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Variations in Genesis Locations and Typhoon-Induced Precipitation Intensity of Typhoons Impacting Northeast China: 2000–2025

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Abstract. Global warming poses persistent challenges to human societies worldwide and is accompanied by an increasing occurrence of intense and anomalous extreme weather events, including those affecting Northeast China. Apart from destruction of infrastructure, these severe weather phenomena are also a threat to food security and livelihoods, and have started attracting attention among climate scientists. Under ongoing climate warming, more tropical cyclones travel northward into Northeast China and produce heavy rainfall. The past related studies mostly concentrated on typhoon occurrence in southeast coastal regions, but comparatively fewer studies have been conducted on the impact of typhoons at high latitudes. This study aims to reveal the statistical relationship between shifts in typhoon genesis locations and typhoon precipitation in Northeast China, by carrying out several sets of regression analysis. It emphasizes how changes in source location influence rainfall intensity and distribution away from coastal landings, thereby providing a statistical basis for regional typhoon disaster risk assessment. The findings can be used for formulating early warnings for local agriculture and water resources management authorities.

Keywords: Precipitation trend, Typhoons, Extreme rainfall

1. Introduction

Previous research suggests that, under the persistent global warming trend, the formation sites of typhoons in the Northwest Pacific may experience a northward and westward displacement [1], while typhoon-induced precipitation may also increase [2]. However, these basin-wide characteristics may not necessarily apply to typhoons affecting Northeast China. Traditional typhoon disasters have been concentrated mainly in southern and eastern China. However, northward-moving typhoons have frequently affected Northeast China, and even after undergoing extratropical transition (ET) [3], the residual circulation of these systems can still contribute to extreme rainfall, as demonstrated by typhoons such as 1818-Rumbia, 2009-Maysak, and 2212-Muifa [4]. Northeast China consists of Liaoning Province, Jilin Province, Heilongjiang Province, and the northeastern part of Inner Mongolia. Most of Northeast China lies above 35°N, with Liaoning located along the northeastern coast of China and connected to the northwestern Pacific. As an important production

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base for commercial grains in China, the Northeast region of China accounts for one-third of the country's overall production of commercial grains [5]. Note that this research does not quantify yield loss due to grain. Thus, heavy precipitation due to typhoons is a real threat to grain production [6].

Although extensive research has been conducted on northward-moving typhoons, most studies were carried out across earlier periods [7], focusing on typhoon tracks primarily [8], or were individual case diagnostics. Based on a search of literature via keywords associated with typhoon formation, rainfall, and Northeast China during 2000-2025, existing literature has limited information about statistical analysis that covers the 2000–2025 period and a comprehensive selection of all typhoon samples affecting Northeast China. Moreover, relatively limited studies had carried out statistical comparisons linking shifts in typhoon genesis locations and variations in typhoon-induced precipitation (TIP) with time over Northeast China.

This study addresses three main research questions: (1) What are the spatiot-emporal characteristics of the genesis locations of typhoons impacting Northeast China from 2000 to 2025? (2) What are the changing patterns of typhoon-induced precipitation across Northeast China from 2000 to 2025? (3) Is there a statistically significant linear relationship between typhoon genesis distance and typhoon-induced precipitation in Northeast China?

The main objective of this study is to examine the variation in typhoon genesis latitude, genesis longitude, and genesis distance, as well as their statistical relationship with typhoon-induced precipitation in Northeast China during 2000–2025.

Using the China Meteorological Administration (CMA) Typhoon Best Track Dataset [9] together with satellite cloud records, this study selects typhoon events from 2000 to 2025 that directly or indirectly affected precipitation in Northeast China. It then examines the variation in genesis positions in terms of latitude and longitude and analyzes the annual variation in typhoon-induced precipitation across four major cities in Northeast China.

