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The applications of UFS-Coastal v1.0.0b01: wave-current coupling of SCHISM and WAVEWATCH III

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Abstract

Accurate prediction of coastal flooding and nearshore processes requires a coupled modeling framework that resolves interactions among ocean circulation, surface waves, ice, and atmospheric forcing across complex coastal geometries. To address this need, we present Unified Forecast System Coastal model (UFS-Coastal), a coupled coastal modeling framework extending the Unified Forecast System Weather Model (UFS-WM). The UFS-Coastal was developed to address this need by disentangle extending the prior infrastructure (called CoastalApp), and combining CaostalApp and UFS-WM, and byintegrating four different coastal hydrodynamic models: SCHISM, ADCIRC, FVCOM, and ROMS, along with the spectral wave model WAVEWATCH III (WW3) and CICE within a unified coupled framework. Here we introduce UFS-Coastal to the community, and focus on one particular aspect, the wave-current coupling between SCHISM and WW3 with two methods: the Longuet-Higgins radiation stress formulation and a three-dimensional (3D) vortex approach. We provide a comprehensive description of UFS-Coastal's infrastructure, coupling methodologies, and its automated regression testing framework. The system's performance is demonstrated through experiments in the Duck, North Carolina (NC) region against Field Research Facility observations. Both wave-current coupling schemes between the SCHISM and WW3 could successfully reproduce observed coastal hydrodynamics and wave conditions; notably, the 3D vortex coupling improved simulations of wave-induced mixing in shallow and stratified environments. Overall, UFS-Coastal offers a robust framework for accurate prediction of

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coastal flooding, storm surge events, and wave-current interactions, supporting both research and operational forecasting applications.

1 Introduction

Coastal zones present unique challenges for numerical modeling. Processes such as storm surge generation and propagation, wave transformation, tidal estuarine exchange, wetting-drying over coastal floodplains and wave current interaction (which shifts wave's infragravity, sea-swell and windwaves compare to the wave alone) require high horizontal and vertical resolution and specialized physical parameterizations (Deb et al., 2022). Existing global and regional numerical weather prediction and Earth system models typically lack the resolution and physics required to accurately represent these complex processes, particularly at the land-sea-wave interface (Ward et al., 2020; Gröger et al., 2021; Thomas et al., 2021; Abdolali et al., 2021) Accurate prediction of coastal flooding, estuarine dynamics, and nearshore wave transformation requires numerical models specifically designed for coastal environments, where horizontal scales can range from meters in tidal inlets to kilometers on the continental shelf.

The Unified Forecast System (UFS) is a comprehensive, community-supported modeling framework designed to provide seamless earth system prediction across spatial and temporal scale (Jacobs, 2021; Worthen et al., 2024). The UFS serves both operational and research applications, from global weather forecasting to regional and local hazard prediction, and supports coupled modeling across the atmosphere, ocean, land, sea ice, and waves (Worthen et al., 2024). The UFS-Weather Model (UFS-WM), the core configuration for numerical weather prediction, provides a coupled atmosphere-land-sea ice-ocean-wave system, but it was originally designed to support large-scale processes and does not explicitly resolve the complex dynamics necessary for accurate prediction of coastal and nearshore processes.

To address this gap and following the CoastalApp initiative from the National Oceanic and Atmospheric Administration (NOAA) 's Consumer Options for an Alternative System to Allocate Losses (COASTAL) Act program (COASTAL Act, 2012), the UFS-Coastal was developed as an extension of the UFS-WM, specifically designed to enhance the modeling and prediction of coastal and nearshore processes. The UFS-Coastal extends the UFS-WM with the addition of four coastal ocean circulation models: (1) the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), an unstructured-grid hydrodynamic model designed for cross-scale applications, particularly in estuaries and coastal regions with complex geometry (Zhang and Baptista, 2008; Zhang et al., 2016); (2) the Finite Volume Community Ocean Model (FVCOM), a finite-volume, unstructured-grid ocean model widely used for coastal and estuarine circulation, which emphasizes conservative transport (Chen et al., 2006; Chen et al., 2013); (3) the Advanced Circulation Model (ADCIRC), an unstructured-grid hydrodynamic model optimized for storm surge, tidal, and hurricane modeling(Luettich and Westerink, 2004; Moghimi et al., 2020a); and (4) the Regional Ocean Modeling System (ROMS), a structured-grid, terrain-following coordinate model used extensively for shelf-scale circulation and biogeochemical modeling (Shchepetkin and Mcwilliams, 2005; Moore et al., 2011).

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These coastal ocean models are coupled within the UFS-Coastal, enabling them to interact dynamically with surface waves (via WAVEWATCH III® (WW3)) (The Wavewatch III® Development Group (WW3DG), 2019; Abdolali et al., 2020; Alves et al., 2024), and sea ice (via Community sea Ice CodE (CICE)) (Rae et al., 2015), and also receive the atmospheric and oceanic forcings from the Community Data Models for Earth Prediction Systems (CDEPS) via the Community Mediator for Earth Prediction Systems (CMEPS). This architecture allows for two-way coupled simulations where atmospheric forcing drives coastal circulation and wave generation, while wave-modified stress and wave setup feed back to the hydrodynamic model. The inclusion of multiple coastal ocean models allows the UFS-Coastal to leverage the unique strengths of each, from the estuarine-scale flexibility of SCHISM and FVCOM to the storm surge capabilities of ADCIRC and the established physical parameterizations of ROMS.

This paper presents a comprehensive description of the UFS-Coastal architecture, including its infrastructure, component models, and coupling strategies, with a focus on the recent developments towards SCHISM and WW3 coupling configurations. Here we also describe the system's continuous integration and continuous deployment (CI/CD) and automated regression testing framework, designed to ensure stability and reproducibility as the system evolves. Finally, we present initial evaluation results from the series of test cases: Hurricane Sandy in the Duck, NC, leveraging nearshore observations made by U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) at their Field Research Facility (FRF). These test cases illustrate the use of UFS Coastal to explore wave-current interactions in the nearshore, and highlight the advantages of coupled ocean–wave simulations driven by prescribed atmospheric forcing for improved prediction of storm-driven coastal flooding and nearshore circulation processes.

The paper is organized as follows: Section 2 describes the overall infrastructure of UFS-Coastal, including details of the model components and the coupling infrastructure. Section 3 presents the configuration and results of the experimental cases used to evaluate the system, with particular focus on Hurricane Sandy and the Duck, NC region. Section 4 discusses the results, and provides an outlook for future development and applications.

2 UFS Coastal Infrastructure description

The CoastalApp, a flexible and portable coastal modeling framework, was developed under NOAA's COASTAL Act program in 2017 (https://github.com/noaa-ocs-modeling/CoastalApp). The CoastalApp was developed by NOAA's National Ocean Service (NOS) Storm Surge Modeling Team and partners, and is hosted within the Office of Coast Survey's modeling GitHub organization (https://github.com/noaa-ocs-modeling/). It employs a coupled multi-model approach driven by the NOAA Environmental Modeling System (NEMS) and follows National Unified Operational Prediction Capability (NUOPC) best practices. It supported a wide range of coastal applications, including storm surge and wave modeling, with capabilities for both one-way and two-way coupled configurations(Moghimi et al., 2019; Moghimi et al., 2020b, a). To streamline efforts and align closely with NOAA's UFS, the NOS team deprecated CoastalApp in favour of developing UFS-Coastal, a fork of the UFS-WM. During this transition, the UFS-Coastal inherited the four specialized coastal hydrodynamic components originally

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developed within CoastalApp: ADCIRC, FVCOM, SCHISM and ROMS, facilitating continuity in model capabilities and leveraging prior advances made under CoastalApp.

This transition introduced two key architectural changes: (1) the NEMS driver was replaced by the CMEPS, providing standardized regridding, flux calculation, and time management across components; and (2) the coastal models gained direct access to the UFS-WM's existing component suite, including FV3 atmosphere, land surface models, WW3, and CICE . The UFS-Coastal retained the four specialized coastal hydrodynamic models originally developed within CoastalApp (ADCIRC, FVCOM, SCHISM, and ROMS) while embedding them within this broader coupled framework (Fig. 1). External forcing data (e.g., atmospheric reanalysis, observed boundary conditions) is ingested through the CDEPS.

