BASIC STUDY ON A STOCHASTIC TROPICAL CYCLONE RAINFALL MODEL AROUND JAPAN

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BACKGROUND AND MOTIVATION

Coastal disasters and environmental issues are not only influenced by waves and tides but also cannot ignore the impact of rainfall. For example, assessing the simultaneous occurrence risk of storm surge and river floods is important in tide gate operations. There have been many researches on the potential for climate change to alter the intensity and precipitation of tropical cyclones. In the formulation of adaptation strategies, it is necessary to conduct disaster frequency assessments based on a large ensemble of disaster prediction data. In the past studies, the methods for simplified assessment of storm surges through a stochastic tropical cyclone model approach that can statistically generate a large number of tropical cyclone track data has been already proposed. However, the method of corresponding flood risks is not so sufficient. If a method for probabilistically predicting rainfall patterns from tropical cyclone track data could be developed, it could also be applied to real-time forecasting for rainfall disaster risk assessment.

While physical models can provide detailed confident analysis of future tropical cyclone rainfall, they also need detailed boundary and initial weather condition. Therefore, it is difficult to provide probabilistic evaluations of rainfall caused by tropical cyclone. Models for empirically predicting rainfall from hurricanes, as proposed by Villarini et al. (2022), have been developed, but research focusing on typhoons around Japan is limited. Additionally, the modeling of structural rainfall, such as rainbands around tropical cyclones, is not sufficient.

PURPOSE

The purpose of this study is to construct an empirical probabilistic rainfall model that simulates the rainfall patterns of typhoons around Japan, validate its accuracy, and apply it to future predictions.

DATA AND METHOD

We used Best Track Data of typhoons (2017-2022) and Meso-scale numerical weather forecasting model (MSM) results provided by Japan Meteorological Agency to analyze typhoon track and rainfall. In this study, modeling was performed by separating two types of rainfall: the average rainfall that occurs concentrically and the structural intense local rainfall (SIL rain), such as in wall clouds or rainbands (Figure 1).

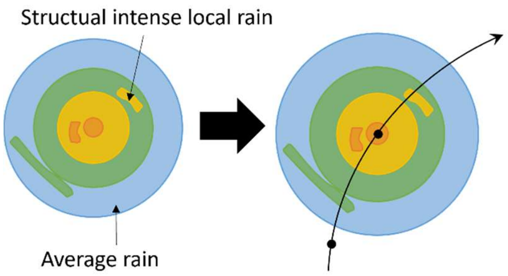

Figure 1 - Conceptual image of modeling on rain pattern caused by tropical cyclone.

To consider the evolution of the rain pattern with the progress of the typhoon, the hourly precipitation at each time step was organized in a coordinate system with the center position of tropical cyclone as the origin. We classified the precipitation data around the tropical cyclone based on factors such as the central pressure, latitude, translation speed and season, then estimated the representative average precipitation distribution model P_i for each category. The choice of which average rainfall pattern P_i to use for estimating precipitation depends on the specific region and typhoon conditions. Therefore, in this study, we opted to select the optimal combination of Pi for each region and determined the weight coefficients (α_i) through multiple regression analysis (Equation 1).

$$P_m(x, t_y) = \sum \alpha_i(x) P_i(t_y) \quad (1)$$

Here, t_y represents the typhoon characteristics, and P_i denotes the precipitation distribution considered around the tropical cyclone center within a range of 600 km. The configuration of this region is based on literature that states the occurrence area of rainbands is within a radius of 600 kilometers.

In modeling SIL rain, the precipitation distribution was transformed into a distribution in a Cartesian coordinate system with distance r from the center of tropical cyclone and azimuth angle θ as axes (Figure 2). Subsequently, precipitation pattern modeling was conducted through cluster analysis and a two-dimensional normal distribution approximation of precipitation. This aimed to attempt the representation of wall clouds near the center of tropical cyclone and the spiral-shaped rainbands. The time variation of SIL rain was analyzed through cross-correlation analysis of rainfall distribution. Table 1 shows the existence ratios of the temporal evolution trends of rainfall areas at consecutive time intervals. Based on these results, we stochastically modeled the time evolution of SIL

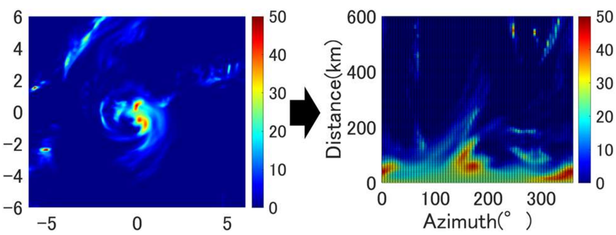

Figure 2 - An example of transformed hourly precipitation (mm/h) pattern around tropical cyclone at each time step.

