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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 **Abstract:** The intraseasonal oscillation (ISO) of the South China Sea (SCS, $105-120^{\circ}E$, $5-20^{\circ}N$) convection and its influences on the genesis and track of the western North Pacific (WNP) tropical cyclones (TCs) w 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 cyc 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 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 summe 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. Th 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 ac 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 (inactivi (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 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 pha 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. 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, entering the area west of 135 °E and south of 25 °N would move straight into the SCS in the active phase, or recurve phases is in favor of straight-moving (recurving) TCs. Meanwhile, the impacts of the locations of TC genesis on the phases is in favor of straight-moving (recurving) TCs. Meanwhile, the impacts of the locations of TC genes 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 s characteristics of
the SCS region. the SCS region. the SCS region.
Key words: tropical cyclone genesis and track; climatological statistics; South China Sea convection; intraseasonal

Key words: tropical cyclone genesis and the oscillation; monsoon trough; trajectory model oscillation; monsoon trough; trajectory model
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1 INTRODUCTION

NIRODUCTION
Monsoon is the most important synoptic and Monsoon is the most important synoptic and
climatic phenomenon in East Asia^[1], which is closely climatic phenomenon in East $Asia^{[1]}$, which is closely related to the social and economic life in this region. related to the social and economic life in this region.
The South China Sea (SCS) monsoon that has attracted The South China Sea (SCS) monsoon that has attracted
much more attention in recent years is one part of the much more attention in recent years is one part of the
East Asian summer monsoon. And the SCS-western East Asian summer monsoon. And the SCS-western
North Pacific (WNP) monsoon trough is an important North Pacific (WNP) monsoon trough is an important
component of the East Asian summer monsoon system. component of the East Asian summer monsoon system.
Besides the monsoon, the tropical cyclone (TC) activity Besides the monsoon, the tropical cyclone (TC) activity
also has severe impacts on East Asia region. The also has severe impacts on East Asia region. The

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of Jiangsu Higher Education Institutions (PAPD) of Jiangsu Higher Education Institutions (PAPD) of Jiangsu Higher Education Institutions (PAPD)
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transition and migration of the large scale monsoon transition and migration of the large scale monsoon
circulation system may have notable influence on TC circulation system may have notable influence on TC
genesis and track. Therefore, the impact of monsoon on genesis and track. Therefore, the impact of monsoon on
TC is a hot issue in TC research field, and has been TC is a hot issue in TC research field, and has been
explored by many domestic and international international explored by researchers. Many studies have found that TC formation is

Many studies have found that TC formation is
remarkably affected by the intensity and location of the remarkably affected by the intensity and location of the SCS-WNP monsoon trough. Harr and Elsberry^[24] found SCS-WNP monsoon trough. Harr and Elsberry^[24] found
that the TC activity is closely related to the variability that the TC activity is closely related to the variability
of the monsoon trough. Active (inactive) periods of the of the monsoon trough. Active (inactive) periods of the WNP TC are found to occur when the large-scale WNP TC are found to occur when the large-scale
circulation anomalies that represent an active (inactive) circulation anomalies that represent an active (inactive)
monsoon trough. Sun and Duan^[5] showed that the change monsoon trough. Sun and Duan^[5] showed that the change
in the intensity of the summer monsoon bears a close in the intensity of the summer monsoon bears a close
relation to the TC frequency in the WNP. Wang et al.^[6] 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 impacts TC genesis mainly through the activity of the monsoon trough, and the strength of the summer monsoon trough, and the strength of the summer
monsoon has impacts on both locations and frequency monsoon has impacts on both locations and frequency
of TC genesis. TC genesis mostly occur in the western of TC genesis. TC genesis mostly occur in the western
(eastern) WNP, and the number is evidently more (less) (eastern) WNP, and the number is evidently more (less)
in the strong (weak) phase of the monsoon trough. Sun in the strong (weak) phase of the monsoon trough. Sun

