On-Demand Hurricane Storm Surge Modeling Using the UFS Coastal Modeling Framework CoastalApp: A Case Study for Hurricane Florence (2018)

NOS Storm Surge Modeling Team

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Emerging Applications - Coastal, Space Weather, Hydrology

Unifying Innovations in Forecasting Capabilities Workshop

July 18-22, 2022. College Park, MD / Virtual.

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All model configurations and results are pre-decisional and for official use only.

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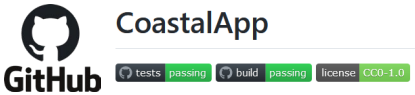
CoastalApp (Coastal Application)



https://github.com/noaa-ocs-modeling/CoastalApp

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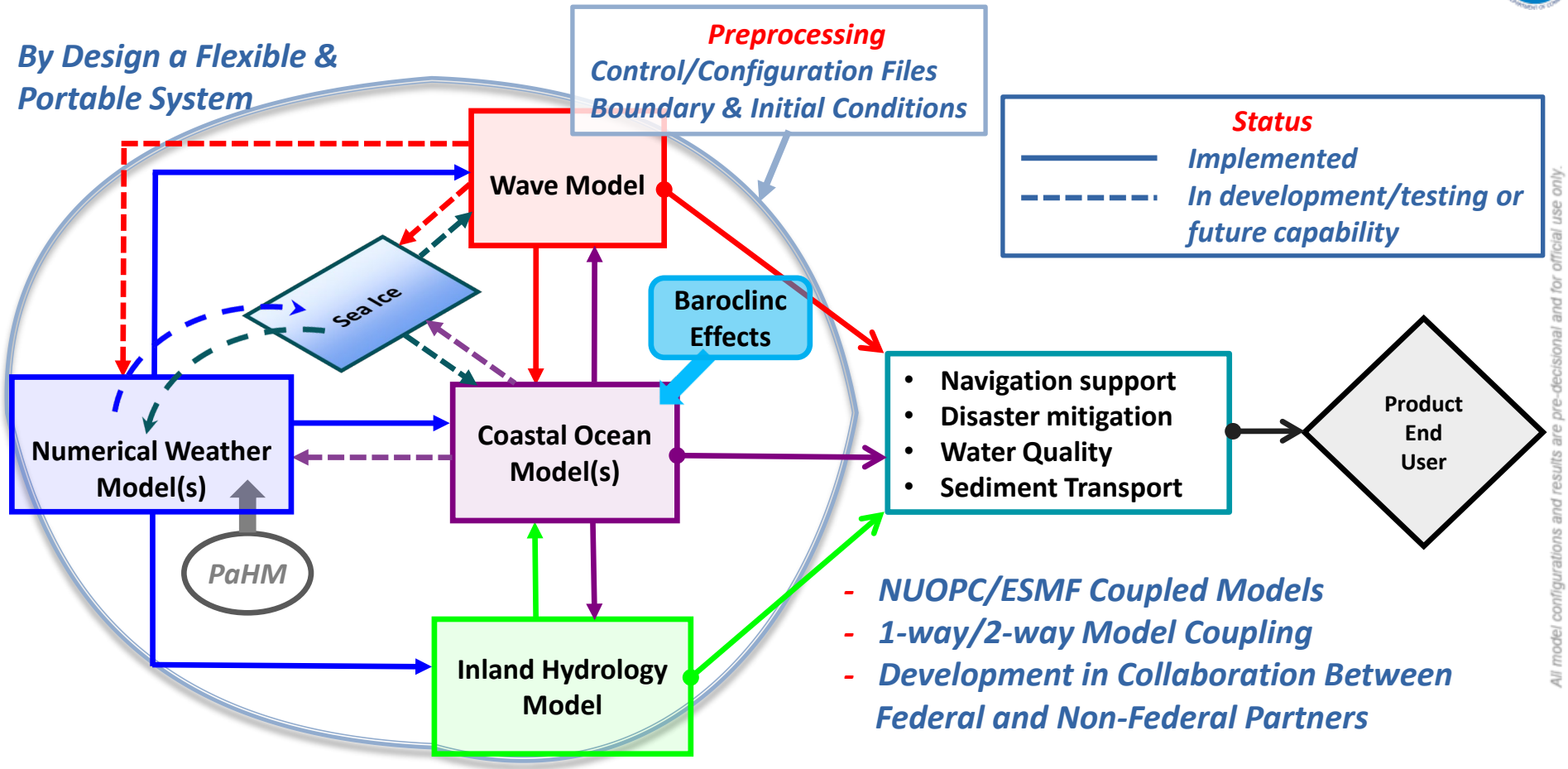
System Workflow

By Design a Flexible & Portable System



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Modeling and Data Components

The components highlighted in dark red are considered tested and fully functional

Atmosphere	Ocean	Wave
ATMESH[1] *(implemented)*	**ADCIRC**[2] *(implemented)*	**WW3DATA**[1] *(implemented)*
PaHM[1] *(implemented)*	**SCHISM**[4,5] *(in development)*	**WW3**[3] *(implemented)*
HWRFcap[1] *(in development)*	**FVCOM**[6] *(in development)*	
HWRF *(future capability)*	**BARDATA**[1] *(implemented)*	
WRF *(future capability)*	**CICE**[7] *(in development)*	
NWM[8] *(in development)*		

