

RELATIONSHIP BETWEEN TROPICAL ISO AND TROPICAL CYCLONE ACTIVITY OVER THE SOUTH CHINA SEA

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Abstract: The relationship between the tropical intra-seasonal oscillation (ISO) and tropical cyclones (TCs) activities over the South China Sea (SCS) is investigated by utilizing the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) global reanalysis data and tropical cyclone best-track data from 1949 to 2009. The main conclusions are: (1) A new ISO index is designed to describe the tropical ISO activity over the SCS, which can simply express ISO for SCS. After examining the applicability of the index constructed by the Climate Prediction Center (CPC), we find that the convection spatial scale reflected by this index is too large to characterize the small-scale SCS and fails to divide the TCs activities over the SCS into active and inactive categories. Consequently, the CPC index can't replace the function of the new ISO index; (2) The eastward spread process of tropical ISO is divided into eight phases using the new ISO index, the phase variation of which corresponds well with the TCs activities over the SCS. TCs generation and landing are significantly reduced during inactive period (phase 4-6) relative to that during active period (phase 7-3); (3) The composite analyses indicate distinct TCs activities over the SCS, which is consistent with the concomitant propagation of the ISO convective activity. During ISO active period, the weather situations are favorable for TCs development over the SCS, e.g., strong convection, cyclonic shear and weak subtropical high, and vice versa; (4) The condensation heating centers, strong convection and water vapor flux divergence are well collocated with each other during ISO active period. In addition, the vertical profile of condensation heat indicates strong ascending motion and middle-level heating over the SCS during active period, and vice versa. Thus, the eastward propagation of tropical ISO is capable to modulate TCs activities by affecting the heating configuration over the SCS.

Key words: tropical intra-seasonal oscillation (ISO); South China Sea (SCS); tropical cyclone; atmospheric circulation; condensation heat

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1 INTRODUCTION

The tropical intra-seasonal oscillation (ISO) is characterized by eastward propagation of enhanced and suppressed convection centers, primarily over the Indian and Pacific Oceans, which has been extensively studied since its discovery (Madden and Julian^[1-2]; Jin et al.^[3]; Li^[4]). The tropical ISO is not only the strongest tropical disturbances with a period of about 7-90 days in lower troposphere, but also a comparatively prevalent phenomenon in the upper tropical ocean (Slingo et al.^[5]; Zhang^[6]; Hendon and Glick^[7]). The tropical ISO signal has been detected and demonstrated by several

important atmospheric and oceanic parameters including outgoing long-wave radiation (OLR), precipitation and wind divergence at 200 hPa (Lorenz^[8]). Significant interaction exists between tropical ISO and large scale atmospheric circulation, which is the most evident in the Eastern Hemisphere with the strongest annual variability of kinetic energy in the Northwest Pacific (Li^[4]). The tropical ISO activity is responsible for the majority of long-term climate anomalies and short-term weather change, such as the outbreak of Asian-Australian monsoon (Mu and Li^[9]), global monsoon system strength and extratropical atmospheric circulation change.

It is well known that tropical cyclones (TCs) activities are strongly modulated by tropical ISO. Studies have determined that the Northwest Pacific is the world's only basin with TCs generated all year round, and the South China Sea (SCS), particularly the Northern SCS, is one of the three main TCs sources over the Northwest Pacific (Chen^[10]; Wu et al.^[11]). According to statistics, since 1949, there are generally an average of 11 cyclones annually appearing at the SCS, 6 of which land in the SCS coast. The sources of the TCs appearing or landing in the SCS are mostly from the Northwest Pacific. The TCs formations present

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obvious seasonal variation that nearly 80 percent of TCs generate during summer and autumn. Moreover, studies have found that TCs formations are not a series of evenly distributed events, but rather have a tendency to cluster in time with periods of approximately 2-3 weeks, which is consistent with a tropical ISO cycle. Subsequent studies indicate that TCs are inclined to generate during active period of ISO, for example, in the Northwest Pacific (Sobel and Maloney^[12]; Zhu et al.^[13]), Indian Ocean (Liebmann et al.^[14]; Bessafi and Wheeler^[15]), Australia (Hall et al.^[16]), Gulf of Mexico (Maloney and Hartmann^[17]) as well as Eastern Pacific (Maloney and Hartmann^[18]). The TCs clustering is prone to take place during active period of ISO, accompanied with the eastward spread of OLR and low-level vorticity (Sun et al.^[19]). In addition, TCs tracks are not only related to the cyclogenesis locations, spread direction and intensity of ISO, steering flow and thermal state of the Western Pacific Warm Pool, but also with the interaction of ISO between high and low latitudes (Huang and Chen^[20]; Tian et al.^[21]). TCs are inclined to land more during active period of ISO due to higher cyclogenesis frequency. The regions affected by the landing TCs are concentrated in the SCS, Korea and Japan (Kim et al.^[22]). Tian et al. also found that the distribution of ISO convection centers corresponds to different typhoon activities^[21]. Further, the condensation heat, released by the strong convection accompanied with the eastward spread of ISO, is an important energy supply for TCs developing.

The SCS is largely influenced by monsoon activity with rich water vapor transportation and air-sea exchange of heat, which is conducive for TCs activities. The TCs occurring over the SCS are characterized by rapid development, strong intensity as well as complex tracks, which brought about severe impact to China. For example, typhoon "David", one of the strongest cyclones, landed in Huanan coast in 2005 and resulted in property cost more than hundreds of billions. Currently, the ISO-TC relationship over distinct basins across the world have been wildly studied^[12-18], especially in the Northwest Pacific^[12, 13]. However, similar research is lacking for the SCS region and fails to reach a conclusion about the modulation mechanism of tropical ISO on the TCs. Therefore, further study in this field is essential to the recognition of the seasonal variation and forecast of the TCs occurring over the SCS.

The data and methodology utilized in this paper are described in section 2. The limitation of the index constructed by the Climate Prediction Center (CPC) in delegating the tropical ISO propagation over the SCS is discussed in section 3. A new ISO index is developed to address the aforementioned CPC index issues, and the mechanism of tropical ISO affecting the TCs activities over the SCS are discussed from both dynamic and thermodynamic perspectives in section 4. A summary and conclusion are given in section 5.

2 DATA AND METHODOLOGY

The daily atmospheric data like wind, geopotential height and pressure are derived from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) global reanalysis dataset with $2.5^{\circ} \times 2.5^{\circ}$ spatial resolution and 17 vertical layers from 1000hPa to 10hPa. The OLR data is from the National Oceanic and Atmospheric Administration (NOAA). The TCs data used here is the best-track data product archived by China Meteorology Administration (CMA) - Shanghai Typhoon Institute (STI). We had included all TCs (tropical depressions are excluded) forming in the SCS (defined as the area between $10\text{-}25^{\circ}$ N and $110\text{-}120^{\circ}$ E), as well as those crossing this defined boundary during some part of their lifetime. The time period chosen for study, from June to October, is consistent with the peak months of TCs activities over the SCS. As TCs generation, clustering and landfalling in the SCS are prone to occur during active period of ISO, years with strong ISO activity were selected to further discuss the topic into details.

