Long Short-Term Memory Model Experiments for Tropical Cyclone Rapid Intensification Prediction in the Western Pacifc from Wind Structure Evolution

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ABSTRACT

Western Pacific Tropical cyclones (TCs) pose significant threats to the Philippines due to their intense winds, heavy rainfall, and strong storm surges. Accurate forecasting of TC intensification, particularly rapid intensification (RI), remains challenging due to the interaction of complex atmospheric processes in the background of the TC and its internal dynamics. This study investigates the predictive capability of wind structure evolution by leveraging a Long Short-Term Memory (LSTM) model with 12 and 24-hour sequences. Utilizing data from the International Best Track Archive for Climate Stewardship, this study analyzed training data from 2001-2018 and testing data from 2019-2022 under four experimental setups with different configurations. The results show that model performance can be improved by applying the synthetic minority oversampling technique to solve the class imbalance problem. In addition, introducing dropout and regularization to the LSTM models enhanced model generalization, increasing its ability to detect RI while limiting its tendency for misclassification. However, stronger regularization increased misclassification, indicating that regularization should be optimized to achieve better model performance. Moreover, the 12-hour LSTM model consistently outperformed the 24-hour model, suggesting that shorter sequences capture relevant information more effectively. Furthermore, attention weight analysis revealed temporal bias. Significant weights at the initial and final time steps could lead the models to undervalue critical information in the intermediate time steps. The best model achieved a probability of detection of 0.503 and a false alarm ratio of 0.109, emphasizing the need for further refinement and integration of additional predictors. This study highlights the potential of LSTM models for TC RI prediction using wind structure evolution. To develop a more holistic and sophisticated TC RI forecast model, future work should explore more regularization techniques, integration of the wind structure with environmental and satellite predictors, and validation against operational forecasts.

Key words: tropical cyclones, rapid intensification, wind structure, long-short term memory

Data mining approaches for classifying tropical cyclone rapid intensification in the Western Pacific from wind structure

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ABSTRACT

Tropical cyclones (TC) are among the most destructive weather phenomena, posing significant threats due to their intense winds, heavy rainfall, and strong storm surges. Accurate forecasting of TC intensification, particularly rapid intensification (RI), has long been a challenge due to the complex interplay between the surrounding environmental conditions and the internal processes within the TC. In particular, this study uses six machine learning classification models to investigate the predictive capability of the wind structure or fullness parameters for TC RI forecasting in the Western Pacific. Leveraging the wind structure obtained from the International Best Track Archive for Climate Stewardship dataset, training data from 2001-2018 and testing data from 2019-2022 were analyzed under various experimental setups. The initial experiments revealed that oversampling RI instances using the Synthetic Minority Oversampling Technique enhances the ML models' ability to detect RI but also increases misclassification. On the other hand, adding time-lagged features yielded mixed results, improving RI detection for some models while reducing it for others. In addition, feature selection through the SelectKBest algorithm generally improved model performance by reducing overfitting and increasing generalization. However, further reducing features led to poorer performance due to decreased model complexity. Moreover, future research should exhaust other ML models, such as tree-based ensemble models and neural network architectures, and employ innovative preprocessing techniques, such as different oversampling methods, feature engineering, and feature selection, to find the balance between sufficiently high RI prediction rate and low RI misclassification rate. Lastly, the results of this study highlight the predictive potential of the wind structure, enabling its use as an additional predictor on top of environmental predictors and TC internal structures observed by radars and satellites to develop a more holistic forecasting model of TC RI.

Key words: tropical cyclones, data mining, machine learning, rapid intensification, wind structure

On the Intensification of Super Typhoon Goni (2020): Environmental Conditions, Deep Convective Clouds, Precipitation, Cloud Microphysics, and Wind Structure

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ABSTRACT

This study investigated the various environmental conditions and internal dynamics of one of the most intense tropical cyclones (TCs) on record and the most intense upon landfall (Super Typhoon Goni, 2020) using TC track, gridded models, and satellite data. Results show that Goni formed and have evolved throughout an environment that is favorable for intensification such as warm and anomalous sea surface temperature, moderate deep-layer and low-level vertical wind shear, and high low and mid-tropospheric relative humidity. Additionally, the presence of an inflow layer in the lower stratosphere might have induced an upper-level warm core which resulted in further intensification during mature stages. Goni's rapid intensification (RI) during early stages can be differentiated from other intensification categories due to the different radial locations of the percentage and temperature of the deep convective clouds, and precipitation. Moreover, the deposition process generally dominated throughout the evolution which made the release of latent heat very efficient. Thermodynamic processes dominated instead of dynamical forcing in the boundary layer during the early stages of development which may have contributed to later intensification. Furthermore, Goni's stable fullness ratio during its early stages led to its subsequent extreme rapid intensification (ERI). Goni's wind structure during ERI was found to be at values close to the optimal size configuration that coincided with the highest intensification rates. Findings in this study can be used to identify crucial environmental conditions and the governing internal dynamics that led to the RI of extremely intense TCs.

Key words: cloud microphysics, deep convective clouds, environmental conditions, precipitation, rapid intensification, wind structure