

Reply to the comments of Anonymous Referee #1.

We thank Referee #1 for his/her valuable comment. Our point-to-point reply raised by the referee are provided below. Please note that the referee's comment will be presented in italics, preceded by a "C", while the corresponding authors' responses will be presented in normal typeface, preceded by an "R". Please note that the line numbers provided in this reply are from the original version of our manuscript. A revised version of the manuscript has been placed at the end of this document and is a result of revisions made following comment from Dr. Q. Zhang, and Referee #1.

General comment

C1: Lv et al. analyzed the precipitation (and related indexes of extreme events, including drought) anomalies during various phases/types of ENSO events by using observational weather station data. The unique new findings from this study are the analyses on the extreme precipitation (and dry) events and the inclusion of the CP events for these analysis and comparisons among them. A big uncertain from this study is using observed daily precipitation data to accounting for the rainfall intensity and frequencies and using the annual period to account the total precipitation (or indexes), rather than the real duration of ENSO events/phases. Another limitation is the authors failed to explain the data/results with possible processes or mechanism; which is more meaningful to enhance out current understanding on the teleconnections during ENSO events.

R1: We would like to thank the referee for this review. Our innovation is to integrate potential anomalies in characteristics of precipitation events with those in precipitation amount to inform climate and hydrology policy. We adopt the observed daily precipitation dataset (Version 3) compiled by the National Meteorological Center in China. It contained 819 stations for the period from 1 January 1951 to 31 December 2013. This dataset is well distributed across China, including the Tibetan plateau, and is widely used in many studies. Although there is a big uncertainty using daily-scale data to define precipitation events, this definition has been a commonly used way to detect climate change (Brunetti et al., 2004; Karl & Knight, 1998; Liu et al., 2005). It is worth mentioning that the meteorological stations have undergone rigorous selection process into our dataset to omit possible non-climatic noises (Qian and Lin, 2005; Qu et.al.2016). This process includes extreme value and consistency check,

spatial outliers test, and homogeneity test, and thus can significantly improve the quality of long-term climatic data. We think these methods are sufficient to discover the ENSO-induced changes in our objectives. In addition, the developing of ENSO events are very complex and varies with strength. Annual scale is one of the commonly used periods to detect the ENSO events. Although annual scale seems fairly large, we discover many interesting findings by this scale. Monthly scales or even more detailed periods can be put forward, but we intend to draw an outline to explain the anomalies of precipitation in daily scale, and thus the annual scale is chosen in our study. Possible driving mechanisms behind the anomalies of precipitation events are discussed in our discussion and conclusion (Line 246 -Line 254 and Line 278-Line 283). We highlight the importance of anomalous Western North Pacific anti-cyclone and variability of East Asian summer monsoon in this study, which is probably the reason causing the regional patterns we find. This analysis is derived from plentiful findings in previous studies. The direct evidence is hard to provide as the daily weather system is very complex to analyse and the needed data are also hard to get. We think lots of further researches are needed to advance our understanding after our study.

Specific comment

C2: Line 86: 713 stations; line 91: 719 stations Table 1. 1. Add definition of "wet days"; 2. Need rephrase the definition of R95P (i.e. need to clarify the time step of precipitation and describe what is the 95th percentile of multi-year average). Line 104: need more detailed descriptions on Mann-Whitney U test.

R2: There are 713 stations in our dataset, sorry for the mistake in line 91. In Table 1.1, wet days means the day with precipitation > 0 (data with trace amount have been deleted); definition of 95th percentile of multi-year daily average has been stated clearly in the note of the table: the 95 quantiles of the daily precipitation distribution over the multi-year, represented by 1971–2000 (percentiles near 100 represent very intense precipitation). More detailed descriptions on Mann-Whitney U test are added in line 107: The Mann–Whitney U test is a nonparametric test applied to site data that does not conform to normality even after several different transformations are carried out (Teegavarapu et al., 2013). It tests whether two series are independent samples from different continuous distributions. One series represents precipitation series under a type of ENSO event (EP, CP, or LN), and the other series represents precipitation series under normal years.

C3: Fig. 2: Line 110: define the "developing years" and "decaying years", and describe their physical meanings. In some certain years, they are both belonging to stages of either developing or decaying years of different phases (EP, CP, or LN). Will this affect the conclusion? Line 130: Should add "decaying" between "CP" and "phases"?

R3: The definition of developing years and decaying years is added: as EP El Niño evolves, the positive SST anomalies expands latitudinally and negative signals eastward, and then reaches its maximum amplitude in autumn and winter (Feng et al., 2011); This year is defined as the developing year in this study. Finally, the warm SST anomalies disappear and is replaced by cool anomalies in the eastern Pacific, which occurs during summer of the next year (the decaying year); We have added "decaying" between "CP" and "phases" in line 130. We don't think this kind of overlap in years (*both belonging to stages of either developing or decaying years of different phases*) affects the final conclusion. The overlap depends on the developing of El Niño, which may reflect the connections among EP, CP, and LN. For example, in the decaying stage of EP El Niño, cool SST anomalies in the eastern Pacific will replace the warm anomalies, which probably denotes a LN event.

C4: Line 135: define "precipitation frequency" and define "precipitation intensity"; are they counted for each precipitation event or each individual rainy day? Line 159: add "(Fig. 4)" after "while more than 70% experienced negative anomalies in precipitation frequency"; Line 188: delete "but also increase"; Line 192-193: Rephrase the sentence "Although a positive anomaly ...".

R4: The definition of "precipitation frequency" and "precipitation intensity" is added in Table 1: intensity is average precipitation on wet days (day with precipitation > 0, data with trace amount have been deleted) and frequency is annual count of wet days; The citation of fig.4 is added after the sentence "while more than 70% experienced negative anomalies in precipitation frequency"; The sentences in line 188 and line 192-193 have been revised.

C5: Line 206: the conclusion that "ENSO events triggered larger changes in both the frequency and intensity of precipitation events and the occurrence of precipitation extremes than during non-ENSO periods" is not supported by the data; to support this claim, a comparison with precipitation indexes from "non-ENSO" period should be conducted.

R5: In our methodology, the anomalies of precipitation indices are derived from the multi-year average. So, the

"non-ENSO periods" is an incorrect expression. We have rephrased this sentence. Thanks for his/her responsibility and carefulness.

C6: Line 226: add "(Fig. 6a)" after "occurred during CP decaying years"; and line 227: add "(Table 3)" after "observed negative anomaly in annual precipitation". Line 227-229: rephrase this sentence. The main point is not clear.

R6: The citations of fig.6a and Table 3 have been added after the sentence. The sentence has been rephrased to explain the strong regional sensitivity in NW of China.

