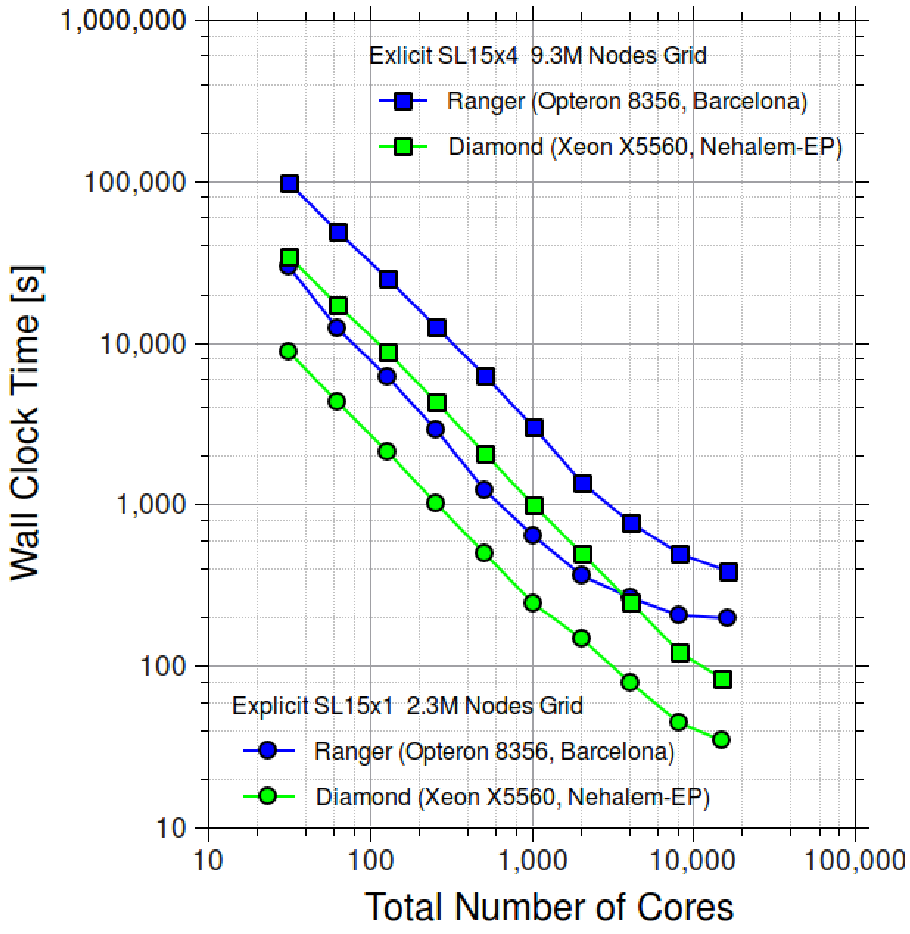
Dietrich et al., *Coastal Engineering*, **58**, 45-65, 2011.
Dietrich et al., *Journal of Scientific Computing*, **52**, 468-497 2012.

ADCIRC+SWAN: Coastal ocean circulation and wave models – the past

HPC: MPI Based Domain Decomposition – Overlapping Element Layer Node to Node Communication

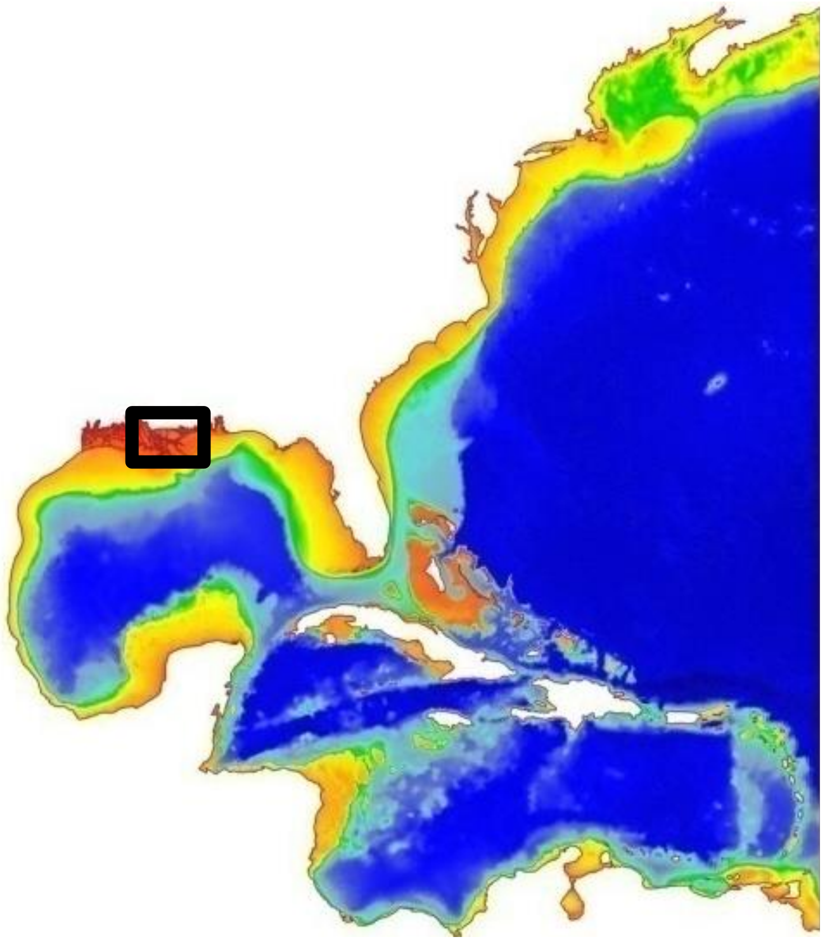


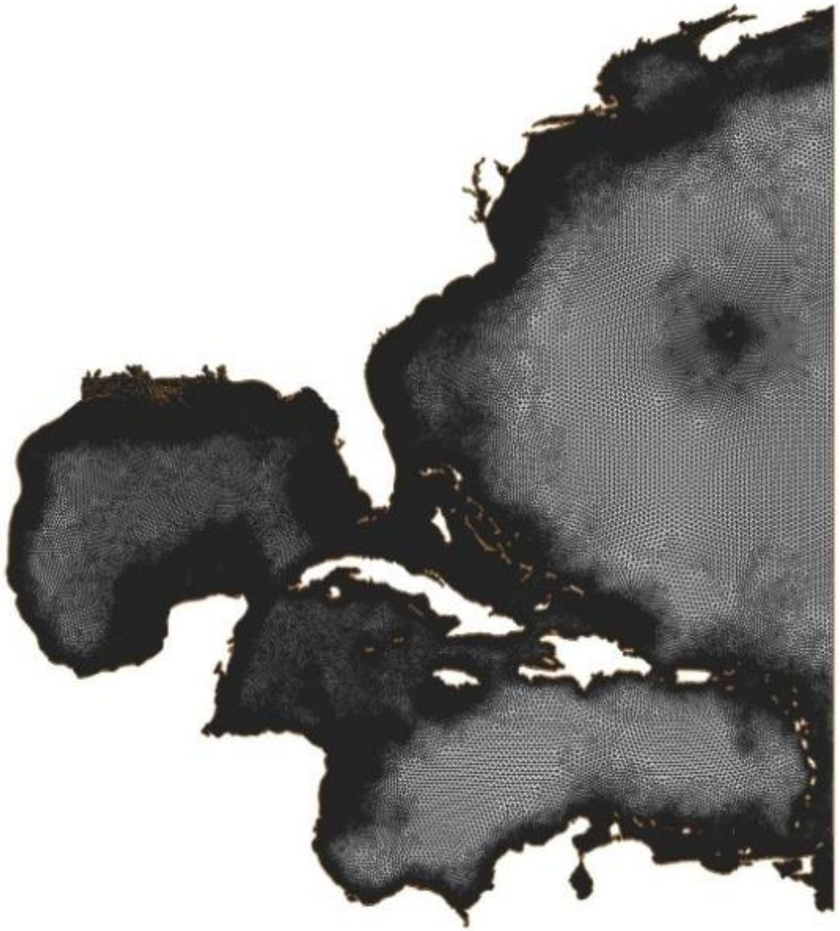
HPC: Parallel Performance



ADCIRC+SWAN: Coastal ocean circulation and wave models – the past

SL16v18 model bathymetry and topography and unstructured mesh

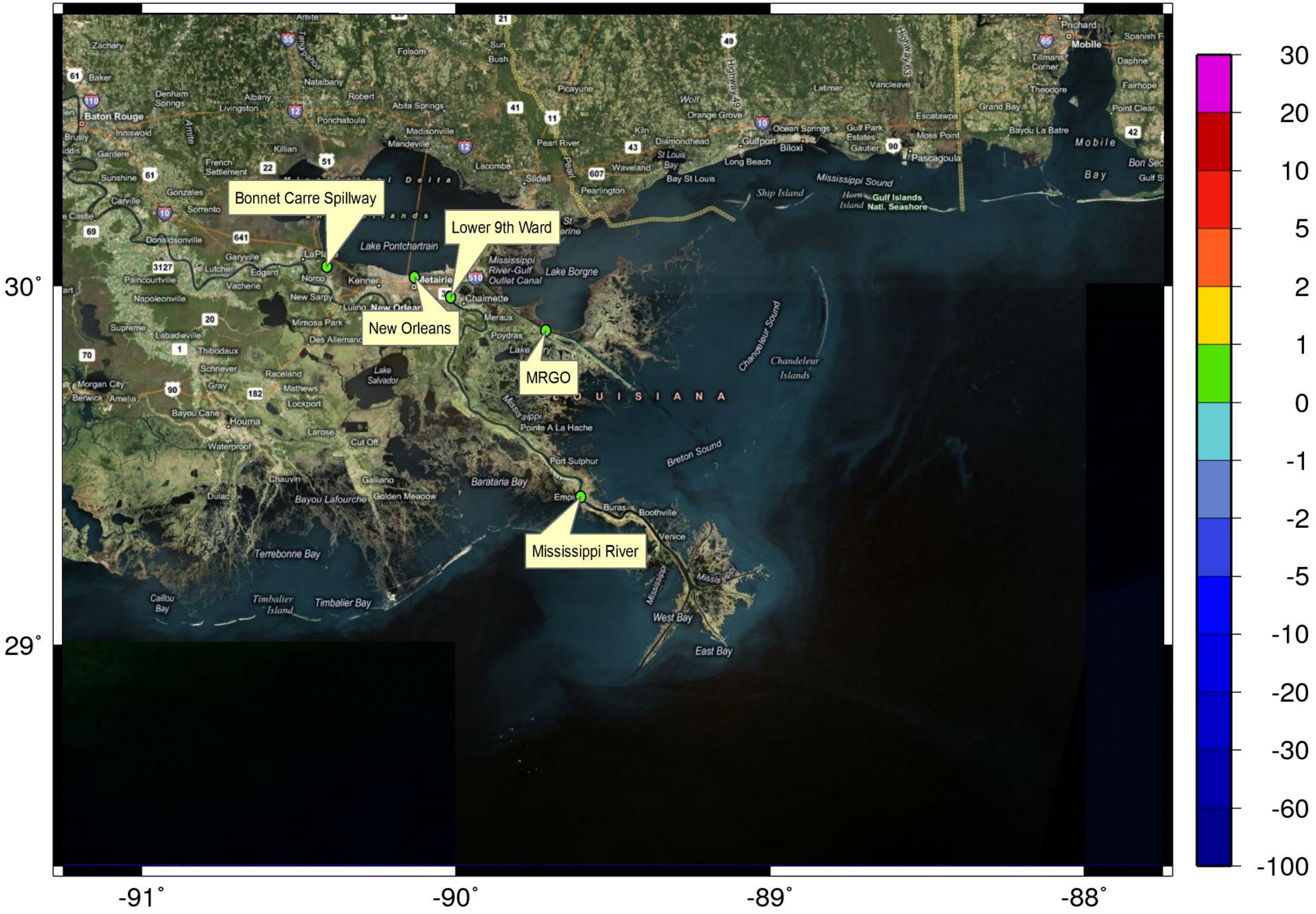




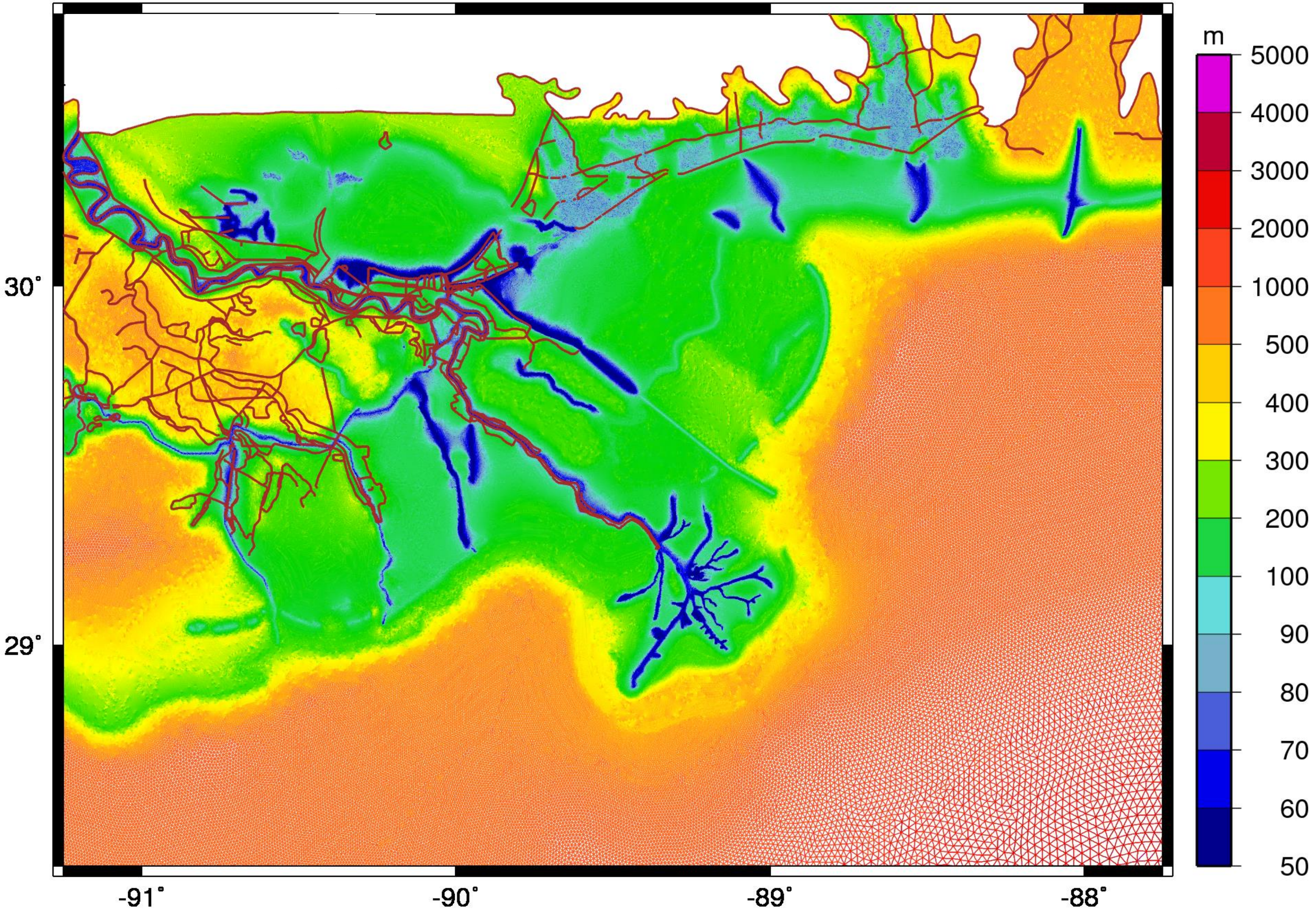
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.
Kennedy et al., ***Geophysical Research Letters***, **38**, L08608, 2011.
Kerr et al., ***Journal of Waterway, Port, Coastal, and Ocean Engineering***, **139,** 326-335, 2013.

