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RESEARCH ARTICLE

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Asia precipitation tripole during boreal summer: Anomalous water vapour transport along the "Southern Silk Road"

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Abstract

East Asia and central India (CI) are significantly affected by the Asian summer monsoon. On the inter-annual time scale, the precipitation in the Hetao region (HT, [35°–42°N, 103°–114°E]) is prominently positively correlated with that in CI (19°–23°N, 78°–83.5°E) during boreal summer, but it is significantly negatively correlated with precipitation over the middle and lower reaches of the Yangtze River valleys (YRV, [30°–34°N, 114°–122°E]), which is manifested as the Asia precipitation tripole (APT). Positive APT represents above-normal precipitation in HT and CI regions, and below-normal precipitation in YRV, which is closely related to a developing La Niña episode. The enhanced Walker circulation and the associated anomalous ascent branch over the western Pacific favour the convective activities in the vicinity of the Philippines, thus stimulating the East Asian-Pacific/Pacific-Japan teleconnection wave trains. In the lower atmosphere, an anomalous anticyclonic circulation is located over the YRV and Japan, corresponding to a cyclonic circulation over the South China Sea and the Philippines islands. In the positive phase of APT, water vapour is transported from the Kuroshio extension area to the YRV along the easterly airflow, while YRV is a divergent region with water vapour deficiency, which is not conducive to the generation of precipitation in this area. One part of the water vapour is transported to the northwest of the YRV and converges in HT, which is in favour of the above-normal summer precipitation in this area. The other part of water vapour is transported westward through an anomalous water vapour transport channel which is called the "Southern Silk Road", which could weaken the water vapour transport from the Arabian sea to East Asia, or vice versa.

KEYWORDS

Asian summer precipitation anomaly, EAP/PJ teleconnection, ENSO, tripole pattern, "Southern Silk Road" anomalous water vapour transport

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1 | INTRODUCTION

China and India are both located in the Asian monsoon region, where the rainy season is mostly concentrated in summer (Guo and Wang, 1988; Huang and Wang, 2007). Eastern China and central India (CI) are densely populated and economically developed. The frequent occurrence of drought and flood in eastern China and CI could be a great threat to personnel safety, economic development, and social stability. For instance, in 1991, 1999, 2011, and 2015, the precipitation was above-normal in the middle and lower reaches of the Yangtze River valleys (YRV), but below-normal in the Hetao region (HT) and CI (figure omitted). Therefore, exploring the mechanism of summer precipitation anomalies in eastern China and India is of great practical importance to understand the causes of drought and flood anomalies in Asian monsoon regions, and to prevent and mitigate against disasters.

The mainland China is the largest area of the East Asian monsoon region (Song and Zhou, 2014). Influenced by the unique geographical location and climatic conditions, the summer precipitation in China has great regional characteristics (Zhou *et al.*, 2009; Yu *et al.*, 2010; Jin *et al.*, 2015). On the inter-annual time scale, the summer precipitation in HT and YRV has a precipitation dipole pattern, that is a north–south antiphase relation (e.g., Zhai *et al.*, 2005; Hsu and Lin, 2007; Jin *et al.*, 2015, 2016; He *et al.*, 2017; Jin and Guan, 2017). Ding and Wang (2005) suggested that such an antiphase relation of summer precipitation is closely related to the circumglobal teleconnection (CGT; Branstator, 2002). Jin and Guan (2017) further revealed that the North Atlantic Oscillation (Walker and Bliss, 1932; Hurrell, 1995) can influence the antiphase precipitation relationship through the mid-high latitudes of atmospheric teleconnection. This north–south antiphase relation of the rainfall anomaly in eastern China is also associated with the East Asian-Pacific (EAP; Huang and Li, 1987)/Pacific-Japan (PJ; Nitta, 1987) teleconnection (Huang, 2004). The El Niño–Southern Oscillation (ENSO) regulates the relationship between the EAP/PJ teleconnection and the antiphase precipitation pattern over eastern China (Huang and Wu, 1989). When the sea surface temperature (SST) in the tropical eastern Pacific is anomalously warmer, namely the eastern Pacific El Niño events, the abnormal water vapour convergence (divergence) in YRV (HT) is beneficial to the antiphase relation of anomalous summer precipitation. On the contrary, when the anomalous SST warming center occurs in the tropical central Pacific, namely the central Pacific El Niño events, the summer precipitation anomaly would mainly occur in South China, which is not conducive to the summer dipole precipitation in eastern China (Ashok *et al.*, 2007; Kug *et al.*, 2009; Jin *et al.*, 2016). Moreover, the spatial distribution of summer precipitation in eastern China has an interdecadal antiphase relation between the south and north (e.g., Yu *et al.*, 2004; Ding *et al.*, 2008; Jin *et al.*, 2016; Si and Ding, 2016; Chen *et al.*, 2017).