C7: Line 247: may need briefly describe the "anomalous Western North Pacific (WNP) anti-cyclone"; how it happens and what its effect.

R7: More detailed description about the Western North Pacific (WNP) anti-cyclone has been added in our manuscript: ENSO has strong effects on the anti-cyclone activity (e.g. number, genesis location, track, landfall frequency, and intensity) in WNP. Variation of the anti-cyclone activity directly influences on water vapor transport over China. As a result, the frequency and intensity of precipitation events in China would change.

C8: Line 258: 1. what is "these and other regions"? 2. Please explain what is "high incidence of anomalies". Line 257-259: need explain why "the continental climate zone (NW) is more sensitive to ENSO events than these and other regions".

R8: We have rephrased the original sentence as " However, in this study, we found that the continental climate zone (NW) is more sensitive to ENSO events than the other regions over China based on the region's magnitude of anomalies in annual precipitation and precipitation events (Fig. 3, Fig.6, and Table 3). For example, the NW region experienced the largest anomalies in annual precipitation during all phases of ENSO events. The NW region also demonstrated high sensitivity to the new type of El Niño, CP El Niño." In our manuscript, we repeat the related finding in annual precipitation, and further compare it with those of precious studies (e.g. Ward et al., 2014; Hui et al., 2006). In fact, this conclusion can be derived from our analysis in results, where lots of evidence to proof strong sensitivity of NW zone can be found.

Finally, we express sincere thanks to him/her for the efforts again!

Additional References

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Influence of three phases of El Niño-Southern Oscillation on daily precipitation regimes in China

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Abstract

In this study, the impacts of the El Niño-Southern Oscillation (ENSO) on daily precipitation regimes in China are examined using data from 713 meteorological stations from 1960 to 2013. We discuss the annual precipitation, frequency and intensity of rainfall events, and precipitation extremes for three phases (Eastern Pacific El Niño (EP), Central Pacific El Niño (CP), and La Niña (LN)) of ENSO events in both ENSO developing and ENSO decaying years. A Mann–Whitney U test was applied to assess the significance of precipitation anomalies due to ENSO. Results indicated that the three phases each had a different impact on daily precipitation in China and that the impacts in ENSO developing and decaying years were significantly different. EP phases caused less precipitation in developing years but more precipitation in decaying years; LN phases caused a reverse pattern. The precipitation anomalies during CP phases were significantly different than those during EP phases and a clear pattern was found in decaying years across China, with positive anomalies over northern China and negative anomalies over southern China. ENSO events which altered the frequency and intensity of rainfall roughly paralleled anomalies in annual precipitation; in EP developing years, negative anomalies in both frequency and intensity of rainfall events resulted in less annual precipitation while in CP decaying years, negative anomalies in either frequency or intensity typically resulted in reduced annual precipitation. ENSO events triggered more extreme precipitation events. In EP and CP decaying years and in LN developing years, the number of very wet days (R95p), the maximum rainfall in one day (Rx1d), and the number of consecutive wet days (CWD) all increased, suggesting an increased risk of flooding. In addition, more dry spells (DS) occurred in EP developing years, suggesting an increased likelihood of droughts during this phase.

Key words: ENSO, daily precipitation, climate extremes, China

1 Introduction

The El Niño-Southern Oscillation (ENSO), a coupled ocean-atmosphere phenomenon in the tropical Pacific Ocean, exerts enormous influence on climate around the world (Zhou and Wu, 2010). Traditionally, ENSO events can be divided into a warm phase (El Niño) and a cool phase (La Niña) based on sea surface temperature (SST) anomalies. An El Niño produces warming SSTs in the Central and Eastern Pacific, while La Niña produces an anomalous westward shift in warm SSTs

31 (Gershunov and Barnett, 1998). Precipitation appears especially vulnerable to ENSO events over a range of spatio-temporal
 32 scales and therefore has been the focus of many ENSO-related studies (Lü et al., 2011). Global annual rainfall drops
 33 significantly during El Niño phases (Gong and Wang, 1999) and a wetter climate occurs in East Asia during El Niño winters
 34 due to a weaker than normal winter monsoon (Wang et al., 2008), but these anomalies are generally reversed during La Niña
 35 phases.

36 Various studies also extensively document the teleconnections between ENSO and precipitation variation in China (Huang and
 37 Wu, 1989; Lin and Yu, 1993; Gong and Wang, 1999; Zhou and Wu, 2010; Lü et al., 2011; Zhang et al., 2013; Ouyang et al.,
 38 2014). Zhou and Wu (2010) found that El Niño phases induced anomalous southwesterly winds in winter along the southeast
 39 coast of China, contributing to an increase in rainfall over southern China. In the summer after an El Niño, insufficient rainfall
 40 occurs over the Yangtze River, while excessive rainfall occurs in North China (Lin and Yu, 1993). During La Niña phases,
 41 annual precipitation anomalies are spatially opposite of those during El Niño phases in China (Ouyang et al., 2014). As ENSO
 42 events progress over the winter and into the following summer they influence both the developing and decaying phases of El
 43 Niño and La Niña (Ropelewski and Halpert, 1987; Lü et al., 2011). Huang and Wu (1989) reported that the developing stage of
 44 an El Niño caused a weak subtropical high which resulted in flooding of the Yangtze River and Huaihe River, but the
 45 subtropical high shifted northward during the decaying phase, resulting in an inverse rainfall anomaly. The delayed response of
 46 climate variability to ENSO provides valuable information for making regional climate predictions (Lü et al., 2011).

47 Until recently, most studies have focused on changes in annual or seasonal total precipitation related to ENSO rather than
 48 changes in individual precipitation events, although possible shifts in characteristics of precipitation events, e.g. frequency
 49 and intensity, have been highlighted in studies of global climate change (Fowler and Hennessy, 1995; Karl et al., 1995; Gong
 50 and Wang, 2000). In China, it was reported that the number of annual rainfall days has decreased even though total annual
 51 precipitation has changed little in the past few decades (Zhai et al., 2005). Precipitation intensity has also changed
 52 significantly, especially across China (Qu et al., 2016), and as a result, drought and flood events occur more frequently
 53 (Zhang and Cong, 2014). Thus, separating out the impact of ENSO events on precipitation frequency and intensity is critical
 54 to understanding ENSO-precipitation teleconnections in China.