Table 1 - The existence ratio of the temporal evolution trends of rainfall areas at consecutive time intervals (t_1 and t_2).

	Temporal evolution			
at t_1	positive		negative	
at t_2	negative	positive	positive	negative
r	49.9 %	50.1 %	19.9 %	80.1 %
θ	59.4 %	40.6 %	0.7 %	99.3 %

A positive change in r indicates moving away from the center of tropical cyclone. A positive change in θ indicates clockwise rotation.

rain.
Using the modeled rainfall distribution with the typhoon center as the origin, it is possible to depict the temporal evolution of rainfall areas as the typhoon moves.
The configuration of the stochastic tropical cyclone model used in this study is the same as in previous research (Nakajo et al., 2014), We calibrated the model based on tropical cyclone track data from d4PDF, a large ensemble GCM dataset. Model biases of GCM in the d4PDF were corrected by comparison with observation data, IBTrACS. In addition to the stochastic model PTC calibrated with GCM results of past reproductions, 6 models (CC, GF, HA, MI, MP, MR), FTCs of future projections were also constructed.

RESULT
Accuracy validation was performed by comparing the MSM data and the estimated results by our model for the distribution pattern of cumulative rainfall from tropical cyclones that followed the same track. Currently, there is a positive correlation between the rainfall distributions of both, and their distribution shapes are similar. However, there is a significant difference in the absolute values of heavy rainfall. This is believed to depend on the probabilistically generated LSI rainfall, making statistical comparisons necessary in the future.
An analysis of present and future tropical cyclone-induced rainfall was conducted using a 300-year tropical cyclone track data obtained from the global stochastic tropical cyclone model. Figure 3 represents an example of the calculation results of the annual average cumulative precipitation. Future tropical cyclone-induced rainfall is mainly showing a significant decrease in annual average cumulative values, particularly on the Pacific side. This is believed to be largely influenced by a decrease in the frequency of tropical cyclone passages. When we calculated on a value per one tropical cyclone event, future rainfall tends to increase. However, it should be noted that what is presented here is the result of one future prediction model (MR) for future predictions, and there is a significant variability among different sea surface temperature scenarios.

CONCLUSION
In this study, we empirically created a probability typhoon rainfall model based on historical typhoon data. The obtained average rainfall distribution was similar to previous research focusing on North American hurricanes (Villarini et al., 2022). Here, we improved accuracy by modeling for different typhoon characteristics and estimating average rainfall

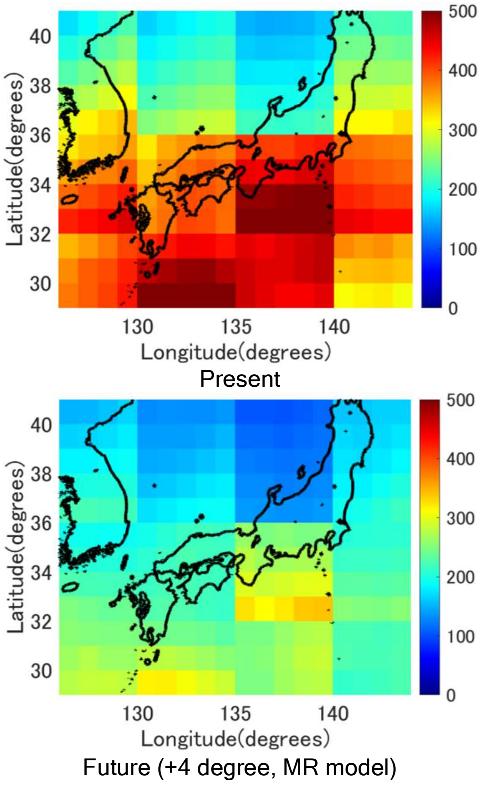

Figure 3 - Annual average cumulative precipitation estimated from 100 year tropical cyclone track data and proposed rain model.

distributions from the multiple regression analysis. However, there is a possibility for improvement in setting the regions for determining regression coefficients. Furthermore, to compensate for the limited sample size, future research should explore improvements in accuracy by using a large number of simulated typhoon analysis data. Additionally, this study has performed modeling based solely on tropical cyclone track data, such as central pressure. We plan to explore the possibilities of statistical modeling concerning the relationship with factors like sea surface temperature and wind shear in the future. While there are many aspects to consider in the future, we have also evaluated the statistical characteristics of the distribution and temporal evolution of rainbands and were able to estimate future changes in rainfall from a large number of typhoon track data.

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