Precipitation in HT not only has a significant negative correlation with that in the YRV, but also has a positive correlation with that in India (Zhang, 1999; Kripalani and Kulkarni, 2001; Ding and Wang, 2005). This positive correlation is closely associated with the strength of the subtropical high ridge in the western Pacific Ocean, the summer monsoon in East and South Asia, and the ENSO effect (Kripalani and Singh, 1993; Wu *et al.*, 2003; Lin *et al.*, 2017). Feng and Hu (2004) argued that the Indian summer monsoon can link and regulate the influence of ENSO on the summer precipitation anomaly in HT. As demonstrated by previous studies, Indian summer monsoon precipitation stimulates CGT in the upper troposphere (Ding and Wang, 2005), which can subsequently affect the summer precipitation anomaly over eastern China (Jin and Guan, 2017), and contribute to the synergistic variation of precipitation anomaly in India and HT (Lin *et al.*, 2018). The anomalous transport of water vapour from the tropical Indian Ocean to East Asia, together with the zonal wave trains at mid-latitudes, jointly affect the inter-annual variation of summer precipitation anomalies in India and East Asia (Wu, 2017). East Asian and Indian monsoon regions are powerful water vapour gathering areas with strong convergence centres during boreal summer (Zhou *et al.*, 2008). The summer monsoon precipitation anomaly in India is transmitted to East Asia mainly through the Silk Road teleconnection pattern (Enomoto *et al.*, 2003; Ding and Wang, 2005). Zhang *et al.* (2019) proposed that midsummer precipitation in the Indian subcontinent, Indo-China Peninsula, and northern China is highly correlated. Liu and Huang (2019) suggested that the summer precipitation from tropical Indo-western Pacific to mid-latitude Asia presents a tripole pattern in meridional. Liu *et al.* (2019) deemed that the summer precipitation displays a "positive–negative–positive" or "negative–positive–negative" structure over northwestern India, the Tibetan Plateau, and northern China.

However, the relationship between the summer precipitation anomaly in YRV and India is lacking research. It is still unclear whether there is an inter-annual relationship between the summer precipitation in YRV and India. Jin *et al.* (2015, 2016, and 2017) pointed out that there is a significant negative correlation between the summer precipitation anomaly in YRV and HT on the inter-annual time scale. However, whether the APT exists among HT, YRV, and CI regions is still not well understood. If the APT does exist, how does the mechanism link them together? In this paper, the relations and mechanisms between precipitation anomalies over CI and precipitation dipole pattern over eastern China are explored. The results will provide scientific clues for a thorough understanding of the precipitation anomaly and its causes in the Asian monsoon regions. After a brief introduction of the data and methodology in Section 2, the relationships and possible mechanisms of the APT are investigated in Section 3. Finally, the conclusions and discussion are presented.

2 | DATA AND METHODOLOGY

2.1 | Data method

The daily precipitation data is obtained from the Asian Precipitation-Highly-Resolved Observational Data Integration Toward Evaluation of Water Resources on 0.5° × 0.5° latitude–longitude horizontal grids (Yatagai *et al.*, 2012). Japanese 55-year Reanalysis (JRA-55) datasets with a horizontal resolution of 1.25° × 1.25° (Kobayashi *et al.*, 2015) are utilized. The monthly mean SST data at 1.0° × 1.0° resolution are obtained from the Met Office Hadley Center (Rayner *et al.*, 2003). The datasets listed above are used to analyse the 55-year period from 1961 to 2015. Outgoing longwave radiation (OLR) data from 1979 to 2015 at 2.5° × 2.5° resolution

