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CONTRAST ANALYSIS OF APRIL TYPHOONS LEO AND NEOGURI

LU Shan (卢 山), WU Nai-geng (吴乃庚)

(Guangzhou Central Meteorological Observatory, Guangzhou 510080 China)

Abstract: The conventional observations data, NCAR/NCEP-2 reanalysis data, and NOAA outgoing longwave radiation data are used to investigate different characteristics of Leo and Neoguri, two April typhoons that ever made landfall on the continent of China over the past 60 years. The results showed that both Leo and Neoguri occurred during the La Nina events. Strong convective activity, weak vertical wind shear and upper-level divergence were in favor of the formation of these April typhoons. Leo originated from a monsoon depression and Neoguri evolved from an easterly wave. The meandering moving track of Leo attributed to strong northeast monsoon and a weak and changeable subtropical high; the steady moving track of Neoguri was governed by a strong and stable subtropical high. Leo and Neoguri had similar terrain conditions and intensities during landfall but were different in precipitation as water vapor transport and duration of kinetic uplifting resulted in apparent discrepancies between them.

Key words: April typhoons; formation mechanisms; moving track; typhoon precipitation

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1 INTRODUCTION

Tropical cyclones (TCs) are the synoptic systems that are most destructive of meteorological disasters. Being able to generate the year round, they concentrate in July–October[1-3]. By long-time practice, summing-up, exploration and research, meteorologists have done much on TCs' generation mechanisms, changes in structure and motion, landfalling processes, heavy rainfall they bring about as well as forecasting techniques[4-10]. Chen has made comprehensive overviews and summaries on the progress made over the past few years in China in TC research[3, 10].

One of the waters most frequented by TC activity, the South China Sea (referred as SCS hereafter) can have TCs the year round. Much effort has been spent on the characteristics of the SCS TCs[11-17]. In their studies on the spatiotemporal distribution of the TCs active during June–October in the SCS over the past 50 years, Li et al.[11] pointed out that chief maritime factors affecting the frequency of TCs in the SCS are related to the El Niño-Southern Oscillation (ENSO). May through September is an active season for the SCS TCs, with September having the highest frequency, as indicated in Yang et al.[12] studying the pattern of cyclogenesis of these TCs for 1949–2003. Simulating the strengthening mechanism of the SCS TCs just off the coast in prime summer, Chen et al.[13] showed that waving motion within the interior structure of a TC that bears some similarity to the Rossby wave is making important contribution to the offshore intensifying mechanism of TCs in the SCS. Analyzing the development of the SCS TCs with the Outgoing Longwave Radiation (OLR) data, Luo et al.[14] defined an index of gradient variations of OLR contours to describe its relationships with the development of tropical depressions in the SCS. Although some significant achievements have been made on the research on TCs in the SCS, they are mostly about their behavior in summer and the yearly second rainy season in the south of China. In spring, TCs appear in the SCS with small frequencies and low intensities, and more than half of them migrate from the Philippine Sea. It is known from surveys through historical data that there are only two TCs in April, one being Leo (coded 9902) and the other Neoguri (0801), in the period from 1949 up to the present, that formed over the SCS and made landfall in China. In mid-April, Neoguri became the earliest typhoon ever since 1949 that generated over the SCS and landed on China later. As it is quite difficult to analyze and forecast this type of TCs and to advise on

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Biography: LU Shan, senior engineer, primarily undertaking research on and forecast of typhoons and heavy rain.

Corresponding author: LU Shan, e-mail: shan_lu@grmc.gov.cn

decision-makers with information related to them, it has great significance of reference for improving the TC forecasting skill and the capabilities of disaster reduction and mitigation to have detailed analysis of their cyclogenesis background, track change and distribution of the rain and precipitation.

With conventional meteorological data, day-to-day global averages from the National Center for Atmospheric Research/National Centers for Environmental Prediction (NCAR/NCEP-2, USA) reanalysis, which consist of geopotential height field and wind field at the levels of 200, 500 and 850 hPa, 2.5° ×2.5° OLR data of the National Oceanographic and Atmospheric Administration (NOAA, USA), and yearbook information by China Meteorological Administration, the cyclogenesis background, track change and distribution of the rain and precipitation of Leo and Neoguri, two typhoons both active in April, are compared and diagnostically studied, with conclusions that have significance of reference.

2 BASIC INTRODUCTION TO LEO AND NEOGURI

Generated from a monsoon trough in central SCS, Leo evolved from a tropical depression to a tropical depression on April 27, 1999, and made loops over the central and western SCS. In the early morning of April 29, Leo further strengthened to become a tropical storm—strong enough to be coded 9902 and named, and moved towards the northeast. It then intensified to be a severe tropical storm in the small hours of the night of April 29 and evolved to be a typhoon on April 30. Leo began to weaken and made a recurvature toward the northwest after it crossed 20° N. It reduced to a tropical depression and made landfall on Huidong country of Guangdong on the night of May 2 (Fig. 1).

