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[KSxAOV1I-23] Accelerating Science-Based Coastal Protection: an AI Emulation Framework for Nature-based Solutions

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Nature-based Solutions (NbS), such as seagrass meadows, are increasingly recognized as infrastructure for mitigating coastal hazards including extreme waves, storm surges, and shoreline erosion. However, designing and optimizing NbS interventions requires evaluating countless "what-if" scenarios with varying plant phenotypic traits, species compositions, and spatial meadow layouts. While physics-based numerical models accurately capture these complex ocean–vegetation interactions, their high computational cost creates a severe bottleneck that prevents their integration into real-time Digital Twins of the Ocean (DTOs).
To overcome this limitation and enable rapid optimization of coastal resilience strategies, we present an AI-based surrogate modeling framework designed for ocean fields emulation within a DTO architecture. Multiple data-driven surrogate models, ranging from ensemble tree methods (Random Forest, LightGBM) to deep convolutional networks, have been evaluated to identify the optimal architecture for learning complex spatial flow regimes.
A U-Net-like deep learning architecture provided best results. The model was trained on a synthetic dataset generated by the coupled SHYFEM-MPI circulation model and WAVEWATCH III wave model, incorporating the ocean–vegetation parameterizations of Shirinov et al. (2025). The dataset encompasses 28 distinct meadow configurations, where key benthic morphological parameters (shoot density, leaf length and thickness) are systematically varied.
The emulator acts as a fast, multi-variable surrogate, inferring vegetation-induced modifications across coastal ocean fields: significant wave height, mean wave period and direction, near-bottom orbital velocity, and currents. Implemented and validated across two pilot sites in Italy (Rimini and Manfredonia), the U-Net model accurately reproduces wave attenuation and flow dynamics, showing strong generalization capabilities when predicting firstly seen intermediate benthic states.
By accelerating complex, physics-based simulations by several orders of magnitude, this work demonstrates how AI can bridge the gap between numerical modeling and interactive DTO platforms. This framework provides an automated, science-based tool to evaluate and deploy NbS for climate adaptation and coastal defense.

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