Reply to the comments of Anonymous Referee #2.

We thank Referee #2 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, Referee #1, and Referee #2.

C1*: The paper attempts to find the impact (if any) of the El Niño-Southern Oscillation (ENSO) on daily rainfall in China. For doing so, it uses rainfall data from more than 700 stations (1960-2013) across the country. It is known that establishing a link between ENSO and rainfall at a specific region is not an easy task, since there are a lot other variables in play.*

R1: We would like to thank the referee for this review. Although various studies have extensively documented the teleconnections between ENSO and precipitation anomalies in different spatio-temporal scales, we have proposed very interesting research gaps where a sufficient attention was paid in previous studies. In this study, we intend to integrate potential anomalies in characteristics of precipitation events with those in precipitation amount to inform climate and hydrology policy. We have made lots of analysis and attempted to reach our objectives in the end.

Major comment

C2*: Major comments: The index used for the selection of ENSO years needs a careful thought. A common index to use to identify a given ENSO year is Multivariate ENSO Index (MEI, https://www.esrl.noaa.gov/psd/enso/past_events.html). Using different indices for the identification may result in (wrongly) classifying the same year as an El Nino, la Nina or a neutral year. This seems to be the case in this paper where several of the years in Table 2 do not correspond with the events identified using MEI. Since the entire analysis and interoperation of the result strongly depends on the ENSO event identification, the authors should make sure that they are using an accurate index. Furthermore, ENSO events can last longer than 1* *calendar year often spanning Fall of one year to Summer of the following year.*

R2: Exactly! The definition of ENSO events determines the accuracy of the results and ultimately the conclusion. We have noticed the different indices for the identification of ENSO events, so we put lots of efforts into it in the beginning of our study.

(1) LN events.

We adopt the method of the NOAA oceanic Niño index (ONI, http://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). It is one of the commonly used indices around the world, which is defined as a 3-month running mean of SST anomalies over 5 consecutive months in the Niño -3.4 region (5°N–5°S, 90–150°W). A detailed list can be found in Table 1 of McPhaden and Zhang (2009). We further add year 2010 according to the ONI table in http://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php.

(2) CP and EP events.

Traditionally, El Niño event is classified as a CP type if SST anomalies averaged over the Niño 4 region are greater than those averaged over the Niño 3 region and vice versa for the EP type (Kug et al., 2009; Yeh et al., 2009). However, Ren and Jin (2011) considered that they cannot effectively separate the two types of El Niño, as these two indices are highly correlated in time. They proposed a new set of indices with little simultaneous correlation, by performing a simple transformation of the Niño 3 and 4 indices. Yu and Kim (2013) reviewed and compared the different indices used to identify the CP and EP events, including Niño 3 and Niño 4 indices, El Niño Modoki Index (EMI), and Ren and Jin (2011) (detailed information can be found in their article). The transformed indices of Ren and Jin (2011) are more sensitive to detect CP events in some cases, such 1987-1988 and 2002-2003. In this study, we adopt the method of Ren and Jin (2011) to identify the CP and EP events.

Thus, we think these methods are sufficient to discover the ENSO events for our study. Multivariate ENSO Index (MEI) is also an efficient method to identify the El Niño/ La Niña. However, it is not for the CP/EP events. The Central-Pacific (CP) type has sea surface temperature (SST) anomalies near the Date Line, and the Eastern-Pacific (EP) type has anomalies centered over the cold tongue. They are not equal to the neutral stages named by MEI. We have noticed the list of MEI events, but are confused by the years identified. For example, the period of 2010-2011 is a traditional La Niña, which emerged in year 2010 and gradually vanish in year 2011 (it is identified by other indices, and also presented by a movie in https://www.esrl.noaa.gov/psd/enso/past_events.html), but this year is not on the list.

C3: *Some precipitation indices presented in the paper are wrongly termed as "new" (line 88), while they have been used by the WMO and several other studies (see for example Zhang et al., 2011, Alexander et al., 2013).*

R3: These indices are not original found in our study. Sorry about the incorrect statement. We have rephrased the sentence.

