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IMPACT OF CONVECTION OVER THE SOUTH CHINA SEA ON TROPICAL CYCLONE MOTION OVER THE WESTERN NORTH PACIFIC DURING SUMMER MONSOON

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Abstract: The intraseasonal oscillation (ISO) of the South China Sea (SCS, 105-120°E, 5-20°N) convection and its influences on the genesis and track of the western North Pacific (WNP) tropical cyclones (TCs) were explored, based on the daily average of NCEP/NCAR reanalysis data, the OLR data and the western North Pacific tropical cyclone best-track data from 1979 to 2008. The mechanism of the influences of ISO on TC movement and the corresponding large-scale circulation were discussed by a trajectory model. It was found as follows. (1) During the SCS summer monsoon, the SCS convection exhibits the ISO features with active phases alternating with inactive phases. The monsoon circulation patterns are significantly different during these two phases. When the SCS convection is active (inactive), the SCS-WNP monsoon trough stretches eastward (retreats westward) due to the activity (inactivity) of SCS monsoon, and the WNP subtropical high retreats eastward (stretches westward), which enhances (suppresses) the monsoon circulation. (2) The amount of TC genesis in the active phase is much more than that in the inactive phase. A majority of TCs form west of 135 °E during the active phases but east of 135 °E in the inactive phases. (3) The TCs entering the area west of 135 °E and south of 25 °N would move straight into the SCS in the active phase, or recurve northward in the inactive phase. (4) Simulation results show that the steering flow associated with the active (inactive) phases is in favor of straight-moving (recurving) TCs. Meanwhile, the impacts of the locations of TC genesis on the characteristics of TC track cannot be ignored. TCs that occurred father westward are more likely to move straight into the SCS region.

Key words: tropical cyclone genesis and track; climatological statistics; South China Sea convection; intraseasonal oscillation; monsoon trough; trajectory model
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1 INTRODUCTION

Monsoon is the most important synoptic and climatic phenomenon in East Asia[1], which is closely related to the social and economic life in this region. The South China Sea (SCS) monsoon that has attracted much more attention in recent years is one part of the East Asian summer monsoon. And the SCS-western North Pacific (WNP) monsoon trough is an important component of the East Asian summer monsoon system. Besides the monsoon, the tropical cyclone (TC) activity also has severe impacts on East Asia region. The transition and migration of the large scale monsoon circulation system may have notable influence on TC genesis and track. Therefore, the impact of monsoon on TC is a hot issue in TC research field, and has been explored by many domestic and international researchers.

Many studies have found that TC formation is remarkably affected by the intensity and location of the SCS-WNP monsoon trough. Harr and Elsberry[2-4] found that the TC activity is closely related to the variability of the monsoon trough. Active (inactive) periods of the WNP TC are found to occur when the large-scale circulation anomalies that represent an active (inactive) monsoon trough. Sun and Duan[5] showed that the change in the intensity of the summer monsoon bears a close relation to the TC frequency in the WNP. Wang et al.[6] indicated that the WNP summer monsoon system impacts TC genesis mainly through the activity of the monsoon trough, and the strength of the summer monsoon has impacts on both locations and frequency of TC genesis. TC genesis mostly occur in the western (eastern) WNP, and the number is evidently more (less) in the strong (weak) phase of the monsoon trough. Sun

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and Ding[7] found that during 1998 and 1999, the anomalous westward and northward movement of monsoon trough in midsummer was an important reason causing the decrease of TC number and westward shift of genesis location. Gao et al.[8] analyzed the behaviors of monsoon trough and their impacts on TCs generated in monsoon trough (MTTC), and found that the intensity of the monsoon trough is closely linked with the frequency of MTTC. In addition, many climate statistical analysis also suggested that the monsoon trough environment is conducive to the formation of TC[9-11]. Thus, over the WNP, monsoon has significant impact on TC formation, and the strength of monsoon trough is directly related to the position and frequency of TC genesis. So what are the mechanisms by which monsoon affects TC genesis? Harr et al.[12, 13] suggested that the mesoscale convective system plays an important role in the process of monsoon depression developing into TC. Kuo et al.[14] showed that the large-scale convergence, the scale contraction and nonlinear effects provide the essential mechanisms for the initial development of tropical disturbances through nonlinear energy/enstrophy accumulation in the confluent zone.

In the 1990's, some researchers abroad noticed that the Asian monsoon activities may affect the TC movement over the WNP, while there were fewer domestic studies on this aspect. Harr and Elsberry[3-4] divided the large-scale variabilities associated with the monsoon trough and subtropical ridge into different circulation patterns, and each pattern is connected to a specific TC track type. When the pattern changes, the TC motion will also change. Camargo et al.[15-16] used a new probabilistic clustering technique to describe TC trajectories in the WNP. They found that different large-scale patterns of atmospheric circulation (such as monsoon trough, subtropical ridge) are linked with different types of TC trajectory. Observations presented that the TCs will turn poleward suddenly when they move into monsoon gyres[17]. Furthermore, approximately 80% of the TCs associated with a reverse-oriented monsoon trough move on north-oriented tracks[18].