The CPC index can be downloaded from the website: http://www.cpc.noaa.gov/products/precip/CWlink/daily_mjo_index/pentad.html. This index was calculated by Xue based on the filtered velocity vector at 200hPa in the tropics (30° S- 30° N) utilizing the extended empirical orthogonal function (EEOF) method. The CPC index is divided into 10 sub-indexes according geographical locations to represent the 40-50 days cycle of tropical ISO (Xue et al.^[23]).

When discussing from the thermodynamic aspect, the energy format of Q_1 and methodology proposed by Yanai et al. in 1973 were applied in the paper^[24]. The Q_1 is given by the following equation (Ding^[25]):

$$Q_1 = c_p \left[\frac{\partial T}{\partial t} + \vec{V} \cdot \nabla T + \left(\frac{p}{p_0} \right)^{\frac{R}{\sigma}} \cdot \omega \cdot \frac{\partial \theta}{\partial p} \right],$$

where T is temperature, θ is potential temperature, R is the gas constant of dry air, c_p is the specific heat of dry air, \vec{V} is horizontal velocity vector, ω is vertical velocity, p is air pressure and p_0 is surface pressure.

A new ISO index was designed primarily based on the filtered zonal wind at 850hPa with 30-60 days period, which enables to present the correspondence between tropical ISO and TCs activities over the SCS. Four CPC sub-indexes (80° E, 100° E, 120° E, 140° E, defined as CPC80, CPC100, CPC120, CPC140) near the SCS were selected to compare with the new ISO index. In order to highlight the influence of tropical ISO, 30-60 days band-pass filtering was conducted on the composite analyses in this paper.

3 RELATIONSHIP BETWEEN CPC INDEX AND TC ACTIVITY OVER THE SCS

3.1 Phase division of CPC index

The relative coefficients of the selected four CPC

sub-indexes were calculated. The CPC120 index was found to be the best option in delegating the ISO activity over the SCS due to its highest relative coefficients with the other three.

In order to reflect the intensity of tropical ISO intensity, another index (VAI) was defined by calculating the standard deviation of variance anomaly of CPC120 index from June to October each year. Six years with active ISO activity were picked out by the threshold line of larger than 0.9 times of VAI, namely 1979, 1997, 2002, 2004, 2006 and 2009. Fig.1 shows eight phases division of active ISO years by CPC120

index. Fig.2a reveals a complete eastward propagation of tropical ISO, which originates from the India Ocean and then disappear in the vicinity of the dateline. The latitudinal averaged phase distribution of OLR anomaly reveals weak convection during phase 1-4 and strong one during phase 5-8. The strongest positive OLR anomaly occurs at phase 3&4 while negative one at phase 6&7. It is noted that the strongest easterly at 850hPa appears at phase 2 while westerly at phase 6 (Fig.2b), thus one phase lag exists between the strongest zonal wind at 850hPa and OLR anomaly.