Martyr et al., ***Journal of Hydraulic Engineering***, **139**, 5, 492-501, 2013.
Hope et al., ***Journal of Geophysical Research: Oceans***, **118**, 4424-4460, 2013.
Kerr et al., ***Journal of Geophysical Research: Oceans***, **118,** 5129–5172, 2013.

SL16v18 model bathymetry & topography in SE Louisiana

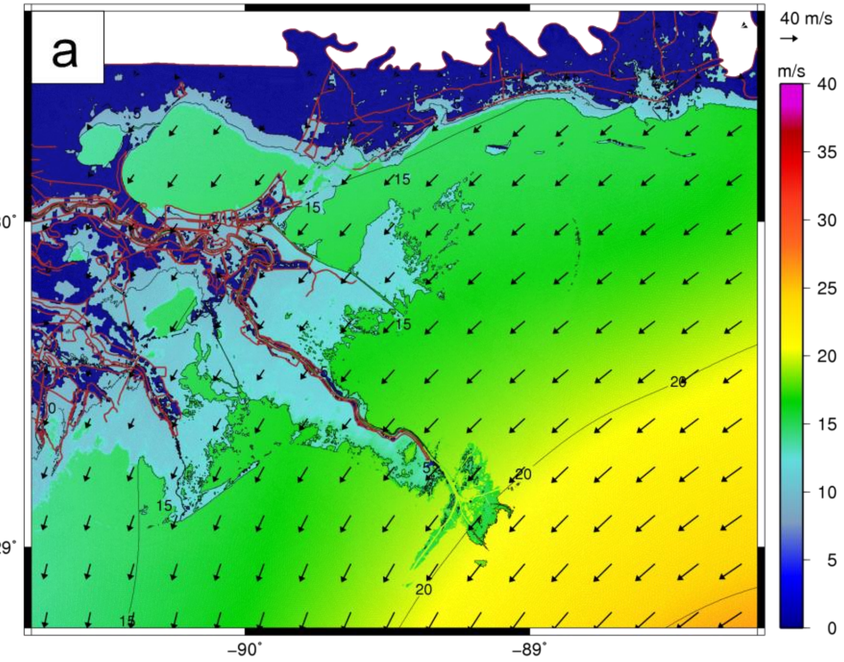


Models: SL16v18 mesh size in SE Louisiana

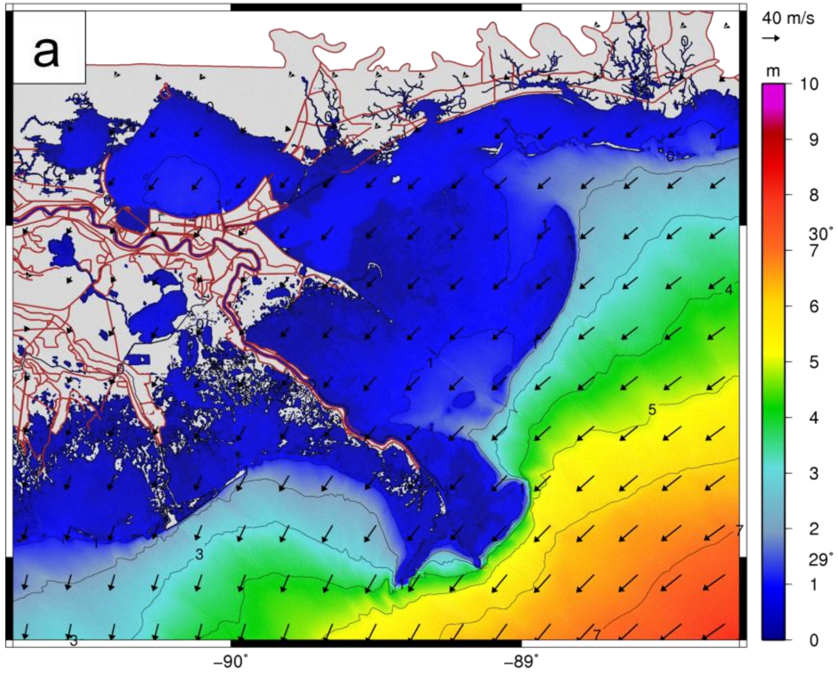


Hurricane Gustav: 2008 / 09 / 01 / 0200 UTC

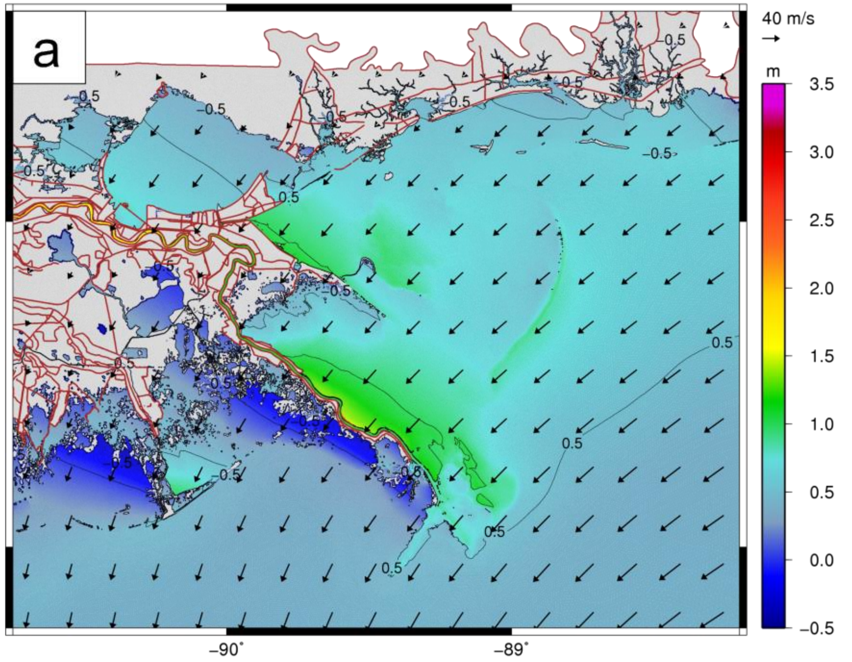
Winds (m/s)



Waves (m)



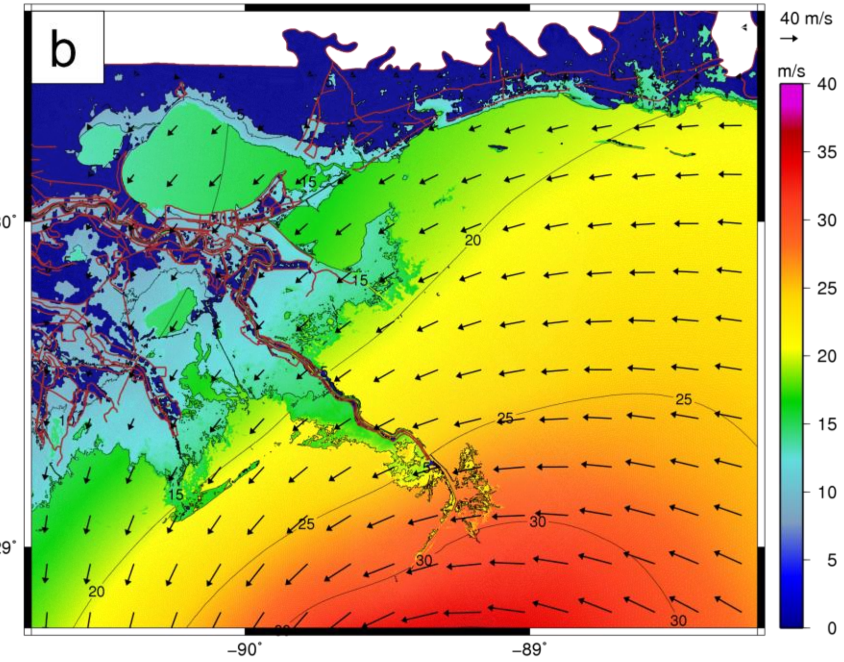
Water Elevations (m)



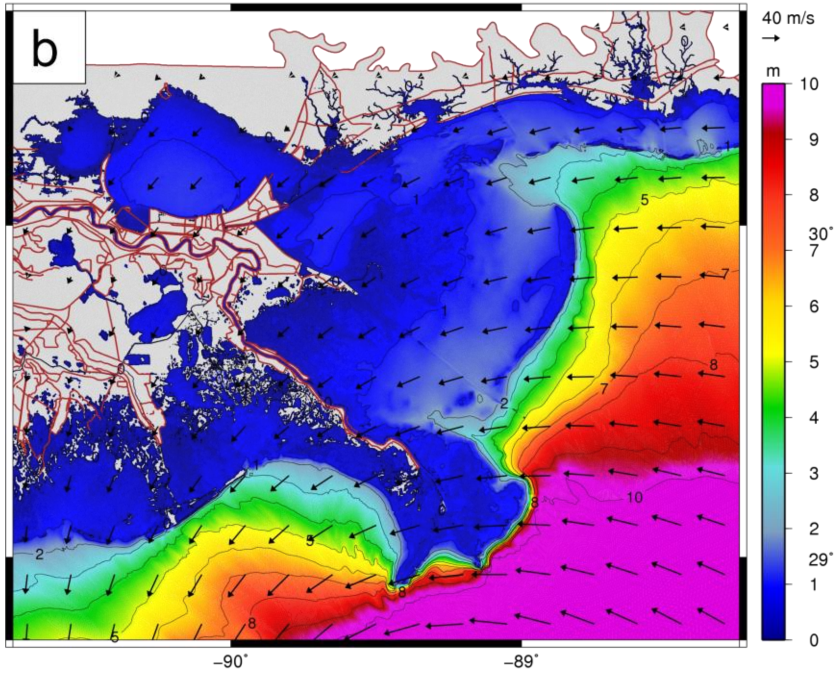
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 0800 UTC

Winds (m/s)



Waves (m)



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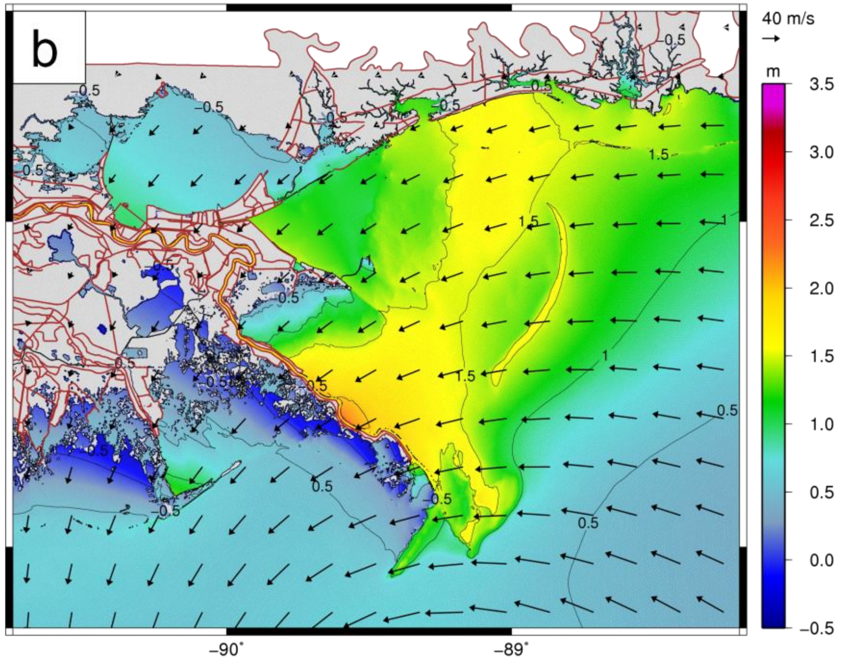
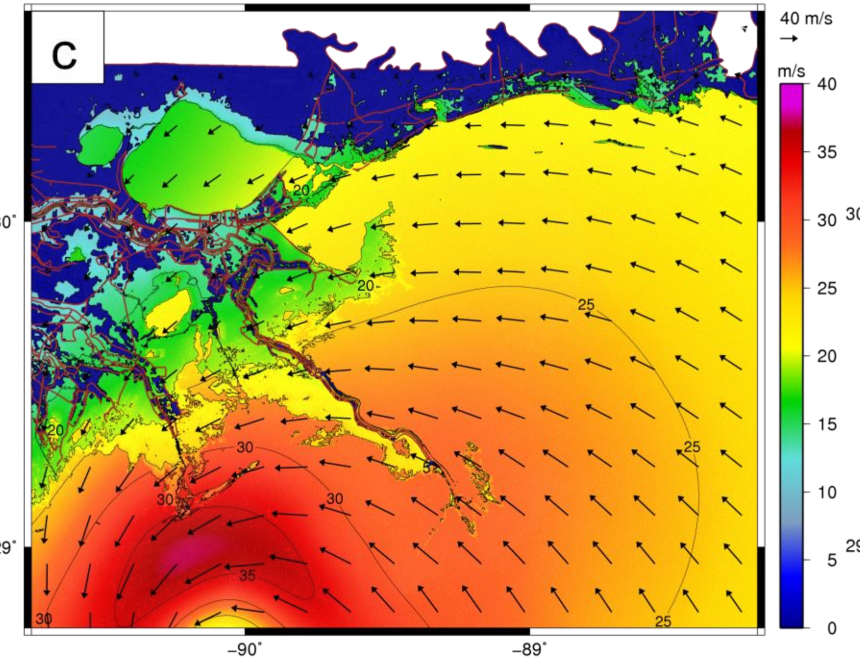


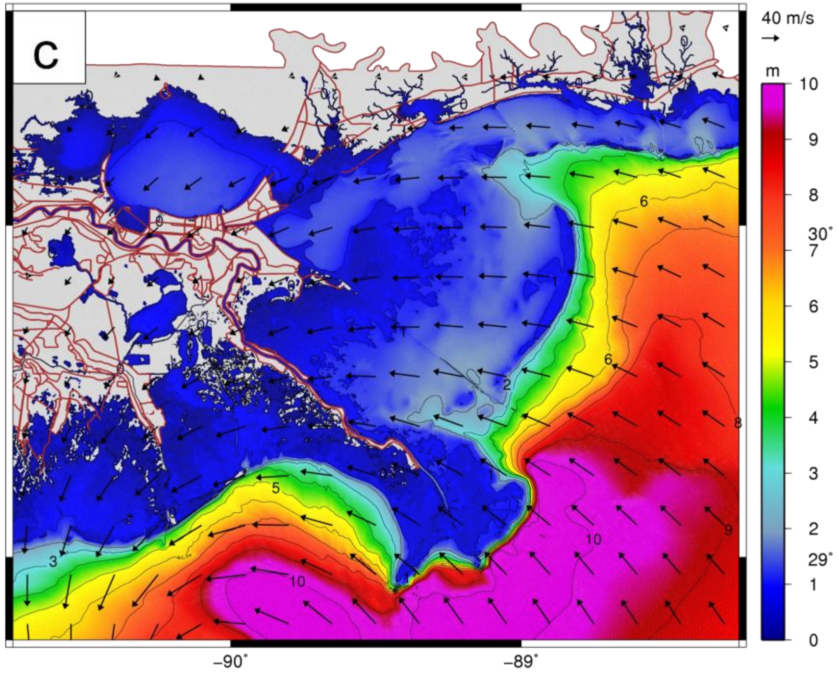
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 1100 UTC

Winds (m/s)



Waves (m)