The tropical WNP during boreal summer is characterized by the multiscale circulation and convection, from synoptic to intraseasonal time scale[19-20]. While the synoptic scale wave[21] can provide initial disturbances for TC formation [22-23], the Quasi-Biweekly Oscillation (QBW)[24-26] and the Madden-Julian Oscillation (MJO)[27-29], which are the components of the intraseasonal oscillation (ISO), can affect TC motion. Ko and Hsu[30] demonstrated that the recurving TCs may have a linkage to the northwestward-propagating submonthly wave patterns. Chen et al.[31] disclosed that a majority of straight-moving (recurving) TCs appear during weak (strong) monsoon westerlies and strong (weak) trade easterlies. Wu et al.[32] revealed that the MJO and QBW components of monsoon flow play an important role in the TC anomalous track through a case study.

As can be seen from these aforementioned studies, most of them focused on the case analysis or the effects of one specific component of the ISO on TC paths. So far, there has been very few researches on the influences of the oscillation characteristics of ISO on TC tracks from the perspective of climatological statistics. Therefore, from this point of view, and based on long time series data, we analyzed the circulation background characteristics of ISO during different phases and their influences on TC passages by using the running mean to filter the synoptic scale disturbances. Then numerical experiments were conducted by using a trajectory model[33] to investigate the mechanisms of the ISO's impact on TC movement from the aspect of large-scale steering flow. This work hopes to gain more insight on the effect of the ISO on TC motion and gives references in TC track prediction during summer monsoon over the WNP. Meanwhile, the influences of the ISO on TC genesis were also analyzed. Although many previous studies have explored the relationship between monsoon and TC formation, but the present study reanalyzed this issue in view of the ISO, in order to provide more comprehensive understanding about the impact of ISO on TC activities.

2 DATA AND METHODS

For the period of 1979–2008, the datasets used in this study including (1) the daily Outgoing Long-wave Radiation (OLR) reanalysis data from the National Oceanic and Atmospheric Administration (NOAA), which have a spatial resolution of 2.5°× 2.5°; (2) the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data of daily average with the horizontal resolution 2.5°× 2.5°; (3) the TC best-track data from China Meteorological Administration (CMA) is provided by Shanghai Typhoon Institute of CMA through the website http://www.typhoon.gov.cn, which include the center position and maximum surface sustained wind speed at time intervals of 6 hours.

All TCs selected for the present study are named TCs. The TC genesis and passage frequencies are defined on each grid box to indicate the spatial distribution of TC activity. And the grid box is 2.5° latitude and 2.5° longitude. The onset and retreat dates of the South China Sea summer monsoon are determined according to OLR fields as well as high and low level wind fields. The specific methods can be found in Gao et al.[34].

3 THE ISO FEATURES OF SCS CONVECTION DURING SUMMER MONSOON

3.1 *Definition of the active/inactive phase*

In this study, the OLR anomalies are used to represent the intensity of convection. To reveal the influences of ISO features of the SCS convection on the

WNP TC activities, moving average method is applied to filter the synoptic scale disturbance in the OLR time series, only retaining the ISO signals.

$$OLR'_{11}(t) = OLR_{11}(t) - 220\ W/m^2 \quad (1)$$

where $OLR_{11}(t)$ is 11-day running mean of the SCS regional average OLR at time t. In general, when OLR $\leqslant$ 220 W/ m^2, it indicates active convection. Therefore, the $OLR'_{11}(t)$ is obtained by subtracting 220 W/m^2 from $OLR_{11}(t)$. Based on this, the period that $OLR'_{11}(t)$ is greater than 0 for five or more consecutive days is defined as an active period, and the period that $OLR'_{11}(t)$ is less than 0 W/m^2 for five or more consecutive days is defined as an inactive period. The active and inactive periods all occur during the SCS summer monsoon. The SCS convection is inactive before the onset and after the retreat of monsoon. Hence ISO phenomenon is absent during those periods.

Since the annual SCS summer monsoon starts with the beginning of the first active convection period, and retreats with the end of the last active period, the amount of inactive monsoon/convective phase is one less than that of active monsoon/convective phase. The statistical results show that there are 4.3 active phases and 3.3 inactive phases annually for the period of 1979–2008. In 1979 (Fig.1), for example, the SCS summer monsoon was from the 3rd pentad of May to the 1st pentad of October. There were 4 active phases (14/5–22/5, 17/6-9/7, 26/7-15/8, 16/9-4/10), and 3 inactive phases (23/5-16/6, 10/7-25/7, 16/8-15/9).

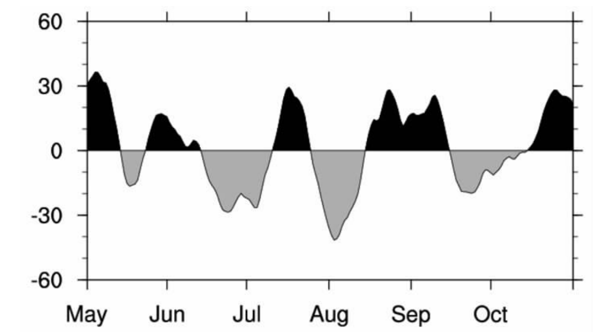

Figure 1. The time series of the OLR′ 11 (t) during May-October, 1979 (Units: W/m^2).