55 ENSO events are also well-known for causing extreme hydrological events (Moss et al., 1994; Chiew and McMahon, 2002;
 56 Veldkamp et al., 2015) such as floods (Mosley, 2000; Räsänen and Kummu, 2013; Ward et al., 2014) and droughts (Perez et
 57 al., 2011; Zhang et al., 2015) which in turn cause broad-ranging socio-economic and environmental impacts. Various
 58 approaches have been introduced to reveal these impacts at global and regional scales. For example, Ward et al. (2014)
 59 examined peak daily discharge in river basins across the world to identify flood-vulnerable areas sensitive to ENSO. Perez et
 60 al. (2011) modelled non-contiguous and contiguous drought areas to analyze spatio-temporal drought development. Water
 61 storage is another index typically used to detect frequency and magnitude of droughts during ENSO events (Veldkamp et al.,

2015; Zhang et al., 2015). Although the link between hydrological extremes and ENSO is usually discussed in the context of the physical mechanisms that influence local precipitation (Zhang et al., 2015), direct precipitation indices such as the number of consecutive wet days and dry spells have rarely been addressed in these studies. Thus, our knowledge of how daily precipitation extremes respond to ENSO events is still very limited and requires a comprehensive set of precipitation indices that describe ENSO-induced precipitation extremes.

A number of recent studies suggest that a new type of El Niño may now exist that is different from the canonical El Niño (Ren and Jin, 2011). This new El Niño develops in regions of warming SSTs in the Pacific near the International Date Line (McPhaden et al., 2006) and has been called “Dateline El Niño” or “Central Pacific (CP) El Niño.” Studies have revealed that CP El Niño appears to induce climate anomalies around the globe that are distinctly different than those produced by the canonical Eastern Pacific (EP) El Niño (Yeh et al., 2009). In addition, CP El Niño has been occurring more frequently in recent decades (Yu and Kim, 2013). Despite a long-term focus on ENSO-climate teleconnections, relatively little attention has been paid to the impacts of the new CP El Niño in China.

The current study began with the observation that EP El Niño has occurred less frequently and that CP El Niño has occurred more frequently during the late twentieth century (Yeh et al., 2009). The main objectives of this work are to document (1) any changes in daily rainfall in China during three different phases of ENSO events; (2) the number and duration of precipitation extremes occurring in both ENSO developing and decaying years. We discuss the total precipitation anomaly, anomalies of precipitation frequency and intensity patterns, and changes in precipitation extremes, and propose possible mechanisms responsible for the various rainfall anomalies.

2 Materials and methods

In this study, we used daily values of climate data from Chinese surface stations compiled by the National Meteorological Center in China. This dataset comprises detailed spatial coverage of precipitation across China, but only 400 stations were operational in the 1950s (Xu et al., 2011). Non-climatic noise can complicate the accuracy of analyses of the dataset (Qu et al. (2016). Stations that experienced observation errors, missing values, or data homogeneity problems were omitted from analysis in this study, according to similar methods used by Qian and Lin (2005). Of the 819 meteorological stations across China, data from 713 were ultimately selected for analysis which covered the time period between 1960–2013 (Fig. 1). Precipitation indices were calculated based on daily observations at the stations (Table 1). Precipitation amount, intensity, and frequency were used to formulate precipitation characteristics. Four new indices were introduced and used to analyse precipitation extremes in this study.

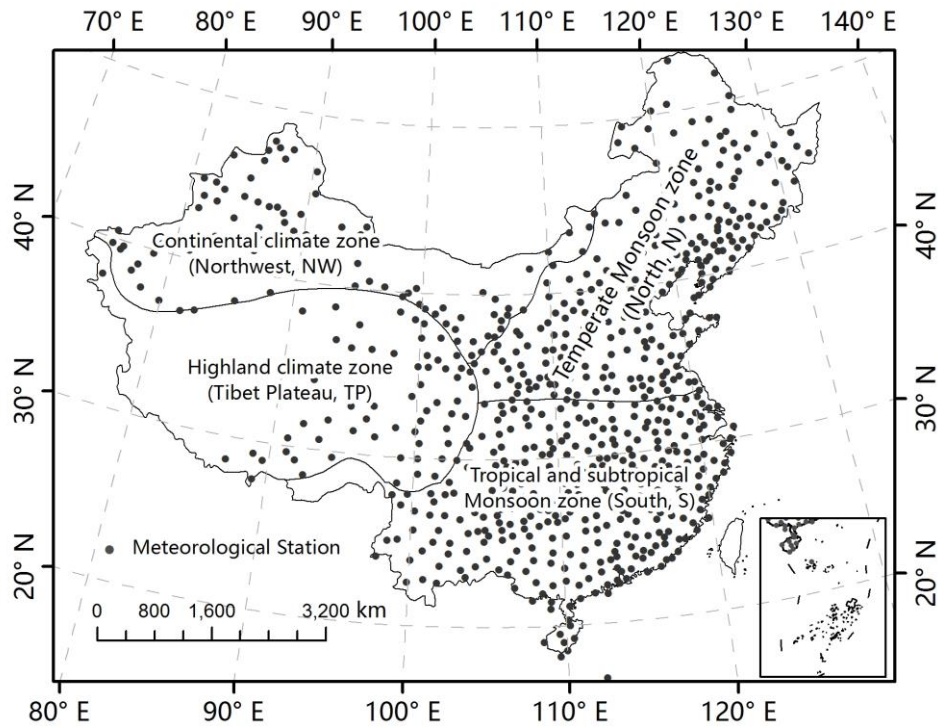


Fig. 1. The distribution of the 713 meteorological stations used in this study. China is divided into four regions based on main climatic types. The two non-monsoon regions are the continental climate zone (Northwest, NW) and the highland climate zone (Tibet Plateau, TP). The monsoon region is divided into two parts: the tropical and subtropical monsoon zone (South, S) and the temperate monsoon zone (North, N).

Table 1. Definitions of precipitation indices used in this study

Index	Descriptive name	Definition	Unit
P	Wet day precipitation	Annual total precipitation from wet days	mm
Intensity	Simple daily intensity index	Average precipitation on wet days (day with precipitation > 0)	mm/day
Frequency	Number of wet days	Annual count of wet days	day
Rx1d	Maximum 1-day precipitation	Annual maximum 1-day precipitation	mm
R95p	Very wet day precipitation	Annual total precipitation when precipitation > 95th percentile of multi-year daily precipitation*	mm
DS	dry spells	Number of consecutive dry days at least 10	-
CWD	consecutive wet days	Number of consecutive rainy days at least 3	-

*95th percentile of multi-year daily precipitation means the 95 quantiles of the daily precipitation distribution over the multi-year, represented by 1971–2000 (percentiles near 100 represent very intense precipitation).