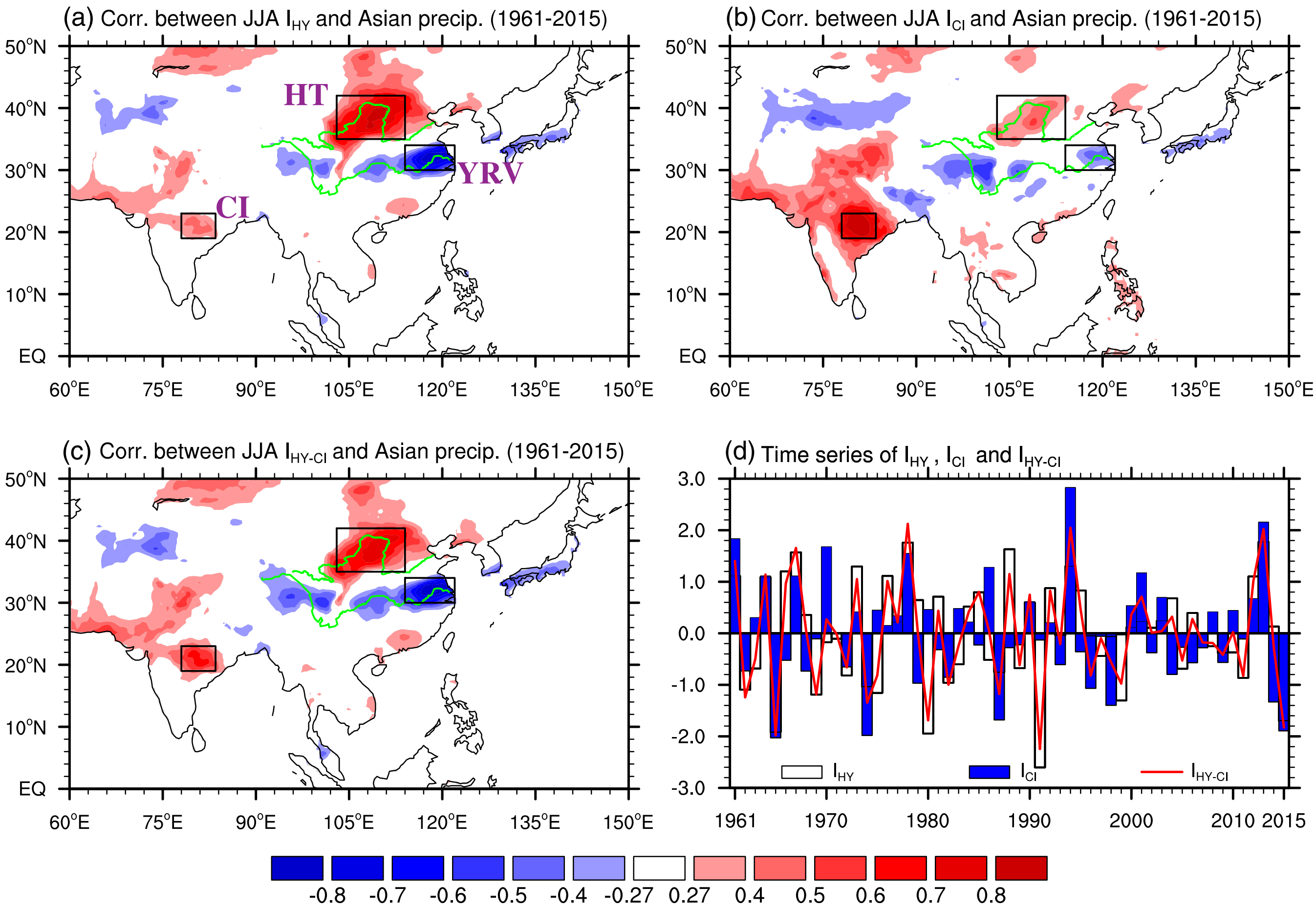

FIGURE 1 The correlation coefficients of Asian precipitation with (a) I_{HY}, (b) I_{CI} and (c) $I_{HY\text{-}CI}$. The black rectangular box areas in Figure 2a–c are defined as HT (35°–42°N, 103°–114°E), YRV (30°–34°N, 114°–122°E) and CI (19°–23°N, 78°–83.5°E). (d) The standardized time series of I_{HY} (white), I_{CI} (blue) and $I_{HY\text{-}CI}$ (red) from 1961 to 2015 [Colour figure can be viewed at wileyonlinelibrary.com]

are collected from the National Oceanic and Atmosphere Administration (Liebmann and Smith, 1996).

To focus on inter-annual variations, we use high-passfiltered periodicities of 9 years and longer using a 9-year running mean filter, which has been extensively used in climate analysis to exclude the decadal signal (e.g., Xie *et al.*, 2009; Huo *et al.*, 2015; Jin *et al.*, 2017). The HT (35°–42°N, 103°–114°E), YRV (30°–34°N, 114°–122°E) and CI (19°–23°N, 78°–83.5°E) are the three key regions in the present work (Figure 1a). The summer here is defined as the time-period of June to August (JJA).