Building upon the foundational infrastructure provided by the UFS-WM and CoastalApp, the UFS-Coastal further enhances the capabilities for modeling coastal and estuarine environments by integrating these four specialized coastal ocean models (Fig. 1): the UFS-WM contributes core modeling components (including atmosphere, land surface, sea ice, and wave models) The UFS-Coastal offers enhanced spatial resolution, resolved accurate coastlines, improved wetting and drying capabilities, and physics tailored specifically for nearshore environments, providing users with significant flexibility to address diverse coastal modeling objectives, which are challenging in UFS-WM, even when using the same unstructured grid

The subsequent sections provide detailed descriptions of UFS-Coastal's infrastructure, components, and their practical applications.

2.1 UFS-WM component descriptions

2.1.1 CDEPS and CMEPS

CDEPS is constructed on the Earth System Modeling Framework (ESMF) and comprises a collection of NUOPC-compliant data components together with ESMF-based "stream" code. In essence, these data compoents ingest data from external sources, process and then send to other NUOPC compliant compoents such as CMEPS mediator. Because the fields passed to the mediator have the same form as those originating from an active component, neither the mediator nor any other CMEPS-compliant component needs to know whether a given component is fully active or merely supplying data. This CDEPS yields two important practical benefits: (1) regridding between the stream resolution and the model resolution is carried out at run time using whichever regridding options ESMF provides, and (2) Parallel I/O (PIO) library is leveraged in CDEPS so that stream data are read in parallel by the stream code (Worthen et al., 2024).

The external data sources that CDEPS interfaces with include (1)Atmospheric reanalysis products — for example,the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) (Hersbach et al., 2020), and (2) Observed or pre-simulated surface fluxes, such as water levels derived from ocean observations or air-sea fluxes obtained from large-scale models, including the observed data from the USACE ERDC's Coastal and Hydraulics Laboratory's FRF (USACE, 2025). This capability is especially valuable when the UFS-WM/UFS-Coastal is applied to limited-area domains, which depend on realistic surface forcing drawn from other simulations or observational datasets. By treating external data streams in the same manner as internal component data streams, CDEPS preserves temporal and spatial consistency across the coupled system.

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CMEPS is an ESMF/NUOPC-compliant mediator for coupling the components of Earth system models. It is presently used in a range of applications, among them the National Center for Atmospheric Research (NCAR) Community Earth System Model (CESM) and NOAA's UFS. The mediator conveys field information from one component to another, a process that may involve one or more operations on the exchanged fields, including the mapping of fields across component grids, the merging of fields from different components, and the time-averaging of fields over differing coupling periods. In this way, CMEPS absorbs the complex coupling operations while leaving the source code of each individual component model in the coupled system unchanged.

CMEPS provides several key functions, including:

1) Regridding: CMEPS maps fields between the structured atmospheric grid and the unstructured meshes used by SCHISM, FVCOM, ADCIRC, and WW3, or the structured grid used by ROMS, WW3, and CICE, applying a range of temporal and spatial interpolation methods.
2) Time management: CMEPS allows the coupling of components on different time intervals by synchroning information exchange at the appropriate coupling intervals, so that atmosphere–ocean–wave interactions can evolve dynamically in time.
3) Data exchange: CMEPS manages the transfer of surface fluxes (wind stress, sea surface pressure), surface elevation, ocean currents, and wave parameters among the components.

The flexibility of CMEPS allows the UFS-Coastal to support configurable coupling intervals for different component pairs, enabling efficient simulations even in high-resolution, computationally intensive domains.

The combination of CMEPS and CDEPS allows the UFS-WM/UFS-Coastal to seamlessly integrate external forcing data (e.g., reanalysis winds, global model forcing conditions) with dynamically evolving coupled simulations. CMEPS manages real-time interactions among the active components, while CDEPS ensures that prescribed external forcing is applied consistently at the domain. Together, these components allow the UFS-Coastal to operate flexibly across scales, from globally forced regional domains to fully coupled hurricane simulations with dynamic wave and surge feedback.

2.1.2 WW3

WW3 is a third-generation, phase-averaged spectral wave model that simulates the evolution of wave action density in frequency–direction space by solving the wave action balance equation (The Wavewatch III® Development Group (WW3DG), 2019). Rather than resolving individual wave phases, WW3 parameterizes the key physical processes that govern wave evolution, including wind-driven wave growth, nonlinear quadruplet wave–wave interactions that redistribute energy across the spectrum, and dissipation due to whitecapping and swell attenuation. This formulation allows WW3 to efficiently resolve multiple coexisting wave systems, such as locally generated wind seas and remotely generated swells, making it the standard model for global and basin-scale operational wave forecasting (Alves et al., 2024; Abdolali et al., 2024).

For coastal applications, WW3 explicitly resolves shallow-water processes that become dominant as waves propagate shoreward, including depth-induced breaking, nonlinear triad interactions, and wave refraction over variable bathymetry

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(Abdolali et al., 2020). To address complex nearshore environments, the model includes advanced source terms, most notably a wave-vegetation interaction sink term that directly computes wave energy dissipation based on vegetation characteristics such as stem height, diameter, and density (Abdolali et al., 2022). These physics are critical for modern operational forecasting systems, including UFS, where an accurate representation of the sea state is essential for high-fidelity coupled predictions (Abdolali et al., 2021).

A major paradigm shift in multi-scale wave modeling was achieved through the implementation of an unstructured triangular mesh framework coupled with a domain-decomposition (DD) parallelization algorithm (Abdolali et al., 2020). Unlike traditional explicit numerical schemes, which are strictly constrained by the Courant-Friedrichs-Lewy (CFL) condition, where the smallest coastal grid cell dictates the global time step, WW3's optional implicit solver relaxes this limitation, enabling efficient integration at very high spatial resolutions (on the order of 10-50 m). The DD algorithm further improves computational scalability by optimizing load balancing across thousands of processors, allowing variable-resolution meshes that smoothly transition from the deep ocean (5-30 km) to complex coastal regions without the computational overhead associated with traditional nesting approaches, while maintaining high efficiency offshore and resolving sharp coastal gradients (Abdolali et al., 2026).

To resolve total water-level dynamics, WW3 is embedded within coupled modeling frameworks using ESMF. As demonstrated by (Moghimi et al., 2020a), this coupling enables two-way exchanges between WW3 and hydrodynamic models such as ADCIRC, whereby currents and water levels modulate wave evolution and wave-induced radiation stresses or vortex forces feed back into nearshore circulation. In river-estuary-coastal transition zones, this integrated modeling approach is essential; (Bakhtyar et al., 2020) showed that accurate inundation predictions require the combined effects of river discharge, tides, storm surge, and waves to be resolved consistently, ensuring a comprehensive assessment of coastal flood hazards.

2.1.3 CICE

The CICE is a multi-categorical sea ice model (Hunke et al., 2017) which is used to model the dynamic and thermodynamic properties of sea ice when UFS-WM is applied in high-latitude regions (Rae et al., 2015). Sea ice affects air-sea fluxes, surface roughness, and momentum transfer between the atmosphere and ocean.There are several parameterizations which are included in CICE which aim to model these different aspects of the sea ice. When sea water freezes it forms a pure water crystal with microscopic brine inclusions, in CICE this is modeled with a mush layer thermodynamic model (Feltham et al., 2006). The material strength of the sea ice is parameterized using several different rheologies (Hunke et al., 1997; Hunke, 2001; Hunke et al., 2002). Parameterizations of ice ridging (Lipscomb et al., 2007), melt pond physics (Flocco and Feltham, 2007; Hunke et al., 2013) and land-fast ice (Lemieux et al., 2016) are also used within CICE . In the UFS, CMEPS manages the exchange of sea ice concentration, thickness, and other state variables between CICE and the ocean models, such as SCHISM.

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2.2 the UFS-Coastal component descriptions

While the UFS-WM was designed for global and regional weather prediction, the UFS-Coastal (Fig. 1) adapts the system for environments where coastal flooding, estuarine circulation, and wave-current interactions are critical. This is achieved by adding caps in each individual coastal ocean model to work on unstructured/structured grids, allowing flexible resolution in regions with complex coastlines, wetlands, and nearshore bathymetry.

These atmospheric fields (including surface winds, pressure, heat fluxes, and precipitation etc.) are ingested through CDEPS, maintaining consistency with the UFS-WM's data handling conventions while simplifying the workflow for regional coastal applications.

