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COMPARISON STUDY ON THE INTRASEASONAL VARIATIONS IN CIRCULATIONS AND PRECIPITATION MODULATED BY THE TROPICAL CYCLOGENESIS OVER SOUTH CHINA SEA–WESTERN PACIFIC DURING GUANGDONG FLOODING PERIOD

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Abstract: Based on tropical cyclone datasets from Shanghai Typhoon Institute of China Meteorological Administration, the National Centers for Environmental Prediction (NCEP, USA) reanalysis data and the rainfall records from 743 stations in China, the impacts of cyclogenesis number over the South China Sea and the western Pacific are studied on the 30-60-day oscillations in the precipitation of Guangdong during the flooding period. The year with more-than-normal (less-than-normal) tropical cyclogenesis is defined as a ‘high year’ (‘low year’). In light of the irregular periodic oscillations, the method used to construct the composite life cycle is based on nine consecutive phases in each of the cycles. Phases 1, 3, 5, and 7 correspond to, respectively, the time when precipitation anomalies reach the minimum, a positive transition (negative-turning-to-positive) phase, the maximum, and a negative transition phase. The results showed that the precipitation of the 30-60-day oscillations is associated with the interaction between a well-organized eastward propagation system from the Arabian Sea/Bay of Bengal and a westward-propagating system (with cyclonic and anticyclonic anomalies in the northwest-southeast direction) from the South China Sea to western Pacific during the high years, whereas the precipitation is affected during a low year by the circulation over the South China Sea and western Pacific (with cyclonic and anticyclonic anomalies in the northeast-southwest direction). During the high year, the warm and wet air mass from the ocean to the west and south are transported to Guangdong by westerly anomalies and an enclosed latitudinal cell, which ascends in the Northern Hemisphere low latitudes and descends in the Southern Hemisphere low latitudes. During the low year, the warm and wet air mass from the ocean to the south is transported to Guangdong by southwesterly wind anomalies and local ascending movements. Because the kinetic energy, westerly, easterly shift, vertical velocity and vapor transportation averaged over (109–119° E, 10–20° N) is stronger in high years than those in low years, the precipitation of the 30-60-day oscillations in Guangdong is higher in high years than that in low years.

Key words: cyclogenesis number over the South China Sea and western Pacific; precipitation in Guangdong province; 30-60-day oscillation

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1 INTRODUCTION

Located in South China—an area of relatively low latitudes, Guangdong experiences weather and climate that are highly subject to tropical influence. Meanwhile, its location in a tropical monsoon region causes its flooding-season precipitation to be regulated by the intraseasonal oscillation of the monsoon. As shown in previous studies, the East Asian summer monsoon (EASM) precipitation is mainly governed by two low-frequency oscillations of, namely, 30-60 days and 10-20 days[1]. While significant periodic oscillations of 30-60 days exist in the Guangdong precipitation, those of 10-20 days are also prominent in some years[2]. Through a synoptics study on a 1994 extremely heavy rain over Guangxi and Guangdong, Li et al.[5] suggested that the EASM exerts profound influences on the local heavy rain. According to Li et al.[6], the intraseasonal oscillations of tropical atmosphere over the South China Sea

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affect the precipitation over South China mainly through the local longitudinal circulation associated with the tropical convection. They are negatively correlated; the stronger the intraseasonal oscillation, the less the South China precipitation, and *vice versa*. By low-frequency oscillations (of about 30-60 days), the South China Sea summer monsoon and low-value TBB bands (used to depict the convection) are transported to where heavy rains fall, thus having an intimate linkage with their genesis (Shi et al.[7]). In the work of Wen et al.[8] and Lin et al.[9], an abnormal heavy rain that occurred in June 2005 is related to the westward and northward transportation of the 30-60-day oscillation of the tropical convection. It is then concluded that the research on the intraseasonal oscillation of the Guangdong precipitation has mainly been conducted from the viewpoint of tropical monsoons. It is noted, however, tropical cyclones (TCs) are also playing a similar role in the rainfall during flooding seasons. Located next to the South China Sea and western Pacific, Guangdong is the province in China that has the most influence and landfall of TCs. Although the distribution of TCs-caused precipitation has been extensively studied in previous works[10-16], the effect of the years with more or less cyclogenesis on the flooding-season precipitation over Guangdong remains to be addressed. For this purpose, this work will focus on obtaining more knowledge about the precipitation pattern so as to provide possible theoretic basis for disaster mitigation and prevention.

2 DATA AND METHODS

The data used in this work include: (1) *Typhoons Yearbook* and *Tropical Cyclones Yearbook* for 1949–2005 compiled by Shanghai Typhoon Institute; (2) 1958–2005 global 2.5° × 2.5° monthly mean reanalysis from National Centres for Environmental Protection (NCEP, USA); (3) 1958–2005 daily precipitation data from 743 observation stations of China provided by National Climate Centre, China.

The methods of research include the Lanczos filter[17], wavelet analysis and composite analysis.

3 DIVISION OF THE HIGH AND LOW YEARS OF CYCLOGENESIS AND SELECTION OF PRECIPITATION PHASES

As June through October is a period of preferred cyclogenesis in South China Sea and western Pacific[18, 19], we have a statistical study of the TCs that are formed within the area (105–160° E, 0–30° N) and named by meteorological institutions in China (Fig. 1). The tendency of cyclogenesis in this area shows clear interdecadal decreasing trend, especially after 1978, which is consistent with the interdecadal shift of the East Asia climate[20-22]. Here in this work, a year of TC number larger (or smaller) than a standard deviation is defined as a high (or low) year. As a result, there are eight high years in the time of interest (1961, 1966, 1967, 1970, 1971, 1974, 1978, and 1994), and six low years (1976, 1983, 1998, 2002, 2003, and 2005).

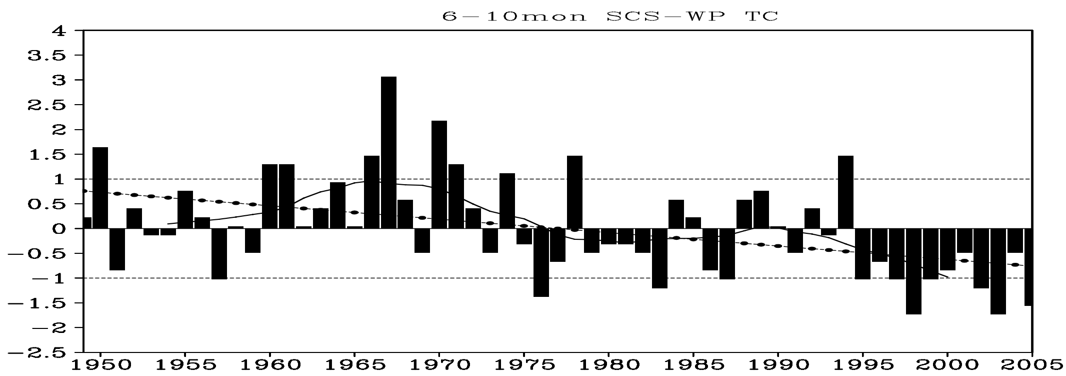


Fig. 1. (Normalized) distribution is shown of the number of cyclogenesis of tropical cyclones in June to October in the region of South China Sea-western Pacific. Solid curve: 10-year running mean; dotted and dashed curve: trend line; dotted curve: positive or negative standard deviation by one unit; abscissa: year.

