The Temporal and Spatial Distribution Patterns and Influencing Factors of Typhoons' Intensity in East Asia

Haoyang Huang*

College of Atmospheric Sciences, Lanzhou University, Lanzhou, 730099, China

* Corresponding Author Email: yhuang20@lzu.edu.cn

Abstract. Against the backdrop of global climate change, extreme weather events are becoming increasingly frequent. Typhoon disasters are among the most frequent and severe meteorological disasters globally. This study, in conjunction with sea surface temperatures and other environmental factors, explores the environmental conditions conducive to the formation of super typhoons and how environmental factors may exacerbate the adverse impact of super typhoons on human life. The study reveals that typhoons are characterized by high occurrence probability, great intensity, unpredictable paths, and wide-ranging impacts. As a mid-sized weather system, typhoon generation and distribution are significantly influenced by natural conditions. By analyzing historical data, it becomes evident that there are distinct patterns in the temporal and spatial distribution of typhoon generation sites. For instance, the likelihood of typhoon formation is greater over warm ocean surfaces during the summer season. To investigate the influence of environmental factors on the intensity of typhoon generation and development, as well as their impact on human production and life, this paper conducted relevant analyses. The research indicates that in the low-latitude ocean surface of the western Pacific with temperatures ranging from 30°C to 30.5°C, particularly from July to September, super typhoons are more likely to occur, posing a greater impact on human production and life in East Asia. Based on the findings, future research on the relationship between typhoon intensity and typhoon generation areas can be further advanced.

Keywords: Typhoon, Typhoon Disaster, Sea Surface Temperature.

1. Introduction

Against the backdrop of global climate change, extreme weather events are becoming increasingly frequent, and the impact of climate disasters on society and national economic development is becoming more evident. Among them, typhoons are powerful low-pressure systems that originate over warm tropical ocean surfaces, characterized by a high likelihood of occurrence, great intensity, unpredictable paths, and wide-ranging impacts [1]. Typhoon disasters are not only among the most frequent and severe meteorological disasters globally but also one of the most severe meteorological disasters affecting China [2].

Research has found that the northwest Pacific is the most frequent region for typhoons globally, with approximately 36% of typhoons generated in this area each year [3]. When typhoons approach mainland China, they typically bring strong winds, rainfall, and storm surges. Typhoon landfalls often result in significant loss of life and property damage, triggering serious cascading natural disasters. China is one of the countries most severely affected by typhoons. Between 1988 and 2010, typhoons caused direct economic losses of up to 29.05 billion yuan in China annually, making it a significant impediment to sustainable development in China's southeastern coastal regions [4].

Typhoon risk assessment work abroad began in the 1970s, primarily focusing on prediction and warning. After years of development and improvement, there have been numerous research achievements in typhoon disaster analysis and assessment models [5]. China's work on typhoon disaster risk assessment started later but has developed rapidly. Overall, China's research on typhoon disasters is mainly divided into four aspects: risk assessment, risk zoning, loss assessment, and risk propagation models.

As a medium-sized weather system, typhoon generation and distribution are significantly influenced by natural conditions [6]. Combining data from previous years reveals clear patterns in the temporal and spatial distribution of typhoon generation sites. However, there is currently a lack

of international research on the relationship between changes in typhoon intensity and their generation areas. Furthermore, when typhoon disasters occur, they often lead to a series of secondary disasters, some of which exhibit a chain-like evolution, constituting a typhoon disaster chain [7]. By approaching from the perspective of disaster chains, it is possible to systematically analyze the interactions between various disaster elements during typhoon occurrence and describe the spatiotemporal characteristics of disasters.

Therefore, to conduct a more in-depth analysis of the impact of typhoon disasters on China, this paper will focus on the historical temporal and spatial distribution of typhoon generation and their disastrous effects. By analyzing the spatiotemporal distribution characteristics of typhoon generation and typhoon disasters, this paper aims to provide data support and a theoretical basis for future related work.

2. Typhoon Concepts and Their Impact

Tropical cyclones are cyclonic systems that form over tropical ocean surfaces. Among them, tropical cyclones with center wind speeds reaching 12 or more on the Beaufort scale are called typhoons. Typhoons are deep low-pressure systems characterized by significantly low central pressure and lower-level airflow converging toward the center, while upper-level airflow primarily diverges outward. Typhoons typically originate in low-latitude regions near the equator. Under the influence of factors such as second-class conditional instability, they gradually develop and move, ultimately forming a powerful weather system. Mature typhoons can be divided into the typhoon eye region, the cloud wall region, and the spiral rainband region. Among these, the spiral rainband region refers to rain (cloud) bands spiraling convergently around the eye wall, with rainband widths ranging from tens of kilometers to hundreds of kilometers and lengths extending up to thousands of kilometers. This region brings extreme weather conditions such as heavy rain, strong winds, and storm surges to the areas it passes through.