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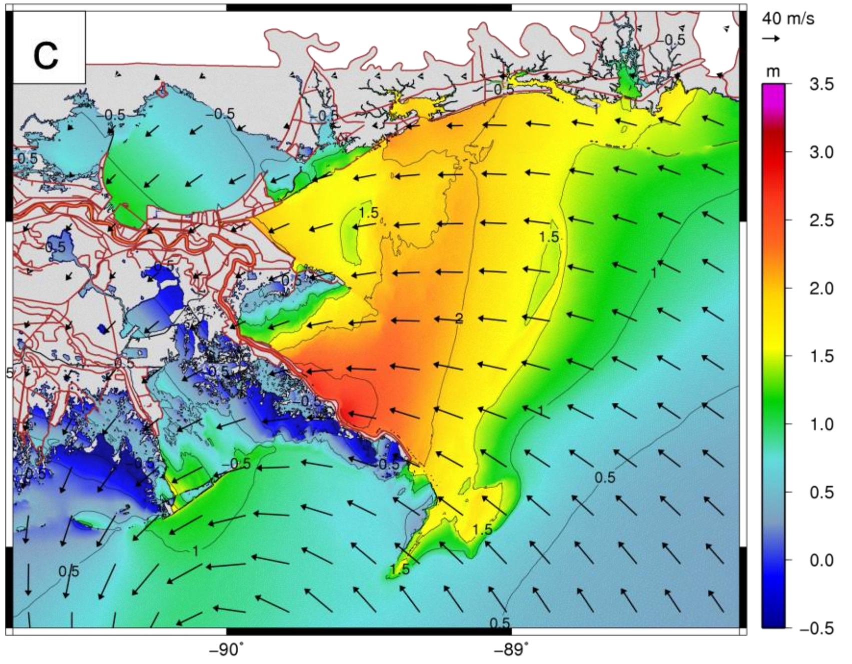
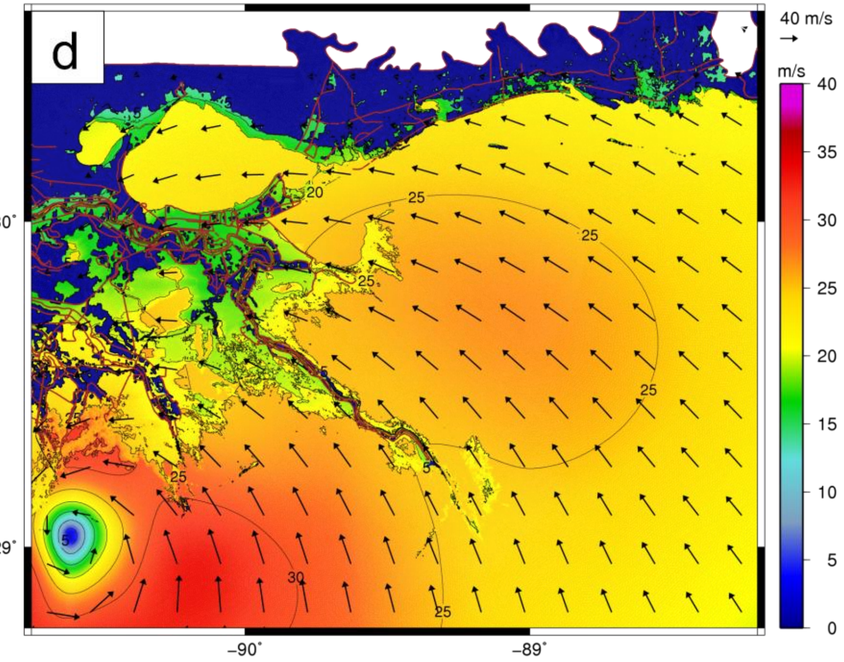


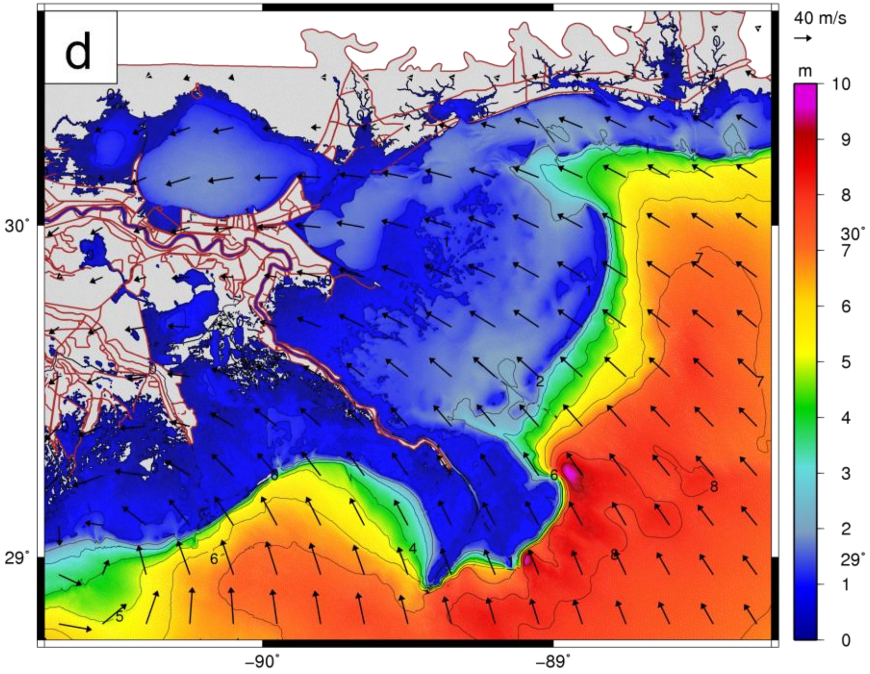
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 1400 UTC

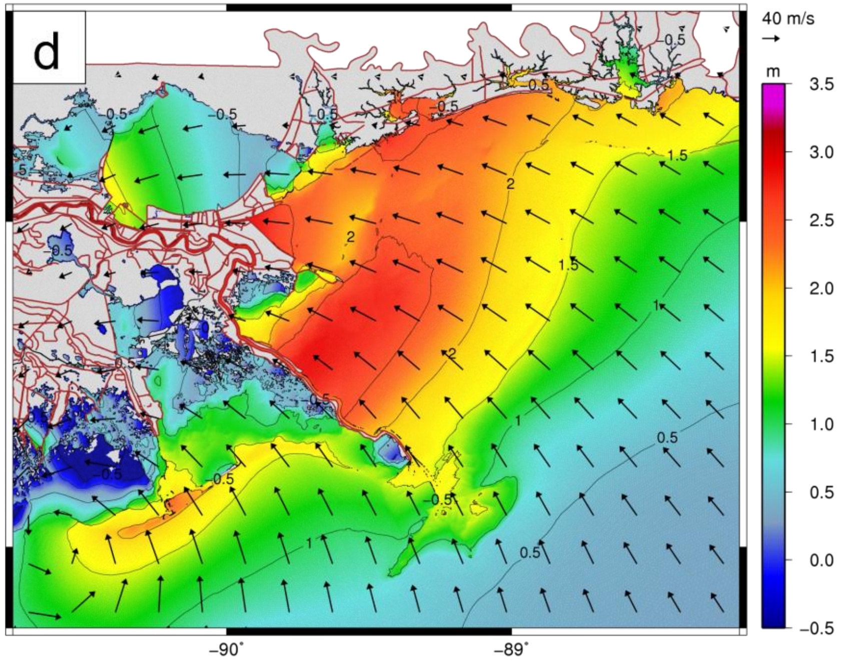
Winds (m/s)



Waves (m)



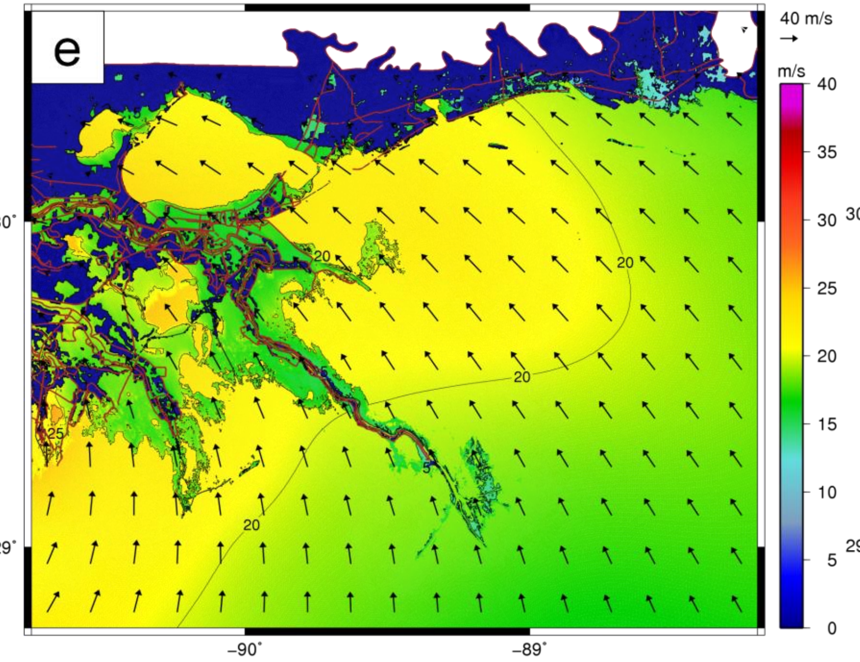
Water Elevations (m)



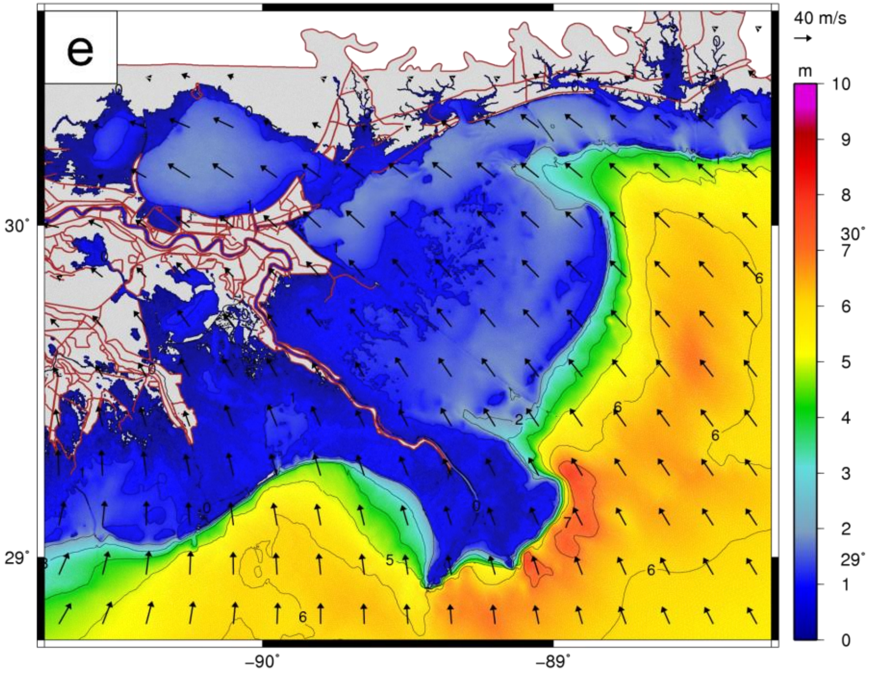
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 1700 UTC

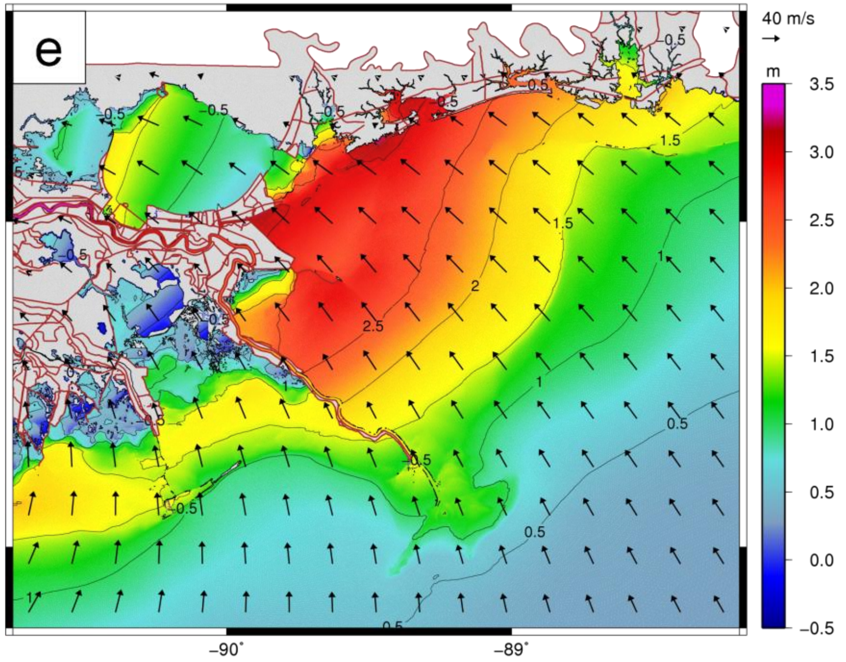
Winds (m/s)



Waves (m)



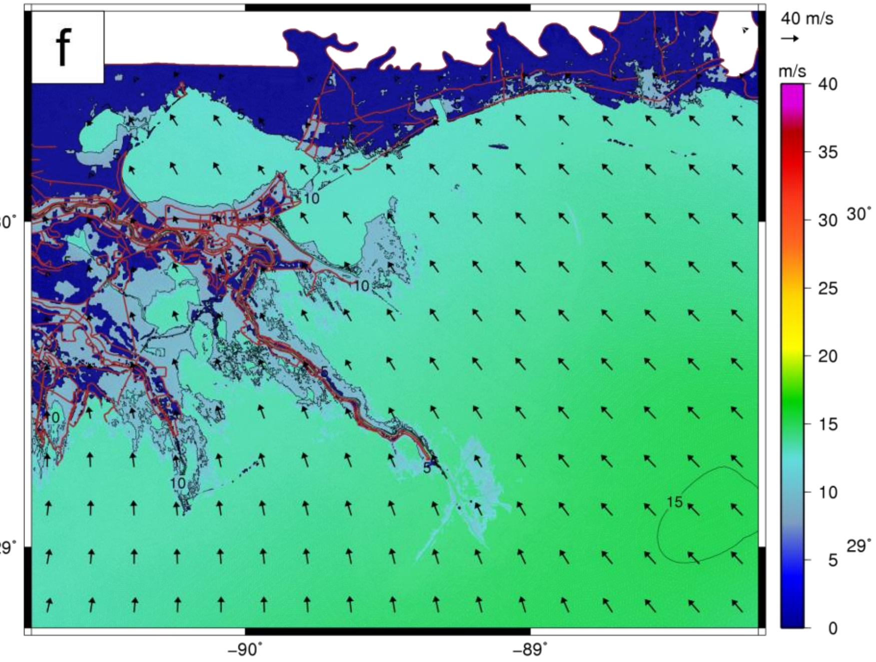
Water Elevations (m)



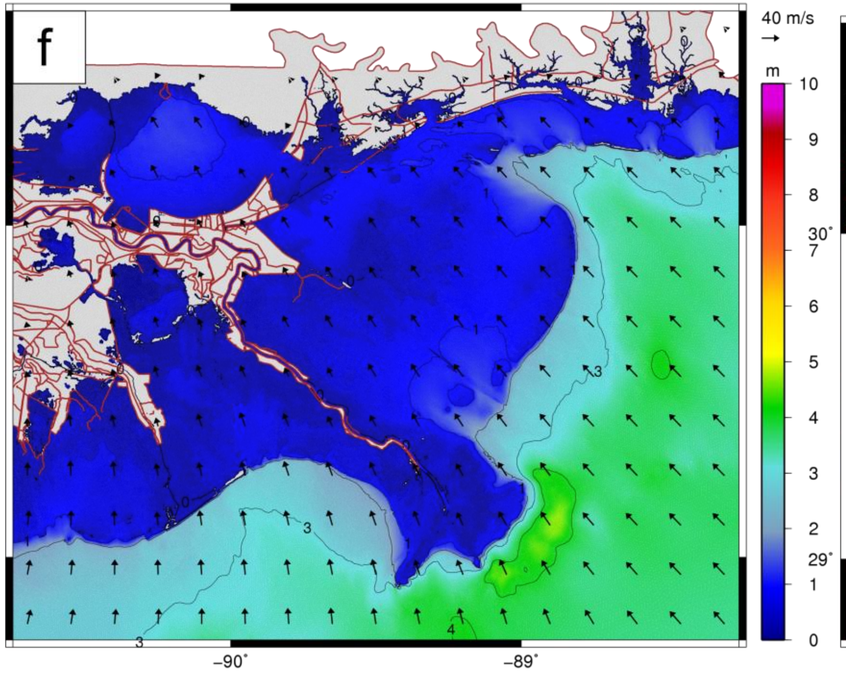
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 02 / 0200 UTC

