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.

Agenda



• CoastalApp

- System Workflow
- Modeling and Data Components
- Parametric Hurricane Modeling System (*PaHM*)
 - Introduction
 - Modeling Components: Holland Model (GAHM)
 - NUOPC Cap
 - System Flowchart

- Case Study: Hurricane Florence (2018)
 - Application
 - Computational Domain
 - PaHM Computed Winds
 - Effects of Wind Reduction Factor
 - PaHM and ADCIRC coupled simulations
 - PaHM and WW3 coupled simulations



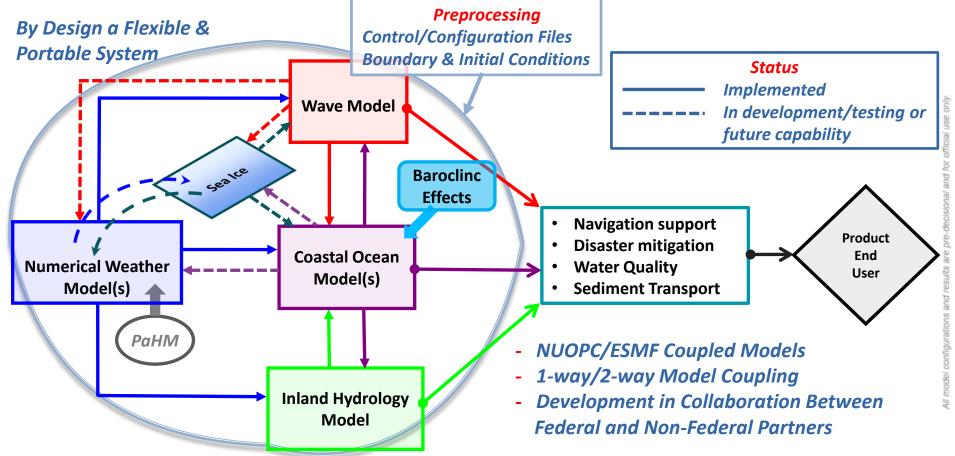
CoastalApp (Coastal Application)



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

System Workflow





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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 (i | | | | | |

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- 6 University of Massachusetts Dartmouth
- 7 Cooperative Institute for Great Lakes Research
- 8 NOAA/NWS National Water Center

Parametric Hurricane Modeling System (PaHM)

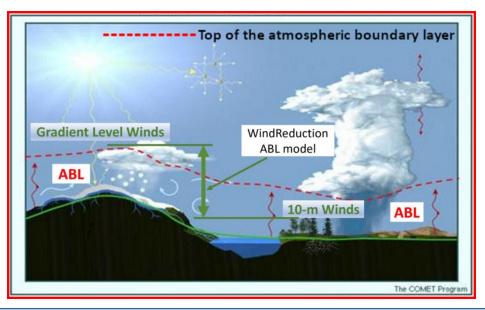
PaHMhttps://github.com/noaa-ocs-modeling/PaHMGitHubOutputhttps://noaa-ocs-modeling.github.io/PaHM/html/index.html





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



Modeling Components: Generalized Asymmetric Holland Model (GAHM)

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Governing equation:

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

Assume hyperbolic pressure profile

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

Substitute (2) into (1) and get:

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

Assume at $r = R_{max}$:

$$V_g = V_{max} \quad dV_g / dr = 0 \tag{4}$$

with:

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



Generalized Asymmetric Holland Model (5) $P(r) = P_c + (P_n - P_c)e^{-\varphi(R_{max}/r)^{B_g}}$ (8) $B_{g} = B(1+1/R_{o})^{e^{-\varphi}/\varphi} \quad (6)$ $\varphi = 1 + \frac{1/R_{o}}{B_{g}(1+1/R_{o})} \quad (7) \quad V_{g}(r) = \sqrt{V_{max}^{2}(1+1/R_{o})e^{\varphi(1-(R_{max}/r)^{B}_{g})}(R_{max}/r)^{B}_{g} + \left(\frac{rf}{2}\right)^{2}} - \left(\frac{rf}{2}\right) \quad (9)$

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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