C4: *The paper needs a wider literature review on hydrological impacts of ENSO. There are important works which are overlooked, leading to mistakenly labelling the central pacific El Nino as a new type (Line 67-70) while it has been recognised since, at least, 2005 (Larkin and Harrison, 2005; Hu et al., 2016). Also see Emerton et al. (2017) for the likelihood of ENSO-driven global flood hazard.*

R4: As is implied in our introduction, the Central-Pacific (CP) type develops in regions of warming SSTs in the Pacific near the International Date Line, while the Eastern-Pacific (EP) type has anomalies centered over the cold tongue. It is not a very newly finding about the emergency of CP events, but it has recently been emphasized as CP appears to induce climate anomalies that are distinctly different than those produced by the canonical EP. In addition, CP has been occurring more frequently in recent decades. Therefore, in our study, we emphasize it as the 'new type' flowing the other studies, such as McPhaden et al. (2006), Yeh et al. (2009), Ren and Jin, (2011), and Yu and Kim (2013).

Thanks for the introduction of the newly excellent article, Emerton et al. (2017). We have reviewed many studies about the precipitation extremes and hydrological consequences of ENSO. For example, Ward et al. (2014) examined peak daily discharge in river basins across the world to identify flood-vulnerable areas sensitive to ENSO. Perez et al. (2011) modelled non-contiguous and contiguous drought areas to analyze spatio-temporal drought development. Water storage is another index typically used to detect frequency and magnitude of droughts during ENSO events (Veldkamp et al., 2015; Zhang et al., 2015). The precipitation extremes can indicate the risk of floodings and droughts. As one of our objectives in this study, we intend to propose possible changes in precipitation extremes induced by ENSO responsible for the anomalies in precipitation amount, frequency, and intensity. However, as there is a nonlinearity between precipitation and flood magnitude, probabilities have large uncertainties due to accuracy of the data and clear differences between the hydrological analysis and precipitation (Emerton et al., 2017).

Other comment

C5: *Other comments: - The three phases of ENSO as commonly known are Neutral, ElNiño or La Niña. It is a bit confusing the way it is used in the title. -*

R5: We would like to emphasize the three types of ENSO (SP, EP, and LN) in the title. If you think the word 'phases' is very confused, we can consider to change it into 'types'.

C6*: Line 47-50: break the sentence into two. - Line 84: remove one bracket - Line 87: what do you mean by amount? Possibly to mean "duration, intensity and frequency"? - Line 96: 2011 is not new. - Table 2. Number of wet days is not really extreme. - What is the threshold for the definition of we days (e.g., 0mm/day)? .*

R6: -The sentences in line 47-50 and line 84 have been revised. -Precipitation amount means annual amount of precipitation. -We have rephrased it in new version. -The sentences in line 96 has been rephrased. -Number of wet days is the precipitation frequency, one of our indices in Table 1. -The threshold of the definition of wet days is 0 mm/day, as the trace precipitation has been deleted in the data processes. The description has been added in the Table 1.

C7*: Are the El Nino/La Nina years excluded from the calculation of the multi-year average?*

R7: The CP, EP and LN are included in our multi-year average (1971-2000). The 30-year time period can include the ENSO variable and other climatic factors, but we consider the long-time period can be used to represent the basic condition of local climate.

C8*: - The blue shading in figures 2, 4, and 5 are interchanged. The dark blue should correspond with the intense rainfall.*

R8: Thanks for his/her chariness and responsibility. We have updated the figure 2, 4, and 5.

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

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

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

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

ENSO events are also well-known for causing extreme hydrological events (Moss et al., 1994; Chiew and McMahon, 2002; Veldkamp et al., 2015) such as floods (Mosley, 2000; Räsänen and Kummu, 2013; Ward et al., 2014) and droughts (Perez et al., 2011; Zhang et al., 2015) which in turn cause broad-ranging socio-economic and environmental impacts. Various approaches have been introduced to reveal these impacts at global and regional scales. For example, Ward et al. (2014) examined peak daily discharge in river basins across the world to identify flood-vulnerable areas sensitive to ENSO. Perez et al. (2011) modelled non-contiguous and contiguous drought areas to analyse spatio-temporal drought development. Water 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 Centre 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). Annual amount and precipitation intensity and frequency were used to formulate precipitation characteristics. Four other indices were introduced (Zhang et al., 2011), and used to analyse precipitation extremes in this study (Table 1).