Winds (m/s)



Waves (m)



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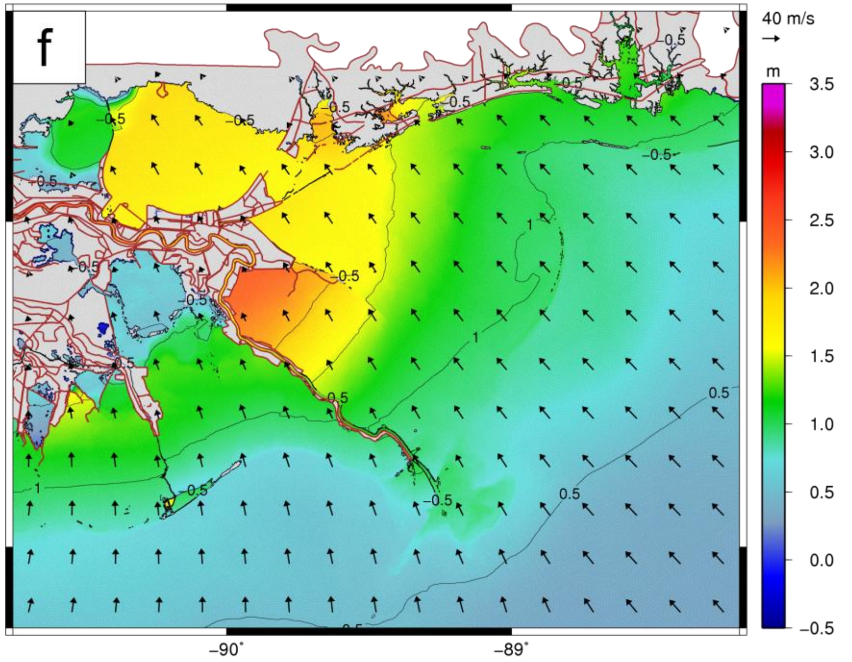


Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Evolution of coastal ocean hydrodynamic models – the future

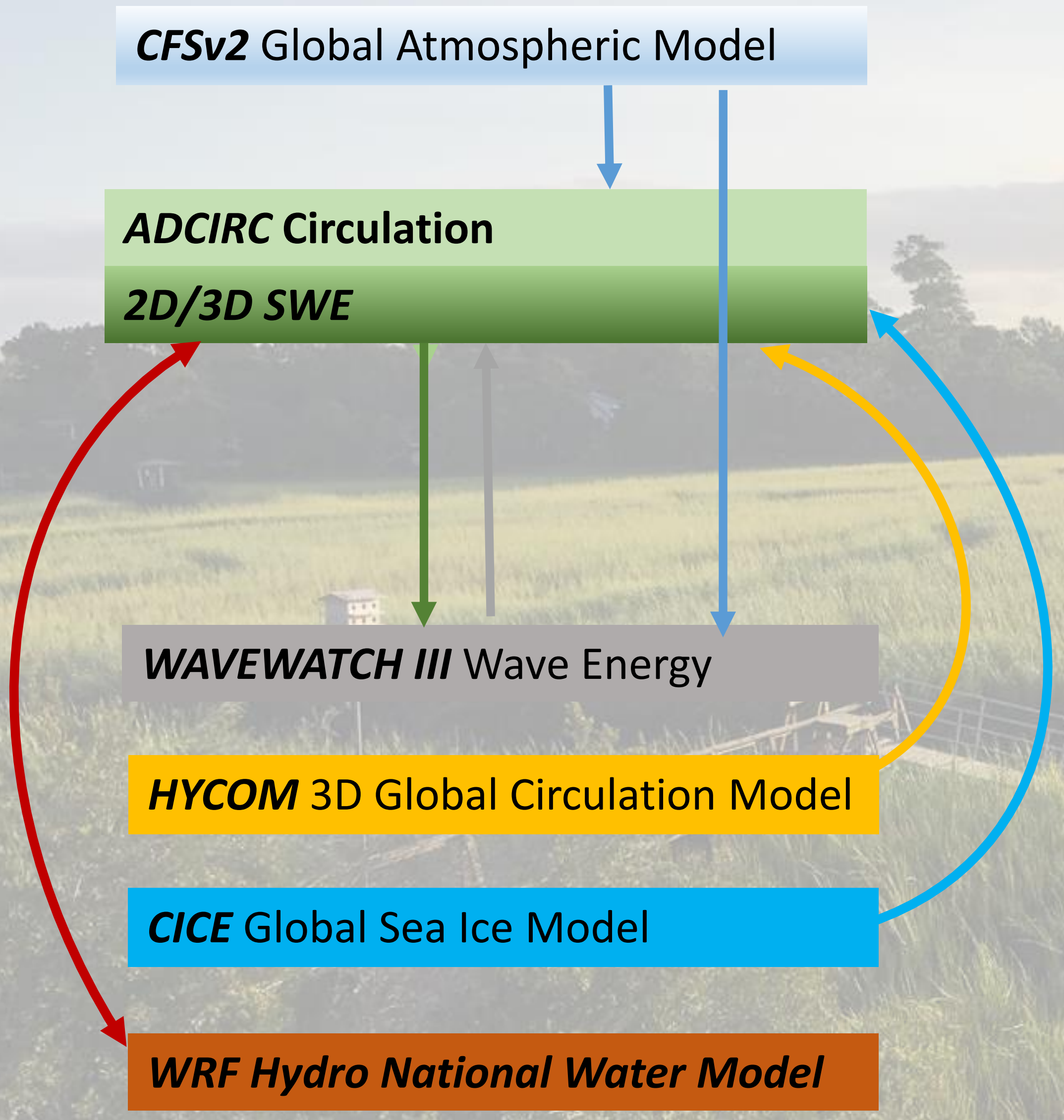
Vision

- Fully dynamic computations that during the simulation select
  - Physics
  - Load balance
  - Grid resolution
  - Order of interpolants

Focus areas

- Develop frameworks that allow dynamic and coupled physics
- Advance engines for load balancing
- Dynamic grid optimization for multi-physics
- High order methods

Advance coupling of multi-physics models

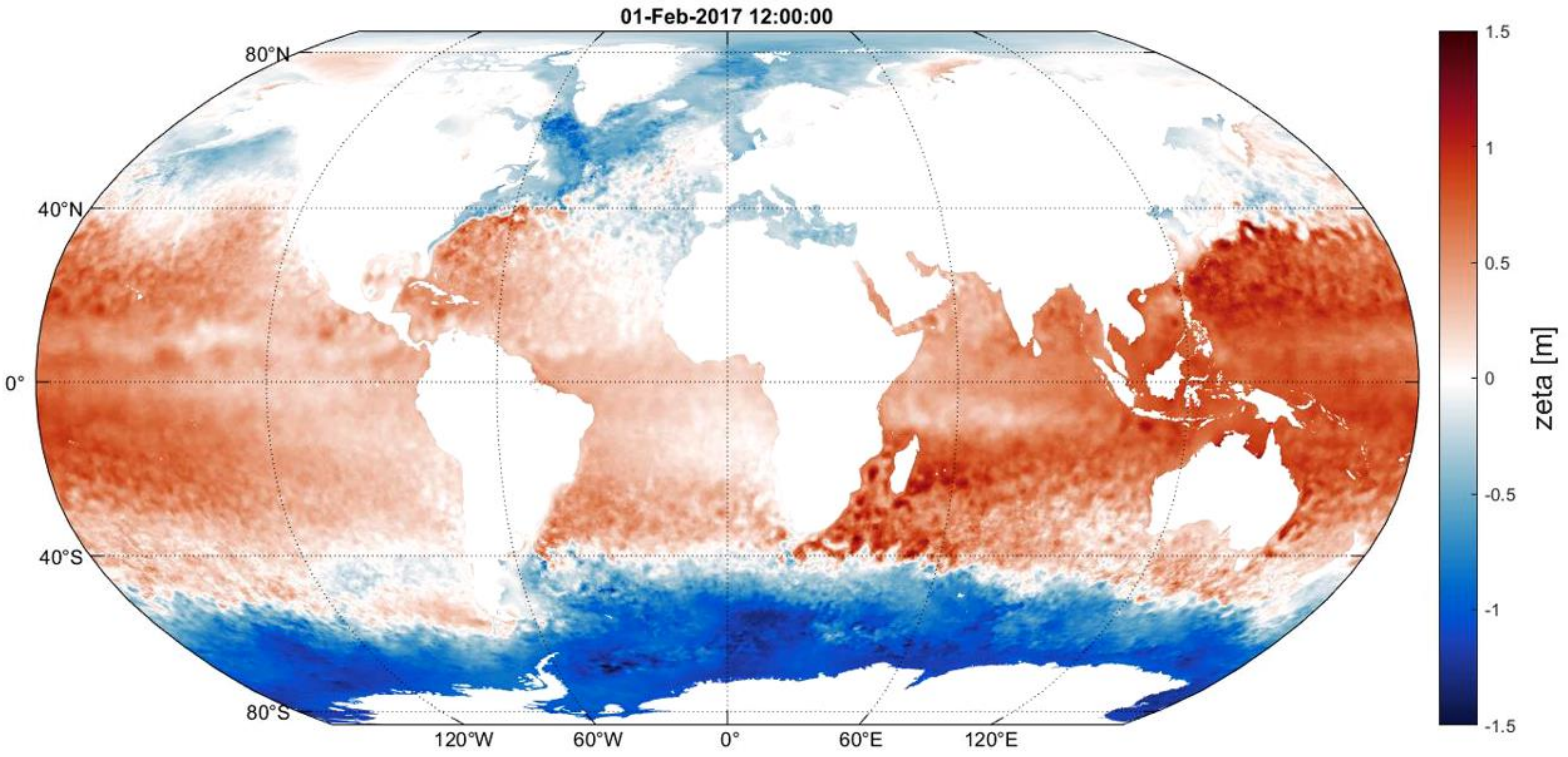


Multi-physics interfacing heterogeneous models over a unified domain

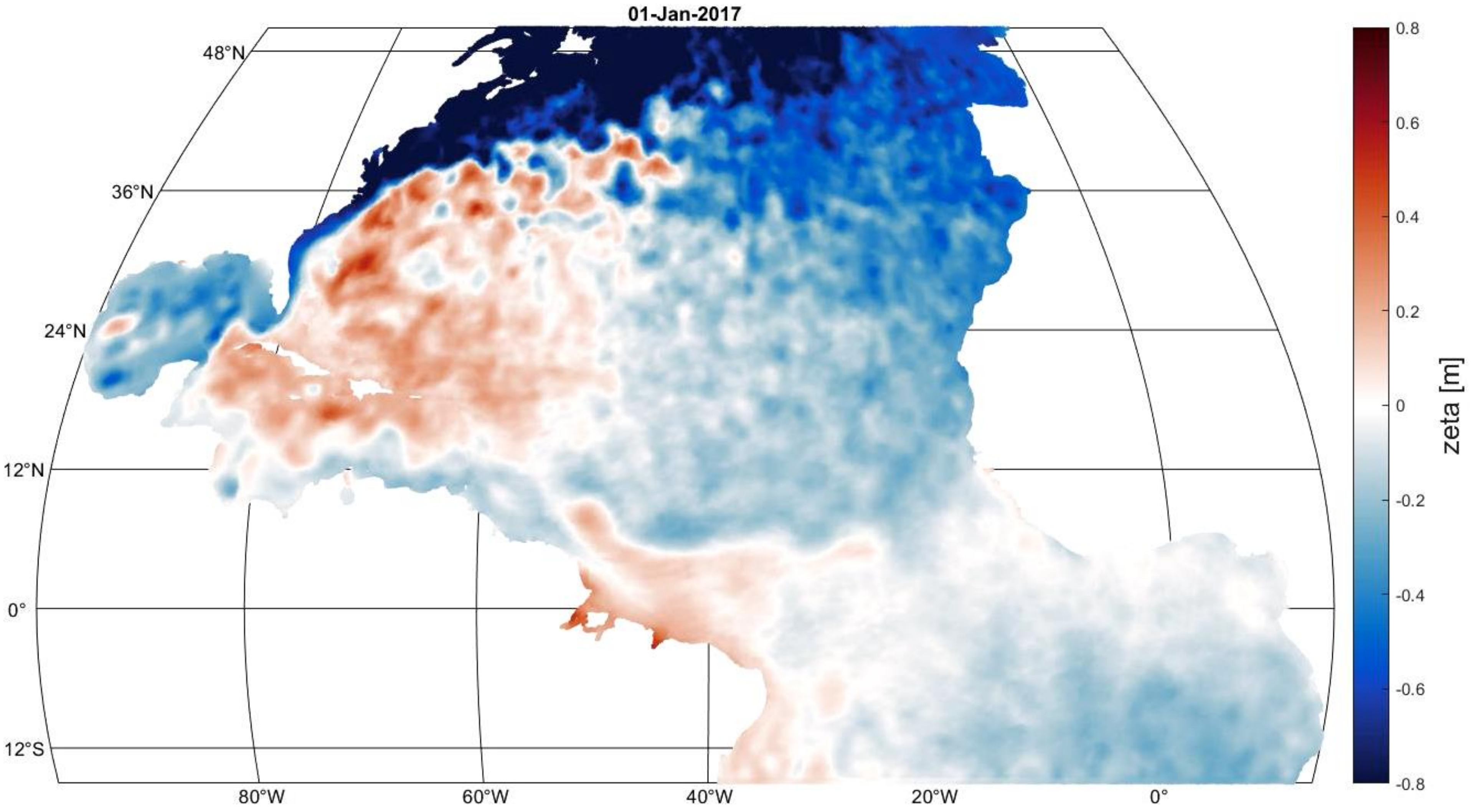
Dynamic coupling of *ADCIRC, WAVEWATCH III, HYCOM* and *CICE* Interleafing over a unified domain on heterogeneous grids communicating through *ESMF/NUOPC*

and boundary based two-way coupling to *WRF-Hydro* through *ESMF/NUOPC*

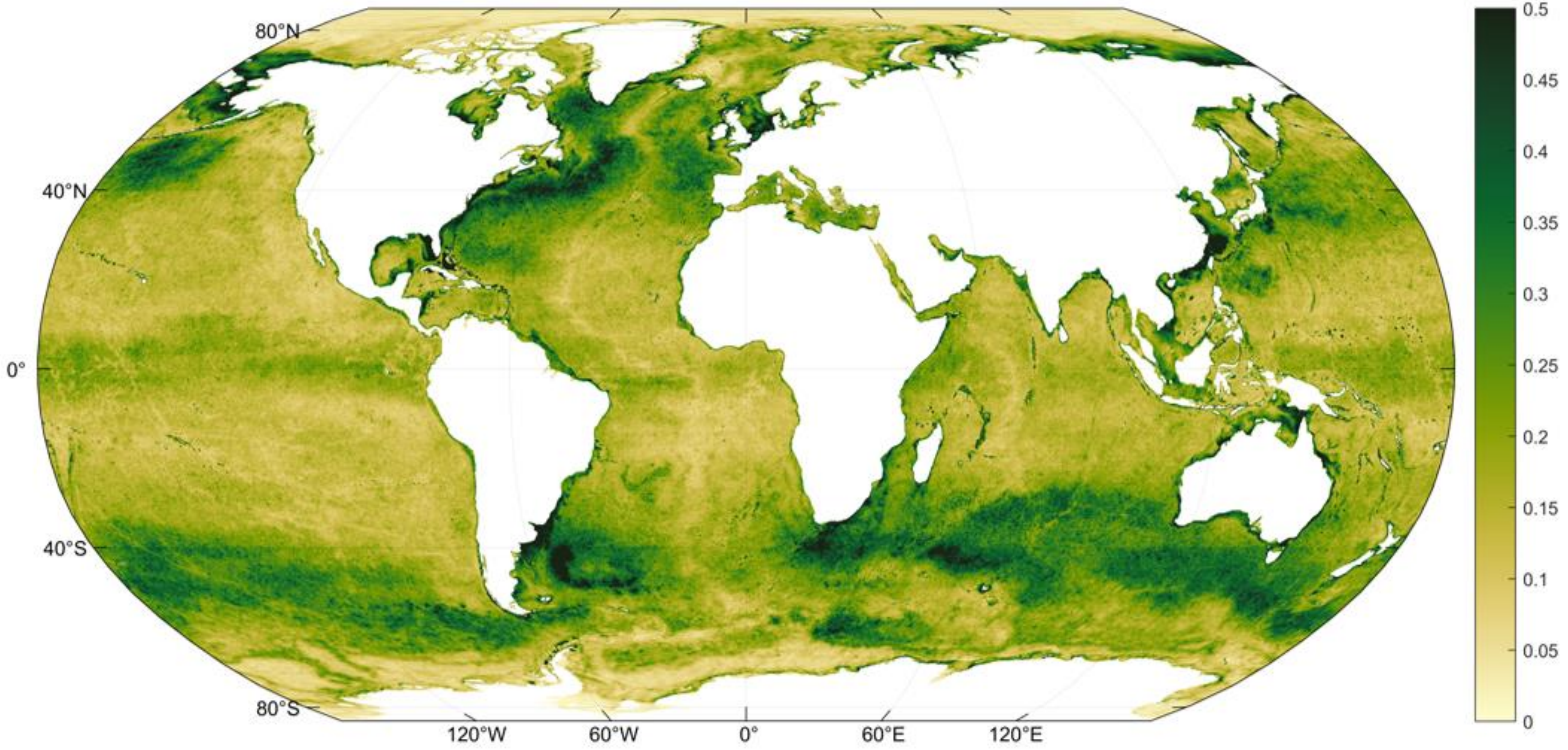
GOFS3.1 forcing of the ADCIRC global model: sea surface elevation