1 *NOAA/CSDL/CMMB*
2 *U. of Notre Dame*
3 *NOAA/NCEP/EMC*
4 *Virginia Institute of Marine Science*
5 *Helmholtz-Zentrum Hereon*
6 *University of Massachusetts – Dartmouth*
7 *Cooperative Institute for Great Lakes Research*
8 *NOAA/NWS National Water Center*

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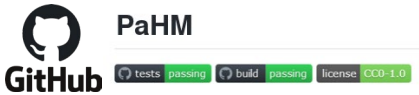
Parametric Hurricane Modeling System (*PaHM*)



https://github.com/noaa-ocs-modeling/PaHM
https://noaa-ocs-modeling.github.io/PaHM/html/index.html

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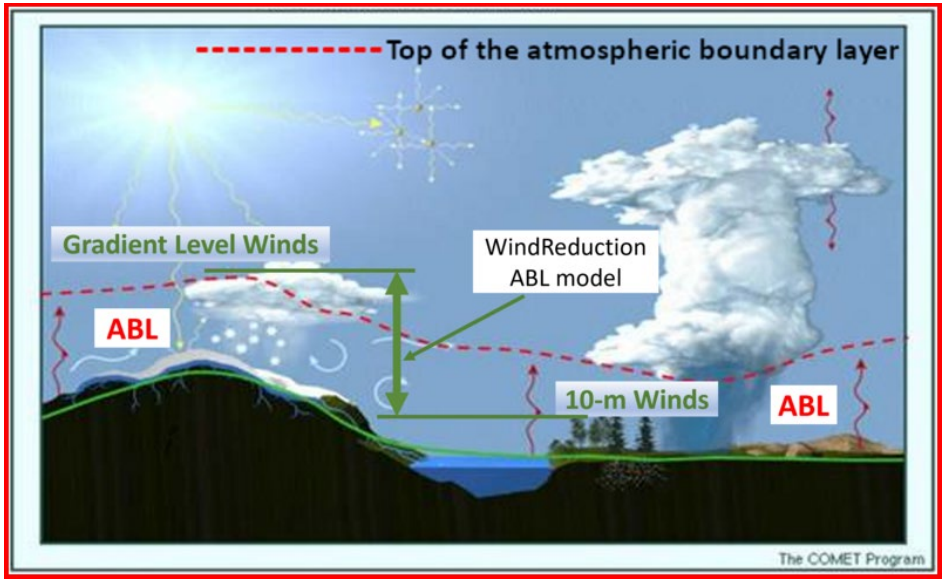
Introduction

- *PaHM is an atmospheric modeling system consisting of multiple parametric tropical cyclone (TC) models that can be activated during run time to generate the required atmospheric wind fields*
  - It can be used as a standalone modeling system or as a coupled modeling component within a NUOPC coupled system



- **Inputs:**
  - "storm track" file(s) and a "grid/mesh" file
- **Procedure:**
  - Converts the "best track" 10-m wind values to gradient wind values.
  - Applies parametric models to generate the wind fields at the gradient level.
  - Converts the gradient wind fields to 10-m winds.
  - Writes the data to a NetCDF-4 file

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Modeling Components: Generalized Asymmetric Holland Model (GAHM)

Governing equation:

$$V_g^2 + frV_g - \frac{r}{\rho}\frac{\partial p}{\partial r} = 0 \qquad (1)$$

Assume hyperbolic pressure profile

$$P(r) = P_c + (P_n - P_c)e^{-A/r^B} \qquad (2)$$

Substitute (2) into (1) and get:

$$V_{g(r)} = \sqrt{AB(P_n - P_c)e^{-A/r^B}/\rho r^B + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right) \qquad (3)$$

Assume at $r = R_{max}$:

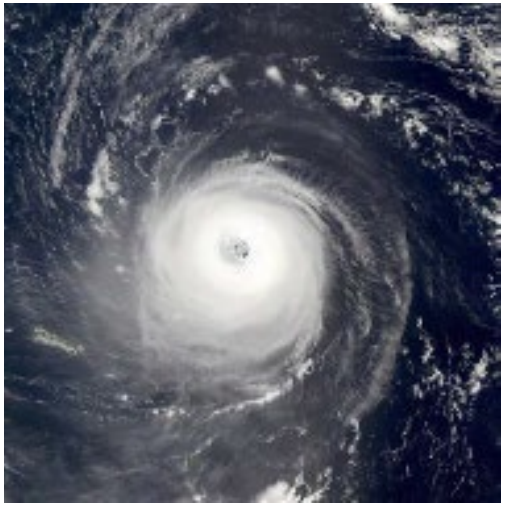
$$V_g = V_{max} \quad dV_g/dr = 0 \qquad (4)$$

with:

$$A = \varphi R_{max}^B \qquad B = V_{max}^2 \rho e/(P_n - P_c) \qquad (5)$$

$$B_g = B(1 + 1/R_o)^{e^{-\varphi}/\varphi} \qquad (6)$$

$$\varphi = 1 + \frac{1/R_o}{B_g(1 + 1/R_o)} \qquad (7)$$



Generalized Asymmetric Holland Model

$$P(r) = P_c + (P_n - P_c)e^{-\varphi(R_{max}/r)^{B_g}} \qquad (8)$$

$$V_g(r) = \sqrt{V_{max}^2(1 + 1/Ro)e^{\varphi(1-(R_{max}/r)^{B_g})}(R_{max}/r)^{B_g} + \left(\frac{rf}{2}\right)^2} - \left(\frac{rf}{2}\right) \qquad (9)$$