and $\text{Ding}^{[7]}$ found that during 1998 and 1999, the and $\text{Ding}^{[7]}$ found that during 1998 and 1999, the anomalous westward and northward movement of anomalous westward and northward movement of
monsoon trough in midsummer was an important reason 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 genesis location. Gao et al.^[8] analyzed the behaviors of monsoon trough and their impacts on TCs generated of monsoon trough and their impacts on TCs generated
in monsoon trough (MTTC), and found that the in monsoon trough (MTTC), and found that the
intensity of the monsoon trough is closely linked with intensity of the monsoon trough is closely linked with
the frequency of MTTC. In addition, many climate the frequency of MTTC. In addition, many climate statistical analysis also suggested that the monsoon trough statistical analysis also suggested that the monsoon tro
environment is conducive to the formation of TC rough
C ^[9-11]. environment is conducive to the formation of TC^{p-1} .
Thus, over the WNP, monsoon has significant impact on 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 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 monsoon affects TC genesis? Harr et al.^[12, 13] suggested that the mesoscale convective system plays an important that the mesoscale convective system plays an important role in the process of monsoon depression developing role in the process of monsoon depression developing
into TC. Kuo et al. [14] showed that the large-scale 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 development of tropical disturbances through nonlinenergy/enstrophy accumulation in the confluent zone. In the 1990's some researchers abroad noticed that
In the 1990's, some researchers abroad noticed that

In the 1990's, some researchers abroad noticed that
the Asian monsoon activities may affect the TC the Asian monsoon activities may affect the TC
movement over the WNP while there were fewer movement over the WNP, while there were fey
domestic studies on this aspect. Harr and Elsberry movement over the WNP, while there were lewer
domestic studies on this aspect. Harr and Elsberry^[34]
divided the large-scale variabilities associated with the divided the large-scale variabilities associated with the monsoon trough and subtropical ridge into different monsoon trough and subtropical ridge into different
circulation patterns, and each pattern is connected to a circulation patterns, and each pattern is connected to a
specific TC track type. When the pattern changes, the specific TC track type. When the pattern changes, the TC motion will also change. Camargo et al. $[15-16]$ used a TC motion will also change. Camargo et al.^[15-16] used a
new probabilistic clustering technique to describe TC new probabilistic clustering technique to describe TC
trajectories in the WNP. They found that different trajectories in the WNP. They found that different
large-scale patterns of atmospheric circulation (such as large-scale patterns of atmospheric circulation (such as
monsoon trough, subtropical ridge) are linked with monsoon trough, subtropical ridge) are linked with
different types of TC trajectory. Observations presented different types of TC trajectory. Observations presented
that the TCs will turn poleward suddenly when they that the TCs will turn poleward suddenly when they move into monsoon gyres^[17]. Furthermore, approximately move into monsoon gyres^[17]. Furthermore, approximately 80% of the TCs associated with a reverse-oriented 80% of the TCs associated with a reverse-comonsoon trough move on north-oriented tracks^[18]. Soon trough move on north-oriented tracks^[18].
The tropical WNP during boreal summer is

The tropical WNP during boreal summer is
characterized by the multiscale circulation and characterized by the multiscale circulation and convection from synoptic to intraseasonal time scale^[19-20] convection, from synoptic to intraseasonal time scale^[19-20]
While the synoptic scale wave^[21] can provide initial While the synoptic scale wave^[21] can provide initial disturbances for TC formation $[22-23]$, the Quasi-Biweekly disturbances for TC formation $^{[22\cdot23]}$, the Quasi-Biweekly
Oscillation (OBW) $^{[24\cdot26]}$ and the Madden-Julian Oscillation (QBW)^[24-26] and the Madden-Julian Oscillation (MIO)^[27-29] which are the components of the Oscillation $(MJO)^{[27-29]}$, which are the components of the intraseasonal oscillation. (ISO), can affect TC motion. intraseasonal oscillation (ISO), can affect TC motion.
Ko and Hsu^[30] demonstrated that the recurving TCs may Ko and $Hsu^{[30]}$ demonstrated that the recurving TCs may
have a linkage to the northwestward-propagating have a linkage to the northwestward-propagating
submonthly wave patterns. Chen et al.^[31] disclosed that a submonthly wave patterns. Chen et al.^[31] disclosed that a majority of straight-moving (recurving) TCs appear majority of straight-moving (recurving) TCs appear
during weak (strong) monsoon westerlies and strong during weak (strong) monsoon westerlies and strong
(weak) trade easterlies. Wu et al. [32] revealed that the (weak) trade easterlies. Wu et al. $[32]$ revealed that the MIO and OBW components of monsoon flow play and MJO and QBW components of monsoon flow play an important role in the TC anomalous track through a important role in the TC anomalous track through a