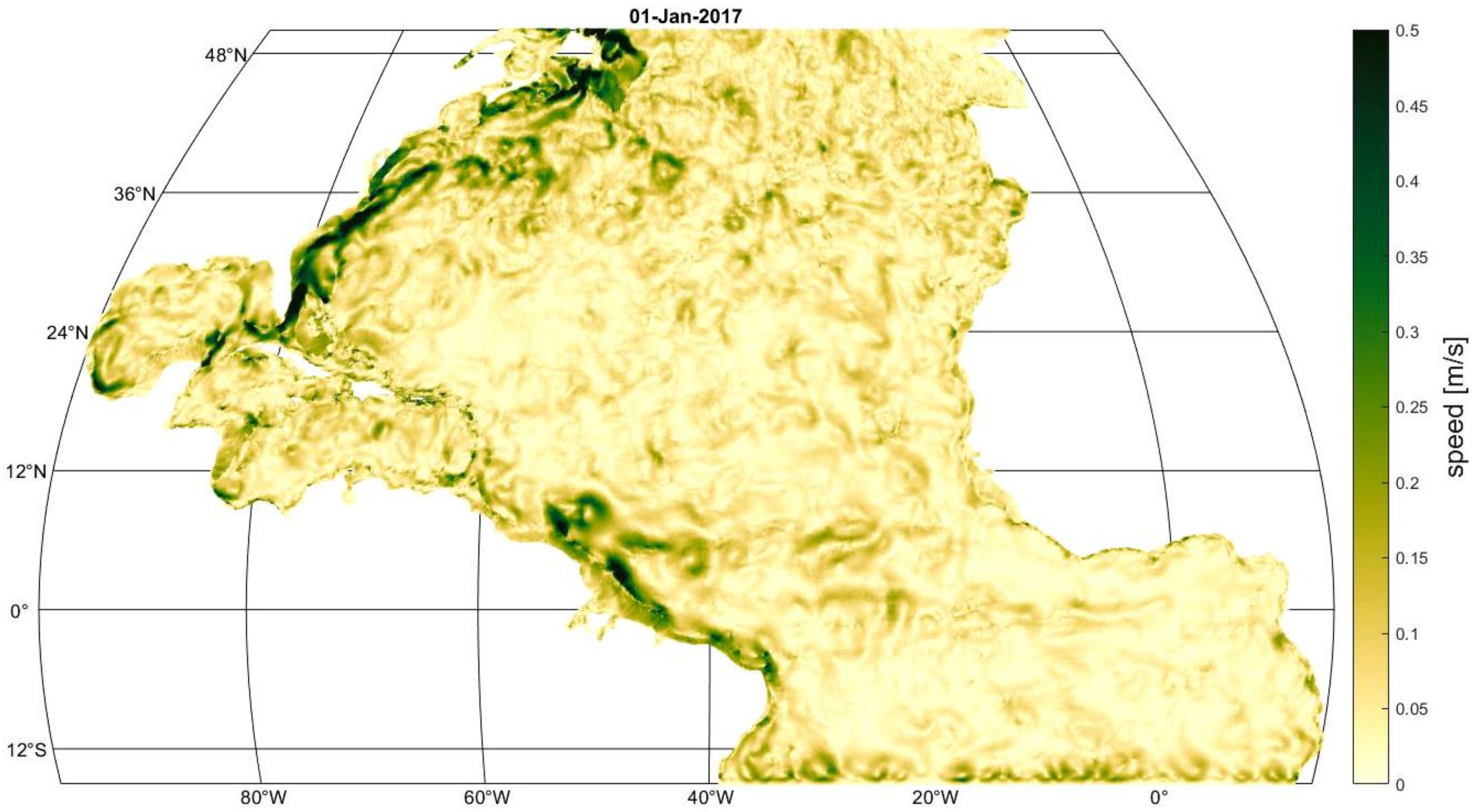
GOFS3.1 forcing of the ADCIRC global model: sea surface elevation



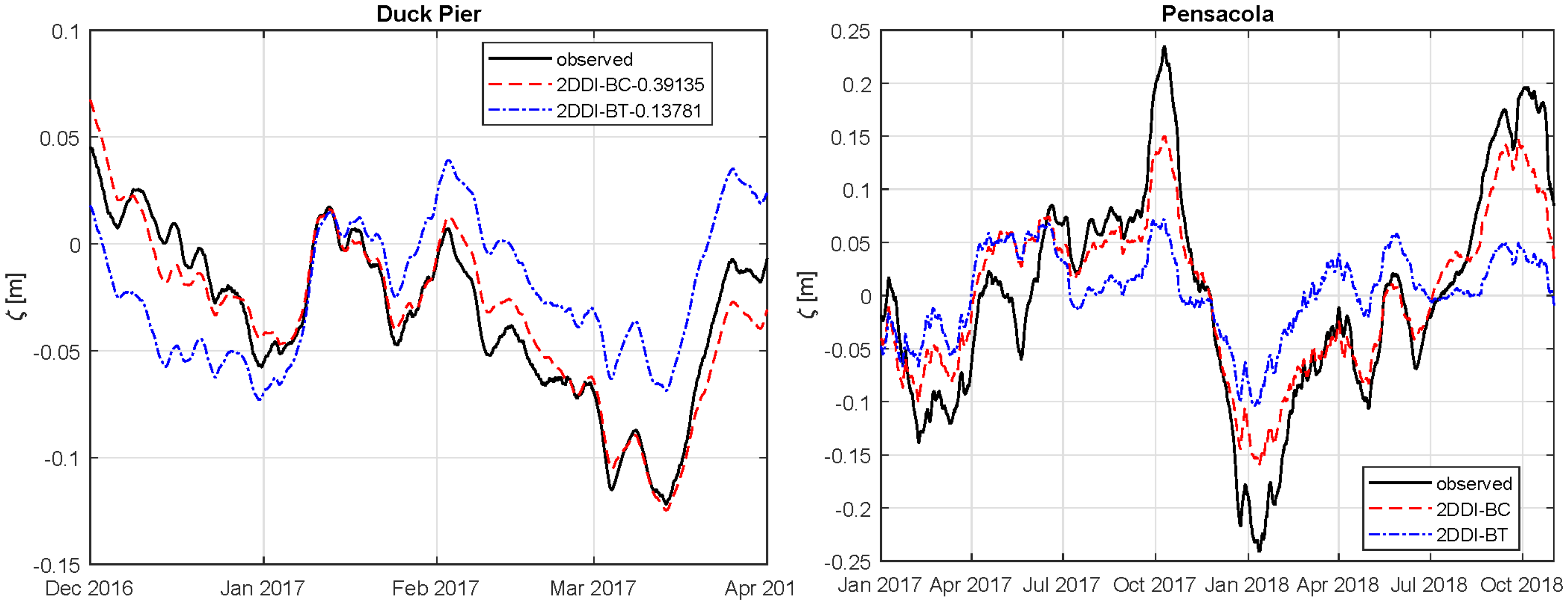
GOFS3.1 forcing of the ADCIRC global model: currents



GOFS3.1 forcing of the ADCIRC global model: currents

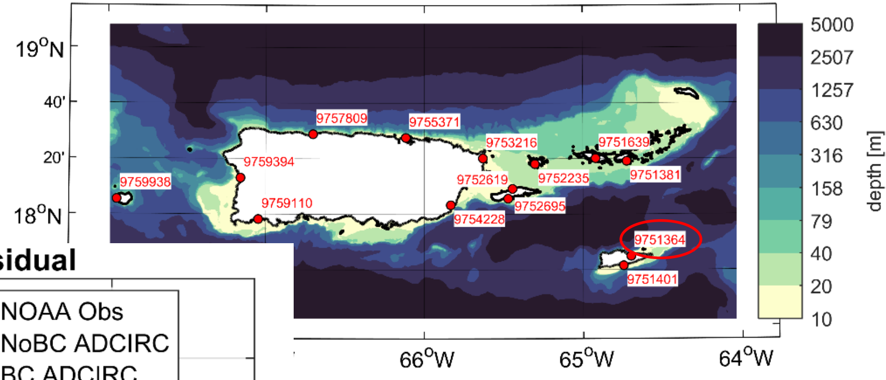


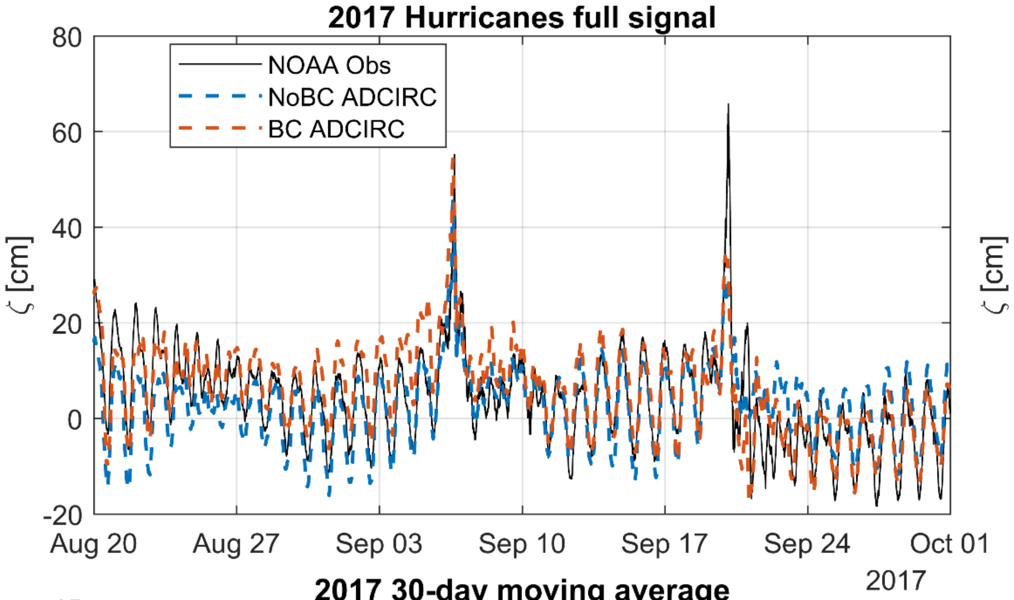
Sample comparison of 30 day averaged water levels – Atlantic Basin