Wavelet analysis was performed on the average precipitation amount from 86 gauge stations in the province for June through October in 1949–2005, and significant oscillatory periods of 30-60 days exist in most of the years (not shown). In the South China Sea through western Pacific, the high years of cyclogenesis are associated with strengthened 30-60-day oscillations while the low years are corresponding to weakened 30-60-day oscillations (not shown). Following the Lanczos filter, we extracted the 30-60-day oscillations from the Guangdong precipitation for both the high and low years and identified irregularities of their periodic oscillations. To have a systematic analysis of the effect of high and low years on the Guangdong precipitation with the 30-60-day oscillations (to be referred to as "the precipitation" hereafter), this work categorizes it into nine phases, i.e., Phases 1, 3, 5, 7, and 9 correspond to the rainfall minimum, point of positive turn (from negative to positive), maximum, point of negative turn (from positive to negative), and minimum, as shown in Fig. 2. Then, composite analysis is conducted with the nine phases of the precipitation, which goes with such circulation as the wind field, Hadley cell and water vapour field.

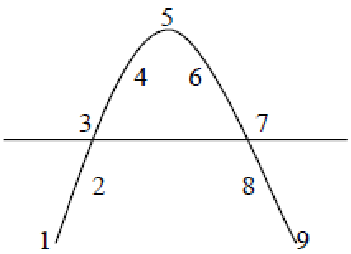
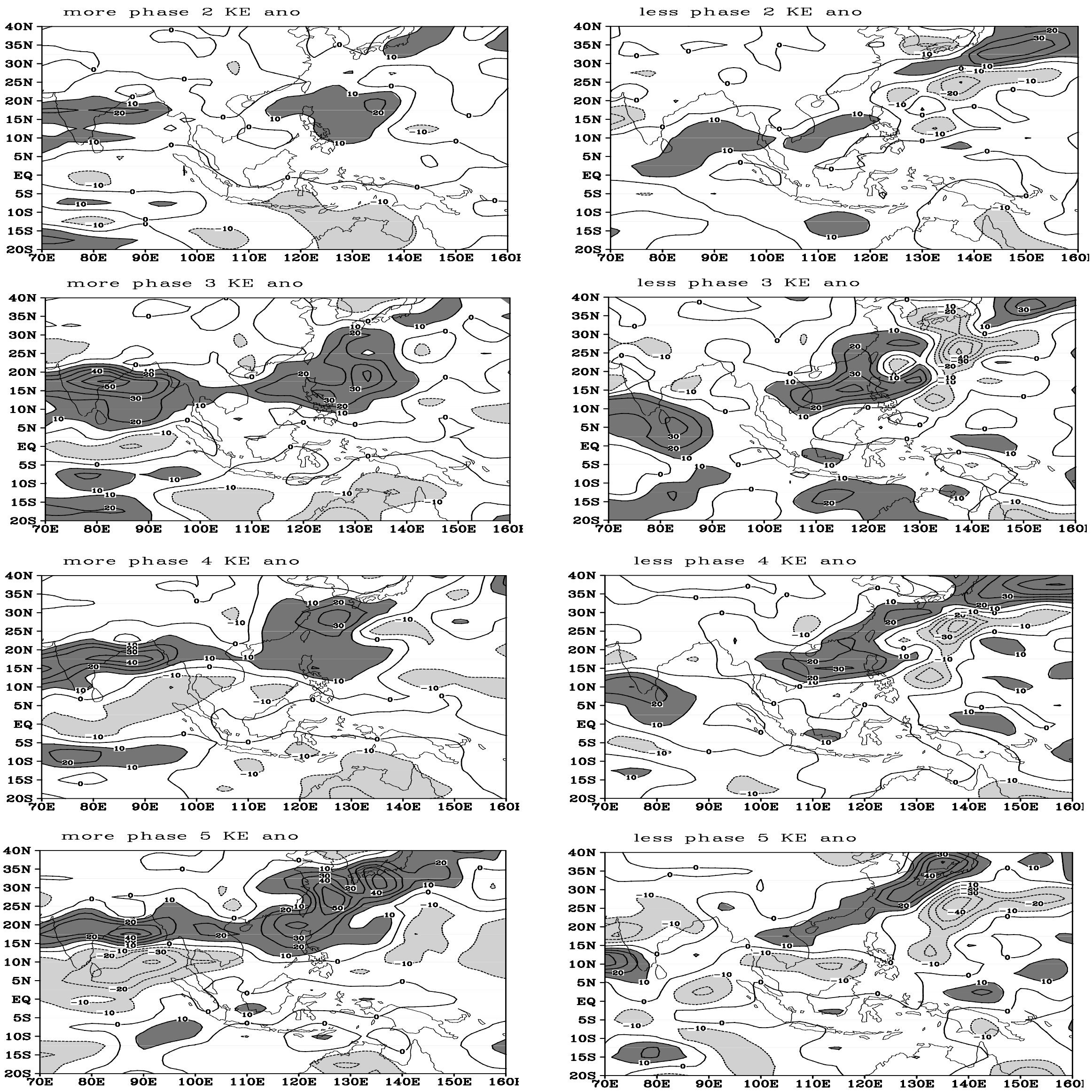


Fig. 2. Phases 1, 3, 5, 7, and 9 correspond to the rainfall minimum, point of positive turn (from negative to positive), maximum, point of negative turn (from positive to negative), and minimum, respectively.

4 VARIATION OF CIRCULATION AND PRECIPITATION

Setting Phase 1 (rainfall minimum) as the base reference, this work subtracted it from the circulation associated with Phase 2 through Phase 9 to study the effect of the circulation change caused by the high and low years on the precipitation within a complete cycling period.

Figure 3 presents the difference charts of the phase composite for the 850-hPa kinetic energy.