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

2 DATA AND METHODS

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

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

3 THE ISO FEATURES OF SCS CONVECTION DURING SUMMER MONSOON 3.1

1 Definition of the active/inactive phase
In this study, the OLR anomalies are used to

In this study, the OLR anomalies are used to represent the intensity of convection. To reveal the represent the intensity of convection. To reveal the influences of ISO features of the SCS convection on the influences of ISO features of the SCS convection on the WNP TC activities, moving average method is applied WNP TC activities, moving average method is applied
to filter the synoptic scale disturbance in the OLR time to filter the synoptic scale disturbance
series, only retaining the ISO signals. s, only retaining the ISO signals.
OLR'₁₁(t) = OLR₁₁(t) - 220 W/m² (1)

$$
R'_{11}(t) = OLR_{11}(t) - 220 \text{ W/m}^2
$$

OLR'₁₁(*t*) = OLR₁₁(*t*) - 220 W/m² (1)
where OLR₁₁ (*t*) is 11-day running mean of the SCS where OLR_{11} (*t*) is 11-day r regional average OLR at time tunning mean of the SCS
e t. In general, when OLR regional average OLR at time *t*. In general, when OLR \leq 220 W/ m², it indicates active convection. Therefore, \leq 220 W/ m², it indicates active convection. Therefore, the OLR'₁₁(t) is obtained by subtracting 220 W/m² from the OLR'₁₁(*t*) is obtained by subtracting 220 W/m² from OLR₁₁ (*t*). Based on this, the period that OLR'₁₁ (*t*) is OLR₁₁ (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 $OLR'_{11}(t)$ 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 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 the retreat of monsoon. I
absent during those periods. absent during those periods. Since the annual SCS summer monsoon starts with

Since the annual SCS summer monsoon starts with the beginning of the first active convection period, and the beginning of the first active convection period, and retreats with the end of the last active period, the retreats with the end of the last active period, the amount of inactive monsoon/convective phase is one amount of inactive monsoon/convective phase is one
less than that of active monsoon/convective phase. The less than that of active monsoon/convective phase. The statistical results show that there are 4.3 active phases statistical results show that there are 4.3 active phases
and 3.3 inactive phases annually for the period of 1979– and 3.3 inactive phases annually for the period of 1979–
2008. In 1979 (Fig.1), for example, the SCS summer 2008. In 1979 (Fig.1), for example, the SCS summer
monsoon was from the 3rd pentad of May to the 1st monsoon was from the 3rd pentad of May to the 1st
nentad of October. There were 4 active phases (14/5pentad 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 22/5, 17/6-9/7, 26/7-15/8, 16/9-4/10),
phases (23/5-16/6, 10/7-25/7, 16/8-15/9). 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/m²).

 Climatological characteristics of active/inactive ^phases es
From the composited OLR fields of active and

From the composited OLR fields of active and
inactive phases, we can see that the convection inactive phases, we can see that the convection
differences between active and inactive phases are differences between active and inactive phases are
highly significant. The low-value centers of OLR are highly significant. The low-value centers of OLR are
located in the eastern Indochina Peninsula and the 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 convection over the eastern SCS is very active with a minimum less than 175 W/m². This convection area, minimum less than 175 W/m^2 . This convection area,
connecting with the WNP convective zone and the connecting with the WNP convective zone and the
Indochina convective region, forms the summer Indochina convective region, forms the summer
Intertropical Convergence Zone (ITCZ). The WNP Intertropical Convergence Zone (ITCZ). The WNP
subtropical high is situated in the east of 120°E, north subtropical high is situated in the east of 120° E, north of 20° N, where the OLR values are high, which of 20 \degree 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 (Fig.2b), there is a high value center existed over the SCS with a maximum higher than 250 W/m² and SCS, with a maximum higher than 250 W/m^2 and inactive convection. Meantime, the Indochina Indochina inactive convection. Meantime, the Indochina
convection weakens, and the WNP convective zone gets convection weakens, and the WNP convective zone gets
shrinking and weakened. The WNP subtropical high shrinking and weakened. The WNP subtropical high
strengthens and stretches westward to the SCS, so the strengthens and stretches westward to the SCS, so the ITCZ is interrupted in the SCS. Hence we can see that ITCZ is interrupted in the SCS. Hence we can see that
the convection over the SCS and east of Philippines is the convection over the SCS and east of Philippines is
intense during the active phase, which can provide a intense during the active phase, which can provide a large number of initial disturbances for TC genesis. large number of initial disturbances for TC genesis.
Conversely the convection over the SCS is suppressed Conversely, the convection over the SCS is suppressed
during inactive periods, which is unfavorable for TC during inactive periods, which is unfavorable for TC
formation and development. And the convection in the formation and development. And the convection in the east of the Philippines weakens accordingly, which can east of the Philippines weakens accordingly, which can
reduce the probability of TC occurrence. These are reduce the probability of TC occurrence
consistent with the statistical results (Fig.3). Stent with the statistical results (Fig.3).
The distribution of low-level (850 hPa) vorticity

