Relationship between the tropical cyclone genesis over the Northwest Pacific and the sea surface temperature anomalies*

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Abstract Using the tropical cyclone (TC) data derived from the Joint Typhoon Warning Center (JTWC) and the sea surface temperature data derived from the Joint Environmental Data Analysis Center (JEDAC) at the Scripps Institute of Oceanography from January 1955 to December 2000, we analyzed the relationship between the TC genesis over the Northwest Pacific (NWP) and the sea surface temperature anomalies (SSTA) over the Pacific basin. A long-term trend indicated that the highest frequency of monthly TC genesis appeared earlier and the annual genesis sum increased gradually during the last half century with some oscillations. No significant synchronous correlation was found between the NWP TC events and the SSTA over the Pacific basin, while the annual sum of TC genesis was closely related with the SSTA averaged from the first three months (January, February and March) of the year in the equatorial western and eastern Pacific and over mid-high latitudes of the North Pacific. The results implied that there are an interannual El Niño SSTA mode in the equatorial western and eastern Pacific and an interdecadal SSTA mode in the northern Pacific, which affected the TC genesis. A regression analysis between the first three-month SSTA and the annual TC sum based on two time scales was conducted. The correlation coefficient between simulated and observed TC sums reached a high value of 0.77.

Keywords: **tropical cyclone, long-term trend, sea surface temperature, Pacific.**

Many studies indicated that the sea surface temperature (SST) or the sea surface temperature anomalies (SSTA) have a crucial impact on the tropical cyclone (TC) genesis[1]. In the tropical Pacific, a famous phenomenon of SSTA is the El Niño cycle, resulting from air-sea interaction. During the process of the El Niño cycle, phase transitions between cool and warm waters in the tropical Pacific will cause the significant changes in atmospheric circulation which is correlated closely with the TC genesis[2,3]. Previous studies usually compared the difference of TC frequency from El Niño and La Nina phases based on various El Niño index series. However, regional SSTA have different magnitudes and effects. Some regional SSTA series, such as NINO3[4,5] (5°N—5°S, 150°W—90°W) or NINOC[6] (0—10°S, 180—90°W) were used before as an index to indicate the El Niño cycle or SSTA in the equatorial eastern Pacific. In recent years, the SSTA from the region of NINO3.4 (5°N—5°S, 170°W—120°W) were widely used as an index in the long-term forecasting operation[7].

This study aimed at finding the long-tern trend of the TC genesis in the NWP for the last half century, tried to explore the possible relationships between the TC genesis in the NWP and regional SSTA over the Pacific, and identify some possible early signals of SSTA to indicate the TC frequency in the NWP. Two datasets of the sea surface/subsurface temperature over the Pacific and the TC over the NWP were used in this study. The former was derived from the Joint Environmental Data Analysis Center (JEDAC)[8] for the period from January 1955 to December 2000 (totally 46 years) with a grid resolution of 5 degrees longitude by 2 degrees latitude. The latter is the Best Track Dataset obtained from Joint Typhoon Warning Center (JTWC)[9], which includes information on TC signature numbers, storm positions observed every 6 hours, central maximum wind speed and pressure. According to the central wind speed, TC can be categorized into three classes: tropical depression (TD, with maximum central wind speed ≤34 kn or 17 m/s), tropical storm (TS, 34—64 kn, 17—32.6 m/s) and severe tropical storm (> 64 kn, 32.6 m/s). In this study, we ignored their discrepancies and regarded them all as TC. The data ranged from 1945 to 2002, covering two regions of the South China Sea (90°E—122°E) and the NWP

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(122°E—180°E).

1 Characteristics of TC events in the NWP

Fig. 1 shows the monthly sum of the TC genesis in the NWP for 1945—2002. Most of the TC events appeared from July to October with a peak in August (totally 289) and less TC events in January to March. Since the summer and autumn are the seasons for TC landfall in China[10], Chinese Climate Center and Chinese Oceanic Prediction Center make prediction of TC events every year in spring (March and April). The procedure is to first predict the SSTA in summer and autumn based on the spring SSTA, and then to predict the sum of TC events of the year. To avoid the spring forecast barrier[11], or the difficulty in forecasting the SSTA or the TC sum in summer and autumn from the spring SSTA, we first examined the relationship between the TC genesis and regional SSTA on interannual and interdecadal time scales.

