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# Contrasting Impacts of Developing Phases of Two Types of El Niño on Southern China Rainfall

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## Abstract

The potential influence of the developing phases of the two types of El Niño (i.e., EP El Niño and CP El Niño) on rainfall over southern China was investigated using observational data sets from 1979 to 2008. The developing phases of the CP El Niño events are associated with enhanced rainfall over southern China during summer, whereas the influence is not significant in autumn. During the developing phases of the EP El Niño events, rainfall significantly increases over southern China during autumn but no significant increases are observed in summer. These increases in rainfall are a result of the circulation anomalies associated with the two types of El Niño events. The western Pacific subtropical high (WPSH) shifts northeastward during developing phases of the CP El Niño events in summer and is accompanied by enhanced convection and ascending flow. The WPSH shifts westward during the developing phases of the EP El Niño events in autumn and is associated with anomalous southwesterlies over southern China. These circulation anomalies favor more rainfall in southern China. No significant circulation anomalies occur during the developing phases of the CP El Niño events in autumn or the EP El Niño events in summer. These results highlight the importance of considering their developing phases when investigating effects of these two types of El Niño events on climate.

**Keywords** EP El Niño; CP El Niño; rainfall; southern China

## 1. Introduction

The El Niño–Southern Oscillation (ENSO) plays a significant role in weather and climate around the world. This phenomenon develops in the Pacific and generates significant anomalies in regional and global climates (e.g., Harrison and Larkin 1998; Trenberth and Caron 2000). Effects of ENSO on Chinese rain-

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fall have been widely investigated, and findings show that different ENSO phases produce varying rainfall anomalies over China. For example, during the decaying stages of the El Niño events, the convection activities around the South China Sea will be strong. As a consequence, the summer rainfall belt is weak and is not easily maintained over the Yangtze and Huai-He River valleys, and positive rainfall anomalies occur over northern and southern China (e.g., Huang and Wu 1989; Zhang et al. 1999; Feng and Hu 2004). During the developing phases of the El Niño events, there are positive summer rainfall anomalies over the Yangtze and Huai-He River valleys and southern China, and negative rainfall anomalies over northern China (Xue and Liu 2007). This relation is statistically demonstrated. An exception to this was the summer rainfall in 1992, which was below average across the Yangtze and Huai-he River valleys. A plausible explanation is that the maximum sea surface temperature anomalies (SSTA) during the winter of 1991 were located over the International Dateline instead of in the eastern equatorial Pacific.

Recently, a new variant of the El Niño phenomenon has been identified, characterized by warm SSTA in the central Pacific. This phenomenon corresponds to the second mode of the empirical orthogonal function (EOF) analysis performed using tropical Pacific Ocean SSTA in the period since the 1970s. This mode is referred to as the El Niño Modoki (Ashok et al. 2007), dateline El Niño (Larkin and Harrison 2005), central Pacific El Niño (Yu and Kao 2007; Kao and Yu 2009), or warm pool El Niño (Kug et al. 2009). The spatial patterns, dynamics, and evolution of this new type of El Niño (hereafter referred to as "CP El Niño") and the canonical El Niño (referred to as "EP El Niño") have been extensively discussed (e.g., Ashok et al. 2007; Yu and Kao 2007; Kug et al. 2009; Yu et al. 2010). Also, new Niño indices have been devised to identify the two types of ENSO events (Ren and Jin 2011). It is found that the intensity of Bjerknes feedback and the recharge–discharge processes are different for the different El Niño types (Jin 1997a, b; Clarke et al. 2007; Ren and Jin 2013).

Several studies have found that this new type of El Niño has important teleconnections and regional climatic effects that differ from those associated with EP El Niño (e.g., Weng et al. 2007, 2009; Feng and Li 2011, 2013; Zhang et al. 2011; Karori et al. 2013; Xie et al. 2012, 2014; Zhang et al. 2015). It has been shown, for example, that CP El Niño has a profound impact on the circulation and rainfall over China. Studies reported that simultaneously in spring and autumn, due to different Rossby wave responses, the western Pacific subtropical high (WPSH) shifts further northwest during the CP El Niño events and is associated with northeasterlies and reduced rainfall over southern China in the boreal spring (Feng and Li 2011) and autumn (Zhang et al. 2011). However, the WPSH shifts southeastward during the EP El Niño events, resulting in increased rainfall over southern China. The WPSH would shift northward in the boreal summer during the CP El Niño events (Weng et al. 2007; Karori et al. 2013), resulting in anomalous cyclones over the South China Sea and above-average rainfall. In the boreal winter, anticyclones associated with the East Asian winter monsoon move northwest during the CP El Niño events, causing negative rainfall anomalies in southern China (Weng et al. 2009). The two types of El Niños also have different effects on both the circulation and rainfall patterns in China during their decaying phases (Feng et al. 2011).

The results discussed above demonstrate that the simultaneous and lagging responses of the climate in China to the two types of El Niño have been extensively studied. However, effects of CP El Niño on climate during its developing phase have not attracted much attention. Meanwhile, the effects of the EP El Niño events on the rainfall in China during their developing and decaying phases differ (e.g., Huang and Wu 1989; Xue and Liu, 2007); therefore, it is important to determine effects of the CP El Niño events on rainfall. If such an influence exists, it would be important to consider the difference in influences on the rainfall of the CP and EP El Niño events. This would be meaningful in both scientific and practical terms for producing better seasonal rainfall forecasts, which would mitigate the losses from flooding or drought during summer and autumn (Huang et al. 2006).

The remainder of this manuscript is organized as follows. Section 2 describes the data sets and methods used in this study, and Section 3 outlines the rainfall anomalies associated with the developing phases of the two types of El Niño. Section 4 discusses possible mechanisms responsible for the rainfall anomalies associated with the two types of El Niño. Finally, a summary and discussion are provided in Section 5.