2.2 | Index definition

The Niño-3 index is calculated by taking the mean SST in the (5°S–5°N, 90°–150°W) region (Cane and Zebiak, 1985; Trenberth, 1997). The definition of EAP index is referred from Huang (2004). To express the out-of-phase characteristics of summer precipitation in HT and YRV, the north–south antiphase precipitation index in eastern China is defined as $I_{HY} = \left[\bar{H}^* - \bar{Y}^*\right]^*$. The positive (negative) anomaly of the index indicates more (less) precipitation in HT and less (more) precipitation in YRV. The precipitation index in CI is defined as $I_{CI} = \bar{CI}^*$. The APT index of HT, YRV, and CI is specified as $I_{HY\text{-}CI} = \left[\left(\bar{H}^* + \bar{CI}^*\right)/2 - \bar{Y}^*\right]^*$. The positive anomaly of the APT index suggests the above-normal precipitation in HT and CI, and below-normal precipitation in YRV; and vice versa. $\bar{H}$, $\bar{Y}$, and $\bar{CI}$ indicate the regional average of precipitation over HT, YRV, and CI, respectively, as shown in Figure 1a. An asterisk (*) represents standardization.

3 | RESULTS

3.1 | Asia precipitation tripole during boreal summer

Figure 1a presents the spatial distribution of the correlation coefficients between precipitation anomalies and the north–south antiphase index in eastern China (I_{HY}). It can be seen that I_{HY} has a significant positive correlation with summer precipitation anomaly in HT, and a negative correlation with that in YRV. Thus, I_{HY} can represent the prominent antiphase relation between HT and YRV summer precipitation (Jin *et al.*, 2016, 2017). Remarkably, positive correlations between I_{HY} and summer precipitation anomaly are also found in CI, indicating an APT structure, that is, positive–positive–negative correlation distribution in the CI-HT-YRV regions. It is noted that the definition of APT in the present study has distinct differences from previous work (Liu *et al.*, 2019; Liu and Huang, 2019; Zhang *et al.*, 2019) on the location of each pole. The distribution of correlation coefficients between I_{CI} and summer precipitation anomaly in Asia (Figure 1b) shows that the summer precipitation over CI is positively correlated to that around CI and over HT, and is negatively correlated to that over YRV. The correlation coefficients between the summer precipitation anomaly and $I_{HY\text{-}CI}$ suggests that the APT index can simultaneously present the inverse relationship between the summer precipitation over the HT and YRV, and the in-phase relationship between the CI and HT (Figure 1c). The correlation coefficients among $I_{HY\text{-}CI}$, I_{CI}, $\bar{H}$, and $\bar{Y}$ are calculated in Table 1. Significant correlations at the 99% confidence level can be easily found between any two indices, further indicating the effective performance of $I_{HY\text{-}CI}$ index could represent the APT among CI, HT, and YRV. The inter-annual time series of I_{HY}, I_{CI}, and $I_{HY\text{-}CI}$ precipitation indices (Figure 1d) show the relatively consistent inter-annual variations among the three indices. To conduct composite analysis in the next section, the years with $I_{HY\text{-}CI}$ index larger than one (less than negative one) standard deviation are defined as high (low) index years. We define 1961, 1964, 1967, 1973, 1976, 1978, 1988, 1994, 2012, and 2013 as high index years. The low index years are 1962, 1965, 1969, 1974, 1980, 1982, 1987, 1991, and 2015.

3.2 | Related circulation background

Figure 2 shows the composite differences of SST, geopotential height, wind, and divergence between high and low index years in the lower and upper troposphere. In Figure 2a, negative SST anomaly (SSTA) appears in the equatorial central-eastern Pacific, accompanied with the positive anomaly over the equatorial western Pacific. This configuration of the SSTA pattern indicates a La Niña event. Further, known

TABLE 1 The pairwise correlation coefficients among the APT index ($I_{HY\text{-}CI}$), the precipitation index in CI (I_{CI}), the regional average of precipitation over HT ($\bar{H}$) and YRV ($\bar{Y}$) from 1961 to 2015

	$I_{HY\text{-}CI}$	I_{CI}	$\bar{H}$	$\bar{Y}$
$I_{HY\text{-}CI}$	1	—	—	—
I_{CI}	0.67	1	—	—
$\bar{H}$	0.78	0.41	1	—
$\bar{Y}$	−0.91	−0.40	−0.57	1

Note: The critical value of correlation coefficient at 95% (99%) confidence level is 0.27 (0.35).

