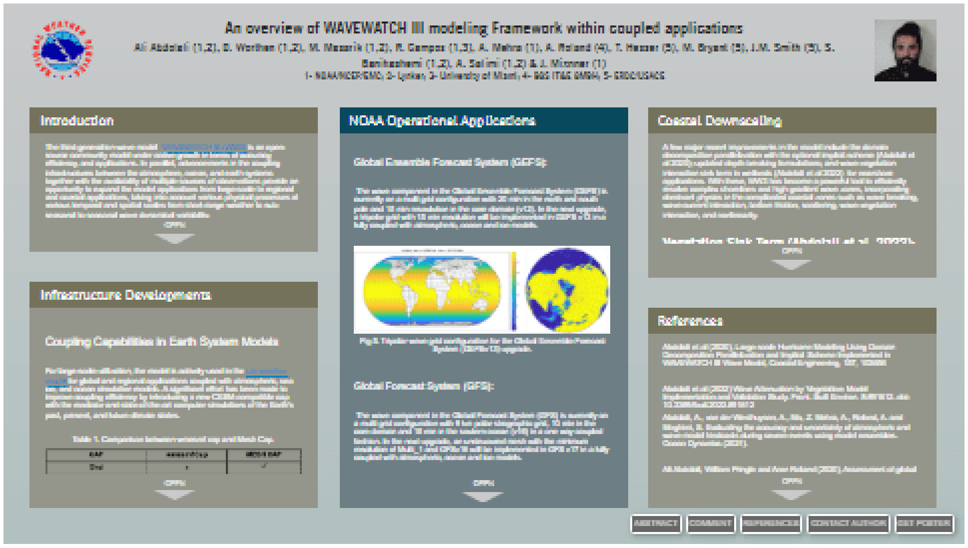
An overview of WAVEWATCH III modeling Framework within coupled applications



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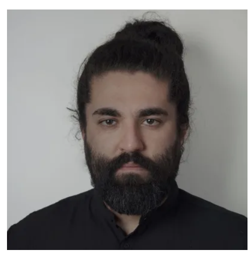


PRESENTED AT:

INTRODUCTION

The third-generation wave model WAVEWATCH III (WW3) (https://github.com/NOAA-emc/ww3)is an open-source community model under active growth in terms of accuracy, efficiency, and applications. In parallel, advancements in the coupling infrastructures between the atmosphere, ocean, and earth systems together with the availability of multiple sources of observations provide an opportunity to expand the model applications from large-scale to regional and coastal applications, taking into account various physical processes at various temporal and spatial scales from short-range weather to sub-seasonal to seasonal wave dynamical variability.

WW3 has been used in different global and regional scale operational applications:

- Global Forecast System (GFSv16)- Fig 1.
- Global Ensemble Forecast System (GEFSv12).
- The Great Lakes Wave Unstructured (GLWUv1)

Next-generation operation applications:

- Global Forecast System (GFSv17).
- Global Ensemble Forecast System (GEFSv13).
- The Great Lakes Wave Unstructured (GLWUv2).
- The Hurricane Analysis and Forecast System (HAFS).
- Regional Wave Prediction System (RWPS).
- UFS-Coastal (https://github.com/noaa-ocs-modeling/CoastalApp)

and will be upgraded in the next generations and other applications.

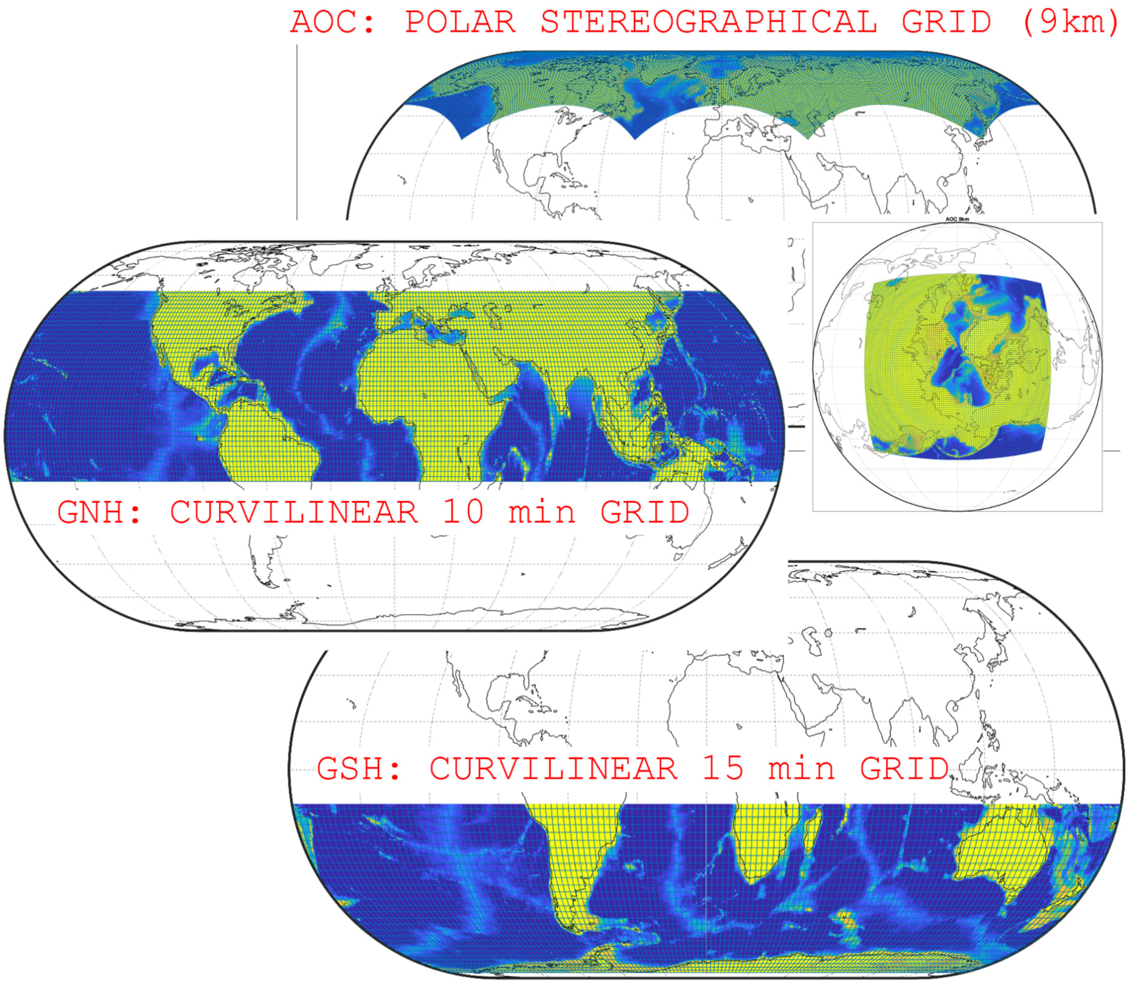


Fig1. Global Forecast System (GFSv16) wave grid configuration.