The UFS-Coastal retains the CMEPS coupling infrastructure, which manages real-time exchanges between the coastal ocean models, and WW3. This allows for two-way coupling between waves and coastal circulation, where wave radiation stress can influence nearshore currents and water levels, and evolving currents and water levels modify how waves propagate, break, and dissipate.

2.2.1 ADCIRC

ADCIRC is a finite-element, unstructured-grid hydrodynamic model that can be run either as a two-dimensional depth integrated (2DDI) model or as a three-dimensional (3D) model designed for simulating tidal dynamics, storm surge, and coastal flooding (Luettich and Westerink, 2004; Westerink et al., 2008; Hope et al., 2013). Its ability to represent large areas, such as entire coastlines or ocean basins, while also resolving small-scale features like inlets, levees, and estuarine channels, makes it particularly useful for storm surge forecasting and flood risk assessment.

ADCIRC has been extensively used in both research and operational environments, particularly for hurricane response (e.g., Hurricane Surge On-demand Forecast System, HSOFS), where it simulates the combined effects of storm surge, tides, and wave setup.

2.2.2 FVCOM

FVCOM is a depth-resolving unstructured-grid, finite-volume 3D hydrodynamic model designed to simulate tidal and estuarine circulation, nearshore dynamics, and particle transport (Chen et al., 2006; Chen et al., 2013). Its finite-volume formulation ensures accurate local conservation of mass and momentum, making it well-suited for environments with complex shorelines, irregular bathymetry, and strong tidal currents. FVCOM is commonly applied in studies of tidal flushing, estuarine exchange, and pollutant transport, and is often used to investigate how tides, river discharge, and winds drive circulation and mixing in estuaries and bays (Sun et al., 2016).

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2.2.3 SCHISM

SCHISM is another depth-resolving unstructured-grid baroclinic/barotropic hydrodynamic model designed to handle cross-scale coastal modeling problems, from shelf circulation to wetting and drying in tidal wetlands and floodplains (Zhang and Baptista, 2008; Zhang et al., 2016). Its dynamic core uses finite-element/finite-volume hybrid methods to efficiently solve the 3D shallow-water equations. Combined with its flexible grid in both the horizontal as well as the vertical dimension, and its efficient semi-implicit solver, it is capable of providing fine resolution in critical areas while maintaining reasonable computational cost for larger domains (i.e. 'seamless' cross-scale applications), without stringent requirement for mesh quality. Unlike most other ocean models, SCHISM does not practice bathymetry smoothing or manipulation, and is thus able to faithfully capture one of the most fundamental drivers of coastal and nearshore processes (Zhang et al., 2024).

One of SCHISM's strengths similar to the other coastal models is its ability to represent wetting and drying processes, which are critical for simulating coastal inundation, barrier island flooding, and tidal marsh evolution, as demonstrated by its in NOAA 3-D Surge and Tide Operational Forecast System (STOFS-3D). SCHISM with the biogeochemistry (BGC) capability and data assimilation (DA) is particularly well-suited for scenarios where water levels fluctuate across intertidal zones, floodplains, and estuarine wetlands, such as during storm surge events.

2.2.4 ROMS

ROMS (Regional Ocean Modelling System) is a 3D structured-grid hydrodynamic model that uses terrain-following vertical coordinates, making it well-suited for simulating processes where vertical stratification and mixing play important roles. ROMS is commonly used to study continental shelf circulation, upwelling and downwelling, and cross-shelf transport. (Shchepetkin and Mcwilliams, 2005; Moore et al., 2011)

ROMS' vertical grid flexibility and extensive turbulence closure options allow it to capture density-driven flows, such as river plumes interacting with shelf currents, as well as vertical mixing caused by tides and winds, which makes ROMS useful for studies of nutrient and sediment transport, as well as applications that involve physical-biogeochemical coupling with DA.

UFS-Coastal's ability to select from these four coastal models (ADCIRC, FVCOM, SCHISM, and ROMS) allows users to choose the most appropriate tool for the scientific or operational application at hand. By leveraging externally provided atmospheric forcing and maintaining dynamic coupling with CICE and WW3, the UFS-Coastal ensures that sea ice, wave, circulation, and flooding processes are represented consistently across all components.

2.3 Wave-Current Coupling Methods

Wave-current interaction plays an important role in the storm surge simulations with context-dependent spatial and temporal impacts on the total water level result (Warner et al., 2010; Sheng et al., 2010; Moghimi et al., 2013; Sun et al., 2013; Kerr et al., 2013; Garzon and Ferreira, 2016; Moghimi et al., 2020; Martins et al., 2022). UFS-Coastal provides two distinct wave-current coupling methods for transferring momentum and energy between wave and ocean circulation models: the Longuet-

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Higgins radiation stress formulation (Longuet-Higgins and Stewart, 1962, 1964) and the 3D vortex formalism(Uchiyama et al., 2010; Kumar et al., 2012). Both methods enable explicit representation of wave-induced effects within ocean circulation models but differ fundamentally in their implementation and level of complexity.

2.3.1 Longuet-Higgins Radiation Stress Coupling

The Longuet-Higgins radiation stress coupling method represents wave-induced currents and coastal water level setup through radiation stress gradients formulation (Longuet-Higgins and Stewart, 1962, 1964). In this formulation, WW3 computes wave properties, such as significant wave height, wave period, and wave direction, and radiation stresses are evaluated from the computed wave energy density(Moghimi et al., 2020a). These radiation stress terms are then passed directly to the coastal ocean model (SCHISM here as a case study), where they serve as surface forcing terms in the horizontal momentum equations. Consequently, the ocean model is able to simulate nearshore currents, wave setup, and associated coastal processes induced by wave action. The details are in S1.

In return, the ocean model provides WW3 with essential hydrodynamic fields, specifically water elevations and surface horizontal velocities, necessary for WW3 to accurately simulate wave transformation, refraction, and breaking. This two-way exchange ensures that wave propagation and wave-induced hydrodynamic responses are consistently represented across both models.

This coupling approach is suitable for scenarios where wave-induced nearshore processes are predominantly depth-integrated and surface-dominated, such as coastal inundation and storm surge modeling.

2.3.2 Three-Dimensional Vortex Coupling

In contrast, the 3D vortex coupling method equation explicitly represents the vertical distribution of wave-induced momentum transfer and mixing processes within the hydrodynamic model (Uchiyama et al., 2010; Bennis et al., 2011; Kumar et al., 2012). Rather than relying solely on surface-based radiation stresses, this approach accounts for wave-induced momentum fluxes throughout the entire water column, enabling realistic representation of vertical current shear, wave-induced turbulence, and wave-enhanced mixing in coastal and estuarine regions.

To facilitate this detailed coupling, WW3 exports several phase-averaged wave variables to SCHISM via CMEPS. These include eastward and northward Stokes drift currents, wave-induced Bernoulli head pressure, near-bottom wave orbital velocities, wave number and direction, total wave energy, and surface and bottom wave-induced stresses (Table S1). SCHISM utilizes these detailed wave parameters internally to calculate 3D momentum forcing terms and turbulence parameters associated with wave-induced vortex forces.

Additionally, SCHISM exports hydrodynamic fields back to WW3 via CMEPS, such as sea surface elevation, surface and depth-averaged velocities, surface Doppler velocities, and a wet/dry cell mask (Table S2). These variables allow WW3 to accurately represent wave conditions influenced by coastal currents, varying water levels, and wetting/drying processes. The details are in S2.

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This comprehensive coupling method is particularly advantageous for modeling scenarios where wave-current interactions exhibit pronounced vertical variability, influencing sediment transport, vertical mixing, and estuarine circulation dynamics. By offering both the Longuet-Higgins radiation stress approach and the vertically explicit 3D vortex approach, the UFS-Coastal provides users with the flexibility to select the coupling methodology best aligned with their scientific goals and computational resources, when using SCHISM.

2.4 Regression System

The UFS-Coastal regression testing (RT) framework plays an essential role in ensuring that model updates, code modifications, and new developments do not negatively affect model stability, scientific accuracy, or reproducibility. Given the complexity and modular nature of UFS-Coastal, systematic testing is vital for detecting unintended changes in model performance or results over different High Performance Computing System (HPCS). The regression system employs automated scripts and continuous integration practices to regularly verify that the model's scientific and numerical outputs remain consistent over time.