## 2. Data sets and methods

Rainfall data used in this study were provided by the National Meteorological Information Centre of the China Meteorological Administration on a $0.5° \times 0.5°$ grid. This data set is the newest released rainfall data set available for the region and is built from observations recorded at 2472 long-term stations (Shen et al. 2010). The atmospheric variables used are from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP/NCAR) reanalysis (Kalnay et al. 1996). The monthly mean outgoing long-wave radiation data are from the National Oceanic and Atmospheric Administration (NOAA, Trenberth et al. 2002). Global SST data are from the Improved Extended Reconstruction SST (IERSST, Smith and Reynolds 2004) on a 2° × 2° grid.

In this study, we focused on the period from 1979 to 2008 for the following reasons: (1) Reanalysis data sets are more reliable after 1979 (Kistler et al. 2001; Trenberth et al. 2001). (2) CP El Niño has mainly occurred since the late 1970s (Ashok et al. 2007). (3) This period parallels the positive phase of the Interdecadal Pacific Oscillation (IPO, e.g., Mantua et al. 1997; Zhang et al. 1997), which strengthened linkage between the ENSO and East Asian circulation reported in this period (Ding et al. 2010). Thus, the modulation of IPO could be avoided during this period.

The CP El Niño events are identified using the El Niño Modoki index, according to Ashok et al. (2007), and the EP El Niño events are identified using the Niño3 index. Maximum SSTA values are used to distinguish the two types of El Niño events, and only those warm events that persist for at least 6 months are taken into account. Therefore, there have been three major CP El Niño events (1994/95, 2002/03, and 2004/05) and three major EP El Niño events (1982/83, 1987/88, and 1997/98). The developing phases of the summer (June–July–August) and autumn (September–October–November) events are the primary focus of the analysis. The composite analysis is employed to detect the relative anomalies associated with the two types of El Niño events. The statistical significance of values of the composite are accessed by means of a two-sided Student's *t*-test.

## 3. Rainfall anomalies associated with developing phases of CP and EP El Niño events

Figure 1 shows the summer and autumn rainfall distributions and their standard deviation over China. Southern China experiences high rainfall during the summer and autumn months (Figs. 1a, b), which is highly variable compared with that in other regions (Figs. 1c, d). In this context, we focus on the rainfall over southern China. The anomalous rainfall patterns associated with the two types of El Niño events are shown in Fig. 2. In the developing phases of the summer CP El Niño events, the rainfall anomalies in eastern China have a positive–negative–positive sandwich structure, corresponding to a strong East Asian summer monsoon (EASM)-like pattern (Zhang et al. 2003; Wu et al. 2009). Significant positive rainfall anomalies are observed to the south of the Yangtze River, reaching up to ~30 % of the climatological mean. This suggests that the developing phase of CP El Niño in summer may significantly increase the rainfall in southern China (Fig. 2a).

In the developing phases of the summer EP El Niño events in eastern China, there is a general trend toward increased flooding in the south and drought in the north over the eastern China, which is dissimilar to the anomalous patterns associated with the CP El Niño events. Moreover, although there is enhanced rainfall in southern China, the signals are insignificant (Fig. 2b). This result indicates that the developing phases of EP El Niño events have a limited effect on summer rainfall in southern China.

These effects differ from effects of the decaying phases of the El Niño events because positive–negative rainfall anomalies are seen over southern China during the decaying phases of the summer EP/CP El Niño events (Feng et al. 2011). Furthermore, the anomalous rainfall patterns observed during the developing phases of both CP and EP El Niño events differ from those reported by Weng et al. (2007). That study found that the EP El Niño events result in significantly enhanced rainfall over southern China, and the CP El Niño events are associated with significantly reduced rainfall in the middle reaches of the Yangtze River valley.

There is no significant signal associated with the developing CP El Niño events in autumn (Fig. 2c). However, there is a classical trend toward flooding in the south and drought in the north during the EP El Niño events (Fig. 2d). The amplitudes of rainfall anomalies are > 30 % of the climatological mean and larger than those associated with the summer CP El Niño events. This is because the summer SSTA associated with the EP El Niño events are larger in magnitude and spatial extent than those associated with the CP El Niño events (Fig. 3). These rainfall anomalies, and especially the lack of significant rainfall anomalies accompanying the CP El Niño events, differ from those described by Zhang et al. (2011). The difference between the results of this study and those described by Weng et al. (2007) and Zhang et al. (2011) are mainly attributed to the fact that those previous studies included both the developing and decaying phases of events in summer and autumn.