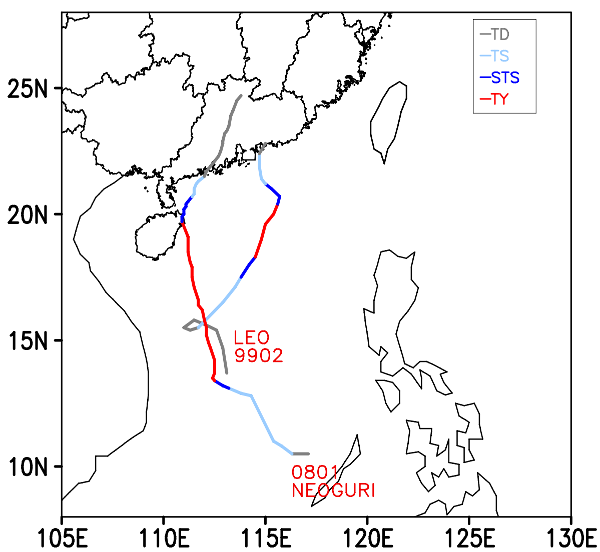

Fig. 1. Movement tracks of Leo and Neoguri.

On April 14, 2008, a tropical depression developed from an easterly wave that had moved into the SCS from the Philippine Sea. In the afternoon of April 15, it intensified to be a tropical storm—coded 0801 and named Neoguri, which then moved to the northwest. On April 16, it further strengthened to become a severe tropical storm and then a typhoon while recurving to the north. Approaching 20° N, Neoguri weakened rapidly and continuously through the daytime of April 19 and soon became a tropical depression. It then turned to head northeastward and landed on the coast of Huidong county, Guangdong (Fig. 1).

3 CLIMATIC BACKGROUND AND RELATED FAVORABLE CIRCULATION CONDITIONS FOR THE CYCLOGENESIS OF LEO AND NEOGURI

3.1 *Climatic background and favorable circulation conditions*

As shown in related studies, the activity of TCs in the SCS and West Pacific has close links with ENSO[19-22]; and the latter's warm episodes are associated with fewer TC landfalls in China while its cold episodes with more landfalls. Fig. 2 gives the series of the month-to-month sea surface temperature (SST) anomaly indexes for the equatorial Pacific (Niño4, 5° S–5° N, 160° E–150° W) available at the National Climate Centre. Two latest strong La Niña episodes occurred, in 1998–2000 and 2007–2008, respectively, while Leo, in 1999, and Neoguri, in 2008, formed in the spring successive to these La Niña episodes. To further examine the effect of the La Niña background on the cyclogenesis in April, Fig. 3 presents the anomalous distribution of the outgoing longwave radiation (OLR) of April in 1999 and 2008. Under the background of the La Niña episode, positive OLR anomalies are over the equatorial central and eastern Pacific and negative ones are mainly seen over the tropical West Pacific and SCS, suggesting that the La Niña episode is making the convection anomalously strong in the SCS-West Pacific, a favorable condition for the typhoon to form in April.

Under the background that the La Niña episode makes the convection in the SCS–West Pacific region anomalously strong, the upper- and lower-level circulation of the atmosphere is so allocated that it is playing an important role in the cyclogenesis of Leo and Neoguri. Fig. 4 gives the 200-hPa stream and divergence fields on the day of their genesis. A well-defined anti-cyclonic circulation over the SCS results in upper-level divergence that maintains and strengthens the persistent development of SCS convection and thus plays a vital role in the formation and evolution of the Leo and Neoguri. Besides, the center of the divergence was at 15° N, 115° E with the 1999 storm (Fig. 4a, on April 27) but it was more to the east and south in the 2008 case (Fig. 4b). The difference explains why Leo was formed over the central SCS while Neoguri was generated in the southeastern part of the sea.

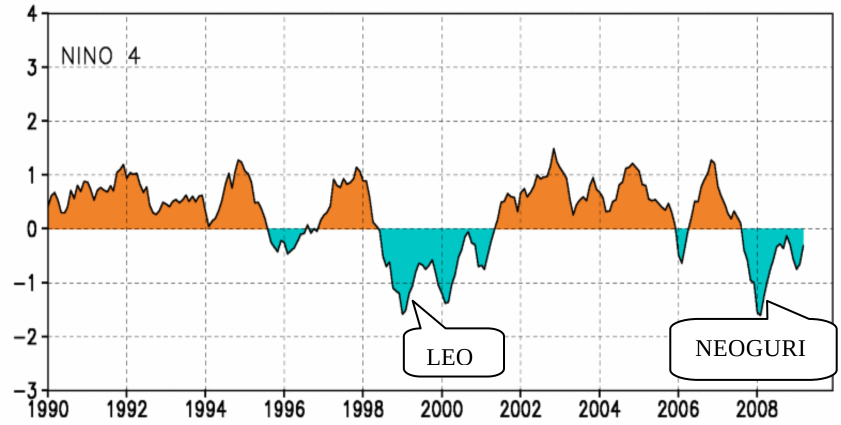

Fig. 2. Series of SST index in Niño4 of the equatorial Pacific in 1990–2009.