The regression system is based on a suite of predefined test cases representing various coastal and estuarine conditions, from simplified idealized scenarios to realistic storm events and high-resolution coastal domains. These test cases validate the performance and interaction of the different coupled components (ADCIRC, FVCOM, SCHISM, ROMS, CICE and WW3) under conditions relevant to coastal modeling, which are available from the the UFS-Coastal Github page and Zenodo. The abbreviation used for ADCIRC, FVCOM, SCHISM, ROMS in the RT system are ADC, FVC, SCH and ROM.

2.4.1 RT Script Operation

The primary tool for running regression tests is the automated script known as rt.sh. This script includes the testing process from model compilation, configuration and execution to comparing simulation outputs with established baseline datasets. Specifically, rt.sh prepares input files, initializes model components, compiles the codes, executes simulations, and compares critical model output variables and log files against previously validated reference solutions.

If outputs from a regression test exceed predefined tolerance limits compared to the baseline, rt.sh identifies and flags these deviations to the log files. This alerts developers to potential issues quickly, facilitating immediate investigation and resolution, thus maintaining the reliability of ongoing model development. The UFS-Coastal rt.sh has been tested on HPCS from Texas Advanced Computing Center (TACC), NOAA's Research and Development High Performance Computing Program (RDHPCS), NOAA's Weather and Climate Operational Supercomputing System (WCOSS), Mississippi State University (MSU) and the Parallel Works.

2.4.2 Workflow

The UFS-Coastal Application (UFS-Coastal-App) workflow (https://github.com/oceanmodeling/ufs-coastal-app) is built on the Unified Workflow Tools (uwtools), an open-source Python package developed for UFS applications, with dedicated drivers

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for SCHISM and WW3. The workflow uses YAML-based configuration files with Jinja2 template rendering and JSON Schema validation, and interfaces with the Rocoto workflow manager for task scheduling and dependency management on HPCS.

The workflow automates the key steps of a coupled coastal simulation: building model executables, generating component-specific configuration and namelist files, staging input data and mesh files, executing the coupled model, and collecting output. Users specify domain settings, forcing datasets, coupling intervals, and component-specific options through a single YAML configuration file, from which uwtools generates all necessary model inputs. Further details and practical examples are available in the UFS-Coastal Application documentation (https://ufs-coastal-application.readthedocs.io).

2.4.3 Continuous Integration and Continuous Deployment (CI/CD)

CI/CD practices are adopted within the UFS-Coastal development process to systematically integrate and validate model changes. The automated regression testing pipeline is managed using the Jenkins automation server (The Jenkins Project, 2024), deployed specifically on MSU's Hercules. Jenkins automatically triggers the execution of rt.sh regression tests nightly and whenever new code commits or merges occur in the repository.

The test script compiles the model, executes predefined test cases using either Rocoto (Harrop, 2015) for job scheduling, and compares outputs against archived baseline solutions stored in Amazon Web Services (AWS) S3 cloud storage. Deviations exceeding predefined tolerances are flagged automatically. Lightweight build and integration checks are additionally performed through GitHub Actions. The regression tests are validated with both Intel and GNU compilers. By continuously monitoring the UFS-Coastal codebase, Jenkins on Hercules ensures rapid detection of numerical inconsistencies, computational instability, or scientific deviations, providing immediate feedback to developers.

2.3.4 Regression Test Suite and Configuration

The regression test suite comprises a comprehensive set of standardized scenarios designed to validate both realistic and idealized coastal modeling applications within the UFS-Coastal. These tests include storm surge simulations, estuarine circulation scenarios, wave-current interaction studies, and simplified hydrodynamic benchmarks. Each scenario evaluates interactions within hydrodynamic models (ADCIRC, FVCOM, SCHISM, ROMS) or with the spectral wave model (WW3), ensuring robust functionality of the CMEPS-based coupling infrastructure. The current status and detailed description of the test cases can be accessed via the UFS-Coastal repository wiki page on GitHub (https://github.com/oceanmodeling/ufs-weather-model/wiki).

The test suite systematically verifies component functionality, coupling consistency, and model reliability across diverse forcing scenarios. It evaluates model stability, numerical accuracy, and computational efficiency across various configurations and computing architectures.

Baseline simulations for all RT cases are systematically archived in an AWS S3 cloud storage bucket. This structured archival system facilitates efficient and transparent comparisons between historical and current simulation outputs. Whenever

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discrepancies arise, they are flagged automatically, prompting a detailed review by developers. Such reviews determine whether differences represent expected numerical variability or indicate issues requiring immediate corrective actions.

This automated and structured regression testing approach significantly enhances scientific rigor, computational stability, and transparency, reinforcing community confidence in the reliability and performance of the UFS-Coastal modeling framework.

2.5 UFS-Coastal App

The UFS-Coastal-App is a comprehensive framework developed to facilitate coastal and regional-scale coupled modeling simulations within the UFS-Coastal. It is different from the RT system, as RT requires fast computation, the UFS-Coastal-App is for comprehensive large domain cases. This integration allows for flexible and modular configuration, enabling users to select the most appropriate modeling components based on specific scientific objectives and regional modeling requirements. A key feature of the UFS-Coastal-App, as a part of UFS-Coastal is its standardized modeling workflow, encompassing model setup, input data processing, execution, and output post-processing. This structured workflow supports efficient deployment and reproducibility across multiple HPCS platforms, facilitating ease of use and consistency in modeling practices. The application's design provides flexibility in specifying key modeling parameters, such as computational domains, spatial resolutions, coupling intervals, and model-specific physics options, allowing users to tailor simulations precisely to their coastal and estuarine modeling needs as a template.

Additionally, the UFS-Coastal-App includes comprehensive documentation that guides users through installation, configuration, model execution, and data management steps, making the tool more accessible to a broad range of coastal scientists, operational forecasters, and stakeholders. Practical examples of larger-domain and operational-scale coastal modeling applications are provided within the UFS-Coastal-App repository (https://github.com/oceanmodeling/ufs-coastal-app), demonstrating the system's capability and scalability for addressing diverse coastal phenomena, including storm surge, wave-current interactions, and flooding events at operationally relevant scales.

3 Experimental Configurations and Results

3.1 Hurricane Sandy in Duck, North Carolina

To evaluate the UFS-Coastal modeling system comprehensively, a series of experiments were conducted for both large-scale storm events and small-scale nearshore hydrodynamics. Specifically, we conducted simulations focused on Hurricane Sandy (2012) storm surge event, complemented by and performed a series of detailed model validation tests in the Duck, NC region, which will be later used as regression tests.

Hurricane Sandy made landfall as a post-tropical cyclone near Atlantic City, New Jersey, on 29 October 2012 (Fig. 2a) (Fanelli et al., 2013). Sandy's trajectory and extensive geographic scale made it one of the most severe storm surge and coastal flooding events on record along the U.S. East Coast (Fanelli et al., 2013). Originating as a tropical cyclone in the southwestern Caribbean Sea, Sandy moved northward parallel to the U.S. Atlantic coastline before sharply turning northwest toward the mid-Atlantic

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region. The storm's center passed approximately 450 kilometers offshore to the east-northeast of Duck, NC, before making landfall further north. Sandy's large wind field extended hundreds of kilometers from its center, producing substantial storm surges, powerful waves, and coastal erosion along extensive stretches of coastline, including the Outer Banks, NC.

The Duck, NC coastal region (Fig. 2b) was specifically selected for detailed validation experiments due to its well-documented observational record (Newberger and Allen, 2007; Moghimi et al., 2013; Martins et al., 2022), maintained by the USACE FRF. Established in 1977, Duck FRF provides comprehensive observational datasets, including wave characteristics, water-level measurements, meteorological data, bathymetric surveys, and current profiles(Fig 2b,c). The region is characterized by a gently sloping sandy beach transitioning smoothly to offshore depths, making it ideal for evaluating coastal wave transformations, storm-induced currents, and water-level changes.

A systematic set of numerical simulations was conducted for the Duck region, driven by atmospheric forcing consisting of spatially homogeneous but temporally varying wind velocities and atmospheric pressures obtained from observational measurements by the "FRF 26m Array" operated by the USACE Coastal Observation and Analysis Branch (COAB) (Fig. 3b,c). The maximum wind speed appeared on October 29, 2012, 00:00 UTC in the Duck region. The atmospheric forcing data (wind and pressure) in these experiments was provided through CDEPS and was integrated with both WW3 and SCHISM via CMEPS, facilitating consistent data exchange and coupling.