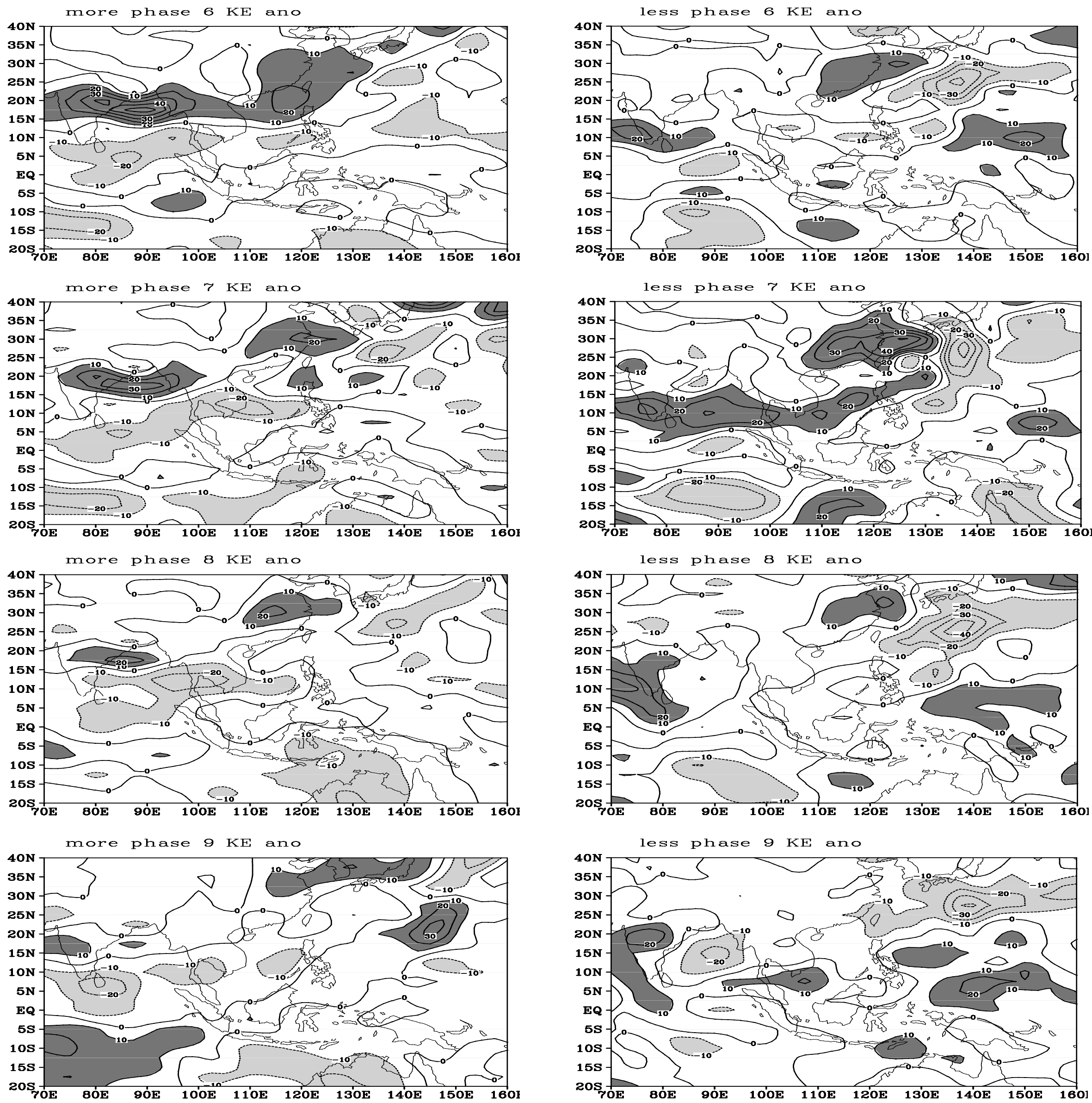


Fig. 3. Difference charts are shown of the phase composite for the 850-hPa kinetic energy. Panels on the first row: Phase 2 minus Phase 1; Panels on the second row: Phase 3 minus Phase 1…Panels on the eighth row: Phase 9 minus Phase 1. Dark shades: positive values; light shades: negative values.