2. Methodology

2.1. Data sources

In this research, four major cities in Northeast China are selected as representative locations. The data points are defined by the geographic locations of four national meteorological stations: Dalian (38.91°N, 121.58°E), Shenyang (41.79°N, 123.43°E), Changchun (43.88°N, 125.32°E), and Harbin (45.76°N, 126.64°E). These four stations provide a spatial gradient from the southern coastal region to the northern inland region of Northeast China. The geographic center of Northeast China is defined as the point at 42.92°N, 124.28°E.

Three different datasets are employed in this research with different roles. CMA Best Track Dataset gives the date of birth of typhoon, its center location, movement track, intensity and date of transition into an extratropical condition for typhoon sample selection and spatio-temporal matching. The NASA POWER precipitation dataset provides precipitation on a daily basis at the four chosen locations. Satellite images are used to help identify the typhoon cloud system and the influence of the typhoon on the chosen sites. The CMA best track data has a time interval of six hours; NASA POWER precipitation data has a daily time interval with spatial resolution of 0.5°×0.5°. Due to the erratic and complex nature of typhoon trajectories, manual identification was conducted based on best track data from the Central Meteorological Observatory and satellite imagery, where genesis location, moving paths and life time data are recorded. Specific criteria for selection are outlined in the next subsection.

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2.2. Criteria: how to define and manage typhoons that affected northeast China

It is extremely hard to monitor every cloud that caused precipitation, let alone tracing its origin. In an easier way, this research categorizes typhoons into three types:

[A] Typhoon center moves entirely into the Northeast China region,

[B] Cloud systems of the typhoon cover Northeast China prior to dissipation or ET, and

[C] Precipitation transported after the typhoon dissipates or undergoes ET, or precipitation induced by the typhoon, neglecting distance.

Therefore, typhoon-induced precipitation for a given typhoon event is defined as the total rainfall at four sites in a duration, from the instance when typhoon starts impacting Northeast China, until the obvious termination of the associated heavy precipitation, or until 48 hours after the typhoon dissipates, undergoes extratropical transition or moves away from Northeast China. In the case of overlapping precipitation data between different typhoons, the precipitation is attributed to the typhoon that has greater influence over the moisture advection. In cases where the precipitation is due to both typhoons and mid-latitude systems, the data is separated using satellite images and synoptic analysis.

2.3. Analysis and visualisation method

2.3.1. Regression model

A linear regression based on the ordinary least-square method is applied to examine the trend of typhoon-related precipitation over 2000-2025. The best-fit straight line is defined as

$$y = kx + b \tag{1}$$

where x and y represent the independent and dependent variables, respectively, k represents the regression slope, and b represents the intercept. A significance test is carried out to evaluate whether the slope differs significantly from zero. A p-value smaller than 0.05 is adopted as the threshold for statistical significance. The R^2 value represents the coefficient of determination and indicates the proportion of variance in the dependent variable explained by the fitted linear model.

Typhoon genesis and tracks exhibit strong stochasticity. Some years contain no typhoons affecting Northeast China, while other years contain multiple events. For the analysis of genesis position, therefore, the x-axis is defined by the sequential order of all Northeast-impacting typhoons from 2000 to 2025 rather than by calendar year. The full typhoon inventory is provided in the appendix. This sequential index represents the chronological order of events rather than equal time intervals. Therefore, the regression based on this index is not interpreted as a linear temporal trend over calendar years. For example, Typhoon 0004-Kai-tak, the earliest identified typhoon affecting Northeast China within the study period, is assigned index 1. The next impacting typhoon, 0012-Prapiroon, receives index 2, and subsequent typhoons follow the same sequential numbering scheme.

2.3.2. Python visualisation

This research partially uses python as the visualisation tool. As genesis longitude, latitude and year are three variables, excel has limited functions. Genesis positions of all selected typhoons are drawn,

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with earlier generated typhoons painted in paler blue and latter generated ones in deeper blue. This diagram simply can make it distinct to observe the shift in generation position of typhoons, but only for visualisation.

2.3.3. Excel visualisation

For other diagrams such as bar diagrams and regression diagram, standard spreadsheets perfectly meets the demand of this research. After analyzing regression using excel functions, different charts are generated for visualisation.

