Stochastic Simulation of Typhoon Tracks in Northwestern Pacific and its Engineering Applications

Xu’nan Yang, Lin Zhao, Lili Song, Genshen Fang and Yaojun Ge

ABSTRACT

To simulate tropical cyclone track, the distribution characteristics and correlation of the parameters were carried out for each grid developed by latitude and longitude in the western Pacific, according to a total of 1618 tropical cyclones were recorded from 1945 to 2015. The results show that the tropical cyclone moving distance and the moving turning angle (6 hour interval) of each grid obey the generalized-extreme-value distribution and t-Location-Scale distribution respectively. For a number of consecutive moments of a tropical cyclone, the autocorrelation of the moving distance is strong, the autocorrelation of the moving turning angle is weak, and the cross-correlation between the moving distance and the moving turning angle is weak. Based on the statistical characteristics of these parameters, the probabilistic model of stochastic track simulation is established. Comparing the results of the simulation with the historical data, the results show that the probabilistic model has a high reliability.

Yang Xu’nan, No. 1339, Siping Road, Yangpu District, Shanghai
Zhao Lin, No. 1339, Siping Road, Yangpu District, Shanghai
Song Lili, No. 46 Meteorological Film and Television Building, Zhongguancun South Street, Beijing
Fang Genshen, No. 1339, Siping Road, Yangpu District, Shanghai
Ge Yaojun, No. 1339, Siping Road, Yangpu District, Shanghai
INTRODUCTION

Typhoon hits China frequently every year and affects the people's lives and property seriously. The present Building-Load-Code doesn’t stipulate design parameters for the climate of typhoon, which makes the research of typhoon wind environment and features more and more important. Calculating the loading probability of typhoon by the tropical cyclone track simulation is the prerequisite of civil engineering structure design and loading analysis. The method can simulate the loading probability of typhoon in the coming years, which is valuable in engineering field. Table 1 lists the relevant research.

| Scholars          | Time | Track simulation model       | Model features                                      |
|-------------------|------|------------------------------|-----------------------------------------------------|
| Vickery et al.    | 2000 | recursive model              | The model parameters are not clear                   |
| Emanuel et al.    | 2006 | markov chain model           | The track simulated by markov chain model is too diffusive |
| Zhou Liang et al. | 2008 | similar track                | The model's goal is to predict the typhoon track and the track simulation is not realized |

At present, the complete track simulations are based on the measured data of the North Atlantic and cannot reflect the occurrence and development of the tropical cyclones in the western Pacific. There are few studies on the track simulation of tropical cyclone in the western Pacific, and the related work needs to be carried out.

In this paper, the probabilistic model is used to simulate the tropical cyclone track by analyzing the statistical characteristics of holding time, moving distance and moving turning angle (6 hour interval). The research process is shown in Fig 1.
THE TRACK OF HOLISTIC TROPICAL CYCLONE

The measured data of tropical cyclone

This paper uses a total of 1618 typhoon measured data from 1918 to 2015 (see Figure 2). The data recorded for each tropical cyclone includes a tropical cyclone center (longitude and latitude), center strength, maximum wind speed. The data cover the Southeast Asian region to the northern China Bohai Bay area, a total of 49881 tropical cyclone records.

Define the moving distance as the minimum distance between two consecutive recording moment during this time interval. In order to facilitate the analysis, for the
data which time interval is not 6 hours, transform the moving distance under the time interval into the moving distance under 6 hours by the linear interpolation method.

For any two consecutive recording moment of a tropical cyclone, define the moving heading as the direction of the connection of these two consecutive recording points. As shown in Fig. 3, define the moving turning angle as the angle between the moving heading of the two consecutive periods. The range of the moving turning angle is \((-\pi, +\pi)\). For the data which time interval is not 6 hours, the moving turning angle transformed by the linear interpolation method has bad influence on the overall characteristics of the original data and discard the non-6-hour-interval data.

**Comparison of statistical characteristics of moving distance**

The western Pacific has been developed using 3 ° × 3 ° grid, and the statistical characteristics of moving distance in different grids are studied.

Figure 4 shows the average moving distance in different areas, Figure 5 shows the standard deviation of moving distance in different areas. It can be seen from the two figures that the mean and standard deviation of the moving distance increase with the increase of the latitude. The mean and standard deviation of the moving distance of the Indo-China Peninsula and the Philippines are higher than the other areas of the same latitude.

![Figure 4. The mean of moving distance.](image1)
![Figure 5. The standard deviation of moving distance.](image2)

**Comparison of Statistical Characteristics of moving turning angle**

Fig.6 shows the average of the moving turning angle in different areas, and Fig.7 shows the standard deviation of the moving turning angle in different areas.
Figure 6 shows that the average value of moving turning angle in the high latitudes is generally greater than zero, indicating that the tropical cyclones tend to move to high latitudes in these areas. Figure 7 shows that the standard deviation of moving turning angle is larger in Japan, the South China Sea, indicating that the direction of the tropical cyclone in these areas is relatively unstable.

Summary

The statistical characteristics of moving distance and moving turning angle of tropical cyclone indicate that there are differences in the parameters of tropical cyclones in different regions. This difference is particularly significant in coastal areas. In order to reflect this difference in the track simulation of tropical cyclone, it is necessary to mesh the Western Pacific.

ANALYSIS OF STATISTICAL CHARACTERISTICS IN LOCAL AREA

Distribution analysis of moving distance and moving turning angle

A local area (N24° E129°, N24° E134°, N29° E134°, N29° E129°) was selected for the distribution analysis of moving distance and moving turning angle. The results show that the generalized-extreme-value distribution has a good fit for the moving distance of the tropical cyclone, as shown in Figure 8. The t-Location-Scale distribution has a good fit for the moving turning angle of the tropical cyclone, as shown in Figure 9.
In order to judge whether the distribution of the moving distance and the moving turning angle of the Western Pacific satisfy the above distributions, the distribution of the moving distance and the moving turning angle is tested by Kolmogorov-Smirnov test (in the 95% confidence interval).