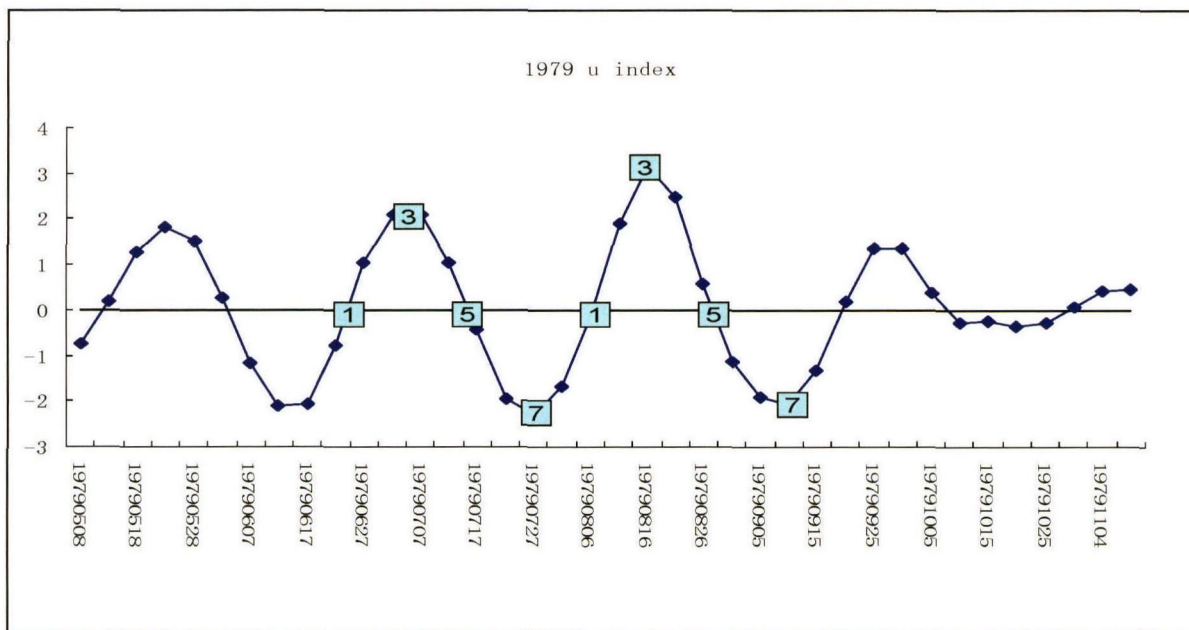


Figure 1. The 8 phases division of tropical ISO activity by the ISO index/

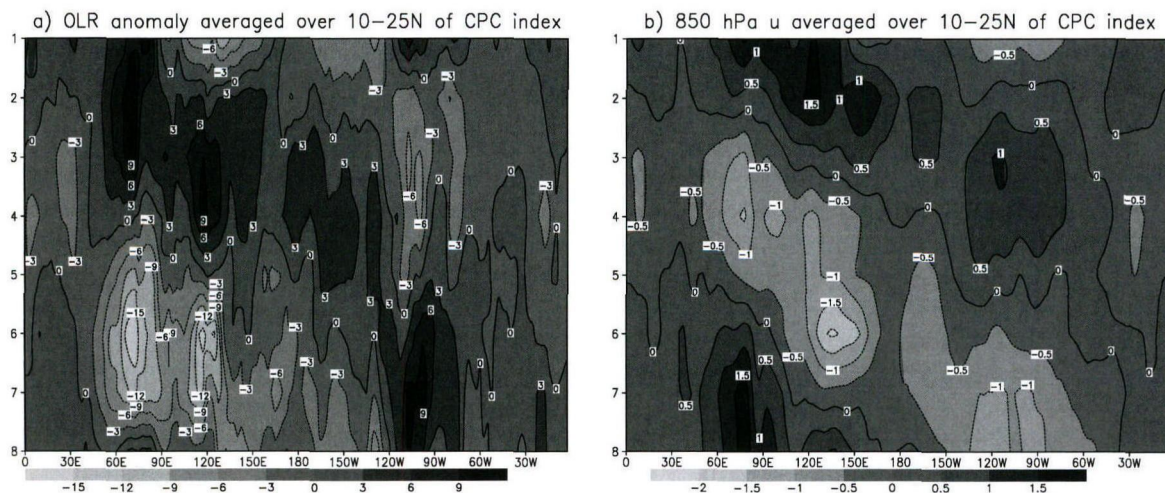


Figure 2. The 8 phases distribution of OLR anomaly (a, unit: W/m²) and zonal wind at 850hPa (b, unit: m/s) averaged between 10-25°N by CPC120 index.

Figure 3 indicates the distribution of wind at 850hPa and OLR anomaly during inactive phase (phase 3) and active phase (phase 7). During phase 3, there are strong subtropical high and anticyclonic shear with the strongest positive OLR anomaly (16 W/m²) over the SCS, which are not favorable for TCs growth (Fig.3a),

and vice versa (Fig.3b). It is noteworthy that the convection scale represented by the CPC120 index covers the whole Norwest Pacific in the tropics, which is too large to characterize the small scale SCS area. Consequently, the CPC120 index is not that specific in delegating the tropical ISO activity over the SCS area.

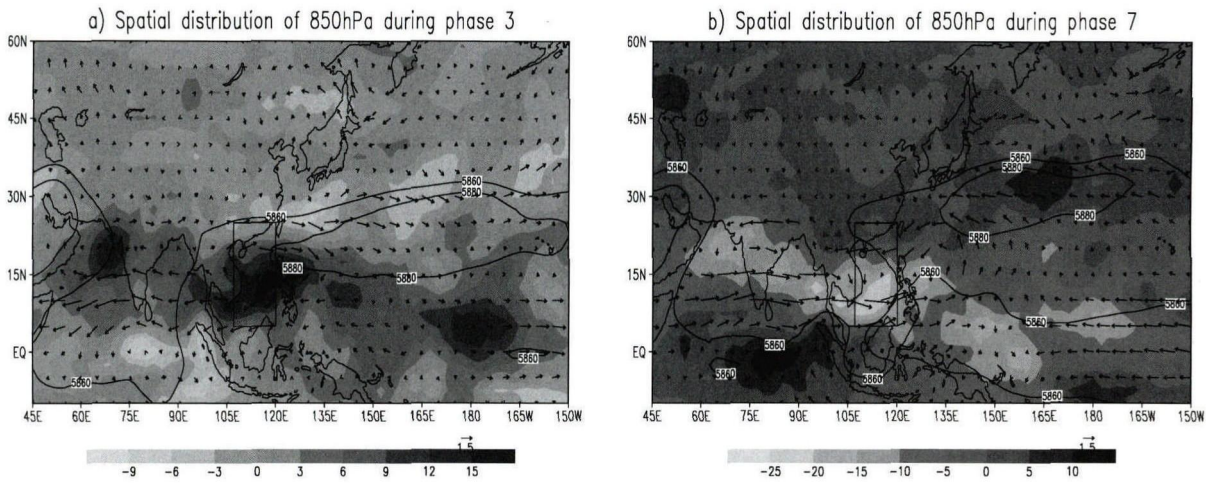


Figure 3. Spatial distribution of wind at 850hPa (unit: m/s) and OLR (unit: W/m²) anomaly of CPC120 index with 30-60 days period, the black line denotes unfiltered 5880 and 5860gpm line. (a) phase 3; (b) phase 7.

3.2 The CPC index and TC activity over the SCS

To examine the correlation between the CPC120 index and TCs activities over the SCS, two groups of statistics were carried out. Tables 1&2 show that the CPC120 index fails to group the TCs activities over the SCS into active and inactive periods clearly. The TCs

activities during phase 3&7 reflect obvious contrast of active and inactive trend, however, the neighboring phases of which are distributed randomly. It is supposed that the large convection scale the CPC index reflected makes the TCs activities over the SCS in the corresponding phase not so regular.

Table 1. The number of samples on different TC Intensity Grade

Phase	TCs appear over SCS	TCs form over SCS	TCs form over Northwest Pacific	Tropical storm	Typhoon	Landfall TCs	Landfall TCs form over SCS	Landfall TCs form over Northwest Pacific
1	3	0	3	2	1	3	0	3
2	2	1	1	1	1	1	1	0
3	2	2	0	2	0	2	2	0
4	5	2	3	5	0	4	1	3
5	5	2	3	4	1	5	2	3
6	2	2	0	2	0	1	1	0
7	8	3	5	2	6	4	1	3
8	4	2	2	2	2	4	2	2

Table 2. Second statistics of landfalling TCs during active years of CPC120 index according cyclone landfalling time.

Phase	Landfall TCs	TCs form over the Northwest Pacific	TCs form over SCS	Tropical storm	Typhoon
1	1	1	0	0	1
2	4	2	2	3	1
3	0	0	0	0	0
4	3	1	2	3	0
5	5	3	2	4	1
6	3	1	2	2	1
7	6	5	1	5	1
8	1	0	1	1	0

4 THE NEW ISO INDEX AND TC ACTIVITY OVER THE SCS

4.1 The calculation and phase division of the new ISO index

To overcome the aforementioned limitations of the CPC120 index, a new ISO index demands to be designed. Studies have found the primary importance of wind in delegating the ISO. For example, Ju considered southwest projection of wind at 850hPa to present ISO activities over the SCS [26], and Wheeler calculated a multi-variable ISO index by utilizing data of OLR, zonal winds at 850hPa and 200hPa [27]. Thus, a new ISO index was identified with regional averaged zonal wind at 850hPa over the SCS from 1978 to 2009. In order to manifest the influence of tropical ISO, the new ISO index was conducted with 30-60 days band-pass filtering, ten-day average processing and standardized construction.