INFRASTRUCTURE DEVELOPMENTS

Coupling Capabilities in Earth System Models

For large-scale utilization, the model is actively used in the ufs-weather-model (https://github.com/ufs-community/ufs-weather-model)for global and regional applications coupled with atmospheric, sea ice, and ocean circulation models. A significant effort has been made to improve coupling efficiency by introducing a new CESM-compatible cap with the mediator and state-of-the-art computer simulations of the Earth's past, present, and future climate states.

Table 1. Comparison between wmesmf cap and Mesh Cap.

CAP	wmesmf Cap	MESH CAP
Shel	x	✓
Multi	✓	x
Unstructured	✓ (single unstr in ww3_multi)	✓
Structured single grid	✓	✓
Tripolar	✓	✓
Multiple grids	✓	x
Restart Reproducibility (Global for concurrent run sequence)	x (requires mediator-wind at t0 -WRST switch)	✓
Mediator	x	✓
Can run with just connectors (for example testing w/atm-wav only and added flexibility)	✓	x
ESMF mesh/grid type	ESMF grid	ESMF mesh
Export/Import Grid	1	1

The mesh Cap satisfies the operational Requirements:

- Efficiency
- B4B reproducibility (Restart, Thread, …)
- Build and test in Debug mode
- Mediator Capability
- Support all the grid types

Cmake Build System

In order to better integrate the WW3 model with coupled models like ufs-weather-model and UFS-Coastal, Cmake build system has been implemented to WW3 model:

- Easier to couple WW3 to NOAA's Unified Forecast System (UFS) which already uses CMake
- Just have to set options and add_subdirectory Simplifies build logic considerably
- Easier to build
- Better integration with coupled models and other packages that use CMake
- Simplified build logic with targets, and find_package
- Multiple builds using the same set of source files with out-of-source builds Faster builds
- ...

Optimization Tools

An optimization tool (ww3-optimization (https://github.com/NOAA-emc/ww3-optimization)) has been developed to tune physical parameters in the model setup in order to minimize the biases between the model outputs and observation data (buoy station and satellite altimeter) in the vicinity of severe events, for long-distance generated swell waves and low seas conditions.

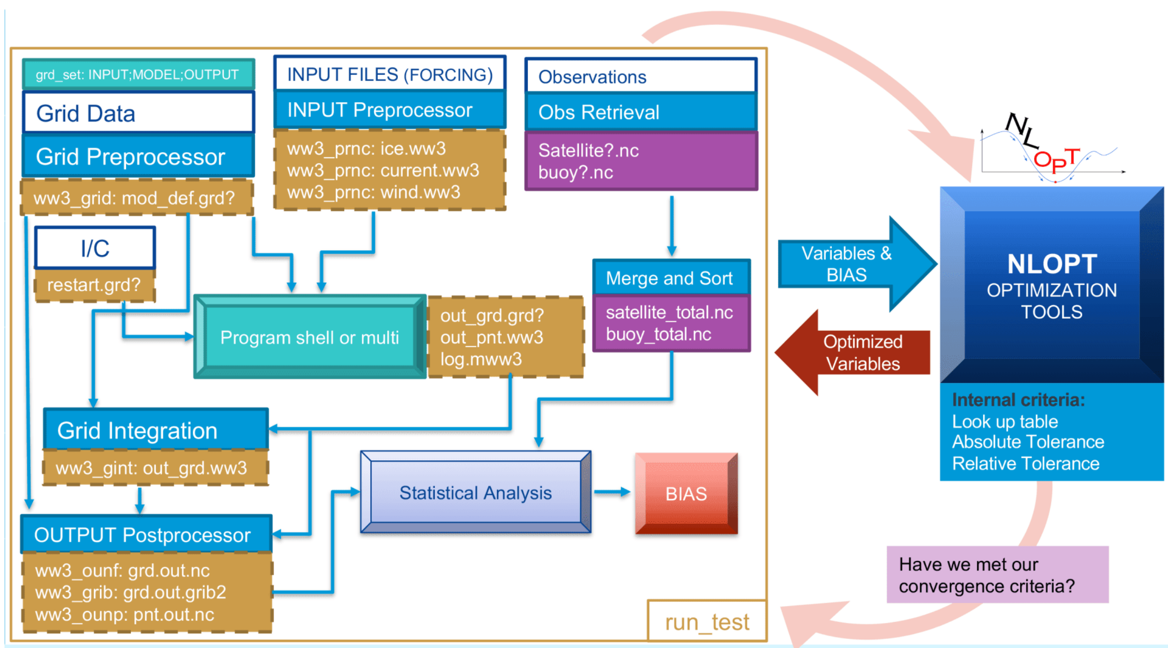


Fig 2. WW3-optimization workflow

Visualization and Validation tools

A toolkit (ww3_tools (https://github.com/NOAA-emc/ww3-tools)) has been developed in parallel to facilitate the wave model data visualization and statistical analysis. It includes but is not limited to the field, time series, and directional spectral data visualization and analysis. Statistical analysis packages are extended to meet the specific requirements of the wave models.