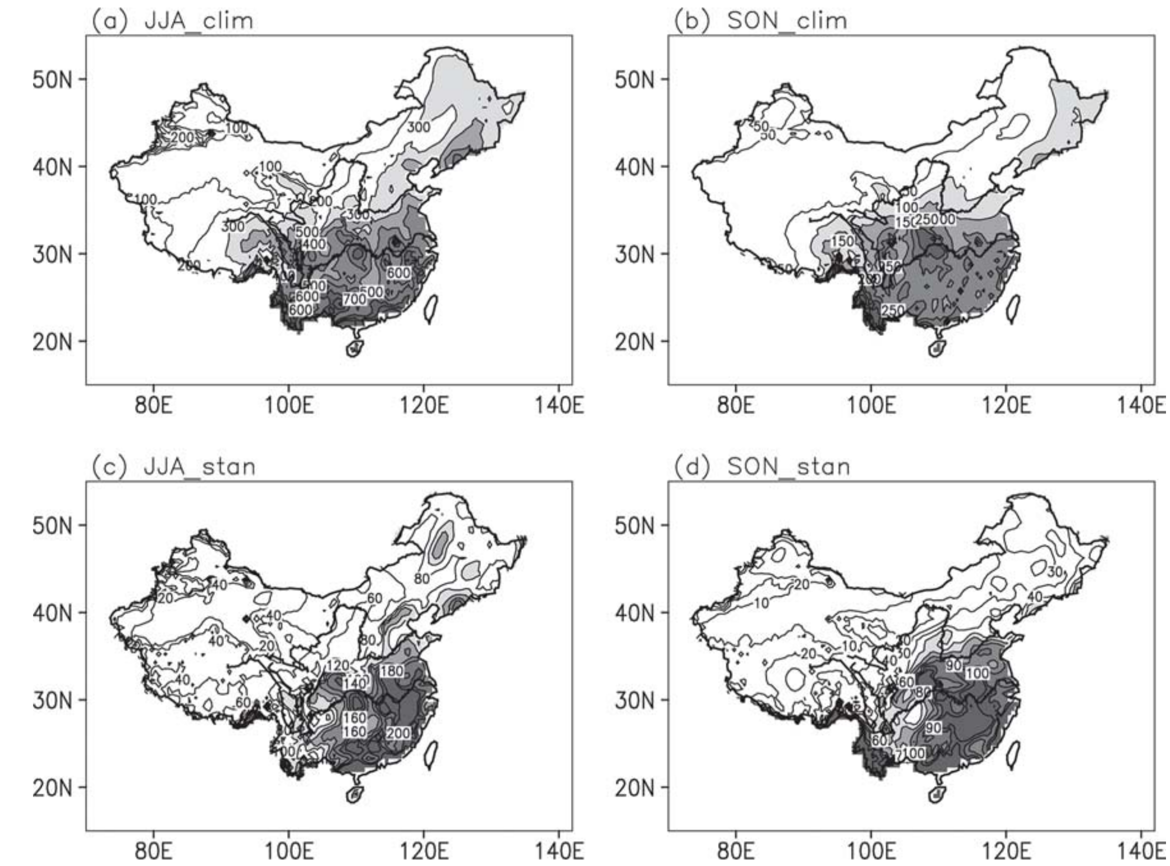


Fig. 1. Climatological (a) summer and (b) autumn rainfall distributions over China (unit: mm). Panels (c) and (d) are their associated standard deviations (unit: mm).

However, as illustrated here, rainfall anomalies during the decaying phases of the summer El Niño events differ from those during the developing phases (see Fig. 6 in Feng et al. 2011).

## 4. Possible mechanisms underlying the rainfall anomalies

The results described in Section 3 indicate that seasonal rainfall varies considerably during the developing phases of the two types of El Niño and that the amplitude of this variation can be more than 30 % of the climatological mean values in southern China. The possible processes underlying these phenomena are discussed in this section.

The SST and circulation anomalies associated with the two types of El Niño events play key roles in the rainfall anomalies over southern China. A classic CP El Niño pattern occurs during the developing phases of the summer CP El Niño events, with positive SSTA in the central Pacific and negative SSTA in the eastern and western Pacific (Fig. 3a). Between the developing summer and autumn phases, the positive SSTA are intensified in the central Pacific to a maximum of 1°C, the negative SSTA in the western Pacific persist, and the negative SSTA in the eastern Pacific become positive (Fig. 3c). In addition, the positive SSTA in the northwest Pacific weaken, and the negative SSTA in the tropical Indian Ocean become positive between the summer and autumn developing phases.

In the EP El Niño events, positive SSTA occur in the eastern Pacific and tropical Indian Ocean (Fig. 3b). The positive SSTA in the eastern Pacific and tropical Indian Ocean both strengthen between the developing summer and autumn phases (Fig. 3d). Note that maximum SSTA associated with the EP El Niño are much larger than those associated with CP El Niño, and SSTA in the tropical Indian Ocean are more extensive and larger in magnitude than those

