Influence of the strongest central Pacific El Niño–Southern Oscillation events on the precipitation in eastern China

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The impact of the strongest central Pacific (CP) El Niño event 2009/2010 and CP La Niña event 1998/1999 from 1979 to 2010 on the precipitation in eastern China has been analysed. During the 2009/2010 CP El Niño event, it is rainy in northern China during maturing winter and decaying spring, but dry during decaying summer. The rainfall centre is located in south China during maturing period and gradually moves northwards, remaining over the Yellow-Huai River valley during decaying summer. When the 1998/1999 CP La Niña event occurs, northern China is in a state of drought throughout. In south China, dry periods gradually evolve into rainy ones from maturing winter to decaying summer. The two strongest events also have notable impact on the extreme rainfall, and they mainly affect the total rainfall by influencing the extreme precipitation in eastern China. When the 2009/2010 CP El Niño event occurs, the Western Pacific Subtropical High (WPSH) is stronger with a northwards shift, and there is an obvious anticyclonic circulation near the South China Sea and Philippines. Furthermore, during decaying summer, the Pacific–Japan (PJ) wave train shows an eastwards shift comparing to the typical PJ wave train locating from low latitudes to high latitudes, associating with clearly northwardly spreading wave activity fluxes (WAFs) from the equator. When the 1998/1999 CP La Niña event occurs, the WPSH is weaker and retreats eastwards, and there is a noticeable cyclonic circulation around the South China Sea. In decaying spring, the convective activity in the South China Sea is strong, and there are correspondingly significant WAFs spreading from southeastern Asia to north. In decaying summer, northern (southern) China is controlled by anomalous anticyclones (cyclones) with weak (strong) convection, and the WAFs extend northwards to the Yangtze and Huai River valleys.

KEYWORDS
eastern China precipitation, extreme rainfall, strongest central Pacific ENSO, wave action flux

INTRODUCTION

It is well known that El Niño–Southern Oscillation (ENSO), the most important mode of inter-annual variability of Pacific sea surface temperature (SST; Rasmusson and Carpenter, 1982; Trenberth, 1997), exerts significant impacts on China rainfall (Huang and Wu, 1989; Zhang et al., 1999; Xue and Liu, 2008; Wang and Chen, 2016; 2017; Chen et al., 2017a; 2017b). Normally, different ENSO phases yield various rainfall anomalies in China (Feng et al., 2016). During the developing phase of an El Niño events, there is a positive summer rainfall anomaly over the Yangtze and Huai...
River valleys and southern China, and a negative rainfall anomaly over northern China (Huang and Wu, 1989; Xue and Liu, 2008). During the mature period of an El Niño event, there is positive rainfall anomaly in southern China (Zhang et al., 1999; Wang et al., 2000). During the decaying stages of an El Niño phase, there is a weak rainfall belt in summer over the Yangtze and Huai River valleys and a positive rainfall anomaly in northern and southern China (Zhang et al., 1999; Feng and Li, 2011).

By using empirical orthogonal function (EOF) analysis of tropical Pacific Ocean SST from 1980 to 2010, Ashok et al. (2007) discovered that the second leading mode of tropical SST variability showed two cold centres over the eastern and western Pacific, and a warm centre over the central Pacific, referred to as El Niño Modoki. This also can be referred to as dateline El Niño (Larkin and Harrison, 2005), central Pacific El Niño (CP El Niño; Yu and Kao, 2007), or warm pool El Niño (Kug et al., 2009). The negative phase of CP El Niño, called CP La Niña, is characterized by two warm centres in the eastern and western Pacific, with a cold centre in the central Pacific. By now, there are many studies that focus on the difference between this new type of El Niño (hereafter also referred to as “CP El Niño”) and the canonical El Niño (referred to as “EP El Niño”) (Ren et al., 2016). It is shown that this difference is not only reflected by different SST modes but also by teleconnections and regional climatic effects (Ashok et al., 2007; Weng et al., 2007; 2009; Ashok and Yamagata, 2009; Feng and Li, 2011; 2013; Zhang et al., 2011; Karori et al., 2013; Zhang et al., 2015; Chen et al., 2018).

