Towards Heterogeneous Process and Scale Coupling in Coastal Ocean and Floodplain Hydrodynamic Modeling

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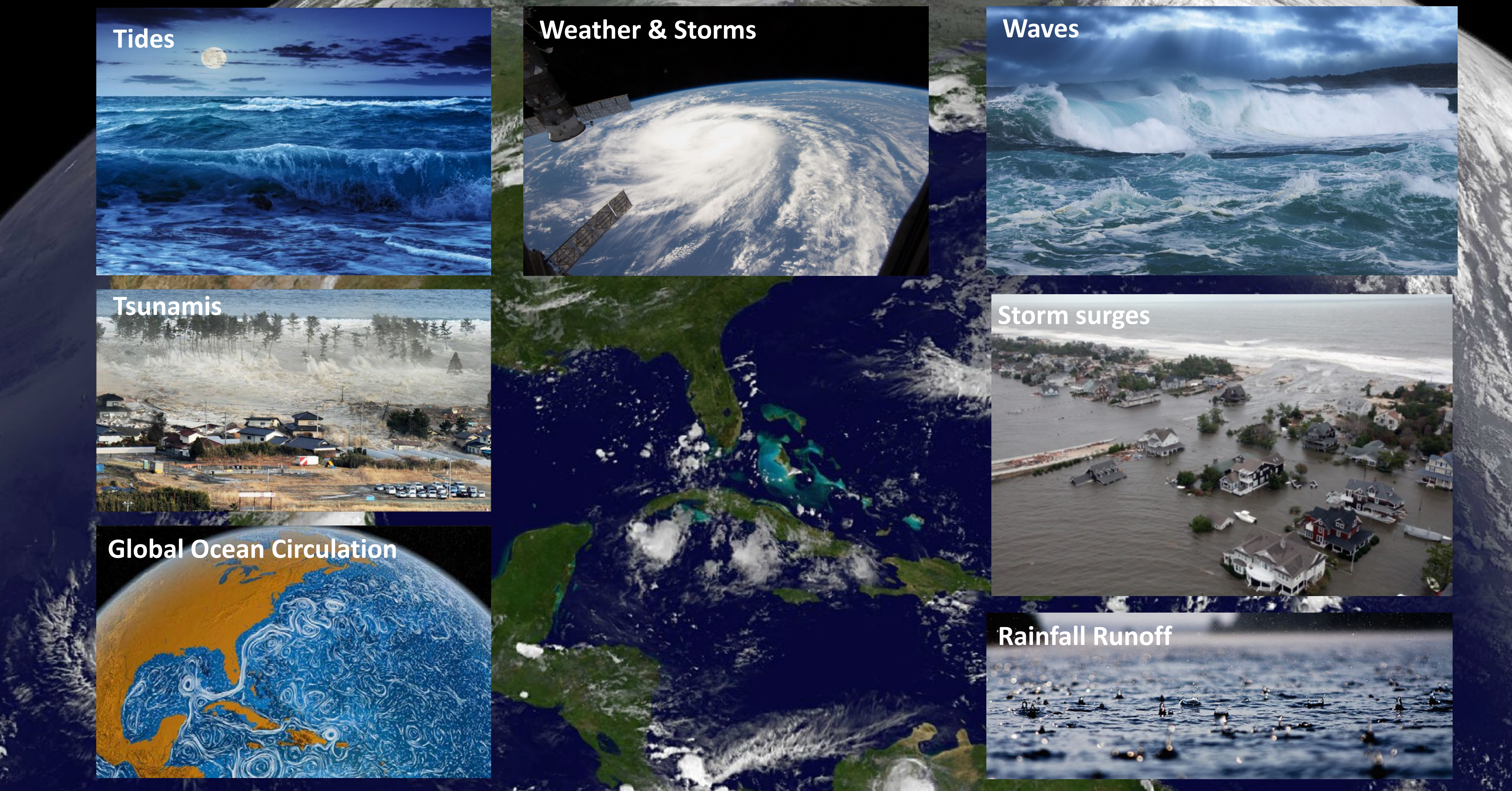
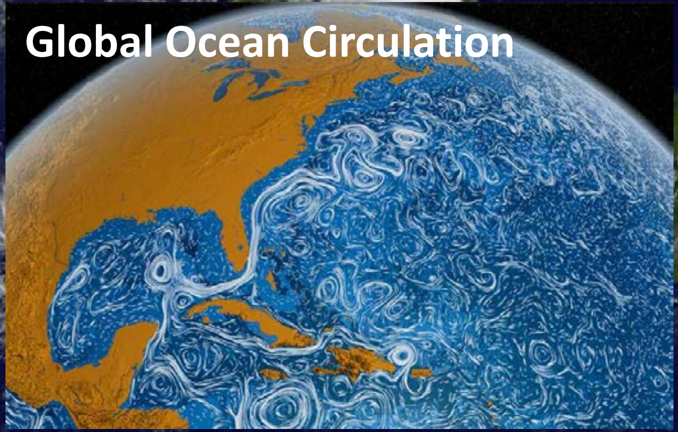
[7]North Carolina State University, [8]Ohio State University

NOAA GLERL
October 8, 2019

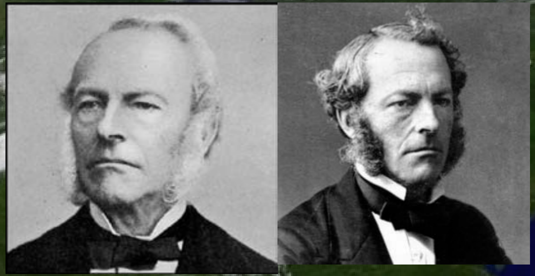
Processes in the ocean and coastal floodplain



Processes in the ocean and coastal floodplain



Navier Stokes Equations (1822)



Mass & momentum conservation

Describes all processes

Solve for 10^{34} unknowns per day of real time

Processes in the ocean and coastal floodplain

Tides

Tsunamis

Process & Scale Separation

Shallow water equations

Laplace 1776

Storm surges

Processes in the ocean and coastal floodplain

Process & Scale Separation

Boussinesq equations

Boussinesq 1872

Peregrine 1967

Processes in the ocean and coastal floodplain

Process & Scale Separation

Spectral action balance equation

Hasselman 1988

Gelci et al. 1957

Processes in the ocean and coastal floodplain

Process & Scale Separation

Kinematic wave equation
Dynamic wave equation

Lighthill 1955

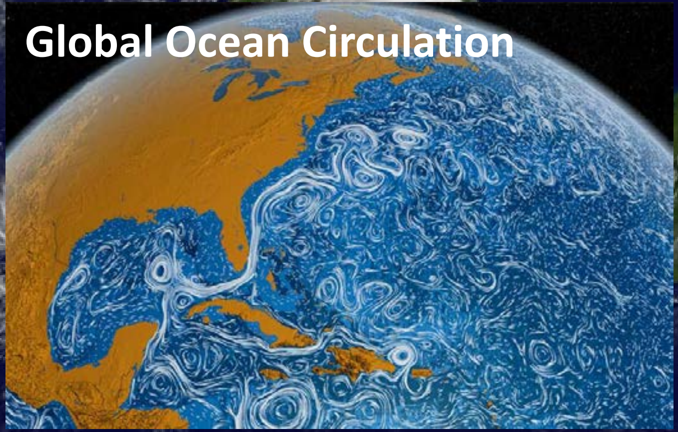
Processes in the ocean and coastal floodplain

Process & Scale Separation

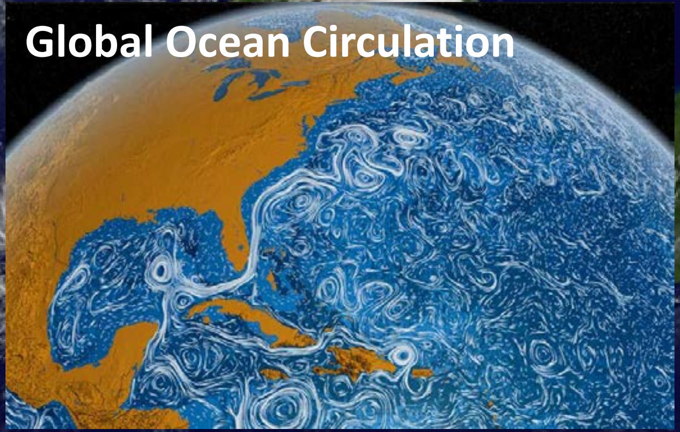
Prognostic ocean circulation equations

Kirk Bryan 1969

Global Ocean Circulation



Processes in the ocean and coastal floodplain



Process Separation

Domain & Resolution Separation

Provide affordable resolution for domain size and alias the rest

Nesting

Data assimilate for missing physics and scales

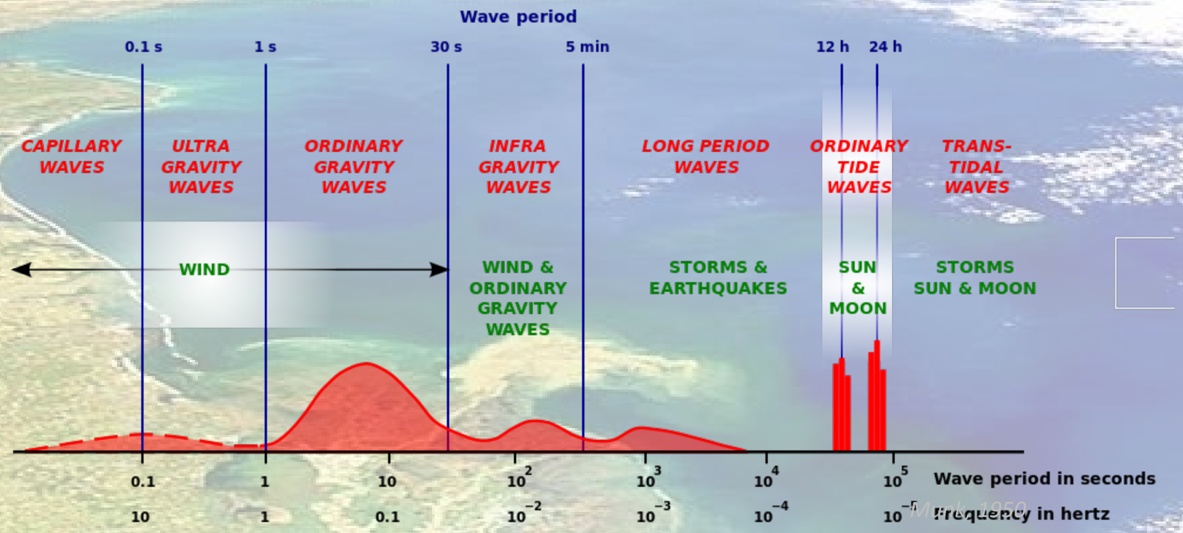
Evolution of coastal ocean hydrodynamics models – the recent past

Dynamic ADCIRC & SWAN Coupling

CFSv2 Global Atmospheric Model

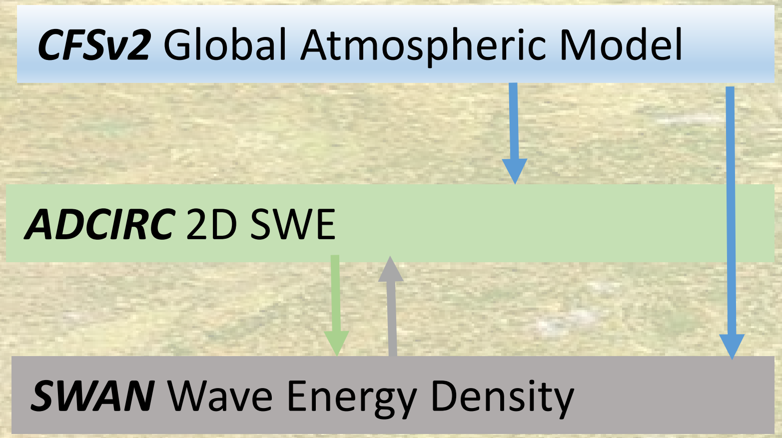
ADCIRC 2D SWE

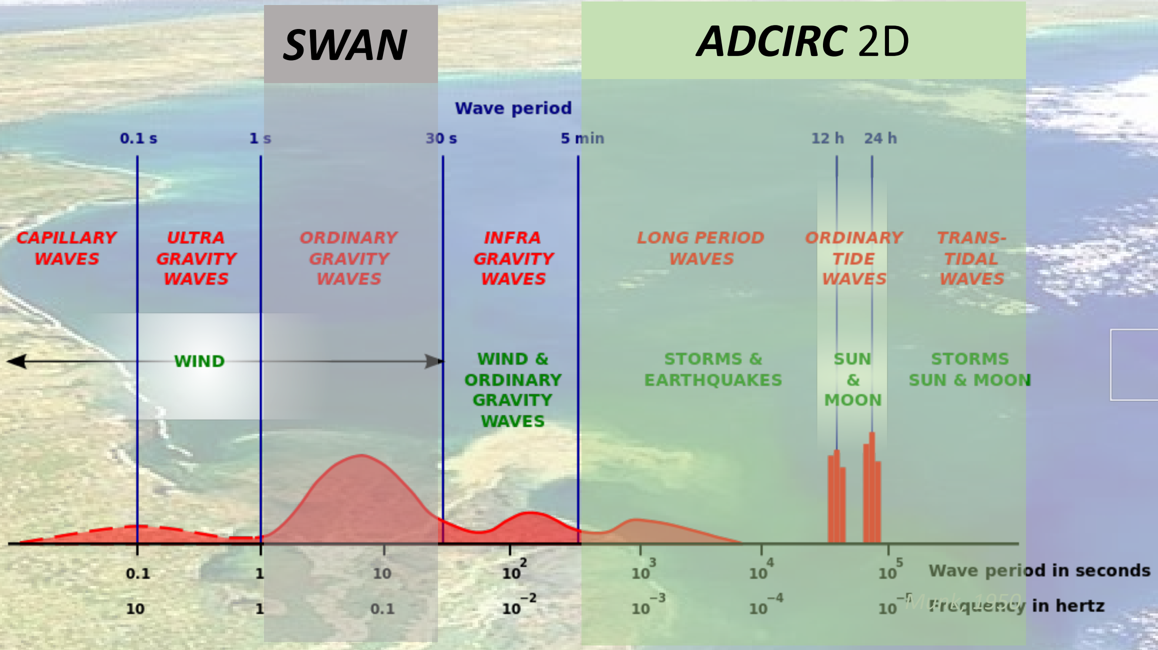
SWAN Wave Energy Density



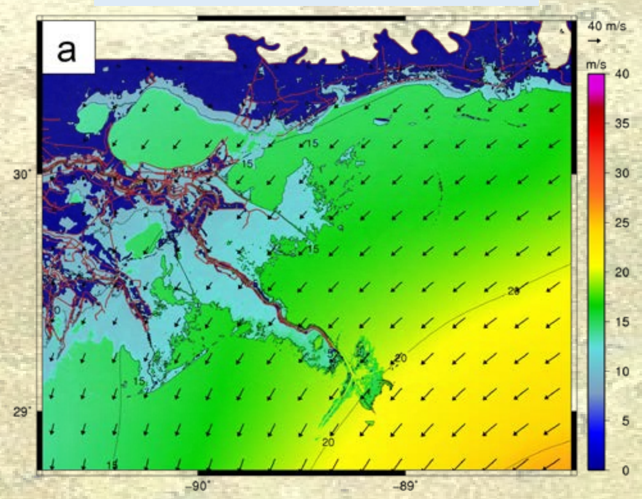
Evolution of coastal ocean hydrodynamics models – the recent past

Dynamic ADCIRC & SWAN Coupling

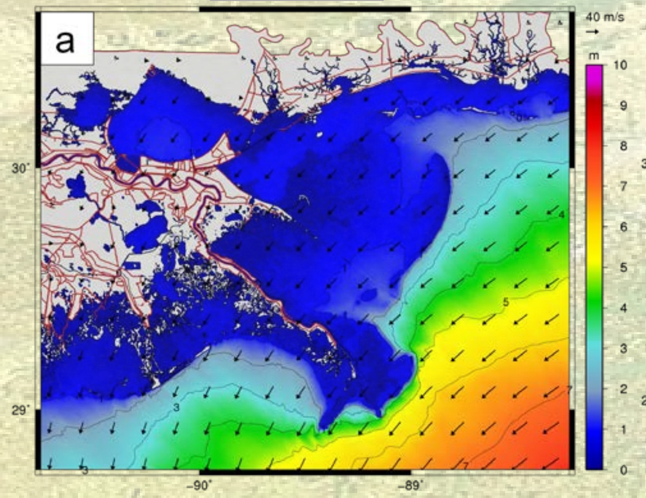




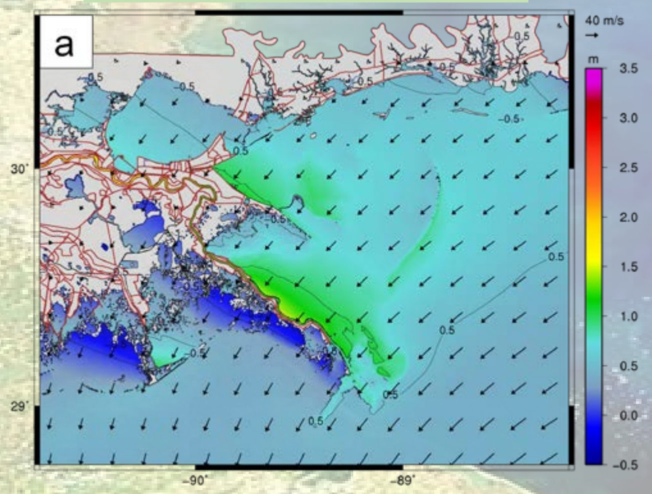
CFSv2



SWAN



ADCIRC 2D

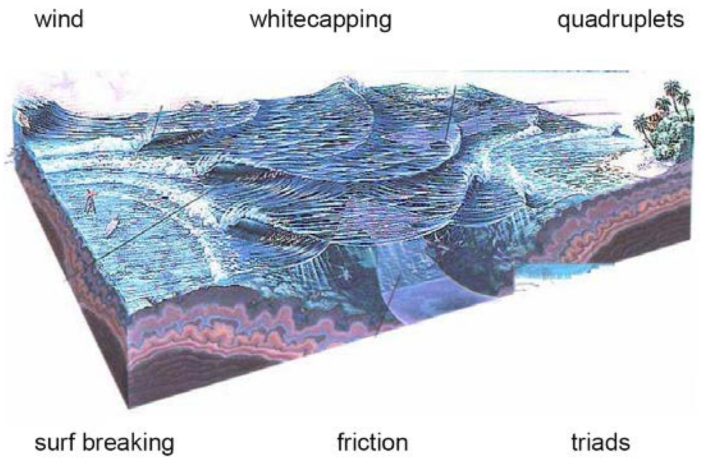


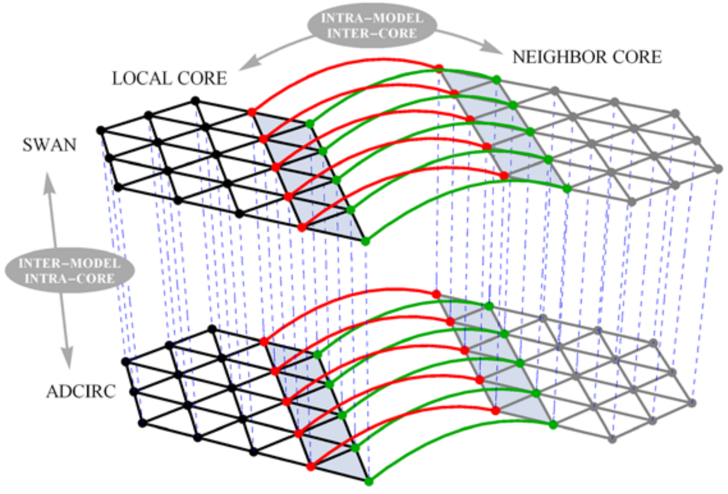
ADCIRC+SWAN: Coastal ocean circulation and wave models – the past

- 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)
  - 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

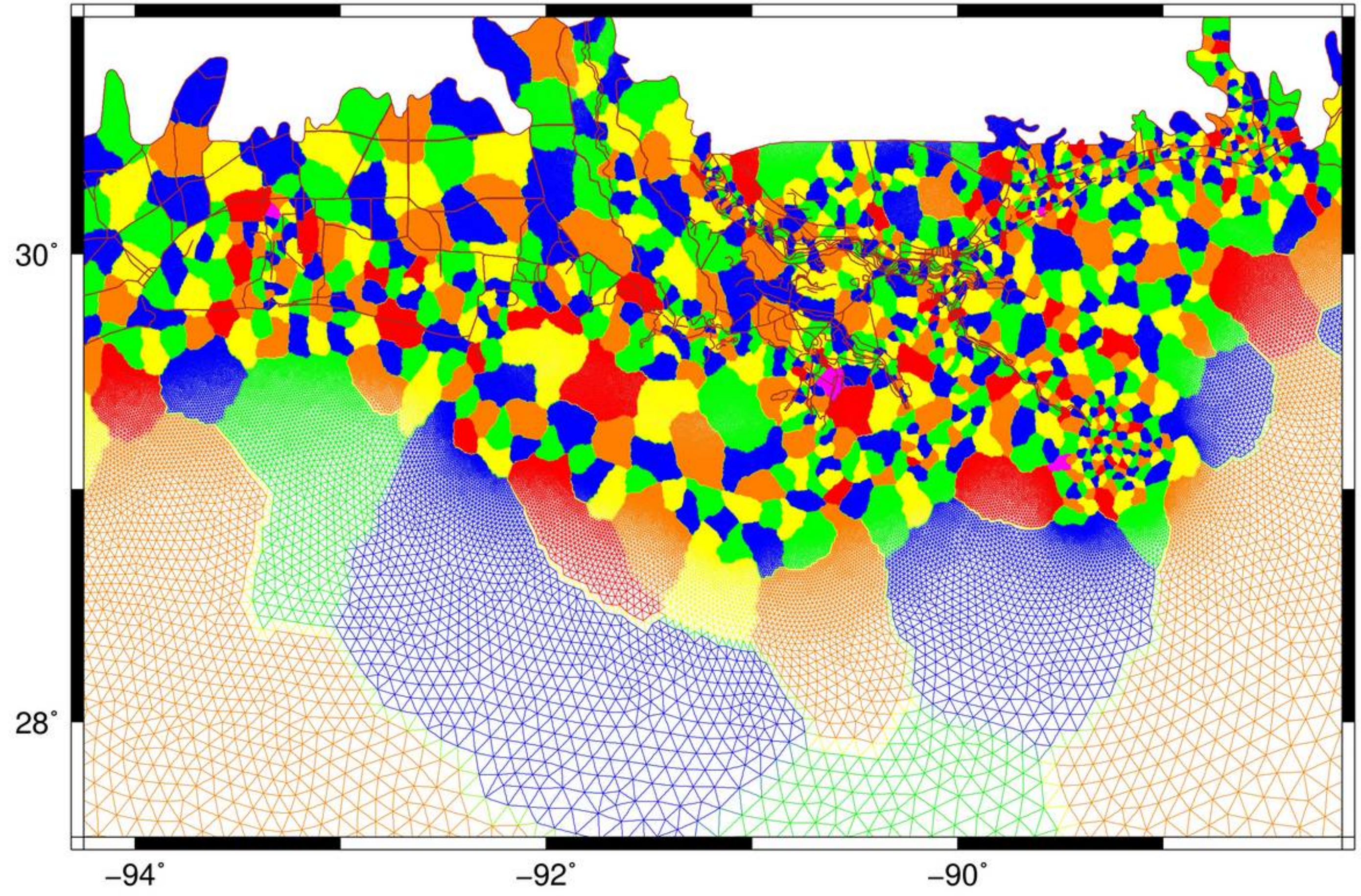




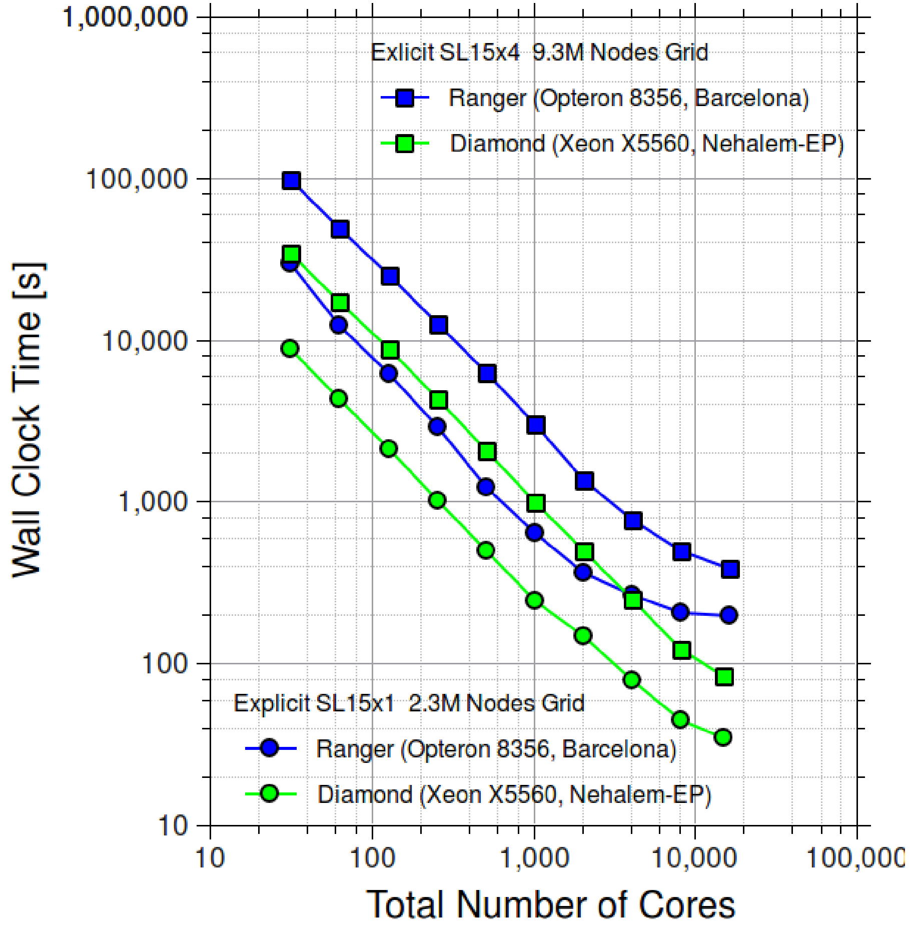
Dietrich et al., *Coastal Engineering*, **58**, 45-65, 2011.
Dietrich et al., *Journal of Scientific Computing*, **52**, 468-497 2012.

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

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

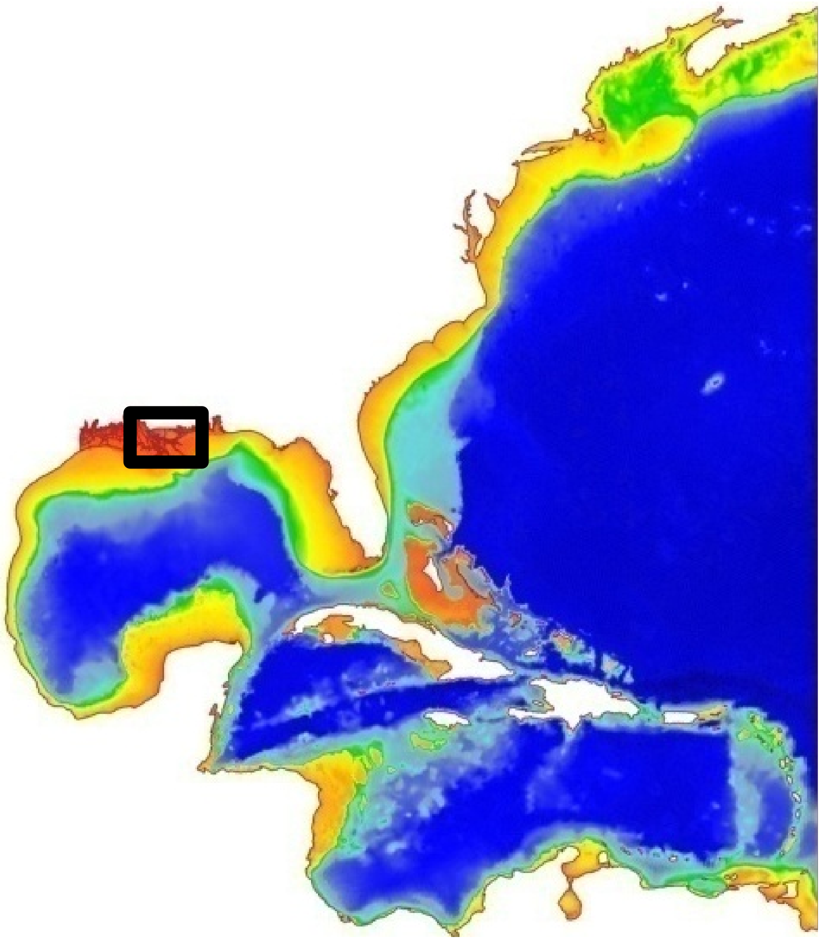


HPC: Parallel Performance



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

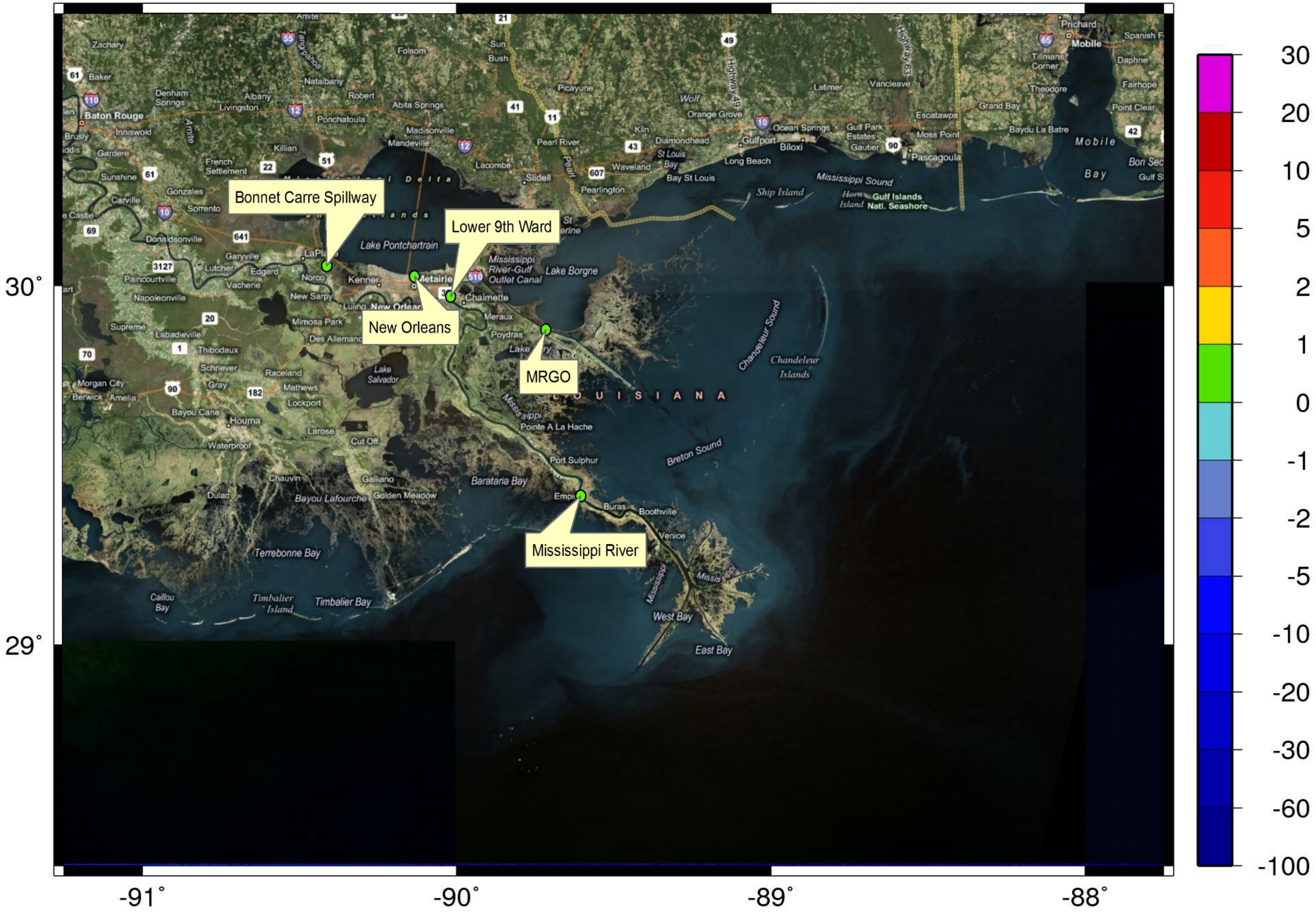
SL16v18 model bathymetry and topography and unstructured mesh



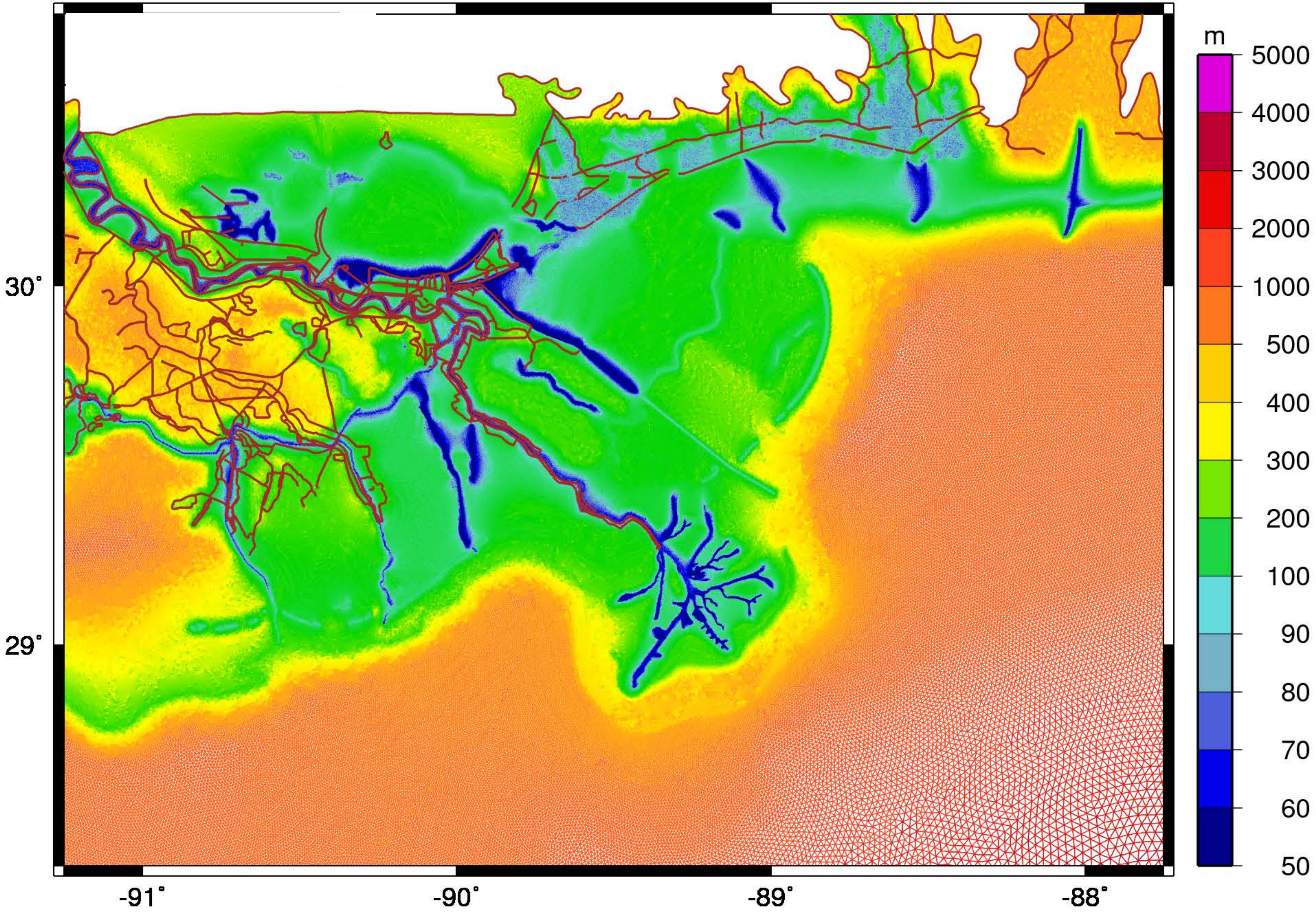
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.
Kennedy et al., ***Geophysical Research Letters***, **38**, L08608, 2011.
Kerr et al., ***Journal of Waterway, Port, Coastal, and Ocean Engineering***, **139,** 326-335, 2013.