The disasters caused by tropical cyclones can be categorized into various types based on wind speed, precipitation, and their impact on societal production. These types include heavy rainfall, strong winds, storm surges, flooding disasters, geological disasters, and many others. Different types often interact with each other, giving rise to new disasters. For instance, the spiral rainbands of typhoons contain a large amount of moisture, which, during their movement, can lead to substantial precipitation, resulting in heavy rainfall. This heavy rainfall may impact hydraulic engineering and urban drainage capacity, thereby causing flooding disasters. Flooding disasters, in turn, can lead to a series of problems such as building damage.

3. Mathematical Equations

3.1. Spatial and temporal distribution patterns of tropical cyclones

Table 1 presents typhoon data for the years 2019-2022, revealing that tropical cyclones occur throughout the year, with a primary concentration from July to September. Taking the year 2019 as an example, a total of 29 typhoons formed that year. Among them, 2 formed from January to March, none in April and May, 1 in June, 5 in July, 6 in August, 5 in September, 4 in October, 6 in November, and 1 in December. Notably, November had an unusually high number of typhoon formations, which can be considered a special case when comparing data from 2020-2022. This occurrence is possibly due to the higher temperatures from July to September, providing more energy for typhoon formation.

Table 1. Typhoon Count Statistics for 2019-2022

	2019	2020	2021	2022
JAN-MAR	2	0	1	0
APR-MAY	0	1	2	2
JUN	1	1	2	2
JUL	5	2	3	2
AUG	6	6	4	5
SEP	5	3	4	7
OCT	4	7	4	5
NOV-DEC	7	3	2	2
TOTAL	29	23	22	25

Furthermore, based on collected sea surface temperature data for August and September 2020 from the China Oceanic Administration, Figure 1 and Figure 2 were generated. Due to the SST data only being given in a figure way, the study has no choice but to roughly mate the latitudes and longitudes of both data. Therefore, Figure 1 and Figure 2 are not perfectly accurate. But some laws can still be found through them. A comparison between the figures reveals that typhoon formation locations are primarily concentrated in tropical ocean areas with sea surface temperatures around 30-30.5 degrees Celsius, as shown by the blue dots in the figure. The reason for this pattern is likely the warm ocean surface providing the necessary energy for typhoon formation. Additionally, during the summer months, water vapor is abundant in the atmosphere above the warm ocean surface, which favors the conditions for second-class conditional instability.

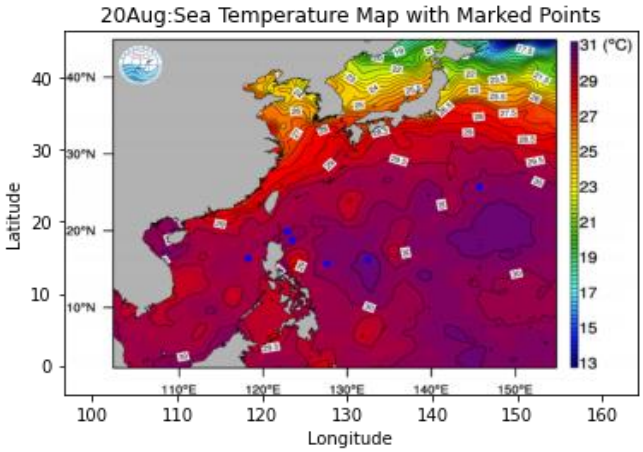


Figure 1. Sea Surface Temperature in August 2020 and Typhoon Formation Locations for the Same Month (Bottom image from https://www.oceanguide.org.cn)

