Statistical Analysis of Typhoons in China and the Western Pacific Ocean

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Keywords: Typhoon, Sea Surface Temperature, ENSO, SOI.

Abstract: Typhoon has the characteristics of sudden strong, destructive power. Typhoons can cause huge economic losses and casualties to coastal countries and regions, so it is considered to be one of the most serious natural disasters in the world. The impact of typhoons has gradually increased in recent years. Therefore, the accurate analysis and prediction of typhoon is particularly important. This paper starts with statistical methods, obtains relevant data in the last hundred years, analyzes and summarizes some important factors that may affect typhoon. Indicators such as barometric pressure and sea surface temperature are most likely to affect typhoons. Therefore, the study started from the subtropical high and SST, collected many years of data and research, and analyzed the relationship between them and typhoons by statistical methods. By analyzing the data of the last hundred years and synthesizing the previous studies, the influence of the Western Pacific subtropical high and ENSO (El Niño-Southern Oscillation) on the Pacific typhoon is discussed. Finally, the correlation between typhoon and these two factors is obtained through analysis.

1 INTRODUCTION

Typhoons are tropical cyclones occurring in the northwest Pacific Ocean and the South China Sea with central sustained winds of 17.2m/s or above, including tropical storms, severe tropical storms, typhoons, severe typhoons, and super typhoons (Wang et al 2021). Typhoon has the characteristics of sudden strong, destructive power. Typhoon can cause huge economic losses and casualties to coastal countries and regions, so it is considered one of the most serious natural disasters in the world (Kossin et al 2013 & Ying et al 2014).

Favorable atmospheric circulation, sea temperature field, and other thermal and dynamic environmental conditions are the direct background of typhoon development. Traditionally, low-level cyclone disturbance, warm and humid SST, and small vertical shear of tropospheric zonal wind are the three basic environmental conditions for typhoon occurrence (Zou 2009). A large number of typhoon case diagnoses and numerical simulation tests have expanded our understanding of the environmental factors affecting the change of typhoon intensity, such as circulation and underlying surface. Cold air, high-altitude jet stream, westerly trough, small and medium scale system, topographic action, and sea surface spray may also have an impact on typhoon intensity. In addition, the degeneration of tropical cyclones by mid-latitude circulation systems will also affect their intensity and track. Therefore, the sea-air environment conditions of China's offshore waters will directly affect the active degree of typhoons entering China's offshore waters. The sea-air environmental conditions in the South China Sea and the tropical West Pacific also restrict the number and distribution of typhoons generated in the sea area, thus indirectly affecting the offshore typhoons in China (Zheng 2015).

The generation and development of typhoons cannot be separated from the heat transfer of the ocean to its system. In the context of the long time scale of global warming, the activity path and influence range of typhoons have changed significantly in the northwest Pacific Ocean.Sea surface temperature (sea surface temperature, SST) and air-sea flux is one of the important factors affect the air-sea interaction (Hu 2013). At the same time, since SST and air-sea interaction are significantly affected by the El Nino-Southern Oscillation (ENSO), the ENSO event is also one of the factors affecting typhoons. It is of great significance to use numerical models to study the impact of ENSO events on typhoons, to forecast and defend typhoon disasters, and to assess the impact of decadal changes of SST on typhoons (Zheng et al 2013).

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2 INFLUENCE OF INTERDECADAL VARIATION OF SUBTROPICAL HIGH ON TYPHOON VARIATION

Northwest Pacific subtropical high (Western North Pacific Subtropical High WNPSH), hereinafter referred to as subtropical high. It is a permanent high-pressure circulation system over the Pacific Ocean, generally represented by the area surrounded by the 5880 gpm line on a 500 hpa elevation chart over the western Pacific (Chai et al 2023). As an important factor affecting the weather system, the inter-annual variation of subtropical high has an important influence on various factors of typhoons.

2.1 Research Data and Methods

Typhoon data are obtained from IBTRACS, the best archive for International Climate Management. The data includes the relative physical quantities of tropical storm locations and intensities, with an interval of 6 h. It records most tropical cyclones developing in the Northwest Pacific Ocean from 1861 to 2020. It is used to study the annual average duration, annual frequency, and longitude and latitude of typhoon path. The 500 hPa altitude field data was used by the Beijing Climate Centre, BCC-CSM2-MR_historical_r3i1p1f1 and the French National Centre for Meteorological Research, CNRM) CNRM _historical_r2i1p1f2 CM6-1-2 sets of CMIP6 data with ERA5.