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

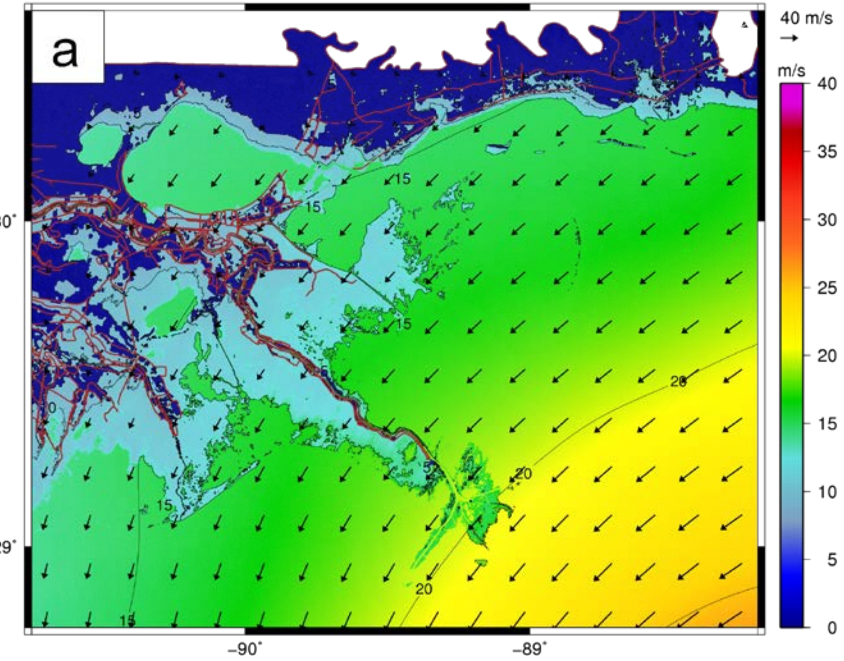


Models: SL16v18 mesh size in SE Louisiana

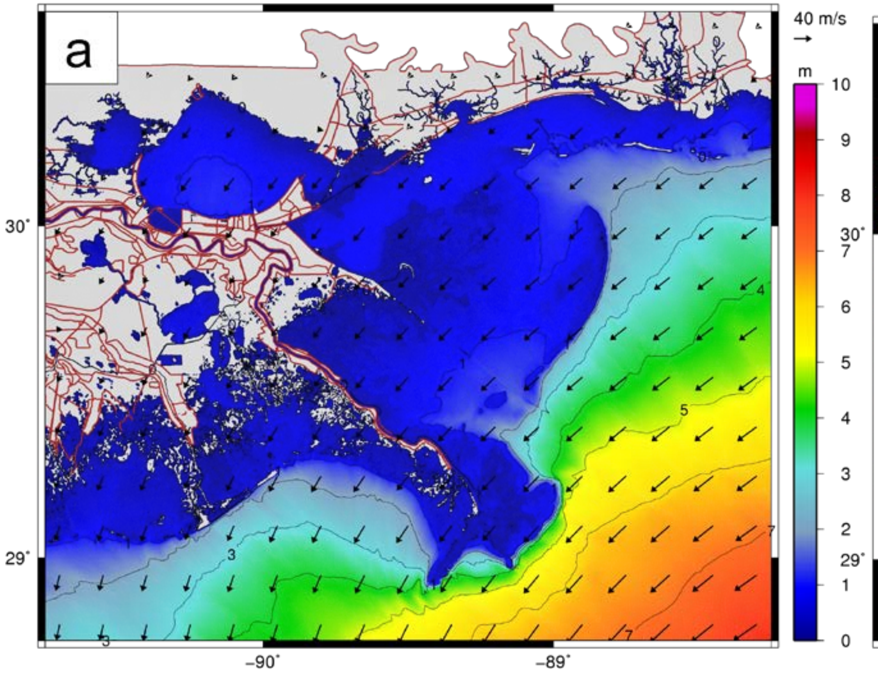


Hurricane Gustav: 2008 / 09 / 01 / 0200 UTC

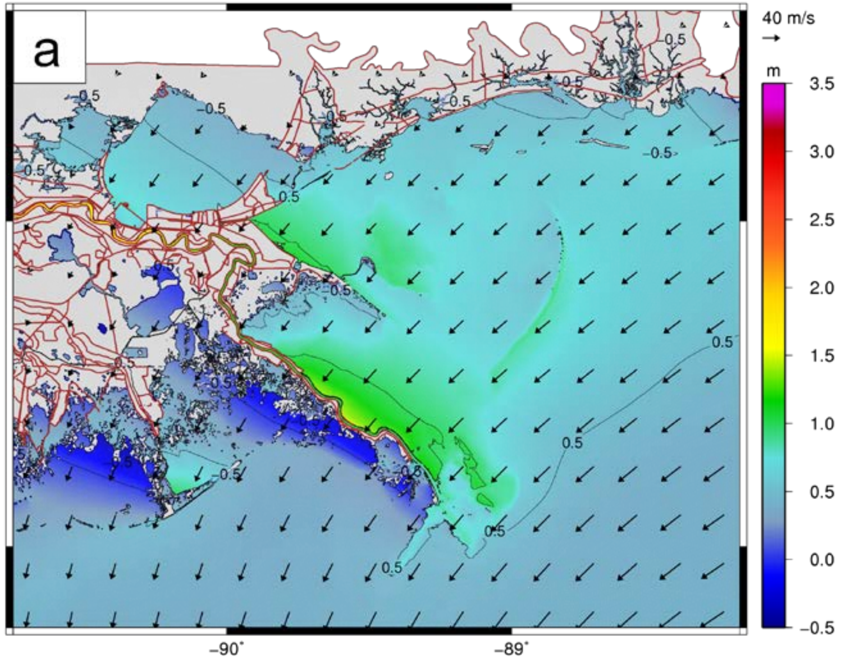
Winds (m/s)



Waves (m)



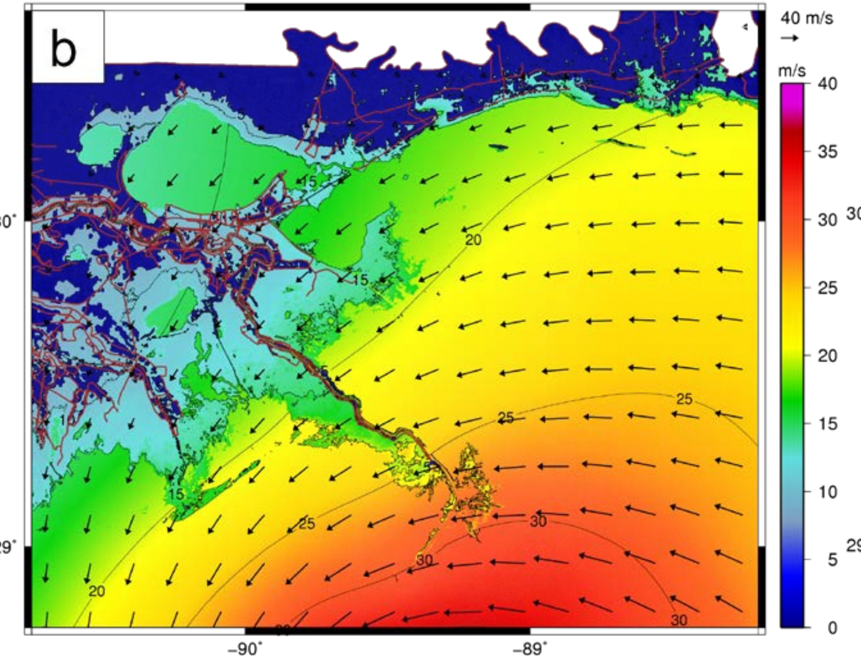
Water Elevations (m)



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

Hurricane Gustav: 2008 / 09 / 01 / 0800 UTC

Winds (m/s)



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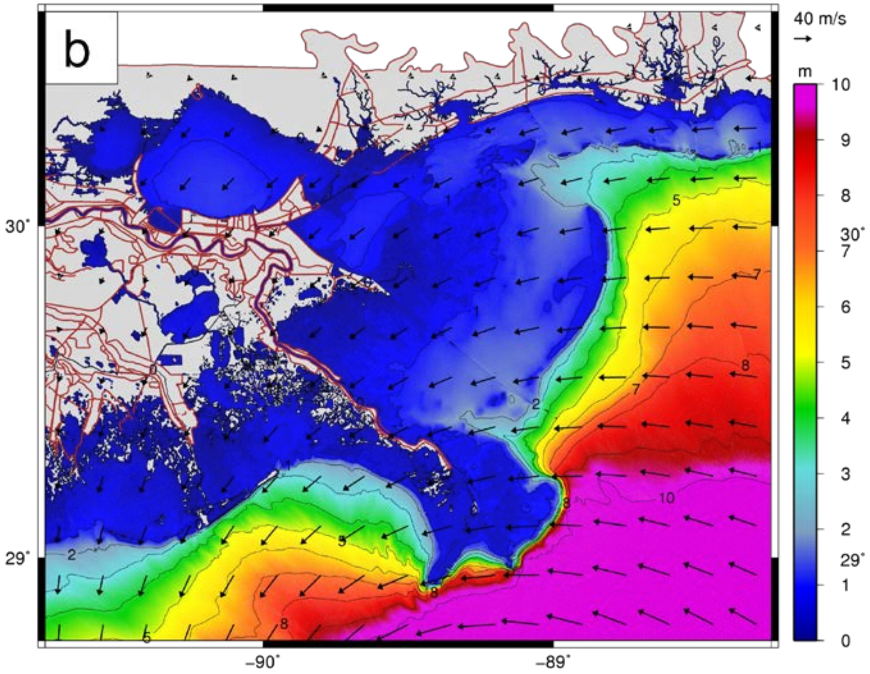

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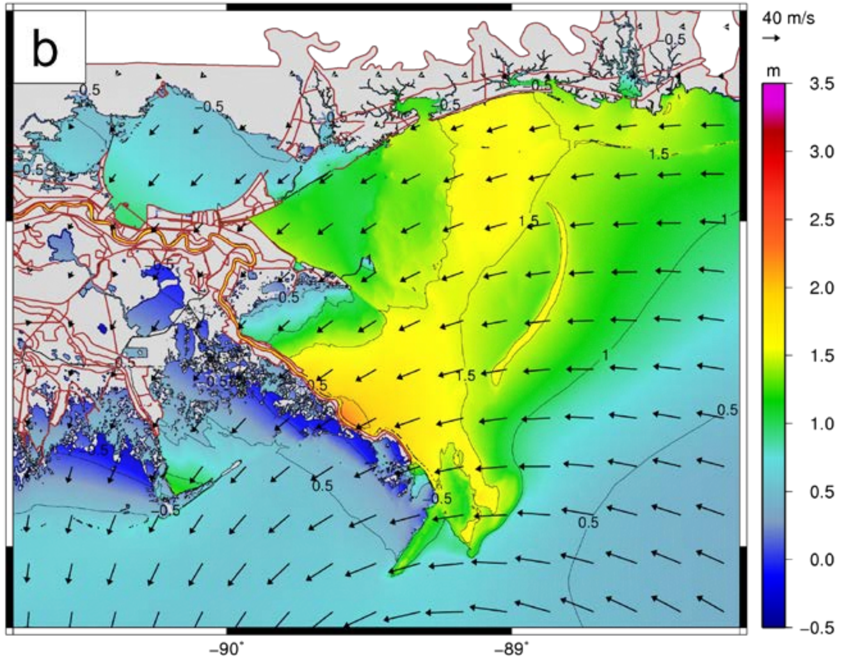
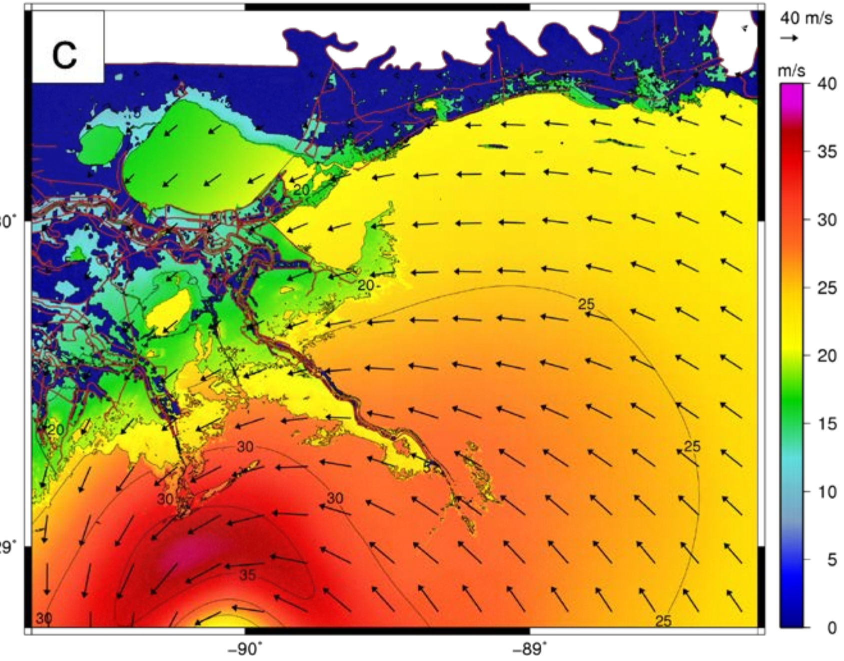


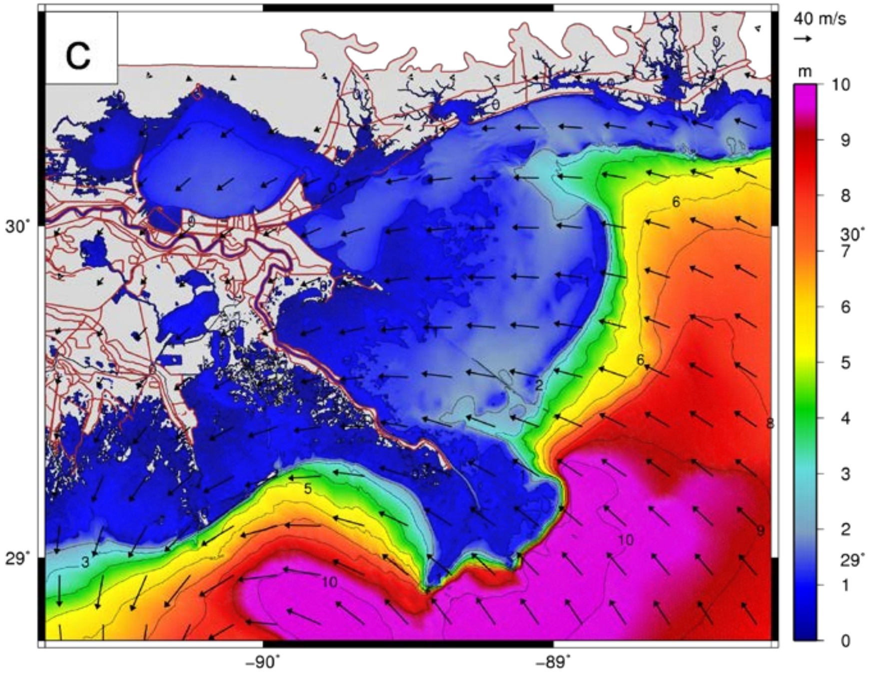
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 1100 UTC

Winds (m/s)



Waves (m)



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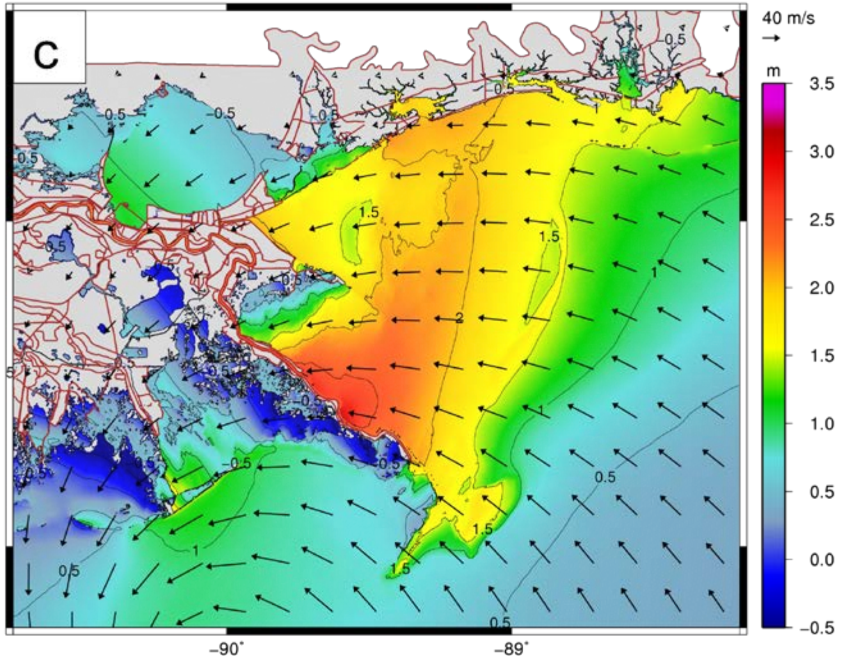
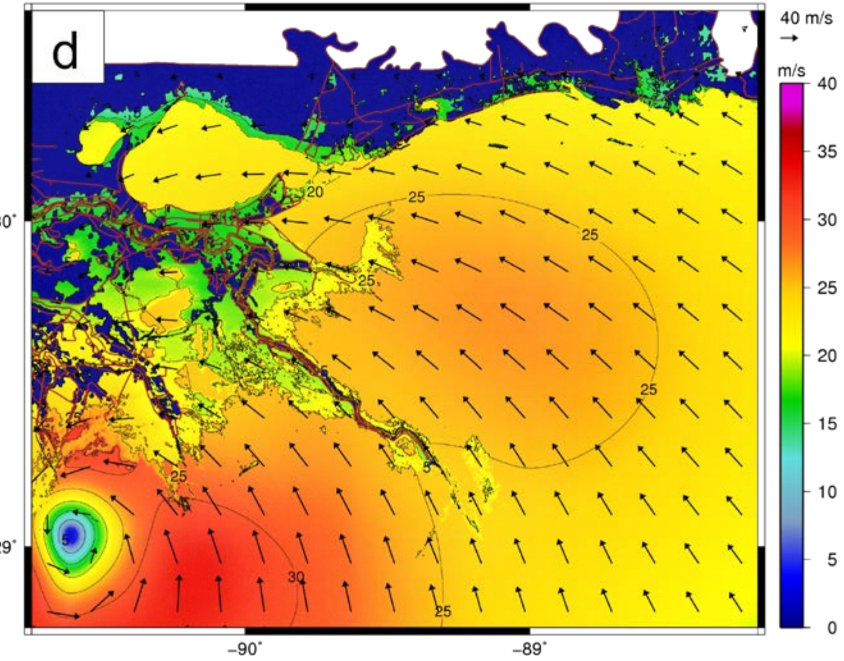


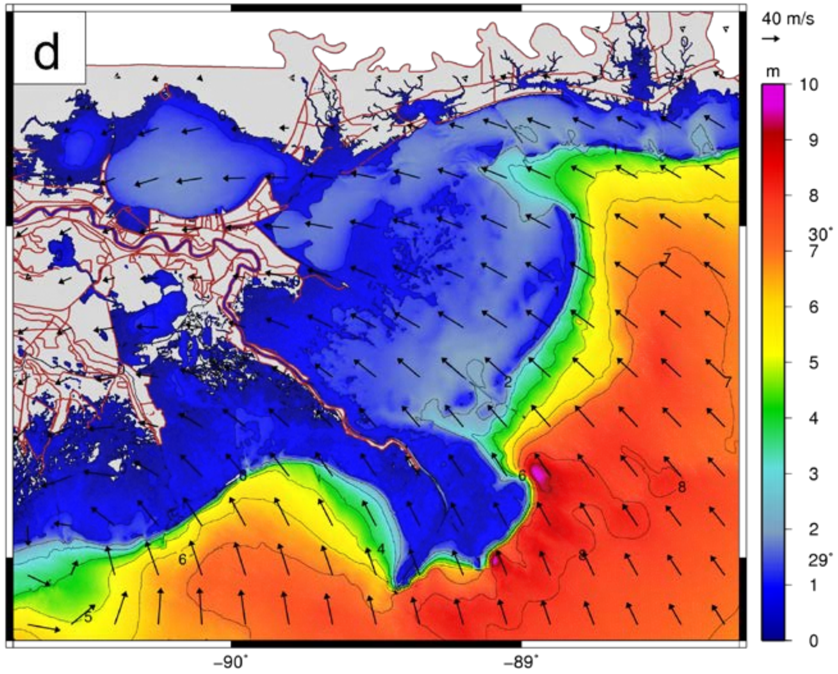
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 1400 UTC

Winds (m/s)



Waves (m)



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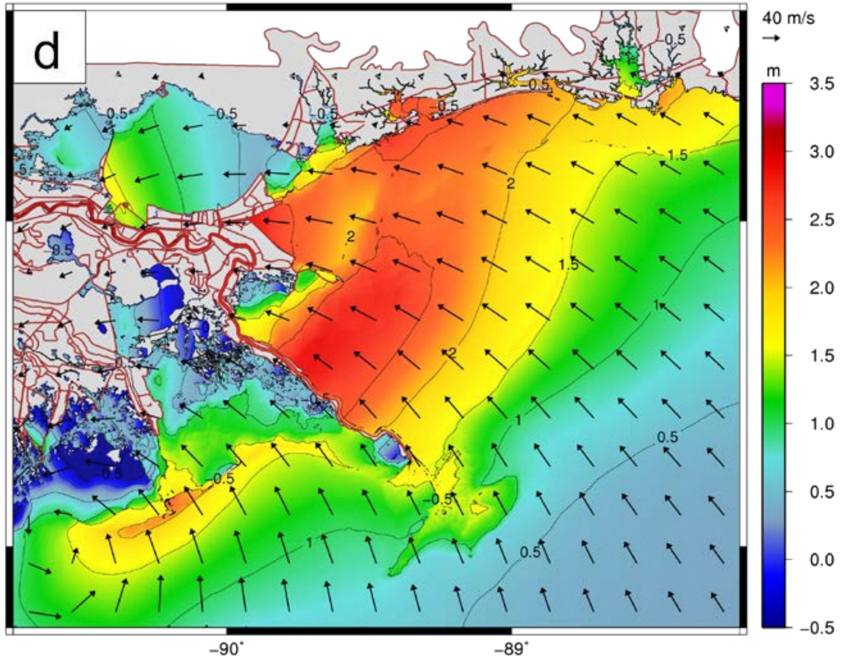
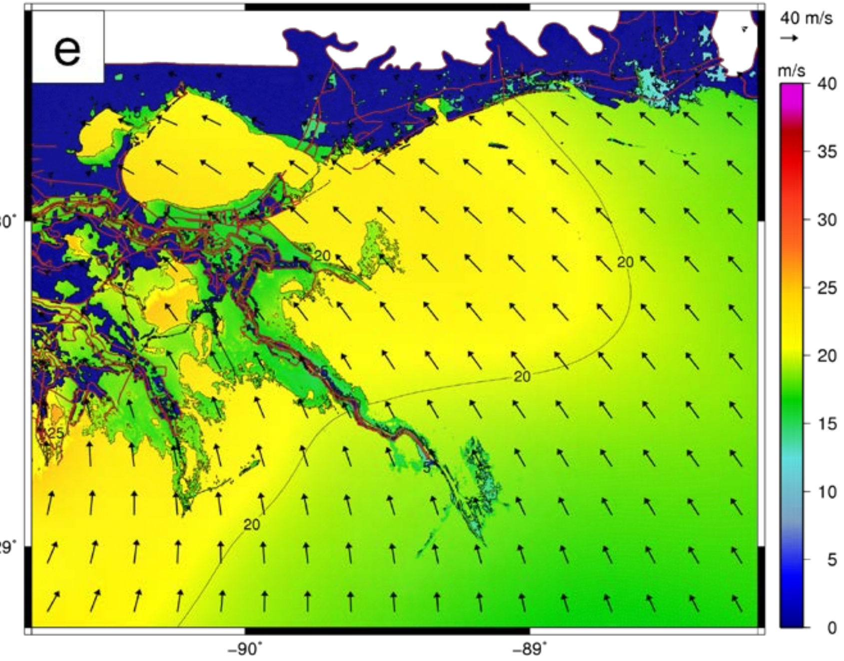


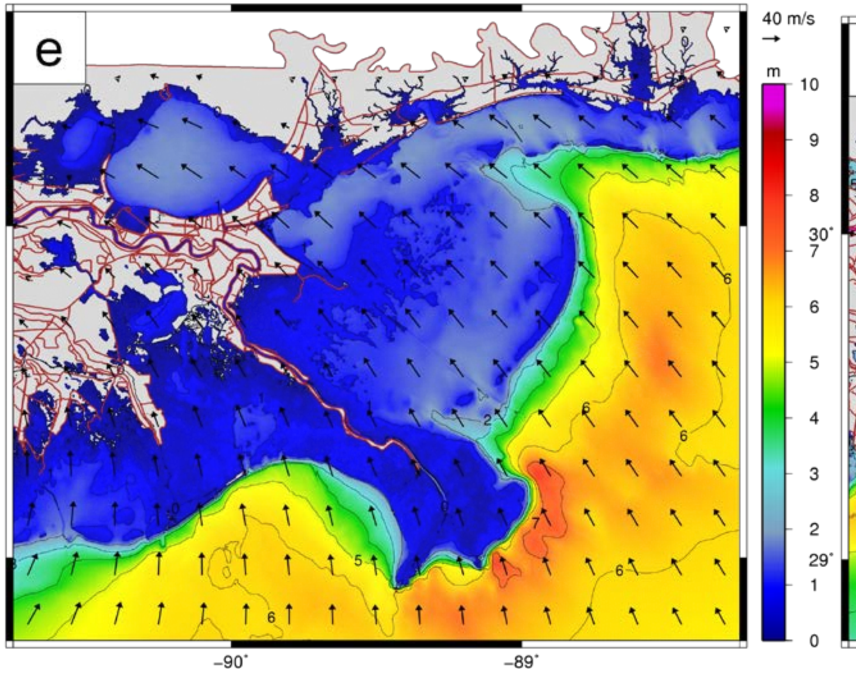
Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 01 / 1700 UTC

Winds (m/s)



Waves (m)