It has been demonstrated that two types of ENSO have the different effect on both the circulation and rainfall patterns in China. By using 160 station rainfall data, Weng et al. (2007) found that during the CP El Niño events, composite rainfall deficits exceed 30% in the lower reach of the Yangtze River valley and the far northern part of northeastern China. Feng and Li (2011) investigated the influence of the CP El Niño on spring rainfall in south China and found that the CP El Niño (EP El Niño) events are accompanied by a significant reduction (enhancement) in rainfall over south China. Zhang et al. (2011) pointed out that the anomalous atmospheric circulation over the western North Pacific (WNP) is nearly opposite in response to these two types of El Niño events in developing autumn, which aids in an increase in southern China autumn rainfall. Karori et al. (2013) demonstrated that the two types of ENSO have asymmetric features with respect to the impact of their positive and negative phases on boreal summer rainfall over the Yangtze River valley and south China. By using 35 meteorological stations in the Huai River basin, Zhang et al. (2016) found that the EP El Niño and CP El Niño cause distinctly different impacts on summer and autumn precipitation: a decrease of summer and autumn precipitation is observed during the CP El Niño periods while there is an increase during the EP El Niño periods.

The results discussed above are true in a statistical sense. There are strong inter-El Niño variations in the teleconnection (Cai and Cowan, 2009), indicating that whether an El Niño event is strong or weak may introduce some differences in the characteristics of its teleconnection patterns. Recently, the super El Niño has already received more and more attention (Chen et al., 2016), but few studies have studied the strong CP El Niño impacts. The influence of El Niño events on the climate over China varies, in that the effects of a strong El Niño event differ to those of moderate events in terms of the patterns of both circulation and rainfall anomalies (Xue and Liu, 2008; Feng et al., 2016). If a CP El Niño event is strong, other major factors such as the Arctic Oscillation that influences the rainfall of the countries in the northern Pacific rim may play more important roles than a weak CP El Niño does from the tropics (Weng et al., 2007). As a result, it is necessary to investigate the influence of the strongest CP El Niño (La Niña) event on rainfall in China, as well as on the extreme precipitation, compensating the lack of smoothness of previous statistical results for more useful information.

It is also shown from above studies that there is regional difference in the impact of CP ENSO on eastern China rainfall. Most studies of CP ENSO influence on China rainfall are based on 160-station monthly mean rainfall data (Weng et al., 2007; Feng and Li, 2011; Karori et al., 2013). Wu and Gao (2013) developed a grid data set of temperature and precipitation with a resolution of 0.25 × 0.25° for the China region from 2,416 station observations (CN05.1). For eastern China, where the rainfall variation is much more sensitive to SST anomalies, coverage of this data set is quite dense, with about 2000 stations in this region with the distance between adjacent stations ranging from several kilometres to over tens of kilometres (Zhou et al., 2016). As of now, CN05.1 has never been applied in the study of CP ENSO impact on rainfall in eastern China. Therefore, what is the influence of the strongest CP El Niño (La Niña) event on rainfall in China by using the high-resolution observation data? Furthermore, what is the possible mechanism of such influence? In this study, the influence of the strongest CP El Niño and La Niña event on the rainfall in eastern China and the mechanism will be investigated, which would be of great significance to produce better information of seasonal rainfall forecasts from typical phase of CP ENSO.

This rest of this manuscript is organized as follows: section 2 describes the data and methodologies. Section 3 presents spatial and temporal features of SST of the strongest CP El Niño and La Niña events. Section 4 outlines influence of the strongest CP El Niño and La Niña event on rainfall and extreme precipitation in eastern China. Section 5 discusses the possible mechanism of rainfall anomaly.
associated with the two events. The results are summarized and discussed in section 6.

2 | DATA AND METHODOLOGIES

2.1 | Data

The daily atmospheric variables used are from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP/NCAR) reanalysis (Kalnay et al., 1996) with a grid resolution of $2.5 \times 2.5^\circ$. The monthly mean outgoing longwave radiation (OLR) data are obtained from the National Oceanic and Atmospheric Administration (NOAA; Trenberth et al., 2001). Global monthly SST data are from the Improved Extended Reconstruction SST (IERSST; Smith and Reynolds, 2004) on a $2 \times 2^\circ$ grid.

Daily rainfall data used in this study, which are referred to as CN05.1, are provided by the National Meteorological Information Centre of the China Meteorological Administration on a $0.25 \times 0.25^\circ$ grid (Wu and Gao, 2013). This data set is the newest released rainfall data set available for the region and is built from observations recorded at 2,472 long-term stations (Wu and Gao, 2013). In eastern China, there are about 2,000 stations in this region, with the distance between adjacent stations ranging from several kilometres to over tens of kilometres. This does not imply that more accurate results must be achieved by a high-resolution data set. Rather, since CN05.1 is derived from denser stations and with higher resolution, it can highlight more detailed information about regional climate change and satisfy the purpose of high-resolution climate model validation (Wu et al., 2012; Wu and Gao, 2013; Zhou et al., 2016). From this aspect, studies on influence of CP ENSO on eastern China rainfall based on CN05.1 can provide more information to the classical system of theories of rainfall anomaly in China associated with SST anomaly in the tropical Pacific.