2.2 Influence of Interannual Variation of the Western Pacific Subtropical High on Typhoon Characteristics

2.2.1 Statistical Characteristics of Minor Heights

The Northwest Pacific Subtropical High is one of the important systems that affect typhoons and other weather processes. The correlation between the 500hPa altitude field and the northernmost latitude and westernmost longitude reached by typhoons is roughly bounded by 40°N, while the relationship between the north and the south is opposite. The correlation coefficient between the maximum latitude reached by typhoon and the 500hPa altitude field is negative north of 40°N and positive south of 40°N. This is because the area south of 40° N is the main active area of the subtropical high, and when the 500hPa altitude field increases and the subtropical high strengthens, it is conducive to the northbound typhoon (Chai et al 2023).

In general, it is of practical significance and research value to study the typhoon activity range by the decadal variation of the subtropical high, west ridge and ridge position.

2.2.2 Correlation Between Typhoon Activity Characteristics and Subtropical High

The region where WNPSH is located is the region where the sinking branch of Hadley circulation is located, and the stronger the sinking branch of Hadley circulation is, the more conducive it is to the sub-high intensification. The ascending branch of Walker circulation is located at the equator between 120 and 160° E. When the West Pacific warm pool is strong and the monsoon trough is more active, the ascending branch of Walker circulation on the equator is also stronger, which will make the subtropical high position to the west and north, which is conducive to typhoon influence on China (Mu et al 2001). A v-w wind synthesis analysis of Hadley circulation at 120~160° E and 0~ 40° N was conducted to obtain the average condition of Hadley circulation at 0~ 40 ° N under the zonal average of 120~160° E during 1861 ~ 2020, as shown in figure 1.

Similarly, to study the ascending branch of the Walker circulation, a synthetic analysis of the average u-w wind over the equator at 120 to 160° E from 1861 to 2020 was also performed, as shown in figure 2.

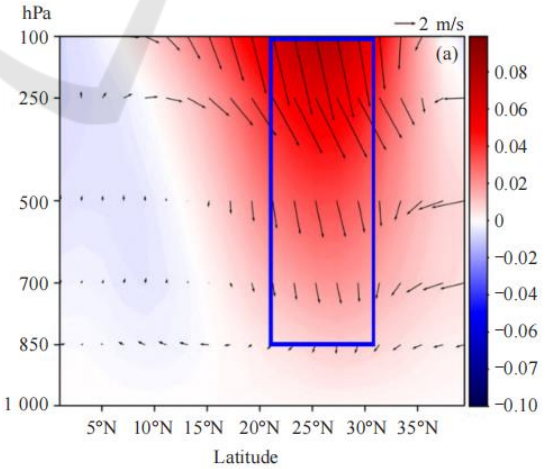

Figure 1: V-W wind synthesis analysis of the zonal mean of 120°~160 °E and 0 °~40 °N from 1861 to 2020 (Picture credit: Original).

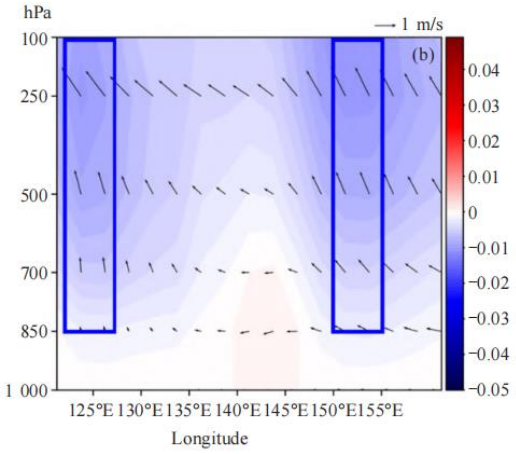

Figure 2: Average u-w wind synthesis analysis of 120 ° ~160 ° E over the equator from 1861 to 2020 (Picture credit: Original).

The ascending branch of the Walker circulation at the equator divides into two branches at 120-160 °E. One is located in the region above 850hPa from 122 to 127 °E, and the other is located in the region above 850hPa from 150 to 155 °E. Calculate the change in the mean value of subsidence motion over 160 years for the large value region of the sinking branch of the Hadley circulation (the region represented by the blue box in Figure 1a), defined as wh; And the change in the mean 160-year upward motion of the high-value regions of the two Walker circulation rising branches (the regions represented by the blue boxes in figure 2, defined as ww (Gong and Wang 2000).

