Predicting Typhoon-Induced Storm Surges in Vietnam Using Machine Learning

An LSTM-Based Approach for Coastal Risk Forecasting

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Introduction and Objectives

Vietnam's coastal regions are frequently impacted by typhoon-induced storm surges, which remain difficult to predict due to the complex interactions between wind, pressure, tides, and coastal geography (1). In this study, a data-driven approach was developed to forecast typhoon-induced storm surges using Long Short-Term Memory (LSTM) neural networks (2,3). Over a decade of atmospheric reanalysis data and observed sea surface height (SSH) records were utilized to train and validate the model. Observational data were collected from seven coastal stations spanning northern, central, and southern Vietnam, including one offshore platform (Fig.1). This spatial diversity allowed the model to capture a wide range of hydrodynamic and weather conditions. The objective was to improve surge predictions at specific coastal locations and evaluate how well models trained on past typhoons (Fig.2) generalize to new events and regions, with the aim of supporting early warning systems and climate-resilient coastal planning.

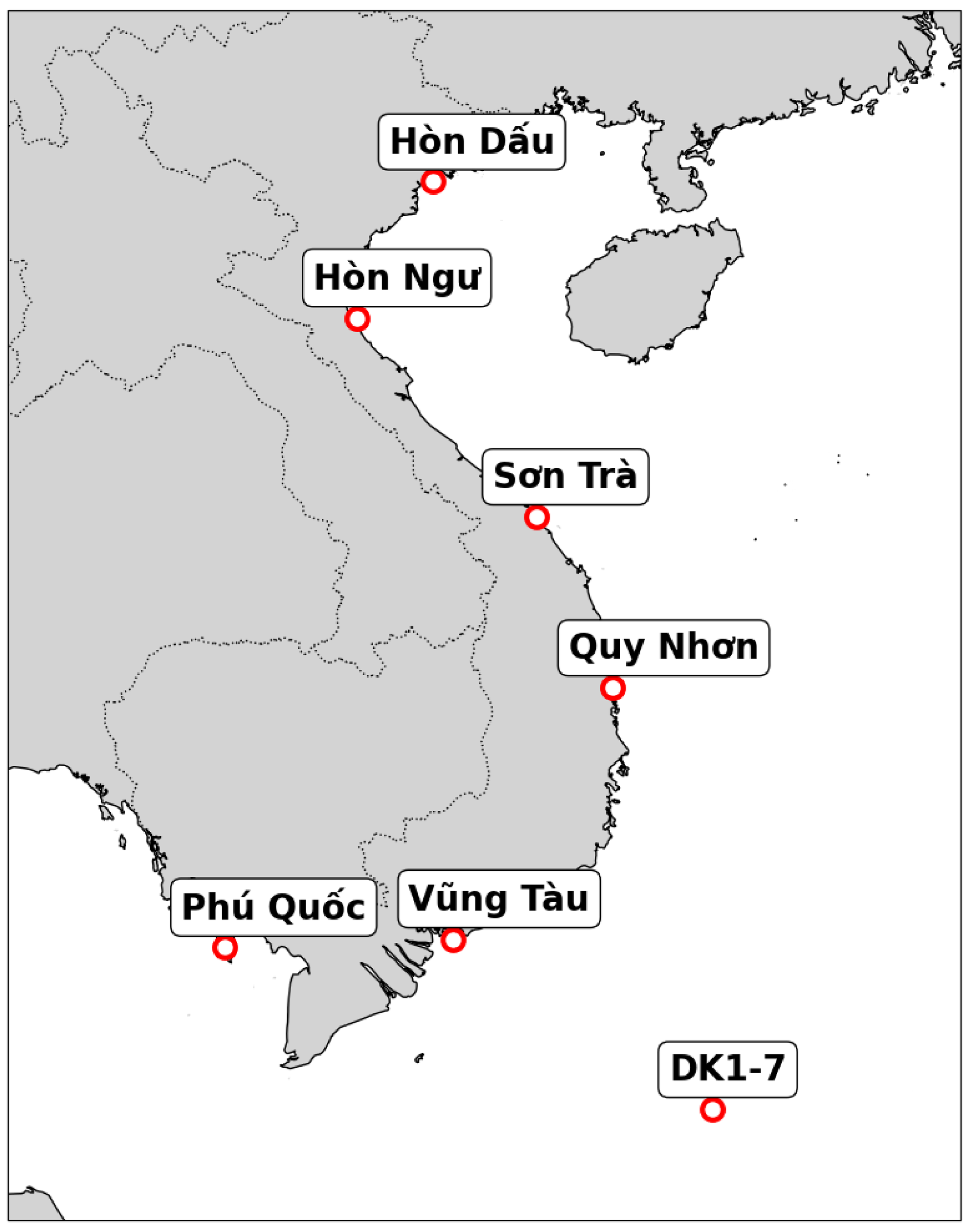

Figure 1: Map of the seven observation stations used along the Vietnamese coast including the offshore platform.

