# Reply to the comment of Dr. Q. Zhang:

We pay our highest tributes to his valuable comment. We would like to mention that we noticed previous studies on ENSO-climate teleconnections and reviewed the progress in their theory and frontier research issue in the introduction part of our manuscript. The following are the detailed explanations for our scientific focus, methodology, and main findings. 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.

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*'I read with great interest this paper, but found it boring and meaningless. Actually, there are numerous researches addressing precipitation changes and relevant connections to ENSO, and other global climatic signals. However, I cannot find anything new or novel from this paper in terms of methods, idea and even results and conclusions.'*

As an influential ocean-atmosphere phenomenon, ENSO has been reported to exert enormous changes on climate and hydrology over the world, especially around the Pacific Rim (e.g. Gershunov and Barnett, 1998; Gong and Wang, 1999; Yeh et.al, 2009). In China, ENSO dominates parts of the abnormal signals in monsoon systems. Various studies have extensively documented the teleconnections between ENSO and precipitation anomalies in different spatio-temporal scales (e.g. Lin and Yu, 1993; Huang and Wu, 1989; Zhou and Wu, 2010). However, most studies have focused on changes in annual or seasonal precipitation amount related to ENSO rather than changes in individual precipitation events. The changes of frequency and intensity are also crucial to assess the ENSO impacts; however, the changes in mean precipitation cannot tell us how precipitation frequency and intensity will change. On the other hand, possible shifts in characteristics of precipitation events, e.g. frequency and intensity, have been highlighted in studies of climate change around China (Zhai et al., 2005). The anomalies in precipitation amount derive directly from anomalies in its frequency, intensity, and precipitation events and their extremes are direct indicators more relevant to hydrology than annual and monthly amounts. What's more, precipitation extremes, such as consecutive wet days and dry spells, which directly relate to droughts and floods, have rarely been addressed in previous studies of ENSO over China.

Thus, we use a comprehensive set of precipitation indices in this study to reach our main objectives: (1) describe ENSO-induced precipitation anomalies between developing and decaying stages; (2) compare the anomalies of precipitation frequency and intensity with those of annual amount; and (3) propose possible changes in precipitation extremes responsible for these anomalies. In the goal-oriented analysis, this study highlights the new type of El Niño events, Central Pacific El Niño, and differences between developing and decaying stages.

Also, in the new version of our manuscript, possible driving mechanisms behind the anomalies of precipitation events are analysed in our discussion. We highlight the importance of summer monsoon and tropical cyclone (TC) in our explanation, which are based on plentiful previous studies on the reason causing the regional patterns we find. This analysis further extends our research into a more solid description. Thus, one more goal can be added: the anomalies of summer monsoon activity and tropical cyclone induced by ENSO and their relationship with the rainfall anomalies. We look forward to more critical comments for this manuscript.

Our innovation is to integrate potential anomalies in characteristics of precipitation events with those in precipitation amount to inform climate and hydrology policy and describe the possible driving mechanisms behind the rainfall anomalies. We respect his opinion about our research innovation, but we think our study have proposed very interesting research gaps where a sufficient attention was paid in previous studies. We hope he was willing to reread our manuscript and rethink the scientific problems we put forward.

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*'Besides, the authors of this paper presented statistical results only but no causes and physical mechanisms were discussed with enough evidences. Therefore, I cannot take this study as a real study. It is nothing but a simple statistical analyses. In general, this paper lacks novelty in methods, idea and even conclusions. No new findings can be found. What's more, it is a kind of repeated work, in this sense, I do think it is boring to read such a repeated work.'*

First of all, in the new version of our manuscript, possible driving mechanisms behind the anomalies of precipitation events are analysed in our discussion. We highlight the importance of summer monsoon and tropical cyclone in our explanation, which are based on plentiful previous studies on the reason causing the regional patterns we find. This analysis further extends our research into a more solid description.

Besides, the manuscript has many other points deserved to be considered as new findings.

In the methodology, we adopt a commonly used way to obtain the anomalies of signals and test the anomalies by the nonparametric Mann–Whitney U (Teegavarapu et al., 2013). Although there is very limited creativity in our methodology, it is worth mentioning that meteorological stations from National Meteorological Centre in China have undergone rigorous selection process into our dataset to omit possible non-climatic noises (Qian and Lin, 2005; Qu et.al.2016). This process is not an easy task, includes extreme value and consistency check, spatial outliers test, and homogeneity test, but 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.

Many interesting findings are discovered in the anomalies of precipitation events. For example, Eastern Pacific (EP) El Niño caused less precipitation in developing years and more precipitation in decaying years, but a clear pattern was only found in decaying Central Pacific (CP) El Niño (fig.2). Anomalies of the amount in EP roughly paralleled anomalies in frequency and intensity, but the anomalies were altered in CP (fig. 3 &4). In CP decaying years, negative anomalies in frequency (Southern China) and positive anomalies in intensity (Northern China) resulted in the total pattern, that means the anomalies of the amount in different regions were dominant by different contexts of precipitation events. In CP developing years, however, clear anomalies in characteristics of precipitation events didn't induce obvious anomalies in the amount across China. Our study provides in-depth explanation in the ENSO-induced precipitation anomalies which is little mentioned in previous studies. More findings can be derived from such comparisons above.

Moreover, this study explains what precipitation extremes ENSO events have triggered and what linkages are there with the anomalies of the amount. For example, 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, which supplemented the linkages between anomalies of the amount and those of frequency and intensity. In addition, risk of floods and droughts may be directly revealed by anomalies of precipitation extremes, such as probable droughts in EP developing years while probable floods in EP decaying years.

The regional distributions of the anomalies in the contexts of precipitation events are very complex, and thus the anomalies of precipitation amount should be treated with care to further inform climate and hydrology policy, such as adaptation efforts ahead of extreme events. Regionally, we found that the continental climate zone of China is more sensitive to ENSO than other regions based on the region's high incidence and magnitude of anomalies in precipitation events.

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*'I cannot suggest acceptance because of its lowest quality and presentation quality.'*

Finally, we respect all his opinions, but we hope he was willing to reconsider our innovation in ideas and findings and accept our manuscript for this publication.

We express sincere thanks to him for his efforts again!

# 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, Referee #1, and Referee #2.

**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 analyzed in our discussion. We highlight the importance of summer monsoon and tropical cyclone in our explanation, which are based on plentiful previous studies on the reason causing the regional patterns we find. However, on daily scale the direct evidence is hard to provide as the daily weather system is very complex to analyse. 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, wet days means the day with precipitation > 0 (data with trace amount have been deleted); definition of $95^{th}$ 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 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 (the decaying year); We have added "decaying" between "CP" and "phases". 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 line192-193 has 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 support 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.6 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) cyclone has been added in our manuscript: as well as the relationships with East Asia summer monsoon. Variation of the 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

Brunetti, M., Maugeri, M., Monti, F., & Nanni, T. (2004). Changes in daily precipitation frequency and distribution in Italy over the last 120 years. *Journal of Geophysical Research: Atmospheres, 109*(D5).

Karl, T. R., & Knight, R. W. (1998). Secular trends of precipitation amount, frequency, and intensity in the United States. *Bulletin of the American Meteorological society, 79*(2), 231-241.

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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 floods 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 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 fig. 2, 4, and 5.

What's more, in the new version of our manuscript, possible driving mechanisms behind the anomalies of precipitation events are analysed in our discussion. We highlight the importance of summer monsoon and tropical cyclone in our explanation, which are based on plentiful previous studies on the reason causing the regional patterns we find. We look forward to more critical comments for this manuscript.