The distribution of low-level (850 hPa) vorticity
(Fig.4) is in agreement with the OLR (Fig.2). The p (Fig.4) is in agreement with the OLR (Fig.2). The nositive vorticity areas from Indochina to the SCS and positive vorticity areas from Indochina to the SCS and
over the east of Philippines constitute the ITCZ during over the east of Philippines constitute the ITCZ during
the active period (Fig.4a). Two positive vorticity centers the active period (Fig.4a). Two positive vorticity centers
are located over the eastern Indochina and central SCS are located over the eastern Indochina and central SCS
respectively. On the wind field, it is characterized by a respectively. On the wind field, it is characterized by a
strong and deep monsoon trough with a May Jun Jul Aug Sep Oct supercurvery. On the wind field, it is characterized by a
Figure 1. The time series of the OLR' 11 (t) during strong and deep monsoon trough with a
northwest-southeast trend. Southwesterly prevails

Figure 2. The climatological mean OLR (Units: W/m^2) distribution in active (a) and impropen of 1979-2008, and the shaded area means that the OLR is less than 220 W/m^2 monsoon of 1979-2008, and the shaded area means that the OLR is less than 220 W/m².

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

south of the trough line, and southeasterly prevails in south of the trough line, and southeasterly prevails in the north. The positive vorticity zone seated over the the north. The positive vorticity zone seated over the east of Philippines is formed by the convergence of the east of Philippines is formed by the convergence of the cross-equatorial flow between $120^{\circ}E$ and $140^{\circ}E$ as well cross-equatorial flow between $120^{\circ}E$ and $140^{\circ}E$ as well as the easterly at south of the WNP subtropical high.
Therefore, the monsoon trough located over the SCS Therefore, the monsoon trough located over the SCS
and the WNP convergence zone can provide low-level and the WNP convergence zone can provide low-level
evolonic vorticity for TC formation during active eyclonic vorticity for TC formation during active
phases Meanwhile vertically the deep warm air over phases. Meanwhile, vertically, the deep warm air over
the monsoon trough can increase the thickness of the the monsoon trough can increase the thickness of the
troposphere, enhance the anticyclonic circulation at high troposphere, enhance the anticyclonic circulation at high

level, and turn the low-level cyclonic shear into level, and turn the low-level cyclonic shear into anticyclonic shear at the top, which is conducive to TC anticyclonic shear at the top, which is conducive to TC genesis $^{[8]}$. In inactive phases (Fig.4b), the monsoon 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 central and eastern part of the SCS becomes a negative
vorticity region, which is unfavorable for TC formation. vorticity region, which is unfavorable for TC formation.
The WNP convergence zone still exists, with weakened The WNP convergence zone still exists, with weakened
intensity and narrowed coverage. Hence, during inactive intensity and narrowed coverage. Hence, during inactive
phases, the TCs mainly occur over the WNP besides the phases, the TCs mainly occur over the WNP besides the SCS, and the TC genesis frequency also decreases SCS, and the TC genesis frequency during the inactive periods (Fig.5). during the inactive periods (Fig.5). In middle troposphere (Fig.5).
In middle troposphere (Fig.6a), the position of the