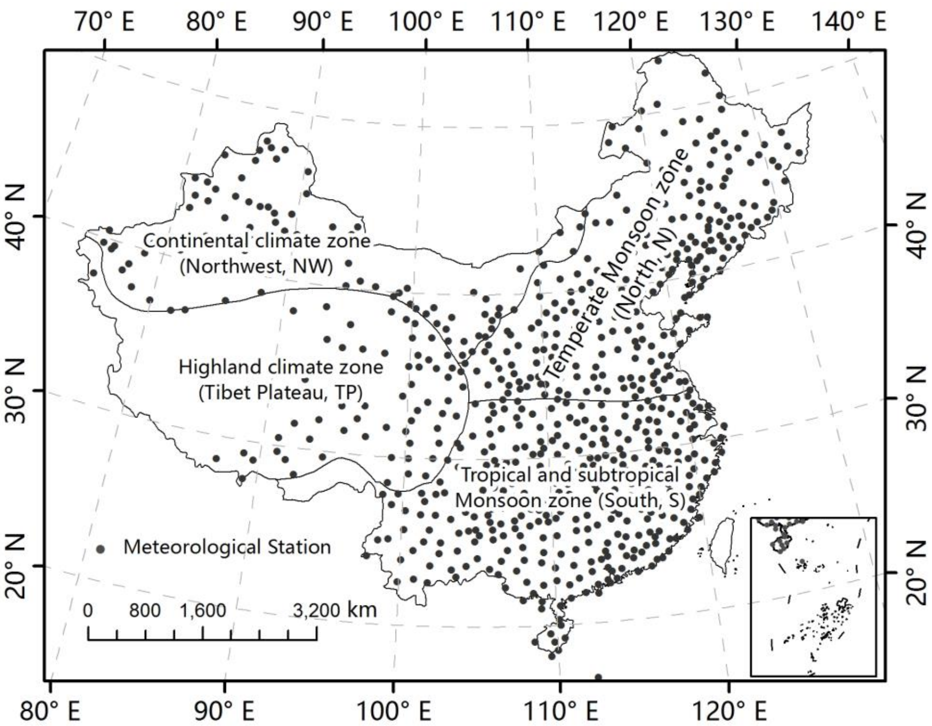


Fig. 1. The distribution of the 713 meteorological stations used in this study. China is divided into four regions based on main climatic types. The two non-monsoon regions are the continental climate zone (Northwest, NW) and the highland climate zone (Tibet Plateau, TP). The monsoon region is divided 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 indices created by Ren and Jin (2011) by transforming the traditionally-used Niño3 and Niño4 indices 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) analysed 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 it 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 disappears and is replaced by cool anomalies in the eastern Pacific, which occurs during summer of the next year (decaying year). Precipitation indices were calculated in both ENSO developing and decaying years. Indices for precipitation anomalies were analysed as follows:

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

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

Table 2. ENSO years from 1960 to 2013

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

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, CW, or LN), and the other series represents precipitation series under normal years. This test was applied to evaluate the significance of precipitation anomalies, performing at a significance level of 5%.