For the timescale, the period from 1979 to 2010 is chosen to allow the use of satellite data. Seasons in this paper are defined as follows: December–February (DJF) is boreal winter, March–May (MAM) is boreal spring, June–August (JJA) is boreal summer, and September–November (SON) is boreal fall. The study region is chosen as eastern China embracing mainland China east of 100°E.

2.2 | Methodology

Following Ashok et al. (2007), the strongest CP El Niño (La Niña) event can be quantified by the El Niño Modoki Index (EMI), which is defined as

$$EMI = [SSTA]_C - 0.5 \times [SSTA]_E - 0.5 \times [SSTA]_W,$$  \hspace{1cm} (1)

where the subscripted brackets represent the area mean sea surface temperature anomalies (SSTA) over the central Pacific region ([SSTA]$_C$: $10^\circ$S–$10^\circ$N, $165^\circ$E–$140^\circ$W), the eastern Pacific region ([SSTA]$_E$: $15^\circ$S–$5^\circ$N, $110^\circ$–$70^\circ$W), and the western Pacific region ([SSTA]$_W$: $10^\circ$S–$20^\circ$N, $125^\circ$–$145^\circ$E). Following study of Feng and Li (2013), a CP El Niño (La Niña) year is one in which the normalized EMI in winter (DJF) exceeds $+1$($-1$) standard deviation.

The criteria of extreme rainfall follow studies of Wang and Zhou (2005), which define extreme events as those that exceed a threshold percentile of daily precipitation. In our study, the extreme precipitation events are based on the 90th percentiles of daily rainfall.

3 | CHARACTERISTICS OF THE STRONGEST CP EL NIÑO AND LA NIÑA EVENTS

First, the annual and seasonal features of standardized EMI during 1979–2010 are analysed, as shown in Figure 1. It is seen that there is only one CP La Niña event (1988/1989) before 1989. However, during 1989–2010, there are four CP El Niño events (1990–1991, 1994–1995, 2004–2005, and 2009–2010) and three CP La Niña events (1998–1999, 2007–2008, and 2010–2011). It is indicated that CP ENSO activity has been increasing in frequency, especially since the 1980s, which has been observed by other studies as well (Ashok and Yamagata, 2009). In addition, the EMI values in 2009 and 1998 are the largest and smallest, respectively, showing that 2009 and 1998 are the strongest CP El Niño and La Niña years, respectively. Therefore, impact of the strongest CP ENSO events on the rainfall in eastern China will be investigated based on the two events hereafter in this paper.

The EMI in CP ENSO years also has typical seasonal variation (Figure 1b). EMI increases starting in June and remains greater than 1.0 from late summer to winter in CP El Niño years, which is different from the EP El Niño events featured by phase-locking with the seasonal cycle (Thompson and Battisti, 2000; Luo et al., 2005). The CP La Niña event also develops from summer to winter, with a negative peak in February. Both the EMI in 2009 and 1998 largely exceed the corresponding climatological value. Meanwhile, seasonal cycles of EMI in the strongest CP El Niño and La Niña are different from the general events. In the strongest CP El Niño year of 2009/2010, there are two positive EMI peaks with values of 1.76 and 1.80 in February, with a peak negative value of $-2.61$ in February 1999.

Figure 2 illustrates seasonal evolution of SST anomaly (SSTA) near the equator ($5^\circ$N–$5^\circ$S) during the strongest CP ENSO events based on the climatological-mean SST during 1979–2010 (Figure 2a,b) and SST composited by the same
type CP ENSO events (Figure 2c,d), respectively. During the strongest CP El Niño or La Niña year, the SSTA based on the climatological-mean is characterized as the tripole pattern (Weng et al., 2007) from the previous late summer to the next spring, with the peak SSTA centre located around 160°W. It is also observed that the tripole pattern in SSTA is not symmetrical, as SSTA east of 100°E is noticeably weaker than that west of 110°E.