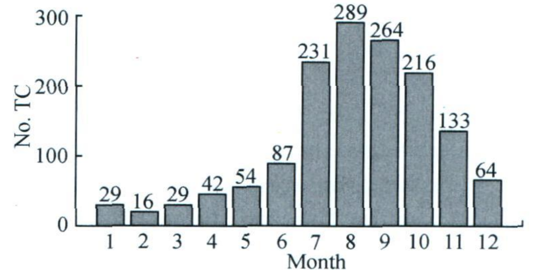

Fig. 1. Monthly sum of the TC events in the NWP, based on all TC records from 1954 to 2002.

Fig. 2 shows monthly departure times of the TC events relative to annual sum from 1945 to 2000. The months with the maximum TC genesis varies from year to year. A trend is clearly seen that the months of maximum TC genesis became earlier gradually in the last 50 years although climatologically the TC genesis concentrated mainly in August and September. In the 1950s and 1960s, the month of maximum TC genesis was in September and October, even November, but in recent decades it was in August and even July.

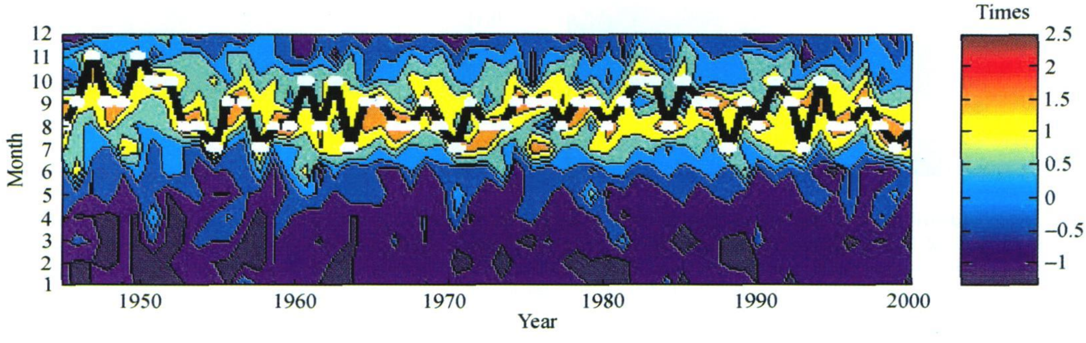

Fig. 2. Monthly departure times of the TC events relative to annual sum from 1945 to 2000. The heavy solid curve indicates those months with the maximum TC events.

An increasing trend and long-term oscillation of the annual TC events in the NWP can be observed from Fig. 3. In the 1960s and 1990s the annual sum of TC events was higher but it was lower in the 1950s.

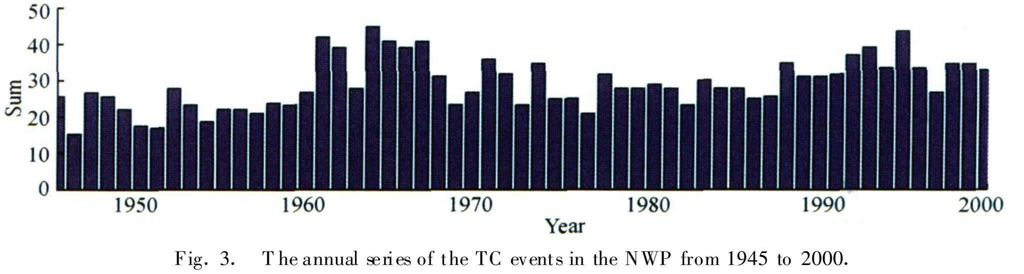

Fig. 3. The annual series of the TC events in the NWP from 1945 to 2000.