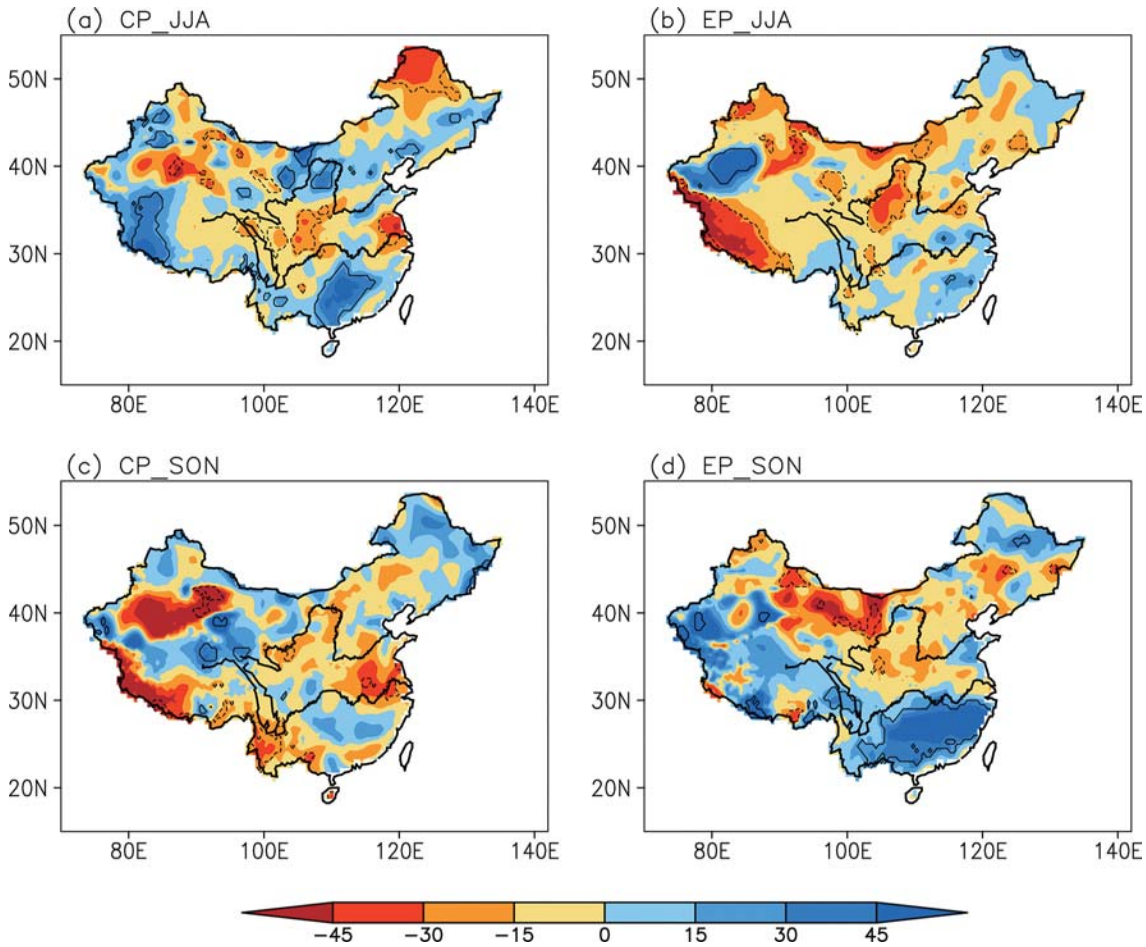


Fig. 2. Composite rainfall anomalies with respect to the climatology mean during the developing phases in (a) summer and (c) autumn for years with CP El Niños. (b, d) As in panels (a) and (c), but for the rainfall anomalies during the developing phases in EP El Niño years (unit: %). Contour lines indicate the 0.2 significance level.

accompanying the CP El Niño events. These findings are consistent with results in Feng and Li (2011) and Weng et al. (2007).

In response to central Pacific warming during the developing phases of the summer CP El Niño events, anomalous convergence is observed in the central Pacific and negative geopotential height anomalies form over the central Pacific (Fig. 4e). Anomalous westerlies associated with cyclonic circulation also occur over the western Pacific (Fig. 4a), indicating a northeastward shift in the position of the WPSH (figure not shown). Under these conditions, an anomalous rising flow (Fig. 4a) and cyclonic circulation prevail over southern China (Fig. 4g), resulting in stronger than normal convection, enhanced vapor transport (Fig. 6a), and increased rainfall in southern China (Fig. 4a).

In the developing phases of the autumn CP El Niño events, anomalous cyclonic circulation occurs in the western Pacific due to the eastward shift of the positive SSTA extension in the central Pacific. The cyclonic circulation and convective centers move eastward and are replaced by anomalous anticyclonic circulation (Fig. 5g) or downward flow (Fig. 5a) over the western Pacific and southern China. At this stage, the ascending flow and convection are suppressed by the reduction in vapor transport, thereby reducing the rainfall over southern China.

During the EP El Niño events, warming in the equatorial eastern Pacific induces a cyclonic response in the northwest (for the Northern Hemisphere) or southwest (for the Southern Hemisphere) (Figs. 4b,

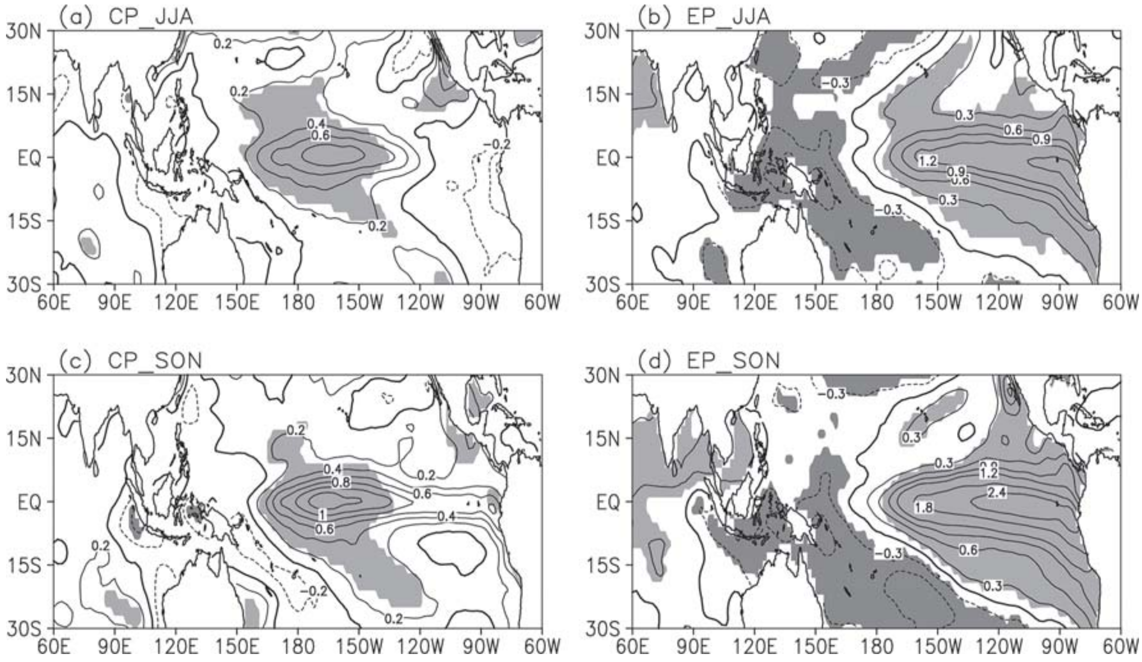


Fig. 3. Composite SST anomalies during developing phases in (a) summer and (c) autumn in CP El Niño years. (b, d) As in panels (a) and (c), but for anomalies during the developing phases in EP El Niño years (unit: °C). Shaded areas indicate the 0.2 significance level.