Compared with SSTA composited by the same type CP ENSO events, SSTA in the strongest CP ENSO years (Figure 2c,d) also yields a tripole pattern, especially during the mature period. Specifically, SSTA of the 2009–2010 CP El Niño event that near the dateline are greater than the general CP El Niño events and persist from the fall of 2009 to the spring of 2010. Especially in the maturation of the 2009/2010 strongest CP El Niño event, the SSTA is 0.6 °C above that of general CP El Niño events, which is consistent with the annual variation characteristics of EMI in 2009 (Figure 1b) that the 2009–2010 CP El Niño event is substantially stronger than the general events in the mature period. Similarly, in the 1998–1999 strongest CP La Niña event, SSTA over the equatorial CP is obviously lower than that of the general CP La Niña events and persist from July 1998 to May 1999. Especially during the mature period, SSTA of the 1998–1999 strongest CP La Niña event is lower by approximately 0.8 °C compared to the general CP La Niña events. It is clearly shown that the CP El Niño in 2009–2010 and CP La Niña in 1998–1999 are both characterized as highly anomalous CP ENSO events with the greatest intensities ever recorded, demonstrating their large research value for their impact on weather and climate.

4 | INFLUENCE OF THE STRONGEST CP EL NIÑO AND LA NIÑA EVENTS ON RAINFALL IN EASTERN CHINA

As discussed above, the strongest CP El Niño and La Niña events develop in summer and autumn, mature in winter, and decay during the next spring and summer. Many existing studies focused on the simultaneous and lagging responses of the climate in China to the CP/EP ENSO phenomena (Feng et al., 2016). For better comparison with similar studies, the influence of the strongest CP El Niño and La Niña events on rainfall in eastern China will be investigated during different stages including the mature and decay periods in this section.

4.1 | Influence of the strongest CP ENSO events on total rainfall

First, the percentage of precipitation anomaly is illustrated in the strongest CP El Niño (2009/2010) and La Niña (1998/1999) events, as shown in Figure 3. During the mature period of the CP El Niño event in the winter of 2009, negative percentages of precipitation anomaly appear in southwest China, and positive anomalies are present in eastern China as well as the eastern region of China. The composite results of the general CP El Niño events (see in Weng et al., 2007) display remarkable differences from the 2009–2010 CP El Niño event in the maturation. The largest rainfall excess appears in the aforementioned
anomalously wet areas when the general CP El Niño events happen, but the precipitation anomaly percentage is approximately 80% smaller, and the arid areas of central China are very small in the general CP El Niño years. In the spring of 2010, the drought range of southwestern China shrinks southwards to Yunnan, Guangxi, and Guangdong provinces. The positive precipitation anomalies of eastern China are mainly located in the northeastern areas, eastern Inner Mongolia, and Yangtze-Huai River Valley, and the precipitation tends to be below normal in south China as the precipitation centres move northwards. This is consistent with the spatial distribution pattern of precipitation in the general CP El Niño years, but more intense. The spatial distribution features of the precipitation anomaly percentage pattern for the strongest CP El Niño event of 2009–2010 is similar to those in earlier studies with various degrees (Feng and Li, 2011). In the summer of 2010, this pattern is accompanied by negative rainfall anomalies over most of northern China and the areas to the south of the Yangtze River. On the other hand, the
precipitation centre also moves northwards from Yangtze-Huai River valley to the Yellow-Huai River valley and Bohai rim areas.

The asymmetric influence on winter rainfall in the area north of the Yangtze River between the 1998–1999 CP La Niña event and the climatological-mean are also apparent in the horizontal distribution of percentage of precipitation anomaly (Figure 3d). In the winter of 1998, negative anomalies of precipitation percentage are apparent in eastern China, with the centre above −80% over regions around the Great Bend of the Yellow River. In the spring of 1999, positive anomalies exist in regions north of the Yellow River and southern China. In the summer of 1999, negative and positive anomalies reside over regions north and south of the Yangtze River, respectively. In addition, there is also some difference between influence of the 1998–99 CP La Niña event and general CP La Niña events (figures not shown). During the maturing winter of the 1998–99 CP La Niña event, uniformly negative rainfall anomalies are shown over most parts of eastern China, whereas a slightly larger amount of precipitation is found in the region north of the Yangtze River. An apparent rainfall deficit is observed in south China for the general CP La Niña events (figures not shown). In the spring of 1999, northeastern and southern China continue to be dry, while precipitation is concentrated in the Yellow-Huai and Yangtze River basins. In addition, positive precipitation anomalies are also presented in southwestern regions, including the provinces of Yunnan, Guangxi, etc. The largest contrast of the rainfall anomalies between the 2009–2010 CP El Niño and the 1998–1999 CP La Niña events in spring is found in northeast China and southwestern regions. Furthermore, the general CP El Niño and CP La Niña events are associated with the opposite rainfall anomalies in eastern China (figures not shown). In the summer of 1999, northeastern China and eastern Inner Mongolia continue to maintain drought, and the Yellow-Huai River valley also changes from rainy to dry, as the precipitation centre moves to the middle and lower reaches of the Yangtze River. This is similar to the effect of the general CP La Niña events on the spatial distribution of precipitation in eastern China, but the impact intensity of the strongest CP La Niña event is markedly enhanced. Moreover, the differences in rainfall anomaly associated with 2009–2010 CP El Niño and 1998–1999 CP La Niña events during the decaying summer are the most obvious in the Yellow-Huai River valley and south of the Yangtze River, similar to situations in the general events.
In recent years, extreme rainfall happens frequently and brings serious impact. In this paper, we use the threshold of 90% to screen out the extreme precipitation events in each season, and then calculate the proportion of rainfall which is produced by the extreme precipitation to the total rainfall. Table 1 illustrates the proportion of the extreme precipitation in total precipitation in eastern China from 1979 to 2010.