In order to testify the new ISO index, similarly the VAI index from June to October was calculated. Seven active ISO years was picked out by the standard of larger than 0.6 times of VAI, namely 1979, 1989, 1996, 2004, 2006, 2007, and 2009. The 30-60 days oscillation cycle is prominent by analyzing the time-longitude profile of OLR and low-level zonal wind, which demonstrates the capability of the new ISO index in delegating the eastward propagation of ISO over the SCS. Fig. 4 shows wind variation at 850hPa during different phases over the SCS, which indicates that the strongest westerly appears at phase 4 while easterly at phase 8. The latitudinal averaged phase distribution of OLR anomaly reveals weak convection during phase 1-4 and strong one during phase 5-8. The strongest negative OLR anomaly occurs at phase 2 while positive one at phase 6, thus 2 phases lag exists between the strongest zonal wind at 850hPa and OLR anomaly.

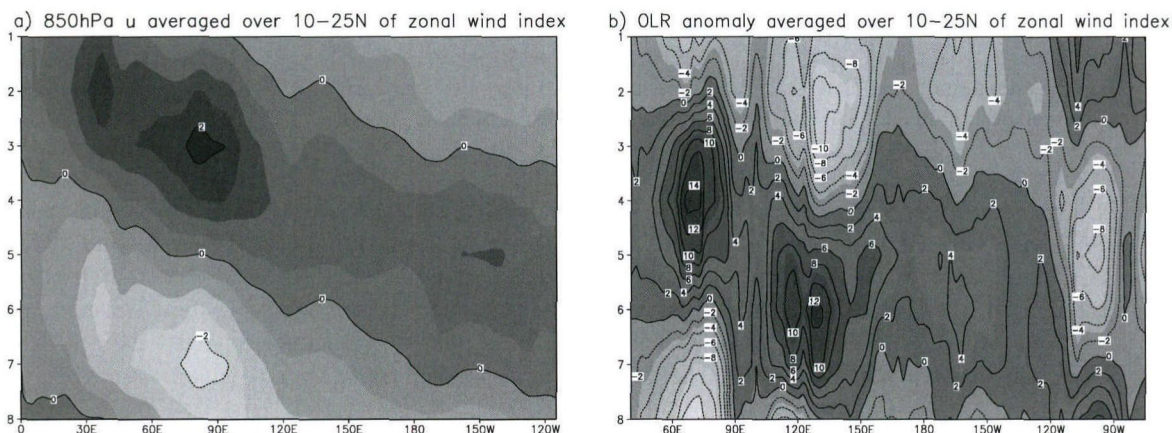


Figure 4. The 8 phases distribution of zonal wind at 850hPa (a, unit: m/s) and OLR (b, unit: W/m^2) anomaly averaged between 10-25°N by the new ISO index.

4.2 The new ISO index and TC activity over the SCS

To exhibit the correlation between the new ISO index and TC activity over the SCS, two groups of statistics are shown in Table 3 and 4. In Table 3, TCs generation and landing are significantly enhanced during active phases (phase 2&3) relative to that during inactive phases (phase 6&7). Many TCs are found appearing and landfalling over the SCS in phase 6, however, none of which formed over the SCS (Table 4). Thus, phase 6 is regarded as inactive phase of TC activity over the SCS. TCs activities over the SCS present gradual change accompanied with the eastward spread of ISO convection centers. Therefore, TCs activities over the SCS correspond well to the ISO propagation described by the new ISO index. The new ISO index successfully divided the TCs activities over the SCS into active period (phase 7-3) and inactive period (phase 4-6).

4.3 Dynamic analysis of tropical ISO influence on TC activity over the SCS

The relationship between TCs characteristics and large-scale weather situations are well established in the scientific literature. Gray identified several preexisting dynamical and thermodynamical large-scale weather situations necessary for TCs formations [28]. The three most important dynamical parameters that are widely used in association with TCs genesis studies are low-level cyclonic relative vorticity, vertical wind shear and upper-level wind divergence. McBride and Zehr held the point of view that dynamic conditions are primary important on affecting the cyclogenesis [29]. It is the relative vorticity [18] and vertical wind shear [15] that play a vital role on affecting TCs growth [29]. Liebmann discovered that the TCs sources are consistent with the locations of low-level cyclonic vorticity and wind divergence, which are relevant with the eastward spread of ISO [14]. Sun also believed that it is the positive vorticity anomaly, stimulated by the unstable westerly jet, that contributes to TCs development [19].

To better understand the ISO-TC relationship, it is

Table 3. First statistics of TCs during active years of the new ISO index according cyclogenesis time.

Phase	TCs appear over SCS	TCs form over SCS	TCs form over Northwest Pacific	Tropical storm	Typhoon	Landfall TCs	Landfall TCs form over SCS	Landfall TCs form over Northwest Pacific
1	6	1	5	1	5	5	1	4
2	8	1	7	6	2	6	1	5
3	7	4	3	3	4	6	3	3
4	2	1	1	1	1	2	1	1
5	3	1	2	2	1	2	1	1
6	6	1	5	1	5	4	0	4
7	11	1	10	6	5	8	1	7
8	8	4	4	5	3	5	2	3

Note: TCs appearing over the SCS include TCs not only form in the SCS but also across the SCS while formed in the Northwest Pacific.

Table 4. Second statistics of landfall TCs during active years of the new ISO index according cyclone landfalling time.

Phase	Landfall TCs	TCs form over the Northwest Pacific	TCs form over SCS	Tropical storm	Typhoon
1	4	2	2	1	3
2	6	5	1	3	3
3	11	8	3	6	5
4	2	1	1	1	1
5	3	1	2	2	1
6	2	2	0	1	1
7	7	6	1	3	4
8	6	5	1	3	3

important to explore the circulation configuration difference between active period (phase 7-3) and inactive period (phase 4-6) of TC activity over the SCS. During active period, there are cyclonic shear and negative convection centers (strong convection) over the SCS with weak and eastward-extended subtropical high, which are conducive for TCs development (Fig.5a), and vice versa (Fig.5b). The subtropical high is found to exhibit periodic oscillations accompanied with the

eastward spread of ISO. The subtropical high starts to weaken and retreat northward in phase 4, then strengthen and extend westward as well as stretching southward to cover the SCS. For brevity, only composite associated with phase 2 and 6 are constructed as the two phases show the most significant enhancement and suppression of TCs activities over the SCS, respectively.