h). This response is manifested in equatorward flow, associated with equatorial westerly anomalies over the eastern Pacific (Fig. 4b). Strong cooling in the tropical western Pacific also results in positive geopotential heights (Fig. 4f) associated with negative convection centers (Fig. 4d) and anticyclonic circulation anomalies (Fig. 4a). Consequently, southern China is located at the boundary of the prevailing cyclonic and anticyclonic circulation anomalies. The interaction between these anomalies forms a negative–positive convection anomaly pattern in eastern China, with positive convection anomalies along the southern margin of this region. However, no significant circulation signals or changes in vapor transport are observed in southern China. These observed circulation anomalies are consistent with the rainfall anomalies shown in Fig. 2b, indicating that the developing phase of the summer EP El Niño has a limited effect on the rainfall in China.

During the developing phases of the autumn EP El Niño events, SSTA intensify in the eastern and western Pacific, and the anomalous anticyclone center extends westward to the middle south peninsula (figure not shown), forming an anomalous anticyclonic circulation in the southern margin of China. Consequently, southern China is located to the rear of the anomalous western Pacific anticyclone, accompanied with anomalous southwesterlies prevailing in the region (Fig. 5b), in turn indicating stronger than normal southwesterlies over southern China. Anomalous upward flow (Fig. 5b) and intensified convection (Fig. 5d) occur over southern China together with increased vapor transport to the region (Fig. 6d). These circulation anomalies tend to favor wet autumn conditions in southern China during the developing phases of the EP El Niño events. Note that anomalies in Figs. 6a and 6d are opposite; however, similar favorable rainfall circumstances are observed. This is due to the associated different climatological circulation background. That is, the averaged position of the WPSH during boreal summer is much more northward compared with that during boreal autumn. Also, there are southerlies/southwesterlies over southern China during boreal summer, whereas it is generally easterlies/northeasterlies over southern China during boreal autumn (figures not shown).

The results described above imply that various SSTA positions and intensities induce different Rossby wave responses, leading to anomalous WPSH locations, convection, circulation, and vapor