2 Relationship between regional SSTA and the TC genesis

According to the analyses of Gray[1, 12], the rising sea temperature should be helpful for more TC genesis. However, our result showed that the synchronous correlation between the monthly SSTA and TC genesis was not significant on the interannual timescale. Lag correlations indicated that the SSTA in the first three months (January, February and March) of the year in the Pacific was associated with the NWP TC events in various periods (Fig. 4). Positive and negative correlations were observed in the equatorial western Pacific, the northern Pacific and in the equatorial central-eastern Pacific. The distribution of positive/negative correlations in the tropical Pacific was likely consistent with an El Niño SSTA mode.

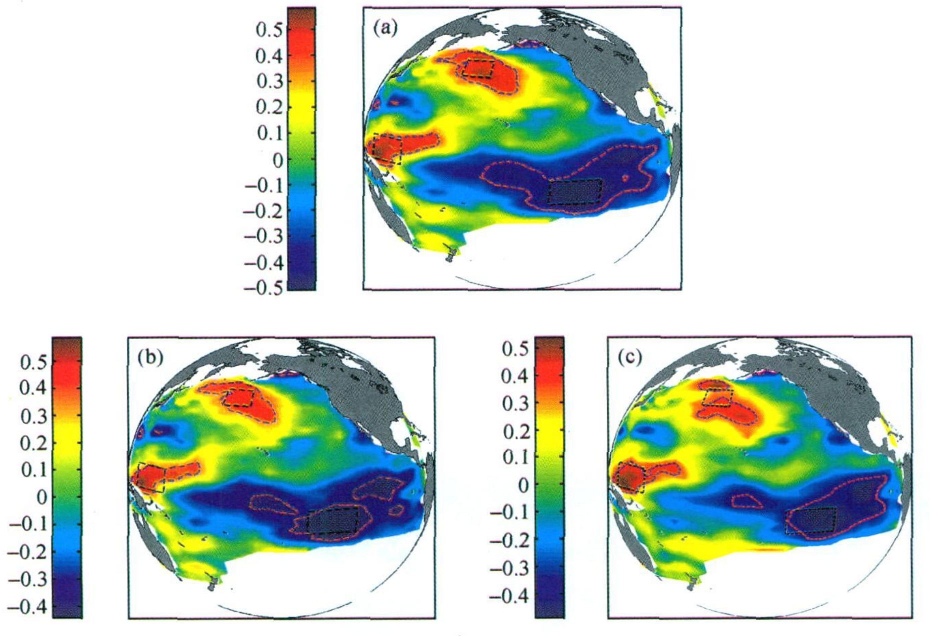

Fig. 4. Correlation distributions of the SSTA from the first three months (January, February and March) in the Pacific to the NWP TC genesis in three periods of (a) 12 months (January to December), (b) 9 months (April to December), (c) 4 months (June to September). Correlation coefficients are marked on the left side. The SSTA in dashed areas was used to construct the regression analysis. Dot line covered areas indicate that the correlation reaches the 0.01 significance level.

3 Two timescale SSTAs and the TC genesis

Based on significant correlations indicated in Fig. 4, SSTA averaged from three areas was chosen as indicators to construct a multi-variable regression equation. First, two SSTA series were obtained from the equatorial western and eastern Pacific as indicated in the boxes (Fig. 4(a)). A multi-variable regression equation to indicate the annual sum of the NWP TC genesis using the SSTA from January to March can be written as

$$N = b_0 + b_1 T_1 + b_2 T_2 \tag{1}$$

where N is the constructed or simulated annual sum of the NWP TC events, variables T_1 and T_2 are the SSTs averaged from January to March in the equatorial western and eastern Pacific, respectively. Three coefficients based on the least square fit are $b_0 = 38$, $b_1 = 2.67$ and $b_2 = -4.15$.

The observed and constructed annual sums of the NWP TC events can be compared from Fig. 5. The annual variations of the TC genesis were simulated, especially since the 1970s but those oscillations in the 1960s and 1990s were not fitted well.

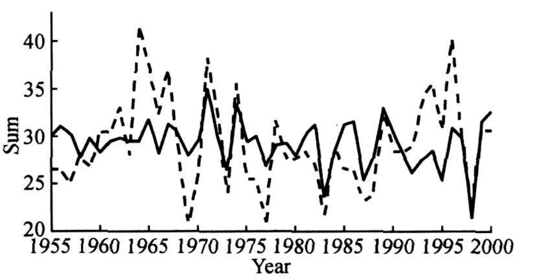

Fig. 5. Simulated (solid line) and observed (dashed line) annual sums of the NWP TC events. Correlation coefficient of two series is 0.59 at the 0.05 significance level.