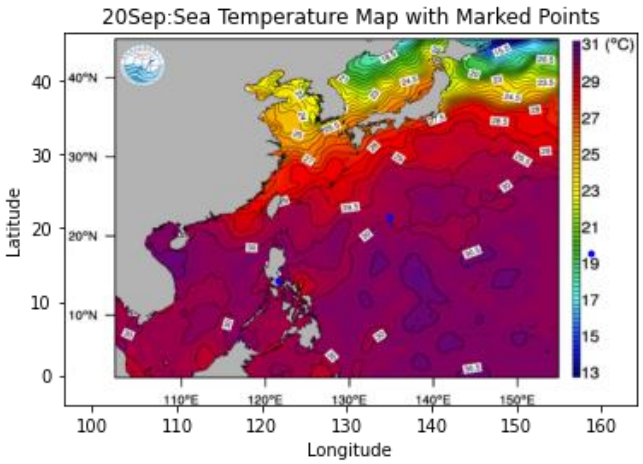


Figure 2. Sea Surface Temperature in September 2020 and Typhoon Formation Locations for the Same Month (Bottom image from https://www.oceanguide.org.cn)

3.2. Patterns of tropical cyclone impact

Considering the complexity of building a network of disasters caused by typhoons, this paper selects several indicators as references for assessing the impact of typhoons [8]. These indicators include the number of fatalities, the affected area, and direct economic losses, which are the three most representative indicators [9]. Research has found that during the years 2000-2016, Typhoon Saomai in 2006 had an extremely severe impact on China. This paper will analyze Typhoon Saomai, Typhoon Bilis, Typhoon Gemi, Typhoon Mangkhut, and Typhoon Yutu. Figure 3 illustrates the path changes when Typhoon Saomai, Typhoon Bilis, Typhoon Gemi, and Typhoon Baoxia made landfall in China.

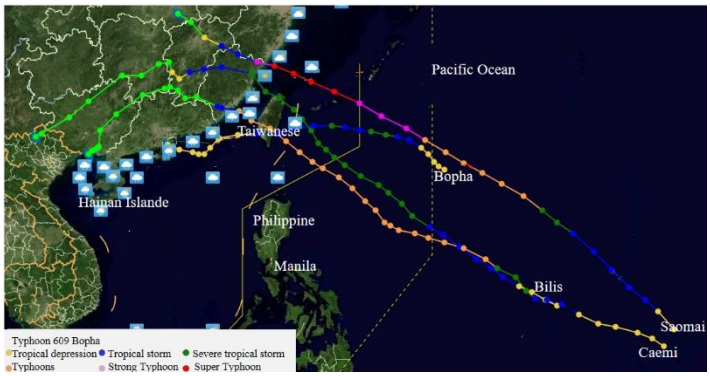


Figure 3. Paths of Typhoon Saomai, Typhoon Bilis, Typhoon Kaemi, and Typhoon Baoxia [10]

Typhoon Saomai brought intense and concentrated rainfall, with heavy precipitation mainly concentrated in southern Zhejiang, northern Fujian, and parts of central-northern Jiangxi. The landfall intensity of Typhoon Saomai was even stronger than Hurricane Katrina, which made landfall in the United States in 2005. It severely impacted the eastern coastal areas of China, resulting in a loss of 19.658 billion RMB. This was due to the exceptional strength of Typhoon Saomai in 2006 and its direct landfall in the southern part of Zhejiang Province, China.

This paper will compare Typhoon Saomai with two other typhoons from the same year, Typhoon Bilis and Typhoon Kaemi, which had similar paths. These three typhoons all formed in the summer over the ocean south of Guam in the western Pacific. Specifically, Typhoon Kaemi had a path extremely similar to Typhoon Saomai, with nearly identical early development over the ocean. However, the key difference lies in their movement speeds. It can be observed that Typhoon Saomai moved much faster than Kaemi and Bilis. This difference in speed can be attributed to the presence of another typhoon, Typhoon Baoxia, to the west of Typhoon Saomai. As these two typhoons gradually approached each other, they underwent the Fujiwhara effect, which accelerated the movement of Saomai. Ultimately, due to their east-west positioning and Saomai's lower pressure relative to Baoxia, Saomai absorbed Typhoon Baoxia and further intensified.

Moreover, Super Typhoon Saomai did not encounter any significant topographical obstacles and made a direct landfall in China. It reached as far as Wuhan, Hubei Province, after landfall. In contrast, both Bilis and Kaemi took a more southern path, making landfall from the direction of Taiwan. They passed over the mountainous terrain of Taiwan, which weakened their intensity. In the waters closer to the mainland, typhoons had difficulty intensifying further. As a result, the intensities of Kaemi and Bilis at landfall were significantly lower than that of Saomai. According to data from the China Meteorological Administration, Typhoon Kaemi had a central pressure of 975 hPa before landfall, while the central pressure of Typhoon Bilis ranged from 975 hPa to 980 hPa before landfall. In contrast, Typhoon Saomai had an extremely low central pressure of 925 hPa before landfall.