3 Results

3.1 Annual rainfall anomalies

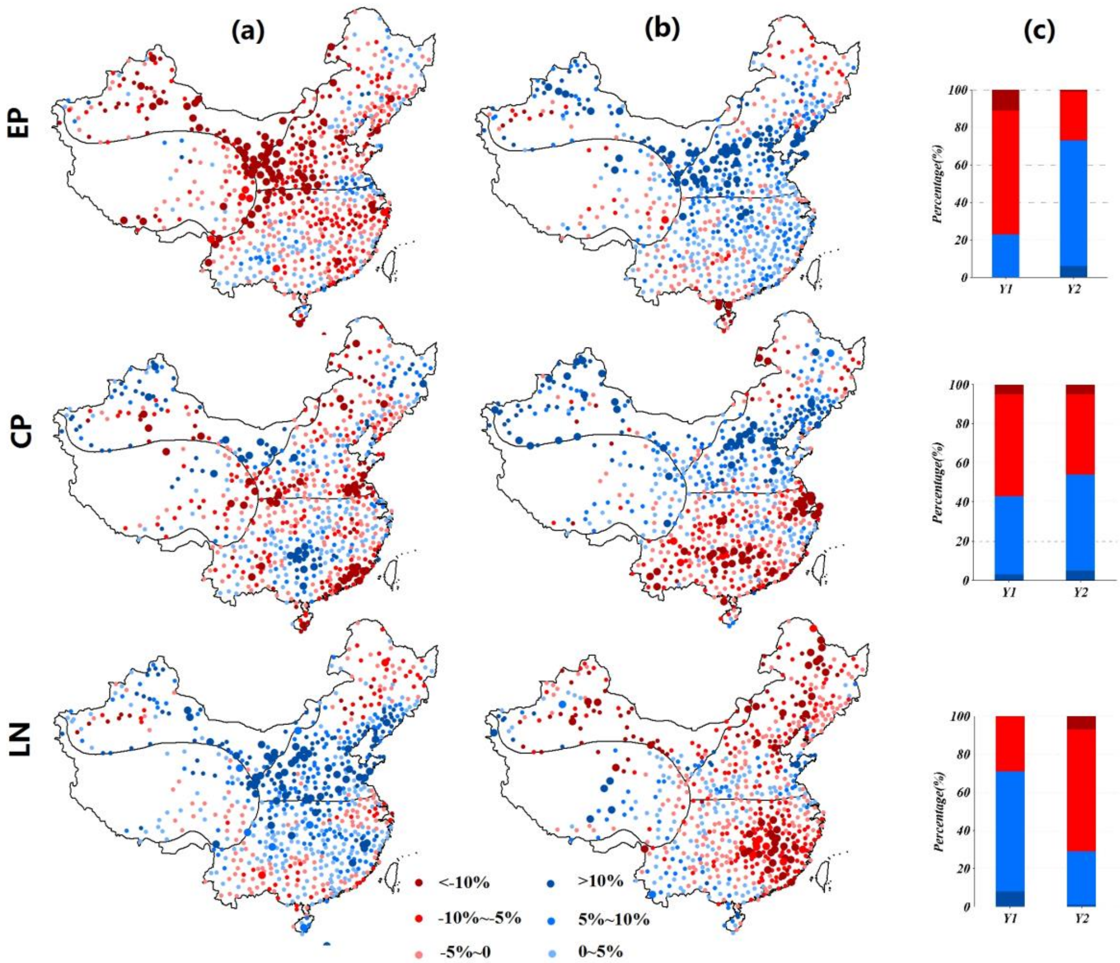


Fig. 2 Anomalies of annual precipitation in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing increases or decreases in the number of rainfall anomalies are shown in (c), with significant increase (blue), increase (light blue), decrease (light red), and significant decrease (red). Y1, Y2 represent developing years and decaying years, respectively.

In EP developing years, 628 stations across China (~80%) had negative anomalies. At 80 of these stations the anomalies were significant. These significant stations were mainly located in the continental climate zone (NW) and the temperate monsoon zone (N) (Fig. 2). All sub-regions experienced negative average annual precipitation anomalies (Fig. 3), especially in the NW region where precipitation was 12.83% lower than the mean. Large positive anomalies of annual precipitation were found during LN developing years (Fig. 2); more than 70% of the stations showed positive anomalies, of which 10% were significant. Similarly, the stations with significant anomalies were mainly in the NW and N regions. In CP developing years, precipitation anomalies were quite different from those in EP developing years (Fig. 2). The proportion of stations with negative anomalies was 57%, but with no clear pattern of distribution.