In this study, two new indices created by Ren and Jin by transforming the traditionally-used Niño3 and Niño4 indices (2011) were used to distinguish between CP and EP El Niño phases. La Niña years were identified using the methods of McPhaden and Zhang (2009). The ENSO events (1960–2013) analyzed in this study are displayed in Table 2. As EP El Niño evolves, the positive SST anomalies expands latitudinally and negative signals eastward, and then reaches its maximum amplitude in

102 autumn and winter (Feng et al., 2011). This year is defined as the developing year in this study. Finally, the warm SST
 103 anomalies disappears and is replaced by cool anomalies in the eastern Pacific, which occurs during summer of the next year
 104 (decaying year). Precipitation indices were calculated in both ENSO developing and decaying years. Indices for precipitation
 105 anomalies were analysed as follows:

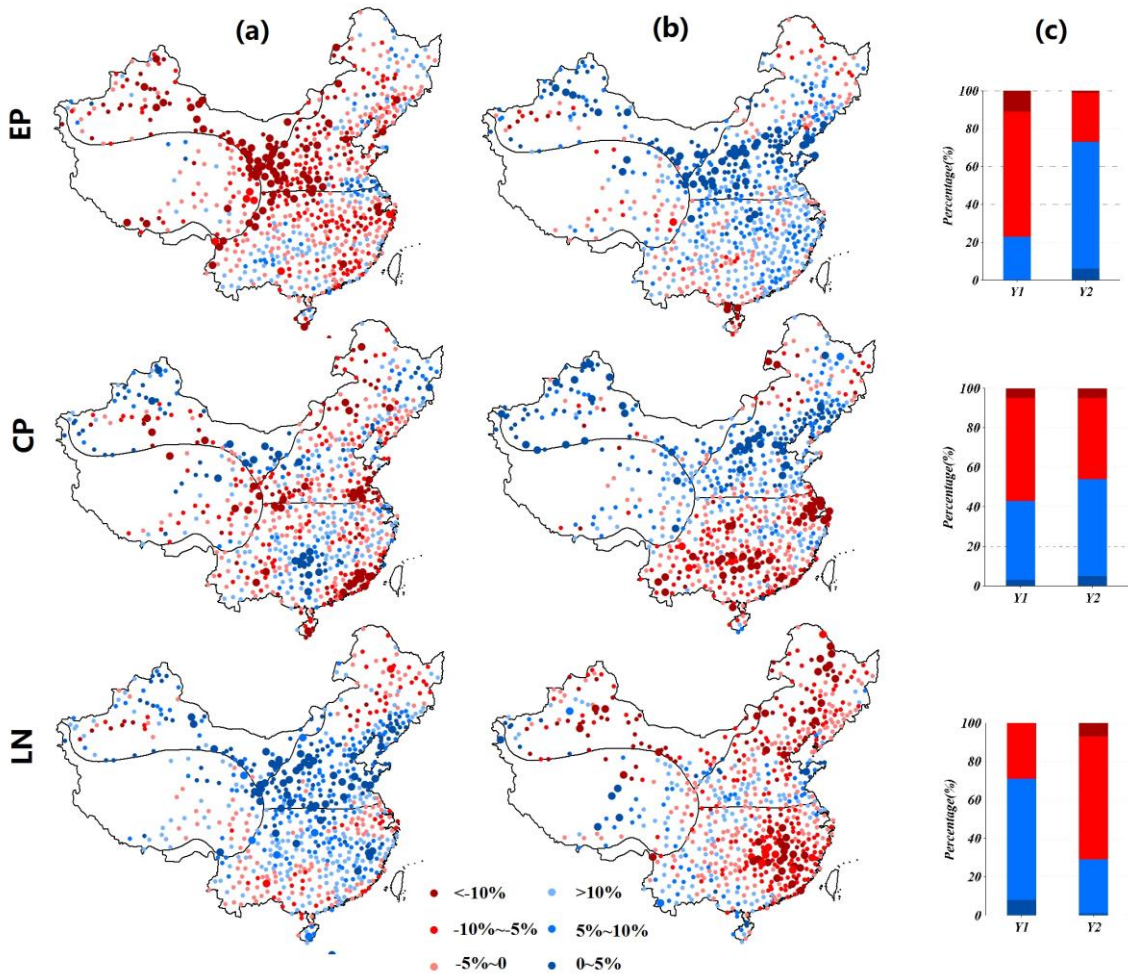
$$106 \quad A_{ij} = \frac{\overline{PI_{ij}} - \overline{PA_{ij}}}{\overline{PA_{ij}}}, \quad (1)$$

107 Where $\overline{PI_{ij}}$ is the average of the i precipitation index in the j meteorological station in a specific time period, and $\overline{PA_{ij}}$
 108 is the average of the i precipitation index in the j station in the multi-year average (represented by 1971–2000).

109 **Table 2.** ENSO years from 1960 to 2013

Phase	Eastern Pacific (EP)				Central Pacific (CP)				La Niña (LN)			
	El Niño				El Niño							
Year	1963	1965	1969	1972	1968	1977	1987	1994	1964	1967	1970	1973
	1976	1982	1986	1991	2002	2004	2009		1975	1984	1988	1995
	1997	2006							1998	2007	2010	

110 The Mann–Whitney U test is a nonparametric test applied to site data that does not conform to normality even after several
 111 different transformations are carried out (Teegavarapu et al., 2013). It tests whether two series are independent samples from
 112 different continuous distributions. One series represents precipitation series under a type of ENSO event (EP, CW, or LN), and
 113 the other series represents precipitation series under normal years. This test was applied to evaluate the significance of
 114 precipitation anomalies, performing at a significance level of 5%.



117 **Fig. 2** Anomalies of annual precipitation in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations
 118 experiencing significant anomalies are represented by large points. The percentage of stations experiencing increases or
 119 decreases in the number of rainfall anomalies are shown in (c), with significant increase (blue), increase (light blue), decrease
 120 (light red), and significant decrease (red). Y1, Y2 represent developing years and decaying years, respectively.
 121
 122 In EP developing years, 628 stations across China (~80%) had negative anomalies. At 80 of these stations the anomalies
 123 were significant. These significant stations were mainly located in the continental climate zone (NW) and the temperate
 124 monsoon zone (N) (Fig. 2). All sub-regions experienced negative average annual precipitation anomalies (Fig. 3), especially
 125 in the NW region where precipitation was 12.83% lower than the mean. Large positive anomalies of annual precipitation
 126 were found during LN developing years (Fig. 2); more than 70% of the stations showed positive anomalies, of which 10%
 127 were significant. Similarly, the stations with significant anomalies were mainly in the NW and N regions. In CP developing
 128 years, precipitation anomalies were quite different from those in EP developing years (Fig. 2). The proportion of stations
 129 with negative anomalies was 57%, but with no clear pattern of distribution.

