Development of a Coupled FVCOM-NWM Model for Ocean–Hydrology Interaction

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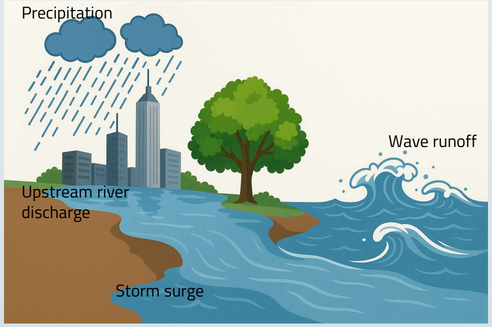
Abstract

An ocean–hydrology coupling framework was developed by integrating the National Water Model (NWM) with the Finite Volume Community Ocean Model (FVCOM) via the Earth System Modeling Framework (ESMF). This online coupling enables the dynamic and continuous injection of river discharge from NWM into FVCOM, improving the representation of coastal–riverine interactions. River discharge from NWM's one-dimensional river network is mapped onto FVCOM's unstructured coastal grid, enabling data exchange across models with differing spatial structures. A new approach, the Route-Informed Discharge Injection (RIDI) method, is then applied to distribute river discharge along the routing network rather than concentrating it at a single coastal point. By spreading the freshwater input over a broader region, RIDI reduces abrupt elevation gradients and enhances numerical stability, particularly in high-resolution unstructured grids. As NWM does not simulate water temperature, river temperature is incorporated using either offline outputs from the Water Balance Model (WBM) or predictions from a pre-trained Physics-Informed Neural Network (PINN) based on hydrologic and meteorological inputs. River salinity is defined empirically or based on observations. The coupled system is applied to the Casco Bay region in the Gulf of Maine to simulate a compound flood event driven by the interaction of storm surge and inland runoff. The current design also retains the potential for coupling with a wave model (SWAVE) and an atmospheric model (WRF) within the same ESMF-based framework.

Background

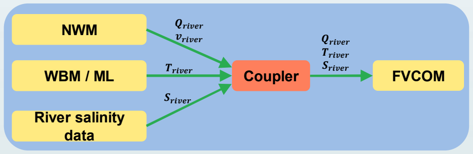


Compound flooding occurs when multiple flooding sources act together within a short period of time. These sources include storm surge, wave runoff, precipitation, and upstream river discharge. While traditional models often treat ocean and hydrology separately, this separation limits their ability to represent compound flooding events accurately. An integrated modeling framework is needed to capture the dynamic interactions among these processes and improve prediction of coastal flood risk. In addition, coupling hydrology with the ocean model enhances the simulation of estuarine and nearshore environments, improving the representation of water quality, fisheries, and sediment transport in these regions.

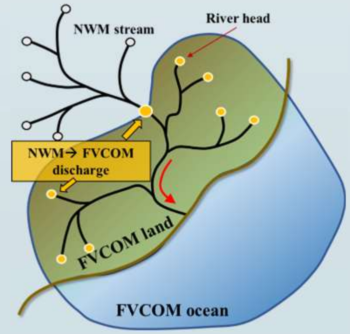
Coupled Model Framework

The coupled FVCOM–NWM system is developed within the Earth System Modeling Framework (ESMF), which provides the infrastructure for model integration and parallel execution. The coupling is implemented in an online method, so changes in river discharge from NWM are immediately transferred to FVCOM during the simulation. Both FVCOM and NWM retain their original parallel computing strategies, while ESMF coordinates data exchange and synchronization across processors. The current design also retains the potential for coupling with a wave model (SWAVE) and an atmospheric model (WRF) within the same ESMF-based framework, supporting the development of a fully integrated atmosphere–wave–ocean–hydrology system.

Exchanged Variables
Four variables are exchanged between NWM and FVCOM: river discharge, velocity, temperature, and salinity. River discharge and velocity are directly simulated by NWM and serve as dynamic boundary forcing conditions for FVCOM. Since NWM does not simulate river temperature, our coupled system provides two options: (1) using results from the Water Balance Model (WBM), or (2) applying a machine learning approach trained on historical river temperature data to generate forecasts. River salinity is user-defined, typically prescribed empirically or based on previous studies and observations.



Mapping Across Models
FVCOM employs an unstructured triangular mesh well-suited for representing complex coastlines and estuaries, while NWM uses a one-dimensional RouteLink river network. Because of these fundamental differences, variable exchange requires explicit mapping. In our implementation, freshwater inputs from NWM are injected into FVCOM at river heads—the joint points where NWM streamlines intersect with the FVCOM land–ocean boundary. This approach ensures that discharge and velocity from NWM are consistently transferred into the FVCOM domain, preserving the physical connection between rivers and the coastal ocean.