The average 500hPa height field h in the key WNPSH region is significantly positively correlated with the vertical velocity wh of the sinking branch of Hadley circulation and negatively correlated with the average vertical velocity ww of the rising branch of Walker circulation. The annual frequency of typhoons in East China is significantly correlated with h. The annual frequency affected by typhoons in South China is significantly correlated with wh and ww. As shown in figure 3, 4 and 5.

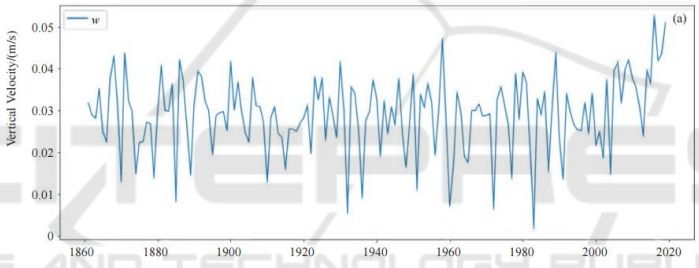

Figure 3: Example of Annual variation of wh and simulation results (Picture credit: Original).

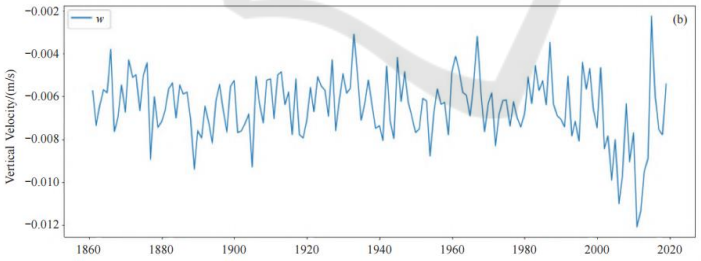

Figure 4: Annual variation of ww and simulation results (Picture credit: Original).

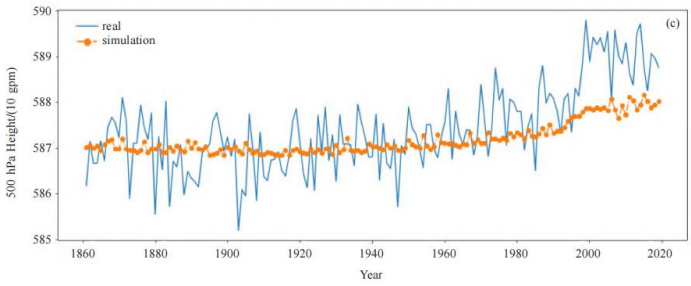

Figure 5: Annual variation of h(c) and simulation results (orange dot line in c) (Picture credit: Original).

2.3 Result Analysis

The average 500hPa height field h in the key WNPSH region is significantly positively correlated with the vertical velocity wh of the sinking branch of Hadley circulation and negatively correlated with the average vertical velocity ww of the rising branch of Walker circulation. The annual frequency of typhoons in East China is significantly correlated with h. The annual frequency affected by typhoons in South China is significantly correlated with wh and ww. Using t and h as independent variables, the curve estimation can successfully simulate the annual frequency of typhoon influence in East China. Using t, wh, and ww as independent variables, the curve estimation can successfully simulate the annual frequency of typhoon influence in South China.

3 ANALYSIS OF THE INFLUENCE OF EL NINO-SOUTHERN OSCILLATION (ENSO) ON TYPHOONS

Sea surface temperature (SST), as an exogenous forcing, has an important effect on the atmosphere. The formation and development of tropical cyclones are closely related to the size and distribution of SST. This is because the wide ocean is the main source of typhoon energy, and the high-temperature seawater provides energy for the formation and development of typhoons in the form of sensible heat flux and latent heat flux. On the other hand, when a tropical cyclone moves over the sea, the SST is reduced by bringing cold water from deep layers to the mixed layer through physical processes such as enrolling and suction. At the same time, since SST is an important component of El Nino-Southern Oscillation (ENSO), and the most intuitive manifestation of ENSO is the inter-annual variation of SST, ENSO is also one of the important factors affecting typhoons (Zheng et al 2013).