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

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

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

4 CLIMATIC CHARACTERISTICS OF TC ACTIVITY

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

The TC genesis frequency in active periods is
markedly different from that of inactive periods (Fig.3). markedly different from that of inactive periods (Fig.3).
There are 177 TCs occurred and developed in active There are 177 TCs occurred and developed in active
phases, but only 49 TCs generated during inactive phases, but only 49 TCs generated during inactive
periods. Among these three kinds of TC, the SCS periods. Among these three kinds of TC, the SCS
monsoon exerts the most direct and obvious influence monsoon exerts the most direct and obvious influence
on the SCS-TC. There are only 2 SCS-TC cases formed on the SCS-TC. There are only 2 SCS-TC cases formed
in inactive periods, but 67 cases developed during active in inactive periods, but 67 cases developed during active
phases. Furthermore, the ISO feature of the SCS phases. Furthermore, the ISO feature of the SCS
monsoon has dominant effect on TC track. During monsoon has dominant effect on TC track. During
active periods about 65% of the WNP-TC cases travel active periods, about 65% of the WNP-TC cases travel
with straight (west- or northwest-oriented) paths, while with straight (west- or northwest-oriented) paths, while
only approximately 30% of the WNP-TC cases move only approximately 30% of the WNP-TC cases move
west-northwestward in inactive phases, and more than west-northwestward in inactive phases, and more than
70% recurve northward before entering into the SCS 70% recurve northward before entering into the SCS.
Thus it can be seen that TCs tend to move straight and Thus it can be seen that TCs tend to move straight and affect Hainan, Guangdong and Guangxi provinces when affect Hainan, Guangdong and Guangxi provinces when
the SCS summer monsoon is active, or they will turn the SCS summer monsoon is active, or they will turn
northward over the AR and pose threat to Fujian and northward over the AR and pose threat to Fujiang provinces when the monsoon is inactive. ang provinces when the monsoon is inactive.
From the TC genesis frequency (Fig.5), we can

From the TC genesis frequency (Fig.5), we can
also see clearly that the TC genesis frequency in active also see clearly that the TC genesis frequency in active
periods is far more than that in inactive periods. It is periods is far more than that in inactive periods. It is
associated with the strong active monsoon circulation associated with the strong active monsoon circulation
and the deep monsoon trough which can provide and the deep monsoon trough which can provide
evelonic vorticity in low level, anticyclonic vorticity in cyclonic vorticity in low level, anticyclonic vorticity in
high level for tropical cyclogenesis. This is one of the high level for tropical cyclogenesis. This is one of the favorable conditions for TC formation^[35-36]. In addition, the favorable conditions for TC formation^[35-36]. In addition, the

monsoon trough is composed of a large number of monsoon trough is composed of a large number of
mesoscale deep convective systems, which can provide mesoscale deep convective systems, which can provide
initial disturbances for TC formation. Both observational initial disturbances for TC formation. Both observational and numerical studies^[3740] indicated that the spontaneous
breakdown of monsoon trough is one mode of tropical breakdown of monsoon trough is one mode of tropical
cyclogensis. Meantime, the monsoon trough also has an cyclogensis. Meantime, the monsoon trough also has an important influence on the location of TC formation. In important influence on the location of TC formation. In active phases, tropical cyclogenesis mainly takes place active phases, tropical cyclogenesis mainly takes place
in the region west of 135° E where the SCS-WNP in the region west of 135° E where the SCS-WNP monsoon trough is located (Fig.5a). Two large-value monsoon trough is located (Fig.5a). Two large-value
centers of the TC genesis frequency are situated over centers of the TC genesis frequency are situated over
the SCS and east of the Philippines. During inactive the SCS and east of the Philippines. During inactive
periods, the convergence zone between 135° E and 150° periods, the convergence zone between 135° E and 150°
E is the main genesis region (Fig.5b), where more than \overline{E} is the main genesis region (Fig.5b), where more than half of TCs form. So, when the SCS summer monsoon half of TCs form. So, when the SCS summer monsoon
is active (inactive), there are more (less) TCs generating is active (inactive), there are more (less) TCs generating
over the WNP, and the main formation location is over the WNP, and the r
located west (east) of 135°E. ed west (east) of 135°E.
The steering by surrounding large-scale flows plays

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

5 NUMERICAL EXPERIMENTS

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

1 *Model description and experimentation schemes*
The model used in this present study is a trajectory