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NUOPC Cap

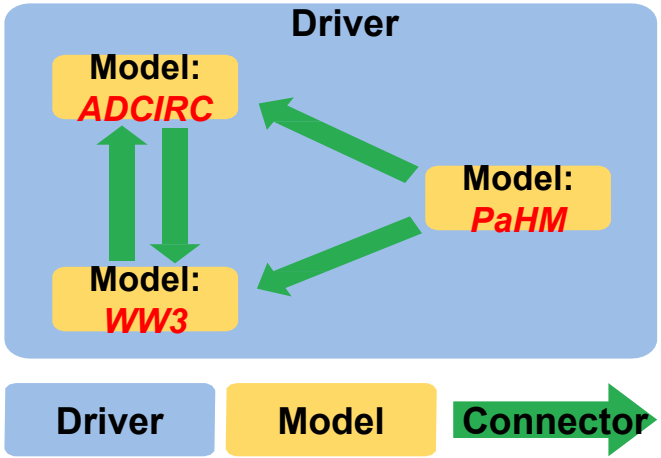
A NUOPC Cap is a Fortran module that is used to interface to a model in a NUOPC based coupled system

The "Cap" comprises from NUOPC subroutines that are called during the initialization (Init Phase), run (Run Phase), or finalize part (Finalize Phase) of the coupled system run

National Unified Operational Prediction Capability (NUOPC) Layer:

NUOPC GENERIC COMPONENTS	
Driver	Harness that initializes components according to an *Initialization Phase Definition*, and drives their Run() methods according to a customizable run sequence.
Connector	Implements field matching based on standard metadata and executes simple transforms (e.g. grid remapping, redistribution). It can be plugged into a generic Driver component to connect Models and/or Mediators.
Model	Wraps model code so it is suitable to be plugged into a generic Driver component.
Mediator	Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component.

CoastalApp configuration for the present study



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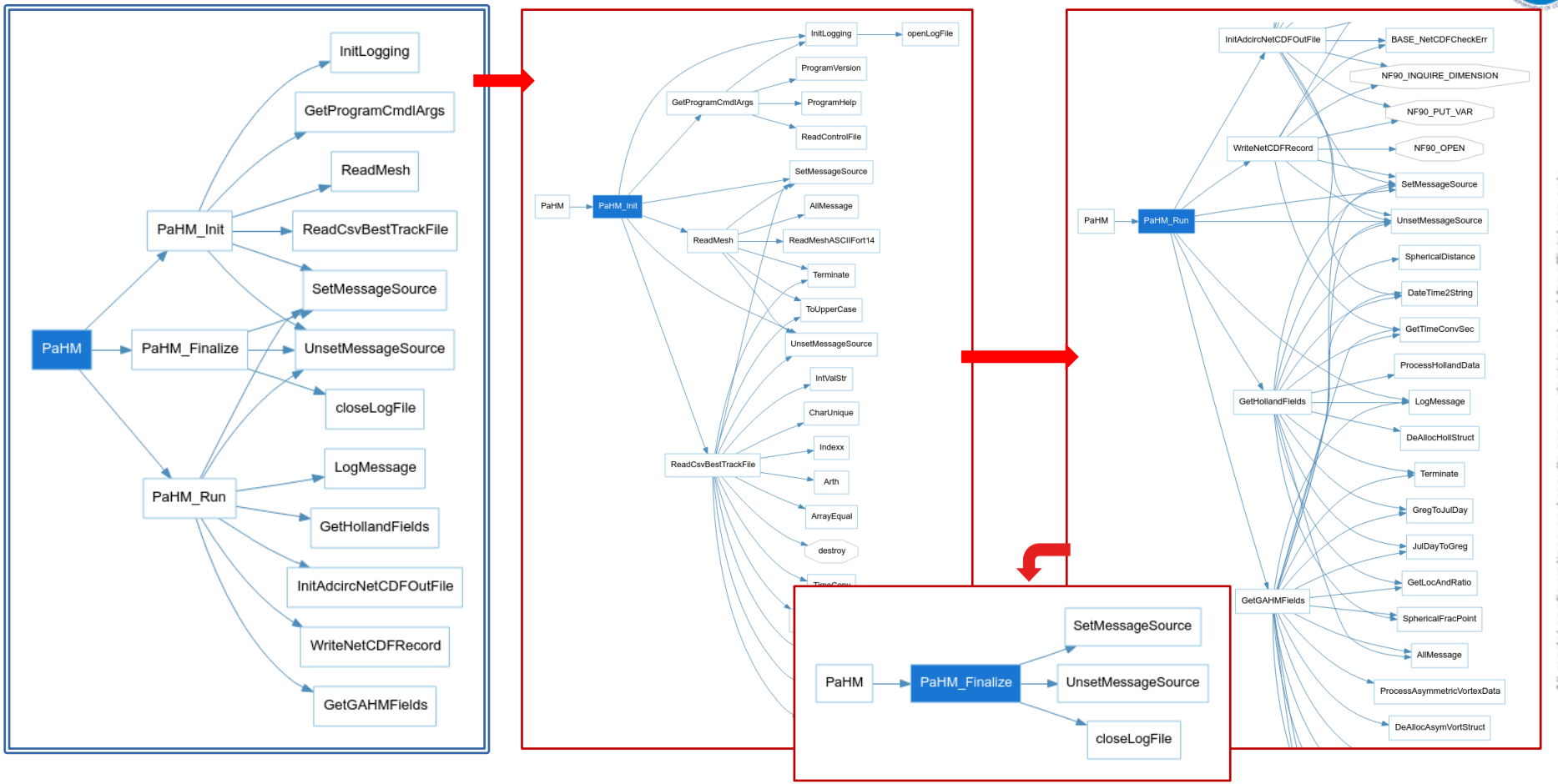
System Flowchart