CoastalApp configuration for the present study

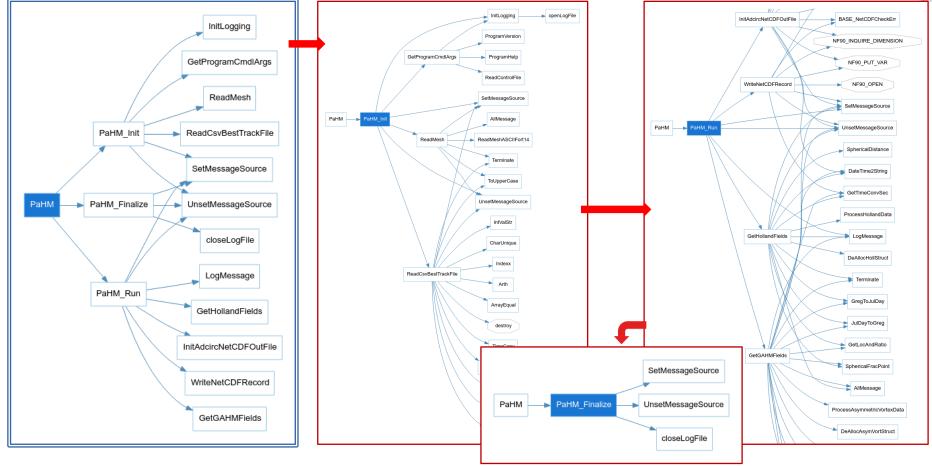
| | | • | 1 | | |
|-----------|---|---------------|------------------|----------------|--|
| Driver | Driver Harness that initializes components according to an <i>Initialization Phase Definition</i> , and drives their Run() methods according to a customizable run sequence. | | Driver Model: | | |
| 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. | ADCIRC | | Model: PaHM | |
| Model | Wraps model code so it is suitable to be plugged into a generic Driver component. | Model: WW3 | | | |
| Mediator | Wraps custom coupling code (flux calculations, averaging, etc.) so it is suitable to be plugged into a generic Driver component. | Driver | Model | Connector | |

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System Flowchart





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10

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Case Study: Hurricane Florence (2018)

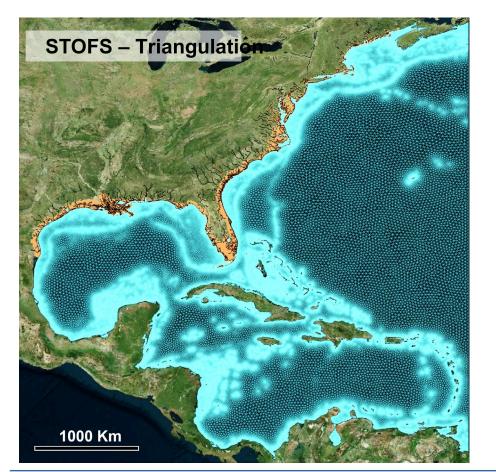
Application: Case Study for Hurricane Florence, 2018

- 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) <u>mesh</u> (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



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 <u>OceanMesh2D</u>
- 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

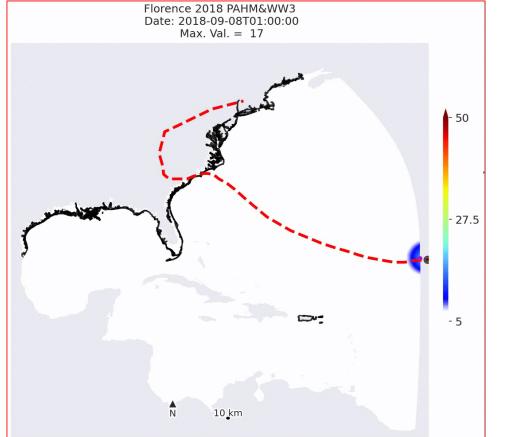
Courtesy of Maria Teresa Contreras Vargas University of Notre Dame

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Case Study Florence, 2018

PaHM: Generated Wind Fields Along the Hurricane's Path





Symmetric Vortex Formulation Holland Model, 1980

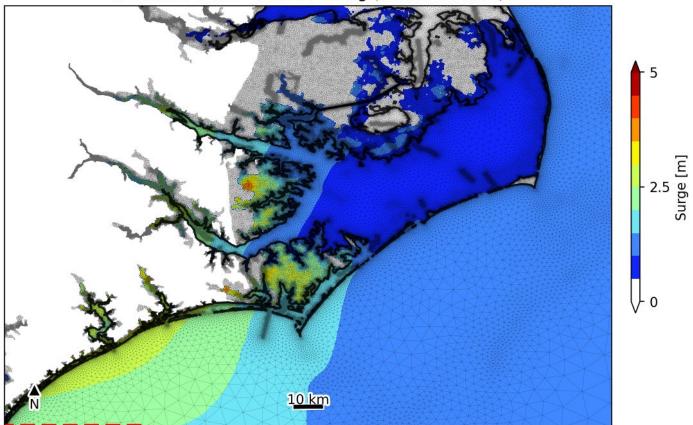
- Wind speeds outside the last closed isobar are set to zero
- Atmospheric pressure is set equal to 1013.25 mb outside the last closed isobar (background pressure)
- Gradient level winds are converted to 10-m winds using a wind reduction factor of 0.9