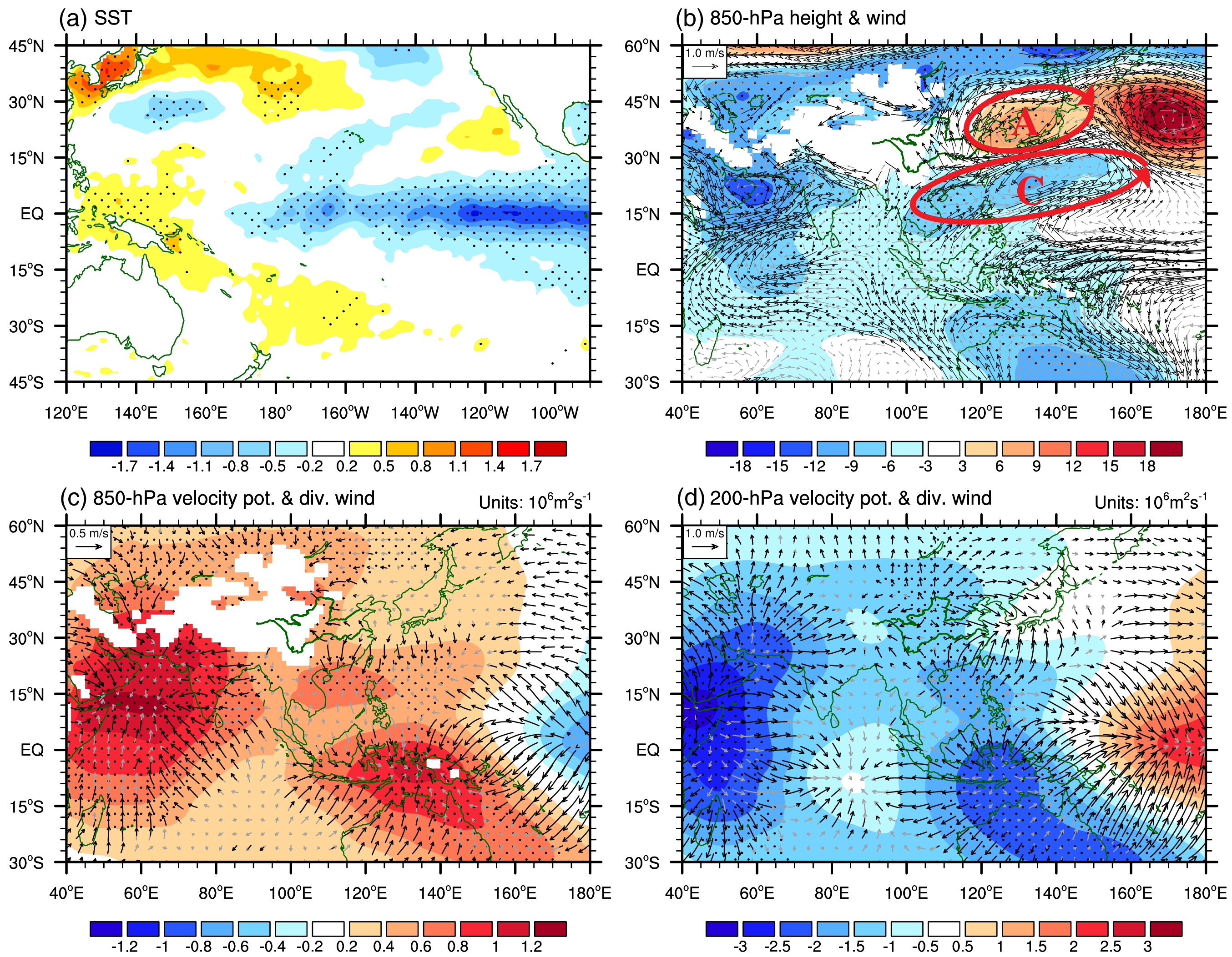

FIGURE 2 The composite differences of (a) SST (units: °C), (b) 850 hPa geopotential height (shading, units: gpm) and wind (vectors, units: $m \cdot s^{-1}$), (c) 850 hPa and (d) 200 hPa velocity potential (shading, units: $10^6\ m^2 \cdot s^{-1}$) and divergent wind (vectors, units: $m \cdot s^{-1}$) in JJA. Stippled areas and black arrows are for those exceeding the 95% confidence level [Colour figure can be viewed at wileyonlinelibrary.com]