3. Results

3.1. Data outcome

A total of 634 typhoon events were screened for this analysis, and 43 of them were captured by Northeast China. The number of typhoons varies annually, with 11 events in Category A, 25 in Category B, and 7 in Category C. They produced significant TIP across Northeast China.

All extracted and summarized data in 2000-2025 are in the appendix, including:

Sample genesis locations,

List of selected typhoons that affected Northeast China indirectly or directly, with their generation positions, categories of their moving paths, affecting intervals and precipitation brought to the four sites,

Annual precipitation of four major cities, with the amount of precipitation that is caused by typhoon, and

Python-generated figures for visualisation.

3.2. Research results

3.2.1. Genesis location change from 2000-2025

The analysis result table (Table 1) and two regression charts (Figure 1 and 2) below show the statistical relationship between genesis positions and generation order, with latitude and longitude separately.

Table 1. Regression analysis for genesis position

	Slope	R-square	P-value for slope	95% C.I.for slope
Latitude	0.0475	0.0123	0.4784	[−0.0866, 0.1816]
Longitude	-0.1454	0.0234	0.3269	[−0.4415, 0.1506]

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For the genesis latitude case, the regression slope is 0.0475 with R^2=0.0123 and p-value=0.4784, while the 95% confidence interval for the slope lies between −0.0866 and 0.1816. For the case of genesis longitude, the slope is −0.1454 with R^2=0.0234, p-value=0.3269, and a 95% confidence interval of [−0.4415, 0.1506]. In neither case does the regression produce any significant trend at the α=0.05 level. Even though there exists a slight trend towards higher latitude and lower longitude when visually inspecting the scatter plot, the confidence intervals for both cases include zero and thus support the idea that the shifts are not statistically significant. The very small values of R2 imply that genesis order has very little explanatory power in explaining the variability in genesis positions.