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Case Study: Hurricane Florence (2018)

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Application: Case Study for Hurricane Florence, 2018

- Simulation period: from 2018-09-07 00 UTC to 2018-09-19 00 UTC
- Simulations are using the newly-developed high resolution Surge and Tide Operational Forecast System (STOFS) mesh (120-m fine resolution)
- Atmospheric model is *PaHM*
  - Fields are exchanged via *PaHM*'s NUOPC Cap
  - Fields were also exchanged via ATMESH Cap using the *PaHM* generated NetCDF data file (for testing)
- Ocean model is ADCIRC, and wave model is WaveWatch III
- Coupled system consists of *PaHM*, ADCIRC, WaveWatch III and ATMESH (for testing).

- Simulations performed:
  - Tide only simulations (ADCIRC)
  - 1-way coupled *PaHM*/ADCIRC simulations using wind reduction factors of 0.65, 0.70, 0.75, 0.90, 0.85, 0.90 and 0.95
  - Coupled ADCIRC/WaveWatch III simulations forced by *PaHM* winds

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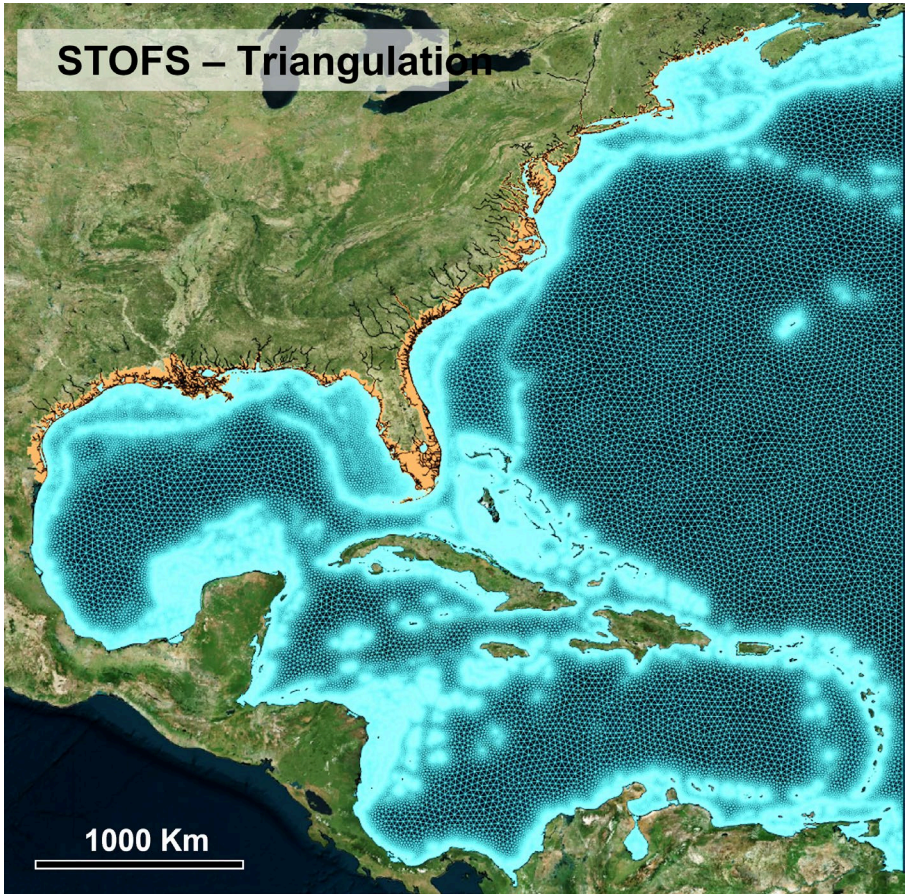
Computational Domain (STOFS), 120-m resolution



The new Hurricane Storm Surge Forecast System (STOFS) mesh, with high resolution elements (120 m) in all coastal areas (including Puerto Rico)

STOFS Mesh:

- Generated by OceanMesh2D
- Fine resolution: 120-m
- Triangular mesh with:
  - 9,997,402 elements
  - 5,131,901 nodes
- 35 boundary segments
  - Tidal boundary conditions
- Bathymetry composed from a variety of sources
  - Vertical datum: MSL
- Data file size ~800 MB