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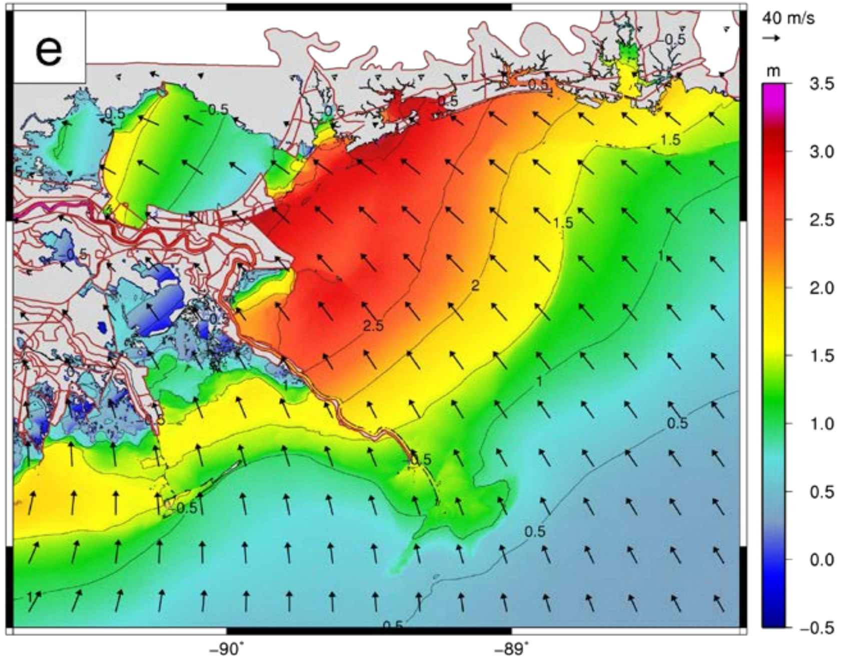
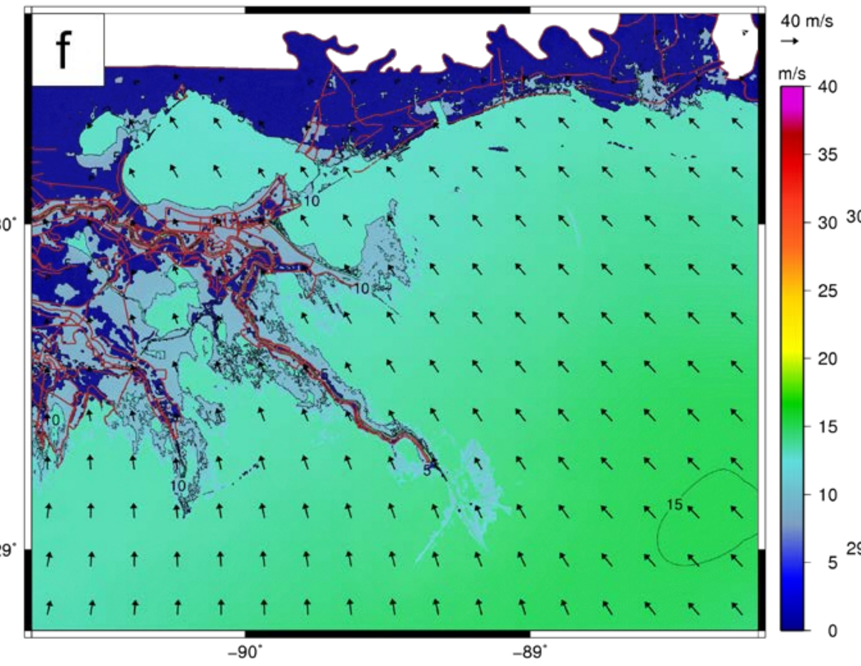


Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Hurricane Gustav: 2008 / 09 / 02 / 0200 UTC

Winds (m/s)



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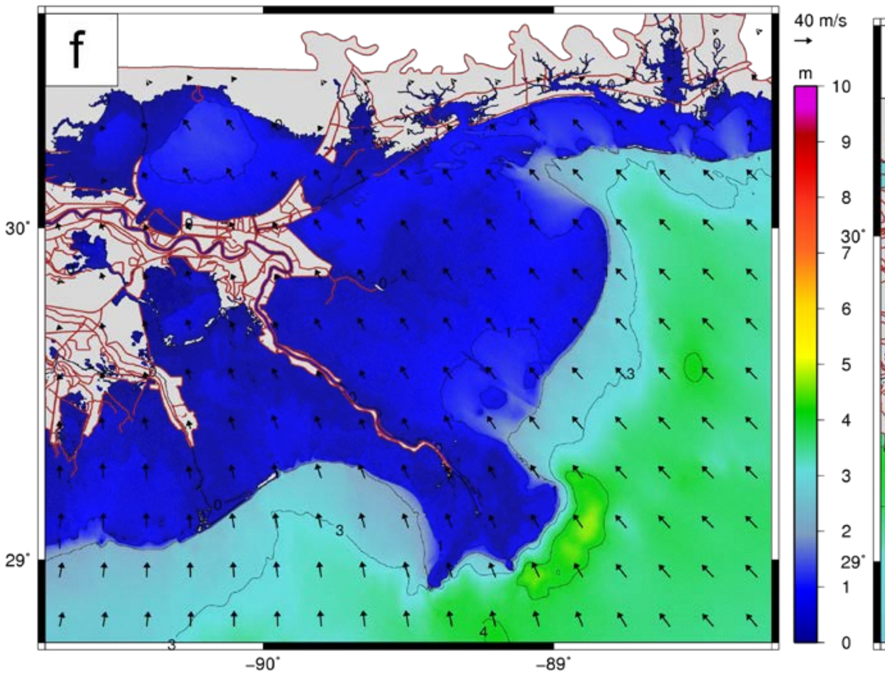

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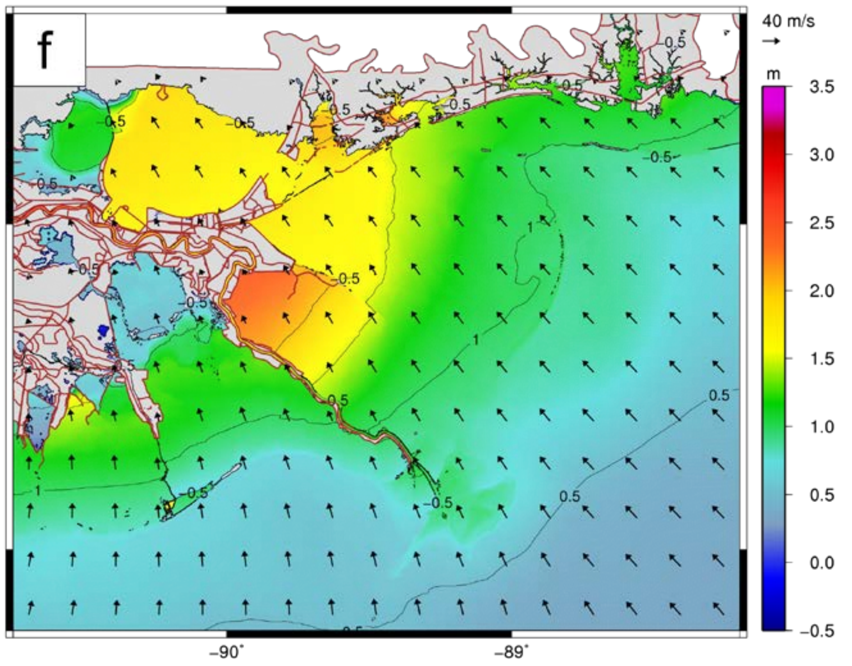


Dietrich et al., ***Monthly Weather Review***, **139**, 2488-2522, 2011.

Evolution of coastal ocean hydrodynamics models – the recent past

The GOOD

- Unstructured grids focusing on localized resolution
- Better resolution
- Better algorithms
- Better physics of sub-grid scale
- Improving parallelism
- More component interaction

The BAD

- Sub-optimal grids
- Largely second order or lower
- Often inefficient parallel processing
- Largely siloed development with disparate communities

Evolution of coastal ocean hydrodynamic models – the present

Dynamic *ADCIRC, SWAN & HYCOM* interleafing

CFSv2 Global Atmospheric Model

ADCIRC 2D/3D Circulation

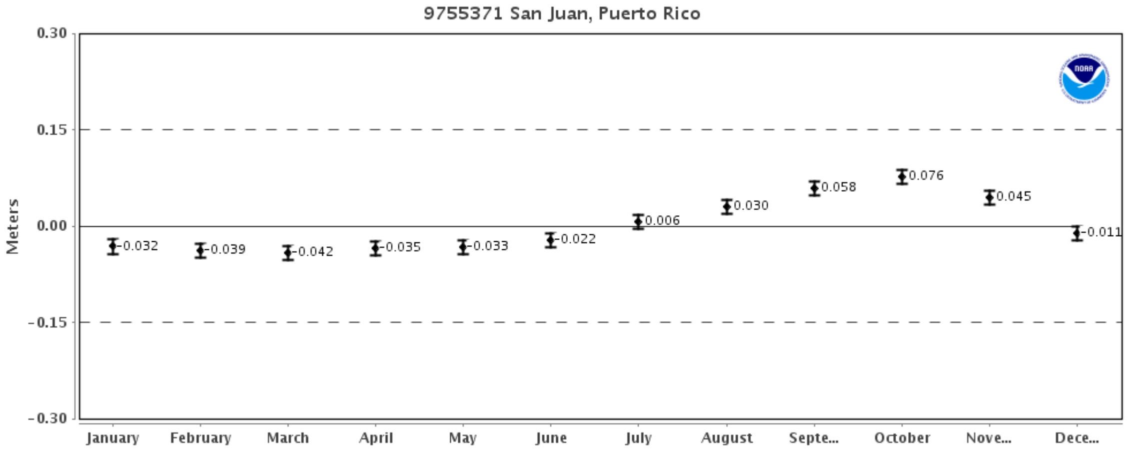
SWAN Wave Energy Density

HYCOM 3D Global Circulation Model

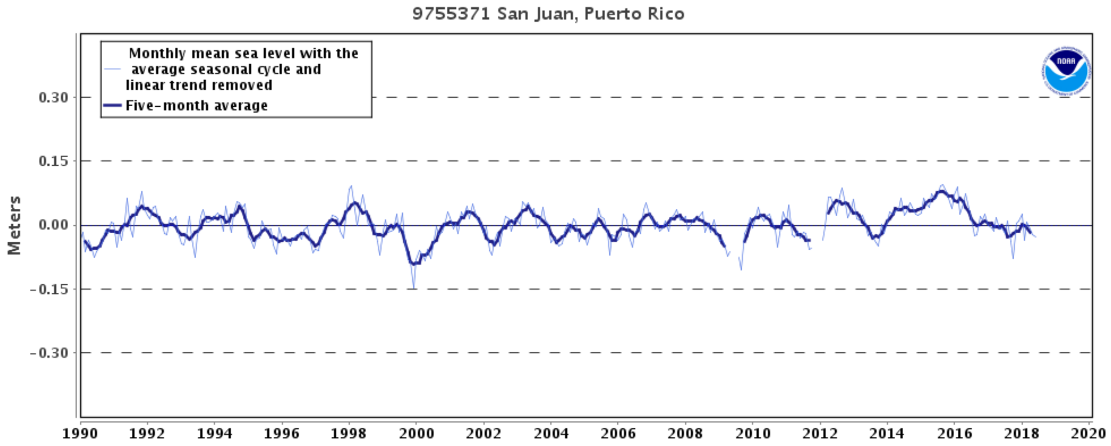
Seasonal sea level variability

- For a certain storm, flooding risks for coastal cities change based on long term, seasonal, and other variabilities in water levels
  - Long term warming of the ocean and melting of glaciers
  - Seasonal warming and cooling cycles

Average Seasonal Cycle
9755371 San Juan, Puerto Rico



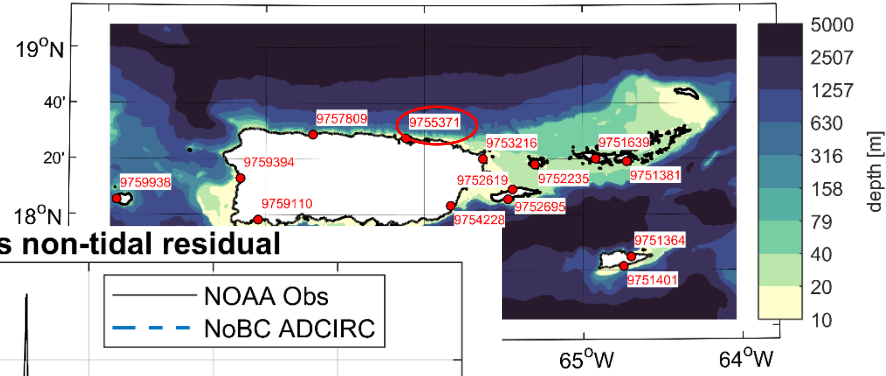
Interannual Variation Since 1990
9755371 San Juan, Puerto Rico

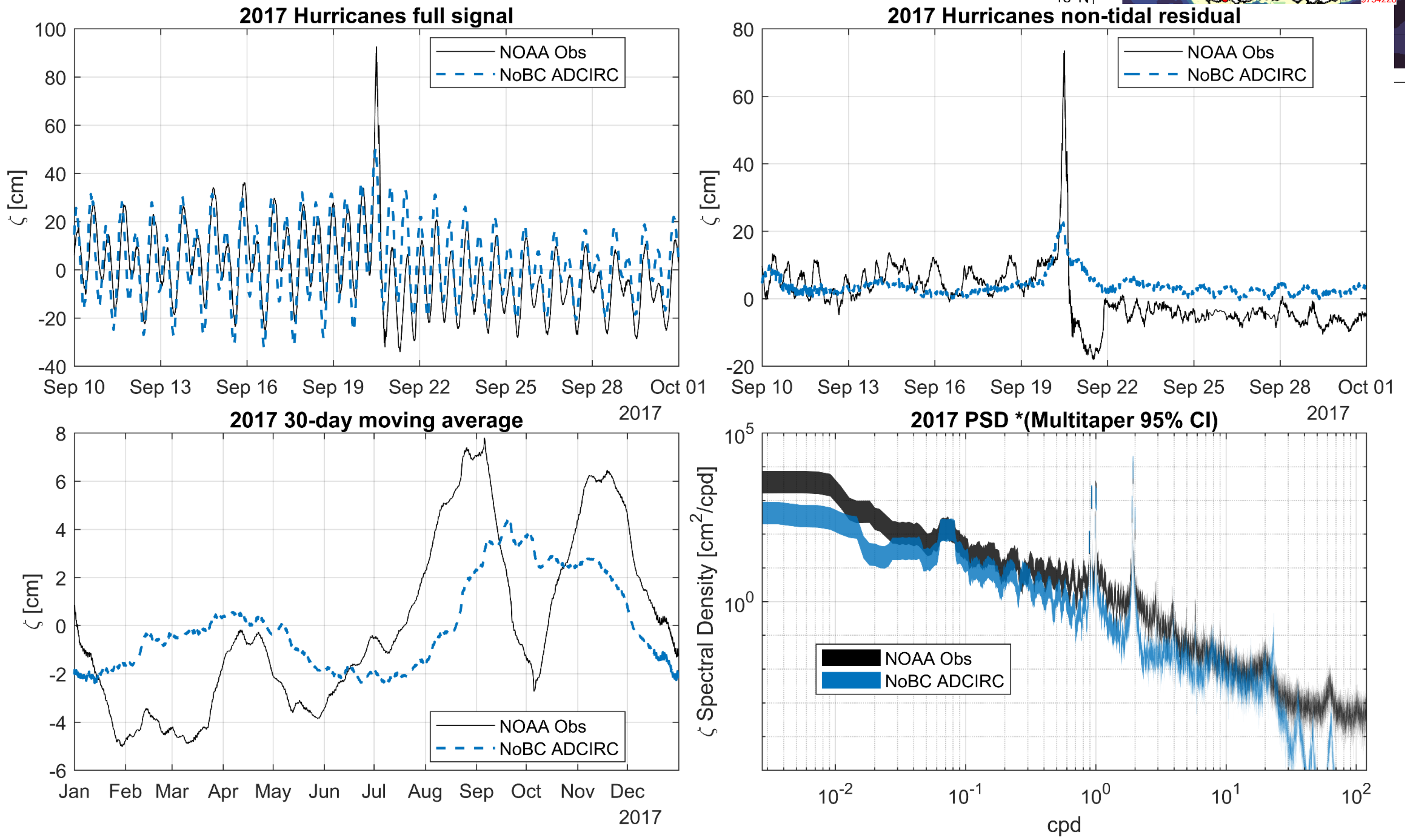


Obtained from: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9755371

  - Changes in ocean current systems
  - Changes to freshwater runoff
  - Interaction of winds and nearshore stratification

Time series and spectral density at San Juan PR



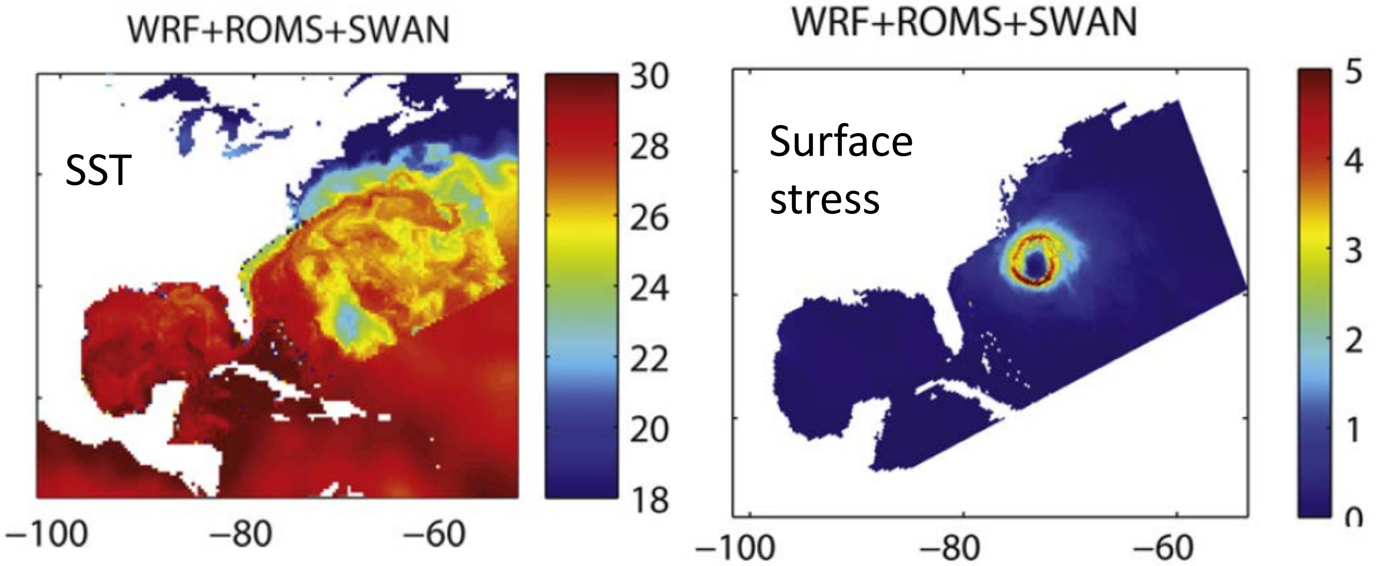


Problem

- Processes that affect background water levels are primarily baroclinic
- Tide + Surge analysis is often conducted using 2D barotropic model
  - Model does not take into account density or vertical velocity structure
- 3D models are being used more for surge analysis but..
  - 3D model is more sensitive and adds a greater degree of freedom compared to 2D
  - Horizontal resolution, temporal resolution, and domain size typically sacrificed

3D baroclinic ROMS coupled system during Hurricane Isabel

J.C., Armstrong, B., He, R., Zambon, J.B., 2010. Development of a Coupled Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modeling System. Ocean Model. 35, 230–244. doi:10.1016/j.ocemod.2010.07.0100



Method (Internal)

- 3D baroclinic terms ∇B and ∇D are calculated from the density ρ and velocity structure $\boldsymbol{v}$ on the HYCOM grid output and interpolated to 2D ADCIRC model
- Internal tide wave drag parameterization uses buoyancy frequencies N computed and interpolated from HYCOM
- Heterogeneous mode splitting

2D Depth-integrated Momentum Equation

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u}\cdot\nabla)\boldsymbol{u} + f\mathbf{k}\times\boldsymbol{u} = -\nabla\left[\frac{p_s}{\rho_0} + g(\zeta - \zeta_{EQ} - \zeta_{SAL})\right] + \frac{\nabla M}{H} - \frac{\nabla D}{H} - \frac{\nabla B}{H} + \frac{\boldsymbol{\tau}_s}{\rho_0 H} - \frac{\boldsymbol{\tau}_b}{\rho_0 H} - \mathcal{F}_{IT}$$

- Baroclinic pressure gradient (BPG):

$$\nabla B = \int_{-h}^{\zeta}\left(g\nabla\left[\int_{z}^{\zeta}\frac{\rho-\rho_0}{\rho_0}\right]dz\right)dz$$

- Momentum Dispersion:

$$\nabla D = \nabla\int_{-h}^{0}\left[(\boldsymbol{v}-\boldsymbol{V})\cdot(\boldsymbol{v}-\boldsymbol{V})\right]dz$$

- Internal tide induced barotropic energy conversion:

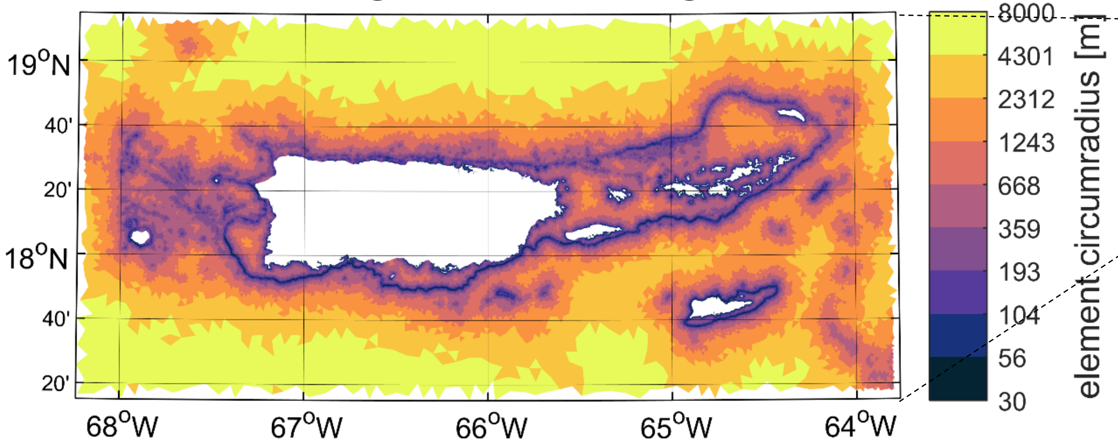
$$\mathcal{F}_{IT} = C_{IT}\frac{\left[(N_b^2-\omega^2)(\tilde{N}^2-\omega^2)\right]^{1/2}}{\omega}(\nabla h\cdot\boldsymbol{u})\nabla h$$

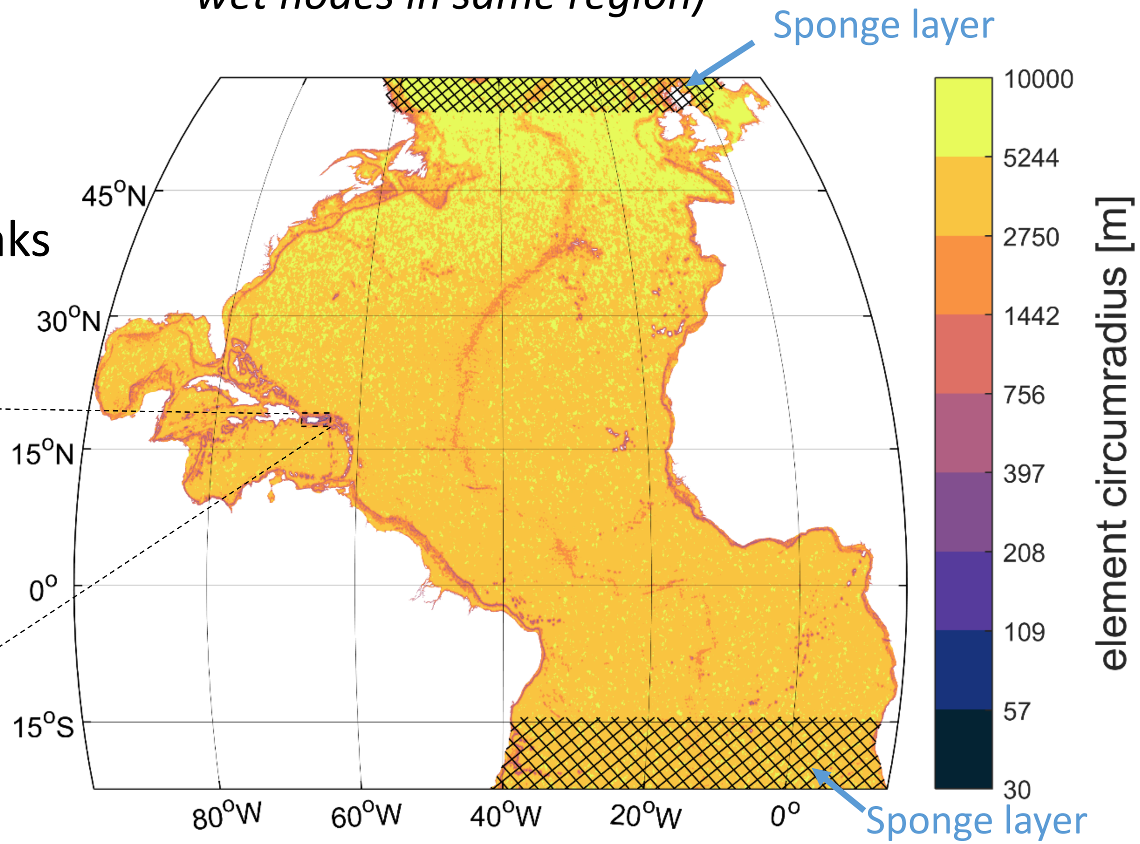
Application to Puerto Rico and the US Virgin Islands (PRVI)

- North Atlantic Ocean unstructured mesh generated using state-of-the-art OceanMesh2D MATLAB toolbox (FREE)
  https://github.com/CHLNDDEV/OceanMesh2D/
  User guide doi: 10.13140/RG.2.2.21840.61446/1
- Maximum resolution ~8 km in ocean (same as HYCOM)
- ~30m resolution around PRVI coast and shelf breaks

North Atlantic Ocean Domain
~1.5 million nodes (HYCOM has ~30 million wet nodes in same region)

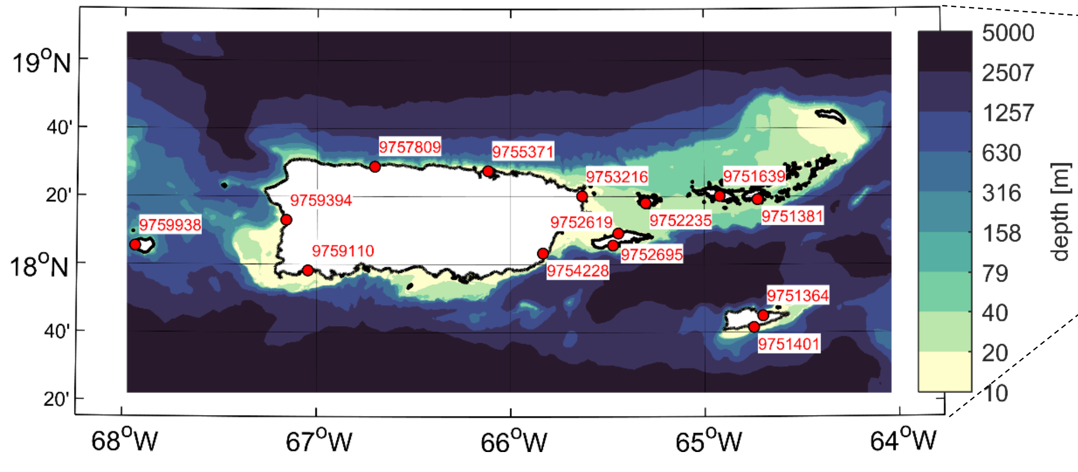
PRVI high-resolution region



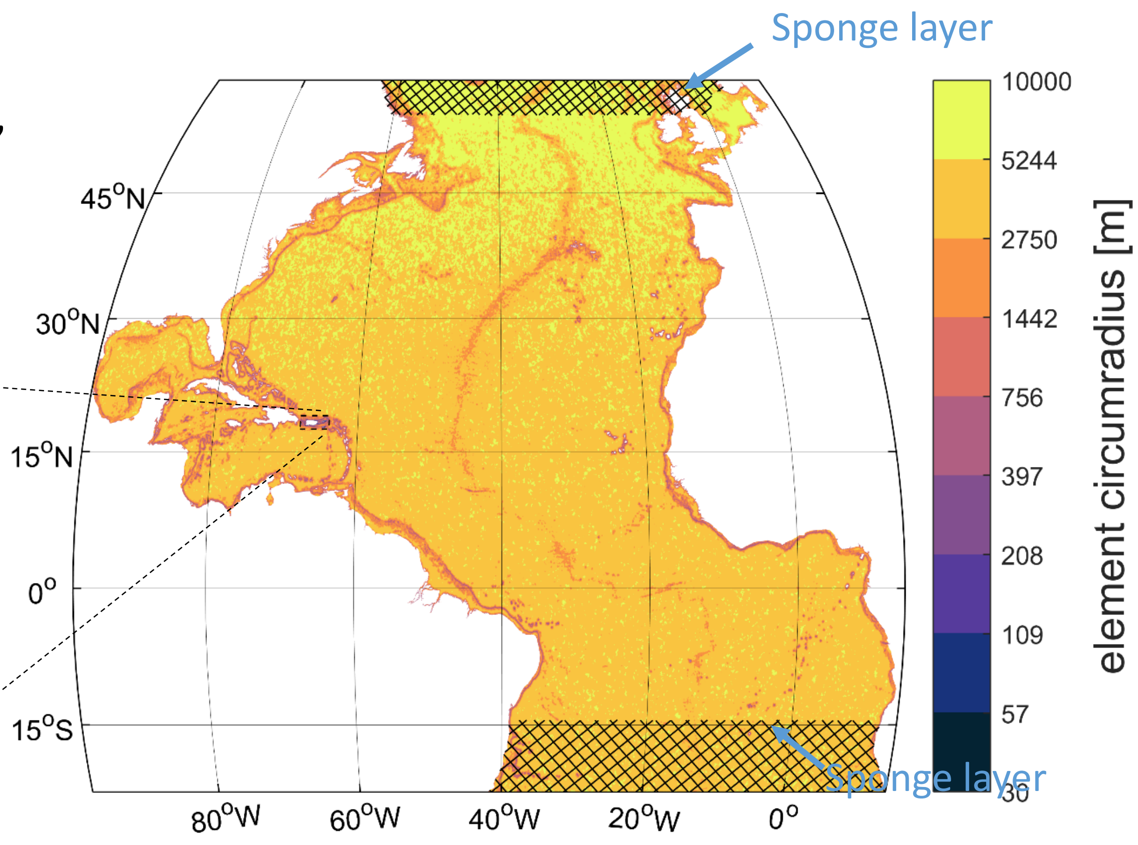


Model setup

- CFSv2 hourly winds and sea surface pressures
- GOFS 3.1 HYCOM 3-hourly oceanographic outputs
- Simulation over whole year of 2017
- Compare 2D barotropic ADCIRC, 2D “baroclinic” ADCIRC, and GOFS 3.1 HYCOM at NOAA tide gauges