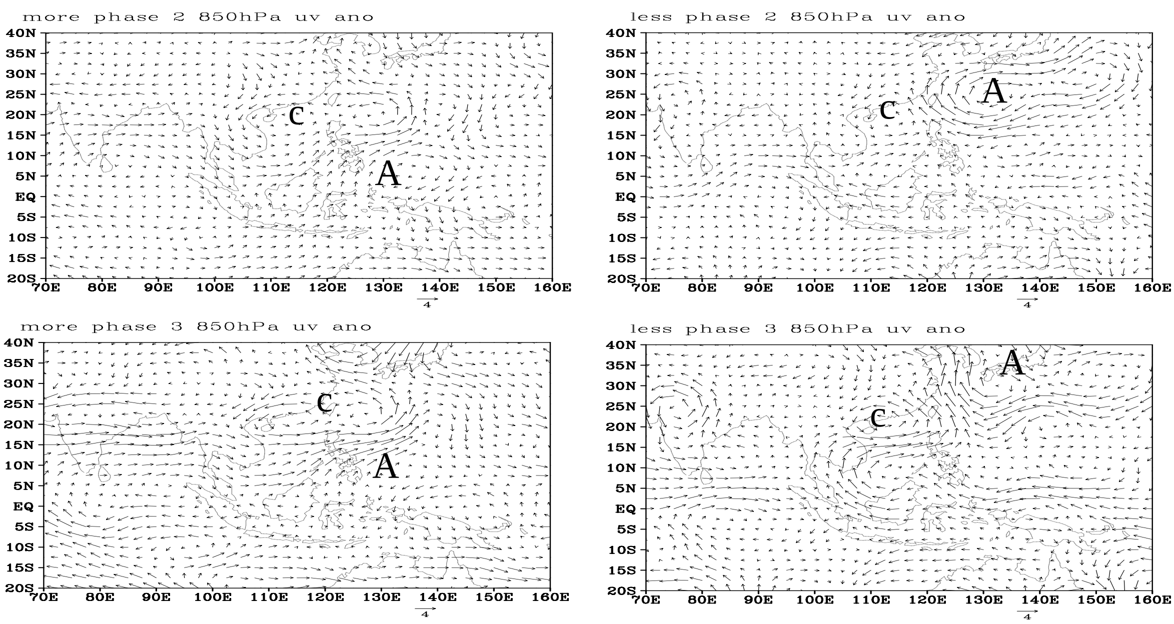
4.1 *The anomalous kinetic energy*

In the high year (Fig. 3), the difference between Phase 2 and Phase 1 (to be referred to as P2 hereafter, and the same coding rule applies accordingly) is marked with a centre of anomalous kinetic energy in the South China Sea/western Pacific and Arabian Sea/Bay of Bengal. At P3, the centre of positive anomalies in the former region is moving to the west while that of the latter region is moving to the south. As they are intensifying and getting closely connected to each other, the two anomalous centres acquire their maximum intensity at P5 and the precipitation is also turning from low to high values (not shown). Correspondingly, a centre of positive anomalous vorticity over the Arabian Sea/Bay of Bengal and that of negative anomalous vorticity over the Indian Ocean south of 10° N are also developing towards the east, intensifying the anomalous westerly winds near 15° N. Additionally, a centre of anomalous kinetic energy in the South China Sea/western Pacific is also advancing northward and reaches Guangdong as it transforms from P2 to P5. A centre of positive anomalous vorticity is associated with the above situation, and a centre of negative vorticity over the southeast tropical Pacific is progressing northwestward. This pair of northwest-southeast-oriented anomalous vorticity also intensifies the westerly winds in Guangdong and increases the precipitation. During the shift from P6 to P9, they begin to split and weaken gradually, decreasing the precipitation. In comparison, in the low years and beginning from P2, the effect on the precipitation is mainly from the strengthening and northwestward propagating positive vortex circulation in the South China Sea, which has powerful kinetic energy, while there is no significant eastward movement in the part of the centre of positive kinetic energy anomalies in the Arabian Sea/Bay of Bengal. With the appearance of the centre of positive anomalous vorticity, a centre of negative anomalous vorticity appears in the northwestern Pacific. Acting in pair, the southwest-northeast-aligned anomalous vortexes enhance the southwest flows over Guangdong and favour more rain.

It is then concluded that cyclonic circulation systems, having high kinetic energy, enhance their interaction over the South China Sea/western Pacific and Arabian Sea/Bay of Bengal, and the northwest-southeast-oriented pair of anomalous vortexes move westward, in the high years. As a result, the precipitation increases. In the low years, however, as the circulation of the Arabian Sea/Bay of Bengal contributes just mildly to the precipitation, a developed and strengthened South China Sea/western Pacific circulation, while progressing northwestward, becomes the main player in affecting the precipitation.

4.2 *The anomalous wind field*

Examination of the differences in the wind-field phase at 850 hPa (Fig. 4) reveals that the 850-hPa wind field displays itself, at P2 of the high years, as an anomalous cyclone over the South China Sea/western Pacific and in the company of an anomalous anti-cyclone to its south. This pair of anomalous cyclone/anticyclone is moving gradually northward. At P5, anomalous westerly winds between the cyclone and anticyclone connect with that originating from the Arabian Sea/Bay of Bengal. Acting upon the ocean surface, the anomalous westerly, due to the Ekman pumping effect, inhibits the seawater from swelling, thus being conducive to the maintenance of anomalously warm sea surface temperature (SST) and constantly channelling warm and humid maritime airflow toward Guangdong to increase the rainfall there. At this time, the cross-equatorial currents near 105° E are also strengthened, favourable for the longitudinal transport of water vapour. From P6 to P9, the anomalous cyclone to the north gradually dissipates while the anomalous anticyclone keeps moving to the northeast, with the easterly flow to the south controlling the province and the anomalous westerly to the west withdrawing westward while weakening. Such anomalous easterly wind makes it easy for seawater to swell, thus unfavourable for SST warming. As a result, less water vapour is transported to cause less of the precipitation. In the low year, there is also a pair of anomalous cyclone/anticyclone over the South China Sea/western Pacific but with a northeast-southwest orientation. From P2 to P5, an anomalous southwesterly within the pair advances northwestward, transporting warm and humid airflow to Guangdong where it meets with the cold air mass from the north and brings about more rain. Similar to the high year, the anomalous cyclone over the province, during the transition from P6 to P9, weakens and dissipates while the easterly south of the anticyclone keeps dominant over Guangdong. It connects with the anomalous easterly from the North Pacific to form a band of large-value anomalous easterly, preventing the southern warm and humid airflow from transporting northward and resulting in the re-entry of another reduction stage of the precipitation.