3.1 Data Sources

The IBTRACS (http://ibtracs.unca.edu/) dataset includes estimates of typhoon location and intensity at intervals of 6h, starting from 1884 in the Northwest Pacific Ocean. The data records 4193 tropical cyclones that have developed in the Western Pacific Ocean since 1884. Among them, the period of the best path data is 1884-2020, and the period of the lowest central pressure and the maximum wind speed near the center is 1946-2020. Select the time node to compare the time of typhoon occurrence. Based on the time series of typhoon locations provided by IBTRACS data, the changes of the northernmost latitude, westernmost longitude, typhoon frequency, frequency of strong typhoons in East and South China, as well as the changes of the minimum central pressure, and the maximum wind speed near the center since 1884 were analyzed. Based on the changes of WNPSH, West Pacific warm Pool, ENSO, flow field, radiation flux, and other fields, the long-term climate change since 1880 is investigated, and the correlation analysis is made. Based on the changes of 500hPa warm pool, radiant flux, ENSO, and related physical quantities, the influence of long-scale changes such as ENSO and radiant flux on tropical cyclones in the Northwest Pacific Ocean in the past 100 years was explored, and comparative analysis was made.

3.2 Influence of ENSO on Typhoon Activity

Previous analyses have shown that physical quantities such as vertical wind shear, vorticity, radiation, and water vapor all have an impact on typhoons, and ENSO activities may further affect typhoon activities through the influence of these physical quantity fields. The main areas of typhoon generation and development in East Asia and Southeast Asia (105° - 180° E) can be calculated. The time series of the average vertical wind shear, vorticity, SDLR, and specific humidity of 5° -30° N, to calculate the correlation coefficient between these variables and the Southern Oscillation index (SOI), and calculate the correlation distribution diagram between the physical quantity field that passes the 95% significance test and the typhoon activity frequency at the corresponding location (Zheng et al 2013).

The SOI index is a representative index to measure ENSO activities. The correlation coefficient between the frequency of typhoons in the Northwest Pacific Ocean since 1884 and the SOI index has reached 0.1337, passing the 90% significance test. The sliding correlation analysis between the SOI index and the frequency of typhoons in the Northwest Pacific Ocean since 1884 is carried out. Thus, the influence of ENSO activities on the frequency of typhoon generation in different years was explored (Liang 2021).

As shown in figure 6, 7, 8, in this region, the typhoon generation frequency in the LaNina year is the highest, and the typhoon generation frequency in ElNino year is the lowest, and the typhoon generation probability in ElNino year is high in the ocean, while the typhoon generation probability in LaNina year is high in the offshore.

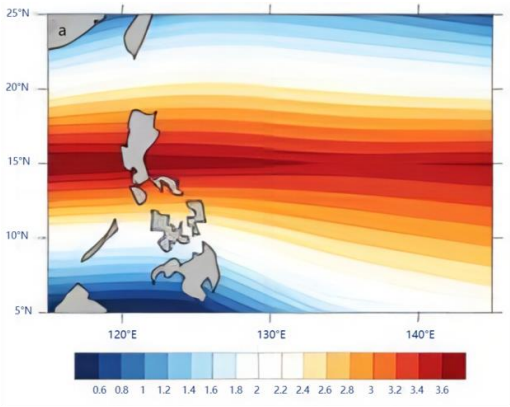

Figure 6: Annual frequency distribution of typhoons in the main typhoon-generating regions of the tropical Northwest Pacific perennial LaNina years (Picture credit: Original).

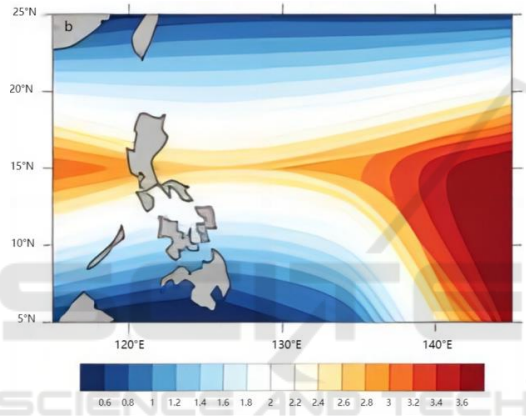

Figure 7: Annual frequency distribution of typhoons in the main typhoon-generating regions of the tropical Northwest lNino (Picture credit: Original).