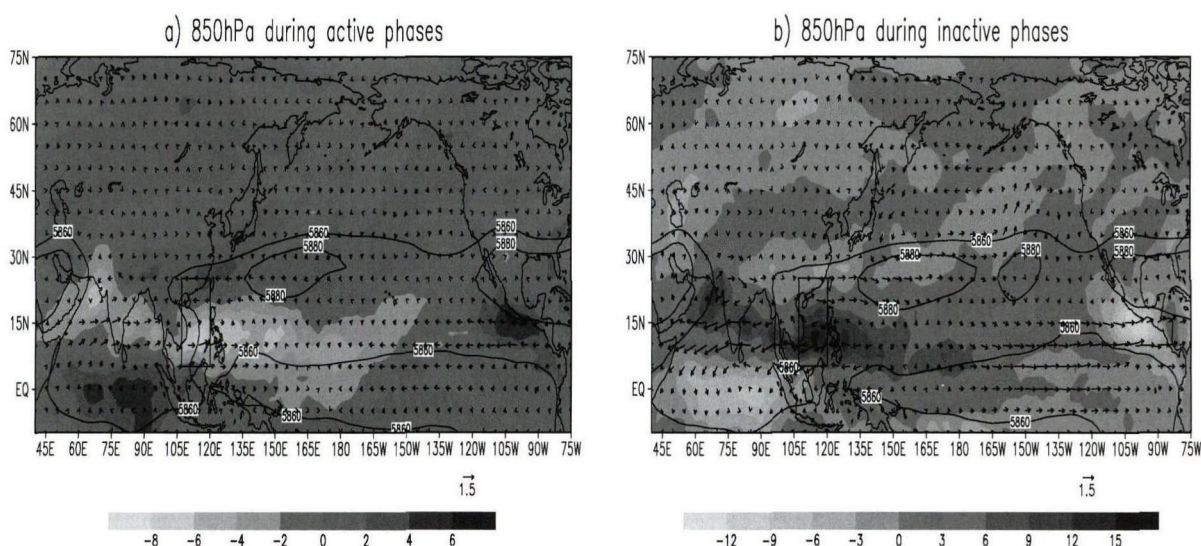


Figure 5. Spatial distribution of wind at 850hPa (unit: m/s) and OLR (unit: W/m²) anomaly of the new ISO index with 30-60 days period, the black line denotes unfiltered 5880 and 5860gpm line. (a) active phases; (b) inactive phases.

Figure 6 shows strong westerly and negative OLR anomaly over the SCS with weak and eastward-extended subtropical high during phase 2, which is favorable for TCs development, and vice versa. The strongest convection center (-17 W/m^2) is found at the northern part of the SCS during phase 2 while 17 W/m^2 during phase 6. It is noted that the convection scale represented by the new ISO index is more specific over the SCS area than that reflected by the CPC20 index (Fig.3). Fig. 7 shows the distribution of geopotential height anomaly at 500hPa. During phase 2 (6), there are negative (positive) anomaly center of geopotential height over the SCS and positive (negative) one over the Okhotsk, which contribute to (suppress) the TCs growth over the SCS.

Vertical wind shear is another vital parameter affecting TCs strengthening, which is defined as the

deviation of zonal winds at 200hPa and 850hPa. In the case of small vertical wind shear, the condensation heat released by the dispersive clouds and cumulus, induced by initial perturbations in the tropics, would concentrate to warm the same gas column and thus contribute to the immediately reduced pressure and strengthened cyclone. Fig.8 indicates that the zero shear line locates over the Northwest Pacific and Northern SCS during phase 2, which is northwest-southeast extended and corresponded to the monsoon trough location. The wind vertical shear during phase 2 provides favorable large-scale environment conditions in which the TCs generate, for example, with obvious wind convergence and cyclonic shear in the vicinity of the zero shear line. During phase 6, there are wind divergence and suppressed TCs activities over the SCS.

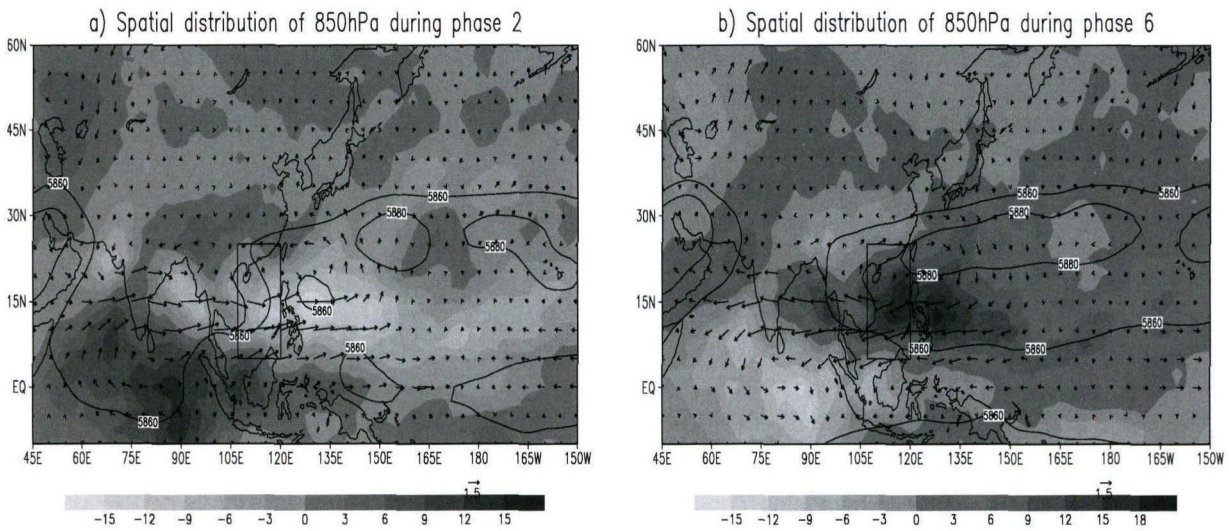


Figure 6. Spatial distribution of wind at 850hPa (unit: m/s) and OLR (unit: W/m^2) anomaly of the new ISO index with 30-60 days period, the black line denotes unfiltered 5880 and 5860gpm line. (a) phase 2; (b) phase 6.