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~~On the other hand, more dry spells (DS) occurred in EP developing years, suggesting an increased likelihood of droughts during this phase~~.~~. Possible mechanisms responsible for these rainfall anomalies are speculated by the summer monsoon and tropical cyclone anomalies in ENSO developing and decaying years.

**Key words: ENSO, daily precipitation, climate extremes, summer monsoon, tropical cyclone, 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, although 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 northern and southern 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 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 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 physical mechanisms by which ENSO affects the climate of East Asia ~~(EA)~~ ~~climate~~ have also been discussed ~~with great emphasis~~extensively in recent ~~over past~~ decades. Many studies have revealed that ~~the~~ anomalous summer monsoons ~~plays a crucial role in the~~contribute to rainfall anomalies in East Asia during ENSO. A wet East Asian summer monsoon tends to occur after warm eastern or central equatorial Pacific SST anomalies ~~in~~during the previous winter (Chang et al., 2000). Floods and droughts during ENSO are also associated with the anomalous water vapor transport caused by the anomalous summer monsoon (Chang, 2004). On the other hand, tropical cyclones (TCs) over the western North Pacific (WNP) ~~is~~are also ~~a~~ key contributors to ~~the~~ rainfall events~~formation~~ in ~~over~~ China. When TCs move westward, a huge amount of moisture is transported into East Asia ~~continent~~, accompanied by strong winds and heavy and continuous rainfall. By using satellite-derived Tropical Rainfall Measuring Mission (TRMM) data, Guo et al. (2017) revealed that TCs occurring during the~~TC~~ peak TC season (from July to October, JASO~~-~~) contributed ~20% of ~~the~~ monthly rainfall and ~55% of daily extreme rainfall over the East Asian coast. Strong TC activity ~~implies~~suggests that there is excessive transport of water vapor ~~transport~~into ~~for precipitation in~~ China.

Until recently, most studies have focused on changes in annual or seasonal total precipitation related to ENSO rather than changes in individual precipitation events. ~~The c~~Changes ~~of~~in precipitation frequency and intensity are ~~also~~ crucial ~~to~~for accurate assessment of ~~assess the~~ ENSO impacts, but~~; however, the~~ changes in mean precipitation cannot identify such changes ~~tell us how precipitation frequency and intensity will change~~. ~~On the other hand,~~Recently, however, ~~P~~possible shifts in the 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~~has been reported that the number of annual rainfall days ~~has~~ decreased in recent decades even ~~though~~while total annual precipitation has changed very little ~~in the past few decades~~ (Zhai et al., 2005). Precipitation intensity has also changed significantly 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 impacts of ENSO events on precipitation frequency and intensity is critical to understanding ENSO-precipitation teleconnections in China. 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; (3) ~~the~~anomalous ~~anomalies of~~ summer monsoon ~~activity~~ and ~~tropical cyclone (~~TC~~)~~ activity induced by ENSO, and their relationships with rainfall anomalies. 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 the dataset analysis (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~~ Annual precipitation amount, as well as~~, and precipitation~~ intensity~~,~~ and frequency of precipitation events, were used to formulate precipitation characteristics. Four ~~new~~other indices were introduced (Zhang et al., 2011), and used to analyse precipitation extremes in this study (Table 1). Precipitation indices were calculated ~~in~~for ENSO developing and decaying years. Indices for precipitation anomalies were analysed as follows:~~.~~

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

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

To quantify the variability of the summer monsoon and ENSO impacts over China, the monsoon index proposed by Wang and Fan (1999) ~~is~~was used in this study. It is defined ~~by~~as the 850hPa wind speed averaged over ~~(~~5 ºN-15 ºN, 100-130 ºE~~)~~ minus ~~that~~the wind speed averaged over ~~(~~20 ºN-30 ºN, 110-140 ºE~~)~~, and is frequently used ~~for~~to study~~ing~~ interannual and decadal variability of summer monsoons over the western North Pacific-East Asian region (WNP-EA). For ~~the~~ TC activity, the best-track dataset from the Joint Typhoon Warning Center ~~is~~was obtained ~~on Wed site~~at ~~(~~http://www.metoc.navy.mil/jtwc/jtwc.html~~)~~. Following the methods by Kim et al. (2011), ~~the~~ TC genesis and track density ~~is~~was generated ~~in~~for ~~the~~ ENSO developing and decaying years for the period 1960-2013. ~~The~~T~~t~~rack density anomalies are defined as annual average TC frequency during a specific type of ENSO event minus the long-term mean value in each 2°×2° grid box.

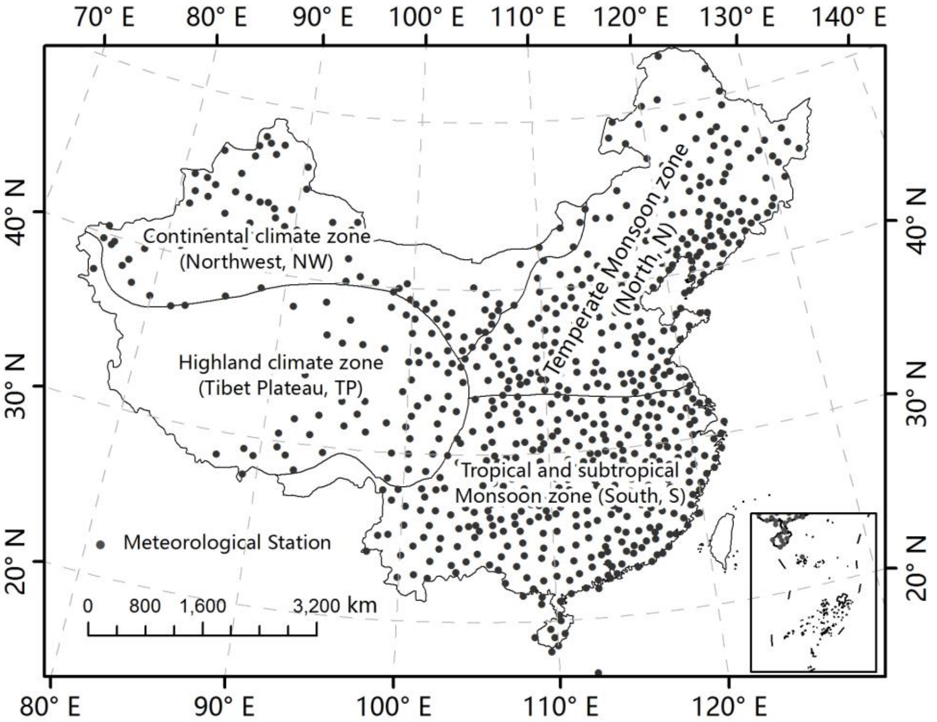



**Fig. 1.** ~~The~~D~~d~~istribution of the 713 meteorological stations used in this study. China is divided into four regions based on ~~main~~ climatic types. The two non-monsoon regions are the continental climate zone (Northwest, NW) and the highland climate zone (Tibet Plateau, TP). The monsoon region is divided into two ~~parts~~regions: 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~~Annual precipitation | Annual total precipitation ~~from wet days~~ | mm |

| | | | |
|---|---|---|---|
| Intensity | ~~Simple d~~Daily intensity index | Average precipitation per rain event~~on wet days~~ (day with precipitation > 0) | mm/day |
| Frequency | Number of ~~wet~~rainy days | Annual number of~~r~~ rainy~~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 ~~average~~ 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 events ~~means~~are the 95th quantile~~s~~ of the daily precipitation distribution over ~~the~~ multiple- years ~~(, represented by~~ 1971–2000). ~~–~~(P~~p~~ercentiles near 100 represent ~~very~~extremely intense precipitation).