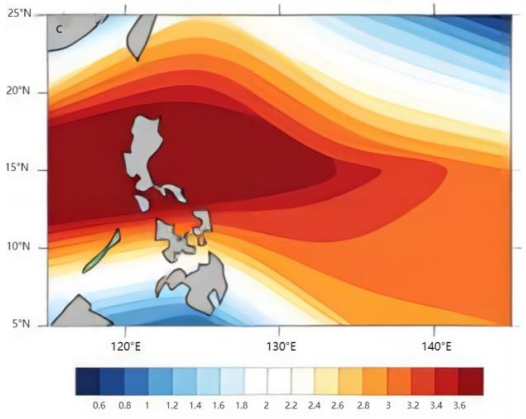

Figure 8: Annual frequency distribution of typhoons in the main typhoon-generating regions of the tropical Northwest Pacific LaNina years (Picture credit: Original).

As shown in figure 9, the positive correlation between SOI and the frequency of typhoon generation in the Northwest Pacific Ocean is on the rise, and since 1980, except for a short negative correlation in the early 21st century, the remaining time has been positively correlated, and the positive correlation between the two has been significantly enhanced since around 2008. This positive correlation enhancement trend indicates that when the SOI index is higher, the frequency of typhoon generation in the Northwest Pacific Ocean is higher. When the LaNina event occurs, the frequency of typhoon generation in the northwest Pacific tends to be higher (Zhang and Lv 2012).

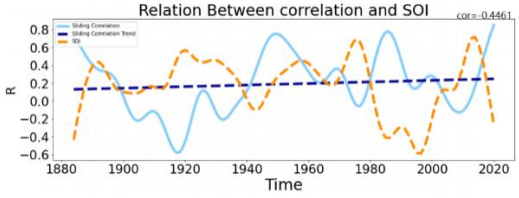

Figure 9: Analysis of the smooth-sliding correlation between SOI index and typhoon frequency in the Northwest Pacific Ocean since 1884 (Picture credit: Original).

Combined with figure 6, 7, 8 and 9, it is found that ENSO activity can affect the location of typhoon generation, but the influence on typhoon frequency is uncertain to a certain extent, and further study on the influence of ENSO on typhoon activity is needed.

4 CONCLUSION

By analyzing the data of the last hundred years and synthesizing the previous studies, the influence of the Western Pacific subtropical high and ENSO on the Pacific typhoon is discussed.

In the past hundred years, the duration and annual frequency of typhoons after 1930 have increased in all regions. The average annual impact duration of typhoons in the Northwest Pacific during 1975-2020 has decreased compared with that during 1930-1975, but the annual frequency of typhoons has no significant change. There is no significant change in the annual influence duration and frequency in South China. However, the annual average duration and annual frequency of typhoons in the East China coastal area have increased significantly, which is significantly related to the change of WNPSH in the past 160 years. The annual frequency of typhoons in East China is significantly correlated with h. The annual frequency affected by typhoons in South China is significantly correlated with wh and ww. Moreover,

using t and h as independent variables to estimate the curve, the annual frequency of typhoon influence in East China can be simulated successfully. Using t, wh, and ww as independent variables, the curve estimation can successfully simulate the annual frequency of typhoon influence in South China.

There is a general causal relationship between radiation flux and ENSO-related variables, some of which are directly caused and some are indirectly related. In general, changes in radiative fluxes can affect changes in ocean heat, and changes in ocean heat can affect changes in atmospheric circulation, thus creating a causal relationship between radiative fluxes and ENSO-related variables. In ElNino years, typhoons tend to form ocean-going, and the typhoon tracks tend to be east-north, with large intensity variance. In LaNina year, typhoons tend to generate near the coast, the typhoon path is west-south, the intensity variance is small, and the average impact time of southeast coastal areas of China is long.

There are still some areas that need to be further explored in this study. First, the intensity of the physical quantity field involved in this paper can also be defined from different angles. How to define the radiation amount, the intensity of ENSO activity and the intensity of typhoon activity from various angles, so as to study the interaction between these elements is a very worthwhile problem. Second, more comprehensive studies can be conducted from the perspective of more physical quantities, such as ENSO changes over long time scales. There are still many related physical quantities and the interaction between ENSO worthy of further study. Moreover, the various ENSO-related physical quantities mentioned in this paper, such as radiation flux, are also worthy of further study, so as to have a deeper understanding of the effect of ENSO changes on typhoons over a long time scale.

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