The results show that during the winter in eastern China, the rainfall that is caused by extreme precipitation events account for 72.1% of the total rainfall. The proportion in the areas to the north of the Yangtze River is especially large, as it can account for 73.9% of the total rainfall. During the spring in eastern China, the proportion of extreme precipitation rainfall to the total rainfall is slightly lower than that in winter, but it can still account for 67%, especially in the northern part of the Yangtze River which accounts for 72.5%. During the summer in eastern China, the proportion of extreme precipitation rainfall to the total rainfall is the lowest at 52.9%, and 54.8% for the northern part of the Yangtze River.

In this section, the effects of the 2009–2010 CP El Niño and 1998–1999 CP La Niña events on the frequency of extreme precipitation are discussed in eastern China. Figure 4 shows the extreme precipitation frequency anomalies of the strongest CP El Niño event 2009–2010 and the strongest CP La Niña event 1998–1999 based on the climatological-mean extreme precipitation frequency during 1979–2010. It is shown that the spatial distribution characteristics of the frequency of extreme precipitation are consistent with those of the percentage of precipitation anomaly shown in Figure 3. Further, we illustrate the frequency anomaly of normal precipitation (total precipitation eliminated by the extreme rainfall) during the 2009–2010 CP El Niño and 1998–1999 CP La Niña events in eastern China (figure not shown), and the result shows that the character of proportion of normal precipitation is totally different from that of total precipitation and extreme precipitation.

### Table 1

|                | DJF | MAM | JJA |
|----------------|-----|-----|-----|
| Eastern China  | 72.1| 67.0| 52.9|
| North of the Yangtze River | 73.9| 72.5| 54.8|
| South of the Yangtze River  | 70.3| 61.5| 51.0|

### Figure 4

The extreme precipitation frequency anomalies of the strongest CP El Niño event 2009/2010 and the strongest CP La Niña event 1998–1999 based on the climatological-mean extreme precipitation frequency during 1979–2010. (a–c) represent the maturing winter, decaying spring and summer of the 2009–2010 CP El Niño event, respectively; (d–f) same as (a–c), but for the 1998/1999 CP La Niña event, unit: days [Colour figure can be viewed at wileyonlinelibrary.com]
From the above results, it can be known that the rainfall produced by extreme precipitation events accounts for most of the total in various season of eastern China. Since this paper also makes a composite analysis of the impact of the general CP/EP El Niño and CP/EP La Niña events on both extreme precipitation and normal precipitation after removing extreme rainfall in eastern China, it is found that the impacts on the extreme precipitation are more pronounced than that of normal precipitation (figures not shown), similar to the situations in the 2009–2010 CP El Niño and 1998–1999 CP La Niña events. Therefore, the 2009–2010 CP El Niño and 1998–1999 CP La Niña events mainly affect the total rainfall in eastern China by influencing the extreme precipitation. It is indicated that the CP ENSO event is an important factor in impacting the extreme rainfall in eastern China. Considering the complex mechanism of extreme rainfall, this paper mainly discusses the impact of the 2009–2010 CP El Niño and 1998–1999 strongest CP La Niña events on the total precipitation in China, the following analysis will mainly focus on the mechanism of the two strongest events affecting the precipitation in China. The reason for the dramatic change of the extreme rainfall in China in the two strongest episodes will be explained in a separate paper.

5 | THE MECHANISM OF THE STRONGEST CP ENSO EVENTS AFFECTING THE PRECIPITATION IN EASTERN CHINA

The involved mechanism of the 2009/2010 strongest CP El Niño and the 1998/1999 strongest CP La Niña events on precipitation in eastern China will be analysed from the aspects of water vapour transport, wind field, geopotential height field, OLR, and wave active flux (WAF).