In this study, two ~~new~~ indices, created by Ren and Jin (2011) 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. ~~Precipitation indices were calculated in both ENSO developing and decaying years.~~ As an EP El Niño evolves, ~~the~~ positive SST anomalies expand~~s~~ latitudinally and negative signals expand eastward, ~~and~~reaching~~ then reaches it~~ a maximum amplitude in autumn and winter (Feng et al., 2011). The first year ~~is~~was defined as the ~~aXXX~~ developing year ~~in~~in this study. ~~Finally, the w~~Warm SST anomalies disappear~~s~~ and ~~is~~are replaced by cool anomalies in the eastern Pacific~~, which occurs~~ during summer of the ~~next year (~~decaying year~~)~~. ~~Indices for precipitation anomalies were analysed as follows:~~

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

~~Where $\overline{PI_{ij}}$ is the average of the $i$ precipitation index in the $j$ meteorological station in a specific segment, 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

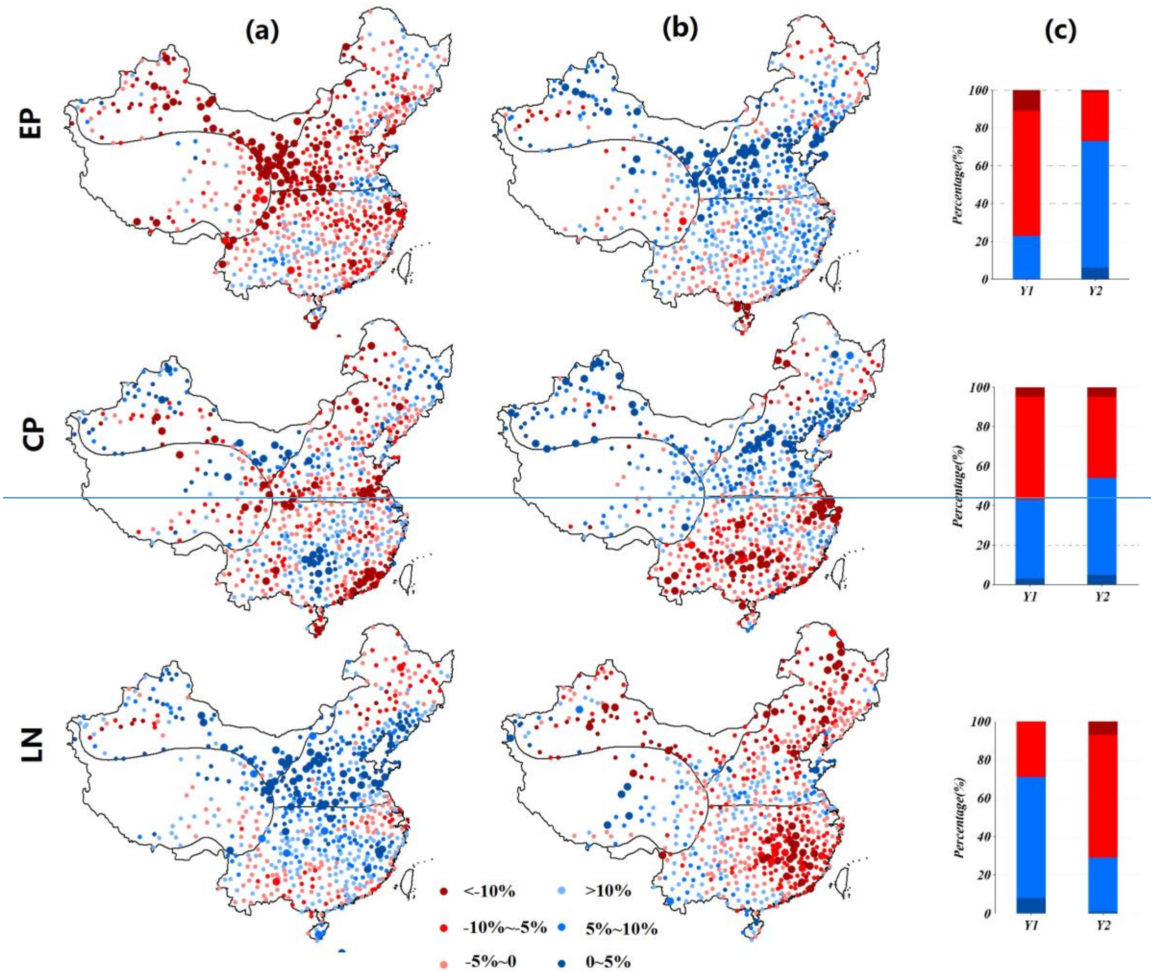
| Phase | Eastern Pacific (EP) El Niño | Central Pacific (CP) El Niño | La Niña (LN) |
|---|---|---|---|
| Year | 1963 1965 1969 1972 1976 1982 1986 1991 1997 2006 | 1968 1977 1987 1994 2002 2004 2009 | 1964 1967 1970 1973 1975 1984 1988 1995 1998 2007 2010 |

The Mann–Whitney U test is a nonparametric test applied to site data ~~that~~ which does not conform to normality even after several ~~different~~ transformations are ~~carried out~~performed (Teegavarapu et al., 2013). It tests whether two series are independent from each other~~samples from different continuous distributions~~. One series represents precipitation ~~series under~~during an~~ type of~~ ENSO event phase (EP, CW, or LN), and the other series represents precipitation ~~series under~~during