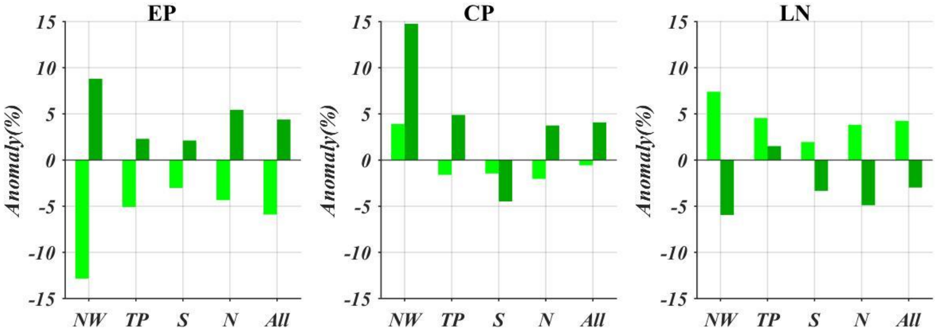


Fig. 3 Average annual precipitation anomaly by sub-region during EP, CP, and LN phases. Light color represents developing years and dark color represents decaying years.

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).

3.2 Rainfall frequency and intensity anomalies

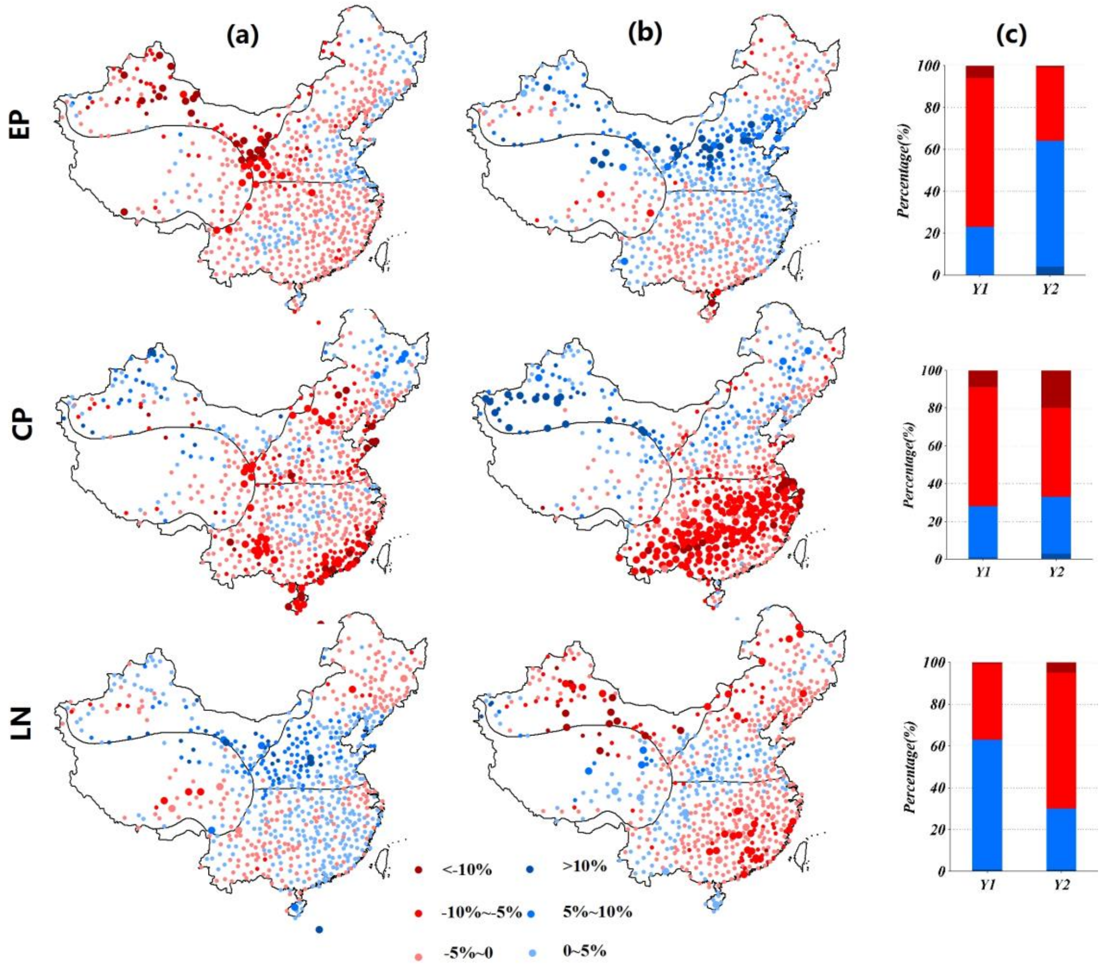