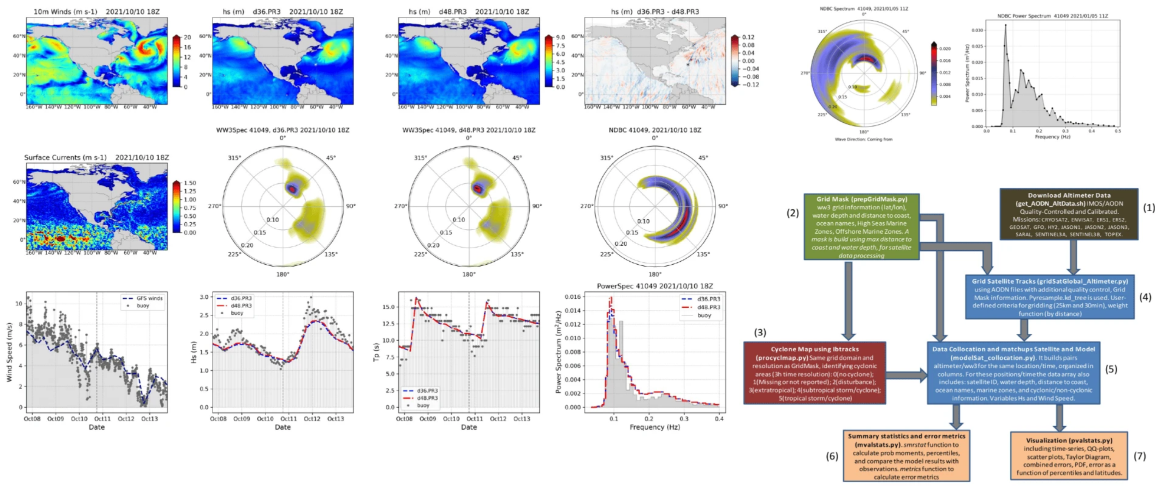


Fig 3. An example output of WW3-tools and architecture.

NOAA OPERATIONAL APPLICATIONS

Global Ensemble Forecast System (GEFS):

The wave component in the Global Ensemble Forecast System (GEFS) is currently on a multi grid configuration with 20 min in the north and south pole and 15 min resoulution in the core domain (v12). In the next upgrade, a tripolar grid with 15 min resolution will be implemented in GEFS v13 in a fully coupled with atmospheric, ocean and ice models.

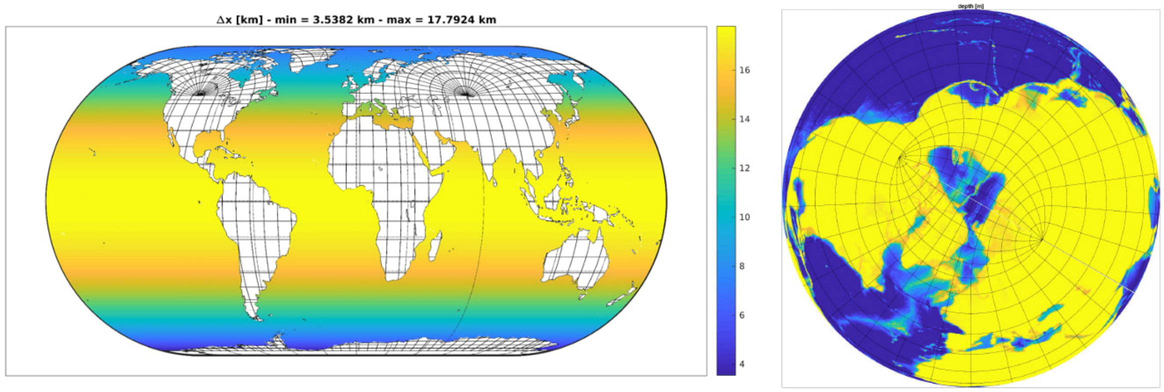


Fig 5. Tripolar wave grid configuration for the Global Ensemble Forecast System (GEFSv13) upgrade.

Global Forecast System (GFS):

The wave component in the Global Forecast System (GFS) is currently on a multi grid configuration with 9 km polar strographic grid, 10 min in the core domain and 15 min in the soutern ocean (v16) in a one way coupled fashion. In the next upgrade, an unstrucured mesh with the minimum resolution of Multi_1 and GFSv16 will be implemented in GFS v17 in a fully coupled with atmospheric, ocean and ice models.