Route-Informed Discharge Injection (RIDI)

Traditional approaches inject all river discharge into the ocean at a single coastal point (point-source method). This approach is acceptable in low-resolution models, but as the resolution increases to several meters, concentrating discharge into a single grid cell often leads to abrupt water elevation gradients and numerical instabilities. To overcome this limitation, we developed the Route-Informed Discharge Injection (RIDI) method. RIDI distributes river discharge along the routing network, following the natural pathways of rivers as they approach the ocean. The spatial extent of injection is determined by the river velocity and the model time step, ensuring a physically consistent distribution of freshwater inputs.

A key challenge in applying the RIDI method is defining the routing network with sufficient spatial detail. The resolution of NWM's RouteLink network (tens of meters to kilometers) is much coarser than that of FVCOM (up to ~5 m). To bridge this gap, we incorporated high-resolution river geometry from the National Hydrography Dataset (NHD) provided by the U.S. Geological Survey. With resolutions down to 10 m, NHD offers more precise river channel information, enabling accurate mapping of freshwater pathways into FVCOM.

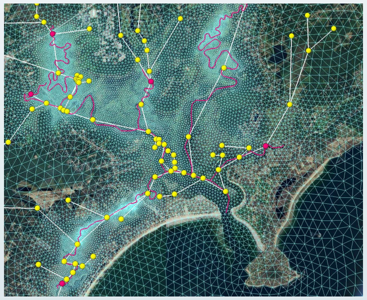
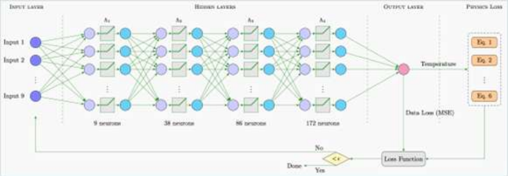


Illustration of the RIDI routing network. Pink line: NHD river segments; White line: NWM RouteLink; Yellow points: NWM nodes; Pink points: selected injection locations in FVCOM.

Machine Learning for River Temperature

The NWM does not simulate river temperature, yet realistic thermal inputs are critical for estuarine and coastal dynamics. To provide this missing variable, our coupled framework incorporates river temperature through either offline simulations from the Water Balance Model (WBM) or a machine learning–based approach.
We evaluate three modeling approaches for short-term river temperature prediction: a physics-based model derived from the Water Balance Model, a data-driven multilayer perceptron (MLP), and a physics informed neural network (PINN). All models use the same set of meteorological and hydrological inputs from the Isinglass River in New Hampshire, covering 2021 to 2024.



Results show that the MLP achieves the best one-hour forecast accuracy with RMSE around 0.14, followed by the WBM-Based Model (RMSE=0.16–0.17). The PINN performs less accurately (RMSE=~0.19), possibly due to constraints imposed by the simplified physics. A 24-hour iterative forecast using the PINN shows error accumulation over time, though the model retains diurnal trends. Future work will focus on using PINN for parameter estimation, improving network architecture for long-term forecasts, and applying the framework to additional river systems.

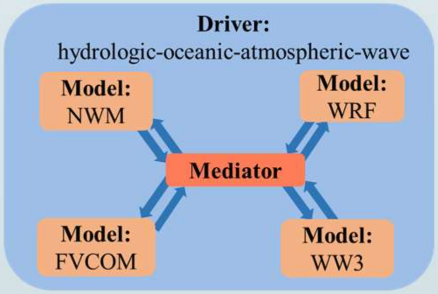
RMSE	WBM-based	MLP	PINN
Training	0.17	0.15	0.20
Tuning	0.16	0.14	0.19

Summary & Future Work

Summary
We developed an ESMF-based coupled FVCOM–NWM system with online river–ocean data exchange. The new RIDI method improves the stability and realism of freshwater injection, while high-resolution meshes and machine learning–predicted river temperatures enhance the representation of estuarine and coastal processes.

Future Work

- Expand to Hampton River: The coupled system has been successfully tested in the Saco Bay model. Our next step is to apply it to the Hampton River system, which features more complex river–estuary interactions, to further evaluate the robustness and adaptability of the RIDI approach.
- Regional-scale application: We plan to extend the framework to the entire Northeast U.S. coastal region, incorporating all rivers represented in the NECOFS model. This will enable a more comprehensive assessment of compound flooding hazards and riverine impacts across the region.
- Toward full integration: Building on the current FVCOM–NWM coupling, we aim to achieve a fully integrated ocean–hydrology–atmosphere–wave system within the ESMF framework. This four-way coupling will allow more realistic simulations of coastal processes and support advanced forecasting of extreme events.



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