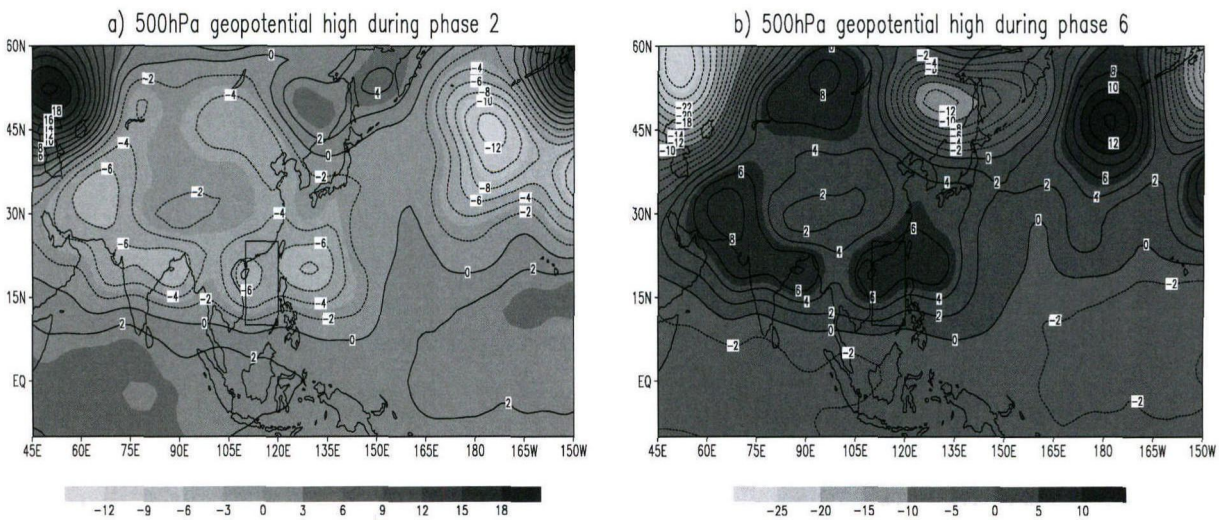


Figure 7. Spatial distribution of geopotential height (unit: gpm) anomaly at 500hPa with 30-60 days period. (a) phase 2; (b) phase 6.

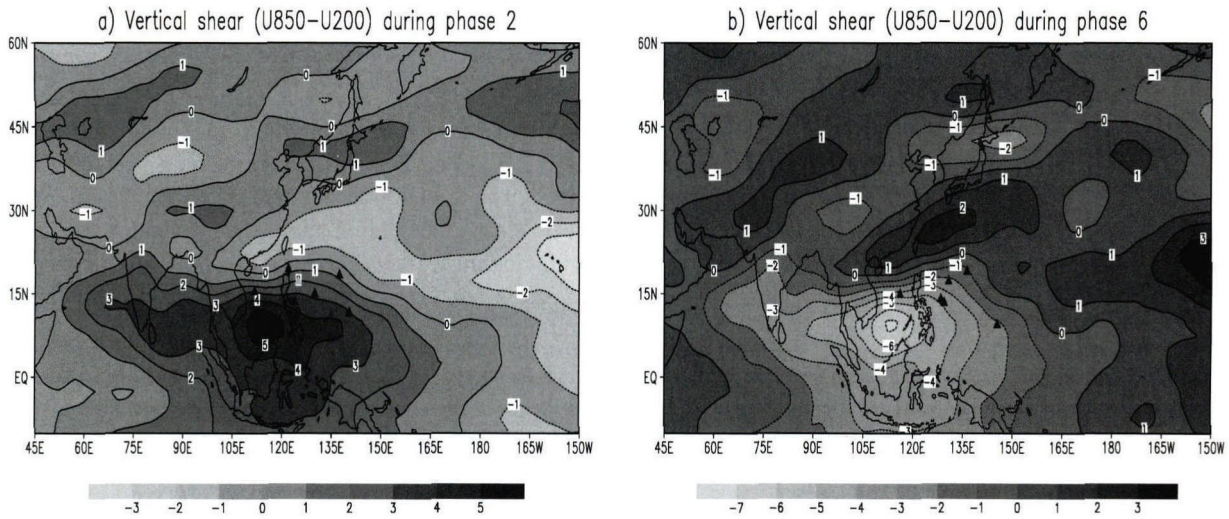


Figure 8. Composite of vertical shear ($U_{850}-U_{200}$) (unit: m/s). (a) phase 2; (b) phase 6.

4.4 Thermodynamic analysis of tropical ISO influence on TC activity over the SCS

In order to explore the mechanism of tropical ISO influence on affecting the TCs activities over the SCS, the ISO-TC relationship over the SCS was discussed from the thermodynamic aspect. Of particular interest is the active cumulus convection activity in the tropics, which is closely related to the TCs development. There is a strong interaction between the condensation heat released by cumulus convection and TCs generation. For one thing, the continuous condensation heat is the main energy source for TCs generation, which increasingly warms the same gas column to elevate high-level pressure and reduce low-level pressure. For another, the reduced low-level pressure contributes to strong wind convergence with sustained water vapor transportation,

which benefits the cumulus development conversely. Fig. 9 shows the distribution of heat source Q_1 during phase 2 and 6, which is integrated from surface to the top of the troposphere. During phase 2, strong heat source appears over the SCS, which coordinates well with the strong convection centers. The condensation heat release over the SCS is powerful when the ISO convection centers propagate to the SCS region, which provides sufficient energy for TCs generation and growth. During phase 6, the whole layer of troposphere is cooling over the SCS with heat source east of the Philippines. Therefore, thermodynamic conditions over the SCS exists dramatic variation due to the heat source movement accompanied with the eastward spread of tropical ISO.

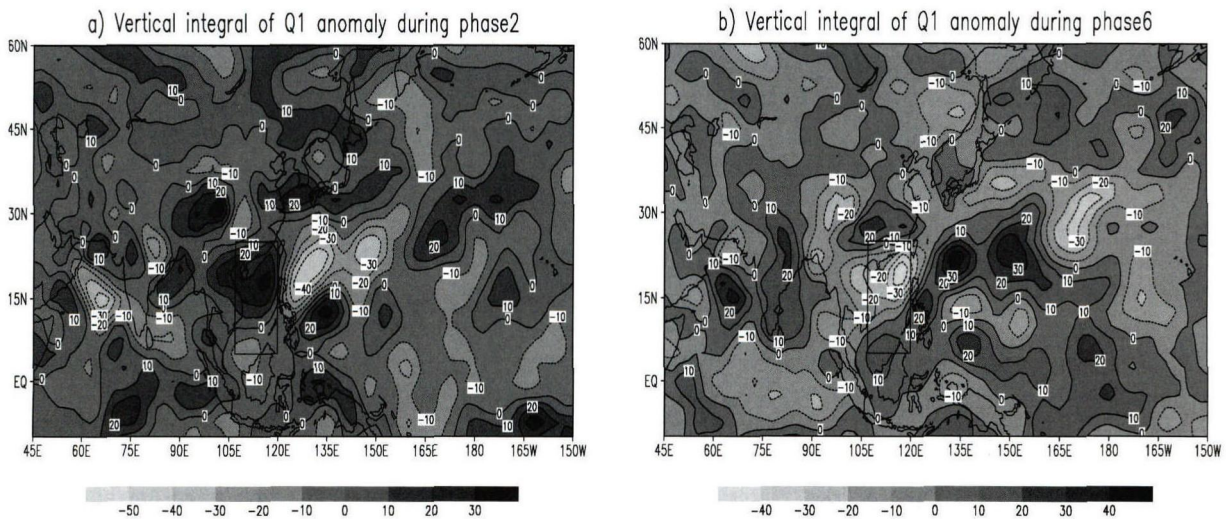


Figure 9. Composite of heat source Q_1 integrated from surface to the top of the troposphere (unit: K/day). (a) phase 2; (b) phase 6.