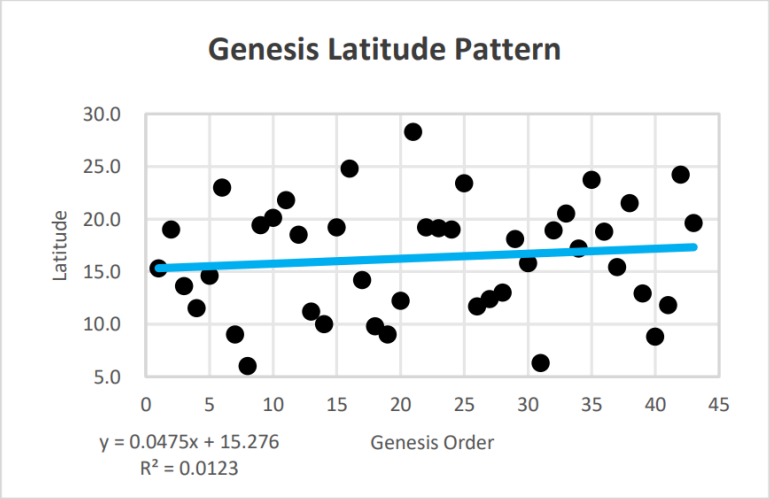


Figure 1. Scatter plot and regression for genesis latitude

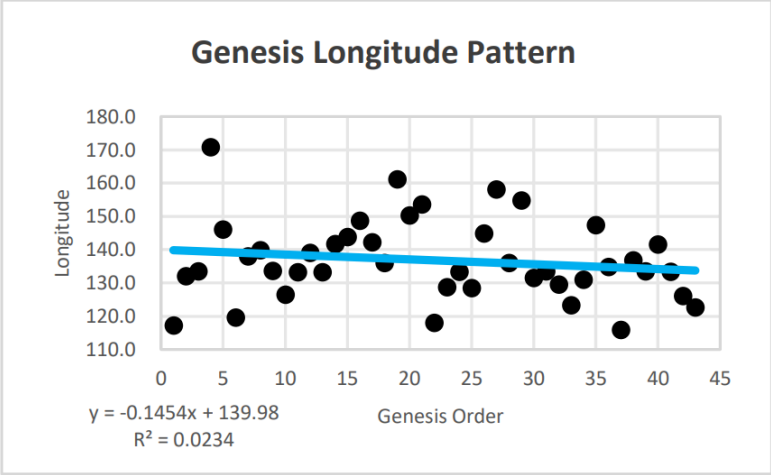


Figure 2. Scatter plot and regression for genesis longitude

3.2.2. Variation in typhoon-induced precipitation intensity across northeast China

The analysis result table (table 2) and two regression charts (figure 3-6) below show the statistical relationship and data visualisation between typhoon-induced precipitation (TIP) and year, stratified by the four individual cities.

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Table 2. Regression analysis for typhoon-induced precipitation

City	Slope	R-square	P-value for slope
Dalian	28.448	0.5265	0.0088
Shenyang	16.291	0.4257	0.0515
Changchun	11.995	0.4091	0.0257
Harbin	12.568	0.5121	0.0469