Experiments conducted (Table 1) at Duck included:

(1) Wave simulations using WW3(ATM+WW3) (Case #1&2),

(2) Hydrodynamic simulations using SCHISM (ATM+SCH) (Case #3), and

(3) Fully two-way coupled wave-current simulations integrating SCHISM and WW3 (ATM+SCH+WW3), using two distinct wave-current coupling methodologies: the traditional Longuet-Higgins radiation stress method (Case #4) and the advanced 3D vortex coupling approach (Case #5).

All of the Duck experiments utilized a common unstructured computational mesh consisting of 23,018 nodes and 46,034 triangular elements for both SCHISM and WW3(Fig. 2b). The spatial resolution ranged from approximately 45 m near the shoreline to roughly 1500 m offshore. Observationally derived atmospheric forcing from Duck FRF data (Fig. 3b,c) was uniformly applied spatially and varied temporally to provide realistic and consistent simulation conditions for detailed model validation. The timespan of all experiments (Case #1-5) was 2.33 days, from October 27, 2012, 00:00 UTC to October 29, 2012, 04:00 UTC, which covers the passage of Hurricane Sandy over the study region

3.2 Experiments

A systematic series of numerical experiments (Table 1) were performed to comprehensively evaluate the predictive capabilities of the UFS-Coastal modeling system for the Duck region. These experiments incrementally validated individual model components as well as their coupled effects. Each experiment utilized the consistent computational mesh, observational datasets, and observational atmospheric forcing conditions that were described in Section 3.1. The following subsections detail the experimental setups, validation processes, and rationale for each set of comparisons.

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3.2.1 ATM + WW3

The initial experiments specifically evaluated the wave modeling performance of WW3, driven by observational atmospheric forcing. The primary objective was to assess WW3's capability to predict key wave parameters, including significant wave heights, wave periods, and directional spectra, under realistic coastal conditions. Establishing a reliable wave-modeling baseline was critical, as accurate wave predictions are essential for successful coupled wave-current simulations.
The differences of Case 1&2 is that the CDEPS provided the water elevation at FRF8m (Fig.2c, Fig. 3a) via CMEPS to WW3 in Case 2, while no water elevation forcing is used in Case 1. Simulations conducted with WW3 were extensively validated against wave buoy observations collected at the Duck FRF site. The rationale for this validation was to ensure WW3 accurately represented nearshore wave processes, enabling subsequent coupled-model experiments to confidently attribute any observed improvements to explicit wave-current interactions rather than fundamental wave-model performance (Fig. 4).

3.2.2 ATM + SCH

The experiments independently validated the SCHISM hydrodynamic model driven by the same observational atmospheric forcing. The water elevation at FRF8m was used as an open boundary condition here. The purpose of this validation was to confirm SCHISM's reliability in simulating coastal hydrodynamics-including water-level fluctuations, storm-induced surges, and nearshore circulation without the influence of wave-induced processes. Establishing SCHISM's standalone accuracy was crucial for clearly attributing subsequent coupled-model improvements specifically to wave-current interactions.

3.2.3 ATM + SCH + WW3 (Longuet-Higgins and vortex Coupling)

The most comprehensive experiment sets involved fully coupled wave-current simulations integrating SCHISM and WW3 under observational atmospheric forcing. This experiment explicitly evaluated two distinct wave-current coupling methodologies: the widely used Longuet-Higgins radiation stress method and the advanced 3D vortex coupling approach, previously described in Section 2.2.5.
The rationale for comparing these two coupling approaches was to explicitly investigate the advantages of resolving vertical momentum exchanges and wave-induced turbulence, as well as to evaluate if those formulations were implemented correctly in the UFS-Coastal. The Longuet-Higgins method served as a well-established benchmark, particularly useful for capturing surface-driven wave setup and currents. In contrast, the 3D vortex coupling method explicitly resolved vertical wave-induced momentum transfers and turbulent mixing, potentially offering significant improvements in modeling accuracy for vertically stratified coastal zones, nearshore circulation, and sediment transport processes.
Both coupling approaches utilized identical computational meshes, observational forcing conditions, and initial setups, ensuring direct comparability. Model outputs (including coastal water levels, wave conditions, and nearshore currents) were validated against extensive observational datasets from Duck FRF.

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3.3 Results

Fig. 4 demonstrated robust agreement between modelled and observed wave characteristics, confirming WW3's standalone (#1 & #2) accuracy as a critical baseline for further coupled studies. With including water elevation forcing, #2 clearly improves the significant wave height (Hs), especially in the shallower region (Fig. 4 and Table 2). The Longuet-Higgins method was generally accurate for representing wave-induced setup and flow patterns; however, it inherently lacked the capability to resolve vertical momentum transfers and associated turbulent mixing. In contrast, the 3D vortex coupling method captured these vertical complexities, leading to improved accuracy in storm surge predictions, particularly in regions where vertical gradients in velocity and turbulence are significant. Wave simulations revealed only subtle differences between the two coupling approaches, especially in the deeper stations, as both effectively reproduced observed nearshore wave conditions. Nonetheless, during peak storm activity characterized by intensified wave-current interactions, the 3D vortex coupling method exhibited slightly better skill in capturing wave transformations and energy dissipation processes, reflected in improved predictions of significant wave height and directional spectra (Fig. 4 and Table 2).

Fig.5 was the comparisons between modelled and observed water levels to assess SCHISM's ability to accurately simulate observed coastal hydrodynamic conditions independently, the results of #3 ensured confidence in its fundamental predictive performance prior to coupled-model experiments. Comparative evaluations of sea-surface elevations indicated that both coupling methods effectively captured overall storm surge magnitudes, phase and patterns, ignorable differences between experiments #3#4 and #5 were shown in all stations due to the small geodomain (Fig. 5).

The most substantial improvement from the 3D vortex coupling was evident in the modelled vertical structure of nearshore currents. Vertical velocity profiles and associated turbulence metrics obtained from the 3D vortex simulations aligned closely with real observations, capturing the vertical gradients and mixing patterns missing in the Longuet-Higgins approach. Spatial distributions and vertical cross-sections of simulated current velocities (Fig. 6) provided clear evidence of enhanced realism and accuracy using the 3D vortex method compared to the depth-integrated approach, highlighting the critical role of vertical momentum exchanges and turbulence in accurately capturing nearshore hydrodynamics. This vertical resolution is critical for accurate predictions of sediment transport, pollutant dispersion, and ecological processes in coastal systems.

Sensitivity analyses performed on coupling interval frequency and internal model time-step settings indicated clear trade-offs between computational efficiency and model accuracy. Specifically, shorter coupling intervals and finer internal time-steps enhanced predictive accuracy, particularly for the 3D vortex coupling method, due to its detailed representation of vertical processes. However, these improvements came with increased computational costs. Eventually, 300 seconds exchange frequency is chosen here. Optimal operational configurations thus depend on specific modeling objectives, available computational resources, and the particular importance of resolving detailed vertical hydrodynamics.

In summary, the numerical experiments presented in this section have systematically validated the performance and reliability of the UFS-Coastal modeling system. Standalone evaluations and fully coupled wave-current simulations at Duck, NC demonstrated the accuracy and robustness of WW3 and SCHISM, particularly highlighting the advantages of the 3D vortex

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coupling in capturing complex vertical dynamics in coastal environments. The validation against observational datasets from Duck FRF confirmed the effectiveness of UFS-Coastal in predicting storm surge, wave conditions, and nearshore circulation.

4 Discussion and conclusion

This study has presented a comprehensive description, systematic validation, and detailed evaluation of the UFS-Coastal modeling framework (an advanced extension of the UFS-WM) developed specifically to enhance predictions of coastal and nearshore processes. The core advancement of UFS-Coastal lies in its integration of specialized coastal hydrodynamic models (SCHISM, ADCIRC, FVCOM, and ROMS), the wave model WW3 and the sea ice model CICE, coupled through the flexible and modular CMEPS infrastructure, significantly improving predictive capabilities in coastal environments.

Experimental validations conducted at Duck, NC, rigorously assessed individual model components as well as their interactions within fully coupled model configurations. Validation results confirmed robust performance of each modelling component: WW3 accurately reproduced observed nearshore wave conditions, including significant wave heights and spectral characteristics, while SCHISM reliably predicted observed coastal water-level variations, storm-induced surges, and nearshore circulation.