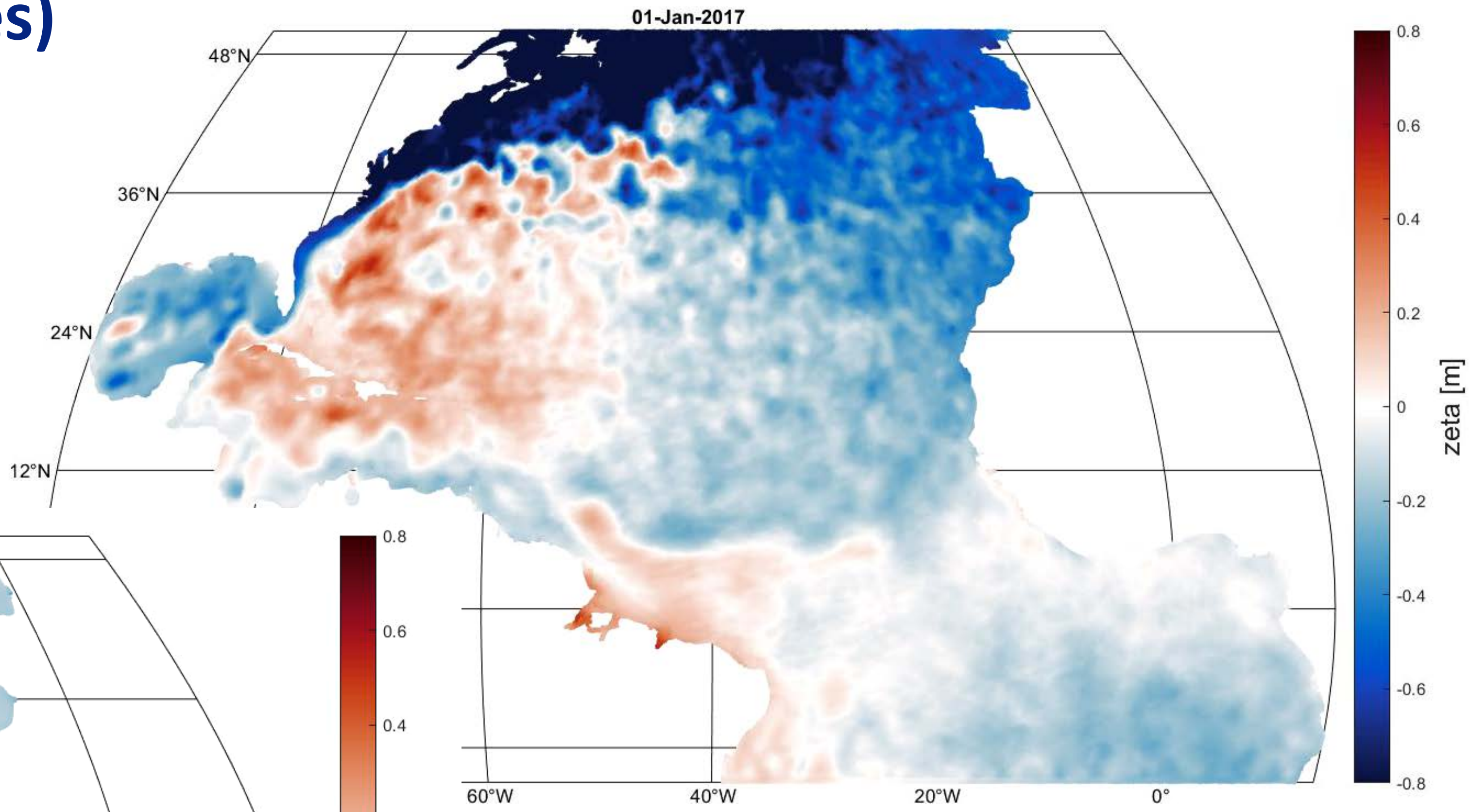


PRVI bathymetry and NOAA tide gauges

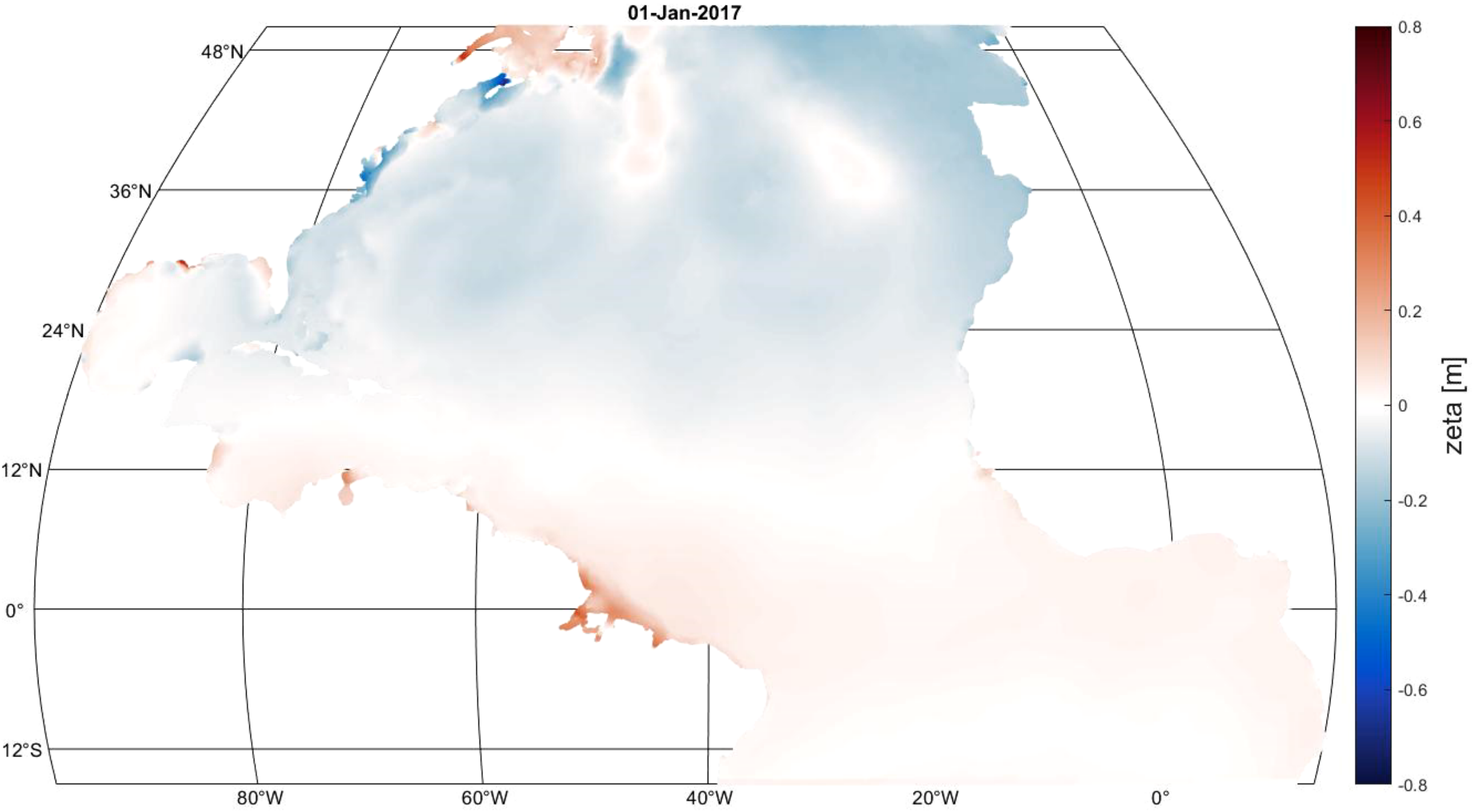


2017 SSH Daily outputs (no tides)

2D Baroclinic ADCIRC



2D Barotropic ADCIRC



2017 SSH Daily outputs (no tides)

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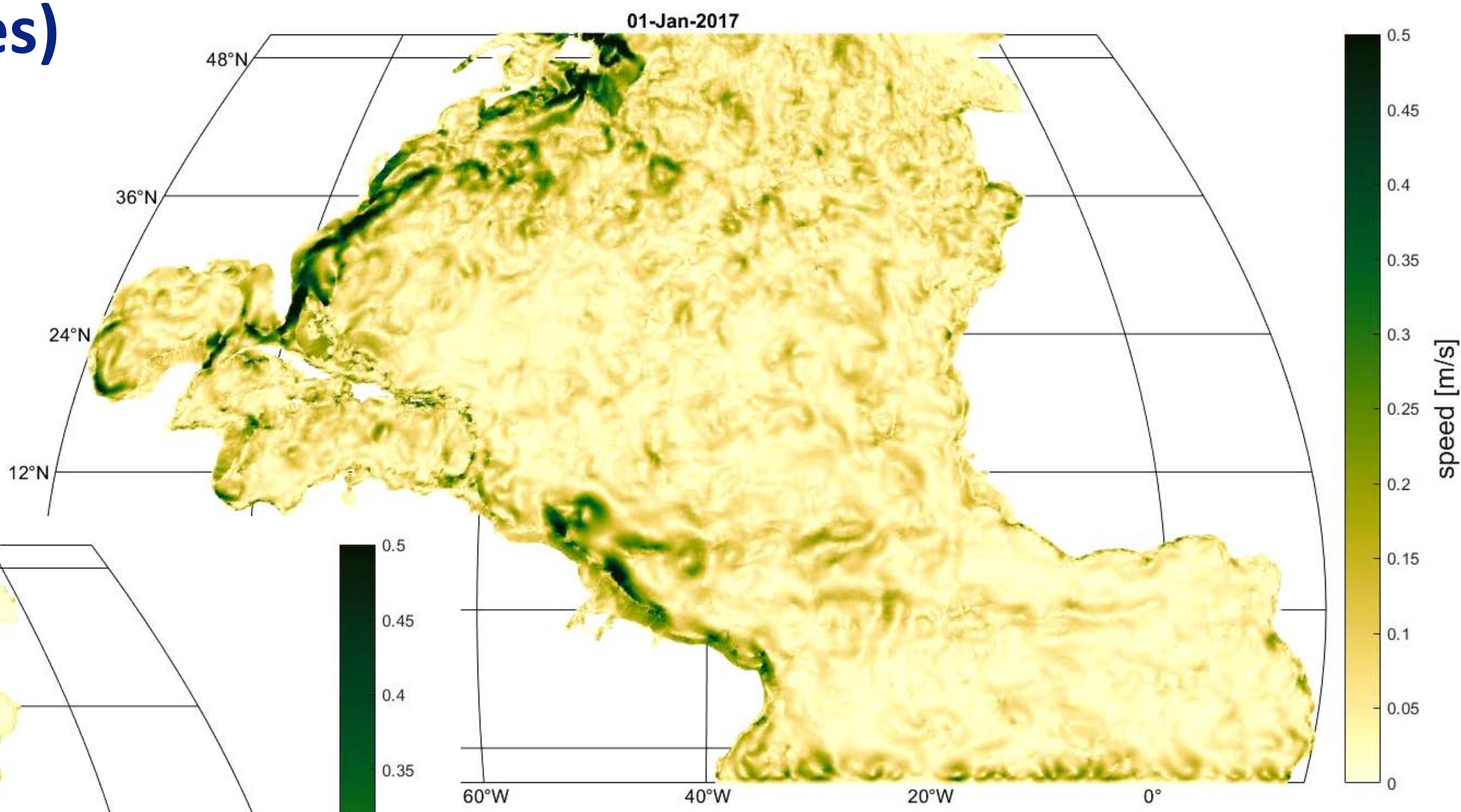
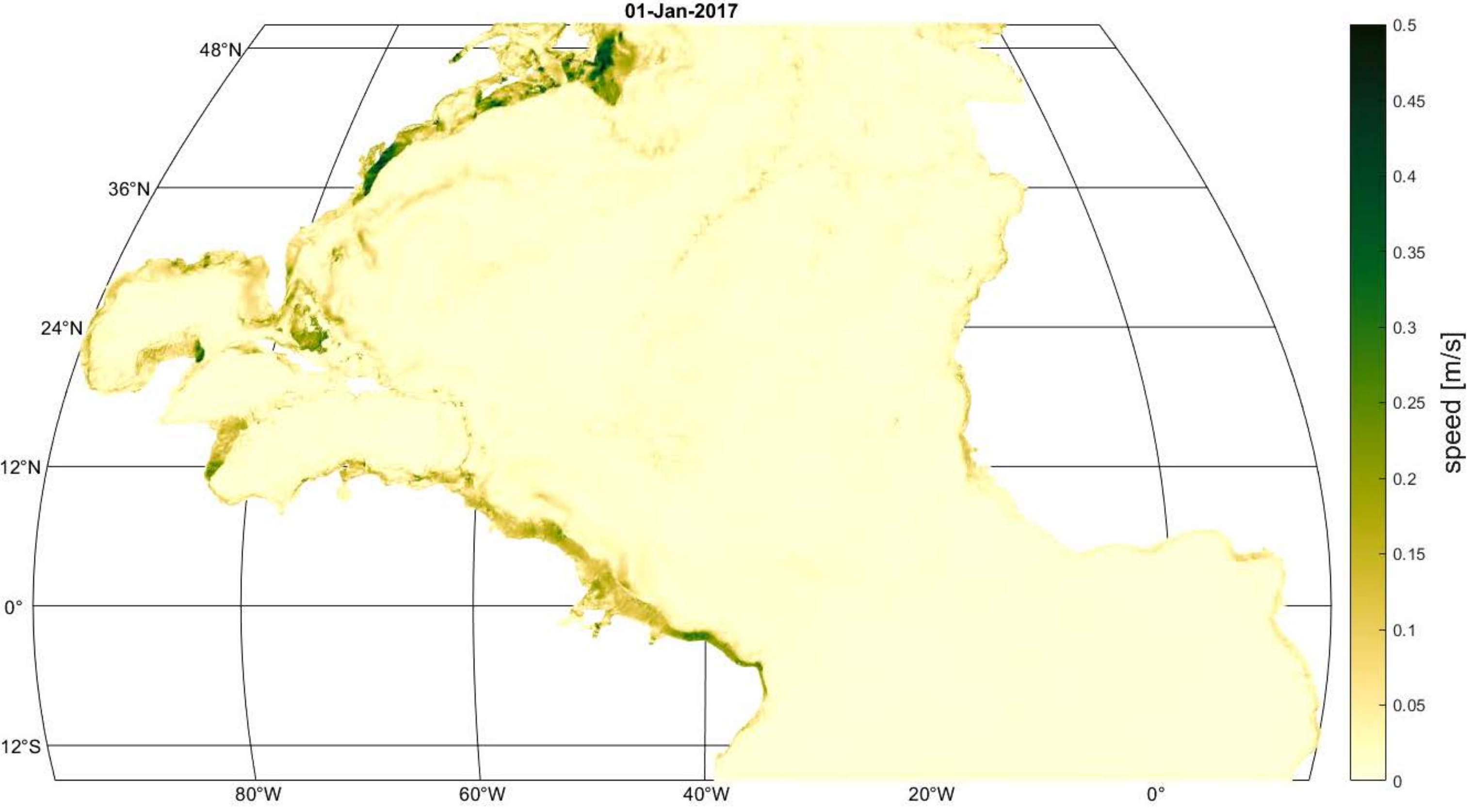
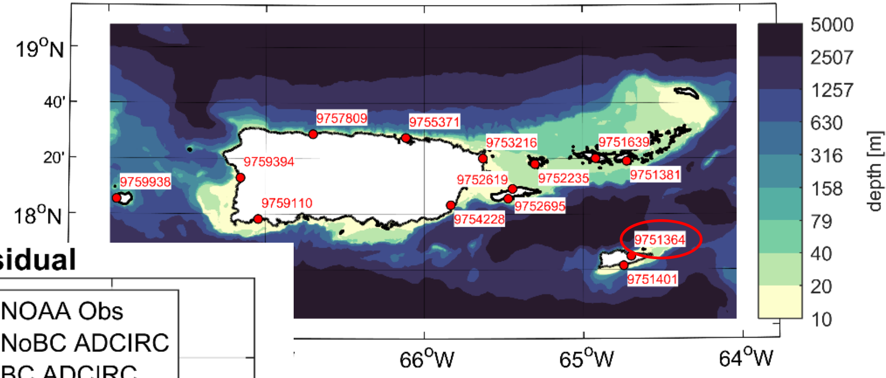