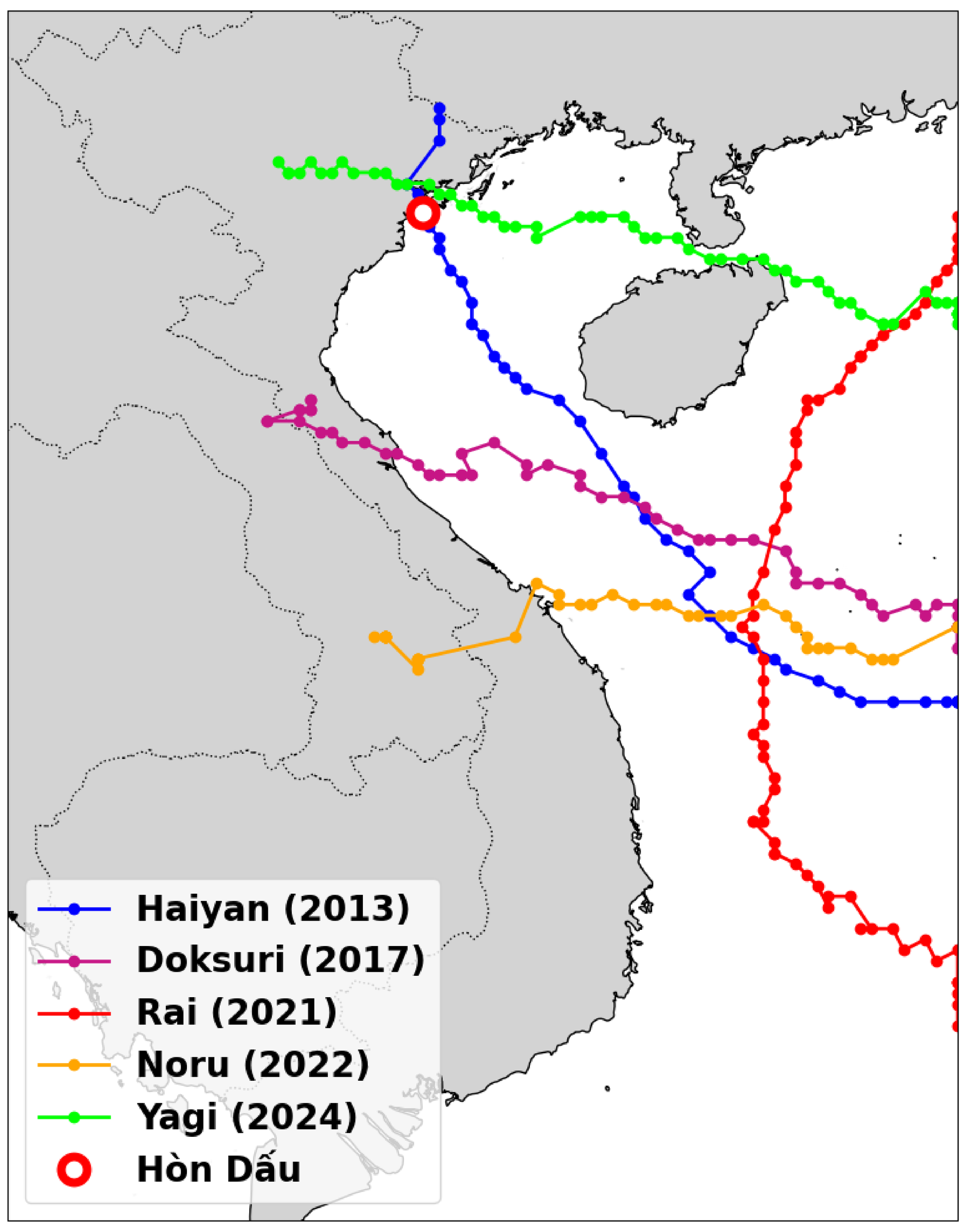

Figure 2: Computed tracks of five major typhoons from the past decade near the HònDau Station