~~normal~~average 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



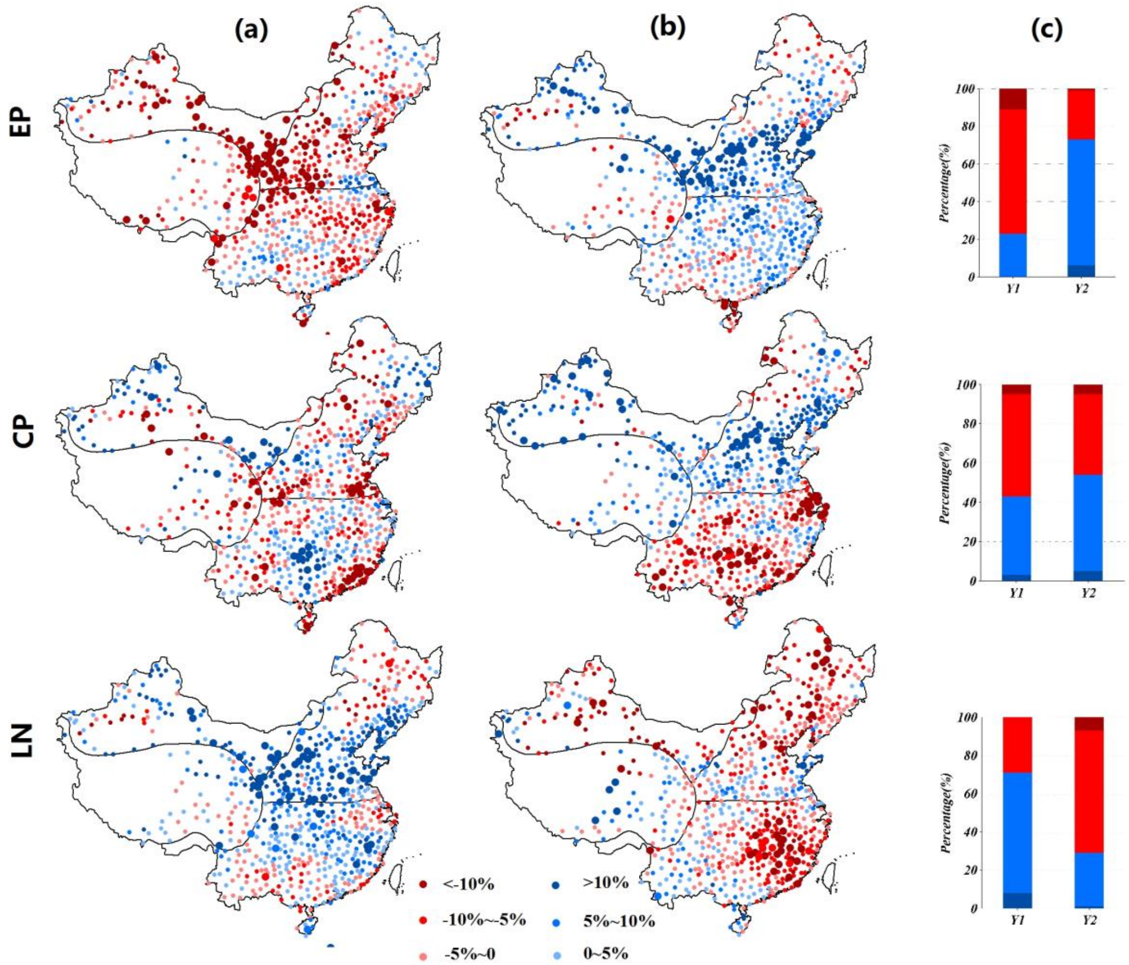



**Fig. 2** Anomalies of annual precipitation in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing increases or decreases in the number of rainfall anomalies are shown 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.

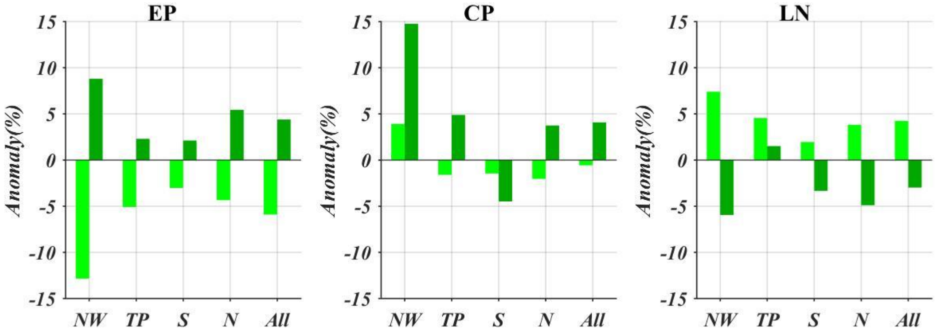
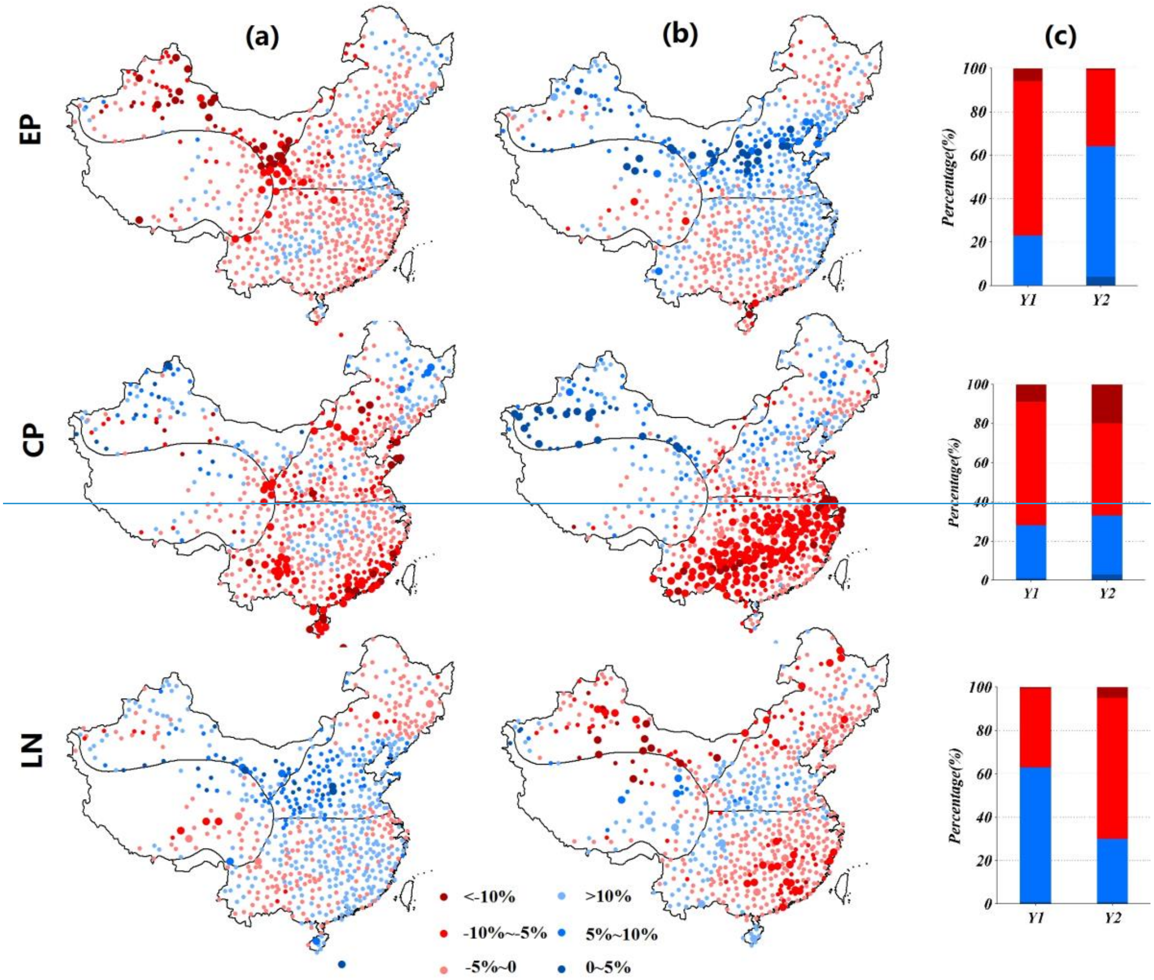



**Fig. 3** Average annual precipitation anomaly by sub-region during EP, CP, and LN phases. Light color represents developing years and dark color represents decaying years.