3.2 *Climatological characteristics of active/inactive phases*

From the composited OLR fields of active and inactive phases, we can see that the convection differences between active and inactive phases are highly significant. The low-value centers of OLR are located in the eastern Indochina Peninsula and the eastern SCS during active periods (Fig.2a). The convection over the eastern SCS is very active with a minimum less than 175 W/m^2. This convection area, connecting with the WNP convective zone and the Indochina convective region, forms the summer Intertropical Convergence Zone (ITCZ). The WNP subtropical high is situated in the east of 120°E, north of 20 °N, where the OLR values are high, which indicates inactive convection. During the inactive period (Fig.2b), there is a high value center existed over the SCS, with a maximum higher than 250 W/m^2 and inactive convection. Meantime, the Indochina convection weakens, and the WNP convective zone gets shrinking and weakened. The WNP subtropical high strengthens and stretches westward to the SCS, so the ITCZ is interrupted in the SCS. Hence we can see that the convection over the SCS and east of Philippines is intense during the active phase, which can provide a large number of initial disturbances for TC genesis. Conversely, the convection over the SCS is suppressed during inactive periods, which is unfavorable for TC formation and development. And the convection in the east of the Philippines weakens accordingly, which can reduce the probability of TC occurrence. These are consistent with the statistical results (Fig.3).

The distribution of low-level (850 hPa) vorticity (Fig.4) is in agreement with the OLR (Fig.2). The positive vorticity areas from Indochina to the SCS and over the east of Philippines constitute the ITCZ during the active period (Fig.4a). Two positive vorticity centers are located over the eastern Indochina and central SCS respectively. On the wind field, it is characterized by a strong and deep monsoon trough with a northwest-southeast trend. Southwesterly prevails in the

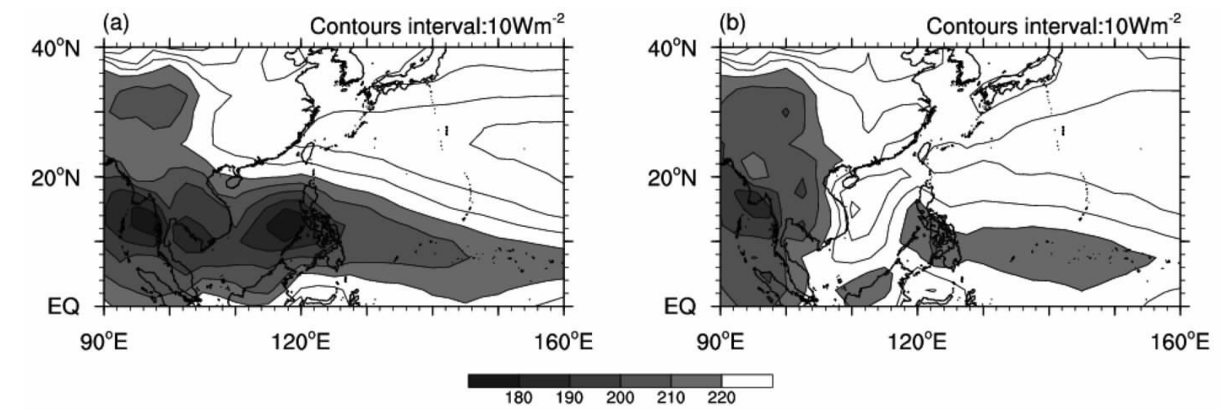

Figure 2. The climatological mean OLR (Units: W/m^2) distribution in active (a) and inactive (b) phases during the SCS summer monsoon of 1979-2008, and the shaded area means that the OLR is less than 220 W/m^2.

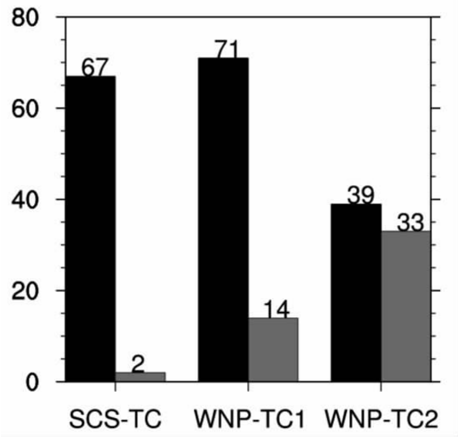

Figure 3. The amounts of the three categories (SCS-TC, WNP-TC1, WNP-TC2) TC cases in active (dark) and inactive (gray) periods during 1979-2008.

south of the trough line, and southeasterly prevails in the north. The positive vorticity zone seated over the east of Philippines is formed by the convergence of the cross-equatorial flow between 120°E and 140 °E as well as the easterly at south of the WNP subtropical high. Therefore, the monsoon trough located over the SCS and the WNP convergence zone can provide low-level cyclonic vorticity for TC formation during active phases. Meanwhile, vertically, the deep warm air over the monsoon trough can increase the thickness of the troposphere, enhance the anticyclonic circulation at high level, and turn the low-level cyclonic shear into anticyclonic shear at the top, which is conducive to TC genesis [8]. In inactive phases (Fig.4b), the monsoon trough retreats westward, out of the SCS, and the central and eastern part of the SCS becomes a negative vorticity region, which is unfavorable for TC formation. The WNP convergence zone still exists, with weakened intensity and narrowed coverage. Hence, during inactive phases, the TCs mainly occur over the WNP besides the SCS, and the TC genesis frequency also decreases during the inactive periods (Fig.5).