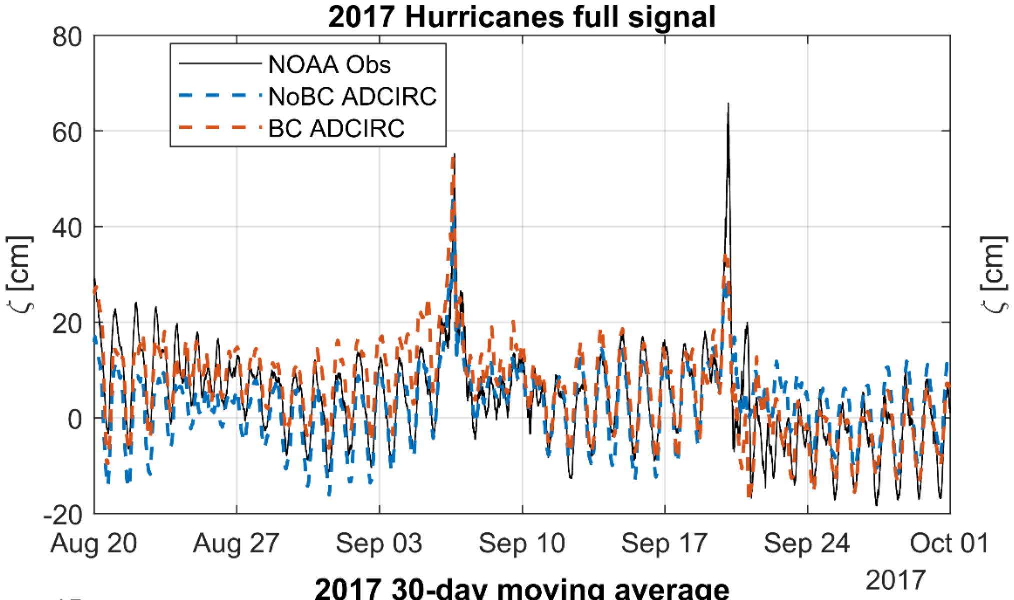
2D Barotropic ADCIRC

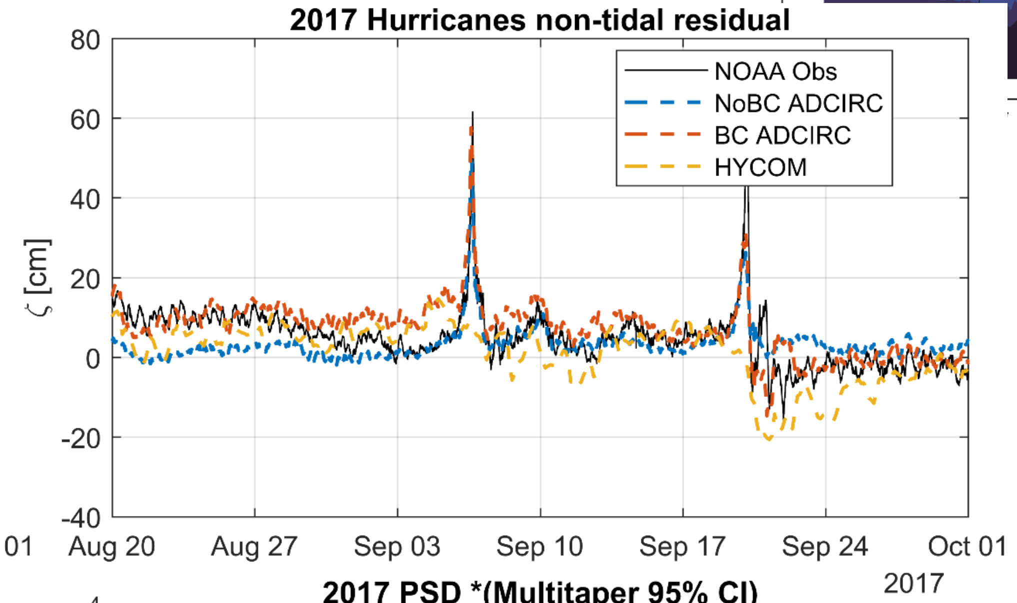


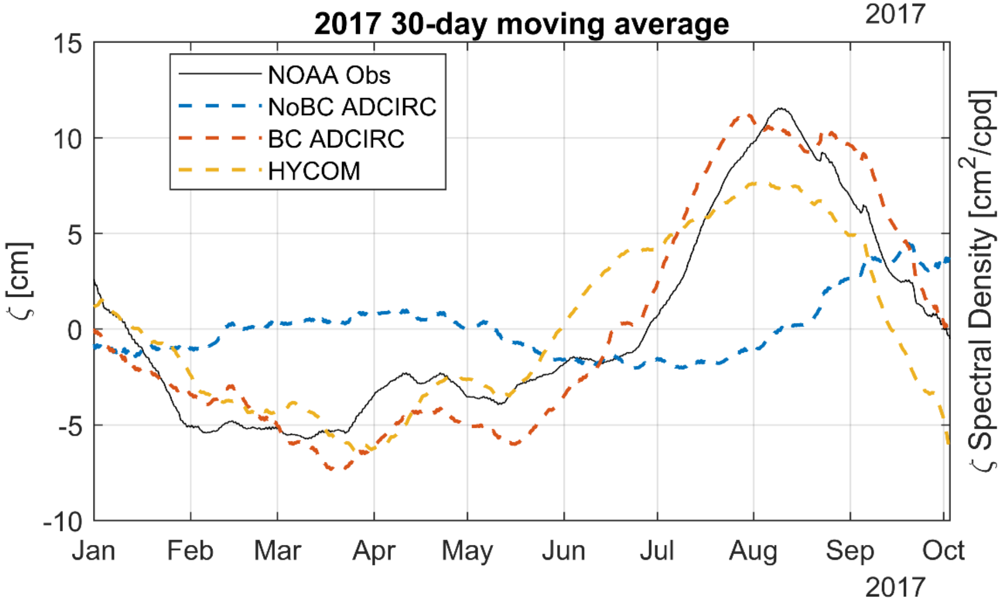
Time Series and Spectral Density

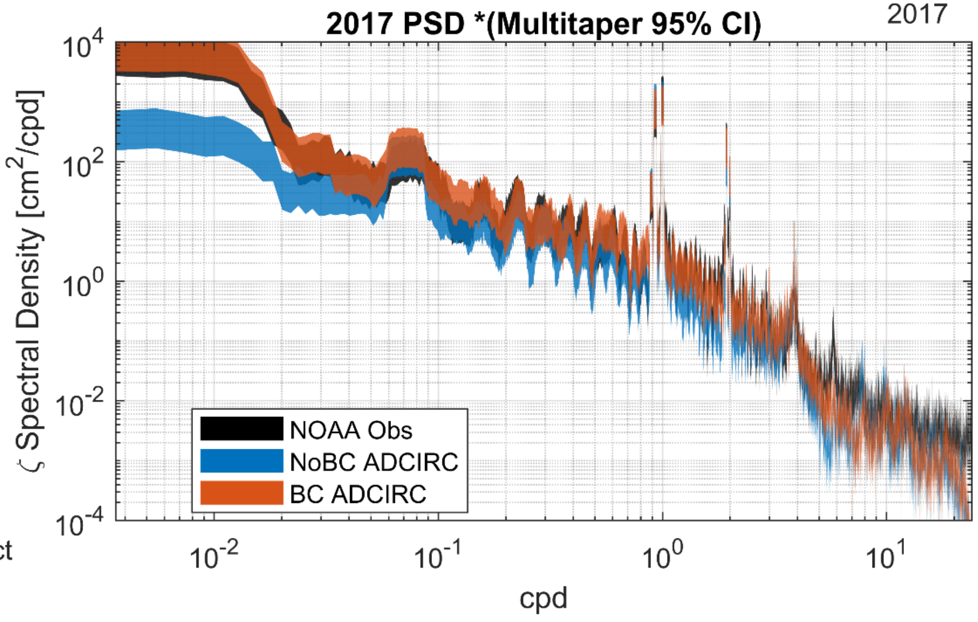
Christiansted Harbor St Croix, VI





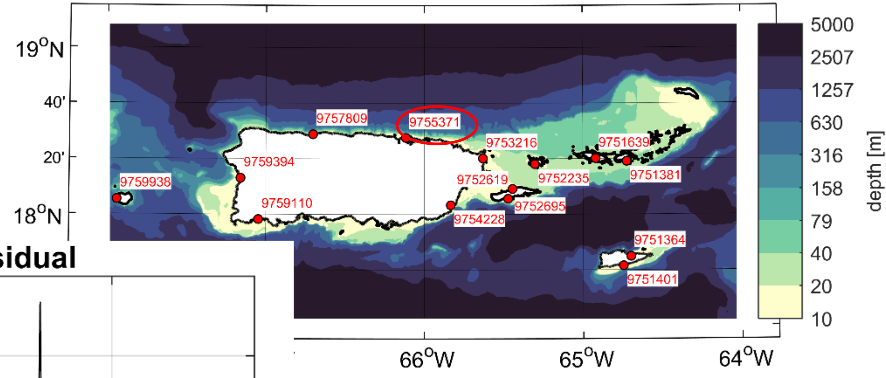


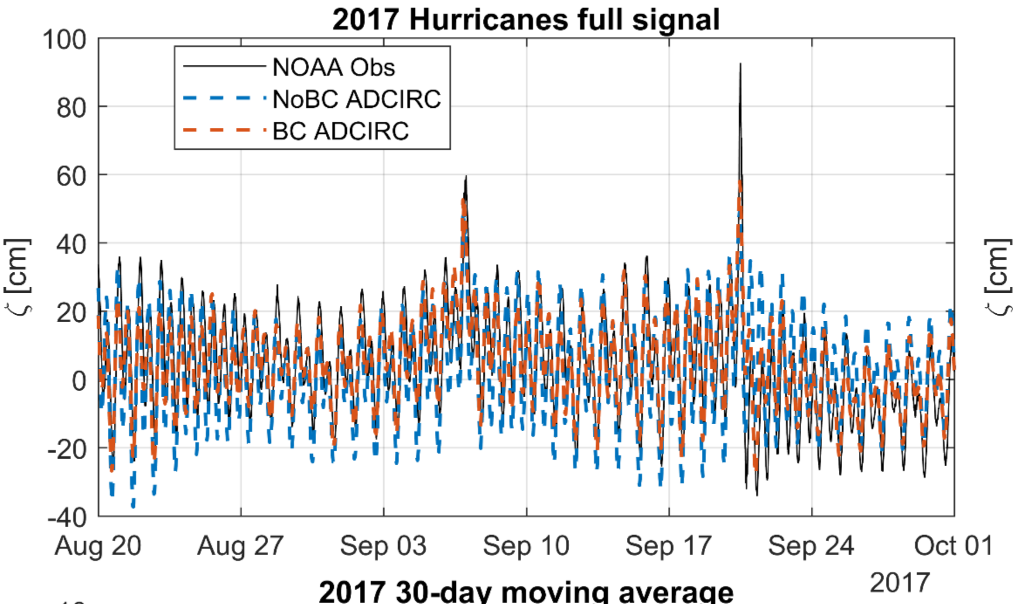


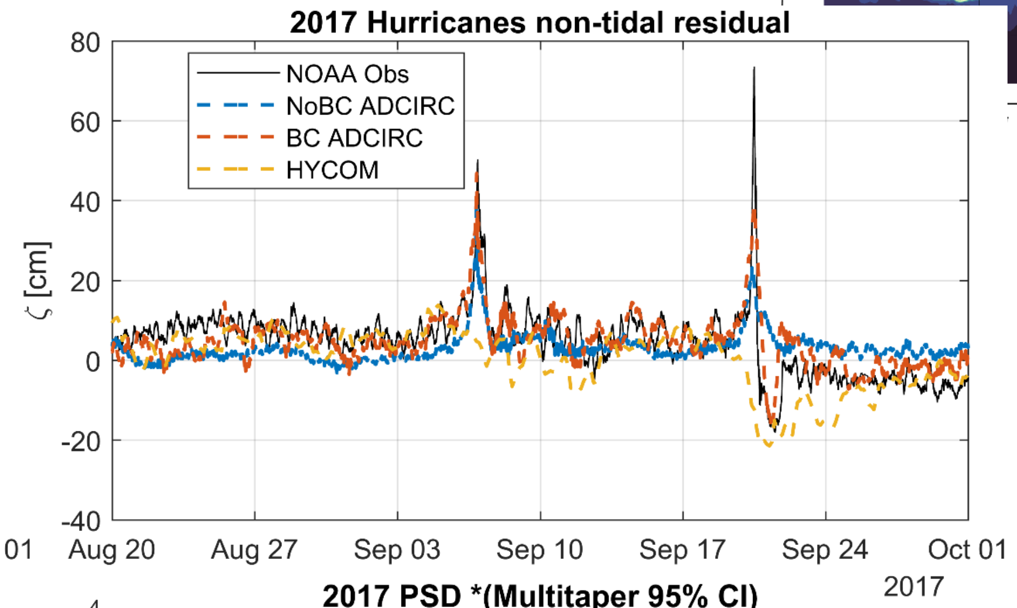


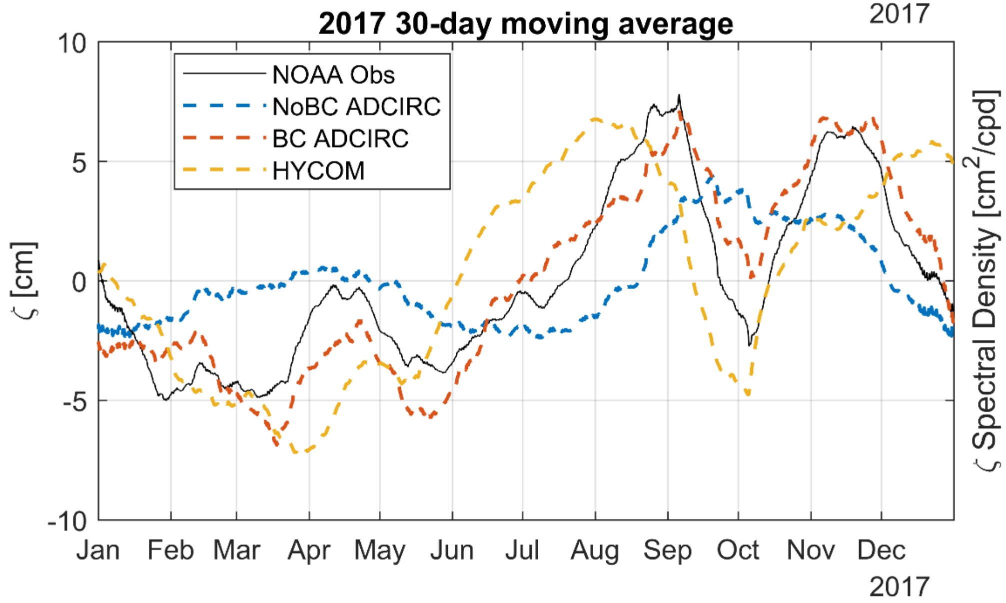
Time Series and Spectral Density

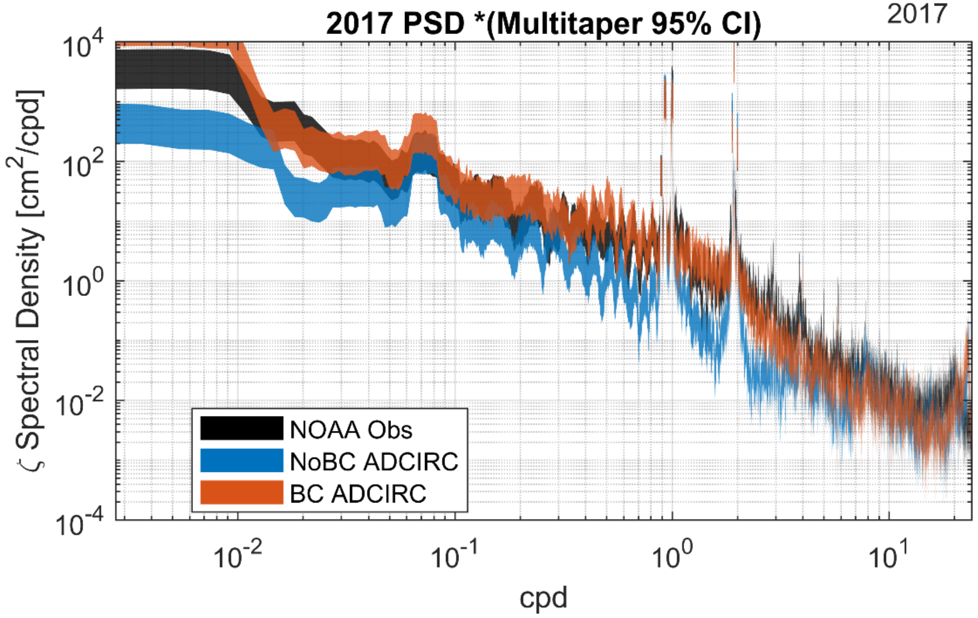
San Juan, La Puntilla, San Juan Bay, PR



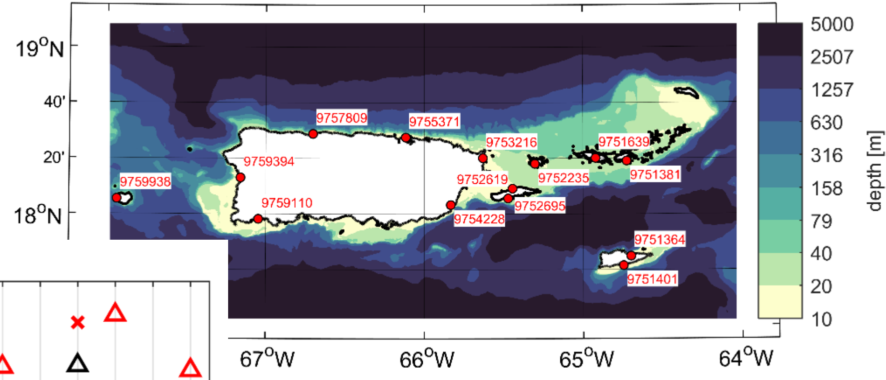


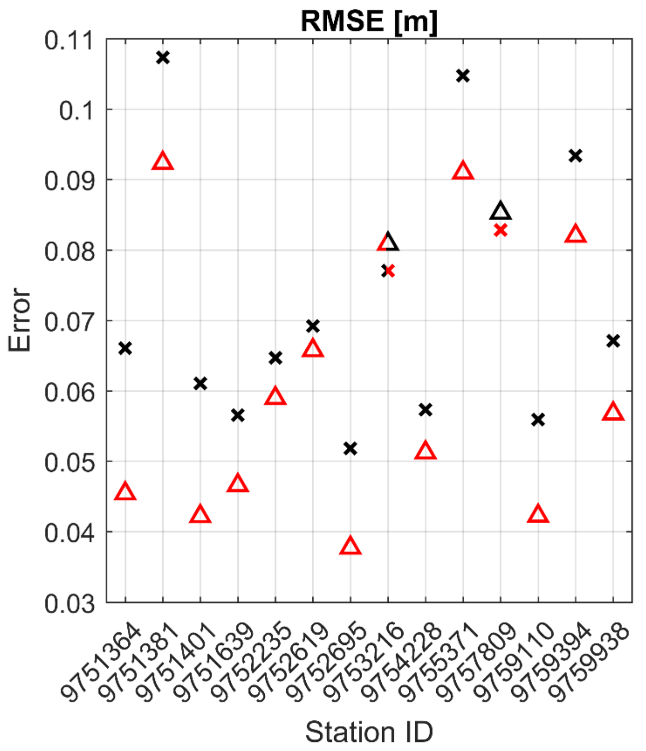


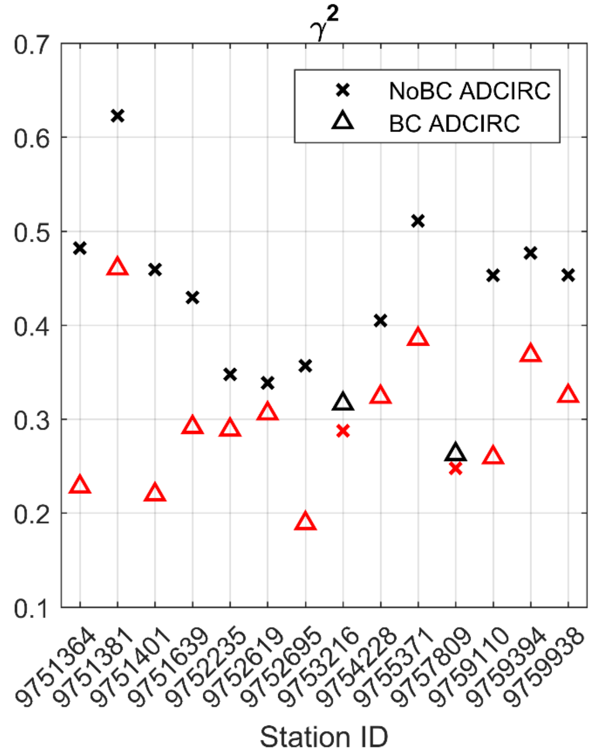


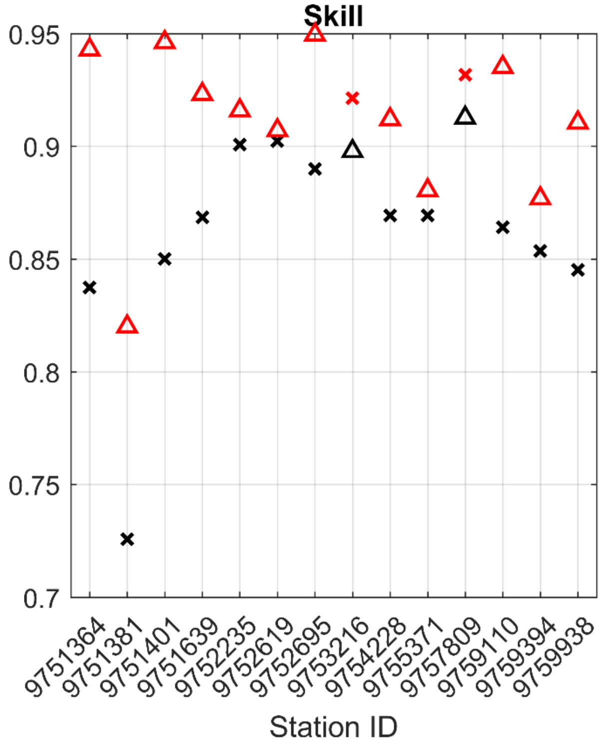


Summary of model error/skill









Red is better

$$RMSE = \left[\frac{1}{T}\int_0^T (\zeta_m - \zeta_o)^2 \ dt\right]^{1/2}$$

$$\gamma^2 = \frac{var(\zeta_m - \zeta_o)}{var(\zeta_o)}$$

$$Skill = 1 - \frac{\int_0^T (\zeta_m - \zeta_o)^2 \ dt}{\int_0^T \left(|\zeta_m - \overline{\zeta_o}| + |\zeta_o - \overline{\zeta_o}|\right)^2 \ dt}$$

Shallow water wave equations for global simulations

GWCE models (ADCIRC)

- Reformulates SWEs into the generalized wave continuity equation (GWCE) – a 2nd order PDE to remove oscillations by FE
- So far has been used to model local and regional domains
- Some modifications required to extend ADCIRC to correctly solve the SWE on the sphere (Global model)

Shallow water equations in spherical coordinates (full version)

$$\frac{\partial \zeta}{\partial t} = -\frac{1}{R\cos\phi}\left[\frac{\partial (UH)}{\partial \lambda} + \frac{\partial (VH\cos\phi)}{\partial \phi}\right] \tag{1}$$

$$\begin{aligned}\frac{\partial U}{\partial t} = & -\frac{U}{R\cos\phi}\frac{\partial U}{\partial \lambda} - \frac{V}{R}\frac{\partial U}{\partial \phi} - (\mathcal{C}_{\lambda\phi} - f')V - \frac{1}{R\cos\phi}\frac{\partial \Psi}{\partial \lambda} + \tau_w U_w - (\tau_b + \mathcal{C}_{\lambda\lambda})U \\ & + \frac{\nu_t}{R}\left[\frac{1}{\cos\phi}\frac{\partial \tau_{\lambda\lambda}}{\partial \lambda} + \frac{\partial \tau_{\lambda\phi}}{\partial \phi} - \tan\phi(\tau_{\lambda\phi} + \tau_{\phi\lambda})\right]\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{\partial V}{\partial t} = & -\frac{U}{R\cos\phi}\frac{\partial V}{\partial \lambda} - \frac{V}{R}\frac{\partial V}{\partial \phi} - (\mathcal{C}_{\phi\lambda} + f')U - \frac{1}{R}\frac{\partial \Psi}{\partial \phi} + \tau_w V_w - (\tau_b + \mathcal{C}_{\phi\phi})V \\ & + \frac{\nu_t}{R}\left[\frac{\partial \tau_{\phi\phi}}{\partial \phi} + \frac{1}{\cos\phi}\frac{\partial \tau_{\phi\lambda}}{\partial \lambda} + \tan\phi(\tau_{\lambda\lambda} - \tau_{\phi\phi})\right]\end{aligned} \tag{3}$$

$$f' = 2\Omega\sin\phi + \frac{\tan\phi}{R}U$$

Current ADCIRC model equations

- **tan(ϕ) terms ignored…**

$$\frac{1}{R\cos\phi}\frac{\partial(VH\cos\phi)}{\partial\phi} = \frac{1}{R}\frac{\partial(VH)}{\partial\phi} - \cancelto{0}{\frac{\tan\phi}{R}VH}$$

$$\frac{\partial\zeta}{\partial t} = -\frac{1}{R\cos\phi}\left[\frac{\partial(UH)}{\partial\lambda} + \frac{\partial(VH\cos\phi)}{\partial\phi}\right] \tag{1}$$

$$\begin{aligned}\frac{\partial U}{\partial t} = &-\frac{U}{R\cos\phi}\frac{\partial U}{\partial\lambda} - \frac{V}{R}\frac{\partial U}{\partial\phi} - (\mathcal{C}_{\lambda\phi} - f')V - \frac{1}{R\cos\phi}\frac{\partial\Psi}{\partial\lambda} + \tau_w U_w - (\tau_b + \mathcal{C}_{\lambda\lambda})U \\ &+ \frac{\nu_t}{R}\left[\frac{1}{\cos\phi}\frac{\partial\tau_{\lambda\lambda}}{\partial\lambda} + \frac{\partial\tau_{\lambda\phi}}{\partial\phi} - \cancelto{0}{\tan\phi(\tau_{\lambda\phi} + \tau_{\phi\lambda})}\right]\end{aligned} \tag{2}$$

$$\begin{aligned}\frac{\partial V}{\partial t} = &-\frac{U}{R\cos\phi}\frac{\partial V}{\partial\lambda} - \frac{V}{R}\frac{\partial V}{\partial\phi} - (\mathcal{C}_{\phi\lambda} + f')U - \frac{1}{R}\frac{\partial\Psi}{\partial\phi} + \tau_w V_w - (\tau_b + \mathcal{C}_{\phi\phi})V \\ &+ \frac{\nu_t}{R}\left[\frac{\partial\tau_{\phi\phi}}{\partial\phi} + \frac{1}{\cos\phi}\frac{\partial\tau_{\phi\lambda}}{\partial\lambda} + \cancelto{0}{\tan\phi(\tau_{\lambda\lambda} - \tau_{\phi\phi})}\right]\end{aligned} \tag{3}$$

$$f' = 2\Omega\sin\phi + \cancelto{0}{\frac{\tan\phi}{R}U}$$

Current ADCIRC model equations

- **Main problem**

$$\frac{1}{R\cos\phi}\frac{\partial(VH\cos\phi)}{\partial\phi}$$

- Solving this term in the continuity equations is difficult with the continuous Galerkin FEM due to the nonlinearity of the ϕ dependent terms
- The tan(ϕ) terms in momentum eq's tend to stay small and are relatively easy to solve through current method
- **Expanding this term** eliminates the nonlinearity but the tan(ϕ) term is extremely stiff for the numerical method so it has just been ignored…

$$\frac{1}{R}\frac{\partial(VH)}{\partial\phi} - \cancelto{0}{\frac{\tan\phi}{R}}VH$$

Proposed solution by reformulation

- Use an arbitrary cylindrical projection to map (λ,ϕ) onto (*x*,*y*):
  (Select desired *p* = 0, 1, 2)

(λ_0,φ_0) is arbitrary origin

$$x = R(\lambda - \lambda_0)\cos\phi_0$$

$$y = \begin{cases} R\sin\phi\sec\phi_0 & \text{if } p = 0: \text{ Equal-area} \\ R\phi & \text{if } p = 1: \text{ Equidistant (CPP)} \\ R\ln(\tan\phi + \sec\phi)\cos\phi_0 & \text{if } p = 2: \text{ Conformal (Mercator)} \end{cases}$$

- Multiply continuity by *cos^p(φ)* [= 1 when *p* = 0]:

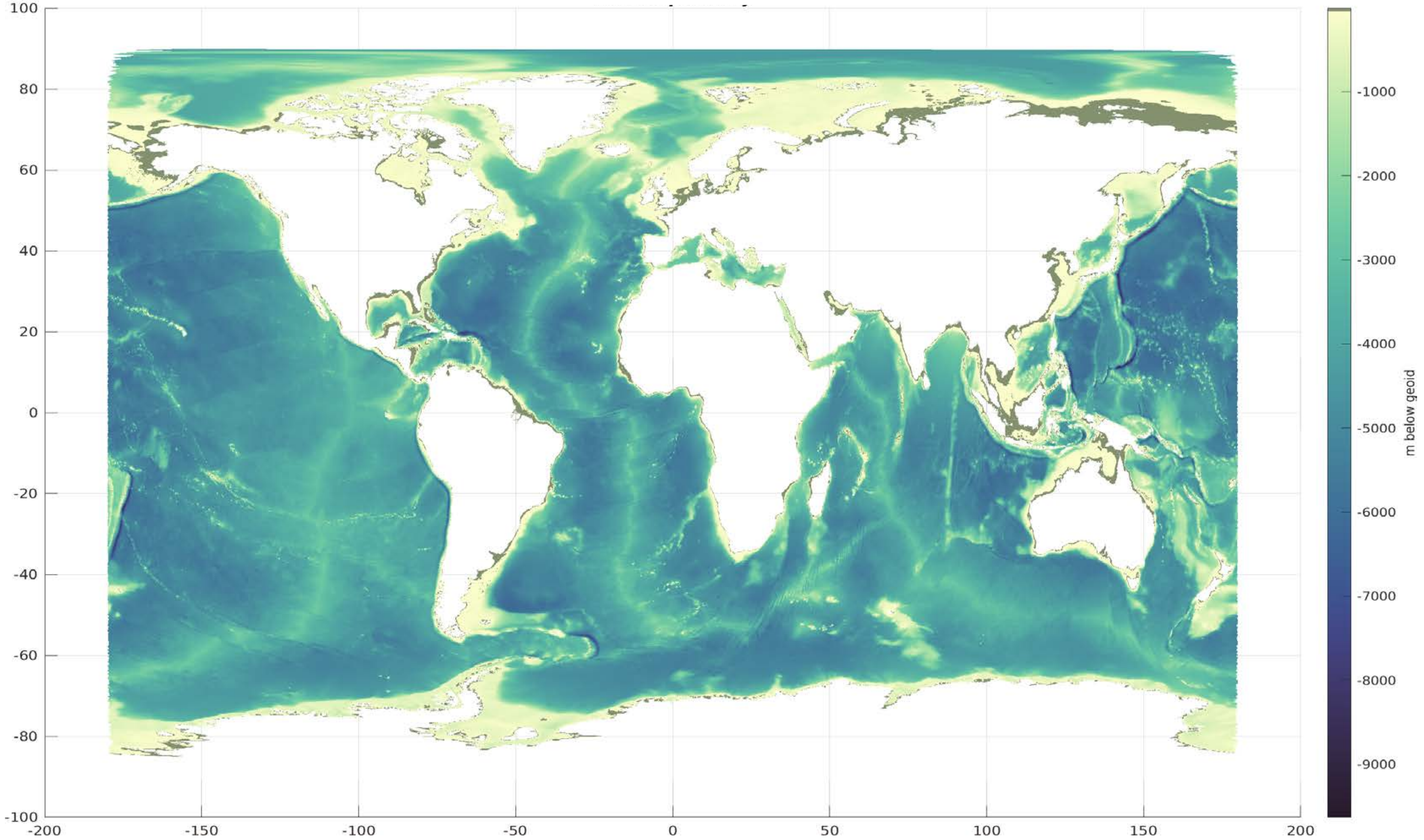
We can easily solve this!

$$\frac{\partial(\zeta\cos^p\phi)}{\partial t} = -L_x\frac{\partial(UH)}{\partial x} - L_y\frac{\partial(VH\cos\phi)}{\partial y}$$

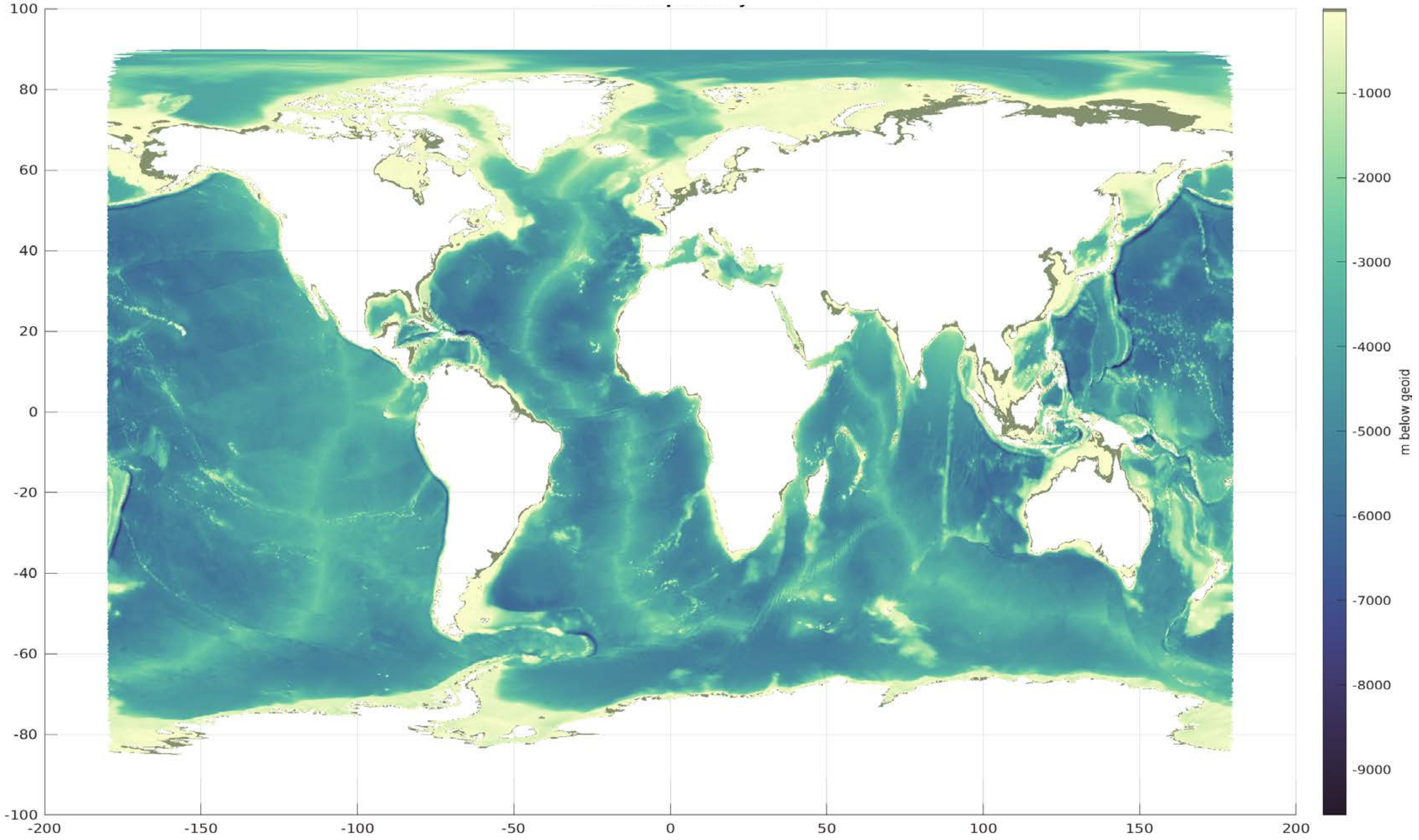
$$L_x = \cos\phi_0(\cos\phi)^{p-1}, \qquad L_y = (\cos\phi_0)^{p-1},$$

this is just a constant

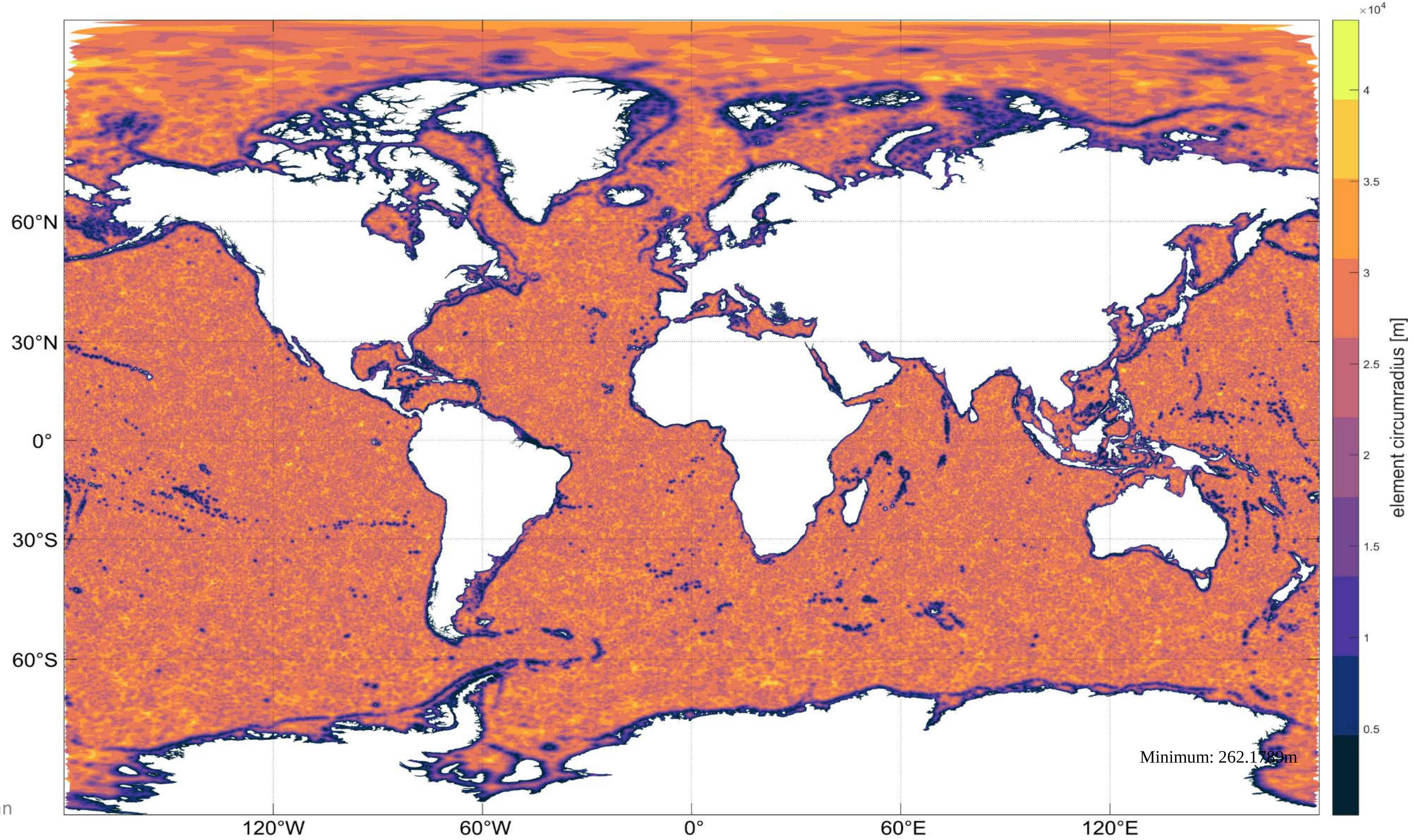
Global mesh 1 (SRTM+v2.0)



Global mesh 2 (GEBCO 2019 with Canadian 100 m data)

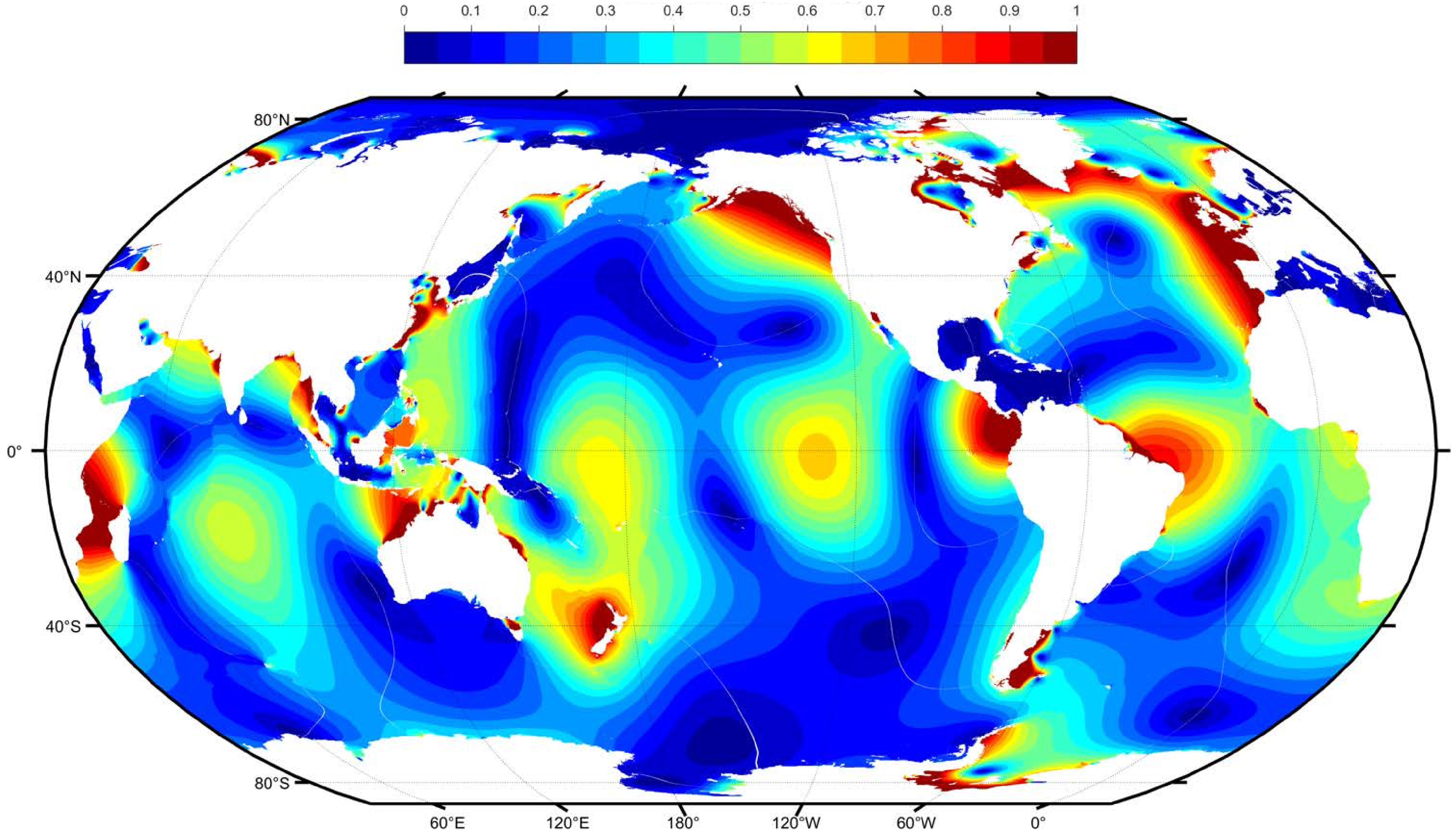


Global mesh – element sizes

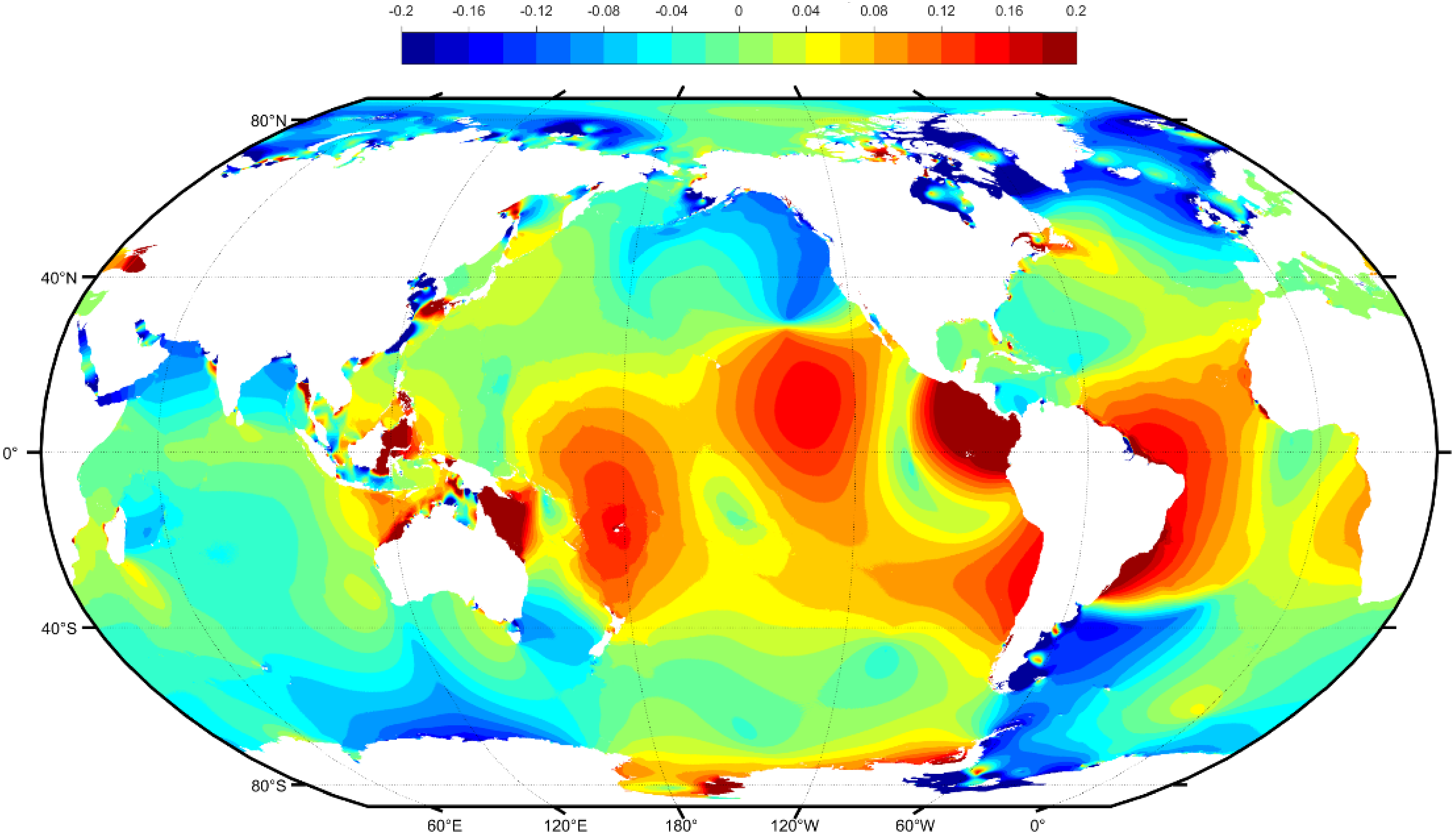


Jan

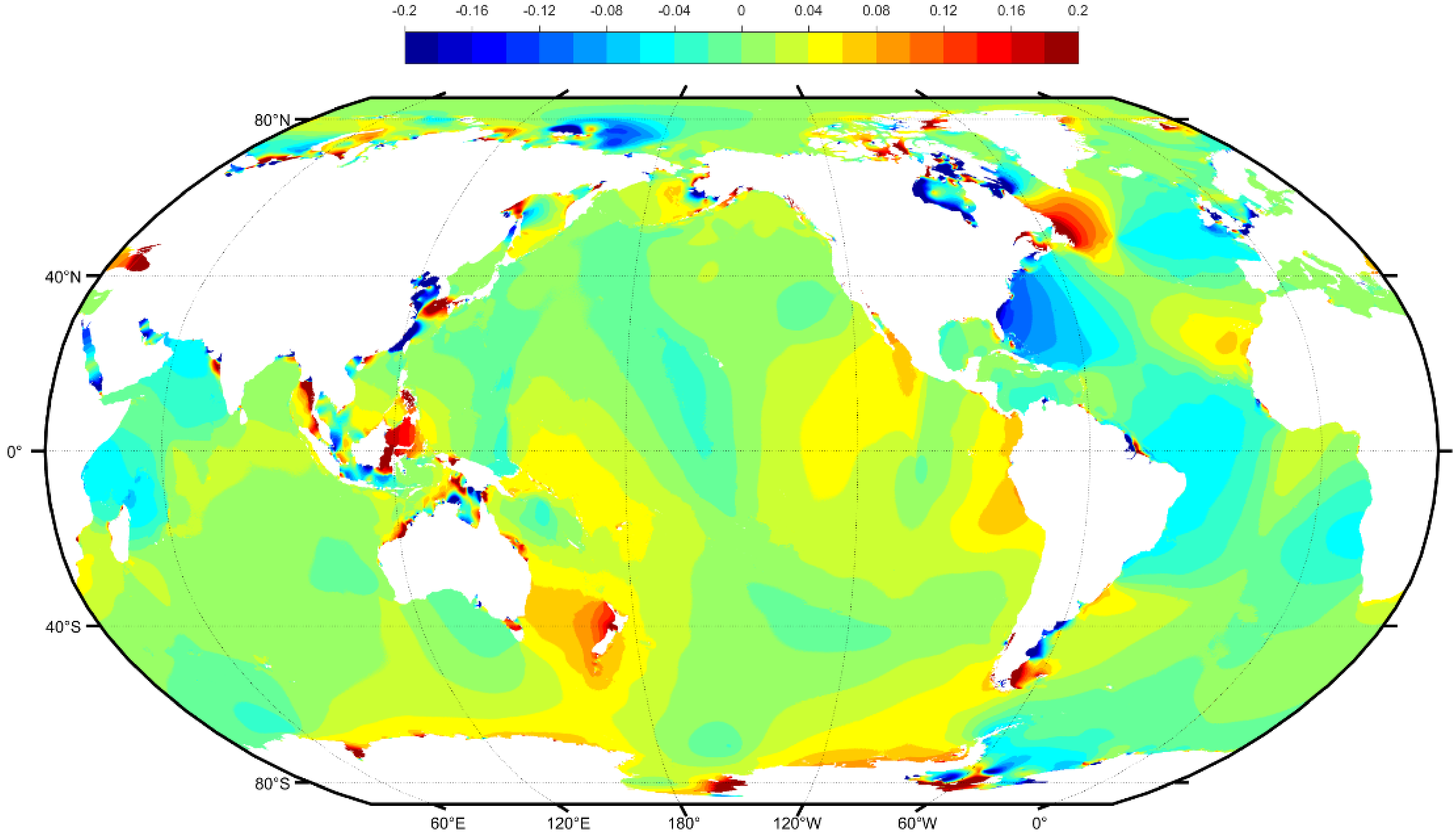
Global mesh 1: M_2 amplitude (meters)