Unstructured Mesh 5 km coastal and 10-12 km offshore

Total node number: 2-2.5 M

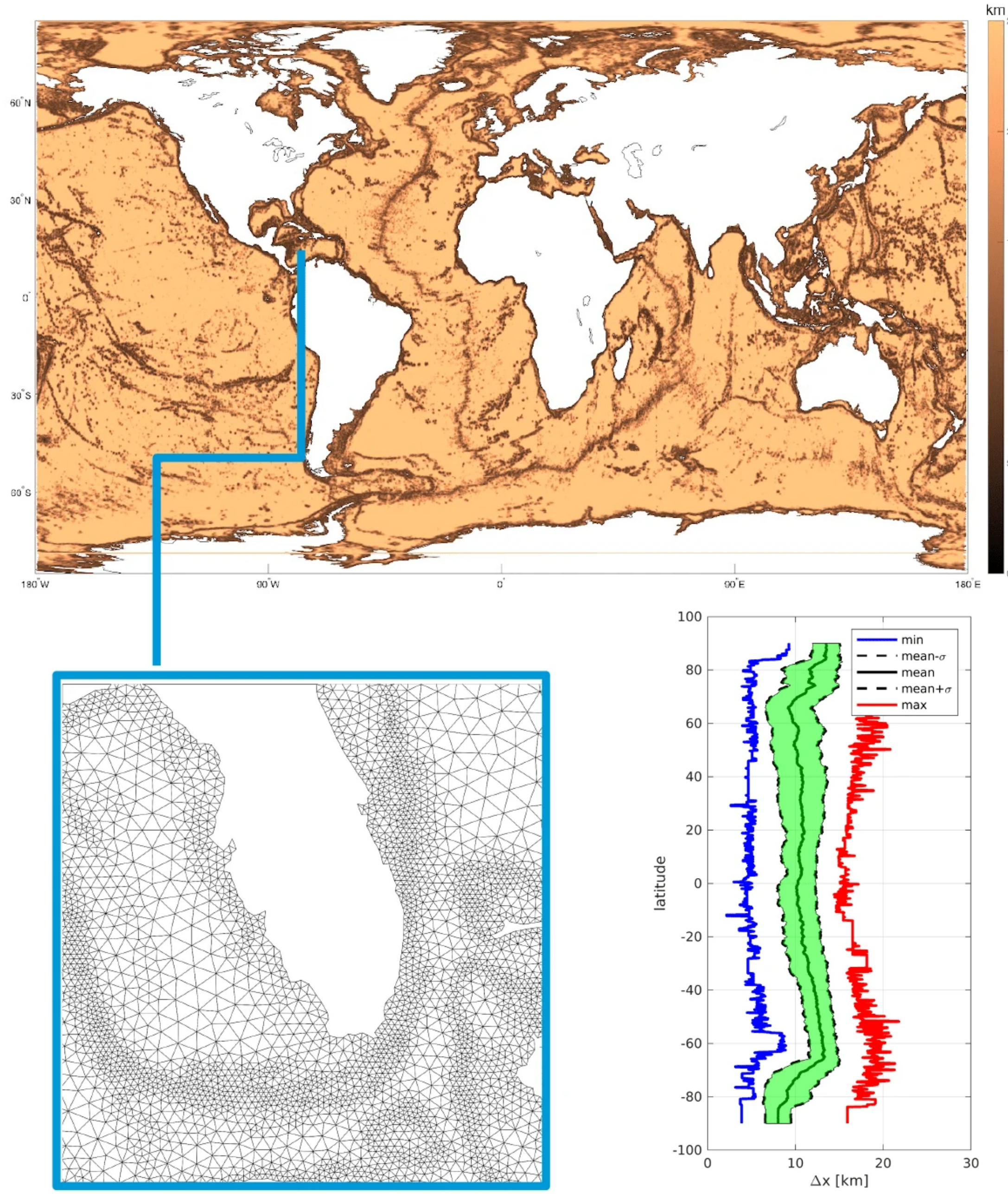
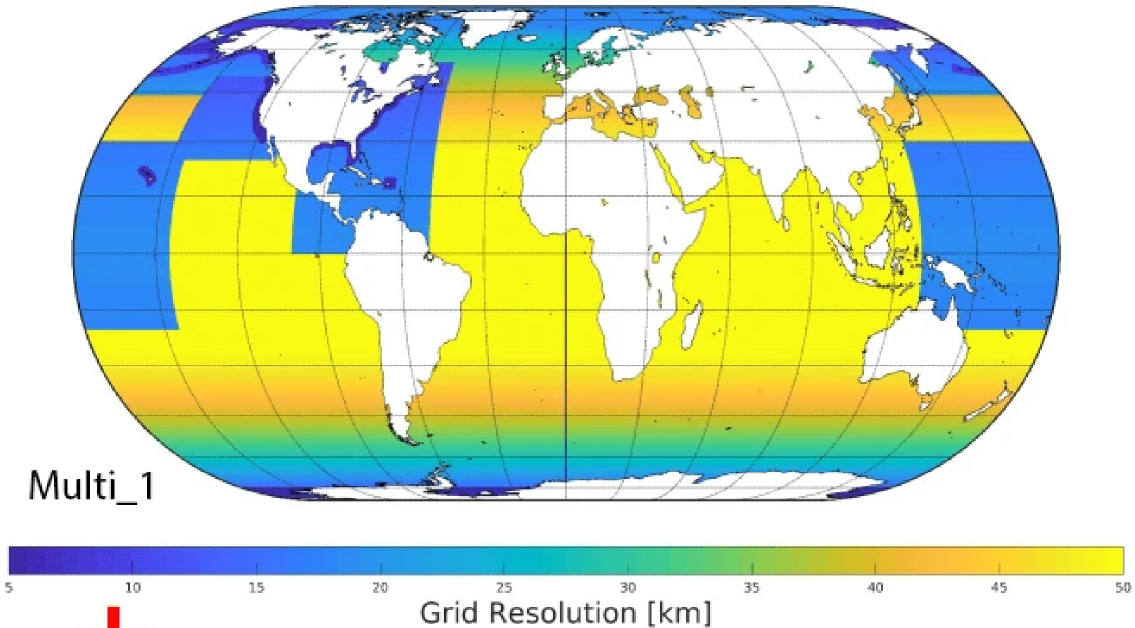
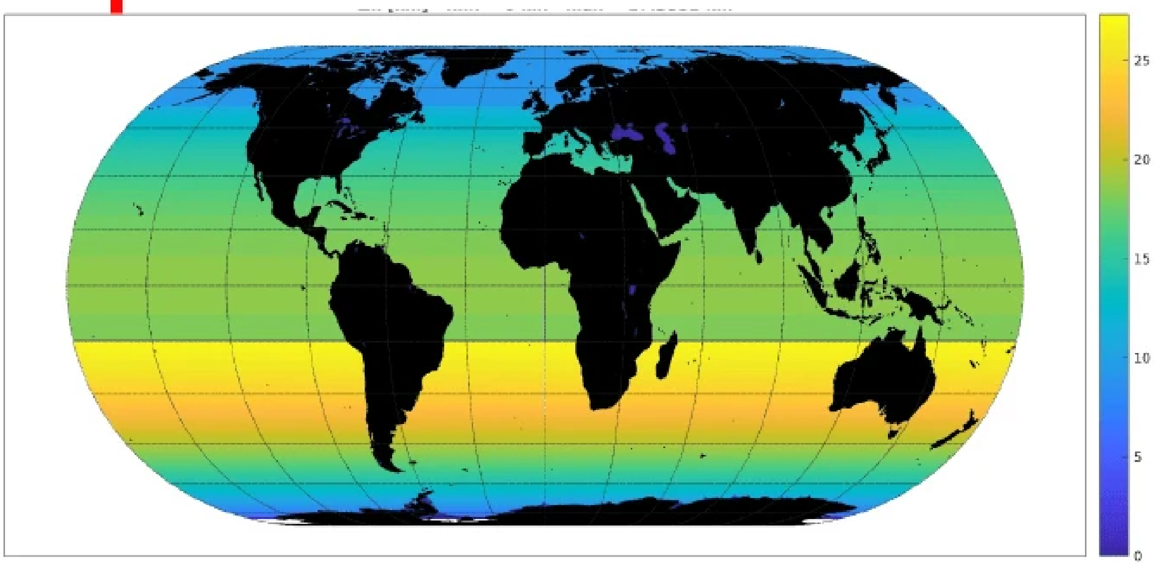
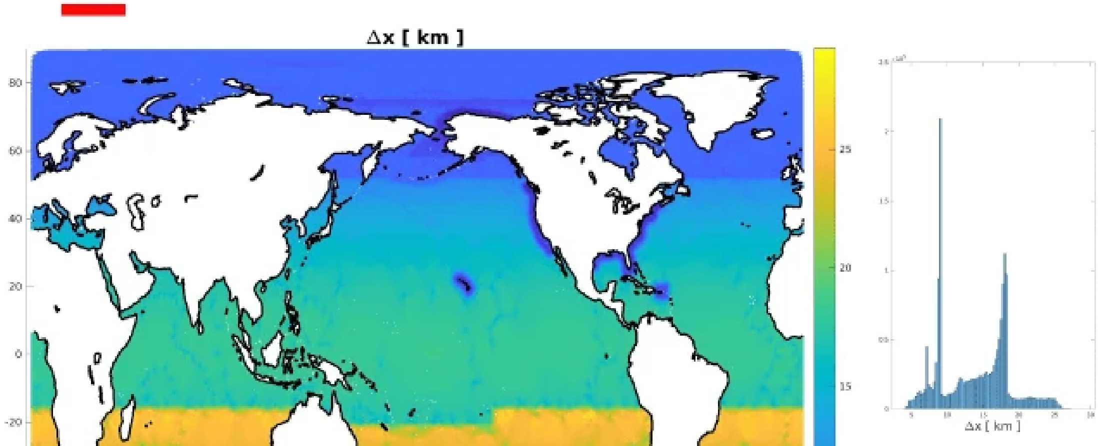