Chan found that the Walker circulation plays an important role in impacting on the cyclogenesis over the Northwest Pacific, which exerts significant effect on the activity of cumulus convection^[30]. To explore the influence of vertical circulation on TCs activities over the SCS, we analyze the configuration between heat source and vertical circulation. Fig.10 shows the correspondence between the vertical circulation and heat source over the SCS. During phase 2, there are middle-level heating over the SCS with heating centers between 105-150°E and middle-level cooling to the east

of dateline. Consequently, there are strong upward motion over the Northwest Pacific and downward motion over the Eastern Pacific, which benefit the development of Walker Circulation and TCs activities over the SCS. During phase 6, downward motion and middle-level cooling exist over the SCS, which suppress the TCs activities over the SCS. Further, the meridional averaged vertical circulation shows Hadley Circulation with downward motion over the SCS during phase 6, which is not favorable for TCs activities over the SCS, and vice versa.

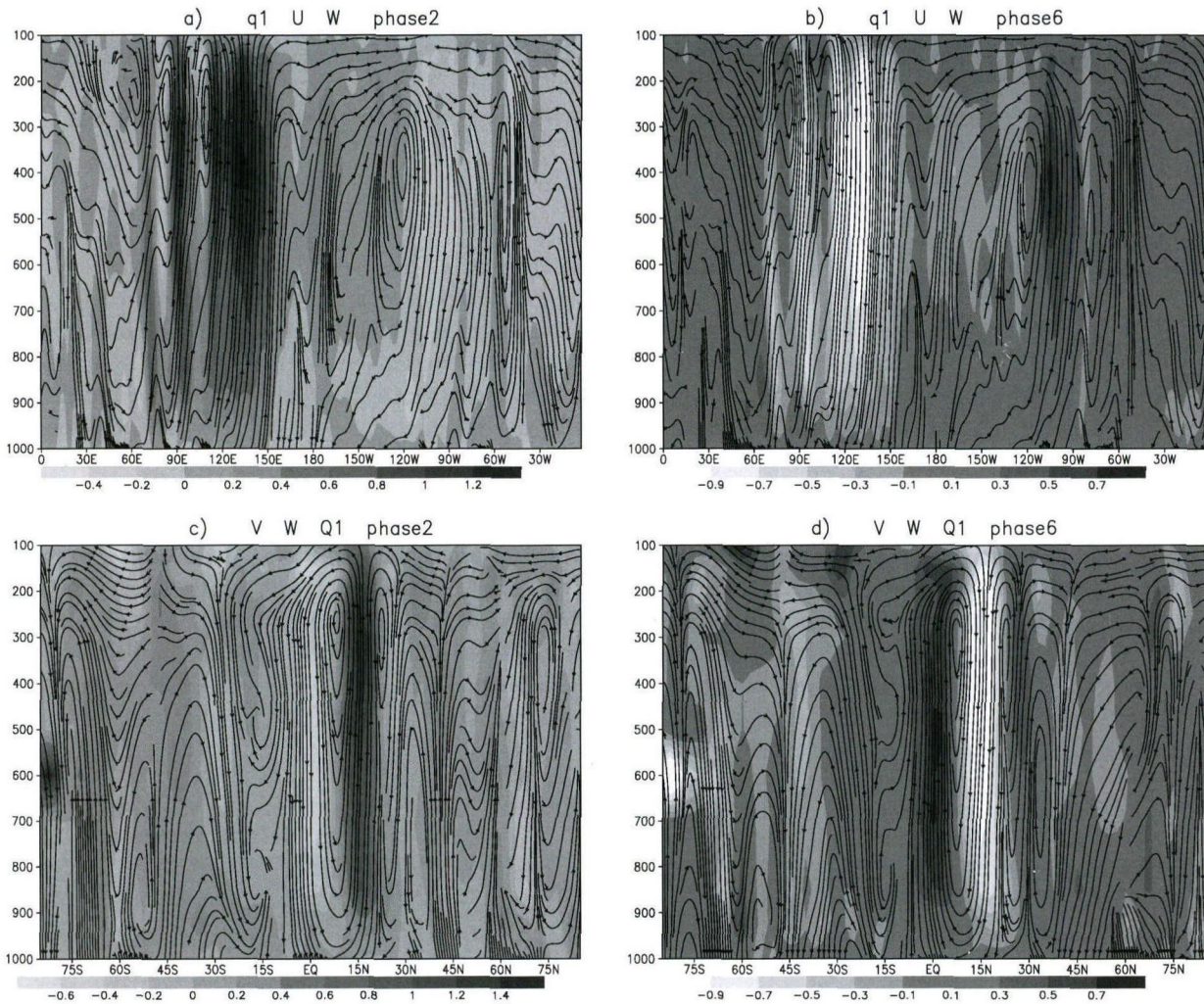


Figure 10. Cross-sections composite of heat source Q1 (shaded; unit: K/day) and vertical circulation anomaly (a and b: vertical-latitude circulation averaged between 10-25°N; c and d: vertical-meridional circulation averaged between 110-120°E). (a and c) phase 2; (b and d) phase 6.

Figure 11 shows the spatial distribution of water vapor flux and divergence with 30-60 days period during phase 2 and 6. The eastward spread of ISO exerts influence on the distribution of water vapor source and sink by affecting the large scale environmental conditions. During phase 2, there is obvious water vapor convergence over the SCS with water vapor from Eastern Philippines and India Ocean transported by the southwest monsoon, which is

beneficial for the TCs activities over the SCS. During phase 6, there are water vapor divergence over the SCS and small-scale convergence east of Philippine.

Li found that the condensation heat influence is not only connected with convection intensity, but also with the vertical distribution of heat. Li found that the non-adiabatic heating in the troposphere can stimulate the outbreak of tropical ISO^[31]. Jia and Li considered non-adiabatic heating profile is of great importance on

affecting the convective parameterization scheme when simulating the ISO activity. Better simulation result was achieved when heating at middle and low level (Jia and Li [32]). Some research also found that the cumulus convection heating are primary important on the explosively development of TCs (Xu et al. [33]) with obvious heating configuration difference (Huang et al. [34]). Fig.12 shows vertical profile of the regional averaged condensation heat over the SCS during phase 2 and 6, the distributions of which are opposite between the two phases. During phase 2, there are obvious middle-level heating with the strongest heating center at 300-400hPa and maximum heating rate of 0.65 K/day. During phase 6, middle-level cooling exists over the SCS with the

strongest cooling center at 300hPa. Studies found that the peak height of heating center is closely related to the different developing period of TCs, namely 200-300hPa corresponds to mature period while 400-500hPa to developing period of TCs (Pan et al. [35]). Fig.12a indicates that the peak height of 300-400hPa corresponds to developing period of TCs, which conforms to the active phase (phase 2) of TC activity. To sum up from the thermodynamic perspective, the OLR anomaly, condensation heating and water vapor transportation coordinate well with each other, which lead to the different TCs activities during different phases of tropical ISO.