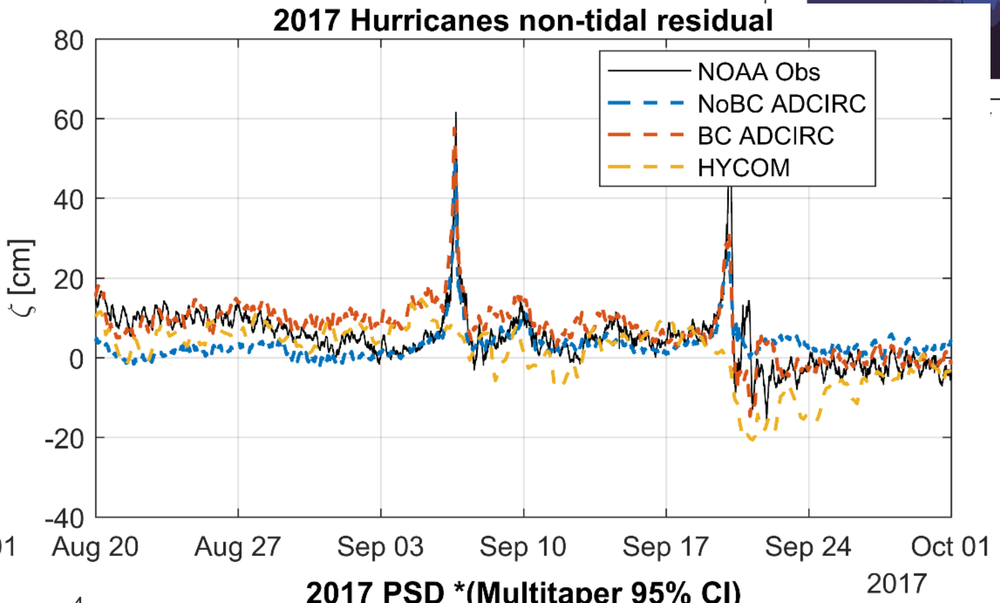


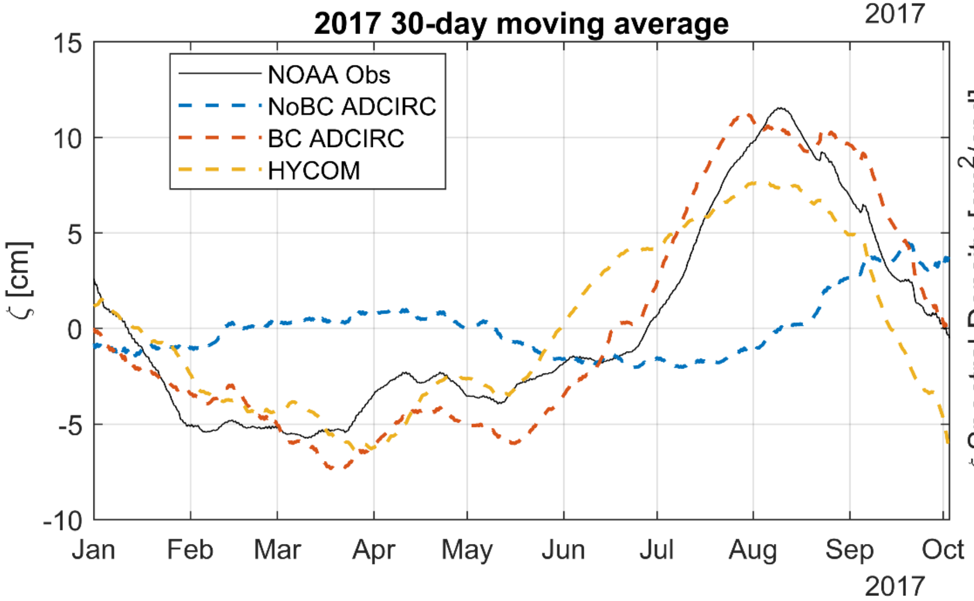
Time Series and Spectral Density -

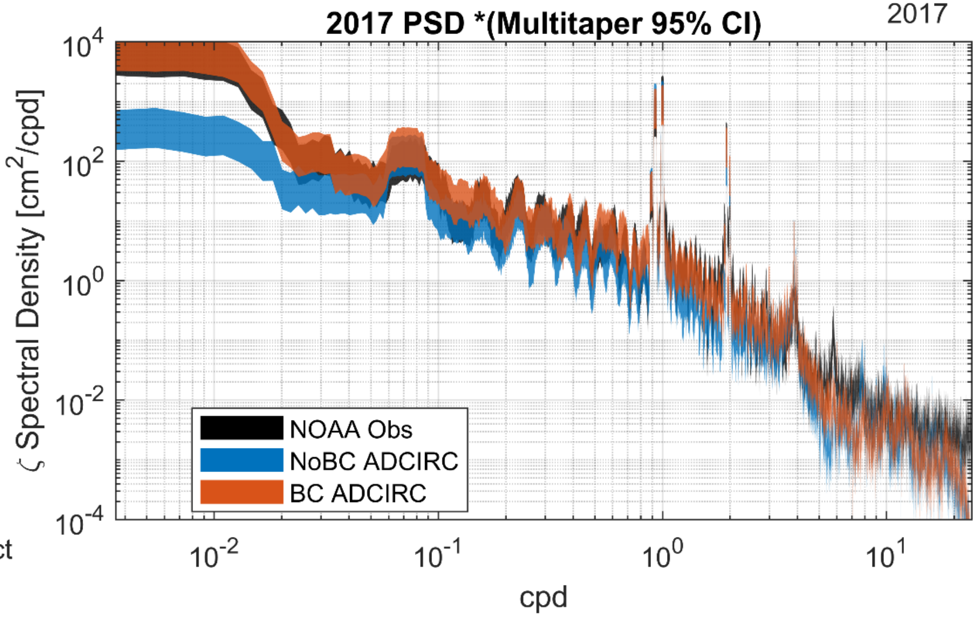
Christiansted Harbor St Croix, VI



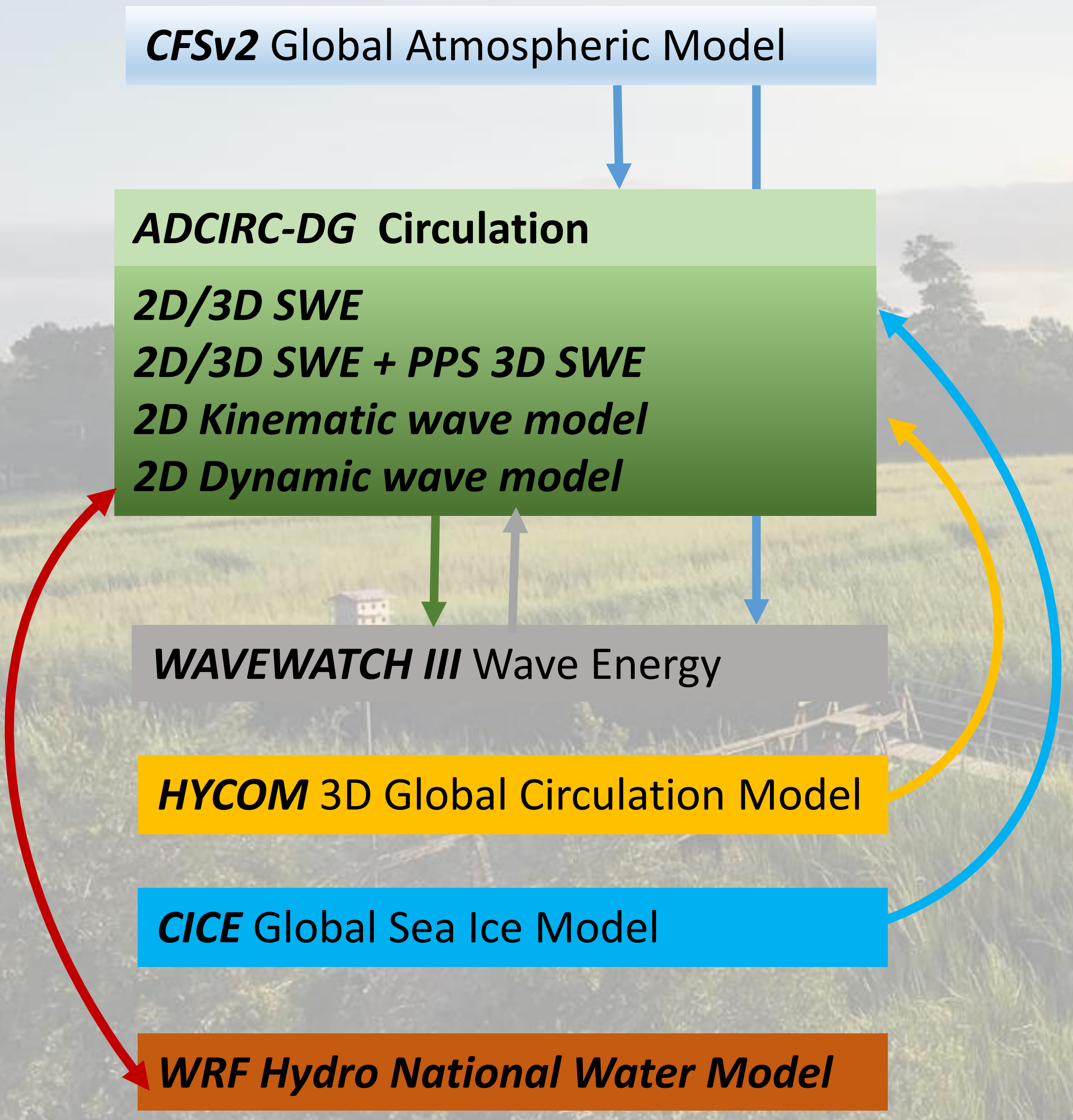








Develop dynamic hydrodynamic equation selection frameworks

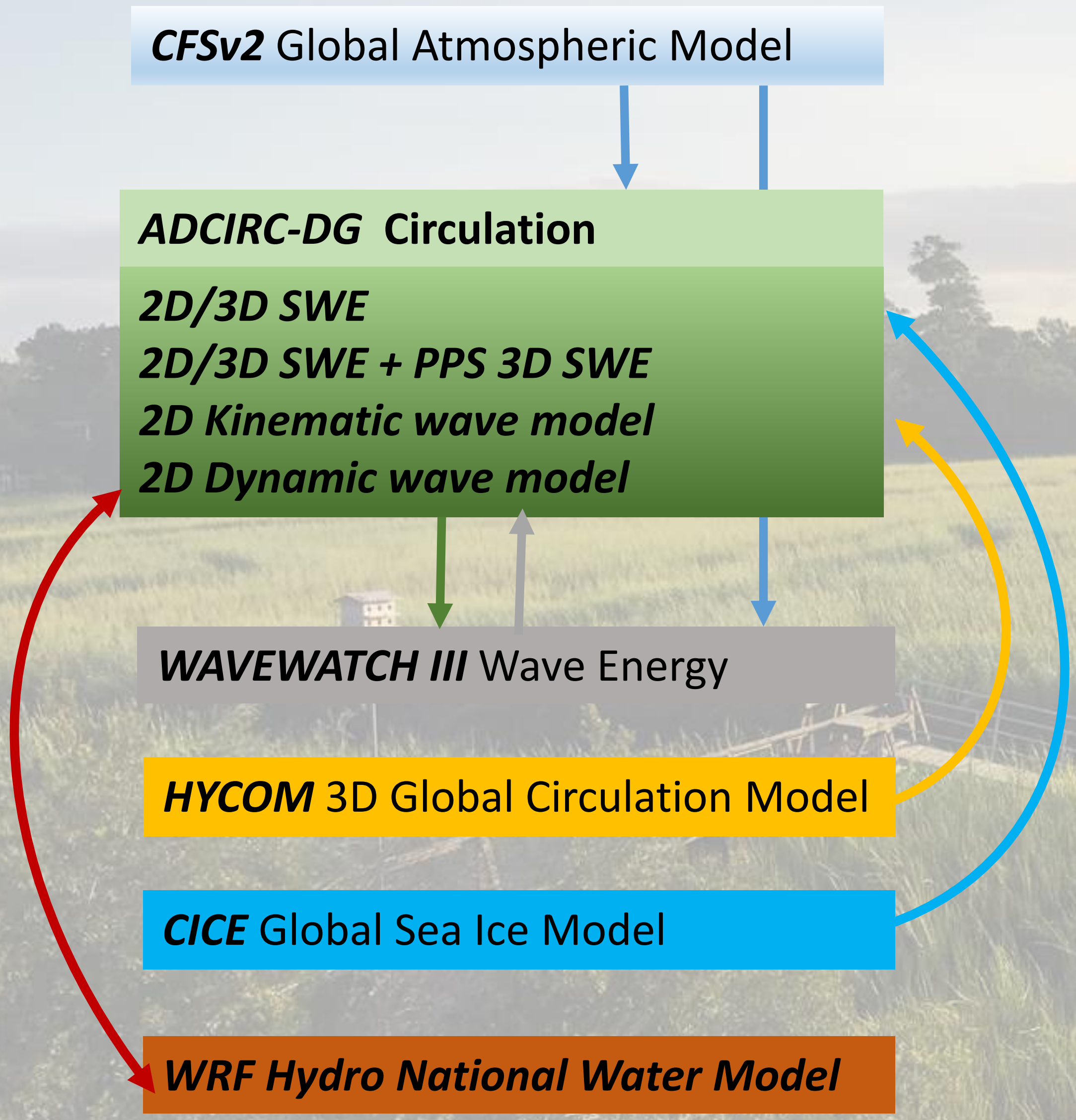


Multi-physics within a single algorithmic framework dynamically selecting physics

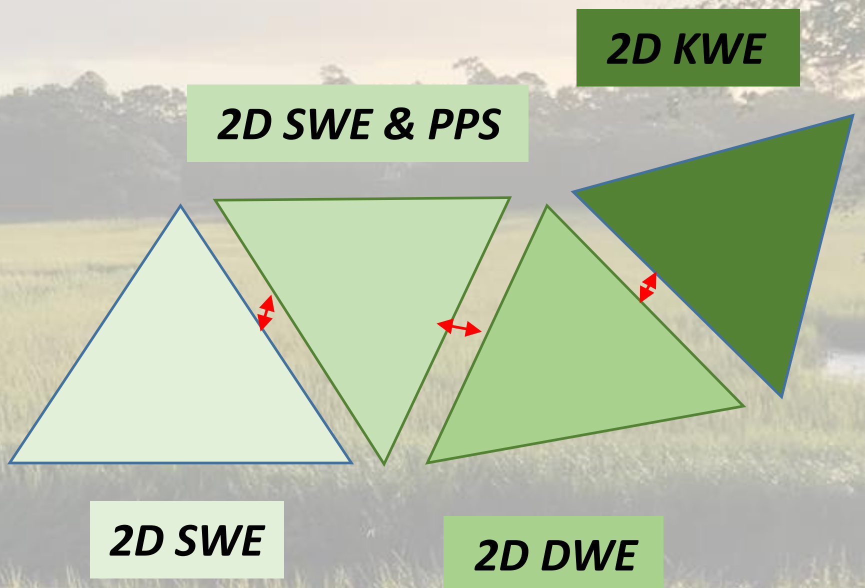
Dynamic equation selection within ADCIRC-DG to accommodate Boussinesq type solutions as well as the Kinematic and Dynamic Wave Equations solution

WWIII, HYCOM, CICE **interleafing**
WRF-Hydro **interfacing**

Develop dynamic hydrodynamic equation selection frameworks



Multi-physics within a single algorithmic framework dynamically selecting physics

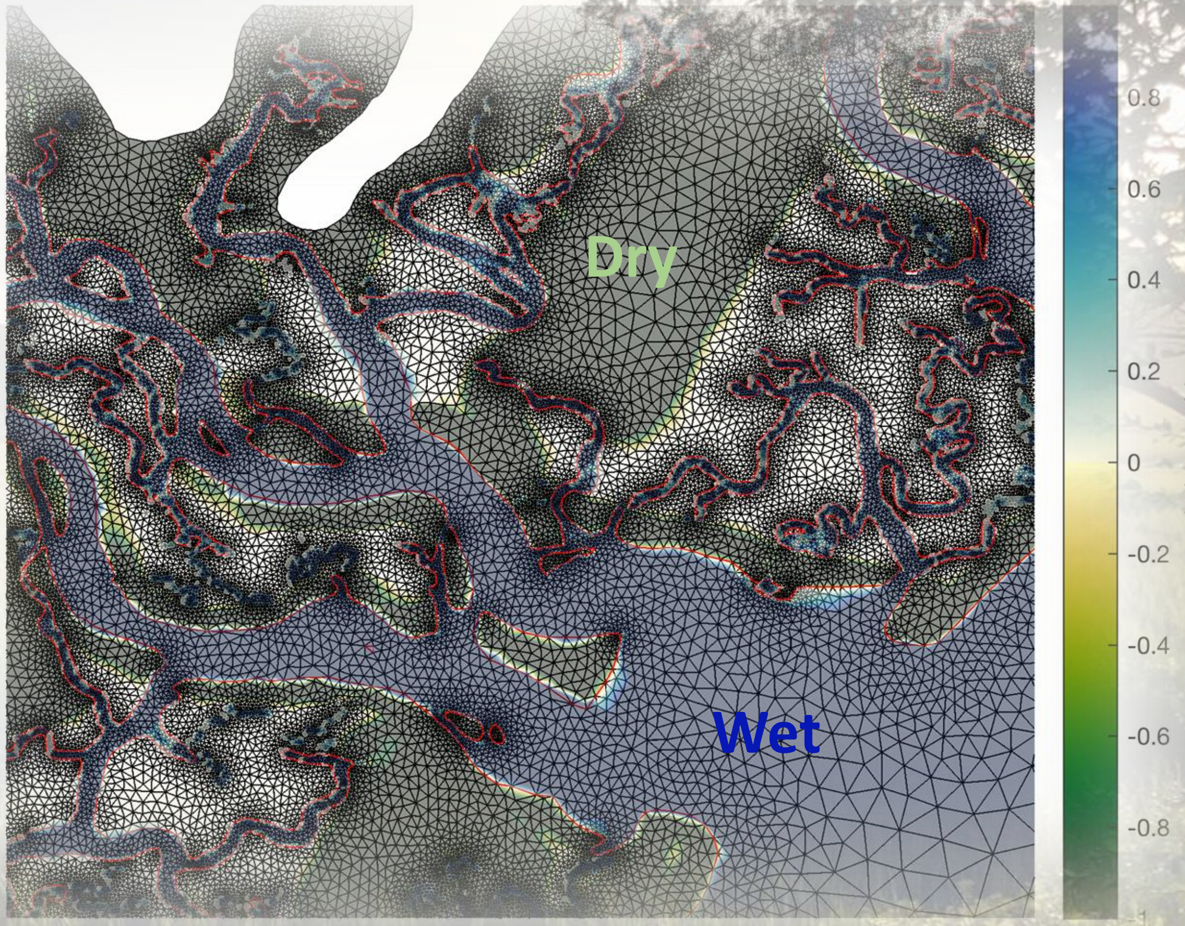


Dynamic load balancing

Eliminating dry element from the computation through loop clipping will reduce total cycle costs