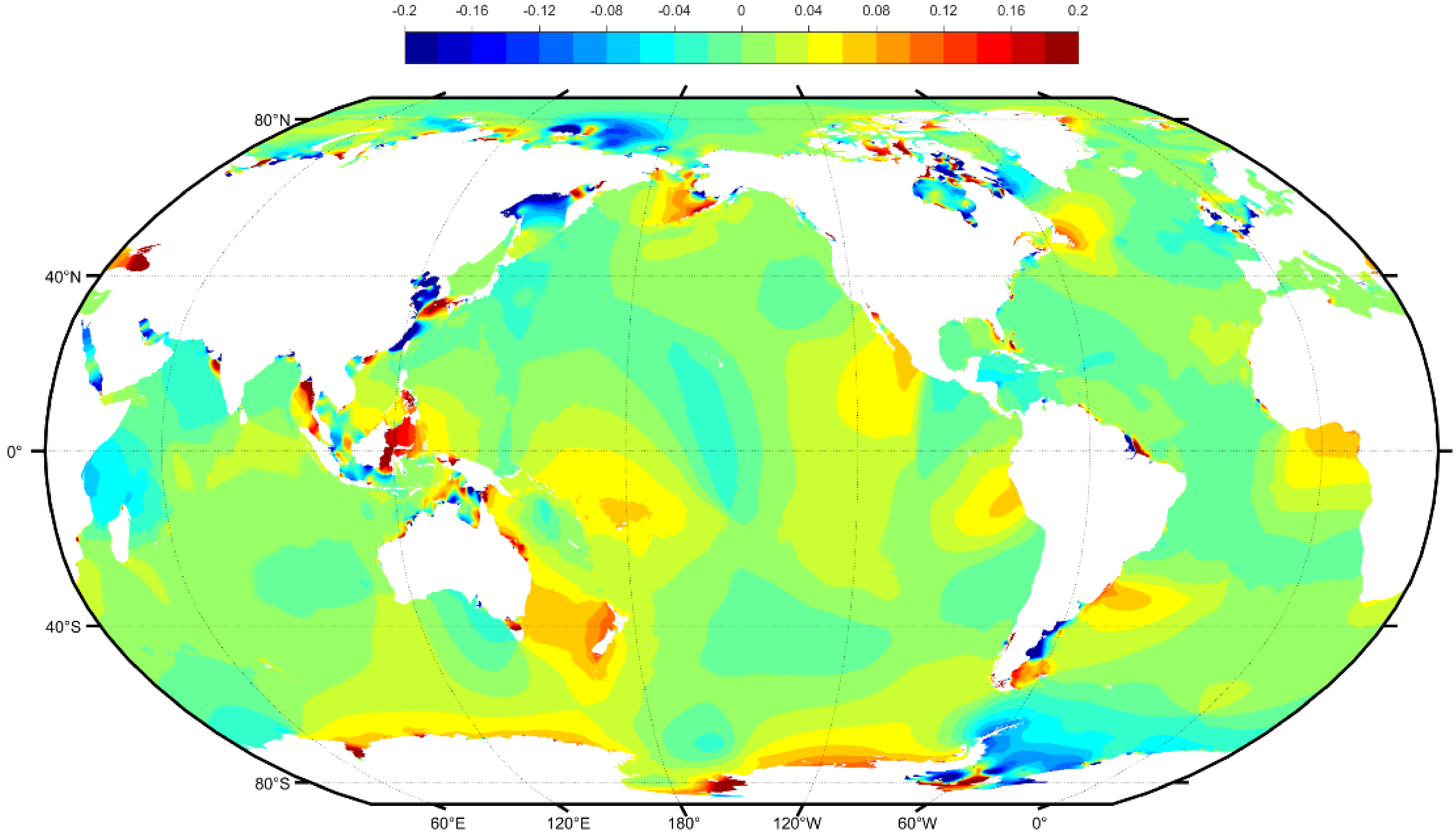
Global mesh 1 compared to TPX09 Atlas computed with legacy ADCIRC



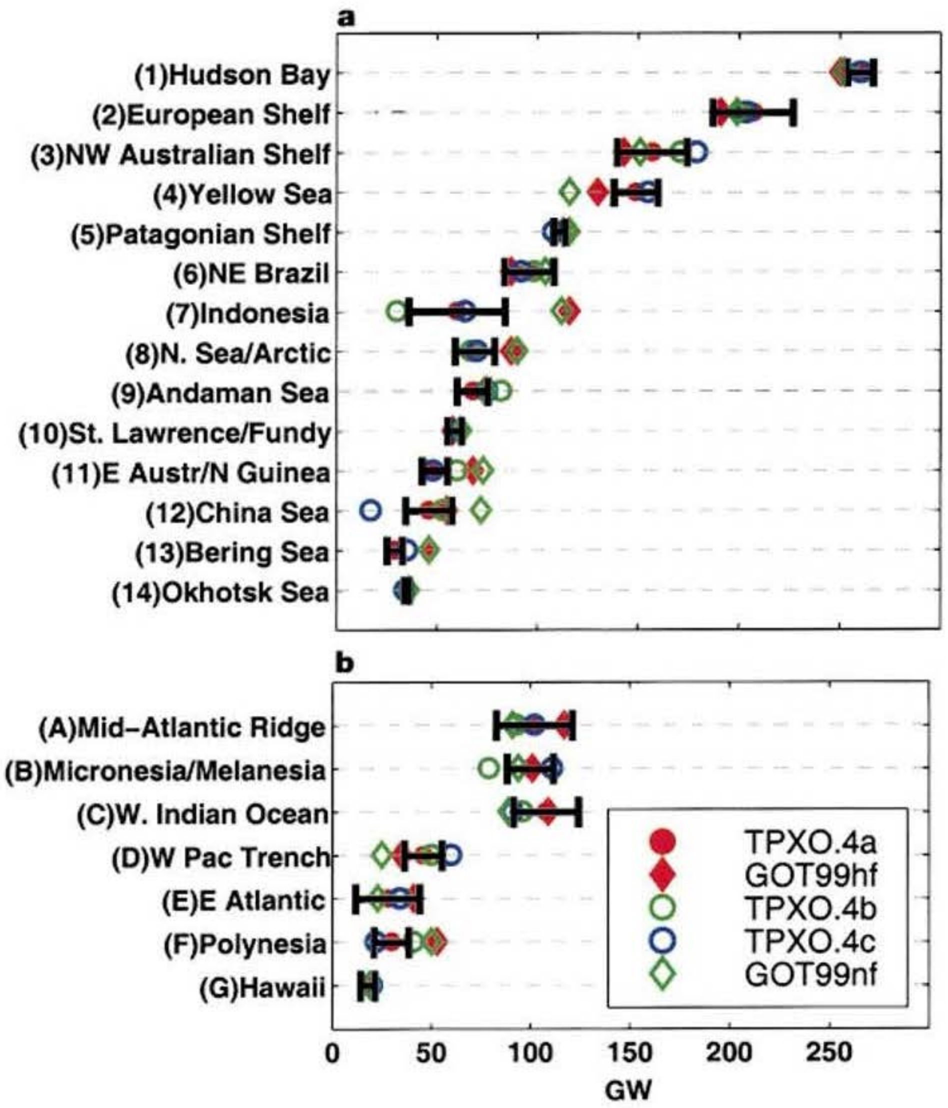
Global mesh 1 compared to TPX09 Atlas with *corrected* ADCIRC



Global mesh 2 compared to TPX09 Atlas with *corrected* ADCIRC



Regions of strong global tidal dissipation



Egbert and Ray, 2000

Evolution of coastal ocean hydrodynamic models – the present

The GOOD

- Advancing heterogeneous model integration and interleafing component interactions
- Advancing higher and more targeted resolution
- High order algorithms using Discontinuous Galerkin non-conforming algorithmic frameworks

The BAD

- Still largely static grids that are costly to generate
- Static physics
- Poor load balance on component computations
- Falling peak processor performance

Evolution of coastal ocean hydrodynamic models – the future

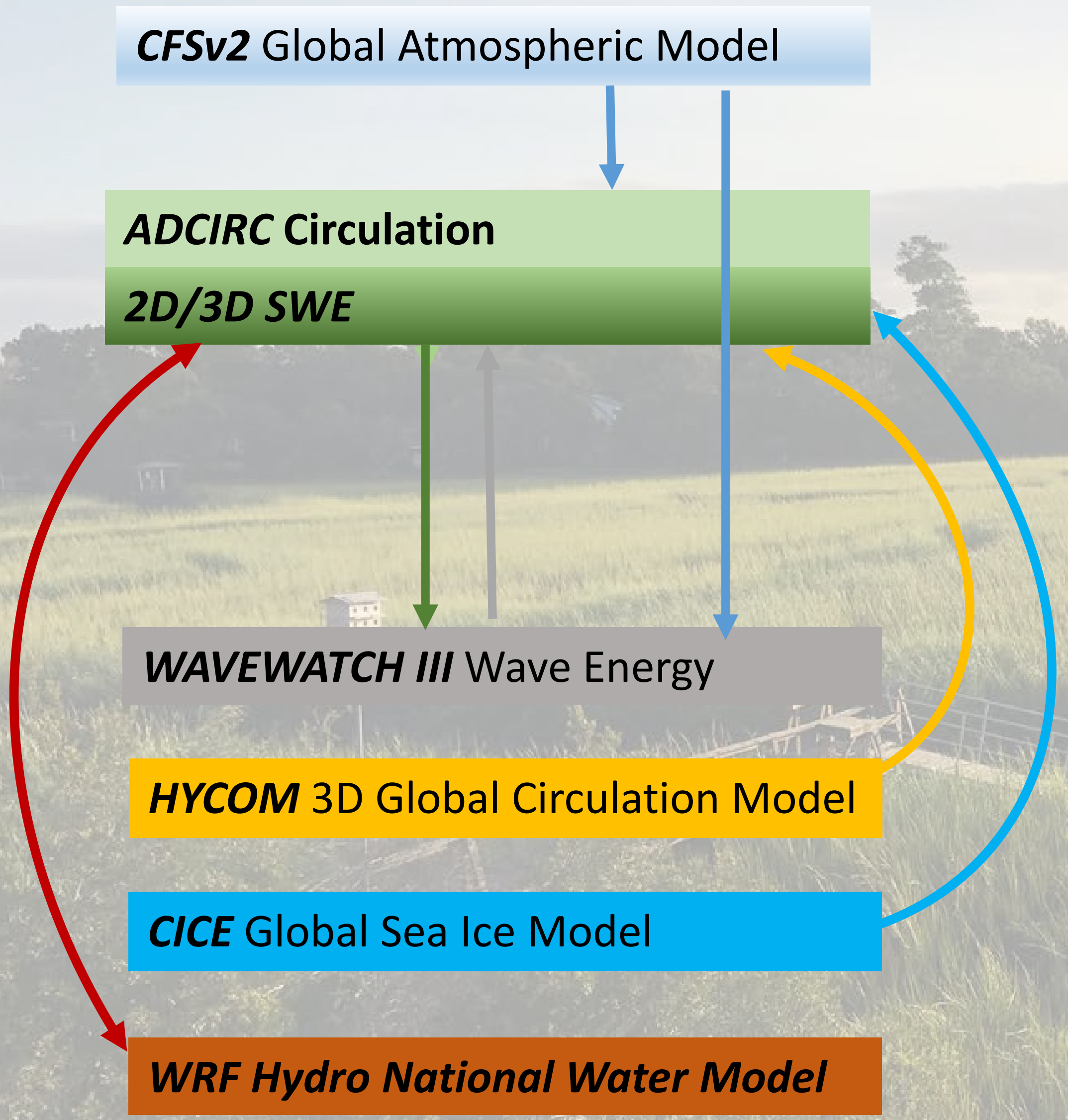
Vision

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

Focus areas

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

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*

Develop dynamic hydrodynamic equation selection frameworks

CFSv2 Global Atmospheric Model

***ADCIRC-DG* Circulation**

2D SWE
2D SWE + Pressure Poisson Solver
3D SWE
3D SWE + Pressure Poisson Solver

WAVEWATCH III Wave Energy

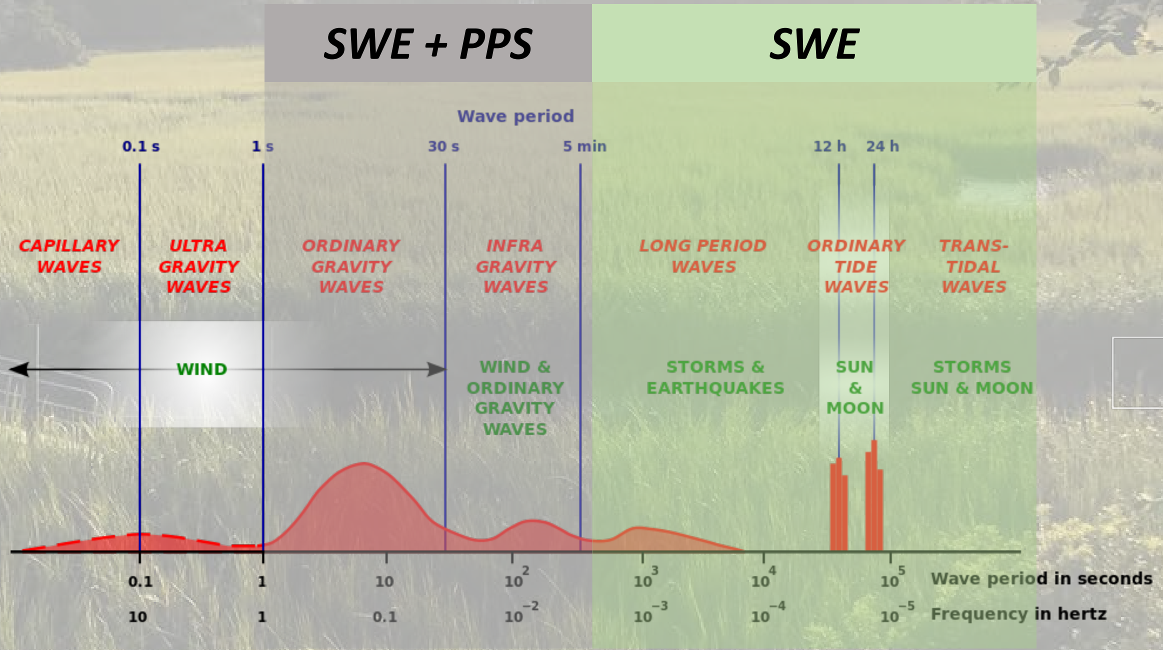
HYCOM 3D Global Circulation Model

CICE Global Sea Ice Model

WRF Hydro National Water Model

Multi-physics within a single algorithmic framework dynamically selecting physics

Dynamic equation selection within *ADCIRC-DG* to accommodate Boussinesq type solutions (in shallow water)

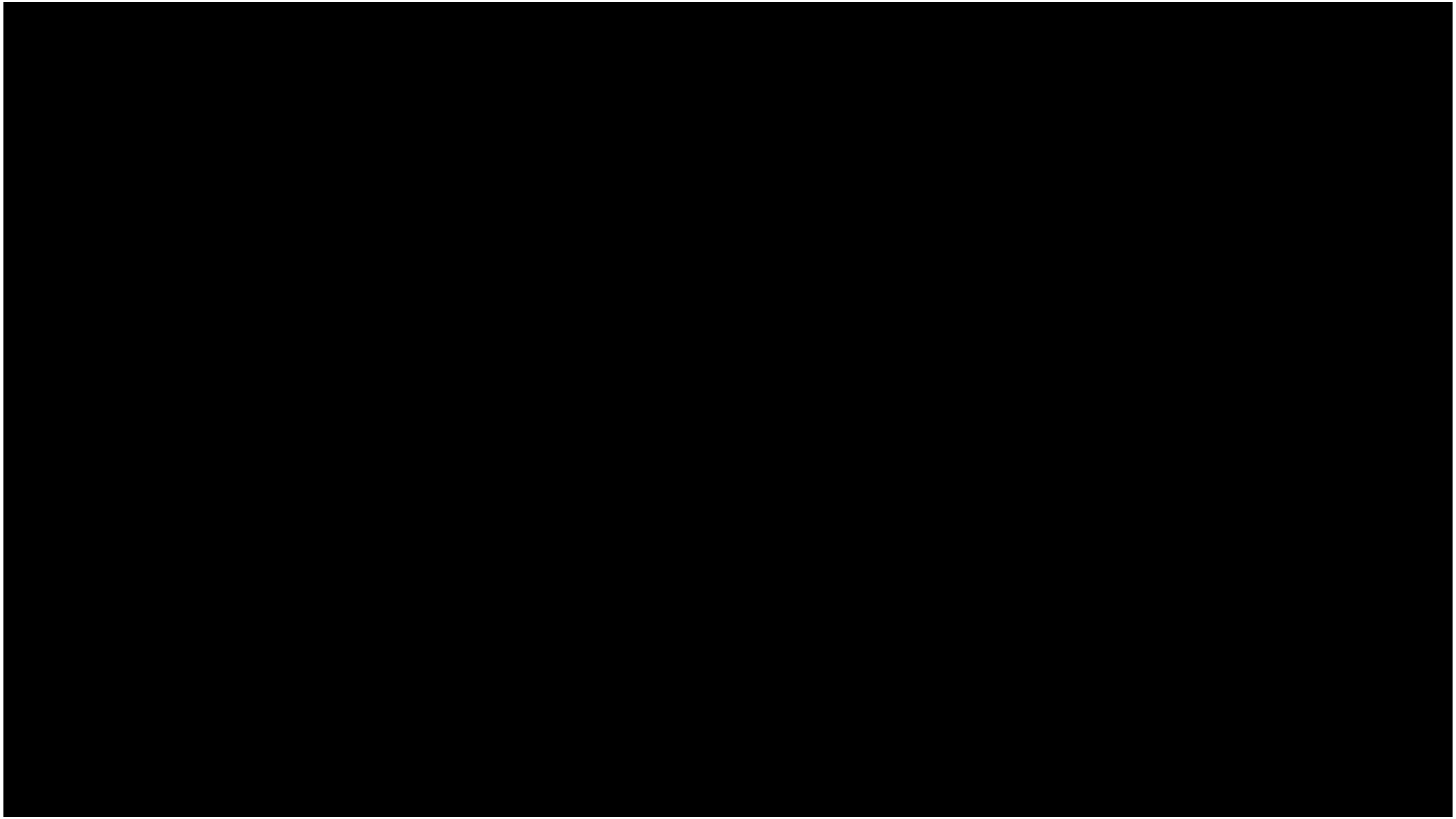


***WWIII, HYCOM, CICE* interleafing**
***WRF-Hydro* interfacing**

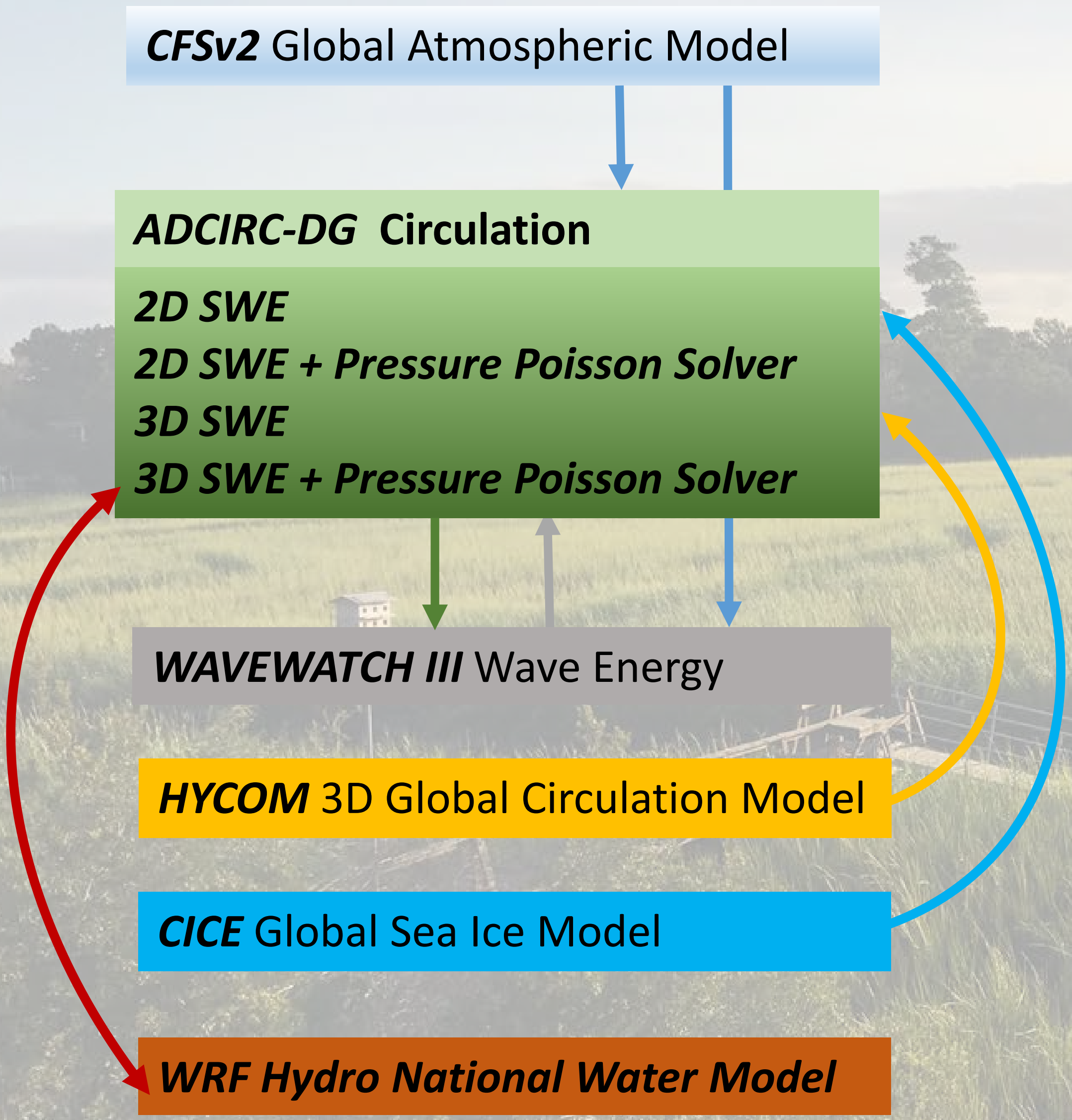
Donahue et al., *Coastal Engineering*, 114, 61-74, 2016.

The hydrodynamics of the coastal ocean and floodplain

Coastal Flooding – infragravity portion of the spectrum

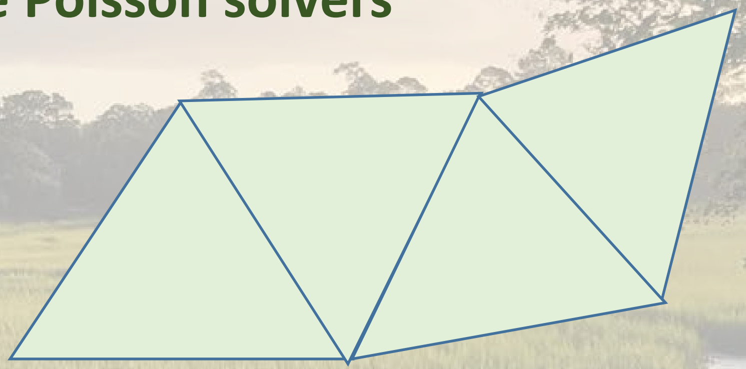


Develop dynamic hydrodynamic equation selection frameworks

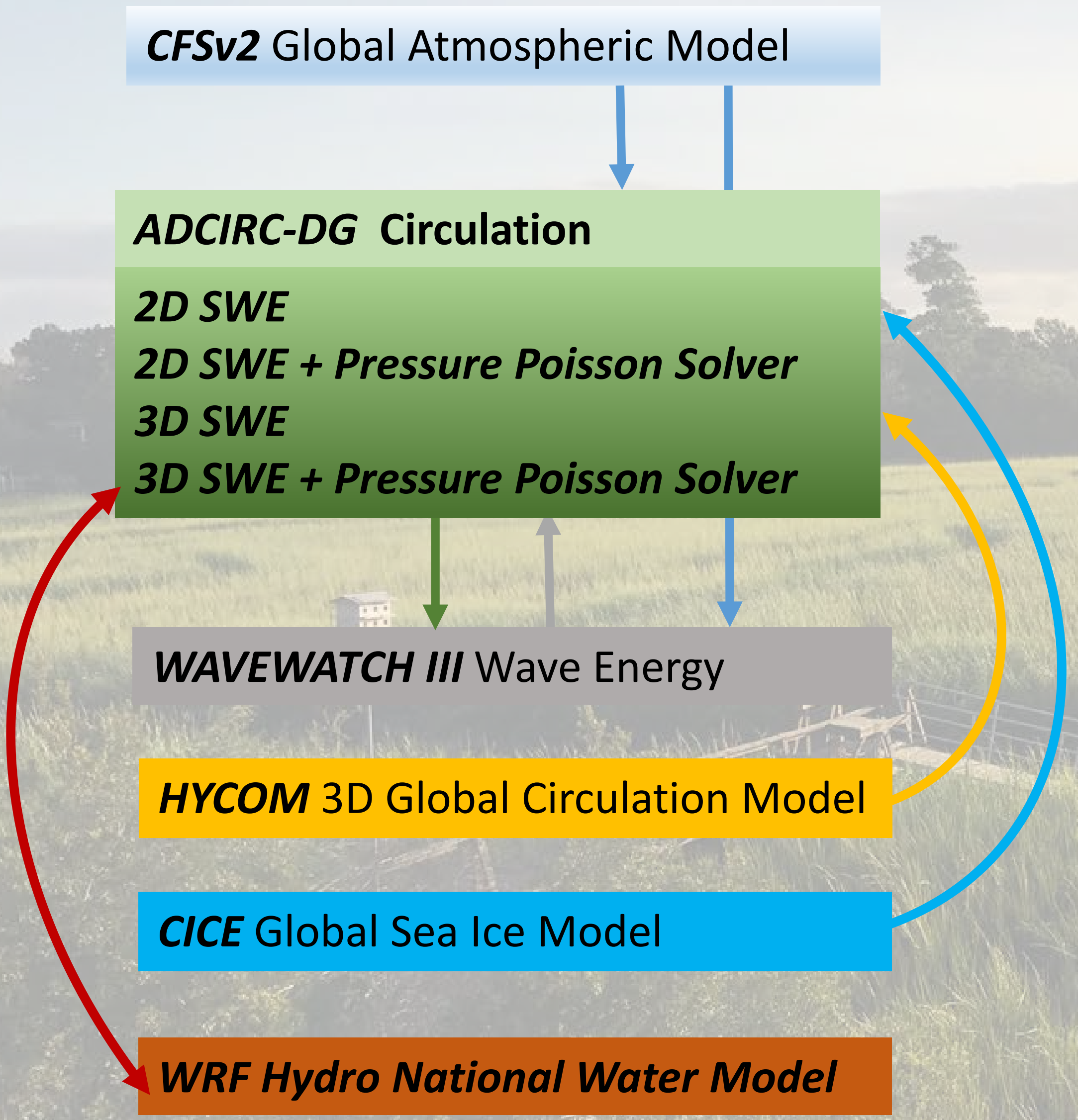


Multi-physics within a single algorithmic framework dynamically selecting physics

Pressure Poisson solvers

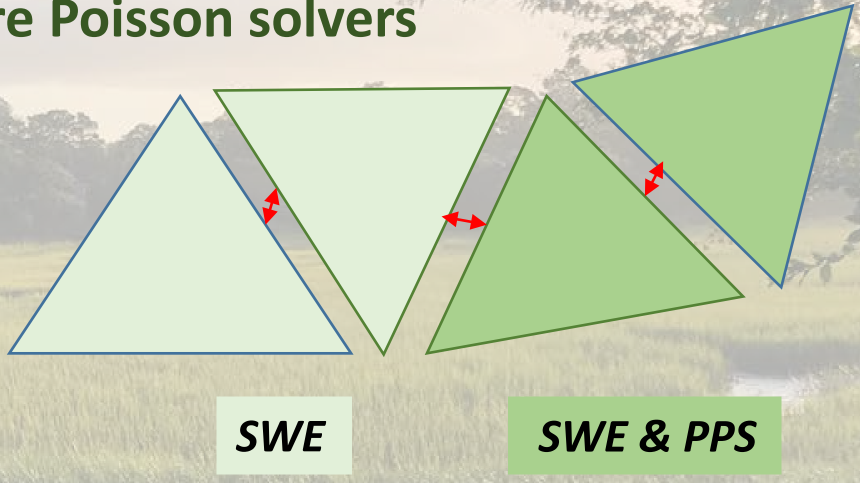


Develop dynamic hydrodynamic equation selection frameworks



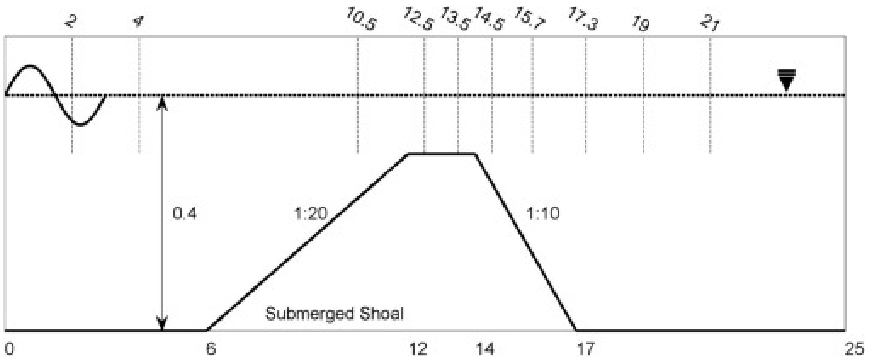
Multi-physics within a single algorithmic framework dynamically selecting physics