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



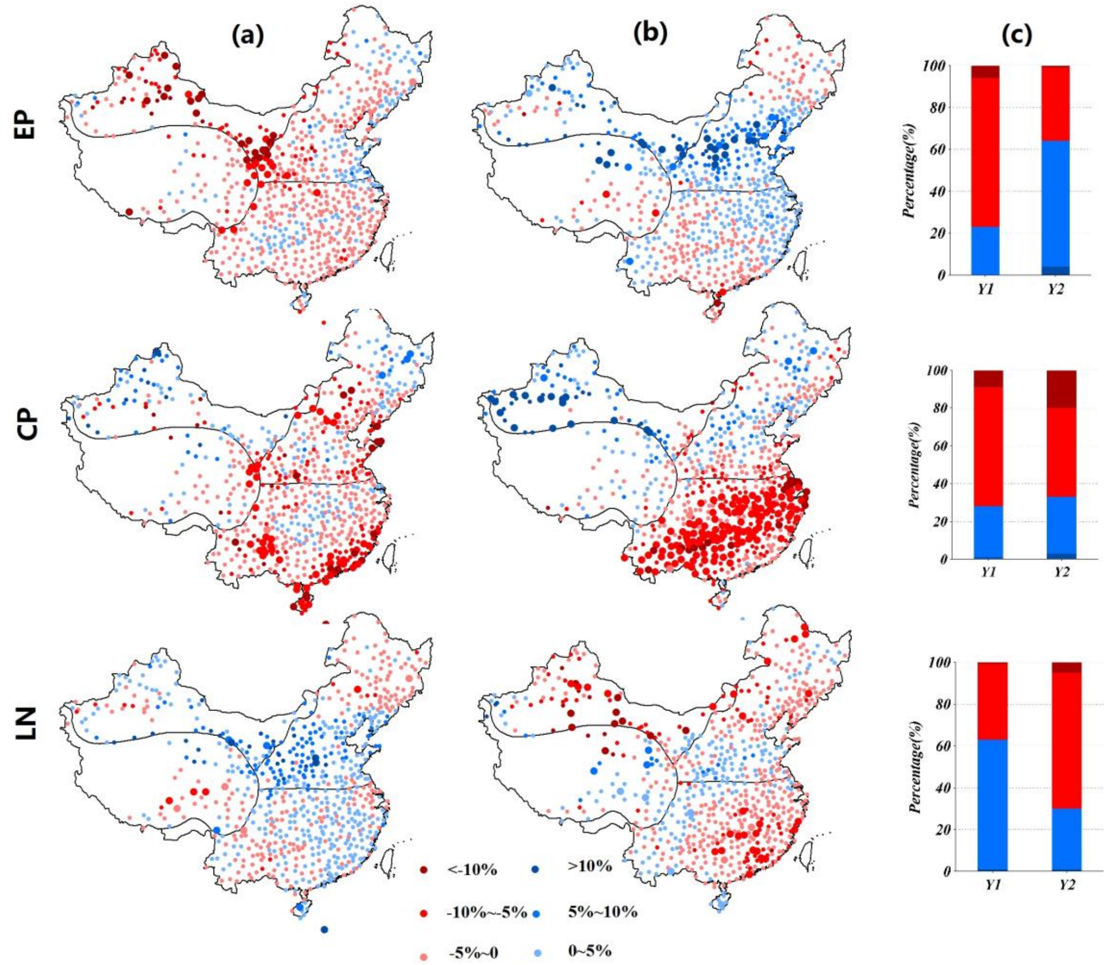
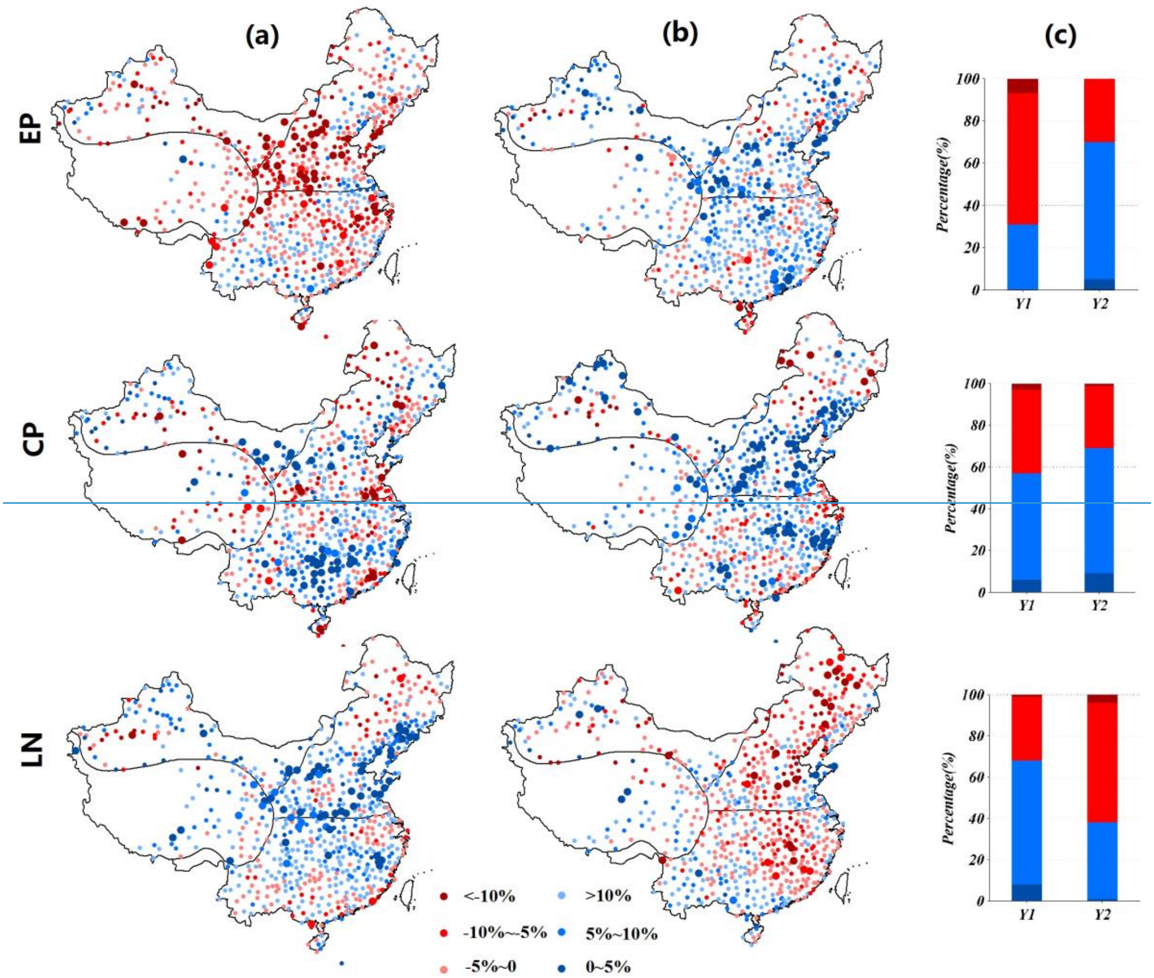



**Fig. 4** Anomalies of precipitation frequency in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing anomalies of precipitation frequency are shown in (c), with significant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