Fig. 4 Anomalies of precipitation frequency in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing anomalies of precipitation frequency are shown in (c), with significant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

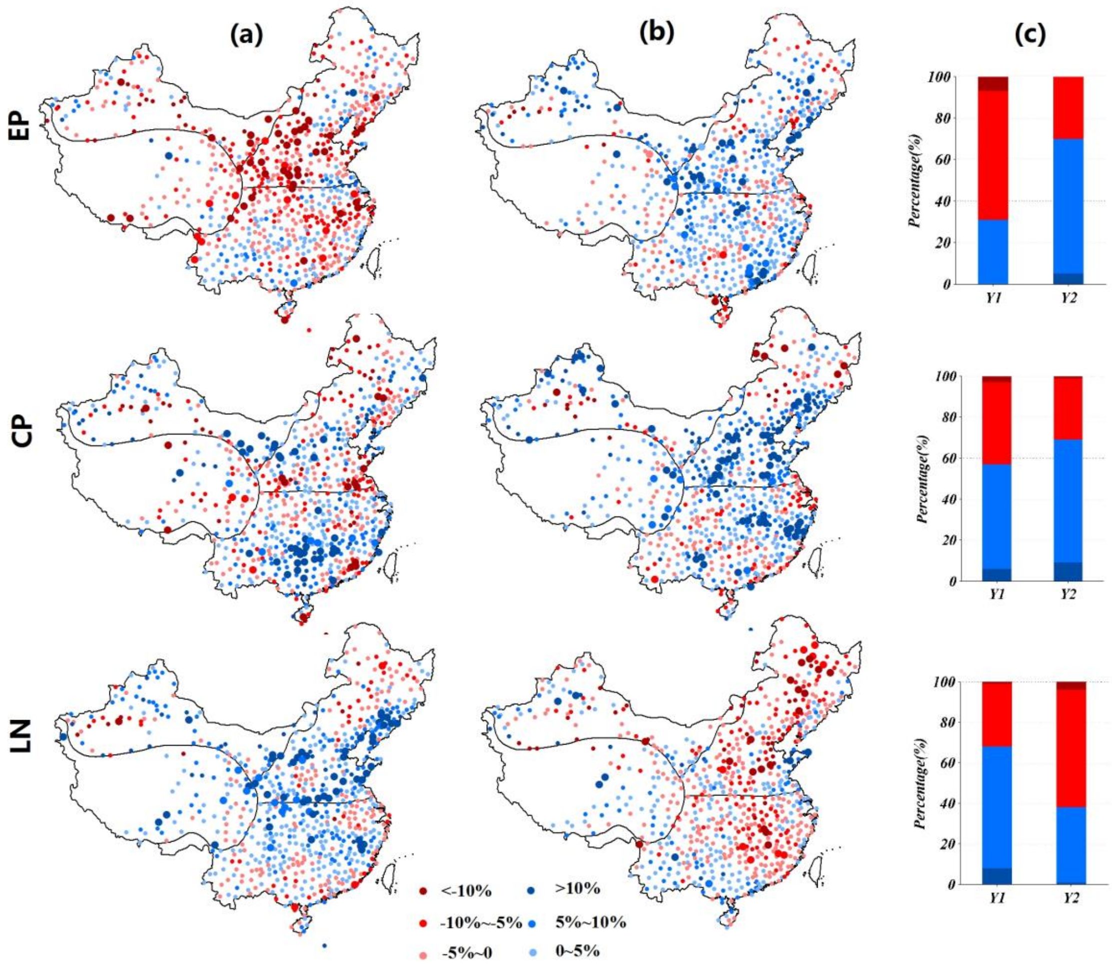
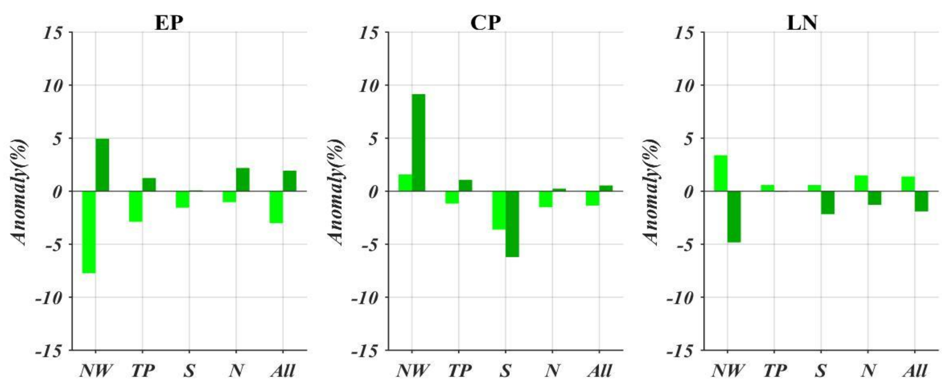
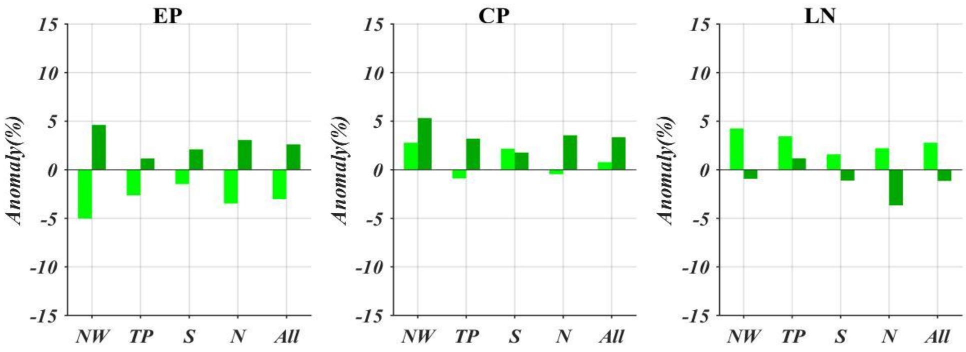