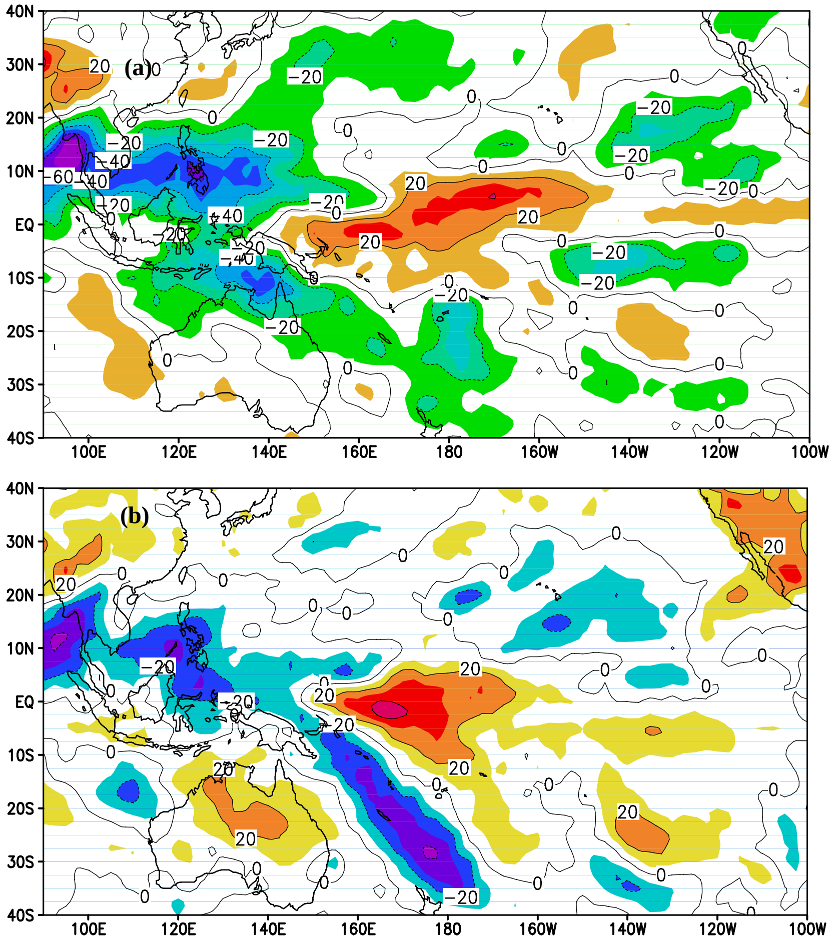

Fig. 3. OLR anomalies for April 1999 (a) and April 2008 (b). The shades are for the areas with the absolute values of the anomalies greater than 10 in the unit of W/s^2.

Vertical shear of weak horizontal winds also makes favorable conditions for the formation of Leo and Neoguri. Fig. 5a gives the latitude-height cross section along 112.5° E of the horizontal wind field in the central- and southern-SCS for April 27, 1999. At the early stage of Leo, as lower levels below 700 hPa were subject to the southwesterly flow in the central- and southern-SCS and a high pressure in northern SCS, the SW wind in southern SCS and NNE wind in northern SCS were quite large but winds were relatively small at 12.5–15° N where these two winds met, in association with small horizontal winds at upper levels (less than 4 m/s at 200–300 hPa). This type of weak vertical shear of horizontal winds is conducive to the formation and development of Leo. At the initial stage of Neoguri (Fig. 5b), however, the southern SCS was dominated by weak vertical shear of horizontal winds due to the presence of large southeasterly winds at upper levels, in spite of relatively large southeasterly winds at mid- and lower-levels that result from the easterly wave south of the West Pacific subtropical high. Under such favorable background, Neoguri was able to form and develop.