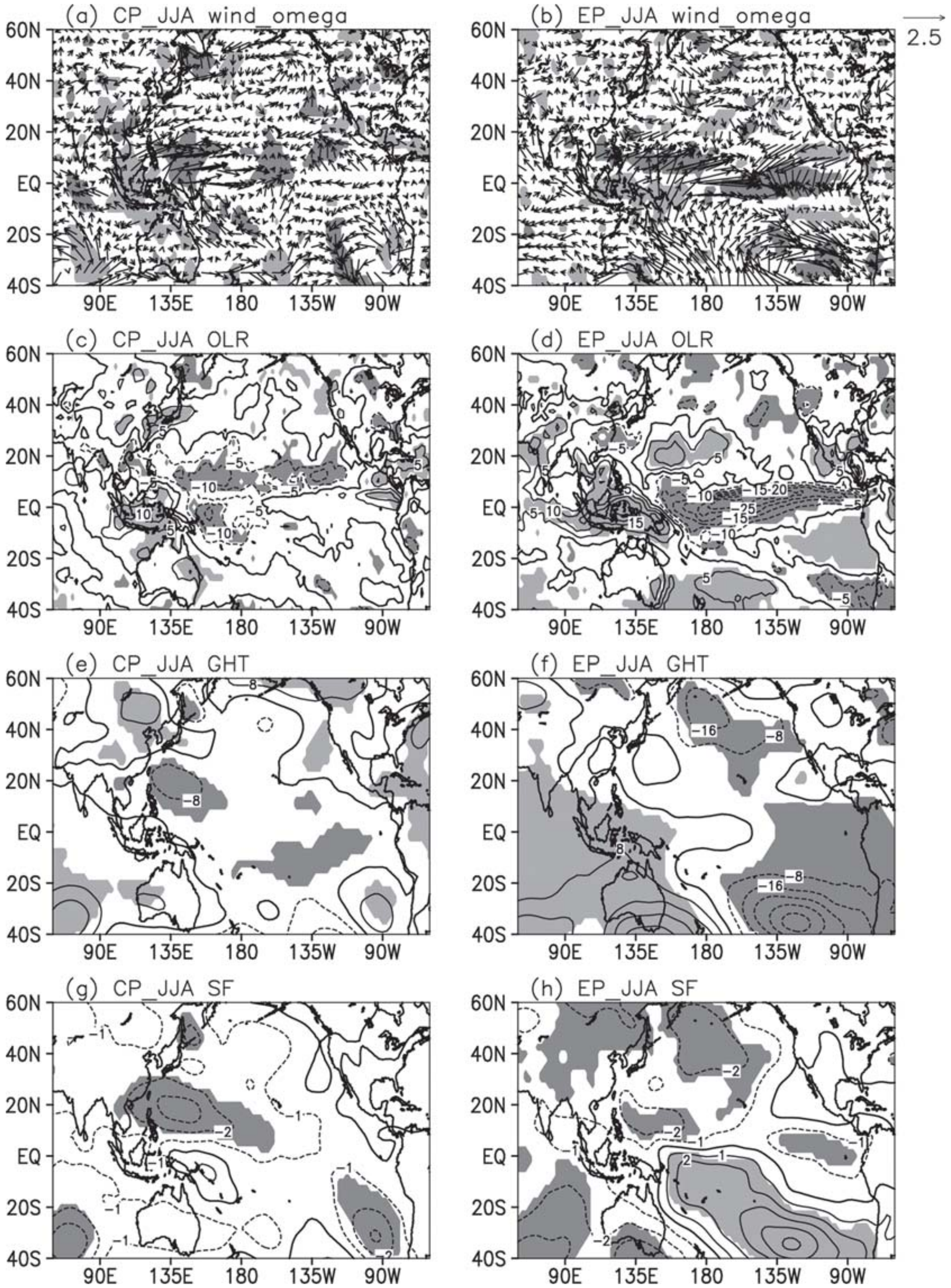


Fig. 4. Summer anomaly patterns during the developing phases in CP El Niño years for (a) surface wind (vectors; unit: m $s^{-1}$) and vertical velocity at 700 hPa (shading; with only values significant at 0.2 are shown), (c) outgoing long-wave radiation (unit: W $m^{-2}$), (e) geopotential height at 850 hPa (unit: m), and (g) stream function at 925 hPa (unit: $10^6$ $m^{-2}$ $s^{-1}$). (b, d, f, and h) As in panels (a), (c), (e), and (g), respectively, but for the developing phases in EP El Niño years. Shading indicates the 0.2 significance level.

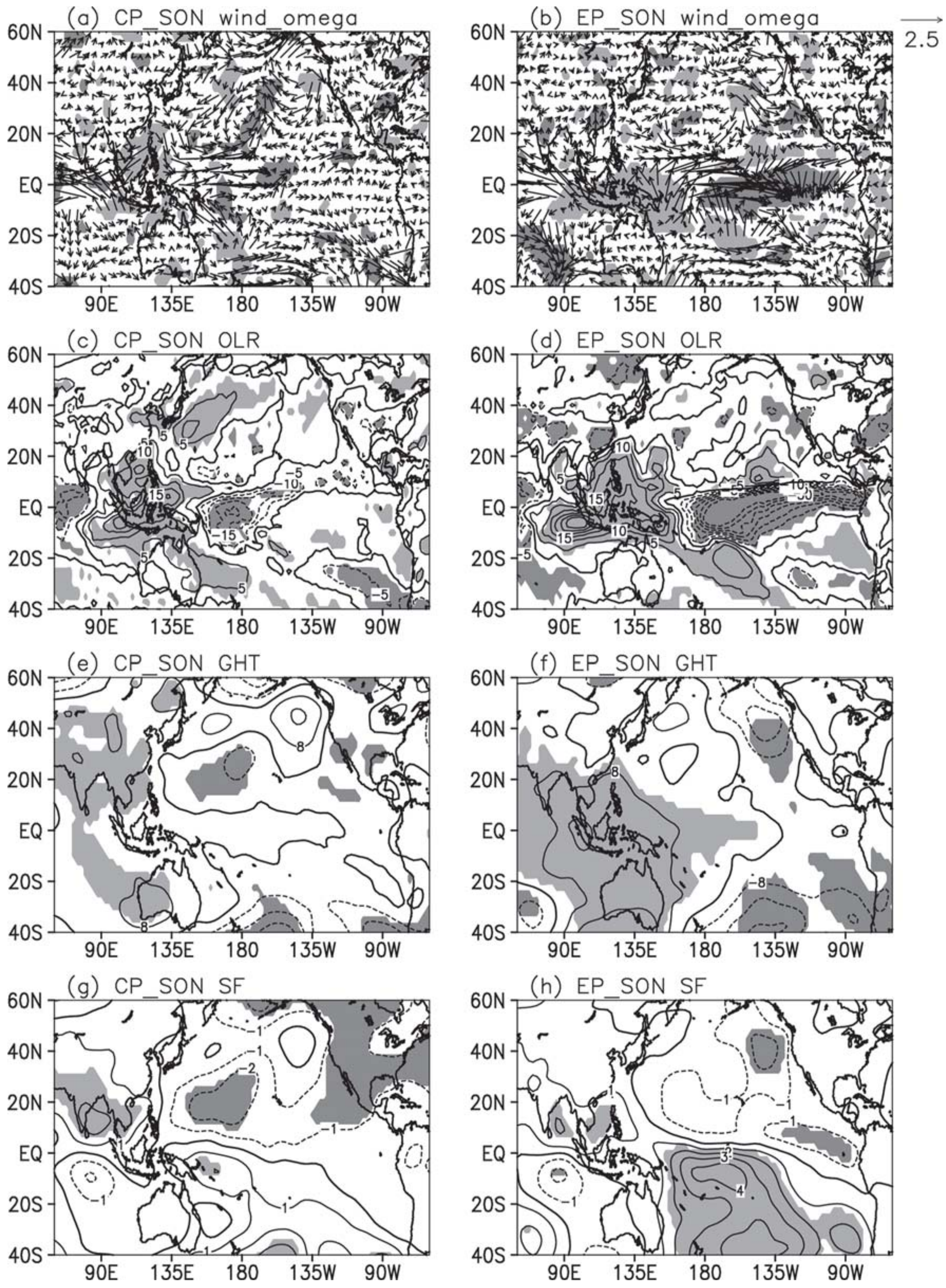


Fig. 5. As in Fig. 4, but for the anomalies during the developing phases in autumn of the two types of El Niño.