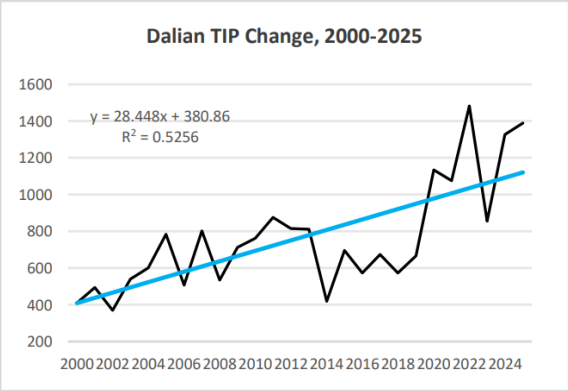


Figure 3. TIP for Dalian, 2000-2025

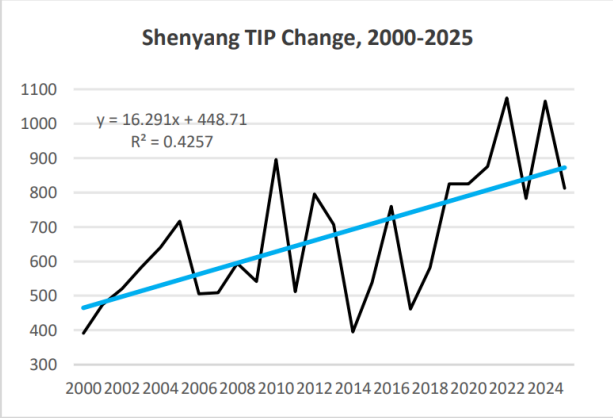


Figure 4. TIP for Shenyang, 2000-2025

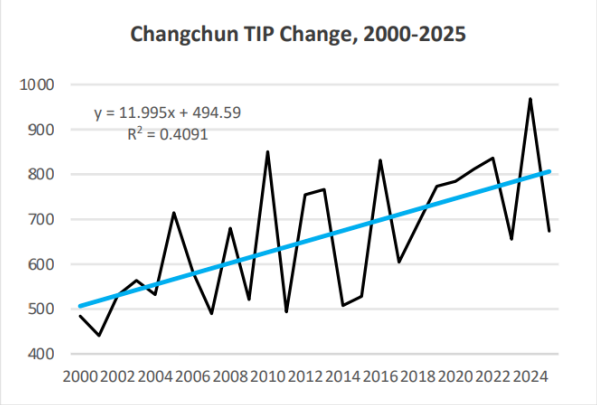


Figure 5. TIP for Changchun, 2000-2025

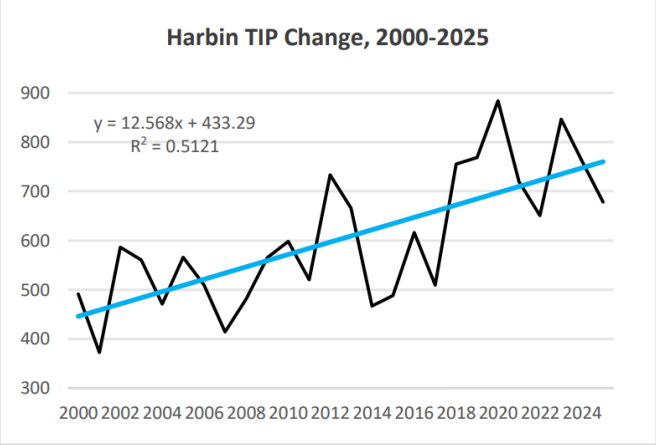


Figure 6. TIP for Harbin, 2000-2025

For the 2000 to 2025 period of study, all the four cities showed positive regression slopes indicating a general trend of increase in rainfall due to typhoons. The statistically significant upward trend was found in Dalian (p=0.0088), Changchun (p=0.0257) and Harbin (p=0.0469). Dalian recorded the highest regression slope indicating the highest estimated linear increase in TIP (mm per year) compared to the four cities. For Shenyang, p-value=0.0515. Since 95% confidence interval crosses zero, the upward trend cannot be considered statistically significant at alpha level of 0.05 despite the weak positive trend that can be noticed in the time series graph.

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In terms of space, the coastal city Dalian shows a much higher increasing rate than the inland cities, Changchun and Harbin. Although this difference might be attributed to the decreasing transport of water-vapor as typhoons pass over the inland areas from their initial landfall site, this statement remains hypothetical in the absence of water-vapor transport data. The relatively low R2 values imply that only a limited proportion of TIP variance can be attributed to the long-term linear temporal trend while inter-annual variations still play an important role.

3.2.3. Relationships between genesis-distance variation and typhoon-driven precipitation intensity

Genesis distance is defined as the great-circle distance between the typhoon genesis point and (42.92°N, 124.28°E), the geographic centroid of Northeast China, calculated using the mid-point formula. This metric is used as a genesis-position proxy.

The analysis result table (Table 3) and the regression charts (Figure 7) below show the statistical relationship and data visualisation between genesis distance and sum of typhoon-induced precipitation of that typhoon in all the four cities in Northeast China.

Table 3. Regression analysis for genesis distance to total typhoon-induced precipitation