Fig. 5 Anomalies of precipitation intensity in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing anomalies of precipitation frequency are shown in (c), with significant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



(a)



(b)

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

Precipitation anomalies during the developing and decaying years of ENSO displayed inverse patterns as well. For example, a decrease in annual precipitation occurred across China during EP developing years, but an increase occurred during EP decaying years. Similar results were observed by Wu and Hu (2003) who documented seasonal rainfall anomalies in East Asia, finding that the rainfall correlation distribution displayed pronounced differences between developing and decaying ENSO years. This inverse relationship suggests a potential teleconnection between atmospheric responses in mid-latitude and the evolution of the SST anomaly over the tropical Pacific. During the developing stage, the warming SST anomaly of EP begins expanding during spring and reaches its maximum magnitude in autumn and winter (Feng et al., 2011). But during the following summer, during the ENSO decaying stage, the warming SST anomaly disappears and is replaced by a cool anomaly in the eastern Pacific. In contrast, the evolution of La Niña displays a reverse pattern that is supported by the same study which shows that the decaying and developing stages had opposite influences on rainfall over China. However, when CP phases occur, these inverse teleconnections seem to disappear. The CP decaying stage exerted a large influence on daily precipitation in China during decaying years, but in developing years it had little impact. The different teleconnections between EP and CP phases reflect differences in atmospheric responses to the evolution of the SST anomaly; CP phases progress more slowly and their peak state is of a shorter duration despite originating from a warmer background SST (Kim et 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 whether the CP occurrence is part of a recurring natural cycle, like the Pacific multi-decadal oscillation, or the result of a 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 repsonse 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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