Fig 6. An example of a global unstructured mesh with variable resolution.





GFSv16: aoc9km; gnh_10min, gsh_15min



Node=1.8 M
Elements=3.5M
Min Size= 3.5 km
max Size=25 km

Fig 7. The resolution of global unstructured mesh for GFSv17 with the minimum resolution of GFSv16 and Multi-1 configuration.

Great Lakes Wave Unstructured (GLWUv2):

- Core model upgrade from 5.16 (v1) to v7.14 (v2)/
- Addition of Lake Champlain to the system.
- Utilize a higher resoltion ice field.
-

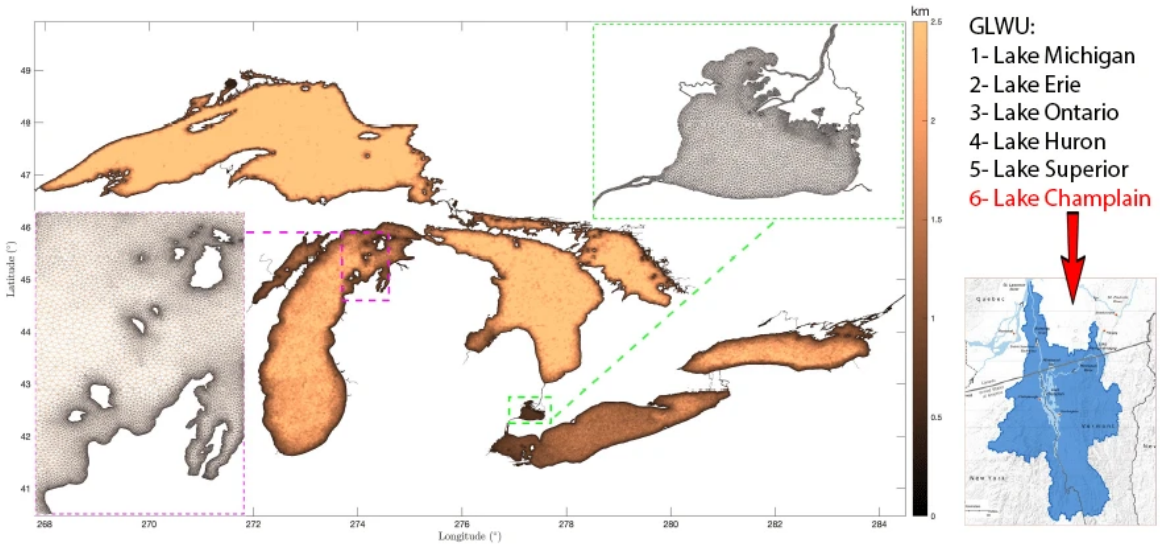


Fig 8. The Great Lakes Wave Unstructured (GLWU) Configuration with the addition of Lake Champlain in V2 (See Baniheshami et al. Presentation).

Regional Wave Prediction System (RWPS):