The model used in this present study is a trajectory model proposed by Wu and Wang $[33]$. In this model, a model proposed by Wu and Wang $[33]$. In this model, a
TC is treated as a point vortex, and moves with the TC is treated as a point vortex, and moves with the
climatological mean translation velocity within a climatological mean translation velocity within a
specified grid box. In other words, all the storms located specified grid box. In other words, all the storms located
within the same grid box move at the same speed. The within the same grid box move at the same speed. The
input data needed in this model are (1) the storm initial input data needed in this model are (1) the storm initial

position data; (2) the TC average movement speed data. position data; (2) the TC average movement speed data.
The climatological mean velocity of TC motion is the The climatological mean velocity of TC motion is the sum of the large-scale steering flow and beta drift. 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 mean steering flow speed between 850 hPa and 300
hPa, calculated from the NCEP/NCAR reanalysis for hPa, calculated from the NCEP/NCAR reanalysis for
the current climate state. The mean beta drift is the current climate state. The mean beta drift is
estimated from the CMA-STI best-track data by estimated from the CMA-
removing the steering flow, as

removing the steering flow, as
\n
$$
\vec{V}_{\text{TC}} = \vec{V}_{\text{steering}} + \vec{V}_{\beta \text{drift}} \tag{2}
$$

 $V_{TC} = V_{steering} + V_{\beta drift}$ (2)
 \vec{V}_{TC} is the mean velocity of TC movement. $\vec{V}_{steering}$ where, V_{TC} is the mean velocity of TC movement. V_{steering}
is the mean large-scale steering flow. \vec{V}_{gdrift} is the beta is the mean largedrift. So, there is drift. So, there is

So, there is
\n
$$
\vec{V}_{\beta \text{drift}} = \vec{V}_{\text{TC}} - \vec{V}_{\text{steering}}
$$
\n(3)
\nSince the active (inactive) SCS convection periods

Since the active (inactive) SCS convection periods
correspond to the active (inactive) TC activity periods, correspond to the active (inactive) TC activity periods,
there are more (less) WNP-TC TCs generated in the there are more (less) WNP-TC TCs generated in the west (east) of 135°E and entering the SCS region in west (east) of 135° E and entering the SCS region in active (inactive) phases. So, we discuss the influence active (inactive) phases. So, we discuss the influence
factors of TC motion from the large-scale steering flow factors of TC motion from the large-scale steering flow
and formation location. Two sets of experiments have and formation location. Two sets of experiments have

 $\frac{1}{2}$ been carried out in this study. There are 110 and 47 TC been carried out in this study. There are 110 and 47 TC
input cases in active (AC) and inactive (IN) (AC) and inactive (IN) input cases in active (AC) and inactive (IN)
experiments. The observational initial genesis locations experiments. The observational initial genesis locations
of the WNP-TC cases are shown in Fig.6. The of the WNP-TC cases are shown in F
experimentation schemes are listed in Table 1. experimentation schemes are listed in Table 1 5.2 Results of the experiments

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

Figure 6. The climatological mean 500-hPa wind (Units: r
(b) phases during the SCS summer monsoon of 1979-2008. (b) phases during the SCS summer monsoon of 1979-2008.

westward and eastward 5 longitudes respectively. It can westward and eastward 5 longitudes respectively. It can
be seen that more WNP-TC cases will move westward be seen that more WNP-TC cases will move westward
and enter into the SCS region when their initial and enter into the SCS region when their initial practions are closer to the SCS, and vice verse. In the practical observations, the genesis locations of active practical observations, the genesis locations of active
phases are farther westward than those in inactive phases are farther westward than those in inactive phases. Hence, in active periods, not only the phases. Hence, in active periods, not only the large-scale circulation is in favor of straight westward large-scale circulation is in favor of straight westward
tracks, but also the further westward genesis locations tracks, but also the further westward genesis loof the WNP-TC cases is another important reason. e WNP-TC cases is another important reason.
There are only 47 cases in inactive phases, and the

There are only 47 cases in inactive phases, and the distribution of the passage frequency is well simulated distribution of the passage frequency is well simulated
(Fig.9a). The dominating tracks are recurving tracks and (Fig.9a). The dominating tracks are recurving tracks and

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

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

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

6 CONCLUSIONS

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

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

(2) The ISO characteristics of the SCS monsoon

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

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

In this study, we only discuss the influence of the
large-scale, steering flow on TC movement. If the large-scale steering flow on TC movement. If the
convection over the SCS can modulate the structure of a convection over the SCS can modulate the structure of a
TC, can, it affect, its movement? Moreover, as the TC, can it affect its movement? Moreover, as the

monsoon trough is constituted of many deep convective monsoon trough is constituted of many deep convective
systems, are there any interactions between these deep systems, are there any interactions between these deep
convective systems and the cyclone circulation? Can convective systems and the cyclone circulation? Can these interactions change the cyclor
above issues need further discussion. above issues need further discussion.

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