A key contribution of this study was the explicit evaluation and comparison of two distinct wave-current interaction methodologies: the traditional Longuet-Higgins radiation stress formulation and the advanced 3D vortex coupling method. While both methods successfully captured overall storm surge magnitudes and nearshore wave characteristics, important distinctions emerged. The depth-integrated Longuet-Higgins approach accurately represented wave-driven coastal setup and flows, effectively handling scenarios dominated by surface and depth-integrated processes. In contrast, the advanced 3D vortex coupling provided significant improvements by explicitly resolving vertical momentum transfers and turbulent mixing, leading to enhanced realism in modeling vertical current structures, mixing processes, and vertical gradients critical for sediment transport, pollutant dispersion, and ecological modeling.

Sensitivity analyses conducted in this study further provided practical guidance regarding optimal model configuration, explicitly addressing the balance between predictive accuracy and computational efficiency, particularly when applying the computationally intensive 3D vortex coupling approach.

Moving forward, the development roadmap for UFS-Coastal includes several key enhancements to further expand its predictive capabilities and usability:

(1) Future developments will incorporate fully dynamic atmospheric coupling by integrating the atmospheric model Geophysical Fluid Dynamics Laboratory (GFDL) Finite Volume Cubed-Sphere Dynamical Core (FV3) within the UFS-Coastal, replacing the current simplified observational atmospheric forcing. This enhancement will enable more realistic representation of air-sea-wave interactions during rapidly evolving storm conditions.

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(2) The UFS-Coastal also plans to integrate advanced biogeochemical and ecological modeling components, enabling the system to address a broader array of coastal issues, such as hypoxia prediction, harmful algal blooms, ecosystem health assessments, and pollutant transport scenarios.
(3) The UFS-Coastal will further foster community collaboration through open-source development practices, providing extensive documentation, training, and user support resources. This community-based approach will encourage wider adoption, shared innovation, and ongoing improvement from the broader scientific and operational forecasting communities.
In summary, the UFS-Coastal presents substantial advancements in both scientific understanding and practical forecasting capability compared to existing coastal modeling frameworks. Its modular structure, advanced 3D wave-current interaction capabilities, demonstrated scalability, and clearly defined roadmap for continuous enhancement firmly establish it as a vital predictive tool for coastal scientists, resource managers, and operational forecasting agencies.

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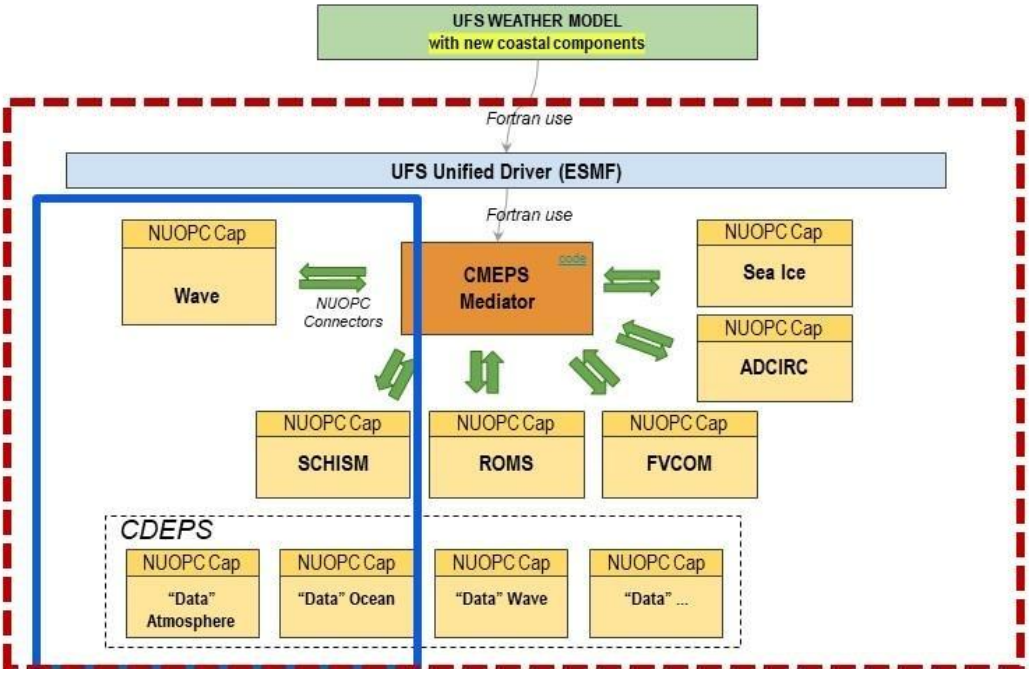
517 **Figure and Tables**

518



519

520 Figure 1. The UFS-Coastal modeling system architecture (the red dash box), the components in the blue box are the models
521 used in this study.

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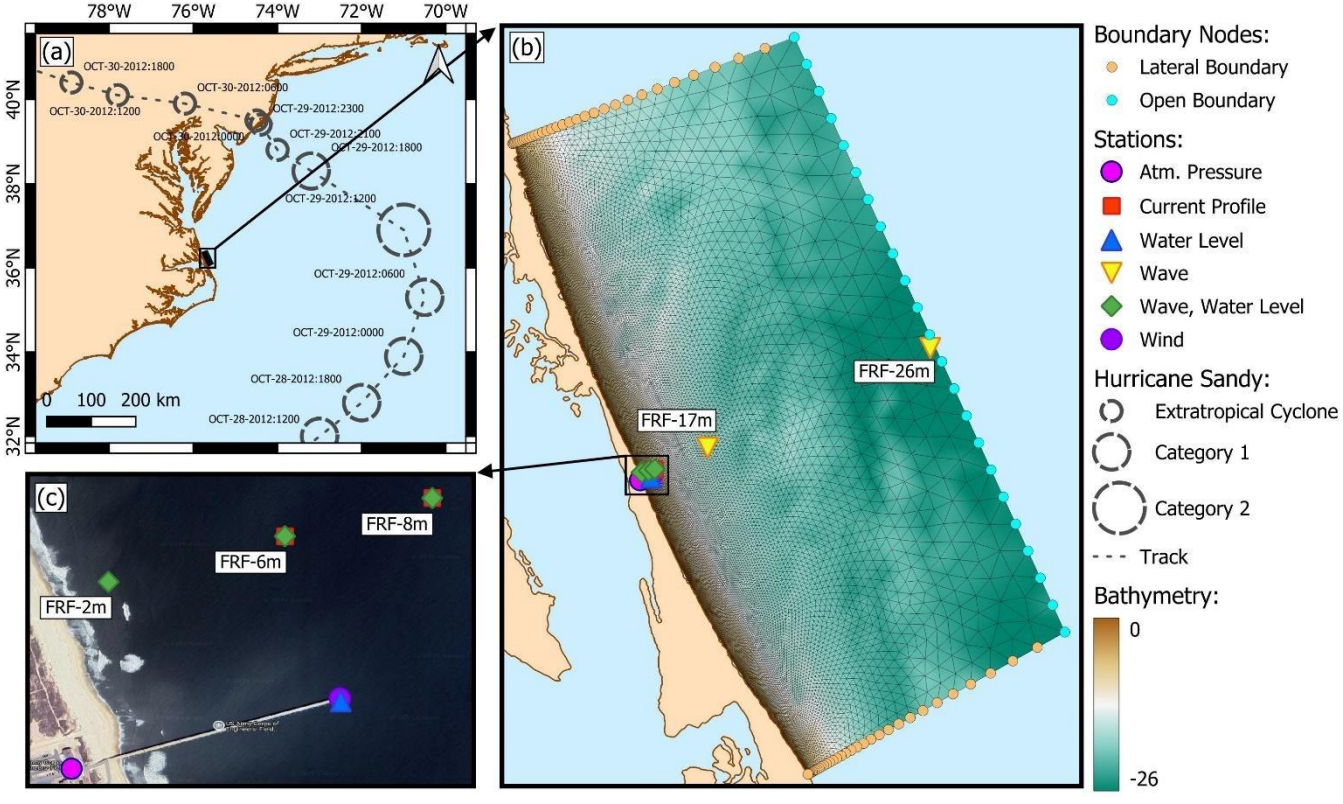

Figure 2. Hurricane Sandy's track is shown in (a), the study region Duck, NC is shown with the zoom in (a) and zoomed out view (b) of the unstructured triangular mesh. The unstructured grid consists of 23,018 nodes and 45,167 elements, with depths represented by the color scale (in meters), (c) zoom in the box in (b). The mesh demonstrates increased resolution near the coastline and areas of interest while maintaining computational efficiency with coarser resolution in the offshore regions. The observation stations are labelled in (b) and (c). Coastlines in (a) and (b) use the Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG, https://www.ngdc.noaa.gov/mgg/shorelines/shorelines.html). Hurricane Data in (a) is from the International Best Track Archive for Climate Stewardship (IBTrACS, https://www.ncei.noaa.gov/products/international-best-track-archive). Basemap in (c) is using Google Maps Satellite Imagery.