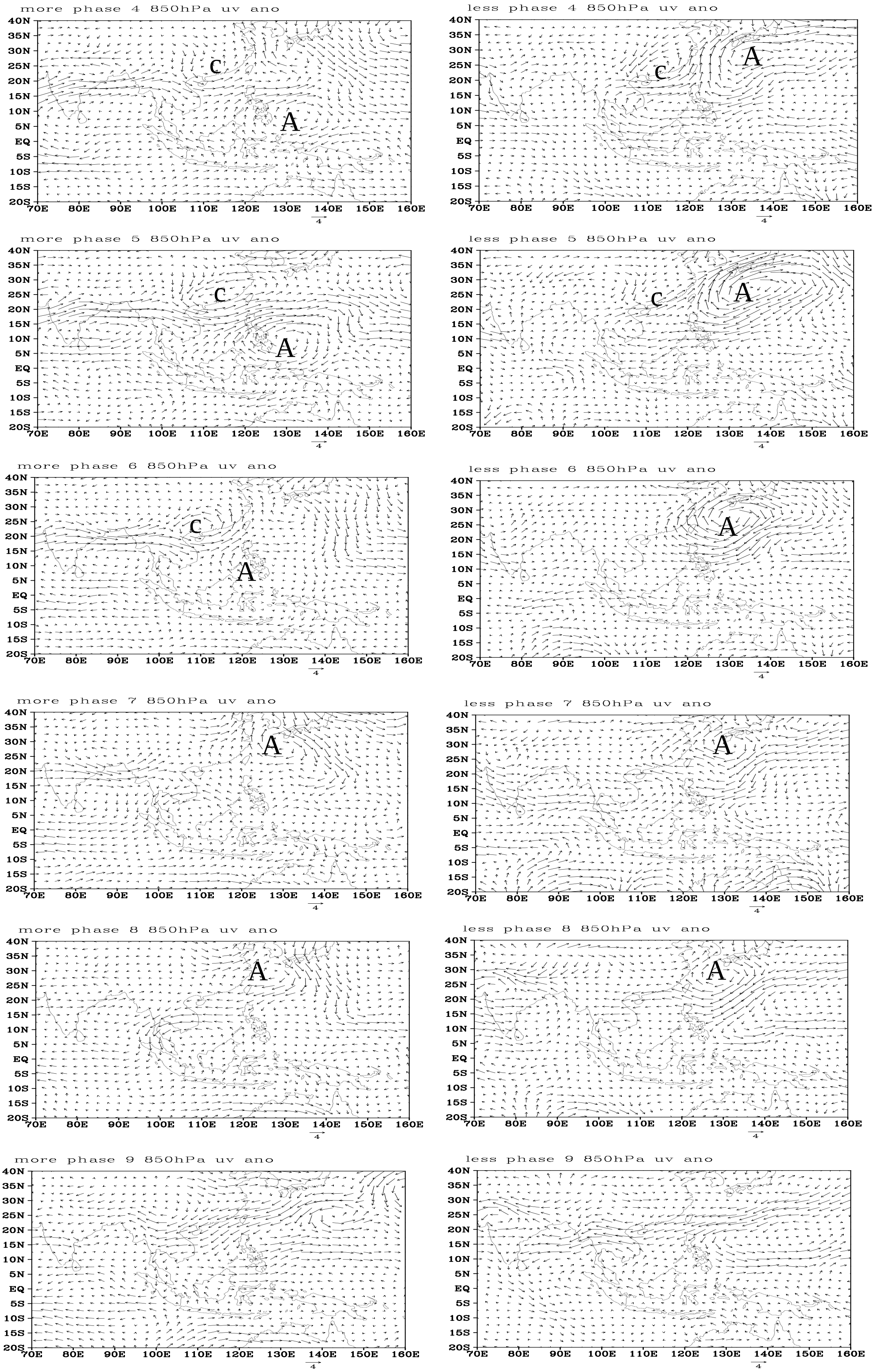


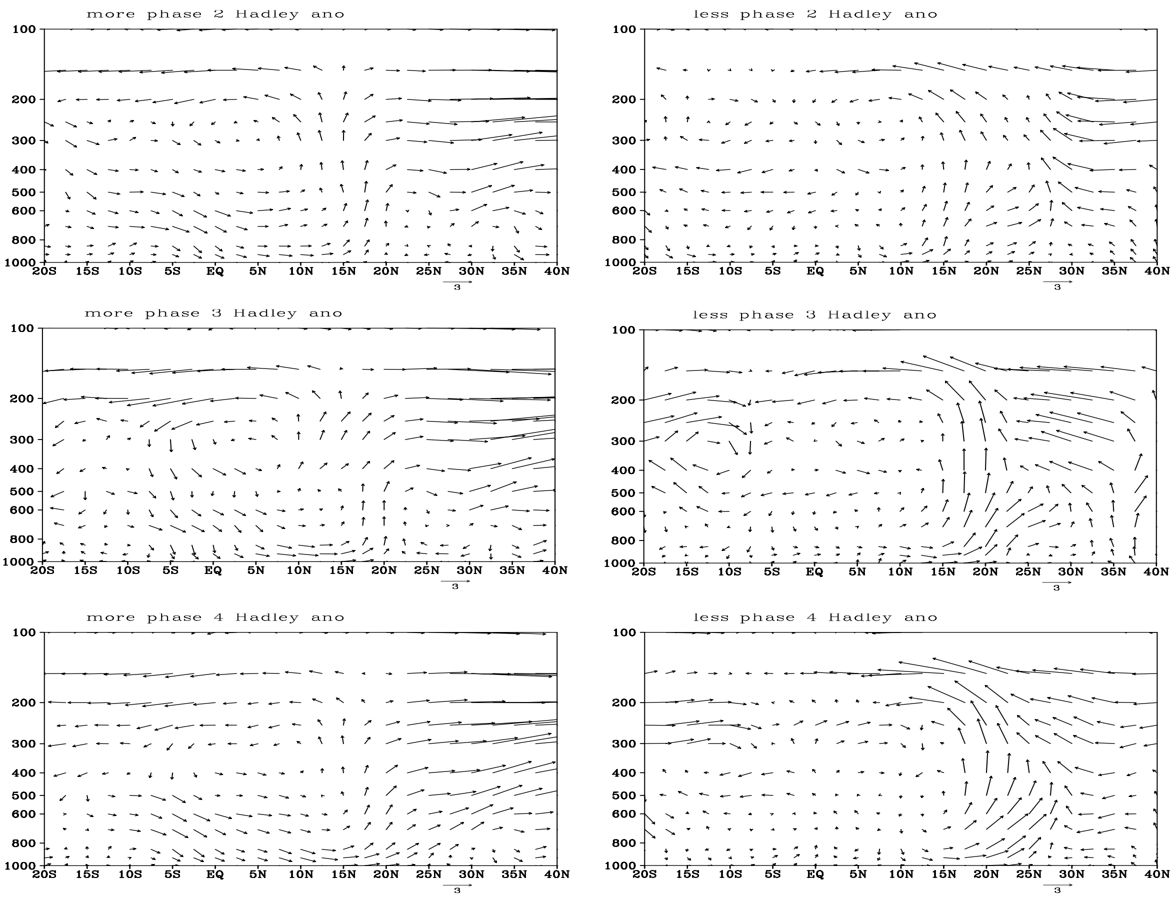
Fig. 4. Same as Fig. 3 but for the phase difference of the 850-hPa wind field in the high and low year. A: anticyclonic circulation; C: cyclonic circulation.

At the level of 200 hPa (not shown), the anomalous easterly is always, from P2 to P5, prevalent in the area south of Guangdong in either the high or low year. In the high year, however, the easterly shear in this area is stronger than that in the low year. It is then known that the precipitation is stronger in the high year than that in the low year due to stronger intensification of the summer monsoon in the South China Sea in the high year.

4.3 *The anomalous vertical circulation*

For the vertical circulation (Fig. 5), the Hadley cell strengthens starting from P2 of the high year, with its anomalous ascending branch located south of 20° N and anomalous descending branch situated in the low latitudes south of the equator. The Hadley cell then pushes northward while strengthening. At P5, a low-level anomalous southerly flow is the strongest near 5–20° N, and so is the ascending current in Guangdong, which is also spreading to a larger area. The anomalous southerly flow strengthens the South China Sea summer monsoon to increase the precipitation. Starting from P6, the low-level anomalous southerly is gradually replaced by an anomalous northerly, inhibiting the growth of the precipitation. By contrast, the longitudinal circulation—ascending in the Northern Hemisphere and descending in the Southern Hemisphere, is not enclosed in the low year. Instead, the anomalously ascending branch gradually intensifies from P2 to P5 while the low-level anomalous southerly is relatively weak over the area 5–20° N, making the South China Sea summer monsoon much weaker than in the high year and exposing the precipitation to the effect of local ascending flows. Like the high year, the anomalous ascending branch over Guangdong begins to weaken and dissipate at P6 of the low year, decreasing the precipitation. Fig. 5 also shows that the easterly shear is stronger in the region (10–20° N) in the high year than that in the low year.