Since water vapour transport is very important to the precipitation anomalies, we have computed the vertically integrated moisture flux and their divergence anomalies for the 2009–2010 CP El Niño and the 1998–1999 CP La Niña events. Figure 5 shows the distribution of moisture flux and moisture flux divergence during the maturing and decaying period for the CP El Niño and CP La Niña, it is seen that for both CP El Niño and CP La Niña events, the large value areas of the moisture fluxes and their divergence in winter are concentrated at low latitudes. During the maturing winter of the 2009–2010 strongest CP El Niño event (Figure 5a), abundant moisture is transported by the southwesternly from the South China Sea to south China, and an obvious moisture flux convergence is formed to the south of the Yangtze River. From the wind field and stream function anomalies at 850 hPa (Figure 6a), the unusual strong anticyclonic rotational flow, accompanied by the more intense Western Pacific Subtropical High (WPSH), occurs over the South China Sea, which strengthens the moist transport from lower latitudes to south China. On the other hand, the negative stream function anomalies cover most of eastern China, indicating cyclonic rotation flow is intensified. This allows moisture to be transported to most parts of northern China, resulting in very large amounts of precipitation in most parts of China in the winter. During the maturing winter of the 1998–1999 CP La Niña event, from the Indo-China Peninsula eastwards to the northwest Pacific, there is an obvious banded moisture flux convergence zone. However, the moisture flux is divergent in south China, and is transported southwards from south China. This scenario is verified by the apparent cyclonic circulation over the South China Sea and weakened WPSH (Figure 6d). Furthermore, from the anomalous positive distribution of OLR in most areas of eastern China (Figure 7), it is known that the convection activity is suppressed in these areas, so the rainfall in most parts of eastern China is substantively less during the winter of the CP La Niña year.

During the decaying spring of the 2009–2010 strongest CP El Niño event, the position of the moisture transport belt in south China is north of that in the maturing winter, and the WPSH is stronger than that during the general CP El Niño events. According to the result in Feng and Li (2011), the anticyclonic circulation in the western Pacific controls south China, accompanying with a northwards shift of the WPSH, reducing the amount of moisture delivered to south China. This point is consistent with the result shown here. However, during the decaying spring of the 1998–1999 CP La Niña event, the WPSH is weak, and the circulation pattern is roughly opposite to CP El Niño. In the decaying summer, for both CP El Niño and CP La Niña events, the abnormal moisture flux and its divergence anomaly have noticeable variation in characteristics in low latitudes and in the mid-high latitudes. During the decaying summer of CP El Niño, there is a moisture flux convergence zone near the East China Sea. The moisture flux in central and eastern China is generally transported northwestwards from the middle and lower reaches of the Yangtze River to northern China. There also is a moisture convergence zone which is oriented NW-SE between the Yellow River and the Yangtze River. From the 850 hPa wind and stream function anomalies feature (Figure 6c), it is seen that there are anomalous anticyclonic circulations in south China and eastern Japan, respectively. Furthermore, the WPSH extends northwards far into the inland region, dominating most regions of south China. This circulation situation facilitates the transport of moisture from the western Pacific to the more northern part of eastern China. This can also be confirmed from Figure 4c in which the precipitation anomalies in Yellow-Huai River valley are indeed much higher, consistent with that shown in Feng et al. (2011). During the decaying summer of CP La Niña, one of the most striking features is the apparent amount of moisture fluxes advecting north from the northwest Pacific. After reaching approximately 40°N, the moisture is transported westwards to north China, whose
transport path is roughly a cyclonic circulation feature. Furthermore, the large regions in south China are moisture convergence areas, and the areas from north China to northeast China are relatively obvious areas for moisture divergence. In addition, the negative stream function anomalies at 850 hPa are located in south China, indicating cyclonic flow. The cyclonic flow transports moisture from the northwest Pacific to the south of the Yangtze River. However, there is an obvious anticyclonic circulation in north and northeast China. This scenario is verified by the anomalous distribution of OLR (Figure 7f), since the convective activity over south China is strengthened, but that in the north China is weakened during the summer of CP La Niña. Those can explain the distribution characteristics of low precipitation in north China and northeastern China and high precipitation in the south of Yangtze River.