from the evolution of the composite SSTA in the Niño-3 region from preceding December to following December (figure omitted), the SST over the tropical central-eastern Pacific has an obvious negative anomaly from the prior winter to following December. In addition, the summer SSTA is in the development phase of La Niña. It is indicated that the APT pattern is usually accompanied by a developing La Niña episode. As suggested by previous studies (Huang and Li, 1987; Nitta, 1987), positive SSTA in the equatorial western Pacific could bring above-normal rainfall to HT, but below-normal rainfall to YRV, owing to the northward shift of the local Hadley circulation and the subtropical high over the western Pacific. Our results are consistent with the interpretation that ENSO is a key signal for the synergistic variation of summer precipitation over India and East Asia (Kripalani and Kulkarni, 2001; Huang and Wang, 2007; Wu, 2017). We further calculate the correlation coefficients among Niño-3 index, $I_{\text{HY-CI}}$, I_{HY}, I_{CI}, $\bar{H}$, and $\bar{Y}$ (Table 2). It clearly shows that the Niño-3 index is negatively correlated to $I_{\text{HY-CI}}$, I_{HY}, I_{CI}, and $\bar{H}$, with coefficients stronger than -0.33. In contrast, only $\bar{Y}$ has a positive correlation with the Niño-3 index, with a coefficient of 0.28, which exceeds the 95% confidence level. It manifests that the La Niña episodes are favourable for the above-normal rainfall production in CI and HT, but would be likely to bring below-normal rainfall to YRV.

In Figure 2b, positive (negative) geopotential height anomalies accompanied by zonal-elongated anomalous anticyclonic (cyclonic) circulation in the lower troposphere are observed over the vicinity region of YRV and Japan (the Philippines). Such configuration of anomalous geopotential height and wind represents the spatial distribution of the EAP/PJ teleconnection (Huang and Li, 1987; Nitta, 1987). Interestingly, the anomalous east-northeasterly winds from

TABLE 2 The pairwise correlation coefficients among the Nino-3 index, the EAP index (I_{EAP}), the APT index ($I_{HY\text{-}CI}$), the north–south antiphase index over eastern China (I_{HY}), the precipitation index in CI (I_{CI}), the regional average of precipitation over HT ($\bar{H}$) and YRV ($\bar{Y}$) from 1961 to 2015

	I_{EAP}	$I_{HY\text{-}CI}$	I_{HY}	I_{CI}	H	Y
Nino-3	***−0.33***	***−0.46****	***−0.45****	***−0.45****	***−0.51****	***0.28***
I_{EAP}	1	***0.53****	***0.42****	***0.48****	0.24	***−0.50****

Note: The values of bold italics and bold italic asterisks have exceeded 95% (0.27) and 99% (0.35) confidence level, respectively.

Japan and YRV can reach CI and lead to strengthening the convergence with the southwesterly monsoon flows, which may subsequently bring abundant summer precipitation to CI. The relations of EAP to other indices in the present study are also calculated in Table 2. It can be clearly seen that I_{EAP} has a most prominent correlation with $I_{HY\text{-}CI}$ among the listing indices, with a correlation coefficient of 0.53. I_{HY}, I_{CI}, and $\bar{H}$ are also positively correlated to I_{EAP}, with correlation coefficients of 0.42, 0.48, 0.24, respectively. Meanwhile, ENSO is closely related to the EAP/PJ teleconnection (Kosaka and Nakamura, 2010), and the correlation coefficient between Nino-3 and EAP index is −0.33. It suggests that ENSO may affect the APT by adjusting the EAP/PJ teleconnection. Responding to the APT (Figure 1a), anomalous convergence (divergence) in the lower (upper) troposphere appears over the vicinity of CI, HT, and Maritime Continent region. Such a configuration of wind divergence anomaly is conducive to summer precipitation enhancement over CI and HT, but reduction over YRV. Summer zonal-vertical circulation averaged over 5°S–5°N (figure is not shown) indicates that the troposphere of the tropical central-eastern Pacific is controlled by the descending motion, while the ascending motion is located in the western equatorial Pacific. In other words, the Walker circulation can be subsequently strengthened, which is consistent with the conclusion that the Walker circulation could be enhanced when La Niña events occur (Clement *et al.*, 1996; Tung and Zhou, 2010). Additionally, positive OLR anomaly is found over the vicinity region of YRV and Japan, associated with weak convective activities. In contrast, negative OLR anomaly and active convective activities are observed over the vicinity of the Philippines, which are conducive to stimulating the EAP/PJ teleconnection wave trains (Huang and Li, 1987; Nitta, 1987), associated with La Niña-like convective activities (Chiodi and Harrison, 2015) (figure omitted).