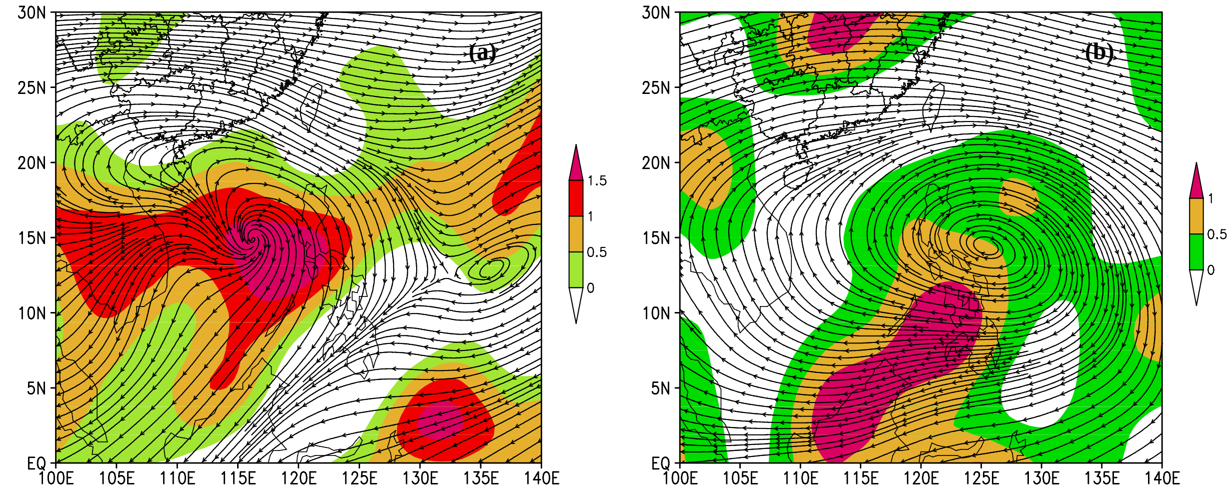

Fig. 4. Distribution of 200-hPa stream field and divergence for April 27, 1999 (a) and April 15, 2008 (b); the shades are for the region of positive divergence in the unit of 10^{-6} s^{-1}.

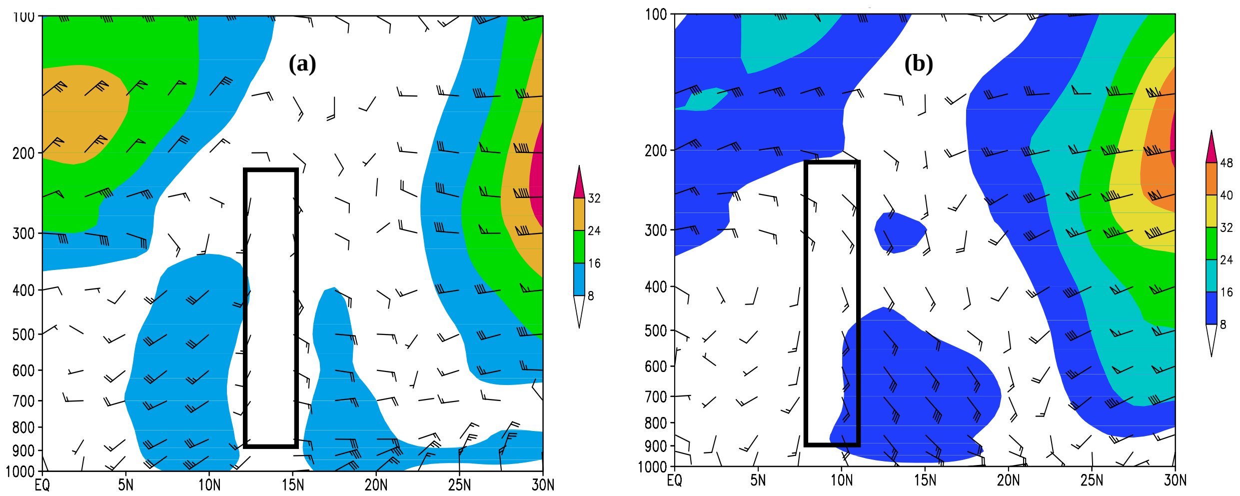

Fig. 5. Latitude-geopotential height cross sections of the horizontal field for April 27, 1999 (a) and April 15, 2008 (b); the shades are for the region of whole wind speeds being greater than 8 m/s; the black box is where the tropical cyclone is latitudinally located.

3.2 *Leo and Neoguri: evolutions from different synoptic systems*

As shown in the analysis above, these two April typhoons were generated in the background of La Niña episodes that had similar environment for them to grow. Examination of the evolution of their disturbance showed that Leo and Neoguri evolved from two different synoptic regimes. As shown in the evolution of 850-hPa wind fields and the associated satellite imagery (figure omitted), a southwesterly airflow was anomalously active in late April, 1999, as Leo grew from a monsoon depression. On the 850-hPa wind field prior to the formation of Leo on April 26 (Fig. 6a), the south of China and northern SCS were dominated by an easterly wind due to a cold high pressure, the central and southern SCS are prevalent with active southwest airflows, and convection developed vigorously in the monsoon trough in central SCS. With the southward advancement of cold air on April 27, a northeasterly wind north of the SCS intensified so that low-pressure convergence strengthened and a depression disturbance on the monsoon trough developed till it became the tropical depression Leo. It is a different story with Neoguri. This storm can be dated back to an easterly-wave cloud cluster that evolved slowly over the ocean east off the Philippines with weak convection and disorganized structure. With the westward propagation and development of the easterly wave and the intensification of convection, together with the convergence of a weak cross-equatorial flow in 115–120° E, the easterly wave eventually strengthened to become the tropical storm Neoguri over the southern waters of SCS (Fig. 6b).