	Slope	R-square	P-value for slope
Genesis Position	11.241	0.1736	0.00626

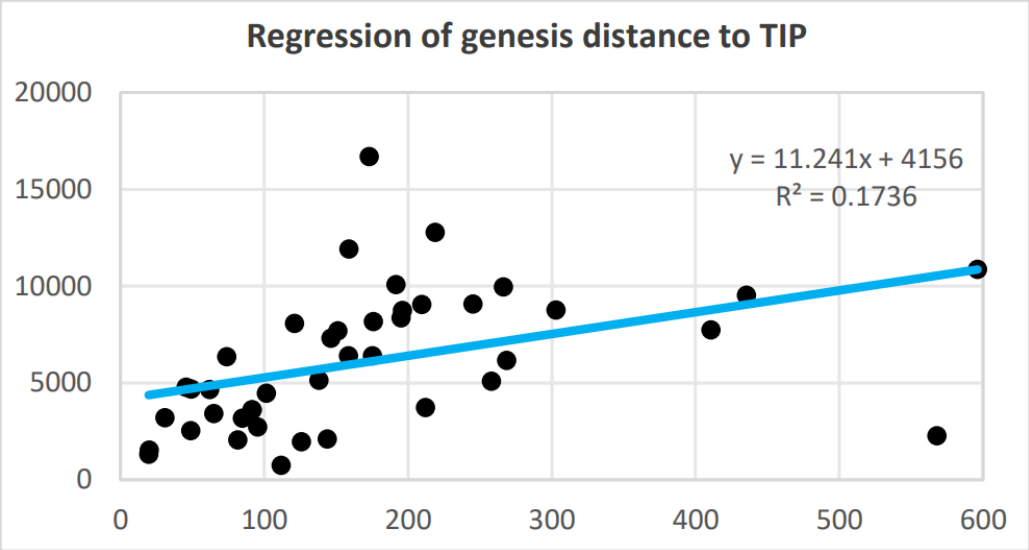


Figure 7. Scatter plot for genesis distance to sum of precipitation

The regression analysis provides a positive slope value of 11.241, showing a significant positive relationship: greater genesis distance implies more precipitation from the typhoon experienced by Northeast China. The slope is p=0.0063, which is below the critical level of 0.05 significance level. The value R2=0.1736 means that genesis distance explains 17.36% of the total variance of typhoon-induced precipitation.

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3.2.4. Synthesis of regression results

Taken together, the three sets of regression outputs reveal a contrasting pattern between typhoon genesis-location metrics and typhoon-induced precipitation (TIP) over Northeast China during 2000-2025. As shown in Section 3.2.1, neither genesis latitude nor genesis longitude of impacting typhoons exhibits statistically significant long-term temporal trends. Although weak northward and westward shifts can be observed in the sample dataset, large stochastic scatter dominates the variation of genesis positions. Meanwhile, Section 3.2.3 demonstrates that the genesis-distance bears statistically detectable linear association with regional total typhoon-induced precipitation. Combining these two findings, changes in typhoon genesis locations cannot explain the observed increasing TIP trends documented in Section 3.2.2.

Within the scope of this dataset, the upward TIP trends identified across most Northeast Chinese cities cannot be attributed to systematic shifts in typhoon genesis sites. Although there is no statistically significant trend in the latitude and longitude of the genesis position, the distance of genesis position displays a statistically significant linear relationship with the total typhoon-induced precipitation for the region. The lack of a trend in the genesis position does not imply that the measures of the genesis position are not related to the TIP. Hence, the increasing trend in TIP cannot be due to any long-term change in the position of genesis of typhoons.

Overall, typhoons with greater genesis distances are associated with higher total typhoon-induced precipitation in the selected dataset. However, the R^2 value of 0.1736 indicates that genesis distance explains only part of the observed variation. Other factors not examined in this study may also contribute substantially to differences in typhoon-induced precipitation..

4. Discussion

4.1. Synthesis with prior studies

These research findings should be considered in relation to existing literature. Kossin et al.[1] reported a significant global poleward shift in the locations where tropical cyclones reach their maximum intensity over their lifetime. A statistically significant shift is not observed in the genesis positions of the Northeast China-impacting typhoons examined in this study. The difference between the present results and previous findings may be related to differences in sample selection and study region. Other possible factors include regional climatic conditions, mid-latitude steering-flow anomalies, and land-sea interactions over Northeast China. These explanations remain hypotheses because they are not directly tested in the present analysis.

Besides, the different climatic conditions for each city, Dalian and Shenyang, also contribute to the inconsistency in the pattern of TIP in both cities. The increasing trend of TIP in Dalian and no trend of TIP in Shenyang is strongly connected with the regional effects of topography, land-sea thermal contrasts, and moisture transport, which affect the reaction of the precipitation in response to the typhoon activity. Moreover, the observed correlation between the genesis distance and TIP in this research only denotes the linear relationship of the factors under study. This correlation cannot be interpreted as causation since it might be regulated by some atmospheric and oceanic factors.

Our findings regarding TIP are compatible with the results of Evans et al.3 who argued that after tropical cyclones lose warm-core structure during their extra-tropical transition (ET), they continue being able to carry large amount of precipitations to mid-high latitudes. Growing amount of typhoon-induced precipitation observed in Northeast China proves that the extra-tropical

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transitioning and recurving typhoons are an important source of hazards for this high-latitude agricultural region.