3.3 | "Southern Silk Road" anomalous water vapour transport channel

Further analysis on moisture transport is presented in Figure 3. The composite differences of total column water vapour flux and its divergence (Figure 3a) show that there is an anticyclonic circulation anomaly of water transport over YRV-Japan region, and a cyclonic circulation anomaly over the South China Sea (SCS) and the vicinity of the Philippines. The distribution of moisture flux is similar to that of the EAP/PJ pattern (Huang and Li, 1987; Nitta, 1987), which links the developing La Niña episodes and the APT pattern. Water vapour flux vectors originating from the Kuroshio Extension region transport abundant moisture to the YRV. The anomalous moisture divergence over the YRV tends to bring below-normal rainfall to the YRV, and splits the water vapour transport into two branches. One carries water vapour to the HT, leading to the anomalous moisture convergence and subsequently above-normal rainfall over the HT. The remaining water vapour is transported westward along the southern margin of the Tibetan Plateau, which is named as the 'Southern Silk Road' anomalous water vapour transport channel (marked by red thick lines in Figure 3a), due to the similarity with the ancient Southern Silk Road in China. As shown in Figure 3a, the anomalous water vapour transport channel propagating from east to west is defined as the positive phase of the 'Southern Silk Road'. It is also found that when the anomalous 'Southern Silk Road' water vapour transport channel is in the positive phase, the water vapour transporting from the Arabian Sea through India and the Bay of Bengal to eastern China is weakened. Vice versa. The zonal component (Figure 3b) of water vapour flux is negative along the whole "Southern Silk Road", with the most abundant water vapour near the East China Sea (130°E). Accompanied by the westward transport, the water vapour flux is gradually diminished along the southern margin of the Tibetan Plateau, but strengthened again near the Bay of Bengal. It should be noted that, in the current study, we only statistically focus on the APT phenomena and its mechanism. It is beyond the scope of this paper to discuss why the anomalous water vapour gradually diminishes in the south side of the Tibetan Plateau. Such an anomalous water vapour transport channel weakens the water vapour transport from South Asia to East Asia. Besides, the southwesterly Indian monsoon flows carry abundant water vapour from the Arabian Sea to CI, which is conducive to the above-normal summer precipitation in CI.

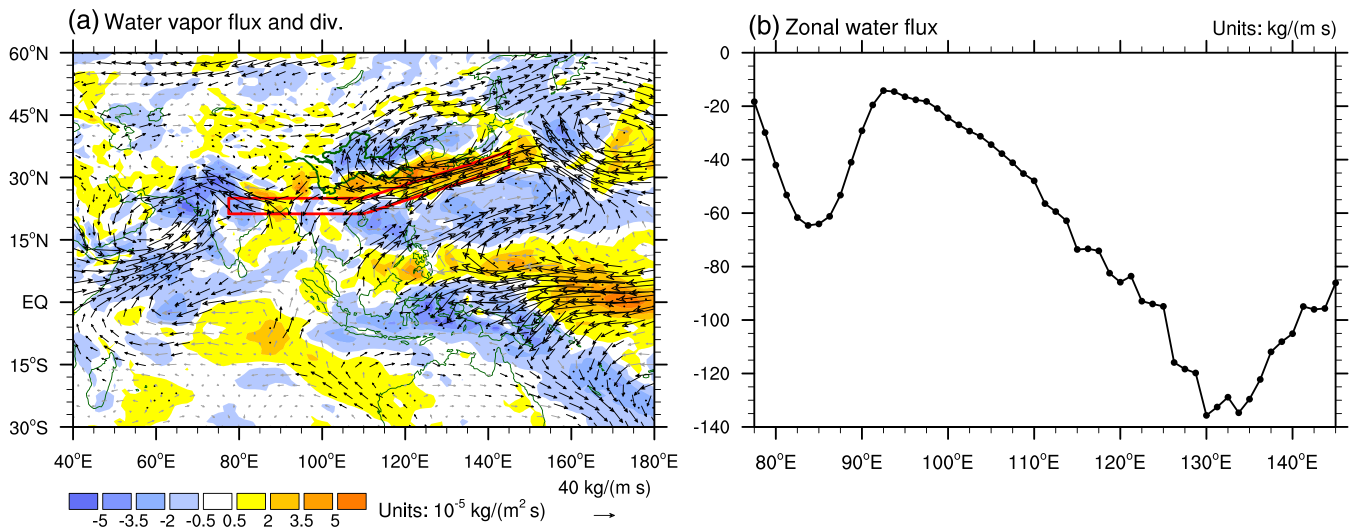

FIGURE 3 (a) Composite differences of the water vapour flux integrated from the 1,000 to 300 hPa (vectors, units: $kg{\cdot}m^{-1}{\cdot}s^{-1}$) and its divergence (shading; units: 10^{-5} $kg{\cdot}m^{-2}{\cdot}s^{-1}$). Stippled areas and black arrows are for those exceeding the 95% confidence level. The red solid line area is the "Southern Silk Road" anomalous water vapour transport channel. (b) Composite differences of zonal water vapour flux from 77.5°E to 145°E after the meridional average of the zonal components in the red solid line area (units: $kg{\cdot}m^{-1}{\cdot}s^{-1}$) [Colour figure can be viewed at wileyonlinelibrary.com]