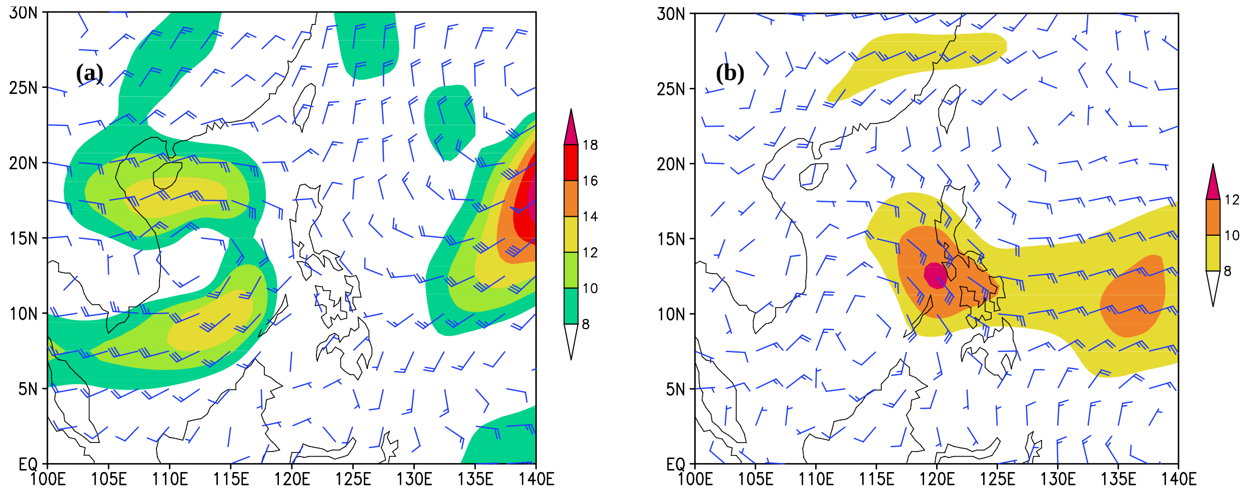

Fig. 6. 850-hPa horizontal wind field for April 27, 1999 (a) and April 15, 2008 (b); the shades are for the region with whole wind speeds greater than 8 m/s.

To further illustrate the impacts of a developed monsoon depression and an evolving easterly wave on the cyclogenesis of Leo and Neoguri, Fig. 7 gives the latitude-time cross sections of the 850-hPa wind field along 115° E. The southwesterly wind was already quite active over the southern SCS (south of 5° N) starting from April 15, 1999, with wind speeds at 4–8 m/s. From April 21, the southwesterly wind moved significantly northward in the southern SCS. By April 25, it had arrived at 12.5° N with wind speeds exceeding 8 m/s. With further intensification and northward progression of the southwesterly wind on April 26, and due to the strengthening of an easterly-to-northeasterly wind over the south of China and the SCS, the monsoon trough intensified. At 0000 Beijing Standard Time (BST) April 27, the tropical depression, Leo, was formed over the central SCS. By contrast, easterly airflows were already strong south of the subtropical high and the easterly wave was active in the early days of April, 2008. On April 11, the easterly wave advanced to the SCS through the Philippines while intensifying. With further eastward propagation and development of the easterly wave, the southeasterly component increased on April 14–15, and together with the entrainment and converging of a weak cross-equatorial airflow in 115–120° E, the easterly wave intensified into a tropical storm, Neoguri, at 0600 BST April 15.

4 ANALYSIS OF THE LEO AND NEOGURI TRACKS

4.1 *Recurving and changeable track of Leo*

Figure 8 gives the day-to-day evolution of the 5870 geopotential meter (gpm) contours in the life cycles of typhoons Leo and Neoguri, respectively. During the life cycle of Leo, the subtropical high pressure was unstable (Fig. 8a). From April 27–28, 1999, the subtropical high pressure was weak with its bulk more to the east and south while the continent of China was in the control of a cold high pressure. As a result, under the conditions of powerful northeasterly winds over the northern SCS, Tropical Depression Leo headed northwest-to-west (Fig. 6a). From April 28 onwards, the cold air moved eastward out to sea, resulting in the reduction of the northeasterly winds over the south of China and northern SCS. Due to the effect of an intensified and northward-advanced Southwest Monsoon, Leo turned to the northeast. With its rapid intensification to the category of typhoon on April 29–30, the subtropical high also strengthened and extended westward. Leo was then steered by its mid- and upper-level southwest-to-south airflow to travel towards the northeast-to-north. Having moved to the waters west off the Dongsha Islands, Leo rapidly weakened and began to be affected by the easterly airflow south of the low-level cold high. It mainly took a northwest direction and finally landed on Huidong County, Guangdong (Fig. 1).

4.2 *Airflow west of the subtropical high as the main steering current for Leo*

Relative to Leo that was changeable in track, Neoguri, during its life cycle, well dominated over the West Pacific through the eastern SCS, remained intense and had a stable westernmost point of the high-pressure ridge and ridgeline at 120° E and 17° N, respectively (Fig. 8). Steered by a deep airflow at the periphery of the subtropical high, Neoguri was moving along a stable track. During the early phase of the cyclogenesis, the storm was located southwest of the subtropical high and moved to the west as it was steered by the southeasterly flow of the subtropical high. On April 16, Neoguri intensified as it approached gradually toward a flow field of southerly wind west of the subtropical high with an increasing northerly component of its moving direction. On the afternoon of April 18, Neoguri made a recurvature to follow a northeast-to-east track, as it stepped into the northwest portion of the subtropical high and the southwesterly airflow in front of the westerly trough, until it weakened and dissipated inside Shixing County, Guangdong.