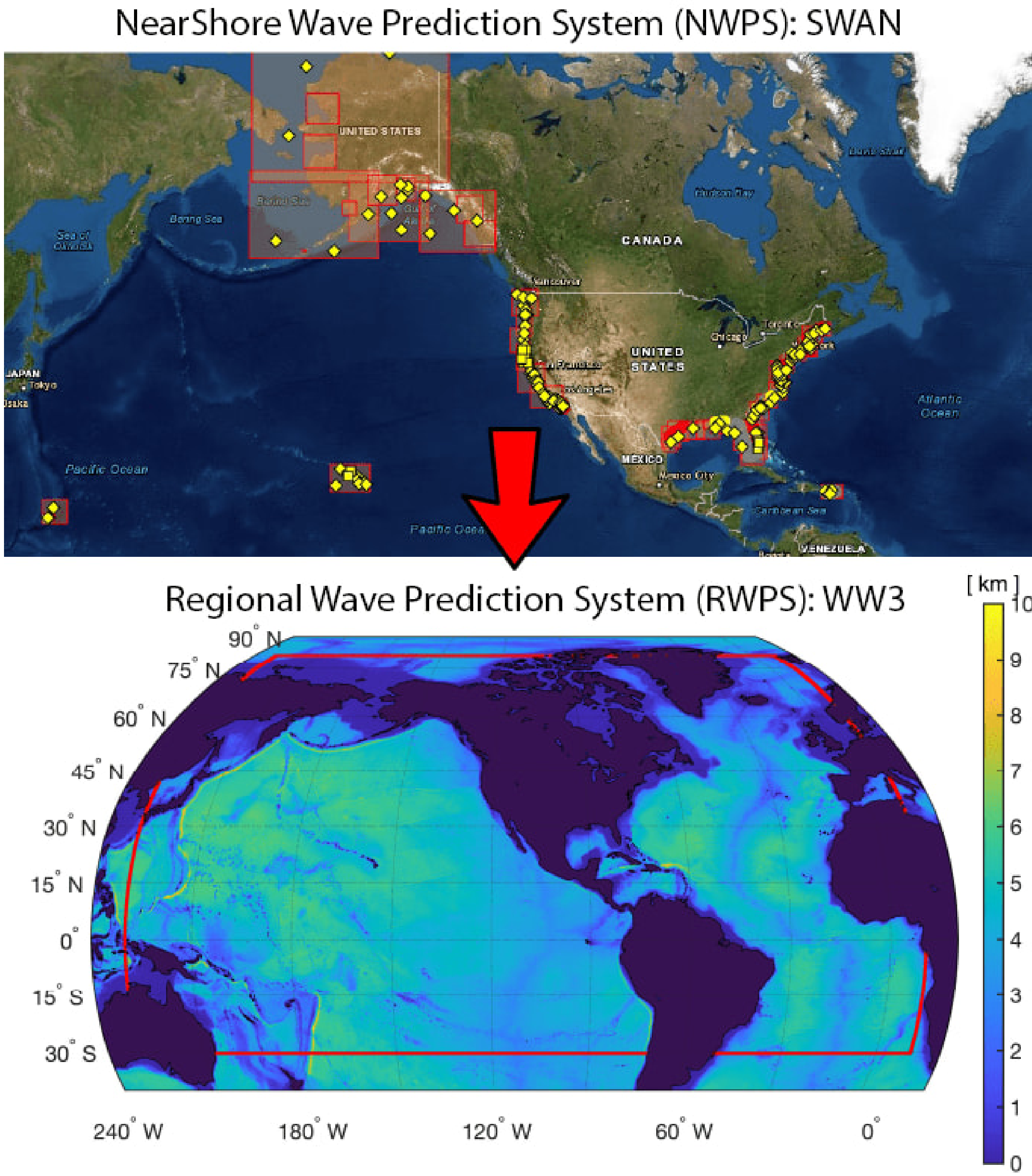


Fig 9. Nearshore Wave Prediction System (NWPS)-SWAN and future Regional Wave Prediction System (RWPS)-WW3

COASTAL DOWNSCALING

A few major recent improvements in the model include the domain decomposition parallelization with the optional implicit scheme (Abdolali et al 2020); updated depth-breaking formulations; and wave-vegetation interaction sink term in wetlands (Abdolali et al 2022) for nearshore applications. With these, WW3 has become a powerful tool to efficiently resolve complex shorelines and high-gradient wave zones, incorporating dominant physics in the complicated coastal zones such as wave breaking, wave-current interaction, bottom friction, scattering, wave-vegetation interaction, and nonlinearity.

Vegetation Sink Term (Abdolali et al. 2022):

The fundamental formulation for wave dissipation through vegetation was derived by Dalrymple et al, (1984) for monochromatic waves using the conservation of energy flux equation

$$F_x = \frac{1}{2}\rho C_d b_v N u|u|$$

where the horizontal force F_x acting on the vegetation per unit volume is expressed in terms of a Morison-type equation neglecting swaying motion and inertial force.

Mendez and Losada (2004) expanded upon Dalrymple et al, (1984) and derived an analytical solution for random wave transformations over mildly sloped vegetation fields under breaking and nonbreaking conditions by assuming a Rayleigh distribution of wave heights.