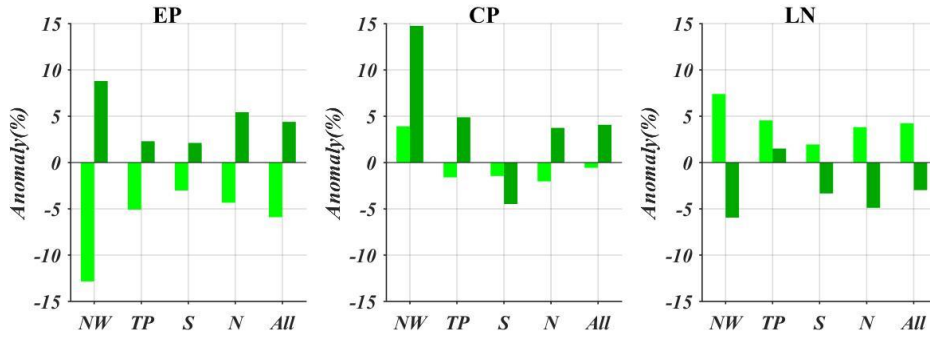
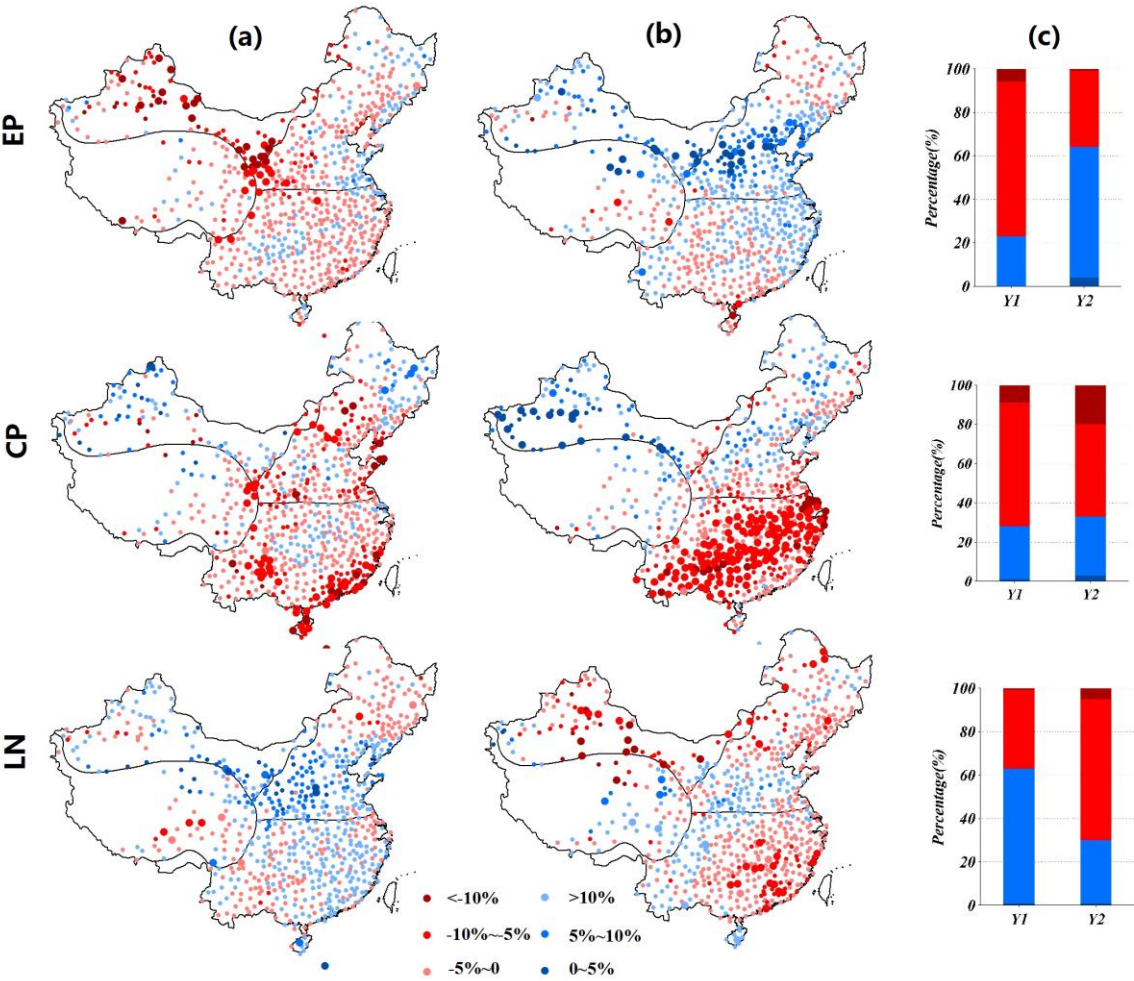


Fig. 3 Average annual precipitation anomaly by sub-region during EP, CP, and LN phases. Light color represents developing years and dark color represents decaying years.

The impacts of EP phases on precipitation in decaying and developing years displayed opposite patterns. Positive anomalies were detected across China during decaying years (Fig. 2), especially in the NW and N regions at 8.8% and 8.9% higher than the mean, respectively (Fig. 3). And negative anomalies were common across China in LN decaying years (Fig. 2). In the NW region, average annual precipitation was 5.95% lower than the mean. As a result, in both the decaying years of EP and the developing years of LN, more water vapor would be transported from the Pacific Ocean to China, while in the decaying years of LN and the developing years of EP, drier conditions would prevail. In the CP phases, average annual precipitation in the NW, Tibet Plateau (TP), and N regions was much greater than the mean, but lower than the mean in the subtropical monsoon zone (S) (Fig. 3).



142
143 **Fig. 4** Anomalies of precipitation frequency in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations
144 experiencing significant anomalies are represented by large points. The percentage of stations experiencing anomalies of
145 precipitation frequency are shown in (c), with significant increase (blue), increase (light blue), decrease (light red), and
146 significant decrease (red). Y1, Y2 represent developing years and decaying years, respectively.