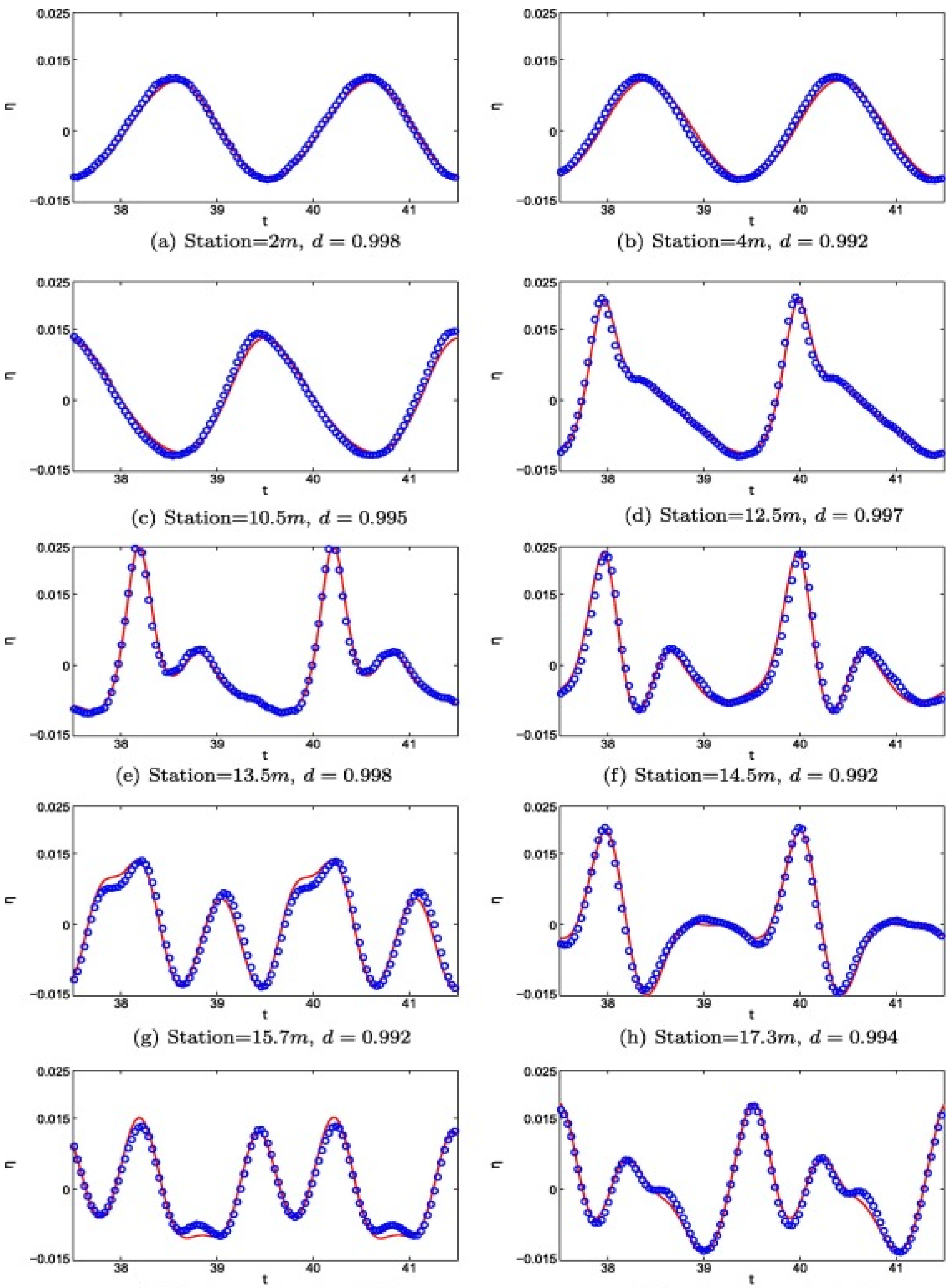
Pressure Poisson solvers



Pressure-Poisson based simulations

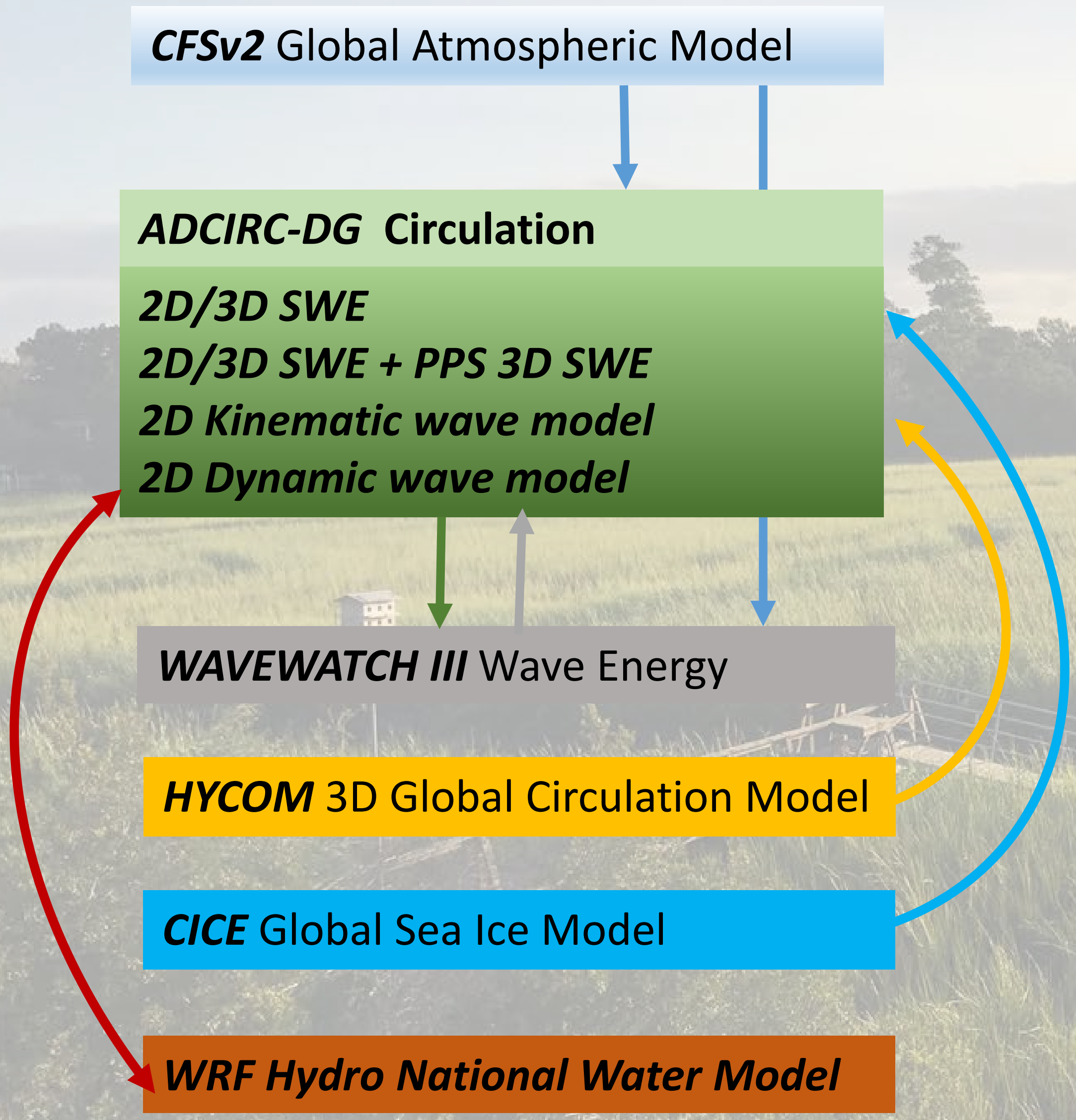
- **Can simulate highly nonlinear waves approaching the coastline, and through to the shoreline**
  - Only in finite depths
- **Different levels of model can provide different levels of accuracy, with corresponding cost increases**
- **Remaining hurdles are largely implementational rather than theoretical**
  - Coding and testing for operational-type problems have not yet been implemented





(a) Station=2m, $d = 0.998$
(b) Station=4m, $d = 0.992$
(c) Station=10.5m, $d = 0.995$
(d) Station=12.5m, $d = 0.997$
(e) Station=13.5m, $d = 0.998$
(f) Station=14.5m, $d = 0.992$
(g) Station=15.7m, $d = 0.992$
(h) Station=17.3m, $d = 0.994$
(i) Station=19m, $d = 0.995$
(j) Station=21m, $d = 0.997$

Develop dynamic hydrodynamic equation selection frameworks

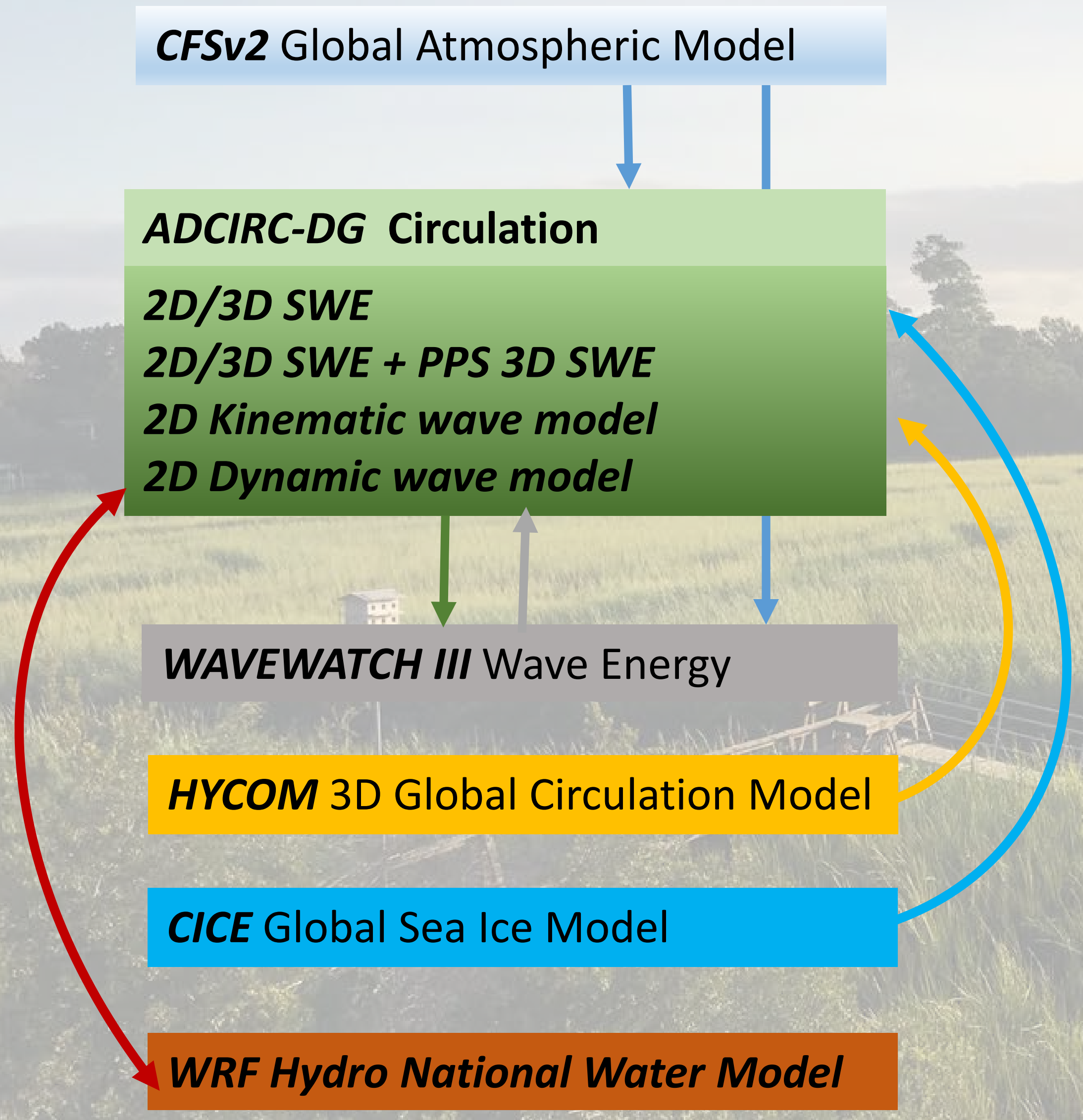


Multi-physics within a single algorithmic framework dynamically selecting physics

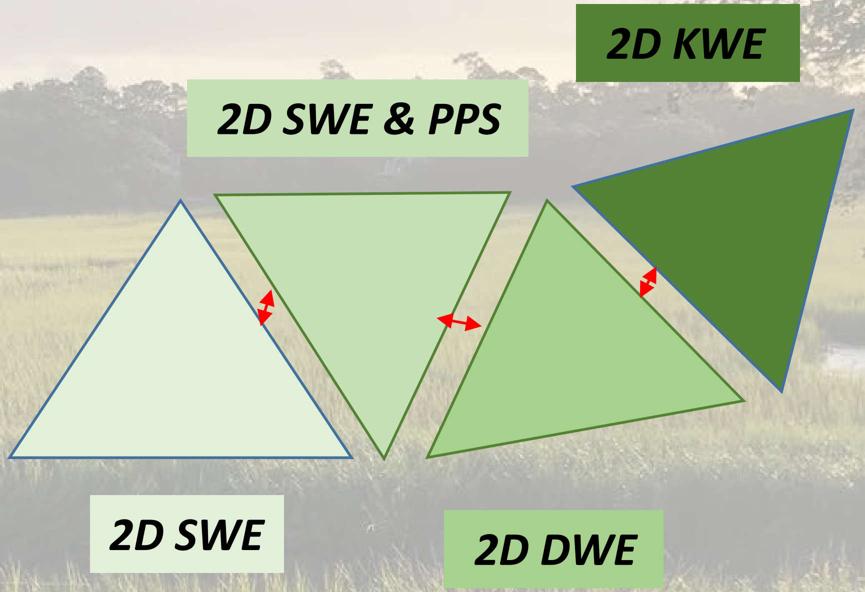
Dynamic equation selection within ADCIRC-DG to accommodate Boussinesq type solutions as well as the Kinematic and Dynamic Wave Equations solution

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

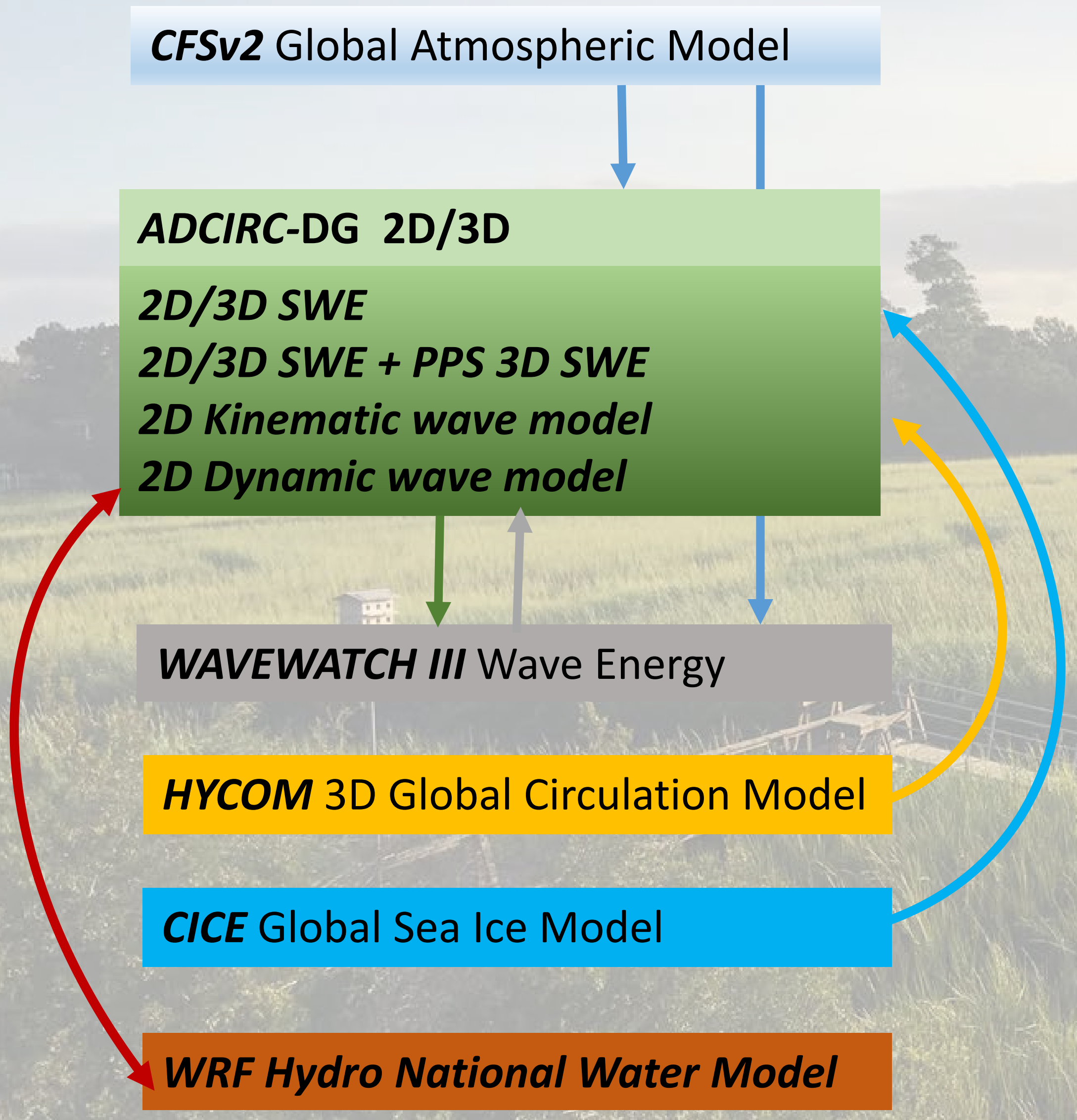
Develop dynamic hydrodynamic equation selection frameworks



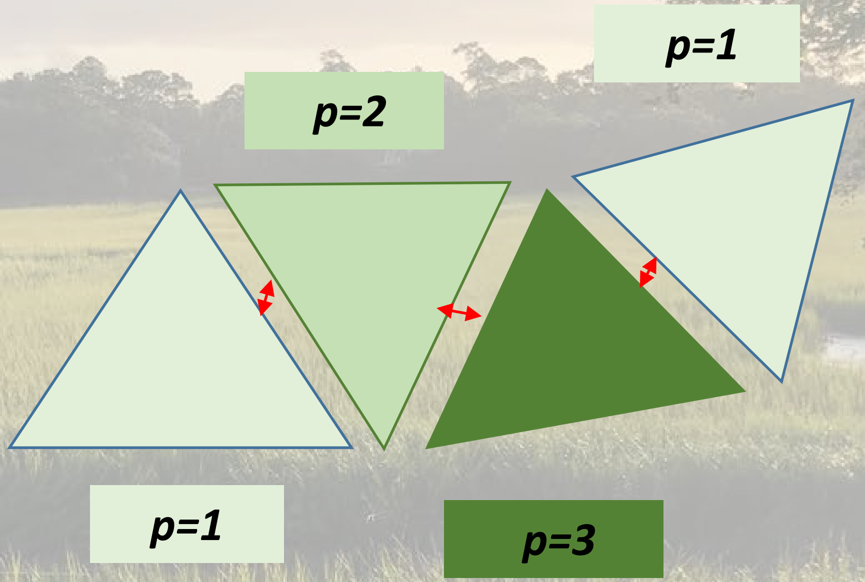
Multi-physics within a single algorithmic framework dynamically selecting physics



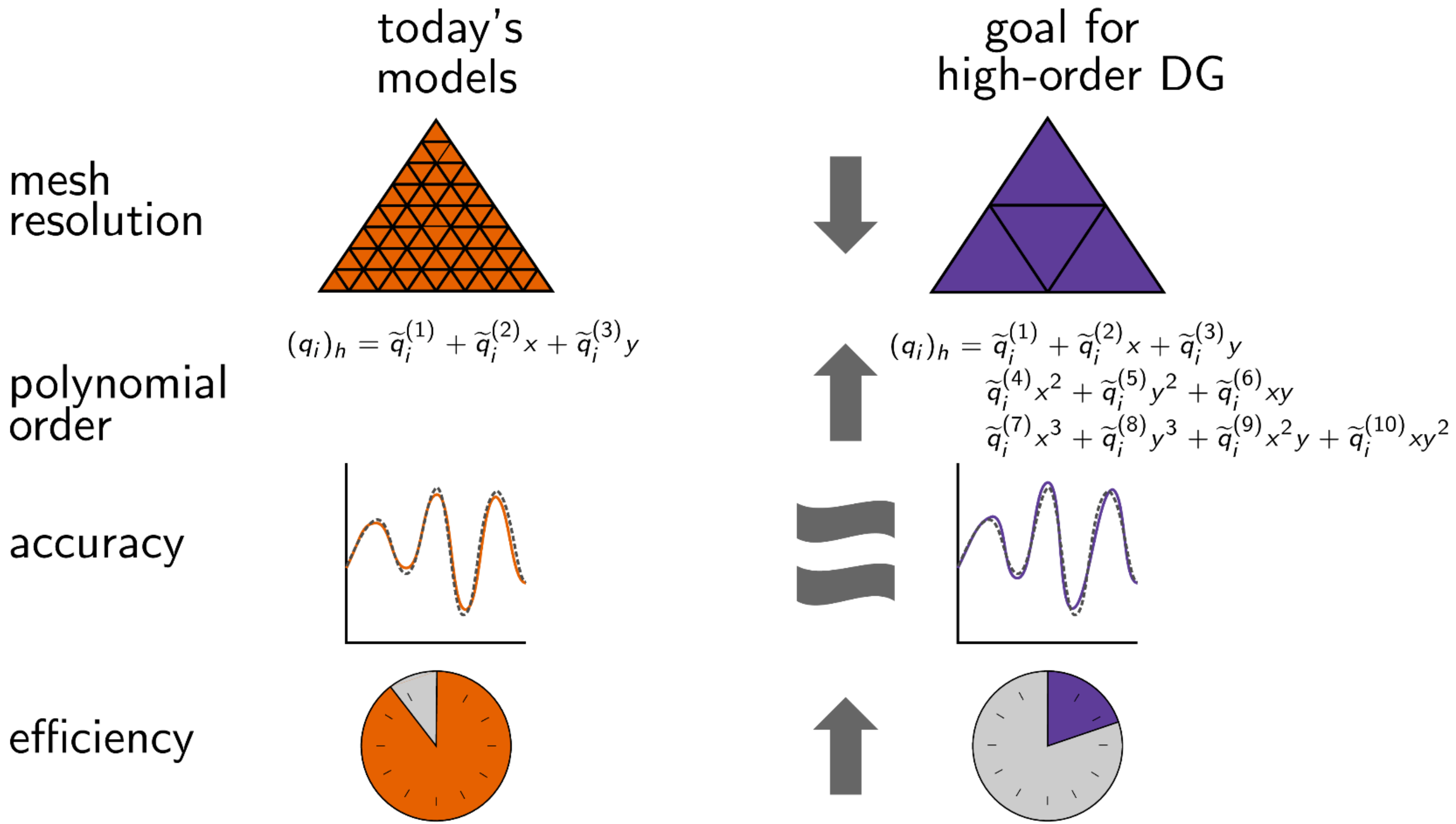
Develop dynamic high order interpolation (*p*-adaptive) frameworks



Dynamic selection of interpolant order
p adaptation

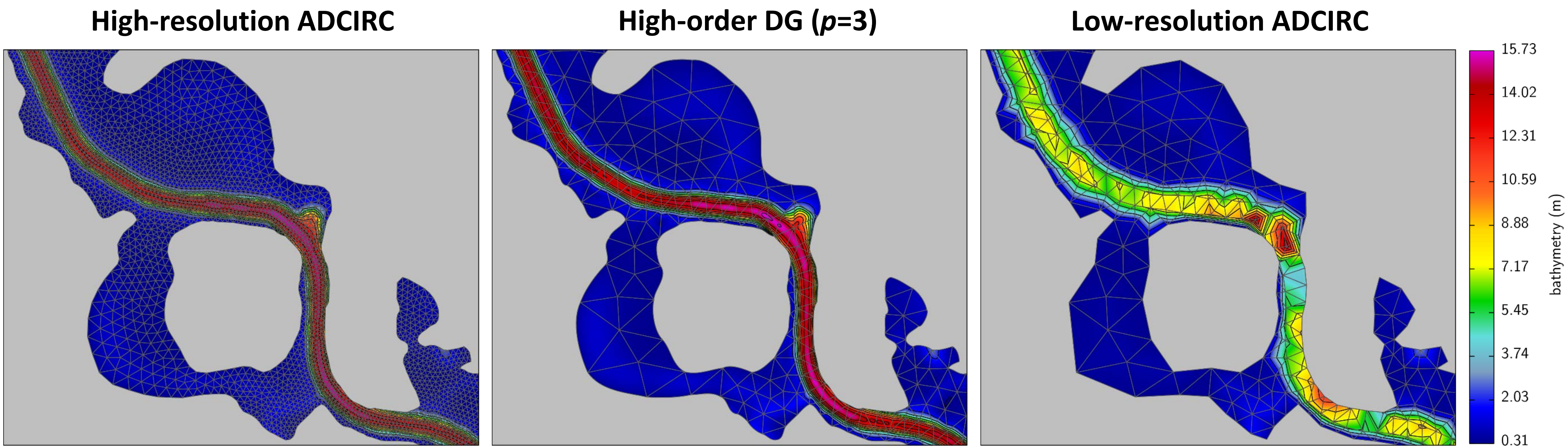


High order interpolants



High order interpolants

- **Discontinuous Galerkin (DG) allows for non-conforming h-p dynamic adaptation**

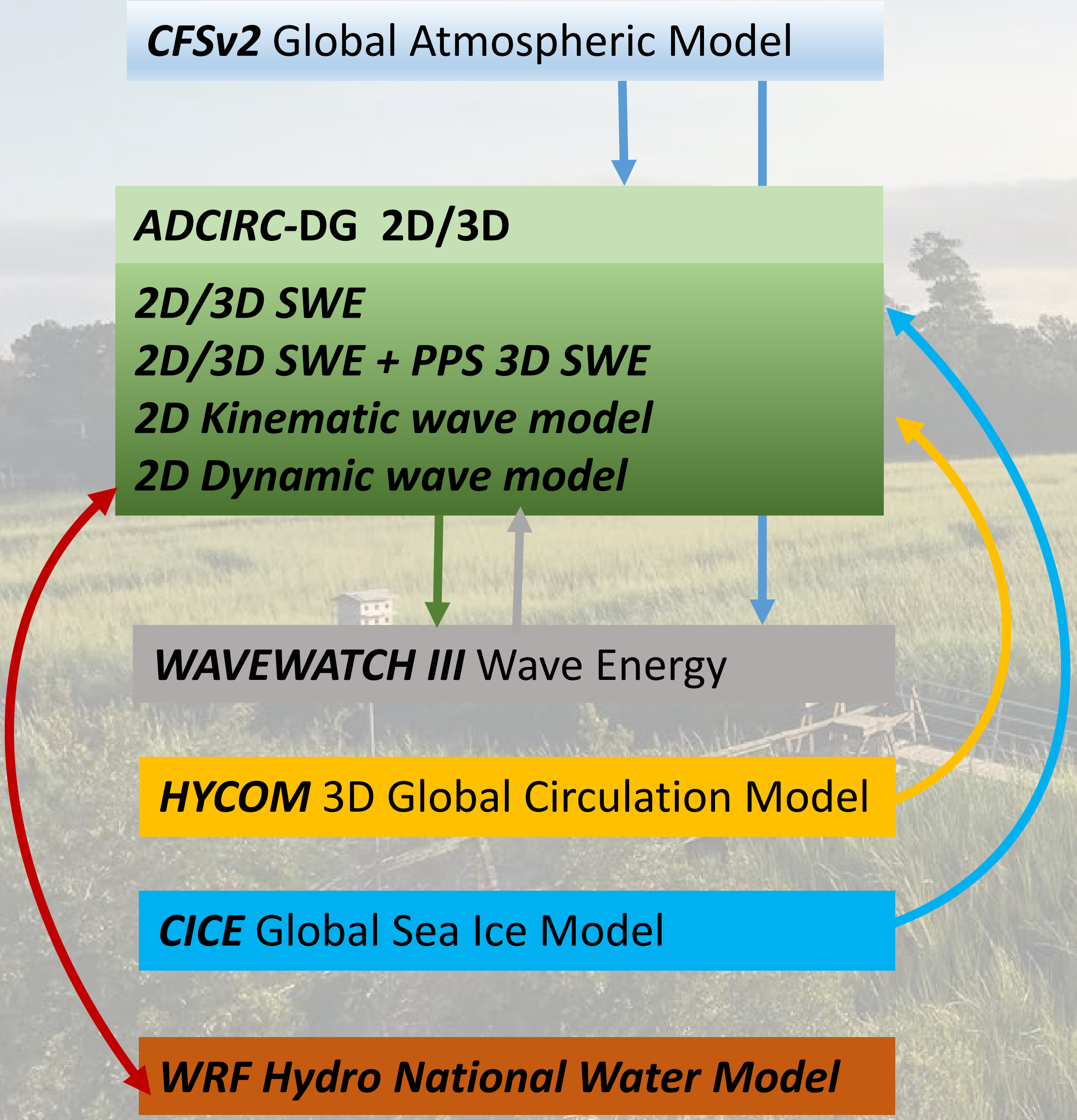


Runs 4 x faster

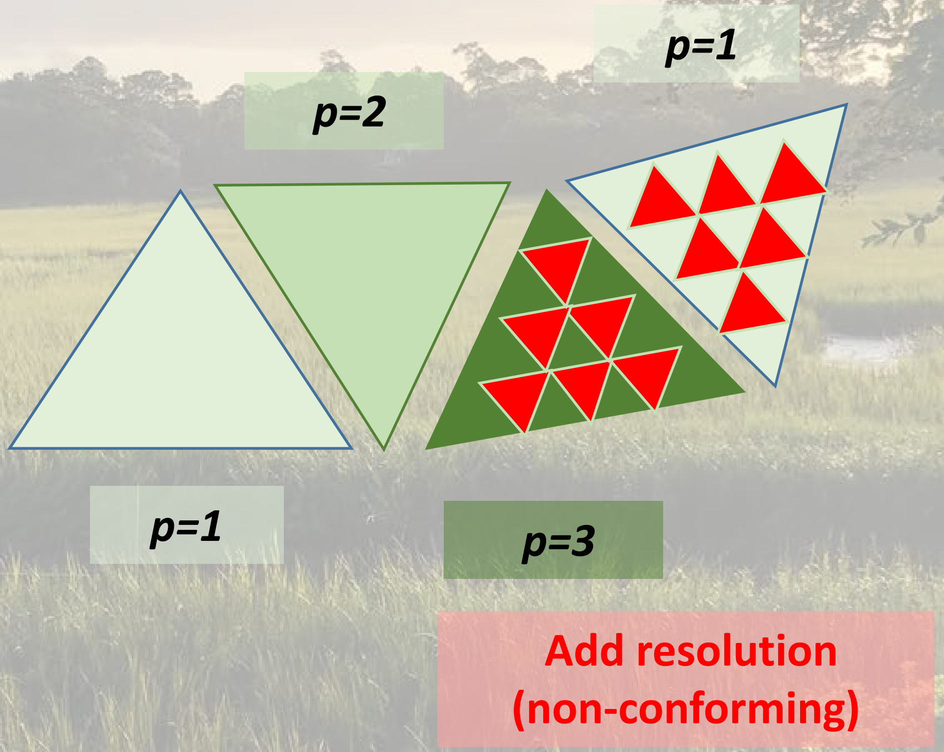
Poor solutions

Wirasaet et al., ***Journal of Computational Physics, 299,***, 579-612, 2015.
Brus et al.., ***Journal of Scientific Computing***, **70**, 210-242, 2017.