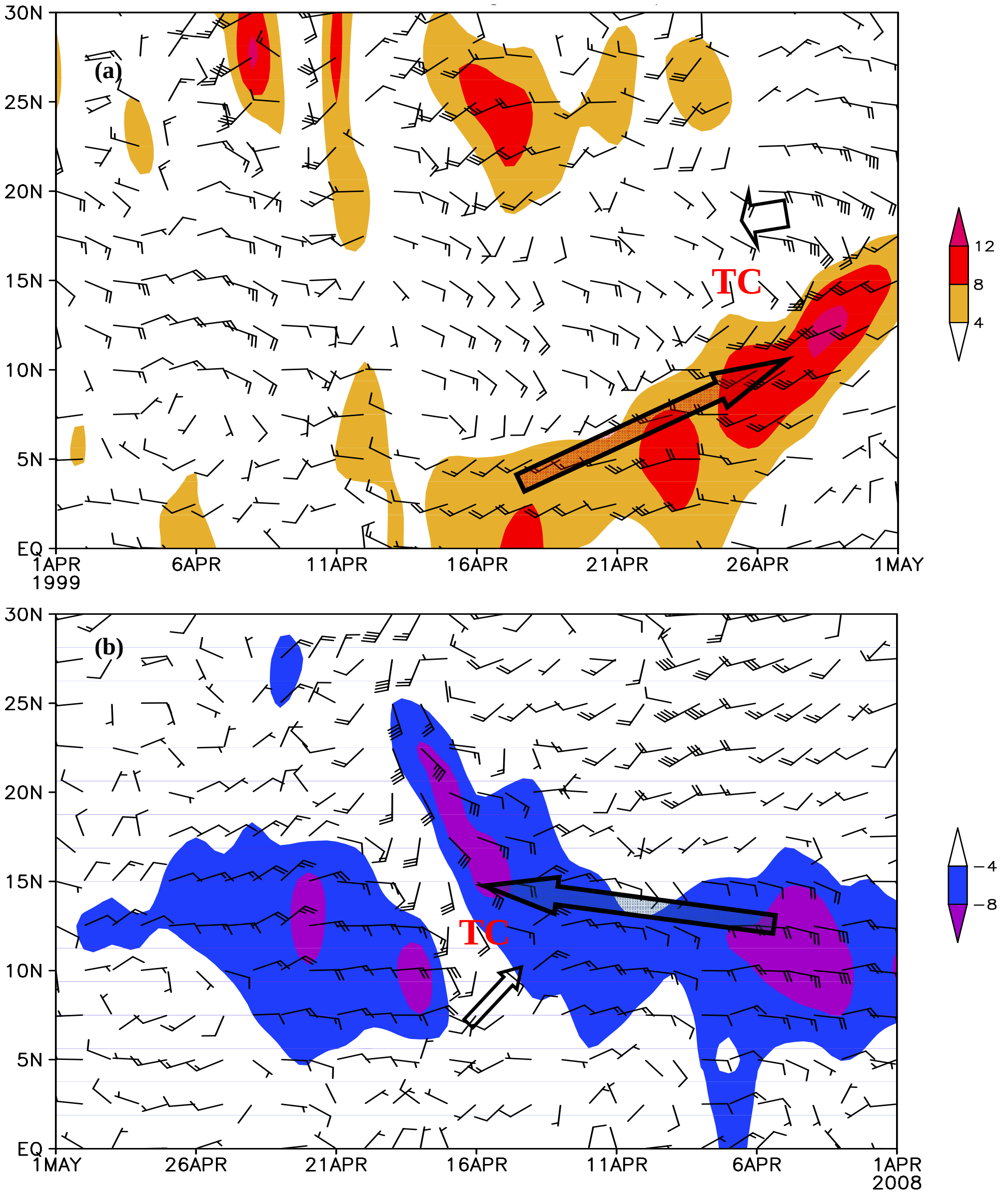

Fig. 7. Latitude-time cross sections of the 850-hPa wind field on 115° E for April 1999 (a) and April 2008 (b). a: Shades for areas where the westerlies >4 m/s; b: shades for areas where the easterlies >4 m/s; TC symbol: the point of time and latitude at which the TCs are formed.

The complicated and changeable tracks of tropical cyclones in SCS are evidenced in Leo. At the early stage of the life cycle, a northeasterly wind prevailed and the subtropical high pressure was weak due to the effect of a continental cold high pressure as Leo moved towards the northwest to west. At mid-term, the northeasterly wind weakened and the subtropical high extended westward and strengthened when Leo was also at its fullest intensity. Then, steered by the southerly airflow west of the mid- and higher-level subtropical high, Leo returned in a loop before heading north. Prior to landfall, Leo turned to be steered by airflows at the mid- and lower-level and took on a changeable route. By contrast, Neoguri followed a simpler path because of an intense and stable subtropical high pressure that dominated its movement (Fig. 8).