In addition, the distribution of the Walker cell (not shown) also shows that the precipitation in the high year is closely related to the intersection between the westward and eastward expansion of the two anomalous ascending airflows over the South China Sea/western Pacific and Arabian Sea/Bay of Bengal. In the low year, however, the anomalous ascending flow is playing a major role.



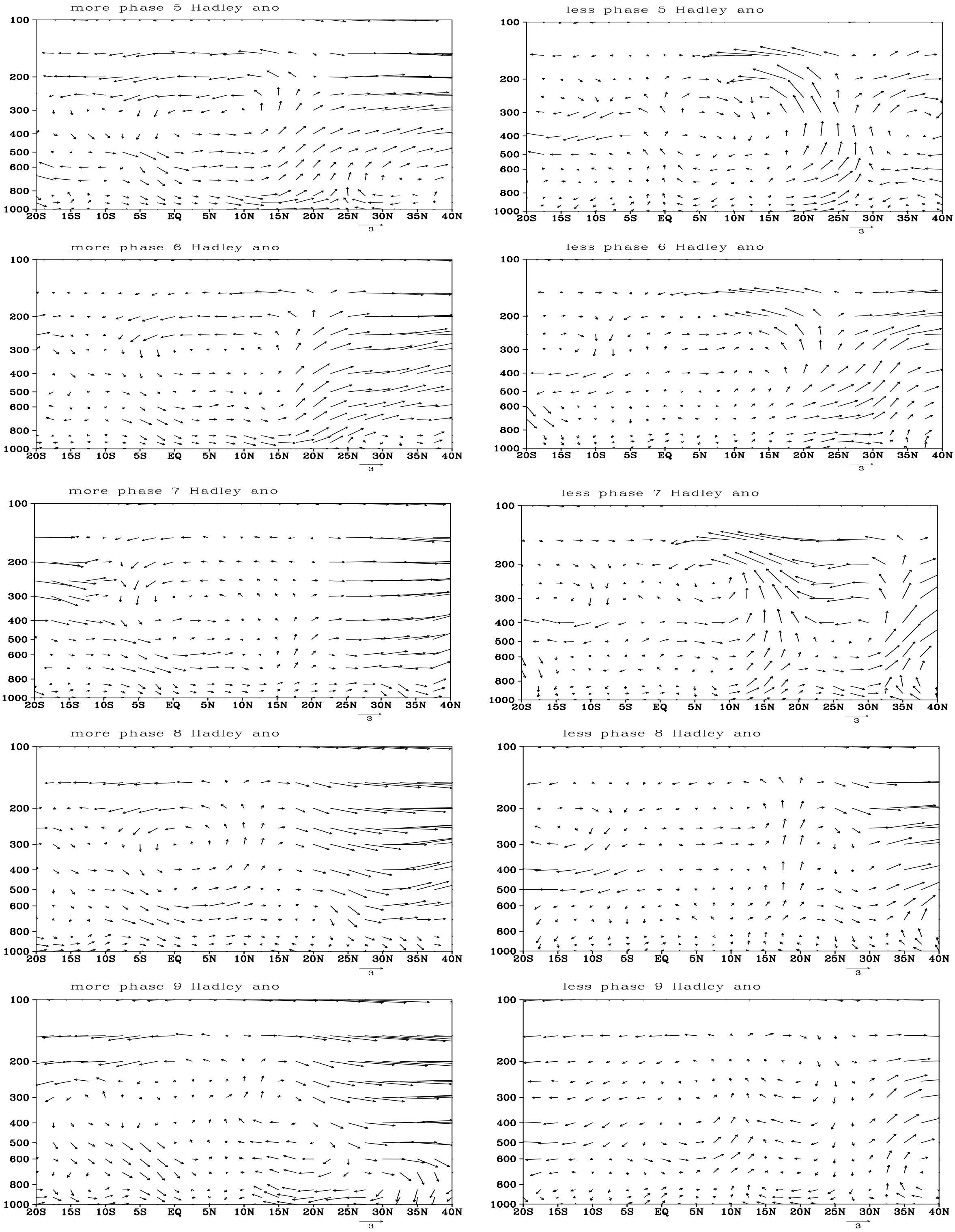
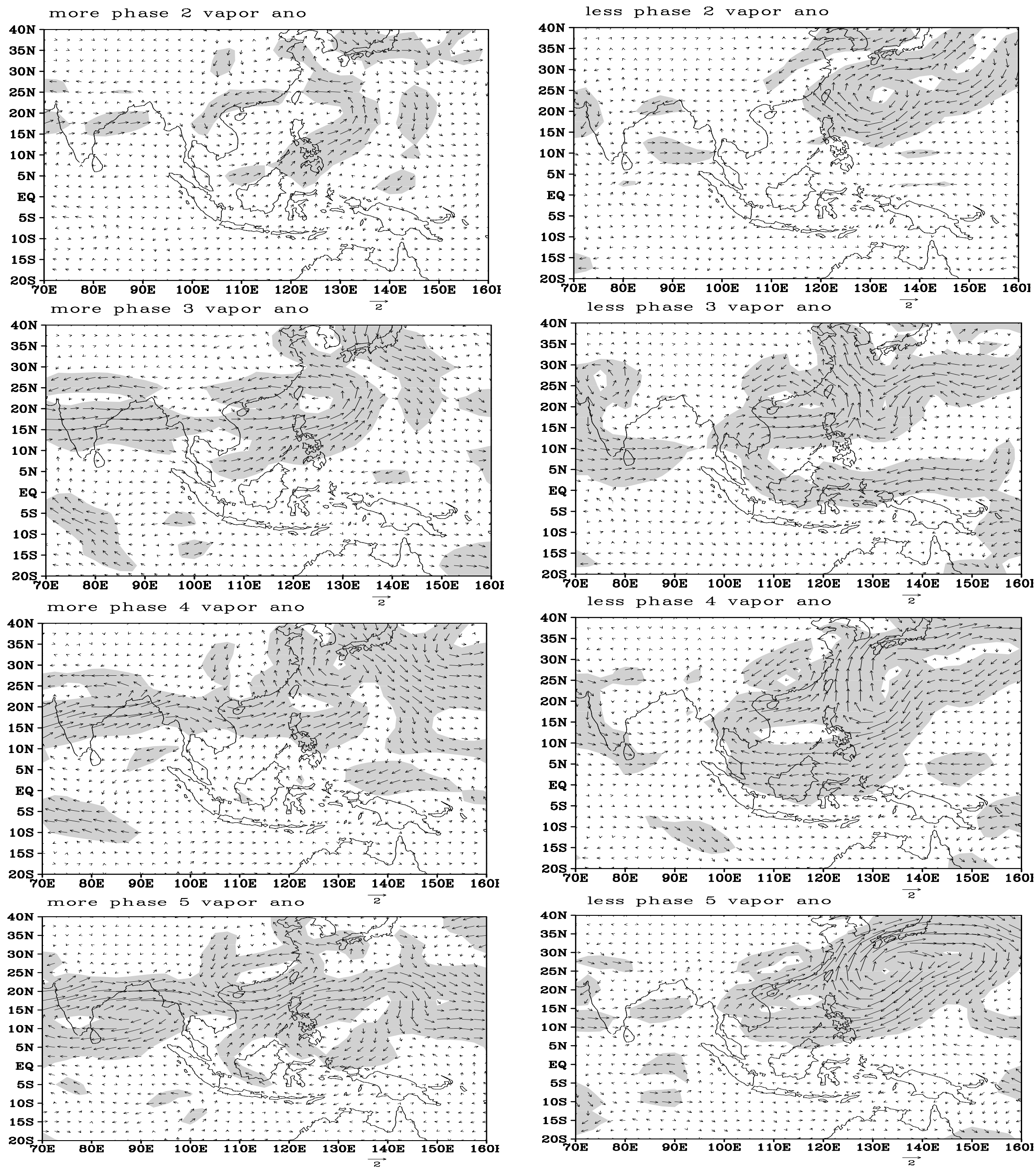