In the Pacific basin, there are two significant time scales of SST variations. On the interannual time scale, SSTA oscillation or El Niño cycle was mainly concentrated in the tropical Pacific basin. On the interdecadal time scale, SSTA oscillation was located at mid-high latitudes over the North Pacific. The El Niño cycle through SSTA can change the location and strength of the inter-tropical convergence zone, and hence the TC genesis. Influence of SST over the equatorial Pacific on the TC genesis has been widely concerned on the interannual time scale while the interdecadal SSTA should also be considered.

An improved approach has been made through introducing the SST at the mid-high latitudes to the regression equation. The new equation occupies three variables

$$N = b_0 + b_1 T_1 + b_2 T_2 + b_3 T_3 \qquad (2)$$

where the third variable T_3 is the SST averaged from the 7-year running series and boxed in Fig. 4(a) over the North Pacific but the SST is also taken from January to March. Their coefficients are $b_0 = -98.6707$, $b_1 = 4.9657$, $b_2 = -3.4875$, and $b_3 = 7.5882$. A simulated result based on three variables from interannual and interdecadal time scales of SST variability well fitted the observation of the NWP TC events. The correlation coefficient between observed and simulated TC sums is 0.77 at the 0.05 significance level.

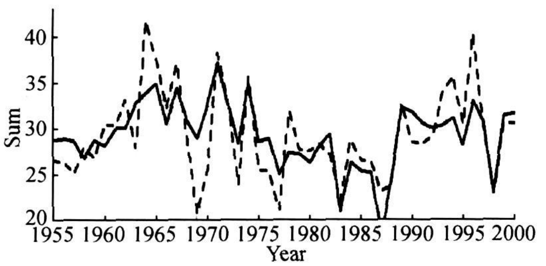

Fig. 6. The same as Fig. 5. except for adding the SST as a new variable in the mid-high latitudes over the North Pacific.

Results from the last two figures indicated that the SST in the tropical Pacific and North Pacific as early signals from the first three months of the year can well indicate the annual sum or several monthly sums of the NWP TC events. Some differences can still exist in simulated and observed sums of the NWP TC events from Fig. 6. The differences may be linked with other factors that need to be further investigated.

4 Conclusion and discussion

By the relation analysis of the NWP TC events and the SST variations over the Pacific basin in the last half century, some results and problems can be proposed as follows.

(i) Long-term trends indicated that the highest frequency of monthly TC genesis became earlier and annual sum of the NWP TC events increased gradually in the last 56 years with some oscillations. The two trends may be directly linked to the SST warming in the tropical Pacific.

(ii) There was no significant synchronous correlation between the NWP TC events and the SSTA in the Pacific basin but significant correlation found from the SST in the first three months of the year and the annual TC sum. High correlation distributions in the equatorial western and eastern Pacific indicated the influence of the El Niño SSTA mode on the TC genesis on the interannual time scale. High correlation distribution in the North Pacific indicated the influence of the interdecadal SSTA mode on the NWP TC genesis. The result implied that the first three month's SSTA can be used as early signals for predicting annual TC events in the NWP.

(iii) It is reasonable to consider the SSTA effect on the TC genesis from interannual and interdecadal time scales. The constructed regression equation by using the SSTA in the first three months of the year to predict annual TC events can well avoid the spring forecast barrier. However, two mechanisms need to further be explained. The first is through what processes of SSTA on interannual and interdecadal time scales affected the TC genesis. The second is why there were regionally and significantly lag relations between the annual TC events and the SSTA from the first three months of the year. On the interdecadal time scale, Ho et al.[13] revealed some facts that the strength and location of the subtropical high in the NWP can directly influence the position, frequency of the TC genesis over the NWP. A possible way may be that the basin scale SSTA first influences the large scale circulation and hence affects the TC genesis in the NWP region.

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