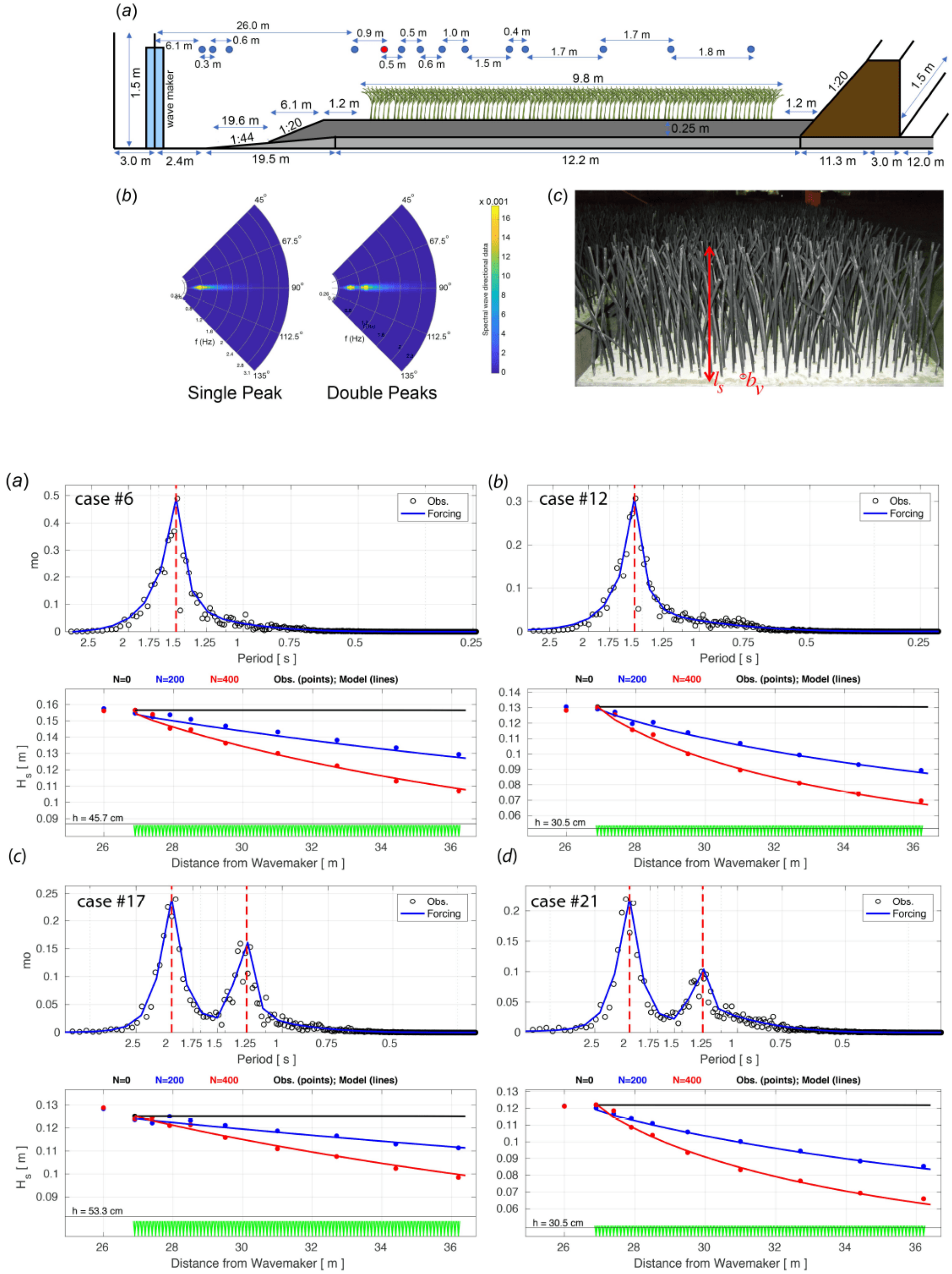


Fig 10. Top) (A) Schematic view of Anderson and Smith (2014) wave flume. (B) Single-peak and double-peak spectral density data for boundary forcing at the wave-maker in the flume and numerical model (red dot in panel (a)). (C) Installed idealized vegetation (vegetation height ls and vegetation thickness b_v). Bottom) Spectral density for single-peak (A,B) and double-peak (C,D) waves at the 5th gauge in the flume (black circles) and boundary forcing in the WW3 model (solid blue). The dashed red lines show the peak(s). Significant wave height observed in the lab (circles) and from the WW3 model (solid) for no vegetation (black), N=200 stems/m2 (blue) and N =400 stems/m2 (black).

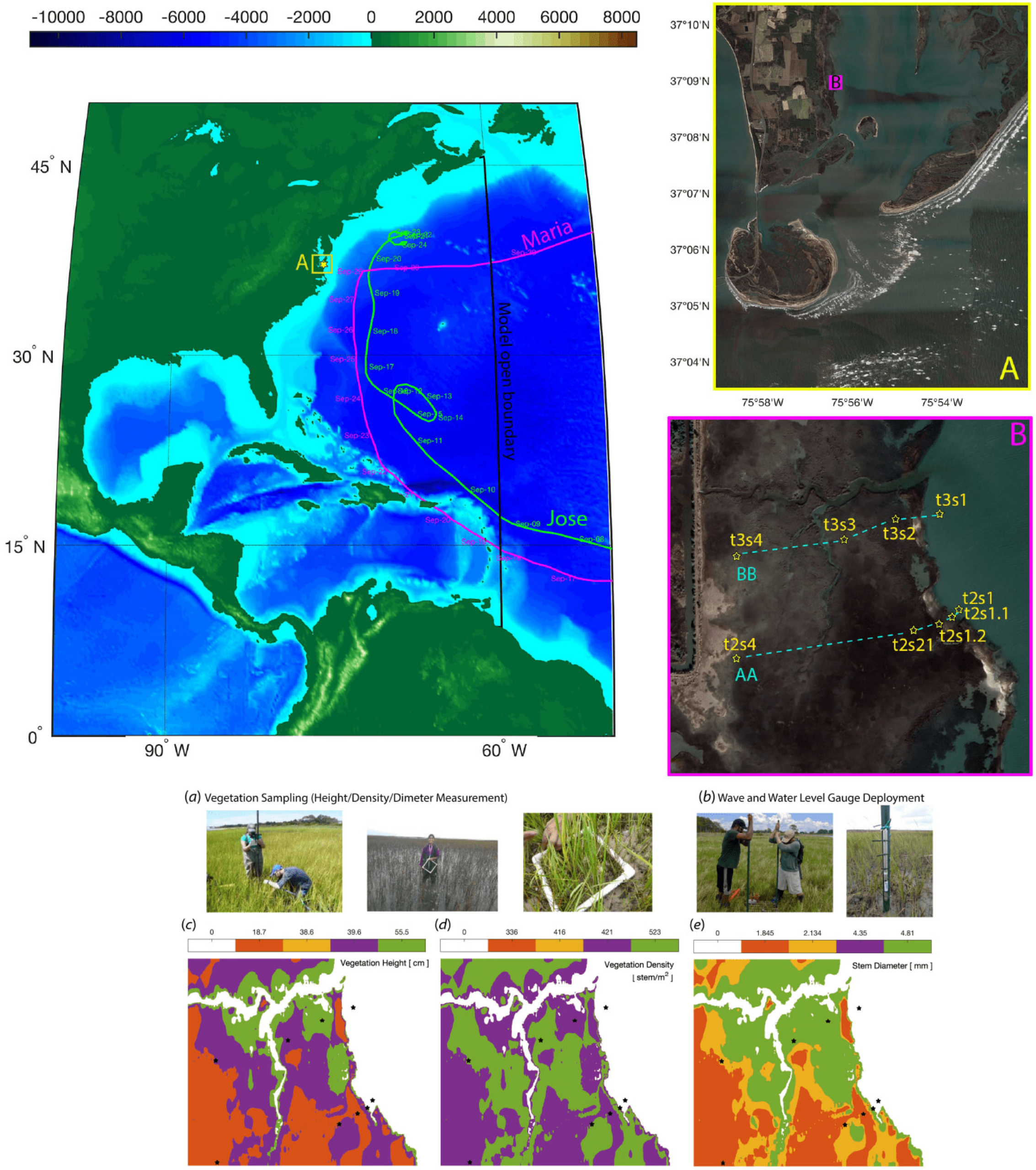


Fig 11. Top) Numerical domain extent for the east coast of the United States; The black line shows the open boundaries. The Hurricanes Maria and Jose (2017) best tracks with time tags are shown by magenta and green lines respectively. The zoom in windows in Magothy Bay and the locations of wave and water level gauges are shown in the left hand side panels; Bottom) Field measurements for vegetation sampling (a) and wave and water level gauges deployment/survey (b); Spatial distribution of vegetation height (c), vegetation density (d) and stem diameters (e) in Magothy Bay.