Additionally, Super Typhoon Mangkhut and Super Typhoon Yutu were two other extremely powerful typhoons that occurred in 2018, sharing several similarities in their paths and typhoon intensities. Figure 4 illustrates the path changes of Typhoon Mangkhut and Typhoon Yutu.

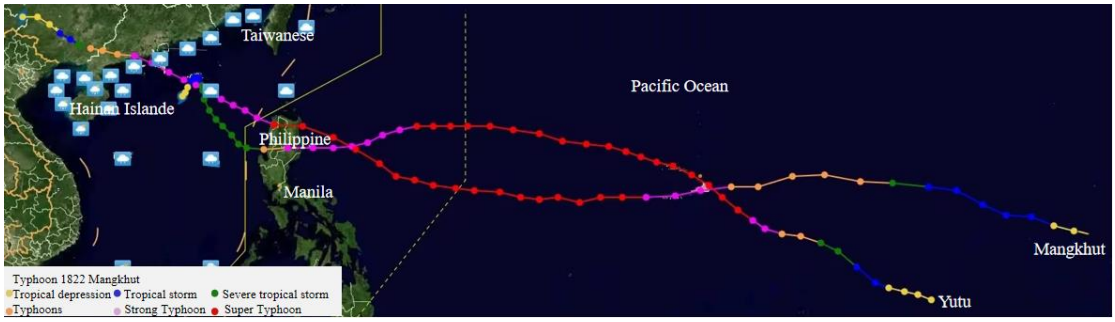


Figure 4. Paths of Typhoon Mangkhut and Typhoon Yutu[10]

The earliest recorded instance of Typhoon Mangkhut was on September 4, 2018, as a tropical disturbance that formed in the waters west of the International Date Line in the Pacific Ocean. After its formation, Typhoon Mangkhut moved westward and gradually intensified. Following its formation as a tropical disturbance, it reached the vicinity of Guam on September 11 and transitioned from a strong typhoon to a super typhoon. It had maximum sustained winds of up to 52 m/s and a central pressure of 935 hPa. Continuing its development over open waters, it reached wind speeds of 65 m/s and a central pressure of 910 hPa in the seas east of the Philippines. Subsequently, Typhoon Mangkhut made landfall in the northern part of Luzon, Philippines. Due to factors such as mountainous terrain, the typhoon's intensity began to weaken, and by the time it reached the South China Sea, it had weakened to a strong typhoon with wind speeds reduced to 48 m/s and a central pressure of 945 hPa. It maintained this status until making landfall in the western Pearl River Delta, ultimately dissipating in the Guangxi region.

The movement path of Typhoon Yutu was quite similar to that of Typhoon Mangkhut. It originated at the southwestern end of Mangkhut, generated on October 21, 2018. It moved northwestward and continued to intensify during its journey. On October 24, just three days after formation, it became a super typhoon. It continued to strengthen, with its central pressure reaching a minimum of 895 hPa and maximum sustained winds of 70 m/s near Saipan. Following this, due to changes in meteorological conditions, the typhoon underwent an eyewall replacement cycle and gradually weakened. By October 28, it had weakened to a strong typhoon as it moved east of Luzon in the Philippines. Further weakening occurred upon landfall, with the typhoon reaching the Philippines with a strength of 945 hPa. Under the influence of terrain, it continued to weaken, and by the time it reached the South China Sea, Typhoon Yutu had degenerated into a strong tropical storm. Near the Dongsha Islands, it changed course from northward to southward before ultimately dissipating.

4. Discussion

In the previous section, this paper discussed the development processes of three super typhoons. Phenomena such as the Fujiwhara effect in Typhoon Saomai and the eyewall replacement in Typhoon Yutu had significant impacts on the final intensity of the typhoons, thereby playing a decisive role in the disasters caused by the typhoons after landfall. Consequently, understanding the patterns of typhoon tracks and various oceanic factors became crucial for further comprehending the strength patterns of typhoons. To delve deeper into the underlying patterns of Typhoon Saomai's track, this section will explore from the following perspective.

4.1. West pacific subtropical high

The West Pacific Subtropical High, abbreviated as West Pac High, is a significant factor in controlling precipitation and other weather systems in China and East Asia during the summer. Typhoons, as small-scale weather systems, are often influenced by the West Pac High, and their movement paths are frequently constrained by it. The West Pac High is a low-pressure system in the 500 hPa height field, generating counterclockwise airflow around its center. Typhoons that affect East

Asia typically form in the low-latitude regions of the Pacific Ocean. Therefore, under the influence of the West Pac High, typhoons generally move from east to west.