Develop adaptive gridding (*h*-adaptive) frameworks

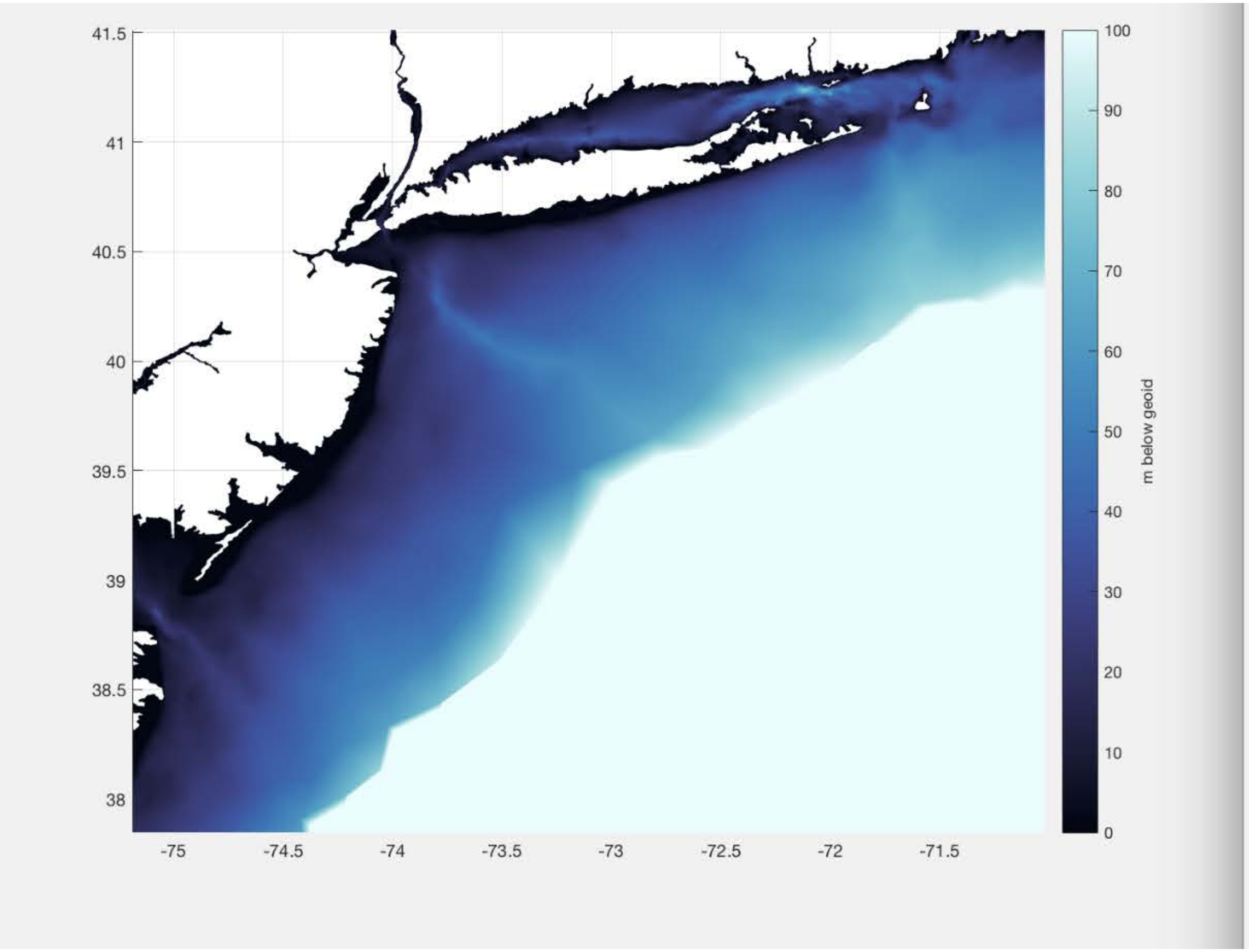


Dynamic selection of grid resolution
h adaptation

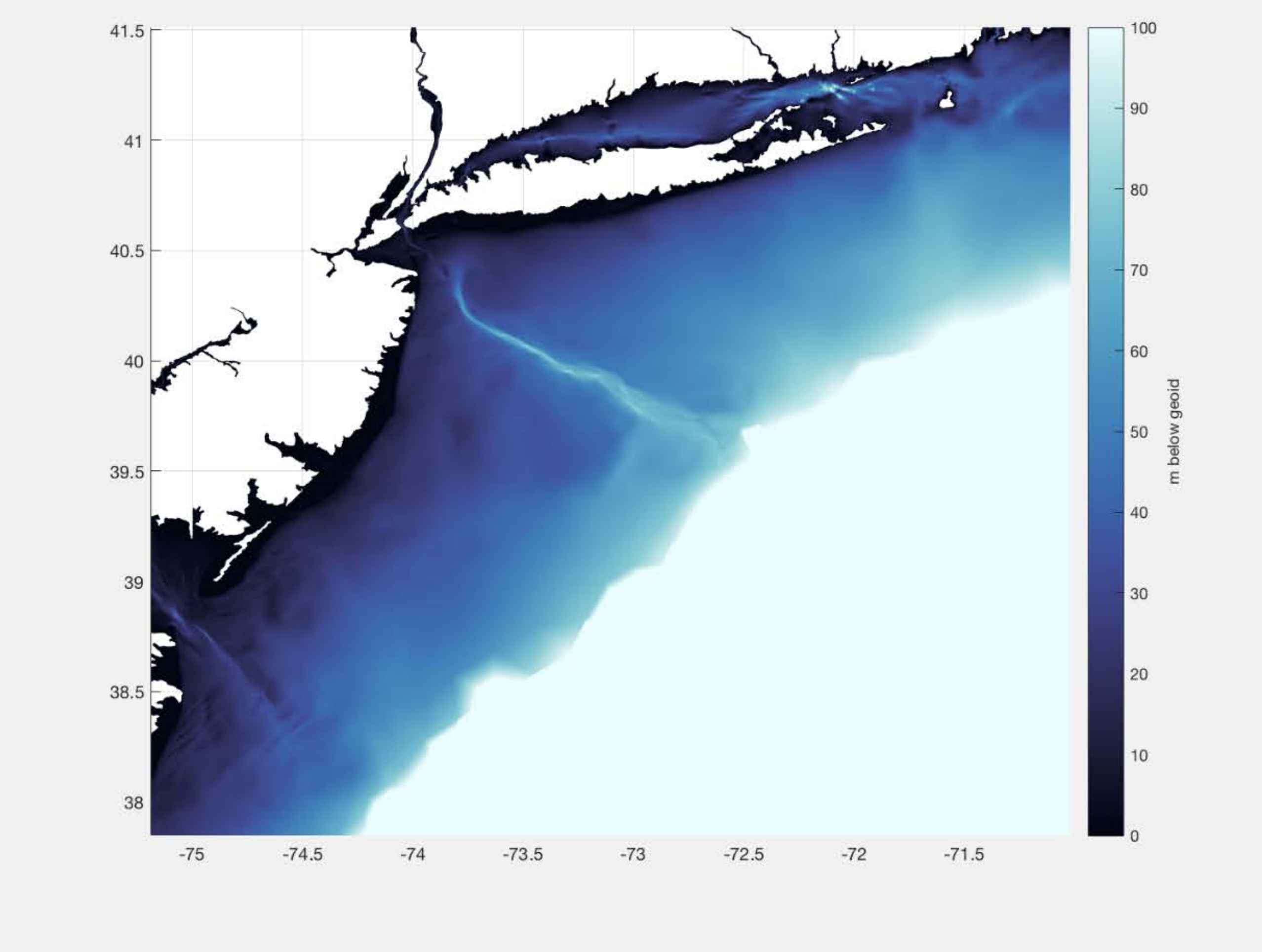


Dynamic grid optimization for evolving physics

Lower energy tides

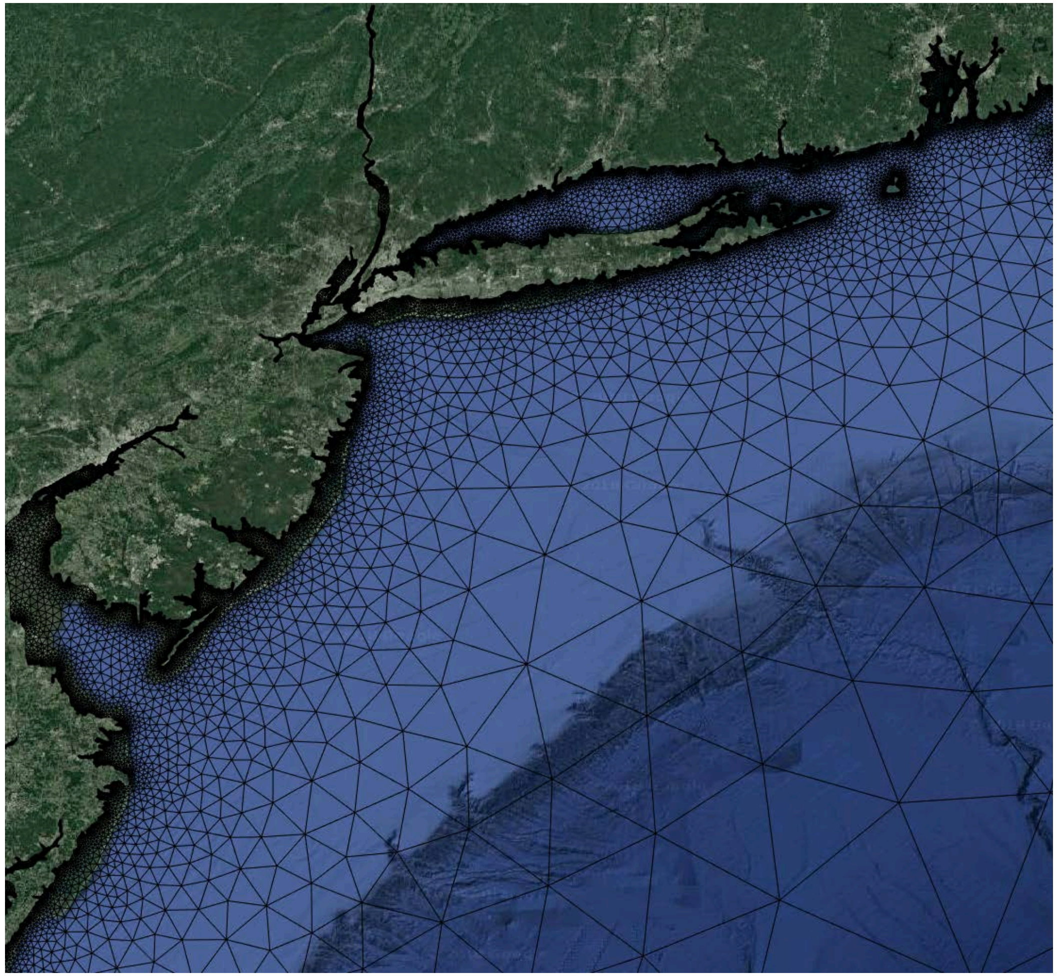


High energy storm driven circulation

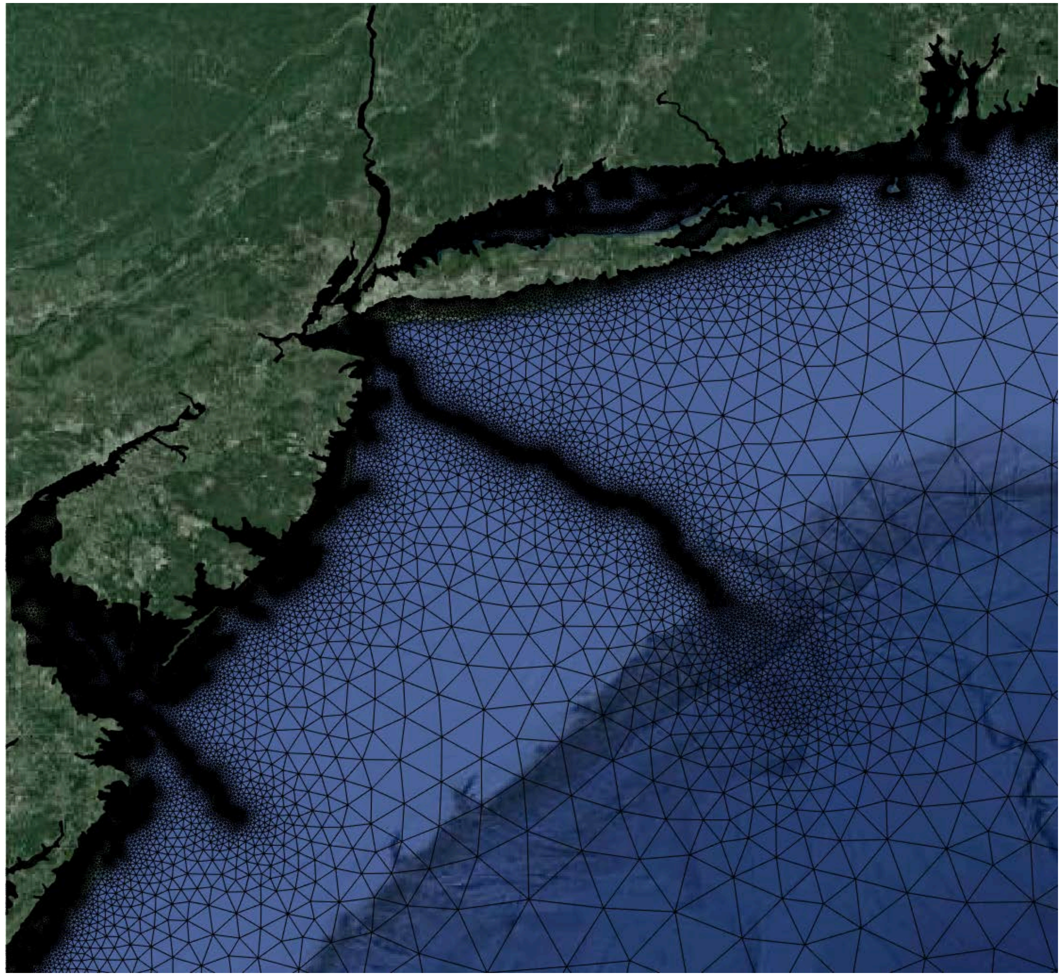


Dynamic grid optimization for evolving physics

Lower energy tides



High energy storm driven circulation

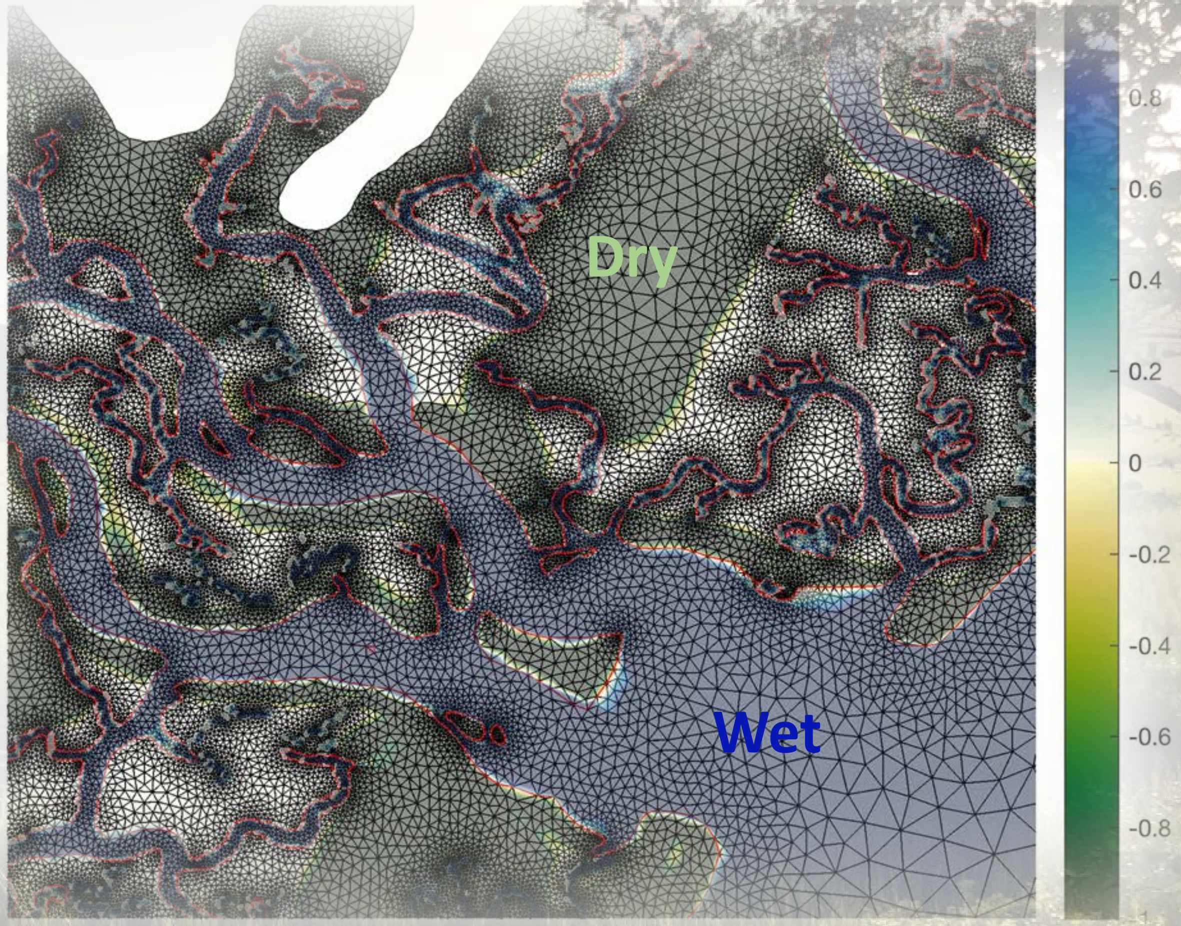


Dynamic load balancing

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

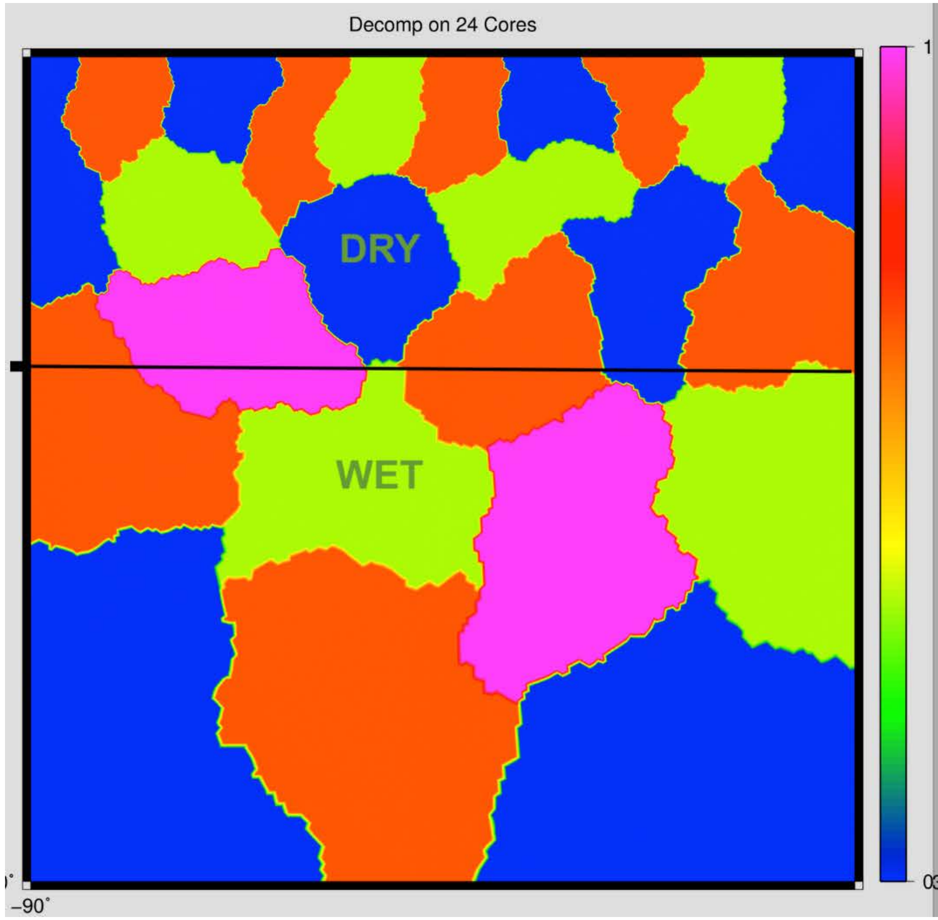
Dynamic rebalancing of the sub-domain loads will reduce total wall clock time

MPI/Zoltan
HPX

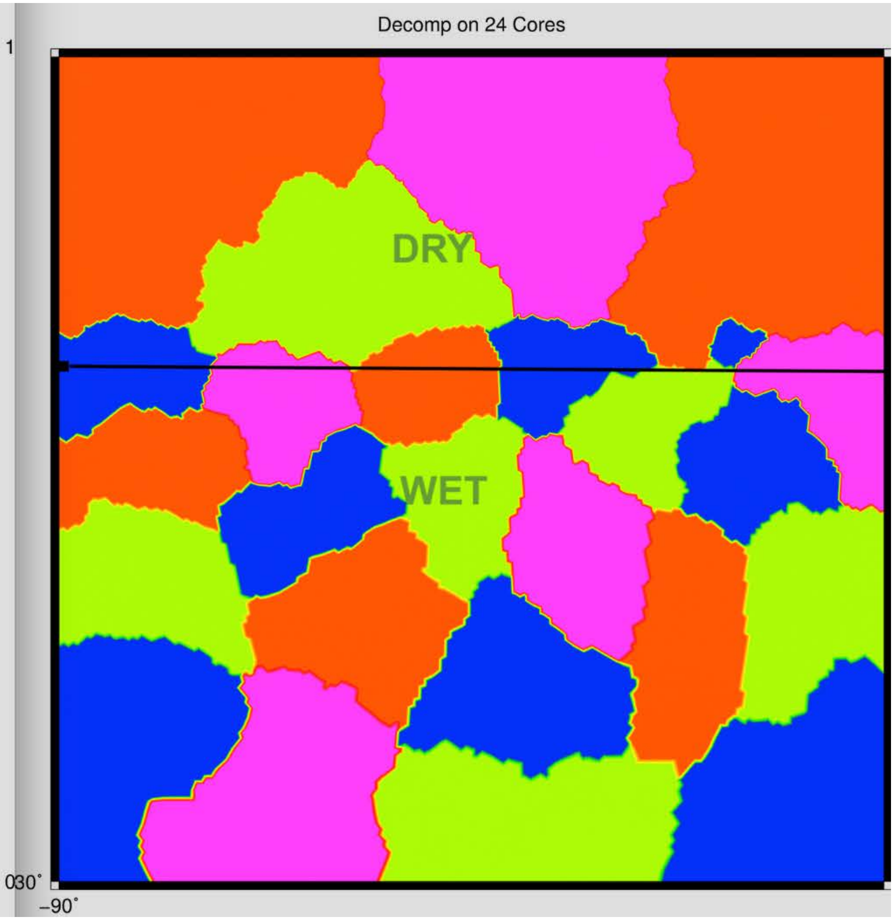


Dynamic load balancing: MPI/Zoltan

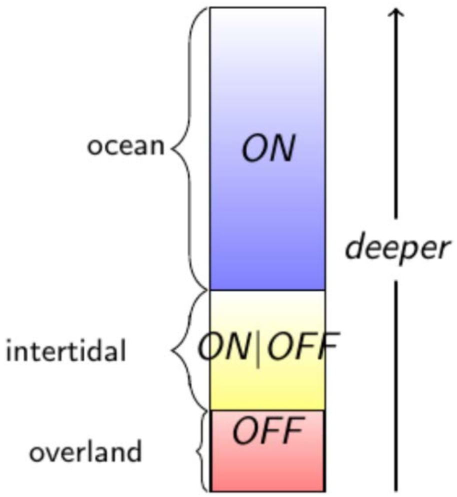
Equal node distribution

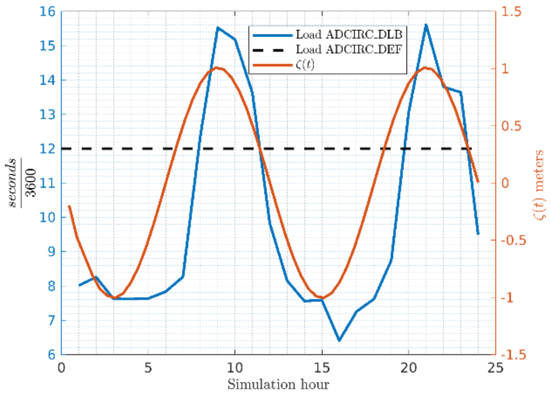


Weighted node distribution



Nodal data structure

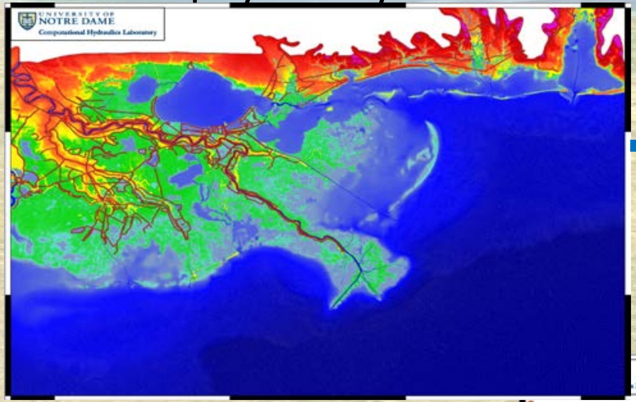




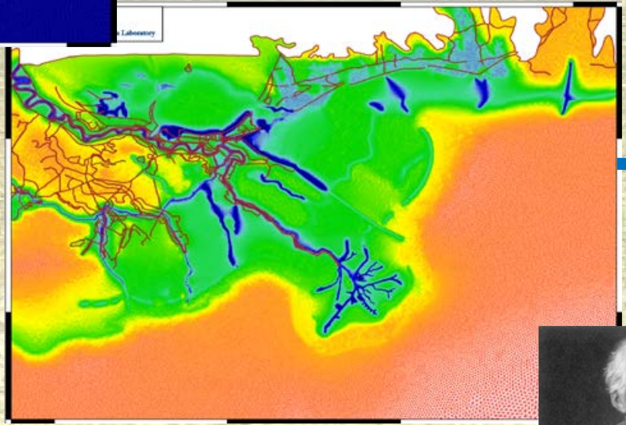
Dynamically redistributing dry elements improves parallel efficiency 45% for 50% average dry nodes

Evolution of coastal ocean hydrodynamic models – the past

Geophysical systems

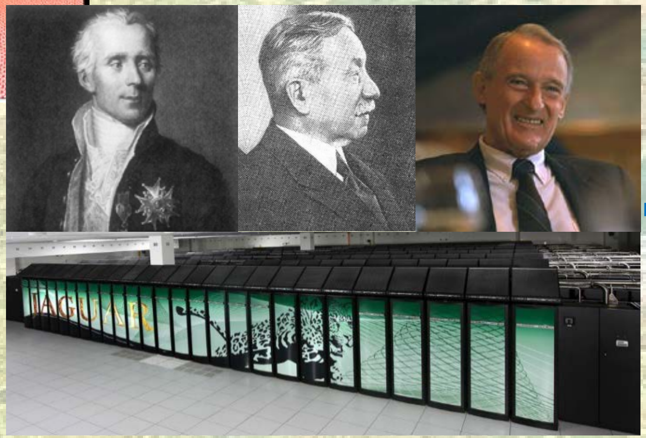


Unstructured grids

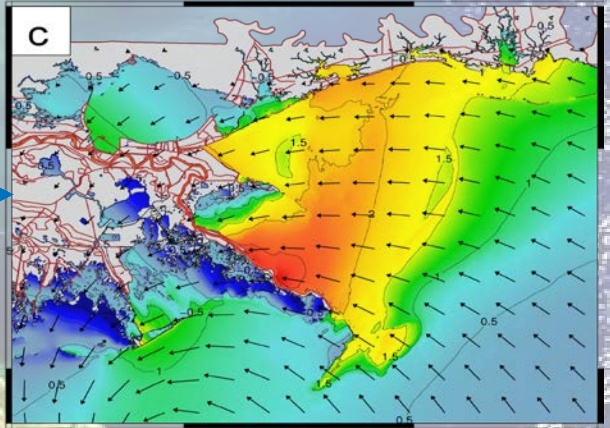


Physics & forcing functions
Model interfacing and interleafing

Pde's + FEM + HPC

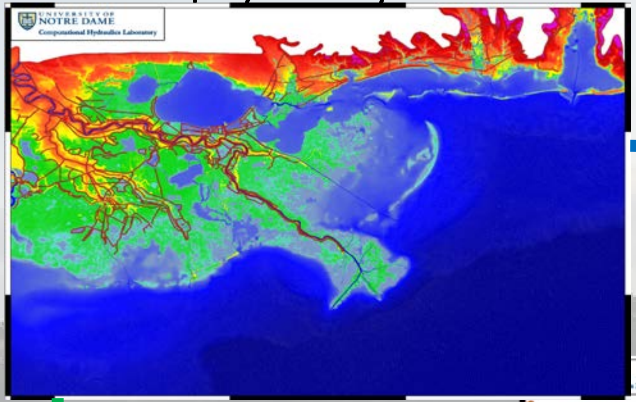


Ocean Responses

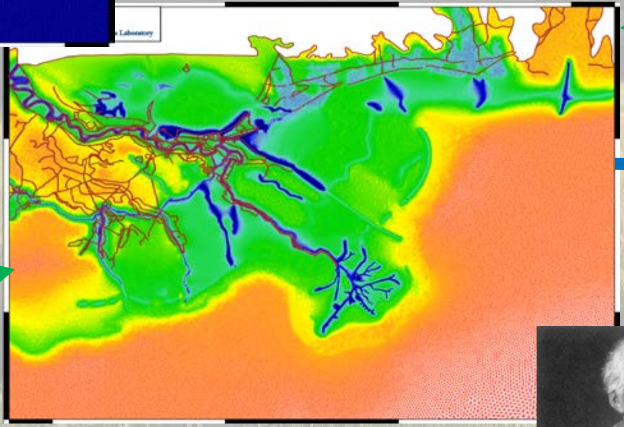


Evolution of coastal ocean hydrodynamic models – the future

Geophysical systems

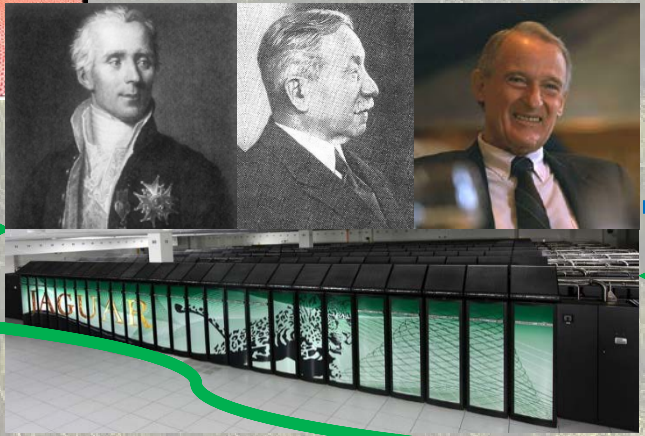


Unstructured grids

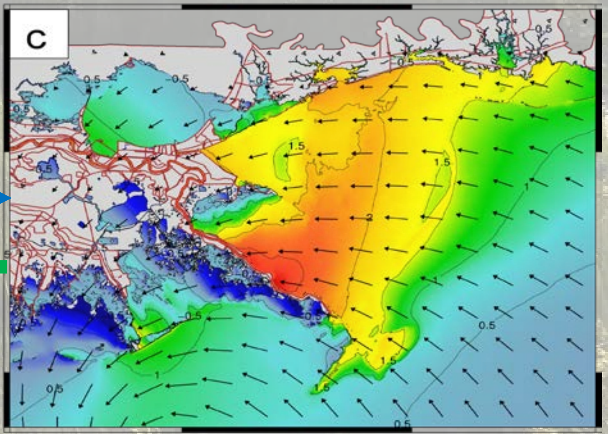


Physics & forcing functions
Model interfacing and interleafing

Pde's + FEM + HPC



Ocean Responses



Dynamic
grids/domains
HPX & MPI-Zoltan