In middle troposphere (Fig.6a), the position of the SCS-WNP monsoon trough is slightly more southward than that at lower level (Fig.4a), located at about 13°N. For the WNP subtropical high, the west boundary of 5,870 gpm (geopotential meter) contour reaches to the vicinity of 124° E. The low-level tropical convergence zone (Fig.4a) no longer exists at the mid-level. In inactive periods (Fig.6b), the WNP subtropical high stretches westward and dominates the northeastern SCS. Easterly prevails over the southern SCS, and southerly in the north part. The circulation pattern of high level (200 hPa, figures are not shown) is basically opposite to that of low level (Fig.4). Anticyclonic circulation prevails over the SCS to WNP, which is stronger in the active phases than that in inactive phases. Therefore, the monsoon circulation of active periods is more intensive than that in the inactive periods both in horizontal and vertical directions.

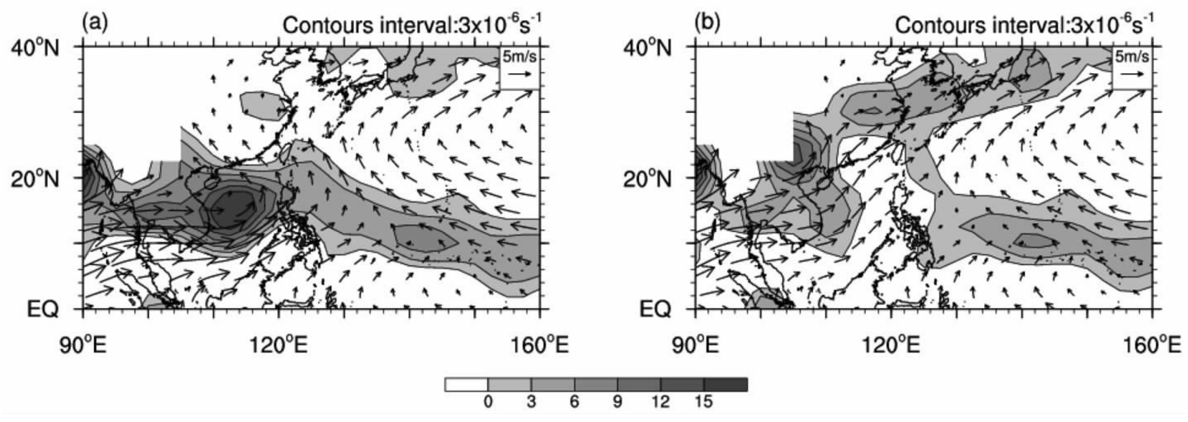

Figure 4. The climatological mean 850-hPa wind (Units: m/s) and vorticity (Units: 10^{-6} s^{-1}) field in active (a) and inactive (b) phases during the SCS summer monsoon of 1979-2008, and the shaded area indicates positive vorticity area.

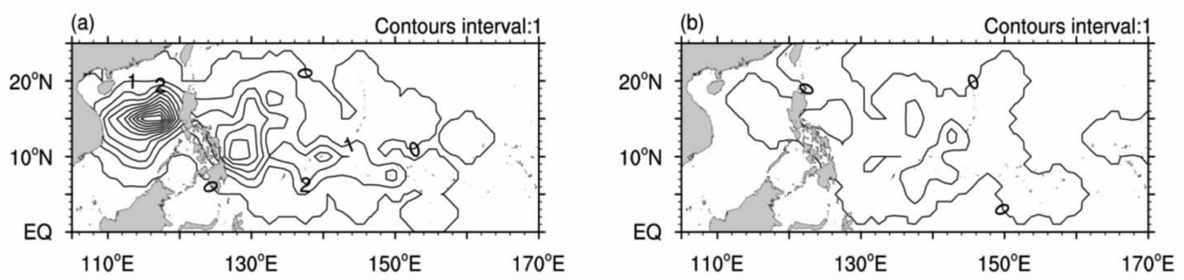

Figure 5. The TC genesis frequency in active (a) and inactive (b) periods during the SCS summer monsoon of 1979-2008.

According to the above analysis, the oscillation phenomenon of the SCS convection is the manifestation of the ISO feature of the SCS summer monsoon. The active (inactive) convection corresponds to the active (inactive) summer monsoon over the SCS. The SCS-WNP monsoon trough stretches eastward (retreats westward) due to the activity (inactivity) of SCS monsoon, and the WNP subtropical high retreats eastward (stretches westward), which enhances (suppresses) the monsoon circulation.

4 CLIMATIC CHARACTERISTICS OF TC ACTIVITY

Due to the limited influence range of the SCS convection, we define 120°-135 °E, 5°-25 °N as the affected region (AR). 226 TC cases were selected to discussed the climatic characteristics of the WNP TC activity during the SCS summer monsoon. They can be divided into three categories based on the genesis location and track. The first category is named SCS-TC, which represents the TCs generated over the SCS (69 cases); The second category stands for the TCs moving straight, which form over the WNP and move straight (westward or northwestward) into the SCS (85 cases), called as WNP-TC1; And the last category, WNP-TC2, refers to the TCs with recurving tracks, which occur over the WNP, move into the AR, then turn to the north before entering into the SCS (72 cases). The WNP-TC1 and WNP-TC2 are collectively defined as the WNP-TC.