The test results of moving distance are shown in Fig.10. The blue grid indicates that the amount of data of the grid is insufficient and failed to carry out the K-S test. The green grid indicates that the generalized-extreme-value distribution has a good fit for the moving distance of the grid. The yellow grid indicates that the generalized-extreme-value distribution has a poor fit for the moving distance of the grid. Fig.10 shows that about 7% of the grids can not pass the K-S distribution test.

The test results of moving turning angle are shown in Fig.11. The blue grid indicates that the amount of data of the grid is insufficient and failed to carry out the K-S test. The green grid indicates that the t-Location-Scale distribution has a good fit for the moving distance of the grid. The yellow grid indicates that the t-Location-Scale distribution has a poor fit for the moving distance of the grid. Fig.11 shows that about 2% of the grids can not pass the K-S distribution test.
**Analysis of the Correlation between Moving Distance and Moving Turning Angle**

In order to understand whether there is a correlation for the movement state between the latter moment and the previous moments, a local area (N24° E129°, N24° E134°, N29° E134°, N29° E129°) was selected for the correlation analysis of moving distance and moving turning angle. The correlation coefficients are shown in Figure 12, λ1-λ3 represents the moving distance of three consecutive moments, and θ1-θ3 represents the moving turning angle of six consecutive moments.

Figure 12. Correlation between the moving turning angle and the moving distance (three consecutive moments).

Figure 12 shows that for three consecutive moments of a tropical cyclone, the autocorrelation of the moving distance is strong, the autocorrelation of the moving turning angle is weak, and the cross-correlation between the moving distance and the moving turning angle is weak.

**THE RESULTS OF TROPICAL CYCLONE TRACK SIMULATION**

Given the initial movement state of the tropical cyclone (6-hour interval), the simulation model estimates the new movement state of the tropical cyclone based on the changes in the moving distance and the moving turning angle over the current 6-h period. The changes in the moving distance λ and the moving turning angle θ among times \( i, i-1 \) and \( i-2 \) are obtained from

\[
\lambda_i = \alpha_1(La, Lo) \cdot G(La, Lo) + \alpha_2(La, Lo) \cdot \lambda_{i-1} + \alpha_3(La, Lo) \cdot \lambda_{i-2}
\]

\[
\theta_i = \tau(La, Lo)
\]

Where \( \lambda_i, \lambda_{i-1} \) and \( \lambda_{i-2} \) represent the moving distance of the tropical cyclone at the times \( i, i-1 \) and \( i-2 \); \( La \) and \( Lo \) represent the latitude and longitude of the center of the tropical cyclone at the times \( i, i-1 \) and \( i-2 \); \( \alpha_1, \alpha_2 \) and \( \alpha_3 \) are the parameters that
depend on the correlation coefficients matrix according to the calculation based on
the grid accordingly; \( \theta_i \) represents the moving turning angle of the tropical cyclone at
the times \( i, i-1 \) and \( i-2 \); \( G \) and \( t \) represent the random function taking the generalized-

extreme-value distribution and \( t \)-Location-Scale distributions respectively, and the
parameters of these two distributions are chosen based on grid accordingly.

The results and the comparison between the simulation and historical data are
shown in Figure 13, Figure 14.

![Figure 13. Simulation track.](image)
![Figure 14. Historical track.](image)

**CONCLUSION**

This paper analyzes the statistical characteristics of the moving distance and the
moving turning angle based on the measured data of 1618 tropical cyclones from
1945 to 2015, the results are summarized as follows:

1. The generalized-extreme-value distribution has a good fit to the tropical cyclone
   moving distance. The \( t \)-Location-Scale distribution has a good fit to the tropical
cyclone moving turning angle.
2. For a number of consecutive moments of a tropical cyclone, the autocorrelation
   of the moving distance is strong, the autocorrelation of the moving turning angle
   is weak, and the cross-correlation between the moving distance and the moving
   turning angle is weak.

**REFERENCES**

1. Vickery P J, Skerlj P F, Twisdale L A. simulation of hurricane risk in the U.S. using Empirical track
   model[J]. Struct. Eng., 2000, 126(10):1222-1237.
2. Emanuel K, Ravela S, Vivant E, Risi C. A statistical deterministic approach to hurricane risk assessment[J].
   Bulletin of the American Meteorological Society, 2006, 54: 1620-1636.
3. Chen Lianshou. An Introduction to the Typhoon of the Western Pacific [M]. Science Press, 1979:13-22, 206-223.
4. Zou Liang, Ren Aizhu, Xu Feng, Zhang Xin. Typhoon track forecasting based on GIS spatial analyses [J]. Tsinghua Univ (Sci & Tech), 2008, 42: 2036-2040. (in chinese).
5. Nakamura J, Lall U, Kushnir Y, et al. HITS: Hurricane intensity and track simulator with north Atlantic ocean application for risk assessment [J]. American Meteorological Society, 2015, 54: 1620-1636.
6. Harry C W. Hurricane track prediction using a statistical ensemble of numerical models [J]. American Meteorological Society, 2003, 131: 749-770.
7. Hallegatte S. The use of synthetic hurricane tracks in risk analysis and climate change damage assessment [J]. American Meteorological Society, 2007, 46: 1956-1966.
8. 1949-2015 Tropical Cyclone Yearbook. China Meteorological Administration, Meteorological Press.