Courtesy of Maria Teresa Contreras Vargas
University of Notre Dame

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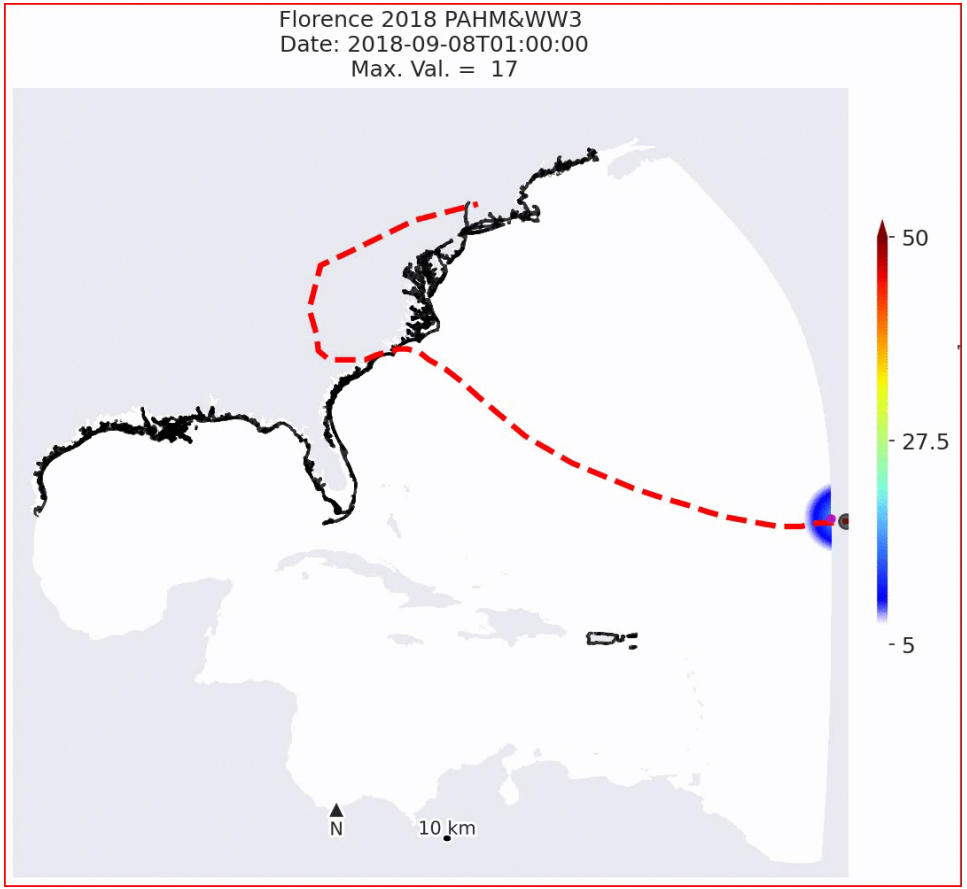
PaHM: Generated Wind Fields Along the Hurricane's Path



Symmetric Vortex Formulation

Holland Model, 1980

- Wind speeds outside the last closed isobar are set to zero
- Atmospheric pressure is set equal to 1013.25 mb outside the last closed isobar (background pressure)
- Gradient level winds are converted to 10-m winds using a wind reduction factor of 0.9

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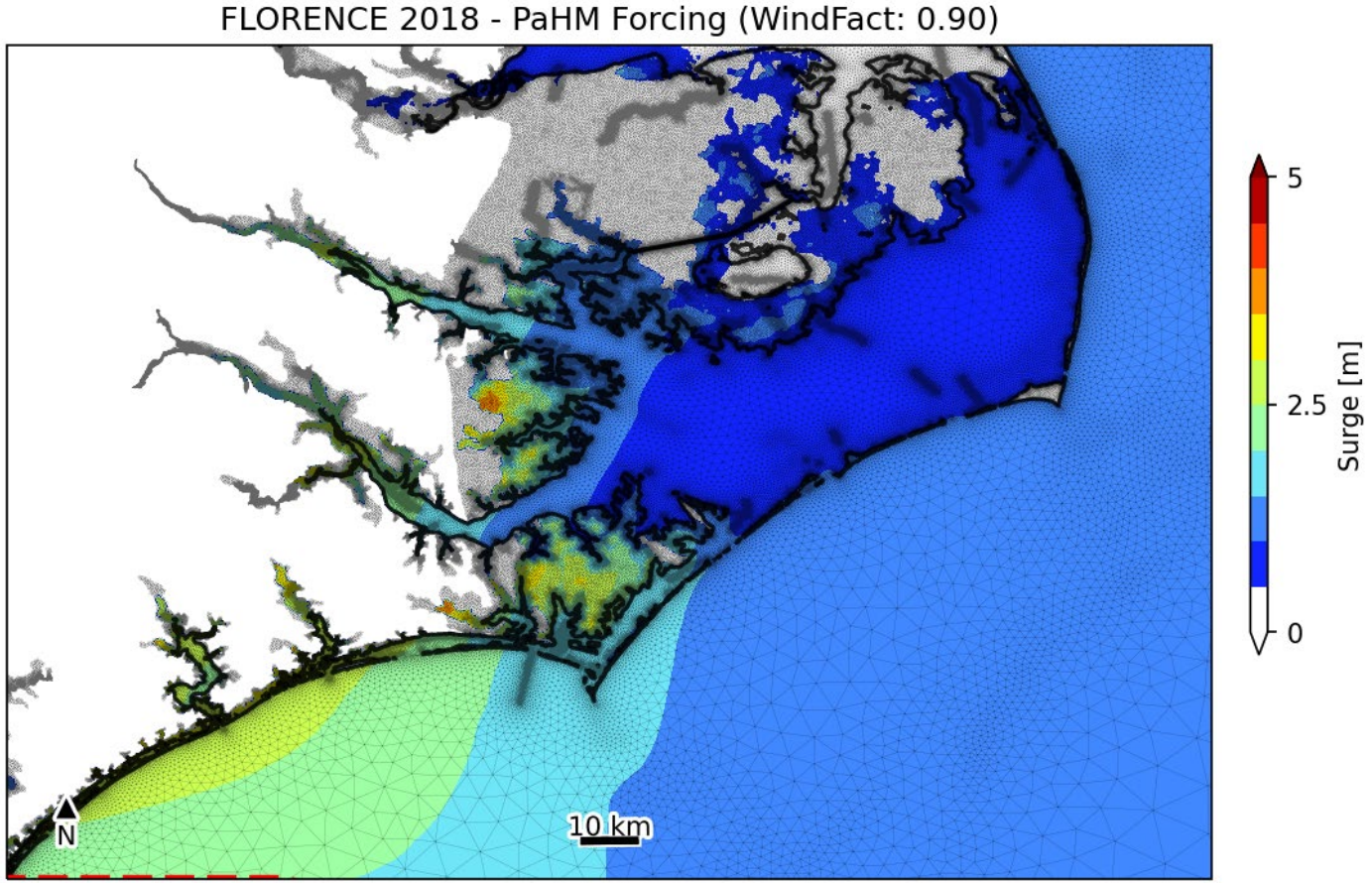
PaHM + ADCIRC: Distribution of Maximum Water Levels at the Landfall Area



