Offshore Operations and Maintenance: A GNN-LSTM Wave Forecasting Framework for safe Marine Logistics Operations in the German Bight

Supreeth Hanumappa[1], Thilo Grotebrune[1], Prof. Dr.-Ing. T. Schlurmann[1]

[1] *Ludwig-Franzius-Institute for Hydraulic, Estuarine, and Coastal Engineering, Leibniz University Hannover, Germany*

Abstract

Accurate, high-resolution sea-state forecasts are crucial for efficient offshore operations and maintenance activities, where vessel deployment, technician safety, and weather-window planning are strictly constrained by local metocean conditions. State of the art numerical wave models are computationally intensive, exhibit localized deviations from in-situ measurements, and lack the responsiveness required for real-time decision-making. To address this, we present a spatiotemporal surrogate framework combining Graph Neural Networks (GNN) and Long Short-Term Memory (LSTM) networks to forecast key wave parameters like significant wave height (SWH), peak period, and wave direction. The proposed framework builds on the sea-state monitoring network of the Federal Maritime and Hydrographic Agency (German: *Bundesamt für Seeschiffahrt und* Hydrographie, BSH) and integrates heterogeneous data streams, including buoy measurements, radar-derived wave parameters, current profiles, water-depth information, and supposedly atmospheric forcing. Initial developments used site-specific temporal models and spatial extrapolation approaches based on LSTM and Random Forest methods, closely linked to the real-time spatio-temporal machine-learning framework for nearshore wave prediction proposed by Chen et al. (2023). While their approaches demonstrated high temporal resolution and very good spatial extrapolation accuracy, they remain sensitive to inconsistent in-situ data availability, limited scalability across locations and parameters. This was addressed in the current unified spatio-temporal approach. Also, by incorporating static features like water depth and distance to the coast, the model accounts for nearshore energy transformation, shoaling, and white-capping effects. Evaluation on German Bight demonstrates that the GNN-LSTM, depending primarily on the in-situ measurements, yields SWH forecast comparable to numerical models, having minimal latency, enabling operators to optimize vessel transit scheduling, minimize logistics downtime, and plan safe boarding windows. This architecture offers a scalable alternative for marine logistics, theoretically adaptable to other coastal domains through fine-tuning with local historical data.