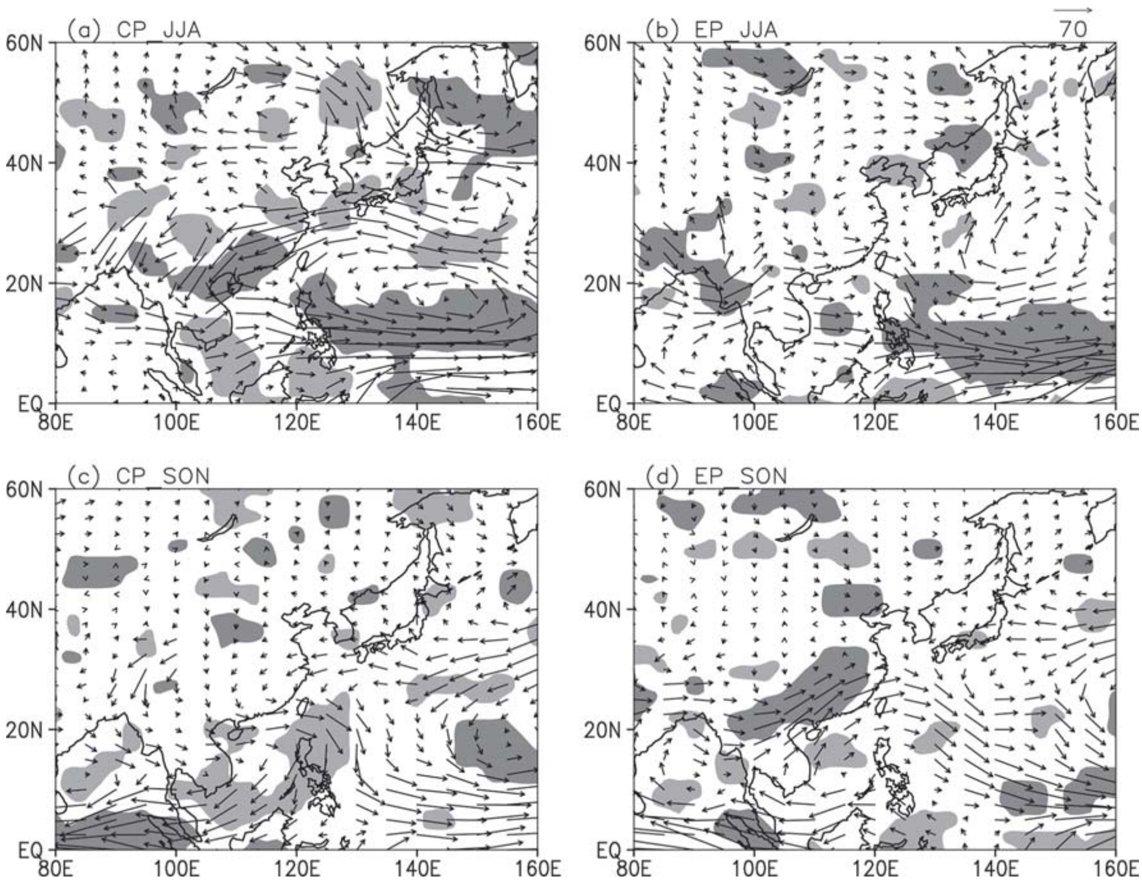


Fig. 6. Composite anomalies of vertical integral moisture transport (vectors; unit: g $s^{-1}$ $m^{-1}$ $Pa^{-1}$) and divergence at 925 hPa (shaded; unit: $10^{-6}$ $s^{-1}$). Only values significant at 0.2 are shown.

transport. These factors combine to produce rainfall anomalies over southern China. These processes are similar to the anomalies linked to the simultaneous and decaying El Niño influences (Feng and Li 2011; Zhang et al. 2011). However, the results also highlight the different influences of the various El Niño phases and also variations during the same phase across different seasons.

## 5. Summary and discussion

Using recent 30-year observational data sets, we have explored influences of the two types of El Niño events on the rainfall in China during their developing phases. The results showed that effects of the developing phases of the El Niño events differ from those of the decaying phases. Effects of the CP El Niño events also differ from those of the EP El Niño events. The developing phases of the CP El Niño events are associated with enhanced summer rainfall over southern China. However, the developing phases during autumn have a limited effect on rainfall in China. In contrast, significantly increased rainfall is observed over southern China during the developing phases of the autumn EP El Niño events, but the developing phases during summer have little effect on rainfall. These results highlight the distinct influences of the two types of El Niño during their developing phases and also illustrate differences that occur between seasons.

Figure 7 shows a schematic of processes that potentially explain the influence of the two types El Niño on rainfall over southern China. During the developing phases of the CP El Niño events in summer, the WPSH shifts to the northeast, convection and vapor transport increase, and cyclonic anomalies occur over southern China. This cyclonic rotation and rising flow produce more rainfall over the region (Fig. 7a). During the developing phases of the CP El Niño