4.2. Limitations

Several major limitations should be considered when interpreting the results of the current study. The first is the exclusion of other important factors, especially the translation speed of typhoons. Precipitation amount is affected by rainfall intensity and duration. When typhoons enter the mid-latitude westerlies, their movement may be influenced by multiple atmospheric systems, including mid-latitude troughs, cold vortices, and frontal zones. These systems may change the translation speed and movement path of a typhoon depending on their location and timing. Since accumulated precipitation is related to rainfall intensity, duration, and spatial coverage, differences in translation speed may directly affect the period during which a typhoon influences a particular region. Other factors are also not considered. Tropical-cyclone activity has substantial interannual and decadal variability and may be influenced by large-scale climate phenomena, including ENSO and mid-latitude atmospheric processes [10–12]. The relatively small sample size may also result in limited statistical power, sensitivity of p-values to individual unusual events, and a disproportionate influence of individual cases on regression results. In addition, the 25-year time series is relatively short for distinguishing natural low-frequency climate variability from longer-term externally forced changes.

Secondly, the determination and discrimination of the typhoon events in Northeast China have been performed manually in type A, B and C, as well as an empirically derived 48-hour cutoff period in order to stop the accounting for typhoon-induced precipitation. As it is clear, subjective interpretation cannot be avoided in this process. The 48-hour subjective criteria used may pose systematics uncertainty in estimating TIP because of its potential to either lead to an overestimation of total typhoon-related precipitation through inclusion of uncorrelated post transition precipitation, or lead to underestimation of TIP due to truncation of precipitation record too early.

Thirdly, this research focuses primarily on exploring linear statistical relationships. In the current study, the genesis longitude minus latitude have been used as proxies and other important factors have not been considered, such as peak intensity of typhoons, their translation speed, the landfall location, extratropical transition status, and mid-latitude synoptic-scale environment. Thus, no potential nonlinear relationship has been assessed in this framework. So far, we can make conclusions regarding the linear correlations only.

4.3. Future work implications

With the restrictions mentioned above, there are several possibilities worth pursuing in subsequent research endeavors. To begin with, objective algorithms can be used to classify typhoon impacts on precipitation rather than relying on subjective classification approaches. Criteria for stopping typhoon-precipitation calculation can be established to eliminate any subjective ambiguity in the process of partitioning of rainfall into components. In addition, appropriate multivariate statistical models will be developed for the comprehensive incorporation of important influencing variables; an example of an appropriate model structure is formulated as: TIP~Genesis Distance+Maximum Intensity+Translation Speed+Landfall Location+ET Condition+ENSO/PDO. This mathematical model formulation will help in estimating the impact of each variable on TIP variations and any possible nonlinear interaction among them.

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Furthermore, multivariate statistical models can be utilized to include other factors, including typhoon peak intensity, typhoon speed, location of typhoon landfall, extratropical transition of typhoons, and indicators of large-scale climate oscillations (ENSO, PDO). In this way, it will be possible to estimate the relative contribution of each of those factors and examine the existence of possible nonlinearities between the place of typhoon genesis and typhoon-precipitation relation.

Apart from recommendations for future research, this work also provides some practical implications. Even if there is no change in the locations of genesis of typhoons, the amount of typhoon-induced precipitation in Northeast China tends to increase. Thus, for disaster-risk assessment and agricultural flood-preparedness purposes, one cannot rely only on the locations of genesis of typhoons in Northeast China.

5. Conclusion

The research aimed at studying the correlation between differences in typhoon genesis locations and TIP in Northeast China for the period 2000-2025. The findings reveal that typhoon genesis locations in terms of latitude and longitude do not have significant temporal tendencies, while TIP shows an increasing tendency over the four examined cities, with only three having statistical significance. It is worth noting that there is a statistically significant positive correlation between typhoon genesis distance and TIP in Northeast China. Thus, typhoons which form at greater distances bring more precipitation to the region. Nonetheless, such correlation does not imply causation since in the course of research, other typhoon parameters including moving speed, along with large scale environments such as ENSO, were not controlled. Despite the fact that the patterns discussed above have practical value regarding flood and agriculture management in Northeast China, the physical mechanisms underlying increasing typhoon precipitation in the region require further multivariate investigations.

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