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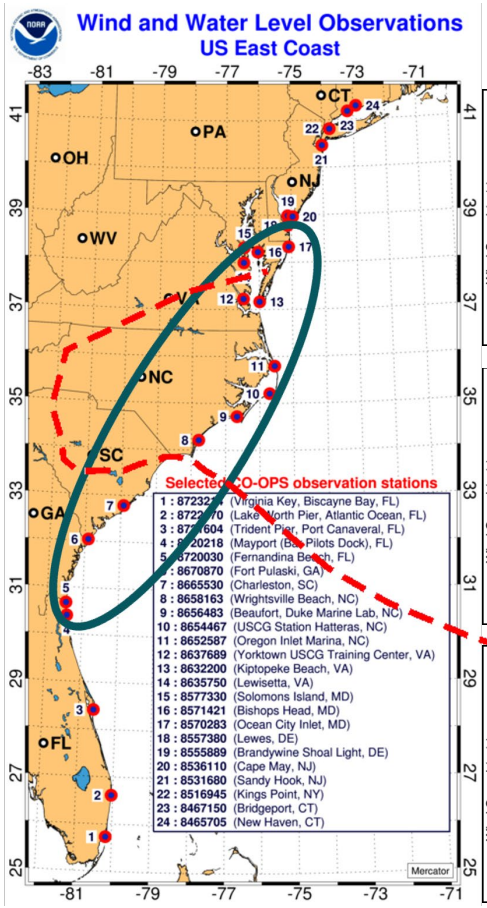
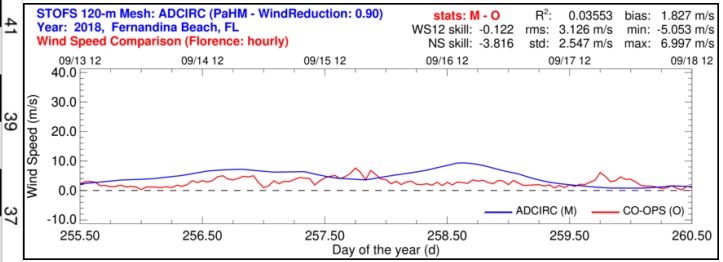
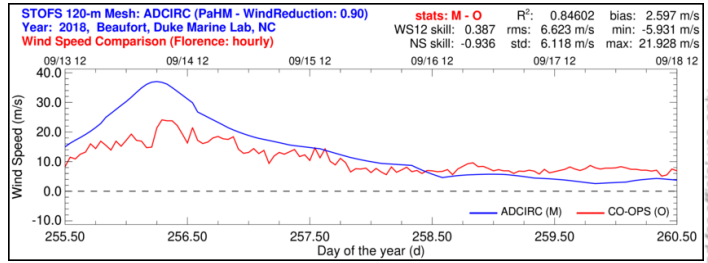
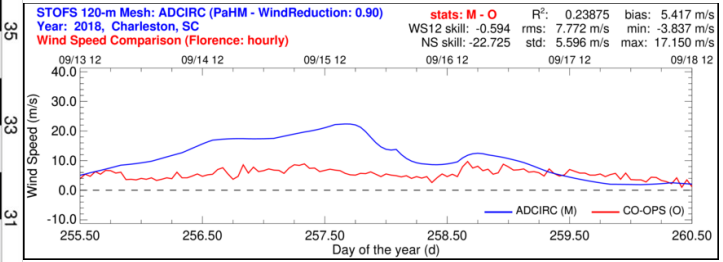
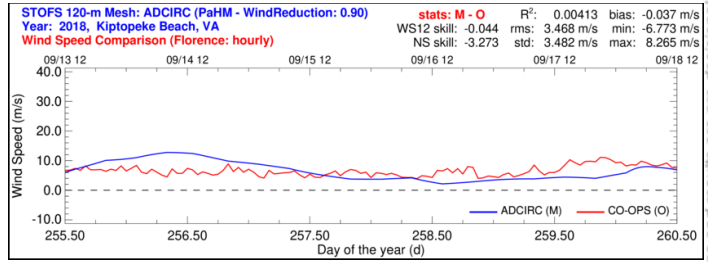
PaHM + ADCIRC: Computed Winds Speeds at Selected Locations Away From the Hurricane's Path