The TC genesis frequency in active periods is markedly different from that of inactive periods (Fig.3). There are 177 TCs occurred and developed in active phases, but only 49 TCs generated during inactive periods. Among these three kinds of TC, the SCS monsoon exerts the most direct and obvious influence on the SCS-TC. There are only 2 SCS-TC cases formed in inactive periods, but 67 cases developed during active phases. Furthermore, the ISO feature of the SCS monsoon has dominant effect on TC track. During active periods, about 65% of the WNP-TC cases travel with straight (west- or northwest-oriented) paths, while only approximately 30% of the WNP-TC cases move west-northwestward in inactive phases, and more than 70% recurve northward before entering into the SCS. Thus it can be seen that TCs tend to move straight and affect Hainan, Guangdong and Guangxi provinces when the SCS summer monsoon is active, or they will turn northward over the AR and pose threat to Fujian and Zhejiang provinces when the monsoon is inactive.

From the TC genesis frequency (Fig.5), we can also see clearly that the TC genesis frequency in active periods is far more than that in inactive periods. It is associated with the strong active monsoon circulation and the deep monsoon trough which can provide cyclonic vorticity in low level, anticyclonic vorticity in high level for tropical cyclogenesis. This is one of the favorable conditions for TC formation[35-36]. In addition, the monsoon trough is composed of a large number of mesoscale deep convective systems, which can provide initial disturbances for TC formation. Both observational and numerical studies[37-40] indicated that the spontaneous breakdown of monsoon trough is one mode of tropical cyclogensis. Meantime, the monsoon trough also has an important influence on the location of TC formation. In active phases, tropical cyclogenesis mainly takes place in the region west of 135° E where the SCS-WNP monsoon trough is located (Fig.5a). Two large-value centers of the TC genesis frequency are situated over the SCS and east of the Philippines. During inactive periods, the convergence zone between 135°E and 150° E is the main genesis region (Fig.5b), where more than half of TCs form. So, when the SCS summer monsoon is active (inactive), there are more (less) TCs generating over the WNP, and the main formation location is located west (east) of 135°E.

The steering by surrounding large-scale flows plays a predominant role in determining TC motion[41]. Are the TC motion characteristics related to the different steering flow during two reverse ISO periods? We will discuss this issue by using the trajectory model[33] below.

5 NUMERICAL EXPERIMENTS

There are many factors affecting TC movement. Wang et al. [41] summed them up in three categories: external forcing factor, internal dynamics factor, and the interactions with the environment. Among them, there are two fundamental mechanisms operating in TC motion, one is the advection of the relative vorticity or potential vorticity associated with the TC by the large-scale circulation (large-scale steering), and the other one is the propagation or beta (β) drift that involves the nonlinear interactions among the environmental flow, the planetary vorticity gradient and the vortex circulation. Observation analysis suggests that the TC movement has better correlation with the vertical mean steering flow than the steering flow at a specific level, and because the TC is a coupled system in vertical direction, it moves as a whole. Due to the intense convergence and divergence in the boundary layer and outflow layer, it is unfavorable to correctly estimating the vorticity advection. Therefore the vertical mean steering flow between 850 hPa and 300 hPa is a reasonable choice[42]. Numerical and observational studies indicated that the propagation component can be 2-4 ms-1 and it becomes important in causing a systematic deviation when the steering currents are weak[33].

5.1 *Model description and experimentation schemes*

The model used in this present study is a trajectory model proposed by Wu and Wang [33]. In this model, a TC is treated as a point vortex, and moves with the climatological mean translation velocity within a specified grid box. In other words, all the storms located within the same grid box move at the same speed. The input data needed in this model are (1) the storm initial position data; (2) the TC average movement speed data. The climatological mean velocity of TC motion is the sum of the large-scale steering flow and beta drift. The mean large-scale steering flow speed is the vertical mean steering flow speed between 850 hPa and 300 hPa, calculated from the NCEP/NCAR reanalysis for the current climate state. The mean beta drift is estimated from the CMA-STI best-track data by removing the steering flow, as

$$\vec{V}_{TC}=\vec{V}_{steering}+\vec{V}_{\beta drift} \quad (2)$$

where, $\vec{V}_{TC}$ is the mean velocity of TC movement. $\vec{V}_{steering}$ is the mean large-scale steering flow. $\vec{V}_{\beta drift}$ is the beta drift. So, there is

$$\vec{V}_{\beta drift}=\vec{V}_{TC}-\vec{V}_{steering} \quad (3)$$

Since the active (inactive) SCS convection periods correspond to the active (inactive) TC activity periods, there are more (less) WNP-TC TCs generated in the west (east) of 135°E and entering the SCS region in active (inactive) phases. So, we discuss the influence factors of TC motion from the large-scale steering flow and formation location. Two sets of experiments have been carried out in this study. There are 110 and 47 TC input cases in active (AC) and inactive (IN) experiments. The observational initial genesis locations of the WNP-TC cases are shown in Fig.6. The experimentation schemes are listed in Table 1.