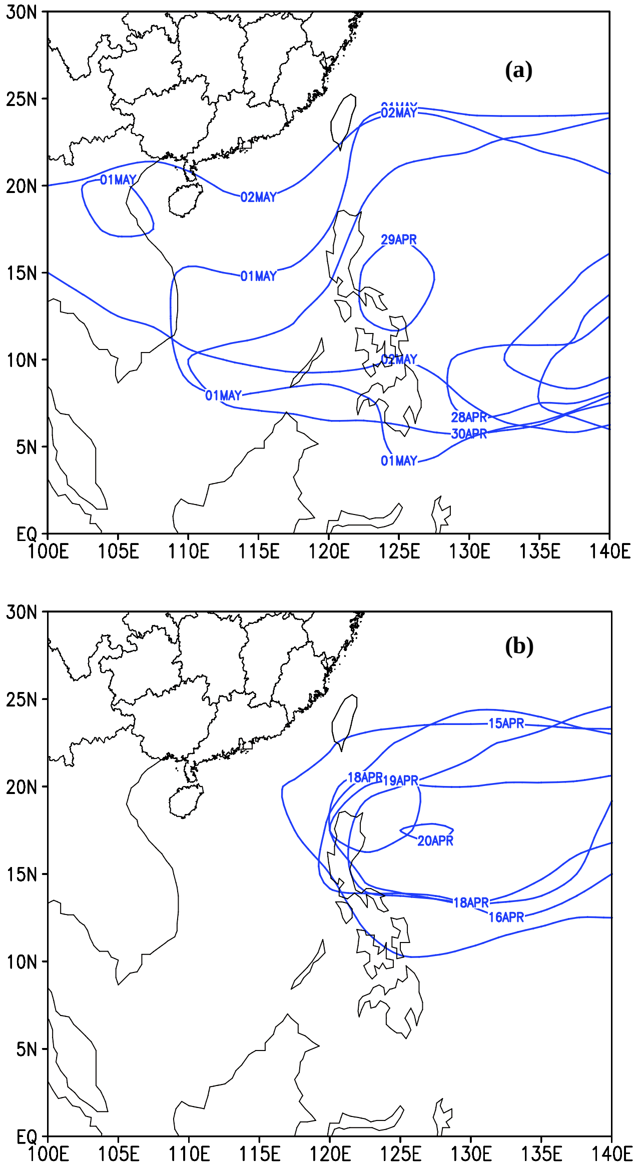

Fig. 8. 5870-gpm contours at 500 hPa for April 27–May 2, 1999 (a) and April 15–20, 2008 (b).

5 COMPARISONS OF THE PRECIPITATION BETWEEN LEO AND NEOGURI

By the time of landfall, both Leo and Neoguri had reduced to the category of tropical depression with compromised core structure, making them possess similar intensity at landfall. After landfall, they both moved into the westerly zone and followed a northeast track. The two storms were much alike with regard to the environmental flow field prior to and after landfall, such as the location and shape of the subtropical high, low-latitude troughs and ridges, and the wind field, but differ dramatically in the rainfall amount they brought about. Leo was associated with rainfall on the scale of heavy rain (with maximum cycle amount at 127.4 mm at Puning observation site) while Neoguri was associated with heavy-rain level of precipitation (with maximum cycle amount at 314.0 mm at Chaoyang observation site).

As Leo and Neoguri landed where heavy rain usually occurs, similarities exist in their topographic conditions of mountain ranges and amplifying effect of the underlying surface on typhoon-spawned heavy rain. Therefore, dynamic lifting and water vapour will be our focus of analysis.

5.1 *Comparison and analysis of vertical motion and convergence/divergence*

Figure 9 gives the altitude-time evolutions of regionally averaged vertical velocity and divergence. Substantial dynamic differences are found prior to and after the landfall of Leo and Neoguri. The two typhoons were examined in terms of the value and height of the centre of vertical velocity. For Leo, -0.15 Pa/s distributes in a range of 800–600 hPa with the centre value, -0.18 Pa/s, at the level of 700 hPa, and intense ascending motion occurs just one day before landfall. For Neoguri, -0.15 Pa/s spreads over a range of 900–400 hPa with the centre value, -0.21 Pa/s, appearing at the height of 650 hPa, and intense ascending motion maintains more than two days. Both Leo and Neoguri are marked with low-level convergence and upper-level divergence, though with the convergent layer of Leo extended to as high as 600 hPa while that of Neoguri only to 800 hPa. On the other hand, Neoguri, due to upper-level divergence, had a stronger sucking effect than Leo. The comparisons of dynamic conditions indicated that Neoguri is much more advantageous than Leo as far as the background for heavy precipitation is concerned.