(a)
(b)
(c)
EP
CP
LN
Percentage(%)
Y1
Y2
<-10%
-10%~-5%
-5%~0
>10%
5%~10%
0~5%

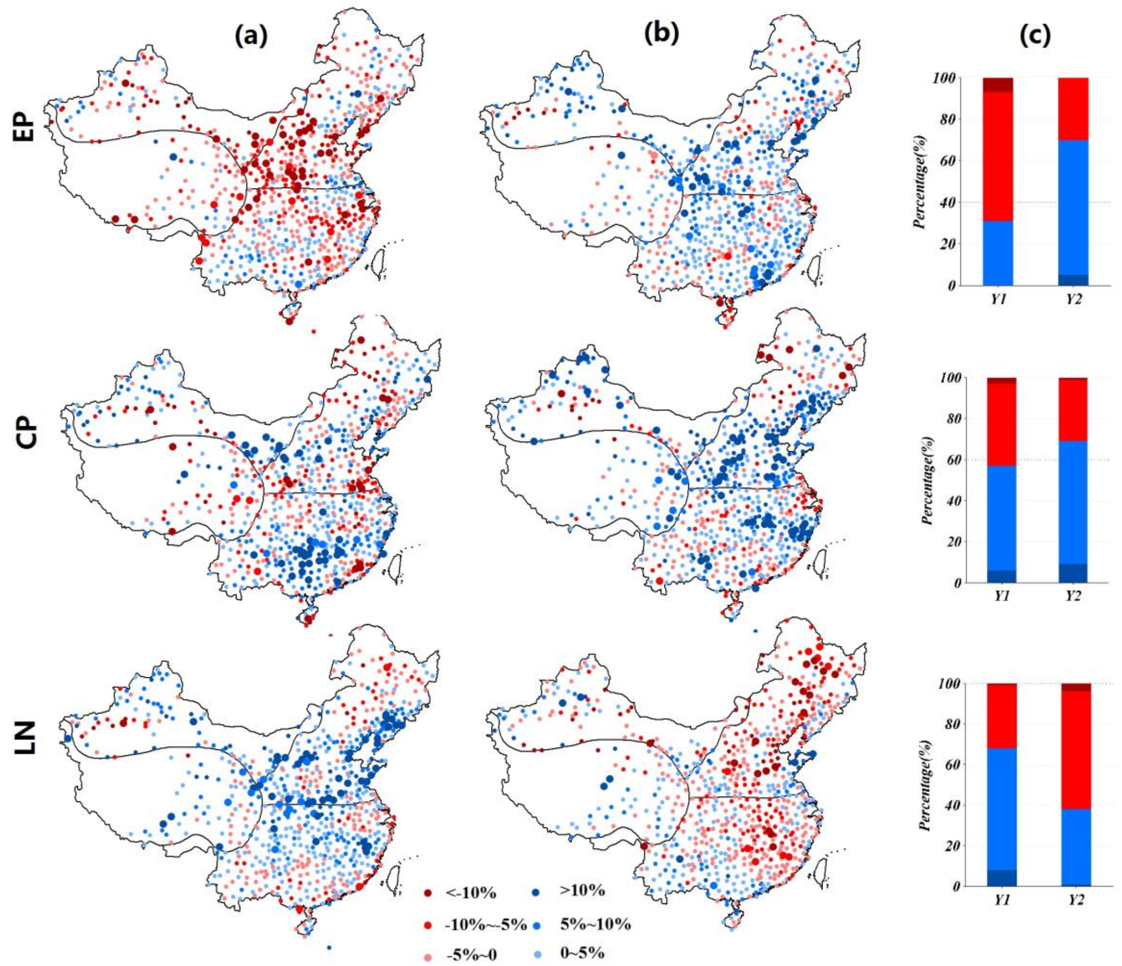
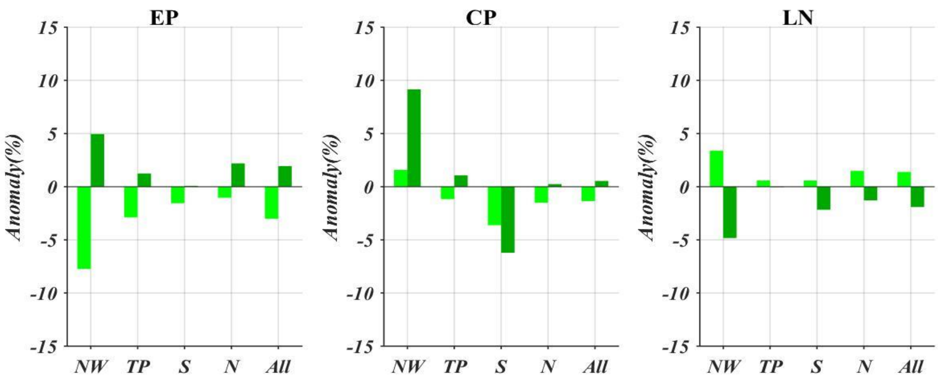
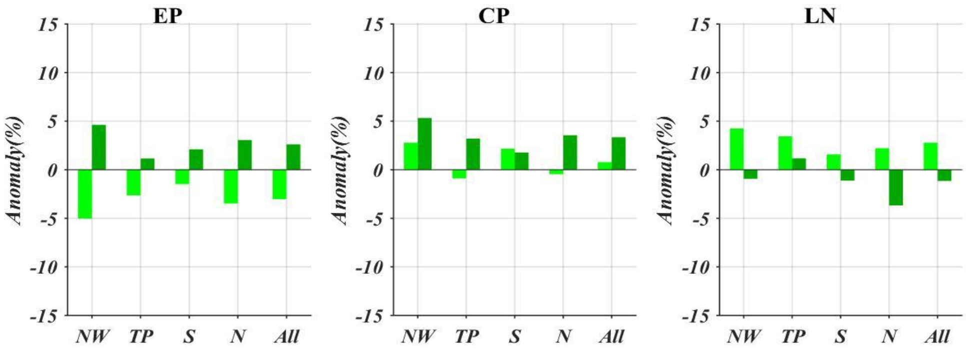



**Fig. 5** Anomalies of precipitation intensity in developing years (a) and decaying years (b) of EP, CP, and LN phases. Stations experiencing significant anomalies are represented by large points. The percentage of stations experiencing anomalies of precipitation frequency are shown in (c), with significant 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~~ and increase~~, runoff, ~~but also increase ~~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 ~~nevertheless ~~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~~

~~The~~S~~ s~~ummer monsoons over East Asia (EA) consist~~s~~ of staged progressions of zonally~~–~~-oriented rain belts ~~when~~as ~~the~~ fronts advance~~s~~ and ~~withdraws~~retreat. Huang and Wu's (1989) study first revealed that ~~this~~these summer monsoon rain belts are closely ~~related~~linked ~~to~~with ~~the stages of ~~ENSO cycle phases. Figure 7 shows the mean WNP-EA monsoon index and its significant~~ce in~~ difference from ~~the long-term~~average conditions (1971-2000).

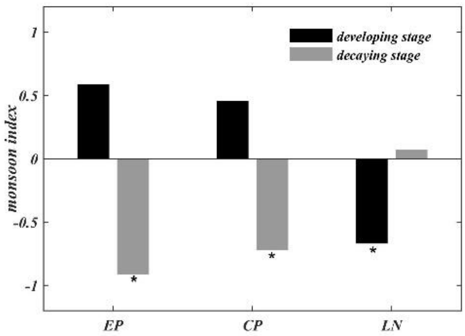



**Fig. 7** The western North Pacific-East Asian (WNP-EA) summer monsoon index ~~in~~during different ENSO phases (average for 1971-2000 is -0.007). * 95% significance

Results reveal that the WNP-EA monsoons tend to be weak ~~in~~during ~~the~~ EP decaying years (fig. 7). Wang et al. (2001) showed that a weak WNP-EA monsoon usually features enhanced rainfall along the monsoon's front over East Asia. As ~~to~~for the mechanism, ~~the~~ anomalous anticyclones in the subtropical WNP ~~is~~are ~~found~~ the key systems linking the ENSO and the East Asian climate (Feng et al., 2011; Wang and Chan, 2002; Wang et al., 2001; Yuan et al., 2012). ~~The~~An anomalous WNP anticyclone during a weak WNP-EA monsoon ~~will~~ brings plentiful moisture to southern China; meanwhile, it can also shift the ridge of the sub-tropical high westward (Feng et al., 2011). When summer monsoons advance and retreat along the WNP anticyclone fronts, heavy and continuoues rainfall ~~usually~~typically develops ~~over~~along the monsoon fronts (Chang, 2004). In this study, ~~the~~our examination of variations in precipitation anomalies reveals ~~the~~that rainfall is largely enhanced over the NW and N region during ~~the~~ EP decaying years (fig. 2).