The responses of the atmospheric circulation to the 2009–2010 strongest CP El Niño and 1998–1999 strongest CP La Niña event [Colour figure can be viewed at wileyonlinelibrary.com]
CP La Niña events have been analysed from the perspective of WAF, which can be used to diagnose the magnitude and propagation direction of the wave energy (Takaya and Nakamura, 2001). During the maturing winter of the 2009–2010 strongest CP El Niño event, OLR is strong near the Philippines in low latitudes, indicating that the convective activity is weak there. At this time, the WAF near the Philippines is not apparent. It is seen that there is a good correspondence between the OLR anomaly and the magnitude of WAF, especially in the middle and lower latitudes (Figure 7 vs. Figure 8). Wherever OLR anomalies are negative, WAF at 850 and 500 hPa are generally stronger. Whereas OLR
anomalies are positive, WAF is not evident. This may be due to the strong convection stimulating stationary waves. During the maturing winter of the 1998/1999 CP La Niña event, contrary to CP El Niño, the OLR in South China Sea and much of Southeast Asia is negative, which means the convective activity there is intense. Meanwhile, the WAF travels northwards from the Indo-China Peninsula to China Yunnan, etc. regions. During the decaying spring of CP El Niño, the OLR near the South China Sea and Philippines is still strong, while it is weak in north China and Mongolia (Figure 7b), and the corresponding WAF is not obvious (Figure 8b). During the decaying spring of CP La Niña, the convective activity in the vicinity of the South China Sea has expanded and increased in comparison with that in winter. Correspondingly, the WAF that spreads from Southeast Asia to the north is also more pronounced. In addition, there is a good relationship between OLR and moisture flux divergence. For instance, in the winter of CP La Niña, the

![Figure 7](https://example.com/figure7.png)

**FIGURE 7** The OLR anomalies of the strongest CP El Niño event 2009/2010 and the strongest CP La Niña event 1998/1999 based on the climatological-mean OLR during 1979–2010. (a–c) represent the maturing winter, decaying spring and summer of the 2009–2010 CP El Niño event, respectively; (d–f) same as (a–c) but for the 1998–1999 CP La Niña event), unit: W/m² [Colour figure can be viewed at wileyonlinelibrary.com]
convective activity in Southeast Asia is strong, which intensifies the moisture convergence there, forming a distinct moisture convergence zone.

During the decaying summer of the 2009–2010 CP El Niño event, completely different from winter and spring, the OLR anomalies in the South China Sea and Philippines have changed from positive to negative. Correspondingly, the WAF there is also obviously stronger, and spreads northwards from the equator, that is, to south China and to the northwestern Pacific. It is noteworthy that there is a
significant positive geopotential height anomaly centre the east of Japan around 160°E, and both the eastern and western sides of the centre have WAFs that propagate northeastwards. Furthermore, there are negative geopotential height anomalies in both the low-latitude and mid-high latitude areas which exist on the southern and northern sides of the positive anomaly centre, respectively. This is similar to the Pacific–Japan (PJ) wave train (Nitta, 1987) from the view of the overall characteristics of WAF and geopotential height anomalies, although the geopotential height negative anomalies are less pronounced. Compared to the typical PJ wave train, this PJ wave train is further east which leads to the weaker influence of the geopotential height field and wind field anomalies on the precipitation in the central and eastern parts of China, especially the areas south of Yangtze River. Therefore, in the summer of CP El Niño, the precipitation anomalies in the regions south of Yangtze River are not very obvious. However, due to the impact of the abnormal high pressure to the east of Japan, precipitation is obviously higher in parts of northern and northeastern China. During the decaying summer of the 1998/1999 CP La Niña event, the convective activity near the Philippines is weakened (Figure 7f), compared to that in the winter and spring. Therefore, the corresponding geopotential height and WAF are not as significant as those of CP El Niño. However, there are “−, +, −” anomalous geopotential height centres over south China, east of Japan around 150°E and near the Bering Sea, respectively. Namely, there is a PJ wave train existing in those places, along with the WAF spreading northwards.

6 DISCUSSIONS AND CONCLUSIONS

Using the precipitation data which is referred as CN05.1 and NCEP/NCAR reanalysis data, the impact of CP El Niño event 2009–2010 and CP La Niña event 1998–1999 on the precipitation in eastern China is studied. First, through the analysis of the inter-annual variation of the winter EMI index, the CP El Niño in 2009–2010 and CP La Niña in 1998/1999 are found to be the strongest two incidents during 1979–2010 period. Then, the evolution characteristics of the SST structure over the equatorial Pacific region during the two events are analysed. The results show that both events reach their peak in winter, and the maximum anomalies of SST in the central equatorial Pacific exceed 1.6 and −1.6 °C, respectively. Furthermore, the SST anomalies exhibit typical tripolar characteristics in the zonal direction. In addition, when the strongest CP El Niño event 2009–2010 reaches its peak in the winter, the SST in the central equatorial Pacific is approximately 0.6 °C higher than that of the general CP El Niño events. In the peak of the 1998–1999 strongest CP La Niña event, the SST in the central equatorial Pacific is approximately 0.6 °C lower than that of the general CP La Niña events, showing a greater amplitude of the SST anomalies.