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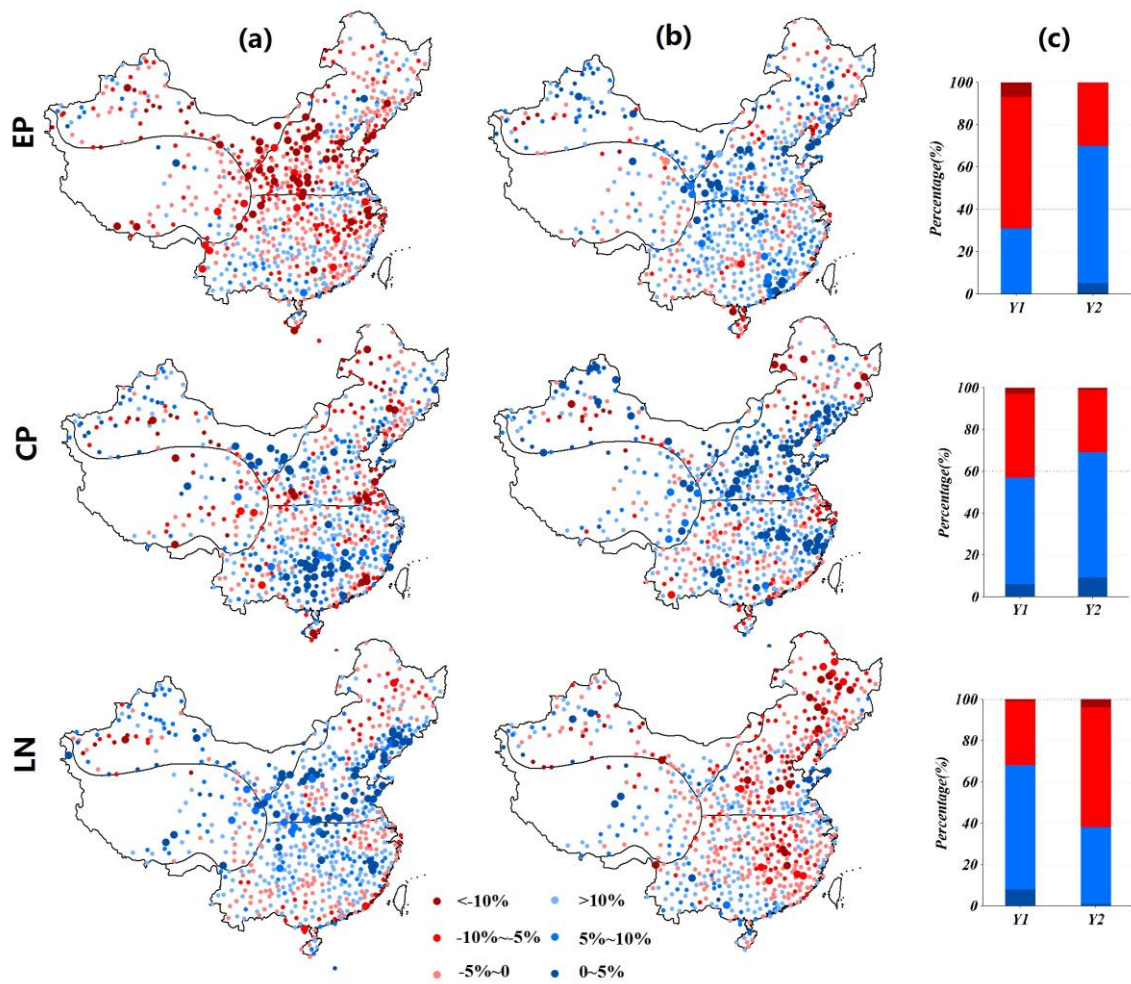
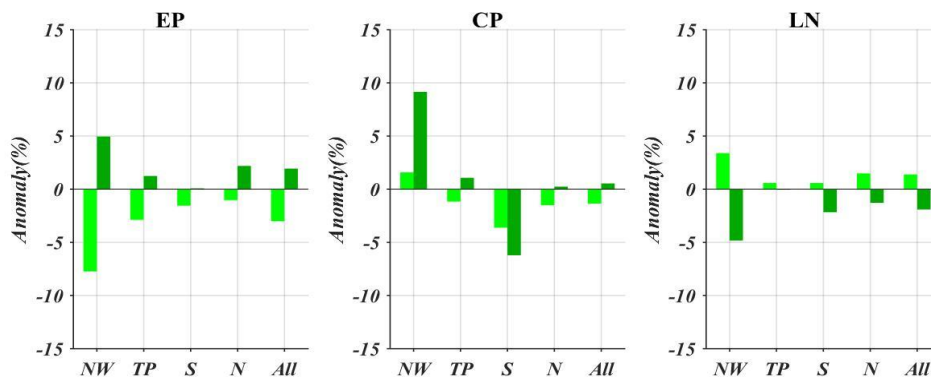


Fig. 5 Anomalies of precipitation intensity in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing anomalies of precipitation frequency are shown in (c), with significant increase (blue), increase (light blue), decrease (light red), and significant decrease (red). Y1, Y2 represent developing years and decaying years, respectively.



(a)

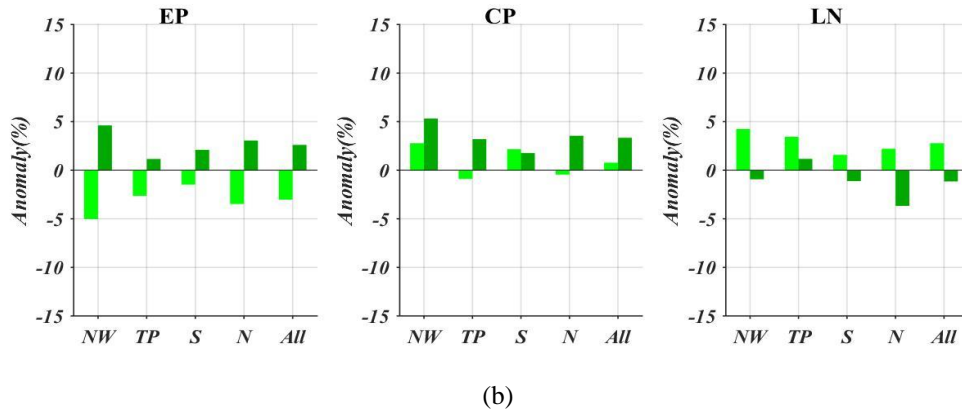


Fig. 6 Average anomalies of precipitation frequency (a) and precipitation intensity (b) by sub-region during EP, CP, and LN phases. Light color represents developing years and dark color represents decaying years.

In EP developing years, only negative anomalies of precipitation intensity and frequency occurred, with decreases of 3.04% and 3.01%, respectively, across all of China (Fig. 6). Stations with significant decreases in precipitation frequency were mainly located in the NW region (Fig. 4) and stations with significant decreases in precipitation intensity were mainly located in the N region (Fig. 5). In contrast, anomalies of precipitation intensity and frequency in EP decaying years were positive, presenting a reverse pattern to the developing phase. Anomalies of precipitation intensity and frequency were also positive in LN developing years, with stations of significance concentrated in the N region.

In the CP phases, anomalies of precipitation intensity and frequency displayed more complex patterns than those in the EP years. In developing years, slightly more than half of the stations experienced positive anomalies of precipitation intensity (Fig. 5), while more than 70% experienced negative anomalies in precipitation frequency (Fig. 4). Of the stations experiencing negative precipitation frequency anomalies, 64 were significant (Fig. 4) and were concentrated in the S and N regions (Fig. 4). Precipitation frequency anomalies also formed a clear distribution pattern in CP decaying years. Of all the meteorological stations, 145 (20%) experienced significant negative anomalies and were concentrated in the S region. In contrast, all regions experienced positive anomalies of precipitation intensity.