Weak WNP-EA summer monsoons also tend~~s~~ to occur ~~in~~during CP decaying and LN developing years (fig. 7). ~~Generally~~Typically, ~~WNP~~ anomalous WNP anticyclones originate~~s~~ and develop~~s~~ ~~from~~during the previous autumn in the El Niño developing year and persist~~s~~ ~~through next~~until the following spring and summer before ~~the~~ intensities~~y~~ decrease~~s~~ (Wang et al., 2003). Yuan et. al (2012) found that ~~the evolution of~~ WNP anticyclones displays ~~–~~distinct location, intensity, and lifetime evolutions ~~for~~in the CP and EP El Niños due to the different anomalous SSTs in the equatorial Pacific. ~~The condition under T~~the EP El Niño tends to ~~is~~create ~~prone to form a~~ stronger, wider, and longer-lived WNP anticyclones than ~~that under~~the CP El Niño (Shi and Qian, 2018). In terms of~~the~~ rainfall pattern, the CP El Niño ~~phases~~ induced ~~some~~ asymmetric anomalies ~~which~~that do not follow the patterns seen in the EP El Niño (fig. 2). For example, during CP decaying years, the S region experienced a negative annual precipitation anomaly. ~~The~~A ~~a~~nomalous WNP anti-cyclones may explain this incongruity between the influences of the EP and CP El Niño phases, reflecting the potential for changes in atmospheric diabatic forcing over the tropics. In contrast, ~~the~~ weak WNP-EA summer monsoons ~~in~~during LN developing years possibly ~~associates~~correlate with the disappearance of~~a~~ EP ~~vanish in~~during ~~the~~ decaying years when ~~the~~ WNP anticyclones tend~~s~~ to re-invigorate and extend northwestward ~~towards~~and ~~the~~ inland ~~region~~ (Feng et al., 2011). Precipitation anomalies in China also reveal~~s~~ a marked consistency between EP decaying years and LN developing years (fig. 2).

Fig. 7 further reveals that ~~a~~ strong WNP-EA summer monsoons occur~~s~~ during ~~an~~ EP or CP developing years, although ~~it's~~ not significantly. However, only the EP developing stage induces a negative rainfall anomaly over China (fig.2). Similar results were observed by Wu et. al (2003), who documented seasonal rainfall anomalies in East Asia, finding that the rainfall correlation distribution displayed pronounced differences between developing and decaying ENSO years. ~~The~~A reversed monsoon signal~~s~~ ~~from~~between ~~the~~ developing and~~to the~~ decaying years suggests that~~implies the response of~~ WNP anticyclones respond in terms of ~~(~~location and intensity~~)~~ to the evolution of ~~the~~ SST anomalies over the tropical Pacific (Chang, 2004).

Using a climate model, Chou et al. (2012) found that changes in precipitation frequency and intensity are closely associated with changes in atmospheric water vapor and vertical motion. As demonstrated by Chou et al. (2012), an increase in water vapor reduces the magnitude of the ~~required~~ vertical motion required to generate ~~a~~the same strength of precipitation, resulting in ~~the~~an increase in precipitation frequency and intensity. Therefore, large amounts of water vapor transported during ~~the~~ EP and CP decaying years, or during LN developing years, when WNP-EA summer monsoons are ~~is~~ relatively weak may ~~induce the~~ enhancement ~~of~~ both precipitation frequency and intensity. On the other hand, ~~the~~ atmospheric vertical motion ~~is also prone~~also tends to be intense during these periods, as ~~the~~ summer monsoons over China feature~~s~~ strong southerly winds (Chen et al., 2013). This~~ese~~ leads to further anomalous R95p, Rx1d, and CWD, resulting in increased~~ing~~ flood risk during these years (table 3). However, a reduction ~~of~~in water vapor availability and vertical motion may occur ~~in~~during EP and CP developing years as WNP-EA summer monsoons tend~~s~~ to be strong (fig. 7), resulting in a negative anomaly in frequency and intensity of precipitation (fig. 4 & 5).

In addition, the relative stability of the~~stable~~ atmosphere tends to reduce the frequency and intensity of precipitation ~~because of~~by reducing vertical motion ~~reduction~~ (Chou et al., 2012). The WNP subtropical high is a prime circulation system over the WNP-EA and ~~the~~ anomalies of ~~its~~ location and intensity largely affect ~~the EA~~ summer monsoon activities in East Asia (Wang et al., 2013). Huang and Wu (1989) found that when the location of ~~the~~a subtropical high is ~~unusually northward~~ shifted unusually northward, ~~a~~ hot and dry weather occurs in ~~the~~ East China due to the dominance of the~~t~~ stable atmosphere. ~~Its~~The location and intensity of subtropical highs are also closely ~~related~~associated with ~~to~~ the development of ~~the~~ WNP anticyclones, and the northward shift usually coincides with~~a~~ strong WNP-EA summer monsoons (Wang et al., 2001). Therefore, ~~the~~ anomalous WNP subtropical highs possibly exacerbate~~s~~ ~~the~~ negative precipitation frequency anomalies~~y of precipitation frequency~~ and ~~the~~ positive DS anomalies~~y of DS~~ in the S region during LN decaying years (fig4 & table 3). ~~It~~This may also explain the strong reductions ~~of~~in precipitation frequency in the S region during CP decaying years (fig.4), because ~~the~~ WNP anticyclones display~~s a~~ different anomalies~~y~~ than ~~from~~ EP phases.

ENSO is one of the most important factors affecting TC activity over the WNP (Wu et. al, 2012). In this study, the modulation of TC activity by ENSO ~~is~~was analyzed ~~in~~during ~~the~~ developing and decaying phases for the period 1960-2013. Fig. 8 shows ~~the~~ ENSO-induced anomalies in terms of TC number and ~~formation~~ location of formation. ~~The~~T~~t~~rack density anomalies are shown in fig. 9.

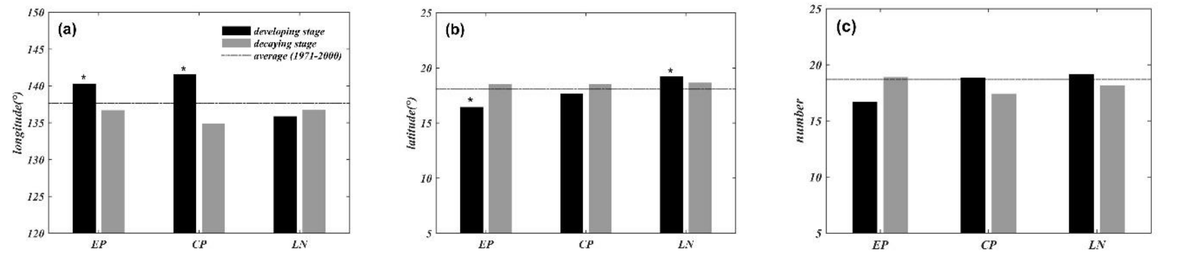


**Fig. 8** Anomalies in TC genesis longitude (a), latitude (b), and number (c) during JASO over the WNP. The d~~D~~ashed line ~~shows~~indicates the average value for 1971-2000. * 95% significance.