After understanding the evolution characteristics of the SST in the 2009–2010 CP El Niño and 1998–1999 CP La Niña events, we then analyse the effects of the two events on the precipitation in the eastern China. The results show that, when the 2009–2010 CP El Niño event occurs, it is rainy in northern China during the maturing winter and decaying spring, but dry during the decaying summer. Meanwhile, in the areas south of the Yangtze River the precipitation centre is located over south China during the maturing period and gradually moves northwards. The precipitation centre has been located in the Yellow-Huai River valley during the decaying summer. When 1998–1999 CP La Niña event occurs, northern China is always in a state of drought. However, in southern China the weather gradually evolves into rainy periods with little rainfall during the mature period. During the decaying summer, it produces a dipole structure of drought in the north of Yangtze River and wet in south. The 2009–2010 CP El Niño and 1998–1999 CP La Niña events also have an impact on the extreme rainfall in eastern China. When the two events occur, the spatial distribution characteristics of the extreme precipitation frequency anomalies over eastern China are similar to that of the total precipitation anomalies in the region. Furthermore, in the precipitation of various seasons over eastern China, rainfall from extreme precipitation accounts for more than half of the total rainfall, especially over the area north of the Yangtze River during winter, which can account for 74%. Also, the 2009–2010 strongest CP El Niño and 1998–1999 strongest CP La Niña events mainly affect the total rainfall in eastern China by influencing the extreme precipitation.

Various weather systems play an important role in the effects of the CP El Niño and CP La Niña events on precipitation in China. When the CP El Niño event occurs, the WPSH is stronger, its ridge line moves northwards, and there is an obvious anticyclone circulation near the South China Sea and Philippines. During the maturing winter of CP El Niño, southern China is on the northwest side of the WPSH with moisture being transported from the South China Sea to south China, and the moisture convergence in south China is obvious, which leads to an increase of precipitation in south China. In the decaying period, the WPSH moves northwards, especially in the decaying summer the WPSH dominates over south China, and there is evident moisture divergence in south China. While the moisture is convergent in the Yellow-Huai River valley, and the Yellow-Huai River areas are on the northwest side of the WPSH that facilitates the transport of moisture from northwestern Pacific to the Yellow-Huai River areas. In addition, a PJ wave train exists from low latitudes to high latitudes, but it is more easterly than the typical PJ wave trains, and there are clearly northwardly spreading WAFs from the equator. When the CP La Niña event occurs, the WPSH is weaker and retreats eastwards, and there is a clear cyclonic circulation near the South China Sea. During the maturing
winter of CP La Niña, there is obvious moisture divergence in south China, and there is a moisture convergence zone from the Indo-China peninsula to the northwestern Pacific. This circulation situation causes less precipitation in south China. In spring, the convective activity in the South China Sea is stronger than that in the winter, and the WAF spreading from the southeastern Asia to the north is also more pronounced. In summer, northern China is controlled by anomalous anti-cyclones, while southern regions are affected by cyclonic circulation. In addition, from the distribution characteristics of OLR, it can also be seen that the convection activity is suppressed in northern China, while it is strong in the southern region. At the same time, the moisture is divergent in northern China but convergent in the southern region, which leads to less precipitation in northern China and more precipitation in southern areas.

Precipitation in eastern China is influenced by many factors such as snow cover in the Tibetan Plateau (Ding et al., 2009), Pacific Decadal Oscillation (PDO; Chang et al., 2000), Arctic Oscillation (AO; Ju et al., 2005), climate effects of sulphate and black carbon aerosols (Ramanathan et al., 2001), and so on. From aspect of influence of SST anomaly in the tropical Pacific, this paper analyses the influence of the strongest CP El Niño and La Niña events on rainfall in eastern China during 1979–2010. The possible mechanism is also discussed. The analysis in this study shows that the influence of the strongest CP ENSO events as well as the teleconnection patterns on rainfall in eastern China is not only different from the canonical EP ENSO, but also different from influence of the general CP ENSO events. Such studies will help to get better understanding for ENSO itself and its climate impacts. In further study, the impact of such typical ENSO events on extreme climate events should be investigated. Moreover, as the relationship between the ENSO and reginal rainfall is also modulated by other factors such as Interdecadal Pacific Oscillation (IPO; Feng et al., 2016), it is also needed to study deep physical mechanism of the influence of ENSO.

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