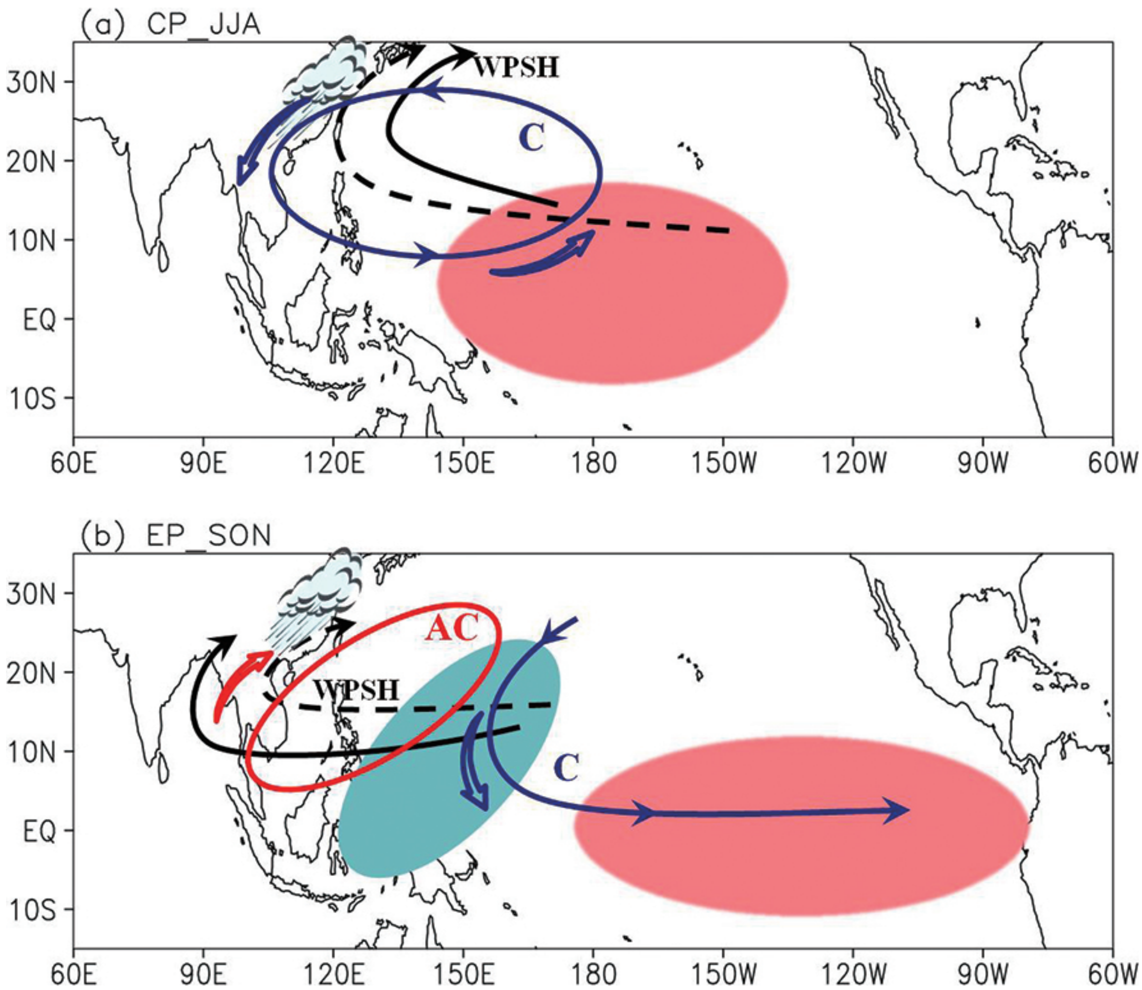


Fig. 7. Schematic diagrams showing the circulation anomalies associated with (a) developing summer of CP El Niño and (b) developing autumn of EP El Niño. Red/blue shaded areas indicate positive/negative SSTA. WPSH: western Pacific subtropical high. Dashed lines represent the climatological mean. Solid lines indicate anomalous circulation, and heavy arrows represent anomalous wind directions. "C" and "AC" indicate cyclonic and anticyclonic circulation anomalies, respectively.

events in autumn, the warm SSTA and circulation anomalies in the central Pacific shift eastward, the circulation anomalies weaken over southern China, and there is little effect on rainfall.

In contrast, in EP El Niño years, there is a limited effect on the rainfall over southern China during the developing phases in summer. This is because southern China lies at the boundary between the anomalous warming and cyclonic circulation in the eastern Pacific and the anomalous cooling and anticyclonic circulation in the western Pacific. The combined influence of these effects results in an insignificant rainfall signal over southern China. During the developing phase in autumn, the WPSH shifts westward away from southern China to the middle south peninsula (figures not shown) because of the intensification of SSTA in both the eastern and western Pacific. Accordingly, anomalous southwesterlies prevail over southern China, associated with rising flow, increased convection and vapor transport, and enhanced rainfall over the region (Fig. 7b).

The findings of this study highlight the different influences of the different El Niño events, even in the same phase; e.g., the insignificant/significant role of the developing phase of EP El Niño in summer/autumn on the rainfall in southern China and the opposite scenario for CP El Niño. Although the developing and decaying phases of the El Niño have different effects, this variability is not yet well understood, and it is therefore important to investigate the influence of the El Niño during different phases and in different seasons. A more detailed understanding will improve seasonal rainfall forecasts and allow us to fully understand effects of El Niño on climate. Moreover, the possible influences of the 2009/2010 event are not included in the text due to controversy of whether this event could categorize to the CP El Niño events (Jadhac et al. 2015). This is because that the magnitude of the index of CP El Niño during the summer of 2009 falls below the threshold (Ashok and Yamagata 2009; Shamal et al. 2015) and thus does meet the criterion of the persistence of CP El Niño. However, consistent rainfall anomalies are observed even if this event was considered (figures not shown). Besides, it is noted that the SST anomalous pattern during the developing summer and autumn of the two types El Niño events within the eastern Pacific shows differences in both intensity and meridional range; we could not specify to the relative contribution of the roles played by the SST intensity or its extent. However, as pointed out in Zhang et al. (2009), the meridional extent of El Niño is an important aspect and shows strong interdecadal variations; it is important to further examine the relative roles of the SSTA intensity and extent in determining impacts of the ENSO events.

Finally, several studies have shown that relationships between regional rainfall and ENSO are modulated by multidecadal variability (Cai et al. 2009), including the IPO. Therefore, whether the IPO plays any role in modulating these relationships and what other factors contribute to this multidecadal variation must also be investigated.

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