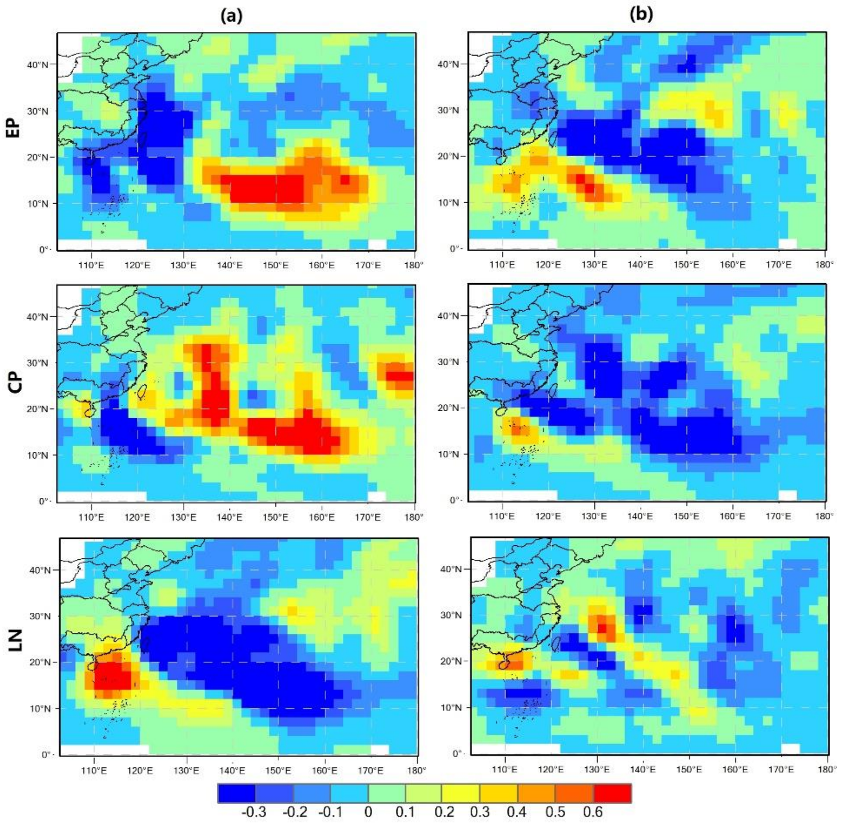



**Fig. 9** Track density anomalies during JASO in developing years (a) and decaying years (b) of EP, CP, and LN phases.

Although the total number of TSs formed in the WNP ~~does~~did not vary significantly from year to year, TCs tended to form ~~more~~further east~~ward~~ and south~~ward~~ during EP developing years (fig. 8). Th~~is~~e shift in the~~of genesis~~ location of TC genesis constrained~~s~~ TCs westward propagation into East Asia~~ continent~~ (Wang and Chan, 2002). Therefore, ~~the ~~track density ~~is~~was largely reduced over the ~~China ~~coast of China (fig. 9). This ~~implies~~suggests that the EP developing stage ~~induces~~induces a ~~less~~smaller ~~TCs impact~~impact by TC on ~~China ~~rainfall in China. Conversely, d~~D~~uring LN developing years, ~~conversely, ~~TCs tend to form ~~more~~further north~~ward~~ (fig. 8), and the track density shows a remarkable increase in the South China Sea (fig. 8). ~~The TC activity ~~The enhancement of TC activity tends to induce ~~more ~~heavier~~y~~ rainfall events, leading to ~~the ~~positive ~~anomalies ~~anomalies of precipitation intensity, Rx1d, R95p, and CWD during ~~these~~such years (fig. 4 & 5, table 3). TCs during CP developing years also form at ~~a ~~higher latitudes than during EP phases, but the average latitude is lower than ~~in~~during the LN phase (fig. 8). In contrast, t~~T~~he CP developing stage~~, on the other hand, produces an increase in the~~increases track density ~~over~~from ~~the region from ~~the central–western Pacific to the eastern China coast and ~~a reduction~~decreases it over the South China Sea (fig. 9). Kim et al. (2011) revealed~~s~~ that ~~the~~a shift in TC genesis location ~~shift~~during~~ in~~ CP years is closely ~~related~~associated with~~ to the~~ anomalous westerly winds induced by the westward shift ~~of~~in ocean heating, and that this shift further provides ~~a~~more favorable conditions for ~~TC~~ westward TC propagation. Zhang et. al (2012) also claimed that TCs during ~~the summer of~~ CP summers~~years~~ are more likely to make landfall over East Asia because of a westward shift ~~of~~in ~~the~~ subtropical highs and a northward- shift in~~ed~~ TC genesis. However, TCs during CP developing years do~~es~~ not exert~~s~~ significant rainfall anomalies over China. The anomalous WNP-EA summer monsoons induced by ENSO may further explain this discrepancy. As discussed above, the strong WNP-EA monsoons during CP developing years do~~es~~ not induce ~~a~~ negative rainfall anomalies~~y~~ over China (fig. 7). This ~~implies~~suggests that enhanced TC activity may cause a reduction in rainfall along monsoon fronts~~complement the reduction monsoon front rainfall~~, resulting in ~~a~~ neutral conditions over China. However, ~~but~~ further studies are ~~necessary~~needed to examine how the CP developing stage influences rainfall over China.

In contrast, no significant shifts in the locations of TC genesis ~~location occur~~occurred during ~~in the~~ decaying years (fig. 8). This ~~implies~~suggests that the impact of ENSO on TC formation may decrease after ~~the~~ ENSO ~~matures~~maturation. However, ~~almost~~nearly opposite TC track density patterns occur over the WNP during~~to the~~ developing ~~years occur over WNP in the~~and decaying years of an EP or CP (fig.9). For example, in ~~the~~ EP decaying years, TC activity increased~~s~~ in the South China Sea and decreased~~s~~ from the western Pacific to the eastern China coast. ~~The~~This shift ~~of~~in track density ~~changes~~affected ~~the~~ water vapor transport and contributed~~s~~ to a reversed pattern of~~the reversed~~ rainfall anomalies between developing and decaying years.

## 5 Summary

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~~ on a ~~both~~ daily ~~and annual~~ time ~~scales. In addition,~~ scale. ENSO events triggered ~~larger~~large changes ~~in both~~ in the frequency and intensity of precipitation events and in the ~~degree~~occurrence of precipitation extremes~~ than during non-ENSO periods~~. 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 on 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 which likely caused the sharp increase in annual precipitation, although the contribution of R95p cannot be ruled out as it was 23.32% greater than in no-ENSO years.~~

~~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 XXX and the evolution of the SST anomaly over the tropical Pacific. During the ENSO 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 and its direct influence on water vapor transport (Feng et al., 2011). The frequency and intensity of precipitation events in China would change as a result. This study reveals that due to increased WNP anti-cyclone events 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~~Previous studies have~~s~~ revealed that some ~~–~~regions in China are especially 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 the Yangzi River (Huang and Wu, 1989; Tong et al., 2006; Zhang et al., 2007; Zhang et al., 2015). However, ~~in this study,~~~~by the~~using daily precipitation indices, we found that the continental climate zone (NW) is more sensitive than other regions to ENSO events ~~than these andthe other regions based~~ due to~~on~~ the ~~region's~~ its high incidence and magnitude of anomalous ~~ies in~~ ~~average annual~~ precipitation~~.~~ events (Fig. 4 & 5 and Table 3).~~.~~ For example, the NW region experienced the largest R95p and CWD anomalies ~~in annual precipitation in China~~ during all ~~phases of~~ ENSO event phases~~s~~. ~~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~~ a global scale, Ward et al. (2014) found that ENSO has a greater impact on annual floods in arid regions than in 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~~ research has been ~~done~~ conducted on the mechanisms behind ~~the~~ climatic responses to ENSO events in ~~the~~ China's continental climate zone ~~of China,~~ ~~since~~ because 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~~ Although the ~~major~~primary physical processes and mechanisms responsible for ~~the~~ precipitation anomalies ~~are also discussed with special emphasis on~~have been discussed in the context of summer monsoons and TC~~tropical cyclone~~ activity, 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~~Therefore, even though some physical mechanisms ~~exists~~may ~~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~~ temporal and spatial scales.

~~Finally~~~~Besides~~In addition, the year-to-year variability of ~~the~~ East Asian summer monsoons ~~is~~ are 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~~ that 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). .~~, such as global warming. In a warmer climate, water vapor in the atmosphere tends to increase, ~~then~~which destabilizes the atmosphere and ~~further~~ enhances precipitation (Chou et al., 2012). ~~So~~Therefore, most positive precipitation anomalies are expected from a theoretical point of view in spite of the associated atmospheric circulation does not change too much.

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