In general, anomalies of total precipitation tend to result from changes in both the frequency and intensity of precipitation events. Combined with the analysis in section 3.1, the results suggest that increases in precipitation frequency and intensity during EP decaying years and LN developing years resulted in the positive anomalies of annual precipitation across China during these phases. And the decreases in precipitation frequency and intensity during EP developing years and LN decaying years resulted in the negative anomalies of annual precipitation. But, in the CP phases, few regions displayed such clear relationships between anomalies in total precipitation and precipitation events. For example, in the N region, precipitation frequency changed very little, and the observed positive anomalies of annual rainfall in CP decaying phases appear to have resulted from increased precipitation intensity. Likewise, in the S region, precipitation intensity increased by 1.77% even though the precipitation frequency and total precipitation decreased.

3.4 Precipitation extremes

ENSO can trigger extreme hydro-climatological events such as floods, droughts, and cyclones (Zhang et al., 2013). Table 3 shows the average percent change in the number of extreme precipitation events (anomalies of precipitation extremes) in sub-regions and the whole of China, based on data from all meteorological stations.

Table 3. Average anomalies of precipitation extremes during EP, CP, and LN phases (%).

Years	Phases	Index	NW	TP	S	N	All
Developing years	EP	Rx1d	-7.54	-2.23	-0.34	-0.32	-2.29
		R95p	-20.68	-7.02	-4.76	-5.55	-8.78
		DS	3.38	3.93	1.94	1.59	2.67
		CWD	-15.42	-6.07	-0.95	-3.70	-5.96
	CP	Rx1d	4.89	-1.00	1.02	-2.73	0.27
		R95p	5.79	-0.99	0.57	-2.93	0.28
		DS	-2.12	0.83	-0.10	2.18	0.34
		CWD	9.91	-2.11	-3.66	-3.33	-0.42
	LN	Rx1d	4.87	4.73	3.40	2.84	3.90
		R95p	10.79	8.90	4.76	8.10	7.97
		DS	-1.21	3.58	-0.25	0.26	0.71
		CWD	8.59	2.82	0.99	4.31	3.89
Decaying years	EP	Rx1d	9.52	1.30	2.43	1.94	3.43
		R95p	15.26	5.27	4.22	7.24	7.53
		DS	-3.83	1.70	0.26	1.76	0.21
		CWD	5.96	2.22	-1.48	6.72	3.18
	CP	Rx1d	7.54	4.36	2.39	0.28	3.39
		R95p	23.32	7.99	-0.33	7.13	8.64
		DS	4.08	-3.00	13.24	-1.88	3.05
		CWD	17.78	4.14	-4.78	1.11	3.71
	LN	Rx1d	-2.50	2.22	-1.00	-4.17	-1.29
		R95p	-4.73	2.14	-3.31	-9.06	-3.67
		DS	1.85	-2.48	1.35	0.87	0.30
		CWD	-7.86	-0.70	-1.81	-3.04	-3.06

During EP developing years and LN decaying years China experienced markedly negative anomalies in very wet daily rainfall, as expressed by the R95p index, and positive anomalies during EP decaying years and LN developing years. These impacts of the EP and LN phases on R95p were observed in nearly all sub-regions of China. An R95p positive anomaly was also observed in CP decaying years, but only in the NW, TP, and N regions. In CP developing years, the R95p identified no significant anomalies. The Rx1d index, a measure of maximum daily rainfall, revealed similar patterns to those identified by the R95p index. Positive R95p and Rx1d values during EP and CP decaying years and LN developing years indicate an increased likelihood of extreme precipitation events during these years than normal.

As shown in Table 3, negative anomalies of consecutive wet days (CWD) occurred in EP developing years and LN decaying years across China while the opposite pattern occurred in EP and CP decaying years and in LN developing years. The CWD

is a measure of wet conditions that is closely related to soil moisture and river runoff. A greater number of CWDs will enhance soil moisture, runoff, and the risk of floods. The NW region, a continental climate zone, is the most sensitive of China's sub-regions to ENSO events in terms of CWDs. In EP developing years, the N, TP, and NW regions experienced large decreases in CWDs (5.69%, 6.07%, and 15.42%, respectively). Such decreases have the potential to induce droughts in these sub-regions as soil moisture decreases. But the dry conditions in these sub-regions reversed in EP decaying years. Although a positive anomaly occurred in annual precipitation during CP decaying years in the N region, it experienced fewer CWD anomalies. This was possibly due to the increase in intensity of rainfall events.

Dry spells (DS) are extended periods of 10 days or more of no precipitation and are a strong predictor of droughts. As shown in Table 3, all sub-regions of China experienced positive anomalies in DS during EP developing years, displaying an inverse pattern to that observed for CWDs discussed above. In other words, fewer CWDs and more DS occurred simultaneously and indicated an increased risk of drought. Negative anomalies in DS were observed in the NW and N regions during EP decaying years. In CP decaying years, DS displayed dipole anomalies across China which were opposite of observed CWD patterns during the same period. But during the same years, DS anomalies were positive in the NW region even though annual precipitation had increased. DS displayed far weaker anomalies during both LN developing years and decaying years.

4 Discussion and conclusion

Using a nonparametric hypothesis test, this study investigated the impacts of three different ENSO phases on daily rainfall regimes in China during the past half century. Rainfall data collected from meteorological stations across the country revealed that the impacts of the three phases were significantly different from each other over both daily and annual time scales. In addition, ENSO events triggered larger changes in both the frequency and intensity of precipitation events and the occurrence of precipitation extremes than the multi-year average. This finding is significant because past studies examining teleconnections between ENSO events and climate variation in China have primarily focused on annual and/or monthly rainfall rather than individual precipitation events. Since ENSO events can be predicted one to two years in advance using various coupled ocean/atmosphere models (Lü et al., 2011), this study can provide a means of climate prediction on a daily time scale and enable the prioritization of adaptation efforts ahead of extreme events.