5.2 *Comparison and analysis of water vapour*

Abundant water vapour is particularly important to the formation and persistent development of the severe precipitation brought about by tropical cyclones[3, 4]. Comparisons of water vapour flux fields at 850, 700, and 500 hPa showed that water vapour, around the point of landfall, is more favourable with Neoguri than with Leo, a result indicated by examining either the source or the amount of water vapour transport (Figure omitted). At landfall, Neoguri had two belts of water vapour transport, the southwest branch of airflow from the Bay of Bengal to the coastal southern China and a southerly airflow over the SCS, which formed a centre of water vapour flux over southern China. Its long axis runs WSW-ENE and peaks at 20 g/(cm hPa s) at the core, with the maximum at 700 hPa still at 12 g/(cm hPa s). With the slow advancement of the centre with Neoguri over to the eastern part of Guangdong, water vapour flux began to decrease on April 21. The case of Leo tells a different story. At landfall, the transport of water vapour was mainly northerly in the northwestern SCS and there was only a transporting band of southerly water vapour to the east of the SCS with the centre at eastern Guangdong and southern Fujian and a maximum of 12 g/(cm hPa s). Water vapour fluxes were not well-defined at 700 hPa, with the centre over southern Fujian through the Taiwan Strait and a maximum of 8 g/(cm hPa s). 24 hours after the landfall of Leo, the centre of 850-hPa water vapour was already out at sea.

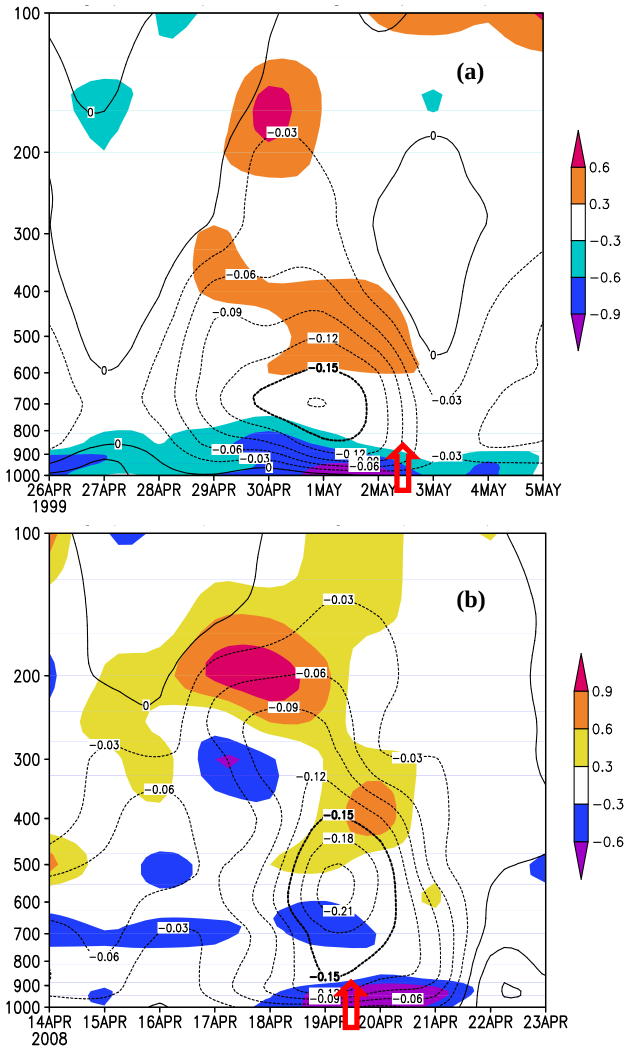

Fig. 9. Height-time evolutions of vertical velocity (Pa/s, contours) and divergence (10–16 s^{-1}, coloured shades) for April 26–May 5, 1999 (a) and April 14–23, 2008 (b). Range shown: 112.5–117.5° E, 22.5–25° N; red arrows indicate the time of landfall.

It is suggested from the analysis above that in spite of similar characteristics and allocations of the atmospheric circulation around landfall, the dynamics and water vapour transport conducive to severe precipitation during landfall are much better with Leo than with Neoguri, resulting in precipitation in the level of heavy rainfall with the former storm but in the level of unusually heavy rainfall with the latter.

6 CONCLUSIONS

Tropical cyclones in the SCS are characterized by unexpected genesis and development as well as complicated tracks. Their behaviour is especially hard to predict in spring when the general circulation experiences rapid changes. Through comparisons and analyses of the activity of Leo and Neoguri, two April typhoons in the past 60 years that ever made landfall in mainland China, this work has drawn the conclusions as follows:

(1) Both Leo and Neoguri happened against the background of strong La Niña events when intense convection, weak shear of horizontal winds and upper-level divergence took place in the SCS region, which were conducive to cyclogenesis in April. While Leo was formed out of a monsoon depression, Neoguri evolved from the easterly wave.

(2) As the subtropical high was relatively weak and changeable while the continental cold high was relatively intense, Leo followed a complicated and changeable track while Neoguri, due to a relatively stable circulation of the subtropical high, showed a stable northwestern route.

(3) Both Leo and Neoguri are similar in the intensity around landfall, circulation allocation and topographic effect but they differ much in the level of rainfall. The magnitude and persisting duration of the water vapour transport and dynamic lifting are playing distinctively essential roles.

It needs to be pointed out that this study is just a preliminary work. It is historically rare that typhoons make landfall as early as April. As a result, extensive analysis and diagnosis are needed to study conditions associated with forecasting, mechanisms for cyclogenesis, tracks and intense precipitation they cause.

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