Fig. 5. Same as Fig. 4 but for the phase difference between the high year and the low year in the Hadley Cell (averaged over the latitudinal average at 105–120° E) over 20° S–40° N.

4.4 *The anomalous water vapor transport*

The water vapour transport is also an important factor that affects the precipitation[23]. Changes in the number of cyclogenesis of tropical cyclones in the South China Sea/western Pacific inevitably have an impact on the changes in the atmospheric circulation. Consequently, the source of water vapour will also change, affecting the precipitation. With the methods above, we conducted an analysis of phase composite for the flux of water vapour transport (Fig. 6). At P2 of the high year, differences exist in the cyclonic circulation over the South China Sea/western Pacific while water vapour begins its anomalous eastward transport over the Arabian Sea/Bay of Bengal. During its intensification and eastward progression, the water vapour joins with that from an anomalous westerly south of it to provide constant supply of warm and humid airflow to Guangdong to increase the precipitation. With the reduction of the transport of anomalous cyclonic moisture, the eastward transport of anomalous moisture from the Arabian Sea/Bay of Bengal also withdraws to the west, splits and weakens, decreasing to its weakest point at P9. Meanwhile, the province is dominated by the transport of moisture from anomalous easterly zones, which blocks moisture from being carried from south to north, causing the precipitation to return to a low value again. The low year is different from the high year. First, anomalous anti-cyclonic moisture is transported over northwest Pacific at P2 and the anomalous cyclonic moisture begins to develop at P3 in northern South China Sea. These two channels of moisture gradually move to the north and anomalous northward transportation of moisture between them carries maritime warm and humid airflow to Guangdong to result in more precipitation. By contrast, the moisture transport is relatively weak and therefore does not affect the precipitation. Afterwards, with the northward progression and reduction of the transport of anomalous anti-cyclonic moisture over the northwestern Pacific, the transport of moisture in the anomalous easterlies takes the control of Guangdong to decrease the precipitation.