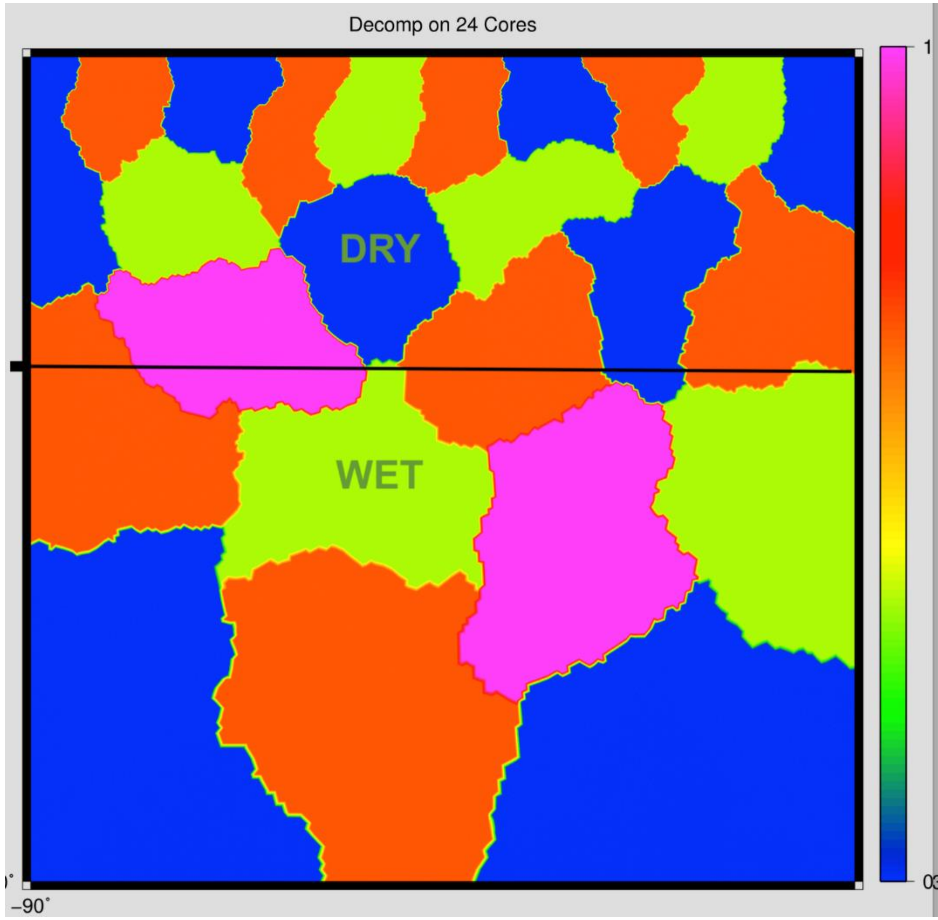
Dynamic rebalancing of the sub-domain loads will reduce total wall clock time

MPI/Zoltan
AMPI

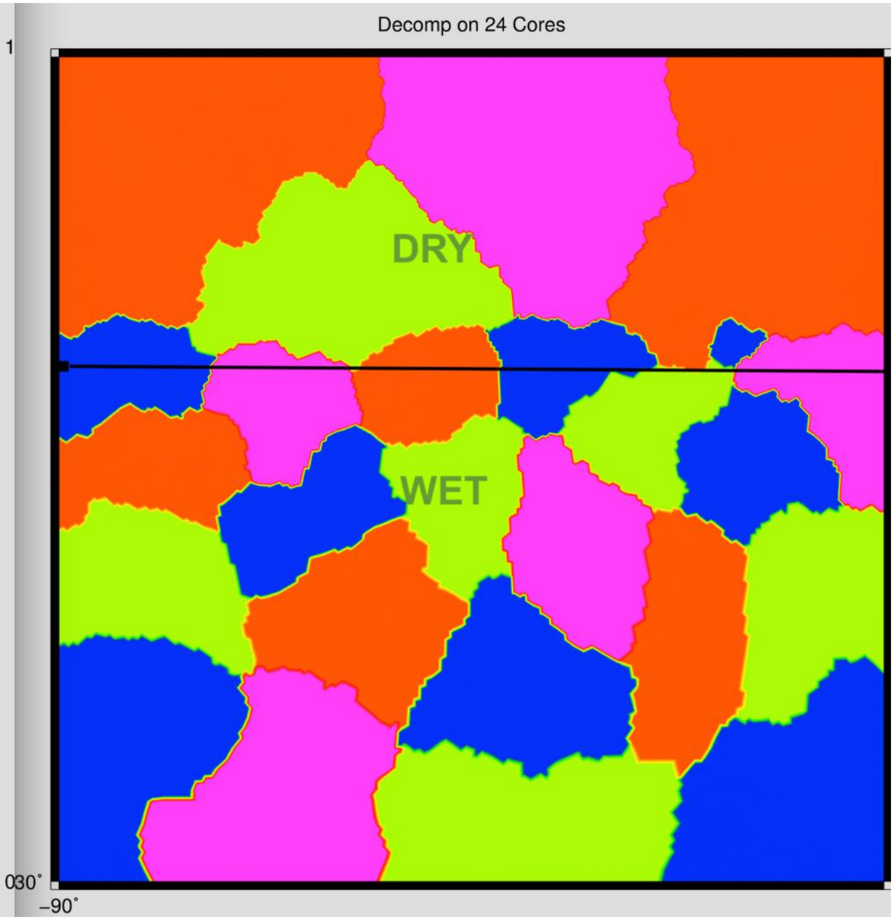


Dynamic load balancing: MPI/Zoltan

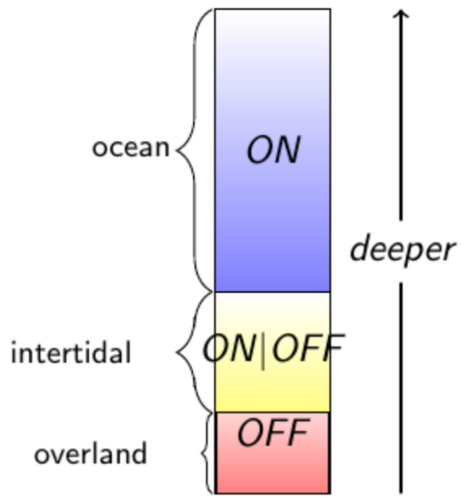
Equal node distribution

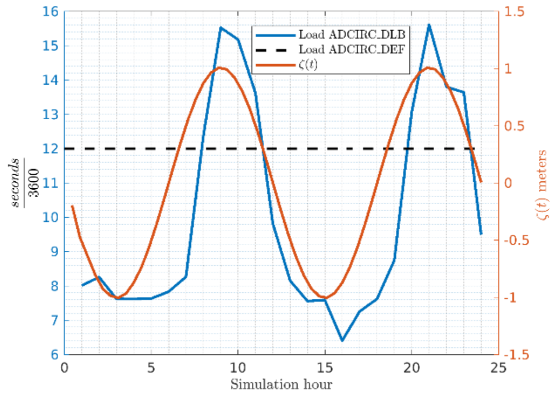


Weighted node distribution



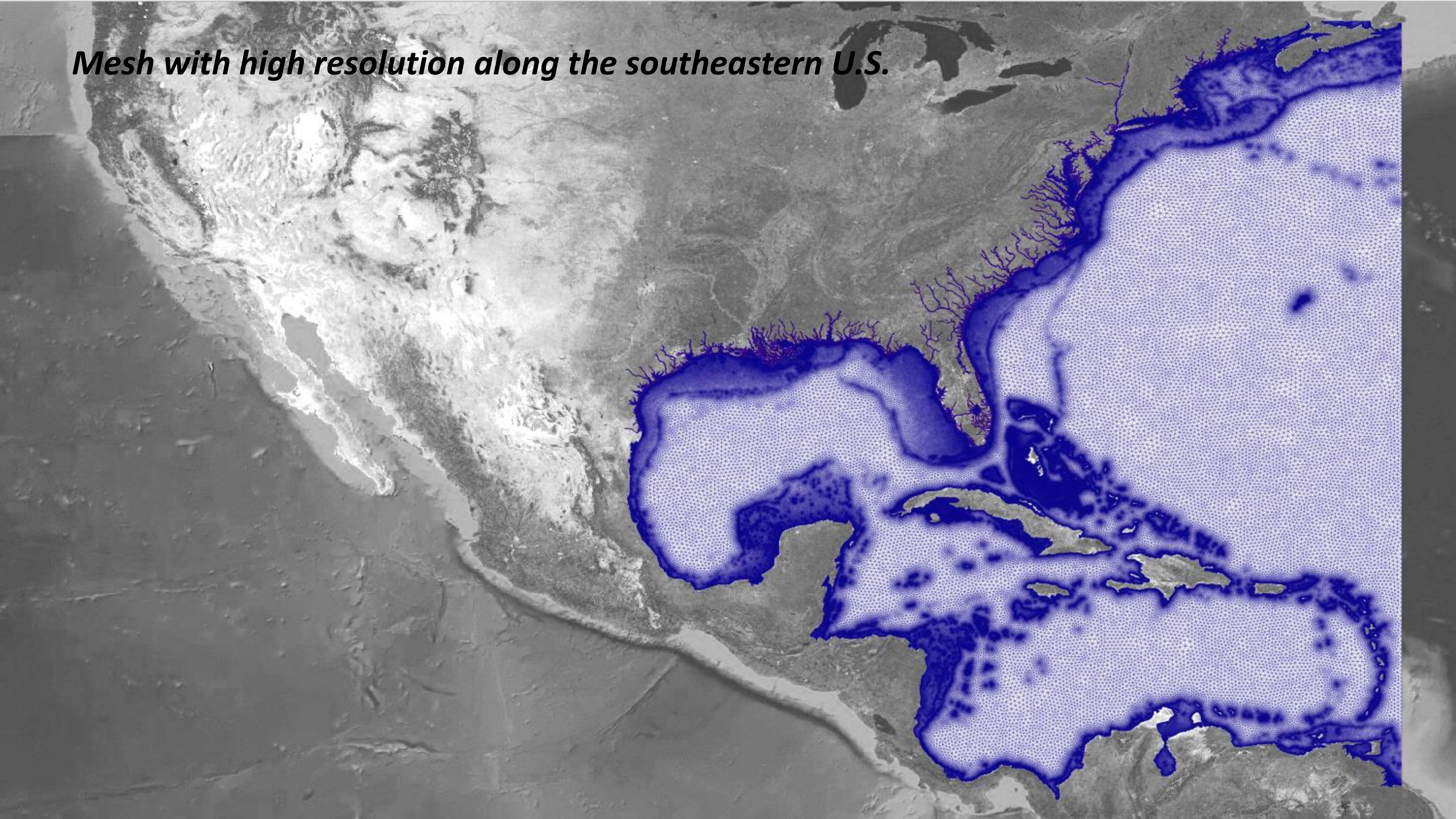
Nodal data structure





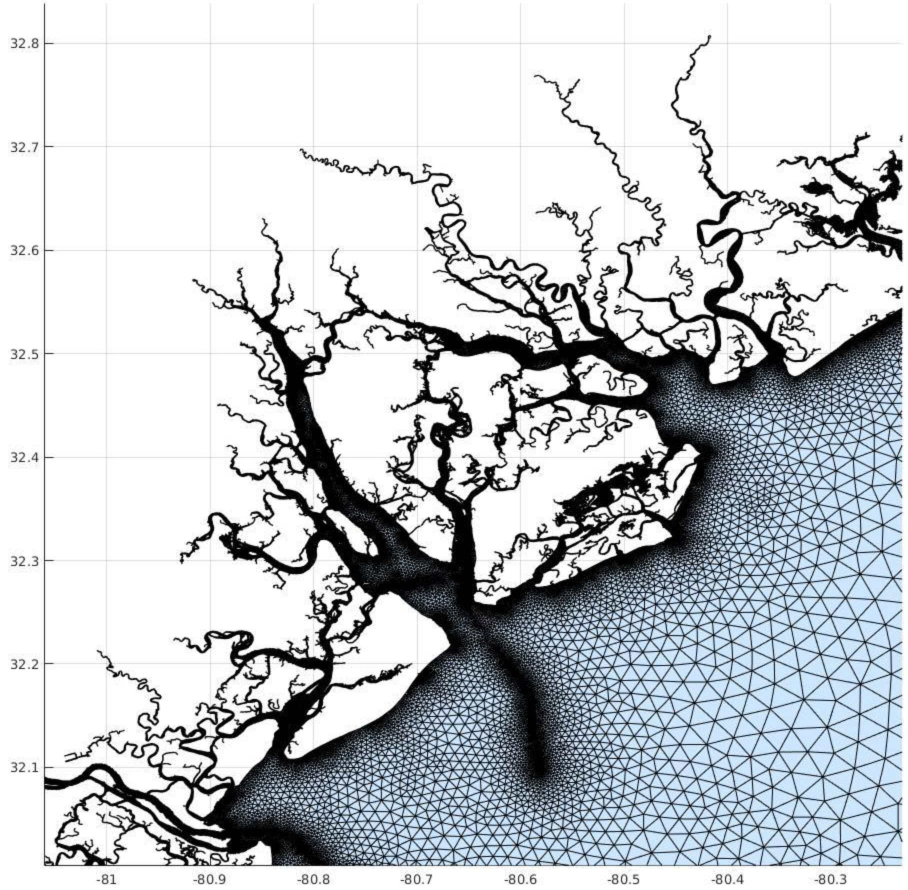
Dynamically redistributing dry elements improves parallel efficiency 45% for 50% average dry nodes

Mesh with high resolution along the southeastern U.S.