The examination of variations in precipitation anomalies caused by different ENSO phases reveals a striking contrast between the influences of canonical El Niño events (EP El Niño) and La Niña in China, which is consistent with previous studies on global and regional scales (Ouyang et al., 2014; Veldkamp et al., 2015) and is due to opposite SST patterns over the central to eastern Pacific Ocean. Namely, these SST patterns are positive in an EP El Niño phase and negative in a La Niña phase. In contrast, during CP El Niño phases, precipitation over China displayed some asymmetric anomalies which do not follow the patterns seen during either EP El Niño or La Niña years. For example, during CP decaying years, the N region

225 experienced a positive annual precipitation anomaly but a negative anomaly during La Niña decaying years. Meanwhile, the
226 S region experienced a negative annual precipitation anomaly during the CP decaying phase. In addition, annual
227 precipitation decreased notably during EP developing years, especially in the N and NW regions, but much less so during CP
228 developing years. This incongruity between the influences of EP and CP El Niño phases reflects the potential for changes in
229 atmospheric diabatic forcing over the tropics to modify tropical–midlatitude teleconnections to the El Niño (Yeh et al., 2009).
230 When CP occurs, the evolution of the SST anomaly over tropical Pacific Ocean regions is significantly different than that
231 which occurs during EP (Ashok et al., 2007); in other words, the magnitude of SST signals is not only weak during CP, but
232 its position is also shifted westward, resulting in different atmospheric responses in the tropical Pacific Ocean. We also
233 found that the S and NW regions are more sensitive to CP phases than other sub-regions of China in terms of precipitation
234 events. In region S, for example, a remarkably negative anomaly in the frequency of precipitation events occurred during CP
235 decaying years, resulting in a large increase in DS which partially explains the observed negative anomaly in annual
236 precipitation. During the same years, the NW region displayed a strong positive anomaly in precipitation frequency and
237 R95p, which probably caused the sharp increase in annual precipitation.

238 Precipitation anomalies during the developing and decaying years of ENSO displayed inverse patterns as well. For example,
239 a decrease in annual precipitation occurred across China during EP developing years, but an increase occurred during EP
240 decaying years. Similar results were observed by Wu and Hu (2003) who documented seasonal rainfall anomalies in East
241 Asia, finding that the rainfall correlation distribution displayed pronounced differences between developing and decaying
242 ENSO years. This inverse relationship suggests a potential teleconnection between atmospheric responses in mid-latitude
243 and the evolution of the SST anomaly over the tropical Pacific. During the developing stage, the warming SST anomaly of
244 EP begins expanding during spring and reaches its maximum magnitude in autumn and winter (Feng et al., 2011). But during
245 the following summer, during the ENSO decaying stage, the warming SST anomaly disappears and is replaced by a cool
246 anomaly in the eastern Pacific. In contrast, the evolution of La Niña displays a reverse pattern that is supported by the same
247 study which shows that the decaying and developing stages had opposite influences on rainfall over China. However, when
248 CP phases occur, these inverse teleconnections seem to disappear. The CP decaying stage exerted a large influence on daily
249 precipitation in China during decaying years, but in developing years it had little impact. The different teleconnections
250 between EP and CP phases reflect differences in atmospheric responses to the evolution of the SST anomaly; CP phases
251 progress more slowly and their peak state is of a shorter duration despite originating from a warmer background SST (Kim et
252 al., 2009). It is important not to infer too much from only a few cases. As mentioned in Kim et al. (2009), it is hard to know
253 whether the CP occurrence is part of a recurring natural cycle, like the Pacific multi-decadal oscillation, or the result of a
254 warming climate.

A possible origin of the physical processes causing changing precipitation regimes in China may be related to the evolution of the anomalous Western North Pacific (WNP) anti-cyclone (Feng et al., 2011), as ENSO has strong effects on the anti-cyclone activity (e.g. number, genesis location, track, landfall frequency, and intensity) in WNP. Variation of the anti-cyclone activity directly influences on water vapor transport over China. As a result, the frequency and intensity of precipitation events in China would change. This study reveals that due to increased WNP anti-cyclones during EP decaying phases, annual precipitation and the frequency and intensity of precipitation events increased, especially in northern China. During CP developing years, the anomalous WNP anti-cyclone weakens and causes no significant rainfall anomalies in China. However, during summer of CP decaying years, the WNP anti-cyclone re-invigorates and extends north-westward toward inland regions (Wu et al., 2003). As a result, plentiful moisture is transported to northern and northwestern China. Also, precipitation extremes may change in response to the different duration and magnitude of precipitation events.

The climate of several regions in China are vulnerable to ENSO events via teleconnections, such as the South China Sea (Qu et al., 2004; Rong et al., 2007; Zhou and Chan, 2007; Liu et al., 2011) and Yangzi River (Huang and Wu, 1989; Tong et al., 2006; Zhang et al., 2007; Zhang et al., 2015). However, in this study, we found that the continental climate zone (NW) is more sensitive to ENSO events than the other regions over China based on the region's magnitude of anomalies in annual precipitation and precipitation events (Fig. 3, Fig.6, and Table 3). For example, the NW region experienced the largest anomalies in annual precipitation during all phases of ENSO events. The NW region also demonstrated high sensitivity to the new type of El Niño, CP El Niño. In an earlier study on daily river discharges at the global scale, Ward et al. (2014) found that ENSO has a greater impact on annual floods in arid regions than non-arid regions, but suggested that the hydro-climatic response to ENSO in arid regions has drawn much less attention than tropical regions. In China, Hui et al. (2006) analyzed the interdecadal variations in summer rainfall in response to the SST anomaly over the Niño-3 region. They found that summer rainfall in northwestern China was well-predicted by ENSO events between 1951–1974 (Hui et al., 2006). Over a longer period, Ouyang et al. (2014) found that most parts of northwestern China experienced greater precipitation during El Niño months over the last century than during non-El Niño months. But little work has been done on the mechanisms behind the climatic responses to ENSO events in the continental climate zone of China, since most of studies have focused on monsoon zones (Matsumoto and Takahashi, 1999; Wen et al., 2000; Wang et al., 2008; Zhou and Wu, 2010). Approaches to understanding the forces influencing daily precipitation events coinciding with ENSO are more complex than those directed toward precipitation influences on a monthly or annual scale. This complexity can be illustrated by the observation that in CP decaying years, the N region experienced a positive anomaly of annual precipitation due to an increase in precipitation intensity, but the S region experienced a negative anomaly due to a large decrease in precipitation frequency. And in terms of precipitation extremes, a new index, R95p, was required to reveal an increase in precipitation intensity in the N region while the DS and CWD indices revealed anomalies in the S region. Therefore, even though solid

physics exists to explain precipitation variabilities related to ENSO events, there is a need for more research on the mechanisms driving atmospheric circulation to advance our understanding of these influences over time and spatial scales. Finally, the year-to-year variability of the East Asian summer monsoon is likely also influenced by complex air–sea–land and tropical–extratropical interactions in addition to ENSO events. These interactions may include Tibetan Plateau heating, Eurasian snow cover, and polar ice coverage (Wang et al., 2000). Other factors that may simultaneously contribute to precipitation anomalies in China during ENSO events include forces which generate large-scale circulation events that alter the extension–retreat of the monsoon trough (Chen et al., 2006), tropical cyclones (Wang and Chan, 2002; Kim et al., 2011), and vertical wind shear (Chia and Ropelewski, 2002).

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