By observing the position of the West Pac High, it is possible to predict the path and potential landfall locations of typhoons. For instance, when the West Pac High is strong and its center is close to the Asian continent, typhoons are more likely to move from east to west, impacting provinces such as Guangdong, and Guangxi in China, and countries like Vietnam. This path may also lead typhoons to pass over the Philippines, where the terrain can sometimes weaken their intensity, reducing their impact on China and other Southeast Asian countries. Conversely, when the West Pac High is weak and its center is farther away, typhoons tend to move in a more north-south direction and may approach regions such as Zhejiang and Jiangsu in China. In such cases, typhoons may continue to move northward, affecting Japan and the Korean Peninsula, among others. It's important to note that aside from the West Pac High, other factors like the South Asian High can also influence typhoon tracks and require more detailed analysis and calculations.

4.2. Sea surface temperature

Sea surface temperature is a crucial factor in determining typhoon development. Typhoons, as tropical cyclones, require warm ocean water to form and intensify. If a typhoon encounters areas of lower sea surface temperatures during its movement, it will lose its energy source, potentially halting development or causing weakening. The variation in sea surface temperature is generally systematic in the meridional direction, which also explains why typhoons often weaken after turning northward near the East China Sea. Apart from meridional changes, there are also latitudinal variations in Pacific sea surface temperatures. In general, the low-latitude regions of the western Pacific have warmer sea surface temperatures, but there are fluctuations. This interannual variation is known as the El Niño-Southern Oscillation (ENSO) cycle.

The ENSO cycle can influence atmospheric circulation and ocean surface temperatures, thereby affecting typhoon formation and tracks [11]. This phenomenon typically manifests as alternating El Niño and La Niña events. During El Niño events, sea surface temperatures in the eastern Pacific rise, potentially leading to more typhoon formation and impacting their tracks. In contrast, during La Niña events, sea surface temperatures decrease, potentially reducing typhoon formation and strengthening the influence of the West Pac High. Therefore, sea surface temperature and the ENSO cycle are critical factors for understanding and predicting typhoon activity.

5. Conclusion

This paper has comprehensively compiled several key factors and physical reasons influencing typhoon development and discussed the relationships between various meteorological elements and the potential impacts of typhoons. It also introduced current quantitative indicators and research progress related to the disasters and effects caused by typhoons. Through the summary and discussion of previous work, this paper can draw the following conclusions:

In general, when a typhoon's movement path remains over warm ocean surfaces, it is more likely to develop and intensify due to the ample energy supplied by the warm sea surface. Particularly, when two typhoons come close to each other, an interaction phenomenon known as the Fujiwhara effect may occur, leading to a significant increase in the typhoon's movement speed. The specific path of a typhoon is often determined by the atmospheric pressure field in which it resides. Among these pressure fields, the two most prominent and stable ones are the West Pacific Subtropical High and the South Asian High, with the former having the most pronounced influence.

Based on this understanding, when estimating the potential impacts and disasters caused by typhoons, one can start by analyzing the atmospheric pressure field to determine the possible movement path of the typhoon. By considering changes in sea surface temperature, the likelihood of typhoon intensification can be assessed. If a typhoon remains over temperate sea areas for an extended period, the chances of its intensification will be greater. Conversely, when a typhoon's movement

path remains over cooler sea areas for an extended period, the likelihood of typhoon development decreases. Additionally, it is crucial to monitor whether there are other typhoons with projected paths close to the typhoon's path during the same period, as the Fujiwhara effect can significantly impact the typhoon's movement speed. Lastly, attention should be paid to the presence of islands or other geographical factors along the typhoon's path that could lead to a reduction in its intensity, with a particular focus on Taiwan and the Philippine Islands.

The research presented in this paper is primarily based on theoretical discussions of meteorological principles and atmospheric physics. Specific data related to typhoons are lacking, particularly when discussing the influences of factors like atmospheric pressure fields and sea surface temperatures. Therefore, the discussions in this paper are limited to general patterns. Due to the lack of specific data, detailed analyses of individual years, especially how the ENSO cycle further affects typhoon development through changes in sea surface temperatures and atmospheric pressure fields, were not conducted. Future research should prioritize data collection and advancements in ENSO predictions to further elucidate the patterns of typhoon variation.

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