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Case Study Florence, 2018

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





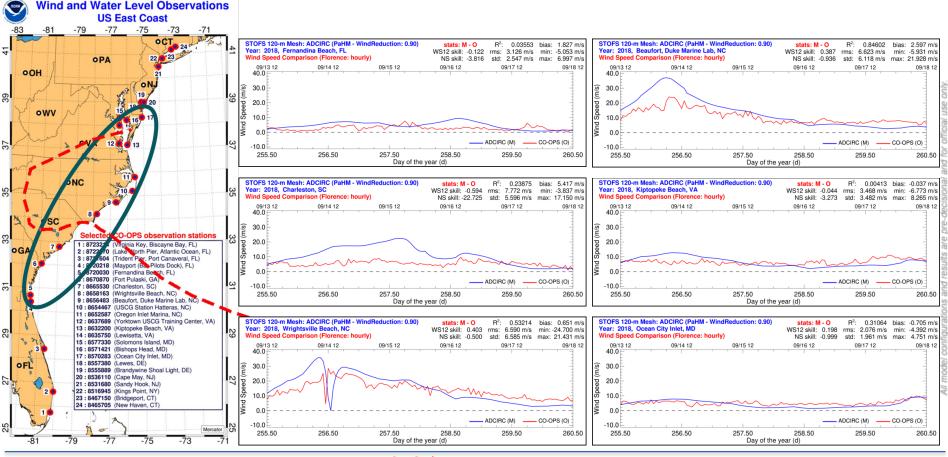
FLORENCE 2018 - PaHM Forcing (WindFact: 0.90)