5.2 *Results of the experiments*

The observation (Fig.7a) and the results of AC-I experiment (Fig.8a) are very similar, and two kinds of prevailing tracks (straight westward and northwestward tracks) are simulated well. The simulated maximum center shifts westward slightly relative to observational high value center, which may be related to the land and sea parameters. The difference field between AC-II and AC-I (Fig.8b) shows that the frequencies of northwestward and recurving trajectory increase, and the straight westward tracks decrease when the mean steering flow of inactive periods takes the place of that in active periods. This indicates that the environmental background of inactive phases is disadvantageous of straight westward passages, which is consistent with the observations (Fig.7). Fig. 8c and 8d show the changes of TC passage frequency when the initial locations shift

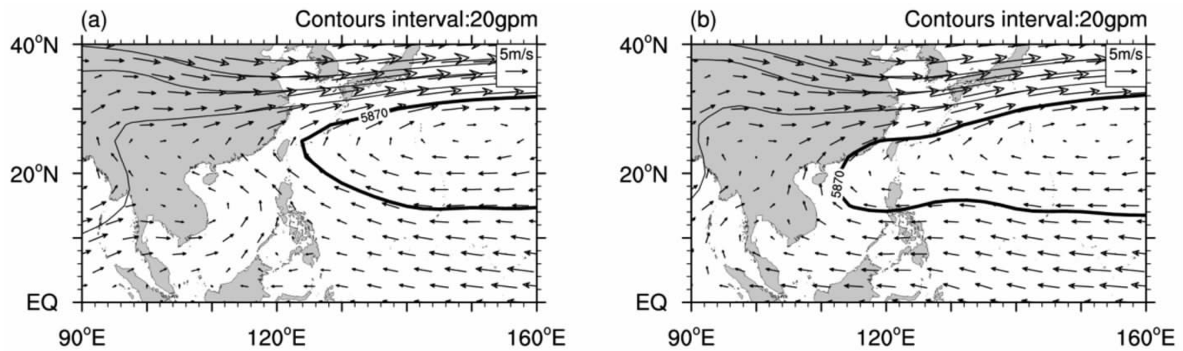

Figure 6. The climatological mean 500-hPa wind (Units: m/s) and geopotential height (Units: gpm) field in active (a) and inactive (b) phases during the SCS summer monsoon of 1979-2008.

Table 1. The experimental designs of two categories of WNP-TC cases.

a. The experiments of the WNP-TC cases (110) in active (AC) periods;

Experiments	Initial genesis location	Mean velocity of TC movement
AC-Ⅰ	Observational locations	$\vec{V}_{steering}$ of AC periods +$\vec{V}_{\beta drift}$ of AC periods
AC-Ⅱ	Observational locations	$\vec{V}_{steering}$ of IN periods+$\vec{V}_{\beta drift}$ of AC periods
AC-Ⅲ	Shifting westward 5 longitudes relative to observational locations	$\vec{V}_{steering}$ of AC periods+$\vec{V}_{\beta drift}$ of AC periods
AC-Ⅳ	Shifting eastward 5 longitudes relative to observational locations	$\vec{V}_{steering}$ of AC periods+$\vec{V}_{\beta drift}$ of AC periods

b. The experiments of the WNP-TC cases (47) in inactive (IN) periods.

Experiments	Initial genesis location	Mean velocity of TC movement
IN-Ⅰ	Observational locations	$\vec{V}_{steering}$ of IN periods +$\vec{V}_{\beta drift}$ IN periods
IN-Ⅱ	Observational locations	$\vec{V}_{steering}$ of AC periods+$\vec{V}_{\beta drift}$ IN periods
IN-Ⅲ	Shifting westward 5 longitudes relative to observational locations	$\vec{V}_{steering}$ IN periods+$\vec{V}_{\beta drift}$ IN periods
IN-Ⅳ	Shifting westward 5 longitudes relative to observational locations	$\vec{V}_{steering}$ IN periods+$\vec{V}_{\beta drift}$ IN periods

westward and eastward 5 longitudes respectively. It can be seen that more WNP-TC cases will move westward and enter into the SCS region when their initial locations are closer to the SCS, and vice verse. In the practical observations, the genesis locations of active phases are farther westward than those in inactive phases. Hence, in active periods, not only the large-scale circulation is in favor of straight westward tracks, but also the further westward genesis locations of the WNP-TC cases is another important reason.

There are only 47 cases in inactive phases, and the distribution of the passage frequency is well simulated (Fig.9a). The dominating tracks are recurving tracks and northwestward tracks, which is coincide with observation (Fig.7b). When we replace the mean steering flow in inactive periods with the mean steering flow in active periods, the frequencies of the recurving and northwestward tracks decrease and the straight westward tracks increase. This suggests that the large-scale atmospheric flow in active phases is favorable for straight passages. The results of the IN-III and IN-IV (Fig.9c and 9d) are in agreement with that of AC-III and AC-IV (Fig.8c and 8d). The farther eastward formation locations are advantageous to the recurving tracks.