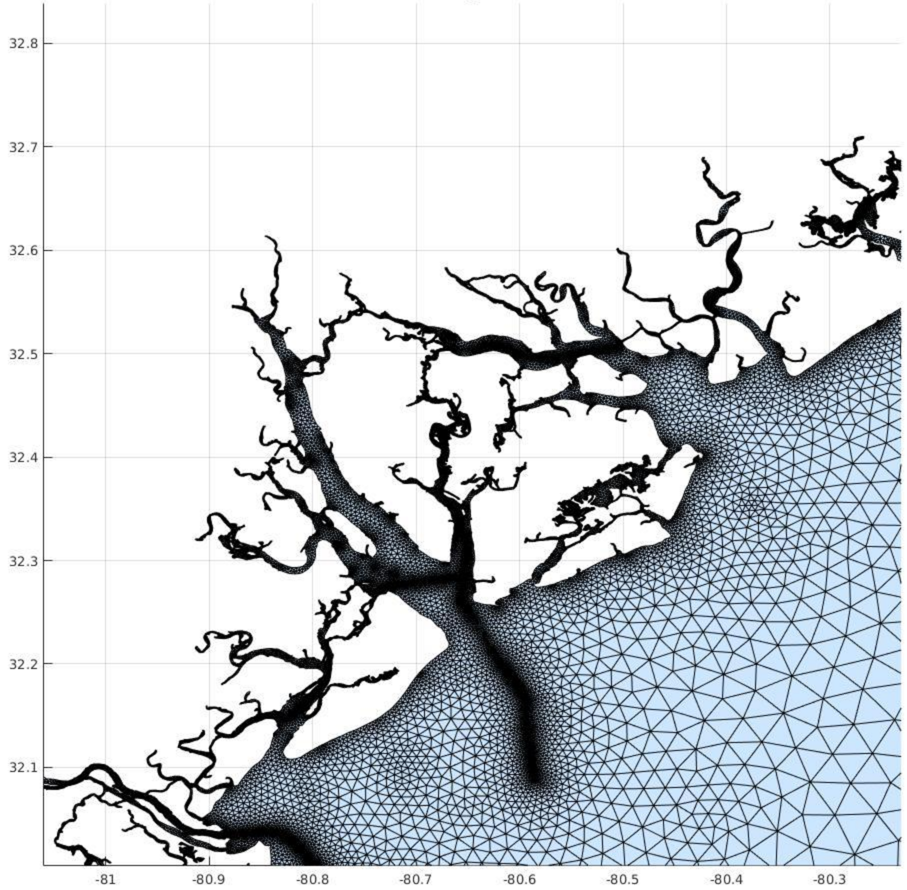


Water side of meshes under development for the U.S. East and Gulf Coasts

30m



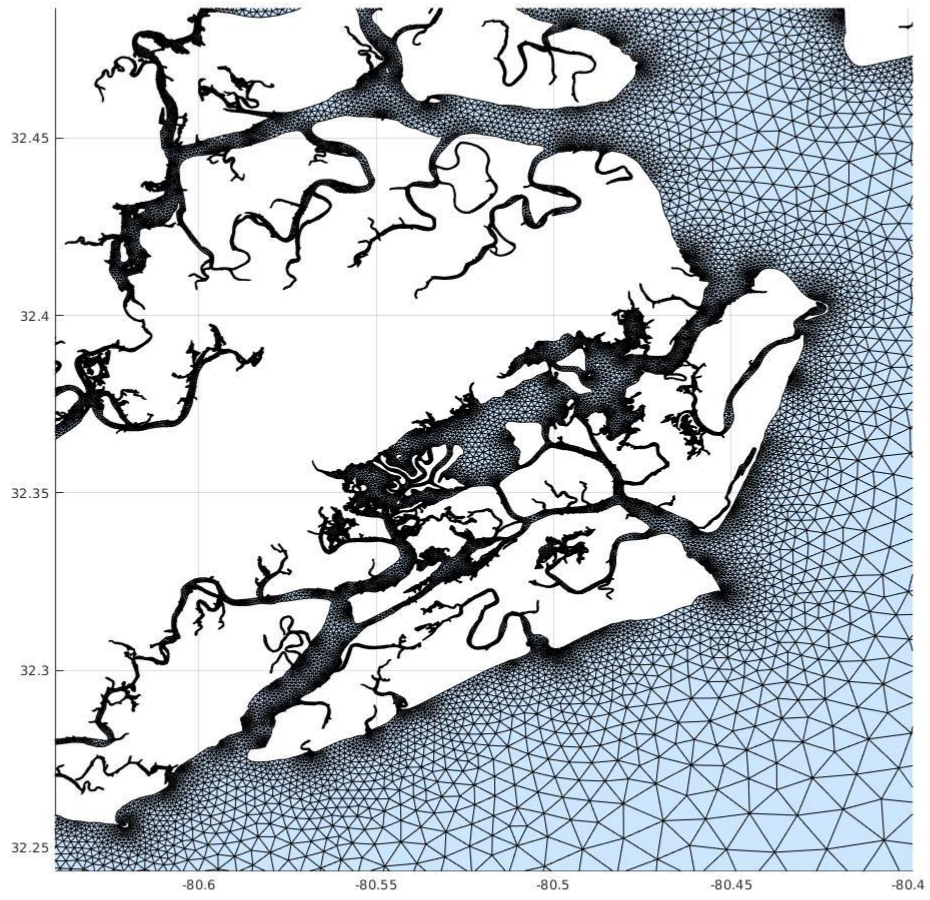
120m



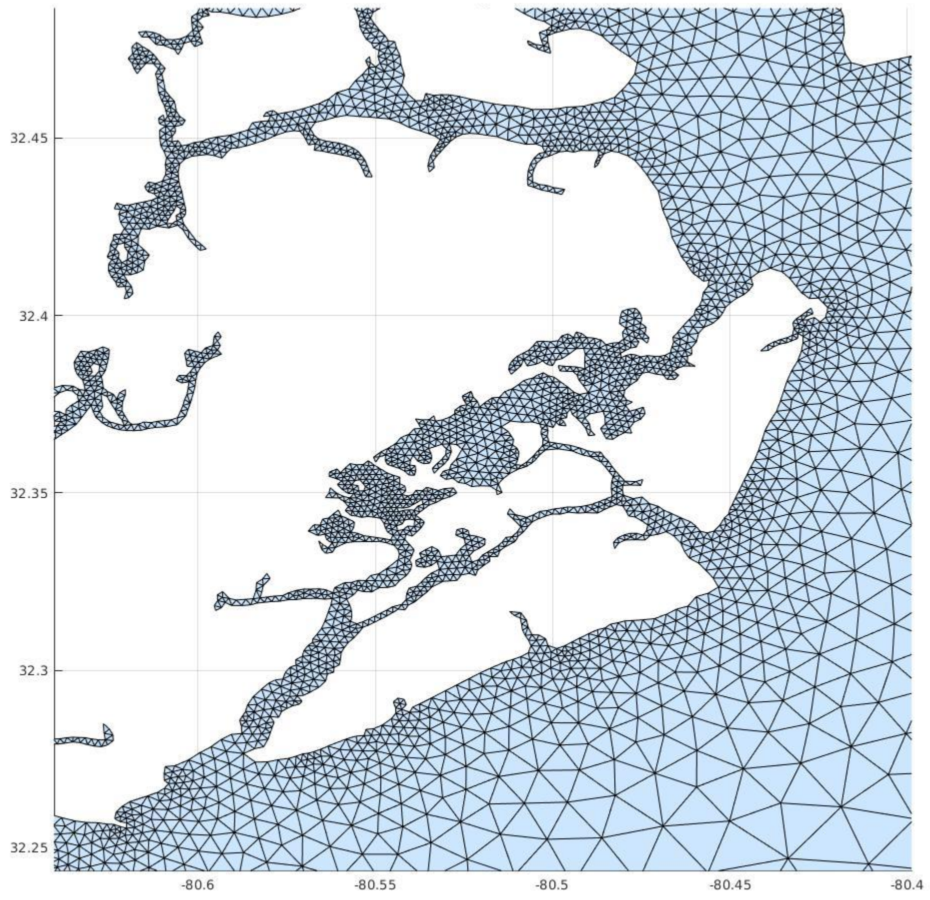
South Carolina inlets

Water side of meshes under development for the U.S. East and Gulf Coasts

30m



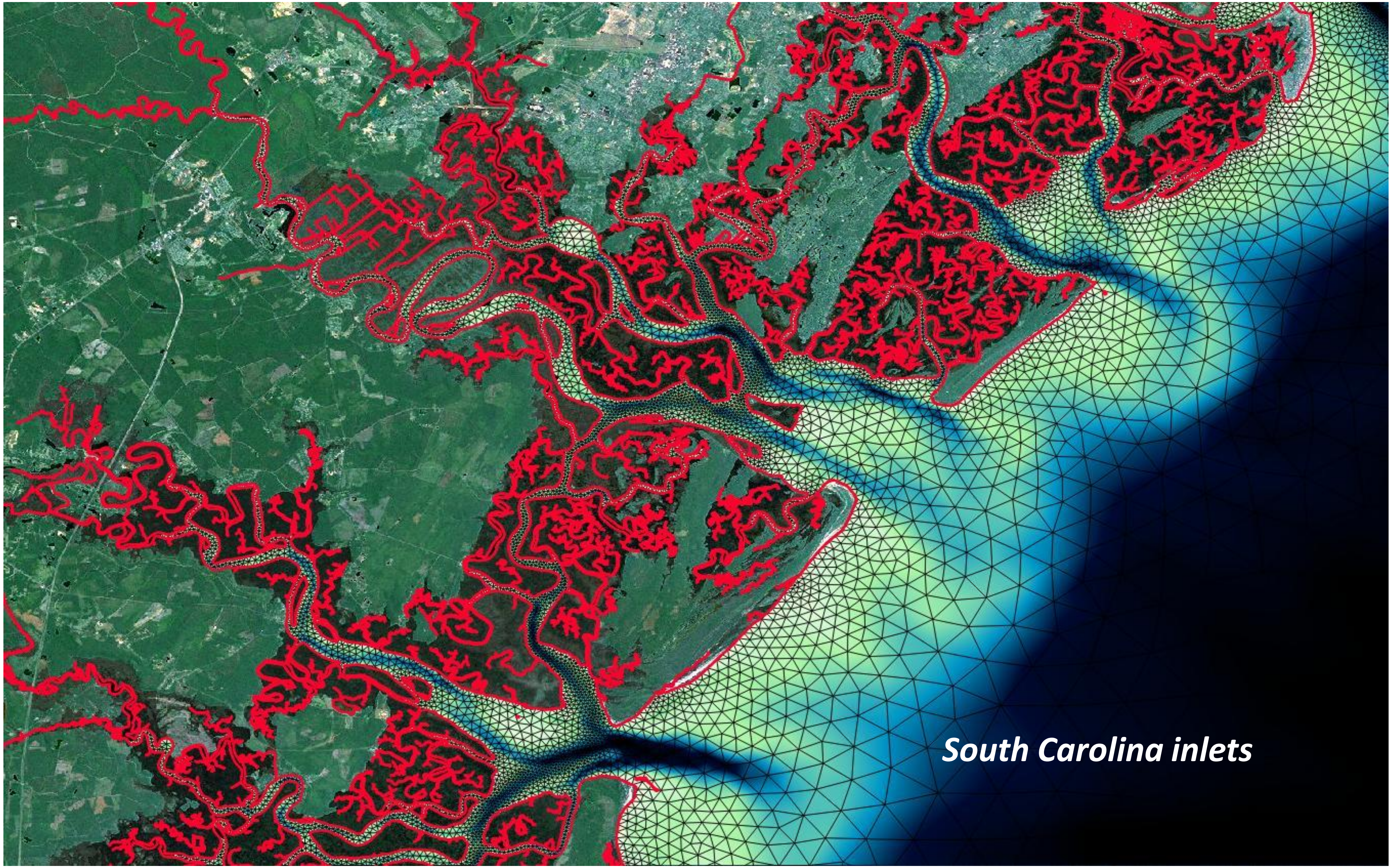
120m



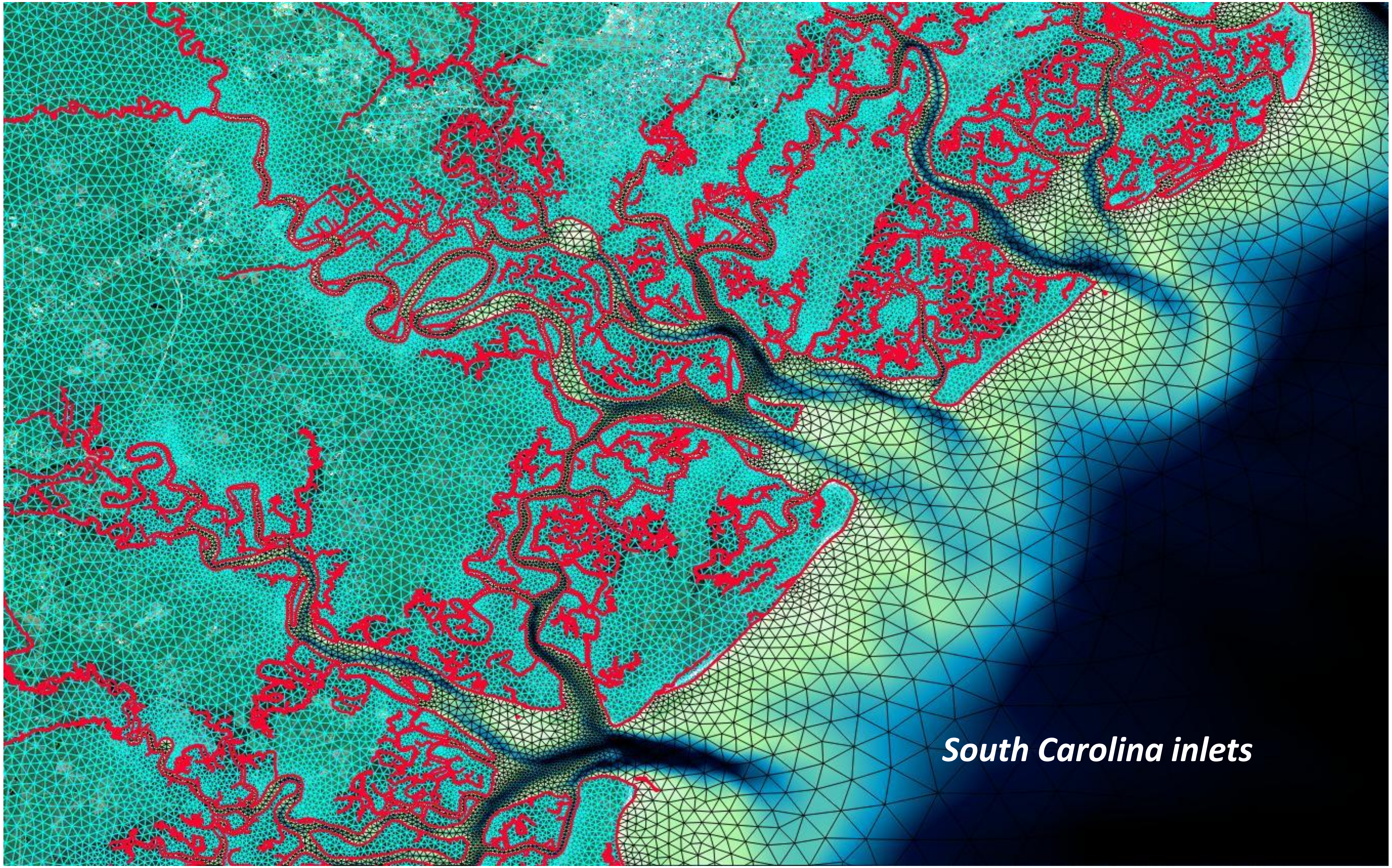
South Carolina inlets - detail

120 m mesh water and land sides

120 m mesh water and land sides

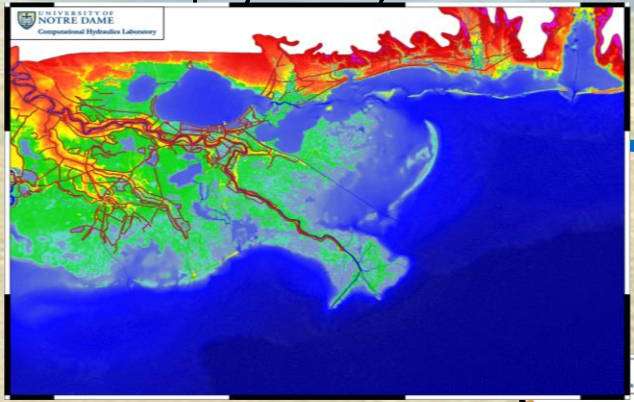


120 m mesh water and land sides

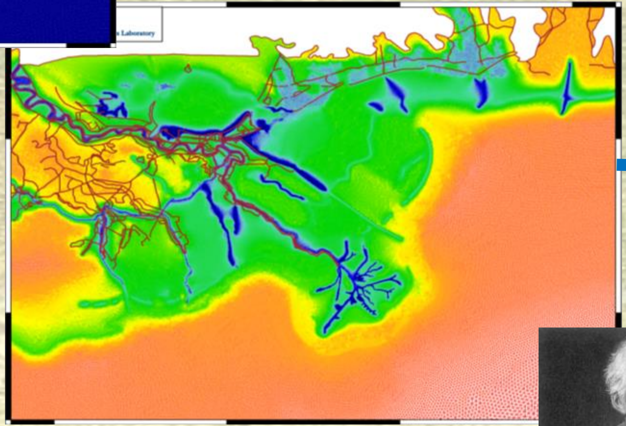


Evolution of coastal ocean hydrodynamic models – the past

Geophysical systems

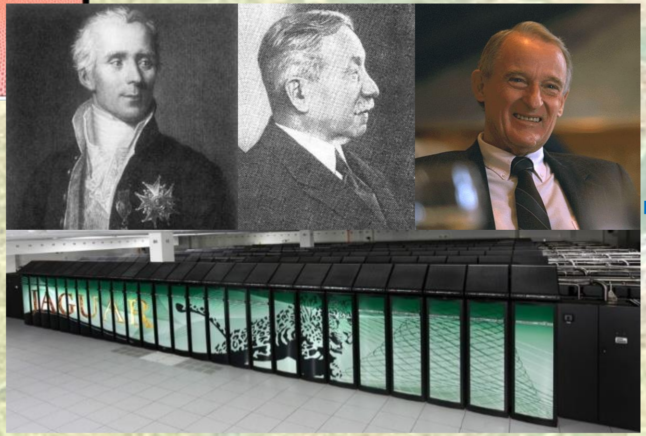


Unstructured grids

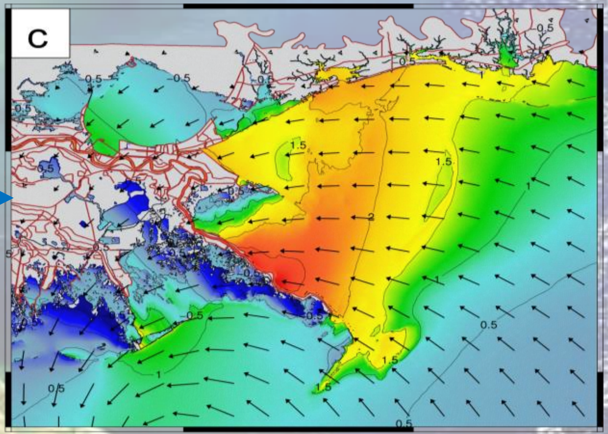


Physics & forcing functions
Model interfacing and interleafing

Pde's + FEM + HPC



Ocean Responses



Evolution of coastal ocean hydrodynamic models – the future