Materials and Methods

A dataset spanning 2012–2024 was compiled, including hourly weather variables and sea level measurements along Vietnam's coastline. Atmospheric inputs such as wind speed and sea-level pressure were retrieved from the European Centre for Medium-Range Weather Forecasts (ECMWF) via the MARS (Meteorological Archival and Retrieval System) platform. Observed sea surface height (SSH) data from multiple coastal stations were preprocessed by removing tidal components and seasonal signals, isolating the storm surge component. For each typhoon, relevant features including its position, category, and distance from each station were extracted and used as inputs (Fig.2). An LSTM neural network was trained to predict SSH based on sequences of meteorological and typhoon-related variables. The model was validated using past major events, such as Doksuri Typhoon, to assess its generalizability across different spatio-temporal scenarios.

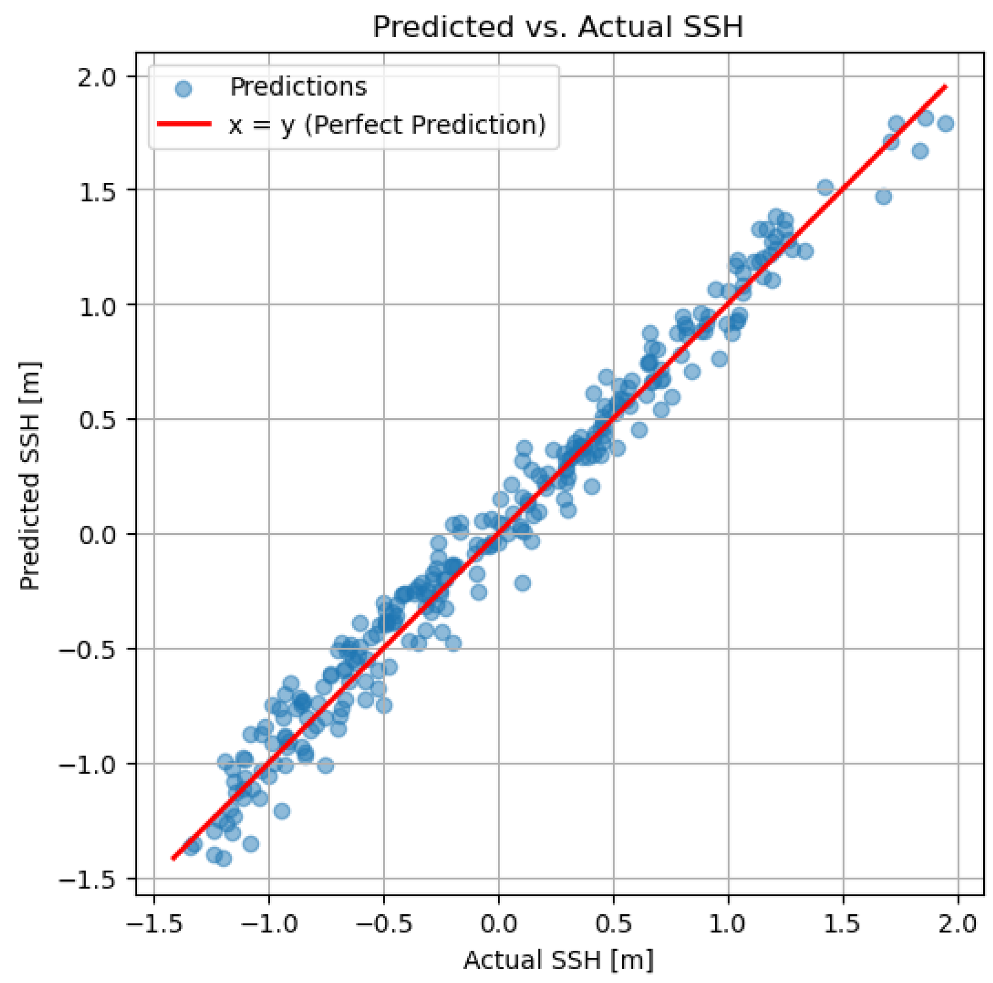

Figure 3: Scatter Plot of Model Predictions vs. Observed SSH Values During Typhoon Events

Results and Discussion

The LSTM model was tested on Typhoon Doksuri (2017) at the HònDau station. Predicted sea surface height values closely matched the observed data, successfully capturing both the timing and intensity of the storm surge (Fig.3 & 4). A mean absolute error (MAE) of approximately 11.6 cm and an R^2 score of 0.95 were achieved, indicating high predictive accuracy. Slight underestimations were observed near the surge peak, likely due to rapidly changing atmospheric conditions (Fig.4). Most prediction errors remained below 15 cm, and the model's performance was consistent across the event duration. These results demonstrate the model's capability for accurate storm surge forecasting along the Vietnamese coastline, even under severe storm conditions.