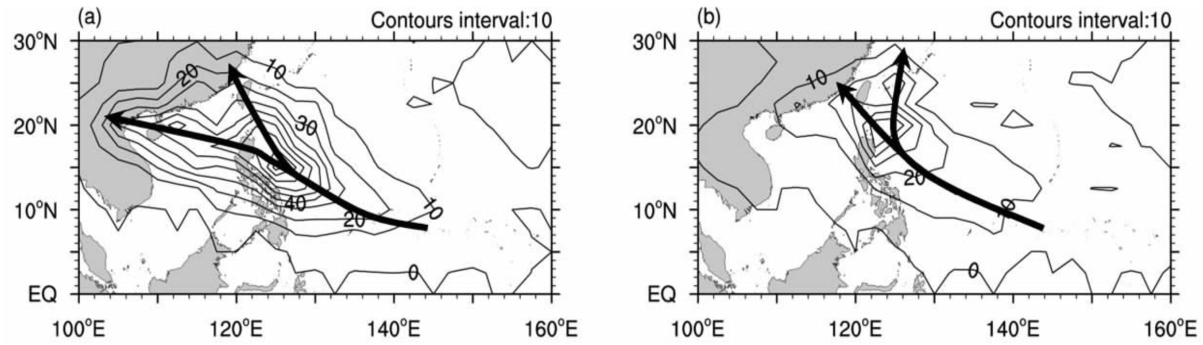

Figure 7. The TC passage frequency in active (a) and inactive (b) periods during the SCS summer monsoon of 1979-2008.

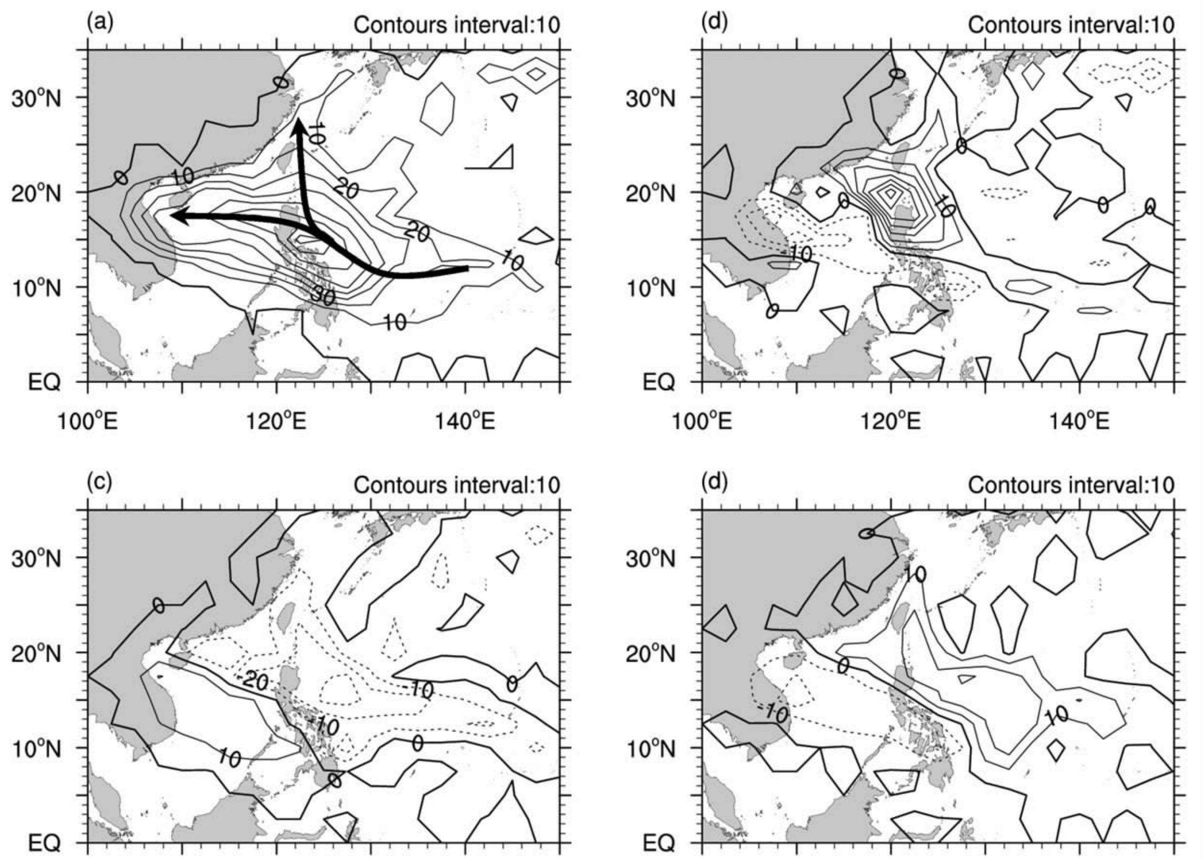

Figure 8. The simulation results of the active (AC) TC cases. (a) AC-I; (b) the differences between AC-II and AC-I; (c) the differences between AC-III and AC-I; (d) the differences between AC-IV and AC-I.