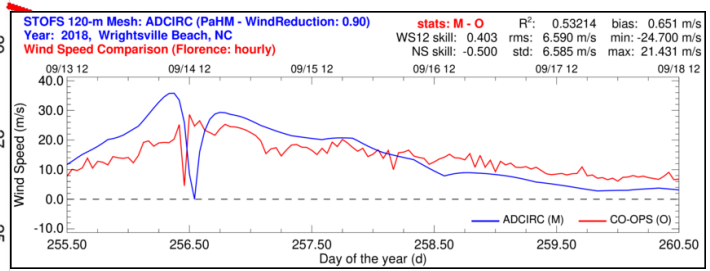


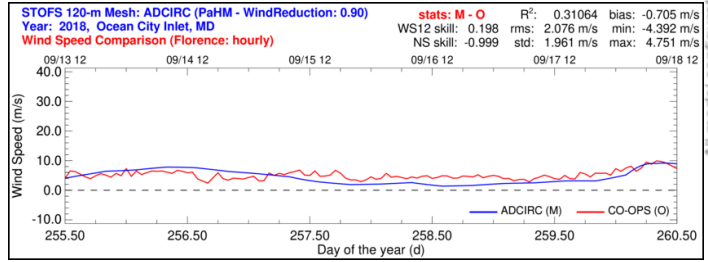












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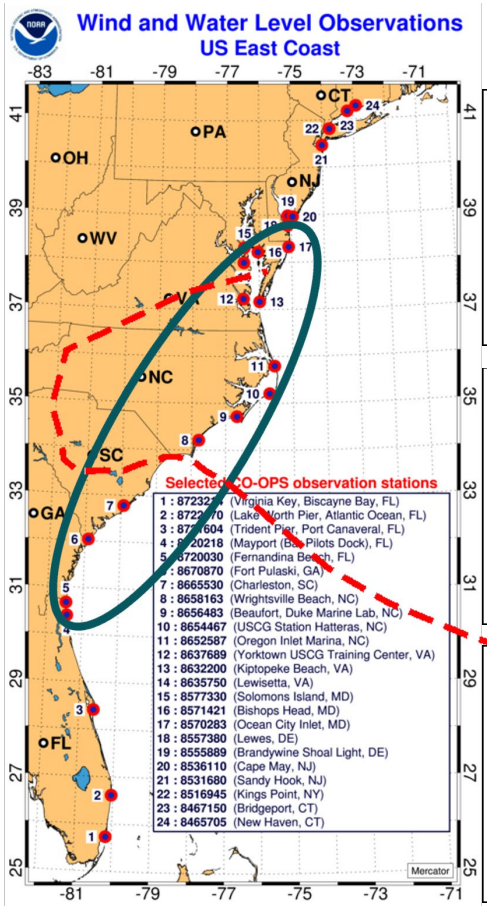
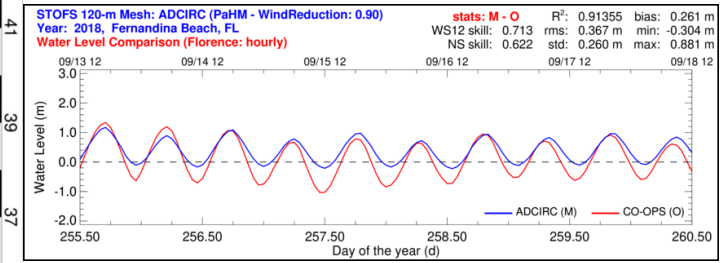
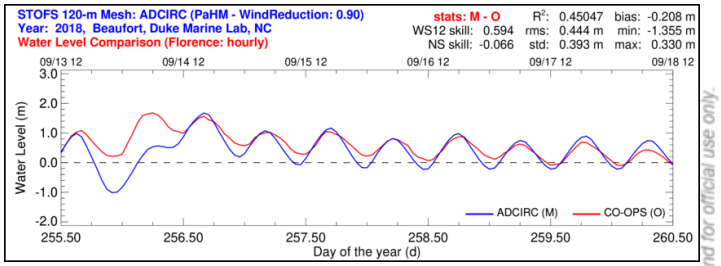
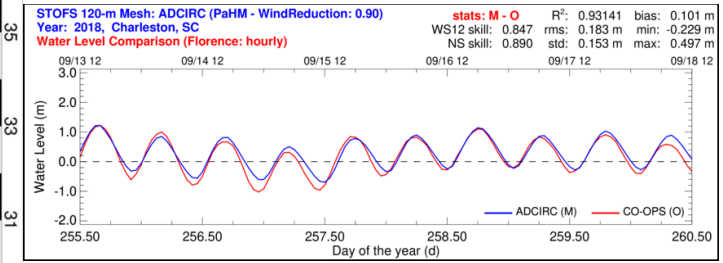
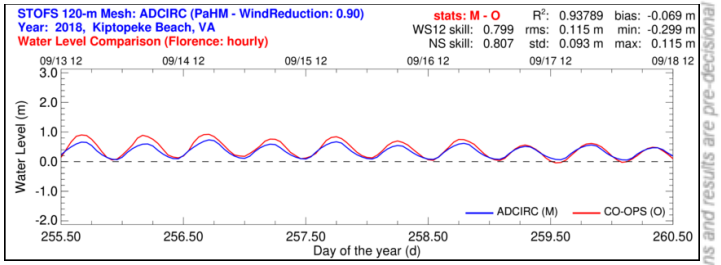
PaHM + ADCIRC: Water Level Comparisons at Selected Locations Away From the Hurricane's Path