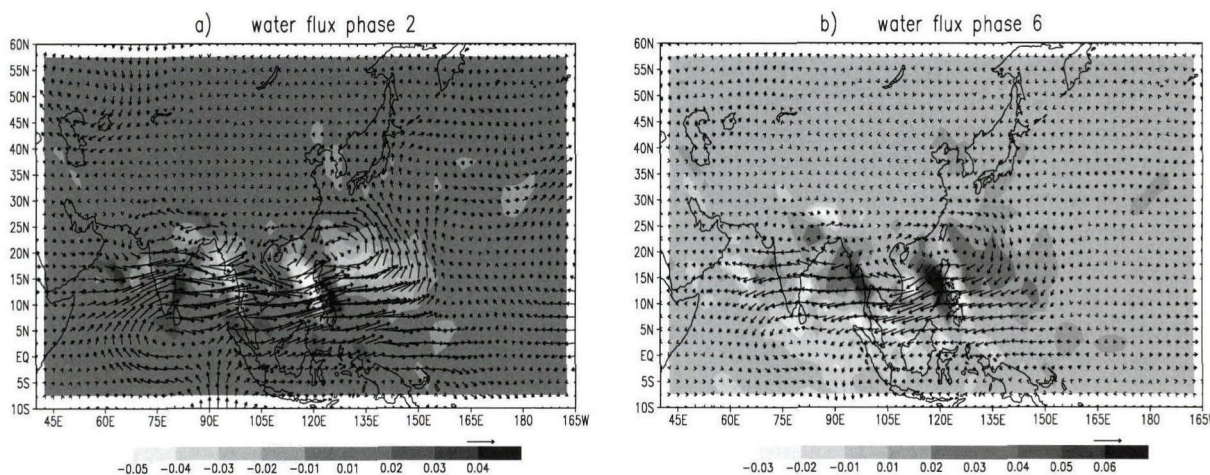


Figure 11. Spatial distribution of water vapor flux integrated from surface to the top of the troposphere (unit: $g\ s^{-1}\ cm^{-1}\ hPa^{-1}$) and its divergence (shaded, unit: $10^{-5}g^{-1}s^{-1}$) with 30-60 days period. (a) phase 2; (b) phase 6.

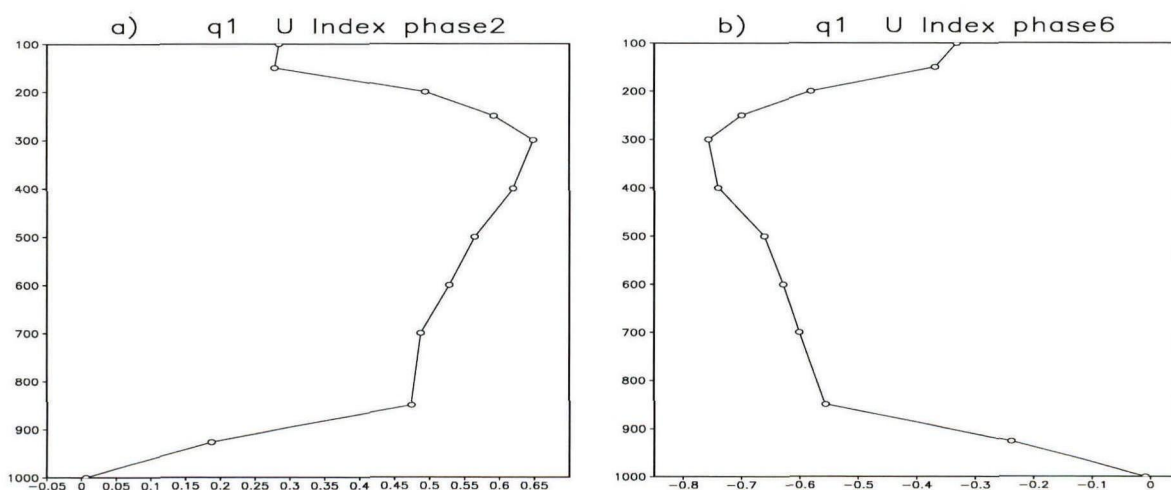


Figure 12. Regional averaged profile of anomalous non-adiabatic heating Q1 over the SCS (unit: K/day). (a) phase 2; (b) phase 6.

5 CONCLUSIONS AND DISCUSSION

In summary, the CPC index and the new ISO index are examined and discussed in detail respectively, and difference exists between the two indexes in instructing the tropical ISO activity specifically over the SCS. The

main conclusions are as follows:

- (1) The new ISO index is designed to describe the tropical ISO activity over the SCS, which can simply express ISO for SCS. After examining the applicability of the CPC index, we find that the convection spatial scale reflected by this index is too large to characterize

the small-scale SCS and fails to divide the TCs activities over the SCS into active and inactive categories. Consequently, the CPC index cannot replace the function of the new ISO index;

(2) The eastward spread process of tropical ISO is divided into eight phases using the new ISO index, the phase variation of which corresponds well with the TCs activities over the SCS. TCs generation and landing are significantly reduced during inactive period (phase 4-6) relative to that during active period (phase 7-3);

(3) The composite analyses indicate distinct TCs activities over the SCS, which is consistent with the concomitant propagation of the ISO convective activity. During ISO active period, the weather situations are favorable for TCs development over the SCS, e.g., strong convection, cyclonic shear and weak subtropical high, and vice versa;

(4) The condensation heating centers, strong convection and water vapor flux divergence are well collocated with each other during ISO active period. In addition, the vertical profile of condensation heat indicates strong ascending motion and middle-level heating during ISO active period, and vice versa. Thus, the eastward propagation of tropical ISO is capable to modulate TCs activities by affecting the heating configuration over the SCS.

Inevitably, the mechanism of the tropical ISO influence on the TCs activities over the SCS is not quite so simple, further research needs to be conducted, for example, on the relationship between ISO and landing TCs. It is noted that phase lag exists between the strongest zonal wind at 850hPa and OLR anomaly, which indicates that the convection activity might have trigger mechanism and forecasting significance on the zonal wind at 850hPa. Moreover, the new ISO index demands improvement and perfection due to the bias induced by few samples of TCs over the SCS and the subjectivity of tropical ISO phase division.

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