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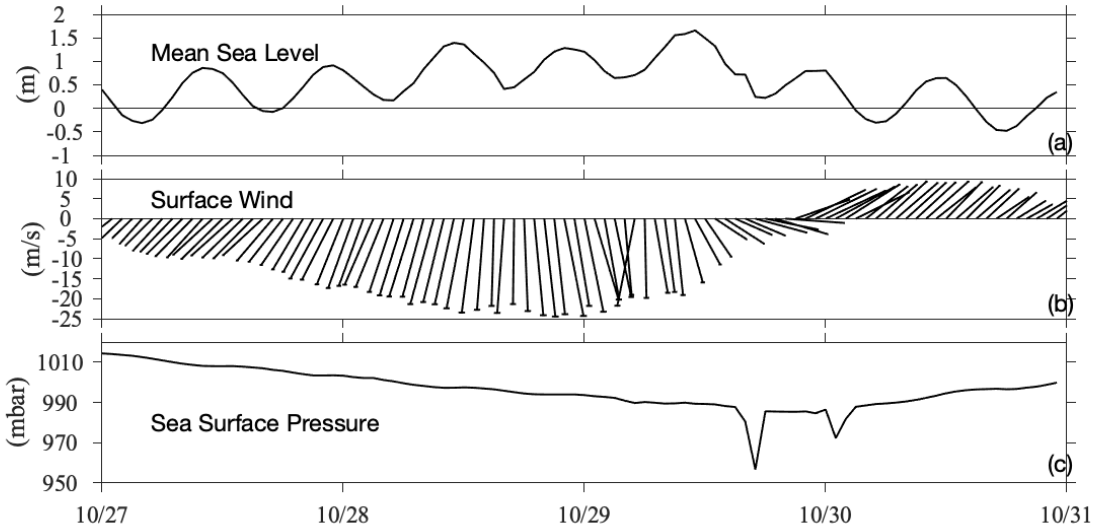

Figure 3. The observed atmospheric and oceanic forcing during the passage of Hurricane Sandy in the Duck, NC

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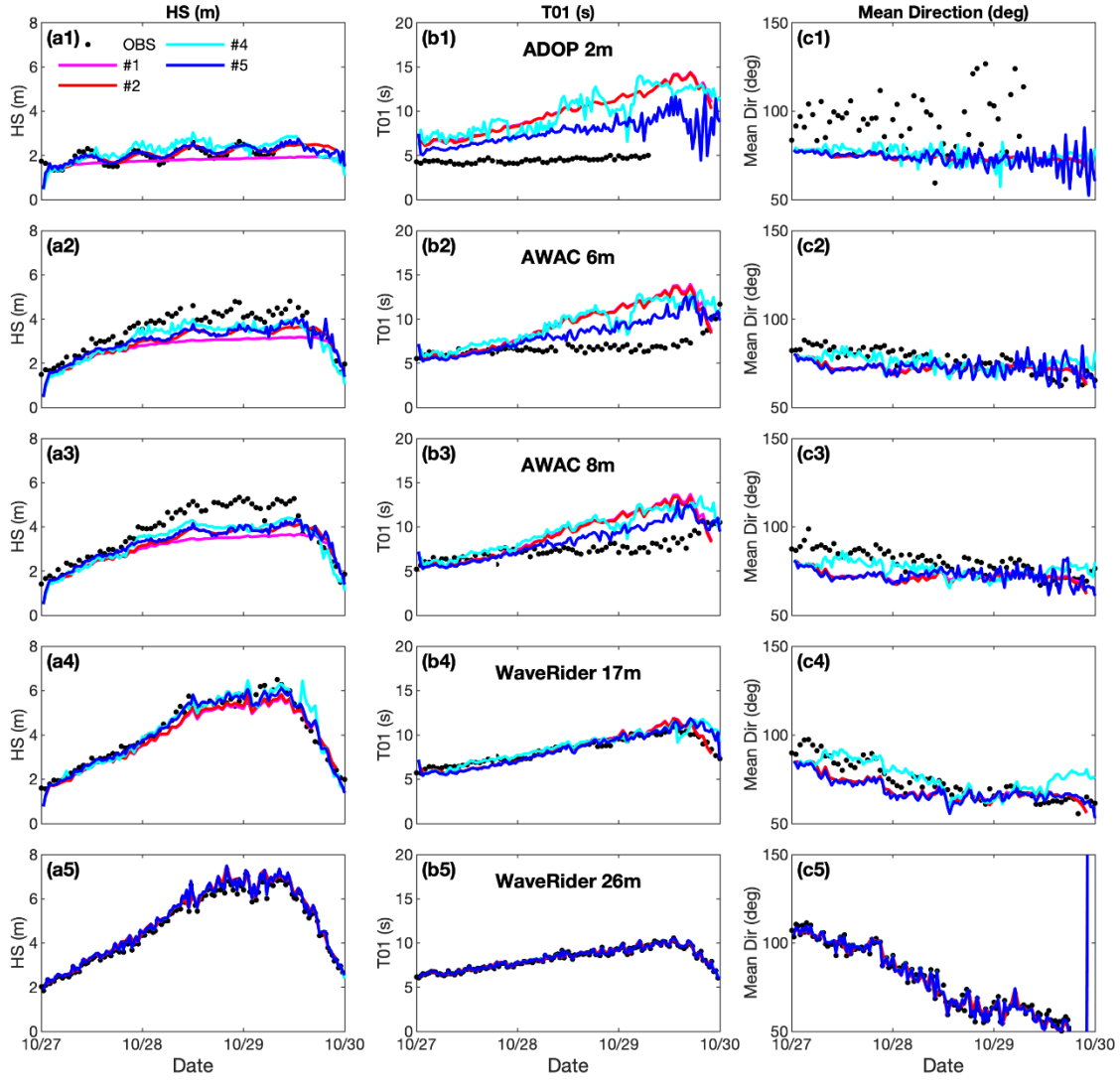

540

541 Figure 4. Significant wave height, Mean time period, and mean direction comparisons between observations and numerical
542 experiments #1, #2, #4, #5. The 5 stations are shown in Fig. 2.

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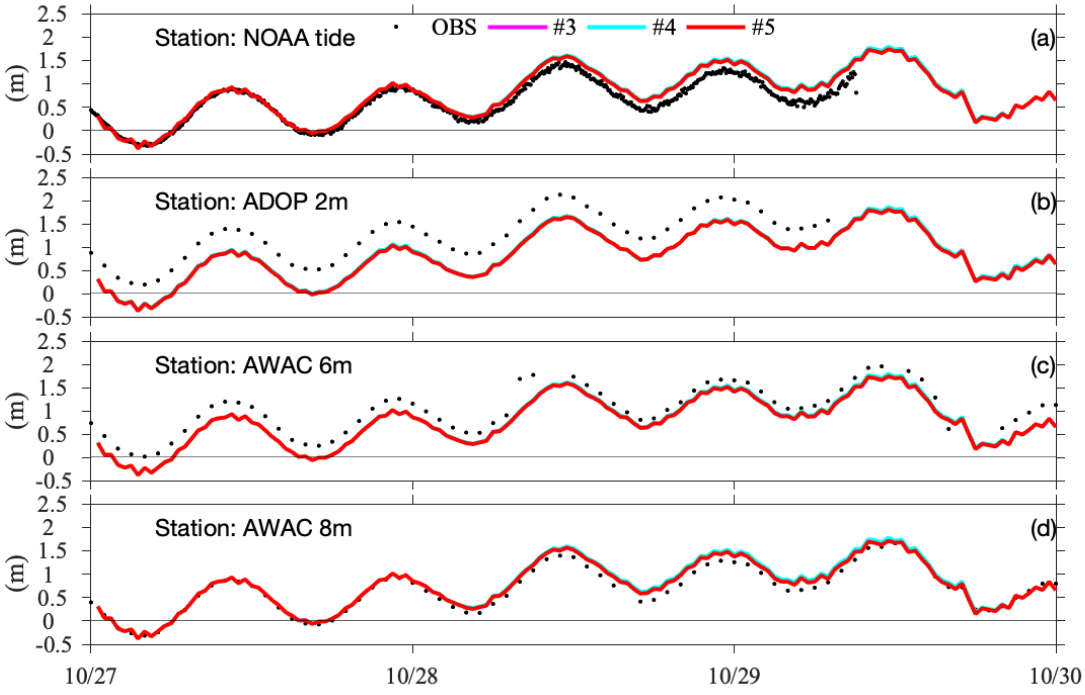

Figure 5. Water elevation comparisons between observations and numerical experiments #3, #4, #5. The 4 stations are shown in Fig. 2.