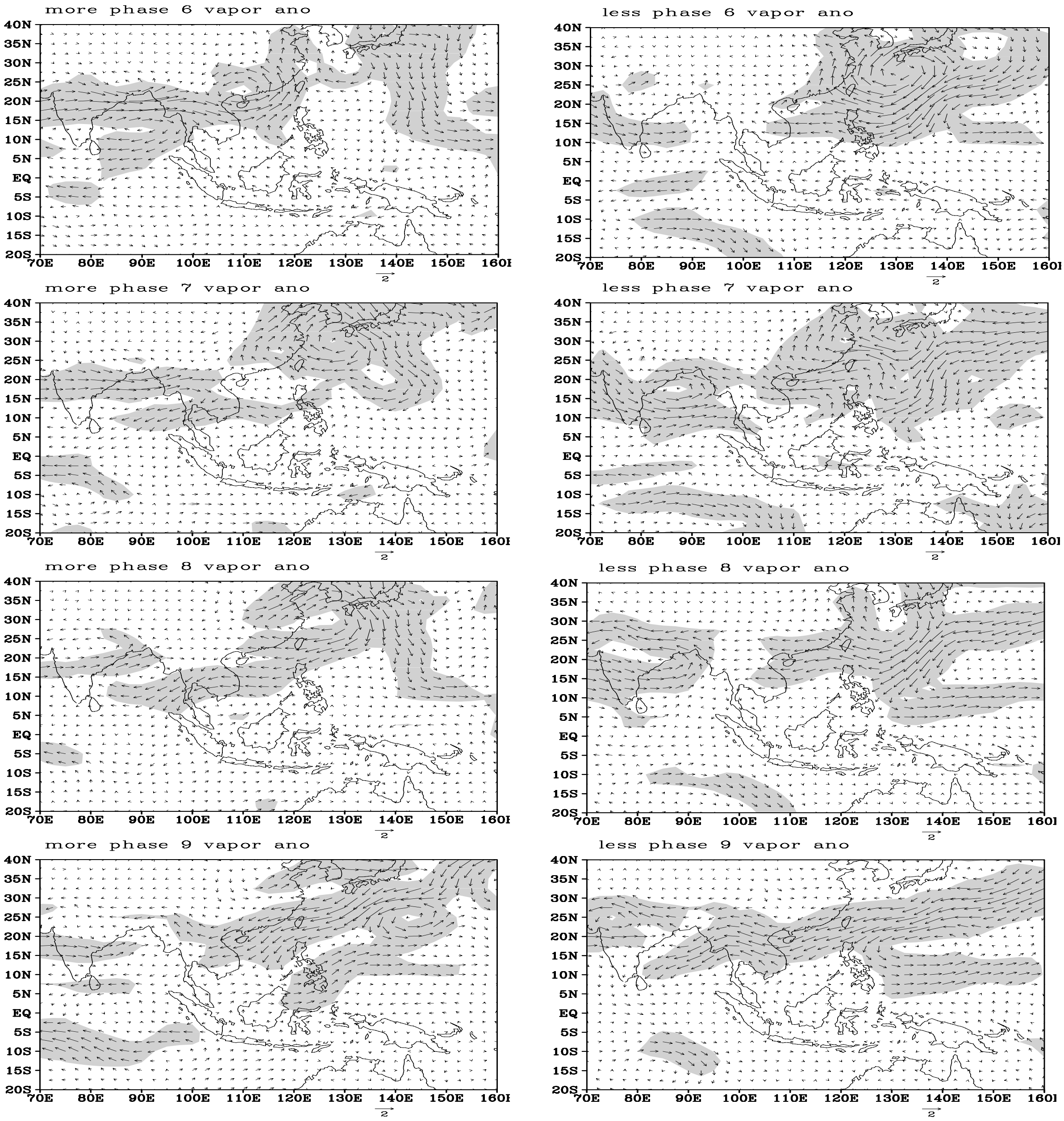


Fig. 6. Same as Fig. 3 but for the phase difference in the flux of moisture transport in unit of kg/(cm·s). The shades are where the moisture transport is greater than 0.7 kg/(cm·s).

In summary, the high and low years differ in the precipitation-related circulation systems they affect and the intensity of the South China Sea summer monsoon they cause for the same range of longitude. To better illustrate this point, we sought averages of individual meteorological elements over the area (109–119° E, 10–20° N) associated with all phases of the precipitation (Fig. 7). It shows that the high years, at P1 through P5, generally have higher area-mean anomalous kinetic energy, westerly and easterly shears, vertical velocity and moisture transport than in the low years (Fig. 7b-7f), resulting in stronger precipitation over the corresponding period in the Guangdong region (109–119° E, 21–25° N) in the high year than in the low year (Fig. 7a). It further shows that the eastward progression of the Arabian Sea/Bay of Bengal circulation, co-acting with the westward advancement of the South China Sea/western Pacific circulation system in the high year, has greater impacts on the precipitation than the South China Sea/western Pacific circulation system alone, making the precipitation stronger in the high year than that in the low year.

5 CONCLUSIONS

It is shown in comparisons and analyses that the precipitation is stronger in the high year than that in the low year mainly due to the fact that in the high year, the circulation over the Arabian Sea/Bay of Bengal, having larger kinetic energy, moves east and joins with a pair of anomalous northwest-southeast-oriented cyclone/anti-cyclone that is travelling west. Through a circulation of anomalous enclosed latitudinal circle that ascends in the Northern Hemisphere and descends in the Southern Hemisphere and moisture transport, the warm and humid maritime airflow is transported to Guangdong from the west and the south to increase the precipitation. In the low year, however, the precipitation has a much weaker linkage with the Arabian Sea/Bay of Bengal circulation than with the pair of anomalous northwest-southeast-oriented cyclone/anti-cyclone. Through the local effect of an anomalous ascending branch that strengthens over the low latitudes of the Northern Hemisphere and moisture transport, the warm and humid airflow from the southern ocean is transported continuously to Guangdong to increase the precipitation. Besides, the anomalous kinetic energy, westerly and easterly shears, vertical velocity and moisture transport, which are averaged over the Guangdong region (109–119° E, 10–20° N), are stronger in the high year than those in the low year, making the precipitation more intense in the high year than that in the low year.

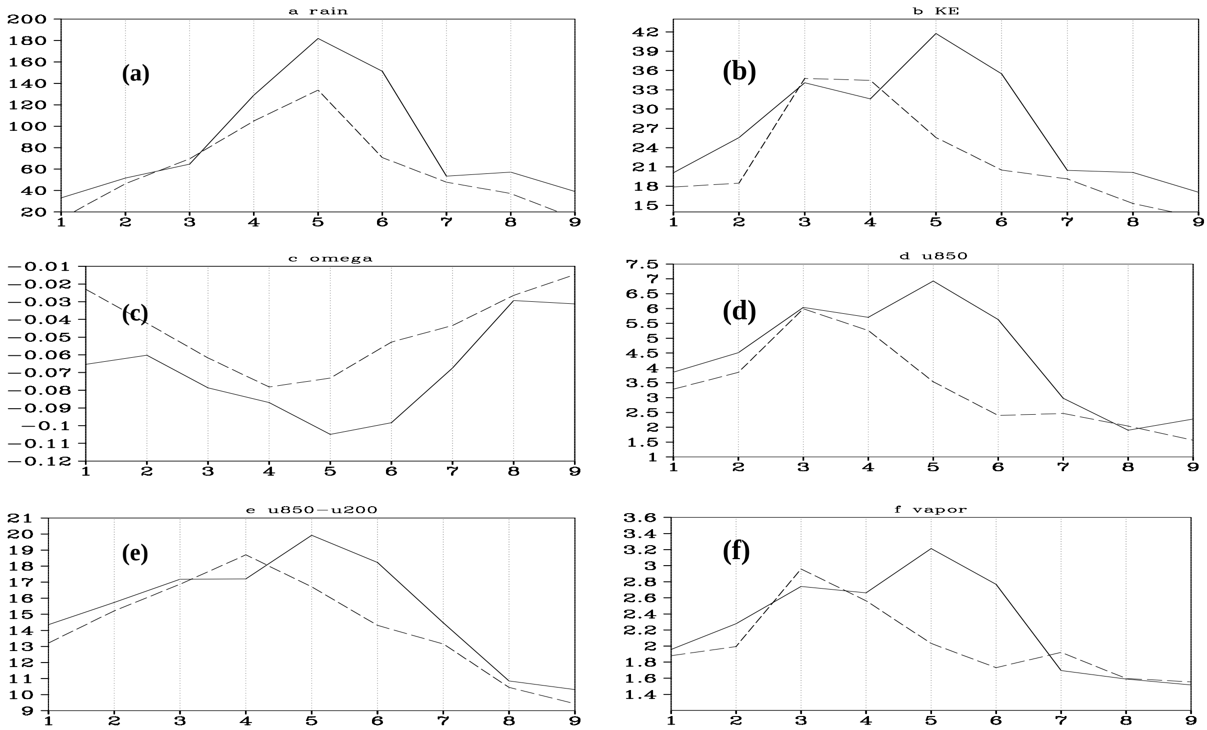


Fig. 7. The precipitation of 30-60-day oscillation over Guangdong (109–119° E, 10–20° N) (a, unit: mm), areal-averaged anomalous kinetic energy of the nine phases (b, unit: m^2/s^2), westerlies (c, unit: m/s), easterly shear (d, unit: m/s), vertical velocity (e, unit: Pa/s), moisture transport (f, unit: kg/(cm·s)). The abscissa is the phase. The solid line stands for the high year and dashed line for the low year.

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