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A Hybrid AI–physics Framework for Surface Drifter Trajectory Prediction around the Korean Peninsula

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Predicting the trajectories of surface drifters is vital for understanding upper-ocean circulation, material transport, and marine hazard response, yet this task remains challenging under multi-forced environmental conditions. Surface motion arises from the nonlinear interaction among winds, tides, mesoscale currents, and surface waves—processes that remain difficult to represent accurately in conventional numerical models.

This study develops a hybrid machine-learning and physics-based framework that integrates multi-source oceanic model outputs (HYCOM, TPXO, SCHISM) with atmospheric and wave forcings from ERA5 to predict surface-drifter trajectories. Within this framework, the eXtreme Gradient Boosting (XGBoost) algorithm predicts surface-drifter velocity components, which are time-integrated to reconstruct trajectories. Model skill is evaluated against drifter observations, and SHapley Additive exPlanations (SHAP) analysis is used to identify dominant environmental drivers controlling surface transport.

Applied to the marginal seas around the Korean Peninsula, the hybrid model reduced 24-hour trajectory root-mean-square error (RMSE) by approximately 38 % and increased the normalized cumulative Lagrangian separation (NCLS) skill score by 54 % relative to SCHISM-based simulations. SHAP interpretation revealed systematic regional contrasts—tidal dominance, mixed forcing, and eddy-driven variability. These findings demonstrate that physics-informed and explainable AI can effectively bridge deterministic modelling with data-driven learning, providing a robust foundation for the emerging Intelligent Ocean forecasting framework.