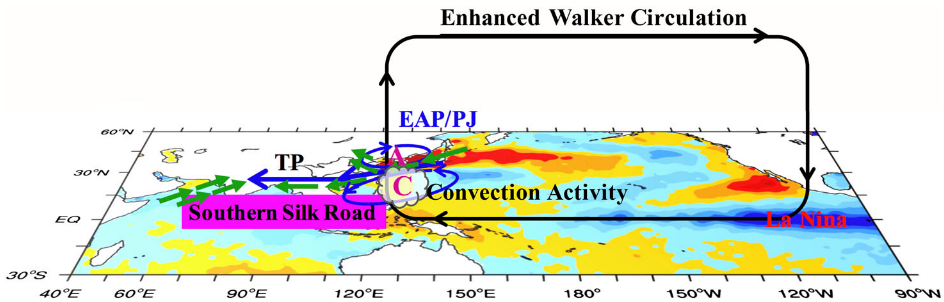

FIGURE 4 The schematic diagram of influencing mechanism of the tripole precipitation pattern in Asia [Colour figure can be viewed at wileyonlinelibrary.com]

4 | CONCLUSIONS AND DISCUSSION

This study investigates the distribution of anomalous summer precipitation and associated atmospheric circulation over eastern China and CI during 1961–2015. It shows that the summer precipitation anomaly in CI has a significant positive correlation with that in HT, while a negative correlation with that in YRV, characterizing an APT structure. We use the index of $I_{HY\text{-}CI}$ to describe the precipitation triple pattern of the HT, YRV, and CI, showing a clear "positive–negative–positive" correlation distribution in the HT-YRV-CI regions.

In Figure 4, we conduct a schematic diagram to present the mechanisms of the tripole precipitation pattern in Asia. It reveals the close connectivity between the APT and ENSO. When a developing La Niña event occurs, the negative SSTA in the tropical central-eastern Pacific is opposite to that in the tropical western Pacific, which enhances the Walker circulation. The abnormal ascending motion over the western Pacific favours the convective activities in the vicinity of the Philippines, which is favourable for triggering the EAP/PJ teleconnection wave trains.

We further verify that the water vapour transport of APT is a manifestation of EAP/PJ pattern, showing an anticyclonic-cyclonic pattern of anomalous water vapour transport over YRV-SCS region (Figure 4). The anomalous easterly flows carrying the water vapour from the Kuroshio Extension region diverges over the YRV. The water vapour divergence over YRV contributes to the local below-normal precipitation. Part of the diverged water vapour over YRV is transported toward the northwest and converged over HT, favouring the above-normal precipitation production over HT. Moreover, the positive anomalous 'Southern Silk Road' water vapour transport channel can weaken the water vapour transport from South Asia to East Asia. The Indian southwest monsoon flows can bring abundant water vapour from the Arabian

Sea toward CI, favouring the summer precipitation production over CI.

In this study, we emphasize the inter-annual relations among the summer rainfall anomaly over the HT, YRV, and CI. Previous studies suggested that the summer precipitation anomaly in HT and YRV shows an inter-annual antiphase oscillation (Hsu and Lin, 2007; Huang *et al.*, 2012; Jin *et al.*, 2015, 2017), and also presents significant decadal variations (Jin *et al.*, 2016). Does the APT have similar decadal variations? Moreover, we are aware that the location of the western Pacific subtropical high could exert great influence on the variation of summer rain belt over eastern China, concerning the close relationships among the western Pacific subtropical high, monsoon flows, and ENSO (Dong *et al.*, 2017; Xue *et al.*, 2018; Li and Lu, 2019). Now the question is whether the APT phenomenon also has different features during early and late summer, as the variation of the summer rain belt. It should be mentioned that, while the summer precipitation anomaly in India and North China can be connected by the CGT in the upper troposphere (Ding and Wang, 2005; Lin *et al.*, 2016; Wu, 2017), it remains unclear whether the CGT could influence the APT. It is also noted that the summer precipitation in southwestern Japan and APT is remarkably correlated (Figure 1a–c), and the correlation coefficient between southwestern Japan (31.0–35.7°N, 129.6–140.0°E) and I_{HY} ($I_{HY\text{-}CI}/I_{CI}$) is −0.47 (−0.52/−0.41) as calculated. From Figures 2b and 3, we can see that Japan is under the control of strong east-northeasterly wind, which means the summer precipitation anomaly in the southwestern Japan is also influenced by the large-scale circulation on the interannual time scale. Thus, the detailed mechanism connecting APT with summer precipitation in southwestern Japan still requires further investigation.

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