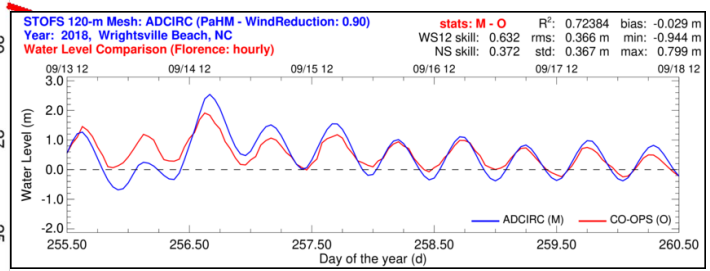


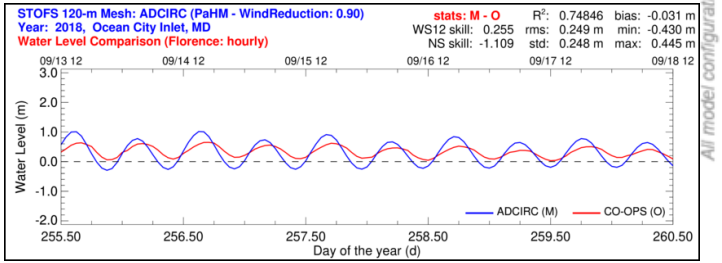












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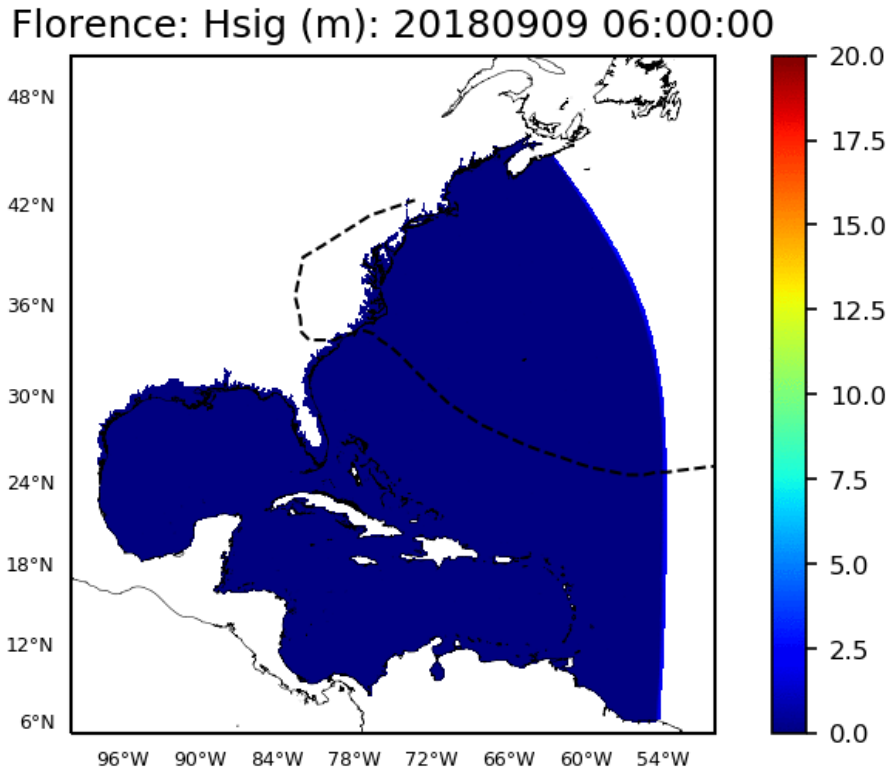
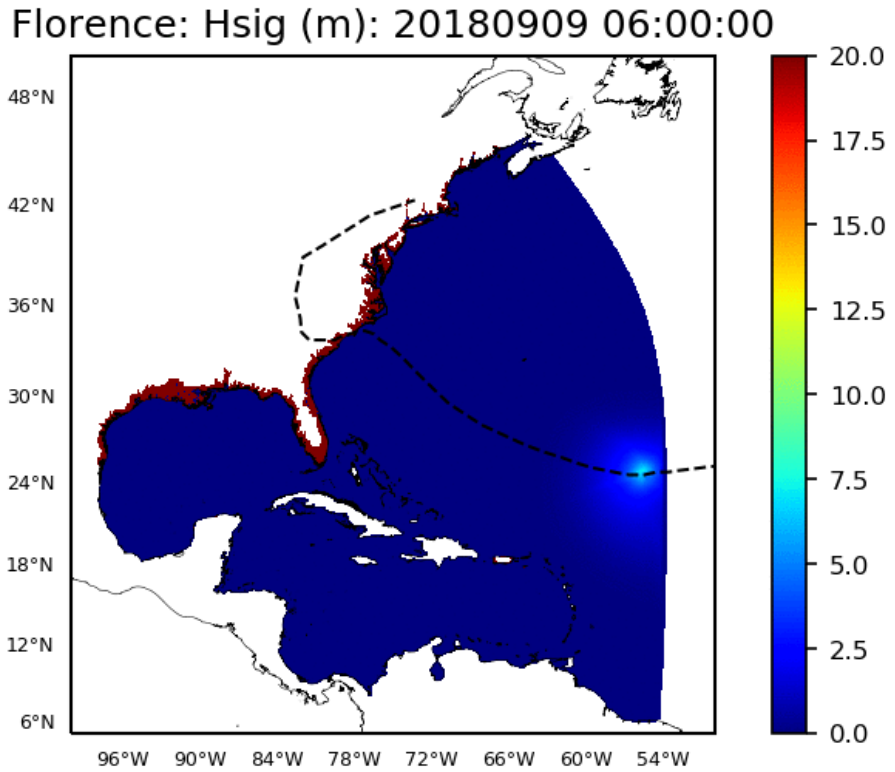
PaHM+ADCIRC+WW3: Two-Way Coupled ADCIRC and WW3

Forced by HWRF Winds



Forced by PaHM Winds



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