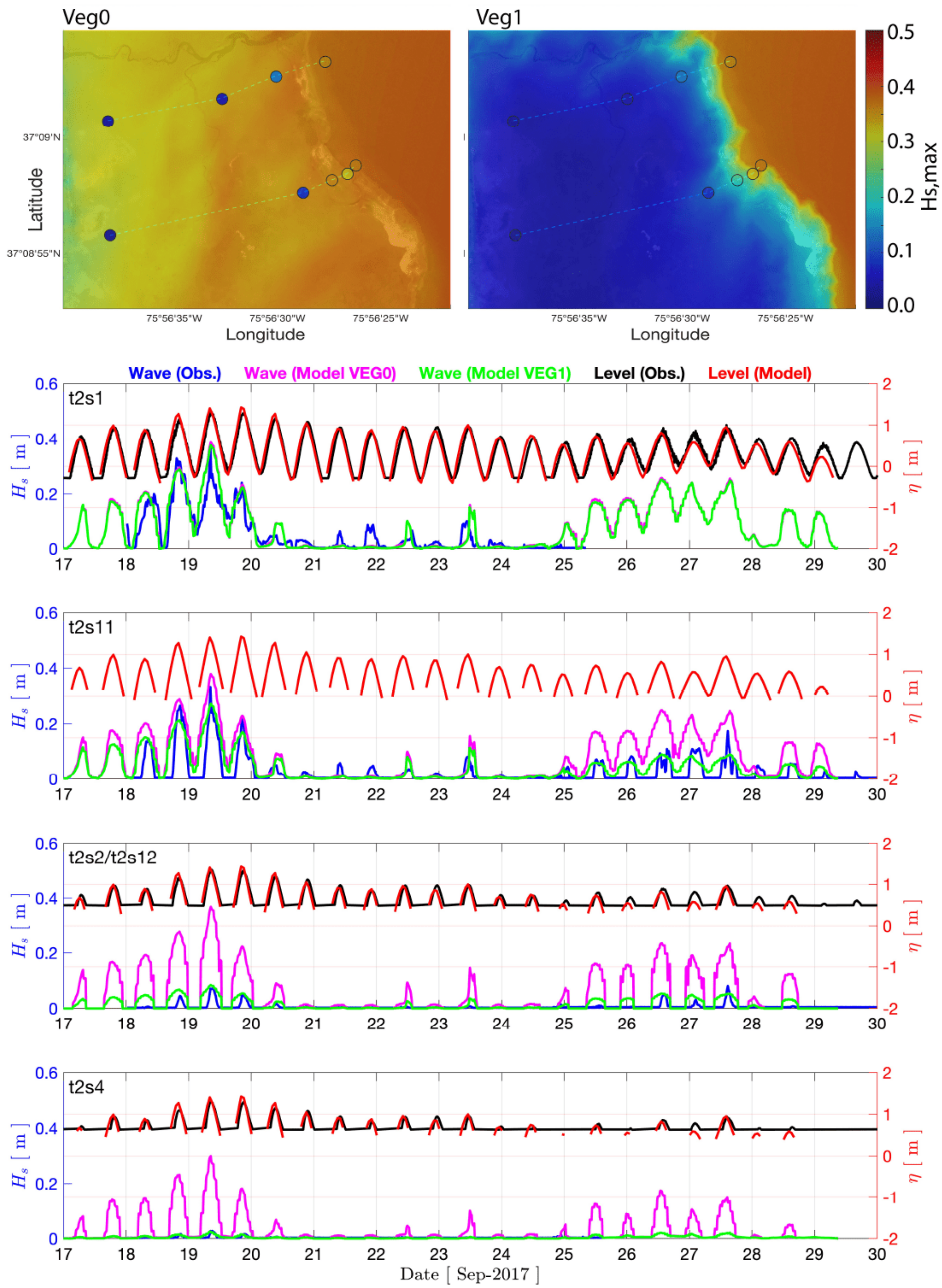


Fig 12. Top) Wave model sensitivity to wave–vegetation interaction in terms of the spatial distribution of the envelope of significant wave height Hs, extracted from the model without wave–vegetation interaction (left) with wave–vegetation interaction (right). The observed maximum values at wave gauge locations are shown with the circles.; Bottom) Wave and storm surge Models' validation at the wave and water level gauges locations (transect AA) for significant wave height Hs(observation: blue; WW3 without wave–vegetation interaction: magenta; and WW3 with wave–vegetation interaction: green) and water level elevation η (observation: black; and ADCIRC: red).

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ABSTRACT

The third-generation wave model WAVEWATCH III (https://github.com/NOAA-emc/ww3) (WW3) is an open-source community model under active growth in terms of accuracy, efficiency, and applications. In parallel, advancements in the coupling infrastructures between the atmosphere, ocean, and earth systems together with the availability of multiple sources of observations provide an opportunity to expand the model applications from large scale to regional and coastal applications, taking into account various physical processes at various temporal and spatial scales from short-range weather to sub-seasonal to seasonal wave dynamical variability.

A few major recent improvements in the model include: the domain decomposition parallelization with the implicit scheme (Abdolali et al 2020) (https://doi.org/10.1016/j.coastaleng.2020.103656); updated depth breaking formulations; and wave-vegetation interaction term (Abdolali et al 2022) (https://doi.org/10.3389/fbuil.2022.891612) for nearshore applications. With these, WW3 has become a powerful tool to efficiently resolve complex shorelines and high-gradient wave zones, incorporating dominant physics in the complicated coastal zones such as wave breaking, wave-current interaction, bottom friction, and scattering, wave-vegetation interaction, and nonlinearity.

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An overview of these recent advancements in the WAVEWATCH III model will be presented at the conference.

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