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





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16

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



Wind and Water Level Observations **US East Coast** -77 -75 -81 -79 -73 -71 oCI STOFS 120-m Mesh: ADCIRC (PaHM - WindReduction: 0.90) STOFS 120-m Mesh: ADCIRC (PaHM - WindReduction: 0.90) stats: M - O R2: 0.91355 bias: 0.261 m stats: M - O R2: 0.45047 bias: -0.208 n Year: 2018, Fernandina Beach, FL Year: 2018, Beaufort, Duke Marine Lab, NC WS12 skill: 0.713 rms: 0.367 m min: -0.304 m WS12 skill: 0.594 rms: 0.444 m min: -1.355 n Water Level Comparison (Florence: hourly) Water Level Comparison (Florence: hourly) NS skill: 0.622 std: 0.260 m max: 0.881 m NS skill: -0.066 std: 0.393 m max: 0.330 m OPA 09/13 12 09/14 12 09/15 12 09/16 12 09/17 12 09/18 12 09/13 12 09/14 12 09/15 12 09/16 12 09/17 12 09/18 12 OOH 3.0 3.0 oN 2.0 Ê 2.0 33 30 le le/ 1.0 1.0 Fe owv 0.0 Nater 0.0 -1.0 1.0 - CO-OPS (O) 37 12 0 ADCIRC (M) ADCIRC (M) CO-OPS (O) -2.0 .2 0 255.50 256.50 257.50 258.50 259.50 260.50 255.50 256.50 257.50 258.50 259.50 260.50 Day of the year (d) Day of the year (d) STOFS 120-m Mesh: ADCIRC (PaHM - WindReduction: 0.90 STOFS 120-m Mesh: ADCIRC (PaHM - WindReduction: 0.90) stats: M - O R²: 0.93141 bias: 0.101 m stats: M - O R²: 0.93789 bias: -0.069 m Year: 2018, Charleston, SC 35 WS12 skill: 0.847 rms: 0.183 m min: -0.229 m Year: 2018, Kiptopeke Beach, VA WS12 skill: 0.799 rms: 0.115 m min: -0.299 m Water Level Comparison (Florence: hourly NS skill: 0,890 std: 0.153 m max: 0.497 m Water Level Comparison (Florence: hourly) NS skill: 0.807 std: 0.093 m max: 0.115 m 09/13 12 09/14 12 09/15 12 09/16 12 09/17 12 09/18 12 09/13 12 09/14 12 09/15 12 09/16 12 09/17 12 09/18 12 3.0 3.0 2.0 Ê O-OPS observation stations 33 cω /el (Virginia Key, Biscayne Bay, FL) 10 (Lake Vorth Pier, Atlantic Ocean, FL) 1.0 1:87232 2:8722 0.0 0.0 20218 (Mayport (Ba, Pilots Dock), FL) 3:87 Na Ň 8720030 (Fernandina Beech, FL) 8670870 (Fort Pulaski, GA) -1.0 -1.0 ADCIRC (M) - CO-OPS (O) CO-OPS (O) 33 : 8665530 (Charleston, SC) -2.0 -20 8:8658163 (Wrightsville Beach, NC) 255.50 257.50 256.50 257.50 258.50 259.50 260.50 255.50 256.50 258.50 259.50 260.50 9:8656483 (Beaufort, Duke Marine Lab, NC) Day of the year (d) Day of the year (d) 10:8654467 (USCG Station Hatteras, NC) 11:8652587 (Oregon Inlet Marina, NC) 12:8637689 (Yorktown USCG Training Center, VA) STOFS 120-m Mesh: ADCIRC (PaHM - WindReduction: 0.90) STOFS 120-m Mesh: ADCIRC (PaHM - WindReduction: 0.90) R2: 0.72384 bias: -0.029 m R2: 0.74846 bias: -0.031 r stats: M - O stats: M - O 13:8632200 (Kiptopeke Beach, VA) Year: 2018, Wrightsville Beach, NC Year: 2018, Ocean City Inlet, MD WS12 skill: 0.632 rms: 0.366 m min: -0.944 m WS12 skill: 0.255 rms: 0.249 m min: -0.430 n 29 14:8635750 (Lewisetta, VA) Water Level Comparison (Florence: hourly) NS skill: 0.372 std: 0.367 m max: 0.799 m Water Level Comparison (Florence: hourly) NS skill: -1.109 std: 0.248 m max: 0.445 m 15:8577330 (Solomons Island, MD) 09/14 12 09/15 12 09/16 12 09/17 12 09/18 12 09/13 12 09/14 12 09/15 12 09/16 12 09/17 12 09/18 12 09/13 12 16:8571421 (Bishops Head, MD) 3.0 3.0 17:8570283 (Ocean City Inlet, MD) 18:8557380 (Lewes, DE) OFL 2.0 2.0 Ê 19:8555889 (Brandywine Shoal Light, DE) 20:8536110 (Cape May, NJ) N vel e 1.0 21:8531680 (Sandy Hook, NJ) 22:8516945 (Kings Point, NY) 0.0 23:8467150 (Bridgeport, CT) 24:8465705 (New Haven, CT) Š -1.0 2 CO-OPS (O) ADCIRC (M) ADCIRC (M) CO-OPS (O) -2.0 -2.0 Mercator 256.50 257.50 257.50 255.50 258.50 259.50 260.50 255.50 256.50 258.50 259.50 260.50 Day of the year (d) Day of the year (d)

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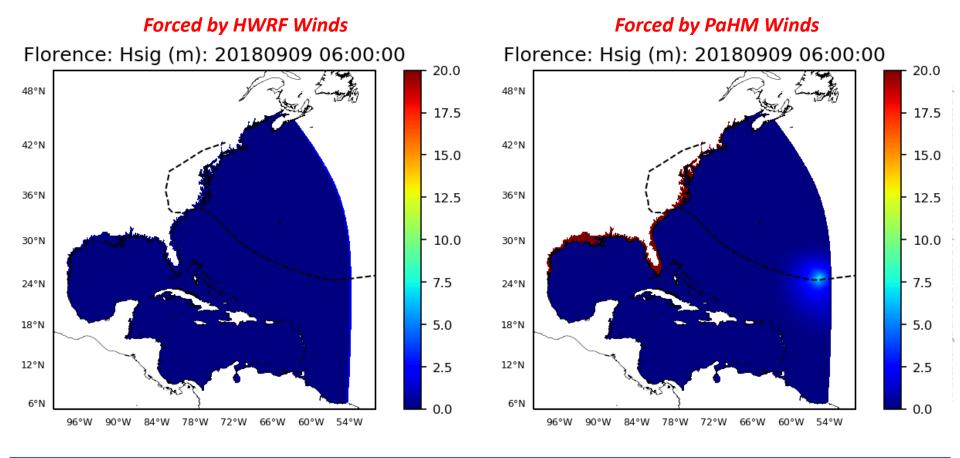


17

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





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Case Study Florence, 2018



Thank you for your attention!