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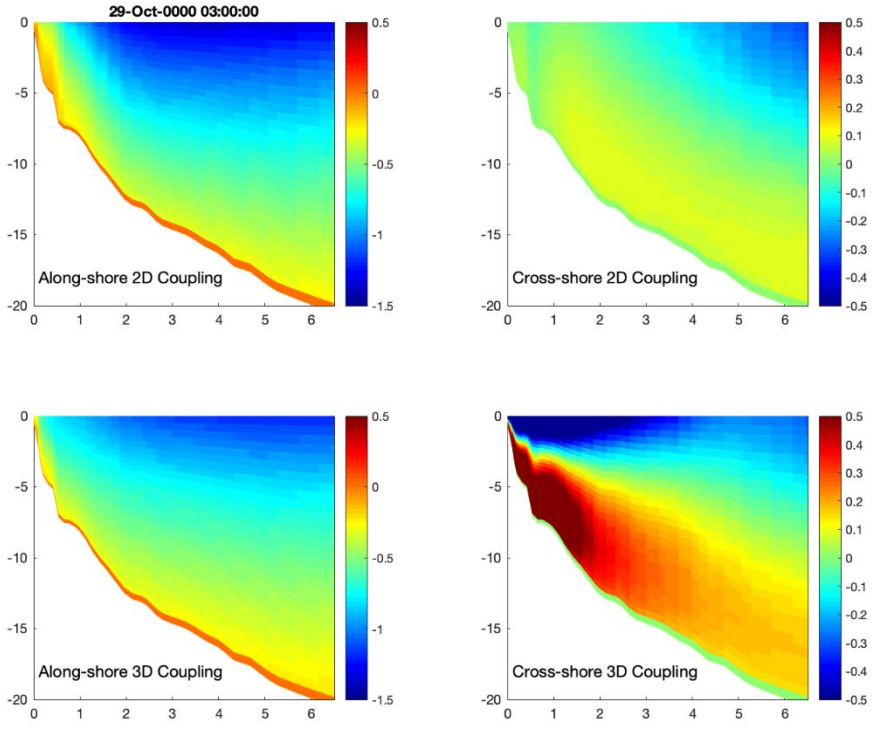

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550 Figure 6. The along shore and cross shore velocity components from coast to awac6m station at the time of 03:00 October 29
551 2012 as a typical scenario.

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Table 1. Details about the 6 experiments

Case	Components	Details
#1	ATM+WW3	Without water elevation forcing
#2	ATM+WW3	With water elevation forcing
#3	ATM+SCH	
#4	ATM+SCH+WW3	Longuet-Higgins Radiation Coupling
#5	ATM+SCH+WW3	3D Vortex Coupling

Table 2. Statistics of the wave parameter between the observation and experiments, Significant wave height (Hs), Mean period (T01), Mean direction (Dir), Root Mean Square Error (RMSE), Mean Absolute Error (MAE)

Instrument	Variable	#1			#2			#4			#5		
		Bias	RMSE	MAE	Bias	RMSE	MAE	Bias	RMSE	MAE	Bias	RMSE	MAE
ADOP 2m	HS	-0.25	0.38	0.30	0.00	0.20	0.17	0.20	0.39	0.33	0.04	0.20	0.15
	T01	4.63	4.92	4.63	4.58	4.89	4.58	4.60	4.94	4.60	2.76	2.90	2.76
	Dir	-19.40	24.03	19.98	-19.66	24.23	20.22	-18.26	22.50	18.80	-19.62	23.52	20.01
AWAC 6m	HS	-0.85	0.97	0.86	-0.64	0.75	0.67	-0.50	0.55	0.50	-0.53	0.66	0.58
	T01	2.63	3.51	2.78	2.52	3.40	2.68	2.55	3.19	2.58	1.43	2.09	1.64
	Dir	-3.96	7.08	6.05	-4.48	7.35	6.29	-1.00	6.39	5.23	-3.95	8.08	6.88
AWAC 8m	HS	-0.85	1.05	0.89	-0.66	0.84	0.74	-0.55	0.67	0.56	-0.56	0.78	0.65
	T01	1.85	2.74	2.17	1.73	2.63	2.07	1.98	2.52	2.05	0.93	1.66	1.29
	Dir	-7.82	9.75	8.38	-8.41	10.16	8.88	-4.22	7.32	6.49	-7.80	10.09	8.69
WaveRider 17m	HS	-0.26	0.41	0.34	-0.22	0.37	0.31	0.01	0.40	0.27	-0.04	0.26	0.19
	T01	0.05	0.61	0.50	0.02	0.59	0.48	0.33	0.81	0.52	0.03	0.74	0.55
	Dir	-4.41	7.22	5.89	-4.81	7.39	6.10	2.63	7.90	6.21	-5.19	7.93	6.56
WaveRider 26m	HS	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.13	0.12	0.12	0.14	0.13
	T01	0.05	0.08	0.06	0.05	0.08	0.06	0.05	0.10	0.07	0.04	0.10	0.07
	Dir	-0.63	2.25	1.52	-0.63	2.25	1.52	-0.40	2.77	1.64	-0.60	2.74	1.64
Mean	HS	-0.42	0.59	0.51	-0.28	0.46	0.41	-0.14	0.43	0.36	-0.19	0.41	0.34
	T01	1.84	2.37	2.03	1.78	2.32	1.98	1.90	2.31	1.96	1.04	1.50	1.26
	Dir	-7.24	10.07	8.36	-7.59	10.27	8.60	-4.25	9.37	7.67	-7.43	10.47	8.76

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Code and data availability

The version of the UFS-Coastal modeling system used in this study, including the workflow, the active model components (CICE and WW3), and the input files required to reproduce the results presented in this paper, is archived on Zenodo at https://doi.org/10.5281/zenodo.18458640 (Sun, 2026) under the Lesser GNU Public License v3. Because the individual components of the UFS-Coastal system are pinned by Git commit hashes rather than released under independent version numbers, the exact configuration used here is captured by the single project-level tag v1.0.0b01 This tag records the specific commit of every component in the coupled system, and the complete list of component repositories and their corresponding commit hashes is included in the archived release.

Author contributions

YS: conceptualization, methodology, UFS-Coastal code development, workflow development and implementation, data curation, visualization, validation, writing (original draft). UT: conceptualization, methodology, UFS-Coastal code development, workflow development and implementation, writing (review and editing). MJ: conceptualization, methodology, UFS-Coastal code development, workflow development and implementation, writing (review and editing HY: conceptualization, methodology, UFS-Coastal code and SCHISM development, workflow development and implementation, validation. JZ: conceptualization, methodology, UFS-Coastal code and SCHISM development, writing (review and editing). CL: conceptualization, methodology, UFS-Coastal code and SCHISM development, writing (review and editing). AA: conceptualization, methodology, UFS-Coastal code and WW3 development, workflow development and implementation, data curation, writing (review and editing). DW: conceptualization, methodology, UFS-Coastal code and WW3 development.). IT: UFS-Coastal project management, writing (review and editing). JH: conceptualization, UFS-Coastal project management, writing (review and editing). PV: UFS-Coastal code development, writing (review and editing). FC: workflow development and implementation, visualization, writing (review and editing). SM: workflow development and implementation. FD: workflow development and implementation, writing (review and editing). SB: WW3 development. AS: WW3 development. JS: UFS-Coastal: CICE development, writing (review and editing). EM: conceptualization, UFS-Coastal project management. SM: conceptualization, UFS-Coastal project management, writing (review and editing).

Competing interests

The authors declare that they have no conflict of interest.

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