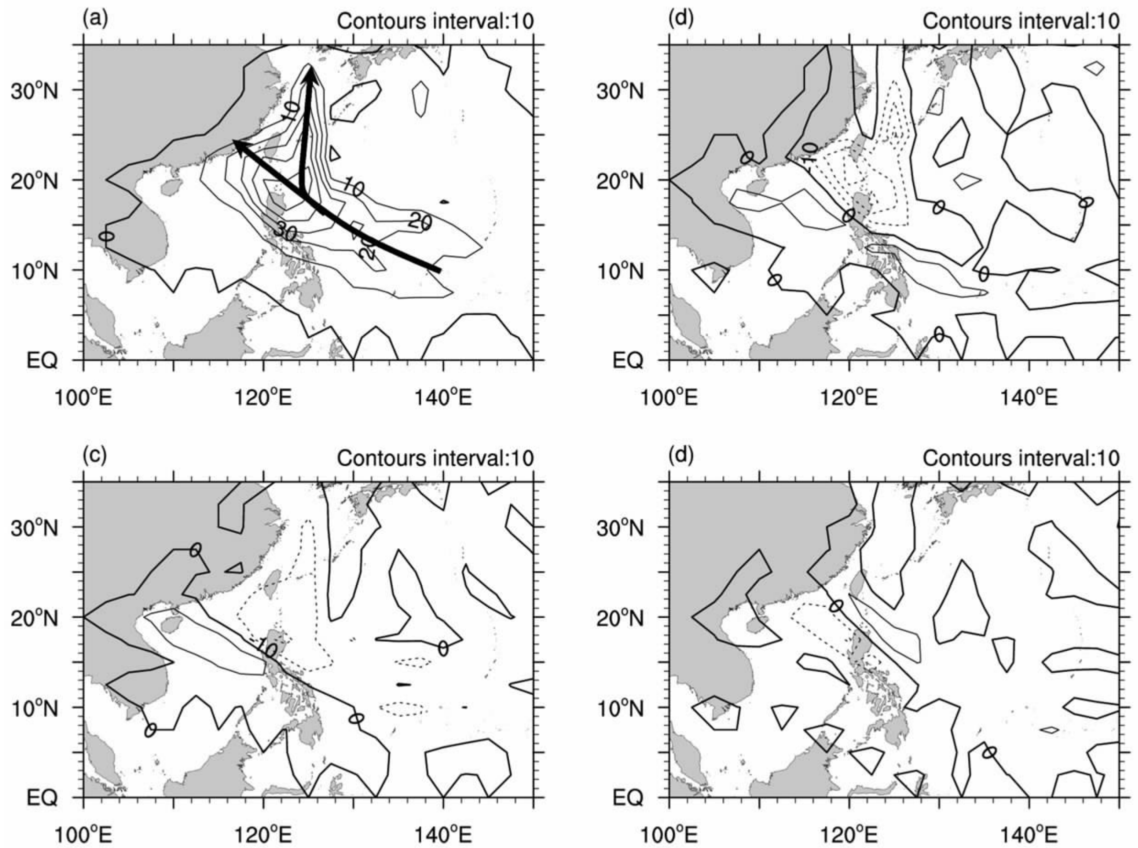

Figure 9. The simulation results of the inactive (IN) TC cases. (a) IN-I; (b) the differences between IN-II and IN-I; (c) the differences between IN-III and IN-I; (d) the differences between IN-IV and IN-I.

According to the above analysis, the trajectory model has the capacity to simulate the climatological characteristics of the WNP-TC during the SCS summer monsoon. The simulation results show that when the SCS monsoon is active (inactive), the large-scale circulation background is favorable for straight (recurving) movement of WNP-TC and westward (northward) tracks. And the genesis locations also have influence on TC track types, the farther westward (eastward) locations are conducive to westward (northward) passages.

6 CONCLUSIONS

This present study investigates how the ISO features of the SCS summer monsoon affect the TC activities over the WNP, especially the TC motion. The main conclusions are as follows.

(1) During the SCS summer monsoon, the convection over the SCS exhibits ISO features, the active phases alternate with inactive phases. When the SCS convection is active (inactive), the monsoon is active (inactive), the SCS-WNP monsoon trough deepens (weakens) and stretches eastward (retreats westward), the WNP subtropical high weakens (strengthens) and retreats eastward (stretches westward), with the enhanced (suppressed) the monsoon circulation.

(2) The ISO characteristics of the SCS monsoon have notable effects on both the TC track and genesis. The active (inactive) periods of the SCS monsoon correspond to the active (inactive) periods of the TC activity. Among the SCS-TC, WNP-TC1 and WNP-TC2, the SCS monsoon exerts the most direct and obvious influence on the formation of the SCS-TC. Almost all the SCS-TC cases developed during active phases. The WNP-TC cases tend to move straight westward, enter into the SCS region, and affect Hainan, Guangdong and Guangxi provinces when the SCS summer monsoon is active, or they will turn northward over the AR and pose threat to Fujian and Zhejiang provinces during inactive monsoon periods.

(3) The simulation results of the trajectory model reveal that the large-scale atmospheric circulation is the major factor controlling the motion of the WNP-TC. The large-scale steering flow is advantageous to the straight (recurving) movement of WNP-TC and westward (northward) tracks during active (inactive) periods. Meanwhile, the genesis locations of the WNP-TC also have influence on track types, the farther westward (eastward) locations are conducive to westward (northward) passages.

In this study, we only discuss the influence of the large-scale steering flow on TC movement. If the convection over the SCS can modulate the structure of a TC, can it affect its movement? Moreover, as the monsoon trough is constituted of many deep convective systems, are there any interactions between these deep convective systems and the cyclone circulation? Can these interactions change the cyclone's motion? All of above issues need further discussion.

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