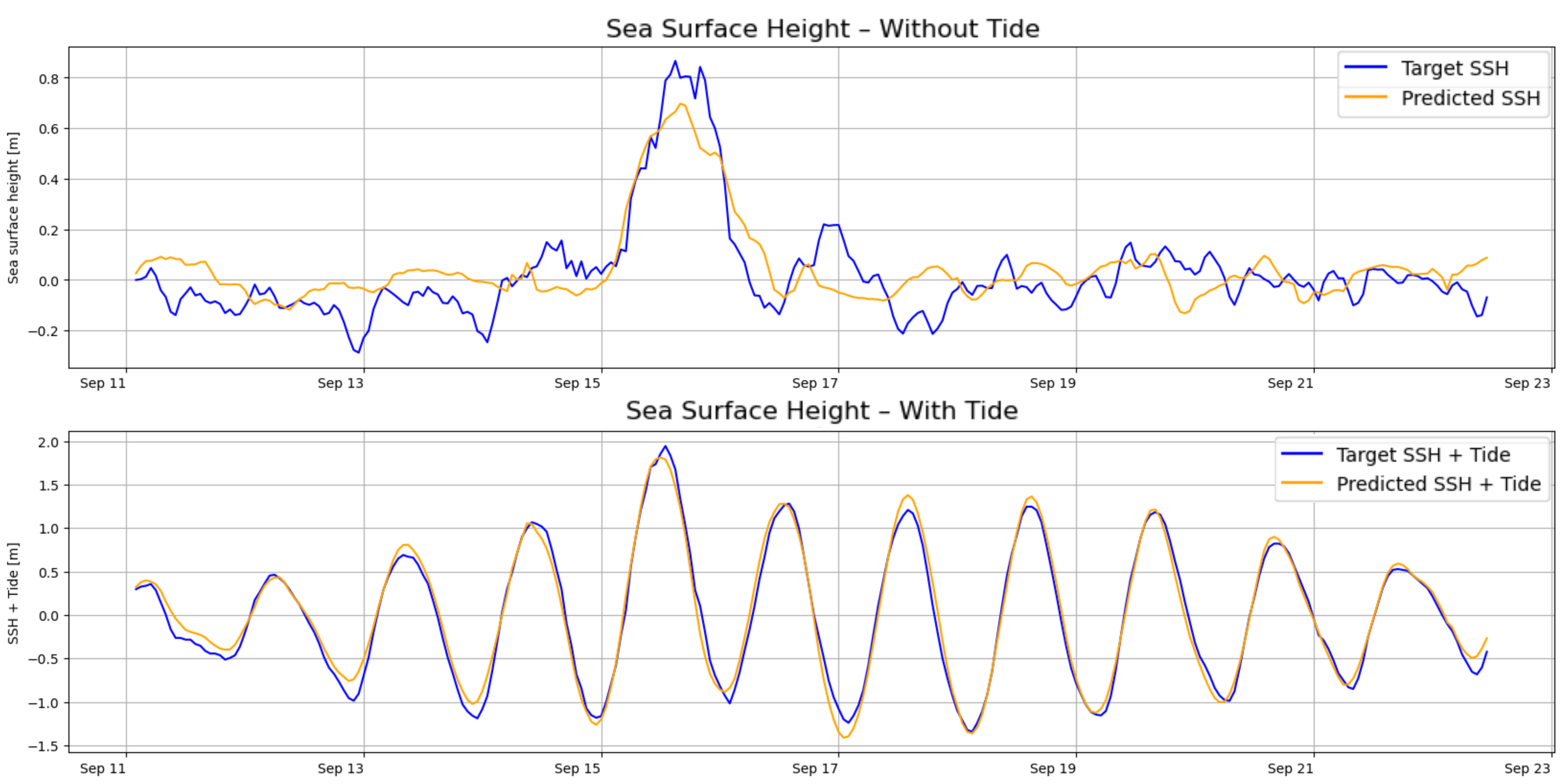

Figure 4: Predicted vs. Observed Storm Surge and Sea Surface Height during Typhoon Doksuri at HònDau Station.

References

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